Seismic Restraint Approaches in Existing Buildings

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ABSTRACT

Improving the seismic performance of non-structural elements (NSEs) in existing buildings is a relatively new field in New Zealand, leading to inconsistency in approaches taken by industry. The base-line method focuses on assessing and addressing Significant Life Safety Hazards (SLSH) and was introduced as part of the New Zealand Society for Earthquake Engineering (NZSEE) Seismic Assessment Guidelines (2017). While this approach mitigates major risks to life-safety, it often overlooks other vulnerabilities and risk, particularly when considering damage and downtime.

This paper explores other approaches to the assessment and improvement of seismic performance of NSEs in existing buildings. These approaches include factors that extend beyond the SLSH framework, such as damage and operational functionality considerations. The paper discusses positives and weaknesses of the various approaches and provides recommendations on where each approach may be best applied.

Given the impacts of non-structural damage observed in past earthquake incidents, this paper advocates for adopting a targeted risk-based approach as a minimum. Such assessment methods have the potential to significantly enhance safety, property protection, and operational continuity.

1 INTRODUCTION

Earthquake damage to non-structural elements such as ceilings, partitions, and building services has been well documented for many years in New Zealand and other seismic regions worldwide. It is also well understood that earthquake damage to NSEs can severely impact building functionality as well as risk life-safety (Dhakal, 2010, Baird, 2017). Even so, prior to 2017, there is no established standard for assessing and improving the seismic performance of NSEs in existing buildings, leading to inconsistency across the industry.

The baseline method, introduced as part of the New Zealand Society for Earthquake Engineering (NZSEE) Seismic Assessment Guidelines (2017), focuses on reducing Significant Life Safety Hazards (SLSH). However, this life-safety-centred framework often overlooks other essential considerations, such as minimising damage and ensuring operational continuity after an earthquake. This paper examines a range of potential approaches that extend beyond the SLSH framework to include factors like damage prevention and functional performance.

2 BACKGROUND

The regulatory requirement for existing non-structural elements is provided in the Building (Earthquake-prone Buildings) Amendment Act 2016, in which only elements that cause significant life safety risk under moderate earthquake events (therefore earthquake-prone) will require consideration. The MBIE's Technical Guidelines for Engineering Assessments (2017) is cited as the assessment methodology. This is a globally acknowledged challenge, as highlighted by FEMA E-74, which identifies sources of non-structural earthquake damage and offers effective methods to mitigate associated risks. It provides guidance on recognising potential hazards and implementing specific upgrades to reduce damage (FEMA, 2012).

In 2016, MBIE commissioned several studies (MBIE, 2017a and 2017b, and Yeow et al, 2017) to better understand the state of the construction industry and identify improvements needed for the seismic performance of non-structural elements in both new and existing buildings. Key conclusions from these studies are outlined in this section.

2.1 Non-Compliance

Based on the survey of a wide range of existing buildings (MBIE,2017a) , existing services, partitions, and ceilings in existing buildings have very poor levels of compliance with seismic restraint design codes. The majority of non-structural elements in New Zealand commercial buildings are inadequately seismically restrained as shown in Figure 1.

