Seismic risk and the Building Code: A regulatory perspective

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ABSTRACT

NZ is at the forefront of earthquake engineering and innovative solutions and strategies for dealing with seismic risk. Recent earthquakes have presented both opportunities and challenges for improving how the regulatory system responds to and supports the engineering industry to approach seismic risk. From a regulatory perspective, the management of seismic risk should be considered holistically, which requires an understanding of the contribution of all variables and uncertainties within the building system.

MBIE has initiated several projects to support a review of how seismic risk can be addressed holistically within the building regulatory system.

This paper introduces the high level Building Code objectives, functional requirements and performance criteria that are the basis of the current regulatory system for managing seismic risk in buildings in New Zealand. In practice however, demonstrating compliance with the Building Code currently relies heavily on Standards and technical documents cited by the Building Code.

This paper seeks to present the background to the work underway and decisions that will need to be made in response to lessons learned and advancements in the science of earthquake engineering, earthquake risk assessment and new practices for managing and mitigating seismic risk.

1 INTRODUCTION

1.1 The Building Act and Building Code

The foundation of the building regulatory system in New Zealand is the Building Act 2004. The Building Act required the creation of a number of different sets of regulations. One of these sets of regulations is the Building Code (Schedule 1 of the Building Regulations 1992). The purpose of the Building Code is to provide a set of functional requirements and performance criteria that provide more detailed requirements that support the Building Act. The Building Act and Building Code work together to form a set of mandatory legal requirements that must be complied with when undertaking building work in New Zealand.

The Building Code covers all aspects of building construction and materials, not just structural or seismic issues (Figure 1). Within each of the Building Code clauses, the Building Code addresses issues as diverse as structural integrity, fire protection, safe exits, lighting, ventilation, drainage and escape routes.

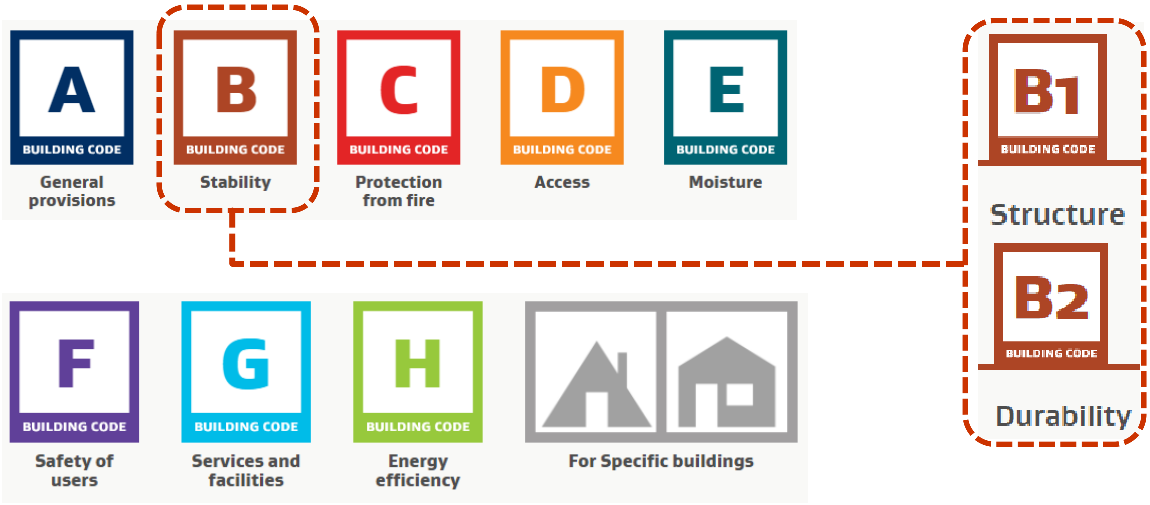

Figure 1: The range of Building Code clause areas (within Schedule 1 of the Building Regulations 1992)

The Building Code clause "B1-Structure" sets out the minimum expectations for buildings via Objectives, Functional Requirements and Performance (OFP) provisions. These OFP's set out the minimum regulatory requirements for Buildings for both life safety and amenity of occupants.

