Part C - Detailed Seismic Assessment

Part C1 – General Issues

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Contents

C1. General Issues

C1.1 Introduction

C1.1.1 Overview of Detailed Seismic Assessments

Part C sets out a methodology for engineers to conduct a Detailed Seismic Assessment (DSA) to assess the structural load paths of the building, the capacities of the structural elements, the likely inelastic mechanisms, the global building response to earthquake shaking and the earthquake rating for the building.

> **Note:**
>
> Please refer to Part A for the basis behind the approaches adopted for the DSA and the seismic assessment process in general.
>
> Familiarity with the underlying principles in Part A is considered essential for those completing seismic assessments in accordance with these guidelines. These principles are applicable to all DSAs irrespective of analysis methods or material type.

The detailed procedures for assessment given in Part C are intended to provide a more reliable and consistent outcome than is available from the Initial Seismic Assessment (ISA) (described in Part B).

> **Note:**
>
> It is highly recommended that engineers develop a qualitative view of the building behaviour as a first step to a DSA. While achieving this by carrying out an ISA before the DSA is not a prerequisite, it is strongly encouraged.
>
> The value of conducting an ISA in this context is not necessarily the earthquake rating that it delivers but the opportunity to gain a holistic view of the building's potential structural weaknesses.

The focus of the DSA is to achieve an understanding of the likely behaviour of the building in earthquakes by quantifying the strength and deformation capacities of the various structural elements, by checking the building's structural integrity against the loads/ deformations (demands) that would be used for the design of a similar building on the same site.

> **Note:**
>
> The overall assessment process requires a significant departure in mindset when compared to the process used for a conventional new building design, in which a prescriptive "deemed-to-comply" approach is generally adopted. Although the procedures presented for the DSA are focused on quantifying the building capacity, the whole approach is necessarily still reliant on the judgement that can be applied by the engineer.

As is the case for the ISA, the DSA can be completed to various levels of detail depending on the circumstances and the level of reliability required. The onus is on the assessing engineer to understand the level of reliability available from the chosen assessment approach and to be able to articulate this to the end user of the DSA.

Note:

Situations will vary from small simple buildings to large complex ones. The approach to determine demand and capacity will be up to the assessing engineer. The intention of these guidelines is to help the engineer to adopt the simplest available approach consistent with the circumstances and still achieve a consistent assessment outcome.

Existing buildings involve a wide range of structural types, materials and details. As the procedures presented in these guidelines focus on the most common situations and elements they will not cover every aspect the assessing engineer is likely to encounter. The intention is that an experienced earthquake engineer will be able to adapt and extend the guidance to best match the particular situation.

Communicating the results of a DSA to end users in an appropriate and consistent manner is considered a crucial aspect of the assessment process and one that warrants particular attention by the engineer.

C1.1.2 Definitions and acronyms

ADRS	Acceleration-displacement response spectrum (spectra)
BPON	Basic Performance Objective Equivalent to New Building Standards defined in ASCE 41 for use with that document
Catastrophic collapse	Complete collapse of one or more storeys in a building
Collapse prevention (CP) performance level	A performance level defined in ASCE 41 for use with that document
Critical structural weakness (CSW)	The lowest scoring structural weakness determined from a DSA. For an ISA all structural weaknesses are considered to be potential critical structural weaknesses.
Detailed Seismic Assessment (DSA)	A quantitative seismic assessment carried out in accordance with Part C of these guidelines
Earthquake Prone Building (EPB)	A legally defined category which describes a building that has been assessed as likely to have its ultimate capacity (which is defined in Regulations) exceeded in moderate earthquake shaking. In the context of these guidelines it is a building with an earthquake rating of less than 34*%NBS* (less than one third of new building standard).
Earthquake 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*). Also see earthquake score.
Earthquake Risk Building (ERB)	A building that falls below the threshold for acceptable seismic risk, as recommended by NZSEE (i.e. <67*%NBS* or two thirds new building standard)
Earthquake score	The score given to an individual aspect of the building (member/element/non-structural element/foundation soils) to indicate the seismic standard achieved in regard to human life safety compared with the minimum seismic standard required for the same aspect in a similar new building on the same site. Expressed in terms of percentage of new building standard achieved (*%NBS*). The aspect with the lowest earthquake score is the CSW and this score will represent the earthquake rating for the building.
Importance Level (IL)	Categorisation defined in the New Zealand Loadings Standard, NZS 1170.0:2002, used to define the ULS shaking for a new building based on the consequences of failure. A critical aspect in determining new building standard.
Initial Seismic Assessment (ISA)	A seismic assessment carried out in accordance with Part B of these guidelines. An ISA is a recommended first qualitative step in the overall assessment process.
Life safety (LS) performance level	A performance level defined in ASCE 41 for use with that document
Maximum Considered Earthquake (MCE)	Often used to define the maximum level of shaking that needs to be considered in a design or assessment process. Sometimes (historically) referred to as the Maximum Credible Earthquake.
Moderate earthquake (shaking)	The level of earthquake shaking (defined in Regulations) used in the process to determine whether or not a building is earthquake prone
Nonlinear time history analysis (NLTHA)	An analysis of the building using strong motion earthquake records and modelling the nonlinear behaviour of the structure (also referred to as nonlinear response history analysis)
Non-structural element	An element within the building that is not considered to be part of either the primary or secondary structure

(Performance) step change	A significant change in seismic performance with increasing earthquake shaking levels typically associated with collapse of a building rather than just an increase in damage to its members/elements. Can be in the structure and/or the foundations/foundation soils.
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 be part of the primary lateral structure.
Primary lateral structure	Portion of the main building structural system identified as carrying the lateral seismic loads through to the ground. May also be part of the primary gravity 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 this is determined using probable material strengths. For geotechnical issues the probable resistance is typically taken as the ultimate geotechnical resistance/strength that would be assumed for design.
Probable material strength	The expected or estimated mean material strength. For geotechnical issues assessed in accordance with these guidelines it is typically the ultimate geotechnical strength/resistance that would be assumed for design.
Secondary structure	Portion of the structure that is not part of either the primary lateral or primary gravity structure 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.
Serviceability limit state (SLS)	Limit state defined in the New Zealand loadings standard NZS 1170.5:2004
Severe structural weakness (SSW)	A defined structural weakness that is potentially associated with catastrophic collapse and for which the probable capacity may not be reliably assessed based on current knowledge
Significant life safety hazard	A hazard resulting from the loss of gravity load support of a member/element of the primary or secondary structure, or of the supporting ground, or of non-structural elements that would reasonably affect a number of people. When shelter under normally expected furniture is available and suitable, mitigation of the hazard below a significant status is assumed.
Simple Lateral Mechanism Analysis (SLaMA)	An analysis involving the combination of simple strength to deformation representations of identified mechanisms to determine the strength to deformation (push-over) relationship for the building as a whole
SSI	Soil-structure interaction
SSNS element	Secondary structural or non-structural building element
(Structural) element	Combinations of (structural) members that can be considered to work together; e.g. the piers and spandrels in a penetrated wall, or beams and columns in a moment resisting frame
(Structural) member	Individual items of a building structure; e.g. beams, columns, beam/column joints, walls, spandrels, piers
(Structural) resilience	Ability of the building as a whole to perform acceptably from a structural and geotechnical point of view at levels of earthquake shaking greater than XXX%ULS shaking. Includes potential impact of the supporting soils on the performance of the building structure.
Structural system	Combinations of structural elements or structural sub systems that form a recognisable means of lateral or gravity load support; e.g. moment resisting frame, frame/wall. Also used to describe the way in which support/restraint is provided by the foundation soils.

Structural weakness (SW)	An aspect of the building structure and/or the foundation soils that scores less than 100%*NBS.* Note that 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.
Ultimate capacity (seismic)	A term defined in regulations that describes the limiting capacity of a building for it to be determined to be an earthquake-prone building. This is typically taken as the probable capacity but with the additional requirement that exceeding the probable capacity must be associated with the loss of gravity support (i.e. it creates a significant life safety hazard).
Ultimate limit state (ULS)	A limit state defined in the New Zealand loadings standard NZS 1170.5:2004 for the design of new buildings
Unreinforced masonry (URM)	A member or element comprising masonry units connected together with mortar and not containing any steel, timber, cane or other reinforcement
(XXX)%*NBS*	The ratio of the ultimate capacity of a building as a whole or of an individual member/element and the ULS shaking demand for a similar new building on the same site, expressed as a percentage. It is the rating given to a building as a whole expressed as a percent of new building standard achieved, based on an assessment of the expected performance of an existing building relative to the minimum that would apply under the Building Code (Schedule 1) to the Building Regulations 1992) to a new building on the same site with respect to life safety. A score for an individual building element is also expressed as a percent of new building standard achieved. This is expected to reflect the degree to which the individual element is expected to perform in earthquake shaking compared with the minimum performance prescribed for the element in Clause B1 of the Building Code (Schedule 1 to the Building Regulations 1992) with respect to life safety. The %*NBS* rating for the building as a whole takes account of, and may be governed by, the scores for individual elements.
(XXX)%ULS shaking (demand)	Percentage of the ULS shaking demand (loading or displacement) defined for the ULS design of a new building and/or its members/elements for the same site. For general assessments 100%ULS shaking demand for the structure is defined in the version of NZS 1170.5 (version current at the time of the assessment) and for the foundation soils in NZGS/MBIE Module 1 of the Geotechnical Earthquake Engineering Practice series dated March 2016. For engineering assessments undertaken in accordance with the EPB methodology, 100%ULS shaking demand for the structure is defined in NZS 1170.5:2004 and for the foundation soils in NZGS/MBIE Module 1 of the Geotechnical Earthquake Engineering Practice series dated March 2016 (with appropriate adjustments to reflect the required use of NZS 1170.5:2004). Refer also to Section C3.

