NRC·CNRC

Research Towards a Performance-Based Building Code for Earthquake Design in Canada: Including a review of international practice (United States and New Zealand)

Volume: Research Report
Report No.: A1-020198.1
Date: 15 July, 2022
Authors: Jitender Singh, Perry Adebar

Construction Research Centre

National Research Council Canada | Conseil national de recherches Canada

Canada

Cat. No. NR24-107/2022E-PDF

ISBN 978-0-660-45126-8

Table of Contents

List of Figures

List of Tables

List of Acronyms

Acronym	Definition
CCBFC	Canadian Commission on Building and Fire Codes
ICC	International Code Council
ICCPC	International Code Council Performance Code for Buildings and Facilities
MBIE	Ministry of Business, Innovation and Employment
NBC	National Building Code of Canada
NRC	National Research Council Canada
NZC	New Zealand Building Code
PBC	Performance-Based Code
PBD	Performance-Based Design
VM	Verification Method

Definition of Terms

The definitions below were directly taken (in full or in part) from the NBC, the ICCPC (United States), and the NZC.

Acceptable solutions/methods: means a solution that must be accepted as complying with the building code and an implicit expression of the levels of building performance that are acceptable to society.

Alternative solutions: Where a design differs from the acceptable solutions, then it should be treated as an *alternative solution*. The alternative solution must address the same issues as the applicable acceptable solutions and perform *as well as* a design that would satisfy the applicable acceptable solutions.

Amenity (NZC): means an attribute of a building which contributes to the health, physical independence, and well-being of the building's users but which is not associated with disease or a specific illness.

Authoritative documents: A document containing a body of knowledge commonly used by practicing architects or engineers. It represents the state of the art, including accepted engineering practices, test methods, criteria, loads, safety factors, reliability factors and similar technical matters. The content is promulgated through an open-consensus process or a review by professional peers conducted by recognized authoritative professional societies, codes or standards organizations, or governmental bodies.

Building consent: A consent issued by a building consent authority for building work to begin in accordance with the approved plans and specifications.

Canadian Commission on Building and Fire Codes (CCBFC): The CCBFC is responsible for the content of the NBC as well as the other Canadian National Model Codes.

Design guides: A document containing a body of knowledge commonly used by practicing architects or engineers that is not required to meet an open consensus requirement. It represents accepted architectural/engineering principles and practices, tests and test data, criteria, loads, safety factors, reliability factors, and similar technical data.

High Importance Category building: Buildings that are likely to be used as post-disaster shelters and buildings and facilities that represent a substantial hazard to human life in the event of a failure.

Objective-based building code: Compliance to the code is achieved by comparing the design against the acceptable solutions provided in the NBC.

Performance-based design (PBD): Clearly sets out the minimum level of performance that the building and building elements must meet.

Performance-based code (PBC): Provides a framework in which numerous design solutions are available, including the current prescriptive codes. Compliance is achieved by assessing the design against the objectives and performance requirements.

Prescriptive Code: Codes which provide specific (design, construction and maintenance) requirements for building, energy conservation, fire prevention, mechanical, plumbing and so forth.

Performance group classifications for buildings and facilities: International Code Council Performance Code for Buildings and Facilities (ICCPC defines a maximum level of damage that can be tolerated for the performance group under various levels of hazard.

Performance requirement: A requirement that states the level of performance that an acceptable solution or alternative solution must meet.

Post-disaster building: Building that is essential to the provision of services in the event of a disaster; for example hospitals, emergency response facilities, power generation stations, water and sewage treatment plants, and communications facilities.

Product certificate: Product certificate means a certificate issued under section 269 of the Building Act 2004 [New Zealand] that a building consent authority must accept as establishing compliance with the building code.

Standing Committee on Earthquake Design (SC-ED): A technical committee under the CCBFC. The technical committees are responsible for developing proposed changes to the National Model Codes.

Verification method: A method by which compliance with the building code may be verified.

Executive Summary

The report starts with a brief discussion on the relevance of a performance-based design approach. Some advantages of performance-based requirements compared to prescriptive requirements are presented. This is followed by a brief summary of the evolution of performance-based design requirements and the five level system for performance-based regulatory framework that is generally used in performance-based codes (PBC) around the world.

A review of the performance-based building codes of selected countries, with regard to earthquake design, including their development process and regulatory framework, is provided. This includes analysis of the requirements in the International Code Council Performance Code for Buildings and Facilities (ICCPC) from the United States (U.S.) and the New Zealand Building Code (NZC). The similarities and differences in the implementation of the performance-based approach in the two countries are described.

The current objective-based approach in the National Building Code of Canada (NBC), which provides prescriptive acceptable solutions and the option to develop alternative solutions (known as equivalency prior to 2005), is discussed along with an analysis of the objectives and functional statements related to earthquake design. These provide a good starting point for developing a performance-based framework. The purpose of the available intent statements and application statements is also briefly reviewed.

An article-by-article analysis of the current requirements in NBC is included. The requirements are grouped into three broad categories: (i) prescriptive requirements; (ii) general requirements that are already in, or can easily be adopted to, a performance-based format; and (iii) basic information or analysis procedures also needed as part of a performance-based solution.

Information is presented on the next steps towards the development of a PBC for earthquake design in Canada using the current NBC as the starting point. This includes discussion of the performance objectives and expected baseline performance of the current earthquake design requirements in the NBC, as well as information on developing the compliance requirements. An example is included of a recently developed Canadian guideline for earthquake design and two closely-related U.S. reference documents.

The report ends with a brief discussion of some additional issues that require further consideration.

The key findings are summarized as follows:

1. The ICCPC and NZC PBCs have a similar structure that is based on Nordic Five Level System.
2. The prescriptive codes and standards continue to exist as a compliance option in both ICCPC and NZC.
3. The objectives, functional statements (requirement) and performance requirement (performance) in ICCPC and NZC for earthquake design are similar in both codes.
4. The objective-based approach in NBC provides a good starting point for the development of a PBC.
5. Many requirements for earthquake design in NBC 2015 are already in performance-based format.
6. CSA standards that are required for designing buildings for earthquake in the NBC will have to be reviewed and updated to implement a PBC.
7. Authoritative documents that are already available in Canada, U.S. and other countries can be adopted to provide compliance solutions for a future PBC in Canada.
8. A phased approach for the development of a PBC is recommended.

Purpose of Report

This report is one in a series of reports intended for the *Research towards a Performance-Based Building Code* project. The other reports in this series include:

- J. Su, *Review of Performance-Based Fire Safety Regulations in Selected Countries: New Zealand*, Report No. A1-018529.1, National Research Council Canada, 2021;
- N. Benichou, *Review of Performance-Based Fire Safety Regulations in Selected Countries: Australia*, Report No. A1-018529.2, National Research Council Canada, 2021; and
- A.P. Robbins, *Research towards a Performance-Based Building Code Preliminary Analysis NBC Part 3 Fire and Life Safety Provisions*, Report No. A1-018529.3, National Research Council Canada, 2021.

This report deals with the development of performance-based design (PBD) requirements for earthquake design as part of the potential transition of the National Building Code of Canada (NBC) into a performance-based code (PBC). It examines the implementation of the performance-based design approach in the International Code Council Performance Code for Buildings and Facilities (ICCPC) in the U.S. and the New Zealand Code (NZC), and explores the synergies between them. The objective-based approach and current requirements for earthquake design in the NBC are reviewed in order to identify what will be required to make the transition to a performance-based approach.

1 Overview

1.1 Background

Building codes address society's most important needs and expectations such as life safety, health, and environmental protection. To stay relevant, building codes must respond to the challenge posed by the changes in the societal needs and expectations, the rapid advances in construction technologies, and the dynamic nature of market forces. The prescriptive makeup of the current building codes is a handicap in responding to this challenge, as their requirements are based on accepted building materials and established techniques, and it takes a long time to change them. Performance-based codes (PBC) provide an effective response to this challenge as they can more specifically focus on the desired outcome, provide the rationale for it and accept different ways to demonstrate compliance with the desired outcome. This transparency and flexibility of a PBC encourages innovation and supports harmonization of requirements.

Recognizing the benefits offered by a performance-based approach and its success in other jurisdictions, a project *Research towards a Performance-Based Building Code* was initiated to set the stage for potential evolution of the National Building Code of Canada (NBC) in this direction. The overall scope of the project covers fire and life safety provisions in Part 3 and earthquake provisions in Part 4 of Division B of the NBC 2015.

This report focuses on earthquake design aspects and is intended to inform discussions on the transitioning of the NBC into a PBC for earthquake design.

1.2 Research conducted under the project

In support of the project, a review of performance-based building codes of selected countries was conducted, including their development process and regulatory framework. The objective of this review was to learn from their experiences in order to help advance the development of performance-based requirements for the NBC. The review included the International Code Council Performance Code for Buildings and Facilities (ICCPC) from the U.S., and the New Zealand Building Code (NZC).

A high-level analysis of the current requirements for earthquake design in Part 4 of the NBC objective-based framework was conducted; the objectives and functional statements related to earthquake design were reviewed; and the intent and application statements were briefly reviewed, but no detailed analysis of these last two was conducted.

An article-by-article analysis of the existing earthquake design requirements in Subsection 4.1.8. of the NBC was carried out.

Finally, the next steps towards the development of a PBC for earthquake design in Canada, using the current NBC as the starting point, were devised.

1.3 Outline of the report

Section 2 – **Performance-based design framework for earthquake design** presents some advantages of performance-based requirements compared to prescriptive requirements. This is followed by a brief summary of the evolution of performance-based design (PBD) requirements. Lastly, the Nordic Five Level

System for performance-based regulatory framework is summarized. The international codes that were reviewed follow a similar framework.

Section 3 – **Review of international performance-based codes for earthquake design** presents a summary of the performance-based requirements in the ICCPC and the NZC. Further details are provided in the Appendix A for the ICCPC and in the Appendix B for the NZC, including a high-level review of the code development process and regulatory framework in the two countries. A comparison of the two codes is included in Appendix C, and a brief discussion is presented in Section 4 on the similarities and differences in the implementation of the performance-based approach in the two countries.

Section 4 – **Current building code requirements in Canada for earthquake design** presents a high-level summary of the objective-based framework of the NBC, including the objectives, sub-objectives, functional statements, intent statements, and application statements. Further details of the objective-based framework in the NBC is presented in Appendix D. Sentence level (requirements in Subsection 4.1.8.) analysis is provided in Appendix E as an embedded file for general reference. The section ends with an article-by-article analysis of existing earthquake design requirements in Subsection 4.1.8.

Section 5 **– The way forward** presents information on what would be required to develop performance-based requirements for earthquake design using the current NBC as the starting point. It begins with a discussion of the performance objectives and baseline performance of the current code, and presents information on the compliance requirements that would need to be developed. Information is presented on a recently developed verification guideline that will serve as a useful template for other documents. The section ends with a summary of some additional issues that require further consideration.

2 Performance-Based Design Framework for Earthquake Design

This section provides a brief introduction of the framework used internationally for specifying performance-based design (PBD) requirements in building codes for structural design in general, and more specifically, earthquake design for building structures.

2.1 Prescriptive requirements versus performance-based requirements

Building code requirements can generally be characterized into two different types. The first is the traditional prescriptive requirements that are usually simple and have easy-to-follow rules for how to design a building similar to what was done in the past. The simple requirements normally do not provide any detailed information on how the building will actually perform.

Performance-based requirements, on the other hand, clearly set out the target level of performance that the building and building elements must meet. The procedures may not be as simple to use and generally require a higher level of expertise on the part of the designer; however, there are a number of significant advantages of performance-based building requirements.

One advantage is that a performance-based approach can more readily be applied to alternative materials and alternative forms of construction, which encourages the use of innovative solutions that may result in cost savings. Current building codes provide minimal guidance for the use of alternative solutions. The approach used in the prescriptive codes for alternative solutions requires equivalency, but, often does not describe how equivalency should be demonstrated, nor does it provide an administrative process to follow. A performance-based code (PBC) provides specific provisions within the body of the code for an alternative solutions approach.

Performance-based requirements provide clear information in the code on exactly what the code is trying to achieve. The current (non-enforceable) Commentary[1] to the earthquake design provisions in the National Building Code of Canada (NBC) explains what the minimum requirements in the code are trying to achieve; however, PBC make this clear as part of the normative requirements and allow the opportunity for different levels of performance rather than just a minimum level as is currently the case.

A PBD code for earthquake design would identify and quantify the level of damage that is acceptable after a certain level of earthquake event, which is something that most people (i.e., designers, building owners and society in general) are currently unaware of.

Finally, a PBC provides a framework in which numerous design solutions are available, including a design that meets the current prescriptive requirements.

---

[1] Structural commentaries (User's guide – NBC 2015: Part 4 of Division B)

2.2 Evolution of performance-based design requirements

The concept of developing (full) performance-based building requirements started in the 1980's, but it was not until the 1990's and later that some countries developed the framework, and content required for performance-based building codes. Now, thirty years later, a number of countries have introduced performance-based building regulations including New Zealand and Australia. Section 3 below summarizes two examples, the U.S. and New Zealand regulations, and further details are given in the Appendices.

2.3 Basic framework of performance-based design requirements

The international PBC follow a framework similar to the Nordic Five Level System. The Nordic Five Level System was published by the Nordic Committee on Regulations in 1978 for the purpose of harmonizing the building regulations of Denmark, Finland, Iceland, Norway, and Sweden in a logical and transparent manner that was compatible with the countries' existing regulations (See Appendix C.2). The components of a typical framework for performance-based requirements are summarized in Table 1.

Table 1: Summary of performance-based requirements

Objectives (goals)	Defines what is expected in terms of societal goals, i.e., what society expects from buildings and facilities, such as safeguarding people during escape and rescue.
Functional statements (functional requirements)	Addresses one specific aspect or required performance of the building to achieve the objective (other functional requirements may contribute to achieving the same goal).
Operative requirements (performance requirements)	Detailed statements that break down the functional statements into measurable terms. This is where the link is made to the acceptable solutions.
Verifications	Instructions or guidelines for verification of performance.
Examples of acceptable solution	Supplements the regulations with examples of solutions deemed to satisfy the requirements.

3 Review of International Performance-Based Codes for Earthquake Design

This chapter presents a summary of two international performance-based codes (PBC), namely the International Code Council Performance Code for Buildings and Facilities (ICCPC) from the U.S. and the New Zealand Building Code (NZC).

The structure of ICCPC and NZC are variations of the Nordic Five Level System for performance-based regulatory framework, described in Section 2. In both codes, the requirements are presented in terms of objectives, functional statements (functional requirements), and performance requirements. Table 14 in Appendix C provides a comparison of the complete requirements. The aspects that are relevant to structural/earthquake design are compared below.

3.1 Objective and functional statements in ICCPC and NZC

ICCPC has a general objective statement and specific functional statements, while NZC has the reverse, specific objective statements and a general functional requirement. The combination of the two types of statements are very similar in the two codes as shown below:

Table 2: ICCPC and NZC objective statements and functional requirements comparison

ICCPC	NZC
Objective To provide a desired level of structural performance when structures are subjected to the loads that are expected during construction or alteration and throughout their intended lives.	**Objective** 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 statements *501.2.1 Life Safety and Injury Prevention.* Structures shall be designed and constructed to prevent injury to occupants due to loading of a structural element or system consistent with the design performance level determined in Chapter 3. *501.2.2 Property and amenity protection.* Structures shall be designed and constructed to prevent loss of property and amenity consistent with the design performance level determined in Chapter 3.	**Functional requirements** B1.2 Buildings, building elements, and site work shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives.

3.2 Performance requirements in ICCPC and NZC

The performance requirements in the two codes are similar as shown Table 3.

Table 3: ICCPC and NZC performance requirements comparison

ICCPC	NZC
Stability. Structures, or portions thereof, shall remain stable and not collapse during construction or alteration and throughout their lives. **Disproportionate failure.** Structures shall be designed to sustain local damage, and the structural system as a whole shall remain stable and not be damaged to an extent disproportionate to the original local damage. **Loss of amenity.** Structures, or portions thereof, shall have a low probability of causing damage or loss of amenity through excessive deformation, vibration or degradation during construction or alteration and throughout their lives.	Buildings, building elements, and site work shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during construction or alteration and throughout their lives. Buildings, building elements, and site work 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.
Expected loads. Structures, or portions thereof, shall be designed and constructed taking into account expected loads, and combination of loads, associated with the event(s) magnitude(s) that would affect their performance, including, but not limited to 1. Dead loads. 2. Live loads. … 11. earthquake loads. 11.1 Small: 43 years (mean return period) 11.2 Medium: 72 years (mean return period) 11.3 Large: Two-thirds of intensity of very large loads 11.4 Very large: The Risk-Targeted Maximum Considered earthquake defined in Chapter 21 of ASCE 7.	Account shall be taken of all physical conditions likely to affect the stability of buildings, building elements and sitework, including: (a) Self-weight, (b) Imposed gravity loads arising from use, … (f) earthquake, … (o) Adverse effects due to insufficient separation from other buildings, (p) Influence of equipment, services, non-structural elements and contents, …
Safety factors. the design of buildings and structures shall consider appropriate factors of safety to provide adequate performance from: 1. Effects of uncertainties resulting from construction activities. 2. Variation in the properties of materials and the characteristics of the site. 3. Accuracy limitations inherent in the methods used to predict the stability of the building. 4. Self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep and similar effects.	Due allowance shall be made for: (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.

5. Uncertainties in the determination of the expected loads.	

3.3 Design performance levels in ICCPC

ICCPC provides a framework for the design of buildings for different levels of performance. The Design Performance Level concept provides a framework for choosing the performance level of the building based on the desired damage state. A building owner can increase the level of performance if the desire is to reduce the consequences of the earthquake on the building. This concept provides a link between the policy makers and the designers. It establishes performance groups for buildings and facilities and minimum acceptable losses based on those performance groups.

NZC does not have a framework for choosing level of performance in a building. All (normal) buildings are designed to one performance level and the user does not have a choice of performance levels/damage states. NZC does provide for enhanced levels of performance in post-disaster and High Importance Category buildings. In this respect, the approach in NZC is similar to the approach in the National Building Code of Canada (NBC).

ICCPC performance group classifications for buildings and facilities is more comprehensive than the approach in NZC and NBC but it can be mapped to the NBC (or the NZC) building importance categories as shown below:

Table 4: ICCPC and NBC importance categories

ICCPC	NBC
Performance Group I	Low Importance Category
Performance Group II	Normal Importance Category
Performance Group III	High Importance Category
Performance Group IV	Post-disaster

ICCPC defines a maximum level of damage that can be tolerated for the performance group under various levels of hazard as summarized in the Table 5. Buildings must be designed to the levels of performance and magnitudes of event indicated in every applicable cell within the table.

Table 5: ICCPC performance groups

Design Event	Performance Group			
	I	II	III	IV
Very Large	**Severe**	**Severe**	High	Moderate
Large	**Severe**	High	Moderate	Mild
Medium	High	Moderate	Mild	Mild
Small	Moderate	Mild	Mild	Mild

The tolerable impacts of the design loads are assumed as summarized in Table 6.

Table 6: ICCPC tolerable impacts of the design loads

Structural damage	Non-structural damage
Mild. The building or facility does not have structural damage and is safe to occupy.	**Mild.** Non-structural systems needed for normal building or facility use and emergency operations are fully operational.
Moderate. There is moderate structural damage, which is repairable; some delay in re-occupancy can be expected.	**Moderate.** Non-structural systems needed for normal building or facility use are fully operational, although some cleanup and repair may be needed. Emergency systems remain fully operational.
High. There is significant damage to structural elements but there is not large falling debris; repair is possible. Significant delays in re-occupancy can be expected.	**High.** Non-structural systems needed for normal building or facility use are significantly damaged and inoperable; egress routes may be impaired by light debris; emergency systems may be significantly damaged, but remain operational.
Severe. There is substantial structural damage, but all significant components continue to carry gravity load demands. Repair may not be technically possible. The building or facility is not safe for re-occupancy, as re-occupancy could cause collapse.	**Severe.** Non-structural systems for normal building or facility use may be completely non-functional. Egress routes may be impaired; emergency systems may be substantially damaged and non-functional.

