

The Seismic Assessment of Existing Buildings

Technical Guidelines for Engineering Assessments

Draft for Sector Briefings June 2016

Part A: Assessment Objectives and Principles



New Zealand Society for
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HIKINA WHAKATUTUKI



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This document is likely to be incorporated by reference to the Earthquake Prone Buildings (Chief Executive's) Methodology to be developed under the provisions of the Building (Earthquake-prone Buildings) Amendment Act. It will also be endorsed by MBIE for use as guidance under section 175 of the Building Act to the extent that it assists practitioners and territorial authorities in complying with the Building Act.

Document Access

This document may be downloaded from www.EQ-Assess.org.nz in the following file segments:

- 1 Contents
- 2 Part A – Assessment Objectives and Issues
- 3 Part B – Initial Seismic Assessment
- 4 Part C – Detailed Seismic Assessment

Updates will be notified on the above website.

The document will be formally released in early 2017, when the final form of the regulations and EPB Methodology associated with the Building (Earthquake-prone Buildings) Amendment Act 2016 is established.

Document Management and Key Contact

This document is managed jointly by the Ministry of Business, Innovation and Employment, the Earthquake Commission, the New Zealand Society for Earthquake Engineering, the Structural Engineering Society and the New Zealand Geotechnical Society.

Please contact the New Zealand Society for Earthquake Engineering via questions@EQ-Assess.org.nz if you require further information on these draft Guidelines, or if you wish to provide feedback.

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These Guidelines were prepared during the period 2014 to 2016 with extensive technical input from the following members of the Project Technical Group:

Project Technical Group Chair	
Rob Jury	Beca
Task Group Leaders	
Jitendra Bothara	Miyamoto International
Adane Gebreyohanness	Beca
Nick Harwood	Eliot Sinclair
Weng Yuen Kam	Beca
Dave McGuigan	MBIE
Stuart Oliver	Holmes Consulting Group
Stefano Pampanin	University of Canterbury

Other Contributors	
Graeme Beattie	BRANZ
Alastair Cattanach	Dunning Thornton Consultants
Phil Clayton	Beca
Charles Clifton	University of Auckland
John Hare	Holmes Consulting Group
Jason Ingham	University of Auckland
Stuart Palmer	Tonkin & Taylor
Lou Robinson	Hadley & Robinson
Craig Stevenson	Aurecon

Project Management was provided by Deane McNulty, and editorial support provided by Ann Cunninghame and Sandy Cole.

Oversight to the development of these Guidelines was provided by a Project Steering Group comprising:

Dave Brunsdon (Chair)	Kestrel Group
Gavin Alexander	NZ Geotechnical Society
Stephen Cody	Wellington City Council
Jeff Farrell	Whakatane District Council
John Gardiner	MBIE

John Hare	SESOC
Quincy Ma	NZSEE
Richard Smith	EQC
Mike Stannard	MBIE
Frances Sullivan	Local Government NZ

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A1. Introduction

The purpose of these Guidelines is to assist assessors, building owners, and territorial authorities (TAs)/ building consent authorities (BCAs) to deal with the challenges involved in understanding, managing and, over time, reducing seismic risk in existing buildings.

A1.1 Objectives of Seismic Assessment

The principal objectives of seismic assessment are ultimately:

- to inform users about the risk posed by buildings under earthquake actions
- to facilitate the reduction of risk to acceptable levels over a reasonable timeframe.

The establishment of acceptable risk sits with building owners, building users and the public in general. From an overall societal perspective, for buildings it is expressed through the Building Act, which sets the minimum standards for seismic safety and damage limitation for both new and existing buildings. The earthquake-prone buildings provisions have a focus on identifying and addressing the ‘worst’ buildings (from a life safety perspective) within defined time frames. There are, however, also buildings that fall outside the scope and focus of the earthquake-prone buildings legislation which represent a potentially significant risk in strong earthquake shaking.

It is therefore recognised that many people may wish their buildings to achieve greater levels of safety and damage prevention. This may be driven, amongst other things, by market pressures, by insurance considerations or by a societal push for greater resilience.

It is important that seismic assessment methods used provide consistent and reliable outcomes, while recognising that different engineers may adopt different methods according to the nature of the buildings under review, the time available for the task and the requirements of the client commissioning the assessment. A range of assessment methodologies that reflects these, sometimes conflicting demands, is provided in these Guidelines.

A1.2 Purpose and Objectives of this Document

The basic purpose of these Guidelines is to provide engineers with the means to assess the seismic behaviour of existing buildings and through the processes presented enable the expected seismic performance to be put in context with minimum objectives. The associated objectives of the Guidelines are:

- providing engineers with the framework and technical tools to undertake assessments that:
 - address the regulatory requirement of identifying whether or not a building is earthquake prone in terms of the Building Act
 - provide a seismic rating for a building assessed against minimum expectations/ requirements for a new building
 - provide information at an appropriate level of detail to meet the needs of the person commissioning the assessment

- enable engineers to arrive at an understanding of how a building might perform across a range of ground shaking levels
- enable consistent assessments between different engineers when based on the same information and briefing, with an appropriate level of conservatism based on the level of detail available
- providing engineers with the communication tools to:
 - effectively and consistently communicate the outcomes of assessments
 - enable building owners to understand and be able to improve the seismic safety of their buildings, and where necessary prioritise mitigation works
- to support the wider risk reduction objective of addressing the buildings most likely to perform poorly in significant earthquakes.

With respect to the latter point, the overall objective of this work is the reduction of seismic risk via seismic retrofit or other improvement measures where required. A general overview and key principles associated with seismic improvement are provided in Section A6, with more specific guidance and examples to come in separate documentation.

A1.3 Background

This version of the Guidelines is a full revision of the 2006 New Zealand Society for Earthquake Engineering (NZSEE) document *Assessment and Improvement of Structural Performance of Buildings in Earthquakes* (2014 version, including Corrigendum Nos. 1, 2, 3 and 4).

This section provides background on the development of legislation to address earthquake risk and earthquake-prone buildings, and the historical role of the NZSEE in producing technical guidance in support of the legislation and related activities.

A1.3.1 Earthquake Risk and New Zealand Buildings

The earthquake risk of existing buildings has been recognised for many years. The initial legislation in 1968 (the Municipal Corporations Act) was directed at unreinforced masonry (URM) buildings, whose potential dangers were apparent in the 1931 Napier earthquake. URM construction ceased with the introduction of New Zealand’s first earthquake standard in 1935, but a large stock of buildings in this material remain throughout the country. Action was taken by some TAs via the passage of by-laws in response to the 1968 legislation, and a number of buildings (most notably in Wellington) were strengthened to its requirements and sometimes beyond.

The level of strength below which a building required strengthening or demolition was set at one-half of the 1965 New Zealand Standard (NZS 1900 Chapter 8). While this has always been considered to be a low threshold by structural engineers, it was maintained as these provisions were incorporated within the earthquake prone buildings provisions of the 1991 Building Act.

The NZSEE first produced guidelines to assist in the assessment and strengthening of URM buildings in the 1970s. In 1986 the guidance was fully revised and published as the ‘Red Book’, a label which has stayed with subsequent versions.

Valuable information and experience has been brought back from overseas earthquakes via the NZSEE reconnaissance programme, funded by the Earthquake Commission (EQC). Most notably the Northridge (1994) and Kobe (1995) earthquakes brought to light concerns about the adequacy of more recent designs, particularly those constructed in the period of early seismic codes between 1935 and 1976. Most buildings designed before the publication of the 1976 structural loadings standard NZS 4203:1976 and associated materials codes typically do not have either the level of *ductility* or appropriate hierarchy of failure (ie. the principles of capacity design) required by current design standards.

Acknowledging these concerns, the then Building Industry Authority commissioned NZSEE in 1994 to produce a document setting down the requirements for structural engineers to follow when evaluating and strengthening post-1935 buildings. An initial draft produced in 1996 was further developed into the 2006 NZSEE Guidelines *Assessment and Improvement of the Structural Performance of Buildings in Earthquake* to accompany the widened scope of the earthquake-prone building provisions of the Building Act 2004.

The 2006 NZSEE Guidelines, and particularly the Initial Evaluation Procedure (IEP), were widely used both by TAs and structural engineers carrying out assessments and improvement measures for existing buildings.

The Building Act 2004 extended the scope of earthquake-prone buildings from URM to include any building found to have significantly inadequate seismic capacity. The threshold for an earthquake-prone building also was raised to one-third of current code levels. TAs were required to have earthquake-prone building policies stating what their approaches and timetables would be in identifying and requiring action on “earthquake-prone” buildings (those assessed to have their “ultimate capacity” exceeded in a moderate earthquake). Implementation by TAs varied considerably, but each TA had to assess its local earthquake risks and produce a policy. The implementation of these policies meant that many buildings around the country were noted as *earthquake prone*, and many buildings were strengthened around the country. Some TAs had *active* policies which typically involved screening of commercial buildings to identify those that were potentially earthquake prone (typically using the NZSEE Initial Evaluation Procedure); others had *passive* policies which only addressed earthquake-prone buildings when they came to their attention at the time of consent applications.

The initial TA policies were due for their 5-year review in June 2011. The then Department of Building and Housing and the EQC sponsored a major workshop of TAs, owners, developers and designers in July 2010 to share their experiences of developing and implementing earthquake-prone building policies. The aim was to better inform each TA ahead of the policy update.

The Canterbury Earthquake Sequence, which began with the Darfield earthquake on 4 September 2010, however forced other priorities on TAs, owners, designers and the community. The revision of earthquake-prone building policies was put on hold in many locations as the impacts and implications of these events were considered.

A1.3.2 Drivers for this Revision

Damage to URM buildings was a feature of the 4 September 2010 Darfield earthquake, with the subsequent 22 February 2011 Christchurch earthquake causing major damage to buildings of all types and eras in Christchurch and surrounding areas. The Canterbury

Earthquake Sequence led to an unprecedented level of seismic assessments to be undertaken, both within the Christchurch earthquake region for regulatory and insurance purposes, and nationally in response to the heightened awareness of seismic risk. This high demand for assessments plus the availability of a unique volume of relevant information on the behaviour of New Zealand buildings has driven the need for updated guidelines for assessment of existing buildings.

In reviewing the factors involved in all the buildings where lives were lost, the Canterbury Earthquakes Royal Commission gave extensive consideration to the failure of URM buildings and to the collapses of the two buildings where most lives were lost. Their recommendations, along with the research that has been undertaken into building failures, have been taken into account in the development of these Guidelines.

It is clear from experience since 2004 that URM buildings remain a significant challenge. The section covering URM buildings (released in 2015) was revised and expanded to acknowledge the most recent research and to take advantage of the lessons from Canterbury.

The number of structural and geotechnical engineers in New Zealand experienced in seismic assessments was relatively limited at that time, and this resource quickly became overloaded. Many of the subsequent assessments have been undertaken by engineers with limited seismic assessment experience and little or no formal training in seismic assessment. It should also be noted that the 2006 NZSEE Guidelines focused on pre-1976 concrete and steel multi-storey and URM buildings, and provided limited guidance on low-rise buildings generally, and timber structures in particular. There was also no guidance on geotechnical matters.

These gaps have been addressed in the revision process, as these Guidelines seek greater consistency in assessment and reporting outcomes. It is recognised that improved consistency will require extensive and ongoing education and training of structural engineers involved in the assessments.

These new Guidelines include consideration of the latest available information and are intended to take advantage of the lessons learnt from the Canterbury earthquakes as well as to target the wider areas of need and concern amongst engineers, owners and the public.

A1.4 Purposes and Types of Seismic Assessments

A1.4.1 Overview

The Guidelines support seismic assessments undertaken for a range of purposes, covering general property risk identification as well as building regulatory requirements.

These guidelines apply to all assessments by default, including within the provisions of the Building Act 2004 and the Building (Earthquake-prone Buildings) Amendment Act 2016 (The Amendment Act), and it will be explicitly stated in the relevant sections where this application differs.

Where specific provisions of these Guidelines or other viewpoints do not apply for the purposes of an earthquake-prone building assessment, they will be represented in the following format:

Comment:

[provision/viewpoint beyond the requirements of the earthquake prone provisions of the Building Act]

In addition to earthquake prone considerations, other building regulatory considerations include change of use and alterations.

A1.4.2 Earthquake Prone Building Regulatory Provisions

For the subset of engineering assessments undertaken under the earthquake-prone buildings provisions of the Building Act, the following section outlines key elements of the legislation and the supporting regulatory framework that apply to engineers.

A1.4.2.1 Current system based on the 2004 Building Act

The operational interface between these Guidelines and the earthquake-prone buildings provisions of the Building Act has been prepared with a focus on the new Building (Earthquake-prone Buildings) Amendment Act 2016 framework, as outlined in the subsequent section. The provisions of these Guidelines may however be used to establish a building's seismic capacity with respect to the current provisions of the Building Act and associated regulations.

A possible technical definition of ultimate capacity is provided for information purposes below. It is considered that this interpretation may be used with the earthquake-prone provisions of the Building Act 2004.

A1.4.2.2 Building (Earthquake-prone Buildings) Amendment Act 2016

The Building (Earthquake-prone Buildings) Amendment Act 2016 contains major changes to the current system for identifying and remediating earthquake-prone buildings under the Building Act 2004. The Amendment Act provisions will come into force on either a date set by Order in Council, or by 12 May 2018, whichever is the earlier.

The new framework for managing earthquake-prone buildings includes several interdependent system components:

- the Building (Earthquake-prone Buildings) Amendment Act
- the associated regulations
- the EPB Methodology, set by the Chief Executive of the Ministry of Business, Innovation and Employment
- the Engineering Assessment Guidelines (this document); and
- the Earthquake-prone Buildings Register.

It is envisaged that the arrangements associated with the implementation of the Amendment Act 2016 will come into effect at the same time as the Act comes into force.

The key components of the new system with direct relevance in an engineering assessment are summarised below. Some of these components are still subject to public consultation and parliamentary process, and subsequent versions of this document will provide further elaboration.

Building (Earthquake-prone Buildings) Amendment Act 2016

The 2016 amendments to the earthquake-prone provisions of the Building Act contain substantial additions and key changes, including centralising the system rather than TAs having individual earthquake-prone building policies.

The new provisions include a change to the definition of an earthquake-prone building, which will be defined in the new system as (changes from the 2004 Act are highlighted in blue):

133AB Meaning of earthquake-prone building

- (1) A building **or a part of a building** is *earthquake prone* if, having regard to the condition of the building **or part** and to the ground on which the building is built, and because of the construction of the building **or part**
 - (a) the building **or part** will have its ultimate capacity exceeded in a moderate earthquake (as defined in regulations); and
 - (b) **if the building or part were to collapse**, the collapse would be likely to cause
 - (i) injury or death to persons in **or near** the building or on any other property; or
 - (ii) damage to any other property.

