The Resilient Buildings Project

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Report for Stage 3: Relating Societal Expectations to Building Seismic Performance

APPENDICES

FEBRUARY 2024

nzsee NEW ZEALAND SOCIETY FOR EARTHQUAKE ENGINEERING
Toka Tū Ake EQC

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The authors gratefully acknowledge the many people who have participated in the workshops or have otherwise contributed through interviews, shared information and associated research to our understanding of how society uses buildings and expects them to perform. We want to acknowledge subject matter experts Mike Stannard, Pam Johnston, Tal Sharrock-Crimp and Kay Saville-Smith whose insights into the New Zealand built environment and associated economic analysis matters greatly assisted the project team. Also reviewers Professor Mary Comerio, Associate Professor Julia Becker and Alistair Cattanach who identified key missing elements in the framework and a range of important clarifications. Their inputs and perspectives were an invaluable addition to the project.

The Resilient Buildings Project has drawn on knowledge contributed by technical societies (NZSEE and SESOC), research consortia (QuakeCoRE) and research institutions (Universities and CRIs) – all having supported the project through provision of advice and active participation in workshops and meetings, all of whom we wish to acknowledge as providing very valuable support for the project.

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Contents

Appendix A:

The Building Control System in New Zealand

The building regulatory system in New Zealand provides for the regulation of buildings, building work, and various occupational groups in the building industry, as well as the setting of building performance standards. All building work in New Zealand must meet certain requirements, which are set out in legislation and regulations that determine how work can be done, who can do it, and ensure the system has checks and consumer protection in place.[1] The legislation and regulations work together as the building regulatory system:

> *Building Act 2004* – the primary legislation governing the building and construction industry
>
> *Building Code* – contained in Schedule 1 of the Building Regulations 1992, sets the minimum performance standards buildings must meet

The Building Code describes performance requirements for the outcome of building work aspects including, structure, durability, fire safety, access, moisture, safety of users, services and facilities, and energy efficiency. Being performance-based, the Building Code states how a building must perform in its intended use rather than describing how the building must be designed and constructed. It is important to note that while you cannot design to less than the minimum standards, owners and designers can choose to exceed them in order to meet their own requirements.

Any systems, materials and methods can be used provided the building owner or designer can demonstrate that the performance criteria are met. This allows for innovation and design flexibility. For many buildings and building work, traditional or empirical methods are all that are required. To reduce compliance costs and time for both designer and consenting authority, the regulator Ministry for Business, Innovation & Employment (MBIE) publishes deemed-to-comply Acceptable Solutions (AS) and Verification Methods (VMs) for the various Building Code clauses. Guidance may also be issued by MBIE under s175 of the Building Act to achieve the desired performance, particularly when assessing Alternative Solutions (Figure A1).

These prescriptive documents are collectively often referred to as ‘Code-supporting documents’. If they are followed, the building consenting authority (usually the Territorial Authority) is required to issue a building consent for the work. If the consenting authority contests the approach, MBIE may issue a Determination which is legally binding.

The performance of a building in an earthquake is the physical manner in which it responds to shaking (or the displacement of its foundation). Building performance is often described by the extent of damage it has suffered, and the impacts of this damage in terms of functionality or potential casualties. The relevant performance requirements for Clause B1 (Structure) of the Building Code are:

[1] building.govt.nz/building-code-compliance/.

> B1.3.1 Buildings, building elements and sitework shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during construction or alteration and throughout their lives.
>
> B1.3.4 Due allowance shall be made for: a) the consequences of failure; b) the intended use of the building.

For seismic design, the loadings Standard NZS 1170.5 is the most relevant document.[2] The Standard NZS 1170.5 provides procedures for the determination of earthquake actions on structures in New Zealand. It gives the requirements for verification procedures, site hazard determination, the evaluation of structural characteristics, structural analysis for earthquake action effects, the determination of and limits for, deformations and the seismic design of parts of structures.

The AS/NZS 1170 series uses importance levels, among other factors, to determine the loadings for earthquake, snow and wind that a building needs to be designed for. The importance level classifications in AS/NZS 1170 are from 1 (lowest) to 5 (highest) and are determined in accordance with a building's occupancy and use, the potential consequences of failure in terms of loss of human life, and the economic, social, and environmental effects of structural failure. A building with a higher importance level is required to be designed for stronger forces than a building designed to a lower importance level.[3]

The Standard NZS 1170.5 includes consideration of three design points for seismic design: an ultimate limit state (ULS) for life safety and two serviceability limit states (SLS1 repair not required and SLS2 operational continuity maintained). Consideration of the serviceability design points (SLS1 and SLS2) depends on the building importance level, with the primary focus on the life safety limit state (ULS). This reflects the performance requirements of Clause B1 (Structure) of the Building Code.

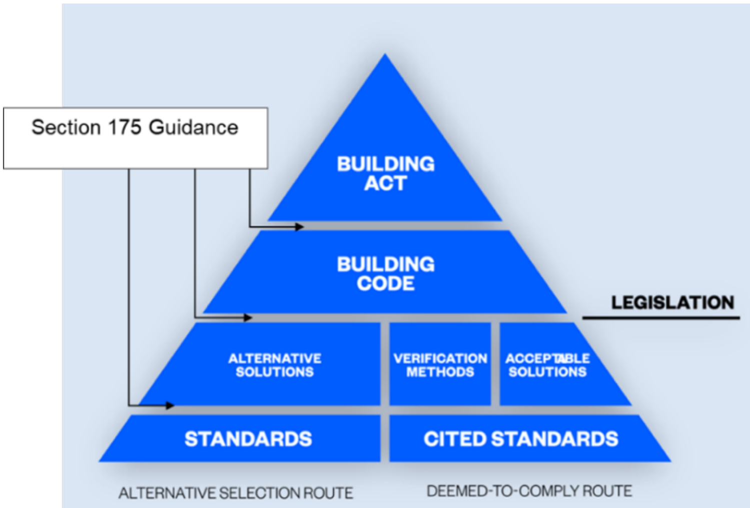

Figure A1 New Zealand Building Control System (schematic). Adapted from MBIE (2020) [4]

[2] codehub.building.govt.nz/resources/nzs-1170-52004-a1-excl/.

[3] Importance levels are also found in Clause A3 of the Building Code, but the reference pertains to the C-Clauses of the Code relating to fire safety, not earthquakes.

[4] Seismic Risk and Building Regulation in New Zealand. Findings of the Seismic Risk Working Group, November 2020, Ministry of Business Innovation and Employment, New Zealand Government.

Appendix B:
Project Structure and Approach

B.1 Introduction

The Resilient Buildings Project (RBP) was conceived in late 2019 as a programme of work to inform a broader rethink of the framework for New Zealand's earthquake standards and design approach suitable for the 21st century. The RBP contributes to a multifaceted multiagency work programme focussed on enhancing building performance in earthquakes.

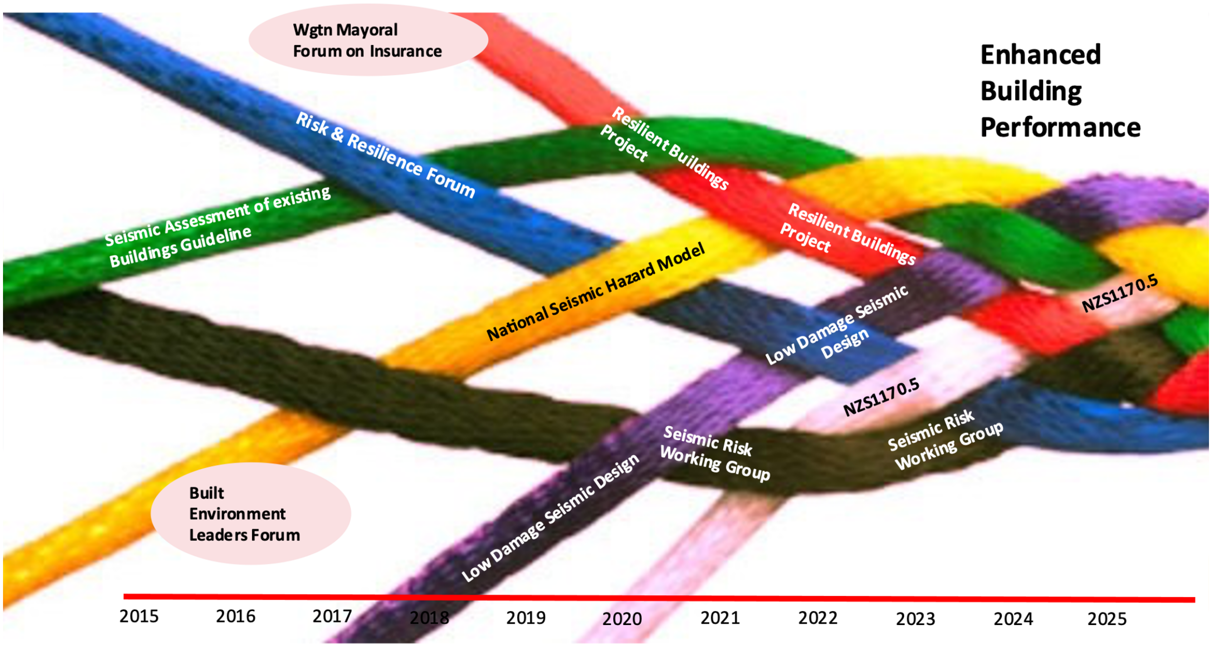

Figure B1. Multifaceted multiagency programme aiming for more resilient buildings

Initiated and led by the New Zealand Society for Earthquake Engineering (NZSEE) with funding from Toka Tū Ake EQC, the project since inception has been developed in stages as follows:

Stage 1: Establish the need and set the vision for the project.

Stage 2: Obtain a 'snapshot' of societal expectations on seismic performance of buildings.

Stage 3: Define tolerable and intolerable outcomes and impacts to inform performance objectives.

Stages 1 and 2 have been delivered, verifying the purpose of the project and obtaining a rigorous 'snap-shot' of societal expectations of future building performance.

This report outlines the findings from Stage 3 of the project.

B.2 Project Structure and Team

In Stage 1, a small team of engineers – Rob Jury, Dave Brunsdon, John Hare, Ken Elwood along with Helen Ferner as project lead – formed a project establishment group focussed on laying the groundwork, identifying the need, and setting the vision for the project.

For Stage 2, this group then constituted a project steering group, supplemented by several additional members to diversify the team skill sets and experience (social science, economics, insurance, risk governance, and public policy), and to ensure representation from Toka Tū Ake EQC; Hugh Cowan as project director, Sarah Beaven, Derek Gill, Caleb Dunne, and Jo Horrocks. The steering group focus is on project governance, strategy, quality assurance, audience focus, and advocacy.

A project team was also assembled for Stage 2 – led by Charlotte Brown – to undertake the societal expectations research. Shannon Abeling also joined the team as a jointly funded University of Auckland/Toka Tū Ake EQC post-doctoral research fellow.

Stage 2 was undertaken by the project team with input and overview from the steering group.

For Stage 3, the steering group became the project team (see Table B1). This project team was supplemented by experts providing specialist advice; Mike Stannard, Pam Johnston, Tal Sharrock-Crimp, and Kay Saville-Smith (see Table B2).

An independent review team comprising Alistair Cattanach (structural engineer), Mary Comerio (architect and academic), and Julia Becker (social scientist) reviewed the Stage 3 key outputs. The independent review had the objective of identifying what may be missing or not otherwise accounted for in terms of the future useability of the key outputs.

Throughout, we had periodic input from other subject matter experts and larger groups of external researchers and practitioners.

Table B1 Project team members

Project team member	Area of expertise
Shannon Abeling	Engineering Research
Sarah Beaven	Social Science Research
Charlotte Brown	Social Science Research and Practice
Dave Brunsdon	Engineering Practice
Hugh Cowan	Insurance, Risk governance
Caleb Dunne	Policy
Ken Elwood	Engineering Research
Helen Ferner	Engineering Practice
Derek Gill	Economics, Policy
John Hare	Engineering Practice
Jo Horrocks	Risk
Rob Jury	Engineering Practice, Building Code writing

Table B2 Subject matter experts

Subject matter experts	Area of expertise
Mike Stannard	Performance-based regulatory systems and seismic risk settings

Pam Johnston	Land use planning
Tal Sharrock-Crimp	Economic analysis
Kay Saville-Smith	Urban development
Michael Bealing	Economic analysis

B.3 Project process

Stage 1 was an establishment phase undertaken in 2020 to contextualise the project, frame the issues, and establish the project structure and framework with three main tasks:

- Engaging with the engineering community about the issues, context, and vision for this project
- Clarifying and mapping the relationships between various projects related to seismic risk recently completed and underway.
- Forming an establishment group to:
  a. frame the problem
  b. establish key considerations
  c. develop the proposed operational structure for the project, and
  d. convene a steering group to provide project guidance and an overview of Stage 2.

Stage 2, undertaken in 2021, focussed on an engagement process using interviews and focus groups in selected towns and cities throughout New Zealand to collect data on perceptions and expectations of performance of the built environment in earthquakes. Participants were asked to consider the expected performance of different types of buildings (functions, settings, user groups, geographic settings), considering human, social, financial, and natural capital outcomes.

The findings were published in a report titled “Societal expectations for seismic performance of buildings” dated March 2022.[1]

Stage 3, undertaken in 2022 and 2023, focussed on:

- Development of an Earthquake Performance Outcome framework (EPO),
- Development of a system to categorise building usages (relevant to seismic performance outcomes),
- Exploration of whether the current Code matches the societal expectations collected in Stage 2, using the EPO framework, and
- Activities that place the framework within a wider context of seismic risk factors and exploratory analysis of the cost effectiveness of potential treatment options.

Concurrently though all stages of the project engagement activities have been undertaken with engineering and the wider research and practitioner community to ensure the findings of

[1] https://www.nzsee.org.nz/db/PUBS/RBP_SocietalExpectationsReport-FINAL-for-Release.pdf

the project were shared with people responsible for technical input to New Zealand's earthquake standards and design approaches.

Table B3 and Table B4 summarise the project workshops for the development of the Earthquake Performance Outcome Framework and the building scan and cost review, respectively.

Table B3 Workshops to support Earthquake Performance Outcome framework development and building typology categorisation

Workshop	Date	Attendees
Exploratory workshop on Integrating Societal Expectations into the Design of Buildings	30 March 2022- 3 hour virtual	32 attendees representing social science, engineering, policy, practice, and research perspectives
Performance outcome framework development	8 June 2022 – half day in person	Project team and subject matter experts
Performance outcome framework development	13 September 2022 – one hour virtual	Project team
Societal expectations gap analysis and impact descriptors	27 September 2022 – half day in person	Project team and subject matter experts
Mapping outcomes and building groups	14 October 2022 – full day in person	Project team
Mapping outcomes and building groups	2 November 2022 – 3 hour virtual	Project team
Updated Conceptual Approach, Building Elements and Looking Forward	13 December 2022 – 3 hour virtual	Project team
Evaluation of current Code settings and societal expectations for 'Typical' Buildings	8 February 2023 – full day in person	Project team
Evaluation of current Code settings and societal expectations for 'Typical' Buildings	22 February 2023 – full day in person	Project team

Table B4 Workshops to support building system and cost review

Workshop	Date	Attendees
Intervention analysis	8 June 2022 – half day in person	Project team and subject matter experts
Gap analysis of the built environment to establish 'stylised facts'	16 June 2022 – full day in person	Project team and subject matter experts

Gap analysis of the societal expectations research workshop	27 September 2022 – half day in person	Project team and subject matter experts
Pinch Point Analysis	29 March 2023 – 1 hour in person	Mike Stannard, Helen Ferner, Kay Saville-Smith, and Hugh Cowan and Derek Gill.
Managing Seismic Risk	29 March 2023 – 1 hour in person	Mike Stannard, Helen Ferner, Kay Saville-Smith, and Hugh Cowan, Michael Bealing and Derek Gill.
Cost effectiveness	29 March 2023 – 2 hour in person	Derek Gill, Helen Ferner, Hugh Cowan, Kay Saville-Smith, Michael Bealing and Mike Stannard.

Figure B2 provides a high level conceptualisation of the scope, process and activities within the Resilient Buildings Project and how the work will, in turn, help to inform future codes, standards and practices.

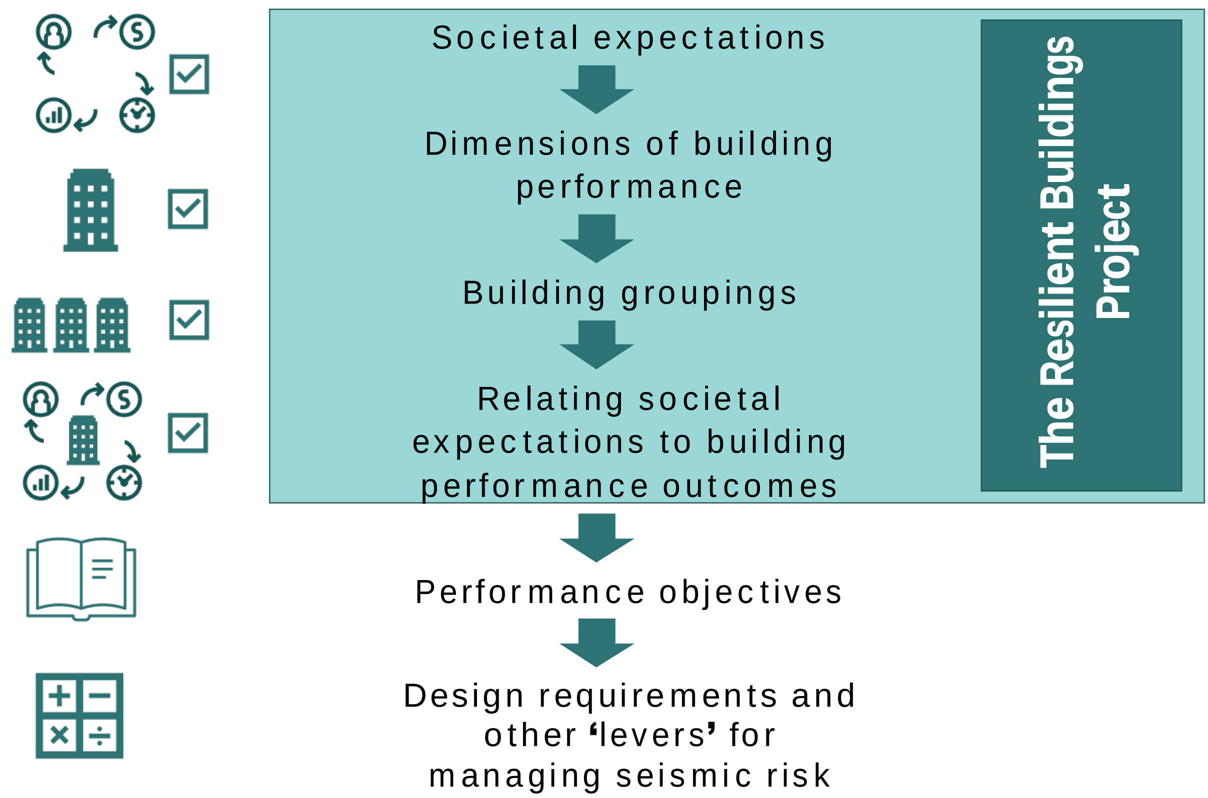

Figure B2. The Resilient Buildings Project Scope

B.4 Project Scope and Focus (Project Establishment Workshops held 2020)

Key takeouts from the project establishment workshops are summarised below.

Key Takeouts:

i. Project focus is future buildings.
ii. Scope is **vertical buildings and their services**, rather than all horizontal and vertical infrastructure (i.e., informed by relevance to NZS1170.5).
iii. The project contemplates all levels of earthquake shaking and across all levels of building performance.
iv. Outputs to be structured so they can inform other built environment infrastructure (e.g., bridges, etc.).
v. The project is to be completed in multiple stages with an initial focus on exploring societal preferences, the development of a clear definition of intolerable/tolerable building performance based on societal expectations.
vi. The aim is to be collaborative in nature, utilising wide industry involvement and associated work that has come before, and sharing project developments progressively with industry researchers and practitioners.
vii. Align timing of outputs so they can inform allied workstreams, (e.g., possible future NZS1170.5 updates).

B.5 Development of the Earthquake Performance Outcomes Framework

The aim was to use, interpret and translate the research findings on societal expectations (Stage 2) to define a framework for performance outcomes for the design of new buildings.

The approach used was to first explore the societal expectations research and then progressively develop an understanding of the parameters impacting building seismic building performance exploring the complexities and interdependencies. The performance framework methodology evolved through a series of workshops involving the project team. The work was iterative involving continuous refinement. In addition, several workshops were held during the course of the work with wider groups to explore concepts and test ideas and approaches.

Each workshop explored an aspect of Stage 3. Materials were prepared for each workshop by members of the project team and then the materials were revised and updated following each workshop to reflect the group's findings. These materials informed future workshops as the framework was progressively developed and the outputs form the appendices to this report.

A summary of the activities undertaken in support of the development of the framework is noted below:

1. **Exploratory Workshop on Integrating Societal Expectations into the Design of Buildings** held 30 March 2022 with specially selected and invited 32 attendees.

The purpose of the session was:

- To explore and test findings from the NZSEE resilient buildings project against expert opinion/research
- To explore how societal expectations can be mapped to engineering-based design principles and targets.
- To identify future research needs to enable the integration of societal expectations into engineering design.

The 3-hour virtual workshop involved three activities completed in groups, following a briefing about the project objectives and findings from the societal expectations research. Each group comprised a range of social science, engineering, policy, practice, and research perspectives. As well as testing the societal expectations, the workshop was an exploration of methods for connecting societal expectations with engineering-based outcomes.

Activity 1 focussed on sense checking the societal expectations findings against expert knowledge and understanding of disaster impact and recovery following earthquakes.

Each group was provided a map of a typical town or city with a range of common building types and prioritisation from a disaster recovery perspective as indicated by the survey. The groups were asked if they agreed or not with the research findings.

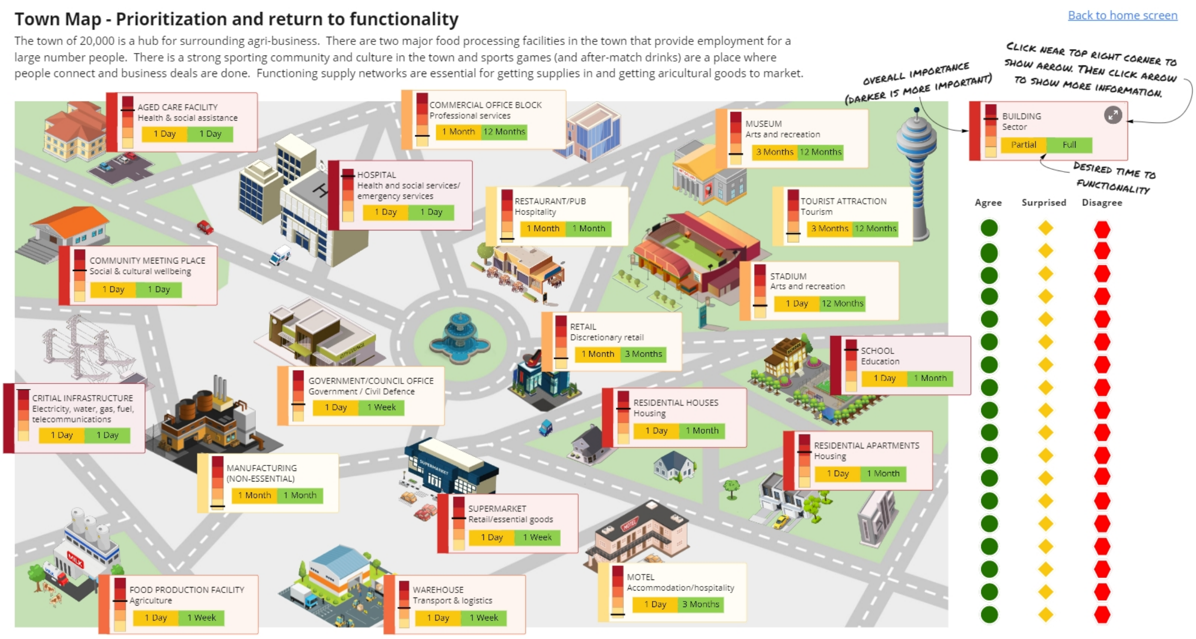

Figure B3. Typical town/city map used to communicate societal expectations findings in the 30 March workshop

Activity 2 focussed on reviewing with participants the prioritisation from an engineering perspective and exploring if / why they think current Code / design practice / regulations do not meet these expectations for the different building types.

Activity 3 focussed on exploring ways in which building user experiences and impacts of disruption could be mapped to engineering performance criteria (at a building level). Each group was assigned a building type. For each building type, they explored the elements of the building, and their minimum condition for five states of performance, ranging from fully operational through partially operational, shelter, life-safe during an earthquake, or near-collapse. They then considered the relative level of earthquake shaking that would be acceptable for each building performance state.

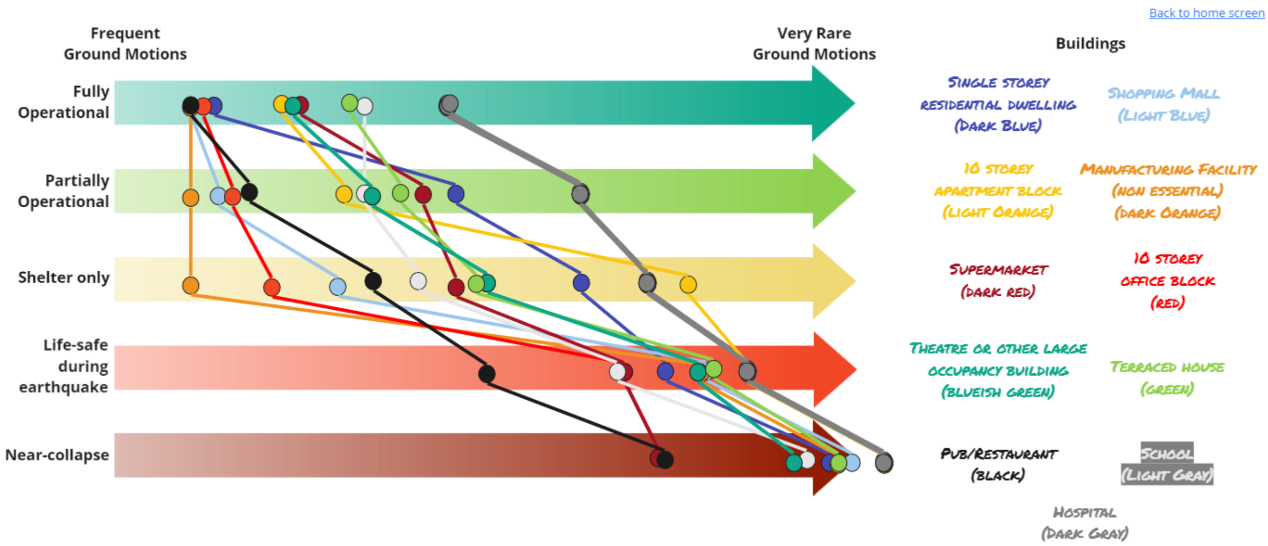

Figure B4. Results of Activity 3 for all groups held at the 30 March workshop

2. Performance Outcome Framework Development Workshop held 8 June 2022

The purpose of this activity was to collate and review previous work on developing societal expectations, identify key issues, and a prospective methodology for articulating contemporary expectations of building performance (in broad terms) and mapping these to dimensions of building performance.

The work was completed with the project team, along with subject matter expert Mike Stannard, through a workshop held on 8 June 2022. The work was informed by a literature scan and exploratory interviews with experts in the field, shared and debated in the workshop.

The group reworked Activity 3 of the 30 March 2022 workshop and mapped five states of performance ranging from fully operational through partially operational, shelter, life-safe during an earthquake, to collapse, ranked against earthquake return frequency for each building type. The approach was to combine the findings from this study with a fragility curve for each building type focussed particularly on amenity values. It is anticipated that future analysis will explore using a scenario-based approach the limits of likelihood and consequence.

Key Takeouts:

i. Need to consider full range of impacts and how they might map to building performance criteria.

ii. A desire for specificity when considering performance objectives has led in the past to dead ends. The level of specificity required needs careful consideration to avoid repeating past mistakes.

iii. Consistent terminology is required within the project (and across natural hazard risk more generally), and a data dictionary is required.

iv. Protection of property is not in the current NZ legislation; unlike Japan. A potential change for consideration is to add in property protection which would allow a focus on minimising damage in smaller earthquakes thus improving building resilience.

v. The recent societal expectations research highlighted the current NZ Building Code does not adequately differentiate between tolerable and acceptable.

vi. Amenity values are a key focus for improving building resilience.

vii. Scenarios offer a way to communicate risk (and test the approach).

viii. A diagram of the interdependencies for a building from design through whole-of-life would be a useful step in identifying hierarchies of need for information, sufficiency, and sequencing for decision making and would test the allocation of accountabilities and liabilities.

3. Earthquake Performance Outcome Framework Development

A series of workshops were held with the project team to explore different aspects of the framework as it was progressively developed (Figure B5).

Planning Meeting

One hour online meeting held on 13 September 2022

Objectives were to:

1. Discuss and consolidate the planned approach and execution of Stage 3 workshops regarding the framing of RBP project goals, deliverables, and linkages to other projects,
2. Confirm or refine expectations of timing and demand for project team contributions to project activities,
3. Consider any priority gaps in relevant skill sets or sector perspectives, and identify any topics or issues to be ‘parked’ or considered elsewhere, and
4. Review overall project stage governance and direction of effort to ensure that expectations are clear and well managed.

Workshop 1: Societal Expectations Gap Analysis and Impact Descriptors

All-day in-person workshop held 27 September 2022 in Wellington

Topics included:

1. Gap Analysis – Societal Expectations, and
2. Describe outcomes / in a general sense, including defining:
    a. Outcome categories – classification of effects that building damage has on the building owner, users, wider community, and environment,
    b. Descriptors – ways to measure or describe outcomes (e.g., number of casualties or financial loss),
    c. Levels - the continuum of outcome/impact severity (minor to catastrophic).

Workshop 2: Mapping Outcomes and Building Groups

All-day in-person workshop held 14 October 2022 in Wellington

Topics included:

1. Review proposed outcome descriptions,
2. Identify and group building typologies/functional characteristics based on the proposed outcome categories, and
3. Initial discussion about a framework for mapping impact levels and shaking severity or frequency for the different building groupings.

Workshop 3: Mapping Outcomes and Building Groups

Three hour online workshop held 2 November 2022

Topics included:

1. Review and revise outcome categories, descriptors, levels, and building groups, and
2. Use the proposed building groupings to explore and map outcomes to shaking severity and frequency (in a relative sense) for the different impact categories.

Workshop 4: Updated Conceptual Approach, Building Elements and Looking Forward

Three hour online workshop 13 December 2022

Topics included:

1. Review and revise outcome / impact measures and dimensions of building performance,
2. Relating dimensions of building performance to building elements, and
3. Discuss next steps.

Workshop 5: Evaluation of Current Code Settings and Societal Expectations for 'Typical' Buildings

All-day in-person workshop held 8 February 2023 in Wellington

Topics included:

1. Review the process being used to translate societal expectations to building performance, and
2. Evaluate expected performance of a "typical building" designed under existing Code settings and compare to desired outcomes based on the societal expectations research.

Workshop 6: Evaluation of Current Code Settings and Societal Expectations for ‘Typical’ Buildings

All-day in-person workshop held 22 February 2023 in Wellington

Topics included:

1. Review descriptions of the continuums of impacts for ‘Protection of Injury,’ ‘Protection of Amenity and Function,’ and ‘Protection of Assets’,
2. Evaluate expected performance of a “typical building” designed under existing Code settings and compare to desired outcomes based on the societal expectations, and
3. Review the building groupings, functional attributes, and characteristics for enhanced performance for each of the three dimensions of building performance based on human, social, economic, and environmental considerations.

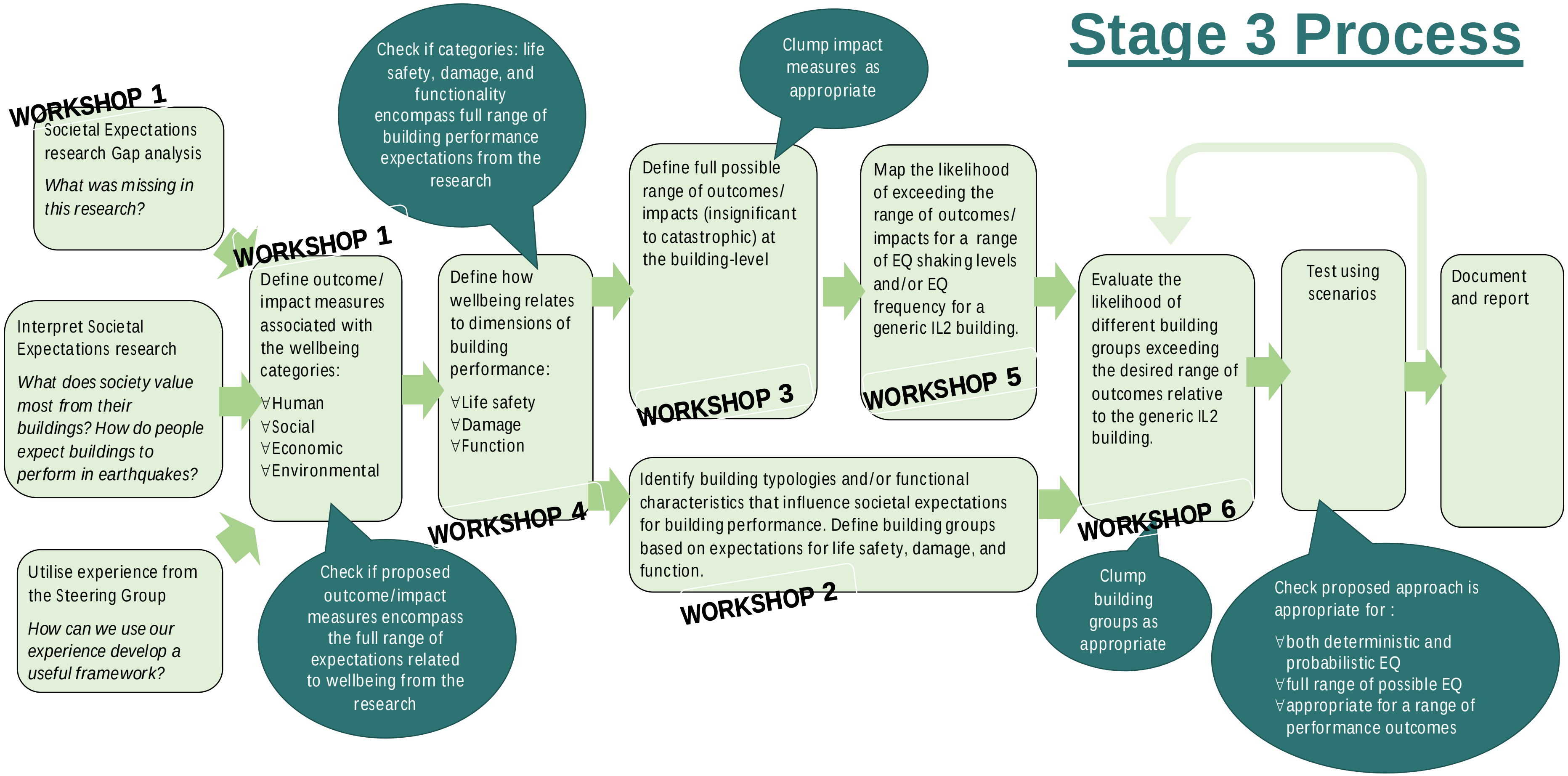

Figure B5. Stage 3 process

B.6 Context Development

Concurrently with the development of the performance outcome framework the project team completed a series of activities to inform and frame the development of the context of the framework within the built environment.

1. Gap Analysis of the Built Environment to Establish 'Stylised Facts' Workshop held 16 June 2022

The purpose of this activity was to undertake a comparison of the built environment (housing types, urban and town building typologies, density, and concentration of risk) as it was when the current Building Code settings were first conceptualised in the 1970s with that of current and possible future buildings.

The exercise provided context for how and why our engineered buildings have evolved over time and identified the complexities and interdependencies for change, particularly drivers for the expansion or densification of urban centres. The objective was to establish 'stylised facts' about the New Zealand built environment to inform the development of performance objectives.

The workshop was informed by both a literature scan and exploratory interviews with experts in the field: Ken Elwood (MBIE EQC Chief Engineer Building Resilience), Eric Crampton (Principal Economist The NZ Initiative), David Dowdell (BRANZ), David Johnson (Massey University), Hugh Cowan, Helen Ferner (NZSEE). The workshop provideda distillation of knowledge on changes over time for land use planning and resilient building design in New Zealand.

The workshop provided briefings on changes in land use planning, changes in the policy environment, and changes in the insurance environment and explored the following series of questions:

- How have residential, commercial, industrial, and public buildings changed? How we use them over time? Possible future changes?
- What were the drivers for change?
- Have the interdependencies between building types and infrastructure changed over time?
- How have urban centres in New Zealand changed over time?
- Are there also geographic differences across NZ? Are there differences between urban and more rural areas in different parts of NZ?

Key take-outs from the workshop are included in Appendix K.

2. Gap Analysis of the Societal Expectations Research Workshop held 27 September 2022

The purpose of this activity was to explore and identify any possible gaps arising from the societal expectations research to inform the development of tolerable impacts to guide the development of building performance objectives. The work was undertaken using a workshop approach held on 27 September 2022 where the discussion questions for the workshop were:

1. Is there anything within the provided information about societal expectations that do not align with your own observations / expert opinion?
2. Are there any ambiguities or elements that more clarity or evidence is needed?
3. How might these expectations change with current or emerging trends affecting our built environment and the nature of how communities use buildings?

Materials to inform the discussion at the workshop on a review of societal expectations were:

- Findings from the gap analysis of the built environment, completed in June 2022, and
- Risk Tolerance Slides (Full presentation available at https://youtu.be/Ty326nnv2Ok).

Key take-outs from the workshop are included in Appendix D.

B.7 Insights into Managing Seismic Risk

The aim of these activities was to gain insight into the issues associated with managing seismic risk and to develop a first-pass approach to improve building performance in earthquakes.