3.4 Compliance requirements in ICCPC and NZC

The compliance paths are similar in both codes. Compliance can be achieved through use of prescriptive codes (acceptable solutions), use of Authoritative Documents and Design Guides, and use of other design documents. ICCPC does not provide granular information about acceptable methods, Authoritative Documents and Design Guides. It requires use of these methods and guides and provides a framework; NZC provides Acceptable Solutions and Verification Methods published by a regulatory body. There is at least one acceptable solution or verification method for compliance with each of the code requirements.

Further details on the two international codes are provided in three appendices. Appendix A presents a review of regulatory framework in the U.S., and the performance-based requirements in ICCPC. Appendix B presents a review of the regulatory framework in New Zealand, and the performance-based requirements in NZC. Finally, Appendix C provides a high-level comparison of the two regulatory systems and the two performance-based requirements.

4 Current Building Code Requirements in Canada for Earthquake Design

The National Building Code of Canada (NBC) is an objective-based building code. The objective-based code was originally envisioned as a step or a transition towards a performance-based code (PBC) and, therefore, provides a head start for transitioning the NBC to a PBC.

This section shows how the objectives and functional statements required for earthquake design in a performance-based code can be derived from the existing objectives, sub-objectives and functional statements in the NBC. The next level (in the Nordic Five Level System) is the performance requirements.

The current earthquake design requirements in the NBC are a combination of prescriptive and performance-based requirements. Some of the current requirements can be readily adopted into a performance-based format (as performance requirements). However, a consequence of the mixture of prescriptive and performance-based requirements is that it is not clear which requirements have a very limited scope of application and what that limited scope is, and as a result, the prescriptive requirements have sometimes been incorrectly applied to a different type of building than was intended when the requirements were developed.

For example, in NBC 2015, the amplification effects of local ground conditions are represented by site coefficients. The variety of ground conditions is condensed into distinct site classes, and an amplification factor—termed a site coefficient or foundation factor—is associated with each site class, depending on input acceleration and period. Some of the issues resulting from this approach are:

1. it is sometimes difficult to decide which site class a complex ground condition should be assigned to;
2. for sites that are close to the boundaries of site classes, site effects can change abruptly if they fall in one site class compared to another; and
3. a single factor given in the code does not capture the variation in site amplification within the site class.

The second part of this section provides an article-by-article review of the earthquake design requirements in the NBC to determine the nature (prescriptive/performance/mix) of the current requirements.

4.1 Objective-based framework of NBC

Appendix D provides a detailed description of the objective-based framework of NBC. A brief summary is provided here.

NBC became an objective-based building code in 2005 and provides both the prescriptive acceptable solutions and the option to develop alternative solutions (known as equivalency prior to 2005).

The introduction of the objective-based code was originally envisioned as a transition towards a performance-based code. The Canadian approach was positioned as a benchmark where compliance to the code is achieved by comparing the design against the acceptable solutions provided in Division B of the NBC. It is different than a true performance-based approach where the compliance is achieved by assessing the design against the objectives and the more specific performance requirements.

The acceptable solutions in the NBC represent an implicit expression of the levels of building performance that are acceptable to society. This is the primary compliance option. However, the second compliance option in NBC is through the use of alternative solutions. To be acceptable, an alternative solution must provide a level of performance at least equivalent to that of the acceptable solution(s) it is replacing in the areas defined by the objectives and functional statements attributed to them.

The acceptable solutions in the NBC consist of a mixture of performance and prescriptive code provisions with each requirement tied to at least one code objective and functional statement, and is supplemented with detailed intent and application statements. When evaluating alternative solutions for compliance, the areas of performance to be examined are clearly identified by the objectives and functional statements attributed to each specification of the acceptable solutions. Additional information about the objectives, functional statements, intent statements, and application statements are given in the next section.

4.2 Structure of the NBC

Appendix D.2 provides a comprehensive summary of the structure and format of the NBC. This section provides a brief overview of the information relevant to earthquake design.

The NBC is structured in three divisions. The earthquake design provisions (Subsection 4.1.8.) are located within Division B—acceptable solutions. The components of the objective-based framework in NBC are found in Division A—compliance, objectives, and functional statements. The third part of NBC is Division C—administrative provisions.

4.2.1 Objectives

The objectives state what the code aims to achieve. The two objectives identified in NBC that are relevant to earthquake design are:

> ***Safety (OS)*** *– to limit the probability that, as a result of the design, construction, or demolition of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury.*
>
> ***Fire and Structural Protection of Buildings (OP)*** *– to limit the probability that the building or adjacent building will be exposed to an unacceptable risk of damage due to fire or structural insufficiency, or the building or part thereof will be exposed to an unacceptable risk of loss of use also due to structural insufficiency.*

Sub-objectives (second-level or third-level objectives) provide more detailed information about what the code is trying to accomplish. The following are the second- and third-level objectives relevant to earthquake design:

> ***OS2 Structural Safety*** *– to limit the probability that, as a result of the design or construction of a building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to structural failure. The risks of injury due to structural failure addressed in the Code (relevant to earthquake design) are those caused by:*
> ***OS2.1*** *– loads bearing on the building elements that exceed their loadbearing capacity*
> ***OS2.2*** *– damage to or deterioration of building elements*
> ***OS2.3*** *– vibration or deflection of building elements*
> ***OS2.4*** *– instability of the building or part thereof*

OP2 Structural Sufficiency of the Building – t*o limit the probability that the building or part thereof will be exposed to an unacceptable risk of damage or loss of use due to structural failure or lack of structural serviceability.*

The risks of damage and loss of use due to structural failure or lack of structural serviceability addressed in the Code are those caused by:
***OP2.1** – loads bearing on building elements that exceed their loadbearing capacity*
***OP2.2** – loads bearing on building that exceed loadbearing properties of supporting medium*
***OP2.3** – damage to or deterioration of building elements*
***OP2.4** – vibration or deflection of building elements*
***OP2.5** – instability of the building or part thereof*

***OP4 Protection of Adjacent Buildings from Structural Damage –** to limit the probability that adjacent buildings will be exposed to an unacceptable risk of structural damage.*
The risks of structural damage to adjacent buildings addressed in this Code are those caused by:
***OP4.2** – collapse of the building or portion thereof onto adjacent buildings*
***OP4.3** – impact of the building on adjacent buildings*

4.2.2 Functional statements

Functional statements translate objectives into operational terms. They describe the general conditions to be achieved. A functional statement is expressed in qualitative terms, and describes the outcome required, but not how to achieve that outcome. Any one objective can be related to one or more functional statements, and vice versa.

The functional statements relevant to earthquake design are:

***F20** – to support and withstand expected loads and forces.*

***F22** – to limit movement under expected loads and forces.*

***F23** – to maintain equipment in place during structural movement.*

Appendix E provides a summary of the functional statements for all the Articles within Subsection 4.1.8.

4.2.3 Intent statements

The intent statements describe in simple terms what the particular acceptable solution in Division B (Articles in Subsection 4.1.8. for earthquake design) aims to achieve and explains the link between the acceptable solution and its attributed objective(s) and functional statement(s). The intent statements are not part of NBC, but are available as reference material.

4.2.4 Application statements

The application statements describe the situations to which each code provision applies and does not apply. Like the intent statements, the application statements are not part of NBC, but are available as reference material.

Application statements were originally published with the first edition of the objective-based codes in 2005. Since then, the application statements were not maintained nor developed for future revisions of the NBC.

Example

Appendix D.3 presents all of the material related to the objective-based framework for Article 4.1.8.13. Deflections and Drift Limits. This includes the attributions to the objectives and functional statements, as well as the intent statements and application statements.

Further information

Appendix E provides a table with the underlying objectives, functional statements, and intents of all the earthquake design requirements in Subsection 4.1.8. This information is qualitative in nature but was included as it may be useful as a reference in the process of developing the performance requirements for earthquake design.

4.3 Article-by-article analysis of existing requirements

An article-by-article review of the earthquake design requirements in Subsection 4.1.8. is provided in Table 7. The analysis revealed that the requirements fit into three broad categories: (1) prescriptive requirements; (2) general requirements that are already in, or can easily be adopted to, a performance-based format; and (3) basic information or analysis procedures needed as part of a performance-based solution.

Table 7: Article-by-article analysis of existing requirements in Subsection 4.1.8.

Legend for row colours below:
Prescriptive requirements.
General requirements that are already in, or can be easily adopted to, a performance-based format.
Basic information or analysis procedure needed as part of a performance-based solution.
Article 4.1.8.1. Analysis Prescriptive: simplified procedures for calculating specified loading and deflections due to earthquake motions in regions of low seismicity.
Article 4.1.8.2 Notation N/A
Article 4.1.8.3. General Requirements High-level general statements; most can be directly adopted into a PBD format.
Article 4.1.8.4. Site Properties Definition of site-specific spectrum; needed for both prescriptive and performance-based provisions
Article 4.1.8.5. Importance Factor and Seismic Category Prescriptive: definition of parameters needed for simplified procedures
Article 4.1.8.6. Structural Configuration Prescriptive: definition of irregularities needed for simplified procedures
Article 4.1.8.7. Methods of Analysis Prescriptive: definition of when simplified equivalent static analysis can be used.
Article 4.1.8.8. Direction of Loading Simplified procedures for analyzing building in more than one direction.

Article 4.1.8.9. SFRS Force Modification Factors, System Overstrength Factors, and General Restrictions Prescriptive procedures
Article 4.1.8.10. Additional System Restrictions Prescriptive requirements related to irregularities; Post-disaster and High Importance buildings
Article 4.1.8.11. Equivalent Static Force Procedure **Article 4.1.8.11.(1) to (8)** Simplified procedure for determining seismic force demands.
Article 4.1.8.11.(9) General statement about accounting for torsion; can be adopted in PBD
Article 4.1.8.11.(10)&(11) Simplified procedures for accounting for accidental torsion
Article 4.1.8.11.(12) Prescriptive requirement for buildings with a timber SFRS and more than 4 storeys
Article 4.1.8.12. Dynamic Analysis Procedure **Article 4.1.8.12.(1) to (7)** General procedures for dynamic analysis
Article 4.1.8.12.(8) to (9) Prescriptive procedures for scaling results for regular and irregular buildings
Article 4.1.8.12.(10) to (11) General procedures for dynamic analysis
Article 4.1.8.12.(12) Prescriptive requirement for buildings with a timber SFRS and more than 4 storeys
Article 4.1.8.13. Deflections and Drift Limits Guidance on how to calculate deflections; important drift limits that also apply in PBD
Article 4.1.8.14. Structural Separation General statement about separation; can be adopted in PBD Also guidance on how to calculate
Article 4.1.8.15. Design Provisions Collection of mostly prescriptive requirements: diaphragms; discontinuous elements; vertical variation of R_dR_o; …
Article 4.1.8.16. Foundation Provisions A mixture of some very prescriptive requirements as well as more general statements (see next row)
Article 4.1.8.16.(1) General statement about accounting for foundation movements; can be adopted in PBD Article 4.1.8.16.(5) General statement about required strength of foundation Article 4.1.8.16.(10) General statement about design for liquefaction; can be adopted in PBD
Article 4.1.8.17. Site Stability High-level general statement; most can be directly adopted into a PBD format.
Article 4.1.8.18. Elements of Structures, Non-structural Components and Equipment Mostly prescriptive procedures.
Article 4.1.8.19. Seismic Isolation

General requirements that can easily be converted into PBD
Article 4.1.8.20. Seismic Isolation Design Provisions General requirements that can easily be converted into PBD
Article 4.1.8.21. Supplemental Energy Dissipation General requirements that can easily be converted into PBD
Article 4.1.8.22. Supplemental Energy Dissipation Design Considerations General requirements that can easily be converted into PBD
Article 4.1.8.23. Additional performance requirements for Post-disaster Buildings, High Importance Category Buildings, and a Subset of Normal Importance Category Buildings General requirements that can easily be converted into PBD

4.4 Summary of existing requirements in NBC

As described above, the requirements can be divided into groupings. A number of the existing Articles provide very general requirements that are already in a (near) performance-based format, or can easily be adopted into a performance-based format. This includes: Articles 4.1.8.3. General Requirements, 4.1.8.14. Structural Separation and 4.1.8.17. Site Stability, Sentences 4.1.8.11.(9) Torsion and, 4.1.8.16.(1), (5) and (10) Foundation Provisions.

The five newest Articles (added within the past two code cycles) provide very general requirements and generally provide much more information than would be included in a performance-based code. A reduced version of these Articles could go directly into a new performance-based code: Articles 4.1.8.19. Seismic Isolation, 4.1.8.20. Seismic Isolation Design Provisions, 4.1.8.21. Supplemental Energy Dissipation, 4.1.8.22. Supplemental Energy Dissipation Design Considerations, and 4.1.8.23. Additional performance requirements for Post-disaster Buildings, High Importance Category buildings, and a subset of Normal Importance Category buildings.

Several Articles in Subsection 4.1.8. provide basic information on the seismic analysis of buildings. These Articles would continue to be important reference material: Sentences 4.1.8.12. (1) to (7) Dynamic Analysis Procedure, 4.1.8.11.(1) to (8), (10) and (11) Equivalent Static Force Procedure for Structures Satisfying Conditions of Article, and Article 4.1.8.8. Direction of Loading.

Article 4.1.8.4. Site Properties defines the seismic hazard. This information will be required for performance-based design. One consideration is whether different definitions for the seismic hazard could or should be used for the simple prescriptive versus the performance-based procedures. Perhaps simpler definitions of the hazard, that do not change every code cycle, could be used for the prescriptive methods, while the latest, best estimate of the hazard could be used for performance-based design. Additional information that is important for performance-based design is site-response analysis and the selection and scaling of ground motions (currently described in the Commentary[2]).

[2] Structural commentaries (User's guide – NBC 2015: part 4 of division B)

The remaining Articles in Subsection 4.1.8. are in a prescriptive format. These Articles will need to be reviewed and different solutions developed. For example, Article 4.1.8.1.Analysis is a simplified procedure for regions with low seismic hazard; this procedure should remain prescriptive. Article 4.1.8.18. Elements of Structures, Non-structural Components, and Equipment is primarily prescriptive procedures; CSA standard S832, *Seismic risk reduction of operational and functional components (OFCs) of buildings,* is a performance-based standard that could be referenced. Article 4.1.8.15. Design Provisions contains a collection of different prescriptive requirements for diaphragms, discontinuous elements, and vertical variation of the seismic force resistance systems (SFRS); diaphragms is an example of a topic that needs to be added to the performance-based code.

5 The Way Forward

This section describes what will be required to develop performance-based requirements for earthquake design in Canada using the current National Building Code of Canada (NBC) as the starting point. It begins, in Section 5.1, with a discussion of the performance objectives of the current earthquake design requirements in NBC and the expected baseline performance of a building designed to the current code.

Section 5.2 presents information on compliance requirements, including Verification Methods, Authoritative Documents, Design Guides, and the requirement for formal peer review. It also explains how the current NBC requirements and the CSA standards will become examples of acceptable solutions deemed to satisfy the requirements.

Section 5.3 presents some recent developments, including an example Verification Method for the design of tall buildings in British Columbia developed from two Authoritative Documents on performance-based earthquake design from the U.S. Information is also presented from a recently developed unified procedure for determining the force modification factors R_dR_o, which are the *heart* of the prescriptive method for earthquake design in NBC. Many of the issues considered in the development of the unified procedure are fundamental to the development of instructions and guidelines for the verification of building performance needed to implement performance-based design.

Finally, some of the additional issues that require further consideration are summarized in Section 5.4.

5.1 Performance objectives and baseline performance of current requirements in NBC

As summarized in Section 4.2.1 of this report and described in detail in Appendix D, the NBC has clearly defined objectives, which provides a good starting point for the development of performance-based design requirements.

Very succinctly summarized (see Section 4.2.1 for the complete wording), the objectives that are relevant to earthquake design are:

- Safety (OS)—to prevent persons from being exposed to an unacceptable risk of injury, and
- Structural protection (OP)—to prevent the building from being exposed to an unacceptable risk of damage or an unacceptable risk of loss of use.

The development of the current prescriptive requirements for earthquake design have generally focussed on the safety objective (OS). Little attention has been paid to the structural protection objective (OP) for earthquake design. This is where the discussion on a performance-based code for earthquake design will have to start. What is the appropriate extent of *loss of use* and extent of *damage* resulting from different design-level earthquakes?

Recent discussions held within the Standing Committee on Earthquake Design (SC-ED), one of the technical committees of the Canadian Commission on Building and Fire Codes (CCBFC), have resulted in a general consensus on the performance objectives and expected performance of buildings designed according to the current NBC requirements for different categories of buildings. These discussions have taken place during the updating of the Commentary, as well as during the development of a unified procedure for determination of force reduction factors R_dR_o within SC-ED.

Table 8 summarizes the performance objectives for the design ground motions (DGM), having a probability of exceedance of 2% in 50 years, for three different categories of buildings.

Table 8: Performance objectives for the design ground motions

Building Importance Category	Performance objective (2% in 50 y. hazard)
Normal Importance Category buildings	Life safety
High Importance Category buildings	Immediate occupancy
Post-disaster buildings	Functional

There have also been discussions recently within SC-ED about the expected baseline performance of buildings designed according to the current earthquake design requirements. There is a general consensus that *regular buildings* designed according to the current NBC earthquake requirements in Subsection 4.1.8. of Division B will very likely achieve (or exceed) the performance objectives summarized in Table 8. A regular building is one that does not have any of the (currently 10) irregularities defined in Subsection 4.1.8., as well as other types of irregularities that are not yet defined in Subsection 4.1.8. There is growing concern that buildings with one of the more significant defined irregularity or a not-yet defined irregularity may not meet the performance objectives of the code. One of the advantages of a performance-based earthquake design code will be the ability to better ensure adequate performance of a building that includes an irregularity that is not yet defined.

NBC 2015 has different performance groups (Low, Normal, High Importance Categories, and post-disaster) but uses only one level of hazard, i.e., 2% in 50 years. As described in Section 3.3 of this report, the International Code Council Performance Code for Buildings and Facilities (ICCPC) of the U.S. defines different performance objectives (acceptable levels of damage) for different building performance groups and different levels of hazard. The 2020 edition of NBC recently took a step in this direction by introducing additional performance requirements in the new Article 4.1.8.23. Additional Performance Requirements for Post-disaster Buildings, High Importance Category Buildings, and a Subset of Normal Importance Category Buildings The requirements have only one new performance objective—*no structural damage*; but, this is applied to different components of the building at different hazard levels depending on the performance group. The three different types of components are: (i) the seismic force resisting systems (SFRS), (ii) the structural framing elements not considered part of the SFRS, and (iii) the connections of elements and components. The lower intensity ground motions for which the building components must achieve the performance objective have a probability of exceedance of either 10% or 5% in 50 years depending on the building performance group. The building performance groups depend on the type of building (the three types that are including are post-disaster, High Importance and Normal Importance Category with height greater than 30 m) and the seismic category (SC2, SC3, and SC4).

5.2 Compliance requirements

A new performance-based code (PBC) for earthquake design is expected to cover the first three levels of the basic framework of performance-based design (PBD) requirements (see Section 2.3)—objectives, functional statements, and performance requirements. This new, succinct PBC is likely to be brief (only a few pages long), and can be developed from the objective-based framework of NBC, the current provisions in Subsection 4.1.8. that are in a performance-based format (discussed in Section 4), and the performance objectives discussed in the previous section.