Further, the term ‘moderate earthquake’ is currently defined in Regulation 7 under the Building Act 2004. Clause 43 of the Building Amendment Act 2016 modifies this definition slightly in order to establish the date of the applicable building standards. It will now read:

7 Earthquake-prone buildings: moderate earthquake defined

- (1) For the purposes of **section 133AB** of the Act (meaning of earthquake-prone building), **moderate earthquake** means, in relation to a building, an earthquake that would generate shaking at the site of the building that is of the same duration as, but that is one-third as strong as, the earthquake shaking (determined by normal measures of acceleration, velocity, and displacement) that would be used to design a new building at that site if it were designed on the commencement date.
- (2) **In this regulation, commencement date means the day on which section 133AB of the Act comes into force.**

New Regulations

The Building Amendment Act 2016 allows for the development of a series of new regulations, and these cover:

- definition of *ultimate capacity* (refer below)
- earthquake ratings
- granting exemptions
- criteria to define ‘substantial alterations’
- forms/building notices
- additional information for register
- infringements.

The regulations will undergo public consultation later in 2016.

For the purposes of illustrating how the elements of the new arrangements are intended to operate, a working technical interpretation of *ultimate capacity* (as at May 2016) may be taken as:

Ultimate capacity means the building's probable lateral load resisting capacity to withstand earthquake actions and maintain gravity load support calculated by reference to the building as a whole and its individual elements/parts.

The establishment of a building's ultimate capacity is intended take into account and provide information on the governing mode of failure of the building or part, having regard to the impact of that failure on life safety. It is envisaged that this information will be used by the TA when assessing the consequence of failure of those elements on life safety, other property or egress – ie in the application of the earthquake-prone building test in section 133AB(1)(b).

The application of this interpretation involves consideration of the following components:

- *Ultimate capacity* means probable capacity (strength and deformation) of the building to withstand earthquake actions.
- It is intended that it be calculated for the building as a whole and also to be calculated for any parts that may fall externally onto a public thoroughfare or place of assembly or other property or egress route, and for parts inside the building that would represent a significant life safety hazard to occupants of the building and from which alternative evasive action could not be taken.

Exceedance of ultimate capacity involves the situation where the failure of the building or part would result in loss of gravity support of the building or part as a whole and thereby create a significant life safety hazard, which is defined in these Guidelines as:

A hazard resulting from the loss of gravity support of a member/element of the primary or secondary structure, or of the supporting ground, or of critical non-structural items that would reasonably affect a number of people.

It is anticipated that this definition will be included in the EPB Methodology, including the definition of critical non-structural items expected to be included in the assessment of the building seismic rating.

EPB Methodology

The EPB Methodology will be set by the Chief Executive of the Ministry of Business, Innovation and Employment in accordance with section 133AZ of the Amendment Act. It is a key new document that will provide the operational basis for identifying earthquake-prone buildings.

It is proposed that the EPB Methodology will cite relevant parts of these Guidelines, which would in turn set the technical methods that engineers will be required to meet in undertaking assessments to determine whether or not a building is earthquake prone under section 133AB of the Amendment Act.

The EPB Methodology will also include criteria for TAs to accept engineering assessments, resulting in minimum standard reporting requirements for engineers.

Engineers undertaking seismic assessments for earthquake-prone building purposes are encouraged to become familiar with the EPB Methodology throughout the consultation period in mid-late 2016, and when it is formally released.

A1.4.3 Other Building Regulatory Purposes

A1.4.3.1 Change of Use

For the TA to approve a change of use under section 115 of the Act, it is required to believe that the building will meet the structural performance standards of the building code as nearly as is reasonably practicable as if it were a new building.

An engineering assessment will therefore be requested from the owner for change of use applications. The nature and extent of this assessment will depend on the nature and implications of the change of use. Any work required to meet the structural performance objective of section 115 is to be carried out before a Code Compliance Certificate can be issued.

Any previous notices or agreements allowing an extended timetable for improvement of structural performance will no longer apply and, if necessary, revised notices will need to be issued to match the change of circumstances.

A1.4.3.2 Alterations

The basic requirement of section 112 of the Building Act in terms of structure is that alterations cannot result in the building complying with the Building Code to a lesser extent than before the work (s112(1)(b)).

Whether a building may be acceptable for alteration, with or without firstly, an engineering assessment and secondly, strengthening, will depend on the circumstances of the building.

A1.5 Scope of Buildings Covered by These Guidelines

These Guidelines are specifically for the assessment of existing buildings. It is also intended to be used for the assessment of the capacity of existing building construction when this is included in upgrade (e.g. retrofit) of an existing building. The assessment methods and criteria contained in these Guidelines are not intended for use in designing new buildings or new parts of an existing building when the building is being upgraded (e.g. retrofitted).

The Guidelines cover buildings from all eras from early unreinforced masonry buildings to the most recent designs, and all types and materials. Information for the assessment of parts of buildings is also included.

A1.5.1 Primary Structural Systems

The building types and seismic resisting elements and systems for which direct guidance is offered in this document include the following:

- Unreinforced masonry buildings
- Reinforced concrete moment resisting frames
- Reinforced concrete structural walls

- Reinforced concrete dual wall/frame systems
- Structural steel moment resisting and braced frames
- Frame structures (concrete or steel) with masonry infill.
- Timber structures.

The Guidelines also provide guidance on assessment of these systems in combination in the same building.

Guidance is also provided on the geotechnical considerations in assessing existing buildings, including when these can be expected to significantly influence the overall behaviour of a particular building.

The Guidelines are not intended to be specifically applied to bridges, towers, masts, retaining walls, or building contents. Even so, many of the approaches outlined and criteria presented may be helpful for this purpose if suitably adapted.

A1.5.2 Secondary Structural and Non-Structural Elements

One of the changes to the earthquake-prone buildings provisions of the Building Act is the requirement that the behaviour of building parts must be considered in the overall assessment of the building.

The scope and extent of ‘Parts’ for the purposes of an earthquake-prone building assessment is different to the ordinary engineering usage of the term ‘parts’ for design purposes, as provided for in NZS 1170.5, Appendix A: *a Part is an element that is not intended to participate in the overall resistance of the structure to horizontal displacement under earthquake conditions, for the direction being considered.*

In the Act, the definition of an earthquake-prone building is broadened to cover any part of the building, the failure of which may lead to significant life safety hazard or damage to adjacent property; and therefore may include also consideration of individual elements of the primary structure, as distinct from the structure as a whole. However, by limiting the consideration to significant life safety hazard and damage to adjacent property, the Act excludes from consideration many secondary structural and non-structural elements that would otherwise require consideration in the design of new buildings.

Comment:

For the seismic assessment of buildings for purposes other than compliance with the earthquake-prone provisions of the Act, and particularly for buildings that are approaching 100%NBS, consideration should be given to including a wider range of non-structural elements or a specific note made that these have been excluded from consideration.

In broad terms, the parts of buildings that should be included in an earthquake-prone building assessment include, but are not limited to:

- masonry parapets
- precast panels
- heavy items of plant
- heavy partition walls.

Parts of a building not intended to be included in the assessment include:

- items that can be considered building contents, e.g. furniture, office equipment, etc.
- building services
- lightweight suspended ceilings
- lightweight partitions.

For the purposes of earthquake-prone assessments, Table A1.1 following indicates the secondary structural and critical non-structural elements that are required to be considered as ‘parts’, and contrasts them with those that are not required to be considered in earthquake-prone buildings assessments.

Note:

This section will be revised following preparation of the EPB Methodology.

Table A1.1: Secondary Structural and Critical Non-structural ‘Parts’ of buildings for inclusion in in Earthquake-Prone Buildings Assessments

Required to be considered	Not required to be considered
Heavy external cladding elements, including connections	
Heavy vertical or horizontal cantilevering elements over egress paths, public property or other areas where people may congregate in the course of regular occupancy or common use.	Heavy vertical or horizontal cantilevering elements NOT over egress paths, public property or other areas where people may congregate in the course of regular occupancy or common use.
Brittle or heavy appendages and ornamentation that may fall onto egress paths, public property or other areas where people may congregate in the course of regular occupancy or common use.	Individual bricks or spalled concrete caused by movement in the primary lateral or gravity systems.
Support frames for light cladding systems including curtain walls	Light cladding elements including glazing elements
All stairs and stair supports	
Heavy monolithic ceiling systems and/or ceiling grids in over height spaces (height of fall greater than 3m) and/or open spaces with no furniture	Conventional lightweight ceiling grid systems and ceilings in normal height spaces with furniture (for shelter)
Heavy partitions and walls (e.g. blockwork or clay tiles) > 100 kg/m ²	Conventional timber framed partitions and walls <100 kg/m ²
Heavy signs or billboards that may fall further than 3m onto egress paths, public property or other areas where people may congregate in the course of regular occupancy or common use.	Heavy signs or billboards that cannot fall further than 3m onto egress paths, public property or other areas where people may congregate in the course of regular occupancy or common use.
Vessels containing hazardous materials, the spillage of which could cause a life safety hazard for occupants of the building or adjacent spaces.	
Heavy racking systems in generally occupied spaces such as retail warehouses.	Racking systems in buildings not generally occupied
Heavy items of building services plant	Lighting, heating, ventilation and air conditioning ducts and equipment.

A1.5.3 Importance Level 4 Buildings

Given that the focus of seismic assessments using this document is on the life safety of building occupants and those immediately outside the building, the assessment of an Importance Level 4 (IL4) building (ie. one with critical post-disaster functions) is not required to give consideration to the effect of earthquake-induced damage on operational requirements.

However the effect of damage on the ability of a building classified as Importance Level 4 to continue to function in the post-disaster period is an important consideration for the intended operational purpose of the building to be met – i.e. serving community needs at a time of crisis. In its broadest sense this is a life safety consideration, but beyond the requirement for a building to be considered earthquake prone.

It is noted that the required serviceability (ie. at SLS2) to provide confidence that an existing IL4 building will be able to maintain operational continuity may be satisfied by simply assessing behaviour at an appropriate level and using judgement to determine what the outcomes may be for usability.

Comment:

It is recommended that an IL4 building should attain a 67%NBS rating as a minimum and fully satisfy SLS2 requirements, or be re-designated.

A1.6 Levels of Experience Required

Seismic assessments at any level are expected to be undertaken by experienced engineers. They require considerable knowledge of the earthquake behaviour of buildings, as well as the ability to exercise judgement regarding key attributes and their effect on building seismic performance.

It is therefore essential that an assessment be carried out, or be reviewed by, a New Zealand Chartered Professional Engineer (CPEng), or equivalent, who:

- has sufficient relevant experience in the design and evaluation of buildings for earthquake effects to exercise the degree of judgment required, and
- has specific training in the objectives of and processes involved in the assessment procedures contained in these Guidelines.

The requirement for high levels of judgement when establishing a seismic rating from the Initial Seismic Assessment process cannot be understated, and is discussed further in Part B.

A1.7 Overview of this Document

This document is structured in three parts, with an overview of the key contents as follows:

Part A: Assessment Objectives and Principles

- This part outlines the scope and application of the Guidelines, and provides an overview of the seismic assessment process generally. The linkage with the relevant requirements of the Building Act is described, including with the

earthquake prone buildings regulations via the EPB (Chief Executive’s) Methodology.

- A brief section that provides a general overview and outline of the key principles associated with designing seismic ‘improvement’ is also included.

Part B: *Initial Seismic Assessment*

- This part describes the method of application of the Initial Seismic Assessment methodology (including the Initial Evaluation Procedure), which enables a broad indication of the seismic rating of a building. The linkages with the earthquake prone buildings regulations via the EPB (Chief Executive’s) Methodology, covering both the *initial identification* and *engineering assessment* processes are defined.

Part C: *Detailed Seismic Assessment*

- This part describes the method of application of the Detailed Seismic Assessment methodology, which provides a more comprehensive assessment of the likely seismic rating of a building. The linkages with the earthquake prone buildings regulations via the EPB (Chief Executive’s) Methodology, covering the *engineering assessment* process are defined.

Guidance on the reporting of seismic assessment results is provided in each of the three parts.

A1.8 Definitions

Building Code	Section B1 of the New Zealand Building Code (Schedule 1 to the Building Regulations 1992)
Detailed Seismic Assessment (DSA)	Comprehensive quantitative assessment of the strength and deformation capability of a building. A seismic assessment carried out in accordance with Part C of these guidelines
Earthquake Prone Building	A legally defined category which describes a building that that has been assessed as likely to have its ultimate capacity (as defined in Regulations) exceeded in moderate earthquake shaking (which is defined in the Regulations as being one-third as strong as the shaking that a new building would be designed for on that site). In the context of these guidelines it is a building with a seismic rating less than 34%NBS (less than one third of new building standard).
Earthquake Risk Building	A building that falls below the threshold for acceptable seismic risk, as recommended by NZSEE (i.e. <67%NBS or 2/3rds new building standard)
Initial Seismic Assessment (ISA)	Recommended first qualitative step in the overall assessment process. A seismic assessment carried out in accordance with Part B of these guidelines
Non-structural item	An item within the building that is not considered to be part of either the primary or secondary structural systems. Non-structural items are not typically included in the assessment of the building seismic rating unless their failure represents a significant life safety hazard. When required to be included in the seismic assessment they are referred to as a critical non-structural item. Non-structural items include individual window glazing, ceilings, building services and building contents.
Primary lateral structure	Portion of the main building structural system identified as carrying the lateral seismic loads through to the ground. May also be the primary gravity structure.
Primary gravity structure	Portion of the main building structural system identified as carrying the gravity loads through to the ground. Also required to carry vertical earthquake induced accelerations through to the ground. May also incorporate the primary lateral structure.
Probable capacity	The expected or estimated mean capacity (strength and deformation) of a member, an element, a structure as a whole, or foundation soils. For structural aspects is determined using probable material strengths.
Probable Material Strength	The expected or estimated mean material strength
Secondary structure	Portion of the structure that is not part of either the primary lateral or primary gravity structural systems but nevertheless is required to transfer inertial and vertical loads for which assessment/design by a structural engineer would be expected. Includes precast panels, curtain wall framing systems, stairs and supports to significant building services items.
Seismic rating	The rating given to a building as a whole to indicate the seismic standard achieved in regard to human life safety compared with the minimum seismic standard required of a similar new building on the same site. Expressed in terms of percentage of new building standard achieved (%NBS).
Significant life safety hazard	A hazard resulting from the loss of gravity support of a member/element of the primary or secondary structure, or of the supporting ground, or of critical non-structural items that would reasonably affect a number of people
Structural Weakness (SW)	An aspect of the building structure and/or the foundation soils that scores less than 100%NBS. An aspect of the building structure scoring less than 100%NBS but greater than or equal to 67%NBS is still considered to be a Structural Weakness even though it is considered to represent an acceptable risk.