1. Intervention Analysis Workshop held 8 June 2022

The purpose of this activity was to investigate the options available to address the gaps between societal expectations and current Code settings and explore the economic implications of reform to improve building resilience.

The work was completed with the project team through a workshop held on 8 June 2022. The workshop was informed by both a literature scan and exploratory interviews with experts in the field: Ken Elwood (MBIE EQC Chief Engineer Building Resilience), Eric Crampton (Principal Economist The NZ Initiative), David Dowdell (BRANZ), David Johnson (Massey University), Hugh Cowan, Helen Ferner (NZSEE). The aim was to clarify the knowns and known-unknowns for a group of key questions:

- Is there a cost premium and if so, what is its level for improving seismic resilience in new building construction?
- What are the types or categories of potential economic benefits for improving seismic resilience and how large are the likely benefits in economic terms?
- Why don't we find many buildings in New Zealand constructed above Code when Kiwis seem to want more resilient buildings?
  - o What factors are at play on the supply side? Perceptions of increased costs, inertia including traditional building industry construction structure and practices? Others?
  - o What factors are at play on the demand side? Insurance policy distortions to people not understanding risk for low frequency high impact events? Others?
- What policy levers exist in addition to the seismic provisions of the Building Code to improve new building seismic resilience?

Key take-outs from the workshop are included in Appendix L.

2. Pinch Point Analysis Workshop held 28 March 2023

The purpose of this activity was to explore and identify possible pinch points in each of the design process, procurement and funding processes, and the building construction and compliance processes across the system. The aim was to assist in identifying possible levers that could be used to reduce the impacts of earthquakes on the built environment.

The activity was informed by both a literature scan and discussion with participants at a workshop held on 29 March 2023. Workshop participants included: Derek Gill, Mike Stannard, Helen Ferner, Kay Saville-Smith, and Hugh Cowan.

Key takeouts from this activity are included in Appendix K.

3. Scenarios For Building System Response to Shaking

The purpose of this activity undertaken in February and March 2023 was to develop outcome scenarios for a range of earthquake shaking levels, from intermediate to severe to test the framework settings for current Code-compliant ordinary buildings at a community level and to explore the potential impact the framework proposes. The scenarios were derived from the national seismic hazard model using approximate mean ground motions and a plausible range of durations for one geographic region of New Zealand. The idea was to develop scenarios that can be used to support discussions with a range of stakeholders about building performance over a range of significant earthquake shaking and to explore the potential cost implications of different resilience options.

The key takeouts from this activity are included in Appendix J.

4. Options for Managing Seismic Risk

The purpose of this activity was to identify, group, and document the range of possible options for managing seismic risk. These have been identified as possible ‘levers’ that potentially could be used to improve the resilience of New Zealand buildings, recognising that these extend well beyond considerations of hazard levels or other Code settings.

This activity undertaken in March and April 2023 followed the pinch point analysis and drew on the project team’s insights gained through the full course of the project from its inception. The objective was to consider the full context in which buildings in New Zealand are conceived, procured, designed, constructed, and used. The aim was to explore the question:

- What are the levers and options that exist to meet the need for more resilient buildings identified by the societal expectations research?

The key takeouts from this activity are included in Appendix K.

5. Cost effectiveness Workshop held 29 March 2023

The purpose of this activity was to develop and test a methodology for investigating the cost effectiveness of different options for improving seismic resilience.

The methodology was tested and developed in a pilot workshop held on 29 March 2023 with a small group comprising Derek Gill, Helen Ferner, Hugh Cowan, Kay Saville-Smith, and Mike Stannard.

The aim of the workshop is to test the question.

- What are the behavioural and other structural/ physical options that could be effective in limiting the onset of damage in earthquakes?

Key takeouts from this activity are included in Appendix L.

B.8 Engagement and Outreach Workshops

A series of engagement and outreach activities, workshops, and presentations were also held during this Stage of the project:

- **2022 NZSEE Conference Plenary: The Resilient Buildings Project** held 28 April 2022 with 230 attendees

  The purpose of the session was to report the results of the Resilient Buildings Project snapshot of societal expectations toward seismic risk to inform future performance objectives for new buildings. This session was designed to inform and engage the earthquake engineering and related technical community in the project.

  The session provided background to the project and an overview of the project method and research findings. Participants were asked to participate through a Miro board developed using the results of the research.[2]

  Participants were also asked to contribute to a series of interactive polls with questions posed throughout the session. The primary goal of these polls was to bring to life the findings from the study and to engage the audience.

  1. What does life safety mean to you?
     a) Protecting the most people possible
     b) Prioritising protection of the most vulnerable people
     c) Preserving capacity for recovery
     d) Reducing psychosocial trauma

  2. Of the following buildings, which would you prioritise most for improved seismic performance?
     a) Marae or other community meeting places
     b) Residential houses
     c) Residential apartments
     d) Supermarkets
     e) Aged care facilities

  3. All communities have the same priorities for investment in seismic resilience?
     a) Yes
     b) No, communities place different values on different buildings

[2] https://miro.com/app/board/uXjVO6UoTUY=/?share_link_id=39111383631.

c) No, community context (geography, isolation, capacity) impacts risk tolerance and resilence priorities
d) I don't know

4. Building owners and users believe seismic resilience is the most important aspect of a building design?
    a) Yes, life safe and low damage design is critical
    b) Yes, but only the life safety part of seismic resilience
    c) No, seismic resilience is something forced upon them by regulation
    d) It depends on the type of building

The session included a discussion among panelists: David Kelly (CE, Master Builders), Dan Neely (Manager, WREMO), Eric Crampton (Chief Economist, NZ Initiative), and Alistair Luke (Principal, Jasmax Architects).

Panel discussion questions were:

- The voices we heard through the project had a very broad take on concepts such as 'life safety' and 'immediate post-event functionality'. What are your view(s) on these concepts based on your role and lived experience?
- It seems a building stock that is able to support social and economic recovery following an earthquake is becoming an important priority. What is your sense of what enables social and economic recovery?
- The study identified a diversity of risk tolerance and preferences across participants and communities. What are your thoughts on communities having different seismic risk preferences and risk tolerances? Is this your experience? And should/could we be doing more to account for this?
- The RBP project asked participants to put seismic resilience in the context of all the other priorities in our built environment, where do you think seismic risk sits against other things building owners, occupiers, and communities are concerned about? And do you anticipate that might change over time?

The session concluded with all participants being asked to consider:

- Having heard about the RBP findings – How does this compare to what you are hearing in your respective markets and social circles?
- What are clients demanding? In your mind, what are the priorities for improving the seismic resilience of our building stock?

The session offered participants an insight into some of the complexities of the topic, together with comment on the need for a systems view (and approach) to improvements in seismic risk treatment – in client conversations, in policy and regulation, and greater clarity around the possible distribution of potential costs and benefits.

- **Presentation at the 12th National Conference on Earthquake Engineering** held 27 June – 1 July, 2022, Salt Lake City Utah, USA.

  The presentation titled *"Investigation into societal risk tolerance for the seismic performance of new buildings in New Zealand* highlighted the findings of the societal expectations research.

- **Resilient Buildings Project presentation to QuakeCoRE** held 12 August 2022, Presenter Shannon Abeling.

  The presentation focussed on findings from the societal expectations research and planned approach to map tolerable impacts into a framework.

- **Resilient Buildings workshop with the United States National Institute of Science and Technology (NIST)** team held 9 November 2022

  The workshop shared approaches being used in the USA and NZ to identify tolerable impacts and translate these to performance objectives.

- **Presentation at the Fifth International Workshop on Seismic Performance of Non-structural elements (SPONSE)** held 5-7 December 2022 at Stanford University, USA

  The presentation titled "*A Snapshot of Societal Expectations for the Seismic Performance of Buildings in New Zealand – what this reveals about future design considerations for non-structural elements"* highlighted the findings of the research and how non-structural element performance objectives are being considered in the development of tolerable impacts.

- **Community and Urban Resilience (CURe) Annual Poster Symposium, University of Canterbury**, held Christchurch 21 March 2023

  The poster titled *"Resilient Buildings Project: Understanding Societal Expectations for the Seismic Performance of Buildings"* outlined the findings of the societal expectation research.

- **2023 NZSEE Conference Plenary: The Resilient Buildings Project** held 20 April 2023 with 420 attendees

  The purpose of the session was to report the development of the performance outcomes framework since the last NZSEE conference a year ago. The session was designed to inform, engage and seek feedback from the earthquake engineering and related technical community on the project.

  The session outlined the framework in a brief presentation. Participants were invited to participate in a series of interactive polls during the following Q+A session with some members of the project team.

1. Do you think the requirements for a building's performance should depend on the setting of the building?
   a. Yes
   b. Yes but this seems to hard to do
   c. No
   d. Not Sure

2. From your perspective, is it better to have more or less building groups (and subsequent design requirements):
   a. As few as possible
   b. Somewhere in the middle
   c. As many as needed to represent all nuance
   d. Don't know

3. Going forward, which aspects of performance do you think need the most attention to support the resilience of our building stock?
   a. Structural elements
   b. Interior fit-out

c. Building envelope
d. Services (in-building)
e. Emergency systems (fire systems etc)
f. Egress paths
g. Other

4. Where do you think we have the biggest opportunity for influencing the resilience of our building stock?
    a. Design demand (changes to hazard levels in Code)
    b. Design standards (e.g. regularity requirements, LDD technology)
    c. Industry practices (design, construction and compliance)
    d. Land use planning
    e. We don’t need to improve the resilience of our building stock

5. In terms of wider industry practice, where do you think we need to focus attention to improve the resilience of our building stock?
    a. Engineering sector design capability
    b. Design quality assurance processes
    c. Construction quality
    d. Regulatory compliance processes and practices
    e. Risk communication and client education
    f. Liability regime
    g. Other

6. What do you see as the biggest barrier to improving the resilience of our building stock?
    a. Cost
    b. The management of existing building stock
    c. Designer capacity
    d. Client preferences
    e. Tenant preferences
    f. Sustainability/carbon performance objectives
    g. Trust in engineers
    h. Compliance barriers

Appendix C:

Consequence Information Sheets

The following information sheets were presented during a workshop titled "Interpreting Societal Expectations for Tolerable Performance," which was held on 8 August 2022 at the QuakeCoRE Annual Meeting and had approximately 70 attendees.

The information sheets represent a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the dimensions of building performance. The information provided reflects sentiments expressed by the original research participants. The information sheets were intended to be used as a resource for the QuakeCore workshop participants to describe outcomes and impacts.

Note that some language has been revised to reflect updates to terminology made after the workshop. Changes include removing the term 'impact categories' and replacing it with either 'dimensions of building performance' or 'consequences,' with consequences referring to both outcomes and impacts. Additionally, the consequences used to describe the dimensions of building performance were revised as thinking on the topic developed. For example, 'damage and disruption to adjacent properties' was removed from consideration in the proposed framework because the consequence occurs outside of the building footprint and can be dependent on external factors (e.g., adjacent building proximity and height).

C.1 Types of Consequences Considered

Societal expectations of buildings in earthquakes reflect both community and individual interests. so, the consequences (i.e., the outcomes and impacts of earthquakes) can be described at either a community or an individual building level.

RBP Stage 3 Workshop 1 focused on exploring consequences that are site-specific (i.e., at the individual building level). This narrowing of scope was based on the reasoning that tolerable or acceptable impacts at a community level will be achieved through the design of individual buildings and lifeline infrastructure systems to support resilience1.

Community resilience is a product of the design (and performance) of individual buildings over decades because buildings are planned, financed, and constructed by different owners at different times. Achieving tolerable outcomes at a societal level must rely on dependencies among many aspects of the built environment. So, anticipating where incremental adjustments would accrue significant performance value over time is an objective of this work.

[1] Considering performance at the individual building level to improve community resilience is also the approach proposed in the NIST-FEMA Special Publication FEMA P-2090/NIST SP-1254 *Recommended Options for Improving the Built Environment for Post-Earthquake Reoccupancy and Functional Recovery Time* (available at https://doi.org/10.6028/NIST.SP.1254)

Dimensions of Building Performance and Related Consequences

a) Protection from Injury
    i. Fatalities and Injuries
    ii. Ability to Evacuate
b) Protection of Property
    i. Damage to Systems and Elements
    ii. Damage to Contents
    iii. Damage/Disruption to Adjacent Property
    iv. Building Waste and Carbon Emissions
c) Protection of Amenity and Function
    i. Ability to Shelter in Place
    ii. Ability to Reoccupy/Function
    iii. Ability to Repair (Time and Cost)

Discussion Questions for the Workshop

Participants were asked to reflect upon the following questions as they read the information sheets. The topics were discussed during the workshop.

Topic 1: Review of Societal Expectations

1. Is there anything within the provided information about societal expections that does not align with your own observations / expert opinion?
2. Are there any ambiguities or elements that indicate more clarity or evidence is needed?
3. How might these expectations change with current or emerging trends affecting our built environment and the nature of how communities use buildings?

Topic 2: Describing outcomes and impacts

1. What are your thoughts on the dimensions of building performance?
    - Do these dimensions make sense?
    - Is there anything missing?
    - Are they grouped appropriately?
2. What are possible outcome indicators for each dimmensions of building performance?
    - How can the proposed indicators be measured?

Fatalities and Injuries

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection from Injury. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

New Zealanders expect new buildings to withstand a major earthquake without creating a significant threat to the life safety of building occupants or passers-by. This provision of safety appears to be a non-negotiable item and is not, within reason, influenced by cost.

"So we kind of accept that there's going to be some level of damage, but there should not be any ongoing risk to life safety."

Generally, properties with high-peak and long-duration occupancies were prioritised.

- Many believed that buildings with **high maximum occupancy**, particularly buildings with multiple stories, should be built to a higher standard. Catastrophic failure of these larger buildings could result in mass loss of life and injuries, which would be unacceptable.
- Reducing the risk of failure in buildings where occupants are **exposed for long periods** was also a priority (e.g., people sleeping in their residences, patients in hospital beds, and prisoners).

Participants often conflated the risk of fatalities and injuries with the capacity to sustain life immediately after an event and to provide emergency response services.

- **Facilities that sustain life** (e.g., hospitals) and **support response activities** (e.g., civil defence hubs) are important.
- Participants also highlighted the importance of facilities that, if severely damaged, would create significant pressure on other critical facilities (e.g., damage to aged care facilities could put additional pressure on hospitals).

Priorities for life safety are not necessarily linked to objective calculations of building occupancy. More common is consideration of the individuals likely to occupy a building.

- There is a strong desire to **protect vulnerable building occupants**, such as those with low mobility or reduced capacity to take life-saving measures (e.g., injured, sick, physically or mentally disabled, elderly, and children)
- Not as strongly but commonly, participants felt that the **protection of people with skills** essential to the response and recovery or vital to the economic recovery of a region should also be prioritised.
- Participants often noted that buildings that act as **natural gathering points** should be prioritised to protect life safety in the event of an aftershock (e.g., community centres, maraes, hospitals and civil defence centres).

"Wanting to feel safe" was a common sentiment when discussing the life safety of buildings.

- This feeling of safety is often based on the perceived seismic performance of structural elements as well as non-structural elements and contents (e.g., supermarket stacking).
  Perceptions of safety, particularly for buildings housing vulnerable persons, are also considered important for alleviating mental health strain post-event.

Ability to Evacuate

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection from Injury. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Preserving life remains the minimum requirement for the seismic performance of buildings in New Zealand. There is a widely held expectation that everyone should be able to exit a building safely following a major earthquake.

"I think probably the most important thing is that the building allows people to get out safely."

Participants discussed potential hazards during the evacuation process.

- **Structural failure** of egress routes (e.g., stairwells) was largely considered unacceptable.
- Unsecured contents and damaged to non-structural systems (e.g., ducting) have the potential to **block egress routes**, preventing the evacuation of building occupants.
- **Items falling from damaged buildings** may pose a risk to evacuating occupants or passers-by. Falling glass was cited as a particularly concerning hazard in urban areas.
- If earthquake shaking damages reticulated gas lines and fire protection systems (e.g., firewall barriers and sprinkler systems), **fire** in one building could cause a conflagration that spreads to adjacent structures. This would be an imminent threat, potentially trapping people inside buildings.

Participants prioritised some building types over others based on the number and vulnerability of building occupants.

- Buildings or situations with the **potential for panic or chaos** post-earthquake should be designed to reduce the risk of injuries and fatalities relating to human responses to events. For example, participants emphasised the need for safe evacuation routes from buildings that house **large crowds** to encourage safe, calm, and quick egress from a building.
- When considering the **vulnerability of building occupants**, participants often discussed the ability of occupants to protect themselves and/or escape. Many believed that buildings that accommodate high risk occupants (e.g., prisoners) or who require support for evacuation (e.g., children, elderly, sick, or disabled) should be designed to a higher standard.
- Some queried whether higher standards are warranted for buildings where users have less **choice about entering the building** (e.g., a prison or hospital, versus a retail shop).
- Additionally, a few participants believed that building users' **familiarity with the building** and seismic risks (or lack thereof) should be considered, recognising that visitors to an area may feel anxious following an earthquake and may lack the means to self-care post-event. This approach would prioritise buildings such as motels, hotels or some tourist attractions.

Many participants expressed a **desire to 'feel safe'** within their buildings in case of aftershocks.

- The feeling of safety could come from a lack of physical building damage, reliable and redundant egress routes within the building and assurance from an engineer of building stability after a moderate or large earthquake.

Damage to Systems and Elements

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Property. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Experience from recent earthquakes revealed that many members of the public were surprised by the amount of damage buildings sustained, despite being Code compliant. This points to an expectation that buildings should be designed not just to prevent loss of life, and support building functionality, but also to prevent damage.

"You shouldn't get much damage in buildings, unless it's a fairly major earthquake… They shouldn't be needing to be fixed by the occupant after every single quake."

Most participants expected their building or buildings in the community to withstand moderate earthquakes with minimal to no impact on amenity.

- Building **durability** (i.e., buildings that don't require continuous significant repairs) was valued by participants as it reduces personal or business disruptions, as well as whole-of-life costs.

Minor to moderate earthquake damage was generally acceptable to participants (provided it does not occur too frequently) and would be expected given that New Zealand is a seismically active country.

- Minor damage was typically described as damage to **non-structural systems** (e.g., cosmetic cracks to plasterboard, damage to ceiling tiles or mechanical ducts). Moderate damage could affect the **weather tightness** of a building and could also include damage to **service connections** (i.e., water).
- Minor to moderate earthquake damage was typically viewed as **non-urgent** (i.e., minimal disruption to services) and able to be incorporated into regular building maintenance schedules. This type of damage was not expected to affect building functionality.

Tolerance for earthquake damage is subjective and depends on a number of factors, including previous earthquake experience, the vulnerability of the building occupants, and the primary use of the building.

- The **dependence of users** on their building affects tolerance for building damage. For example, many jobs in the hospitality, manufacturing and primary production industries require physical place of operations. On the other hand, many service-based jobs can be adapted for working from home, and some retail can be moved online.
- Tenants appeared to be slightly less tolerant of minor and moderate building damage.
- Some participants noted that non-structural damage could represent a **visual reminder of earthquake shaking**, which may be detrimental to mental health.

Damage to Contents

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Property. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Damage to building contents from earthquake shaking can result in a significant loss (financial or cultural) and negatively affect the wellbeing of building users. Overall, contents damage was not an emphasised topic in the interviews or focus groups, but some insights were collected.

"I think staff coming in and seeing any sort of damage was really detrimental to their wellness. One of the things we did was make sure that the ceilings were intact, any damage to plant had been rectified, and any furniture that'd been overturned was upright. From a wellness perspective, those things did have a fair impact on people."

Following an earthquake, participants generally expected unsecured items to have moved around.

- There was typically high tolerance for disturbance to contents, provided it did not present a significant **life safety risk** to building occupants (e.g., small items falling off shelves was OK, but bookshelves falling over was less acceptable).
- Some participants noted that damage to contents could represent a **visual reminder of earthquake shaking**, which may be detrimental to mental health.

The contents of some buildings represent a higher cultural or fiscal value than the building itself. For these building types, the protection of contents is often more important than ensuring low damage to the structure.

- Participants often felt it was important to ensure that the contents of buildings that hold items with **heritage and cultural value** (e.g., museums, art galleries, maraes) are undamaged. Loss of important taonga may occur if these building types suffer significant damage.
- Manufacturing facilities and buildings that house computer servers were identified as building types with contents that represent a significant financial investment, where **limiting damage to plant** is a key performance objective.
- It is essential to ensure that buildings **containing hazardous materials** (e.g., acids) are not damaged in a way that would cause containment issues.

Damage/Disruption to Adjacent Properties

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Property. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Participants were aware that damage to one building could impact surrounding buildings and infrastructure through direct damage during an earthquake, the presence of cordons, and disruption during repair/demolition.

"Even if you had a highly resilient, base-isolated building in the CBD, you might be surrounded by buildings that are vulnerable…. You may not be able to access [your] building for months, if not a year or two, simply because of the dangers that those adjacent buildings pose to your highly resilient building."

There was low tolerance for damage to buildings that would damage or cause **health and safety risks** to their surroundings.

- Participants generally expect buildings to withstand a major earthquake without creating a significant threat to the life safety of neighbouring building occupants or passers-by.
- **Fire** following an earthquake was a concern for some participants. Damage to the fire safety system in one building could result in a conflagration that spreads to adjacent structures.
- Many noted the importance of ensuring that **critical access routes**, **critical infrastructure** and other buildings with important functions or high community value are not impacted by damage to neighbouring buildings (i.e., building debris or risk of collapse).

The damage to adjacent buildings may cause a safety hazard that **prevents access** to other buildings in the area, delaying repairs and, ultimately, the return to function of those buildings.

- Major earthquake damage to surrounding buildings that results in **cordons** or similar restrictions that prevent people from accessing their buildings for extended periods (e.g., two years or more) was considered irrecoverable for some participants.
- One participant suggested that building owners should be **liable for the costs** associated with preventing the return to function of adjacent properties.

The expected (poor) performance of neighbouring buildings was cited significant **inhibitor to building more seismically resilient buildings**.

- Building owners/developers were concerned that they may not be able to realise the benefits of a seismically enhanced building due to damage associated with neighbourhood properties, including the presence of a cordon, reduction in foot traffic, or perception of safety of an area.

Building Waste and Carbon Emissions

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Property. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Reducing the impacts of earthquakes on the natural environment is an emerging priority. Many participants discussed the environment's role in underpinning human existence and community wellbeing through the provision of water and food (mahinga kai). Some noted that we have a duty of kaitiakitanga (guardianship).

"It doesn't matter what happens, if we don't look after the environment, we have nowhere to live." … "The environment doesn't come before people, but it's pretty high up there."

In general, participants had low tolerance for impacts on the natural environment that were perceived to be long-lasting or potentially irreversible.

- **Contamination of ground and waterways** were often viewed as consequences that could last for generations.

Reducing building waste following earthquakes is a priority for many.

- Participants noted that many places are already constrained in their ability to manage waste and therefore believed that large quantities of building waste following an earthquake would likely **overwhelm waste management facilities** in most parts of the country.
- The inefficient management of building waste, in particular, **hazardous building waste** (e.g. asbestos), could lead to the contamination of the surrounding environment and have adverse effects on public health.
- Some participants were concerned that modern building techniques/materials, such as the presence of composite and mixed materials, could result in lost opportunities to **re-use** or **recycle** building materials.

The carbon cost of earthquakes was discussed by some participants but was not a universally understood concept.

- There was concern over the potential loss of **embodied carbon** through building demolition and disposal and the embodied and **operational carbon** required to replace damaged buildings. However, the relative impact of this was not generally well understood.
- Some participants discussed building **lifecycle assessments** and observed that repairing a damaged building is often more sustainable than demolishing and rebuilding. Although, it was noted that new buildings can have operational carbon saving.

Containing other potential pollutants (not from building demolition waste) was also a priority.

- It is essential to ensure that buildings **containing hazardous materials** (e.g., acids) are not damaged in a way that would cause containment issues.
- **Sewage** was also identified as a potential pollutant of land and waterways if there is damage to underground piping or wastewater treatment facilities.

Ability to Shelter in Place

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Amenity and Function. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

One of the main priorities following a major earthquake is to ensure that the **basic survival needs** of the affected population can be met. This can be achieved through the provision of shelter (i.e., a warm, dry, safe and secure location) where clean water, sanitation, food, medication, and rubbish collection services can be obtained.

"We can't stop earthquakes from happening, but we can have processes in place where disruption to people's lives due to lack of basic necessities (shelter, food, water) can be addressed."

People sheltering in damaged buildings should be able to maintain **safe** and **sanitary** living conditions.

- Many expressed a desire to not only be safe but **'feel safe'** in their buildings following a major earthquake to ease anxiety about possible damage in aftershocks.
- **Telecommunications** and **power** were often highlighted as the highest priority utilities to allow for communication, heating, and cooking.
- People were generally accepting of disruptions to utilities such as water and sewerage for days, weeks or even months after a major earthquake, as long as **temporary measures** (e.g., community water points and portaloos) could sustain basic needs. However, temporary sewerage measures were often considered unsustainable for large apartment buildings.
- Buildings used for shelter should be absent of **hazardous material** (e.g. friable asbestos).

It is preferable that people take shelter in their own residences.

- This is particularly important in **higher-density urban areas**, where the displacement of large numbers of people may be beyond what emergency services can reasonably manage.
- Similarly, it is important that residents of **assisted living facilities** are not disrupted in a way that would require high-dependency or high-risk residents to be relocated: placing individuals at risk and potentially further increasing the burden on other healthcare facilities.

Temporary accommodation needs to be provided for stranded visitors or locals with damaged homes.

- Participants often suggested that hotels/motels could provide this accommodation, or if too many people are displaced, community buildings (e.g., Maraes, community centres, schools, stadiums) could be repurposed to offer temporary housing.

People are likely to move away from an area if they cannot obtain/maintain safe, secure, and sanitary housing in a reasonable timeframe after an earthquake.

- An unstable home environment, such as a quake-damaged house, can affect **physiological and psychological health** and reduce one's ability to recover socially and economically.

- Participants often viewed **mass displacement of populations** as permanent and intolerable.

To encourage people to shelter in place, stay in their communities, and reduce ongoing burden to emergency services, it is important to enable individuals to look after themselves and others.

- Buildings in the community identified as helpful for individuals to **retain independence** include essential retail (supermarkets and pharmacies), petrol stations, and banks (for ATM/cash access).

Ability to Reoccupy/Function

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Amenity and Function. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

Prolonged disruption to building occupancy and functions can have cascading economic, social, or environmental impacts on individuals and communities. There are growing expectations that post-earthquake functionality should be considered in order to mitigate these adverse impacts.

"I think we need to aspire to something greater than [life safety]. I think the experience out of Christchurch suggests that society wants and expects more than that."

Functionality refers to the availability of a building to be used for its intended purpose. Research participants discussed many of the ways that damaged buildings could be used at a reduced capacity following a major earthquake (e.g., access limitations, reduced services or output capacity).

- Buildings in which safety (fire, structural, overhead hazards) is maintained or restored following an earthquake could be used to **provide shelter**. Buildings used for shelter may not be weathertight and could have damage to mechanical, electrical, and plumbing systems that cause disruptions to building services. There may also be some access restrictions (e.g., non-functional elevators).
- Not all building types will need to provide shelter for occupants after an earthquake but may still be expected to **protect contents** (e.g., computer servers or machinery) until repairs are made and functionality is restored.
- Some buildings may only be operational for **essential services** (e.g., health care or animal welfare) or **emergency functions** (e.g., stadiums or community meeting places acting as civil defence centres). These buildings may have alternative means of utilities (power, water, etc.).
- Other buildings could operate with **reduced production capacity**. These buildings may have intermittent power or power in only some parts of the building. There may be restrictions on the number and type of people allowed in the building at any time (e.g., closed to the public).
- Larger buildings may continue to operate with sections of the building cordoned off.

The level of functionality required after an earthquake depends on the building type. The desired level of functionality in a given building also changes over time.

- Early priorities are buildings with functions that support life, including **emergency response** services and **healthcare**, and buildings that support physiological health, such as shelter. Basic building-based services that support **animal welfare** are also a priority in rural areas.
- It is essential to ensure that buildings **containing hazardous materials** (e.g., acids) are not damaged in a way that would cause containment issues.
- It is also important to ensure some function is restored/maintained in facilities that could have a **cascading impact** on the recovery if they are not operational. For example, (basic) transport/warehousing services and aged-care facilities.
- The **dependence of users** on their building affects functionality requirements. For example, many jobs in the hospitality, manufacturing and primary production industries require physical place of operations. On the other hand, many service-based jobs can be adapted for working from home, and some retail can be moved online.

Ability to Repair (Time and Cost)

The following is a summary of findings from 'Societal Expectations for the Seismic Performance of Buildings' related to the proposed dimension of building performance, Protection of Amenity and Function. The information provided reflects sentiments expressed by research participants. It is to be used as a resource for describing outcomes and impacts.

There are growing societal expectations for swift social and economic recovery and to minimise the environmental impacts of earthquakes. These expectations reflect an increasing desire for buildings to remain functional and/or be readily repairable after an earthquake.

"The expectation is that we need to provide more resilience, not just to protect life, but so that buildings can be reused [after a major earthquake]."

Participants typically indicated that earthquake damage with repair timelines in the order of weeks with minimal disruption to services is generally acceptable and would be expected given that New Zealand is a seismically active country.

- This repair timeframe was typically associated with relatively **superficial damage** that does not represent a **safety hazard** (e.g., cosmetic damage such as damage to paint, plaster, or plasterboard and other superficial cracks).
- Building operations would typically continue to function leading up to and during repairs.
- Some participants suggested that repairs could be incorporated into regular building maintenance schedules, **minimising disruptions** to building users and tenants.

Participants were less accepting of earthquake damage with repair timelines in the order of months, or that may cause significant disruption to building services.

- This repair timeframe was typically associated with more **intrusive** and significant repairs for both **structural and non-structural elements**.
- Disruptions from more significant types of damage could be mitigated if repairs are **completed in sections,** such that parts of the building are closed for days to weeks rather than the entire building being closed for months.

Major damage (where a building would require replacement) was considered unacceptable for most, though not all, participants.

- The **dependence of users** on their building affects tolerance for building damage. For example, many jobs in the hospitality, manufacturing and primary production industries require physical place of operations. On the other hand, many service-based jobs can be adapted for working from home, and some retail can be moved online.
- Damage that is beyond repair was most often associated with structural damage that represents a significant **life-safety hazard**.
- However, it was noted buildings may be demolished if they become **economically infeasible** to repair, despite being structurally sound.

Several participants pointed out that tolerance for disruptions and costs from earthquake damage and the associated repairs is highly variable.

- Factors affecting individual tolerance for disruption included previous earthquake experience, the vulnerability of the building occupants, and the primary use of the building.
- The availability of **earthquake insurance** influenced some participants' tolerance for the cost of repairs, with some indicating that having insurance made them more accepting of damage that would require repairs.

Many building owners wished to maximise the **return on their investments** in seismic resilience.

- They discussed balancing the upfront cost of building to higher seismic standards with **whole-of-life costs** that consider the potential direct (e.g., materials and labour) and indirect (e.g., downtime) costs associated with repairing an earthquake-damaged buildings.

Some participants noted that there are **social and environmental consequences** to having major building damage that results in long repair timeframes or demolition.

- Long and uncertain timeframes for repairs or rebuilding may be beyond what some individuals are willing to tolerate and could result in people permanently moving away from an area.
- Buildings that require major repairs in their lifetime or premature replacement can impact the environment through the use of natural resources, including embodied carbon.

Appendix D:
Interpreting Societal Expectations

The process of translating the Stage 2 societal expectations research into building performance outcomes inevitably raised many questions along the development journey.

Those ranged from queries about the societal expectations research itself and its scope, any ambiguities in the results, and how the outcome preferences may change with emerging trends, to considerations of the built environment.

A number of workshops and related activities were held within the project team and with wider groups to explore these and related questions and to start the translation process from social science research to a performance outcome framework.

D.1 Interpreting the Societal Expectations Research

Key takeouts from the Stage 2 research on societal expectations (from research report, https://www.nzsee.org.nz/db/PUBS/RBP_SocietalExpectationsReport-FINAL-for-Release.pdf).

Key Takeouts:

i. Safety is non-negotiable.
ii. Kiwis want more than life safety. In particular, social and economic recovery are important objectives.
iii. Speed of recovery is a particular priority for some building types – marae, community centres, and homes – that currently are not a priority.
iv. Minimising environmental impact is an emerging priority
v. People want buildings that are perceived as safe (beyond just safe). Important for alleviating mental health strain post-event.
vi. Appetite for risk and expectations of buildings' seismic performance varies significantly amongst Kiwis.

D.2 Testing the Societal Expectations Research Using Expert Opinion (Workshop 30 March 2022)

The purpose of this wider research community workshop was:

- To explore and test findings from the NZSEE resilient buildings project against expert opinion/research
- To explore how societal expectations can be mapped to engineering-based design principles and targets.

- To identify future research needs to enable the integration of societal expectations into engineering design.

Key Takeouts:

i. Surprise about people's perceptions of acceptable recovery times for different building types, noting expectations for return to function were significantly shorter than anticipated. Are they attainable?

ii. Acknowledgement that a schema for prioritising buildings for rapid return to function needs review, in particular, to assess the needs of vulnerable groups (e.g., aged care residents).

iii. Suggestion that people conflate life safety with functionality, so there is need for greater clarity of expectations and outcomes.

iv. Consultation is needed to determine the actual cost difference for more resilient buildings and willingness to pay.

D.3 Gap Analysis Societal Expectations Research (Workshop 27 September 2022)

The purpose of this project workshop was to explore:

- Is there anything within the provided information about societal expectations that does not align with your own observations / expert opinion?
- Are there any ambiguities or elements that more clarity or evidence is needed?
- How might these expectations change with current or emerging trends affecting our built environment and the nature of how communities use buildings?

Key Takeouts:

Approach to Building Design

i. Making buildings more life-safe does not equate to making buildings more usable after an event. Therefore, as we move to the later phases of the project, we want to be sure that our efforts include a focus on more than simply life safety to also include consideration of damage and functionality given the societal expectations research findings. Do we need to review the way the building is designed to ensure protection of property and/or functionality objectives can be met?

Life Safety

ii. We are using some buildings today very differently than when the codes and guidelines were written. Cities are expanding and have increased urban density. This, along with a tendency for some previously centralised workplaces to disperse among homes, has led to an increased intensity of use of residential apartment buildings. Therefore, the occupancy rates used to inform statistics for life safety in previous codes and standards have been rapidly changing.

iii. The societal expectations research has reaffirmed that life safety (fatalities and injuries) should be a focus for building performance objectives. Ability to escape is also a key consideration for life safety.

iv. The life safety impact category should be solely focused on the immediate life-safety impacts. Post-earthquake safety and wellbeing considerations (e.g., the ability for hospitals to function and the protection of natural gathering points) fall out of scope for the 'life-safety' category. These types of considerations are better suited for the 'functionality' category or as part of a disaster management plan. Additionally, the participants' desire to 'feel safe' is out of scope for this impact category and could be considered more related to observations of building damage.

v. The protection of skilled individuals, which was suggested by some of the research participants, is morally ambiguous, and will not be pursued further.

vi. The societal expectations research did not address tsunami risk following an earthquake. Earthquake shaking and tsunami may likely coincide in nearby New Zealand events. The Steering Group members shared several instances of building evacuation points known to be located in areas at risk of tsunami surges.

Functionality

vii. Time is the key measure for return to function for all building types. How long is it acceptable to have no or reduced function?

viii. Different building types have different functionality requirements as the societal expectations research obliquely identified. These requirements will need to be described when identifying tolerable impacts.

ix. What is considered important after an event needs to be re-evaluated. For example, there is a growing reliance on data centres. Is there an expectation that these will be functional after an earthquake?

x. Weathertightness was noted in the societal expectations research in relation to homes. It is a requirement for a building's ability to function for all buildings. There could be a distinction between temporary and permanent measures for weather-tightness.

xi. Shelter in place following an earthquake is a reduced functionality condition that needs to be considered. The functions required for shelter in place depend on the building function (e.g., aged care requirements differ from apartments and houses, or office buildings and warehouses).

xii. Uncontained hazardous materials affect functionality and need consideration.

xiii. Functionality is impacted by people's perceptions, for example, visible damage that makes people feel unsafe to occupy.

Protection of Property

xiv. It was suggested that the protection of most personal or privately-owned contents should be out of scope for this project because this level of protection falls beyond the scope of the Building Code.

xv. There needs to be more consideration in the design process about limiting damage to plant and machinery (e.g., computer servers in data centres, sensitive health care equipment in hospitals).

xvi. The protection of contents should consider who has an interest in the contents. For example, publicly owned assets of significant social value (e.g., museum contents) should be treated differently to privately owned assets of significant fiscal value (e.g., manufacturing equipment).

xvii. The distinction between protection of property and life safety for building contents is somewhat unclear in the current Building Code. For example, library stacks toppling is a potential life safety hazard but falls outside the Building Code.

Sustainability

xviii. Potential trade-offs between sustainability and economics need consideration (e.g., speed of demolition and material recovery, also scale effects of post-disaster debris and demolition management).

xix. What can be dealt with through building codes for building design and what is dealt with through other mechanisms? (e.g., waste management systems or requirements for recycling during building demolitions)

Protection of Other Property

xx. Resilience of a network of buildings compared to a single building needs consideration. The Building Code considers each building, one at a time, while community resilience often relies on the integrity of a network of buildings.

Repairability.

xxi. Repairability needs definition. Anything is theoretically repairable with an unlimited budget.

xxii. The desired timelines expressed through in the societal expectations research, of days and weeks with minimal disruption, mean buildings must be essentially undamaged to meet these expectations.

xxiii. There is a spectrum of repair types less than full repair. For example, repairs to reoccupy sometimes differ based on occupancy. These are among the diverse outcomes not canvassed by the research. New Zealanders have likely gained an expectation for repairs that return a building to the before-earthquakes state (based on the experience of insurance outcomes a decade ago), but we know the insurance landscape has since changed.