C1.1.3 Notation, symbols and abbreviations

Symbol	Meaning
%*NBS*	Percentage of new building standard as assessed by application of these guidelines
A_g	Gross section area of the column
f'_c	Probable concrete compressive strength
S_p	Structural performance factor in accordance with NZS 1170.5:2004
v_c	Probable shear stress carried by concrete mechanism in a shear wall
v_s	Probable shear stress carried by shear reinforcement in a shear wall

C1.2 Outline of Part C

Section C1 – General Issues

Section C1 (this section) provides an overview to the DSA process. It explains the objectives and sets out key steps for an assessment at this level, including specific guidance on the calculation of *%NBS* in the context of a DSA.

This section also covers the use of alternative assessment procedures, categorisation of assessments based on the influence of geotechnical aspects, the approach to building inspection and investigation, and reporting of DSA results. A recommended report template is included as Appendix C1A.

Section C2 – Assessment Procedures and Analysis Techniques

Section C2 sets out the DSA procedures proposed by these guidelines.

The section specifies general analysis requirements including basic assumptions, selection of seismic analysis procedures, requirements and limitations for the types of analysis procedure, and specific considerations of CSWs. The procedures presented include a first principles, mechanism-based method based on either a force based or displacement based approach.

Note:

It is expected that the engineer will use Section C2 in conjunction with the relevant specific provision chapters (Section C5 to C10) as the detailed assessment progresses.

Section C3 – Earthquake Demands

Section C3 explains how to determine the earthquake hazard and loading requirements used to assess the ultimate limit state (ULS) demands that are then used to determine the earthquake rating.

This section relates the guidelines to the appropriate version of the New Zealand loadings standard NZS 1170.5:2004 depending on the purpose of the assessment, and it provides guidance on the derivation of spectral displacement demand and the acceleration-displacement response spectra (ADRS). It also covers the determination of earthquake demand (e.g. peak ground acceleration, number of cycles, representative (effective) magnitude) for geotechnical considerations.

It is intended that all provisions of NZS 1170.5 that relate to defining the seismic demands for a new building will also apply for the assessment. This includes aspects such as allowance for irregularity, accidental eccentricity, direction of actions, structural performance factor, requirements for parts and components and P-delta.

Section C4 – Geotechnical Considerations

Section C4 provides guidance for considering geotechnical behaviour and its impact on the seismic behaviour and earthquake rating of existing buildings. This section includes guidance on the recommended interactions between structural engineers and geotechnical engineers and their particular roles and responsibilities. It also explains the identification and assessment of geohazards, selection of geotechnical parameters, and the consideration of soil-structure interaction (SSI) and foundation systems.

Note:

As all structural assessments are expected to include consideration of the influence the ground can have on structural performance, engineers assessing buildings for a DSA are expected to be familiar with the information in this section.

Sections C5 to C9 – Recommendations for specific materials

These sections include provisions for various common construction materials (concrete, structural steel, moment resisting frames with infill masonry panels, unreinforced masonry (URM) and timber). They include specific recommendations for buildings generically constructed of the specific material as well as guidance on establishing capacities for structural elements and components made from that material.

It is recognised that existing buildings often comprise elements and components of different construction materials that work together to provide resistance to seismic shaking. Each material section aims to take a consistent approach to establishing element and component capacities to allow the capacities to be integrated, as appropriate, after making due allowance for deformation compatibility issues.

Where specific guidance is not provided for a particular material of situation it is intended that the relevant current material design standard will be used but substituting probable for characteristic material strengths and using nominal capacities based on these.

Note:

The material sections also include information on the observed performance and historical construction practices relating to the particular material. It is recommended that all engineers become familiar with these sections before attempting an assessment. This is because without an holistic view of the expected performance of the particular materials and configurations it will be impossible to apply the considerable judgements that are intended and required by these guidelines.

Section C10 – Secondary Structural Elements and Critical Non-structural Components

Section C10 provides guidance on the assessment of secondary structural and non-structural (SSNS) elements that would be expected to pose a significant life safety hazard (refer to Part A). How these influence the overall earthquake rating for the building is indicated in Section C1.5.

C1.3 Objectives of a Detailed Seismic Assessment

The objectives of the DSA procedure set out in these guidelines are to:

- provide a procedure that allows different engineers carrying out assessments to consistently assess the level of earthquake shaking at which the ultimate capacity (seismic) is reached for an existing building and to identify the point at which the conditions are met for a significant life safety hazard
- determine an earthquake rating for that building in terms of *%NBS* that is more reliable than the rating available from an ISA
- provide details on the expected mode of failure to assist territorial authorities to make decisions on life safety issues to determine earthquake prone building status
- determine whether or not a building is an earthquake risk building (ERB) as defined in these guidelines (i.e. <67*%NBS*)
- provide guidance on the likely needs for retrofit.

Note:

Some building owners/occupiers may also be interested in serviceability aspects such as post-earthquake functionality and the ability to occupy the building after an earthquake. While these aspects are not covered specifically by these guidelines they may need to be considered and commented on as part of providing holistic advice and meeting a wider brief than assumed for these guidelines.

The approach taken to performing a DSA may vary considerably depending on the circumstances and stated objectives. Many buildings will not require, or justify, the use of lengthy and detailed analyses. For some buildings, effort may even be better spent in completing an appropriate retrofit rather than necessarily understanding fully how the existing building configuration might perform.

Note:

An example of this is a simple building that is obviously earthquake prone and that the building owner has already decided to strengthen it seismically. In this case, establishing the *%NBS* of the un-retrofitted building quantitatively may be unnecessary. Instead, the effort may be better spent analysing the building assuming that the intended retrofit has been completed.

For more complicated buildings, proceeding immediately to a strengthening scheme without completing a DSA may be counterproductive unless there is significant prior knowledge of the building. A DSA is likely to be essential in such cases to gain a suitable understanding of the building and to identify any significant issues that need to be addressed.

C1.4 Key Steps

The key steps in the DSA procedure covered by these guidelines are as follows (also refer to Figure C1.1).

Note:

It should not be assumed that the assessment will always proceed in a linear, step by step process. Iteration should be expected and will generally be required, as indicated in Figure C1.1.

The possibility of using alternative assessment procedures is acknowledged but is not the focus of the guidelines. The exception is use of a nonlinear time history analysis (NLTHA) approach following the approach set out in ASCE 41 (refer to Section C1.6 for specific guidance).

Step 1 Establish the scope of work and assessment objectives

It is important that the scope of work and objectives of the DSA are well understood from the outset by all relevant parties.

In particular, engineers need to be aware of the complexity of the building structure, the likely assessment procedure and analysis techniques to be employed, the level of documentation/drawings available, and the inputs likely to be required from other disciplines (e.g. geotechnical engineers, heritage architects, etc.).

Step 2 Information collection, initial review, appraisal of building complexity and input required from a geotechnical engineer

Collect relevant information and documents about the building including drawings, design feature reports, geotechnical data, calculations and specifications, and any historical material such as test results, previous assessments and inspection reports (if available). Obtaining this information often involves detailed research of the property files in the relevant Territorial Authority's records, the building designer's archives and building owners' records.

If the building has been previously altered or strengthened collect all available drawings, calculations and specifications for this work.

Review the available information and structural drawings thoroughly to determine the lateral and gravity load resisting structural systems, potential SWs, SSWs, fall hazards and "hot spots" for on-site inspection.

Note:

Secondary structural and non-structural elements will not always be shown on the structural drawings and may need to be identified from site inspections (refer to Step 3).

If there is no existing ISA conduct an initial appraisal of the building structure's overall complexity following the drawing review. Completing an ISA is considered an excellent way of gaining a high level view of the issues that might exist in the building.

