# Design, Construction and Seismic Performance of Non-Structural Elements in New Zealand

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## Abstract

The performance of buildings in recent New Zealand earthquakes (Canterbury, Seddon and Kaikōura), delivered stark lessons on seismic resilience. Most of our buildings, with a few notable exceptions, performed as our Codes intended them to, that is, to safeguard people from injury. Many buildings only suffered minor structural damage but were unable to be reused and occupied for significant periods of time due to the damage and failure of non-structural elements. This resulted in substantial economic losses and major disruptions to our businesses and communities.

Research has attributed the damage to poor overall design coordination, inadequate or lack of seismic restraints for non-structural elements and insufficient clearances between building components to cater for the interaction of non-structural elements under seismic actions.

Investigations have found a clear connection between the poor performance of non-structural elements and the issues causing pain in the industry (procurement methods, risk aversion, the lack of clear understanding of design and inspection responsibility and the need for better alignment of the design codes to enable a consistent integrated design approach). The challenge to improve the seismic performance of non-structural elements in New Zealand is a complex one that cuts across a diverse construction industry.

Adopting the key steps as recommended in this paper is expected to have significant co-benefits to the New Zealand construction industry, with improvements in productivity alongside reductions in costs and waste, as the rework which plagues the industry decreases.

## Introduction

Non-structural elements generally can be classified into three broad categories:

- Architectural elements, such as exterior cladding and glazing, ornamentations, ceilings, interior partitions and stairs,
- Building services components and equipment, including air conditioning equipment, ducts, pipework, cabling and cable trays, sprinklers, lifts, escalators, pumps, plant items and emergency generators,
- Building contents, such as movable furniture, bookshelves, computers and entertainment equipment.

The Architectural elements and Building services (which constitute the majority of drift and acceleration sensitive non-structural elements) can cost between four and seven times of the total structural system cost in most buildings (Khakurel et al, 2020), and their repair cost can dominate the total repair cost of buildings after major earthquake (Bradley et a 2009).

Non-structural elements suffered extensive damage in the Canterbury (Dhakal 2010, Dhakal et al 2011), Seddon and Kaikoura earthquakes (Baird & Ferner 2017). Figures 1 and 2 illustrate samples of the observed damage.

**Figure 1: Illustrating damage to non-structural elements observed in the Canterbury earthquakes (from Dhakal, 2010)**

**Figure 2: Illustrating exterior damage to non-structural elements observed in the Kaikoura earthquake (from Radio NZ/Susie Ferguson)**

The cost to repair the material damage and the value of the business interruption due to poor performance of non-structural elements in these earthquakes was substantial, although difficult to quantify due to the repair costs often not being publicly documented by insurers and repairs which cost less than the insurance excess completed by building owners and not captured in overall losses. Research showed that Business Interruption costs were significantly higher than material damage repair costs in recent New Zealand earthquakes (Stanway & Curtain 2017). It is now recognized that damage to non-structural elements is a bigger issue than the damage to primary structure.

The damage to non-structural elements was greater than expected by building owners, tenants/users and insurers. This was especially the case for buildings which suffered significant damage despite being subjected to shaking significantly lower than the ultimate limit state earthquake (defined as an earthquake with a 10% probability of exceedance in 50 years). Verbally the insurance industry has advised that numerous buildings suffered major insurance claims as a result of damage to non-structural elements but were only subjected to seismic shaking around a 1 in 100-year event (defined as an earthquake with a 40% probability of exceedance in 50 years).

The performance of our buildings caused many to pause and consider if current design and construction practices are delivering the buildings that meet the needs of our communities. Do we have the right balance between designing to preserve life in extreme, infrequent events versus designing for lesser more frequent events that enable continued functional use of the buildings in a way that meets the needs and expectations of our communities?

To better understand the underlying reasons for the poor compliance and seismic performance of non-structural elements in New Zealand, a strategic review of the New Zealand construction industry in relation to non-structural elements in both new and existing buildings was completed in 2020 (Building Innovation Partnership, 2020).

