Joint Committee for Seismic Assessment and Retrofit of Existing Buildings

Applying Engineering Judgement in Determining When a Significant Life Safety Hazard Occurs

Report JC 25-01

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Foreword

The Joint Committee for Seismic Assessment and Retrofit of Existing Buildings is responsible for the joint oversight of the system used to assess, communicate, manage and mitigate seismic risk in existing buildings. It reviews how the Seismic Assessment Guidelines are functioning in practice, identifies areas that require further input and development, and either advises on or assists in the development of proposals for work programmes that contribute towards these objectives. The Joint Committee includes representatives from the Natural Hazards Commission Toka Tū Ake, the Ministry of Business, Innovation & Employment, and the technical societies (New Zealand Society for Earthquake Engineering, New Zealand Geotechnical Society and the Structural Engineering Society of New Zealand).

The Joint Committee's Vision is that:

- Seismic retrofits are being undertaken when necessary to reduce our seismic risk over time while limiting unnecessary disruption, demolitions and carbon impacts, promoting continued use or re-use of buildings.
- Decisions on retrofitting are informed by an appropriate understanding of seismic risk and are aligned with longer term asset planning.
- Seismic assessment and retrofit guidelines help engineers focus on the most critical vulnerabilities in a building, serve the needs of the market and regulation, and evolve through a stable ongoing cycle allowing new knowledge and improvements to be included in a predictable manner, including the consideration of objectives beyond life safety.
- Engineers are supported in the implementation of Seismic Assessment and Retrofit Guidelines through a range of training and information sharing strategies, including tools for risk communication to manage unnecessary vacating of buildings.
- Society is informed about the level of risk posed by existing buildings.

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Version Record

Version	Date	Purpose/ Summary of changes
1	April 2025	For industry feedback

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Please submit any feedback via design.resilience.nz.

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1. Overview

Establishing when a *significant life safety hazard* occurs is a key part of the assessment process to determine element scores, and hence the overall rating of a building. This requires the application of engineering judgement, and in many cases looking beyond the directly calculated values of where ultimate capacities are exceeded.

This report provides a framework for the application of engineering judgement in determining when a *significant life safety hazard* occurs – that is, the point at which the loss of gravity load support occurs. The key considerations in going from the element scores initially indicated from analysis outputs to produce the overall building rating are outlined with reference to the Seismic Assessment Guidelines.

Where force-based assessment procedures are used, it is important that displacement-based thinking is applied to evaluate the extent to which the structure can deform beyond the initially calculated point at which ultimate strength is reached without the loss of gravity support.

Case studies which illustrate the application of engineering judgement in determining when significant life safety hazards occur are separately available at design.resilience.nz.

This report has been produced by the Joint Committee for Seismic Assessment and Retrofit of Existing Buildings and seeks to augment the Seismic Assessment Guidelines to inform and improve aspects of current assessment practice.

2. Understanding *Significant Life Safety Hazard*

There are many areas within seismic assessments that require the application of engineering judgement. One of the key areas is whether or not exceedance of ultimate capacity at the element level gives rise to a *significant life safety hazard (SLSH)*, as defined in C1.1.2 of the Guidelines (emphasis added):

> *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.*

This is further emphasised in Section A3.1.1 in Part A of the Assessment Guidelines, which states:

> *Failure of building or building section as a whole (leading to collapse) is considered to be a significant life safety hazard, but failure of individual members/element in the primary structure will only constitute a significant life safety hazard, when considered individually,* ***if their failure causes them to fall****.*

This requires a clear understanding of how the elements and the structure overall deforms with increasing lateral load, taking into account the ability to redistribute the load to other primary load paths and all possible secondary load paths, as well as the resulting consequence of 'failure' (i.e. occurrence of loss of gravity support) of an element.

In all situations, engineering judgement should be carefully applied in order to determine whether an element has yet reached its ultimate deformation capacity, and if so, whether (in the context of all elements and available load paths) this is likely to give rise to a SLSH, rather than simply assuming that this is the case. This typically involves consideration of how the element itself, along with adjacent elements, deform in response to increasing levels of ground shaking, and how the building overall is likely to respond – all with a focus on assessing whether gravity support is maintained or lost.

This is particularly important for buildings assessed using the force-based approach, which needs to look beyond the point at which ultimate strength is exceeded in the modelled structure. Ideally the deformability of the primary structure is evaluated via some form of pushover analysis (e.g. a Simple Lateral Mechanism Analysis or SLaMA) as per the Guidelines recommendations, but even if this isn't undertaken, qualitative pushover thinking should be applied.