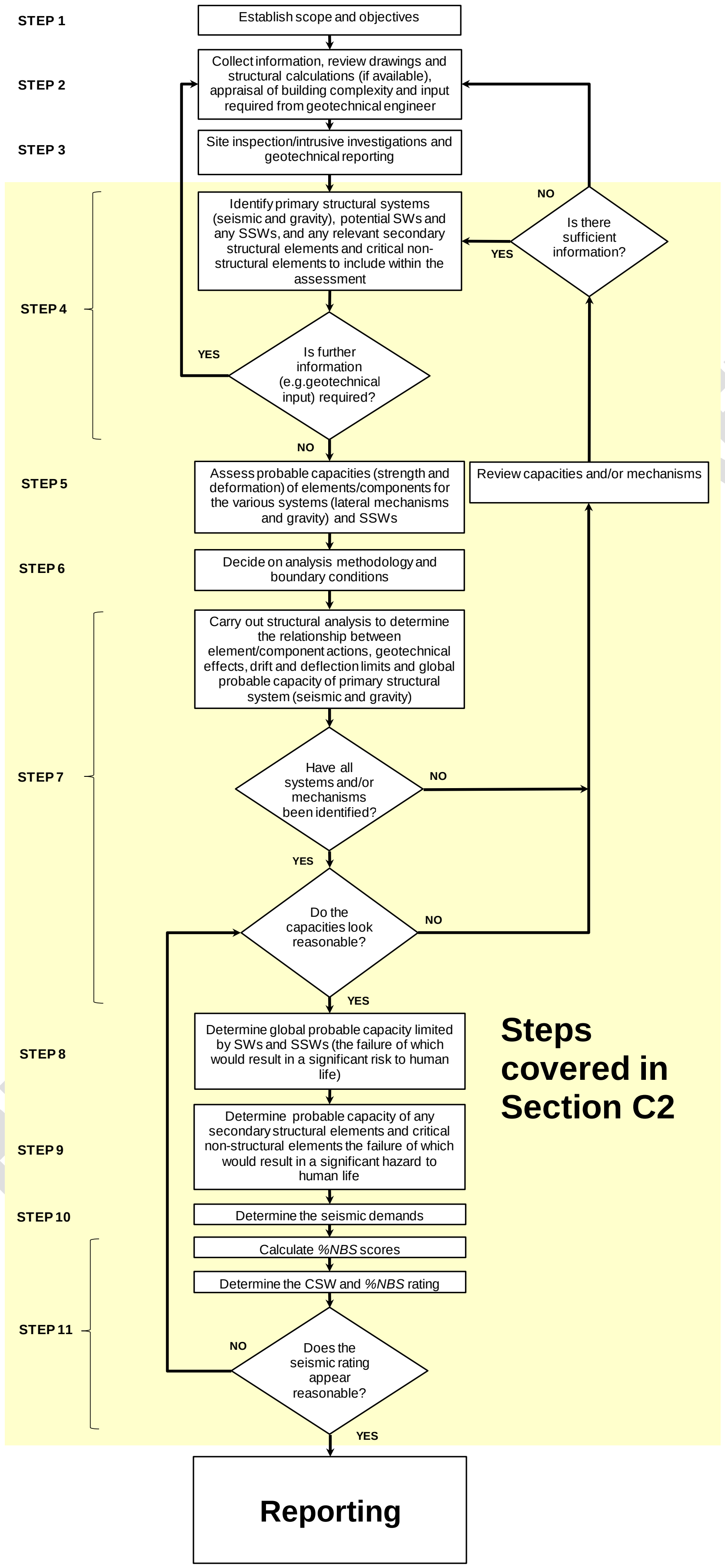

Figure C1.1: Detailed Seismic Assessment process

This initial stage of drawing review and appraisal will inform the assessment strategy and on-site inspection, allowing the engineers to concentrate effort on the key elements.

Form an initial view of the extent of geotechnical input required by categorising the assessment approach as one of the following:

- structurally dominated (geotechnical parameters required for structural analysis)
- interactive (specialist geotechnical input required to evaluate the structural behaviour), or
- geotechnically dominated (significant specialist geotechnical input required to determine the behaviour of the ground and/or evaluate the structure behaviour).

Refer to Section C1.8 for further guidance on these categories.

Step 3 Site inspection/intrusive investigation and geotechnical considerations

Undertake visual site inspections to confirm the as-constructed structure is as documented in the available structural drawings. Note any deterioration in the condition of the structure that could potentially affect its seismic behaviour; e.g. settlement, cracking, corrosion or decay. Identify any site conditions that could potentially affect the building behaviour.

The lack of structural drawings is often a source of uncertainty and conservatism in a DSA. If specific detailing or material properties are deemed critical to the seismic performance of the building, and are not available from other sources, carry out intrusive investigation in sufficient detail to confirm these.

Note:

While a minimum level of knowledge of the building is required, the cost of undertaking extensive intrusive investigations often cannot be justified by the benefits that the additional knowledge of the building will provide. Refer to Section C1.7 for more guidance on building inspection and intrusive investigations.

Decide on the extent of geotechnical investigation and reporting required. Discussion between the geotechnical and structural engineer is likely to be necessary, especially if the interactive or geotechnically dominated categories in Step 2 apply. Refer to Section C4 for guidance on how to approach the geotechnical issues that might be present.

Step 4 Identify primary structural systems, potential structural weaknesses (SWs), severe structural weaknesses (SSWs), and relevant secondary structural and critical non-structural elements and review potential effect of geotechnical aspects

Identify the primary structural systems in the building (both lateral and gravity (vertical)) and identify potential SWs and SSWs. For example, a reinforced concrete wall system may have a number of potential mechanisms or SWs such as foundation uplift, in-plane shear mechanisms, flexural mechanism, etc. The identification of potential SWs requires a good understanding of the issues that might be present in buildings of the same generic type. SSWs are discussed further in Section C1.5.3.

Note:

Typically, this will essentially be a visual process that starts with the determination of likely load paths for both lateral and gravity loads. Note that, particularly for lateral load paths, there may be alternatives that were not considered or relied on by the original designer but are still viable.

Early recognition of SWs and SSWs and their relative criticality and interdependence is likely to reduce assessment costs and focus the assessment effort. Engineering judgement is considered essential when identifying the SWs in complex buildings.

The relative vulnerability of various members/elements and mechanisms needs to be established in terms of strength and in terms of deformation demands. Separate the various members/elements into those that are part of the primary lateral system (primary seismic resisting system), those that are part of the primary gravity system (primary gravity load resisting system), and those that would be considered secondary structural elements. Some components may be categorised as having both a primary seismic resisting function and a primary gravity load resisting function (e.g. moment resisting frames).

Identify any relevant secondary structural and critical non-structural elements that should be assessed in calculating the earthquake rating of the building. (Refer Part A for the rationale for choosing the building elements that need to be considered).

The potential impact of geotechnical issues on the various members/elements/structure as a whole should be reviewed at this stage.

Decide if further information is required to carry out the assessment and what this is. If necessary, return to Step 2.

Step 5 Assess structural component probable capacities for various mechanisms (e.g. flexural, shear)

Identify the potentially critical structural members/elements within the overall system.

Note:

Identification of the critical areas is likely to be an iterative process which is continually reviewed as the assessment proceeds.

For the potential critical element, calculate the probable strength and deformation capacities for the various members and failure mechanisms. For example, for reinforced concrete moment resisting frames it would be necessary to calculate the flexural and shear capacities for the beams and columns, joint shear capacity and anchorage/lap-splice capacity if applicable.

Consideration of the various probable capacities within the critical sub-assembly/load path will indicate the probable inelastic mechanism for the element under lateral load. Some simplifying assumptions (e.g. first mode response dominant, contraflexure points, etc.) will generally be required.

Calculate the probable seismic capacities (strength and deformation) from the most to least vulnerable members/elements in both the primary lateral and gravity systems in turn. There may be little point in expending effort on refining existing capacities only to find that the capacity is significantly influenced by a more vulnerable item that will require addressing to meet earthquake-prone requirements or the target earthquake rating.

Note:

For members/elements within the primary gravity structure (that is not also part of the primary lateral structure) this will be the capacity relevant to sustaining the lateral deformations imposed by the primary lateral structure.

An element may consist of a number of individual members. For example, the capacity of a penetrated wall (an element) loaded in plane will need to consider the likely behaviour of each of the piers and the spandrel regions (the members) between, above and below the openings respectively. For some elements the capacity will be a function of the capacity of individual members and the way in which these members act together. Therefore, establishing the capacity of an element may require structural analysis of that element to determine the manner in which actions in its members are distributed and how they interrelate.

For each member/element assess whether or not exceeding its capacity (which may be more easily conceptualised as failure for these purposes) would lead to a significant life safety hazard. If it is determined that it will not, that member/element can be neglected in the assessment of the expected seismic performance of the structure.

Note:

When assessing the capacity of an element/member in relation to a significant life safety hazard it may be necessary to consider several aspects at increasing levels of loading before the capacity of that element/member can be confirmed.

The requirements in NZS 1170.5:2004 and the materials standards for particular items (e.g. design ledge lengths in Section 8 of NZS 1170.5:2004) also need to be reflected in the capacity values determined.

Step 6 Decide assessment procedure, analysis methodology and boundary conditions

Decide on an appropriate analysis methodology (e.g. simplified hand calculation, elastic computer model, nonlinear hand calculation, nonlinear static procedure) and establish the boundary conditions (e.g. restraints at foundation level) with reference to Section C2.

Note:

The completion of the analysis is intended to support the seismic assessment and is not the “goal” in itself.

The engineer must have a good understanding of the building structure and its supporting ground and likely behaviour before undertaking any analysis. As part of the assessment, the engineer can then select the analysis methodology that most appropriately investigates the issues that matter. While simpler analysis may typically be adequate, it follows that the degree of complexity of analysis should be determined by the problem. Overly complex methods have the potential to confuse and provide a false sense of precision: these should be used with care.

For example:

- For simple systems with easily identifiable inelastic mechanisms (e.g. a timber frame structure or URM building in a region of low seismicity) a simple elastic based calculation of the capacity to demand using force based assessment procedures may yield a conservative, but adequate, result. The term "adequate" here refers to the level of refinement and confidence in the results with respect to the objectives of the DSA itself.
- The presence of a non-ductile, gravity only load resisting system that may be susceptible to failure under significant lateral displacement will require specific consideration.
- When parallel systems of varying ductile capability are present, a displacement based seismic assessment is likely to be more appropriate to address the deformation compatibility issues.
- For complex structural systems a 3D dynamic analysis may be necessary to supplement the simplified nonlinear Simple Lateral Mechanism Analysis (SLaMA) described in Section C2.

The more sophisticated the structural modelling and analysis, the greater the need to verify the model and validate the input data and modelling assumptions. It is highly recommended that advanced structural analysis is cross-checked with simpler first principles based analysis as part of the verification process.

In all situations a SLaMA should be completed as part of the assessment strategy. This is part of the general requirements for the assessment process described in Section C2.

Step 7 Carry out the structural analyses

Structural analyses will be required to establish the relationship between the member/element actions and the global capacity of the building.

This will generally be done by applying a lateral load distribution to the structural model. However, it should be recognised that the aim is to find the maximum ground motion intensity (or lateral load) that can be sustained by the building and not the actions that result from a certain level of lateral load.

Start with simple analyses, progressing to greater sophistication only as necessary. In general, the complexity and extent of the analysis should reflect the complexity of the building.

The analysis will need to recognise that the capacity of members/elements will not be limited to consideration of elastic behaviour. Elastic linear analysis is likely to be the easiest to carry out, but the engineer must recognise that restricting to elastic behaviour will likely lead to a conservatively low assessment score and/or potentially erroneous distributions of lateral loads between different structural systems.