Critical Structural Weakness (CSW)	The lowest scoring Structural Weakness determined from a DSA. For an ISA, all Structural Weaknesses are considered to be <i>potential</i> Critical Structural Weaknesses.
Severe Structural Weakness (SSW)	A defined Structural Weakness that is potentially associated with catastrophic collapse and for which the capacity may not be reliably assessed based on current knowledge. For an ISA, potential SSWs are expected to be noted when identified, and may extend to issues that require detailed seismic assessment before they can be removed from consideration.
Ultimate Capacity (seismic)	The probable (expected) seismic capacity for the building A term defined in Regulations that describes the limiting seismic capacity of a building or part of a building, for it to be determined to be an earthquake-prone building. Based on probable (expected) material strengths
XXX%NBS	Seismic rating for a building as a whole expressed as XXX percent of new building standard achieved. Intended to reflect the degree to which a building is expected to perform in earthquake shaking, from a life safety perspective, compared with the minimum performance prescribed for a new building in B1 of the Building Code. Seismic score for an individual member/element /system/foundation/supporting soil expressed as XXX percent of new building standard achieved. Intended to reflect the degree to which the individual member/element /system/foundation/supporting soil is expected to perform in earthquake shaking, from a life safety perspective, compared with the minimum performance prescribed for the element or component in B1 of the Building Code. In general the seismic rating for the building should not be greater than the seismic score for the lowest scoring element or component.
XXX%ULS demand	Percentage of the ULS demand (loading or displacement) defined for the ultimate limit state design of a building. For the structure this is defined in the New Zealand Earthquake Loadings Standard NZS 1170.5. For the foundation soils this is defined in Earthquake Geotechnical Engineering Practice Module 1 (2016) with appropriate adjustments when considering whether or not the building is earthquake prone. Refer also Section C3.

A2. Understanding the Context of Seismic Assessment

There are three key areas of context for the seismic assessment of existing buildings that must be understood, namely:

- the differences between existing and new buildings
- the difference in approach between seismic assessment and new building design
- the particular objectives of the seismic assessment.

A2.1 Differences between existing and new buildings

The main difference between a new building at the end of the design phase and an existing building is that the existing building is a physical entity, whereas a new building, yet to be constructed, only exists in conceptual form.

An assessment is based on the physical reality of a building. Aspects such as poor construction, poor design and poor integration of secondary structural and non-structural elements, if they are found by inspection to be present, can be explicitly allowed for.

While knowledge of an existing building (e.g. material strengths, hidden details, etc.) will not always be complete, it is considered that the physical presence of an existing building, and what can be determined from it, provides a significant advantage from the point of view of establishing its seismic performance when compared with a theoretical building defined only on drawings.

If a new building is confirmed as being well conceived, designed and constructed and then assessed in accordance with the guidance contained in this document, a seismic rating above the minimum accepted standard of 100%NBS (refer Section A3.3) is expected to be achieved. The reduced life safety performance that this higher rating may suggest when compared with a building that just meets the minimum rating of 100%NBS is not expected to be significant, and well within the overall uncertainties in establishing the likely behaviour that are contained in the assessment process generally. Undue focus on these differences is not encouraged, and a rating presented as >100%NBS is recommended (refer Section A5.2), rather than to present a fixed value. This will better serve to preserve the relativity to new buildings, which will also generally be well above 100%NBS if rated post construction.

Note:

Assessing a new building in accordance with these guidelines solely off drawings is not encouraged for similar reasons that comprehensive site inspections of an existing building are always recommended (refer Section A4.2.2.2). Also assessments post-construction by the original designer should be objective and include an appropriate evaluation of how well the design objectives (including interaction with secondary structural and critical non-structural items) have been implemented in the actual building.

A2.2 Differences between seismic assessment and new building design

There are distinct differences between the processes of design and assessment. In design, a building is required simply to meet or exceed a target. The adopted design methodologies and subsequent detailing of the structure are all calibrated to provide reasonable assurance of reliable performance, but the designer does not need to specifically consider *how* reliable the actual performance is, and how much greater the capacity may be than the minimum requirements. Further, the designer has the ability, within reason, to modify the behaviour of the building to support the design assumptions.

Most importantly, designers are generally only required to consider a single design point (Ultimate Limit State), as the deemed to comply provisions of the design standards ensure that the full range of performance objectives will be met for other levels of loading. The exception to this is in applying alternative solutions, where designers may need to consider the range of performance explicitly.

By contrast, assessors must be much more aware of the range of possible building performance, as the same safeguards do not necessarily exist. The building performance is already determined by the form and detailing of the structure as it was originally designed and constructed, along with such alterations as it may have been subjected to since construction (including the effects of deterioration over time).

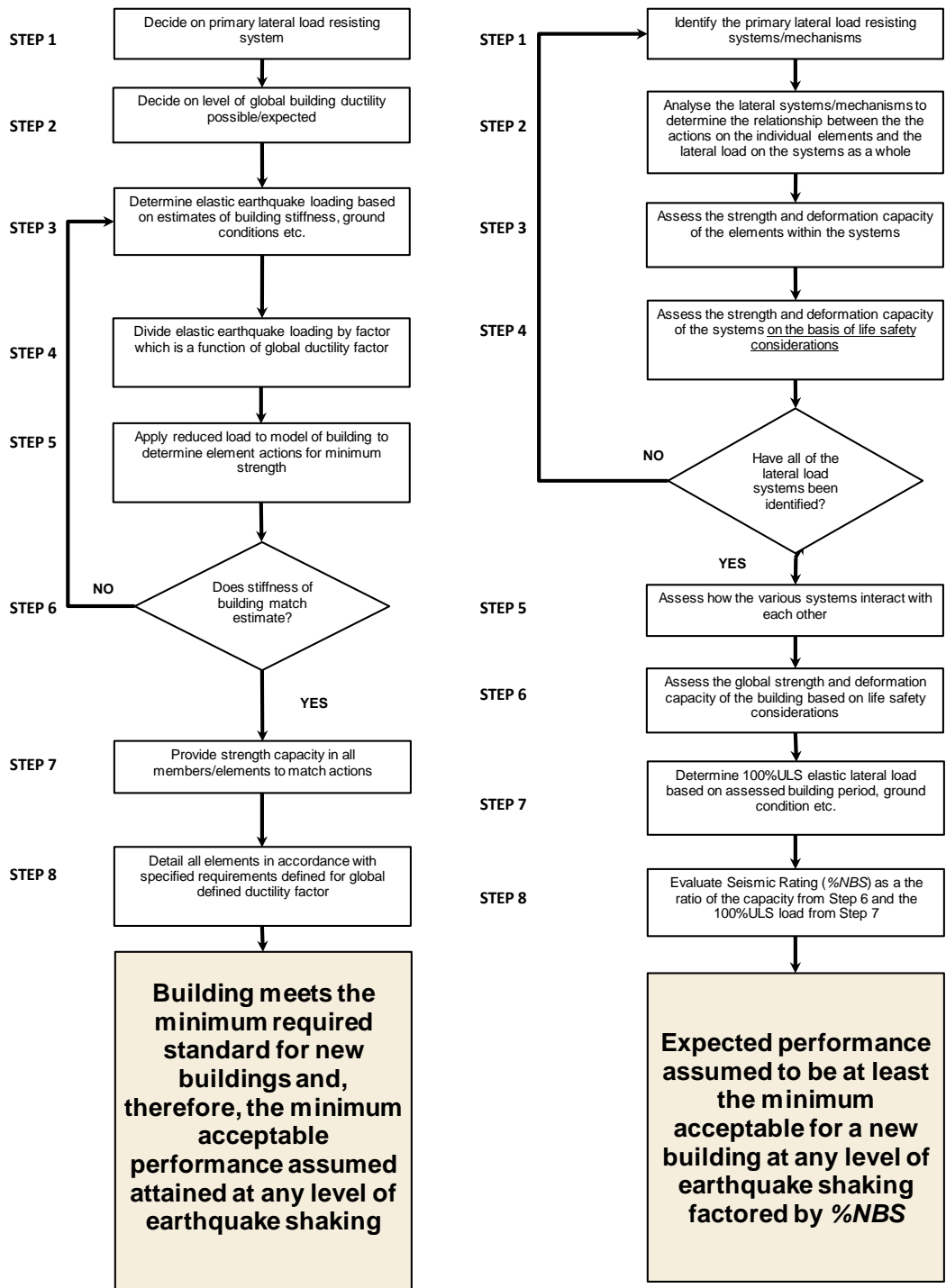
A2.2.1 Differences in Design and Assessment Process

Figure A2.1 following maps the key elements of the processes of new building design and assessment of existing buildings.

A minimum seismic standard for new buildings has been traditionally achieved by determining design loads for the required limit states, applying these to a “model” of the building to determine design actions and then proportioning the strength capacity and appropriate detailing of the individual elements in accordance with the material design standards. The approach is summarised in Figure A2.1(a).

Under the approach for new building design, the design loading for new building design is typically set at the level where the building is on the point of notional yield (non-linear behaviour), and is obtained by dividing the full defined elastic design load by a scaling factor (proportional to the global ductility factor) that reflects the level of detailing provided. The provisions of both the design loadings and materials standards are intended to ensure that the ductile capability of the primary structural elements is sufficient to provide the defined global ductility. This is typically achieved by ensuring that the energy dissipation is reasonably well distributed throughout the primary lateral system and that the vertical load carrying capacity of the primary gravity system is assured at the level of lateral deformation expected.

However, these fundamental assumptions made in the traditional design process are rarely valid when assessing an existing building, unless the structure remains predominantly elastic (i.e. the structural ductility factor is close to 1). Therefore, the approach taken for seismic assessment must be different.



(a) Traditional Design Approach

(b) Generic Assessment Approach

Figure A2.1: Design and assessment approaches compared

The approach to seismic assessment for existing buildings is therefore intended to be fundamentally different to that employed for the design of new buildings. The use of traditional design approaches for assessment can lead to an assessment result that is significantly in error if assumptions inherent in the design process are ignored. The result can be either excessively conservative or non-conservative.

The generic assessment process adopted in these guidelines is shown in Figure A2.1(b).

The identification of the various systems/mechanisms (Steps 1 to 4), and establishing how they work together (Step 5) are significant iterative parts of the assessment process which are not required for new building design, where reliance is typically placed on a particular mechanism type that is chosen by the designer. In the case of assessment, the mechanisms are already present and need to be identified and assessed.

Other differences between the design of new buildings and the assessment of existing include:

- There is a focus on life safety in assessment (refer Section A3.2.2). The assessment process outlined addresses the life safety focus by allowing elements that are not expected to lose gravity support (and, therefore, fall) once their capacity is exceeded either to be removed from further consideration, or to sustain a residual capacity with or without a deformation limit as appropriate.

The consequence is that, in assessment, the assumed system mechanism can be fully developed until the first element that constitutes a life safety hazard reaches its deformation capacity. This is a potentially significant concession compared with new building design.

Note:

An assessment which includes all elements but limits the global capacity of the building to the element with the lowest capacity, without considering whether or not this element is critical from a life safety perspective, will not meet a key principle of these guidelines.

- The intention of new building design procedures is to deliver a building that can be expected to perform to meet the minimum seismic performance objectives set out in Clause B1 of the Building Code for overall life safety risk and acceptable loss of amenity. In contrast, the assessment process seeks to establish how well the existing building will perform in terms of the minimum performance objectives defined in the Building Code.
- As a result of the process used, many new buildings could be expected to exceed these minimum requirements if they have been designed correctly as envisaged by the code writers and have been constructed as intended by the designer. However, this is not always realised in practice. The Building Code procedures (Verification Methods) have built-in conservatisms that make some allowance for this eventuality, such as use of lower characteristic material strengths and capacity reduction factors. Moreover, design algorithms and detailing requirements have generally been tested to considerably greater displacements than the design standards strictly require to meet ULS requirements. However, these factors are not intended to deal with gross errors or omissions.
- In the assessment of an existing structure, realistic values for the material properties, particularly strengths, must be used to obtain the best estimate of the strengths and displacements of members, joints and connections. Seismic assessments make use of

probable (expected) element capacities to reflect that the building physically exists. The justification for using probable rather than nominal capacities for assessment is outlined in Section A2.1, and in more detail in Section C1.

- Mixed ductility structural systems may be present in new building design and, if they do occur specific provisions are provided to ensure they are correctly incorporated. In contrast, these systems are almost always present in older existing buildings and must be correctly evaluated if a realistic and reasonable assessment result is to be obtained.

A2.3 Objectives of the Assessment

All assessments need to have a clearly defined set of objectives, without which the outcomes will be unclear and inconsistent. This is often a significant factor when assessments of the same building by different engineers have had very different outcomes. Regardless of the purpose of the assessment, a clearly identified set of objectives should be defined and the outcomes of the assessment should be validated against these objectives on completion.

The objectives of the earthquake-prone building provisions of the Building Act as outlined in Section 1.4.1 essentially require only consideration of life safety, egress and protection of adjacent property. The guidance provided in this document is generally aimed at addressing these matters.

Comment:

This document does not provide specific guidance on damage limitation, although many of the principles and methods described are applicable.

A3. Overview of the Seismic Assessment Process

A3.1 Introduction

The main technical objective of any seismic *assessment* is to come to an understanding of the likely *performance* of the building in earthquakes. There are several important aspects to consider in this:

- An holistic assessment of seismic performance must consider a wide range of events that the building may be subjected to. Thus, when the standard that a building achieves is reported in %NBS terms (refer A3.3), this implies different levels of reliability of performance across a range of shaking levels which, when considered together imply that a minimum performance level is achieved. Although engineers may consider only one level of shaking in design, the other levels of shaking are implicitly accounted for in our general design methodologies. It is the intent of these guidelines that a full understanding of the behaviour of the building including an assessment of this behaviour against ULS shaking and the identification of severe structural weaknesses (refer Section A3.3.4) will also provide confidence that the minimum level of performance has been achieved overall without necessarily the need to assess at multiple levels of shaking. However, the level of experience and understanding of building behaviour in earthquakes needs to be at a significantly higher level for assessment, than required for design, to achieve this objective.
- The assessment should include consideration of both the capacity of the building system as a whole, as well as the capacity of individual elements, the failure of which may represent a significant hazard to life safety.
- Assessment should be undertaken to an appropriate level of detail, having due regard to the scale of the building, the potential consequence of its failure and the other work that may be undertaken in parallel with, or as an outcome of, the assessment.
- There needs to be a clear understanding that assessment is not a prediction of the way in which a particular building might perform when subjected to a particular level of earthquake shaking. The implied accuracy of the assessment process belies the fact that the assessment is generally a relative assessment of a single building against the wider building population.

This section outlines the key principles associated with seismic assessment, how the seismic rating is expressed, and provides an overview of the two levels of seismic assessment – the *Initial Seismic Assessment* and the *Detailed Seismic Assessment* – for context when using Part B and Part C of these Guidelines.

A3.2 Key Principles

In addition to understanding the fundamental process differences between designing new buildings and assessing existing buildings as outlined in the previous section, the four key principles associated with seismic assessment are:

1. Understanding the objectives of assessment
2. Focusing on life safety
3. Consistent expression of seismic performance
4. Understanding and determining building failure modes.

A3.2.1 Understanding the Objectives of Assessment

Although there is generally a desire on the part of building owners and occupiers to quickly arrive at a capacity expressed as a single number, by far the most important part of any assessment is to form a view of the likely *behaviour* of the building. Behaviour encompasses both the elastic and potential inelastic deformation of a building under seismic loading; and its consequential effect on the other elements of the building. It must also include consideration of soil-structure interaction, which may be a significant modifier of the overall building behaviour.

A summary of the key differences between assessment and design was outlined in Section A2.1.