The most obvious examples of where low element scores don't correspond to significant life safety hazards come from the typologies of timber and steel framed low-rise buildings. For these types of structures, alternative or secondary load paths almost always exist, although often not readily quantifiable. There are however other building typologies where the calculated exceedance of ultimate capacity does not necessarily correspond to a significant life safety hazard.

3. Recap on the wider objectives of seismic assessment

A seismic assessment is primarily intended to identify significant vulnerabilities that could lead to physical failure of sections of a structure or its parts at levels of earthquake shaking much less than full design loadings. It is not intended to be an exercise in cataloguing all the design shortcomings and non-compliances in a building. This observation is relevant to any building, but particularly applies to buildings of more modern construction.

Section A3.2.2 of the Guidelines includes the following note:

> *The degree of compliance with B1/VM1 should not be confused with the degree to which a building meets or does not meet the minimum performance requirements of B1. It is quite possible for a building not to meet the full requirements of B1/VM1 and still meet the minimum life safety performance requirements of B1. It is fundamental to the approach set out in these guidelines that a seismic assessment consider how well a building meets the minimum holistic performance requirements rather than solely the extent to which is satisfies the deemed to comply requirements of the prescribed verification method.*

The objective of a seismic assessment is to establish the *expected* performance of the building. It is therefore important that the assessment outcome doesn't focus on how poorly the building *might* perform in a particular earthquake if this is considered to be a low probability outcome. The most appropriate *%NBS* rating for the structure should arguably be the best rating, not a lower bound value.

The following note in Section A4.1.2 also refers to the importance of looking beyond the lowest calculated element scores in determining the overall assessment outcome:

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

This is further emphasised in Step 11 of Section C1.4:

> *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.*

4. Force-based assessments require displacement-based thinking

Force based assessment processes are often selected by assessors of low-rise buildings for their simplicity and familiarity of process. Under the heading *Key Objectives of the DSA,* Section C2.2.1 of the Guidelines notes that *the focus in all cases should be on determining the displacement of the structure and the governing inelastic lateral and loss-of-gravity support mechanisms during "severe" earthquakes. Internal actions generated, such as shear, moment and axial load, should be considered as consequences of this deformation, not the cause of it.*

The subsequent commentary note emphasises that engineers are expected to adopt displacement-based thinking when using force-based procedures, especially when mixed mode systems are present, and goes on to note that more focus on the assessment of loss of gravity load support and "brittle" inelastic mechanisms is also recommended.

Force-based design and assessment processes allow the effects of inelastic behaviour to be accounted for. Care is however required in assessments in order to ensure the available ductilities are expressly calculated for the components and behaviours being considered, rather than adopting standard/conservative values as might be done in design. The SLaMA process provides the information necessary to effectively apply this displacement-focused thinking into force-based assessments. However, many force-based assessments of low-rise (and other) buildings are not sufficiently informed by SLaMA, and report the lowest scores based on the point at which ultimate strength is exceeded. This is likely to significantly understate the expected performance of the structure and produce a rating that is unnecessarily conservative.

5. The importance of understanding the mode of element failure

Assessments of more modern buildings often generate low ratings that result from non-compliance with detailing requirements of current design standards (for example steel connections in buildings of lightweight and low-rise construction), than more fundamental critical structural weaknesses. In a number of cases, these low ratings do not correspond to failure modes observed in major earthquake events, either in New Zealand or overseas. This can often be attributed to secondary load paths such as sheet cladding that enable greater levels of lateral load beyond those indicated by calculation to be distributed to other lateral load resisting elements. These cases are clearly different to the buildings that are the focus of the earthquake prone buildings provisions based around ‘moderate’ earthquake shaking (i.e. the ‘worst of the worst’ buildings). They are also different from other larger, heavier buildings with poor structural configuration or detailing and hence the potential to perform poorly in significant ground shaking, and whose failure would endanger a large number of people.

The term ‘failure’ is in itself potentially misleading. For a significant life safety hazard to develop, physical structural failure involving loss of gravity support needs to have developed or be imminent. This requires the element exceeding its deformation capacity (rather than just its strength), hence the importance of a pushover analysis such as a SLaMA. In many situations, the exceedance of ultimate strength in an individual connection, element or local part of the structure does not necessarily correspond to a likely physical failure.

Some generic examples of this include:

- Tension bracing in metal clad roofs and walls
- Moderately eccentric connections in steel framing
- Local foundation uplift

Examples of where low-rise buildings with low scoring elements can be rated more favourably following consideration of their mode of failure are shown in the text box on the following page.

Examples of consideration of modes of failure

The following two examples illustrate situations where a building with low scoring elements can be regarded differently following consideration of their likely modes of failure.

The first example is the relatively common situation of single-storey buildings with limited capacity of roof bracing in sheet metal-clad roofs and walls.