The analysis will need to consider the likely impacts of plan eccentricities (mass, stiffness and/or strength) and the ability of the diaphragms to resist and distribute the resulting actions.

Cross check any inelastic displacement response results using simple elastic based analyses based on equal energy or equal displacement concepts as appropriate.

Review the validity of any assumed boundary conditions.

Consider the potential impacts of the results of variability in input parameters; particularly with respect to assumptions relating to the supporting soils.

Critically review the analysis against the actual building to confirm that all key systems and/or mechanisms have been identified and also to confirm whether the capacities that have been determined appear reasonable. If not, review the assessment to date obtaining further information as required.

Note:

It is recommended that any elastic analysis (e.g. modal response spectrum analysis) is completed using the full unscaled elastic derived response spectrum demand. The loading can then be scaled back as required to match the available strength and the nonlinear behaviour can be considered separately.

Reducing the loading (demand) by a globally applied ductility factor, as is done for force based design, is not generally recommended for assessment. This is because the criteria that often make this valid for design (e.g. ductility well spread in the structural system and reliably achieved through a strength hierarchy) are not typically present in older buildings.

Step 8 Assess global capacity based on the governing mechanism and capacity of any SSWs

From the structural analyses determine the global seismic capacity of the building. This will be the lateral strength and deformation capacity of the building as a whole determined at the point at which the most critical member/element of the primary structure (lateral and/or gravity) reaches its determined probable capacity, or the building as a whole reaches its defined drift/deflection limits.

Note:

Drift limits specified in NZS 1170.5:2004 are intended to provide assurance that the nonlinear demands in new buildings are limited to levels that can be relied on.

For relatively lightweight existing buildings (e.g. light timber buildings and light steel industrial buildings) the drift limit of 2.5% may be too severe a constraint when there is confidence that additional drift can be accommodated without compromising either the lateral or vertical load carrying capacity of the building. To recognise this, the limits prescribed in NZS 1170.5:2004 for this type of building may be exceeded in an assessment provided that it can be shown that the capacity of the building is not compromised.

Notwithstanding that the life safety hazard of the various members/elements was reviewed in Step 5, reflect again on whether or not the identified global capacity is likely to represent a significant life safety hazard. If it is determined that it does not, refine the residual seismic capacity (or adjust to zero where appropriate) of the lowest scoring member/element and repeat to find the new global capacity. Identify the impact of any identified SSWs.

Continue the assessment process until the appropriate capacity is identified. This will provide the probable global capacity score for the building.

It may also be useful to determine the global capacity assuming that successive SWs and/or SSWs are addressed (retrofitted). This will provide information on the extent of retrofit that would be required to achieve a target rating for the building as a whole.

Review if the assumed mechanisms require amendment: if so, reassess.

Review the impact of any global geotechnical issues.

Step 9 Assess the probable capacity of relevant secondary structural and non-structural (SSNS) elements

Determine the probable capacity of any SSNS building elements that would constitute a significant life safety hazard if they were to fail. Refer to Part A for further guidance on the types of element that are to be considered. Refer to Section C10 for guidance on how to determine their capacity. Section C1.5 shows the impact of SSNS elements on the building's earthquake rating.

Step 10 Determine the ULS seismic demands

Determine the ULS seismic demands from Section C3.

The demand values are obtained from NZS 1170.5:2004 as this is fundamental to the calculation of *%NBS*, but their form (e.g. response spectra, peak ground acceleration, member actions, displacements) will depend on the aspect for which the *%NBS* is being calculated.

For the calculation of *%NBS* the reference level demand might be expressed in terms of the ULS base shear, design response spectrum (acceleration and displacement), or scaled strong motions obtained from Sections 5 and 6 of NZS 1170.5:2004.

At the member/element level the demand might be the actions (stress and strain) obtained from a structural analysis using the global demands as inputs.

For some aspects of primary structure (e.g. floor restrained face-loaded walls) and for secondary structural items, the design actions for parts obtained from Section 8 of NZS 1170.5:2004 will be more appropriate. This will include, where appropriate, imposed deformations from the primary lateral structure.

Consideration of geotechnical effects may require the reference demands to be in the form of design ground shaking (e.g. peak ground accelerations and/or displacements at the appropriate return period).

Note:

It is intended that the version of NZS 1170.5 that is cited in the Building Code at the time of the assessment is used. Engineering assessments for the purposes of evidence of earthquake proneness are required by the EPB methodology to be referenced to the version of NZS 1170.5:2004 cited in the Building Code as at 1 July 2017. Refer Part A for further discussion on this point.

Step 11 Calculate *%NBS*

Refer to Section C1.5 for a detailed discussion of the calculation of *%NBS*.

The *%NBS* earthquake rating for the building is the minimum of the earthquake scores assessed for the global performance of the primary structure for each principal direction and the earthquake score for each individual secondary and non-structural element that also meets the significant life safety criterion (refer to Part A).

Before considering the assessment as being complete, reflect on the earthquake rating that has been determined and whether or not it appears reasonable. If not, investigate whether the identified critical members/elements have been adequately assessed or whether more reliable data should be obtained.

Step 12 Reporting

This is perhaps the most critical part of the assessment process as the technical output needs to be communicated to the client, stakeholders and building users in a way that puts the results in context.

The report of findings should cover a clear description of the structural system and key structural vulnerabilities, the *%NBS* and the expected structural behaviour in earthquakes, the assessed seismic risk, and the assessment methodology and analysis undertaken.

An important aspect of the assessment process is reporting all individual *%NBS* scores that have been evaluated and the rationale for decisions on life safety potential and modes of failure. This will provide a complete picture of the issues associated with the building's seismic performance, will aid in the development of a retrofit program if this is to be considered, and will also assist the relevant Territorial Authority's consideration of earthquake-prone building status.

Refer to Section C1.10 for further guidance and Appendix C1A for a recommended report template.

There are specific requirements set out in the EPB methodology for reporting on results of engineering assessments for earthquake prone status. Refer to Part A.

C1.5 Calculation of *%NBS* for a DSA

C1.5.1 General

Note:

The earthquake rating for the building, expressed as *%NBS*, is discussed in Part A. The material is largely repeated here for convenience.

%NBS earthquake rating from a DSA is obtained by dividing the calculated ultimate capacity (seismic) of the building or part by the ULS seismic demand as shown in the following equation:

$$\%NBS = \frac{Ultimate\ capacity\ (seismic)}{ULS\ seismic\ demand} \times 100 \qquad \text{...C1.1}$$

where:

Ultimate capacity (seismic) is taken as:

- probable capacity of the primary lateral structure of the building including the impact of geotechnical issues (refer to Section 0), or
- probable capacity of structural elements, the failure of which could lead to a significant life safety hazard (refer to Section 0), or
- capacity assessed for any identified SSWs (refer to Section C1.5.3), or
- probable capacity of SSNS elements which would pose a significant life safety hazard (refer to Section C1.5.4)

ULS seismic demand is as described in Section C3, including the appropriate value of S_p (the structural performance factor) for the particular aspect under consideration. Refer to Section C1.5.6 for further discussion.

The earthquake rating will be the minimum value of *%NBS* calculated as above.

Note:

These guidelines provide methods that can be used to calculate the ultimate capacity (seismic) of buildings and their component parts.

The ultimate capacity (seismic) is defined as "*the probable capacity to withstand earthquake actions and maintain gravity load support*". It is the position of these guidelines that "*probable capacity*" is used in the definition in the natural/ordinary sense of it being unlikely that the building has a capacity less than this value. This differs from the scientific use of probable as synonymous with 50^{th} percentile, mean, or average. The natural/ordinary interpretation of "*probable capacity*" is consistent with the expectation of Section A3.2.4 that a building rated at XX%NBS, subjected to shaking at XX% of the design level shaking for an equivalent new building (XX%ULS shaking), is expected to perform to at least the same minimum level as a new building subjected to the design level of shaking (100%ULS shaking), i.e. to have a low probability of causing injury or death.

Capacity can refer to either strength or deformation.

As discussed in Part A, the general expectation of these guidelines is that probable (i.e. 50^{th} percentile or average) strengths of elements are used for assessments.

It is not generally the case that probable (50th percentile) deformation capacities are used for assessments. Instead, deformation capacities are defined so that there is an acceptably low probability of the capacity of the building being exceeded during stronger than ULS shaking. To achieve this, several factors need to be considered when calibrating assessment methods for specific elements so that outcomes are consistent with the expectations of these guidelines. The acceptable probability of exceedance (POE) depends on consequences that exceedance would have on stability of structure and ability to maintain gravity load support, and also on how sudden/brittle the failure would be. Calibration of assessment criteria also needs to consider whether adjustments are required to account for underlying experimental testing that is more or less demanding than expected real-world demands.

Examples of the application of this conceptual framework include:

- Exceedance of the capacity of a ductile beam is expected to create a relatively low risk of serious consequences. A 50% POE for ULS shaking would be appropriate, i.e. specified deformation limits would be 50th percentile/average/mean values.
- Axial failure of a column would be expected to create a high risk of serious consequences. A 25% POE during greater than ULS shaking is considered appropriate in line with other similar documents (ASCE 2017).
- Before adjustment, procedures for assessing precast floor units give an approximately 35% POE of a 2 mm drop at the support during ULS shaking. While failure of a floor unit is likely to be less serious than collapse of a column, it should still be unlikely during greater than ULS shaking. This was factored into the final calibration for precast floor assessment. Also considered were the likelihood of there being some additional displacement capacity beyond the occurrence of a 2 mm support drop, and the likelihood that experimental loading was less onerous than real-world demands.

Other elements can be considered within the framework illustrated above. For example, exceedance of the flexural capacity of a wall would be more serious than for the beam referred to above because it would typically be the case that the wall represented a substantial portion of the total lateral resistance of the building, and additionally its failure might materially change the centre of stiffness of the structure.