The role of the assessor is to ascertain what the behaviour of the building is likely to be, with regard to these factors, and may need to explicitly address the consequences of failure of elements in more detail than a designer would. This means that an assessor must consider a number of factors, including:

- the materials that the building was constructed with, and how these may vary from what was originally intended
- the designer's intended structural form and behaviour, and how that may be modified by the actual execution
- the detailing used in design (and as constructed), and how it may modify the intended behaviour
- the changes that may have happened over time and how they may impact on reliability and performance.

In all of the above, the role of the codes and standards of the day are significant, as they would have informed the design and construction process. However, assessors should not simply assume that anything that predates current standards will not perform adequately. One of the most significant issues is that, where a designer may have considered the lateral load resisting and gravity load resisting structures separately, assessors must consider the behaviour of both responding together as one structure. Decisions to exclude elements of the structure from an analysis must be made carefully.

The role of the assessor is therefore as much about forensic aspects as it is about analysis. The assessor must be conscious of the designers' intent but open to consideration of what

other factors may influence behaviour and which may not have been within the designers' knowledge, experience or ability to control during construction or subsequent alterations.

A3.2.2 Focusing on Life Safety

These assessment guidelines are focused on life safety as the primary objective. A life safety issue is assumed to arise when the *ultimate capacity of the building as a whole or specific parts is exceeded*, with a failure mode that could give rise to a *significant life safety hazard*.

Ultimate capacity will be defined in regulations that come into force in 2017. The general intent associated with establishing a definition for ultimate capacity is provided in Section A1.4.2.

These Guidelines seek to identify issues with the building that *could* lead to collapse (either of the building as a whole, sections of a building or parts of a building as defined in Section A1.3.1.2). This includes consideration of primary and secondary structural items and non-structural components which could fall from the building. Failure leading to collapse in this context is assumed if gravity load support of a structural element is lost or a large or heavy non-structural element falls such that it could come into contact with several people.

Accordingly, *significant life safety hazard* is defined as:

A hazard resulting from the loss of gravity support of a member/element of the primary or secondary structure, or of the supporting ground, or of critical non-structural items that would reasonably affect a number of people (i.e. more than two).

While there has been no attempt to quantify the risk of collapse or the resulting life safety risk, it is assumed that if the failure of the building element or of the supporting ground could lead to collapse, then this will constitute a significant life safety risk. The level of occupancy is assumed to be addressed by the Importance Level classification in accordance with NZS 1170.0. However, it is recognised that consideration from first principles may be required in cases where high occupancy is infrequent or the number of people at risk from the failure is considered acceptably low. It is the intent that clause 133AB(1) (b) of the definition of an earthquake-prone building in the Building Act will address this from an earthquake prone building perspective, with the TA providing the direction. For other assessments the assessor will need to make a judgement call (further guidance to be provided).

The falling of relatively small pieces of the primary or secondary structure, such as individual bricks in an unreinforced masonry building or from a veneer, or spalling of concrete in a reinforced concrete building, are not considered to be of sufficient severity to constitute a significant life safety hazard as defined above.

Similarly, the Health and Safety considerations associated with non-structural components in general and contents are outside the scope of these guidelines.

Note:

It is important that the decision making process for what is and isn't included within the scope of an assessment is clearly recorded, irrespective of the level of assessment being carried out.

The onset and progression of building damage, other than to the extent that it can affect adjacent property and the ability to egress a building, is not a primary consideration in the approaches outlined in these Guidelines. Assessment of behaviour at serviceability limit state levels of loading is therefore not expected in the assessment process outlined. This is a significant difference to new building design, where the application of the serviceability limit state requirements is intended to limit damage at moderate levels of earthquake shaking and therefore often determines the minimum strength of an element or of the building as a whole.

Often building owners and occupiers may also be interested in the damage potential to the building, including structural and non-structural items, and how this might affect business continuity and economic considerations. These aspects are beyond the scope of these Guidelines and the guidance provided will not necessarily address them.

For additional commentary in relation to Importance Level 4 buildings (as defined in NZS 1170.0) where there is arguably a wider community post-disaster life safety objective that supports consideration of SLS2 (ie the ability to continue to function), refer to Section A1.3.1.3.

A3.2.3 Consistent Expression of Seismic Performance

The assessment processes outlined in these guidelines, whether they are at the level of the ISA or the DSA, quantify seismic performance/behaviour as a seismic rating. The rating provides a measure of the expected performance from a life safety point of view, compared with the minimum required by the Building Code for new buildings. This is expressed as a percentage of the standard achieved from application of the building code requirements, or *%NBS*. The derivation of this term is discussed in more detail in Section A3.3.

Note:

The use of *%NBS* to describe the result from all levels of assessment (ISA through to DSA) is deliberate. The rating for the building need only be based on the lowest level of assessment that is warranted for the particular circumstances. The *%NBS* obtained from a full DSA process will likely be more reliable than that obtained during an ISA where only an exterior inspection has been completed, but the latter may be sufficient if the building is obviously either above or below the earthquake prone building threshold, if this is the primary purpose of the assessment.

Table A3.1: Assessment outcomes (potential building status)

Percentage of New Building Standard (<i>%NBS</i>)	Alpha rating	Approx. risk relative to a new building	Life-safety risk description
>100	A+	Less than or comparable to	Low risk
80-100	A	1 - 2 times greater	Low risk
67-79	B	2 – 5 times greater	Low to Medium risk
35-66	C	5 – 10 times greater	Medium risk
20-34	D	10 – 25 times greater	High risk
<20	E	25 times greater	Very high risk

In addition to the %NBS rating, the corresponding seismic ‘grade’ and relative risk should be indicated. Table A3.1 outlines the *grading system for earthquake risk* as developed by NZSEE in 2000.

Note:

The assessment processes outlined in this document are not intended to provide a means of predicting the actual performance of a particular building in a particular level of earthquake shaking.

Observations from actual earthquakes indicate that the performance of even quite similar buildings in reasonable proximity can vary over a considerable range and, therefore, any prediction must be associated with considerable uncertainty. This uncertainty arises from a lack of current knowledge but also the inability to predict, in advance, the considerable variability in the way in which the earthquake waves propagate from their source to the building, the way in which the building responds to the shaking due to the complex nature of building structures, involving the interaction of many elements, and the way in which the complex nature of the ground on which the building is sitting affects the building response.

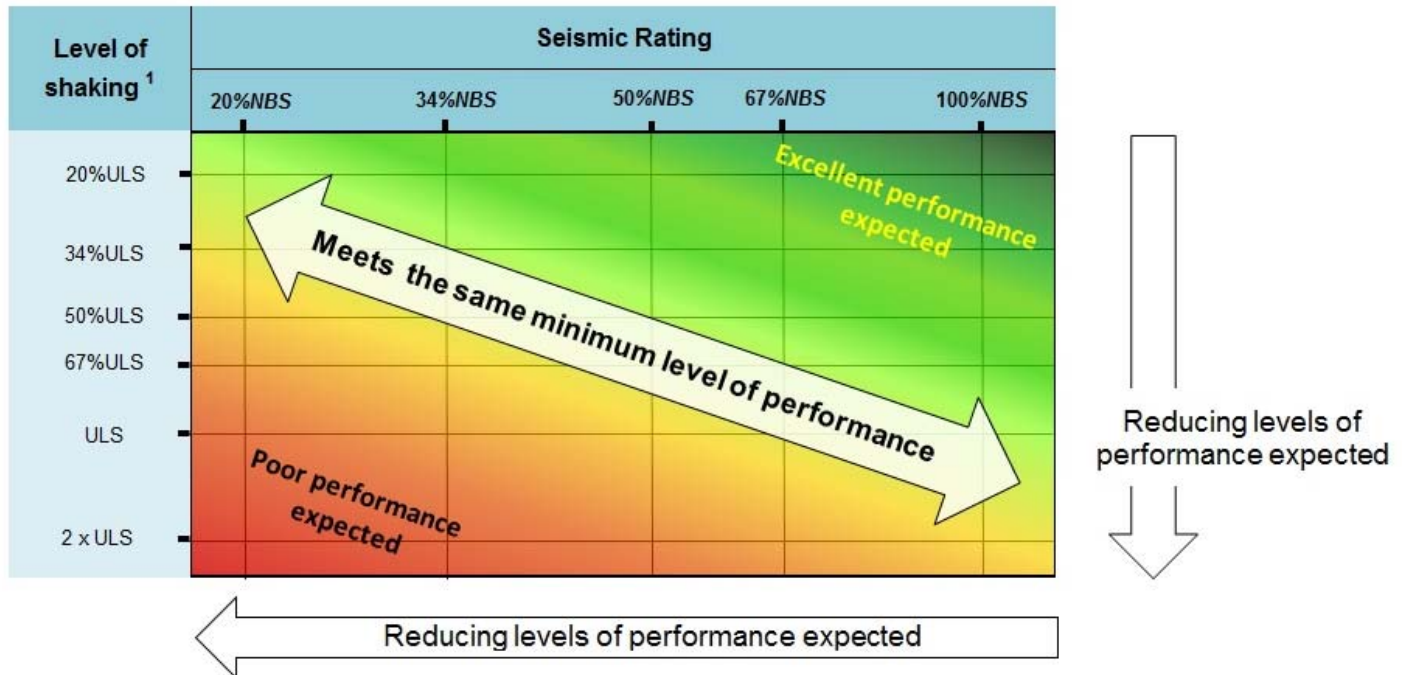
Therefore, it is unreasonable to believe that seismic performance can be predicted in absolute terms, and this means it should always be communicated within a probabilistic framework. This is however not easily done.

For these reasons, the approach taken in these guidelines is to assess how the building will perform compared with a new building that just meets the minimum seismic standard for life safety defined by the Building Code. This is achieved, in simple terms, by comparing various aspects of the building against the minimum standard for a similar new building. By definition, the minimum standard is assumed to provide an acceptable level of performance across all levels of earthquake shaking.

By adopting a measure of relative performance against a minimum acceptable level, it is possible to avoid the need to quantify the actual expected performance of the building.

The way this is achieved in these Guidelines is to determine a seismic rating for the building. The seismic rating is expressed in terms of percentage of the minimum standard that would apply to a similar new buildings, or %NBS.

Figure A3.1 illustrates the interpretation of the %NBS rating scale across all levels of shaking. In essence, a building will perform similarly (from a life safety point of view) to the lowest standard required of a compliant new building, when subjected to a level of shaking factored by the %NBS rating. For example, a building rated at 34%NBS, when subjected to shaking at 34% of the design level shaking for an equivalent new building, will perform to a similar level as a new, just code compliant building at the design (ULS) level of shaking.



Notes:

1. The diagram represents the tolerable (minimum) outcomes for buildings of any seismic rating, at any level of shaking.
2. For any seismic rating, the expected seismic performance represented on the vertical axis should be achieved over the full range of shaking.

Figure A3.1: Relationship between seismic performance, seismic rating and level of shaking

If the buildings are different, e.g. in configuration, size, material type, etc., a similar level of performance may not be expected at all levels of shaking by simply factoring by the rating. However, when compared with a new building, the performance at any level of shaking should be at least the minimum required level when the shaking is factored by %NBS.

Note:

For example, just as no compliant new building would be expected to collapse at 1.5 times the design level shaking, nor should a building collapse at 1.5 times the level of ground shaking associated with its %NBS rating.

It is not expected that the seismic rating be determined at multiple levels of shaking. The procedures outlined typically focus on assessing the building when it is subjected to the ULS shaking. Allowances are made within the assessment process to ensure that there is confidence that the building will also meet the minimum performance requirements at other levels of shaking while recognising that as the level of shaking increases, the level of reliability in the matching of the performance is expected to reduce. Often these allowances are inherent within the general process, but sometimes specific adjustments need to be made.

Discussion on how the %NBS rating is to be determined can be found in Section A3.3, and in Part B for the ISA and Part C for the DSA.

It is essential that the %NBS seismic rating given to a building reflects its expected relative performance. Therefore, a building should not be rated as 100%NBS unless there is

confidence that it will perform to the minimum level expected of a new building (life safety only) across all levels of shaking. If confidence does not exist that this will be the case, then a lower rating would be appropriate.

A3.2.4 Understanding and Determining Building Failure Modes

Building failure, in common language, implies the complete failure of a structure, resulting in widespread physical harm to the occupants. However, failure requires a more comprehensive definition for the purposes of building assessment. In a life safety context (as discussed in Section A3.2.2), building failure implies a form of failure that will lead to a significant life safety hazard (noting that the Building Act is also concerned with damage to adjacent buildings).

Once again, the differences between design and assessment are critical:

- When designing buildings, it is relatively easy to ensure that building elements will meet or exceed their target capacity (either strength or displacement). It does not follow that no elements will ever fail, but the design approach including, for example, the principles of capacity design generally provide confidence in the overall building performance. By detailing elements for the assumed ductility demand and keeping redistribution within code limits, designers are assured that elements are not pushed beyond their likely deformation capacity. This is especially critical of elements which carry significant axial gravity load.
- In assessment, it is important to address the implications of element failure more comprehensively. Failure of individual elements of a building does not necessarily lead to failure of the building as a whole.

For example, a beam which has its shear capacity exceeded may ‘fail’, but is likely to hang in catenary action and so would not be regarded a life safety hazard. However, a column that has its shear capacity exceeded also loses the capacity to resist simultaneous axial load and hence may cause a localised or more widespread collapse condition. The former does not limit the building capacity, but the latter does.

Limiting the building capacity to the capacity of the first failing element is unnecessarily conservative and may lead to expensive retrofit, which may not always be appropriate to the overall building behaviour. Instead, the consequence of failure of the elements will need to be addressed specifically, considering:

- the capacity of the structure to redistribute actions
- the deformation capacity of the elements once they have exceeded their elastic limits
- the potential consequences for life safety of failure of the elements.

Failure of a building as a whole may be considered to have been reached when elements of the building that support significant gravity load have reached their deformation limits.

This is illustrated in Figure A3.2 following.