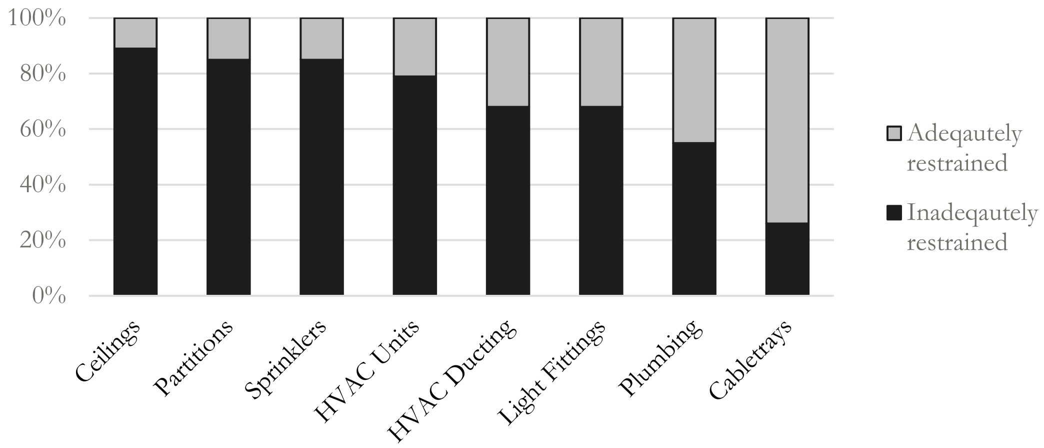

Figure 1: Proportion of NSE adequately restrained in New Zealand commercial buildings (MBIE, 2017a)

2.2 Damage and Disruption

Research has also shown that damage to non-structural elements is the main contributor to property losses and business disruption following an earthquake (MBIE, 2017b). Property losses include both direct damage, e.g., broken water pipes, and indirect damage, e.g., water damage to facilities and contents. Business continuity disruption encompasses issues such as inaccessibility, damage to critical systems, or damage to support systems like HVAC for server room cooling.

MBIE more recently prepared a seismic risk resource to help commercial buildings tenants make decisions about the seismic risk of the buildings they lease and occupy (MBIE, 2024). This resource discusses seismic risk in terms of life-safety, property losses and business disruption. It notes that property losses and business disruption can occur at much lower levels of shaking than life-safety risks. Because lower levels of shaking can be expected more often, property loss and business disruption are therefore more likely to occur.

The resource includes mitigation measures that can be taken to reduce the risk of property loss or business disruption within an existing lease. These are shown in Figure 2 and include securing non-structural elements and seismic strengthening. Potential mitigation measures for life safety risks also includes bracing of services.

What you can advocate your property manager and/or building owner to do:

- secure or replacement of heavy contents/fittings/non-structural building elements (items that are not part of your tenancy),
- undertake seismic strengthening,
- provide back-ups for key services you depend on (eg water, electricity).

Even after mitigation actions have been implemented, you will still need to accept at least some residual risk; that is, risk posed by the building that you cannot reasonably avoid.

Figure 2: Mitigation measures that can be taken to reduce the risk of property loss or business disruption within an existing lease (MBIE, 2024)

2.3 Life-Safety Risks

Research in New Zealand (Yeow et al, 2017) has also found that the majority of injuries in recent earthquakes have been due to damage to non-structural elements, as shown in Figure 3 below. This research further reinforces the fact that non-structural elements pose a health and safety risks to building occupants, and thus PCBUs have a responsibility to manage this risk.