D.4 Built Environment 'Stylised Facts' (Workshop 16 June 2022)

The purpose of this activity was to undertake a comparison of the built environment (housing types, urban and town building typologies, density, and concentration of risk) as it was when the current Building Code settings were first conceptualised in the 1970s with that of current and possible future buildings. The workshop focused on exploring

- How have residential, commercial, industrial, and public buildings changed? How the use of buildings has changed over time? What are possible future changes?
- What were the drivers for change?
- Have the interdependencies between building types and infrastructure changed over time?
- How have urban centres in New Zealand changed over time?
- Are there also geographic differences across NZ? Are there differences between urban and more rural areas in different parts of NZ?

Key Takeouts:

i. Significant changes in the New Zealand urban environment are anticipated, particularly greater urban density in large cities and increased investment in public transport. This is largely to reduce transport emissions in response to climate change. The social acceptability of the consequences of this policy is not well established.

ii. Technology and an increasingly service-based economy are changing building usage. Particularly evident in increased working from home, leading to reduced office space requirements in urban centres and allowing more remote working in general for some professions.

iii. Risk tolerance and built environment resilience are not well aligned across the existing range of legislation. Increasing awareness of this but whether better alignment is achieved in the future is not clear.

iv. Land use rules are not currently well aligned with building regulations for natural hazard risk management including climate change adaptation.

v. The New Zealand insurance market is underpinned by global reinsurance capital. While the latter remains well capitalised it is increasingly constrained by risk aversion to natural hazard exposure with claim levels persistently higher in recent years affecting profitability.

vi. New Zealand is one of the most highly insured countries and has retained protection despite a decade of unprecedented insurance losses. Partly this reflects the stabilising effect of the compulsory EQC natural disaster scheme, which provides a government-guaranteed ‘floor’ to the residential insurance market. However, the recent loss experience together with rising natural disaster impacts worldwide means that terms for insurance coverage are more stringent than before.

vii. The potential for underinsurance is rising as inflation of property asset values and rebuild costs threaten to outstrip insurance covers and overall capacity for the local market. Insurers are managing their exposure to earthquakes in high seismic risk areas, and greater scrutiny is anticipated for exposure to flooding and coastal hazards.

viii. Improving building resilience to mitigate the onset of damage by natural hazards, and developing a coherent science-led national view of risk(s) will help sustain New Zealand’s access to affordable risk capital.

Appendix E:
Outcome and Impact Indicators

The Resilient Buildings Project set out to describe the consequences associated with the seismic performance of buildings that are both specific to building users' needs and meaningful to decision-makers. Outcomes and impacts were defined to describe the effects that building performance can have on building users and the community, respectively, following an earthquake.

The following definitions were adopted:

Outcomes: Specific short-to-medium-term effects on wellbeing. Outcomes are typically site-specific and evaluated within the individual building footprint.

Impacts: Broad long-term effects on wellbeing impacts. Impacts are typically location-specific and evaluated at the community level.

Indicator: An observable criterion that describes, measures, or otherwise summarises an effect.[1] Indicators may be direct (e.g., shaking damage) or consequential (e.g., the casualties that may result from the damage).

The terms 'outcome' and 'impact' are often used interchangeably – different sources use the terms in opposite ways. For the purposes of this Project, outcome refers to the specific short-to-medium-term effects, and impact refers to broader long-term direct and indirect effects on wellbeing. Impacts and outcomes can be either qualitative or quantitative.

For simplicity, the consequences of seismic performance described in the performance outcome framework will be referred to as outcome indicators. These are consequences that contemplate the short-to-medium term effects of seismic performance and are measured within the building footprint. Outcome indicators are described in detail in Section E.2.

Long-term, community-level impacts such as urban degeneration, fluctuations in GDP, and long-term environmental impacts are beyond the scope of the performance outcome framework. A brief discussion on impact indicators, which are measured at the community level, is provided in Section E.3.

[1] Kay, E., Stevenson, J., Bowie, C., Ivory, V., & Vargo, J. (2019). The Resilience Warrant of Fitness Research Programme: Towards a method for applying the New Zealand Resilience Index in a regional context. (https://resiliencechallenge.nz/wp-content/uploads/NZRI_Regional_Applications_Research_Report_June_2019.pdf).

E.1 Describing the Consequences of Building Seismic Performance

The findings of the Stage 2 societal expectations research showed that risk perceptions and tolerances are diverse, with life safety remaining of central importance in our built environment.[2] Participants also emphasised social and mental wellbeing, including the need to focus on reducing disruption through the swift restoration of economic and social wellbeing as well as the reduction of environmental impacts associated with earthquake damage. An overview of the priorities for the seismic performance of buildings is shown in Figure E1.

1: LIFE SAFETY

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

2: SOCIAL RECOVERY

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

3: ECONOMIC RECOVERY

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

4: MINIMISE ENVIRONMENTAL IMPACT

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

Figure E1. Priorities for the seismic performance of buildings from the 2010/11 societal expectations research.

Following the precedent set in the societal expectations research, outcomes have been categorised by Community Wellbeing.[3] For the purposes of this project, community wellbeing has four categories:

- **Human** wellbeing includes people's physical and mental health.
- **Social** wellbeing involves the capabilities and capacity of people to engage in work, study, recreation, and social activities. It includes the norms, rules, and institutions that influence the way in which people live and work together and experience a sense of belonging. Includes trust, reciprocity, the rule of law, cultural and community identity, traditions and customs, common values, and interests.

[2] The findings of the societal expectations research were published in a main report, with two complimentary data reports.
Main Report: https://www.nzsee.org.nz/db/PUBS/RBP_SocietalExpectationsReport-FINAL-for-Release.pdf
Focus Group Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Focus-Group-Report-final.pdf
Interviews Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Interviews-Report-FINAL.pdf.

[3] For the purposes of this assessment, the wellbeing definitions are based on the Taituarā community wellbeings (https://taituara.org.nz/Article?Action=View&Article_id=216), with some influence from the Treasury Higher Living Standards Framework (https://www.treasury.govt.nz/information-and-services/nz-economy/higher-living-standards/our-living-standards-framework).

- **Economic** wellbeing includes physical assets, usually closely associated with supporting material living conditions; includes building, equipment, and infrastructure damage and the loss of income/productivity associated with damage to these. The employment and wealth necessary to provide many of the requirements that make for social wellbeing, such as health, financial security, and equity of opportunity.
- **Environmental** wellbeing involves all aspects of the natural environment needed to support life and human activity, including air quality, land, soil, water, plants and animals, minerals, and energy resources.

The outcomes described in the following section are deliberately broad indicators meant to capture the range of consequences associated with earthquake-related building damage. They are intended to be relevant to all buildings, agnostic of building type and usage, for application in the performance outcome frame.

E.2 Outcome Indicators

Outcome indicators refer to the consequences of seismic performance described in the performance outcome framework. These are building-level outcomes which contemplate the immediate and short-to-medium-term consequences measured within the building footprint.

Outcomes beyond the control of the building owner or occupier (e.g., delayed recovery due to damage to networked infrastructure or limited availability of labour and materials for repair[4]) are not included in the framework, as the focus is confined to site-specific building attributes that are sensitive to design and construction approaches.

Outcome indicators can be direct or indirect and span both immediate outcomes and longer-term impacts. *Direct* outcomes are consequences apparent immediately, or shortly after, the earthquake occurs and can be linked unambiguously to building damage. *Indirect* outcomes are secondary effects that are often a result of a direct outcome. For example, a building that functions as a retail store may have structural damage that makes it unsafe to occupy. This will result in the direct outcome of user disruption, while the business is unable to operate from the premises. An indirect outcome would be the financial losses that the business incurs while not operating.

The following subsections describe the outcome indicators used in the performance outcome framework, which were identified based on the findings of the societal expectations research, augmented with expert opinion.

E.2.1 Human Outcomes

Human wellbeing includes people's physical and mental health. The outcome indicators related to human wellbeing are *casualties* and *consequential stressors*.

Casualties is a direct outcome that is measured in the number of deaths or injuries that result from the failure of structural and non-structural elements.

[4] Canterbury earthquake recovery (DPMC archives/Built environment Leaders Forum 2015).

Consequential stressors are broad indicators intended to capture the indirect effects that building owners and users experience because of their experience during earthquake shaking, the damage that the building sustains, loss of amenity and function in their buildings, and the stress of the recovery process. Consequential stressors are measured by the number of people affected as well as the acuteness and duration of the stressor.

Casualties

Casualties include loss of life (i.e., fatal injuries), significant injury requiring hospitalization, and moderate injury requiring doctor-level care, occurring as a result of building damage caused by an earthquake[5]. Casualties are measured by the number of people impacted and the severity of injury.

Casualties resulting from human action taken during an earthquake are considered out of scope[6]. Additionally, the description of casualties only captures physical injuries, but it is acknowledged that earthquakes can cause adverse impacts on mental health. Mental health impacts are outside the scope of 'casualties' but are considered in the consequential stressors outcome indicator.

Excerpts from the Main Report:

Preserving life remains the minimum requirement for the seismic performance of buildings in New Zealand. There is a widely held expectation that everyone should be able to exit a building safely following a major earthquake. Those who thought fatalities and injuries were acceptable following a major earthquake generally believed that eliminating all risk is impossible given the seismically active setting of New Zealand.

Excerpts from the Focus Group Report:

Fatalities and injuries were of most concern

Loss of life was a key driver for risk acceptability. Tolerance for fatalities is low for most; 'Fatalities is most important; facilities can be rebuilt'. Views on acceptability of loss of life ranged from the majority view that 'one loss of life is too much' to others who thought that eliminating fatality risks was impracticable and multiple fatalities were tolerable, as long as they were less frequent than once in every 100 years.

Excerpts from the Interviews Report:

Safety is the first priority

Health and safety requirements, both day to day and in extreme events, are the top priority. All buildings are expected to provide baseline safety for occupants.

[5] Fatalities and injuries classifications are based on the RiskScape casualty states definitions, which depend on the level of care required to treat the injury (King & Bell, 2009). Fatalities are injuries that result in death. Significant injuries require intensive care (brain damage, spinal column injuries, nerve injuries, crush syndrome, internal organ failures due to crushing, organ puncture, other internal injuries, uncontrolled bleeding, and traumatic amputations of arms or legs) or hospitalisation (open head or face wounds, concussions, and fractures). Moderate injuries require doctor-level care (cuts requiring stitches, serious sprains, dislocations, and minor concussions). Minor injuries are injuries for which a person does not seek help from a health professional (first-aid type injuries such as bruising/contusion, minor cuts, and sprains).

[6] Johnston et al (2014) found that action taken during ground shaking (e.g., helping children) was a common cause of injuries. Johnston, D., Standring, S., Ronan, K. et al. The 2010/2011 Canterbury earthquakes: context and cause of injury. Nat Hazards 73, 627–637 (2014). https://doi.org/10.1007/s11069-014-1094-7.

Consequential Stressors

Earthquakes and disruption from earthquake-induced building damage can cause strong physiological and psychological responses. Studies have shown increased incidence of cardio vascular disease in the months following when the disaster occurs[7,8,9] with increases between 1.5 and 3-fold after an earthquake[10]. Additionally, earthquakes have been also associated with increases in symptoms of post-traumatic stress disorder, anxiety disorder, nicotine dependence, and the total number of psychiatric disorders[11].

Consequential stressors, as considered within the framework, are a broad indicator category that is intended to capture the secondary effects that building owners and users experience as a result of their experience during earthquake shaking, the damage that the building sustains, loss of amenity and function in their buildings, and the stress of the recovery process.

Consequential stressors are measured by the number of people impacted and severity of impact, which includes both the acuteness and the length of time of the impact. While several consequential stressors could be mentioned, we highlight post-traumatic stress, perceived safety, loss of agency, and loss of social cohesion below.

Post-traumatic stress

Participants in the societal expectations research were concerned with the ongoing mental health impacts associated with experiencing a damaging earthquake.

Post-traumatic stress disorder (PTSD) is a mental health condition that's triggered by experiencing or witnessing a traumatic event, such as a deadly earthquake. Following the Canterbury earthquakes, studies found that residents of affected communities were more likely to feel on edge and have depression and anxiety symptoms[12]. Additionally, many adolescents were found to have PTSD symptoms in the years following the Canterbury earthquakes. These symptoms were linked to trauma exposure (i.e., exposure to earthquakes) and fear (e.g., of an aftershock)[13].

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[7] Schwartz BG, French WJ, Mayeda GS, et al. Emotional stressors trigger cardiovascular events. *Int J Clin Pract.* 2012;66:631–9.
[8] Brown DL. Disparate effects of the 1989 Loma Prieta and 1994 Northridge earthquakes on hospital admissions for acute myocardial infarction: importance of superimposition of triggers. *Am Heart J.* 1999;137:830–6.
[9] Teng, A. M., Blakely, T., Ivory, V., Kingham, S., & Cameron, V. (2017). Living in areas with different levels of earthquake damage and association with risk of cardiovascular disease: a cohort-linkage study. *The Lancet Planetary Health*, *1*(6), e242-e253.
[10] Nishizawa M, Hoshide S, Shimpo M, Kario K. Disaster hypertension: experience from the great East Japan earthquake of 2011. *Curr Hypertens Rep.* 2012;14:375–81.
[11] Beaglehole B, Boden JM, Bell C, Mulder RT, Dhakal B, Horwood LJ. The long-term impacts of the Canterbury earthquakes on the mental health of the Christchurch Health and Development Study cohort. Australian & New Zealand Journal of Psychiatry. 2022;0(0). doi:10.1177/00048674221138499.
[12] Martin J. Dorahy & Lee Kannis-Dymand (2012) Psychological Distress Following the 2010 Christchurch Earthquake: A Community Assessment of Two Differentially Affected Suburbs, Journal of Loss and Trauma, 17:3, 203-217, DOI: 10.1080/15325024.2011.616737.
[13] Heetkamp, T., & De Terte, I. (2015). PTSD and resilience in adolescents after New Zealand earthquakes. *New Zealand Journal of Psychology*, *44*(1), 32. https://www.psychology.org.nz/journal-archive/NZJP-Volume-44-No-1-2015.pdf#page=31.

Excerpts from the Focus Group Report:

Mental health impact of injuries

The impact of building damage and injuries/deaths on mental health can take a long time to restore. It can lead to anxiety when in unfamiliar buildings or entering into particular buildings (e.g., some people affected by the 2011 Christchurch earthquake avoid multistorey buildings).

Mental health impacts are an important consideration

Ongoing mental health impacts were also a consequence of concern for many. Impacts to mental health reduce a person's ability to recover and their overall wellbeing. Impacts that cause enduring mental health issues (12 months or more) are unacceptable.

Perceived Safety

A key finding from the research into societal expectations was the importance to building users of 'feeling' the building they are occupying is safe – before, during and after an event. A perception of safety is particularly important for buildings that house vulnerable persons. Knowing loved ones are in a "safe building" during an earthquake may reduce the urgency to check on them following an event. It may also reduce ongoing anxiety (and related mental health impacts) after an event for those who continue to occupy earthquake-affected buildings[14].

The feeling of safety could come from a lack of physical building damage, reliable and redundant egress routes within the building and assurance from an engineer of building stability after a moderate or large earthquake. Visual reminders of ground shaking (e.g., cracking) were often cited as being anxiety-inducing for building occupants.

Excerpts from the Main Report:

Second, and related to the nature of the occupants, is the importance of knowing a building is safe – before, during and after an event. A perception of safety is particularly important for buildings that house vulnerable persons. Knowing loved ones are in a safe building during an earthquake may reduce the urgency to check on them following an event. It may also reduce ongoing anxiety (and related mental health impacts) after an event for those who continue to occupy earthquake-affected buildings.

Excerpts from the Focus Group Report:

Feeling of safety and confidence in buildings pre-event

"Wanting to feel safe" was a common sentiment when discussing life safety of buildings. All buildings should make you feel safe, especially buildings housing vulnerable populations such as children. This includes the structural elements as well as non-structural elements and contents (e.g., supermarket stacking).

Excerpts from the Interviews Report:

Perception of safety is important

In addition to actually being safe, many interviewees expressed that they wanted to 'feel safe' within their buildings. The feeling of safety could come from a lack of physical

[14] Perception of safety was an important factor in the self-evacuation of inner-city residents following the 2016 Kaikōura earthquake. Blake, D., Becker, JS, Hodgetts, D., Hope, A. (in review), The 2016 Kaikōura Earthquake: Experiences of safety, evacuation and return for apartment dwellers in Te Whanganui-a-Tara (Wellington), Aotearoa New Zealand. International Journal of Mass Emergencies and Disasters.

building damage, reliable and redundant egress routes within the building and assurance from an engineer of building stability after a moderate or large earthquake.

Loss of Agency

Research participants also discussed how earthquake damage can cause a loss of agency or control. This could stem from the chronic stress related to having an unstable living environment, employment uncertainty, and/or having a lengthy insurance settlement or dispute, all of which can negatively affect personal and professional relationships.

Excerpts from the Focus Group Report:

Self sufficiency

Social recovery is impacted when people's ability to fend for themselves is removed. A key example was the ability to purchase food for themselves from a supermarket rather than relying on food banks. The removal of choice and autonomy has significant impacts on mental health and slows recovery.

Excerpts from the Interviews Report:

The chronic stress related to having an unstable living environment, employment uncertainty, and/or having a lengthy insurance settlement or dispute can negatively affect personal and professional relationships. The stress of an earthquake and the recovery process may impact an individual's ability to perform at their job if that stress makes them distracted and tired. Dealing with issues related to the earthquake and recovery process can also result in a lack of spare time and time spent with loved ones. These mental health-related issues can have a multi-generational impact if parents are unable to provide adequate care for their children, who may also be traumatised by the earthquake.

People who have had their homes, businesses and communities impacted may feel as if they have lost control over their environment, which can adversely affect their mental health. This feeling of losing control is heightened by long and drawn-out insurance settlements or other hindrances to the recovery process (e.g., a difficult consenting process or a safety hazard from a neighbouring building restricting site access) that make individuals feel as if they are at the mercy of others. Overall, the ability of an individual to be resilient to the mental health impacts of an earthquake largely depends on their personal circumstances prior to the earthquake. The stress of an earthquake has the potential to exacerbate existing mental health conditions. It also may be the tipping point for someone already dealing with multiple or significant hardships in their everyday life (e.g., COVID-19 impacts, securing housing and/or employment).

Loss of Social Cohesion

Research participants often discussed a desire for a swift return to normalcy after an earthquake. While 'normalcy' may look different for different people, it often involves the ability to engage in work, study, recreation, social, and cultural activities (i.e., social cohesion). Damage to buildings that enable these types of activities can adversely affect mental health and wellbeing, resulting in a loss of one's sense of place and fractured social ties[15].

Excerpts from the Focus Group Report:

Enable a sense of normality as soon as possible

Normalcy was a key priority for social recovery. Providing the opportunities to go back to school or work, return to supermarkets and retail, community meeting places, arts and recreation were all important aspects of normality. The value of going back to normality and engaging in regular day to day activities was heavily weighted for its positive impact on mental health and wellbeing.

Fractured social ties

Communities may start to break down after the loss of key community gathering places such as schools and sporting facilities. The loss of social networks in a community can loosen personal ties to a place (e.g., friends or family moving away after an earthquake).

Excerpts from the Interviews Report:

In general, the best way to alleviate adverse effects on mental health, identified by the interviewees, was to prevent a lengthy recovery process and facilitate a return to normalcy as quick as possible.

Individual buildings within a community are locations that can provide social connectedness and a sense of belonging for building users and community members. These connections are particularly important to maintain to aid in social recovery following an earthquake.

Buildings with cultural significance and/or architectural or heritage appeal can provide a sense of place for those in a community, even if community members don't use the building daily.

E.2.2 Social Outcomes

Social wellbeing involves the capabilities and capacity of people to engage in work, study, recreation, and social activities. It includes the norms, rules, and institutions that influence the way in which people live and work together and experience a sense of belonging. Includes trust, reciprocity, the rule of law, cultural and community identity, traditions and customs, common values, and interests. The outcome indicators related to social wellbeing are *user disruption*, *social disruption*, and *loss of cultural treasures*.

User disruption is a direct outcome and is defined as the inability to use a building for its intended function following an earthquake due to building damage. Here we are considering only damage within the building footprint because this may be influenced by design, whereas wider (neighbourhood) disruption is not. The severity of user disruption is measured as the extent and duration of disruption to building use.

Social disruption is a broad indicator that is intended to assess the indirect effects that damage to an individual building has on the surrounding community. The severity of social

[15] Prayag, Ozanne, & Spector (2021) highlight that re-establishing sense of place and supporting social ties and networks after a distaster can improve both psychological resilience and psychological wellbeing. (https://doi.org/10.1016/j.ijdrr.2021.102438).

disruption is measured by the extent and duration of the disruption on the community, and will be influenced by how significant the building is to the community.

Loss of cultural treasures is a direct outcome and reflects a desire expressed by the social research participants to protect cultural assets (buildings or contents) in order to preserve cultural identity and maintain a sense of place in their communities. The severity of a loss of cultural treasure is measured by the extent of damage to the asset and whether it can be repaired or replaced.

User Disruption

User disruption is caused by the inability to use a building for its intended function following an earthquake due to building damage. This outcome indicator is very similar to downtime, which is described in FEMA P-58 as the time following an earthquake until a building can be safely restored to service[16]. The severity of user disruption is measured as the extent and duration of disruption to building use.

User disruption includes the time to identify, plan, and permit the work, arrange financing (including insurance settlements), hire and mobilize contractors, and complete repairs. The amount of downtime that is tolerable to an individual or organization will be contingent on the dependence of the building user on the facility and the cost benefit ratio associated with designing or preparing systems for reducing downtime[16].

Participants in the societal expectation research often expressed concern over the cascading consequences of user disruptions. For example, they were worried that disruption to the function of residential facilities would lead to the displacement of occupants, resulting in fractured social ties and possibly permanent dislocation of residents. They also expressed concern about the loss of the ability of an organisation to function if they are unable to use their building. This type of disruption could lead to loss of revenue for the organisation and job loss for the employees. Additionally, participants often discussed the psychological effects of long and uncertain disruption timeframes. It is believed that having clearer expectations of the time to return to service to buildings will reduce the mental health impacts of a future earthquake event.

Excerpts from the Focus Group Report:

Mass displacement of population and community dislocation are intolerable
Connectivity between people is important for community wellbeing. Community connection takes years to build up, and the permanent loss of people from an area can dislocate a community. The loss of community support and neighbourhood networks on remaining residents can diminish their sense of community. This can have secondary effects including increased crime and disharmony, impacting the wellbeing of community members. Enabling community connection also allows society to solve problems together and is important for effective recovery. Significant displacement of people (>10%) from a community was therefore intolerable.

Job loss is an intolerable risk

[16] FEMA. (2018). *Guidelines for Performance-Based Seismic Design of Buildings. FEMA P-58-6.* https://femap58.atcouncil.org/documents/fema-p-58/28-fema-p-58-6-guidelines-for-design/file.

Loss of livelihoods was one of the main drivers for economic risk intolerance. Over 10% job loss for most was intolerable. This was felt particularly strong in towns, where a significant loss of jobs would significantly impact recovery and potential cause the town to become a 'ghost town'. The social impacts were felt strongly, with smaller towns feeling like job loss would be more acutely felt than in an urban setting, as 'everyone would know someone' who was affected. In turn this would affect community wellbeing.

The severity of loss of business revenue is dependent on the duration of reduced earnings.

The tolerance of loss of business revenue was dependent on the length of the time the business revenue was impacted. However, the loss of a 1/3 of business revenue was viewed as quite severe.

Consider the dependence of users on buildings

Some users and the services they provide are not dependent on their building. Commercial office blocks are a good example of where services can be undertaken elsewhere (e.g., working from home) with limited disturbance if their buildings were unusable. Other services are more dependent on their buildings (e.g. warehouses and manufacturing facilities).

Excerpts from the Interviews Report:

The interviewees that spoke about a desire for certainty and confidence in the recovery process often reiterated the idea several times throughout their interview. Having confidence that their building(s) are safe and their community can bounce back in a timely manner was key to achieving positive recovery outcomes. Uncertainty in the recovery process could lead to poor mental health, encumbered social and economic recovery, and, ultimately, the retreat of people and businesses from the affected area.

Critical loss of permanent housing stock

People will begin to move away from an area if they cannot obtain/maintain safe/secure/sanitary housing in a reasonable timeframe after an earthquake. A lack of housing may result from damage to single-family or multi-unit dwellings, or to neighbourhoods where the land is damaged (as was the case for the Christchurch residential red zone). Long and uncertain timeframes for repairs or rebuilding may be beyond what some individuals are willing to tolerate.

Social disruption

Social disruption was included as an outcome indicator with the intention of capturing the importance of buildings to their communities. Disruptions to certain building types can have negative effects on overall community wellbeing as well as the post-disaster response and recovery efforts. Social disruption evaluates the community impacts resulting from the loss of function in an individual building, with severity measured in terms of both the extent and the duration of the disruption.

Research participants often spoke about the importance of ensuring that buildings that provide essential public utilities to communities continue to have the capacity to serve the community, or at least restore that capacity in short order after an earthquake (e.g., power-generating facilities, telecommunication facilities, water treatment, and wastewater treatment facilities, and other public utilities).

Participants also highlighted the importance of facilities that contain contents with high community value (e.g., wholesale food distribution centres, essential goods manufacturing facilities, and facilities with medical imaging equipment). These types of facilities enable self-sufficiency within communities by producing or warehousing essential goods and services at a large scale. They also may contain difficult-to-replace equipment that serves the community.

Following an earthquake, participants generally expected that emergency services will continue to operate after a major earthquake so that those who need help are able to receive it. Additionally, participants often discussed different buildings that have the capacity to support recovery and are important for reducing social disruption. This could include any community hubs that have strong existing social and physical infrastructure (e.g., maraes, community centres, and churches).

A strong theme from the societal expectations research was that facilities that provide care for dependants (e.g., child-care centres, schools, and aged care) enable economic recovery by allowing guardians to return to work. It was also noted that some communities, particularly smaller communities, may have one main employer. Disruptions to the building that houses this large employer could have cascading impacts on community members.

Excerpts from the Focus Group Report:

Ensure capability for response and recovery

Protection of buildings with the capability to support response and recovery are important. Response capabilities included Civil Defence and Emergency Management (CDEM) activation and communication, buildings housing CDEM hubs/centres, immediate government functions (decision making, critical infrastructure enablement and rubbish collection) and critical infrastructure access.

Protection of critical infrastructure

Critical infrastructure facilities and personnel should be protected to enable life sustaining services in other buildings. If critical infrastructure is impacted, it affects functionality of other infrastructure. This is particularly important in areas with limited/basic critical infrastructure services (e.g., widespread low occupancy rural areas).

Support industries that are integrated into the social fabric of a community

Some industries are part of the social fabric of a small community and provide employment for a large portion of the society. Place based industries of importance include tourism, manufacturing, commercial etc.

Prioritise buildings / industries that employ a lot of people

In communities with reliance on a particular industry, buildings that large proportion of a population are important. Whether that employment is in one large organisation/facility (e.g., hospital, primary production) or through a large quantity of smaller ones (SME's) (e.g., retail and hospitality) it is important to limit job loss and the cascade impact through the community of that job loss.

Community meeting places

Community meeting places play significant role in urban settings, enabling social connection and community wellbeing through localised and supportive community run networks. The loss of these facilities has a large impact on community wellbeing (e.g., the loss of community facilities in East Christchurch following the 2011 earthquake). These community facilities support existing hubs (neighbourhood support groups) and can have large catchments of people connecting with their peers. The locations are usually well-attended and become places of support in the aftermath of an event. They can include religious buildings, maraes, town and country clubs, pools, libraries and sporting clubs.

Excerpts from the Interviews Report:

Storage facilities are critical to the supply and distribution of goods. A representative from a national supermarket chain stressed the criticality of ensuring the ongoing operation of supermarket distribution centres, as the supply of goods in a region (i.e., up to 50+ stores) is dependent upon deliveries from these centres.

Schools opening in the short term (i.e., less than eight weeks) was a priority for many. Schools assist students to regain a sense of normalcy by attending class and seeing their peers. Schools also enable parents to return to work and/or attend to repairs.

Loss of Cultural Assets

Preserving cultural treasures is vital to the cultural and social wellbeing of communities. The cultural value of the contents of some buildings (e.g., of a museum, art gallery, marae) is beyond the value of the building structure.

The societal expectations research participants often felt it was important to ensure that the contents of buildings that hold items with heritage and cultural value are undamaged. The preservation of these socio-cultural assets ensures there are places for people to connect with their culture and ensures that historic artefacts are preserved.

Excerpts from the Focus Group Report:

Critical cultural capital should be protected

Loss of critical cultural assets is intolerable. Cultural assets can comprise maraes, religious or heritage buildings and public gathering places. The preservation of these socio-cultural assets ensures there are places for people to meet and connect with each other and our culture. Culture also emerges between buildings, the feeling of the system as a whole and the vibe of the community. This can be hard to restore.

What is considered cultural capital evolves over time

The cultural value of buildings changes over time. It is important to take stock of the cultural value of buildings regularly to identify what needs to be protected.

Contents within buildings

Often the drive to invest in buildings of cultural value is to protect the taonga inside a building more than the building itself. The cultural value of the contents of some buildings (e.g. of a museum, art gallery, marae) are higher than the building itself.

Excerpts from the Interviews Report:

Loss of a iconic buildings can impact the vibe of a city, how it looks and feels, and disruption to this could negatively impact people’s sense of place in a community.

E.2.3 Economic Outcomes

Economic wellbeing includes physical assets, usually closely associated with supporting material living conditions; includes factories, equipment, houses, and roads. The employment and wealth necessary to provide many of the requirements that make for social wellbeing, such as health, financial security, and equity of opportunity. The outcome indicators related to economic wellbeing are *direct losses* and *indirect losses*.

Direct losses are the financial costs associated with the repair and/or replacement of building elements and contents damaged in an earthquake. It is measured in dollars.

Indirect losses are the consequential financial losses associated with disruptions to building use. This could include loss of income due to business interruption during repair work or expenses incurred renting a property while repairs are being undertaken or loss of market position. Indirect losses are measured in dollars.

Direct losses

Earthquake-induced damage to building elements and contents will result in financial losses, which include the repair & replacement costs of building elements (structural & non-structural) and contents (e.g., inventory, plant, and machinery).

Participants generally recognised that extensive damage to non-structural building elements can be costly and time-consuming to repair. In the worst-case scenario, buildings may be demolished if they become economically infeasible to repair, despite being structurally sound. Overall, participants were typically accepting of costs associated with moderate levels of damage, if it did not affect the building function (i.e., there was minimal disruption for repairs). Major damage, where a building may require replacement, was generally unacceptable.

Many building owners we talked to expressed a desire to maximise returns on their investments in seismic resilience. A primary incentive identified for building more seismically resilient buildings was the opportunity to lower whole-of-life costs. Therefore, building durability (i.e., buildings that don’t require continuous significant repairs) was valued by participants.

Research participants often discussed earthquake insurance when discussing the cost of damage. Some participants were more accepting of damage if they had earthquake insurance. However, others indicated that the availability (or lack of) earthquake insurance would not change their outcome preferences.

Excerpts from the Focus Group Report:

Durability and whole of life cost

Durable buildings have a lower whole of life cost and are better value for money. If buildings are going to have higher cost, they need to last longer.

Excerpts from the Interviews Report:

Overall, interviewees indicated that minor to moderate earthquake damage is generally acceptable and major damage from an earthquake is generally unacceptable.

Return on investments

Initial investment (capital costs) can keep operational, maintenance, and repair costs (whole of life costs) down. A desire for affordable options that keep whole of life costs down was often expressed.

At an individual building level, interviewees wanted to maximise the returns on their investments in seismic resilience. They wished to balance the upfront cost of building to higher seismic standards with whole-of-life costs, including maintenance and repair costs and reduced business disruption after an earthquake. This balancing of capital and whole-of-life costs was particularly important for owners/developers with long-term investment interests (i.e., owners that build and hold property). Several interviewees also expressed a desire for more cost-effective solutions, which may include more guidance on achieving higher performance targets and materials that are seismically resilient and budget-friendly.

Upon completing the ranking of building design requirements, interviewees were asked whether priorities would change if they or their community could not access insurance. Approximately half of the interviewees did not think a lack of insurance access would change how they ranked the importance of building design requirements. Rationale for this included that they were self-insured or did not consider insurance as an influencing factor when assigning the rankings. The other half of the interviewees indicated that the loss of access to affordable earthquake insurance would heighten the importance of incorporating seismic resilience into buildings to mitigate the financial impacts of earthquake damage.

Indirect Losses

The total inability to use a building or a loss in the ability to fully utilise a building because of earthquake damage can result in financial losses. These losses may include loss of revenue, costs of temporarily or permanently relocating, and/or imputed rent (i.e., the rental price an individual would pay for an asset they own).

The research participants often had low tolerance for earthquake damage that would cause disruptions to building users because of the social and economic consequences associated with loss of function. Participants generally understood the indirect financial benefits of reducing building damage in earthquakes, such as reduced business disruption. A few participants also spoke about possible economic consequences of poor performance, such as the loss of reputation which may result in smaller customer bases or less ability to attract tenants.

Excerpts from the Interviews Report:

At an individual building level, interviewees wanted to maximise the returns on their investments in seismic resilience. They wished to balance the upfront cost of building to higher seismic standards with whole-of-life costs, including maintenance and repair costs and reduced business disruption after an earthquake. This balancing of capital and whole-of-life costs was particularly important for owners/developers with long-term investment interests (i.e., owners that build and hold property).

Loss of reputation from earthquake damage

A business that owns and/or operates from a building that was severely damaged in an earthquake and caused injuries or deaths to building occupants may suffer irrecoverable damage to their reputation for a perceived failure to provide safety for the building occupants.

E.2.4 Environmental Outcomes

Environmental wellbeing involves all aspects of the natural environment needed to support life and human activity, including air quality, land, soil, water, plants and animals, minerals, and energy resources. The outcome indicators related to environmental wellbeing include the *uncontrolled release of hazardous materials, building waste* from demolition or debris from damage, and the *operational and embodied carbon* required to repair and rebuild structures.

Building waste is a direct outcome indicator that is measured by the amount and nature of building debris that will be sent to a landfill during the repair or replacement process. It is a proxy for the operational and embodied carbon[17] required to repair or rebuild structures though we did not attempt to measure this for the purposes of this Project.

Uncontrolled release of hazardous materials is a direct outcome indicator associated with the toxicity and scale of pollution and the longevity of its impact on human health and the environment.

Building Waste

Reducing the impacts of earthquakes on the natural environment is an emerging priority. Many participants discussed the environment's role in underpinning human existence and community wellbeing through the provision of water and food (mahinga kai). Some noted that we have a duty of kaitiakitanga (guardianship).

Many participants expressed a desire to reduce building waste following earthquakes, noting that many places are already constrained in their ability to manage waste. Large quantities of building waste following an earthquake would likely overwhelm waste management facilities in most parts of the country. Some participants were concerned that modern building techniques/materials, such as the presence of composite and mixed materials, could result in lost opportunities to reuse or recycle building materials. Additionally, inefficient management of building waste, in particular, hazardous building waste (e.g. asbestos), could lead to the contamination of the surrounding environment and have adverse effects on publi c health.

The carbon cost of earthquakes was discussed by some participants but was not a universally understood concept. There was concern over the potential loss of embodied carbon through building demolition and disposal and the embodied and operational carbon

[17] Gonzalez RE, Stephens MT, Toma C, Dowdell D. The Estimated Carbon Cost of Concrete Building Demolitions following the Canterbury Earthquake Sequence. *Earthquake Spectra*. 2022;38(3):1615-1635. doi:10.1177/87552930221082684.

required to replace damaged buildings. Some participants also discussed building lifecycle assessments and observed that repairing a damaged building is often more sustainable than demolishing and rebuilding. Although, it was noted that new buildings can have operational carbon savings.

Excerpts from the Focus Group Report:

Impact on future generations

Like some social consequences, natural environment consequences can have generational impacts. The impact of decisions made today can affect our whakapapa. There is a need to think about future generations and how our current built environment can prevent long term impacts for future generations. Consequences like creation of large volumes of normal and hazardous waste as well as unnecessary destruction of embodied carbon can have long-term or permanent impacts. We need to ensure resources for the future and reduce intergenerational impacts.

Excerpts from the Interviews Report:

One of the most common concerns was managing the waste generated from demolished buildings. The Christchurch earthquake was often cited as an example of an earthquake that resulted in widespread building demolition, which required innovative approaches to waste management. Interviewees were concerned that the uncontrolled demolition of buildings would result in ground contamination from hazardous building materials (e.g., asbestos) and a lost opportunity to re-use or recycle building materials.

The carbon cost of demolishing a building due to earthquake damage was also discussed by some interviewees. Reducing carbon emissions is an emerging priority for many individuals and organisations. The untimely demolition of a building would counteract environmental sustainability objectives. Several interviewees observed that fixing a building is more sustainable than demolishing and rebuilding it.

Uncontrolled Release of Hazardous Materials

Containing other potential pollutants (not from building demolition waste) was also a priority for many of the research participants. They believed that is essential to ensure that buildings containing hazardous materials (e.g., acids) are not damaged in a way that would cause containment issues. Sewage was also identified as a potential pollutant of land and waterways if there is damage to underground piping or wastewater treatment facilities.

In general, participants had low tolerance for impacts on the natural environment that were perceived to be long-lasting or potentially irreversible. Contamination of ground and waterways were often viewed as a consequence that could last for generations.

Excerpts from the Focus Group Report:

Intolerant of impacts with perceived permanence

Natural consequences are perceived to be more permanent with no means of recovery in short, or even long term. For example, some participants do not accept an outcome where hazardous waste gets into our environment. These long-term permanent consequences can also have long term downstream implications that we may not even understand right now. Intolerance for this type of risk tends to be independent of the likelihood of the consequences occurring.

Excerpts from the Interviews Report:

Containing other potential pollutants (not from building demolition waste) was also a priority. Some interviewees thought it was important to take precautions prior to an earthquake to ensure buildings that hold hazardous materials (e.g., acids) are not damaged in a way that would cause containment issues. Sewage was also identified as a potential pollutant if there is damage to underground piping or wastewater treatment facilities.