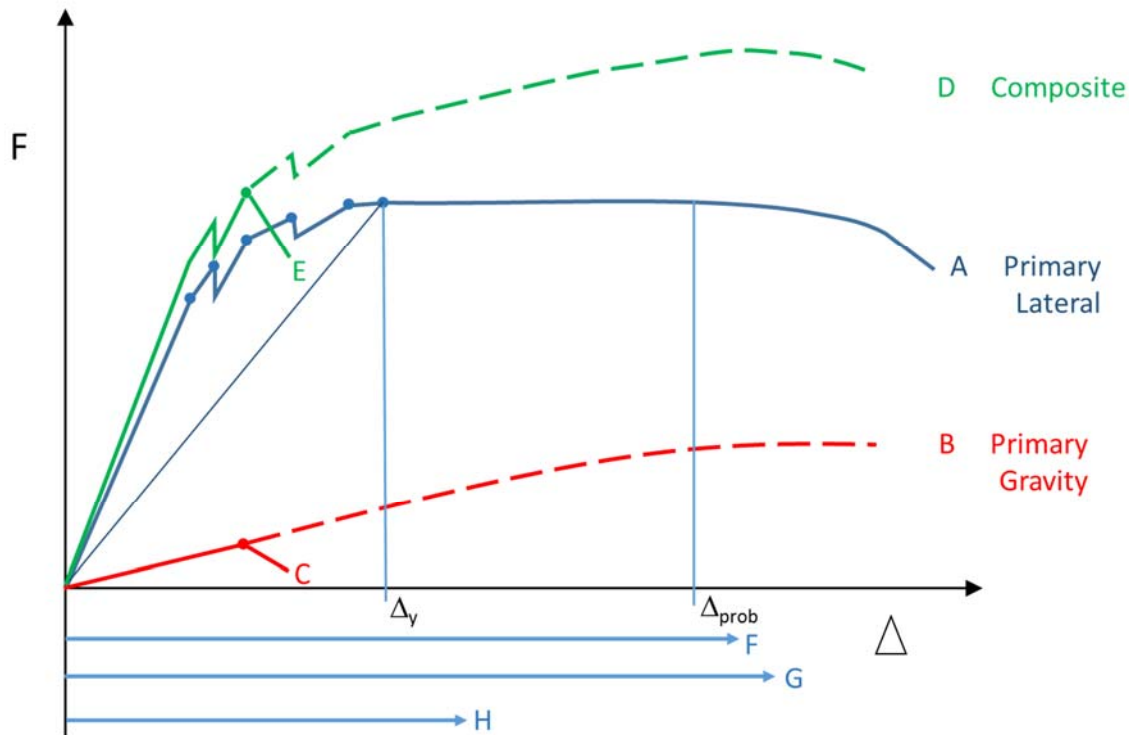


Figure A3.2: Force-deflection relationships for systems and individual elements

Curve A represents the capacity of the primary lateral system. As elements of the system yield, the stiffness drops. Elements that lose stiffness after yield may drop out of consideration or attain a residual capacity. In either case the overall strength and stiffness would drop. The last yielding element that forms results in a full yielding mechanism at Δ_y . When the system reaches the point where the capacity begins to degrade significantly, this is the full probable displacement capacity, Δ_{prob} , defining the system ductility. In this case the system has a displacement ductility of approximately $\mu = 2$.

Curve B (extending as a dotted line) represents a primary gravity system which has sufficient displacement capacity to tolerate the full displacement of the primary lateral system.

Curve C (solid line) represents a primary gravity system which does not have sufficient displacement capacity to tolerate the full displacement of the primary lateral system, for example the case of a gravity column failing in shear.

Curve D (extending as a dotted line) is a composite curve of both the ductile primary lateral and gravity systems, A and B. This may be derived from an analysis that combines both systems directly, such as a non-linear time history analysis, non-linear pushover analysis or in its simplest form, the Simple Lateral Mechanism Analysis (SLaMA) method. The increased strength capacity that is gained from having both systems included may be marginal, as the more critical issue is the deformation capacity of the full system but can still offer significant benefits especially if both strength and deformation capacity is used to determine the seismic rating, i.e. by using the displacement based assessment approach with the acceleration- displacement response spectra (ADRS) formulation of the seismic demand. Refer Part C1.

Curve E is a similar composite combination of curves A and C. From the perspective of the overall building capacity, this illustrates how a primary gravity system may limit the building capacity to less than the calculated capacity of the primary lateral system.

The straight lines (F, G and H) below the chart area represent consideration of parts that are not separated from the primary structure. Their strength is irrelevant in terms of the global building score, since they are not required to contribute to the overall building capacity, but their limiting displacement is critical. F and G illustrate parts that do not reach their limiting displacement capacity before the primary structure and therefore do not limit the building capacity, but H represents a part which will fail prematurely.

There are several discussion points that follow from this chart:

- The solid lines representing the system that is limited by the deformation capacity of the primary gravity system (curves C and E) require careful consideration.
- Conversely, the deformation capacity of the systems represented by the dotted lines (curves B and D) are not limited by the primary gravity system and so the primary lateral system determines the overall seismic rating for the building.
- In a complex building, there may be more than one primary system to consider, representing either parallel systems or different mechanisms.
- When considering parallel systems, the ability of diaphragms to redistribute forces and the stiffness of the diaphragm may become significant issues that need reconciliation.
- In other words, parallel systems must be considered separately when the diaphragms have insufficient stiffness and strength to redistribute loads to alternative systems.
- If a part reaches its deformation limit at less than the deformation of the primary system (as represented in Figure A3.2 by line H), then its score is less than that of the primary system and it may reduce the final seismic rating. However, it is important to report both the underlying primary system capacity as well as the limiting part capacity, as the consequences of failure for the part are likely to be quite different to the consequences of the primary system failure; and if the part is removed or upgraded, the seismic rating will increase to the underlying building score.

These issues are illustrated with reference to building types in Figure A3.3 below. Behaviours of two generic building types are illustrated, with the implications for the seismic rating indicated.

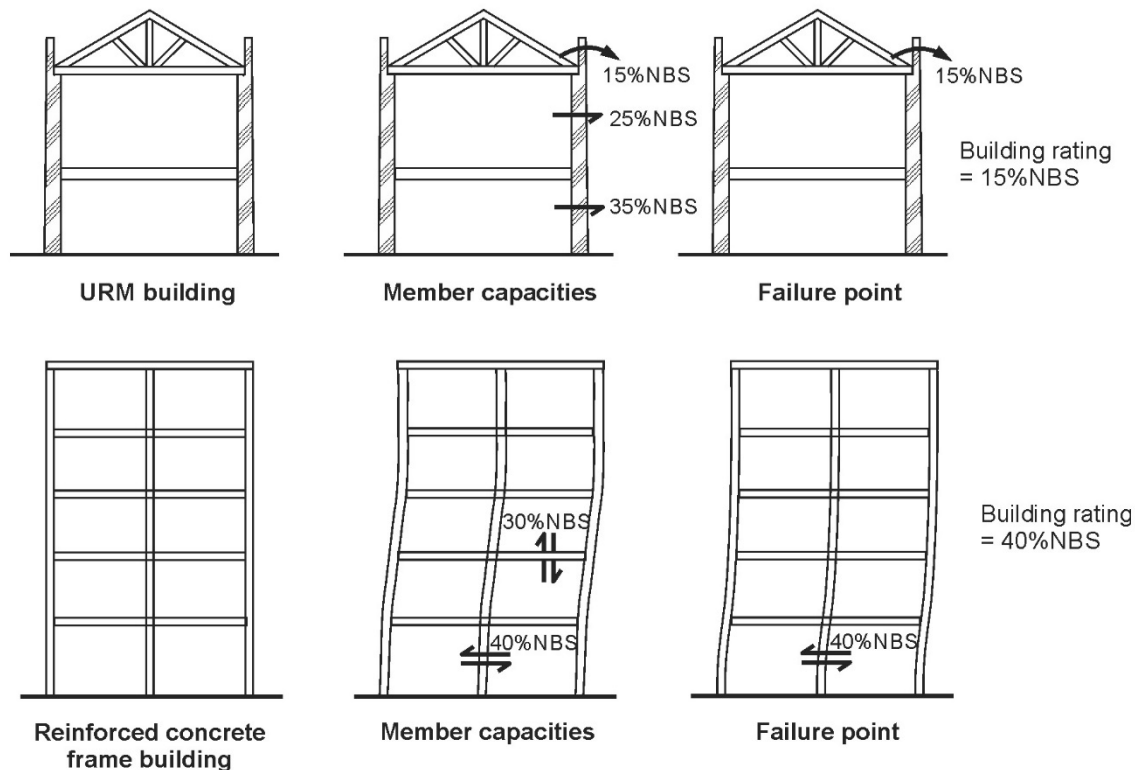


Figure A3.3: Illustration of the Calculation of %NBS for the Building as a Whole

In the case of the URM building, the limiting element is the parapet, at 15%NBS. The seismic rating will increase to 25%NBS if the parapet is upgraded and then to 35%NBS (no longer earthquake prone) if the upper level walls are upgraded.

The reinforced concrete frame building indicates two possible critical elements, a concrete beam which has capacity of 30%NBS and a column with 40%NBS. Assuming that the beam is not at risk of falling and/or dropping a significant floor area, it does not represent a life safety hazard in its own right. If its contribution to the overall seismic capacity can be redistributed among other elements, it does not limit the capacity of the system as a whole. However, the column clearly supports gravity load and so its failure does represent a life safety hazard. Therefore the overall building rating is 40%NBS.

A3.3 Percentage of New Building Standard (%NBS) Seismic Rating

A3.3.1 Introduction

The %NBS seismic rating is intended to provide a measure of the expected seismic performance of the building relative to the minimum that would meet the performance objectives set out in the Building Code (for new buildings) for life safety.

When establishing the %NBS rating, the procedures require consideration of the following in the context of the consequence to life safety:

- capacity of the building (both strength and deformation) defined as the *ultimate capacity (seismic)*

- degree of resilience available where this is not adequately accounted for in the assessment of the capacity
- expected behaviour of the ground on which the building is located and how this might affect the response of the building
- influence of adjacent buildings (pounding)
- behaviour of secondary structural items
- behaviour of critical non-structural items.

The other input into the calculation of %NBS is the *ULS seismic demand*.

A3.3.2 %NBS (Percentage of New Building Standard)

%NBS is obtained by dividing the calculated *ultimate capacity (seismic)* of the building by the *ULS seismic demand* as shown in Equation A3.1.

$$\%NBS = \frac{\text{Ultimate capacity (seismic) of the building}}{\text{ULS seismic demand}} \times 100 \quad \dots A3.1$$

where: *Ultimate capacity (seismic)* of the building is taken as the lesser of:

- Probable capacity of the primary structure of the building including the impact of geotechnical issues. Refer Section A3.3.3.
- Probable capacity of secondary structural items, the failure of which could lead to a significant life safety hazard. Refer Section A3.3.4
- Probable capacity of critical non-structural, the failure of which could lead to a significant life safety hazard. Refer Section A3.3.4
- Capacity assessed for any identified SSWs. Refer Section A3.3.5

ULS seismic demand as described in Section C1.5.6, including the appropriate value of S_p (the structural performance factor). Refer Section A3.3.6 below for further discussion.

This is essentially the same for both the ISA (typically via the Initial Evaluation Procedure (IEP)) and the DSA. For the ISA (IEP), %NBS for the primary structure is assessed *qualitatively* against the design requirements that would have applied at the time the building was designed (adjusted for presence of structural weaknesses and the presence of secondary and critical non-structural items), whereas for the DSA it is determined *quantitatively*.

The seismic rating should always be quoted together with the Importance Level that was assumed to determine the ULS seismic demand. The recommended representation is:

XXX%NBS (ILY)

A3.3.3 Ultimate Capacity (Seismic)

The ultimate capacity (seismic) is based on the same definition provided in A1.4.2.2 with respect to the Building Act – ie for any assessment objective, not just for consideration of whether or not a building is earthquake-prone.

The ultimate strength and deformation capacities are based on probable or expected values. Careful consideration of the effect of variations in the material strengths will be required to ensure that the hierarchy of strength within mechanisms is fully understood.

The objective is to identify the probable capacity of all potential structural systems and mechanisms, including, where appropriate, the influence of the foundation soils. The elements that limit the capacities of these systems and which would have a life safety consequence if they exceed their capacity are referred to as structural weaknesses (SWs). The SW that limits the capacity of the building is referred to as the critical structural weakness (CSW). At the ISA level of assessment, all identified SWs are considered to be *potential* CSWs until a DSA can determine which of these is the CSW.

Particular care also needs to be taken to also identify all SWs that relate to the primary gravity systems.

If the CSW is addressed by retrofit, the SW that next limits the building capacity becomes the CSW and so on. Accordingly, listing the SWs and their effect on the capacity of the building is important for understanding the sensitivity of the results and invaluable when determining any retrofit strategy.

A3.3.4 Structural resilience

The %NBS seismic rating must reflect the ability of the building to continue to perform in earthquake shaking beyond the ULS shaking levels. This ability is defined as the *available structural resilience*.

Structural resilience is necessary to allow a building to meet the overall performance objectives set in the Building Code. These objectives would not be met if the building had a high probability of failure once the ULS loading levels are exceeded. Structural resilience is inherent in most building systems as observed from actual building performance in earthquakes that exceed ULS levels of shaking.

However there are some systems that experience indicators have little structural resilience, are susceptible to a sudden reduction in their ability to continue to carry gravity load as the earthquake shaking increases beyond a particular value, and are difficult to quantify based on current knowledge or inability to analyse. These are referred to in these Guidelines as *Severe Structural Weaknesses* (SSWs). If SSWs are present they require careful assessment and a process that ensures that there is sufficient margin against them causing system failure.

The general criteria for a SSW feature is that it must satisfy **all** of the following criteria:

- **has a demonstrated lack of structural resilience** so that there is very little margin between the point of onset of nonlinear behaviour (e.g. cracking of structure or large deformation of soil) and step-change brittle behaviour of the building that could result in catastrophic collapse, and
- **has a severe consequence** if catastrophic collapse occurs. A severe consequence is intended to only be associated with building typologies with potentially large numbers of occupants and where the mode of failure could lead to full collapse, and
- **where there are recognised limitations in the analysis and assessment of the behaviour** so that the reliability of the assessment of probable capacity of the expected aspect is low. This could be simply because there is currently considered to be

insufficient experimental data or experience to confirm the behaviour to generally accepted levels of reliability.

The currently identified potential SSWs (ISA) and actual SSWs (DSA) are listed in Sections B3 and C1 respectively, and cover aspects such as columns and walls in multi-storey buildings with high levels of axial load under dead and live loads, significantly inadequate connections between floor diaphragms and lateral load resisting elements and complex slope failure situations.

The manner in which the effect of the SSWs are to be accounted for is covered in Part B and Part C for an ISA and DSA as appropriate.

A3.3.5 Geotechnical considerations

Geotechnical issues are covered in a similar manner to Structural Weaknesses. To affect the calculation of %NBS, the impact of the behaviour of the ground on the building must lead directly to a significant life safety consequence.

Ground conditions influence the behaviour of buildings in several ways, depending on the nature of the ground, the likely building behaviour and the nature of the earthquake. Some of these are discussed below.

The first direct influence is on the seismic actions, as the soil class is a critical input to the spectral shape factor in NZS 1170.5. For ISAs and relatively simple DSAs, it will generally be suitable to infer the soil classification from local knowledge, surrounding buildings and desktop study if required. For a more complex DSA and where the soil classification may have significant impact on the outcomes, more detailed investigation may be required.

Soil structure interaction effects at foundation level may have significant influence on the assessment in cases where there is significant non-linearity, either through the behaviour of the soils, for example in cases involving liquefaction, or through the behaviour of the building itself, for example where foundation rocking occurs.

Non-linear behaviour in the soil requires careful consideration but a key question to consider in all cases, is whether the non-linearity is an impact on life safety or simply amenity and serviceability. Only life safety concerns need to be addressed in assessing %NBS, although in some cases, the brief may include a request to consider serviceability. That is beyond the scope of this document, although some of the guidance may be relevant.

The most obvious form of soil non-linearity is liquefaction, but it is important that the impact of liquefaction on building behaviour is considered before embarking on exhaustive geotechnical analysis. The significant settlement that results from widespread liquefaction may not have any significant impact on life safety, especially if the foundations are well connected and when there is an element of toughness in the building superstructure. Conversely, even relatively nominal differential effects may have a significant life safety impact on unreinforced masonry buildings with isolated footings.