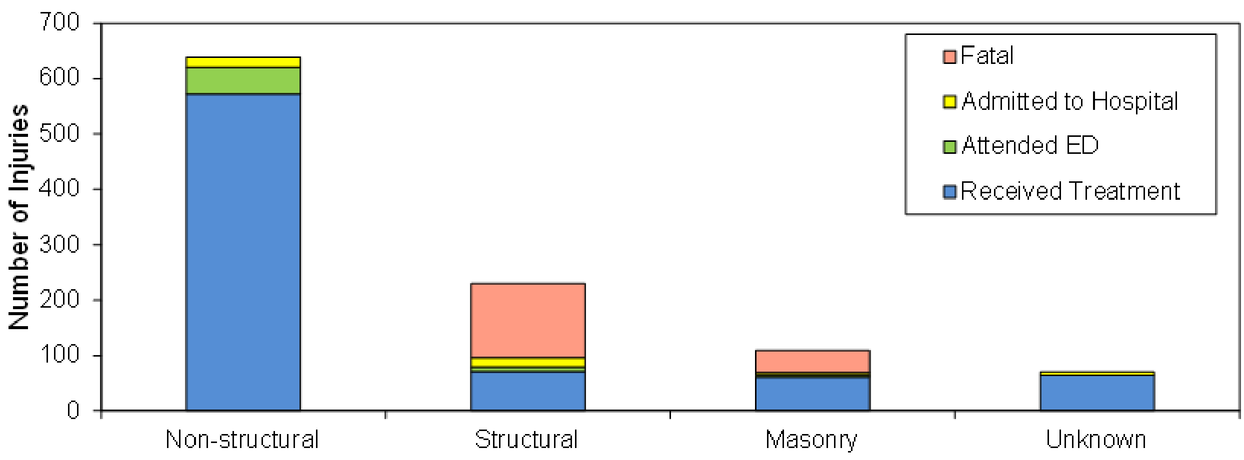

Figure 3: Cause of earthquake injuries in New Zealand (Yeow et al, 2017)

In this context, if an assessment and retrofit were to address only Significant Life Safety Hazards (SLSH), there may still be residual risks to individuals that may not be mitigated. Under the Health and Safety at Work Act, PCBUs have a responsibility to identify and manage risks in the workplace (HSWA, 2015). This includes building owners' duty to identify and eliminate or minimise earthquake-related health and safety risks, where reasonably practicable. Minimisation measures might involve securing parts or isolating people from them (Worksafe, 2018).

3 SEISMIC RESTRAINT APPROACHES FOR EXISTING BUILDINGS

The seismic restraint of existing non-structural elements is a relatively new and evolving field in New Zealand. While it has not yet fully matured, several approaches have emerged within the industry to address the issues identified above. These approaches can be viewed as existing on a spectrum, as illustrated in Figure 4. This spectrum ranges from taking no action at all to designing seismic restraints for existing elements to achieve full compliance with current codes. Beyond this, there is an even more rigorous approach—designing restraints that exceed code requirements—though this is not commonly practiced. This section explores each of these potential approaches in detail, providing insights into their application, benefits, and limitations.

Figure 4: Spectrum of approaches for the seismic restraint of existing elements

3.1 Do Nothing

This approach balances the seismic risk of the non-structural elements and the cost of undertaking the seismic retrofit work. Undertaking seismic retrofit of existing non-structural elements can be costly due to the impact to the existing finishes and the ongoing operations of buildings. Therefore, for some typologies of buildings (e.g. low occupancy or low value) in low-seismic zones, the cost-benefit of assessing and upgrading seismic restraints of non-structural elements may not be warranted. Therefore, “Do Nothing” can be a viable approach especially if used in conjunction with other risk measures such as insurance risk transfer and redundancy in building operations.

3.2 Significant Life Safety Hazards (SLSH) Approach

This approach focuses on providing seismic restraint to elements that pose a significant life safety hazard, as defined by the New Zealand Society for Earthquake Engineering Assessment (NZSEE) Guidelines. According to the NZSEE Guidelines, a significant life safety hazard (SLSH) is one that could reasonably affect multiple people if it were to fall. These hazards are typically identified through a Secondary Structural and Non-Structural (SSNS) Assessment. SLSHs impact the %NBS score of a building and therefore can be contributing factors to a building being deemed either an ‘Earthquake Prone Building’ or an ‘Earthquake Risk Building’. Figure 5 summarises the non-structural elements that are considered as SLSH in the NZSEE Guidelines.