The review was based on literature research, university research, post-earthquake observations and industry workshops which included participants from a wide cross section of the construction industry (owners, regulators, project managers, quantity surveyors, consultants, contractors and specialist sub-contractors).

## Current Industry Challenges

The New Zealand construction industry is challenged at its heart by risk avoidance. Contracts and procurement methodologies transfer risk from the asset owner to the construction team.

There appears to be a lack of appreciation by the asset owners and project managers of the value of collectively managing the risk and responsibility for the design, coordination and construction of non-structural elements and their seismic restraints.

Current procurement methods (often lowest price conforming) have significant implications for construction teams, with additional risks assigned to the construction teams through the expectation to provide a fixed price, without tags, based on incomplete documentation where the detailed design and coordination for non-structural elements has not been undertaken. It often follows that when the construction teams complete the design and coordination of the non-structural elements, wider issues are uncovered. For example, it is not uncommon to find that there is insufficient room to install code compliant non-structural elements and seismic restraints within the space provided within the building envelope. Changes of this magnitude are too difficult to make during the construction phase and therefore lead to compromises in compliance and have the potential to lower the seismic performance expected.

Contractors have reported (Building Innovation Partnership, 2020) that they want to construct and install fully resolved designs but they are currently taking on design risk for seismic elements that is difficult to accurately assess and price at tender. They noted it is common for items to need to be reconfigured 3+ times to get the installation right.

To be competitive in a market driven by risk transfer and lowest cost, many subcontractors try to manage the cost risk by choosing the easiest and cheapest support points and reticulation routes without due consideration of the potential significant effects for other subcontractors or other elements of the building. An uncoordinated installation by one subcontractor can change a compliant installation from another subcontractor into a non-compliant one.

Industry participants at workshops noted that some contractors and sub-contractors are using the fact that no independent inspection occurs to check the use of inferior products (for example, fixings that are not approved for seismic loading), or not installing seismic braces in accordance with the design and standards and reducing their fees accordingly to win the work. They also noted that without full coordination, product substitutions are often offered to the project team with an associated cost saving. The substitution is approved on the basis of the cost saving. However, in practice it is common that the knock-on effects of the change in the equipment/product to other building elements is far reaching and the costs to adjust other components to achieve clearances and not compromise the seismic performance of other components results in variations and project delays that far outweigh the cost saving originally offered.

Currently, the design, coordination and construction of non-structural elements and their seismic restraints rely, in the most part, on self-regulation of the industry. Research (Building Innovation Partnership, 2020) has indicated that self-regulation is not working, and New Zealand is falling well short of the seismic performance expected of non-structural elements in the new building stock.

There is currently a lack of coordination during the design and construction and a lack of on-site observation, by all parties, to verify that what is required, has been constructed. Figures 3, 4 and 5 show examples from a recent building where numerous non-compliance issues were found towards the end of construction.

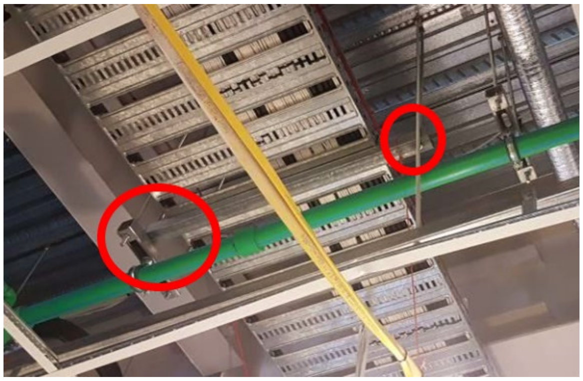

**Figure 3: Insufficient clearance between gravity hanger and pipe, and gravity support for pipe hung off hanger for cable tray above**

**Figure 4: Ceiling hangers run through cable tray**

**Figure 5: Clash of pipe with insulated pipe and cable tray**

In addition to the coordination and installation issues, university research (Pourali et al 2014, Stanway et al 2018) has demonstrated significant gaps in technical knowledge both nationally and internationally, especially with regard to how various non-structural elements respond to seismic accelerations and building drifts and the interaction, impact and damage of various building components during seismic events. Since the 2010-11 Canterbury earthquake sequence, NZ engineers have become increasingly aware of the importance of the seismic design of non-structural elements and multiple research projects have led to significant progress in understanding and improving seismic performance of non-structural elements and contents (Dhakal et al 2014, 2016a, 2016b, 2019, Pourali et al 2017, Yeow et al 2018, Khakurel et al 2019, Mulligan et al 2020, Arifin et al 2020). The New Zealand Seismic Assessment Guidelines (albeit not capturing the essence of all recent research findings) have also been developed for practicing engineers to estimate seismic capacity of non-structural elements in existing buildings (NZSEE, 2017).