Rocking of foundations (that often have been designed originally as fixed base foundations) has often been regarded as the saviour of buildings that may otherwise have been significantly overstressed by larger earthquakes. Rocking has the effect of lengthening the building period and consequently increasing the displacements of the system. In many cases,

this will not be critical, but the consequences of the additional displacement must be considered, particularly on the primary gravity structure, which must ‘go along for the ride’.

A3.3.6 ULS seismic demand

This is the demand determined from the current version of NZS 1170.5.

The demand may be different when determining %NBS to check for earthquake-proneness. Then, the demand is determined from NZS 1170.5:2004 (including amendments X X X), which may not be the current loading Standard.

The quantification of the seismic demand is required for the DSA and is discussed further in Sections C1 and C3.

A3.4 Different Levels of Seismic Assessment

A3.4.1 Introduction to ISA and DSA

The Initial Seismic Assessment (ISA) is a largely qualitative procedure that takes into account the known attributes of a building in order to provide a simple assessment of the seismic rating. An ISA may include limited quantitative analysis if an assessor feels that further knowledge is required of specific element performance to augment the overall assessment.

An ISA should generally be performed as the first part of a seismic assessment, as it provides a valuable ‘first look’ at the likely building performance and provides a valuable benchmark against buildings of similar age and of similar characteristics.

The ISA procedure is outlined in Part B.

A Detailed Seismic Assessment (DSA) is a quantitative procedure that may take several forms. The DSA procedures have been developed specifically for the assessment of existing buildings and it is important to note that the DSA is not simply a reversal of the design process for new buildings.

A DSA may be used to determine a seismic rating for a building, and to provide final confirmation of whether a building is earthquake prone or not. It may also be used as the basis for improving seismic performance, both as a benchmark for existing (unimproved) capacity and to test proposed upgrading strategies.

Whether assessors are undertaking an ISA or DSA, it is important that the quality and quantity of data discovered on the form and condition of the existing building is appropriate to the level of reliability required for the assessment.

The EPB Methodology will also specify requirements for assessments under the new earthquake-prone building framework.

A3.4.2 Assessment Continuum

The ISA and DSA processes presented in these guidelines make up a continuum in seismic assessment. This is represented in Figure A3.4.

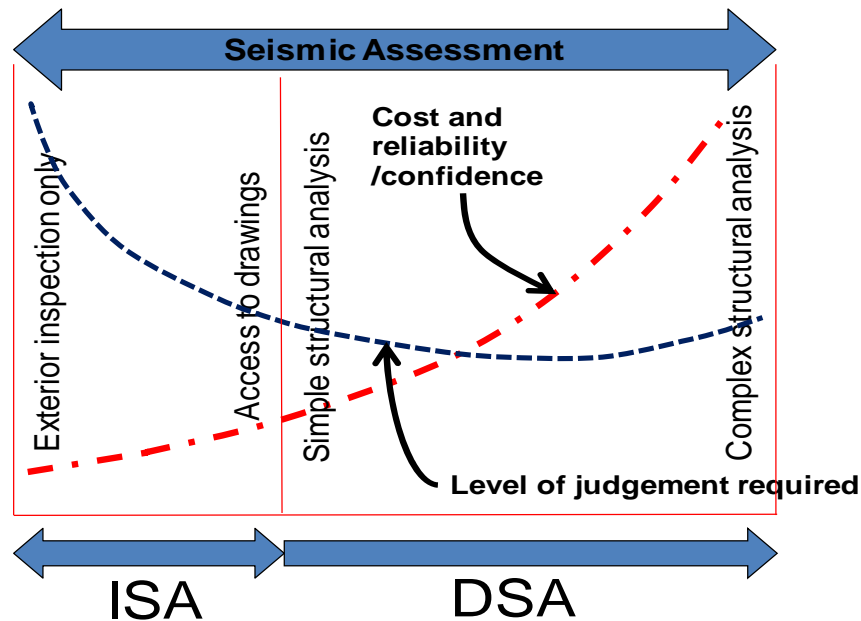


Figure A3.4: Assessment continuum

Each of the ISA or DSA processes can be carried out with a varying degree of knowledge and detail. At the extremes, a well-executed ISA may yield a result that is at least as reliable as a DSA carried out using very simplistic analyses.

Generally, however, the further the assessment processes moves to the right in Figure A3.4 the more reliable should be the result, albeit at generally greater cost for the assessment.

At all levels of assessment, the judgement of the assessor is an important input. As shown indicatively in Figure A3.4 the level of judgement required is highest during an ISA when there is little data on which to base the assessment. The level of judgement reduces as the assessment proceeds from ISA to DSA as the understanding of the attributes of the building become clearer. However, the need for judgement/experience rises if more sophisticated analysis techniques are employed in a DSA because the results can become very dependent on the inputs, and experience will be necessary to judge if the results are reasonable and valid.

A3.4.3 Distribution of Assessment Outcomes

All assessment involves assumptions of:

- the materials used in the original construction
- the structural mechanisms that will form as the level of shaking increases
- the founding conditions for the building
- the alterations to the building over time.

As the assessment proceeds, assumptions are validated or changed to suit what is learned. The more assumptions that are validated, the greater the knowledge of the building's likely behaviour. Hence the assessment may be considered more reliable.

Of necessity, the more unverified assumptions are involved, the more conservative the assessment of capacity should be, relative to the actual capacity of the building. This is illustrated in Figure A3.5 below.

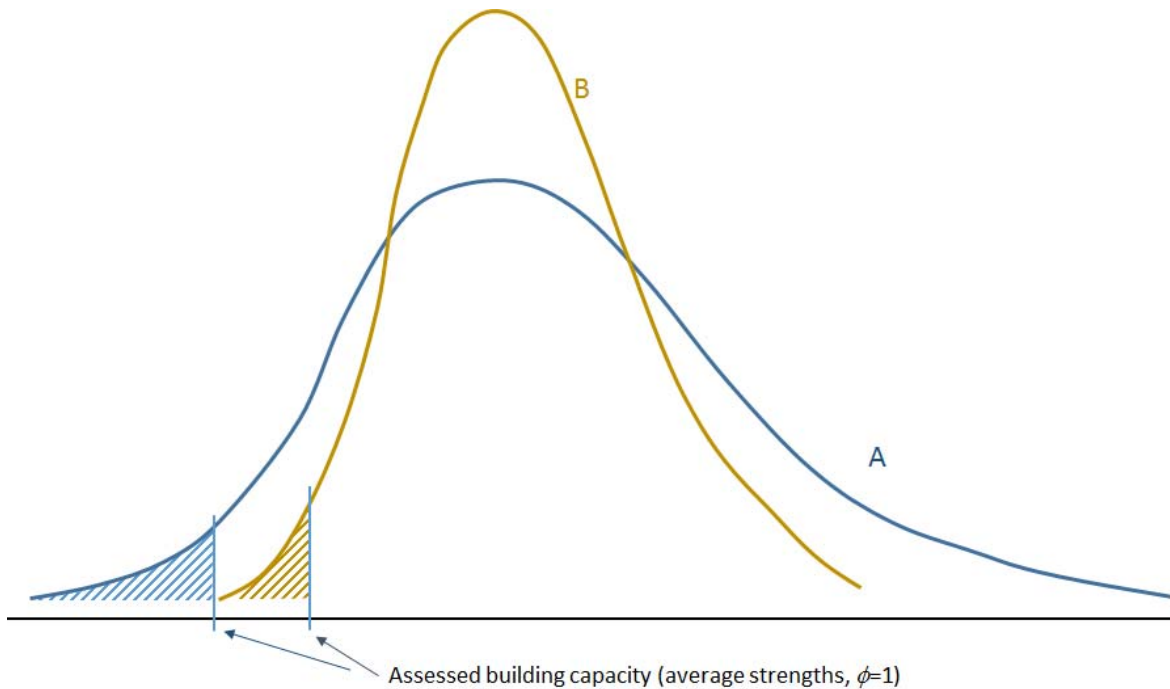


Figure A3.5: Distribution of Assessments

The two curves represent a hypothetical population of identical buildings assessed using two different methods. Method A may represent a detailed assessment using a simplified analysis with a large number of unvalidated assumptions. Curve B may represent a detailed assessment using more complex analysis and/or a greater level of validation of assumptions. The more assumptions that are validated and the more comprehensive the modelling process, the narrower the bounds of the assessment outcomes will be.

The assessed seismic rating should never match the actual capacity of the building. Although the assessment may use probable (average) material properties instead of lower characteristic values and no capacity reduction factors, there are other factors that introduce an element of conservatism, notably in the algorithms that are used to calculate capacities and in the displacement and rotation limits that are used to assess building elements.

It is a matter of judgement as to how much effort should be expended in refining the assessment, either by completing more extensive (and possibly destructive) investigation of the building itself, or by using more elaborate methods of assessment. In some cases, it may be more appropriate to expend the time (and cost) on improvement, especially in cases where the building is clearly earthquake prone.

Note:

Additional information and new findings over the course of an assessment may reduce (or increase) the assessed building capacity.

A3.4.4 Level of Detail of Assessment

Assessment of existing buildings requires considerable judgement to be exercised, not least in determining what elements of the building require assessment and how detailed that assessment should be.

There are two generally useful principles¹ that assessors should be mindful of:

1. The *Principle of Requisite Detail*, which states that there is a minimum level of detail necessary in a (system) model for adequately emulating the reality which is intended to be modelled. In other words, it is important that assessors do not over-simplify the assessment to the extent that poor behaviour of a building is not identified or captured.
2. The *Principle of Decision Invariance*, which states that the system should be sufficiently detailed that the addition of further refinement will not affect the decision. The point here is that there is no value in making models ever more complicated or comprehensive in the name of accuracy, if the additional detail makes no difference to the outcome; in fact, it may serve to obscure the outcome and simply add time and cost to the assessment.

It may often be the case that until a model has been run and the hypothesis tested, a suspected outcome cannot be discounted. However, there is little point in modelling elements to a high level of detail, if there are other aspects of the building that have much more significance for the overall performance, within the broad range of interest of the assessment.

Note:

Boundary conditions assumed in modelling often play a critical role in the assessment and should be carefully considered. An example of a critical boundary condition is whether to assume a fixed base condition under a shear wall. If a fixed base is assumed, the building model may be artificially stiffened, shortening the period and increasing demand, which may at first look conservative. However, this may also have the effect of decreasing the displacement of the system, which may artificially reduce deformation demand on the primary gravity and secondary systems. Conversely, if the wall is modelled with too soft a foundation support, the base may over-rotate, reducing load demand but possibly over-estimating drifts.

A realistic assessment of the geotechnical conditions is one of the most important boundary condition assumptions for building modelling. It is advised to consider a range of options for soil stiffness when modelling building systems for which this may be critical. Typically, this will occur when there are soft soil conditions and/or where assessing building types that are vulnerable to significant ground deformations. This includes in particular unreinforced masonry, which has relatively little tolerance to ground deformation. At the other extreme, most moment frame structures should be able to tolerate significant differential settlements.

¹ Brown & Elms, Engineering decisions: Information, knowledge and understanding, Structural Safety 52 (2015) 66-77, Elsevier.

A3.4.5 Off-site hazards

Comment:

The assessment should also consider the nature and implications of off-site hazards that may impact on the building being assessed. These may not directly affect the seismic rating of a building, but nevertheless have implications for the overall seismic risk and should be reported alongside the seismic rating. Factors that may be specifically considered include:

- adjacent buildings. Hazards that may have a direct effect on the seismic rating include pounding. Hazards that may have an indirect effect include adjacent walls or parapets that may topple onto the building being assessed.
- rockfall or slope instability
- tsunami hazard.

While these matters are outside the scope of consideration for earthquake prone buildings and life safety as implied in these guidelines, they are nevertheless significant factors in an overall risk assessment. Such hazards should be noted in the assessment report.

A4. Planning a Seismic Assessment

A4.1 Introduction

This section outlines the steps involved in planning a seismic assessment, which involves working through the steps of briefing, gathering information, carrying out physical inspections and investigation, undertaking initial qualitative assessments followed by quantitative assessments to the extent considered appropriate.

Emphasis is placed on developing a strategy and approach that reflects both the assessment objectives and the nature of the building, taking into account the level of available information.

A4.2 Assessment Procedure

A generalised assessment process is as illustrated in Figure A4.1. The steps in the process are summarised in the sections that follow.

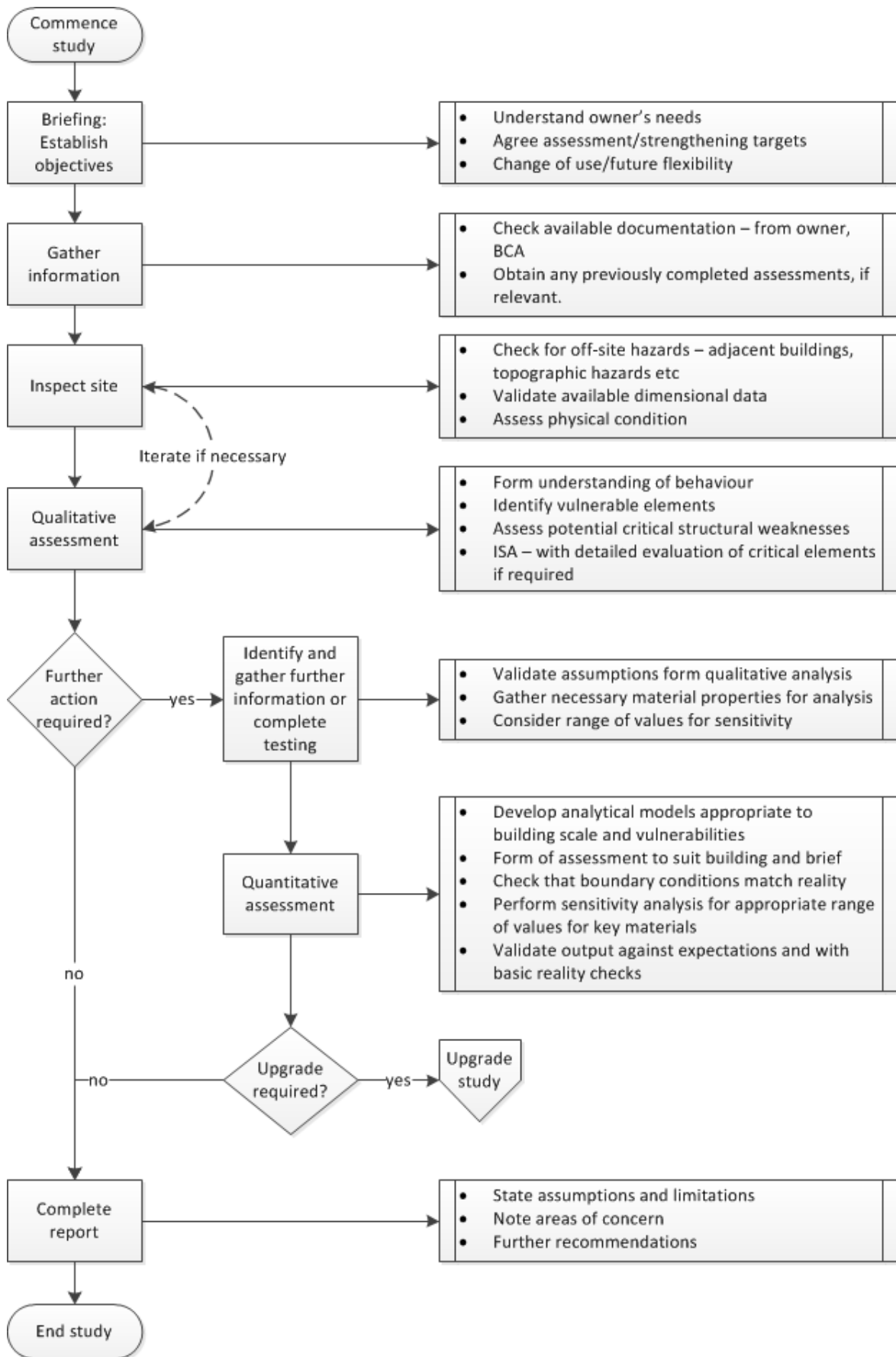


Figure A4.1: Generalised Assessment Process Flow

A4.2.1 Briefing - Clarifying Scope and Objectives

Before commencing an assessment, the brief should be clearly understood. This is not always clear cut, as building owners or occupiers are often unsure what they need, beyond the need for an assessment of whether or not their building is earthquake-prone and what that may mean for them.