The remaining two levels (four and five) of the basic framework of PBD requirements include verifications (instructions or guidelines for verification of performance) and examples of acceptable solutions deemed to satisfy the requirements. These compliance requirements are discussed briefly in this section.

The two international codes that were reviewed in Section 3 address these requirements very differently. The current ICCPC provides a framework, but does not actually provide any detailed instructions or guidelines for verification of performance, or examples of acceptable solutions. It relies on other organizations to provide these documents. The New Zealand Code (NZC), on the other hand, provides Acceptable Solutions and Verification Methods that are published by a regulatory body.

Verification Methods for earthquake design normally include calculations using recognised analytical methods and mathematical models that were calibrated to physical tests. The tests are often full-scale component tests, but sometimes include smaller scale system or even large-scale system tests. For well-established SFRS such as concrete shear walls, these analytical methods are readily available. For a new innovative SFRS, the verification procedure may require conducting tests and developing the analytical methods.

As described by ICCPC (see Section A.2.4), Authoritative Documents include technical references that are widely accepted and utilized by design professionals, professional groups, and technical societies that are active in the design of buildings and their systems. This includes documents developed through open-consensus process conducted by recognized governmental bodies, professional or technical societies, codes or standards organizations, and documents that have undergone peer review process and have been published in professional journals, conference reports, and recognized technical publications. Design Guides include documents developed by professional organizations, and technical societies published for use in PBD.

An important issue is whether a formal peer review is required as part of the verification process. The current NBC requires a formal peer review whenever nonlinear dynamic analysis is used for design. It is expected that the calculations required for verification of performance-based earthquake design will often require nonlinear analysis and therefore a formal peer review will be required as part of the verification process. Many of the Design Guides that were developed for use in PBD require a formal peer review. Another situation when a formal peer review would be required is when the verification procedures used do not come from Authoritative Documents or Design Guides.

Many different Authoritative Documents and Design Guides for performance-based earthquake design were developed in the U.S. and these will be a valuable resource for PBD in Canada. Ideally, a version of these documents that is tailored to Canadian needs should be developed for use with NBC. An example of such a recently developed document for the design of tall concrete buildings in British Columbia is discussed in Section 5.3.1. This document builds on two U.S. reference documents written for the performance-based earthquake design of tall buildings on the west coast of the U.S.

The remaining level of the basic framework of PBD requirements is examples of acceptable solutions deemed to satisfy the requirements. The existing earthquake design provisions in Subsection 4.1.8. could be retained as an acceptable solution for a building that complies with the scope of the provisions. It is expected that these provisions will be updated with new systems using the knowledge and experience gained from designing these systems using the performance-based procedures. The Commentary provides important information such as background information on Subsection 4.1.8. and will continue to be a valuable reference document. The current prescriptive earthquake design requirements for buildings are contained in two separate documents, Subsection 4.1.8. and a Clause within a CSA standard for the type of building (e.g., steel, concrete, timber, etc.). The design requirements within the CSA standards will continue to be an important part of the acceptable solution.

Finally, it is recommended that a compendium (database) of alternate solutions that are approved based on PBD procedures be developed in Canada. The information will assist others that are seeking approval and will be helpful for the update of the current prescriptive requirements in NBC.

5.3 Some recent developments

5.3.1 Verification method: guidelines for tall concrete buildings in BC

The Engineers and Geoscientists of British Columbia have recently developed a document entitled *Professional Practice Guidelines – Structural Engineering Services for Tall Concrete Building Projects.* This consensus document deals with the design of tall concrete buildings for gravity loads, lateral wind forces, and earthquake ground motions. Section 3.4.8 entitled *Evaluation of Life Safety Performance Using Non-linear Dynamic Analysis* provides guidelines for verification of performance consistent with the performance-based requirements of Subsection 4.1.8. of Division B of the National Building Code of Canada (NBC).

This new document serves as an example of how Verification Methods (instructions or guidelines for verification of performance) for performance-based earthquake design can be developed to be consistent with Subsection 4.1.8., and this document can be used as a template for the development of future documents for all materials and other building types. Some important aspects of the document are briefly discussed below.

The existence of the following two important reference documents on the performance-based earthquake design of tall buildings from the U.S. greatly simplified the development of the BC Guidelines:

- (LATBSDC) *Los Angeles Tall Buildings Structural Design Council, An Alternative Procedure for Seismic Analysis and Design of Tall Buildings Located in the Los Angeles Region*. Los Angeles, CA, 2020.
- (PEER TBI) *Pacific earthquake Engineering Research Center Tall Buildings Initiative Guidelines for Performance-Based Seismic Design of Tall Buildings*, Version 2.03, PEER Report 2017/06, May 2017.

It is interesting to note that both U.S. reference documents and the BC Guidelines require that performance-based design (PBD) must be peer reviewed by a qualified independent review panel. The peer review panel must approve all engineering work on the project.

With the existence of the two U.S. reference documents, the BC Guidelines do not present a comprehensive summary of all required procedures for the evaluation of life-safety performance of tall concrete buildings. Where information is not present in the BC Guidelines, the procedures described in either the LATBSDC or PEER TBI guidelines are to be used; however, all Canadian code requirements summarized in the BC Guidelines must always be met. In some instances, the two U.S. reference documents do not meet the minimum requirements of Canadian codes and therefore cannot be applied to the design of buildings in BC. The life-safety performance level of NBC corresponds to significant damage in the structure and loss of stiffness; however, at this performance level, the structure still has reserve capacity before reaching the collapse level. The LATBSDC and PEER TBI guidelines provide procedures for evaluating the *collapse prevention* performance of buildings subjected to risk-targeted maximum considered earthquake (MCE_R).

The following is a list of the topics covered (sections) in the BC Guidelines for the PBD of tall concrete buildings. Many of these will need to be part of any guidelines developed for verification of performance of other types of buildings.

Modelling considerations: System idealization; gravity-load resisting elements; floor diaphragms; horizontal mass; vertical mass; vertical ground motions; damping; p-delta; gravity load; torsion; backstay effect; foundation modelling; modelling of structural components; concrete walls; coupling beams; transfer slabs; slab–column connections; required number of analyses and assumed component strengths; types of demands (actions).

Seismic hazard: Design spectrum; shear wave velocity; site-specific response analysis; period range; number of ground motions; scaling of ground motions.

Evaluation of life-safety performance: Evaluation criteria; design seismic demand parameter; unacceptable response; global response; peak transient storey drift; residual storey drift; evaluation of core walls; deformation demands on SFRS: wall piers; deformation demands on SFRS: coupling beams; shear force demands on wall piers; force demands on other members; critical force-controlled actions; slab-column connections; inter-storey drift ratio due to shear strain; sloped columns.

A factor that simplified the development of the guidelines for verification of performance of tall concrete buildings is that the SFRS—concrete ductile coupled walls and ductile shear walls—are a standard SFRS that have full prescriptive requirements in NBC. Thus, a building designed using the BC performance-based requirements must also meet the minimum strength requirements of NBC. The next section discusses procedures to be used when the type of SFRS does not have prescriptive requirements in NBC.

5.3.2 Unified procedure from Task Group on force modification factors R_dR_o

The force modification factors R_d and R_o used in the calculation of minimum earthquake force are the *heart* of the prescriptive procedures for earthquake design in NBC. Recently the SC-ED formed a Task Group (TG) to develop a unified procedure for determining these important factors for any type of SFRS. This is meant to facilitate the easier adoption of new prescriptive requirements for new SFRS in NBC. The TG presented a complete draft unified procedure to SC-ED in September 2021 and is expected to approve a final procedure in early 2022.

Many of the issues that the TG considered are fundamental to the development of the instructions and guidelines for verification of building performance needed to implement PBD. The TG dealt with the procedures for approving a new type of building with many different possible archetypes in many different locations in Canada. Guidelines for verification of performance, on the other hand, deal with one building at a time.

Due to the significant differences between different building types, the TG did not develop a detailed procedure that can work for any building type. Rather, they developed a general framework, and many of the important decisions for the particular type of building must be made in consultation with an independent peer review panel consisting of at least three experts. The requirement for an independent peer review panel is consistent with the requirements of the BC Guidelines for the PBD of tall concrete buildings and the two U.S. reference documents as discussed above.

One of the important requirements of the SC-ED procedure for determining the force modification factors R_d and R_o is the documented design requirements (not included in NBC). For new SFRSs, these design requirements are usually adopted by a CSA standard. For a single (new type of) building designed using PBD, the design requirements will need to be developed by the *project team* from available (e.g., international) documents for that type of SFRS. The design requirements need to be approved by the peer review panel.

Another important requirement is that all possible modes of failure for the particular type of SFRS must be identified, and the most critical failure modes identified. Again, this is expected to be developed by the *project team* and approved by the peer review panel. This information is needed to evaluate the nonlinear modelling that is used for the building.

The life-safety performance objective can be described as *not on descending branch of force-displacement response of the structure.* This will occur at different drift levels for different types of SFRS. The maximum drift limit must also account for the ability of the entire building (not just the SFRS) to tolerate drift. Depending on the type of SFRS, a component-level evaluation of the system may be appropriate. The criteria used to satisfy life-safety performance level of a particular SFRS must be proposed by the *project team*, and endorsed by the peer review panel.

State-of-the art nonlinear dynamic analysis must be done to determine the performance of the building structure. Analytical models that can explicitly calculate cyclic effects (stiffness and strength degradation, plastic deformations, etc.) are preferred over models that are fit to backbone curves. The physical reason for the building not meeting the performance level must be reported for each ground motion. The project team must report the observed failure modes and compare with the expected failure modes based on the design method for the system.

5.4 Some additional issues to consider

This section briefly summarizes some of the additional issues that require further consideration.

The performance objectives for the three different building importance categories subjected to the 2% in 50 years seismic hazard has recently been articulated by SC-ED, as summarized in Section 5.1 of this report. For High Importance Category and post-disaster buildings, the performance objectives include both safety (preventing persons from being exposed to an unacceptable risk of injury) and structural protection (preventing the building from being exposed to an unacceptable risk of damage or loss of use). For Normal Importance Category buildings the performance objective is *life safety*. Before developing the PBC to achieve these objectives, it would be appropriate to spend additional time to define exactly what is meant by *life safety*, *immediate occupancy*, and *functional*.

In recent years, there was considerable discussion about extending the structural protection objective to Normal Importance Category buildings, and this was actually done for a small subset of buildings in the additional performance requirements of Article 4.1.8.23. Additional Performance Requirements for Post-disaster Buildings, High Importance Category Buildings, and a Subset of Normal Importance Category Buildings introduced in the 2020 edition of the NBC. The issue of protecting cities (providing resilience) by preventing an unacceptable risk of damage or loss of use of numerous buildings at the same time in a city due to a single earthquake deserves consideration.

An analysis of the current earthquake design requirements in Subsection 4.1.8. presented in Section 4 has revealed that a number of Articles and some of specific Sentences can be easily characterized as performance-based or prescriptive. However, some of Articles and specific Sentences require additional discussion and debate. It would be important for a group of experts to use the information presented here as a starting point of a discussion of these Articles and individual Sentences.

The prescriptive earthquake design requirements for buildings are contained in Subsection 4.1.8.; but also within CSA standards for particular types of building (e.g., steel, concrete, timber). An important question that needs to be discussed is who will develop the information normally contained within a CSA standard for a new type of building not covered by an existing CSA standard, and who will certify these documents as authoritative?

Finally, it will not be possible to develop all required instructions or guidelines for verification of performance and examples of acceptable solutions for all different types of buildings at one time. Thus, an important discussion to have is to develop a plan for what documents will be written first. The existence of international documents, such as reference documents from the U.S., will be an important factor in deciding which systems to move forward first.

Acknowledgments

The research that led to this report would not have been possible without the funding provided by the Natural Resources, Canada and the support of the NRCan team. Special thanks to Mohammad Mohammad (NRCan) for supporting inclusion of earthquake design as part of the broader initiative on Performance Based Design project.

John Sherstobitoff, Principal, Seismic & Structures, Ausenco provided helpful technical review comments, and Hayley Martin, Technical Advisor, Codes Canada, greatly improved the readability of this report.

Special thanks to the team at NRC Fire Research consisting of Alex Bwalya, Noureddine Benichou and Joseph Su for the valuable discussions on the project which helped in the writing of this report.

References

Websites

Significant content in this report is reproduced from the information that is publically available on the ICC (https://www.iccsafe.org/) and MBIE (https://www.mbie.govt.nz/).

Codes, Standards and Guidance Documents

ICC, 2021 International Code Council Performance Code for Buildings and Facilities, International Code Council, U.S.A, 2020

ICC, 2021 International Code Council Performance Code for Buildings and Facilities User's Guide, International Code Council, U.S.A., 2020

NZBC, Building Regulations 1992, Schedule 1, The building code, Parliamentary Counsel Office, New Zealand, 2017.

MBIE, New Zealand Building Code Handbook, Ministry of Business, Innovation and Employment, Wellington, New Zealand, February, 2014.

MBIE (2019), Acceptable Solutions and Verification Methods for New Zealand Building Code Clause B1 Structure, Ministry of Business, Innovation and Employment, Wellington, New Zealand.

MBIE (2019), Acceptable Solutions and Verification Methods for New Zealand Building Code Clause B2 Durability, Ministry of Business, Innovation and Employment, Wellington, New Zealand.

NZS 1170.5-2004 Structural design actions Part 5: earthquake actions- New Zealand,

NZS 4219:2009 Seismic Performance of Engineering Systems in Buildings, Standards New Zealand

CCBFC, Supplement to the National Building Code of Canada 2015: Intent Statements, Issued by the Canadian Commission on Building and Fire Codes, National Research Council of Canada, Canada, 2018, https://codes-guides.nrc.ca/IA/15NBC/intentframe.html.

CCBFC, User's Guide – NBC 2005, Application and Intent Statements. Second Release, Issued by the Canadian Commission on Building and Fire Codes, National Research Council of Canada, Canada, 2007 includes revisions are errata up to and including June 20, 2008, https://codes-guides.nrc.ca/ia/05nbc/intenttoc.html

NBC, National Building Code of Canada, Issued by the Canadian Commission on Building and Fire Codes, National Research Council of Canada, Canada, 2015.

NCC, National Construction Code of Australia, Australian Building Codes Board, Australia, 2019.

Engineers and Geoscientists of BC, "*Professional Practice Guidelines – Structural Engineering Services for Tall Concrete Building Projects,*" To be published in Early 2022.

Other References

Bénichou, N., Review of Performance-Based Fire Safety Regulations in Selected Countries: Australia, Report No. A1-018529.2, National Research Council Canada, 2021; and

Su, J., Review of Performance-Based Fire Safety Regulations in Selected Countries: New Zealand, Report No. A1-018529.1, National Research Council Canada, 2021

Wade, C.A., C/VM2 Update, BUILD Magazine, Vol. 144 pp.56-57, 2014,

Bergeron, D., Canada's objective-based codes [NRCC-42800], 5th International Conference on Performance-Based Codes and Fire Safety Design Methods, Luxembourg, October 6, 2004.

FEMA P-2156, The Role of the NEHRP Recommended Seismic Provisions in the Development of Nationwide Seismic Building Code Regulations: A Thirty-Five Year Retrospective, FEMA February 2021

Rossberg J., Leon R.T., Evolution of codes in the U.S.A., (UNJR 2013)

Holmes, W.T., The Evolution of Seismic Design Provisions of U.S Building Codes, Proceedings of the 9th U.S. National and 10th Canadian Conference on earthquake Engineering, Toronto, July 25-29,2010.

Oleszkiewicz, I., The Concept and Practice of Performance-Based Building Regulations, Internal Report IRC-IR-697, National Research Council, November 1994 https://doi.org/10.4224/20375492

Nwadike A., Wilkinson S., Building Code Amendment Process: A Case Study of New Zealand, 9th International Conference on Building Resilience, ICBR 09 Bali, Indonesia, January 2020

"SC-ED Procedure for Determining Force Modification Factors Rd Ro in NBC," Report to SC-ED from the Task Group on Rd Ro and SFRS, Sept. 2021, 10 pp.

Appendix A - United States

A.1 Regulatory framework in the United States

In the U.S., as a result of the Federal system, the power to regulate design and construction of buildings rests with the government of individual states, cities, and towns. In order to promote consistency of requirements across the country, Model Codes are developed by a national organization (for example, the International Code Council). Model Codes have no legal standing until they are adopted by a government that has the authority to regulate construction; in the U.S., those jurisdictions are the states. Each state has its own building code, based on the applicable Model Code. Some states adopt the Model Codes outright. Other state building codes differ from the Model Codes.

In the U.S., the Model Building Code is called *The International Building Code*, or IBC. The International Code Council (ICC), a non-profit organization, publishes a suite of model codes (I-Codes), including codes that provide requirements for building construction, plumbing, fire protection, and many other aspects of building and infrastructure design and maintenance. The ICC suite of Model Codes consists of 15 codes.

- Building, Residential:
  - International Building Code (IBC)
  - International Residential Code (IRC)
- Fire:
  - International Fire Code (IFC)
  - International Wildland-Urban Interface Code (IWUIC)
- Fuel Gas, Mechanical, Plumbing, Pool:
  - International Fuel Gas Code (IFGC)
  - International Mechanical Code (IMC)
  - International Plumbing Code (IPC)
  - International Private Sewage Disposal Code (IPSDC)
  - International Swimming Pool and Spa Code (ISPSC)
- Existing Buildings, Property Maintenance:
  - International Existing Building Code (IEBC)
  - International Property Maintenance Code (IPMC)
- Energy, Green, Performance, Zoning:
  - International Energy Conservation Code (IECC)
  - International Green Construction Code (IgCC)
  - ICC Performance Code for Buildings and Facilities (ICCPC)
  - International Zoning Code (IZC)

The first edition of the full suite of I-Codes was published in 2000. The ICC works to publish a new set of I-Codes every three years that can be adopted and modified by each state. Most states follow a three-year code adoption cycle in order to keep up-to-date with the ICC revision process. The ICC develops the I-Codes through a governmental consensus process. **Error! Reference ource not found.** provides a snapshot of the ICC code development process. Additional details are available at the ICC website https://www.iccsafe.org/. The process leaves the final determination of code provisions in the hands of public safety officials.

Figure 1 – ICC code development process

Every model code that is adapted and/or adopted by a state government becomes a legal regulation within that jurisdiction, for example *The Florida Building Code*. The adoption of model codes varies across the U.S. Maps showing adoption of I-codes are available at the following link: https://codeadoptions.iccsafe.org/code-adoption-map/IBC.

The state governments do not generally enforce the building codes. Under most circumstances, they are enforced by local authorities; usually cities or townships. The code is usually enforced by a building department, led by a building official. Building design is also affected by local government bylaws and planning policies. These affect the site plan review, and they may set limits on, for example, the building's height or distance from the property lines. Zoning regulations can limit the types of buildings that can be constructed on a site, as well.

The system is similar in Canada where the model building code is called the *National Building Code*, or NBC. It is developed by the Canadian Commission on Building and Fire Codes (CCBFC). The CCBFC is an independent body made up of volunteers from across the country and from all facets of the code-user community. Codes Canada of the National Research Council of Canada (NRC) provides technical and administrative support to the CCBFC. As in the U.S., provincial and territorial governments have the authority to enact legislation that regulates building design and construction within their jurisdictions. This legislation may include the adoption of the NBC without change or with modifications to suit local needs, and the enactment of other laws and regulations regarding building design and construction, including the requirements for professional involvement.