1.2 Compliance Solutions

Compliance with the Building Act and Building Code is mandatory but there are a number of different ways to demonstrate compliance. When a Building Consent application is assessed, the Building Consent Authority needs to decide whether or not there is sufficient evidence within the application to demonstrate that the design complies with the relevant clauses of the Building Code. The three options designers can use to demonstrate compliance with the Building Code are via a Verification Method, an Acceptable Solution or an Alternative Solution.

The Building Act allows for (but does not require) the Ministry of Business, Innovation & Employment (MBIE) to develop Verification Methods and Acceptable Solutions. An Acceptable Solution (AS) is generally a prescriptive set of design rules e.g. NZS 3604:2011 Timber-framed buildings Standard is cited as an Acceptable Solution. A Verification Method (VM) is generally a design process or method e.g. NZS 3603:1993 Timber Structures Standard is cited as a Verification Method. If a designer can demonstrate they have complied with an AS or VM, then the Building Act deems that they have complied with the requirements of the Building Code and the Building Consent Authority is required to accept the design as complying with the relevant Building Code clause.

The key Building Code clause controlling seismic risk in buildings is "B1 Structure" which falls under section "B Stability" of the Building Code (Figure 1). Compliance with the B1 Structure requirements relating to seismic risk is predominately achieved via the cited technical Standards (loading and material standards) within Verification Methods and Acceptable Solutions such as B1/VM1 and B1/AS1.

The third method for demonstrating compliance with the Building Code is via an Alternative Solution. An Alternative Solution is a design that does not follow the methods or rules set out in an AS or VM but does comply with the requirements of the Building Code. Using a Standard that is not cited within an AS or VM or taking input loads from an alternate source means the design can only be assessed as an Alternative Solution. The Building Consent Authority, when assessing whether or not a design complies with the Building Code, can choose to take into account the credibility of information used to support the design, e.g. international design standards, MBIE issued guidance, test results, etc. However, ultimately, the BCA needs to ensure the design complies with the Building Code and the OFP criteria in the relevant code clause e.g. B1 Structure for seismic risk and design.

1.3 Objectives, Functional Requirements and Performance

Table 1 indicates several examples on how the requirements of clause-B1-structure of the Building Code have been used to justify the development of various quantitative technical terms and/or performance measures within the design and loading standards.

It is noted that Clause B1-structure was primarily developed in the public policy space and is deliberately designed to be future proofed as much as possible. The terms used in the Building Code clauses are flexible, minimising the need to change these regulations as public expectations, or design practice evolves over time. This flexibility means there is latitude in how the qualitative Building Code requirements are translated into quantified technical standards or guidelines. This allows new research and technical developments to be implemented relatively quickly within the Acceptable Solutions and Verification Methods.

A few of the interpretations of the qualitative OFP requirements as outlined in Table 1, particularly as they relate to seismic risk, do not have obvious quantitative measures. In the future, wider discussions are likely to be required for creating a conversation framework to get further resolutions on the interpretation of OFP settings.

In light of the National Seismic Hazard Model (NSHM) project and Seismic Risk Working Group (SRWG) recommendations, a number of new projects are underway to explore various options on how seismic risk across the whole building system can be better managed. Also, a wide range of stakeholder's engagement will be designed to work closely with them on how to improve the translation of seismic requirements of the B1-structure to the relevant technical standards such as NZS 1170.5:2004. Hence, there is an opportunity for technical experts to actively participate in the discussion on appropriate seismic risk measures.

The seismic risk assessment of an individual building is primarily a function of the degree of seismic hazard and its consequences for an individual building (or the impacts on an individual building). The consequences can be further divided into the vulnerability (or to a certain extent fragility curves to represent the continuum of building response) of a building and the degree of exposure to a given seismic hazard. While the development of the B1- Structure provisions might not purely reflect the principles of the systematic seismic risk assessment, the B1 - Structure provisions incorporate most of the variables required for undertaking the seismic risk assessment of buildings and/or elements.