Limits on available data or understanding of structural behaviour mean it is not universally possible to specify limits based on statistical measures. However, the approach outlined above is intended to guide the deformation limits specified in Sections C4 to C10.

It is not intended that users of the guidelines have to consider the specific POE appropriate for particular elements during an assessment.

The earthquake rating should always be quoted together with the Importance Level that was assumed to determine the ULS seismic demand. The recommended presentation format, showing the percentage as XXX, the Importance Level as Y, and with "*%NBS*" always italicised, is:

XXX*%NBS* (ILY)

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

Rather than just evaluating the ultimate capacity (seismic) for the building as indicated above and then dividing by the global demand on the building, it may be more appropriate to evaluate the *%NBS* score for each aspect of the building and then take the lowest value. This is because the demand may need to be represented in different ways depending on the particular aspect under consideration. This is discussed further in Section C1.5.6.

It is also considered important that the *%NBS* scores for the individual aspects are included in the DSA report, as this helps to put the earthquake rating in context and assists when retrofit to a particular target level is being considered.

When determining *%NBS* scores for aspects of the building it is often not appropriate to simply calculate a ratio of capacity to demand as indicated by Equation C1.1. This is because gravity actions may be responsible for a proportion of the demands. Instead earthquake scores should more generally be calculated so that the following equation is fulfilled:

$$S_{prob} = G + \psi_E Q + \psi_{NBS} E_u \qquad \text{...C1.2}$$

Where:

S_{prob}	=	Probable capacity of structural element, identified SSW, or SSNS element which would pose a significant life safety hazard
$G + \psi_E Q$	=	Permanent and imposed gravity actions for combination with earthquake actions, as defined by AS/NZS 1170.0
ψ_{NBS}	=	%NBS/100
E_u	=	ULS seismic demand on the element as described in Section C3, including the appropriate value of S_p (the structural performance factor) for the particular aspect under consideration. Refer to Section C1.5.6 for further discussion.

C1.5.2 Probable capacity of primary structure

C1.5.2.1 Assessing the probable structural capacity

The probable structural capacity of the primary structure is assessed using probable material strengths and nominal member/element capacities calculated using these. Guidance is provided in Sections C5 to C9 and the methods of analysis and assumptions set out in Section C2. The term "primary structure" is intended to describe both the seismic lateral structural and the gravity (vertical) structural support systems in a building. Identification will be particularly important when these systems are separate.

Note:

It is the intent that the probable capacity is typically the capacity determined from application of the Building Code design Verification Method, B1/VM1, substituting probable material properties for characteristic design values and using strength/capacity reduction factors equal to 1.0. When further concessions from the design values, modified as indicated above, are possible these are outlined in Sections C4 to C9.

It is also intended that member/element stiffnesses defined in B1/VM1 are taken for assessment.

The response of the ground under the building and its effect on the building needs to be factored in, as discussed in Section C4. This will include the effect on the dynamic characteristics of the building (SSI considerations and the subsoil amplification) and also structure support conditions (e.g. degree of restraint to foundations).

As discussed throughout these guidelines, the structural capacity is described both in terms of the strength capacity and the deformation capacity. Inclusion of the nonlinear deformations in the assessment can significantly influence the calculated earthquake rating for the building but it is recognised that not all of the assessment procedures (e.g. force based approaches) will fully account for this.

The primary structure includes such items as URM parapets, face-loaded walls, building penthouses, and stiff panels that are required to participate because of inadequate separation from the intended primary lateral structure. These will typically be considered both as building elements not part of the primary lateral structure and as part of the building lateral load resisting system for assessment of seismic loading (the demand).

Note:

Items such as parapets have been considered as secondary structure or even non-structural elements in the past. However, in the context of these guidelines, and to avoid confusion, it is considered that they are part of the primary structure as they are required to provide both gravity and lateral load support to their own, often not inconsiderable, weight/mass, and they often contribute to the in-plane capacity of URM walls. Whether or not they are considered as primary or secondary structure (they are not non-structural as defined in these guidelines), the assessment of their capacity and effect on the *%NBS* rating does not change.

Once analysis of the complete primary structure is completed and the behaviour of the various members/elements in the primary structure has been assessed, the global probable seismic capacity of the primary structure will be limited by the member/element with the lowest probable capacity; **provided the failure of that element would result in a significant life safety hazard**. The capacity of elements that do not fulfil this requirement should be set to a residual value (or zero if appropriate) and the analysis repeated until the lowest scoring member/element is identified that would result in a significant life safety hazard.

C1.5.2.2 What constitutes a significant life safety hazard?

What is considered to constitute a significant life safety hazard for primary structure is discussed in Part A. In summary, it is a hazard resulting from the failure of a member/element of the primary structure or of the supporting ground that would lead directly to collapse of the building as a whole or to a part of it and that could reasonably affect a number of people.

What does and what does not constitute such a hazard will rely to some extent on the judgement of the engineer. Therefore, it is important that the decision making process for this is recorded in the DSA report.

C1.5.2.3 Other considerations

The analysis of the primary structure often focuses only on the primary lateral structure under horizontal earthquake shaking.

The assessment of the primary structure must also consider all of the systems that support gravity loads. Often, these will not be relied on to resist lateral loads. However, experience in numerous earthquakes has highlighted that it is the performance of assumed non-lateral load resisting gravity load supporting systems that is often critical when determining the collapse potential of the building, and the extent to which collapse might occur (e.g. pancaking of floors for SSWs).

The assessment of assumed non-lateral load resisting systems (e.g. frames assigned to be gravity only) requires consideration of the effects of imposed deformations from the primary lateral system. It is intended that the stiffness and strength of members/elements in such systems be based on probable values. However, care must be taken to ensure that actions within these systems are cautiously appraised. This will require the stiffness of joints, for example, to be reasonably modelled and an understanding of the sensitivity of any assumptions on the conclusions reached. The support stiffness at foundation level may also be important in this regard.

Vertical earthquake motions may also be important in the same situations as identified in design standards for new buildings; e.g. for horizontal cantilevers, etc. If present, vertical demands should also be included in the assessment.

Note:

Although the assessment of SWs in these guidelines is focused on the demands at XXX%ULS levels of shaking, the expectation is that a building will be able to continue to perform to a satisfactory level in shaking much higher than this to meet the overall performance objectives. The provisions of these guidelines (acceptance criteria, treatment of SSWs and the like) have been set at a level to provide confidence that this will be achieved. Therefore, it is not the intention that higher levels of shaking are specifically addressed in the assessment process.

However, some buildings are complex and will not always be fully covered by the guideline provisions. The engineer should always be mindful that the intensity of earthquake shaking is not limited, even when MCE levels are defined, and consider the implications of this when scoring aspects that are not fully covered within the scope of these guidelines.

Refer also to Section C1.5.3 for further discussion relating to SSWs.

C1.5.3 Capacity of SSWs

C1.5.3.1 General

While the assessment process outlined in these guidelines is primarily focused on determining the probable seismic capacity and relating this to the XXX%ULS loading demands, as discussed in Part A and Section C1.5.1, the intention is also that this process needs to deliver a reasonable expectation of satisfactory performance at higher levels of shaking to meet the overall performance objective. This is referred to in Part A as the structural resilience available and is a necessary aspect of a building's behaviour if it is to deliver the overall expected seismic performance.

In many cases there will be inherent structural resilience (i.e. sufficient margin will have been provided when setting the acceptance criteria, etc. given in Sections C4 to C10) and it is not necessary to specifically account for this other than by adhering to the assessment procedures outlined in Sections C4 to C10.

However, it should be recognised that there are potentially some aspects of a building's seismic behaviour which may not be adequately captured within general assessment procedures but are likely to have a step change response resulting in sudden (brittle) and/or progressive, but complete (i.e. pancaking), collapse of the building's gravity load support system in shaking greater than that represented by XXX%ULS shaking.

These guidelines define complete collapse of this type as catastrophic collapse. Collapse of this type has the potential to result in high fatality rates for occupants and little or no chance of escape after the earthquake. Experience indicates that while the public may accept some fatalities as being a consequence of living in an earthquake hazardous region they are intolerant of such collapses, particularly for more modern buildings. Therefore, it is essential that the overall assessment procedure satisfactorily accounts for such behaviour when it is identified.

Experience from past earthquakes also indicates that such behaviour is typically restricted to a relatively small number of mechanisms. In these guidelines these mechanisms are referred to as SSWs (refer to Part A for the criteria used to determine these).

For the purposes of these guidelines the aspects that need to be assessed as SSWs in a DSA have been predetermined and may be assumed to be restricted to the particular SSWs listed below:

- Lightly reinforced concrete columns and/or beam-column joints (refer to Section C5 for definition) with axial loads greater than $0.2A_g f'_c$ which are part of the primary structural system of buildings. To be a SSW the failure of a column and/or beam/column joint would need to lead to a progressive collapse scenario for the entire storey.
- Interconnected concrete shear walls (shear core) with axial loads greater than 0.15 $A_g f'_c$ which are shear dominated and which are required to carry, in total, more than 60% of the seismic lateral demand.
- Flat slab configurations in buildings with more than two storeys where gravity support is reliant on low ductility cast insitu concrete slab to column connections without shear reinforcement that are susceptible to imposed lateral drift and punching shear failure. This is only intended to apply to systems with gravity-only shear demand exceeding 40% of the probable shear capacity (v_c+v_s) at the critical shear interface.

- Lack of positive connection between diaphragm(s) and primary lateral structure comprising a single element (e.g. shear core) of buildings.
- Complex slope failure resulting in significant ground mass movement and the loss of support over more than 50% of the building platform (i.e. where the building is on a slope or cliff edge).
- Liquefiable ground supporting poorly tied together URM buildings (refer to Section C8 for definition) with more than two storeys.
- Reinforced concrete wall vulnerable to through-the thickness failure, meaning sudden axial failure featuring crushing and shifting in the out-of-plane direction across the length of the entire wall (refer to Section C5 for definition of susceptible walls).