E.3 Impact Indicators

Community-level impacts were not directly addressed within the performance outcome framework. Nonetheless, the working group discussed the overarching impacts of earthquakes, as these are important to understanding risk tolerance. The following subsections list consequences associated with earthquake damage that can be measured at the community level in terms of human, social, economic and environmental impacts.

We propose that realistic earthquake scenarios are undertaken to test how building-specific outcomes translate into community-level impacts. The suggested impact indicators can be used to calibrate building-level outcomes and assess the performance necessary to achieve desired community impacts. In turn, the potential feasibility and cost-effectiveness of different design/construction approaches relevant to entire communities can be evaluated.

E.3.1 Human Impacts

Potential indicators of human impacts include:

- Total number of casualties (i.e., fatalities and injuries), including any mass casualty events
- Ongoing mental health challenges (from event-related disruptions)

E.3.2 Social Impacts

Potential indicators of social impacts include:

- Loss of social capital (e.g., social network disruptions such as the loss of family, friend, and neighbourhood networks)
- Mass (dislocation) displacement of residents
- Homelessness & ‘sorting’ – poorest communities forced to leave homes &/or move into most damaged areas, often in damaged buildings (as is where is) sometimes without or with reduced access to services
- Urban degeneration, building closures, loss of sense of place
- Loss of bicultural and cultural diversity consideration

E.3.3 Economic Impacts

Potential indicators of economic impacts include:

- Loss in regional and potentially national output (GDP) (generally short term, 2-3 years)
  - Output losses uneven across place, type of industry, and households
  - Also hard to measure losses (e.g., frozen assets in residential property)
- Job loss

E.3.4 Environmental Impacts

Potential indicators of environmental impacts include:

- Total number of buildings requiring demolition, and tonnage of building waste sent to landfill
- Waste produced relative to normal waste volumes managed in the area and/or capacity of the existing system to cope with additional waste
- Recyclability of waste materials
- Carbon
  - Loss of embodied carbon
  - Savings of operational carbon (through more efficient building design)
- Release of hazardous substances and their effects on the natural environment (e.g., contamination of air, soil, groundwater, or waterways)

Appendix F:
Dimensions of Building Performance

F.1 Describing Building Seismic Performance

Building performance is a term used to describe how well a building responds to exterior loads and environmental factors. Performance can be measured through any number of building attributes, and critical aspects of building performance will vary based on the building type and use, as well as the goals of the party evaluating its performance.

To evaluate the critical aspects of seismic performance that affect outcomes, we propose the term 'dimensions of building performance,' which describe the overarching goals for building performance.

The dimensions of building performance relevant to earthquake shaking are as follows:

- Protection from Injury.
- Protection of Property
- Protection of Amenity and Function.

Each dimension relates to a different aspect of a building's performance in earthquakes as shown in Figure F1.

Dimensions of Building Performance	**Protection from Injury**	**Protection of Property**	**Protection of Amenity & Function**
Description	Building performance that causes damage and may result in physical or mental harm to building occupants or passers-by.	Building performance that results in physical damage and the financial and environmental burden of repair or replacement.	Building performance that disrupts building usage, excluding disruptions caused by structural or non-structural instability.
Relationship to aspects of a building's performance	This is related to failure of building structural elements or falling of heavy non-structural elements.	This is related to the onset of visible physical damage to any building components.	This is related to the onset of loss of normal building functionality.

Figure F1 Dimensions of Building Performance

F.1.1 Performance Indicators

The dimensions of building performance can be measured using performance indicators. Performance indicators for each dimension of building performance should be considered separately, as the desired performance outcomes (and subsequently developed performance objectives) will vary between the different dimensions.

The proposed indicators are intended to be used to help identify critical building attributes for each dimension of building performance, agnostic of building type and usage. We recognise that buildings comprise complex systems and it may initially appear there is overlap between some of the proposed indicators and the dimensions of building performance. The indicators have been related to the most directly relevant aspect of a building's performance where the onset of loss/failure of this indicator is first relevant. That is, from onset of any physical damage (protection of property), onset of loss of normal building functionality (protection of amenity and function) or structural failure (protection from injury).

The indicator groupings are informed by New Zealand's approach to seismic design whereby buildings are expected to suffer initial damage at lower levels of shaking than would cause loss of building functionality. Building damage that may result in personal harm (life safety) will occur at significantly higher levels of earthquake shaking again. For example, damage to any of the building elements (protection of property) may be expected to occur at relatively low levels of earthquake shaking compared with loss of stability of the structure (protection from injury). In specialised settings like hospitals and research labs (e.g., a sterile or negative pressure environment), the requirements may span several dimensions of performance.

As performance objectives for individual building types are subsequently developed, greater emphasis may be placed on some performance indicators than others. For example, when considering protection of amenity and function after a major earthquake, secure facilities such as banks will likely prioritise security above all else, whereas large apartment complexes may prioritise sanitation to ensure the building remains occupiable.

The notion of 'repairability' is a metric sometimes associated with building performance. Under the proposed framework, ease and cost of repair is viewed as a design consideration made when determining how to meet desired performance outcomes. In the EPO framework, repairability (or time, cost and disruption due to repair) is considered when looking at the continuum of outcomes for *Protection of Property* and *Protection of Amenity and Function*.

F.1.2 Performance Objectives

It is important to note that dimensions of building performance *are not* performance objectives. They are simply a way to categorise performance targets.

A performance objective is defined when an aspect of building performance is paired with a hazard. These types of statements are typically qualitative and include terms such as 'low probability' and 'acceptable' or 'unacceptable'.

Example of Seismic Performance Objectives

The objectives of NZS1170.5 are that buildings achieve a level of performance during earthquakes so that:

1. Frequently occurring earthquake shaking can be resisted with a low probability of damage sufficient to prevent the building from being used as originally intended; and
2. The fatality risk is at an acceptable level.

In the first objective, the hazard is ‘frequently occurring earthquake shaking,’ which is defined in the supporting commentary using probabilistic terms. The building performance aspect seems to describe loss of function, but the supporting commentary refers to both loss of amenity and the cost of damage repair. The term ‘low probability’ is used to acknowledge that the Code and Standards cannot entirely prevent undesirable outcomes.

The second objective is slightly less straightforward. It alludes to a targeted annual earthquake fatality risk in the order of 10^{-6} (i.e., one in a million). This earthquake fatality risk includes the probability of an earthquake occurring (the hazard) and the probability of collapse (the building performance aspect). The term ‘acceptable’ is used to acknowledge that the Code and Standards cannot eliminate all risk, with ‘acceptable risk’ being the risk remaining once compliance has been achieved.

The loadings standard exemplifies the complexity of performance objectives that involve multiple layers of probability while masking aspects of the building performance described. This project has set out to define the different dimensions of building performance so that code and guidance writers, and ultimately building designers and clients, can identify the performance aspects most important to achieving acceptable outcomes (which are described in Appendix E). With this clarity, performance objectives can be discussed and agreed upon.

F.2 Dimensions of Building Performance

Each dimension of building performance and the associated performance indicators are described in the following subsections.

F.2.1 Protection from Injury

The ‘protection from injury’ dimension is related to building performance that results in damage to the building that has the potential to cause physical or mental harm to building occupants or passers-by. To protect from injury, buildings should provide a safe environment such that occupants inside or adjacent to the building will not be exposed to an unacceptable risk of injury.

The project team recognises the protection from injury dimension of building performance aligns with the objective in the New Zealand Building Code Clause B1.1 (a) *safeguard people from injury caused by structural failure*. Refer to Appendix A for more information on the current New Zealand Building Code settings.

The performance indicators for protection from injury include:

- Stability of the primary structure
- Stability of the secondary structure
- Stability of non-structural elements that present a falling hazard
- Maintenance of egress routes

Of note is that, for the proposed framework, projection from injury does not include damage to building systems that contain hazardous waste which could harm occupants. Containment is considered a functional aspect of building performance and is therefore covered under protection of amenity and function.

Each of the performance indicators considered for protection from injury is described below.

Stability of the Primary Structure

A primary structural element is a component of a building that provides gravity and/or lateral-load resistance as part of a continuous load path to the foundation, including beams, columns, slabs, braces, walls, wall piers, coupling beams, and connections[1].

Instability of primary elements can lead to global or local collapse, which presents a risk of injury to building occupants or passers-by.

Stability of the Secondary Structure

Secondary structural elements are those elements of the building that are not part of either the primary lateral or primary gravity structural systems but nevertheless are required to transfer inertial and vertical loads. Examples of secondary structural elements include

[1] The definition of primary structural elements is adopted from Appendix A of FEMA-P2055 (https://www.fema.gov/sites/default/files/2020-07/fema_p-2055_post-disaster_buildingsafety_evaluation_2019.pdf).

precast panels, curtain wall framing systems, heavy internal partitions, stairs, significant building services, and large building ornaments[2].

Instability of secondary elements can lead to localised failures, which presents a risk of injury if these elements fall onto building occupants or passers-by.

Stability of Non-structural Elements that Present a Falling Hazard

Non-structural elements are those elements within a building that are not considered to be part of either the primary or secondary structural systems. Examples of non-structural elements include components such as mechanical and electrical plant, ducting, pipework, cable trays, suspended ceilings, overhead glazing, non-load bearing partitions, and cladding systems such as brick veneer[3].

Instability of non-structural elements that are suspended or have a high centre of gravity present a risk of injury if they fall onto building occupants.

Maintenance of Egress Routes

An egress route is a continuous and unobstructed path of exit travel from any point within a structure to a place of safety. Egress routes include building entrances/exits, corridors, doors, stairs, ramps, and lifts. The blockage of egress routes can be caused by damage to the primary structure, secondary structure, non-structural elements, or contents.

The failure or overturning of elements that may obstruct egress routes presents a life safety hazard as it may prevent evacuation of injured occupants. This could result in delayed access to health care, which may be life-threatening in some situations. Occupants may also experience additional trauma if they are trapped in a building after an earthquake.

F.2.2 Protection of Property

The ‘protection of property’ dimension is related to building performance that results in physical damage and the financial and environmental burden associated with repairing or replacing damaged elements and contents. To protect property, buildings should be designed such that damage causing an unacceptable financial loss or environmental burden does not occur.

The performance indicators for protection of property include:

- Damage to structural elements
- Damage to non-structural elements
- Damage to contents

It is important to emphasise that, for the proposed framework, protection of property is limited to the direct financial cost associated with repairing or replacing damaged elements and contents. It does not include the financial burden associated with downtime while

[2] The definition of secondary structural elements is adopted from Practice Advisory 20: Improving earthquake performance of secondary structural elements (https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-20/).
[3] The definition of non-structural elements is adopted from Practice Advisory 19: Improving earthquake performance of non-structural elements (https://www.building.govt.nz/building-code-compliance/b-stability/b1-structure/practice-advisory-19/).

elements are being repaired. That is considered under protection of amenity and function. Similarly, the environmental burden associated with protection of property is limited to the building waste and carbon impacts associated with repairs or building replacement.

Each of the performance indicators considered for protection of property is described below.

Damage to Structural Elements

For the purpose of protection of property, structural elements include the primary and secondary structural elements described in the previous section.

Structural elements are often covered by non-structural elements (e.g., partition walls covering load columns and beams). Therefore, repairing damage to structural elements represent a significant financial cost, as both the damaged element and surrounding finishes require replacement. Also, damaged building elements are typically not reusable, creating waste that often ends up in landfills.

Damage to Non-structural Elements

Non-structural elements for protection of property are the same as those described in the previous section.

It was not uncommon following the 2010/2011 Canterbury earthquakes for buildings to be declared an economic write-off (and subsequently be demolished) due solely to damage to non-structural elements. As with structural elements, most non-structural elements are not reused or recycled, and the waste often ends up in landfills.

Damage to Contents

Contents are items inside a building that are not fixed to the property. They include anything that can be carried away from the building.

The RBP does not propose that *all* contents need to be protected in an earthquake. This would be unreasonable in terms of the amount of effort required and unenforceable given the variance in building users over time. However, we do recommend that the protection of essential or high-value contents be considered, as building contents can represent significant financial or cultural capital for the building occupants and/or the community.

F.2.3 Protection of Amenity and Function

The ‘protection of amenity and function’ dimension is related to building performance that results in damage that disrupts building usage and occupants. To protect amenity and function, buildings should be designed such that an unacceptable loss of amenity and functionality does not occur.

For the purpose of this project, the following definitions were used:

- **Amenity**: An attribute of, or system in, the building that provides services or functions related to the use of the building by occupants or that contributes to the comfort of the occupants, and that is not necessary for the minimal protection of the occupants (for example an automatic sprinkler system is not an amenity),[4]

- **Function**: An attribute of, or system in, the building that contributes to the ability to fully utilise a facility. The basic functions of a building are to provide shelter and protection and to support activities within it.

The performance indicators for protection of amenity and function include the maintenance or protection of:

- Access to the building
- Accessibility within the building
- Weathertightness
- Emergency systems
- Security systems
- Sanitation
- Other building services
- Essential contents (required for function)

It is understood that building function can be disrupted by factors outside of the control of the building owner/occupier (e.g., accessibility disruption due to damage to neighbouring buildings or transportation routes and/or disruption to services due to damage to surrounding infrastructure). However, these factors are outside the scope of this assessment.

Each of the performance indicators considered for protection of amenity and function is described below.

Maintenance of Access to the Building

Access includes exterior doors to a building as well as the approach to the main entrance of a building.

Lost or impeded access to the building will inhibit the use of the building. Access routes need to be maintained to ensure that the amenity is preserved (people can easily come and go) and functionality is retained (people can enter the building to use it).

Maintenance of Accessibility within the Building

Accessibility within the building includes routes through corridors, doors, stairs, ramps, and lifts. Accessibility may also include enabling people with disabilities to access the building.

Lost or impeded accessible routes within the building will cause a loss of amenity and function in a building, depending on the severity of the disruption. For example, the use of the building will be inequitable for people with limited mobility if accessible routes (e.g., wheelchair ramps or lifts) are impeded. Similarly, the building loses function capacity if building users cannot access parts of it.

Maintenance of Weathertightness

[4] The definition of amenity is adopted from the 2021 ICC Performance Code for Buildings and Facilities (ICCPC).

Weathertightness is a building's ability to prevent elements of the weather from adversely penetrating the building envelope. The requirements for weathertightness depend on the building's location, design, materials, construction, and maintenance. They commonly include protection from elements such as rain and wind but may also include elements such as flood waters, salt, and UV. Building components related to weathertightness include building cladding, walls, doors, and windows.

Loss of weathertightness can cause major disruptions to the use of a building. Weathertightness contributes to amenity as it protects the building users from the outdoor environment. Loss of weathertightness can also cause loss of function if, for example, water ingress causes damage to other building systems.

Protection of Emergency Systems

Emergency systems are building systems related to the safety of occupants in an emergency. Emergency systems might include[5]:

- Automatic systems for fire suppression (for example, sprinkler systems).
- Automatic or manual emergency warning systems for fire or other dangers.
- Electromagnetic or automatic doors or windows (for example, ones that close on fire alarm activation).
- Emergency lighting systems.
- Escape route pressurisation systems.
- Riser mains for use by fire services.
- Smoke control systems.
- Emergency power systems
- Other fire safety or evacuation systems.

Disruptions to emergency systems can result in a loss of function. A building may be deemed unoccupiable while emergency systems are non-functional, resulting in significant disruptions to building use.

Protection of Security Systems

Security refers to a building's ability to resist unwanted entry (and/or exit). Relevant systems include security and alarm systems, as well as elements of the building envelope that can be penetrated to gain access to the building, such as doors and windows.

Disruptions to security systems can result in a loss of amenity if building occupants don't feel safe in their building or a loss of function if security is a critical function of the building.

Maintenance of Sanitation

Maintenance of sanitation within a building protects the health and hygiene of building occupants. Sanitation systems include ventilation, water, and sewerage. Sanitation also includes ensuring that hazardous building materials, which may harm building occupants are not present.

[5] The list of emergency systems is based on a list for buildings with compliance schedules for specialised systems (https://www.building.govt.nz/managing-buildings/managing-your-bwof/specified-systems-and-compliance-schedules/).

Sanitation systems have been defined separately from other building systems given their importance for safe building occupancy, particularly if the ability to shelter-in-place after a major event is a performance objective.

Inadequate sanitation can result in a loss of amenity or a loss of function, depending on the severity of disruption. Amenity will be lost if sanitation can largely be maintained, even if it is through temporary measures (e.g., port-a-loos outside of a building). However, many buildings cannot function if there are no means of providing a sanitary environment.

Protection of Other Building Services

Building services are the systems installed in buildings to make them comfortable, functional, efficient, and safe. The building services included in this performance indicator are the services that are part of the 'convenience and comfort systems' which are present in most buildings, as well as the services/systems that provide specialty functions in some buildings.

Other building services might include[6]:

- Building control systems.
- Energy distribution.
- Energy supply (gas, electricity, and renewable sources such as solar, wind, geothermal, and biomass).
- Heating, ventilation, and air conditioning (HVAC).
- Information and communications technology (ICT) networks.
- Lighting (natural and artificial).
- Refrigeration.

'Other building services' does not include emergency, security, sanitation, and accessibility systems as they are covered by other performance indicators.

Disruptions to building services can result in a loss of amenity or a loss of function, depending on the type, duration, and severity of the disruption.

Protection of Essential Contents (required for function)

Some buildings may contain contents that are essential for function. For example, primary production facilities may contain specialised machinery, which, if damaged, would disrupt the use of the building. In these buildings, the owner or occupier may require that special consideration be given in the design process to ensure the essential contents are protected.

[6] The list of building services is based on an article titled 'Understanding Building Services' the 'Understand Building Construction' website (http://www.understandconstruction.com/building-services.html).

Appendix G:

Relating Building Performance to Outcomes

G.1 Mapping Outcomes to Performance

How a building performs in an earthquake potentially will affect many outcomes. Good performance will allow building users to continue ‘business as usual’ whereas poor performance may result in injuries, disruptions, or costs.

As described in Appendix E, outcome indicators can be direct or indirect and span both immediate outcomes and longer-term impacts. *Direct* outcomes are consequences apparent immediately, or shortly after, the earthquake occurs and can be linked unambiguously to building damage. *Indirect* outcomes are secondary effects that are often a result of a direct outcome. For example, a building that functions as a retail store may have structural damage that makes it unsafe to occupy. This will result in the direct outcome of user disruption, while the business is unable to operate from the premises. An indirect outcome would be the financial losses that the business incurs while not operating.

The relationships between the dimension of building performance and outcome indicators, which are agnostic to building usage and type, are shown in Table G1 and explained in the sections below. Indirect outcomes were not included, because of the numerous external factors that can influence them.

The dimensions of building performance are mapped back to the outcome indicators where there is the strongest, most direct, causal relationship. For example, if a building contains important cultural treasures, then *Protection of Property* will be important. Another example, if a building’s function has a high value to the community, such as a school, then interventions that enable *Protection of Amenity and Function* will reduce *Social disruption*. In this latter example, while the building is damaged (and there is property loss) it is the loss of function not the direct damage that users of a school will be affected by. Therefore *Protection of Amenity and Function,* rather than *Protection of Property*, is mapped back to *User disruption* and *Social disruption.*

As noted in Appendix F, we recognise that buildings comprise complex systems and it may initially appear there is overlap between some of the proposed indicators and the dimensions of building performance. The indicators have been related to the most directly relevant aspect of a building’s performance where the onset of loss / failure of this indicator is first relevant. That is from onset of any physical damage (protection of property), onset of loss of normal building functionality (protection of amenity and function) or structural failure (protection from injury).

Table G1. Relationship between dimensions of building performance and outcome indicators. Direct outcomes indicators are bolded, and indirect outcome indicators are not.

		Dimensions of Building Performance														
		Protection from injury				Protection of Property			Protection of Amenity and Function							
		Stability (Primary)	Stability (secondary)	Stability of non-structural elements (falling objects)	Egress / Access routes	Structural elements	Non-structural elements	Contents	Access (to building)	Accessibility (within building)	Weathertightness	Emergency systems	Security	Sanitation	Other services	Essential contents (required for function)
Outcome Indicators	1. Human															
	1.1. Casualties	✓	✓	✓	✓											
	1.2. Consequential stressors (e.g., PTSD, social cohesion)	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
	2. Social															
	2.1. **User disruption** (extend and duration of disruption)								✓	✓	✓	✓	✓	✓	✓	✓
	2.2. Social disruption (importance of building to community)								✓	✓	✓	✓	✓	✓	✓	✓
	2.3. Loss of cultural treasures					✓	✓	✓								
	3. Economic															
	3.1. Direct losses (cost of repair)					✓	✓	✓								
	3.2. Indirect losses (loss of revenue)								✓	✓	✓	✓	✓	✓	✓	✓
	4. Environmental															
	4.1. Building waste (e.g., waste disposal/carbon impacts)					✓	✓									
	4.2. Uncontrolled release of hazardous materials								✓	✓	✓	✓	✓	✓	✓	✓

G.2 Evaluating Dimensions of Building Performance

For each dimension of building performance, three measurable (at the building level) direct outcome metrics have been identified that relate to each dimension. For example, for Protection from Injury, *fatal injuries*, *non-fatal injuries*, and *egress* were selected as measures to describe how a building would perform (or should perform) in a particular earthquake. Indirect outcomes were not included, because of the numerous external factors that can influence them.

The continuums of outcome severity for each of the metrics are tabulated below. The continuum uses a 6-point scale of severity, with severity classes being (1) none/insignificant, (2) minor, (3) moderate, (4) high, (5) severe, and (6) catastrophic. These allow choices for policy settings and to indicate alternative possible outcomes. The severity classes are unique to each building dimension but recognise that each building dimension relates separately to a different aspect of a building's performance. They do not necessarily relate across the different dimensions. That is, a catastrophic outcome for protection from injury is not necessarily equivalent to a catastrophic outcome for protection to property. How these dimensions map to each other, and to overall impact, is work that is still to be done. The scales are also not intended to be linear. That is, the difference between none and minor is not necessarily the same as the step between moderate and high, but rather identify key measurable points relevant to each separate scale.

The framework allows for the inclusion of additional (or other) metrics for the three different building dimensions. This enables metrics to be added where needed evaluate or set performance objectives for highly specialised building types, for example hospitals.

G.2.1 Protection from Injury

As shown in Table G1, protection from injury has been linked with casualties and consequential stressors. Casualties is the direct outcome indicator and consequential stresses is the indirect outcome indicator. An example of a consequential stressor that may result from a casualty is the post-traumatic stress disorder (PTSD) a person may experience after they have been injured by a building element that fell during an earthquake.

The continuum of outcome severity for protection from injury is described in Table G2. The range of casualty outcomes has been divided into three categories: *fatal injuries*, *non-fatal injuries*, and *egress*. This distinction was made because the societal expectations research conducted in 2021/22 found that people are generally intolerant of deaths but are slightly more accepting of injuries in severe shaking, particularly when there is a huge cost associated with preventing all injuries. Egress was included as a category linked to casualties because of the potential for additional trauma from entrapment.

G.2.2 Protection of Property

Protection of property has been linked with loss of cultural treasures, direct financial losses, building waste, and consequential stressors. Consequential stressors are indirect outcomes while the other indicators are direct outcomes. An example of a consequential stressor that may result from damage to property would be the mental health impact a homeowner may experience when they are faced with the unexpected financial burden of having to repair their damaged house and the associated task of dealing with unfamiliar procedures involving their insurance and/or bank.

The continuum of outcome severity for protection of property is described in Table H3. The range of direct outcomes has been described using three categories: *overall extent of damage*, *financial cost*, and *waste cost*.

- Overall extent of damage defines the amount of damage that is likely to occur that would result in the costs described in the other categories (financial and waste).
- Financial cost describes the expenses associated with building repair or replacement. These costs are expressed relative to building value.
- *Waste* is a direct outcome indicator that is measured by the amount and nature of building debris or demolition material that will be stored or sent to a landfill during the repair or replacement process. It is a proxy for the operational and embodied carbon[1] required to repair or rebuild structures though we did not attempt to measure that in this Project.

Loss of cultural treasures was not included in the continuum of outcome severity because this outcome is typically considered to be binary; precious cultural assets are either lost/damaged or not. Furthermore, the degree of loss may be subjective, and therefore the outcome indicator is not suitable for use on the continuum, which is intended to be agnostic of building use.

G.2.3 Protection of Amenity and Function

Protection of Amenity and Function has been linked with user disruption, social disruption, indirect financial losses, uncontrolled release of hazardous materials, and consequential stressors. User disruption is a direct outcome and the other outcome indicators are indirect.

An example of social disruption resulting from user disruption would be the closure of a library building damaged in an earthquake. The closure would disrupt social networks and displace those who may rely on the public space to escape inclement weather or social isolation.

An example of indirect financial loss related to user disruption would be the loss of income a restaurant worker may experience if the restaurant they worked in is closed because the surrounding building is damaged and not occupiable. Another example would be the money that a homeowner may have to spend to rent a place to live elsewhere while their home is being repaired.

The effects of an uncontrolled release of hazardous materials from an industrial plant into a nearby stream is an example of environmental harm that may result from earthquake damage.

[1] Gonzalez RE, Stephens MT, Toma C, Dowdell D. The Estimated Carbon Cost of Concrete Building Demolitions following the Canterbury Earthquake Sequence. *Earthquake Spectra*. 2022;38(3):1615-1635. doi:10.1177/87552930221082684.

An example of a consequential stressor that may result from user disruption would be the mental health impact that an elderly person living in an aged-care facility may experience if the facility is damaged in such a way that typical amenities (e.g., cooking facilities and heating/cooling systems) are impacted by earthquake damage.

The continuum of outcome severity for protection of amenity and function is described in Table G4. The range of user disruption outcomes has been described using three categories: *Intended function* (immediate post-event), *duration of disruption*, and *alternative function* (immediate post-event).

- Intended function (immediate post-event) describes the types of functions that are available immediately after ground shaking, the scale of modifications needed to support the intended function, and the degree of amenity loss.
- Duration of disruption describes the possible extent of repairs necessary to restore amenity and function as well as the expected time to complete those repairs.
- Alternative function (immediate post-event) is an extra category that describes planned purposes to which a building might be put after an event, even with limited functional capacity. This is included to help guide the development of performance objectives if a building's future usages might foreseeably include alternative functions post-event.

Because intended function (immediate post-event) and duration of disruption are not necessarily directly related (e.g., damage that causes moderate disruption to function may take months to repair), there could be alternative methods to determine the outcome severity. Table G5 presents an example approach, where a matrix relates the duration of disruption to the immediate disruption severity to determine outcome severity. This approach is conceptual and needs further analysis and review.

Table G2.Continuum of outcome severity related to Protection from Injury

Outcome Severity	Fatal Injuries	Non-Fatal Injuries	Egress
None / Insignificant	• No loss of life.	• Few if any minor injuries.	NA
Minor	• No loss of life.	• Minor to a small to medium number of people. • Few if any moderate injuries. • Few if any significant injuries.	NA
Moderate	• No loss of life.	• Minor injuries to a medium to large number of people. • Moderate injuries to a small to medium number of people. • Few if any significant injuries.	NA
High	• One or more, localised single loss of life. • No instances of multiple loss of life at a location within building.	• Extensive minor injuries. • Moderate injuries to many people. • Significant injuries to a medium number of people.	• Ability to evacuate building possible for most able-bodied people. • Some vulnerable people may require rescue by specialised rescue teams.
Severe	• Single loss of life in multiple locations throughout building and/or • One or more instances of multiple loss of life at a location within building .	• Extensive minor and moderate injuries • Significant injuries to many people.	• Ability to evacuate building limited for some able-bodied people. • Most trapped/ injured occupants or vulnerable people require assistance to escape requiring specialised rescue teams.
Catastrophic	• Large numbers of loss of life.	• Extensive significant injuries.	• Ability to evacuate building limited for most people. • Many trapped occupants.

Table G3. Continuum of outcome severity related to Protection of Property

Outcome Severity	**Overall Extent of Damage**	**Financial Cost**	**Waste Cost[2]**
None / Insignificant	No measurable impact	*No measurable impact.*	TBD
Minor	Damage to building or facility contents is minimal in extent and minor in cost.	*Within operating budget* • Low cost (e.g., <2% building replacement value)	TBD
Moderate	Damage to building or facility contents may be locally significant but generally moderate in extent and cost.	*Within typical insurance deductible* • Moderate cost (e.g., ~ 5% building replacement value)	TBD
High	Damage to building or facility contents may be locally significant and generally high in extent and cost.	*Within event scenario expected loss limit* • High cost (e.g., ~ 10% building replacement value)	TBD
Severe	Damage to building or facility contents may be locally total and generally severe in extent and cost.	*Repairable damage* • Severe cost, (e.g., ~ 20% building replacement value)	TBD
Catastrophic	Damage to building or facility contents may be total.	*Irreparable damage* • Building written off, (approx. 30% building replacement value)	TBD

[2] Waste Costs is a direct outcome that is related to building performance and was highlighted as a concern in the societal expectation research. However, the Project has not quantified a metric for measuring outcome severity that is applicable to all building types.

Table G4. Continuum of outcome severity related to Protection of Amenity and Function

Outcome severity	Level of function (business-as-usual purpose) (immediate post-event)	Duration of disruption	Level of function (alternative function) (immediate post-event)
None/ Insignificant	• Building usage remains as pre-event. • Building usage unaffected for all.	• No displacement of occupants.	N/A
Minor	• Minimal modifications required to carry out normal functions. • Intended functions are supported. • Modifications have minor impact on amenity (i.e., user comfort, including psychological response).	• Repairs cause minimal disruption to function (**days to weeks**) and can be scheduled for time building is less occupied.	N/A
Moderate	• Modifications required to carry out normal functions. • Basic intended functions are supported. • Modifications have moderate impact on amenity.	• Repairs likely to cause minor to moderate disruption to function. • Repairs carried out with the possibility of people being displaced (within building) for part or all of the repair time (order of weeks to months)	N/A
High	• Normal function is limited as several modifications are required to carry out basic intended functions. • Modifications have major impact on amenity.	• Repairs likely to cause moderate to severe disruption of function. • Many repairs require people and the building functions to move out for the repairs to be completed (order of **months**)	Basic alternative post-event functions possible
Severe	• Only the most basic intended functions (e.g., shelter) are supported. • Modifications have extreme impact on amenity.	• Significant disruption to building occupants and building functions while repairs are carried out (order of **years**)	Shelter in place
Catastrophic	• Building is non-functional.	• Total disruption to building occupants and functions. **Permanent** loss of function.	Building is not safe for occupancy (red-tagged)

Table G5. Matrix alternative to describe outcome severity for Protection of Amenity and Function

Disruption to intended function (immediate post-event)	Duration of disruption: **None** – Insignificant disruption to occupants.	**Days** – Repairs cause minimal disruption to function (**o days to weeks**) and can be scheduled for time building is less occupied.	**Weeks** – Repairs carried out for a maximum of a **weeks to months**, with the possibility of people being displaced (within building) for part or all of the repair time.	**Months** – Many repairs (or specialised repairs) require people and the building functions to move out for the repairs to be completed (order of **months to years**)	**Years** – Significant disruption to building occupants and building functions while repairs are carried out (order of **years**)	**Permanent** – Total disruption to building occupants and functions. **Permanent** loss of function.
Building usage remains as pre-event. (Building usage unaffected for all).	Insignificant	Minor	Minor			
Minimal modifications required to carry out normal functions. Intended functions are supported. Modifications have minor impact on amenity (i.e., user comfort, including psychological response).		Minor	Minor	Moderate	Moderate	
Modifications required to carry out normal functions. Basic intended functions are supported. Modifications have moderate impact on amenity.		Minor	Moderate	High	Severe	
Normal function is limited as several modifications are required to carry out basic intended functions. Modifications have major impact on amenity.		Moderate	High	High	Severe	
Only the most basic intended functions (e.g., shelter) are supported. Modifications have extreme impact on amenity.		Moderate	High	Severe	Severe	Catastrophic
Building is non-functional.		High	Severe	Severe	Catastrophic	Catastrophic

Appendix H:
Building Usage Categories

The Stage 2 societal expectation research clearly showed that all those involved valued some building usages more than others. The reasons why certain buildings were important varied; some buildings were seen as important because they are likely to house vulnerable people while others were valued because they enabled society to function normally. In general, buildings were viewed as less important if there were readily available alternatives to their use (e.g., working from home or redundancy in building function).

The importance of buildings also differed depending on the geographical and community context. Buildings located along major arterial routes were understood to have the potential to cause acute consequences for impeding post-disaster response and recovery if they were damaged in an earthquake. Additionally, expectations for building performance differed between urban and rural settings. For example, some rural communities had strong social and economic ties to a particular business or primary industry processing plant. In built-up urban areas some people would prefer enhanced seismic performance given the concentration of risk in those areas. For example, disruption to medium and high density housing could create a challenge post-earthquake if residents were displaced.

The Resilient Buildings Project (RBP) recognises that geographical and community considerations are important to improving seismic resilience in New Zealand. However, these issues are outside of the scope of the proposed framework. Performance objectives related to these aspects should be assessed at the community level.

The RBP project team undertook an exercise to identify building usages that have higher consequences of failure (in terms of human, social, economic, and environmental impacts) relative to 'typical' buildings.

A consistent approach was used to understand (1) *why* certain buildings are valued by their communities and (2) the *consequences* that would result from these important buildings being damaged. After the reason for building importance was identified, the consequences were related to the dimensions of building performance.

Within the EPO framework, each dimension of building performance is considered separately. As such, our vision is that each building usage group can have performance outcomes, and subsequently performance objectives, set that prioritise the dimension(s) of building performance most critical to it.

For example, a large stadium might need enhanced seismic performance to reduce injury, but have few requirements for damage prevention or ensuring ongoing functionality. Whereas, a supermarket might need enhanced seismic performance to ensure ongoing functionality but not necessarily enhanced protection from injury. The differing performance requirements would then inform design decisions. For example, preventing injuries may require more consideration of acceleration loads on structural elements whereas preventing disruption may require more consideration of velocity loads on non-structural elements.

This approach allows for targeted design interventions to improve building performance above code for each of the dimensions of building performance based on the needs specific to a given building.

H.1 Consequence Categories

Consequence categories are proposed to describe the severity of consequences in the event of poor seismic performance from particular building usages. The consequence can be described as extreme, critical, serious, typical, or low (Table H1).

Table H1.Consequence categories for building performance

Consequence Severity	Description
Extreme	Building or building system failure would have **catastrophic** human, social, economic, or environmental consequences on the community or nation. (Extreme consequences were out of scope for RBP)
Critical	Building or building system failure would have **severe** human, social, economic, or environmental consequences for the community.
Serious	Building or building system failure would have **high** human, social, economic, or environmental consequences for building users or the community.
Typical	Building or building system failure would have **ordinary** human, social, economic, or environmental consequences for building users or the community.
Low	Building or building system failure would have **minimal** human, social, economic, or environmental consequences for building users and the community.

H.2 Building Usages Identified for Enhanced Performance

The following subsections describe the building usages identified as having higher consequences in terms of injury, disruption, and damage. We also identify additional building usages which, although not considered to have serious consequences, may require additional consideration (either in the Code or in the design process) to ensure tolerable outcomes can be achieved.

The identification of building usages with heightened consequences was based on our interpretation of the societal expectations research augmented by professional judgment. Excerpts from the report titled “Societal expectations for seismic performance of buildings”, and accompanying data reports, are provided as commentary[1].

The findings are also presented in a tabular format with the following column headings:

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[1] The findings of the societal expectations research were published in a main report, with two complimentary data reports.
Main Report: https://www.nzsee.org.nz/db/PUBS/RBP_SocietalExpectationsReport-FINAL-for-Release.pdf
Focus Group Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Focus-Group-Report-final.pdf
Interviews Report: https://www.nzsee.org.nz/wp-content/uploads/2022/07/Interviews-Report-FINAL.pdf.

- *Outcome indicator* – the post-event consequence on which performance will be judged (See Appendix E for further explanation of outcome indicators).
- *Building usage attribute* – the measure used pre-event to determine the potential for heightened consequences of poor seismic performance.
- *Consequence category* – the severity of consequence relative to a ‘typical’ building (see Table H1).
- *Criteria* – the building usage that requires enhanced performance.
- *Reasoning* – why the criteria has higher consequences relative to ‘typical’ buildings.
- *Example building usages* – selected building usages that fit the criteria.

As a step toward simplifying the long lists of criteria we developed, simplified tables are also presented. These tables summarise the building usages identified as warranting additional targeted design consideration to mitigate critical or serious consequences of poor performance.

The presented tables offer a high level of detail to convey the findings of the societal expectations research. However, we recognise that buildings often are subject to one or many changes of use over their lives. We anticipate that implementation of these findings into code and standards will require differentiation of criteria for enhanced performance which may be beneficial to codify versus others better left to market discretion. We note that this may vary according to whether buildings are privately or publicly owned.

H.2.1 Protection from Injury

The possible outcomes related to Protection from Injury are casualties and consequential stressors. The building usage attribute that influence casualty outcomes are *population risk exposure* and *vulnerable occupants*.

Population risk exposure measures the life-safety risk in terms of peak and/or average building occupancy rate.

Types of occupants considered vulnerable in terms of life-safety risk are those with mobility limitations (e.g., users of hospitals, aged care residents) and those that may require direction or management (e.g., dementia care patients, pre-schoolers, prisoners).

There may also be a case, on a building by building basis, to further reduce life safety risk based on the choice occupants have to enter a building or not, the likelihood of sleeping occupants within the building, and the familiarity of building users with the building layout.

Population Risk Exposure

Findings from the societal expectation research reflected the belief that life safety risk should be lower in buildings with high occupancy and/or exposure rates, given the concentration of risk in these buildings and facilities and societal intolerance of catastrophic structural failures involving multiple casualties. Structures may be considered ‘high occupancy’ based on (a) the maximum number of people in a building at any time, (b) the maximum number of people in a single area at any time, (c) the average number of people in building at any one time, or

(d) the average weekly usage (i.e., person-hours per week).[2]

The Building Code currently assigns importance levels based on peak occupancy for buildings and areas. It does not, however, address the average number of people or exposure time. We propose additional metrics as supplementary ways to determine overall risk exposure.

The inclusion of exposure time could address the concerns of many research participants that the way we use some buildings is changing and, thus, so is the risk profile of these buildings. As New Zealand continues to urbanise, more medium and high-density housing is being constructed. This, paired with growing trends for hybrid or fully remote (work from home) roles in many professions, means that people are spending longer times in larger buildings. The societal expectations research highlighted the importance of ensuring that the occupants of these buildings are protected from injury.