Sullivan et al. (2013) and others have demonstrated that international standards provide poor prediction of floor spectral demands, particularly for non-structural elements characterized by low levels of damping. As an example, the left side of Figure 6 shows that the acceleration demands on non-structural elements characterized by 2% damping atop an 8-storey RC wall building are likely to be underestimated by a factor of around three when the period of the component corresponds to the 2nd mode period of the building (0.5seconds for the case shown).

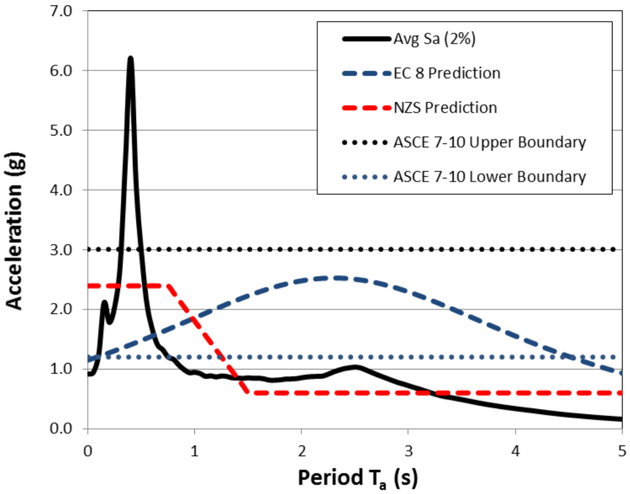

**Figure 6: Comparison of predicted floor acceleration response spectra at top level of an 8-storey RC wall building (from Sullivan et al. 2013)**

Figure 7 reminds us that the amplification of acceleration demands felt by components is not new, with Biggs (1971) reporting high amplification of demands on equipment (with 0.5% damping) almost 50 years ago.

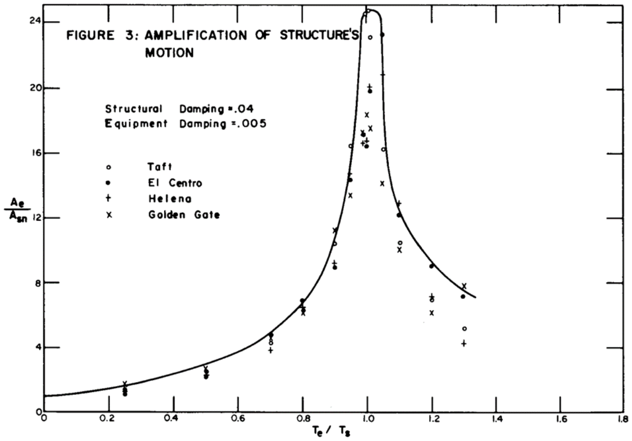

**Figure 7: Dynamic amplification factors (ratio of acceleration demand on a component to peak floor acceleration demand) from Biggs (1971)**

Currently, ductility reduction factors are included in some codes to allow reduction of elastic acceleration demands to design levels that allow for some non-linear response of the component. However, it would appear that there is little evidence from research or in-situ observations that the ductility reduction factors included in codes are appropriate.

Passive fire elements have had little research to test the fire-resistance and smoke rating of passive fire resistance products following an earthquake.

The current issues facing the construction industry are not the fault of the contracting teams. Without appropriate scope definition, risk allocation, project budget and programme to allow full coordination of all non-structural elements from project inception, the outcome is inherently compromised.