A.2 International Code Council Performance Code for Buildings and Facilities (ICCPC)

A.3 Goal and scope of ICCPC

As the name suggests, the ICCPC emphasizes performance rather than prescriptive requirements. It presents provisions based on outcomes rather than prescriptive rules and encourages new design methods by allowing broader options for meeting the intent of the International Codes. The ICCPC defines the objectives for achieving the intended levels of occupant safety, property protection, and community welfare, and provides a framework to achieve these objectives in terms of tolerable levels of damage and magnitudes of design events, such as fire and natural hazards.

The I-Codes mainly direct the user to a single solution to address a safety concern for a building or facility; the ICCPC allows the user to achieve various solutions, systematically. While the ICCPC is different from the other I-Codes, the concepts covered by the ICCPC are not intended to be any different in scope than those covered by the model codes (I-Codes®). The I-Codes suite, which provide prescriptive paths, are considered to provide acceptable solutions that will comply with the ICCPC.

The first edition of the ICCPC was published in 2001. A new edition that reflects current and past edition changes is released every 3 years; the current edition is the 2021 ICCPC.

A.3.1 Structure of the ICCPC and the system for specifying requirements

The ICCPC is organized into four major parts:

> **Part I**—Scope and Application, Administration and Enforcement, Definitions, Determining design performance level (acceptable level of design for the building based on extent of damage or impact), and requirements for reliability and durability (Chapters 1 to 4)
>
> **Part II**—Building Provisions (Requirements for Stability), Fire Safety, Pedestrian circulation. Safety of users, Moisture, Interior Environment, Mechanical, Plumbing, Fuel gas, Electricity, and Energy Efficiency (Chapters 5 to 15)
>
> **Part III**—Fire Provisions (Requirements for fire prevention, Fire impact management, management of people, Means of egress Emergency Notification, Access and Facilities, Emergency Responder Safety, Hazardous Materials (Chapters 16–22)
>
> **Part IV**—Appendices
>
>> **Appendix A** provides guidance to determine the primary use of a building (use and occupancy classification) and use this classification to assign a performance group to the building.
>>
>> **Appendix B** allows the adjustment of performance groups based on occupants or the unique features of a building.
>>
>> **Appendix C** provides the method of validation (individually substantiated design method) which may be used when the design analysis and methodology are not based on authoritative documents or design guides,
>>
>> **Appendix D** is provided as a resource to anyone undertaking a performance-based design or review to assess the qualifications of those performing the task.
>>
>> **Appendix E** gives guidance regarding qualifications and information that should be provided when undertaking computer modeling.)

A.4 System for specifying requirements in ICCPC

All the requirements in the ICCPC are specified in terms of objectives, functional statements, and performance requirements. These follow a particular hierarchy, described below.

Objective – The objectives define what is expected in terms of societal goals or what society *demands* from buildings and facilities. Objectives are topic-specific and deal with particular aspects of performance required in a building, such as safeguarding people during escape and rescue.

Functional statement – The functional statement explains, in general terms, the function that a building must provide to meet the objective or what *supply* must be provided to meet the *demand*. For example, a building must be constructed to allow people adequate time to reach a place of safety without exposure to untenable conditions.

Performance requirement – Performance requirements are detailed statements that break down the functional statements into measurable terms. This is where the link is made to the acceptable methods.

Figure 2 illustrates the system and how it is used for applying a performance-based approach for the design of buildings.

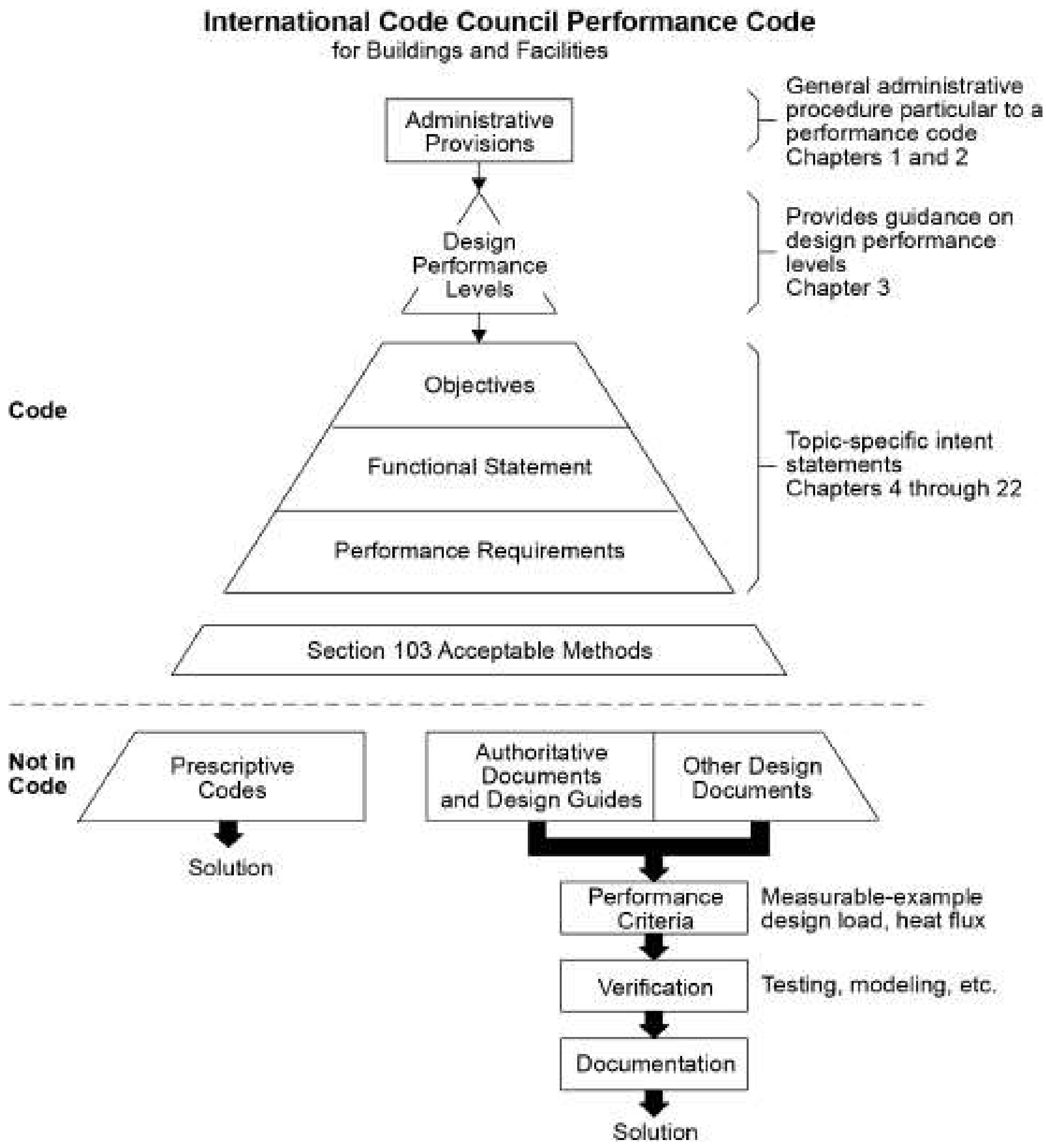

Figure 2 – ICCPC structure (ICC, 2021 International Code Council Performance Code for Buildings and Facilities, International Code Council)

The ICCPC covers all aspects of building design including fire safety, interior environment, mechanical, plumbing, fuel gas, electricity, and energy efficiency. This report deals only with stability aspects (structural design) with a focus on earthquake design.

A.4.1 Requirements in ICCPC for structural (earthquake) design

This section provides a summary of the requirements in the ICCPC for structural and earthquake design of buildings. The requirements for structural and earthquake design are found in Chapter 5 (stability) of the ICCPC but extracts from Part 1 (Chapters 1 to 4) are also included in this report as the requirements in these chapters apply to all parts of the code including structural design.

A.4.1.1 ICCPC Part 1: Includes *scope and application*, *administration and enforcement*, *definitions*, determining *design performance levels*, and requirements for *reliability and durability* (Chapters 1 to 4).

ICC Part 1
Chapter 1:
- Part 1: Scope and Application (Section 101)
- Part 2: Administration and Enforcement (Section 102)

Chapter 2: Definitions
Chapter 3: Design Performance Levels
- Section 302: Use and Occupancy Classification
- Section 303: Performance Groups
- Section 304: Maximum Level of Tolerable Damage
- Section 305: Magnitude of Design Event

Chapter 4: Reliability and Durability
- Section 401: Reliability

Chapter 1
Chapter 1 is in two parts, scope and application (Section 101) and administration and enforcement (Sections 102 and 103).

Part 1—Scope and Application (Section 101): The scope statements encompass all portions of the code and provide an overall understanding of the limits and applications of the document. It provides the Purpose of the Code and its scope as follows:

[A] 101.2 Purpose. To provide appropriate health, safety, welfare, and social and economic value, while promoting innovative, flexible, and responsive solutions that optimize the expenditure and consumption of resources.

[A] 101.3 Scope.

[A] 101.3.1 Building. Part II of this code provides requirements for buildings and structures and includes provisions for structural strength, stability, sanitation, means of access and egress, light and ventilation, safety to life and protection of property from fire, and, in general, to secure life and property from other hazards affecting the built environment.

[A] 101.3.2 Fire. Part III of this code establishes requirements applicable to the use and occupancy of buildings, structures, and facilities; and to the prevention, control, and mitigation of fire, life safety, and property hazards arising from this use and from the storage, handling, and use of explosive, flammable and combustible materials, hazardous materials, and dangerous operations and processes.

Part 2—Administration and Enforcement (Sections 102 and 103)

The Administrative Section (Section 102) discusses how this code works in terms of the practical application of the code including stakeholder qualifications and responsibilities, document submittals, peer review, permit and inspections, project documentation and verification of compliance etc.

Section 103 Acceptable Methods includes discussion on use of recognized authoritative documents or design guides for analysis, measurement of performance and determination of criteria used to evaluate compliance with the performance requirements of this code. In the case of Section 103, no specific reference is provided to any acceptable methods, authoritative documents or design guides. The requirements are specified in terms of objective, functional statements and Performance criteria.

Chapter 2: Definitions

This chapter provides definitions for terminology used in the ICCPC such as Acceptable Methods, Authoritative Document, Design Guide, Registered Design Professional, and Peer Review.

Chapter 3: Design Performance Levels

Chapter 3 provides a framework to establish the acceptable level of design for the building by linking levels of performance with the extent of damage or impact. This is the essence of a performance-based approach as the correlation between chosen level of performance and extent of damage helps the user to pick the desired level of performance.

The steps for determining design performance levels are as follows:

1. Determine a primary use of the building using use and occupancy classifications provided in Section 302
2. Assign performance group as per Section 303
3. Determine magnitude of design event as per Section 305
4. Determine the maximum level of damage that can be tolerated for the performance group (defined in step 2) under various levels of hazard (defined in step 3)

High level details of these sections are presented below:

Section 302 – Use and Occupancy Classification

This section is used to determine the primary uses of the building and the risk factors associated with the uses.

Section 302 of the code defines use and occupancy classification as a means to categorize buildings by their primary use, the characteristics of the persons using them, the level of risk assumed by persons using them during and after certain hazard events, and their importance to the local community.

The use and occupancy classifications in ICCPC are based on the fundamental definitions provided in Chapters 3 and 4 of the IBC but were modified in some cases to better categorize the use group in terms of occupant characteristics, risk, and importance. For example, factors such as the nature of the hazard, number of occupants, length of occupancy, sleeping characteristics, familiarity with the layout and means of egress, vulnerability of occupants, and relationships between occupants were considered in additional to the prescriptive use and occupancy classifications in the IBC. Again, many of these factors may already be implicit in the prescriptive classifications but it is not clear whether or not IBC has taken these factors into account.

Section 303 – Performance Groups

The next step in determining the Design Performance Level as per ICCPC is to assign a performance group to the building. The performance group of a building is assigned using Table 303.1 provided in ICCPC. The concept for Table 303.1 was taken from Chapter 16 of the prescriptive IBC, which establishes the occupancy category for structural design purposes. This table was chosen since the assignment of a building or facility to a particular performance group is a value judgment and is not technical in nature. These Performance Groups are as follows:

Performance Group I. This performance group covers buildings or facilities, such as barns and utility sheds, where hazard induced failure poses a low risk to human life. This group primarily includes utility-type buildings in which there is a low reasonable expectation of performance.

Performance Group II. This performance group is the minimum for most buildings.

Performance Group III. This performance group includes buildings and facilities with an increased level of societal benefit or importance or large occupant load. Examples include post-disaster command control centers, acute care hospitals, and a school used as an emergency shelter. Buildings and other structures that a) are equipped with a reliable means of limiting the area of impact resulting from an explosion or a release of highly toxic gas, and b) contain limited quantities of explosive materials or highly toxic gases can be classified under this performance group.

Performance Group IV. The highest performance group contains buildings or facilities that pose an unusually high risk. Such facilities may include nuclear facilities or explosive storage facilities. These buildings, facilities, and classes of structures require increased levels of performance as they are expected to continue operations after a hazard. Their failure to do so could have a devastating effect within and/or outside the facility with any size incident. Certain businesses or facilities, such as semiconductor facilities, may voluntarily place themselves in this category because of the business interruption caused by a very small event.

The performance groups classification is provided in Table 303.1 of ICCPC reproduced below:

Table 9: ICCPC Table 303.1

[BG]TABLE 303.1
PERFORMANCE GROUP CLASSIFICATIONS FOR BUILDINGS AND FACILITIES

PERFORMANCE GROUP	USE AND OCCUPANCY CLASSIFICATIONS FOR SPECIFIC BUILDINGS OR FACILITIES
I	Buildings and facilities that represent a low hazard to human life in the event of failure, including, but not limited to: 1. Agricultural facilities. 2. Certain temporary facilities. 3. Minor storage facilities.
II	All buildings and facilities except those listed in Performance Groups I, III and IV.
III	Buildings and facilities that represent a substantial hazard to human life in the event of failure, including, but not limited to: 1. Buildings and facilities where more than 300 people congregate in one area. 2. Buildings and facilities with elementary school, secondary school or day care facilities with a capacity greater than 250. 3. Buildings and facilities with a capacity greater than 500 for colleges or adult education facilities. 4. Health-care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities. 5. Jails and detention facilities. 6. Any other occupancy with an occupant load greater than 5,000. 7. Power-generating facilities, water treatment for potable water, wastewater treatment facilities and other public utilities facilities not included in Performance Group IV. 8. Buildings and facilities not included in Performance Group IV containing sufficient quantities of highly toxic gas or explosive materials capable of causing acutely hazardous conditions that do not extend beyond property boundaries.
IV	Buildings and facilities designated as essential facilities, including, but not limited to: 1. Hospitals and other health-care facilities having surgery or emergency treatment facilities. 2. Fire, rescue and police stations and emergency vehicle garages. 3. Designated earthquake, hurricane or other emergency shelters. 4. Designated emergency preparedness, communication, and operation centers and other facilities required for emergency response. 5. Power-generating stations and other utilities required as emergency backup facilities for Performance Group IV buildings or facilities. 6. Buildings and facilities containing highly toxic gas or explosive materials capable of causing acutely hazardous conditions beyond the property boundaries. 7. Aviation control towers, air traffic control centers and emergency aircraft hangars. 8. Buildings and facilities having critical national defense functions. 9. Water treatment facilities required to maintain water pressure for fire suppression. 10. Ancillary structures (including, but not limited to, communication towers, fuel storage tanks or other structures housing or supporting water or other fire suppression material or equipment) required for operation of Performance Group IV structures during an emergency.

A worksheet is also provided in ICCPC appendix b to help the user in assigning specific structures to performance groups.

After the performance group is determined, the user of the ICCPC can determine the maximum level of damage that can be tolerated (Section 304) for the performance group under various levels of hazard using a table provided in the code (Table 303.3). The term *tolerable* is used to reflect the fact that absolute protection is not possible, and that some damage, injury or loss is currently tolerated in structures, especially after a hazard event. Table 303.3 is reproduced below (see Table 10). Structures must be designed to the levels of performance and magnitudes of event indicated in every applicable cell within Table 303.3. The magnitude of design event to be used for determining damage levels is described in Section 305 ahead.

Table 10: ICCPC Table 303.3

[BG]TABLE 303.3
MAXIMUM LEVEL OF DAMAGE TO BE TOLERATED BASED ON PERFORMANCE GROUPS AND DESIGN EVENT MAGNITUDES

MAGNITUDE OF DESIGN EVENT (INCREASING MAGNITUDE OF EVENT ←)	INCREASING LEVEL OF PERFORMANCE →→→ PERFORMANCE GROUPS			
	Performance Group I	Performance Group II	Performance Group III	Performance Group IV
VERY LARGE (Very Rare)	SEVERE	SEVERE	HIGH	MODERATE
LARGE (Rare)	SEVERE	HIGH	MODERATE	MILD
MEDIUM (Less Frequent)	HIGH	MODERATE	MILD	MILD
SMALL (Frequent)	MODERATE	MILD	MILD	MILD

The damage states – mild, moderate, high, and severe – are defined qualitatively in terms of impacts to the building, its content, and its occupant in Section 304 of the ICCPC as reproduced below:

Section 304 – Qualitative Definition of Maximum Level of Damage to be Tolerated

[BG] 304.2.1 Mild impact.

The tolerable impacts of the design loads are assumed as follows:

304.2.1.1 Structural damage. The building or facility does not have structural damage and is safe to occupy.

304.2.1.2 Non-structural systems. Non-structural systems needed for normal building or facility use and emergency operations are fully operational.

[BG] 304.2.1.3 Occupant hazards. Injuries to building or facility occupants from hazard-related applied loads are minimal in numbers and minor in nature. There is a very low likelihood of single or multiple life loss. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.1.4 Overall extent of damage. Damage to building or facility contents from hazard-related applied loads is minimal in extent and minor in cost.

[BG] 304.2.1.5 Hazardous materials. Minimal hazardous materials are released to the environment.

[BG] 304.2.2 Moderate impact.

The tolerable impacts of the design loads are assumed as follows:

[BG] 304.2.2.1 Structural damage. There is moderate structural damage, which is repairable; some delay in re-occupancy can be expected.

[BG] 304.2.2.2 Non-structural systems. Non-structural systems needed for normal building or facility use are fully operational, although some cleanup and repair may be needed. Emergency systems remain fully operational.

[BG] 304.2.2.3 Occupant hazards. Injuries to building or facility occupants from hazard-related applied loads may be locally significant, but generally moderate in numbers and in nature. There is a low likelihood of single life loss with a very low likelihood of multiple life loss. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.2.4 Overall extent of damage. Damage to building or facility contents from hazard-related applied loads may be locally significant, but is generally moderate in extent and cost. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.2.5 Hazardous materials. Some hazardous materials are released to the environment, but the risk to the community is minimal. Emergency relocation is not necessary.

[BG] 304.2.3 High impact.

The tolerable impacts of the design loads are assumed as follows:

[BG] 304.2.3.1 Structural damage. There is significant damage to structural elements but there is not large falling debris; repair is possible. Significant delays in re-occupancy can be expected.

[BG] 304.2.3.2 Non-structural systems. Non-structural systems needed for normal building or facility use are significantly damaged and inoperable; egress routes may be impaired by light debris; emergency systems may be significantly damaged, but remain operational.

[BG] 304.2.3.3 Occupant hazards. Injuries to building or facility occupants from hazard-related applied loads may be locally significant with a high risk to life, but are generally moderate in numbers and in nature. There is a moderate likelihood of single life loss, with a low probability of multiple life loss. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.3.4 Overall extent of damage. Damage to building or facility contents from hazard-related applied loads may be locally total and generally significant. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.3.5 Hazardous materials. Hazardous materials are released to the environment with localized relocation needed for buildings and facilities in the immediate vicinity.