1.4 THE IMPORTANCE OF THE BUILDING CODES IN SEISMIC RISK MITIGATION

It is widely accepted that building codes play a key role in managing the risks associated with natural hazards especially earthquakes. A recent study (by Federal Emergency Management Agency (FEMA)) demonstrated that the adoption of modern building codes helped communities avoid losses from predictable natural hazards. The FEMA report (Building Codes Save, 2020) notes that the adoption of the building codes in the USA has saved around $60 million dollars annually since 2000 for 2.4 million structures across the country exposed to earthquake risks.

Table 1: The Building Code and seismic standards

<table>
<tr><th colspan="2">The Building Act 2004</th></tr>
<tr><td colspan="2">The Building Act 2004 “purposes and principles”:
• people who use buildings can do so safely and without endangering their health; and
• buildings are designed, constructed, and able to be used in ways that promote sustainable development:
• building work for which a building consent is issued complies with that building consent; and
• the costs of a building (including maintenance) over the whole of its life:
• the importance of standards of building design and construction in achieving compliance with the building code:</td></tr>
<tr><th>Building Code-B1 OFP Descriptions</th><th>Examples of related quantitative measures in Standards</th></tr>
<tr><td>**Objective**
B1.1 The objective of this provision is to:
(a) safeguard people from injury caused by structural failure,
(b) safeguard people from loss of amenity caused by structural behaviour, and
(c) protect other property from physical damage caused by structural failure.
Functional requirement
B1.2 Buildings, building elements and sitework shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives.
Performance
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.
B1.3.2 Buildings, building elements and sitework shall have a low probability of causing loss of amenity through undue deformation, vibratory response, degradation, or other physical characteristics throughout their lives, or during construction or alteration when the building is in use.
B1.3.3 Account shall be taken of all physical conditions likely to affect the stability of buildings, building elements and sitework (e.g. self-weight, imposed gravity loads, earthquake, wind, snow etc.)</td><td>These OFP descriptions have been used to justify the development of quantified measures in standards for:
✓ “Life safety” objectives under partial or total collapse of buildings. However, the degree of “injury”(light to fatal injuries) can be matter of interpretation or discussion
✓ “Ultimate Limit State” and “Strength Based Design” in seismic design
✓ usage and/or importance of the “design life” in seismic design
✓ use of “load combinations” and associated coefficients in seismic design
✓ “amenity” in general and particularly under the seismic actions has high degree of subjectivity unlike structural failure or collapse (or “life safety”)
✓ “Serviceability Limit State” performance objective in seismic design
✓ minimum deflection/stiffness or vibration requirements associated with daily operation of a building
✓ compliance documents for building elements including the non-structural elements</td></tr>
<tr><td colspan="2">**B1.3.4 Due allowance shall be made for:**</td></tr>
<tr><td>(a) the consequences of failure,
(b) the intended use of the building,
(c) effects of uncertainties resulting from construction activities, or the sequence in which construction activities occur,
(d) variation in the properties of materials and the characteristics of the site, and
(e) accuracy limitations inherent in the methods used to predict the stability of buildings.</td><td>These Performance descriptions have been used to justify the development of quantified measures in standards for:
✓ the “Importance Levels” for individual buildings
✓ different “occupancy” levels
✓ load and strength factors and underlying probabilistic framework (such as LRFD)
✓ use of “factor of safety” to manage uncertainties implicitly</td></tr>
</table>

It should be acknowledged that hazards associated with earthquakes are not limited to risks to individual buildings. Damaging earthquakes have several direct and indirect impacts on the whole of society, including individuals, built environment, and natural environment. Recent earthquakes also raised the question of whether or not the indirect impacts of earthquakes (social, economic, emotional) on communities are beyond the tolerable levels.

Seismic design standards within building codes should represent society's view on balancing tolerable seismic risks and the costs of designing buildings to withstand those risks. Hence, adoption of any new provisions for seismic design standards within the building codes requires extensive cost benefit analysis locally, regionally and nationally along with full regulatory impact assessment.