Table A4.1: Parts that pose a significant life safety hazard

Parts that could pose a life safety hazard	Expected to be a significant life safety hazard: Yes	Expected to be a significant life safety hazard: No
Vertical or horizontal cantilevering elements	Heavy (>25kg) elements (e.g. URM parapets, chimneys, cantilevering concrete beams, canopies)	Lightweight (≤25 kg) elements
Light cladding systems including curtain walls	Support frames that could fall into space class I	Lightweight cladding elements, including individual glazing elements (moderate sized panes of glass)
External cladding elements, including connections	Heavy elements (e.g. precast concrete panels (not integral with the primary structure) above space class I	Lightweight cladding elements
Appendages and ornamentation	Heavy elements above space class I	All Other
Stairs and their associated supports	Above or supporting space classes I, II and III and Above space classes IV	All other stairs
Ceiling systems and/or ceiling grids	Heavy ceiling systems above space classes I, II, III or IV Ceiling systems above space classes I, II, and IV Unrestrained ceiling tiles >7.5 kg/tile above space class I, II, III and IV	Unrestrained ceiling tiles < 7.5 kg/tile Conventional lightweight ceiling grid systems above space class III Ceiling grids/tiles within space class V
Partitions and walls	> 25 kg/m² (e.g. blockwork or clay tiles) bordering space classes I, II, III or IV	≤ 25 kg/m² (e.g. conventional timber or light gauge steel framed partitions and walls) Any partitions and walls within space class V
Signs or billboards	Large (> 25 m²) or heavy with a fall height greater than 3 m onto space classes I, II, III and IV	All other
Plant and tanks with non-hazardous contents	Large/heavy elements where failure of restraints/supports could lead to the item falling onto building occupants Does not include the integrity of the item itself	All other
Vessels containing hazardous materials	Where spillage would pose a health hazard for building occupants or those within 3 m of its perimeter	Small robust containers that are unlikely to spill their contents
Storage racking systems	Heavy systems in generally occupied spaces	Lightweight systems Systems in space class V
In-ceiling building services	Only when failure of one building element could lead to failure of another that would pose a significant life safety hazard (e.g. a heavy ceiling over a class II area).	Lighting, heating, ventilation and air conditioning ducts and equipment

Explanatory Notes:
A heavy element has a mass >25 kg
A lightweight element has a mass ≤ 25 kg
A large element has an area >25 m²

Figure 5: Non-structural elements that are considered to be significant life safety hazard (NZSEE, 2017)

The SSNS assessment includes a Space Class consideration, which recognises the level of risk to building occupants varies for different spaces, e.g. higher risk where people congregate versus plant rooms which are typically unoccupied. As mentioned previously, for an element to pose a significant life-safety risk, it must pose a risk to a number of people. From a Space Class consideration, this means if people could reasonably shelter from the hazard, e.g. under desks, then the hazard is not considered significant.

When a SLSH approach is taken, life-safety hazards may still remain, but provided that these are not located over egress paths, or where people congregate, or people can reasonably shelter from them, then these life-safety hazards would not be considered significant. This approach is therefore considered the lowest level of risk reduction as it only addresses significant life safety hazards.

3.3 Targeted Risk-Based Approach

Targeted Risk-Based Approaches build on the Significant Life Safety Hazards (SLSH) approach by including additional specific elements known to either be vulnerable in earthquakes or pose an unacceptably high level of risk but fall outside the guidance of the NZSEE Guidelines. For instance, rigid sprinkler droppers are a well-known vulnerability in earthquakes due to their inability to accommodate relative movement between the ceiling and the sprinkler. While the sprinkler may not pose a significant life-safety hazard (or even a life-safety hazard), the risk of damage from interacting with the ceiling is high and can lead to considerable consequences, such as flooding.

Due to the limited scope of a SLSH approach, and the significant other risks associated with damage to non-structural elements, a targeted risk-based approach is becoming more common for seismic restraint of existing elements. While there is not a well-established standard approach for what should and shouldn't be included, there has been a considerable amount of research in this area, particularly in the USA where this has been an area of focus particularly in California for the past two decades. It is widely accepted that designing for life-safety alone is not sufficient to mitigate risks such as downtime and repair costs (FEMA P-2090).

Targeted Risk-Based Approaches will vary depending on the building, the vulnerability of elements within the building, and what elements or systems are most important to the building owner or occupant. Examples of this would include restraining cable trays that provide power to servers that are critical for operational continuity of a business, or restraint of water pipework above building contents that are susceptible to water damage.

An example of a Targeted Risk-Based Approach is illustrated in Figure 6 below. In this approach, SLSH were identified for upgrade alongside elements and systems considered 'Mission Critical' for the building. These 'Mission Critical' elements were determined in collaboration with building services teams, taking into account their importance to the building's continued functionality, potential redundancy, and ease of repair. Additionally, input was sought from the client to identify elements or systems they deemed essential for maintaining post-earthquake functionality or particularly valuable to their operations.