In this example the assessing engineer may calculate that the roof or wall bracing in a low-rise sheet metal clad structural steel portal building is not sufficient to achieve 34*%NBS*. However, in considering the mode of failure, if the strength of the bracing capacity is exceeded the presence of the sheet metal cladding will clearly offer resistance to lateral loads. The engineer can therefore determine that despite the calculated bracing capacity being exceeded, no significant life safety hazard exists as the sheet metal cladding provides an appropriate alternative load path to prevent excessive deformation.

In a second example, a tall brick chimney in a multi-unit house (or house converted to a commercial or retail use) has an initially calculated score of less than 34*%NBS*. All other elements of the building score more than 34*%NBS*.

Considering the chimney's mode of failure and consequence, the following key points are relevant:

- The chimney is located centrally within the building and the roofing is robust consisting of corrugated iron on sarking.
- If the chimney were to fall, it is unlikely to fall on people outside the building as it is centrally located and it is also unlikely to fall on people within the building due to the presence of the corrugated iron and sarking or slide off onto a pedestrian walkway.
- The section of chimney inside the house has been considered and found to score more than 34*%NBS.*

Consideration of both these points leads to the assessment that the chimney is not a significant life safety hazard and therefore the overall building rating need not be limited by this element, and the assessing engineer could discount the element from the rating. This could be dealt with in the report by noting that the element scores less than 34*%NBS*, however if it were to fall it does not present a *significant life safety hazard* and therefore this score is not considered to limit the rating of the building.

6. Utilising the mode of failure and consequence statement

A key tool in understanding the consequence of element failure is the *mode of failure and consequence statement.* As outlined in A8.5.2 of the Guidelines, the mode of failure and physical consequence statement is a description by the engineer of the manner and extent to which the building (or part) could collapse or fall and give rise to a significant life safety hazard. This statement is required by the EPB Methodology to be included in the Assessment Summary Table for assessments undertaken for EPB purposes with outcomes less than 34*%NBS* to inform the territorial authority in making their earthquake-prone decision as to whether a building that is rated less than 34*%NBS* fulfils the second requirement of section 133AB.

While the Assessment Summary Table is widely used, current practice is that the mode of failure statements is often given only cursory treatment by assessing engineers. The space for this statement in the template table is commonly either left empty when reporting on results less than 34*%NBS* or populated with language that talks in engineering mechanism terms rather than describing potential physical impacts. However, having the assessing engineer look more closely at the mode of failure has in some cases led to a review and increase of the overall rating as the likely response of the structure overall (including dependable secondary load paths) is more fully taken into account, albeit qualitatively.

The development of a carefully considered mode of failure statement is considered important for all buildings where low scores are indicated, particularly relevant for low-rise buildings. Their use is encouraged by Part A of the Guidelines for use beyond EPB regulatory purposes.

This should lead the assessing engineer to consider the following:

- (i) Is that low scoring element likely to physically fail in a way that leads directly to loss of gravity support?
- (ii) If this <u>is</u> likely, then what is the impact of that on the occupants or people around the building?
- (iii) If this <u>isn't</u> likely, how would lateral load demands be redistributed to other parts of the structure?

This conscious line of questioning supports the application of engineering judgement in situations where secondary load paths clearly exist but are difficult to quantify, or other mitigations exist (refer to the examples on the previous page).

7. How to demonstrate the application of engineering judgement

There is currently no structured process for an assessing engineer to demonstrate how they have applied engineering judgement to override an initially calculated ultimate capacity that is exceeded below 34%ULS shaking demands, or other relevant threshold.

An example of language used in a report summarising a Detailed Seismic Assessment to convey the difference between exceedance of ultimate capacity and the onset of a significant life safety hazard occurring is shown below:

> *It is observed in the pushover analysis of the 3D analytic models that even though the loading demands in an element may exceed its calculated strength during low levels of shaking, it does not necessarily result in an immediate significant life safety hazard.*

While the context of this text was a DSA that was based on a pushover analysis, the same approach can be applied qualitatively when a pushover analysis is not undertaken.

The following process is suggested for situations where initially calculated scores less than 34*%NBS* result from a Force-based Detailed Seismic Assessment, but further specific qualitative consideration supports element scores and an overall building rating above the calculated level.