Note:

This list of SSWs is similar to the list of SSWs that must be highlighted in an ISA (if they have been identified). However, it excludes those building aspects which should be adequately addressed in the DSA using the quantitative assessment procedures set out elsewhere in these guidelines; e.g. ledge/sliding supports and weak or soft storeys.

C1.5.3.2 Determining the capacity of SSWs

Additional factors (typically 0.5) are applied to reduce the available probable capacity of SSWs to reflect their potential catastrophic nature. How this factor is intended to be applied is shown in Section C2 (Appendix C2G)

Note:

It is important to recognise that the above procedures for dealing with SSWs are not replaced by subjecting the model of the building to the traditional concept of a Maximum Credible/Considered Earthquake (MCE). The SSWs are not mechanisms where it is considered that the step change behaviour can currently be adequately assessed from calculation/analysis; nor should there be any expectation that the shaking the building could be subjected to is capped at a specific level.

The use of the additional factor of 0.5 on the probable capacity for these critical mechanisms (which can also be considered as a factor of 2 on the ULS demand, although reduction in capacity is preferred) is considered sufficient to provide a reasonable expectation of satisfactory performance overall.

It may be assumed that, for SWs covered by these guidelines and not listed as SSWs, adherence to the recommendations of Sections C4 to C10 will provide the required level of resilience without the need to apply any additional factors/margins.

C1.5.4 Probable capacity of secondary structure and non-structural (SSNS) elements

For SSNS elements to influence the building rating they must be of sufficient size and located such that their failure would lead to a significant life safety hazard. This will typically relate to their ability to continue to support gravity loads (including their own weight). Refer to Part A for a description of elements that should be considered when determining the earthquake rating.

Guidance on assessing the probable capacity of SSNS elements is provided in Section C10. SSNS elements spanning between levels in a building or between adjacent buildings and supported on ledges is considered particularly vulnerable.

The probable capacity of SSNS elements should be assessed in the same manner as for members/elements in the primary structure as outlined in Section 0.

Note:

Restraints (tethers) can be used to mitigate the life safety hazard of SSNS elements if the restraint is sufficient to arrest their fall above a height that would constitute a significant life safety hazard. Refer to Section C10 for further discussion.

C1.5.5 Critical structural weakness (CSW)

The CSW is the issue that finally limits the *%NBS* earthquake rating for the building after consideration of the capacity of the primary structure (seismic and gravity) and the SSNS elements. The process should deliver a CSW, the failure of which would result in a significant life safety hazard.

It is recommended that a final check is made that this is the case before accepting this as the CSW.

C1.5.6 ULS seismic demand

Guidance for assessing the ULS demand is provided in Section C3.

The appropriate value of S_p needs to be used when assessing the demand if it is not otherwise accounted for in the assessment of the capacities. This may require different values for S_p depending on the level of nonlinear deformation possible from the aspect under consideration, in accordance with NZS 1170.5:2004 and Section C3. S_p for the primary structural system is set based on the displacement ductility that is assessed to be available from the global capacity. This may be limited by any primary system element/member's ductile capability. Refer to Section C2.

C1.6 Use of Alternative Verification Methodologies

C1.6.1 General

The adoption of internationally used assessment methodologies (e.g. ASCE 41 and Eurocode-8 Part 3) is not precluded by these guidelines. However, engineers must be confident that compliance with these methodologies will lead to the expected level of performance that is outlined in Part A and, where not otherwise noted, use of international methodologies should be considered to be outside the scope of the guidelines.

Irrespective of the method of assessment, it is essential that the result is delivered in terms of a *%NBS* earthquake rating to avoid market and community confusion.

There will be instances where the component performance (deformation) acceptance criteria prescribed in ASCE 41 will provide valuable information where, otherwise, none exists.

Use of linear (elastic) verification methods other than those set out in Section C2 is not recommended nor supported by these guidelines. However, it is recognised that alternative nonlinear methods may provide additional insight into building performance and, therefore, assessment using nonlinear time history analyses (NLTHAs) and the Tier 3 approach in ASCE 41 is considered an acceptable alternative provided that some minimum requirements as outlined in Section C1.6.2 are satisfied.

Note:

Sufficient verification to "test" the ASCE 41 linear elastic or the Eurocode 8 Part 3 methods against the objectives of these guidelines has not been completed to provide the necessary confidence that these objectives will be met.

C1.6.2 NLTHA using ASCE 41 Tier 3 assessment

The ASCE 41 Non-linear Dynamic Procedure (NDP) Tier 3 assessment prescribes what is referred to as a performance based method of assessment. Using this approach the engineer decides, in consultation with the client, on the level of performance required. This defines a hazard level and acceptance criteria that must be met at that level of hazard. A range of structural and non-structural performance levels corresponding to various performance objectives can be selected.

Note:

It is expected that the latest version of ASCE 41 would be used for assessments. At the time of publication this is ASCE 41-23 (2023),

ASCE 41 NDP Tier 3 does not represent a full performance based method of assessment as it does not predict the *actual likelihood* of achieving a given level of performance. It is still a deterministic assessment based on pass/fail acceptance criteria completed on an element by element basis. In that respect it is still checking the degree of compliance against defined minimum criteria for the particular performance level being assessed.

The general approach outlined in the ASCE 41 NDP Tier 3 systematic assessment is considered to be an acceptable alternative to the DSA as outlined in these guidelines and may be assumed to comply with these guidelines provided that the following recommendations are followed:

- The assessment outcome should be reported in terms of a *%NBS* earthquake rating. This may require a modification to the ASCE 41 process as outlined below.
- The target building performance objective for the reference 100*%NBS* should be the Basic Performance Objective Equivalent to New Building Standards (BPON) for the appropriate return periods defined in Table C1.1.

> **Note:**
>
> Only target performance levels associated with Life Safety (LS) and Collapse Prevention (CP) need to be considered to meet the recommendations of these guidelines. However, in the case of Importance Level 4 buildings it may also be appropriate to consider the calculated performance at a level consistent with the functionality limit state SLS2 in NZS 1170.5:2004. Refer to Part A.

- The acceptance criteria and recommendations given in ACSE 41, unless specifically modified for use with NLTHA in these guidelines, should be used in their entirety. This includes the process of selection and scaling of strong motion records.
- The *%NBS* for each target performance level is the scale factor that needs to be applied to the input strong motion record so that the acceptance criteria for that performance level are just met. Duration of shaking is not adjusted.
- The *%NBS* global earthquake score for the building is the lowest of the global *%NBS* values determined for both performance levels.
- The behaviour of SWs not otherwise included in the analysis model (e.g. support of precast floor units and frame elongation effects) must be considered separately as required elsewhere in these guidelines and the *%NBS* earthquake rating adjusted accordingly.
- The behaviour of SSNS elements (as defined by these guidelines), if not otherwise included in the analysis model, must be considered separately as required elsewhere in these guidelines and the *%NBS* earthquake rating adjusted accordingly.
- If SSWs listed in Section C1.5.3 are identified as being present the *%NBS* rating should be adjusted down to achieve the required margin of two on the calculated score for the SSW at the life safety performance level. The earthquake rating may also require adjustment if the SSW is not specifically addressed in the analysis; e.g. the impact of slope failure or liquefaction.

> **Note:**
>
> The intention is that the score for SSWs is determined as follows:
>
> - Identify the members/elements that participate in the mechanism that leads to the SSW.
> - Determine the earthquake score for these members/elements at the Life Safety (LS) performance level.
> - Halve the Life Safety score to obtain the *%NBS* score for the SSW.

Reliance is not placed on the results from the Collapse Prevention level for SSWs because the method is not considered to provide the necessary margins against catastrophic collapse; nor does it recognise the uncertainties involved in predicting such behaviour.

Table C1.1: Reference return periods and ground motion scaling factors for 100%*NBS* for BPON[1]

Importance level (IL)	Building performance level	
	Life safety (return period)	Collapse prevention (scale factor)*
IL1	100	1.5
IL2	500	1.5
IL3	1000	1.5
IL4	2500	1.5

Note:

* These scale factors are intended to be applied to the ground motion that is used for the life safety analyses. The values have been set so that the outcomes of assessments using Section C1.6.2 are reasonably consistent with outcomes using the general approach of these guidelines (Thompson & Oliver 2019). A margin against actual collapse at the collapse prevention level is still expected to meet overall performance objectives.

Note:

NLTHA carried out in accordance with the general requirements of ASCE 41 NDP Tier 3 methodology provides a way of applying the principles of these guidelines provided the additional considerations as outlined are made. The typical approach is that the structural components are modelled (elastically and inelastically) in accordance with rules specified. The demand is established for the required performance level, strong motion records are chosen to match the required hazard level (demand), the model of the building is "shaken", and the acceptance criteria for the performance level are checked. If the analysis shows the criteria are met it is assumed that the performance level has been met.

Further to the ASCE 41 methodology, if the criteria are not met the input motions can be dialled back (by scaling), and the analyses rerun until the criteria are met. The degree to which the building meets the 100%ULS shaking demands is then effectively the scale factor applied to achieve compliance with the acceptance criteria.

The performance levels typically assessed using ASCE 41 are "life safety" and "collapse prevention". Thus, a check is made at two levels of demand (ULS and greater than ULS) rather than the single level check made at the ULS level of shaking using the standard guideline approach. This approach provides an assessment of the structural resilience of the structural system beyond ULS shaking levels (500 year return period demands for IL2 buildings) and is often presented as a major benefit of this methodology over the guideline methods.