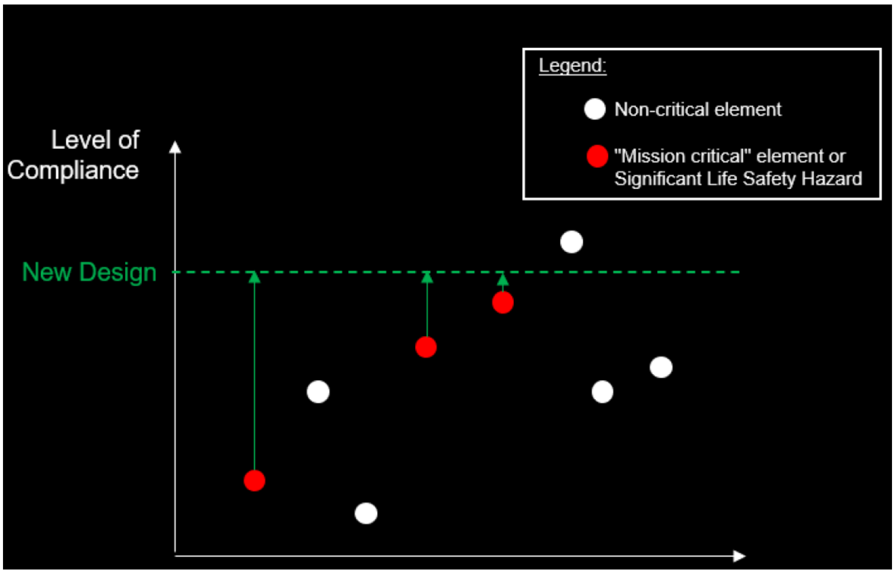

Figure 6: Graphical illustration of a Targeted Risk-Based Approach – applying upgrades to mission critical elements and earthquake-prone SLSH elements.

3.4 As Near As Reasonably Practicable (ANARP)

The As Near As Reasonably Practicable (ANARP) approach focuses on bringing as many existing elements as close to code compliance as is practical to do so. This method recognises that it is often impractical to bring all existing elements all the way up to full building code compliance. However, risk can still be reduced by partially retrofitting existing elements or only targeting those areas where it is feasible.

The ANARP approach requires the assessor to undertake an assessment of the existing condition and vulnerability of non-structural elements, and the retrofit measures required to upgrade them. This includes qualitatively assessing the sacrifices and benefits of undertaking the upgrades required to achieve full Building Code compliance of seismic restraint. The graph in Figure 6 illustrates that a point is reached where a significant increase in the sacrifice is made for a comparatively small gain in the resulting benefit. This point can be considered ANARP (MBIE, 2025)

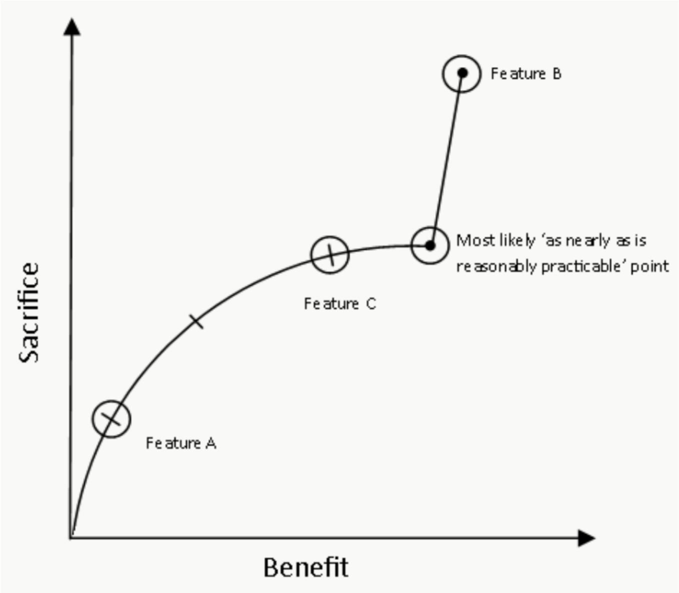

Figure 6: Graphical illustration of ANARP (MBIE, 2025)

'Sacrifices' include the tangible and intangible costs that a building owner will meet by proceeding with certain upgrades (MBIE, 2025). These can include:

- the direct cost of carrying out upgrades,
- factors such as business interruption and loss of amenity values.