Any step changes to the current seismic design provisions within the Building Code compliance documents need to take account of an evaluation of the likely increase in costs resulting from the seismic design changes in commercial, high-rise residential, industrial, office and low-rise dwellings across the country. This evaluation would provide better clarity on how any step changes to the seismic design provisions would impact the various types of buildings. Care also needs to be taken not to underestimate the benefits of designing for very low probable earthquakes because they should account for the benefits of reducing fatalities, injuries, fire potential and economic losses. Regulatory impact studies that evaluate the effects of any changes will provide a range of options to facilitate feedback from stakeholders on how to implement new seismic provisions and hence support any recommendations for changes or prioritising of the incremental approach.

2 WHY EARTHQUAKES ARE FUNDAMENTALLY DIFFERENT FROM THE OTHER PHYSICAL CONDITIONS? CAN SEISMIC RISK BE TREATED DIFFERENTLY?

The prediction (accuracy, precision, and reliability) of loads and capacities under seismic actions are more complex than the other physical conditions. The fundamental differences can be attributed to the nature of earthquake loads such as the complex characteristics of expected ground motion on a site, cyclic dynamic and duration of ground shakings.

The nature of structural design under seismic actions ideally should directly rely on energy-based (hysteresis based) formulations because in reality the seismic energy input (demand) should be dissipated by seismic energy supply (capacity). However, in practice, the seismic design process is hugely simplified within the cited Standards in order to align the seismic design process with other physical conditions such as gravity or wind loads. Although this is a pragmatic approach, which is supported by extensive experimental (empirical) research and field observations, it is likely that the impact of some key seismic design input variables is being masked or misused over the course of the design process. It is worth mentioning that the state of knowledge in earthquake engineering and science continues to evolve following the large damaging earthquakes and there has been an accelerated improvement of seismic design standards based on shaking model tests that better model the realistic performance of buildings.

The following table (Table 2) shows the various examples of seismic design subjects and some of their associated design variables. Currently, the level of contribution of each subject and variable is not clearly articulated (even qualitatively) in the seismic standards or practice. Hence, this ambiguity creates significant challenges for decision makers to understand which aspects of seismic risks contribute towards the final objectives of the Building Code. In other words, the fundamental question for the regulator is whether we can apply an approach similar to the capacity design principle to the whole seismic design process to understand the hierarchy of variables and weak links throughout the seismic design process.

It seems that a spectrum of opinions exists on which aspects of the seismic design process contribute the most to uncertainties. While some experts might argue that seismic demands and ground motions are much more uncertain, some others believe that the seismic capacities at the system levels might also have the same level of uncertainties. This view is being exacerbated by various recent unsuccessful blind predictions of large scale shake table experiments under known ground motions.

Table 2: Uncertainties and/or randomness of seismic design variables

Subjects	**Examples of seismic design variables**	**Uncertainty and randomness**	**The level of importance or contribution towards outcome**
Bedrock spectral values	Source characteristics, path dependency, topography, basin, past data	Do we know the level of uncertainty (even **qualitatively**) and randomness in each aspect?	Do we know the level of importance of each aspect (even **qualitatively**) in relation to the building code objectives?
Design spectral values	Ground motion intensity measure, damping, building periods, and soil conditions, codified (smoothed) spectra, design ductility level, MDOF to SDOF, elastic to inelastic design spectra		
Interactions between ground and structure	Soil conditions and periods, damping, building periods, various foundations		
Analysis and design actions	Analyses types, direction of ground motion, load combinations, floor response spectrum, dynamic amplification factors, torsional effects, p-delta actions, irregularities		
Capacity of various engineering materials ,elements and systems	Material properties, hysteretic loops, ductility capacity , dynamic capacity versus static capacity of buildings, failure modes, components versus systems capacities, rate of loading, scale effects, the art of detailing and configuration		
People's actions contributed to the seismic design	Designers, contractors, trades, end-users, quality management (quality control, quality assurance) and design coordination		

3 CHALLENGES OR ISSUES AHEAD

It is evident that significant randomness and uncertainties still exist and continue to remain across the seismic design process. The basic process of seismic design, in which the design practitioner tries to design a structure capable of meeting a specific set of performance levels, carries with it potential liability as many building owners may feel that the structural designers have provided a warranty on the design's performance capability. The effective management of seismic risk in buildings requires a wide engagement with stakeholders to design a model where all key uncertain design variables are well understood and allocated fairly to ensure the best performance outcomes is likely to be required.