[BG] 304.2.4 Severe impact.

The tolerable impacts of the design loads are assumed as follows:

[BG] 304.2.4.1 Structural damage. There is substantial structural damage, but all significant components continue to carry gravity load demands. Repair may not be technically possible. The building or facility is not safe for re-occupancy, as re-occupancy could cause collapse.

[BG] 304.2.4.2 Non-structural systems. Non-structural systems for normal building or facility use may be completely non-functional. Egress routes may be impaired; emergency systems may be substantially damaged and non-functional.

[BG] 304.2.4.3 Occupant hazards. Injuries to building or facility occupants from hazard-related applied loads may be high in numbers and significant in nature. Significant risk to life may exist. There is a high likelihood of single life loss and a moderate likelihood of multiple life loss. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.4.4 Overall extent of damage. Damage to building or facility contents from hazard-related applied loads may be total. The nature of the applied load, such as fire hazards, may result in higher levels of expected injuries and damage in localized areas, whereas the balance of the areas may sustain fewer injuries and less damage.

[BG] 304.2.4.5 Hazardous materials. Significant hazardous materials are released to the environment, with relocation needed beyond the immediate vicinity.

Section 305 – Magnitudes of Event

The events include building and facility-related and occupancy-related loads, as well as loads resulting from natural and technological hazards. These loads and events can vary across a broad spectrum, from seismic, wind, temperature, and water on the natural hazard side, to fire, explosion, moisture, occupant safety, and air quality hazards on the technological side.

Normal loads and events can also vary broadly, from the myriad of live and dead loads associated with a structure to factors such as the potential for changes in soil conditions due to temperature and moisture variations. In order to evaluate the performance of a building or facility against these loads and events, a representative number of design loads needs to be considered and applied. (For simplification purposes, the term “design load” covers normal and hazard events as well.)

The Design loads in ICCPC are characterized by four classes: small, medium, large, and very large, indicating increasing magnitudes. As each type of load has unique characteristics, details are not provided in Chapter 3, but rather are provided in appropriate chapters of the code [e.g. Stability (Chapter 5), Fire Safety (Chapters 6 and 17) and Hazardous Materials (Chapter 22)] and are based on the Committee’s understanding of current practice and limits on quantification.

As per ICC, Magnitude of event can be defined, quantified, and expressed either deterministically or probabilistically in accordance with the best current practice of the relevant profession as published in recognized authoritative documents. Where authoritative documents do not present magnitude of event in this format, it will be the responsibility of the designer to relate the loads to this format and to demonstrate that the minimum design performance levels will be met by the proposed design

ICCPC prescribes a minimum design performance level, based on the intended use of the building, but an owner may need to enhance the performance for different reasons. For example, a local government may increase the performance of any class of buildings if there are specific reasons. These reasons might include a situation in which the facility is the only employer, school, or only hospital.

This is the essence of a performance-based approach. Chapter 3 provides a link between the policy makers and the designers. It establishes performance groups for buildings and facilities and minimum acceptable losses based on those performance groups. The current prescriptive approaches do not clearly state the performance level the code provides. Therefore, an owner is often not aware that he or she may not be getting the performance level desired from the building. The approach provided in Chapter 3 is intended to address this issue.

The performance code gives the designer more flexibility in determining the expected forces and prescribing the performance of the structure when subjected to particular forces. The designer can look to the design performance level desired of the structure rather than simply applying a minimum solution.

Chapter 4: Reliability and Durability
Chapter 4 underscores the importance of the reliability of individual protection systems and strategies, as well as the reliability of the interaction of these systems in achieving the design performance level for a particular building or facility addressed in Chapter 3.

The requirements for reliability and durability in ICCPC are expressed in terms of objective, functional statements, and performance requirements. The discussion is primarily focused on fire safety systems and strategies but is intended to address other aspects of building design such as structural stability, mechanical systems, and plumbing.

Section 401 - Reliability **[BG] 401.1 objective.** To ensure reliability of the system necessary to meeting the performance objectives of building, facility, or processes in accordance with the design.

[BG] 401.2 Functional statements.

[BG] 401.2.1 Design, installation and maintenance. Design, install, and maintain systems, system components, and equipment that provide a safety function in strict accordance with the manufacturers' instructions and with any applicable codes and standards.

[BG] 401.2.2 Testing and inspection. Test and inspect systems, system components, and equipment that provide a safety function in strict accordance with the manufacturers' instructions and with any applicable codes and standards for both the methods employed and the frequency.

[BG] 401.2.3 Active fire protection systems. Active fire protection systems such as fire alarm, suppression, and smoke management systems shall undergo commissioning testing when first placed into service or following any substantial alteration.

[BG] 401.2.4 Training. Provide appropriate training to any people who operate, test, maintain, or interpret information from any safety systems. Where such work is done by contractors, ensure that they have the necessary training and skills.

[BG] 401.3 Performance requirements.

[BG] 401.3.1 Qualifications. Design, installation, and maintenance shall be performed only by qualified people as approved. Certification or records of training shall be provided.

[BG] 401.3.2 Documentation. Documentation shall be maintained at the building that details the systems installed and their required maintenance and testing methods and frequency. Records of such maintenance and testing shall be maintained that demonstrate compliance, the persons conducting the work, and their qualifications.

Section 402 – Durability

[BG] 402.1 objective. To assist in the selection of appropriate materials and construction systems.

[BG] 402.2 Functional statement. To ensure that a building will continue to satisfy the objectives of this code throughout its life.

[BG] 402.3 Performance requirements.

[BG] 402.3.1 Normal maintenance. From the time a certificate of occupancy is issued, primary building elements shall, with only normal maintenance, continue to satisfy the performance requirements of this code for the intended life of the building.

[BG] 402.3.2 Intended life of a building. Where the useful life of building or facility elements or systems is less than the intended life of the building, provisions shall be made for timely replacement of those elements, so that the objective of this code and the design are maintained.

[BG] 402.3.3 Damage and deterioration. Where damage or deterioration to building or facility elements or systems will impact the objectives of this code or the design, those elements or systems shall be repaired or replaced in order to maintain the level of performance intended by this code.

[BG] 402.3.4 Determination of durability and service life. In determining the useful service life of building elements, products, or systems, an acceptable method for determining durability and service life shall be used.

A.4.1.2 ICCPC Part II—Building

Chapter 5: Stability

Chapter 5 provides the requirements for the structural design of buildings and other structures. Section 501 specifies the forces for which structures need to be designed and the required performance. This chapter requires a structure to be designed for the expected forces it will be subjected to throughout its life. This is the same requirement found in Chapter 16 of the IBC.

Section 501 – Structural Forces
501.1 objective To provide a desired level of structural performance when structures are subjected to the loads that are expected during construction or alteration and throughout their intended lives.
501.2 Functional statements 501.2.1 Life safety and injury prevention. Structures shall be designed and constructed to prevent injury to occupants due to loading of a structural element or system consistent with the design performance level determined in Chapter 3.

501.2.2 Property and amenity protection. Structures shall be designed and constructed to prevent loss of property and amenity consistent with the design performance level determined in Chapter 3.

501.3 Performance requirements

501.3.1 Stability Structures, or portions thereof, shall remain stable and not collapse during construction or alteration and throughout their lives

501.3.2 Disproportionate failure. Structures shall be designed to sustain local damage, and the structural system as a whole shall remain stable and not be damaged to an extent disproportionate to the original local damage.

501.3.3 Loss of amenity. Structures, or portions thereof, shall have a low probability of causing damage or loss of amenity through excessive deformation, vibration or degradation during construction or alteration and throughout their lives.

501.3.4 Expected loads. Structures, or portions thereof, shall be designed and constructed taking into account expected loads, and combination of loads, associated with the event(s) magnitude(s) that would affect their performance, including, but not limited to:

1. Dead loads.
2. Live loads.
3. Impact loads.
4. Explosion loads.
5. Soil and hydrostatic pressure loads.
6. Flood loads (mean return period).
    - 6.1 Small: 100 years
    - 6.2 Medium: 500 years
    - 6.3 Large: Determined on a site-specific basis
    - 6.4 Very Large: Determined on a site-specific basis
7. Wind loads (mean return period).
    - 7.1 Small: 300 years
    - 7.2 Medium: 700 years
    - 7.3 Large: 1700 years
    - 7.4 Very Large: 3000 years
8. Windborne debris loads.
9. Snow loads (mean return period).
    - 9.1 Small: 25 years
    - 9.2 Medium: 50 years
    - 9.3 Large: 100 years
    - 9.4 Very Large: 500 years
10. Rain loads. See Table 501.3.4.

11. Earthquake loads.
    11.1 Small: 43 years (mean return period)
    11.2 Medium: 72 years (mean return period)
    11.3 Large: Two-thirds of the intensity of very large loads
    11.4 Very large: The Risk-Targeted Maximum Considered earthquake defined in Chapter 21 of ASCE 7.
12. Ice loads, atmospheric icing (mean return period).
    12.1 Small: 25 years
    12.2 Medium: 50 years
    12.3 Large: 100 years
    12.4 Very Large: 200 years
13. Hail loads.
14. Thermal loads.

501.3.5 Safety factors. The design of buildings and structures shall consider appropriate factors of safety to provide adequate performance from:

1. Effects of uncertainties resulting from construction activities.

2. Variation in the properties of materials and the characteristics of the site.

3. Accuracy limitations inherent in the methods used to predict the stability of the building.

4. Self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep, and similar effects.

5. Uncertainties in the determination of the expected loads.

501.3.6 Demolition and alteration. The demolition or alteration of buildings and structures shall be carried out in a way that avoids the likelihood of premature collapse.

501.3.7 Site work. Site work, where necessary, shall be carried out to provide stability for construction on the site and avoid the likelihood of damage to adjacent property.

Table 11: ICCPC Table 501.3.4.

MAGNITUDE OF EVENT	DRAINAGE SYSTEM	MRI (YEARS)	STORM DURATION (MIN.)
Small	Primary	25	60
Small	Secondary	25	15
Medium	Primary	50	60
Medium	Secondary	50	15
Large	Primary	100	60
Large	Secondary	100	15
Very Large	Primary	100	30
Very Large	Secondary	100	10

A.5 Compliance Process in the ICCPC

Section 103 Acceptable Methods provides three options to demonstrate compliance with ICCPC:

- Prescriptive approach
- Performance approach
- Combination of prescriptive and performance approaches

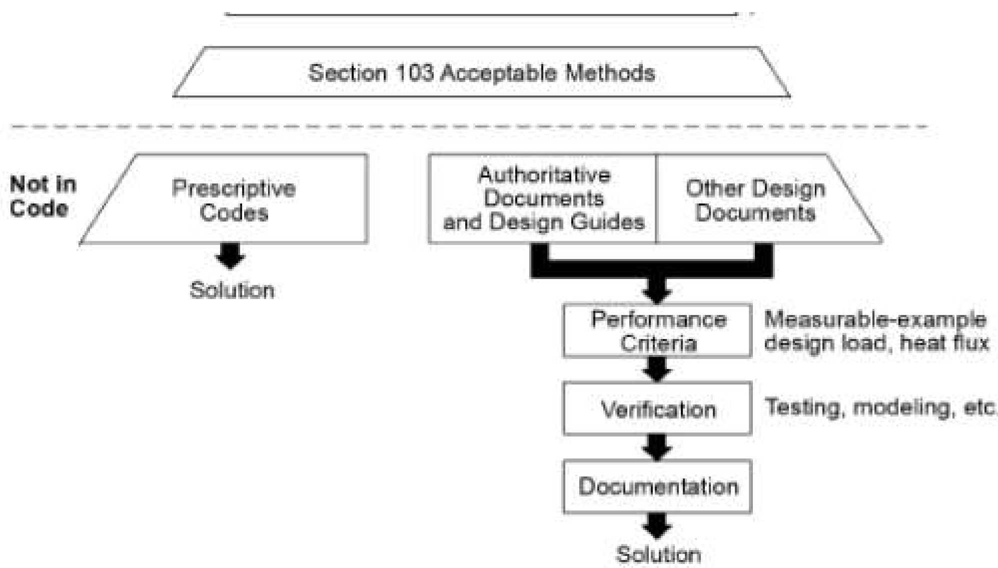

Figure 3 – ICCPC Section 103 Acceptable Methods

Prescriptive approach: Designs based strictly upon prescriptive codes satisfy the performance objectives of this code without any additional analysis or verification. The prescriptive codes are considered *authoritative documents*. The IBC and *International Fire Code* (IFC) have been deemed to satisfy at least one of the acceptable methods for complying with the performance code. Essentially, buildings and facilities or portions of buildings and facilities that are designed and constructed in accordance with all applicable requirements of the IBC and IFC associated with the uses and occupancies listed in Chapters 3 and 4 shall be deemed to comply with the performance groups for that use group or occupancy. For example, a school designed and built to all applicable requirements in the IBC for an educational occupancy is deemed to comply with the performance group requirements for a building in the educational occupancy. Though it is assumed that the IBC is deemed to comply with the design performance levels outlined in this code, the performance of buildings designed and constructed according to the IBC has not been analytically determined.

Performance approach and combination of prescriptive and performance approach: Designs based on these approaches require verification against performance criteria and specific documentation to support the designs. These approaches relies on the use of Authoritative Documents, Design Guides, and other documents.

Authoritative Documents include technical references that are widely accepted and utilized by design professionals, professional groups, and technical societies that are active in the design of buildings and their systems. Documents developed through open consensus process conducted by recognized governmental bodies, professional or technical societies, codes or standards organizations, and documents that have undergone peer review process and have been published in professional journals, conference reports, and recognised technical publications are regarded as Authoritative documents.

Design Guides include guidance documents developed by architectural professional organizations, engineering professional organizations, and technical societies published for use in performance-based design.

Documents that are not considered **Authoritative Documents** or **Design Guides** (other documents) may be able to be used for a design when they comply with Appendix C of ICCPC for "individually substantiated designs." Because of the limited review of such approaches, Section 104.3.4 specifically requires a peer review of such methods.

There are also no singular acceptable methods of performance. Rather, a suite of acceptable methods (acceptable analytical tools and methods) is required to be applied to demonstrate that the design performance levels and magnitudes of event comply with the performance group requirements for the pertinent use groups or occupancy types.

A.5.1 Example to illustrate the use of ICCPC for earthquake design

Assume: A high school (Grades 9–12) with an attendance of approximately 400 students is to be built in Anytown, Mystate, U.S.A.

Step 1
The first step in determining the requirements of this example would be to turn to Section 302 and/or Appendix A of the code to determine under which use group classification the school would fall. The school would fall under Educational.
Step 2
Next, one refers to Section 303, Performance Groups, to determine the appropriate performance group for educational use buildings. The first place to look is Table 303.1. From Table 303.1, it is determined that the performance group will be dependent upon whether there are more than 250 students expected to attend the Anytown High School. Because the expected attendance is 400, Anytown High School would be placed in Performance Group III.
Step 3
Now that the school is classified as Performance Group III, one then would go to Table 303.3 to determine the appropriate design performance level for the associated magnitudes of event to which the school is likely to be subjected. The first thing that should be noted is that Performance

Group III allows only minimal impact for the medium magnitude of event for design purposes as well as the small magnitude of event.
Step 4
At this point, one could choose to take the prescriptive approach and simply meet all the applicable requirements for an Educational Occupancy found in the IBC and IFC. Alternatively, one could choose to take a performance-based approach.
Step 5
If the performance-based approach is taken, the next step is to look at the descriptions of the tolerable impact for the appropriate design performance levels indicated in Table 303.3. These provide a qualitative description of the design performance levels required and can be used directly for a deterministic performance-based design approach or, in conjunction with the magnitude of event (load) found within Section 305, can be used for a probabilistic performance-based approach. Specific details on design load-related levels of performance are found in appropriate chapters (e.g., Chapter 5, Stability; Chapter 6, Fire Safety).
Step 6
Given defined magnitude of event, design performance levels, and commentary as discussed previously, a structure can be designed. In the case of the structural design, one would take the magnitude of event and design performance levels and translate them into loads and resistances. Guidance on translating the ground motion into loads can be found in acceptable solutions (e.g., prescriptive code, SEAOC Blue Book[3], ASCE 7[4], etc.) where a set of maps and formulas provide a set of loads, based on geophysical conditions, that the structural engineer can apply to the structural design process.

[3] Structural Engineers Association of California's Recommended Lateral Force Requirements "Blue Book" - Seismic Design Recommendations

[4] American Society of Civil Engineer's Minimum Design Loads and Associated Criteria for Buildings and Other Structures (ASCE/SEI 7)

Appendix B - New Zealand

B.1 Review of the regulatory framework in New Zealand

The Ministry of Business, Innovation, and Employment (MBIE) manages the regulation of building work in New Zealand and is the lead policy advisor to government on building regulation. MBIE is responsible for, but not limited to:

- policy advice on legislation and regulations, including the Building Code,
- reviewing and maintaining the Building Code,
- producing documents that show ways to comply with the Building Code,
- monitoring the performance of district and city councils in the building regulatory system,
- investigating complaints about alleged breaches of legislation,
- making determinations about disputes on building matters, and
- administering occupational regulation of some building professions, including licensed building practitioners.[5]

[5] Building for the Future - MBIE's Building System Regulatory Strategy: https://www.mbie.govt.nz/dmsdocument/12608-building-for-the-future-mbies-building-system-regulatory-strategy

Local government plays a key role in implementing the building regulatory system. They are responsible for the consenting and compliance elements of the system and are the primary interface with other users of the building regulatory system on a daily basis. Additionally, they administer the annual building warrants of fitness process and have a key role in managing dangerous, insanitary, or earthquake-prone buildings and buildings in areas that have been affected by an emergency. Statutory boards support the licensing of architects, building practitioners, engineers, plumbers, gasfitters, drainlayers, and electricians. Occupational regulation aims to protect the public from harm by ensuring services are performed with reasonable care and skill.

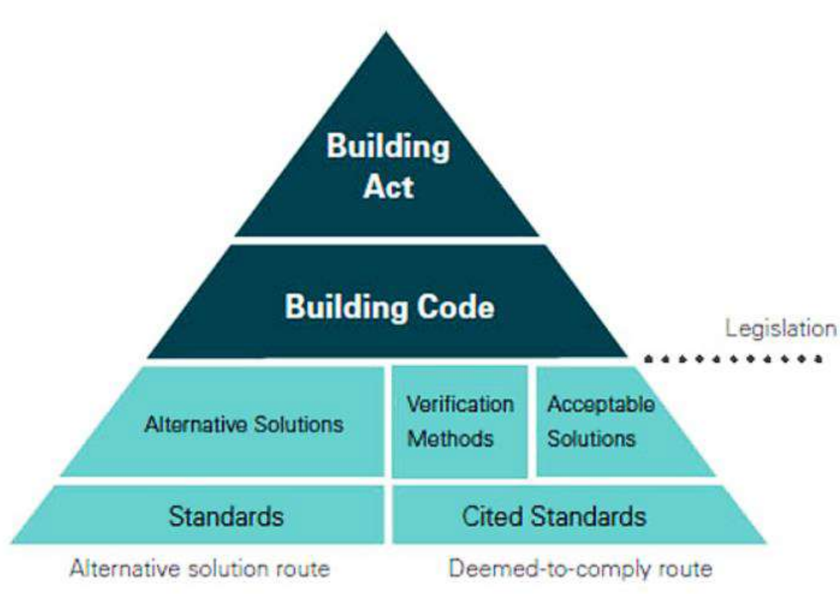

Figure 4 – New Zealand's regulatory framework[6]

Figure 4 – New Zealand's regulatory framework and Figure 5 - New Zealand's regulatory framework show the regulatory framework for the building sector in New Zealand. The building system is primarily regulated by MBIE under the Building Act.