Excerpts from the Main Report:

Some believed priority should be on buildings that housed residents of a community rather than visitors given their likely duration of exposure. These distinctions, although not always explicit, highlight the challenge of differentiating 'what when' (impact and consequence) from 'what if' (frequency and likelihood).

Excerpts from the Focus Group Report:

Reduce risk of failure in buildings with high occupancy
Buildings with higher maximum occupancy, in particular buildings with multiple stories, should be built to a more stringent level than single storey low occupancy buildings. Failure of these buildings, resulting in mass loss of life and injuries, would be unacceptable, particularly in communities where a significant portion of the population are working in a particular building (e.g. food processing/ manufacturing facilities in rural towns). These buildings also provide the biggest "bang for buck" for protecting lives.

Reduce risk of failure in buildings where occupants are exposed for long periods
There should be less risk to life safety in buildings where people spend majority of their time.

High occupancy buildings
Preservation of life and reduction of injury are important. Investment in buildings with either high peak occupancy (e.g., stadium) and/or high occupancy rates (e.g., apartment blocks) were of top concern

Changing density in residential areas
There was concern for the protection of life safety in the future due to a rise in higher density, multi-storey buildings (in particular residential housing). A need for these buildings to be more robustly built was clear.

Vulnerable Occupants

[2] Average weekly usage is suggested as a risk exposure metric in the 2021 BRANZ report 'Managing earthquake-prone council buildings – a decision making framework'. https://www.resorgs.org.nz/wp-content/uploads/2021/12/EQ-Prone-Buildings-Framework-Dec21.pdf.

Vulnerable occupants of buildings require special consideration. Consistent with international guidelines on performance based design,[3] buildings are considered a 'serious' life safety risk if a significant percentage of occupants are, or are expected to be, members of vulnerable population groups such as infants, young children, elderly persons, persons with physical disabilities, persons with medical disabilities, or persons with other conditions or impairments that could affect their ability to make decisions, egress without physical assistance of others or tolerate adverse conditions. Additionally, buildings are considered a 'serious' life safety risk if they are likely to have a significant percentage of occupants that are unlikely to take protective action during ground shaking (e.g., young children or elderly persons) or would require supervised evacuation following ground shaking (e.g., detainees).

Excerpts from the Focus Group Report:

Vulnerable people should be protected
Buildings containing vulnerable people need to be seismically resilient. Vulnerable occupants include injured, sick, elderly, children/young people, and tourists (i.e., those unfamiliar with the area).

Mobility
Mobility is a key factor in determining vulnerability of occupants. People who are unable to get in a safe position (drop, cover, hold) or are unable to safely egress a building without requiring outside help are more vulnerable than those that are mobile. People with lower mobility include unwell or hospital patients, the elderly and the very young. Low mobility can also mean that occupant spends a lot of time in the same building (e.g., in hospital beds, elderly at home or in aged care), therefore having increased exposure.

Ability to protect oneself
The ability to protect oneself is a component of vulnerability. Children/younger people, visitors, cognitively impaired persons are some of the groups of people that may need support to respond to an earthquake appropriately (e.g., teachers or trained staff at attractions). Therefore the safety of the building they are in becomes more important.

Additional Risk Considerations

Agency/Choice of Occupants

Higher life safety standards may be desired if building users are likely to have limited choice about whether they enter a building or not (e.g., a prison, school, or hospital, versus a retail shop). It was suggested that owners of these building usages may have a higher duty of care given the lack of choice of building occupants.

Excerpts from the Main Report:

[3] International Code Council (ICC). (2021). *ICC Performance Code for Buildings and Facilities (ICCPC 2021).* https://codes.iccsafe.org/content/ICCPC2021P1.

Beyond the common life safety priorities described above, some other views were shared that attracted less consensus but provide useful insight. In particular, contrasting views were shared over whether the agency of the person using the building should be considered. In other words, are higher standards warranted for buildings where users have less choice over whether they enter the building or not (e.g., a prison, school or hospital, versus a retail shop)?

> *"If you are asking people to rely on a community facility, then that has to be to a higher code than something that's private." – Interview Participant (Public sector, National perspective, Environmental expert)*

Sleeping occupants

Buildings in which people normally sleep may require enhanced safety given that sleeping occupants will be unlikely to take immediate protective action and may struggle to evacuate promptly, if required, following ground shaking. Buildings with sleeping occupants could include residential housing and apartments, as well as overnight accommodations such as hotels and motels.

Excerpts from the Main Report:

First, priorities for life safety are not necessarily linked to objective calculations of building occupancy. The peak number of people potentially in a building, the duration people are likely to be in a building for or whether occupants are likely to be asleep in that building were all noted; however, they were not common in everyone's calculation.

Familiarity of building users with building

Similarly, consideration should be given as to whether building occupants and other users are expected to be familiar with the building layout and means of egress. Buildings which are likely to accommodate users unfamiliar with the layout may require enhanced design related to safety.

Excerpts from the Main Report:

Related, some believed that building users' familiarity with the building and seismic risks (or lack thereof) should be considered to recognise the high anxiety that visitors to a town or location may feel during a seismic event and the lack of means to self-care post-event. This approach would prioritise buildings such as motels, hotels or some tourist attractions.

Excerpts from the Focus Group Report:

Familiarity of users with building/location

Buildings and surrounding areas where there is a high chance of having occupants that are unfamiliar with the location should be prioritise life safety. This includes central business districts and tourism attractions where people are unlikely to know what to do/where to go during an event. If injured tourists suffer the additional impact of being cared for in an unfamiliar location (away from home).

Building Usage Attributes for Enhanced Performance for Protection from Injury

Table H2 shows the complete list of building usage attributes considered by the project team for enhanced performance for Protection from Injury. The table also shows the reason why the attributes require enhanced performance and lists example building uses.

Table H2. Long list of building usage attributes that may require enhanced performance for Protection from Injury

Outcome Indicator	Building Usage Attribute	Consequence Category[1]	Criteria	Reasoning	Example Building Uses
Casualties	Population Risk Exposure	C/S	Very high occupancy structures	Concentration of risk (higher risk of multiple deaths) AND/OR ability to egress without causing chaos	Stadiums, very large high-rise structures
Casualties	Population Risk Exposure	C/S	Large groups in a single space within a building (determined by peak occupancy)	Concentration of risk in a single location, ability to egress, potential for multiple casualties, socially intolerable	Large Halls, Theatres, large gathering areas within a building (e.g., mall central areas, large atriums within buildings, airport concourses)
Casualties	Population Risk Exposure	C/S	Occupancy density (high)	Average people/sqm	
Casualties	Population Risk Exposure	C/S	Occupancy rate (high)	Exposure time	
Casualties	Vulnerable occupants	S	Occupants likely to have mobility limitations (e.g., elderly, non-walking hospital patients)	Occupant's (lack of) ability to take protective action or independently evacuate	Hospitals, aged residential care facilities including rest homes (retirement village accommodation including apartments, and villas)
Casualties	Vulnerable occupants	S	Need for occupants to take directions or management (e.g., prisoners, young children, dementia patients)	Occupant ability to independently evacuate, potential panic post-event (e.g., by parents retrieving children)	Child-care centres, preschools, schools, dementia care facilities, prisons, secure facilities (e.g., within hospitals and judicial systems)
Casualties	Vulnerable occupants	T*	Sleeping occupants	Occupant ability to take protective action	Residential houses and apartments, hotels
Casualties	Vulnerable occupants	T*	Discretion/choice of occupancy	Duty of care to those with limited or no discretion to act.	Prisons, schools, hospitals, (building ownership vs occupancy)
Casualties	Vulnerable occupants	T*	Familiarity of building users with building layout	Ability to evacuate; those unfamiliar with building layout are more at risk.	
Consequential Stresses (PTSD)	NA	-	*No user / building group identified as requiring enhanced consideration beyond those identified under 'Casualties'*	NA	NA

[1] Consequence categories are Critical (C), Serious (S), and Typical (T). T* indicates generally typical consequences but is flagged for possible additional consideration.

Building Usage Categorisation by Consequence for Protection from Injury

Buildings that have serious, typical, and low consequences related to injuries are identified in Table H3. The building usage attributes that influence casualty outcomes are *population risk exposure* and *impact on vulnerable occupants*.

Table H3.Building usage categorisation, by consequence, for enhanced Protection from Injury

Building Usage Attributes	Consequence Severity		
	Serious	**Ordinary**	**Low**
Population Risk Exposure	• Facilities with high[1] occupancy rates	• Facilities with normal[1] occupancy rates	• Facilities with low[1] occupancy rates
Vulnerable Occupants	• Facilities likely to have high rates occupants with mobility limitations • Facilities likely to have occupants that require direction or management		

[1]Definitions of high, normal and low occupancy rates are to be determined by others.

H.2.2 Protection of Property

The purpose of the protection of property dimension of building performance is to limit damage to assets and minimise the associated direct cultural, economic, and social value. The possible outcomes related to Protection of Property are loss of cultural treasures, direct financial losses, building waste, and consequential stressors. The building usage attributes related to damage are *cultural significance*.

There are few building usages that require enhanced performance to reduce damage, beyond that of a typical building. The societal expectations research highlighted the importance of protecting cultural capital in New Zealand. Therefore, facilities that house cultural treasures or have a high cultural value (e.g., museums) have a serious consequence of damage. The project team also identified that facilities that house important public interests (e.g., police data centres) have a serious consequence of failure.

Additional measures to further reduce damage may be relevant where buildings with high economic value (building or contents), or buildings with financially vulnerable occupants (with limited financial means to repair damage or replace damaged contents) may have cause for enhanced protection from property damage. Enhanced protection of property may also be suitable where environmental impacts (release of hazardous substances or impact of waste/carbon effects if they are damaged) want or need to be reduced.

Cultural Significance

Preserving cultural treasures is vital to the cultural and social wellbeing of communities. The cultural value of the contents of some buildings (e.g. of a museum, art gallery, marae) is beyond the value of the building structure. The preservation of these socio-cultural assets ensures there are places for people to connect with their culture and ensures that historic artefacts are preserved.

Buildings and facilities are considered to have ‘serious’ damage risk if house cultural treasures or have a high cultural value (e.g., museums, maraes, libraries, archives).

Excerpts from the Focus Group Report:

Critical cultural capital should be protected
Loss of critical cultural assets is intolerable. Cultural assets can comprise maraes, religious or heritage buildings and public gathering places. The preservation of these socio-cultural assets ensures there are places for people to meet and connect with each other and our culture. Culture also emerges between buildings, the feeling of the system as a whole and the vibe of the community. This can be hard to restore.

What is considered cultural capital evolves over time
The cultural value of buildings changes over time. It is important to take stock of the cultural value of buildings regularly to identify what needs to be protected.

Contents within buildings
Often the drive to invest in buildings of cultural value is to protect the taonga inside a building more than the building itself. The cultural value of the contents of some buildings (e.g. of a museum, art gallery, marae) are higher than the building itself.

The project team also identified that facilities that house important public interests (e.g., police data centres) have a serious consequence of failure. Damage to these types of facilities negatively affects the ability to effectively govern.

Impact on the Environment

Reducing the impacts of earthquakes on the natural environment is an emerging priority. Limiting building damage would reduce the associated impacts of waste from building remediation or demolition. However, no specific building usages were identified as requiring enhanced consideration for waste/carbon impacts.

Excerpts from the Main Report:

Reducing impacts of earthquakes on the natural environment is an emerging priority. Many participants drew strong connections between impacts on the natural environment and community wellbeing, identifying the role that the environment plays in underpinning human existence. For many the potential impacts following an earthquake, particularly the presence of hazardous waste or waste volumes that exceed the capacity of current disposal facilities, are considered intolerable.

A number of participants believe that reducing embodied and operational carbon in buildings (including minimising the disposal of damaged buildings following an earthquake) is a critical priority.

Excerpts from the Focus Group Report:
Durability and sustainability
Buildings represent carbon emissions created at the time it was built (e.g., 80-year-old heritage building represents emissions made 80 years ago). Buildings that are not durable are demolished and replaced with new buildings creating new emissions. Durable buildings therefore reduce the creation of new carbon emissions

Excerpts from the interviews report:
One of the most common concerns was managing the waste generated from demolished buildings. The Christchurch earthquake was often cited as an example of an earthquake that resulted in widespread building demolition, which required innovative approaches to waste management. Interviewees were concerned that the uncontrolled demolition of buildings would result in ground contamination from hazardous building materials (e.g., asbestos) and a lost opportunity to re-use or recycle building materials.

The carbon cost of demolishing a building due to earthquake damage was also discussed by some interviewees. Reducing carbon emissions is an emerging priority for many individuals and organisations. The untimely demolition of a building would counteract environmental sustainability objectives. Several interviewees observed that fixing a building is more sustainable than demolishing and rebuilding it.

Additional Risk Considerations

There are also additional reasons, which have not been labelled as ‘serious’ consequences within the framework, why building owners or developers may prefer extra measures be taken to reduce damage in their buildings. For example, buildings may have contents of high economic value that need to be protected during earthquakes. Conversely, buildings that are likely to house vulnerable occupants with limited financial means to repair damage might require extra damage protection to ensure equitable recovery. Building owners may also choose low-damage designs if they want to reduce their waste/carbon footprint in the event of a large earthquake and/or boost reputation within their communities.

Facilities with High (Economic) Value Contents

Similar to facilities with contents of high cultural value, the working group identified that facilities that house contents of high economic value may require enhanced performance to ensure the contents are protected. Ensuring the building performs in such a way that the contents are protected would ensure that the building owner or occupier does not sustain a large economic loss in the event of a major earthquake. Example building usages that may fall into this category include data centres and specialist laboratories.

Facilities with Financially Vulnerable Occupants

Many of the research participants were concerned about equity in recovery. They were worried that people who had the least financial means to recover would be most heavily impacted. It was suggested that buildings which are likely to house these financially vulnerable people (e.g., low-income housing) might benefit from additional damage protection in earthquakes. However, there was caution to ensure that any additional costs are not passed on to the already financially vulnerable occupants.

Excerpts from the Focus Group Report:

How losses are felt across a community is important (equity)
Often impacts affect the people who don't have the means to cope. For example, lower income families often live in less resilient buildings on less resilient land.

Equity of impacts should be considered.
Earthquakes have variable impacts on different groups of people. Those that are less resilient/disadvantaged often experience more significant impacts. The inequity in impacts can translate through the recovery process as some vulnerable people cannot access resources and have a slower recovery trajectory.

Excerpts from the Interviews Report:
Multiple interviewees noted here the vulnerability of tenants (e.g., financial situation) would affect their tolerance for the earthquake impacts, with damage and disruptions perceived as being disproportionally harmful to vulnerable people.

Boosting Reputation with Low-damage Designs (Environmental)

Reducing the environmental impacts of earthquakes is an emerging priority. Building owners may wish to implement low-damage designs to ensure that their building is sustainable, even after earthquakes, by reducing the potential for building waste from damaged components.

Excerpts from the Interviews Report:

Sustainability benefits
The design of buildings to be seismically resilient is linked to sustainability objectives (e.g., reducing carbon and mitigating climate change).

Boost reputation in the community

Constructing a seismically resilient building can help boost a company's reputation in its community by demonstrating a willingness to contribute to community resilience

Building Usage Attributes for Enhanced Performance for Protection of Property

Table H4 shows the complete list of building usage attributes considered by the project team for enhanced performance for Protection of Property. The table also shows the reason why the attributes require enhanced performance and lists example building uses.

Table H4. Criteria that may require enhanced performance for Protection of Property

Outcome Indicator	Building Usage Attribute	Consequence Category[1]	Criteria	Reasoning	Example Building Uses
Loss of culture / cultural treasures	Cultural significance	S	Facilities that house cultural treasures or have a high cultural value	Loss of culture	Museums, Maraes, Libraries, Archives
Loss of culture / cultural treasures	Cultural significance	S	Facilities that house important public interests	Loss of important documents	Police data centres
Direct Losses (Economic)	Financially vulnerable occupants	T*	Facilities that are likely to house individuals with limited financial means to repair damage.	Occupants have limited means to recovery.	Low-income housing
Direct Losses (Economic)	Impact on economy	T*	Facilities with high (economic) value contents	Contents are more valuable than the structure that houses them and represent a large economic loss to owner/occupier	Data centres, specialist laboratories, electricity sub-stations
Direct Losses (Environmental)	Impact on environment	T*	*No user / building group identified as requiring enhanced consideration for carbon/waste impacts*		

[1] Consequence categories are Critical (C), Serious (S), and Typical (T). T* indicates generally typical consequences but is flagged for possible additional consideration.

Building usage categorisation by consequence, for Protection of Property

Buildings that may require enhanced performance to prevent damage are identified in Table H5. The building usage attributes relate to damage are *cultural significance*.

Table H5. Building usage categorisation, by consequence, for enhanced Protection of Property

Building usage attributes	**Consequence severity**
	Serious
Cultural significance	• Facilities that house cultural treasures or have a high cultural value • Facilities that house important public interests

H.2.3 Protection of Amenity and Function

The outcome indicators related to Protection of Amenity & Function are user disruption, social disruption, indirect economic losses, consequential environmental losses, and consequential stressors. The building attributes related to Protection of Amenity & Function are *post-disaster response functions, recovery enabler, vulnerable occupants, community wellbeing support, and impact on the environment*.

Post-disaster response functions are buildings where the building is critical after a major event. *Recovery enablers* are buildings that are needed to effectively support community recovery following a major earthquake. *Vulnerable occupants* reflects the dependence of users on the functions of some buildings. *Community wellbeing support* relates to buildings that are required for a community to function normally. *Impact on the environment* relates to the environmental consequences associated with the loss of containment of hazardous materials. These building usage attributes are described in detail below.

Additionally, additional measures toward reducing disruption from loss of amenity and function might be desirable for the following building usages:

- Facilities vital for economic output (regional or national) and/or vital for employment in regional area
- Facilities where damage may cause disproportionate uninsurable loss
- Facilities that house agencies for recovery
- Community facilities that contribute to cultural identity, contribute to community connection and/or a sense of place
- Facilities with occupants sensitive to visible damage
- Accommodation facilities

Post-disaster response functions

Buildings critical to the post-disaster response need to be functional following a major event. Impact on post-disaster response measures the criticality of the building after a major event.

It is generally expected that emergency services will continue to operate after a major earthquake so that those who need help are able to receive it. Buildings identified as critical in the early response phase included hospitals or other medical centres, emergency operations centres (i.e., buildings that host civil defence and search and rescue operations), fire stations, police stations, and ambulance depots.

Furthermore, the preservation of buildings with the functional capacity to sustain life is particularly important if failure could hinder other lifesaving functions (e.g., loss of function in an aged care facility may increase demand on the hospital) or their ongoing operation could reduce pressure on other services (e.g., aged care facilities can be used to take overflow from hospitals given their medically trained staff and life-saving equipment).

Excerpts from the Focus Group Report:

Response and recovery needs to be enabled

Buildings and services that are critical following an event need to be protected. For example, emergency services, civil defence, hospitals and community meeting places are needed to protect life and provide places of support immediately post event. Military installations were also noted as an important response and recovery service need.

Ensure capacity to sustain life following an earthquake

Buildings that house people and facilities that can protect and sustain life following an earthquake are important. These buildings may contain emergency services, medical staff and resources (including services to aid in the aged care sector), critical infrastructure and people with the skillsets to manage it (telecommunication, power and water) and food distribution (including all steps of the food supply chain e.g., supermarkets, food production, manufacturing, warehouses). These services are critical following an earthquake event.

Excerpts from the interviews report:

It is generally expected that emergency services will continue to function after a major earthquake so that those who need help are able to receive it. Buildings identified as critical in the early response phase included hospitals or other medical centres, emergency operations centres (i.e., buildings that host civil defence and search and rescue operations), fire stations, police stations, and ambulance depots.

Recovery Enablers

There are high expectations that some of our future buildings can effectively support community recovery following a major earthquake. Recovery enablers are buildings that are important to effectively support community recovery following a major earthquake.

We propose that buildings are considered to have ‘serious’ disruption risk if they enable individual independence in recovery, economic recovery, or social cohesion.

It is important to enable individuals to look after themselves and others as much as possible in order to reduce the ongoing burden on emergency services following a major event. Facilities that enable individual independence in recovery include essential retail such as supermarkets and petrol stations.

Similarly, it is important that community facilities that enable economic recovery are functional soon after an event. A strong theme from the societal expectations research was that facilities that provide care for dependants (e.g., child-care centres, schools, and aged care) enable economic recovery by allowing guardians to return to work.

Finally, facilities that enable social cohesion were also identified as vital for recovery. Communities often have their own established community hubs that provide strong social and physical infrastructure that can support recovery. Maraes are a key example due to their good physical infrastructure to house large numbers of people but also their strong social infrastructure that provides a community in one location.

Across all of the above, critical infrastructure is important for enabling recovery.

Excerpts from the Main Report:

Participants agreed that current requirements to prioritise buildings that have post-disaster functions are important but should be extended to buildings such as supermarkets and food production facilities, as well as multi-purpose spaces that can be used to support disaster recovery.

Participants noted that equitable access to services and assets is important for successful social recovery. Understanding how recovery priorities can exacerbate inequities is important. For example, closure of schools can not only affect educational outcomes but disrupts food in school programmes and puts increased pressures on families to feed children within constrained household budgets.

Excerpts from the Focus Group Report:

Prioritise buildings with social and physical infrastructure

Regions often have their own established community hubs that provide strong social and physical infrastructure that can support recovery. These micro-communities and the buildings that house them are important to protect for social recovery. Maraes are a key example due to their good physical infrastructure to house large numbers of people but also their strong social infrastructure that provides a community in one location. Town and country clubs and religious buildings are also micro-communities of note.

Protect livelihoods

The ability to work and the fulfilment of a job, while a key part of economic recovery, is also a part of the social fabric of a community and aids in social recovery. Ensuring that people are able to return to work as soon as possible is important. Some may be able to work from home, and protection of residential homes is highlighted to ensure this is a priority. Buildings where employees are unable to work from home are more important so people can continue to work. Examples included transport and logistics, supermarkets, manufacturing, food production. Returning to work rapidly supports wellbeing.

Self sufficiency

Social recovery is impacted when people's ability to fend for themselves is removed. A key example was the ability to purchase food for themselves from a supermarket rather than relying on food banks. The removal of choice and autonomy has significant impacts on mental health and slows recovery.

Excerpts from the Interviews Report:

Schools opening in the short term (i.e., less than eight weeks) was a priority for many. Schools assist students to regain a sense of normalcy by attending class and seeing their peers. Schools also enable parents to return to work and/or attend to repairs.

In order to reduce ongoing burden on emergency services, it is important to enable individuals to look after themselves and others as much as possible. As previously mentioned, keeping people in their own homes reduces the need for temporary housing. Other buildings in the community identified as helpful for individuals to retain independence after a major earthquake include essential retail such as supermarkets and pharmacies, petrol stations, and banks (for ATM/cash access).

Vulnerable Occupants

Vulnerable occupants of buildings require special consideration for protection of amenity and function. Impact on vulnerable occupants reflects the dependence of users on the functions of some buildings.

Buildings are considered to have 'critical' disruption risk if a significant percentage of occupants rely on services or equipment within the building to support life (e.g., ventilators or dialysis systems). Ensuring that buildings continue to have the capacity to support life, even if they are not designated as post-disaster, will prevent cascading disruption to other facilities and prevent an influx of patients to local hospitals.

Buildings are considered to have a 'serious' disruption risk if a significant percentage of occupants are of a population that will require relocation if the facility is non-functional. This includes buildings that contain welfare centres, aged care, and possibly public housing. Ensuring that these buildings continue to have the capacity to provide shelter throughout the recovery will reduce disruption to these already vulnerable individuals.

Excerpts from the Main Report:

Participants also highlighted the importance of facilities that, if severely damaged, would create significant pressure on other critical facilities (for example, damage to aged care facilities could create pressure on hospitals).

Excerpts from the Focus Group Report:

Vulnerable populations
Protection and aid for vulnerable populations is important for social recovery. Ensuring there is functionality in buildings that support those with lower mobility and increased care requirements to provide for their basic needs met (e.g., food provision).

Ensuring consistency in their surroundings during and after an event is also important for mental health, in particular those already in emergency housing and dementia patients.

Reduce potential for population relocation
Tolerance for relocation of residential populations is low. Experience from the Canterbury earthquakes highlight the large impacts community disaggregation can have on community wellbeing. Protection of houses and community structure is important to community wellbeing.

Excerpts from the interviews report:

Vulnerable people may have additional needs in the recovery process.
Vulnerable members of society (e.g., elderly and physically or mentally disabled) have a high risk of becoming isolated if damage to their home and surrounding environment results in disruption to their regular social routines and/or dislocation from their community. Special care needs to be taken by community members to prevent the isolation of these vulnerable individuals.

Community Wellbeing Support

Buildings support and enable human, social and economic wellbeing through the services they provide to the communities. Community wellbeing support relates to buildings that a community relies on to function normally.

Buildings and facilities are considered to have 'critical' disruption risk if they provide essential public utilities to communities (e.g., power-generating facilities, telecommunication facilities, water treatment, and wastewater treatment facilities, and other public utilities). Ensuring that these buildings continue to have the capacity to serve the community, or at least restore that capacity in short order is vital to reducing disruptions from earthquakes. Prolonged disruption or uncertainty in the disruption timeframe for utilities may cause residents and businesses to leave their communities.

Secure facilities (e.g., prisons and forensic mental health) are considered to have a serious disruption risk, as disruption to these types of buildings may result in harm to the occupants or the wider community.

Also a serious disruption risk are facilities that contain contents with high community value not designated as post-disaster (e.g., wholesale food distribution centres, essential goods manufacturing facilities, and facilities with medical imaging equipment). These types of facilities enable self-sufficiency within communities by producing or warehousing essential goods and services at a large scale. They also may contain difficult-to-replace equipment that serves the community.

Residential facilities for medium to high-density housing are also considered a serious disruption risk. This is particularly true in urban environments where there is limited means to provide alternative basic services (i.e., water and sanitation) if reticulated networks are disrupted. Disruptions of this type would require residents to be dislocated from their homes, potentially fracturing social ties within the community. This could lead to an exodus from the affected region due if there is insufficient alternative accommodation.

Excerpts from the Main Report:

Access to essential goods and services such as critical infrastructure (telecommunications, water, electricity for heating etc) and food consistently emerged as critical elements to support social recovery.

Underpinning these early priorities is the need to have facilities operational that, were they not, could have a cascading impact on the recovery. These include critical infrastructure services, and (basic) transport and warehousing services.

Excerpts from the Focus Group Report:

Protection of critical infrastructure
Critical infrastructure facilities and personnel should be protected to enable life sustaining services in other buildings. If critical infrastructure is impacted, it affects functionality of other infrastructure. This is particularly important in areas with limited/basic critical infrastructure services (e.g., widespread low occupancy rural areas).

Avoid mass relocation of people
Damage to housing in previous earthquake events has highlighted the lasting impacts of mass relocations on social recovery. With the current housing crisis (affordability and shortage), there is a greater need to keep people in their current accommodation and reduce the amount of people in emergency and substandard accommodation.

Excerpts from the Interviews Report:

Re-establishing key critical infrastructure was a noted early recovery priority because progress is often dependent on this infrastructure being operational. A functioning power supply helps to enable repair or rebuild efforts. In terms of economic recovery, functional critical infrastructure is required because most businesses will not be able to operate from premises that do not have reliable utilities such as power, telecommunication, and water.

Storage facilities are critical to the supply and distribution of goods. A representative from a national supermarket chain stressed the criticality of ensuring the ongoing operation of supermarket distribution centres, as the supply of goods in a region (i.e., up to 50+ stores) is dependent upon deliveries from these centres.

Impact on the Environment

The natural environment supports human existence, and adverse impacts on the natural environment can cause cascading impacts on human and social wellbeing. Following the precedent set by the existing Building Code, facilities are considered a critical disruption risk if loss of containment of hazardous materials held on the premises is capable of causing hazardous conditions that extend beyond property boundaries and a serious disruption risk if loss of containment would cause hazardous conditions that do not extend beyond the property boundaries.

Excerpts from the Main Report:

Many participants drew strong connections between impacts on the natural environment and social and human wellbeing, and the role that the environment plays in underpinning human existence. For many, the potential impacts following an earthquake, particularly the presence of hazardous waste or waste volumes that exceed the capacity of a current waste management facilities, are considered intolerable.

Intolerance of environmental impacts is driven by the perceived direct impact on public health, long-lasting or potentially irreversible impacts of the waste, and the subsequent impact on future generations. Some also note the potential impact on waterways. Consequently, reducing building waste following earthquakes is a priority for many.

Excerpts from the Focus Group Report:

Intolerant of Impacts with Perceived Permanence
Natural consequences are perceived to be more permanent with no means of recovery in short, or even long term. For example, some participants do not accept an outcome where hazardous waste gets into our environment. These long-term permanent consequences

now. Intolerance for this type of risk tends to be independent of the likelihood of the consequences occurring.

Impact on future generations
Like some social consequences, natural environment consequences can have generational impacts. The impact of decisions made today can affect our whakapapa. There is a need to think about future generations and how our current built environment can prevent long term impacts for future generations. Consequences like creation of large volumes of normal and hazardous waste as well as unnecessary destruction of embodied carbon can have long-term or permanent impacts. We need to ensure resources for the future and reduce intergenerational impacts. Iwi planning works in 100–150-year planning blocks to incorporate future generations.

Excerpts from the Interviews Report:

Containing other potential pollutants (not from building demolition waste) was also a priority. Some interviewees thought it was important to take precautions prior to an earthquake to ensure buildings that hold hazardous materials (e.g., acids) are not damaged in a way that would cause containment issues. Sewage was also identified as a potential pollutant if there is damage to underground piping or wastewater treatment facilities.

Additional Risk Considerations

Additional measures toward reducing disruption from loss of amenity and function may also be beneficial for the following building usages:

- Facilities vital for economic output (regional or national) and/or vital for employment in regional area
- Facilities where damage may cause disproportionate uninsurable loss
- Facilities that house agencies for recovery
- Community facilities that contribute to cultural identity, contribute to community connection and/or a sense of place
- Facilities with occupants sensitive to visible damage

Facilities vital for economic output (regional or national) and/or vital for employment in regional area

It is important to minimise disruption in facilities and infrastructure that support major economic activity within a region. Communities often have specific place-based priorities for economic activity. Understanding the economic drivers of not only regions but New Zealand as a whole helps to understand which industries to protect.

Business confidence is necessary to stimulate recovery. Economic agents in a community need to be perceived by others as being safe, secure, and of high quality to minimise reputational damage and prevent investors from fleeing an area. A loss of confidence could lead to migration of investment and industries, slowing economic development that would have otherwise occurred. This confidence is important to maintain in both commercial hubs and primary production, for continuity in the investment and export markets.

Part of preserving business confidence is the maintlenance of supply chains to allow the flow of goods and supplies in and out of the affected region. Numerous building types (transportation, logistics, warehousing, critical infrastructure, etc.) support supply chains, and all are required to be functional to enable access to food and essential goods. The impact of disrupted supply chains can be large, both in costs to individuals and the export market.

For some communities, tourism is a key economic sector, and the restoration of facilities that provide recreation, accommodation, retail, and hospitality is considered key to stimulating economic recovery.

In rural economies, the timely restoration and return to function of agri-business assets play a key role in recovery. Agricultural businesses may be time sensitive such that disruptions at a particular time of year could result in the loss of an entire year's worth of production. Additionally, buildings that house livestock may require limited disruption in order to ensure the welfare of the animals and continued production.

Some communities have one major employer, often based in tourism or primary industry. Disruption to that employer's ability to provide jobs because of a loss of function of its facilities could cause cascading impacts on the community, possibly resulting in a large portion of the community members needing to relocate to find alternative employment.

Excerpts from the Main Report:

Also evident in rural economies is the key role agri-business plays in social interactions and networks in small towns. The social recovery of a rural community is tightly coupled with the economic recovery as business activity ensures regular interaction between potentially isolated community members. Consequently, the timely restoration and return to function of agri-business assets play a key role in social recovery.

For some communities, tourism is a key economic sector, and the restoration of facilities such as motels, stadiums, museums, retail, and hospitality is considered key to stimulating economic recovery. While a priority for some, a return to operation of around 3 months is considered reasonable.

Other less common sentiments included prioritising efforts around industries that are time sensitive, such as agricultural businesses that, if disrupted at the wrong time of year, could lose a whole year's worth of production.

Excerpts from the Focus Group Report:

Social recovery is underpinned by interconnected industries: Maintaining supply chains

Numerous building types (transportation, logistics, warehousing, critical infrastructure etc) play a role in maintaining supply chains and all are required to be functional to enable access to food and essential goods. It is important that these supply chains are established as soon as possible to enable food supply and allow retail to function.

Prioritise buildings / industries that employ a lot of people
In communities with reliance on a particular industry, buildings that large proportion of a population are important. Whether that employment is in one large organisation/facility (e.g., hospital, primary production) or through a large quantity of smaller ones (SME's) (e.g., retail and hospitality) it is important to limit job loss and the cascade impact through the community of that job loss.

Perception of damage and disruption affects economic confidence: Economic Hubs
Confidence in commercial hubs has to be maintained following an event, to ensure ongoing support of both national and global investors. A loss of confidence could lead to migration of investment and industries, slowing economic development that would have otherwise occurred.

Export Market
The export market is competitive and New Zealand industries cannot afford to lose their advantage. Perceived impacts to the quality and delivery of export goods can significantly affect the reputation of New Zealand's produce, which can be hard to gain back.

Excerpts from the Interviews Report:

Business confidence is necessary to stimulate recovery
Economic agents in a community need to be perceived by others as being safe, secure, and of high quality to minimise reputational damage and prevent investors from fleeing an area.

Maintaining infrastructure that supports the supply chain is critical to economic recovery
Ports and roads need to be functional to maintain supply chains for both essential and non-essential goods. Storage facilities are also critical to the supply and distribution of goods. A representative from a national supermarket chain stressed the criticality of ensuring the ongoing operation of supermarket distribution centres, as the supply of goods in a region (i.e., up to 50+ stores) is dependent upon deliveries from these centres.

Facilities where Damage may cause Disproportionate Uninsurable Loss

Organisations operating from facilities that sustain significant earthquake damage may suffer from a loss of reputation. This loss of reputation could result in additional financial losses. For example, hotels that sustain damage following an earthquake may be less desirable destinations for guests that have ample choice for their accommodation.

Excerpts from the Focus Group Report:

Earthquake damage can affect reputation/image of an area
Economic regions/hubs need to be seen as robust and resilient locations, able to recover quickly from events. Damage to this perception could cause loss of large businesses, retreat of government departments or international investors who are key to the

economics of the region.

Excerpts from the Interviews Report:

Loss of reputation from earthquake damage
A business that owns and/or operates from a building that was severely damaged in an earthquake and caused injuries or deaths to building occupants may suffer irrecoverable damage to their reputation for a perceived failure to provide safety for the building occupants.

Facilities that House Agencies for Recovery

The working group identified that extra consideration should be given to the disruption to facilities that house agencies for recovery (e.g., welfare administration offices or local government service centres). While often these services can be provided in alternative locations, the downtime associated with re-establishing these services and consequential disruption to the services they provide may delay or confuse recovery. The provision of these services is critical in maintaining social order, cohesion and trust in governance.

Excerpts from the Main Report:

Restoration of effective governance is also critical to social recovery for a number of reasons that change over time from: provision of civil defence activities, in particular communication immediately post-event; to critical infrastructure provision (water and waste) within days to a week; to provision of regulatory and governance services that support the community in the medium term. Provision of these services have varying degrees of reliance on local government buildings due to increased capacity to work from home, but are critical in maintaining social order, cohesion and trust in governance.

Community Facilities that Contribute to Cultural Identity, Community Connection and/or a Sense of Place

Facilities that enable social connection and contribute to cultural identity are essential to community wellbeing.

The nature of the connection and relationship with the built environment may differ between communities, but across community types this includes places of worship, community centres and marae. In cities, retail shops and restaurants were considered important locations for social connection. In towns, pubs, sports grounds/stadiums, and clubrooms were high priority gathering locations.

Additionally, access to buildings that support cultural wellbeing and identity is a key part community. What comprises cultural assets can differ significantly across populations. For some urban settings, this includes restaurants and pubs and economic activity hubs. For others, it includes sports grounds and stadiums or access to cultural taonga that are housed in museums.

Excerpts from the Main Report:

An important element of social recovery, beyond essential services, is the capacity for community members to connect. The nature of the connection and relationship with the built environment differed between different communities. Across community types this includes places of worship, community centres and marae. In cities retail shops and restaurants were considered important locations for social connection. In towns pubs, sports grounds/stadiums and clubrooms were high priority gathering locations.

Several participants noted that the ability to connect post-earthquake is particularly difficult for some groups within a community. There was particular concern about older people, people with disabilities, and/or mental health issues. One interviewee from the social housing sector mentioned that they go door to door after major earthquakes to check on tenants. The extent to which buildings can sustain these social connections, particularly for vulnerable or isolated groups, is unclear. Some participants noted that social connections are adaptable and are not dependent on built infrastructure, but the inability to ‘shelter in place’, and forced dislocation of communities can create significant physical barriers to social connection.

Access to buildings that support cultural wellbeing and identity is a key part of the return to normalcy. As above, what comprises cultural assets differs significantly across communities. For some urban settings this includes restaurants and pubs and economic activity hubs. For others it includes sports grounds and stadiums or access to cultural taonga that are housed in museums. It was noted that culture transcends buildings.

Excerpts from the Focus Group Report:

Community meeting places
Community meeting places play significant role in urban settings, enabling social connection and community wellbeing through localised and supportive community run networks. The loss of these facilities has a large impact on community wellbeing (e.g., the loss of community facilities in East Christchurch following the 2011 earthquake). These community facilities support existing hubs (neighbourhood support groups) and can have large catchments of people connecting with their peers. The locations are usually well-attended and become places of support in the aftermath of an event. They can include religious buildings, maraes, town and country clubs, pools, libraries and sporting clubs.