At its simplest level, this may be all that the client thinks that they require, but it is important to verify this carefully. There are more questions that need exploring, including:

- What is driving the need for the study? In particular, consider whether potential alterations or change of use requirements may force the evaluation at a higher level than the earthquake-prone assessment.
- Does the client wish the study to be limited only to those aspects of the building that require assessment under the earthquake-prone building regulation, or do they require the scope expanded to address a broader range of secondary structural and non-structural elements?
- Does the client wish the building to be assessed for more than simply earthquake-proneness?
- Is the assessment in response to another assessment (e.g. by a TA). If so does the scope of the proposed assessment address all of the issues that have been raised?
- Are upgrading options to be considered, and if so, what is the performance target (noting that this is partly about the target loading, partly about the tolerable damage that will be acceptable)? Are there multiple performance objectives?
- Do future insurance requirements have a bearing on the decisions that may need to be taken for the building?
- Does the building have a heritage rating, and/or what are the major heritage features of the building that must be retained?

Accepting a brief from a client is an opportunity to develop an understanding of their needs.

It is recommended that a reflected brief should be prepared and returned to the client for approval before finalising a contract, in order to reduce the potential for miscommunication of expectations.

A4.2.2 Gathering Information

Assessment of existing buildings requires careful information gathering, the level of which may vary considerably according to the building type and the purpose of the assessment. In general, the more complex the building and the more detailed the study, the more care should be taken to assemble the information required.

Equally, it may be possible to complete an ISA with limited information on key aspects of the building only, to a level that may be sufficient for the purposes of determining whether or not a building is potentially earthquake prone. There may be limited value in obtaining further information if this is the sole purpose of the assessment.

Information gathering is generally iterative. It may be more time efficient in many cases to perform preliminary analysis using relatively approximate data, in order to come to an initial understanding of a building; this may then inform the subsequent detailed information

gathering. A targeted information gathering process may then be developed that places more emphasis on the most critical elements.

Equally, it is often found that a study may be limited by the information available. In such cases, the underlying assumptions should be clearly stated and recommendations made on further information that is required to give a more comprehensive assessment. In such cases, a reasonably conservative set of assumptions may be appropriate and should be based on knowledge of the generic details of the age and form of the construction.

Note:

Information gathering should include obtaining access to any prior assessments. All previous views should be taken into account when reviewing a building, although care must be taken to verify any differences in the briefing requirement, particularly when these may lead to differences in the assessment outcomes.

A4.2.2.1 Accessing documentation

Building documentation may be held by a number of sources, including:

- Territorial authorities
- Building designers (from both original design and for subsequent alterations)
- Builders
- Owners, either original or subsequent
- Facilities Maintenance contractors.

It is important to note that the documentation provided may not always be the most current. It is quite common that construction documentation varied considerably from consent (or permit) documentation, and old records often contain a mix of structures that were built and others that were not. Documentation for subsequent alterations may not always be archived or stored with the original documentation. Assessors must satisfy themselves thoroughly before relying on documentation that it is representative of the building being studied.

Documentation may not be available for all buildings, in which case more reliance must be placed on inspections and testing to provide enough information to complete the assessment.

A4.2.2.2 Inspections

A visit to the building is a key part of the assessment process and should be completed as part of both an ISA and a DSA.

It is possible that an ISA may be completed using only external inspection. Where this is the case, it should be noted in the report so that suitable allowance can be made for this when the assessment is being used by others.

An initial visit (prior to undertaking any analysis) is essential to develop a broad understanding of the building and to verify that the documentation obtained is truly representative of the building. The assessor would generally have made a qualitative evaluation of the building first, in order to identify key elements or details for review. Matters to be considered include:

- verification that the general arrangement of the building matches the drawings or assumptions
- checking of key dimensions for overall accuracy
- consideration of neighbouring buildings – assessment of the potential for pounding and adjacent building behaviour
- consideration of the likely geotechnical conditions and how these may vary with shaking intensity (including accounting for variability)
- consideration of off-site hazards, such as landslide
- general condition assessment – can key elements develop their calculated probable capacity?
- identification of key configurational issues, such as irregularity, diaphragm openings, etc.

Note:

Fundamental differences between available drawings and what has actually been built can be observed, even from a relatively brief exterior inspection at the time an ISA is completed. A full inspection to confirm details and potential interaction of primary structure with secondary structural and non-structural items is considered an essential part of a DSA process.

Subsequent visits will be required to investigate key elements and details more closely. This will normally follow sufficient analysis to have a preliminary opinion of the building behaviour, allowing investigation on site to verify that the most critical elements are as analysed.

A4.2.2.3 Geotechnical Investigation

All building assessments require some consideration of the geotechnical conditions, for the assessment of demand, for the assessment of soil-structure interaction and for the assessment of capacity.

The level of geotechnical investigation required may vary from a desk-top study for relatively small structures on ‘good’ ground (i.e. unlikely to be subject to significant differential settlement or liquefaction) for the purposes of determining earthquake-proneness, to comprehensive studies for large, complex structures on ground with the potential for significant differential settlement.

In general, it is recommended that the level of investigation required is determined in conjunction with a suitably experienced geotechnical engineer who has a level of familiarity with the likely site conditions.

Soil conditions may be assumed, based on knowledge and experience, for qualitative analysis. However, such assumptions should be clearly described and should be verified on site in the event that further quantitative analysis is required.

A4.2.2.4 Intrusive investigations

Intrusive inspection may be required for the verification of key details and for material testing.

In the case of verification of key details, assessors must be aware of the potential for variation within the building and choose enough locations throughout the building to have an appropriate degree of confidence in the assumptions that are being made. This may vary according to factors including the criticality of the details being investigated, the stage of the assessment, and the convenience of exposing the details.

For example, in URM buildings, the floor-wall connections are critical. At the preliminary stages of assessment, it may be sufficient to expose only one or two locations to verify whether there are any connections at all, i.e. is there a load path. In later stages, the precise detail and spacings may be critical, in which case further investigation may be required.

Where investigation requires a level of destructive testing or exposure of concealed elements, locations should be selected carefully to provide all of the information that may potentially be required. For example, if exposing reinforcement in concrete buildings, locations should be selected to verify not only the size and location of the reinforcement, but also key detailing and conditions that may affect underlying assumptions. These include:

- Are the bars plain or deformed?
- Where are the laps located relative to potential plastic hinges?
- Where is the transverse (confining) steel and how is it anchored?
- What is the condition of the reinforcement in key locations?

A4.2.3 Assessment

A4.2.3.1 Qualitative assessment

The first step in any building evaluation should be a qualitative assessment. Qualitative assessment is a vital predecessor to quantitative analysis. It informs the assessor of the key elements of the building and assists in focusing the subsequent detailed evaluation.

This requires the assessor to consider not only the intended mechanisms that may have been envisaged by the original designer, but also the combined effect of unrecognised load paths, structural incompatibilities (that may be better understood now than at the time of design) and the impact of alterations over time. The last may include the effects of time itself, that is, aging of the building and maintenance (or lack of it).

The initial assessment of a building should include assessment of available plans and specifications; but this should always be approached with caution. Often the plans that are available are not those that were built from and may not include subsequent alterations. Moreover, then as now, buildings were not always built according to the plans. Part of the role of the assessor is to consider the possible impact of these variables and make reasonable allowance for them in the assessment.

Qualitative assessment should include (but is not limited to) an IEP. This is at the least a useful benchmarking exercise which enables assessors to consider at a high level those attributes of the building that may have significant impact on the behaviour of the building. By approaching this in a qualitative sense before detailed assessment, it gives a sound basis for self-checking of the outcomes of future detailed analysis.

Qualitative assessment may include some ‘back of envelope’ calculations of key element capacities and demands, in order to test the criticality of mechanisms or details and to verify the findings or judgement calls of an IEP.

A4.2.3.2 Quantitative assessment

Quantitative assessment generally consists of a DSA in the form outlined in Part C. It is informed by the findings of qualitative assessment, which should assist in the determination of likely failure mechanisms that should be investigated in more detail.

Prior to commencing quantitative assessment, the outcomes of the qualitative assessment should be reviewed, with emphasis on what matters may need to be included in a detailed assessment, including consideration of:

- Is further investigation required to confirm assumptions made in the qualitative assessment?
- What boundary conditions have been or will be assumed and how do these relate to reality?
- What foundation conditions have been assumed?

Geotechnical conditions are a key consideration for quantitative analysis, requiring a suitable degree of investigation in order to validate assumptions and to provide the required inputs for detailed evaluation.

Note:

Particular emphasis should be given to the impact of significant differential settlements, with close attention being paid to the range of possible outcomes. For example, in sites that may be considered likely to undergo significant liquefaction at a given level of shaking, consideration should also be given to the possibility that liquefaction does not happen. In such cases, liquefaction may be considered to be a limiting factor for the building’s capacity, but a premature failure of a brittle element under higher levels of shaking may represent a greater risk for occupant life safety.

A4.2.4 Establishing the Assessment and Analysis Strategy and Approach

The assessment procedure followed will be determined according to a number of factors, including:

1. **The objectives of the study.** If the primary purpose is simply to establish whether a building is earthquake-prone, it may be enough to complete an ISA, based on relatively generic information. However, if a client requires a more comprehensive assessment of the risks for a building for other purposes, that may determine the need for a detailed assessment.

2. **The complexity of the building.** Although scale may determine the risk (as it impacts occupant numbers), the complexity of the structural form is a more significant factor in determining the assessment methodology.

For example, simple, regular, low-rise structures may be assessed using a combination of an ISA with specific analysis of identified critical elements to establish an overall %NBS rating. The scale of such a building may not be relevant, provided that the load paths are simple and the building may be relied upon to respond in a regular fashion. Conversely, a mid-to-high rise building with significant irregularity (for example a corner building with walls on the internal boundaries) is likely to behave poorly, and is likely to require a full higher order analysis.

3. **The degree of influence of soil conditions.** This can be a significant influence, particularly when there is potential for significant differential settlement, with or without liquefaction. The analysis of buildings should include appropriate allowance for soil non-linearity, foundation flexibility and possible variations (through sensitivity analysis).

In all cases, assessors must consider the limits of applicability of the assessment processes being considered. This is particularly important when assessing buildings with mixed systems and/or unknown ductility demand, or irregular buildings with diaphragms of sufficient rigidity to redistribute actions between lines of support (ie. the potential for torsional response).

A5. Reporting Seismic Assessment Results

A5.1 Introduction

It is important to report assessment results in an appropriate context, even at the ISA level.

To this end it is recommended that the determined seismic rating, together with the assumed Importance Level, is provided, noting that it has been determined in accordance with the requirements of these guidelines. The accuracy of the rating should reflect its reliability as discussed in Section A5.2.

The seismic rating should be followed by a discussion of the appropriate seismic grade in accordance with Section A5.3 and finally a discussion on the relative risk and level of risk in qualitative terms as described in Section A5.4.

Note:

Adherence to these recommendations is considered essential. It is very important that the assessor correctly describes the result of the assessment in terms that define the scope of the assessment.

Just providing a %NBS rating without defining the Importance Level assumed, indicating that it relates solely to a seismic evaluation or that it has been carried out in accordance with these guidelines could suggest that the building meets the new building standard generally (i.e. including gravity and wind, etc.) and earthquake provisions in particular without inclusion of the existing building concessions outlined above.

Inclusion of a discussion of the grading and level of risk is considered important to put the seismic rating in context. Without this there is no reference point for the rating and the need for immediate action (e.g. decamping from a building) may be implied but not intended.

A5.2 %NBS

The assigned %NBS seismic rating should reflect the reliability/accuracy implied. For this reason, ratings should only be quoted as a whole number. Except for 33, 34, and 67%NBS seismic ratings which are close to the earthquake-prone and earthquake risk thresholds respectively, it is further recommended that the scores be rounded to the nearest 5%NBS (up or down). Table A5.1 indicates the intent.

Table A5.1: Rounding of %NBS Seismic Ratings

Raw (Assessed) rating	Assigned rating for reporting purposes
29%	30%
32%	30%
33%	33%
34%	34%
35%	35%
36%	35%

43%	45%
64%	65%
66%	65%
67%	67%
68%	70%
73%	75%

Providing specific scores above 100%*NBS* is also to be discouraged as these may provide an erroneous indication of actual performance. It is recommended that such scores are simply stated as >100%*NBS*.

Assessors should consider carefully before rating a building between 30% and 37%*NBS* or between 65% and 70%*NBS*. If the assessment is at the ISA level, the ramifications of these ratings are potentially significant in terms of additional assessment required and often for arguable benefit. If a DSA is being carried out, more detailed consideration of the CSW might move the rating away from these critical ranges. Refer to Part B for further discussion on the reliability available from the ISA and how to deal with this.

The Importance Level assumed when setting the demand, and therefore the basis for the seismic rating, is critical to establishing the standard to which the building has been assessed.

A5.3 Grading Scheme

In addition to the use of a %*NBS* seismic rating, NZSEE have developed a corresponding grading system. This enables banding of assessment results so that there is less emphasis given to the actual percentage value of the seismic rating.

The wider objective of the grading scheme is to raise industry awareness and allow market forces to work in reducing earthquake risk.

The NZSEE grading scheme and the linkage with the %*NBS* seismic rating is summarised in Table A3.1.

Note that the grading scheme is not required by the current earthquake-prone legislation. However, is seen as a highly desirable risk communication tool to bring about improvement of structural performance over time.

Note:

Other grading schemes are also currently under development, e.g. Quakestar. These are likely to consider a broader range of seismic issues extending beyond life safety and structural aspects.

A5.4 Qualitative Risk Classification

Providing a qualitative risk classification is also considered useful in putting the assessment results in context when they are communicated.

The intended risk classifications are shown in Table A3.1.