Consistency and transparency in achieving the same level of confidence throughout the whole process (consistent crudeness (Elms and Brown: 2006)) is one of the key principles for the development of a fresh seismic design framework. The outputs of the proposed framework would enable the regulator to better moderate the chain of responsibilities in the seismic design process and to better support system wide seismic resilience.

Several attempts have been made to design a few high-level key ideas to initiate conversions in this space. These ideas and questions are still in a preliminary phase and they will be refined once feedback will be sought from the key stakeholders and technical societies. The intent is to test some ideas on how the seismic design settings can go forward in light of new information and knowledge in earthquake engineering.

Table 3 indicates some examples of questions that some resolutions will be required over the course of conversations. It is envisaged that some of these issues or questions will need extensive research in order to find some resolutions or refinements.

Table 3: Examples of issues or questions for reworking on seismic design procedures

Examples of Issues	**Importance**
What is the best approach to calibrate the seismic risk baselines in the Building Code?	Several simplifications or assumptions have been made on what are the ranges of the expected likelihood of collapse under the maximum considered earthquakes. Currently, it is not explicitly evident or articulated how the Building Code (or to a certain degree in the cited seismic Standards) has treated the impact of earthquake hazards on the buildings from the risk science perspectives.
Uniform risk of collapse or uniform hazard?	Recent findings indicate that the Uniform Seismic Hazard (UHS) approach doesn't necessarily generate the uniform risk across the country. Furthermore, a few jurisdictions have already departed from the UHS to ensure that the distribution of the nominal risk of seismic collapse is approximately equal across the whole country.
To what extent are the fragility curves produced for the idealized (analytical) buildings reliable for use in developing a new seismic design framework?	The fragility curves of real buildings are the fundamental ingredients for undertaking the seismic risk assessment. However, due to the complexity, several simplifications and assumptions have been made over the process to conduct the numerical or analytical simulations to get the collapse capacity curves. The credibility or reliability of those fragility or collapse functions is critical to calibrate the baseline seismic risk levels.
What is the best approach to include the elements of community resiliency within the calibration of baselines for seismic risk?	For example, what are the pros and cons of treating some cities or communities (CBD) differently when the baseline tolerable risk levels are set out?
Shall a simple approach address the issues or is a more complicated approach warranted? What is the best approach to balance between simplicity and complexity?	For example, what are the pros and cons of producing seismic design maps with aggregated seismicity data instead of granular seismicity data?
What are the best options to deal with the spectrum of uncertainties in the seismic design process? To what extent and how must the degree of uncertainty in each step be communicated with the public and clients?	It is widely accepted that earthquake engineering deals with significant uncertainties. On the other hand, the regulators and clients will expect more certainty, confidence, and clarity from the practicing seismic engineers. Where is the balance point for reporting the inherent uncertainties

4 ONGOING PROJECTS TO REFRESH SEISMIC DESIGN REQUIREMENTS OF BUILDINGS

As previously mentioned, the compliance documents of B1-Structure must be updated to incorporate some of the recommendations of SRWG and the outputs of the NSHM project. Hence, some projects are in the planning stage to define the scope of potential improvements to the structural compliance documents in the seismic design space.

4.1 Principles:

The SRWG identified 5 principals for translating seismic hazard information into design provisions. The 5 principals are:

1. Be as simple as possible,
2. Deliver consistent and acceptable performance,
3. Consider and reflect the uncertain nature of earthquakes and buildings,
4. Be set at the appropriate level in the building control system e.g. Act, Code or Verification Method,
5. Be stable but adaptable to maintain consistency in design but allow flexibility for future advances in hazard or building performance.