Preserve cultural identity
It is important to protect buildings that represent our cultural identity. These buildings help to preserve our identity in an uncertain world. This includes places to meet and value culture, that represents who we are, what we are proud of and what we want to work towards. While this often broader than buildings you still go to buildings to experience this (e.g., marae, museums).

Facilities with Occupants Sensitive to Visible Damage

The psychological impacts of being exposed to visible damage following an earthquake may affect an occupant's ability to 'feel safe' within the building. Buildings that are likely to have a significant percentage of occupancy that would be vulnerable to the effects of visual damage should consider options to limit this type of damage.

Excerpts from the Interviews Report:

Interviewees also discussed the psychological impacts of ground shaking and earthquake-induced building damage. Even small earthquakes can cause anxiety, triggering individuals to remember past traumatic events or worry that a larger earthquake is going to follow. Similarly, visual reminders of earthquake damage (e.g., cracked windows or GIB) may cause day-to-day anxiety for building occupants.

Perception of safety is important.
In addition to actually being safe, many interviewees expressed that they wanted to 'feel safe' within their buildings. The feeling of safety could come from a lack of physical building damage, reliable and redundant egress routes within the building and assurance from an engineer of building stability after a moderate or large earthquake.

Accommodation Facilities (Permanent and Temporary)

The ability to provide adequate accommodation for residents following a major event is vital to ensuring that residents of a community are able to stay in the community following a major event.

Damage to housing in previous earthquake events has highlighted the lasting impacts of mass relocations on social recovery. This type of mass exodus of residents is considered a long-term or permanent impact that is intolerable to most. With several New Zealand communities already experiencing a housing crisis (affordability and shortage), there is a greater need to keep people in their current accommodation and reduce the number of people in emergency and substandard accommodation.

Limiting disruption to facilities that provide temporary accommodation (e.g., motels and hotels) is also important as these facilities can provide short-term accommodation for visitors to the area or act as emergency shelters for displaced residents.

Excerpts from the Main Report:

The preference is for shelter to be in peoples' own residences particularly in higher-density housing areas (e.g., cities) where significant numbers of people would otherwise be displaced, and communities dislocated.

A strong theme that emerged during the data collection is the intolerance to impacts that have permanent or long-term effects. For example, a mass exodus of residents/social dislocation, impacts on the natural environment, industry collapse and loss of trust. All these types of disruptions are viewed as long-lasting or irreversible and therefore intolerable regardless of earthquake likelihood.

Excerpts from the Focus Group Report:

Avoid mass relocation of people

Damage to housing in previous earthquake events has highlighted the lasting impacts of mass relocations on social recovery. With the current housing crisis (affordability and shortage), there is a greater need to keep people in their current accommodation and reduce the amount of people in emergency and substandard accommodation.

Motels

Motels were considered very low importance relative to other buildings in towns/cities. However, it was desired that buildings of this type be partially functional within 1 day of a major earthquake to provide short-term accommodation for visitors to the area or act as emergency shelters for displaced residents. Motels should be able to provide safe living conditions for occupants during the response phase. Full functionality was desired within 3 months to support the recovery process, particularly if workers need to be brought in to help with the rebuild. In the longer term, operating motels will enable tourists to return to an area.

Excerpts from the interviews report:

The ideal place for most people to take shelter is in their own homes. It was noted as particularly important that medium to high-density housing continues to provide shelter after a major earthquake, preventing large numbers of people from being displaced. Temporary housing needs to be provided for stranded visitors or locals with damaged houses .

Overall, the ability to keep people in their homes after an earthquake (or provide adequate housing alternatives) was identified as one of the most vital aspects of recovery. Ensuring that people can continue to live in safe and healthy homes is essential for mental well-being and enables individuals to contribute to the social and economic recovery of their community.

Building Usage Attributes for Enhanced Performance for Protection of Amenity and Function

Table H6 shows the complete list of building usage attributes considered by the project team for enhanced performance for Protection of Amenity and Function. The table also shows the reason why the attributes require enhanced performance and lists example building uses.

Table H6. Building usage attributes that may require enhanced performance for Protection of Amenity and Function

Outcome Indicator	Building Usage Attributes	Consequence Category[1]	Criteria	Reasoning	Example building uses
User Disruption	Vulnerable occupants	C	Building users health is highly dependent on facilities	Consequences of disruption is life threatening Risk of relocation of building users	Hospitals, hospice, in-patient facilities
User Disruption	Vulnerable occupants	S	Occupants are particularly vulnerable to dislocation	Possible cascading disruption to other facilities Risk of relocation of building users Individuals with strong connection to place	Emergency welfare centres, aged care, public housing
Consequential Stressors	Community wellbeing support	T*	Facilities with diverse occupants sensitive to visible damage	Visual damage can be unsettling and distressing	*NA*
User Disruption	Community wellbeing support	S	Large residential facilities with limited means to provide alternative essential services (e.g. water and sanitation)	High risk of mass dislocation /exodus from affected region due to insufficient alternative accommodation	Large apartment buildings in urban areas
User Disruption	Community wellbeing support	S	Secure facilities	Users may cause harm to self or others without supervision or secure facility	Prisons, forensic mental health
Social Disruption	Post-disaster response functions	C	Facilities and infrastructure with emergency services / post event function	Hazard event management and public health	Hospitals, fire stations, ambulance depots, emergency response centre, police stations
Social Disruption	Recovery enabler	S	Facilities that enable individual independence in recovery	Risk of dislocation without services	Supermarkets, pharmacies, petrol stations, banks, schools, critical infrastructure
Social Disruption	Recovery enabler	T*	Facilities that house agencies for recovery	Functions central to recovery	Welfare administration offices, local government service centres, marae

Outcome Indicator	Building Usage Attributes	Consequence Category[1]	Criteria	Reasoning	Example building uses
Social Disruption	Community wellbeing support	C	Facilities and infrastructure that provide vital utilities for community	Basic human needs post-disaster Risk of social dislocation without services	Power generating and distribution facilities, communications facilities, water treatment and wastewater treatment facilities
Social Disruption	Community wellbeing support	S	Facilities that house specialised equipment and contents with high community value (not post-disaster)	Need to protect equipment important to function that is difficult to replace (e.g. long lead time)	Medical imaging equipment, Manufacturing facilities, wholesale food distribution centres
Social Disruption	Community wellbeing support	T*	Accommodation facilities	Potential for exodus from affected region due to insufficient alternative accommodation	Residential housing, hotels, motels
Indirect Economic Loss (Commercial)	Recovery enabler	T*	Facilities vital for economic output (regional or national)	Impact on regional GDP	Milk treatment facilities, meat processing plants, fruit and vegetable packhouses, other large regional production and storage facilities (e.g. wood processing, fertiliser). Transportation hub buildings, including airport, maritime, rail and road services.
Indirect Economic Loss (Residential)	-	-	*No user / building group identified as requiring enhanced consideration beyond those identified under 'user disruption'*		
Indirect Economic Loss	Recovery enabler	T*	Facilities where damage may cause disproportionate uninsurable loss	Reduce disproportional consequential losses	Universities (business interruption, reputation damage)
Environmental	Impact on the environment	C/S	Facilities that contain hazardous waste	Cascading environmental and/or public health hazards	Buildings that house: Waste treatment infrastructure, chemical manufacturing and storage facilities (e.g. paint and industrial solids, liquids and gases)
Consequential Stressors	Community wellbeing support	T*	Facilities vital for employment in regional area	Maintain employment and social connection Risk mass dislocation without main employer	Agricultural processing facility (e.g. dairy, meat, wood and other horticultural products)
Consequential Stressors	Community wellbeing support	T*	Community facilities that contribute to cultural identity	Places to connect with culturally significant items/taonga	Museums, marae, architectural landmarks

Outcome Indicator	Building Usage Attributes	Consequence Category[1]	Criteria	Reasoning	Example building uses
Consequential Stressors	Community wellbeing support	T*	Community facilities that contribute to community connection and/or a sense of place	Places for people to connect and contribute to a sense of community or place	Community centres, marae, library, schools, places of worship

[1] Consequence categories are Critical (C), Serious (S), and Typical (T). T* indicates generally typical consequences but is flagged for possible additional consideration.

Building Usage Categorisation by Consequence for Protection of Amenity and Function

Buildings that may require enhanced performance to prevent injuries are identified in Table H7. The building usage attributes relate to amenity and function are impacts on the *post-disaster response*, *recovery*, *vulnerable occupants*, *community wellbeing*, and *the environment*.

Table H7. Building usage categorization, by consequence, for enhanced Protection of Amenity and Function

Building usage attribute	**Consequence severity**	
	Critical	**Serious**
Post-disaster response functions	• Buildings and facilities that provide essential services (power, water, communications) • Buildings and facilities with special post disaster functions • Medical emergency or surgical facilities • Emergency service facilities such as ambulance, fire, police and related vehicle garages • Designated emergency shelters, and centres, and ancillary B	
Recovery enabler	• Power-generating facilities, telecommunication facilities, water treatment, and waste water treatment facilities, and other public utilities	• Facilities that enable individual independence in recovery (e.g., schools, preschools, supermarkets) • Facilities that enable economic recovery • Facilities that enable social cohesion (community meeting places)
Vulnerable occupants	• Facilities with specialised life-supporting equipment on which vulnerable occupants rely	• Facilities with vulnerable occupants that will require relocation if function is lost
Community wellbeing support	• Power-generating facilities, telecommunication facilities, water treatment, and waste water treatment facilities, and other public utilities	• Secure facilities • Other facilities that contain contents with high community value not designated as post disaster (e.g., wholesale food distribution centres, essential goods manufacturing facilities, laboratories, medical imaging facilities) • Large residential facilities and medium density housing, where there is limited means to provide alternative basic services (water and sanitation) if reticulated networks are disrupted and people need relocating
Impact on the environment	• Loss of containment of hazardous materials is capable of causing hazardous conditions that extend beyond property boundaries	• Loss of containment of hazardous materials is capable of causing hazardous conditions that does not extend beyond property boundaries

Appendix I:
Applying the Framework

This project set out to understand whether there is a gap between what the current Code provides for and the societal expectations captured in the Stage 2 research. Using the Earthquake Performance Outcome Framework developed in this project, we sought to determine the likelihood of building performance (by outcome severity) for a given level of shaking, both in terms of (1) what we *believe, based on observation and experience,* compliance with current Code can achieve and (2) what we infer the New Zealand public expects of their buildings in earthquakes. Three hazard levels were considered (intermediate shaking, strong shaking, and severe shaking)(refer Appendix J) and *qualitative* loss exceedance curves were derived to express the indicative probability of exceeding a given level of loss. The assumptions, procedures, and results of this exercise are presented below.

I.1 Estimating the Likelihood of Outcomes

The likelihood of an outcome severity occurring for a 'typical' building subjected to different levels of shaking was considered in terms of (1) what we *believe, based on observation and experience,* compliance with current Code can achieve and (2) what we infer the New Zealand public expects of their buildings in earthquakes. The primary purpose of this exercise was to understand how societal expectations *differ* from what compliant Code minima currently achieves. The graphs and discussions presented throughout this Appendix are the results of this exercise, identifying and explaining gaps between anticipated and desired outcomes.

The 'typical' building considered in this exercise was envisaged as being representative of all new buildings in New Zealand, agnostic to building type, usage, and location[1]. Following the principle of consistent crudeness[2] and given the non-specific building description paired with the qualitative nature of the descriptions of both hazard and outcome severity, the goal of this exercise was to achieve *accuracy* of gap identification not a refined *precision* of estimation. We judge that our estimations are within an order of magnitude of what actual performance may deliver or desired outcomes may be.

The presented estimations are conditioned on the given level of shaking having occurred at a single building location. The likelihood of the hazard and the range of shaking intensities that occur in an earthquake due to ground conditions and distance from the fault rupture were excluded from consideration for this step. The purpose of decoupling the effects of shaking from their potential timing and spatial distribution was to develop easy-to-interpret figures that are not shrouded by layers of probability. This approach allowed for a more direct interpretation of the societal expectations research, as participants were asked about their priorities and expectations given that an earthquake had occurred.

[1] Whilst the presented plots are to be interpreted as building type and location agnostic, the working group conceptualised a 'multi-use, mid-rise building in Wellington' during the exercise for consistency in judgement.
[2] Hare, J. (2021) Our use of engineering models. SESOC Conference, Hamilton 5-6 July 2021. 11 pp. And references therein.

I.1.1 Method

The estimates of outcome likelihoods for typical buildings designed and constructed in compliance with the current Code are based on expert opinion of the project team. Those opinions have been informed by decades of industry knowledge, extensive insights into building performance throughout the 2010-11 Canterbury Earthquake Sequence and the 2016 Kaikōura earthquake, as well as the damaging events elsewhere since then, and recent research into the seismic performance of buildings and building systems.

While the societal expectations research explored risk tolerance with participations, and content within this appendix refers to 'acceptance' and 'tolerance' of certain outcomes, discussion did not explore the cost implications and willingness to pay of these tolerance levels. It is possible that when cost is considered, tolerance of some impacts may change. Therefore, the analysis reflects the general sentiment of participants with respect to desired outcomes. As noted above the primary purpose of this exercise was to understand how societal expectations *differ* from what compliant Code minima currently achieves.

Addressing Uncertainty

There is substantial uncertainty associated with the performance of buildings and building elements in earthquakes, particularly when the building or building element nears failure. This uncertainty stems from several factors, including, but not limited to, materials used, connection types, building regularity, site-soil conditions, construction practices, and building maintenance. Because of this inherent uncertainty, it is common to describe building performance and the associated losses probabilistically, often using fragility or vulnerability curves.[3]

The overall risk (i.e., probability of an adverse outcome) associated with building seismic performance is then the product of the probability of an earthquake occurring (hazard) and the likelihood of an adverse outcome (vulnerability) resulting from the earthquake.

$$P(Outcome) = P(Hazard) \times P(Vulnerability|Hazard)$$

Given the generalised description for the 'typical' building considered in this exercise, it is expected that there will be a distribution of performance among a population of buildings. This performance was assumed to be roughly normally distributed. That is, most buildings will have roughly average performance relative to other buildings. Some buildings may perform exceptionally well, while others may perform exceptionally poorly.

When deriving single-point estimates for the likelihood of outcome severity, a threshold for tolerable versus intolerable performance for a population of buildings must be chosen. This decision was made by considering what we think society may be willing to accept in terms of the amount of uncertainty in building performance and the potential for adverse outcomes/impacts because of that uncertainty.

For Protection from Injury, a 1% likelihood of exceedance threshold was adopted as a proxy for the worst-performing Code-compliant buildings. We believe that, following an earthquake, the Code will be judged by the worst performing building for this dimension of building

[3] Porter, K. (2018). *A Beginner's Guide to Fragility, Vulnerability, and Risk*. University of Colorado Boulder. Retrieved Aug. 2018, from http://www.sparisk.com/pubs/Porter-beginners-guide.pdf.

performance. Therefore, the estimates for outcomes related to life-safety should reasonably represent the ‘tail-end’ of the total possible distribution of performance.

A different approach was taken for Protection of Property and Protection of Amenity and Function. We think that people are generally more accepting of uncertainty for outcomes related to damage and disruption than they are for outcomes related to life-safety. For these dimensions of building performance, we believe that the Code will be judged by the overall outcomes for all buildings following an earthquake. Accordingly, the estimates for outcomes related to damage and disruption were informed from the inferred expected average performance of all buildings that are designed and constructed to Code minima.

Shaking Levels

Three qualitative levels of earthquake shaking were considered in this exercise: intermediate, strong, and severe (Table I1). These levels of shaking are site-specific and deterministic. That is, they are meant to represent the shaking felt at a single building location.

As previously mentioned, the descriptions of shaking levels considered did not include the imminence of the event nor the range of shaking intensities that might occur due to ground conditions and distance from the fault rupture. To consider a range of shaking outcomes, when developing the qualitative loss exceedance curves, the project team found it useful to develop descriptions of different shaking levels to inform their judgement. These are described in Table I1. Table I1 also presents the anticipated likelihood and examples of ground motion, duration, and radii of effects. For a description of the derivation of the example shaking intensity refer to Appendix J.

Table I1. Descriptions of intermediate, strong, and severe shaking

Shaking level	Description	Likelihood of earthquake shaking	Example shaking intensity
Intermediate	Shaking is generally felt outside and by almost everyone indoors. Most sleepers are awakened. Unfixed items may topple, possible damage to vulnerable buildings. [Example: 2007 Gisborne earthquake].	People living in moderate to high seismicity areas are likely to experience this level of shaking more than once in their lifetime.	Peak ground accelerations are in the range 0.2-0.3g within a radius of 10-50 km. Duration of shaking in the range 10-20 seconds.
Strong	General alarm. People may experience trouble standing and the steering of vehicles may be affected. Localised ground deformation and damage to buildings and infrastructure. [Example: 2016 Kaikoura earthquake at the Wellington waterfront]	People living in moderate to high seismicity areas may experience this level of shaking at least once in their lifetime.	PGAs are in the range 0.3-0.5g over a radius of 50-100 km. Duration of shaking in the range 60-90 seconds
Severe	Alarm approaches panic. Widespread ground deformation and damage to buildings and infrastructure. [Example: 1855 Wairarapa earthquake]	People living in moderate to high seismicity areas may experience this level of shaking once in a few generations. Unlikely to be experienced in a single lifetime.	PGAs are in the range 0.5->1.0g over a radius of 100-500 km. Duration of shaking exceeding two minutes.

I.2 Interpreting the Graphs

Two types of plots are presented for each dimension of building performance: (1) outcome severity distribution graphs and (2) outcome severity cumulative distribution graphs (aka loss exceedance graphs). Both graphs are derived from the same estimations made by the project team. We reiterate that these estimations were made qualitatively.

For graphical purposes, outcome severity, as discussed in the section above, was considered a discrete variable with six severity classes: (1) none/insignificant, (2) minor, (3) moderate, (4) high, (5) severe, and (6) catastrophic. Points are slightly offset vertically within each severity class purely for clarity of each graph.

The distribution graphs show the estimated likelihood of being in a single outcome severity class. The cumulative distribution graphs show the estimated likelihood of being in a given outcome severity class or worse. Numeric values are shown simply to illustrate the bounds of the qualitative descriptions. For example, a marker for the 'high' outcome severity placed at 10% likelihood-of-exceedance should be interpreted as *'It is unlikely that the outcome severity will be high, severe, or catastrophic.'*

See Table I2 for qualitative descriptors for likelihood used by the project team, which are based on the Intergovernmental Panel on Climate Change (IPCC) recommendations[4] with minor modifications.

Table I2. Likelihood scale

Qualitative Description	Likelihood of outcome
Virtually certain (VC)	>99%
Extremely likely (EL)	>95% – 99%
Very likely (VL)	>90% – 95%
Likely (L)	>66% – 90%
About as likely as not (ALAN)	>33% – 66%
Unlikely (U)	<33% – 10%
Very unlikely (VU)	<10% – 1%
Extremely unlikely (EU)	<1% – 0.1%
Exceptionally unlikely (ExU)	<0.1%

[4] Mastrandrea, M. D., Field, C. B., Stocker, T. F., Edenhofer, O., Ebi, K. L., Frame, D. J., ... & Zwiers, F. W. (2010). Guidance note for lead authors of the IPCC fifth assessment report on consistent treatment of uncertainties.

I.2.1 Outcome Severity Distribution Graphs

Three likelihood graphs are presented for each dimension of building performance, one for each of the indicative levels of shaking. These graphs can be interpreted as follows:

- The **x-axis** represents the outcome severity.
- The **y-axis** represents the likelihood of the outcome given the level of shaking. This is a continuous variable between 0 and 1 whose purpose is to display how societal expectations now differ or align relatively with what compliant Code minima currently achieve.
- The **columns** are histograms that represent our estimations for the likelihood of outcomes, with
    - the **striped fill** representing the anticipated outcomes for a ‘typical’ new Code-compliant building, and
    - the **solid fill** representing the desired outcomes based on societal expectations research.
- The **lines** represent curves that fit the histograms, with
    - the **dashed line** representing the anticipated outcomes for a ‘typical’ new Code-compliant building, and
    - the **dotted line** representing the desired outcomes based on societal expectations research.

I.2.2 Outcome Severity Cumulative Distribution Graphs

Two outcome severity cumulative distribution graphs are presented for each dimension of building performance. Both graphs present the same information, but one graph has a linear scale for the x-axis while the other has a logarithmic scale. These graphs can be interpreted as follows:

- The **x-axis** represents the likelihood of exceeding an outcome given the level of shaking. This is a continuous variable between 1 and 0. The numeric values are shown simply to illustrate whether the plot is linear or logarithmic in nature. However, we recommend using the qualitative description for likelihood when interpreting the results.
- The **y-axis** represents the outcome severity. Points are slightly offset vertically within each severity class purely for clarity of each graph.
- The **markers with connecting lines** represent our estimations for the likelihood of exceeding outcomes, with
    - the **colour** of the markers and connecting lines representing the shaking level (darker lines corresponding to more severe shaking at the building location),
    - the **solid line** representing the anticipated outcomes for a ‘typical’ new Code-compliant building, and
    - the **dashed line** representing the desired outcomes based on societal expectations research. (The absence of a dashed line indicates a belief that societal expectations align approximately with what compliant Code minima currently achieves).

When interpreting the cumulative distribution graphs, it is also important to note that desired outcomes that were generally considered to be ‘unacceptable’ through the societal expectations research were assigned beyond the ‘exceptionally unlikely’ exceedance threshold. However, the lines plotting anticipated outcomes have no such qualification. Given the total possible range of building performance, this outcome could theoretically occur, but it should be exceptionally rare.

I.3 Current Code Performance versus Expectations

The following subsections detail the working group's rationale for the presented estimations for the likelihood of a given outcome. The commentary provided summarises the expert opinion of the group and their interpretation of the societal expectations research. The graphs below illustrate the inferred gaps between anticipated and desired outcomes. Indicative numbering is used to convey relativities that we believe will be accurate within an order of magnitude.

I.3.1 Protection from Injury

The performance indicators for protection from injury include (1) stability of the primary structure, (2) stability of the secondary structure, (3) stability of non-structural elements that present a falling hazard, and (4) maintenance of egress routes (Appendix F). The presented likelihood of outcomes encompass all these building elements. The range of casualty outcomes has been divided into three categories: *fatal injuries*, *non-fatal injuries*, and *egress* (Appendix G).

Anticipated Outcomes for new Code-compliant Buildings

The Building Code includes an objective to 'safeguard people from injury caused by structural behaviour.' Most buildings are designed using either the Acceptable Solutions or the Verification Methods of the Building Code. Compliance with either approach means a building is deemed to comply with the Performance Objectives of the Building Code. Although buildings are designed for a specific Ultimate Limit State condition at the design demand level, it is expected that they should be able to continue to perform adequately, although less reliably, under greater levels of demand from larger, less frequently occurring earthquakes. Further explanation of the building control system in New Zealand is provided in Appendix A.

Intermediate Shaking

Code-compliant new buildings are unlikely to cause any injuries when subjected to intermediate shaking levels. Any deaths would be exceptionally unlikely to occur.

Strong Shaking

For buildings subject to strong shaking, some minor injuries can be expected (though very unlikely overall, occurring in approximately 1 in 100 buildings). Moderate to severe injuries are extremely unlikely (1 in 1,000), and a singular loss of life is extremely unlikely (1 in 10,000). Multiple loss of life is exceptionally unlikely for a new Code-compliant building.

Severe Shaking

For buildings subject to severe shaking, we infer minor injuries to at least a few people in the buildings are about as likely as not to occur. Moderate injuries are unlikely (could occur perhaps in about 10% of buildings), and it is very unlikely that a building will cause a singular loss of life (perhaps 1 in 100). Multiple loss of life is exceptionally unlikely (could occur in about 0.1% of buildings), with very few buildings (perhaps 1 in 10,000) experiencing complete collapse.

As shown in Figure H2, we estimate the likelihood of exceeding outcomes related to protection from injury is roughly one order of magnitude greater in strong shaking than it is in intermediate shaking. However, we estimate that there are roughly two orders of magnitude difference between outcome likelihood for severe shaking and strong shaking. This reflects an expectation that most designed buildings will behave elastically up to a limit beyond which plastic failure will occur.

Societal Expectations for Outcomes Related to Protection from Injury

As discussed in the societal expectations reports, tolerance for outcomes can vary greatly among individuals based on education, experiences, and personal circumstances. Nonetheless, key findings from our social research found that people generally do not accept deaths because of building failures, except in the rarest events. The occurrence of multiple deaths in a single location is largely viewed as unacceptable and would lead to public outrage.

Intermediate Shaking

For earthquakes likely to occur, with frequencies of 100 years or less, opinions were split on whether injuries were acceptable, tolerable, or unacceptable. Most thought that even a few fatalities were unacceptable (interpreted for this exercise as some buildings likely to cause singular deaths), though some participants were tolerant or accepting of deaths in earthquakes likely to occur at that frequency. Almost all participants, however, thought that multiple fatalities (either from one or multiple buildings) were unacceptable.

Therefore, we believe that societal expectations for Protection from Injury in intermediate shaking generally align with anticipated outcomes for new Code-compliant buildings.

Strong Shaking

For stronger shaking in rare events, with frequencies between 250-1000 years, most thought that injuries (up to 1 in 2000 people exposed) were tolerable or acceptable. Minimal fatalities were also tolerable to most, whereas multiple fatalities elicited mixed views.

These expectations largely appear to align with the expected outcomes for Code-compliant buildings, as judged by the expert group.

Severe Shaking

For the most severe shaking contemplated, most were accepting of injuries, and even a few fatalities. Tolerance for multiple fatalities was split between unacceptable, tolerable, and acceptable.

Again, these findings for risk tolerance appear to align with the expected outcomes for new Code-compliant buildings.

Key Points

The Stage 2 societal expectations research indicated outcome preferences relating to injuries and deaths broadly align with the current New Zealand Code requirements for the design and construction of structural and non-structural building elements. The following points are highlighted:

- Safety is non-negotiable.
- New Zealanders have a very low tolerance for loss of life regardless of shaking intensity.

We note that continued focus on protection from injury in large earthquakes is necessary. Ensuring that buildings behave in a predictable manner, even after buildings elements exceed their elastic range, will protect lives. Additionally, compliance with good practices is intrinsic to this expectation. In particular, the seismic restraint of non-structural elements will be a key determinant of outcomes in moderate levels of shaking.

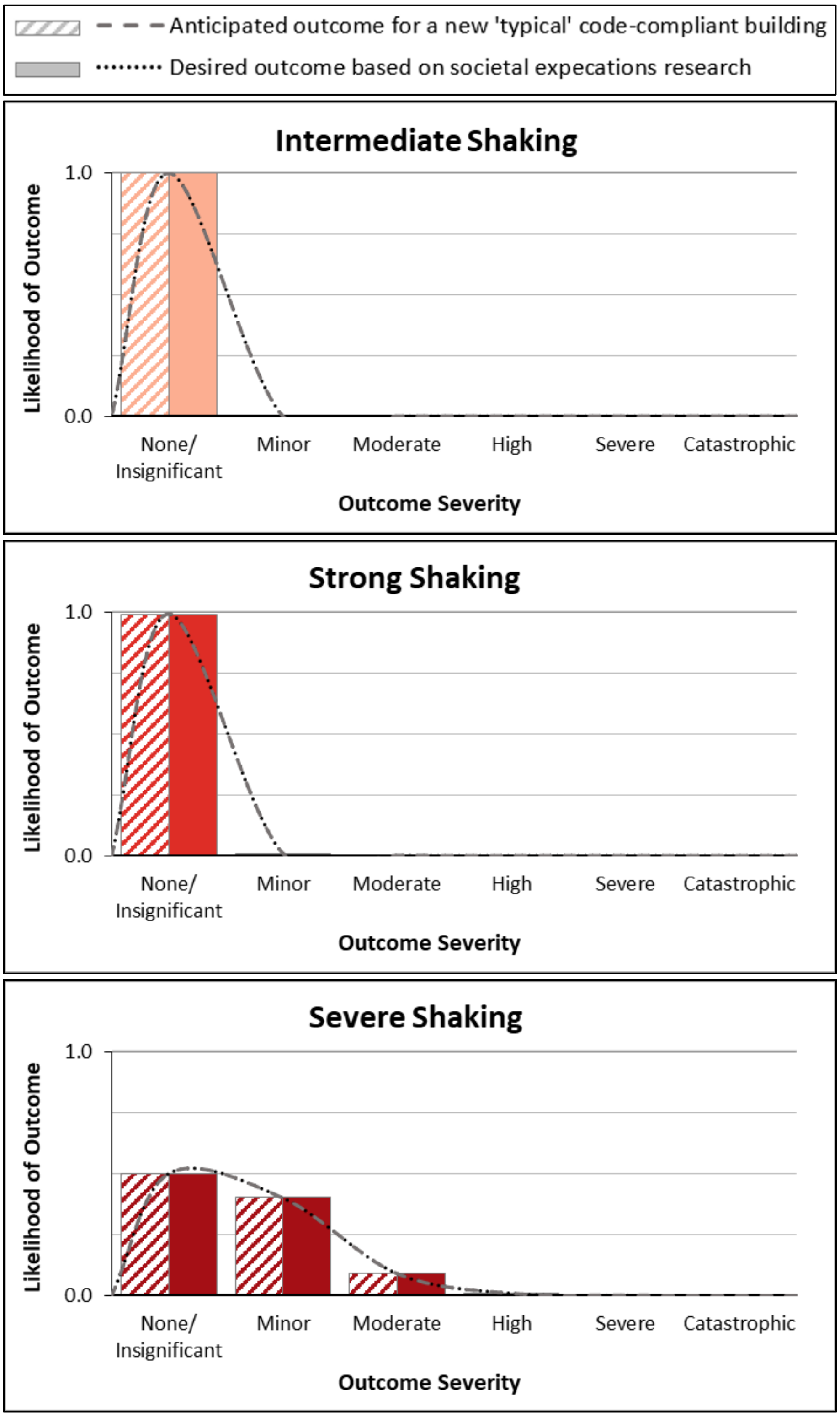

Figure I1. Distribution of anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of related to Protection from Injury. Preferences generally align with the current New Zealand Code requirements.

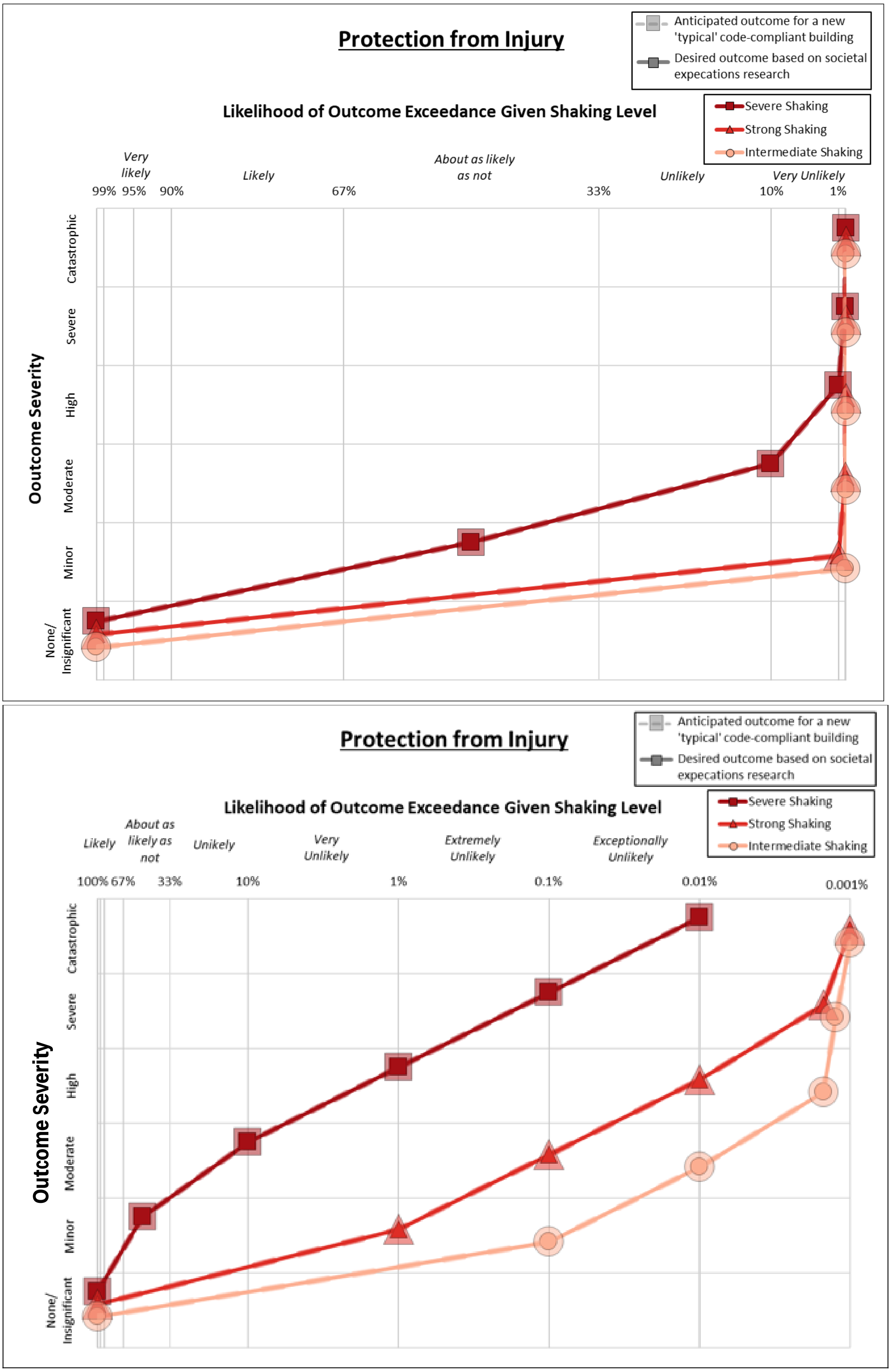

Figure I2. Cumulative distribution of anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of Protection from Injury (linear scale top and logarithmic scale bottom). Preferences generally align with the current New Zealand Code requirements.

I.3.2 Protection of Property

The performance indicators for protection of property include (1) damage to structural elements, (2) damage to non-structural elements, and (3) damage to contents (Appendix F). The range of direct outcomes has been described using three categories: *overall extent of damage*, *financial cost*, and *waste cost* (Appendix G).

Anticipated Outcomes for New Code-Compliant Buildings

The Building Code does not include an objective to protect property or assets caused by structural failure, though it does include an objective to protect *other property* from physical damage caused by structural failure and a requirement to safeguard people from loss of amenity caused by structural behaviour. The building standard NZS1170.5[5] includes a Serviceability Limit State SLS1 repair not required but for an IL2 building it is at a level of shaking that typically does not govern design[6]. Furthermore, the definition of SLS1 has ambiguity within the New Zealand Standards as to whether it contemplates all damage or just damage that is essential to function.[7]

Intermediate Shaking

For buildings subjected to intermediate shaking, it is very likely that buildings will perform such that the cost to repair damage is within their typical operating budget, with most buildings (maybe 67%) sustaining insignificant damage. It is very unlikely that buildings (perhaps 1 in 100) would have damage beyond a typical insurance deductible (i.e., exceeding the high outcome). Damage in the severe or catastrophic outcome range would be exceptionally unlikely.

Strong Shaking

For a building subjected to strong shaking, we anticipate that repairs are about as likely as not to be within a typical insurance deductible (i.e., exceeding the moderate outcome). Perhaps the damage to about a third of buildings will be minor or less (repair costs within the normal operating budget), with about 5% of buildings having no measurable damage impact. About another third of the buildings might have moderate outcomes. The final third of buildings might have high or severe damage outcomes. We believe that it is extremely unlikely (somewhere in the magnitude of 1 in 1000) that buildings will be damaged beyond repair.

Severe Shaking

For buildings subjected to severe shaking, we would anticipate that having repair costs less than a typical insurance deductible (a moderate outcome or better) would be very unlikely (maybe about 1 in 100). Buildings are about as likely as not to have high or severe outcomes, and perhaps a third of the buildings may be uneconomical to repair (catastrophic).

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[5] Standards New Zealand (2004). *NZS1170.5 Supp1:2004 Structural design actions Part 5: Earthquake actions – New Zealand – Commentary*, Wellington, New Zealand: Standards New Zealand.
[6] The return period for an SLS1 event for an IL2 buildings is 25 years.
[7] The performance requirements for SLS1 in NZS1170.0:2002 and NZS1170.5:2004 are subtlety different. NZS1170.0:2002 Section 3.4.2 Serviceability limit states requires that 'the structure and non-structural components do not require repair after the SLS1 earthquake.' NZS1170.5:2004 Section 2.1.4 Earthquake Limit State Design Performance Requirements states that 'Serviceability limit states for earthquake loading are to avoid damage to the structure and non-structural components that would prevent the structure from being used as originally intended without repair after the SLS1 earthquake.'

Societal Expectations for Outcomes Related to Protection of Property

The societal expectations research findings show that minor to moderate earthquake damage was generally acceptable to participants (provided it does not affect function or occur too frequently) and would be expected given that New Zealand is a seismically active country. However, experience from recent earthquakes revealed that many members of the public were surprised by the amount of damage buildings sustained, despite being Code compliant. Overall, the research participants valued durability (i.e., buildings that don't require continuous significant repairs) as it reduces whole-of-life costs. This points to an expectation that buildings should be designed not just to prevent loss of life and support building functionality, but also to prevent damage.

Reducing the impacts of earthquakes on the natural environment is also an emerging priority. In general, participants had low tolerance for impacts on the natural environment that were perceived to be long-lasting or potentially irreversible. For example, participants were concerned that large quantities of building waste following an earthquake would overwhelm waste management facilities. Inefficient management of waste could result in lost opportunities to reuse or recycle building materials and contamination of the surrounding environment. There was also some concern about the potential loss of embodied carbon through building demolition and the embodied and operational carbon required to replace damaged buildings, but this was not a universally understood concept.

Intermediate Shaking

For intermediate shaking, the research showed most were not accepting of significant amounts of damage. Additionally, several participants were concerned that seeing physical damage to buildings (even non-structural cracking) may cause adverse psychological reactions. We interpreted these findings as an indication that the onset of damage needs to be 'delayed' in order to reduce levels of damage overall. Therefore, all points for desired outcomes on the cumulative distribution graph were placed roughly an order of magnitude to the right relative to the anticipated outcomes.