The result is that many recently constructed buildings have Code Compliance Certificates, but feedback from industry (Building Innovation Partnership, 2020) and research (Geldenhuys et al, 2016) suggest that many of the non-structural elements in these buildings do not meet the requirements of the New Zealand Building Code.

## The Vision for the Future

What could our industry look like when the seismic performance of non-structural elements is recognized as a key component to overall building and community resilience? This would require fair and appropriate risk allocation, clear responsibilities and fully coordinated design and construction with procurement methods that support these outcomes.

Even greater improvements in resilience would be achieved if we adopted enhanced design requirements for non-structural elements.

The vision is that following a major earthquake non-structural elements would perform as per the design intent, and that the process to design and install the non-structural elements has been undertaken with fair and appropriate risk allocation and compensation.

## Recommended Steps to Improve Compliance and Seismic Performance of Non-Structural Elements

Research by Stanway & Curtain (2017) and the Building Innovation Partnership (2020), has shown that the poor performance of non-structural elements is a system failure of the New Zealand construction industry.

The New Zealand construction industry, from the regulator (MBIE), building owners, designers, and contractors need to work together if we are going to achieve the productivity and performance outcomes for our future building stock, that meets the expectations of our industry, owners and wider community.

The issues facing the construction industry won't go away simply by tinkering with codes, demanding cheaper costs or scattering enforcement or resilience through random projects. Taking action will challenge the industry. Seven key steps are recommended to deliver more resilient and productive outcomes. Some of these steps will be superseded by future steps.

1. Development of training, guidance documentation, and a Code of Practice.
2. Define roles and responsibilities of different stakeholders.
3. Carry out research and testing to enhance our understanding and design solutions.
4. Develop a seismic classification system and a two-tier compliance pathway to be included in the Code of Practice.
5. Introduce an independent quality provider and certification body for non-structural elements.
6. Update standards to provide a single source document for the seismic design and performance requirements of non-structural elements, including enhancements to design based on outcomes from research and testing.
7. Introduce a new clause in the New Zealand Building Code specifically for non-structural elements and systems.

The following sections summarize each of the recommended steps.

## Training, Guidance Documentation and a Code of Practice

Industry training is developed and offered widely to all parties including clients, councils, consultants, project managers and contractors. The training would provide the technical how and why for consultants and contractors, along with training for quantity surveyors, insurers and owners on what the new system is and what it delivers. Training would continue to be developed and offered to industry in parallel with future steps and developments.

In the future, all important aspects of seismic performance of non-structural elements would be well understood in the industry, similar to fire and acoustic disciplines. Specialist designers and contractors would be widely available to provide advice and share their knowledge to the industry and junior colleagues.

In consultation with stakeholders it is recommended that a suite of industry guidance documentation is developed including:

- *Overarching Principles.* This document would provide the high-level principles and performance requirements to achieve functional recovery of buildings following various seismic events. Guidance will likely include recommendations for earthquake return periods, acceleration and drift limits to achieve various performance states, i) no damage, ii) controlled, repairable damage, and iii) collapse prevention. This guidance document would benefit designers, contractors, building owners and tenants as it will provide, the performance requirements of the building, which will enable better understanding of the risk of loss of function of buildings in moderate earthquakes.

  The document will also define the type of work and upgrades to existing non-structural element systems that would constitute an alteration to the building, in accordance with section 112 of the New Zealand Building Act.
- *Procurement.* There is a need for a guidance document which describes the various procurement methodologies along with the risk allocation and the resulting risk to building owner for each procurement method. Recommended procurement methods would be described as well as a discussion on procurement methods that are not recommended.
- *Code of Practice*. This document will reference the Overarching Principles document, include compliance pathways, the requirements for coordination, a seismic classification system for non-structural elements, which is still to be developed, and individual chapters for various non-structural elements. The proposed seismic classification system for non-structural elements is described in more detail in a later section of this paper. The coordination process and design development for each design phase (concept, preliminary, developed, detailed and construction) would be documented to provide consistency of approach through the industry and support brief development and procurement of consultants and contractors.

  The technical design for each component would include recommended standard details and anchor types (Del Rey Castillo, 2019) for support and seismic restraint of non-structural elements into various substrates.