'Benefits' include:

- meeting the Building Code objectives for seismic:
  - reduced safety risk
  - reduced losses and downtime risk

An assessment of the benefits and sacrifices should consider:

- the level of compliance of the existing building with the Building Code clauses
- the level of upgrade that would be necessary for full Building Code compliance and the cost of compliant construction
- the nature and extent of the alterations, including cost (for example, by a quantity surveyor)
- whether there is any reduction in the level of life safety
- design constraints
- the building size and complexity
- the use of the building, including frequency and nature of occupation,

Unlike the Targeted Risk-Based approach, which requires identifying specific critical elements for retrofitting, the ANARP approach casts a wider net, aiming to reduce risk as much as practically achievable. In some sense the ANARP are the Targeted Risk-Based Approach are interrelated as they apply the same risk-based logic, however often ANARP is seen as a more comprehensive approach while remaining both practical and pragmatic.

Non-compliance can be expected to remain. For instance, achieving seismic clearances or retrofitting existing fixings is difficult but represents a lower risk, so these are not high-priority remediation tasks.

3.5 Full Compliance

Seismic restraint of existing elements to full code compliance in the same way as a new design. Achieving seismic restraint to existing elements that fully complies with New Zealand Standards can be challenging. This is usually feasible only when the entire space is being refurbished and the existing in-ceiling services are easily accessible and new ceilings may be installed. The cost to achieve full compliance can be excessive – for example, installing new seismic braces to existing ceilings and services may necessitate the temporary relocation of existing building elements to provide space for construction access. This will also result in significant disruption to the use of the space.

4 DISCUSSION

There is no well-established approach for the seismic restraint of existing non-structural elements such as services, ceilings, and partitions. Addressing only Significant Life Safety Hazards (SLSH) represents the minimum benchmark for risk mitigation. While this approach reduces significant risks to life during a seismic event, it falls short of addressing broader issues such as property damage, operational downtime, and business disruption. This limitation is highlighted in documents like the MBIE report *Seismic Risk Resource for Commercial Building Tenants*, as well as research conducted in New Zealand and overseas. Such findings strongly indicate that retrofitting exclusively for life-safety is inadequate for the broader risk management required by building owners or occupants (MBIE, 2024).

While there are circumstances where an SLSH-focused approach may be appropriate, we advocate for, at a minimum, the adoption of a Targeted Risk-Based approach for the seismic restraint of NSEs. This approach allows for a tailored response based on the importance of specific elements as well as the level of risk that the building owner or occupant is willing to accept. The recently published *Code of Practice for the Seismic Performance of Non-Structural Elements* offers valuable technical guidance and a foundation upon which further industry-specific resources can build (NSE CoP, 2024)

The Targeted Risk-Based approach provides a simple method for mitigating additional risks. The ANARP (As Nearly As Reasonably Practicable) approach is more comprehensive as it requires assessors to carefully evaluate both sacrifices and benefits to identify an efficient retrofit solution. However, the ANARP approach can have shortcomings, particularly when applied as a blanket approach. In such cases, the responsibility for assessing and deciding what can or cannot be restrained may fall to installers, which can result in lower-risk items being restrained simply because they are easier to address, while higher-risk elements may be overlooked.

The authors advocate for a Targeted Risk-Based or ANARP approach as we consider these methods offer an optimal balance between implementation and effectiveness at reducing risk. This approach enhances the ability to identify health and safety risks to individuals, such that they can be sufficiently mitigated. It also gives the opportunity to mitigate the wider consequences of NSE damage, ensuring a more resilient and functional built environment beyond the scope of SLSH alone.

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