The engineer needs to be satisfied that checking for collapse (collapse prevention) in accordance with ASCE 41 still achieves the level of performance required at a severe level of shaking, beyond those defined for the collapse prevention level. These are the checks required for SSWs as outlined in the specific requirements above.

The required margin of two at the life safety performance level needs to be achieved for any of the SSWs listed.

C1.6.3 Eurocode-8 Part III

It is recognised that EN 1998-3: Eurocode 8 – Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings is available and will be familiar to some engineers in New Zealand. Use of this document is not covered by these guidelines. If this Eurocode is to be used as a basis for assessment in New Zealand it is considered essential that the assessment results are expressed in terms of a *%NBS* earthquake rating and the entire process is subjected to appropriate holistic peer review that includes specific consideration of how the assessment meets the objectives outlined in Part A. The engineer will also need to consider the issues/adjustments discussed for NLTHA using the ASCE 41 Tier 3 approach discussed in Section C1.6.2.

C1.7 Building Inspection and Investigations

Detailed building inspections should be made as part of the assessment of an existing building's earthquake rating and before the preparation of any strengthening proposals.

The following sections list the main items to be inspected during the detailed inspection and what information to record.

The site will also need to be inspected for potential geohazards, refer to Section C4.

C1.7.1 Structural configuration

Most of the details of the structural configuration required for an analysis should be available on design or construction drawings. As-built checks should also be made. Where detailed plans are unavailable, field measurements and invasive exploration and testing may be necessary.

It is recommended that an initial field measure is carried out to confirm the general adequacy of the available documentation. This can be followed by a more detailed inspection to confirm detailed dimensions and detailing as required for the assessment.

Note:

Experience indicates that it is unlikely that tender, consent, or even construction drawings will always fully represent the as-built condition of a building. Therefore, a site inspection to confirm as-drawn details is recommended in all cases.

The structural configuration information gathered should include the following:

- plans, elevations and dimensions of frames and walls on each level
- location and size of openings in walls and floors
- identification of load-bearing/non load-bearing walls
- identification of any discontinuities in the structural system
- arrangement of roof and floor trusses, beams and lintels
- identification and location of reinforcing bands, columns and bracing
- dimensions of non-structural components to allow storey masses to be reliably assessed
- location and configuration of precast elements
- lift and stairwell construction and dimensions
- foundation dimensions, type and identification of connections between foundations and between superstructure and foundations
- clearances to adjacent buildings
- evidence of structural modifications, and
- seismic status of adjacent buildings, if this can be obtained.

Note:

Identifying the structural configuration will enable both the intended load-resisting elements and the effective load-resisting elements to be recognised. Effective load-resisting elements may include both structural and secondary structural elements that participate in resisting lateral loads, whether or not they were intended to do so by the original designers. Potential discrepancies in intended and effective load-resisting elements may include discontinuities in the load path, weak links, irregular layouts, and inadequate strength and deformation capacities.

While the seismic status of adjacent buildings will not affect the earthquake rating it is nevertheless an important consideration when providing holistic advice on a building.

C1.7.2 Member/element properties

The following member/element properties should be obtained:

- cross-sectional shape and physical dimensions of the key members/elements and overall configuration of the structure
- configuration of connections, size and thickness of connected materials, and continuity of load path, particularly for precast elements
- modifications to individual members/elements or overall configuration of the structure
- location and dimensions of braced frames and shear walls
- current physical condition of members/elements and extent of any deterioration present
- reinforcing details in reinforced concrete structures, and
- connection details for primary and secondary structure.

Behaviour of the components – including shear walls, beams, diaphragms, columns, and braces – is dictated by physical properties such as area; material; thickness, depth, and slenderness ratios; lateral torsional buckling resistance; and connection details. The actual physical dimensions should be measured; e.g. 50 x 100 mm timber dimensions are generally slightly less due to choice of cutting dimensions and later shrinkage. Modifications to members need to be noted including notching, alterations, tack welds, etc. that may modify geometric and material properties. The presence of corrosion, decay or deformation should be noted.

These key element/member properties are needed to properly characterise capacities in the seismic assessment. The starting point for establishing member/element properties should be the available construction documents. Preliminary review of these documents shall be performed to identify key gravity and lateral load carrying members and elements and key connections. Site inspections should be conducted to verify conditions and to ensure that remodelling has not changed the original design concept. In the absence of a complete set of building drawings, the engineer must thoroughly inspect the building to identify these members and elements. Where reliable record drawings do not exist, an as-built set of plans for the building could be created (even as sketches) as part of the assessment.

The adequacy of interconnection between the various members and elements of the structural system will be critical to its behaviour. The type and character of the connections should be determined by a review of the plans and a field verification of the conditions. The connection between a diaphragm and the supporting structure is likely to be of prime importance in determining whether or not the separate parts of the structure can act together or if gravity-only members and elements are likely to be sufficiently protected by the lateral load resisting system (e.g. concrete shear walls).

If drawings of reinforced concrete buildings are not available it may be necessary to carry out on-site investigations to obtain details of size and spacing of reinforcing bars or to determine whether plain or deformed reinforcing bars were used. Investigations could include the removal of concrete cover in chosen locations to expose the reinforcing but may be possible using non-destructive scanning techniques (refer to Section C5). Default values given in Sections C5 to C9, based on age of construction, may also be used. Refer to Section C1.7.3 below.

Note:

In the case of steel structures some useful information is contained in Section C6 on the mechanical properties of the steel members and components (fixings such as bolts and rivets) used in these.

C1.7.3 Material properties and testing

Realistic (expected/mean) values for the material properties must be used to obtain the estimates of the probable strengths and deformation capabilities of members, joints and connections. Refer also to the discussion in Part A on the use of probable material strengths in member capacity assessment.

Recognising the significant cost associated with an extensive material testing programme and the difficulty in sampling all materials, these guidelines recommend a more pragmatic approach to setting the probable material strength for seismic assessment based on the use of default values (where not otherwise recorded in the construction documentation) and consideration of the likely sensitivity of the choice of material properties on the final assessment result. The testing effort is then concentrated in the areas of the structure that are likely to yield the greatest benefit in terms of defining the earthquake rating.

In other jurisdictions, a penalty is sometimes applied to the assessment results (e.g. a *lack of knowledge* factor). However, this approach has not been adopted in these guidelines for the reasons outlined above. It is recognised that material variability will always exist and will be difficult to quantify even when extensive testing has been carried out.

The material sections (Sections C5 to C9) provide specific guidance on the default probable material strengths to be used in absence of any documentation of the original prescribed materials or test results. These sections also provide recommendations on the type and frequency of testing if this is considered.

C1.7.4 Condition, maintenance and alterations

The condition of all structural components should be recorded with particular attention given to deterioration such as cracking, spalling, corrosion and decay. Locations and extent of any significant deterioration should be recorded. Any lack of watertightness in the roof and wall openings should be noted.

The foundation soil type should be determined and a careful inspection made to identify any settlement or indications of foundation distress.

Damage from previous earthquakes or other overloads should be carefully inspected and recorded.

The impact of any building alterations on the behaviour of the main structural elements should be considered carefully.

C1.7.5 Previous seismic retrofit

If the building has already been seismically retrofitted it will be necessary to ascertain the extent of this retrofit and the philosophy adopted. For example, in the past, buildings may have only been secured rather than fully strengthened or the strengthening scheme would now be considered incomplete or inadequate.

A design features report, if available, could provide valuable insight into what the design retrofit engineer was intending when completing only previous retrofit works. However, relying on the stated intent of any previous retrofit is not recommended when establishing its capacity as a number of issues have been identified with previous retrofit works that could reduce their effectiveness. If possible, discussions with the engineers who carried out the retrofit should be considered.

Common issues with previous retrofits include:

- Incomplete documentation – details were often varied to suit conditions found on site when the structure was opened up, so what is shown on the retrofit drawings may not always be representative of what was finally installed. Site or contract instructions, if available, can be a valuable source of information in this regard.
- Incomplete retrofit – only the most vulnerable issues may have been addressed. This would have typically been the case where interim securing had been adopted.
- Poor deformation compatibility between the original structure and the retrofit works; e.g. steel bracing used to strengthen in-plane URM walls or infilled concrete/steel frames.

C1.7.6 Intrusive inspections

Intrusive inspections while the building is occupied will typically be costly and disruptive but may not be able to be avoided. Non-destructive techniques such as electronic scanning of concrete members can often provide an attractive alternative to intrusive investigations.

C1.8 Geotechnical Investigations

The extent of geotechnical investigation required will depend on the likely influence on the earthquake rating and/or the target rating required. The categorisation outlined in Section C1.9 may assist. Further guidance is provided in Section C4.

C1.9 Geotechnical Influence on Detailed Seismic Assessments

C1.9.1 General

These guidelines categorise DSAs in terms of the influence that geotechnical issues might have as:

- structurally dominated
- interactive, or
- geotechnically dominated.

Which category a particular assessment falls into should be considered in Step 2 of the DSA process outlined above and reviewed as the assessment proceeds. The category has an impact on the way in which an assessment might proceed, including the respective roles of the geotechnical and structural engineers and the level of geotechnical reporting and investigation required.

A description of each project category and some common examples of situations where each might be considered to apply are given below. This is followed by a matrix of these examples classified by foundation type.

C1.9.2 Structurally dominated

These are assessments where the structural response is unlikely to be significantly influenced by geohazards, foundation soil nonlinearity or SSI up to the capacity of the structure. Such assessments are only likely to require geotechnical input into soil parameters for analysis purposes or in assessing the appropriate site soil class.

Examples include:

- a building on shallow foundations on competent gravels or rock
- a piled building where the ground does not liquefy at ULS levels of shaking
- an URM building on alluvial soils where the limiting structural capacity is lower than the liquefaction triggering level, and
- a building that is structurally well tied together on potentially liquefiable ground or ground prone to shaking-induced settlement, when the deformations expected are unlikely to lead to a significant life safety hazard.