Strong Shaking

For buildings subject to strong shaking, it was noted that people were generally tolerant of damage after a relatively large earthquake. Additionally, the cost associated with ensuring insignificant to moderate damage at this shaking level may outweigh the benefits. However, there seems less tolerance for higher levels of damage.

Therefore, the points for high to catastrophic outcomes were placed an order of magnitude to the right on the cumulative distribution graph.

Severe Shaking

The costs associated with ensuring 'typical' buildings sustain only minimal damage in a beyond-Code event will likely outweigh the benefits, given the rarity of such events. However, in our Stage 2 research, we found that reducing environmental impacts of earthquakes is an emerging priority. Even for the most severe shaking contemplated, many of the research participants felt that impacts from widespread buildings demolition were intolerable (i.e., (a) waste from damaged buildings overwhelms waste management facilities, (b) limited recycling, and (c) significant embodied carbon and new resources required for demolition and rebuild).

Therefore, societal expectations indicate that catastrophic outcomes (building is uneconomical to repair) should be unlikely (perhaps 1 in 10 buildings). The points for severe and high outcomes were also slightly adjusted to reflect this desire for better outcomes in terms of waste management and carbon resources.

Key Points

Our interpretation of the Stage 2 societal expectations research indicated outcome preferences relating to damage exceed what the current Code provides in moderate, strong, and severe shaking. The following points are highlighted:

- There is generally greater tolerance for the direct environmental and economic consequences of damage associated with protection of property than there is for the outcomes associated with protection from injury.
- We compared our interpretation of the societal expectations with our anticipated outcomes and concluded that there is roughly an order of magnitude difference between expectations and current Code settings. This indicates that the onset of damage needs to be 'delayed' and levels of damage in general need to be reduced.
- For intermediate shaking, the research showed most were not accepting of significant amounts of damage.
- For strong shaking, the research showed that most were accepting of some damage but did not want costly or highly disruptive repairs (i.e., causing user displacement from a building) or total building replacement.
- For severe shaking, the research highlighted that many felt that lasting environmental impacts from widespread building demolition were intolerable.

Our findings suggest that Protection of Property should be seriously considered when Code, Standards, and design guidelines are being updated. Potential solutions to address the discrepancies between damage expectations and Code settings, as well as the cost effectiveness of these solutions, should be explored.

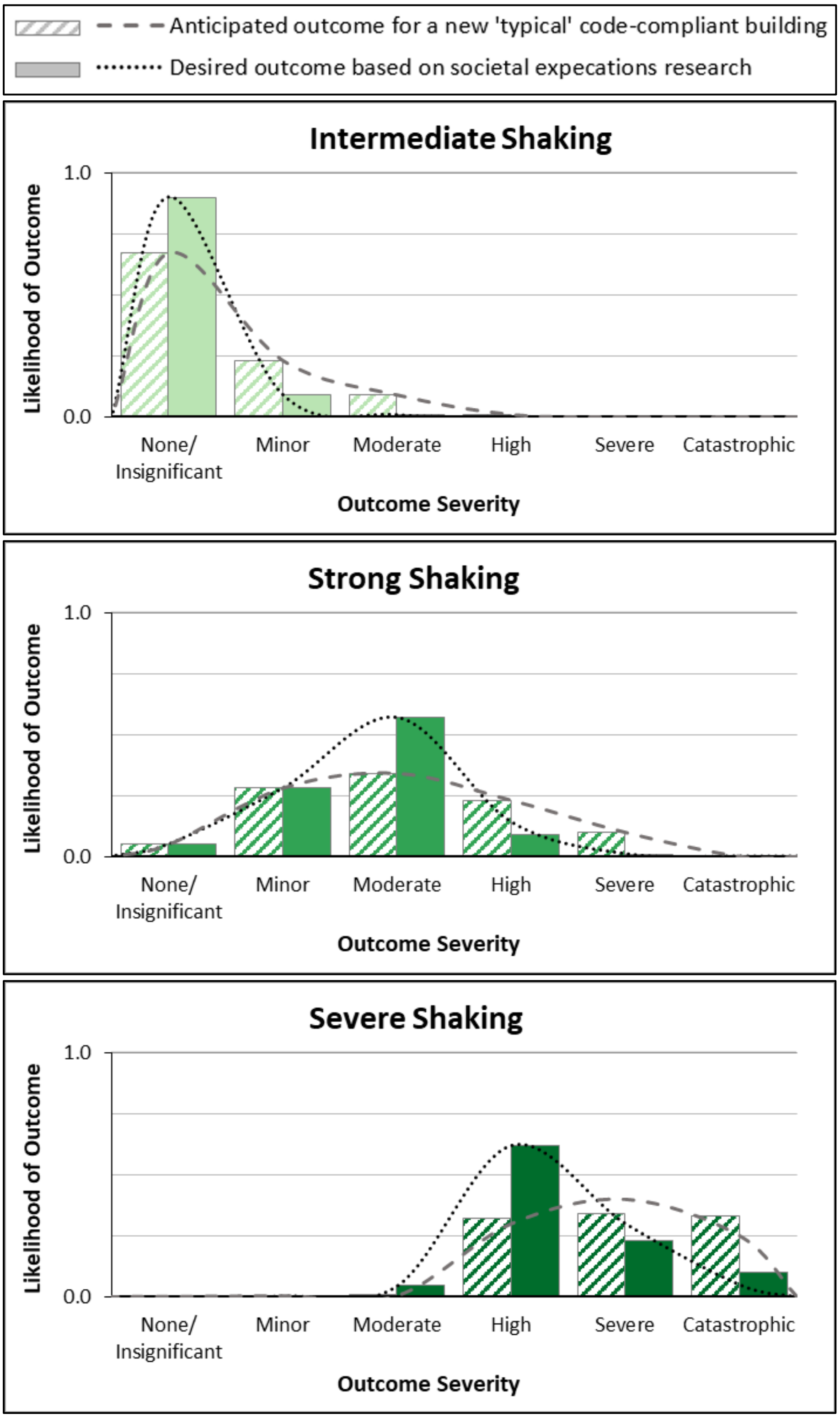
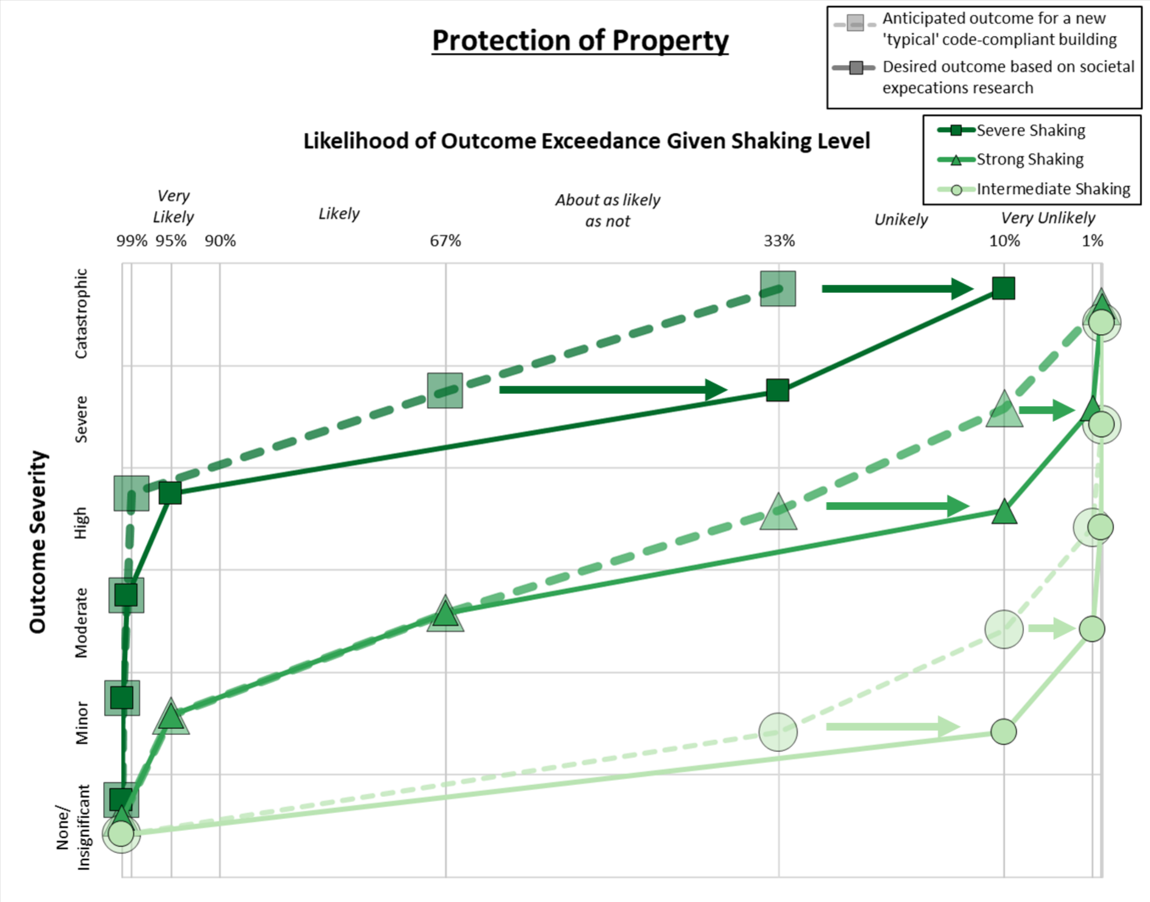


Figure I3. Distribution of anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of related to Protection of Property.



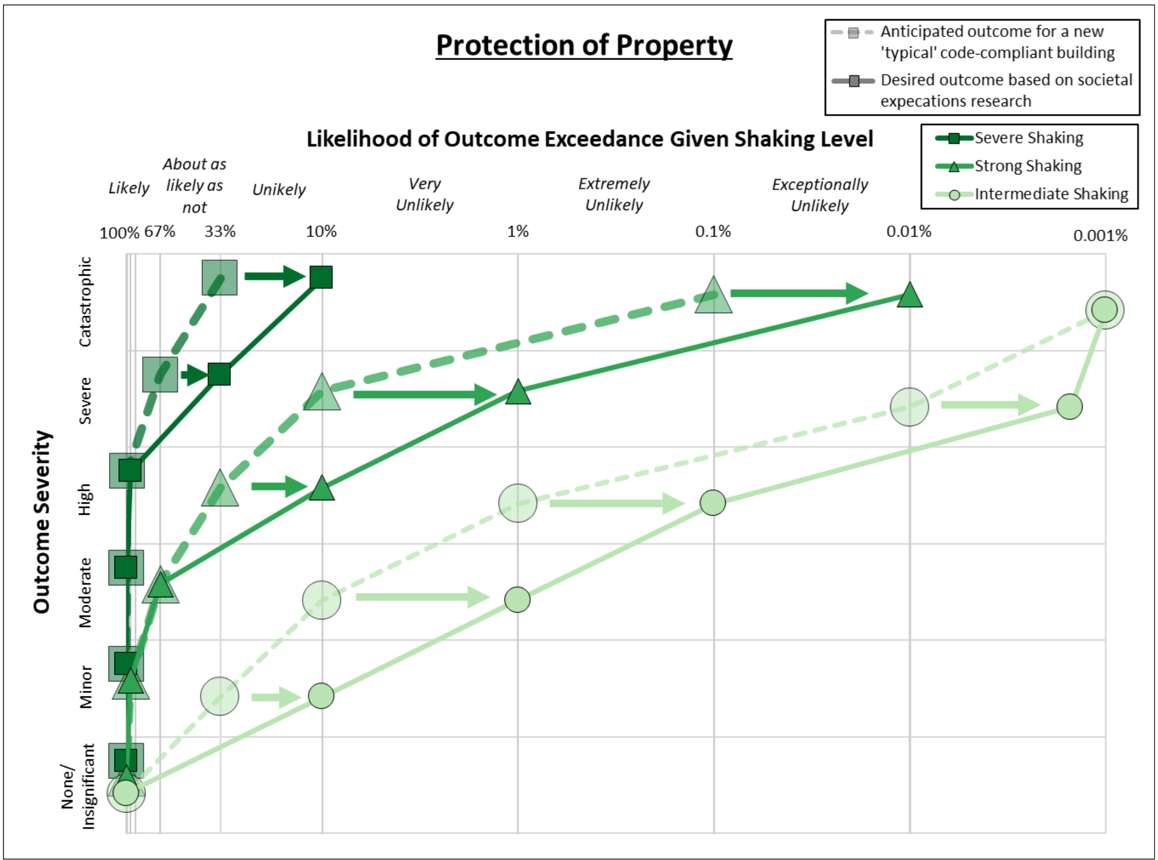


Figure I4. Cumulative distribution of anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of Protection of Property (linear scale top and logarithmic scale bottom).

I.3.3 Protection of Amenity and Function

The performance indicators for protection of amenity and function include maintenance or protection of (1) access to the building, (2) accessibility within the building, (3) weather tightness, (4) emergency systems, (5) security systems, (6) sanitation, (7) other building services and (8) contents that are required for function (Appendix F). The range of user disruption outcomes has been described using three categories: *Intended function* (immediate post-event), *duration of disruption*, and *alternative function* (immediate post-event) (Appendix).

Anticipated Outcomes for New Code-Compliant Buildings

The Building Code includes an objective to 'safeguard people from loss of amenity caused by structural behaviour.' But the current requirements for amenity for 'typical' (i.e., Importance Level 2) buildings are very low. The Serviceability Limit State 1 (SLS1) repair not required for an IL2 building is at a level of shaking that typically does not govern design.[8] Furthermore, the definition of SLS1 has ambiguity within the New Zealand Standards as to whether it contemplates all damage or just damage that is essential to function.[9] The Serviceability Limit State 2 (SLS2) operational continuity maintained) only applies to a narrow range of buildings, importance level 4 (IL4) buildings, those required in the immediate post disaster environment.[10]

Intermediate Shaking

For buildings subject to intermediate shaking, it is anticipated that about a third of buildings will have no disruption to amenity and function. Buildings are about as likely as not to have minor disruptions, but still be functional with minor modifications. We estimate that it is unlikely that buildings will have moderate disruption to normal function (perhaps 10% of buildings). Outcomes that require displacement of occupants (high to catastrophic) are extremely unlikely and might occur in 0.1% of buildings.

Strong Shaking

For buildings subject to strong shaking, we anticipate that it is unlikely that buildings will have no disruption to amenity and function (perhaps 10% of buildings). Buildings are about as likely as not to have minor to moderate disruption to amenity and function, where normal functions are possible with some modifications undertaken post-earthquake. Perhaps a third of buildings would have outcomes that would require the displacement of occupants for repairs (high to severe), but it is very unlikely that a building will be completely non-functional (catastrophic).

Severe Shaking

For buildings subject to severe shaking, few if any buildings are expected to have no disruption. We anticipate that it will be unlikely that buildings (perhaps 10%) are able to

[8] The return period for an SLS1 event for an IL2 buildings is 25 years.
[9] The performance requirements for SLS1 in NZS1170.0:2002 and NZS1170.5:2004 are subtlety different. NZS1170.0:2002 Section 3.4.2 Serviceability limit states requires that 'the structure and non-structural components do not require repair after the SLS1 earthquake.' NZS1170.5:2004 Section 2.1.4 Earthquake Limit State Design Performance Requirements states that 'Serviceability limit states for earthquake loading are to avoid damage to the structure and non-structural components that would prevent the structure from being used as originally intended without repair after the SLS1 earthquake.'
[10] The return period for an SLS2 event for an IL4 buildings is 500 years.

support normal functions with only some modifications (minor or moderate). It is very likely that buildings (about 90%) will have outcomes that are at the level of high or worse. We anticipate that buildings are about as likely as not to be able to still support basic intended functions (high) or only be usable for shelter-in-place purposes (severe). Perhaps a third of buildings may be non-functional (catastrophic).

Societal Expectations for Outcomes Related to Protection of Amenity and Function

Participants in the Stage 2 research focus groups generally expected typical buildings (e.g., non-essential retail, commercial offices, non-essential manufacturing, and restaurants) to be partially functional within 1-3 months following a rare and significant earthquake[11]. Partially functional was often interpreted as some of these building types being open, and others in various stages of recovery. They expected full functionality within 1 year[12].

Following a moderate shake, interview participants typically expected that building contents will have moved around and some cosmetic cracking apparent in the building, but any damage should be non-structural and easily repairable.

Overall, interviewees indicated that minor to moderate disruption from earthquakes is generally acceptable within a building's typical life (given as nominally 50 years). This level of disruption was associated with damage that was viewed as non-urgent and able to be incorporated into regular building maintenance schedules. Significant disruption to normal function (in the order of months or more) was less acceptable to interviewees, and major disruption that could cause a building to be unoccupiable after an earthquake was generally considered unacceptable within a building's typical life.

Intermediate shaking

For an intermediate level of shaking, the desired outcomes line on the cumulative distribution graph was shifted approximately one order of magnitude for the minor, moderate, and high outcomes because the social research participants generally expressed that they did not expect significant disruptions. Additionally, participants reported that observable damage to buildings (even non-structural cracking) undermines confidence and could cause adverse psychological reactions, thereby affecting amenity of building users.

The placement of desired outcomes following an intermediate shake indicates that buildings should be about as likely as not to have no disruption to function following this level of earthquake. Some buildings (about a third) may have minor disruptions to function but will generally still be able to carry out normal functions. Buildings should be very unlikely (perhaps 1 in 100) to have moderate outcomes or worse, with high to catastrophic outcomes being exceptionally unlikely.

Strong Shaking

For a strong level of shaking, the desired outcomes line on the cumulative distribution graph was shifted approximately one order of magnitude for all outcome severities. The primary

[11] The description for the rare and significant earthquake described to focus group participants most closely resembles the 'strong shaking' level.

[12] These time frame should be seen as relative a assessment of importance only (rather than exact expectations).

reasoning for this shift was the focus groups' expectations for buildings' time to return to function following this level of shake, with participants expecting buildings to be functional much sooner than the current Code would deliver. Additionally, we used the performance of buildings subjected to the 2016 Kaikōura earthquake at the Wellington waterfront as a tangible baseline. It was generally agreed that the public disapproved of the outcome of several of the buildings losing functionality for long periods of time or permanently.

The placement of societal expectations for outcomes following a strong shake indicates that most buildings (about 90%) should perform such that disruption is no worse than moderate. This means most buildings would still support normal functions, but buildings are about as likely as not to have to make modifications to support those functions. About 10% of buildings could have disruptions that require the building to be closed for repairs for the order of weeks to months, but it should be very unlikely that a building has severe outcomes (closed for repairs in the order of months to years). Catastrophic outcomes should be extremely unlikely.

Severe Shaking

For severe shaking, functionality isn't expected of many buildings of our chosen type. The costs associated with ensuring such 'typical' buildings are functional in a beyond-Code event may outweigh the benefits, given the rarity of such events. Based on our societal expectations research, we found no reason to assume that societal expectations in this respect have moved beyond what the Code currently delivers if properly applied.

Key points

Our interpretation of the Stage 3 societal expectations research indicated outcome preferences relating to amenity and functionality exceed what the current Code provides in intermediate and strong shaking, with people expecting buildings to retain function or return to function much sooner than the current Code delivers. The following points are highlighted:

- There is generally greater tolerance for the disruption associated protection of amenity and function than there is for the outcomes associated with protection from injury.
- For intermediate shaking, the expectation is that there will not be significant disruptions, which is not guaranteed by current Code minima settings.
- For strong shaking, people generally expect that they will retain more function or return to function much sooner than the current Code minima are likely to achieve.
- For severe shaking, functionality isn't expected of many 'typical' buildings.

We recommend that improving functionality and amenity outcomes should be considered in future Code updates and design guidelines. Potential solutions to address the discrepancies between disruption expectations and Code settings, as well as the cost effectiveness of these solutions, should be explored.

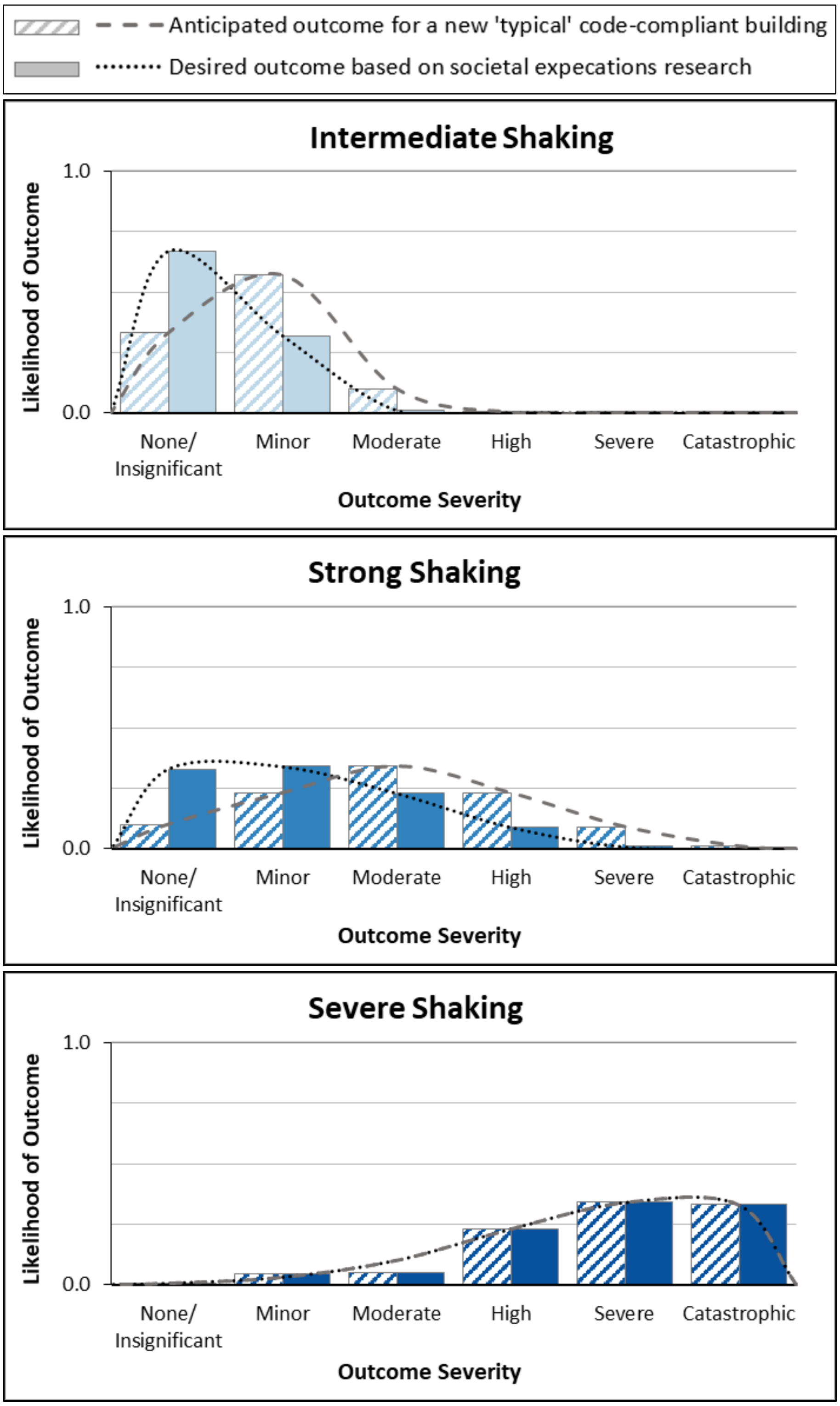
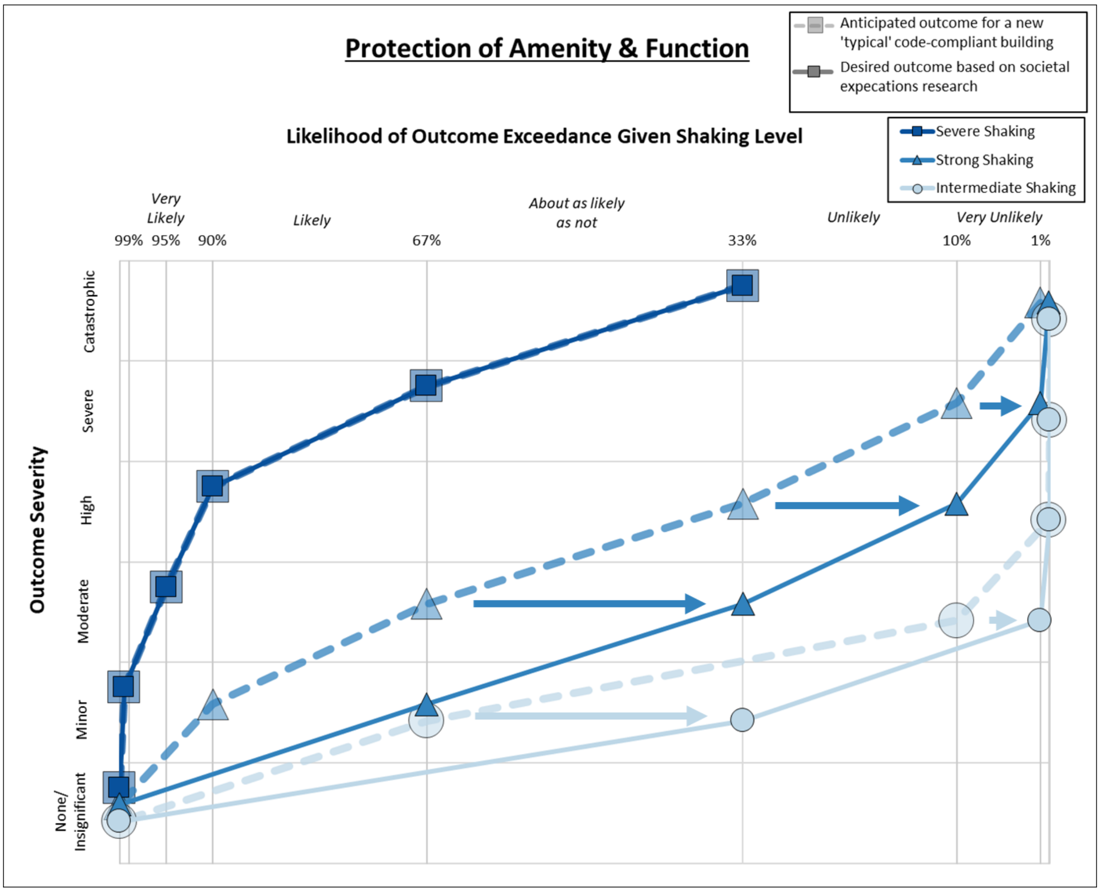


Figure I5. Distribution of anticipated and desired outcomes for a new 'typical' Code-complaint building in terms of related to Protection of Amenity & Function.



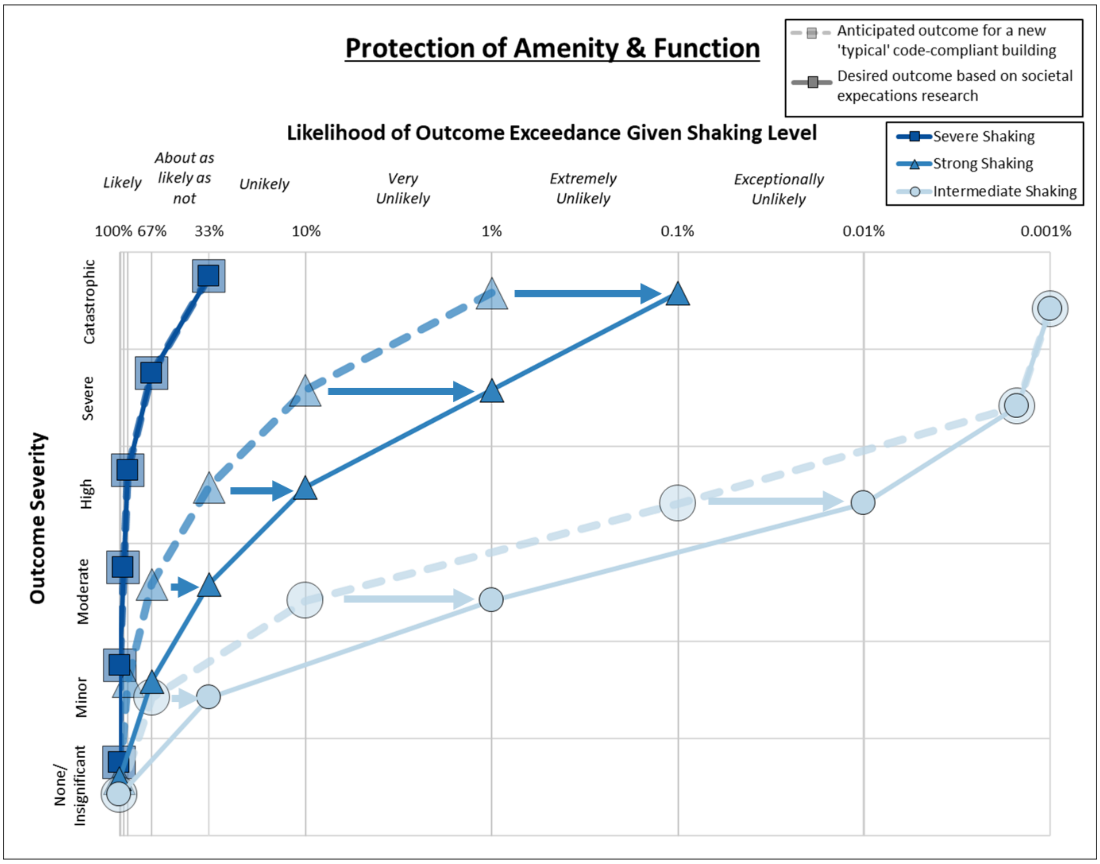


Figure I6. Cumulative distribution of anticipated and desired outcomes a new 'typical' Code-complaint building in terms of Protection of Amenity & Function (linear scale top and logarithmic scale bottom).

Appendix J:
Earthquake Scenarios, Shaking and Impacts

A set of earthquake scenarios were developed to support some of the activities within Stage 3 of the Resilient Buildings Project. Specifically, the scenarios were support the analysis undertaken to assess the gap between what the current Code provides for and the societal expectations for seismic performance of buildings captured in the Stage 2 research. That activity is described separately in Appendix I.

These scenarios were also used to inform development of the cost effectiveness study. It is anticipated these scenarios will be useful in future in other aligned modelling of future outcomes and impacts to earthquake events in New Zealand.

J.1 Earthquake Scenarios and Shaking Levels

In this study, maps showing the extent of approximate mean ground motions over one and a half orders of earthquake magnitude (M6.8-8.3) were contributed by GNS Science for three scenarios to show comparisons of the relative extent and strength of shaking in measures of peak ground and spectral, accelerations. From those indicators of shaking the qualitative terms “intermediate”, “strong”, and “severe” were introduced for a plausible range of ground motion and duration.

The effects of earthquake shaking on buildings and their contents depend on many factors including the adequacy of design to withstand earthquakes and the build quality. The level of shaking at a building is governed by many factors apart from the magnitude of the earthquake. Those factors are imperfectly modelled beforehand so a few key parameters must be related imprecisely but accurately to terms that have general meaning for wider conversations about life-safety and injury, resilience of building functions and protection of property.

An expectation of performance may involve many perspectives, so simple qualitative terms (intermediate, strong, and severe) were adopted to focus attention on the dimensions and expectations of building performance and generalised indications of the seismic demand they may experience under realistic scenarios. This is relevant to differentiating “What When” considerations for building performance from possible “What If” factors and priority settings.

The scenarios derived here were deliberately independent of timing so only the shaking and its spatial extent were contemplated not its imminence. The decoupling of the effects of shaking from their potential timing allows the attributes of building resilience to be assessed against different dimensions of performance and outcomes before the likelihood needs to be considered.

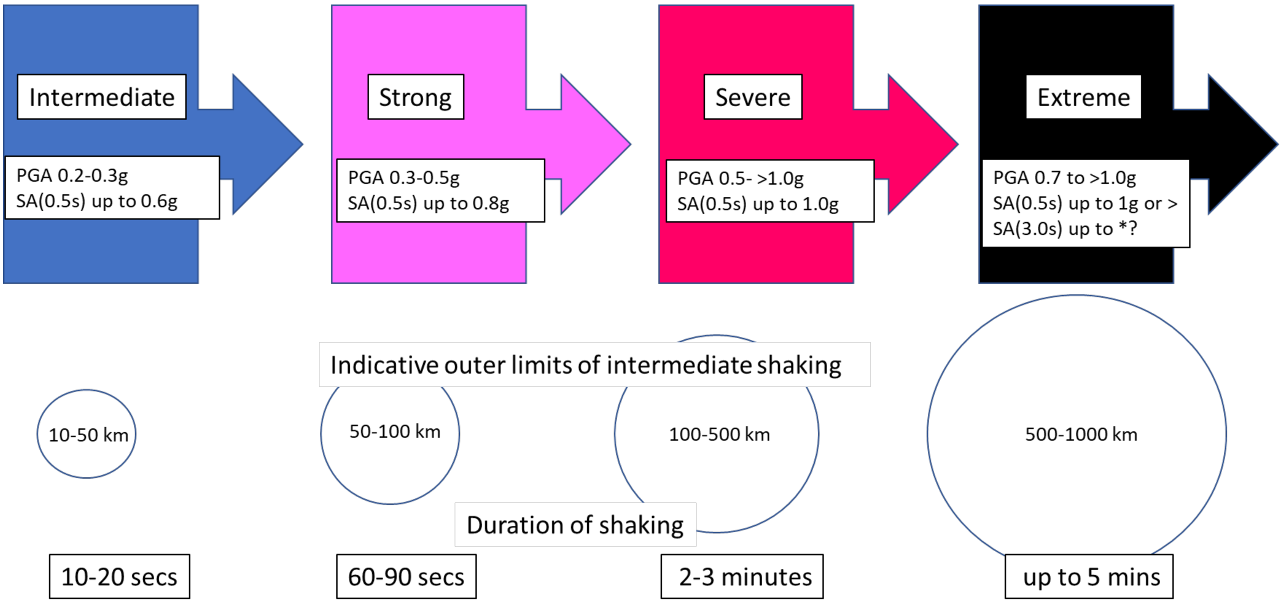


Figure J1. Indicative scenario shaking levels.

Figure J1 relates earthquake parameters of ground motion to qualitative levels of shaking for consideration of site-specific damage, duration of disruption and geographic extent of potential impacts. An "Extreme" level of shaking is included because the potential for a break of the Hikurangi subduction interface along the entire New Zealand sector is geologically possible1. That scenario is relevant to considerations of seismic risk, but the framing of community-level building resilience is adequately accounted for by the "Severe" scenario given the overlapping uncertainties at high levels of shaking.

The presumptive impacts tabulated (Table J1) for "intermediate" and "strong" shaking of current Code-compliant, new ordinary buildings in Wellington, are merely illustrative of how the effects of historical earthquakes together with the ground motion scenarios may be considered to test assumptions about performance objectives if not the means to achieve them. Different results might be expected for buildings constructed to older standards or for those designed for greater resilience.

J.2 The Scenarios

Geologically realistic patterns of earthquake shaking can be generated for any part of New Zealand using the National Seismic Hazard Model (NSHM). The choice of the southern North Island for these examples was arbitrary because each adequately illustrates a pattern of intermediate and strong shaking which could be experienced in almost any region of the country where urban forms are similar. The inclusion of a "severe" event in this set, appropriately reflects the unique tectonic boundary setting of southern North Island and certain other regions.

[1] This would involve a Magnitude 9 earthquake, which would last several minutes. The closest historical comparators for such an event are the 2011 Tohoku, Japan earthquake, and the 1960 Chile earthquake. The science underpinning the plausibility of this scenario in New Zealand has emerged in the past decade, since the 2011 Japan event and research around the Pacific to understand and recognise the potential for such events elsewhere.

J.2.1 Intermediate Shaking

Figure J2 shows a pattern of “Intermediate Shaking” involving a shallow crustal fault rupture in Cook Strait. The scenario energy release and its extent equate to a magnitude M6.8 earthquake. Intermediate shaking occurs within a radius of 30-50km and lasts 10-20 seconds. The 2007, M6.7 Gisborne earthquake is an historical comparator.

The effects of the Intermediate scenario on building performance are limited to a radius of tens of kilometres, not hundreds of kilometres. Because the duration of shaking is also relatively brief, few Code-compliant buildings are expected to experience shaking damage to primary or secondary structural elements. Few compliant buildings should experience damage to non-structural elements but the focus for discussion was on persistent widespread non-compliance of seismic bracing for such elements and the challenge this poses to resilience at relatively low thresholds of shaking.

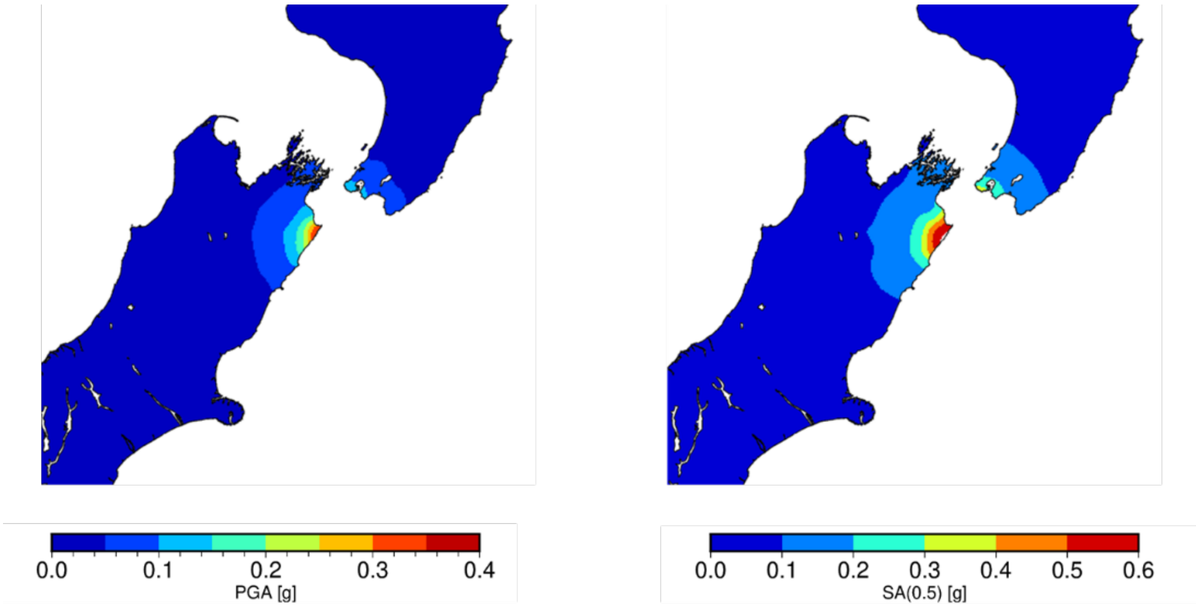


Figure J2: Intermediate shaking scenario. Source: GNS Science.