[6] https://www.building.govt.nz/building-code-compliance/building-code-and-handbooks/

Figure 5 - New Zealand's regulatory framework

B.1.1 **Building Act**

The Building Act 2004, with all the amendments incorporated to 25 September 2020, is the current principal legislation dealing with matters relating to the Building Code and building controls in New Zealand, and works alongside other legislation for health, safety, consumer protection, and land use. The Building Act applies to building construction, alteration, demolition, or removal; and maintenance of a building's specified systems, such as elevators and fire protection installations.

The Building Act has five parts:

Part 1: Contains the purpose and principles of the Building Act.

Part 2 (and Schedules 1 and 2): Outlines matters relating to the Building Code and building control (such as building consents), including requirements of building work and requirements for the use of buildings.

Part 3: Sets out the functions, duties and powers. It also deals with the accreditation and registration of building consent authorities and product certification.

Part 4 (and Schedule 3): Covers matters relating to the licensing and disciplining of building practitioners.

Part 5 (and Schedule 4): Describes miscellaneous matters, including offences and criminal proceedings, implied terms of contracts, regulation-making powers, amendments to other enactments etc.

The Building Act sets a legal framework for regulating building work, establishing a licensing regime for building practitioners, and setting performance standards for buildings. As noted before, the Building Act is administered by the MBIE.

B.1.2 **Building regulations**

Building regulations are made under and in accordance with the Building Act. The Governor-General of New Zealand makes the regulations by Order in Council based on the recommendation of the MBIE Minister. A number of regulations have been made under the Building Act including Building (Specified Systems, Change the Use, and earthquake-prone Buildings) Regulations 2005. Among other things this regulation defines a moderate earthquake in relation to a building. Regulations are also made dealing with matters related to accreditation, certification, and licensing, as well as associated levy and fee structure and declaring restricted building work.

B.1.3 Building Code

The Building Code is contained in the Schedule 1 of the Building Regulations. It sets out the minimum performance standards that buildings must meet. It covers aspects such as structural stability, fire safety, access, moisture control, durability, services and facilities, and energy efficiency. New Zealand's building regulatory system is performance-based. The Building Code does not prescribe how work should be done, but states how completed building work and its parts must perform. All new building work must – and change of use or alteration of a building may trigger the need to – comply with the Building Code throughout New Zealand. The Building Code is administered by the MBIE. The process of building code development (amendment) is shown in Figure 6.

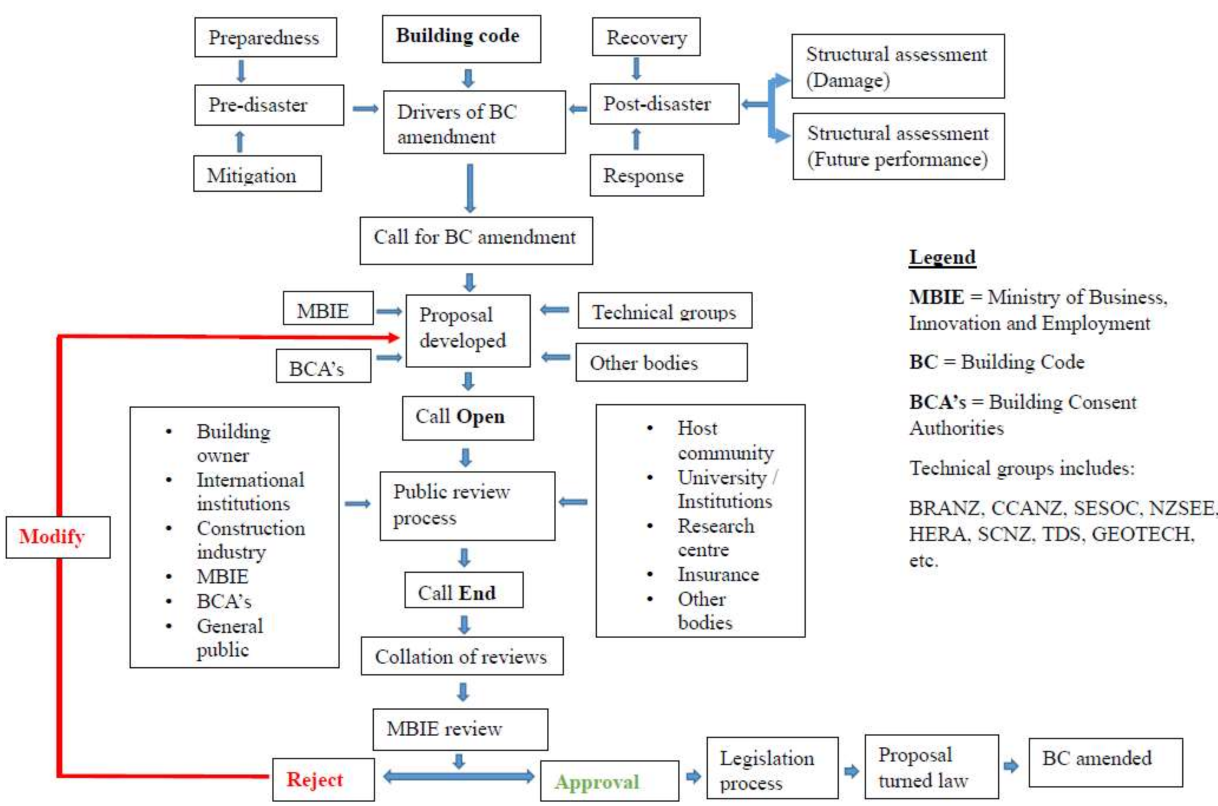

Figure 6 - Building Code Amendment Process: A case study of New Zealand | Amarachukwu Nnadozie Nwadike, Suzanne Wilkinson

Anyone can request for a building code amendment in New Zealand, provided there is substantial evidence to back-up the proposal. The proposal for change must show a detailed description of the proposal, proof of insufficiency in the existing Building Code, how the proposed changes can solve the identified weakness, who the changes will affect, and the related impacts.

Once the proposal is submitted, the MBIE and other regulating agencies will cross-examine the proposal, and assess if there is any deficiency in the existing Building Code. On acceptance of any shortcoming in the Building Code requirement, the call for public review will be declared open.

The MBIE calls for review and consultation to the New Zealand Building Code twice every year (MBIE, 2018a). The public consultation is opened between February/March and August/September each year. At the end of the consultation period, the reviews are collated by MBIE for further detailed interpretation.

After the public review process, the MBIE analyze each comment in line with the aim and objective of the proposal for amendment and the Building Act. Based on the outcome of the review, the proposal may be rejected and returned for modification or accepted for approval. Sometimes, the proposal could be withdrawn. Before approval, all concerns regarding the proposal are cleared to encourage compliance with the new changes. Following the approval of the proposal by MBIE, the changes are legislated into law.

B.2 New Zealand Building Code

New Zealand's building regulatory system is performance-based. Performance-based regulation focuses on how a building must perform in its intended use. Unlike prescriptive regulation, performance-based regulation does not specify how to achieve this performance by describing how buildings must be designed and constructed. So in practice, this means there can be many ways of meeting the requirements.

B.2.1 Goal and scope of New Zealand Building Code

The Building Act 2004 ultimately sets the goals for all New Zealand building regulations including the New Zealand Building Code to ensure that:

- people who use buildings can do so safely and without endangering their health;
- buildings have attributes that contribute appropriately to the health, physical independence, and well-being of the people who use them;
- people who use a building can escape from the building if it is on fire; and
- buildings are designed, constructed, and able to be used in ways that promote sustainable development.

B.2.2 Structure of the NZC

The New Zealand Building Code has general provisions and technical provisions.

General provisions (Clause A):

Clause A1 covers classification of buildings based on use. Buildings are classified according to type under seven categories – Housing, Communal Residential, Communal Non-Residential, Commercial, Industrial, Outbuilding, and Ancillary.

Clause A2 provides definitions specific to the Code.

Clause A3 assigns buildings with different importance levels based on their potential risk posed to human life or the environment, or economic cost, should the buildings fail due to fire. Table 4 shows these assigned building importance levels. Note that these building importance levels are for the purpose of Clause C (Fire).

Technical provisions cover various aspects of buildings – stability (Clause B), fire safety (Clause C), access (Clause D), moisture (Clause E), safety of users (Clause F), services and facilities (Clause G), and energy efficiency (Clause H) and 38 technical clauses. Each technical clause has three levels that describe the requirements for the clause:

Objective: Social objectives the building must achieve.

Functional requirement: Functions the building must perform to meet the objective.

Performance: The performance criteria the building must achieve. By meeting the performance criteria, the objective and Functional requirement can be achieved

Alongside the objective, Functional Requirement, and Performance level given for each building code clause, there is a note of any limits on application on where the clause can be applied.

Table 12: Building importance levels

[CLAUSE A3—BUILDING IMPORTANCE LEVELS

For the purposes of clause C, a *building* has one of the importance levels set out below:

Importance level	Description of building type	Specific structure
Importance level 1	*Buildings* posing low risk to human life or the environment, or a low economic cost, should the building fail. These are typically small non-habitable *buildings*, such as sheds, barns, and the like, that are not normally occupied, though they may have occupants from time to time.	• Ancillary *buildings* not for human habitation • Minor storage facilities • Backcountry huts
Importance level 2	*Buildings* posing normal risk to human life or the environment, or a normal economic cost, should the *building* fail. These are typical residential, commercial, and industrial *buildings*.	• All *buildings* and facilities except those listed in importance levels 1, 3, 4, and 5
Importance level 3	*Buildings* of a higher level of societal benefit or importance, or with higher levels of risk-significant factors to building occupants. These *buildings* have increased performance requirements because they may house large numbers of people, vulnerable populations, or occupants with other risk factors, or fulfil a role of increased importance to the local community or to society in general.	• *Buildings* where more than 300 people congregate in 1 area • *Buildings* with primary school, secondary school, or daycare facilities with a capacity greater than 250 • *Buildings* with tertiary or adult education facilities with a capacity greater than 500 • Health care facilities with a capacity of 50 or more residents but not having surgery or emergency treatment facilities • Jails and detention facilities • Any other *building* with a capacity of 5 000 or more people • *Buildings* for power generating facilities, water treatment for potable water, wastewater treatment facilities, and other public utilities facilities not included in importance level 4

[CLAUSE A3—BUILDING IMPORTANCE LEVELS (continued)

Importance level	Description of building type	Specific structure
Importance level 3 (continued)		• *Buildings* not included in importance level 4 or 5 containing sufficient quantities of highly toxic gas or explosive materials capable of causing acutely hazardous conditions that do not extend beyond property boundaries
Importance level 4	*Buildings* that are essential to post-disaster recovery or associated with hazardous facilities.	• Hospitals and other health care facilities having surgery or emergency treatment facilities • *Fire*, rescue, and police stations and emergency vehicle garages • *Buildings* intended to be used as emergency shelters • *Buildings* intended by the owner to contribute to emergency preparedness, or to be used for communication, and operation centres in an emergency, and other facilities required for emergency response • Power generating stations and other utilities required as emergency backup facilities for importance level 3 structures • *Buildings* housing highly toxic gas or explosive materials capable of causing acutely hazardous conditions that extend beyond property boundaries • Aviation control towers, air traffic control centres, and emergency aircraft hangars • *Buildings* having critical national defence functions • Water treatment facilities required to maintain water pressure for fire suppression

[CLAUSE A3—BUILDING IMPORTANCE LEVELS (continued)

Importance level	Description of building type	Specific structure
Importance level 4 (continued)		• Ancillary *buildings* (including, but not limited to, communication towers, fuel storage tanks or other structures housing or supporting water or other *fire* suppression material or equipment) required for operation of importance level 4 structures during an emergency
Importance level 5	*Buildings* whose failure poses catastrophic risk to a large area (eg, 100 km^2) or a large number of people (eg, 100 000).	• Major dams • Extremely hazardous facilities

B.2.3 Requirements for structural (earthquake) design in New Zealand Code (NZC)[7]

This section of the report provides a summary of the requirements for designing buildings for earthquakes using the New Zealand Code (NZC). It includes extracts from the parts of the NZC that apply for structural and earthquake design.

General Provisions Clauses A1 and A2 apply to structural and earthquake design as **Clause A1** classifies buildings according to type under seven categories – housing, communal residential, communal non-residential, commercial, industrial, outbuilding and ancillary; and **Clause A2** provides definitions specific to the Code.

The **Stability Clause (Clause B)** for structural and earthquake design has two technical clauses (**B1- Structure and B2- Durability**).

Clause B1 Structure requires buildings, building elements, and site work to withstand the combination of loads and physical conditions they are likely to experience during construction, alteration, and throughout their lives. Loads and physical conditions include self-weight, temperature, water, earthquakes, snow, wind, and fire.

[7] https://www.building.govt.nz/building-code-compliance/b-stability/

Clause B2 Durability must always be considered when demonstrating compliance with each of the clauses of the Building Code. It ensures that a building throughout its life will continue to satisfy the performance of the Building Code. It confirms that the materials used will remain functional throughout the specified intended life of the building, but not less than 50, 15, or 5 years.

The objectives, Functional Requirement, and Performance of the two technical clauses related to stability of the building can be found in and .

B Stability

CLAUSE B1—STRUCTURE

Provisions	Limits on application
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*, including:	
(a) Self-weight,	
(b) Imposed gravity loads arising from use,	
(c) Temperature,	
(d) Earth pressure,	
(e) Water and other liquids,	
(f) Earthquake,	
(g) Snow,	
(h) Wind,	
(i) *Fire*,	

CLAUSE B1—STRUCTURE (continued)

Provisions	Limits on application
(j) Impact, (k) Explosion, (l) Reversing or fluctuating effects, (m) Differential movement, (n) Vegetation, (o) Adverse effects due to insufficient separation from other *buildings*, (p) Influence of equipment, services, non-structural elements and contents, (q) Time dependent effects including creep and shrinkage, and (r) Removal of support. **B1.3.4** Due allowance shall be made for: (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*. **B1.3.5** The demolition of *buildings* shall be carried out in a way that avoids the likelihood of premature collapse. **B1.3.6** *Sitework*, where necessary, shall be carried out to: (a) Provide stability for *construction* on the site, and (b) Avoid the likelihood of damage to *other property*. **B1.3.7** Any *sitework* and associated supports shall take account of the effects of: (a) Changes in ground water level, (b) Water, weather and vegetation, and (c) Ground loss and slumping.	

Figure 7 – Clause B1 structure

CLAUSE B2—DURABILITY

Provisions	Limits on application
OBJECTIVE	
B2.1 The objective of this provision is to ensure that a *building* will throughout its life continue to satisfy the other objectives of this code.	
FUNCTIONAL REQUIREMENT	
B2.2 *Building* materials, components and *construction* methods shall be sufficiently durable to ensure that the *building*, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the *building*.	
PERFORMANCE	
B2.3.1 *Building elements* must, with only normal maintenance, continue to satisfy the performance requirements of this code for the lesser of the *specified intended life* of the *building*, if stated, or:	Performance B2.3.1 applies from the time of issue of the applicable *code compliance certificate*. *Building elements* are not required to satisfy a durability performance which exceeds the *specified intended life* of the *building*
(a) The life of the *building*, being not less than 50 years, if:	
(i) Those *building elements* (including floors, walls, and fixings) provide structural stability to the *building*, or	
(ii) Those *building elements* are difficult to access or replace, or	
(iii) Failure of those *building elements* to comply with the *building code* would go undetected during both normal use and maintenance of the building	
(b) 15 years if:	
(i) Those *building elements* (including the *building* envelope, exposed plumbing in the subfloor space, and in-built chimneys and flues) are moderately difficult to access or replace, or	
(ii) Failure of those *building elements* to comply with the *building code* would go undetected during normal use of the *building*, but would be easily detected during normal maintenance.	

CLAUSE B2—DURABILITY (continued)

Provisions	Limits on application
(c) 5 years if: (i) The *building elements* (including services, linings, renewable protective coatings, and *fixtures*) are easy to access and replace, and (ii) Failure of those *building elements* to comply with the *building code* would be easily detected during normal use of the *building*. **B2.3.2** Individual *building elements* which are components of a *building* system and are difficult to access or replace must either: (a) All have the same durability, or (b) Be installed in a manner that permits the replacement of *building elements* of lesser durability without removing *building elements* that have greater durability and are not specifically designed for removal and replacement.	

Figure 8 – Clause B2 durability

Note: Unlike ICCPC, the NZC does not include provisions for designing structures to different performance levels based on different damage states (Reference Section A.2.3.1 in this report: Design Performance Levels in ICCPC).

B.2.4. Compliance Process in the NZC with specific application for Clause B (Stability)

The diagram in Figure 9 illustrates the hierarchy of New Zealand building controls, including the various compliance paths. The top three tiers of the pyamid (the Building Act, Building Regulations, and New Zealand Building Code) are mandatory building legislation that must be followed. The rest of the diagram shows various paths that may be used to demonstrate compliance with the Building Code.

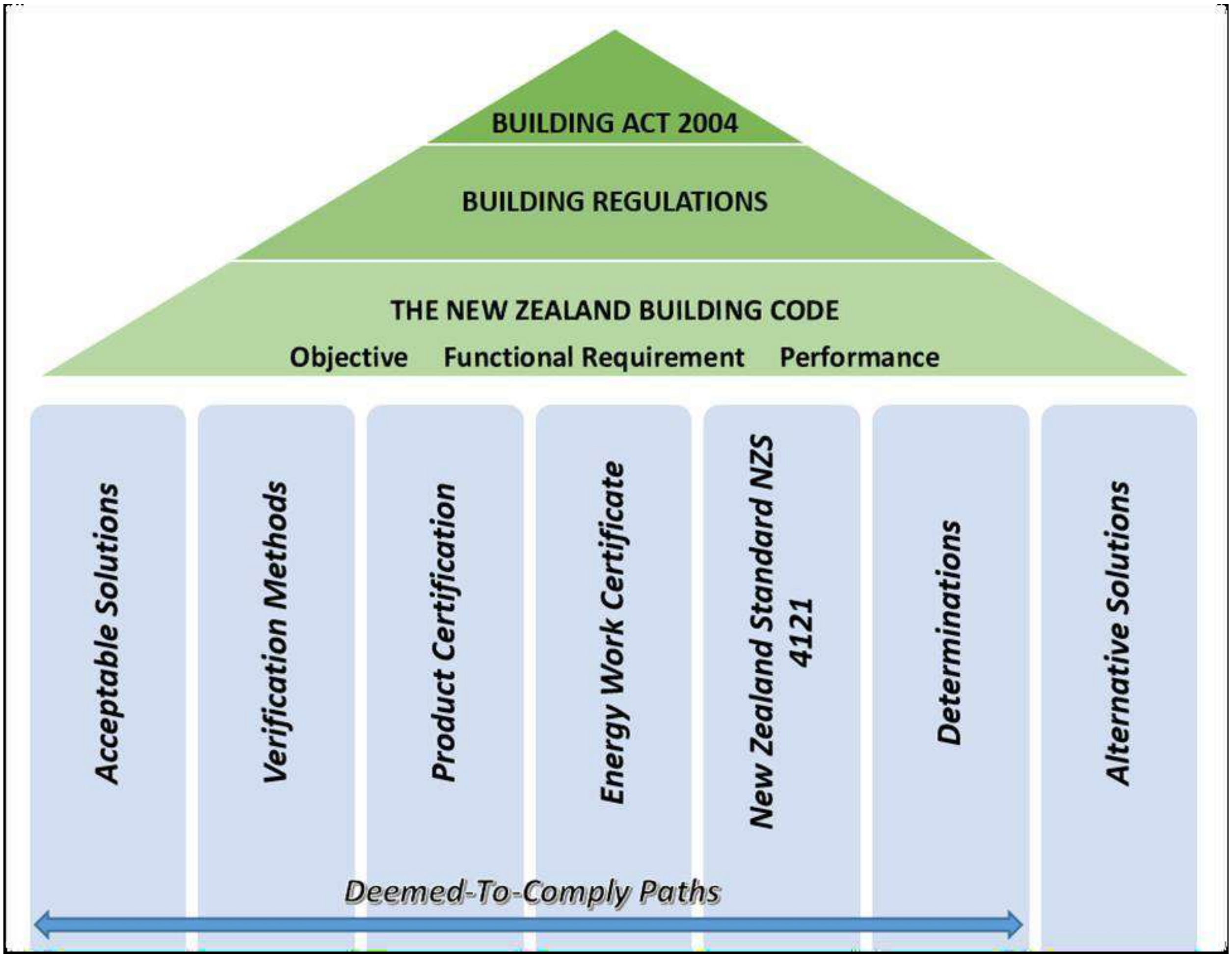

Figure 9 - The Hierarchy of New Zealand Building Controls, including the various compliance paths

Compliance with the Building Code must be demonstrated using one or more of the paths. For structural and earthquake design under Clause B (stability), the possible compliance paths are as follows:

Acceptable Solutions

Acceptable Solutions are simple step-by-step instructions that show one way to comply with the Building Code. They are published by the MBIE. There is at least one Acceptable Solution or Verification Method for compliance with each of the Building Code clauses. For example Clause B1 (structure) of the Building Code has three acceptable solutions. A concise summary of these acceptable solutions are discussed later in this section. A design that complies with an Acceptable Solution is automatically accepted by a building consent authority as complying with the Building Code.