C1.9.3 Interactive

These are projects where geohazards, soil nonlinearity and SSI may have an influence on the critical structural mechanism(s). Discussions with a specialist geotechnical engineer would be expected to evaluate the extent to which the geotechnical issues might affect the rating and how this should be allowed for in the assessment.

Examples include:

- a reinforced concrete frame building on well-tied shallow foundations, where the behaviour of the structure is affected by soil deformations
- a piled structure where liquefaction-induced lateral spreading imposes potentially intolerable lateral displacements

- a piled structure where liquefaction above the founding level of the piles results in significant horizontal ground lurch
- a reinforced concrete frame building on shallow foundations where column restraint may be reduced by foundation rotations/displacements due to soil flexibility
- rocking of shear walls in a combined moment frame building, and
- liquefaction-induced down-drag on a piled structure.

C1.9.4 Geotechnically dominated

For these projects the structure response is likely to be governed by geohazards, ground behaviour and SSI. Geotechnical step change (described in Section C4) is often a characteristic of ground and foundation performance in these scenarios. In addition to discussions as indicated for the interactive category above, the geotechnical engineer may need to carry out assessments of the ground behaviour which may then become a separate SW (noting that it is only issues that have a direct influence on the structure behaviour that can be considered in the earthquake rating, and then only when a significant life safety hazard can result).

Examples include:

- a building on shallow foundations where the pads supporting the bracing elements punch through into liquefiable soils
- a building on shallow foundations on liquefiable soil incorporating tension-only ground anchors holding down its bracing elements
- a piled structure located behind a seawall subject to collapse upon backfill liquefaction, and
- a piled structure on sloping ground subjected to downslope deformations.

C1.10 Reporting

C1.10.1 Communicating seismic risk

Communication of the seismic risk and the assessed seismic behaviour of the building is a very important part of the DSA process. The written report should be carefully written to suit its intended audience.

The level of ground shaking should be expressed in terms of the return period. This can be expressed as the proportion (e.g. one third, one half, two thirds, full) of the 500 year return period shaking for the site or %ULS loading for IL2 and adjusted appropriately for other ILs.

The term "*%NBS* shaking" should not be used as this does not correctly convey the contribution that the building ultimate capacity (strength and deformation) makes to the standard achieved and the expected behaviour of the building. *%NBS* is not solely about the loading. It therefore confuses "seismic demand" with "earthquake rating".

C1.10.2 Suggested report content

The following information is recommended as minimum content for a DSA report:

- the scope and objective of the DSA
- assessment methodology, limitations and list of assumptions. This includes documentation/drawings available and sources of information reviewed, including any previous assessments
- background on the regulatory requirement and assessment process
- general building description including number of storeys, occupancy/use and general dimensions, heritage categorisation
- structural systems (gravity and lateral load resisting systems, foundations, etc.)
- ground condition, site seismicity and geohazards identified and impact on the seismic behaviour of the building
- assessment results
- SWs (including any SSWs) identified and assessed (in primary seismic and gravity structure, secondary structure and critical non-structural components)
- *%NBS* and assumed Importance Level, the CSW that defines the *%NBS*, and reconciliation with any previous assessments
- modes of failure for any SWs scoring less than 34*%NBS* to allow Territorial Authorities to confirm earthquake-prone status
- secondary risks (adjacent building, non-structural element, stairs) if applicable, and
- any recommendations.

An executive summary that summarises the assessment, the key aspects of the building and the key outputs is considered desirable.

Appendix C1A provides a recommended report template.

A separate geotechnical report should be appended to the DSA (the level of geotechnical reporting will depend on the geotechnical contribution to the building's performance) – refer to Section C4 for more details.

C1.10.3 Technical Summary

To achieve consistency in assessment outputs being reported and to allow comparisons between assessments of multiple buildings, a stand-alone technical summary should be provided as part of the reporting using the template that can be found in Part A.

Note:

Providing a technical summary in a consistent form is considered to be an essential part of any DSA. It will be very useful for Territorial Authorities managing the requirements of the earthquake-prone building legislation, to owners of multiple buildings, and also to any future engineers of the same building.

The same template is presented in Part B to record the results of an ISA when this is used as the justification for the earthquake rating for earthquake-prone building purposes.

References

AS/NZS 1170.0:2002. *Structural design actions – Part 0: General principles*, Standards Australia/Standards New Zealand.

ASCE 41-23 (2023). *Seismic Evaluation of Existing Buildings,* American Society of Civil Engineers and Structural Engineering Institute, Reston, Virginia, USA.

EN 1998-3:2005. *Eurocode 8 – Design of structures for earthquake resistance – Part 3: Assessment and retrofitting of buildings*, European Committee for Standardization (CEN), Updated in 2005.

Module 1 of the Geotechnical Earthquake Engineering Practice Series dated March 2016.

NZBC B1 (2014), Acceptable Solutions and Verification Methods for New Zealand Building Code Clause B1 Structure, Ministry of Business Innovation & Employment, Wellington, NZ.

NZS 1170.5:2004. *Structural Design Actions, Part 5: Earthquake actions – New Zealand*, Standards New Zealand, Wellington, New Zealand.

Thompson, A. J., and Oliver, S. (2019). "Reviewing Expected Margins to Collapse in the Assessment of Existing Buildings in New Zealand." Proc. SESOC Conference, Structural Engineering Society of New Zealand, Auckland, New Zealand.

Appendix C1A: Recommended Report Template for a Detailed Seismic Assessment

Detailed Seismic Assessment - XX Tremor Grove, Shakesville

Prepared by ……. **CPEng Nº…………**

Dated …….

Executive Summary

Background

Provide a summary of the background to the Detailed Seismic Assessment (DSA) including:

- *who the report has been carried out for and the intended scope*
- *any previous assessment(s) and the resulting earthquake rating result(s), including assumed IL*
- *The name and/or address for the building.*

Building Description

Provide a brief description of the building including relevant features such as:

- *age*
- *structural configuration*
- *current usage*
- *primary structural system (lateral and gravity)in each direction*
- *relationship to neighbouring buildings*
- *any previous retrofit*
- *heritage status*
- *original design standard, if known*
- *foundation type*
- *subsoil description*
- *any identified geohazards*
- *impact of geotechnical aspects on building behaviour*

Assessed Earthquake Rating

The results of the DSA indicate the building's earthquake rating to be **[XXX]***%NBS* (IL**Y**) assessed in accordance with the guideline document *The Seismic Assessment of Existing Buildings-Technical Guidelines for Engineering Assessments*, dated **[ZZZ]**. The earthquake rating assumes that Importance Level **[Y]** (IL**[Y]**), in accordance with the Joint Australian/ New Zealand Standard – Structural Design Actions Part 0, AS/NZS 1170.0:2002, is appropriate.

Therefore this is a Grade [W] building following the NZSEE grading scheme. Grade **[A+/A/B/C/D]** buildings represent a risk to occupants [**less than/equivalent to/5-10 times/10-20 times/greater than 25 times]** that expected for a new building, indicating a [**low and acceptable/low and acceptable/acceptable/high/very high]** risk exposure**.**

A building with an earthquake rating less than 34*%NBS* fulfils one of the requirements for the Territorial Authority to consider it to be an Earthquake-Prone Building (EPB) in terms of the Building Act 2004. A building rating less than 67*%NBS* is considered as an Earthquake Risk Building (ERB) by the New Zealand Society for Earthquake Engineering. **[XX Tremor Grove, Shakesville]** is [**not]** therefore categorised as an Earthquake Risk Building and also it **[does not fall below/meets one of]** the criteria that could categorise it as an Earthquake Prone Building.

In accordance with the provisions of the Earthquake Prone Building requirements of the Building Act 2004 the determined earthquake rating requires the following actions for this building:

Summarise the requirements for TA confirmation of status, and upgrading and timeframes for addressing if the building is confirmed as earthquake prone.

The assessment identified the following SWs in the building:

List the SWs (including any identified SSWs) and associated earthquake scores in ascending order and note the modes of failure for any SWs scoring less than 34%NBS.

The following secondary structural and non-structural aspects were considered in the assessment of the earthquake rating:

List the non-structural aspects considered

The CSW was found to be **[complete]**.

As part of the assessment we also noted the following:

List other noteworthy items reviewed during the assessment process that would be expected to be of interest to the report recipient. This includes aspects that may or may not have influenced the earthquake rating; e.g. stairs, geohazards, neighbouring buildings.

Also discuss the next lowest scores where the CSW is a relatively easily addressed issue as this will provide context for the earthquake rating.

Acknowledge previous assessments and provide an explanation for any discrepancies.

Basis for the Assessment

This assessment has been based on the following information:

List the information that has been available for this assessment; e.g.

- *original construction (structural/architectural) drawings dated….*
- *original construction specifications dated…*
- *on-site inspection completed on ….*
- *intrusive investigations comprising…*
- *materials testing of….*
- *ISA report dated…*
- *previous assessments….*
- *geotechnical report dated…*

Seismic Retrofit Options (if required)

Depending on the brief, the engineer may wish to include this heading and some options for retrofitting. This may involve addressing the CSWs in turn and the effect this would have on the earthquake rating.

Recommended Next Steps (if required)

Depending on the brief, the engineer may wish to include this heading and some recommended next steps.

Technical Summary (present as pages that can be separable from the report- refer to Part A)

Main Report

The structure of the main report will depend on the assessment brief and personal preference. The following is a suggested contents list.

Introduction

Building Description

Results of the Detailed Seismic Assessment

Commentary on Seismic Risks

Commentary on Associated Seismic Risks/Hazards

Seismic Retrofit Options (if required)

Recommended Next Steps (if required)

Appendices