J.2.2 Strong Scenario

Figure J3 shows a pattern of “Strong Shaking” involving a sudden break in the crust along the northern Wairarapa coast. The scenario energy release and its extent equate to a Magnitude 7.6 earthquake. Shaking will last more than one minute. The few historical comparisons that exist in terms of earthquake size include, the 1931 Hawke’s Bay, and 1929 Murchison, earthquakes. The effects of the 2016 Kaikoura earthquake at the Wellington waterfront and nearby Pipitea precinct provide a modern proxy for aspects of this scenario.

Although smaller, the earthquakes centred near Masterton in June and August of 1942 (M7.2 and M6.8) also provide insights into comparable effects in Wairarapa and Wellington, because of their closer distance to those districts. The following extracts from Te Ara describe the 1942 impacts.

“Structural damage in Wellington and the Wairarapa was extensive, due to the cumulative effects of the two earthquakes”. “Two blocks of Manners Street in Wellington were closed for

several months because of the dangerous state of the buildings". "In Wellington at least 5,000 houses and 10,000 chimneys were damaged by the two major earthquakes." Several years later, many buildings were still unrepaired. This prompted the government to set up an Earthquake and War Damage Commission for earthquake insurance in 1944.[2]

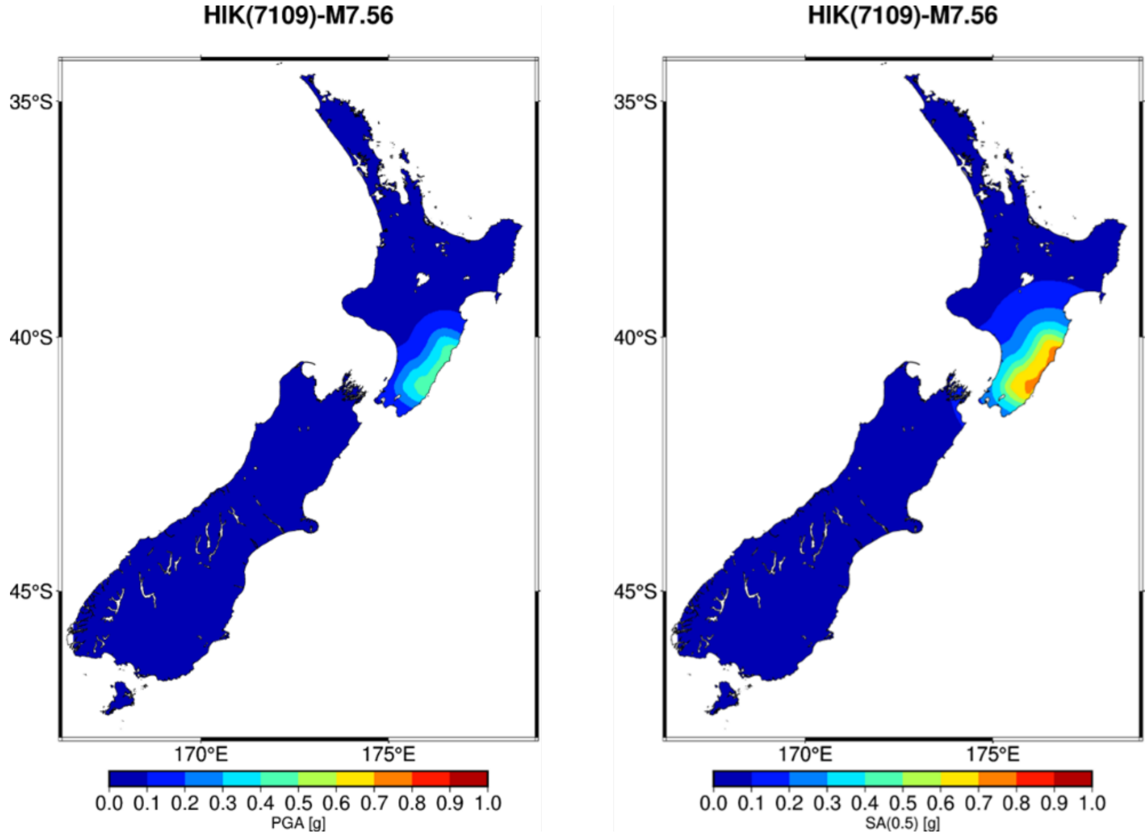


Figure J3: Strong shaking scenario. Source: GNS Science.

J.2.3 Severe Scenario

Figure J4 shows a pattern of "Severe Shaking" involving a sudden break of the 'locked patch' of the Hikurangi subduction interface beneath Wellington, extending towards the northern limits of Wairarapa. The scenario energy release and its extent equate to a Magnitude 8.3 earthquake. Shaking will last 2-3 minutes. A large tsunami onto eastern shores and around Cook Strait is anticipated.

Well-documented examples exist from the past two thousand years and measured geodetic strain which is now continuously monitored by GeoNet indicates locking. These observations underpin the scenario for which there is no comparator in the past 200 years. The break in the same general area in 1855 was largely in the crust above the locked plate interface and before extensive urban and infrastructure development.

The impacts of this scenario are beyond New Zealand's direct experience. The geographic limits around which response and recovery would need to be organised provides some indication of the likely scale, complexity, and duration of disruption. Urban centres and

[2] https://teara.govt.nz/en/historic-earthquakes/page-9

infrastructure from Marlborough to Hawke's Bay will experience significant damage and prolonged disruption.

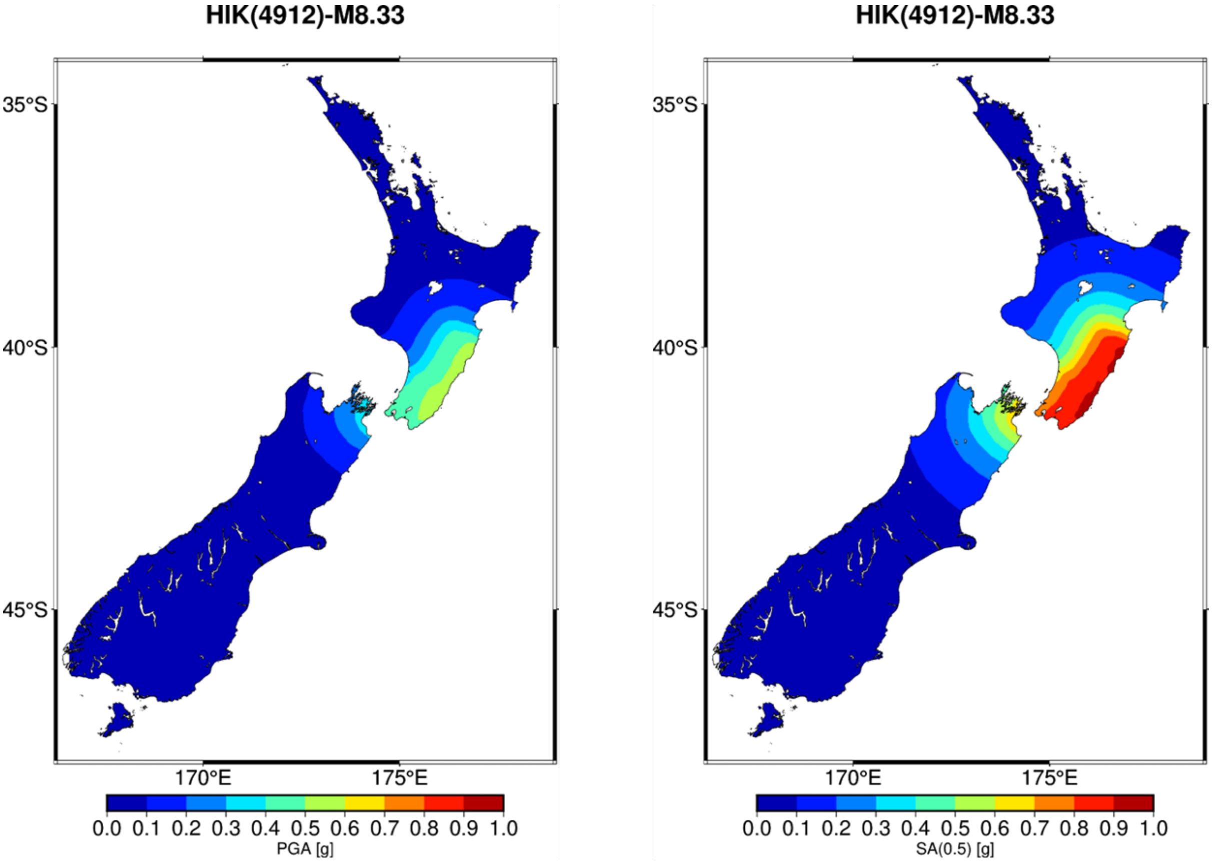


Figure J4: Severe shaking scenario. Source: GNS Science.

Table J1. Scenario Shaking Impacts for Code-Compliant 'Typical' Building

Expected effects for ordinary Code compliant buildings		Indicative Impacts[3]			
		Intermediate shaking[4]	**Strong shaking[5]**	**Severe shaking[6]**	**Extreme shaking**
Damage	**Structural Primary/Secondary**	Nil damage to primary elements and few instances of damage to secondary elements (1%)[7].	Instances of damage to primary and secondary elements (<2%), but repairs are viable. Instances of demolition (<0.5%).	Significant damage likely. Majority continue to carry gravity loads, but many instances of demolition.	As for Severe, but more instances of possible collapse or subsequent demolition.
	Non-structural	Few instances (1%) of operational disruption to systems needed for normal function. Emergency systems fully operational.	Instances of disruption to systems needed for normal function (<5%). Emergency systems may be damaged but remain operational.	Significant disruption to systems needed for normal function. Instances of impaired emergency systems.	Significant disruption to systems needed for normal function. Instances of impaired emergency systems.
Outcomes	**Occupancy hazards**	No loss of life. Few instances of injury (<0.01%)[8] arising from falling contents. No release of hazardous materials. No entrapment. Few impediments to evacuation or occupancy.	No loss of life but potential injury from contents and taking avoidance actions (<0.1%). Isolated instances of temporary entrapment (lifts or blocked egress routes. Few instances of fire following. Shelter in place possible.	Potential loss of life and injury. Secondary hazards e.g., fire, flooding, hazardous materials. Trapped occupants. Unsafe to occupy. Demolition waste management.	Potential loss of life and injury. Secondary hazards e.g., fire, flooding, hazardous materials. Trapped occupants. Unsafe to occupy. Demolition waste management.
	Psychosocial effects	Potential for alarm with minor visible damage (e.g., cracking of coatings and linings). No residual uncertainty for recovery.	Alarm and local distress associated with damage or falling debris, or temporary entrapment. Uncertainty of recovery exceeds 6 months for (5%) of buildings within a defined area of restricted access.	General alarm, distress, and localised trauma. Prolonged regional disruption with uncertainty for affected communities (**months/years**)	General alarm, distress, and localised trauma. Prolonged regional disruption with uncertainty for affected communities (**months/years**)
	Property and Disruption	Few instances of closure for checks (1%) (hours/**days)** or restricted access for repairs (**days/weeks**). Few instances exceed site-deductibles for insurance. Multiple instances of loss of unrestrained fragile goods (unique to usage type and setting)	Instances of closure for checks (**days-weeks**) (5%) and restricted access for repairs (**weeks-months**) (2%). Instances exceeding insurance deductible (2%). Instances of loss of contents. Instances of prolonged disruption (**weeks/months**) with cordons and repair activities (<5%).	Significant loss costs – direct and indirect. Prolonged disruption to building use and precincts (**months/years**).	Significant loss costs – direct and indirect. Prolonged disruption to building use and precincts (**months/years**).

[3] Time independent descriptors of indicative damage and impact outcomes at a community level for new and Code-compliant, ordinary (IL2) buildings (NZS1170.5) under different generalised shaking scenarios. Frequency and likelihood of seismic hazard will differ between regions. Consideration given to international qualitative descriptions of earthquake impacts (Section 304 of the ICC Performance Code, 2003) and the Resilient Buildings Project framework (this Stage).
[4] "Intermediate" is [building and contents subjected to a few seconds of shaking in the range 0.2-0.3g over a defined area. The sway of ordinary buildings is expected to remain in the elastic range].
[5] "Strong" is [building and contents subjected to several cycles of shaking at or above 0.3g over a defined area].
[6] "Severe" and "Extreme" is [building and contents subjected to prolonged cycles of shaking at or above 0.5g over a defined area].
[7] Hypothetical damage to a percentage of buildings in a defined area or location, based on precinct-level outcomes for 2016 Kaikoura earthquake, Wairarapa earthquakes of 1942, and the 2010-2011 Canterbury earthquake sequence.
[8] Hypothetical injury to a percentage of people in a defined population and area, note there is no New Zealand data point for injury to occupants of a compliant current-Code building.

Appendix K:
Contextual Considerations

The process of translating the Stage 2 societal expectations research into building performance outcomes inevitably raised many questions along the development journey.

Those ranged from queries about the societal expectations research itself and its scope, any ambiguities in the results, and how the outcome preferences may change with emerging trends, to considerations of the built environment. We also considered what tools and approaches might be available to address shortfalls between societal expectations and current performance for different levels of earthquake shaking across the different dimensions of building performance and the respective cost implications.

A number of workshops and related activities were held within the project team and with wider groups to explore these and related questions.

K.1 Intervention Analysis (Workshop 8 June 2022)

The purpose of this activity was to investigate the options available to address the gaps between societal expectations and current Code settings and explore the economic implications of reform to improve building resilience. The aim was to clarify the knowns and known-unknowns for a group of key questions:

- Is there a cost premium and if so, what is its level for improving seismic resilience in new building construction?
- What are the types or categories of potential economic benefits for improving seismic resilience and how large are the likely benefits in economic terms?
- Why don't we find many buildings in New Zealand constructed above Code when Kiwis seem to want more resilient buildings?
    - What factors are at play on the supply side? Perceptions of increased costs, inertia including traditional building industry construction structure and practices? Others?
    - What factors are at play on the demand side? Insurance policy distortions to people not understanding risk for low frequency high impact events? Others?
- What policy levers exist in addition to the seismic provisions of the building Code to improve new building seismic resilience?

Key Takeouts

i. Building structural irregularity costs money and reduces building resilience. Incentivising more structurally regular building designs would yield significant resilience benefits at no cost and without unduly inhibiting architectural objectives.

ii. "A Code (minima) designed building is a barely legal building". There is a need to change the communications around seismic risk and building design.

iii. Improving the resilience of buildings is a system-wide issue of which design performance objectives are but one part. Others include procurement, construction, consenting, and liability management.

iv. Improving professional collaboration and oversight of the quality of work is required to lift system benefits and deliver more resilient buildings.

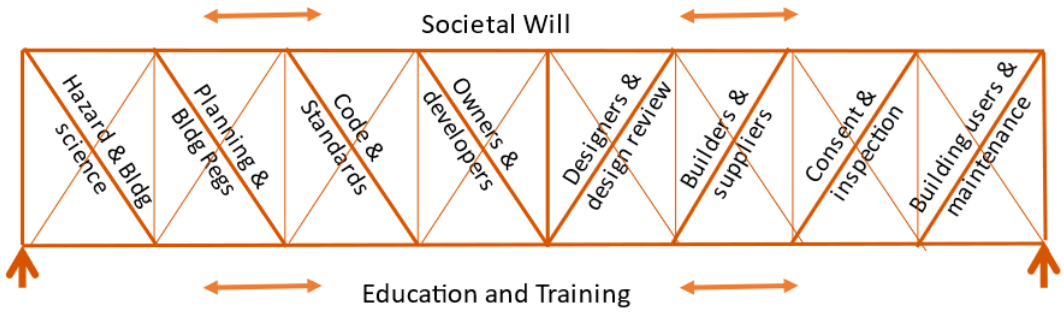
v. Land condition needs to be considered explicitly, either by discouraging development on sites that do not meet agreed resilience criteria, or by setting performance requirements that meet if not exceed them.

vi. Amending and improving liability frameworks across the construction industry to better align risk, capacity, competency, responsibility, and liability will improve building resilience.

K.2 Pinch Points (Workshop 29 March 2023)

The purpose of this activity was to identify pinch points in the current building system, including the subsystems involved in the design, procurement, and oversight of the actual construction.

The aim was to identify factors other than the Code and design settings that directly contribute to the onset and extent of damage to buildings in earthquakes. Those factors and the cultural contexts in which they exist define the total risk environment, illustrated below (Figure K1) using the analogy of a truss that 'supports' the building system. Failure of a combination of chords may result in system failure, highlighting the interconnectedness of the building system.



Starting from the left:

- A knowledge of the hazards provides understanding of the demands on the building during its life.
- Building science informs building capacity. Research underpinning codes and standards is fundamental
- Robust planning and building regulations are needed to ensure that construction is appropriate to the risk.
- Underpinned by a good Code, Standards and Guidance
- Owners initiate building decisions and are key. Nothing better to any building project than an informed client.
- Designers who know what they are doing, and proper design peer review
- Good builders and suppliers, sensible procurement processes and adequate construction monitoring
- Adequate maintenance and oversight of renovations during the life of the building

Figure K1. Building and Construction System: Truss Analogy, source Mike Stannard

This analysis was used to inform a subsequent workshop to explore a pilot methodology to explore cost effectiveness (refer Appendix L).

Key Takeouts:

i. Risk management, allocation, and transfer between parties involved in the design and construction of built environment construction from owners, contractors, and designers to regulatory authorities.

ii. Commercial pressures with high and rapidly increasing construction costs in NZ. Owners often find they can't get as much building as they wished for or expected or are led to believe is possible.

iii. Building construction complexity involves many different parties from owners and developers to contractors, subcontractors, suppliers, designers, and regulators. The interests of the different parties are not well aligned or even understood by others involved in the project often with poor communications among a highly fractured project team.

iv. This complexity aligns poorly with the commercial pressures which drive the speed of design and construction.

v. Procurement models used for building construction typically focus on short-term outcomes particularly initial capital costs and often the incentives for the different parties, owner/developer, designers, contractors, subcontractors, suppliers, and regulators are not well aligned.

vi. It is impossible for every engineered project to be designed and constructed perfectly. Avoidance of building failures relies on checks and balances throughout the design and construction process. This requirement aligns poorly with the fractured nature of the design and construction process.

vii. Communication tools and expectations align poorly with the very nature of the design process – a process that is naturally somewhat chaotic, as options are explored and expectations defined which gradually moves to an increasingly linear process finally resulting in a fully designed and documented building ready for construction. Not helped by design technology which gives a false impression to owners and contractors as to the completeness of the design process at the early stages.

viii. NZ regulatory environment for building construction has been shaped by recent experience, where councils have been left to pick up large costs for building failures through the joint and several liability regulatory regimes resulting in an increasingly risk adverse approach to managing the building regulatory environment. This is resulting in the councils moving away from their role as reviewers and checkers of the design before construction. This role has not been recognised or effectively replaced within the NZ system leading to a lack of technical review.

ix. NZ has a forward-looking performance-based building code system. Innovation is allowed and encouraged. The regulatory environment though has limited requirements for checks and reviews. There are limited mechanisms within the regulatory system to comprehensively verify new components before they are introduced into new building design, or mechanisms to ensure that new components are used in the circumstances and manner for which they were originally developed.

x. The tradition has been to rely on individuals' skills and knowledge and ethics. The occupational regulation requirements in NZ for engineers' skills and knowledge are relatively weak compared with other similar countries with EQs and similar complex building systems. Territorial Authorities have also moved away from extensive checks, instead relying on engineers' and builders' self-certification.

xi. Requirements for building consent documentation in NZ have not kept up with changes in materials and construction methods, leaving some more recently introduced elements outside the building consent process including non-structural elements such as ceilings and services.

xii. Building construction is typically let through a tendering process based on design documentation where the lowest first cost is (almost always) awarded the work. The design documentation defines what is required and sets the standard of what is required. This defines the minimum standard the principal will accept but also defines the highest standard the contractor is required to provide.

xiii. The construction industry has changed over time so now main contractors are typically management contractors with many subcontractors and subcontractors of subcontractors doing the work. Documentation to define the required standards are increasingly important but also a point of conflict and misalignment.

xiv. NZ construction industry allows/requires the ability of the tenderers to substitute materials and methods in order to provide a competitive environment. Alignment of required standards and coordination in an increasingly complex environment is challenging, especially as the objectives of the different parties vary.

xv. The opportunity to substitute in tenders can be used to leave out items in order to create the impression of a more competitive bid. As the industry gets more fragmented with increasingly complex building design and construction materials and methods, this becomes a more and more significant issue.

xvi. There is a misalignment of incentives and outcomes across the building industry between the different parties from owners and developers to designers, contractors, and regulators leading to a lack of clear and shared objectives.

K.3 Managing Seismic Risk (Workshop 29 March 2023)

The purpose of this activity was to identify, group, and document the range of possible options for managing seismic risk. These have been identified as possible 'levers' that potentially could be used to improve the resilience of New Zealand buildings, recognising that these extend well beyond considerations of hazard levels or other Code settings.

The aim was to explore the question:

- What are the levers and options that exist to meet the need for more resilient buildings identified by the societal expectations research?

Key Takeouts	
i.	Changes to hazard levels within Code settings for example Z factor and/or R factor.
ii.	Changes to other aspects of the design codes as identified in the advisory published jointly by NZSEE, SESOC, and NZGS "*Earthquake Design for Uncertainty*" dated August 2022[1].
iii.	Revision of the current PS1- PS4 system of self-certification or supplement it with independent checks through both the design and construction phases of a building project.
iv.	Requirements for design checking by a party acting independent of the provision of the elements / construction to include all elements of the building, not just "structural elements" including for example non-structural elements.
v.	Adding requirements for construction monitoring through all phases of construction by structural engineers.
vi.	Raising the standard for the initial registration of Structural (and Geotech) engineers to broaden and deepen the required experience and skill levels.
vii.	Strengthening ethical requirements for engineers to work within their competency and independent design checking, construction monitoring, etc. (i.e. in the best interests of building performance).
viii.	Strengthening checking of proposed new products, components, building systems, and methods of construction for suitability before allowing their introduction into the built environment. This could be by adopting an overseas system like the US system or similar.
ix.	Clarification of what is meant by independent peer review, so peer reviews are robust and start at the start of design to consider concept designs right through until completion of construction. Ensure the independent peer reviews are truly independent and are completed by appropriately skilled and competent engineers.
x.	Audits of quality assurance systems within design firms.
xi.	Modification of the system for the design of propriety items so they and their bracing are designed by the engineer responsible for the whole of the building design.
xii.	Modification or abandonment of the current joint and several regimes for liability.
xiii.	Use of standardised contracts which provide a balanced risk management approach both for the engagement of consultants and for construction contracts.
xiv.	Education for building owners about resilient design features and how to achieve them.

[1] https://www.nzsee.org.nz/db/PUBS/Earthquake-Design-for-Uncertainty-Advisory_Rev1_August-2022-NZSEE-SESOC-NZGS.pdf

xv. Education for contractors about what constitutes resilient buildings and how to achieve.

xvi. Education for designers and estimators/quantity surveyors and project managers about what constitutes resilient buildings and how to achieve.

xvii. Subsidy/tax concessions for buildings with highly resilient features, e.g. base isolation.

xviii. Public leadership, e.g. through standard property guidelines such as Ministry of Ed guidelines for schools.

This analysis was used to inform a subsequent workshop to explore a pilot methodology to explore cost effectiveness of different “levers” targeted at improving earthquake resilience (refer Appendix L).

The workshop also explored how to group the different possible ‘levers’ along with the linkages between the different possible interventions.

The project team concluded possible levers can be grouped into four broad groups:

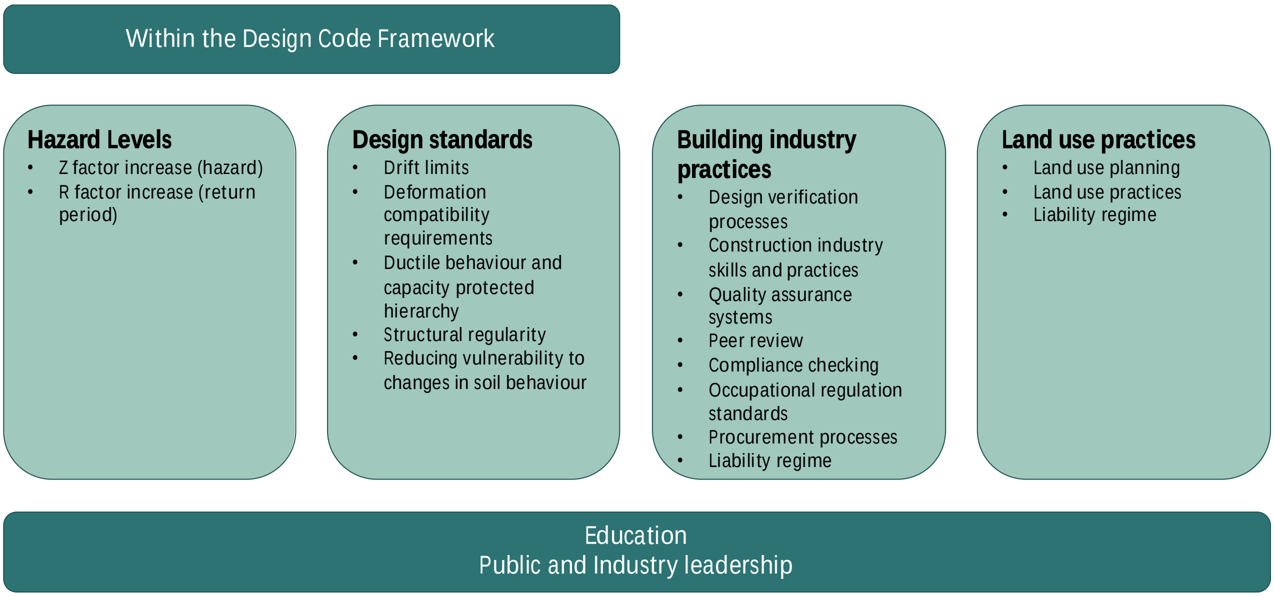


Figure K2. Managing seismic risk

Appendix L:

Cost Effectiveness Analysis

This appendix documents the learnings generated in the pilot workshop held at NZIER on Wednesday 29th March 2023 on the cost effectiveness of levers targeted at improving earthquake resilience.[1] The aim of the workshop was to pilot the approach with a small group to test the feasibility and efficacy of the methodology in the earthquake space. The workshop design was based on similar exploratory research for Toka Tū Ake EQC on the possible policy responses to tsunami risk, undertaken in 2014/5.

The workshop drew on a set of earthquake scenarios (refer Appendix J). The focus was on potential levers other than the seismic provisions of the Building Code. The pilot workshop focused on just one option - to limit the onset of damage - in order to test the approach. It is anticipated future workshops will explore additional options to enhance seismic resilience such as, for example, options that would be effective in limiting onset of loss of functionality in buildings, options that would be effective in limiting duration of loss of full functionality in buildings following earthquakes, and options effective in limiting building demolitions following earthquakes (thus reducing carbon impacts, rebuild costs, and social impact costs).

While only a first pass, the pilot workshop suggests that there are a number of highly cost-effective levers that could improve earthquake resilience because their impact is high, and the costs are generally low and sometimes minimal. While these initial findings need to be tested in a full workshop, the first pass suggests that there is 'low hanging fruit' with levers with high impact at low or minimal cost.

L.1 The Pilot Provided a Proof of Concept

Overall the general approach proved workable and workshop participants discussed a range of possible levers before narrowing down to explore four specific interventions discussed below. Several refinements were also identified to improve how the approach should be applied at any future workshops of this type with a wider group of industry participants. These included refining the menu of potential policy levers and unpacking effectiveness to distinguish between potential effect - what works in principle - and doability - what can be implemented in practice.

L.2 The Workshop Explored the Cost Effectiveness of Levers other than the Seismic Code Provision

[1] Cost effectiveness is defined as meaning the means of achieving a desired outcome at the lowest possible cost. Reference https://www.precursive.com/post/cost-effectiveness-vs-cost-efficiency-what-s-the-difference.

The primary objective of the workshop was to assess the cost effectiveness of levers to improve building resilience, with a particular focus on levers other than the seismic provisions in the Building Code. The workshop focused on the building system including the subsystems involved in the design, procurement and oversight of the actual construction. The main question addressed at the pilot workshop was:

What are the behavioural and other structural/physical options (apart from the seismic provisions in the Building Code) that could be effective in limiting the onset of damage?

Behavioural levers included enacted practices in building design, procurement system, and oversight (consenting and review). By physical/structural levers, we include here physical elements in addition to the structure itself such as mechanical systems, ceilings etc. (i.e., non-structural elements).

By way of background, imagine, as a thought experiment, where the Government declines to strengthen the seismic provisions of the Code because of, for example, misplaced concerns about building industry cost inflation hitting record levels.

What other levers or options exist to meet the need for more resilient buildings identified by the societal expectations research?

The building industry operates in a wider context. These include regulatory regimes in product markets (liability rules), capital (insurance markets), and labour markets, (occupational licencing). Where these help shape building industry practice these will be captured in the parking lot. But the key focus is on the practices in the building industry and what levers could be applied that would directly contribute more resilient buildings by limiting the onset and extent of earthquake damage.

Table L1. Workshop Scope

Workshop Focus	In Scope	Out Of Scope
Direct damage	Onset of and extent of damage	Indirect conditioning influences
Pre-event	Building practices pre-event	Post event disaster response & recovery
Building system	Building system and subsystems	Wider context- liability regime, occupational licencing regimes
New Buildings	Ordinary Code compliant buildings	Existing buildings, infrastructure etc

We worked through two potential levers that participants suggested were promising lines of inquiry:

- Integration of the design of non-structural elements and their bracing into the structural design undertaken by engineers.

- Inspection of construction to check that the non-structural element have actually been installed as designed.

Each lever was assessed in terms of effectiveness cost and certainty of impact where this were ranked as high, medium or low. The main changes identified were the need to refine the menu of potential policy levers (refer Table M3 below) and to unpack the assessment of effectiveness.

L.3 Effectiveness Combines What Works in Theory and What Can Be Executed in Practice

On effectiveness, participants highlighted the importance of distinguishing between "potential effect" – what works if the construction process executes what has designed, from ''doability'' – what can be expected to actually be executed during the construction phase. Overall % effectiveness is the product of "potential effect" multiplied by "doability".

This distinction between 'what works in principle' and 'what can be implemented' in practice draws on the durable policy bargains framework[2] used elsewhere in the project.

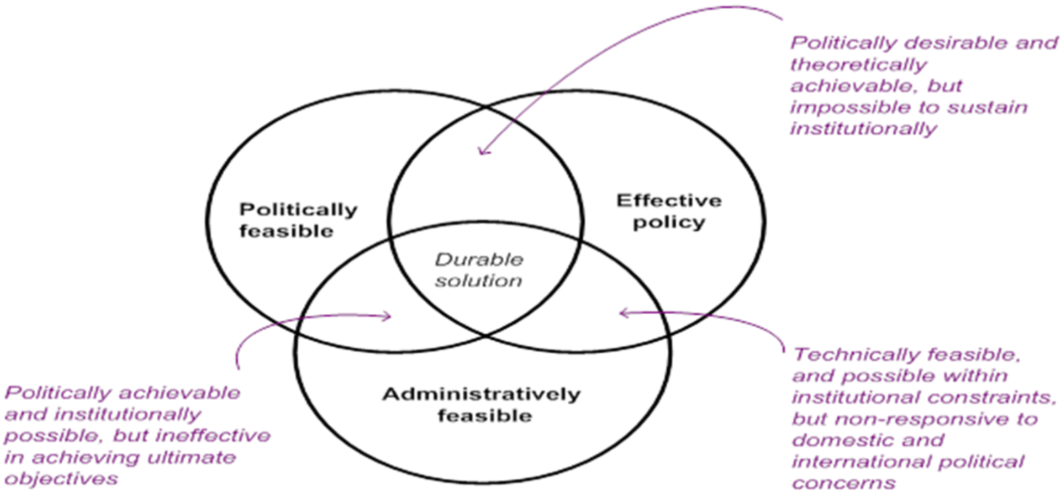


Figure L1. The sweet spot where policy solutions are durable

The focus of any future workshop would be on what works (potential effect if executed as designed) and what can feasibly be implemented (doability). Policy feasibility is not in scope for this exercise as what is political sustainable can shift remarkably quickly in ways that are difficult to predict.

Subsequent to the workshop effectiveness has been split potential effect and doability and more granular scales than High, Medium, and Low were developed. The definitions underpinning the key terms are discussed in the next section. The judgments on levers 1-4 above, as adjusted post-workshop, are shown in Table L2 below.

[2] https://www.nzier.org.nz/publications/durable-policy-approaches-framework-development-and-brief-literature-review-nzier-public-discussion-paper-20162

L.4 Key Terms Defined

Effect The % potential change on any one dimension - reducing adverse outcomes for damage & hence causalities, loss of function and property loss – if lever is executed properly as designed or intended.

- Low – less than 10%
- Medium – 10 to 50%
- High – 50% +

Doability The probability that lever can be executed so what is installed in an ordinary building reflects what was designed or intended i.e. potentially range from 0 to 100%.

Overall Effectiveness % - product of effect (mid-point) multiplied by doability.

- Low – less than 10%
- Modest – 10 to 25%
- Medium – 26 to 45%
- Significant – 46 - 70%
- High – 70% +

Cost % new building construction cost

- Nugatory – de minimis
- Low – less than 0.1%
- Medium – 0.1 to 0.5%
- High – 0.5% +

Certainty Confidence in the sign and the quality of the evidence.

- Low – sign uncertain, limited mixed evidence
- Medium - sign clear, evidence mixed but positive
- High – sign clear, gold standard evidence

Table L2. First pass at assessing leverage cost effectiveness

Levers	Effect H/M/L	Doability%	Effectiveness H/S/Me/Mo/L	Cost H/M/L/N	Certainty H/M/L	Comments
Integrate design of non-structural elements and their bracing into the structure design	H	75%	H	N Change is in timing and by whom	H Studies found low use of seismic bracing	High cost effectiveness. Immediate effect on new building resilience. A precondition for the lever below
Inspection of non-structural element bracing during their construction to ensure their installation	H	50%	S	L Introduces a new layer of supervision	M Uncertainty about how enacted practice will change	Significant cost effectiveness. Requires robust design as a precondition. Applies to commercial/ industrial buildings. Need to clarify applicability to residential buildings.

Table L3. First pass at pinch points and levers

1. Risk management, allocation and transfer between parties involved in the design and construction of built environment construction from owners, contractors, and designers to regulatory authorities.
2. Commercial pressures with high and rapidly increasing construction costs in NZ. Owners often find they can't get as much building as they wished for or expected or are led to believe is possible.
3. Building construction complexity involving many different parties from owners and developers to contractors, subcontractors, suppliers, designers and regulators. The interests of the different parties are not well aligned or even understood by others involved in the project often with poor communications among a highly fractured project team.
4. This complexity aligns poorly with the commercial pressures which drive speed of design and construction.
5. Procurement models used for building construction typically focus on short term outcomes particularly initial capital costs and often the incentives for the different parties, owner/developer, designers, contractor, subcontractors, suppliers and regulators are not well aligned.
6. It is impossible for every engineered project to be designed and constructed perfectly. Avoidance of building failures relies on checks and balances throughout the design and construction process. This requirement aligns poorly with the fractured nature of the design and construction process.
7. Communication tools and expectations align poorly with the very nature of the design process, a process naturally somewhat chaotic as options are explored and expectations defined which gradually moves to an increasingly linear process finally resulting in a fully designed and documented building ready for construction. Not helped by design technology which gives a false impression to owners and

contractors as to the completeness of the design process at the early stages.

8. NZ regulatory environment for building construction has been shaped by recent experience where councils have been left to pick up large costs for building failures through the joint and several regulatory regime resulting in an increasingly risk adverse approach to managing the building regulatory environment. This is resulting in the councils moving away from their role as reviewers and checkers of the design before construction. This role has not been recognised or effectively replaced within the NZ system leading to a lack of technical review.
9. NZ has a forward-looking performance-based Building Code system. Innovation is allowed and encouraged. The regulatory environment though has limited requirements for checks and reviews. The tradition has been to rely on individuals' skills and knowledge and doing the right thing. The occupational regulation requirements in NZ for engineers' skills and knowledge are weak compared with other countries with EQs and similar complex building systems. TAs have also moved away from this role leaving the potential for building failures (e.g., hollow core flooring).
10. Requirements for building consent documentation in NZ have not kept up with changes in materials and construction methods, leaving some more recently introduced items outside the building consent process including non-structural elements such as ceilings and services.
11. Building construction is typically let though a tendering process based on design documentation where lowest first cost is (almost always) awarded the work. The design documentation defines what is required and sets the standard of what is required. This defines the minimum standard the principal will accept but also defines the highest standard the contractor is required to provide. The construction industry has changed over time so now main contractors are typically management contractors with many subcontractors and subcontractors of subcontractors doing the work. Documentation to define the required standards are increasingly important but also a point of conflict and misalignment.
12. NZ construction industry allows / requires the ability of the tenderers to substitute materials and methods in order to provide a competitive environment. Alignment of required standards and quality and to coordinate in an increasingly complex environment is challenging especially as the objectives of the different parties vary
13. The opportunity to substitute in tenders can be used to leave out items in order to create the impression of a more competitive bid. As the industry get more fragmented with increasingly complex building design and construction materials and methods this becomes a more and more significant issue.
14. Misalignment of incentives and outcomes across the building industry between the different parties from owners and developers to designers, contractors and regulators.