When the output from a force-based quantitative assessment indicates element scores below 34%ULS demand, the following additional steps should be followed:

1. Consider the response of the structure to deformation resulting from additional lateral load, and evaluate and briefly describe the physical consequences of the calculated exceedance of ultimate strength to the specific low scoring members. Specific consideration should be given to:
    - Whether inelastic displacement capacity been sufficiently accounted for, and used to directly review the displacement ductilities appropriate to the assessment of the elements concerned?
    - Does the assessment of deformation capacity appropriately recognise when element(s) may not need to contribute to lateral stability (i.e. only sustain gravity loads) and thus might tolerate higher deformations before their ultimate capacity is reached?
    - If the element(s) were to fail, is a *significant life safety hazard* expected (i.e. loss of gravity support) likely to develop at the level of earthquake shaking associated with the element(s) assessed ultimate capacities, having regard to the occupancy context?
2. If loss of gravity support (and a significant life safety hazard) is more likely than not to occur if the element(s) were to fail, then their ultimate capacity relative to the % ULS shaking demand determines the %NBS score for the structural weakness. The lowest of these scores represents the overall building rating.

3. If loss of gravity support is unlikely with increasing lateral load (deformation) due to factors such as
   - the ability of elements of the primary structure to deform further;
   - the presence of secondary load paths;
   - other occupant protection measures; or
   - inherent resilience against collapse under cyclic loads

   then re-evaluate the level of seismic demand at which loss of gravity support is *expected* to occur, indicating which of the above factors are applicable.
4. For low occupancy situations such as plantrooms or other infrequently accessed areas that do not contain workstations and where the life safety exposure is clearly low, consideration could also be given to indicating that a significant life safety hazard does not exist (i.e. applying the risk logic associated with Space Class V in Table A4.2).
5. The overall building rating can be reported as that corresponding to the lowest of the scores determined from steps 2 to 4 above.

A visual representation of the above steps is indicated in Figure 1 below.

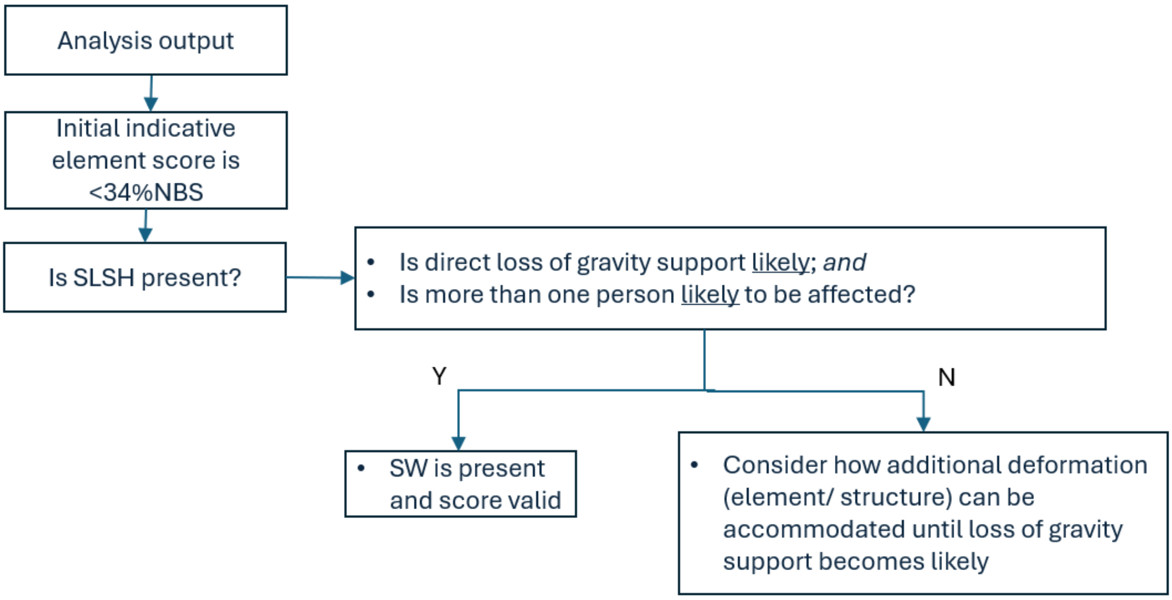

Figure 1: Representation of the key steps in validating initial analysis outputs

An example of how this process has been applied to a two-storey concrete building can be found at design.resilience.nz.

A suggested statement that summarises the application of the above judgement steps is as follows:

> *We have given specific consideration to the level of seismic demand at which loss of gravity support giving rise to a significant life safety hazard is expected to occur in the elements of the structure with low calculated ultimate strengths. Having regard to the deformability of both the elements concerned and the building overall, we have assigned the following element scores:*

A similar justification approach can be applied for structures that are acknowledged as being of low vulnerability (for example, timber-framed buildings) where the calculated lowest score following the above steps is less than but close to 34*%NBS*, but the assessing engineer is comfortable in rating the building overall as ‘34*%NBS* or above’.