Verification Methods

Verification Methods are tests or calculation methods that prescribe one way to comply with the Building Code. Verification Methods can include:

- Calculation methods: using recognised analytical methods and mathematical models
- Laboratory tests: using tests (sometimes to destruction) on prototype components and systems
- Tests-in-situ: which may involve examination of plans and verification by test, where compliance with specified numbers, dimensions, or locations is required (non-destructive tests, such as pipe pressure tests, are also included).

Verification Methods are issued and maintained by the chief executive of the MBIE.

Product Certification

The Product Certification body has the power to issue a product certificate to certify that a building method or product meets designated performance requirements of the Building Code. Building methods or products designed, used, installed, and maintained in accordance within the scope of the product certificates are deemed to meet the performance requirements of the related clauses of the Building Code as specified in the certificates. This would be equivalent to the Canadian Construction Materials Centre (CCMC) certification process in Canada.

Determinations

Determinations are legally binding decisions made by the chief executive of the MBIE dealing with code interpretation and dispute of compliance decisions.

Alternative Solutions

An alternative solution is a building design that deviates partially or completely from the Acceptable Solutions or Verification Methods. The deviation can be minor or major, and single or multiple differences. The deviation may also include cases where Acceptable Solutions or Verification Methods are not available for a proposed building project or where the proposed project goes beyond the applicable scope of relevant Acceptable Solutions or Verification Methods. The performance-based Building Code allows applicants to propose an innovative building work using the alternative solution compliance path. The MBIE publishes guide documents to assist engineers and designers in developing alternative solutions for code compliance. The guide documents are provided for assistance but do not have the same regulatory status as Acceptable Solutions or Verification Methods under the Building Act.

Other compliance paths such as Energy Work Certificate, New Zealand Standard NZS 4121 do not apply to Clause B and are not discussed in this report.

Acceptable Solutions and Verification Methods for Clause B1 (stability-structure)[8]

MBIE publishes Acceptable Solutions and Verification Methods for NZC Clause B1 structure in accordance with the Building Act. The solutions and methods provided in that publication can be used in establishing compliance with the Building Code. A summary of the verification methods and acceptable solution is discussed below:

Verification Method B1/VM1

The Verification Method VM1 for Clause B1 (structure) referenced as B1/VM1 uses Structural Design Standard AS/NZS1170 and Material Standards.

AS/NZS1170[9] includes the entire suite of structural action standards noted below:

- AS/NZS 1170.0:2002 Structural design actions - Part 0: General
- AS/NZS 1170.1:2002 Structural design actions - Part 1: Permanent, imposed and other actions
- AS/NZS 1170.2:2021 Structural design actions, Part 2: Wind actions
- AS/NZS 1170.3:2003 Structural design actions - Part 3: Snow and ice actions
- AS/NZS 1170.5:2004 Structural design actions - Part 5: earthquake actions - New Zealand

In addition, a large number of material standards including, but not limited to, NZS 3101 (Concrete), NZS 3404 (Steel), NZS 3603 (Timber), NZS 4230 (Masonry), NZS 4297 (Earth Buildings), AS/NZS 4600 (Cold Formed) are also referenced.

The verification method B1/VMQ relies on these standards for specifying requirements for compliance with the Building Code. However, there are exceptions, for example standards specific to earthquake design include:

- AS/NZS 1170.5:2004 Structural design actions - Part 5: earthquake actions - New Zealand
- NZS 4219: 2009 Seismic Performance of Engineering Systems in Buildings[10]

NZS 4219 covers the design, construction, and installation of seismic restraints for engineering systems such as air-handling units, tanks, cabinets, pipework, and ductwork.

The Verification Method B1/VM1 includes eight exceptions to the requirements in AS/NZS 1170.5. The requirements as specified in these exceptions must be fulfilled for compliance with B1/VM1. For example, one of the exceptions related to seismic hazard read as follows:

---

[8] https://www.building.govt.nz/building-code-compliance/b-stability/
[9] https://www.standards.govt.nz/search/doSearch?Search=NZS+1170.0
[10] https://www.standards.govt.nz/shop/nzs-42192009/

2.2.14A NZS 1170 Part 5, Clause 3.1.4

Add (to the end of Clause 3.1.4):
“The minimum hazard factor Z (defined in Table3.3) for the *Canterbury earthquake region* shall be 0.3. Where factors within this region are greater than 0.3 as provided by NZS 1170 Part 5, then the higher value shall apply.

2.2.14B NZS 1170 Part 5, Table 3.3

Delete row: 102 Christchurch 0.22 -Replace with: 102 Christchurch 0.3 -
Delete row: 101 Akaroa 0.16 -Replace with: 101 Akaroa 0.3

The following extract from NZS 1170.5 provides an idea about the performance requirements for earthquake design conforming to the NZC:

Clause 2.1.4. earthquake limit state design performance requirement
The design performance requirements are as follows:
(a) Ultimate limit state for earthquake loading shall provide for:
- (i) Maintenance of overall structural integrity and gravity load support, while accounting for horizontal and vertical deflections, soil structure interaction, and sliding of the structure or its parts;
- (ii) Maintenance of stability against overturning;
- (iii) Avoidance of collapse or loss of support to parts of categories P.1, P.2, P.3, and P.4 (Section 8- Parts and Components); and
- (iv) Avoidance of damage to non-structural systems necessary for building evacuation following earthquake that would render them inoperative.

(b) Serviceability limit states for earthquake loading are to avoid damage to:
- (i) The structure and the non-structural components that would prevent the structure from being used as originally intended without repair after the SLS1 earthquake as defined in Clause 2.4; and
- (ii) In a structure with a critical post-earthquake designation (i.e. importance level 4) all elements required to maintain those operations for which the structure is designated as critical, are to be maintained in an operational state or are to be returned to a fully operational state within an acceptable short timeframe (usually minutes to hours rather than days) after the SLS2 earthquake as defined in Clause 2.4.

Clause 2.5 Deformation Control
2.5.1 Ultimate limit state
Structure deformations shall be determined in accordance with Section 7 *(earthquake Induced Deflections).* Deformation shall be limited at the ultimate limit state as provided in Clauses 7.4 and 7.5 so that:
- (a) The structural system continues to perform its load-bearing functions; and
- (b) Damaging contact with neighbouring structures is avoided; and
- (c) Parts when considered as category P.1, P.2, P.3, or P.4, shall continue to be

supported; and (d) Non-structural systems necessary for emergency structure evacuation shall continue to function. **2.5.2 Serviceability limit state** Deformation shall be limited at the serviceability limit state so that: (a) At the SLS1 level, structural system members and parts of structures shall not experience deformations that result in damage that would prevent the structure from being used as originally intended without repair. (b) At the SLS2 level for structures of importance level 4, all parts of the structure shall remain operational so that the structure performs the role that has resulted in it being assigned this importance level.
7.4 HORIZONTAL DEFLECTION LIMITS **7.4.1 Ultimate limit state** 7.4.1.1 *Adjacent to boundaries* The design horizontal deflection of any point on the perimeter of a structure shall not exceed the distance from that point on the structure to the boundaries of adjacent sites, except for street frontages. 7.4.1.2 *Adjacent to structures on the same site, or existing structures on adjacent sites* At any point above the ground, the design horizontal deflection of the structure shall be such that, when combined with the design horizontal deflection of any adjacent structure at the same height, contact does not occur.
7.5 INTER-STOREY DEFLECTION LIMITS **7.5.1 Ultimate limit state** The ultimate limit state inter-storey deflection determined in accordance with Clause 7.3.1 shall not exceed 2.5% of the corresponding storey height or such lesser limit as may be prescribed in the appropriate material Standard. **7.5.2 Serviceability limit state** For the serviceability limit state, the inter-storey deflection shall be limited so as not to adversely affect the required performance of other structure components in accordance with Clause 2.1.4(b). The design horizontal deflections shall not be greater than any separation provided to avoid contact between adjacent parts of the structure, or between the structure and its parts and shall be limited so as not to impair their function nor that of other structure components.

Acceptable Solution B1/AS1

B1/AS1 contains acceptable solutions for masonry, timber, earth buildings, stucco, drains, glazing and steel).

Acceptable Solution B1/AS3

B1/AS3 is an acceptable solution for small chimneys. It is prescriptive in nature.

Verification Method B1/VM4

B1/VM4 covers the ultimate limit state design of foundations, including those of earth retaining structures. Methods are given for determining ultimate bearing and lateral sliding strengths.

Acceptable Solutions and Verification methods for Clause B2 (Stability-Durability)[11]

MBIE publishes Acceptable Solutions and Verification Methods for NZC Clause B2 durability in accordance with the Building Act. The solutions and methods provided in that publication can be used in establishing compliance with the Building Code. A summary of the verification methods and acceptable solution is discussed below:

Verification Method B2/VM1

The Verification Method VM1 for Clause B2 (durability) referenced as B2/VM1 states:

> Verification that the durability of a building element complies with the NZBC B2.3.1 and B2.3.2 will be by proof of performance and shall take into account the expected in-service exposure conditions by one or more of the following:
> a) In-service history,
> b) Laboratory testing,
> c) Comparable performance of similar building elements

Acceptable Solution B2/AS1

The Acceptable Solution B2/AS1 establishes criterion for assessing required durability of the building elements based on the following concepts:

- Difficult to access or replace
- Moderately difficult to access or replace
- Easy to access and replace
- Failure to comply with the NZBC would go undetected during normal use of the building but would be easily detected during normal maintenance
- Failure to comply with the NZBC would be easily detected during normal use of the building

Figure 10, from B2/ASI, provides a means of assessing the durability requirements for building elements. It refers different material standards such as the ones listed below as acceptable solutions for meeting the durability requirements of the materials.

- NZS 3101: Part 1 Section 3 (Concrete)[12]
- NZS 3602 Part 1and NZS 3640 (Timber)[13]

---

[11] https://www.building.govt.nz/building-code-compliance/b-stability/b2-durability/
[12] https://www.standards.govt.nz/shop/nzs-3101-1-and-22006/
[13] https://www.standards.govt.nz/shop/nzs-36022003/

- SNZ TS 3404 (Steel)[14]

In many cases, particularly for timber, B2/AS1 stipulates modifications to the requirements in the Standards.

B2/ASI also provides a table for durability requirements of nominated building elements as shown in Table 13: B2/AS1 Table 1 - Durability requirements of nominated building elements.

14 https://www.standards.govt.nz/shop/snz-ts-34042018/

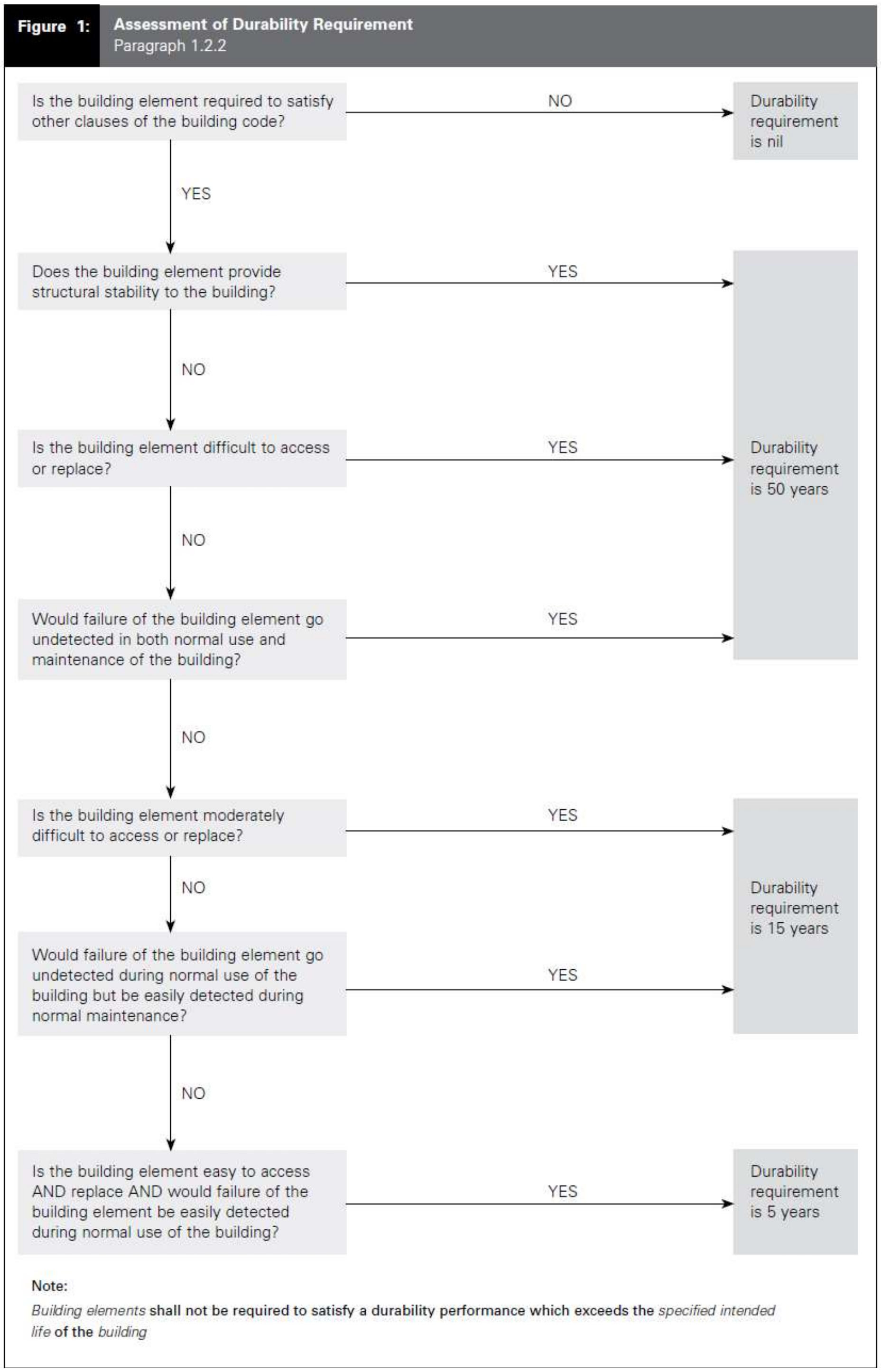

Figure 10 – Assessment of durability requirement

Table 13: B2/AS1 Table 1 - Durability requirements of nominated building elements

Table 1: Durability Requirements of Nominated Building Elements

Note: Clause B2.3.2 requires that all hidden elements have at least the same durability as that of the element that covers it (i.e. must have the same expected life) which may be more than the requirement in clause B2.3.1. For example, the reason that a brick tie has a requirement of not less than 50 years in this table, instead of the 15 year requirement for *cladding*, is that the brick veneer that hides it has an expected durability of 50 years or more.

Building Element	Component	Situation/Function	Not less than 50 years	Not less than 15 years	Not less than 5 years
Acoustic elements		Covered by or integral with structural elements or bracing panels	✓		
		Behind non-structural *claddings* or linings	✓		
		Surface mounted		✓	
Balustrade	(Refer to safety barrier)				
Battens (Cavity battens for wall	Battens	Where wall *cladding* durability requirement is 15 years		✓	
cladding systems) *(See note at top of table)*		Where wall *cladding* provides bracing	✓		
Bracing Elements		All – includes the bracing element and fixings	✓		

Appendix C - Comparison of U.S. and New Zealand Codes for Performance-Based Design

This Appendix provides a high level comparison of first, the regulatory system in the U.S and New Zealand, and second, the performance-based requirements in the International Code Council Performance Code for Buildings and Facilities (ICCPC) from the U.S. and New Zealand Code (NZC) for structural and earthquake design. The purpose of the comparison is to inform the development process for performance-based code (PBC) in Canada by showing the similarities and subtle differences between the two regulatory systems and codes.

C.1 Comparison of regulatory framework

ICCPC is developed by the International Code Council (ICC), a non-profit organization whereas NZC is developed by the Ministry of Business, Innovation, and Employment (MBIE).

The process for development of the ICCPC as well as the NZC reflect the principles of openness, transparency, balance, due process, and consensus. The consultative process involves diverse stakeholders. Both use the concept of public consultations (public review) for amendment and development of the code. However, in case of ICCPC, the ICC's governmental members—public safety officials across the U.S who have no financial or business interest in the outcome—cast the final votes on proposed changes whereas in case of NZC, the changes to the code are approved by the MBIE.

ICCPC is one of the suite of model codes available in the U.S. The model codes, called I-codes, include the International Building Code (IBC), International Plumbing Code, and others. On the other hand, NZC is the only code for buildings available in New Zealand.

ICCPC is a model code and cannot be enforced until legislated by a state in the U.S. On the other hand, NZC is part of the Building Act and is therefore, the applicable code.

C.2 Comparison of requirements in ICCPC and NZC

The structure of ICCPC as well as NZC are variations of the Nordic Five Level System for performance-based regulatory framework, as shown in Table 14.

Table 14: The Nordic Five Level System

TABLE 2. The Nordic Five Level System.

Level	Basic Heading	Description /Comments
1	GOAL	The goal addresses the essential interests of the community at large with respect to the built environment, and/or the needs of the user-consumer.
2	FUNCTIONAL REQUIREMENT	Building or building element specific requirements. A functional requirement addresses one specific aspect or required performance of the building to achieve the stated goal (note that other functional requirements may contribute to achieving the same goal).
3	OPERATIVE REQUIREMENT	Actual requirement, in terms of performance criteria or expanded functional description. This is also some times referred to as PERFORMANCE REQUIREMENT.
4	VERIFICATION	Instructions or guidelines for verification of perfor mance.
5	EXAMPLES OF ACCEPTABLE SOLUTIONS	Supplements to the regulations with examples of solutionsdeemed to satisfy the requirements.

In both the codes, the requirements are spelt out in terms of objectives (Goal), functional statements (Functional Requirements), and performance criteria (Operative Requirement). See Table 15 and

Table 16 for a comparison of requirements for structural and earthquake design.