MBIE is developing a Seismic Risk Work Programme (SRWP) that adopts the 5 principals identified by the SRWG. The overall primary outcome of the SRWP is to ensure buildings are safer in earthquakes, and more cost effective to design and construct. The SRWP intends to deliver:

- Greater transparency on public policy settings for earthquake safety,
- Increased confidence that buildings will be safe in the full range of earthquakes that are expected,
- Greater consistency of building performance – meaning that two buildings of similar height at a similar location, both designed to meet the Building Code, should perform similarly in an earthquake,
- Reduced building design costs due to streamlined compliance solutions.

4.2 Process, sector engagement and delivery mechanism

Some preliminary ideas for the SRWP have been already been developed to define the next steps in moving forward. A three phase approach is proposed for the technical work streams required that will have a concurrent work stream to engage with stakeholders and work through some of the challenges highlighted in this paper. The SRWP represents a significant amount of work and cannot succeed without engagement from all parts of the building sector. The detailed scope of work for the technical work streams will need to be developed and refined as the project progresses.

It is proposed that the technical work streams to be will be split into three major topics:

- Update of B1/VM1: Seismic Design Procedure (Seismic Loading and General Design),
- Update of B1/VM4 : Foundation Design (Seismic Loading and General Design),
- Introduction of a new VM for slope stability and retaining walls.

Currently, most of the content for the seismic design and loading requirements are within a suit of 1170 standards series and NZS 1170.5:2004 in particular. The B1/VM1 work stream will ensure that the requirements of B1/VM1 and NZS 1170.5:2004 will remain fit for purpose.

The geotechnical work streams are already well developed and underway under the Module practice series but there is a desire to better integrate the structural and geotechnical requirements as an objective of the work.

The three phases for the technical work streams to deliver technical content;

Phase 1 – Scoping

This phase will clearly identify the technical basis and settings for seismic risk in the Building Code and its cited documents and develop a mission statement that reflects the long term goals of the regulatory system for seismic risk. This phase will also identify the interactions between compliance solutions and geotechnical and structural solutions and deliver a detailed and co-ordinated scope of work for the development of solutions for the three major topics (e.g. B1/VM1, B1/VM4 and a VM for other geotechnical structures)

This phase is required in order to clearly scope and efficiently deliver the larger pieces or work within Phase 2.

Phase 2 – Drafting

A detailed scope and approach to Phase 2 will be confirmed on completion of Phase 1.

It is anticipated Phase 2 will include the bulk of the technical work for the three major topics e.g. B1/VM1, B1/VM4 and a VM for other geotechnical structures. This work develops or amends compliance solutions that implement the NSHM and confirmed seismic risk policy settings. Phase 2 is anticipated to include delivery of an update of the information currently in NZS 1170.5 (although delivery of this may not be via a Standards NZ process and not all information may remain within NZS 1170.5).

Phase 3 – Finalising

A detailed scope and approach to Phase 3 will be confirmed on completion of Phase 2 and the policy consultation work stream.

It is anticipated Phase 2 will include incorporating the policy consultation conclusions; the final seismic risk settings and the NSHM results into the compliance solutions developed in Phase 2 and implementing the compliance solutions via the Building Code Update process.

5 CONCLUDING REMARKS

Several complex technical, regulatory, social, and economic issues are involved in developing provisions for earthquake risk mitigations particularly those aspects accomplished within the (national) New Zealand Building Code. In light of recent projects to support the seismic resiliency of buildings in New Zealand, several opportunities exist to rework the current seismic design procedures within the Building Code compliance documents. It is also equally important to systematically evaluate the latest research and science findings to understand the spectrum of impacts holistically and the range of uncertainties within the key design variables which contribute the most to the Building Code objectives.

The central regulator is actively initiating several work-streams to support improvements to the Building Code and its associated seismic documents. These work-streams require bringing together representatives of industry, public interests, and local and central regulators to identify and resolve problems to ensure that the seismic design requirements are fit for purpose.

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