Buildings that are classified as earthquake-prone in the Act (i.e. $<34\%NBS$) are regarded as High Risk Buildings. Those with $\geq 67\%NBS$ are regarded as being Low Risk. This leaves a group in between that meet the requirements of the Act but cannot be regarded as Low Risk. These have been termed Low to Medium Risk.

Comment:

For many years NZSEE has referred to buildings $<67\%NBS$ as being Earthquake Risk. Broadly speaking, these can be assumed to be all buildings not classified as Low Risk

A5.5 Reporting Templates and Frameworks

Within Part B, a reporting framework and covering letter for Initial Seismic Assessments is provided (Appendices B4, B5 and B6). A corresponding framework is provided in Appendix C1A of Part C for Detailed Seismic Assessments.

A template for summarising the key points from a Detailed Seismic Assessment is also presented. In the form of a table to be made available as a separate file, it is proposed that this summary be included at the front of all DSAs using the new Guidelines, as a means of enabling more consistency in the information provided and the way it is provided, and hence clearer communication between all parties.

All judgements made need to be justified/substantiated, and preferably recorded as part of the assessment process.

A5.6 Dealing with Differences in Assessment Results

Due to the nature of the seismic assessment process, it should not come as a surprise that, in some circumstances, assessments of the same building by two or more experienced engineers may differ – sometimes significantly. This is to be expected, especially if the level of information available was different for each assessor. This will particularly be the case for seismic ratings determined using the ISA process, but should also not come as a surprise if multiple DSAs have been completed for the same building.

However, it is expected that experienced engineers will be able to identify the critical issues that are likely to affect seismic behaviour and that, through discussion, a consensus position should be able to be agreed. If the assessments are at the ISA level and consensus cannot be reached, a DSA is recommended (refer Part B). If the disagreements occur at the DSA level and cannot be readily resolved, the differences in opinion should be acknowledged and recorded. When the assessments are being carried out to confirm earthquake prone-status, the TA will need to adjudicate.

Comment:

Any assessment that has been independently reviewed is likely to provide a more robust seismic rating than one based solely on the judgement of one engineer. Therefore, independent review is encouraged.

A6. Improvement of Performance

A6.1 Introduction

There are many buildings in New Zealand constructed prior to the introduction of the modern earthquake design approach in 1976. The cost to the community of requiring full compliance with current standards (i.e. all buildings brought to 100%*NBS*) would be considerable, and arguably disproportionate to the risk reduction achieved.

Comment:

It is considered that the community would accept a higher level of risk in an existing building than for a new building, if only for the reason that it will, in general, be economically more feasible to provide higher levels of dependable strength and reliable ductility in a new building than in an existing one. As a result, existing buildings which can be shown to be able to resist demand corresponding to two-thirds of the design event may be categorised as Low Risk (refer Table A3.1).

The acceptance of a factor of 67%*NBS* as a minimum for existing buildings to be categorised as Low Risk corresponds to an increase in risk for an existing building of approximately two to five times that of an equivalent new building. This is judged reasonable and compares well to equivalent levels set for the evaluation of existing buildings in the United States. For example, the approach taken in ASCE 41 leads to approximately 75% of the new building standard for the defined performance objective BPOE (Basic performance objective for existing buildings).

While this increase in risk could appear high on a building-by-building basis, it appears a reasonable minimum target overall and needs to be considered in the context of the low level of risk involved.

Upgrading to as nearly as is reasonably practicable to new building standard is recommended. However, it is considered more important and realistic to identify the high risk buildings, and reduce the risk they pose to a more acceptable level, rather than to attempt to ensure that all existing buildings comply with the latest standards. The elimination of non-ductile failure mechanisms and critical structural weaknesses is in itself of greater importance than the actual assessment and strengthening level. Building failures during earthquakes rarely occur solely because the design forces have been underestimated. More often than not, poor performance results from some obvious configurational or detailing deficiency.

A6.2 Overview of Improvement Processes

A generalised assessment process is as illustrated below in Figure A6.1. The steps in the process are summarised in the sections that follow.

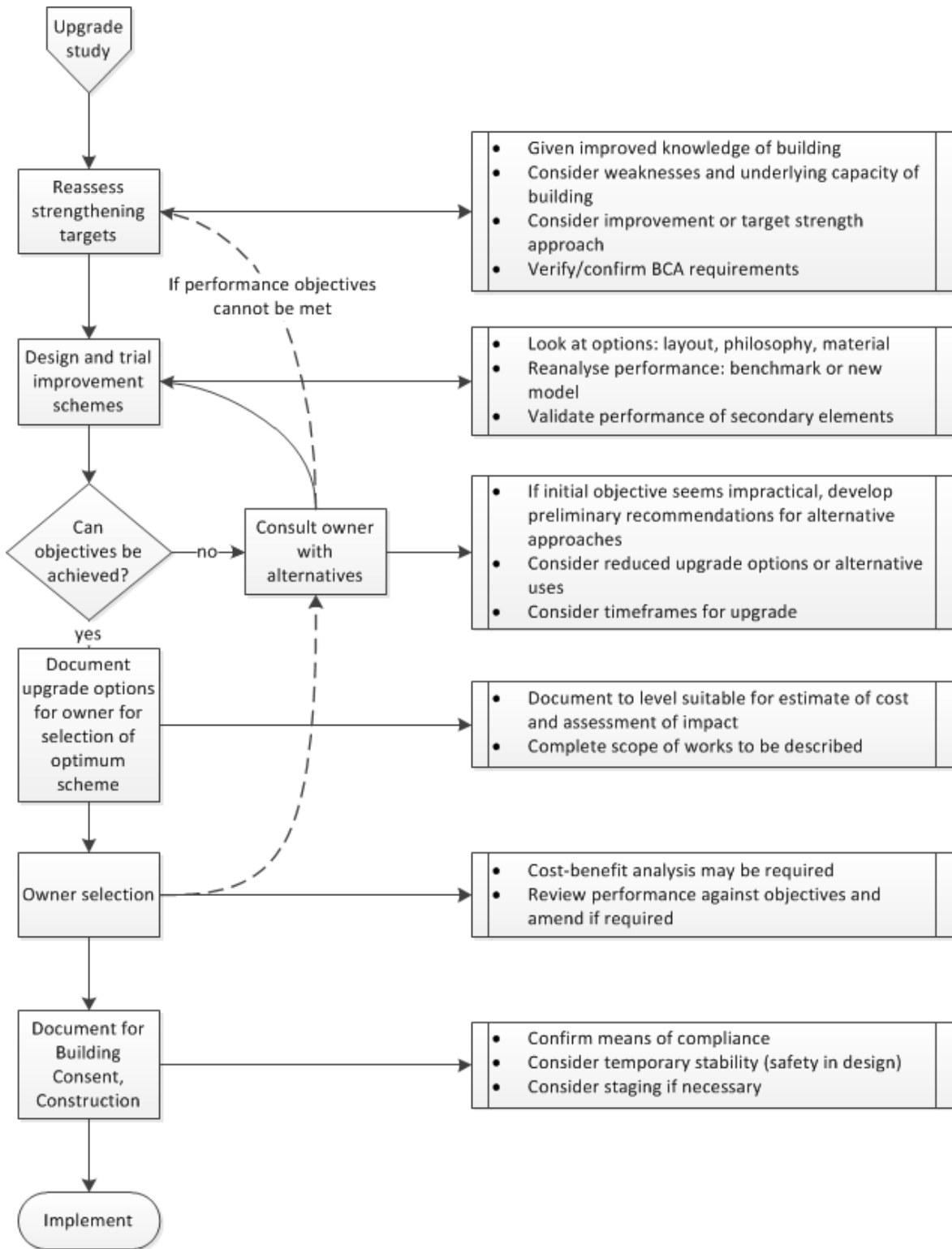


Figure A6.1: Generalised Seismic Upgrade Process Flow

A6.2.1 Establishing Performance Objectives

It is important that a detailed understanding of the owner's future performance requirements/expectations is achieved. Although this will often be expressed simply as a strengthening target in terms of % *NBS*, this may only provide a part of the picture.

Noting that as improving the performance of buildings is essentially about risk reduction, it is important that an understanding is developed of the owner's risk appetite and main concerns over likely outcomes. Factors that may be considered include:

- compliance with Building Act requirements
- usability following earthquake
- reparability
- cost of repairs
- non-structural performance
- future flexibility.

Determining the owner's performance objectives and requirements will inform the repair strategies that may be worthy of investigation.

A6.2.2 Improvement Philosophy

There are many different methods for improving buildings. Some of the most common may be broadly categorised as follows:

- **Replacement:** inserting a new lateral system that will take the majority of the seismic load. This may be used where a building's capacity is very low and would be difficult to improve, or where a building is being extended.
- **Enhancement:** Improving the existing lateral systems without substantially changing the mode of behaviour. May be used where a building requires only a relatively minor increase in capacity.
- **Protection:** Increasing the capacity of the structure (principally the gravity system) to tolerate the imposed displacements. May be used where the primary lateral load resisting structure has sufficient capacity but the primary gravity system and/or secondary systems do not have the displacement capacity to tolerate the ultimate drift.
- **Reduction in demand:** Reducing the demand on the building by isolation or by increasing the damping in the system. May be used where there is a need to reduce damage to contents or where the primary systems cannot tolerate the imposed displacements.

The adoption of any one particular approach often requires the investigation of several alternative approaches and of different levels of intervention. Although direct cost is often one of the primary criteria for assessing improvement concepts, there are other important considerations, including those mentioned in A6.2.1 above.

It is generally recommended that improvement is not approached dogmatically with a specific capacity target in mind - that is to say, compromise in the desired performance objectives or outcomes should be considered.

Comment:

There is generally not a linear relationship between upgrading cost and increase in capacity. For example, the introduction of new elements into a building may create a step change in cost, but the incremental cost increase to increase the building's capacity to the limits of what the new element could contribute may be relatively little.

A6.2.3 Other Considerations**A6.2.3.1 Improvement of Buildings with Higher Importance Levels**

Buildings of higher importance levels (IL3 or IL4) may require improvement to satisfy functional requirements including post-disaster use, or for reduced levels of damage.

Where reduced levels of damage are an essential outcome of the improvement process, consideration should be given to displacement limits based on the most displacement sensitive elements which must be protected.

For buildings which require improvement in order to become an IL4 facility, it is recommended that full compliance with SLS2 requirements is targeted, along with a minimum of 67%NBS for ULS requirements. All parts that are required to be operational following the SLS2 event, or the failure of which might limit the building's use for its intended post-disaster purpose require consideration.

A6.2.3.2 Heritage Buildings

Many heritage buildings are either earthquake-prone or earthquake risk buildings. While the assessment of these buildings will generally follow the same principles as other buildings, their improvement requires more careful consideration in order to determine an acceptable upgrading strategy. In practice this often requires a significant degree of compromise between heritage impact and structural upgrading objectives.

This is outside the scope of this document, but the principles outlined herein will be generally applicable. Reference should be made in particular to the ICOMOS New Zealand charter².

A6.2.4 Use of Analysis Methods from this Document in Conjunction with the Design of New Strengthening Elements

The design of new elements of buildings must comply with section 17 of the Building Act, which requires that all new work must comply with the New Zealand Building Code, to the extent required by the Act. For buildings that are not being upgraded to 100%NBS, this requires careful consideration. Depending on the improvement philosophy being followed, new elements are required to interact with the existing structure in different ways.

In general, the following approach is recommended:

- New building elements should be designed using current building code methods and detailing, so that their dependable capacity meets or exceeds the demand calculated to the seismic provisions of the relevant standards, factored by the target %NBS for the overall building.

² ICOMOS New Zealand Charter, for the Conservation of Places of Cultural Heritage Value, 2010.

- Where the new systems are augmenting the existing building capacity, the new elements may be designed to resist a greater proportion of the overall seismic demand, provided that due allowance is made for the ability of the structure to redistribute loads (through diaphragms or collectors). This may require additional collector elements or diaphragm enhancement, which may be designed for the lesser of the overstrength capacities of the elements being loaded by them, or by rational analysis at the target %NBS. Where a capacity approach has been used, probable capacities may be used for design, in accordance with the appropriate material standards.
- Regardless of the ductility capacity of the new elements, the displacement compatibility of the new and existing elements must be carefully considered. The distribution of demand to new elements may be limited by the displacement capacity of the existing building. (Refer to Section A3.2.4).
- To provide validation of the proposed improvements (if necessary), the building should be re-assessed with the new elements, assuming probable (expected) strength properties and capacity reduction factors in accordance with Part C, as if the new elements were already in place. This approach may be of most value when using non-linear techniques to provide a potential rating for the improved building, possibly in comparing alternatives improvement strategies. This step would not generally be required when simply adding elements to meet or exceed a target capacity (for example, improving a building so that it is no longer earthquake prone or earthquake risk) and using linear analysis to determine design actions.

When the proposed improvement measures essentially replace or substantially replace the existing lateral systems, step 4 would generally be omitted, providing that the stiffness compatibility of the new system has been assessed to ensure that a premature failure of the gravity system is unlikely to occur assuming the worst combination of stiffnesses of existing and new structures. Such analysis should include consideration of the potential impact of foundation strength and stiffness.

For buildings which require improvement solely with the purpose of ensuring that the building is no longer earthquake prone, the building need only be improved to 34%NBS and only those Parts that require consideration as noted in Section A1.5.2 need be upgraded.

Comment:

For buildings that have a higher target standard or different performance objectives, consideration should be given to broadening the scope of the upgrade, particularly with respect to parts.

Where buildings are being altered with no change of use, section 112 of the Building Act must be complied with. This requires that the building complies with the Building Code (for provisions relating to structure) to at least the extent that it complied before the alterations (but need not exceed 100%NBS). If the building is earthquake prone, the TA may request that the building is upgraded to no longer be earthquake-prone at the same time. If the building has no rating, the TA may request a seismic rating is completed to determine the building's earthquake-prone status.

Where buildings are undergoing a change of use, section 115 of the Building Act must be complied with. This requires that the building comply as nearly as is reasonably practicable with the Building Code as if it were an equivalent new building. The determination of “as

nearly as is reasonably practicable” may vary between TAs according to local regulation and practice.

Comment:

In the past, a level of 67%NBS has been regarded as sufficient to comply with section 115 for most uses, but it is recommended that consideration be given to what additional work may be required to bring the building to full compliance, especially for IL 4 buildings. A simple cost-benefit study often enables a suitable target load level to be established.

A6.2.5 Temporary Stability of Buildings during Construction

Unlike new buildings, which generally increase in capacity as the building work progresses, existing buildings may have their capacity reduced during the construction process, prior to the upgrading work being completed. This may occur, for example, through activities such as:

- undermining of foundations to install underpinning
- partial removal of unreinforced masonry walls in order to replace them with reinforced elements
- separation of diaphragms from primarily lateral elements.

It may not be practically possible to ensure no reduction in capacity during construction, and the provisions of the Building Act regarding change of use and alterations generally consider the building in its completed condition. It is recommended that designers collaborate with the owner and contractor(s) responsible for the work and consider safety on site and to the public, where appropriate, in arriving at a suitable solution which satisfies health and safety requirements and good risk management practice.