Chapter 3 of the ICCPC provides a framework for the design of buildings for different levels of performance (Design Performance Levels). The Design Performance Level concept provides a framework for choosing the performance level of the building based on the desired damage state. A building owner can increase the level of performance if the desire is to reduce the consequences of the earthquake on the building. This concept provides a link between the policy makers and the designers. It establishes performance groups for buildings and facilities and minimum acceptable losses based on those performance groups. On the other hand, NZC does not have a framework for choosing level of performance in a building. All (normal) buildings are designed to one performance level and the user does not have a choice of performance levels and damage states. However, NZC provides for enhanced levels of performance in post-disaster and High Importance Category building through the application of AS/NZS 1170, *Structural design actions - Part 0: General principles.*

The compliance paths are similar in both codes. Compliance can be achieved through use of prescriptive codes (acceptable solutions), use of Authoritative Documents and Design Guides, and other design documents. ICCPC does not provide granular information about Acceptable Methods, Authoritative Documents, and Guides. It requires the use of these methods and guides and provides a framework (Section 103: objectives, functional statements, and performance requirements), whereas NZC provides Acceptable Solutions and Verification Methods (for example B1/VM1, B1/VM4, B2/VM1, B2/AS1), which are published by the regulatory body (Ministry of Business, Innovation, and Employment). There is at least one Acceptable Solution or Verification Method for compliance with each of the code requirement.

Table 15: Comparison of requirements for earthquake design: stability

CHAPTER 5 STABILITY: SPECIFIC INTENT STATEMENTS FOR STRUCTURAL DESIGN IN ICCPC

501 Structural Forces
objective To provide a desired level of structural performance when structures are subjected to the loads that are expected during construction or alteration and throughout their intended lives.
functional statements
501.2.1 Life Safety and Injury Prevention Structures shall be designed and constructed to prevent injury to occupants due to loading of a structural element or system consistent with the design performance level determined in Chapter 3.
501.2.2 Property and amenity protection. Structures shall be designed and constructed to prevent loss of property and amenity consistent with the design performance level determined in Chapter 3.
performance requirements
501.3.1 Stability Structures, or portions thereof, shall remain stable and not collapse during construction or alteration and throughout their lives
501.3.2 Disproportionate failure. Structures shall be designed to sustain local damage, and the structural system as a whole shall remain stable and not be damaged to an extent disproportionate to the original local damage.
501.3.3 Loss of amenity. Structures, or portions thereof, shall have a low probability of causing damage or loss of amenity through excessive deformation, vibration or degradation during construction or alteration and throughout their lives.
501.3.4 Expected loads. Structures, or portions thereof, shall be designed and constructed taking into account expected loads, and combination of loads, associated with the event(s) magnitude(s) that would affect their performance, including, but not limited to

1. Dead loads.
2. Live loads.
3. Impact loads.
4. Explosion loads.
5. Soil and hydrostatic pressure loads.
6. Flood loads (mean return period). 6.1 Small: 100 years 6.2 Medium: 500 years 6.3 Large: Determined on a site-specific basis 6.4 Very Large: Determined on a site-specific basis
7. Wind loads (mean return period). 7.1 Small: 300 years 7.2 Medium: 700 years 7.3 Large: 1700 years 7.4 Very Large: 3000 years
8. Windborne debris loads.
9. Snow loads (mean return period). 9.1 Small: 25 years 9.2 Medium: 50 years 9.3 Large: 100 years 9.4 Very Large: 500 years

* +++++++++++++++++++++++++++++++-1q-10. Rain loads. See Table 501.3.4.

11. earthquake loads.11.1 Small: 43 years (mean return period) 11.2 Medium: 72 years (mean return period) 11.3 Large: Two-thirds of the intensity of very large loads 11.4 Very large: The Risk-Targeted Maximum Considered earthquake defined in Chapter 21 of ASCE 7.

STABILITY: STRUCTURAL DESIGN IN BUILDING REGULATION 1992 (NEW ZEALAND)
CLAUSE B1

Clause B1 - Structure
objective
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*, including:
(a) Self-weight,
(b) Imposed gravity loads arising from use,
(c) Temperature,
(d) Earth pressure,
(e) Water and other liquids,
(f) earthquake,
(g) Snow,
(h) Wind,
(i) *Fire*,
(j) Impact,
(k) Explosion,
(l) Reversing or fluctuating effects,
(m) Differential movement,
(n) Vegetation,
(o) Adverse effects due to insufficient separation from other *buildings*,
(p) Influence of equipment, services, non-structural elements and contents,
(q) Time dependent effects including creep and shrinkage, and (r) removal of support.

12. Ice loads, atmospheric icing (mean return period). 12.1 Small: 25 years 12.2 Medium: 50 years 12.3 Large: 100 years 12.4 Very Large: 200 years 13. Hail loads. 14. Thermal loads. **501.3.5 Safety factors** the design of buildings and structures shall consider appropriate factors of safety to provide adequate performance from: 1. Effects of uncertainties resulting from construction activities. 2. Variation in the properties of materials and the characteristics of the site. 3. Accuracy limitations inherent in the methods used to predict the stability of the building. 4. Self-straining forces arising from differential settlements of foundations and from restrained dimensional changes due to temperature, moisture, shrinkage, creep and similar effects. 5. Uncertainties in the determination of the expected loads. **501.3.6 Demolition and alteration.** The demolition or alteration of buildings and structures shall be carried out in a way that avoids the likelihood of premature collapse. **501.3.7 Site work.** Site work, where necessary, shall be carried out to provide stability for construction on the site and avoid the likelihood of damage to adjacent property.	**B1.3.4** Due allowance shall be made for: (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*. **B1.3.5** The demolition of *buildings* shall be carried out in a way that avoids the likelihood of premature collapse. **B1.3.6** *Sitework*, where necessary, shall be carried out to: (a) Provide stability for *construction* on the site, and (b) Avoid the likelihood of damage to *other property*. **B1.3.7** Any *sitework* and associated supports shall take account of the effects of: (a) Changes in ground water level, (b) Water, weather and vegetation, and (c) Ground loss and slumping.

C.2 Comparison of requirements for EQ design in the two Codes

Table 16: Comparison of requirements for earthquake design: durability

TOPIC –SPECIFIC INTENT STATEMENTS
CHAPTER 4 RELIABILITY AND DURABILITY

401 Reliability
objective To ensure reliability of the system necessary to meeting the performance objectives of building
functional statements

- Design, installation and maintenance in strict accordance with the manufacturers' instructions and with any applicable codes and standards.
- Testing and Inspection
- Active fire protection systems
- Training

performance requirements

- Qualifications shall be performed only by qualified people as approved. Certification or records of training shall be provided.
- Documentation shall be maintained at the building that details the systems installed and their required maintenance and testing methods and frequency.

402 Durability
objective. To assist in the selection of appropriate materials and construction systems.
Functional statement. To ensure that a building will continue to satisfy the objectives of this code throughout its life.+*-
Performance requirements.

- Normal maintenance. Primary building elements shall, with only normal maintenance, continue to satisfy the performance requirements of this code for the intended life of the building.
- Intended life of a building. Where the useful life of building or facility elements or systems is less than the intended life of the building, provisions shall be made for timely replacement of those elements, so that the objective of this code and the design are maintained.
- Damage and deterioration. Where damage or deterioration to building or facility elements or systems will impact the objectives of this code or the design, those elements or systems shall be repaired or replaced in order to maintain the level of performance intended by this code.
- Determination of durability and service life. In determining the useful service life of building elements, products or systems, an acceptable method for determining durability and service life shall be used.

DURABILITY: STRUCTURAL DESIGN IN BUILDING REGULATION 1992 (NEWZEALAND) CLAUSE B2

Clause B2 - objective
The objective of this provision is to:
B2.1 The objective of this provision is to ensure that a *building* will throughout its life continue to satisfy the other objectives of this code.
Functional requirement
B2.2 *Building* materials, components and *construction* methods shall be sufficiently durable to ensure that the *building*, without reconstruction or major renovation, satisfies the other functional requirements of this code throughout the life of the *building*.
Performance
B2.3 [Revoked]
B2.3.1 *Building elements* must, with only normal maintenance, continue to satisfy the performance requirements of this code for the lesser of the *specified intended life* of the *building* ,if stated, or:
(a) The life of the building, being not less than 50 years, if:
(i) Those *building elements* (including floors, walls, and fixings) provide structural stability to the *building*, or
(ii) Those *building elements* are difficult to access or replace, or
(iii) Failure of those *building elements* to comply with the *building code* would go undetected during both normal use and maintenance of the *building*.

(b) 15 years if:
(i) Those *building elements* (including the *building* envelope, exposed plumbing in the subfloor space, and in-built chimneys and flues) are moderately difficult to access or replace, or
(ii) Failure of those *building elements* to comply with the *building code* would go undetected during normal use of the *building*, but would be easily detected during normal maintenance.

(c) 5 years if:
(i) The *building elements* (including services, linings, renewable protective coatings, and *fixtures*) are easy to access and replace, and
(ii) Failure of those *building elements* to comply with the *building code* would be easily detected during normal use of the *building*.

B2.3.2 Individual *building elements* which are components of a *building* system and are difficult to access or replace must either:
(a) all have the same durability, or (b) be installed in a manner that permits the replacement of *building elements* of lesser durability without removing *building elements* that have greater durability and are not specifically designed for removal and replacement.

Appendix D - Objective-Based Framework in NBC and its Relevance to a Performance-Based Code

D.1 Introduction

The National Building Code of Canada (NBC) became an objective-based building code in 2005 and provides both the prescriptive acceptable solutions and the option to develop alternative solutions (known as equivalency prior to 2005). The introduction of the objective-based code was originally envisioned as a step or a transition towards a performance-based code (PBC)..

The current approach in the NBC is a mixture of performance- and prescriptive-code provisions. The acceptable solutions required by Division B represent an implicit expression of the levels of building performance that are acceptable to society. This is the primary compliance option. However, the second compliance option in NBC is through the use of alternative solutions. To be acceptable, an alternative solution must provide a level of performance at least equivalent to that of the acceptable solution(s) it is replacing.

Most of the requirements in Division B of the NBC are tied to at least one explicitly stated code objective or functional statement and is supplemented with detailed intent statements. When evaluating alternative solutions for compliance, the areas of performance to be examined are clearly identified by the objectives and functional statements attributed to each requirement of the acceptable solutions.

A brief description of the framework used in the NBC to specify requirements is included in this Appendix. The intent is to show the similarities between the objective-based framework in the NBC and the performance-based framework used in the International Code Council Performance Code for Buildings and Facilities (ICCPC) from the U.S. and New Zealand Code (NZC). The comparison indicates that the approach in the NBC provides a good foundation for transitioning to a performance-based code. It can be seen that the objectives and functional statements in the NBC provide a good starting point for developing the objectives and functional requirements for the performance-based framework. Choices such as use of *multiple design performance levels* (ICCPC) or *minimum performance level* (NZC), specification of performance requirements in qualitative or quantitative terms, and inclusion of Acceptable Solutions and Verification Methods in the NBC, or not, will determine the extent of expected challenges in the transition to PBC. Enforcement, training, and other regulatory considerations are also important but were not discussed as they are not in the scope of this report.

The following section provides a snapshot of the current objective-based framework in the NBC.

D.2 Structure and format of the NBC (framework)

The discussion below provides information about the structure of the objective-based format in the National Building Code of Canada (NBC) and its relevance to the performance-based approach.

The NBC is structured around three divisions:

- Division A – Compliance, objectives, and functional statements
- Division B – Acceptable Solutions
- Division C – Administrative Provisions

The key components of the objective-based framework in NBC are:

- Objectives
- Functional statements
- Acceptable solutions
- Intent statements
- Application statements

D.2.1 Objectives

Objectives state what the codes aim to achieve. The objectives define the codes and provide the rationale behind the acceptable solutions. The objectives identified in the NBC are:

- Safety (OS)
- Health (OH)
- Accessibility (OA)
- Fire and structural protection of buildings (OP)
- Environment (OE)

The objectives are found in Division A of the objective-based codes. Sub-objectives (second-level and third-level objectives) provide even more detailed information about what the codes are trying to accomplish.

The following shows the NBC objective for safety:

Objectives

1) The objective of this Code are as follows (see Note A-2.2.1.1.(1)):

OS **Safety**

An objective of this Code is to limit the probability that, as a result of the design, construction, or demolition of the *building*, a person in or adjacent to the *building* will be exposed to an unacceptable risk of injury.

The NBC objective safety has five second-level objectives:

OS1	Fire safety,
OS2	Structural safety,
OS3	Safety in use,
OS4	Resistance to unwanted entry, and
OS5	Safety at construction and demolition sites.

The sub-objectives relevant to earthquake design – structural safety has the following second level objectives:

OS2	**Structural Safety**
	An objective of this Code is to limit the probability that, as a result of the design or construction of the *building*, a person in or adjacent to the *building* will be exposed to an unacceptable risk of injury due to structural failure. The risks of injury due to structural failure addressed in this Codes are those caused by –
	OS2.1 – loads bearing on the *building* elements that exceed their *loadbearing* capacity
	OS2.2 – loads bearing on the *building* that exceed the *loadbearing* properties of the supporting medium
	OS2.3 – damage to or deterioration of the *building* elements
	OS2.4 – vibration or deflection of *building* elements
	OS2.5 – instability of the *building* or part thereof
	OS2.6 – collapse of the *excavation*

The other objective relevant for earthquake design is the objective for fire and structural protection on buildings (OP) which reads as follows:

OP	**Fire and Structural Protection of Buildings**
	An objective of this Code is to limit the probability that, as a result of the design or construction, or demolition of the *building*, the *building* or adjacent *buildings* will be exposed to an unacceptable risk or damage due to fire or structural insufficiency, or the *building* or part thereof will be exposed to an unacceptable risk of loss if use also due to structural insufficiency.

The NBC objective fire and structural protection of buildings has five second-level objectives:

OP1	Fire protection of buildings,
OP2	Structural sufficiency of buildings,
OP3	Protection of adjacent buildings from fire, and
OS4	Protection of adjacent building from structural damage.

The sub-objectives relevant to earthquake design – structural sufficiency of buildings has the following second level objectives:

OP2	**Structural Sufficiency of the Building**
	An objective of this Code is to limit the probability that, as a result of its design or construction, the *building* or a part thereof will be to an unacceptable risk of damage or loss of use due to structural failure or lack of structural serviceability. The risks of damage and loss of use due to structural failure or lack of structural serviceability addressed in this Code are those caused by –
	OP2.1 – loads bearing on the *building* elements that exceed their *loadbearing* capacity

OP2.2 – loads bearing on the *building* that exceed the *loadbearing* properties of the supporting medium

OP2.3 – damage to or deterioration of the *building* elements

OP2.4 – vibration or deflection of *building* elements

OP2.5 – instability of the *building* or part thereof

OP2.6 – instability or movement of the supporting medium

D.2.2 Functional statements

The next tool in the objective-based framework in the NBC are the functional statements. They translate objectives into operational terms. The functional statements describe the general conditions to be achieved. A functional statement is expressed in qualitative terms and describes the outcome required, but not how to achieve that outcome.

Any one objective can be related to one or more functional statements, and vice versa. The functional statements are found in Division A.

The following shows functional statements that are normally related to the NBC sub-objective of structural safety and structural sufficiency of buildings:

3.2.1.1. Functional statements

1) The objectives of this Code are achieved by measures, such as those described in the acceptable solutions in Division B, that are intended to allow the building or its elements to perform the following functions:

F20 To support and withstand expected loads and forces.
F21 To limit or accommodate dimensional change.
F22 To limit movement under expected loads and forces.
F23 To maintain equipment in place during structural movement.

D.2.3 Acceptable solutions

Each code requirement is linked to one or more objectives and functional statements. This link is termed attributions to acceptable solutions and provides qualitative performance criteria for the required level of performance. Conceptually, this structure is similar to that in various performance-based codes (PBC) such as ICCPC and NZC.

D.2.4 Intent statements

The intent statements describe *in simple terms* what the acceptable solutions in Division B aim to achieve and explain the link between an acceptable solution and its attributed objective(s) and functional statement(s). The intent statements are not part of the codes, but do constitute useful reference material, similar to Explanatory Notes or information normally contained in Users' Guides or Handbooks.

D.2.5 Application statements

The application statements clearly describe the situations to which each code provision applies and does not apply. Like the intent statements, the application statements are not part of the codes, but do constitute useful reference material.

However, since the first publication of the application statements with the 2005 edition of the NBC, they were not maintained and as such, revised and published in subsequent editions of the Code.

D.3 Illustration of the use of objective-based framework in the NBC

The use of the framework is illustrated below using the acceptable solution for deflection and drift limits as provided in Sentence 4.1.8.13.(3) of Division B of the NBC 2015.

4.1.8.13. Deflections and Drift Limits

3) Based on the lateral deflections calculated in Sentences (2), (5), and (6), the largest inter*storey* deflection at any level shall be limited to 0.01 h_s for *post-disaster buildings*, 0.02 h_s for High Importance Category *buildings*, and 0.025 h_s for all other *buildings.*

Attribution for Sentence 4.1.8.13.(3) as provided in NBC 2015:

F22 – OS2.3, OS 2.4
F22 – OP2.3, OP2.4

In simple terms it means that the requirement in Sentence 4.1.8.(13)(3) was attributed the objectives of structural safety (OS) to limit the probability that, as a result of the design or construction of the building, a person in or adjacent to the building will be exposed to an unacceptable risk of injury due to structural failure by limiting movement under expected loads and forces (F22 functional statement) to prevent the risk to injury caused by the sub-objectives OS2.3 (damage to or deterioration of building element) and OS2.4 (vibration or deflection of building elements).

The intent statement for the Sentence 4.1.8.10. (3) explains this in simple terms as follows:

Intent 1: To limit the probability that the design of the Seismic Force Resisting System of the building will not take into account the expected lateral deflection and distortion of the building structure due to maximum expected seismic ground motions, which could lead to damage to or displacement of attached or adjacent building elements, which could consequently fall or slide, which could lead to harm to persons.

The application statements (last updated for NBC 2005) describes the situations to which each code provision applies and does not apply:

Application 1. Limits to the inter*storey* deflections calculated in accordance with Sentence 4.1.8.13.(2). This applies to *buildings* described in Sentence 1.3.3.2.(1) and to *buildings* to which Part 9 applies [see Sentence 1.3.3.3.(1) for application of Part 9] that are required to be designed in accordance with the requirements of Part 4.

The attribution F22- OP2.3, OP2.4 can also be explained in a similar way.

In summary, the existing objective-based framework in NBC, which consists of objectives, functional statements, attributions, intent statements, and application statements, provides a head start for developing a PBC for buildings in Canada. As noted earlier, objectives and functional statements provide qualitative performance criteria only; they do not provide quantitative performance criteria that can be used in assessing compliance.

Appendix E - Objectives, Functional Statements, and Intent Statements for Earthquake Design in the NBC

The National Building Code of Canada (NBC) uses an objective-based approach. The objective-based framework in NBC, which consists of objectives, functional statements, attributions, intent statements, and application statements, provides a head-start for developing a performance-based code for buildings in Canada.

This Appendix provides a listing of the requirements in the NBC 2015 for earthquake design. Where applicable, the objective of each requirement (what the codes aim to achieve), the functional statement (measures to achieve objectives), the attributions (link to objective and functional statement), and intent statement (description of the objective in general terms) have been provided.

The Appendix provides useful information for developing objectives, functional statements, and performance requirements for transitioning to performance-based requirement for earthquake design in NBC. Note that the objectives, functional statements, and intents are all expressed in qualitative terms and do not provide any quantitative definitions of performance and acceptance criteria.

100 Worksheet for
NBC framework.xlsx