The Code of Practice would likely be the first step towards a new Verification Method specifically for non-structural elements and systems.

- *Construction Monitoring and Inspection*. There is also a need for a guidance document for the construction monitoring and inspection of non-structural elements and systems. It would ideally have two sections as follows:
    - Inspection and assessment of existing non-structural elements, seismic restraint systems provided and clearances to other building components. A document specific to existing buildings would provide a consistent approach for assessment and reporting of issues and risks in existing building.
    - Guidance on the inspection of new installations of non-structural elements for consultants, contractors and third party independent inspectors.

## Roles and Responsibilities

Working together with the wider construction industry the roles and responsibilities of owners, tenants, architects, building services engineers, structural engineers, non-structural seismic engineers, contractors and sub-contractors will be defined for non-structural elements and systems. This is important for procurement, brief development and the design and installation process.

Definition of responsibilities will support more effective construction monitoring which is expected to improve compliance and reduce the incidences of unapproved product substitutions being used.

## Research and Testing

Research into the seismic performance of non-structural elements over the past decade in New Zealand has identified a number of areas in which changes should be made. Gaps have been identified in the understanding of the seismic performance of different types of non-structural elements in new and existing buildings (MacRae et al 2012, Pourali et al 2014, Muhammad et al 2020). In response to this a seismic rating system for non-structural elements is proposed which will classify non-structural element systems according to their drift and acceleration capacity (Sullivan et al. 2020).

Further research will be undertaken to better understand and quantify how various non-structural elements respond and interact with other building components during seismic events. The research will inform recommendations for changes to design practice and effective retrofit of deficient non-structural systems in existing buildings.

## Seismic Classification System for Non-Structural Elements and Two-tier Compliance Pathway

Current design standards generally have limited information for the design and checking of the seismic capacity of non-structural elements. There is an increasing body of evidence that a number of drift limits specified in standards and codes will not lead to the intended design outcomes (Muhammad et al 2020, Sullivan et al., 2020).

The likelihood of exceeding the drift and acceleration damage states (no damage, functional recovery and collapse prevention) for non-structural elements depends not only on the intensity of ground motion but also heavily on the selected primary structural system. To achieve good seismic performance of non-structural elements, the structural engineer needs to assess the implications of the choice of primary structure on the selection of non-structural elements and systems and effectively communicate the drift and acceleration demands they anticipate for their specific building to any subcontractors responsible for design and installation of non-structural elements. The proposed seismic classification system for non-structural elements (Sullivan et al., 2020) is intended to facilitate the structural design, non-structural design and communication process.

The seismic classification system would classify specific types of non-structural element according to their critical drift (or acceleration) capacity established relative to defined limit states, a) No Damage, b) Life Safety. A third intermediary limit state may also be appropriate for certain projects, being c) Damage Control limit state. It is recognized that for many non-structural elements there may be little, if any, difference in practice between the design and detailing for no damage compared to a damage control limit state.

Tables 1 and 2 below propose tentative values of drift and peak floor acceleration (PFA) respectively for different classification categories of non-structural elements.

**Table 1: Tentative drive values proposed for the seismic classification of drift-sensitive non-structural elements in New Zealand**

| Non-Structural Element Class | Median Drift Capacity | |
|---|---|---|
| | No damage (SLS) | Life safety (ULS)* |
| D1 | 0.25% | 0.75% |
| D2 | 0.50% | 1.5% |
| D3 | 0.75% | 2.0% |
| D4 | 1.00% | 2.5% |
| D5 | 1.50% | 3.0% |

** only applicable to those non-structural elements for which failure would pose a life-safety threat.*

**Table 2: Tentative PFA values and clearance requirements for the seismic classification of acceleration-sensitive non-structural elements in New Zealand**

| Non-Structural Element Class | Peak Floor Acceleration Capacity* | | Installation Clearance Requirements (mm) | |
|---|---|---|---|---|
| | No damage (SLS) | Life safety (ULS)** | Short Period (T<0.1s) | Medium/Long Period$^{+}$ (T=1.0s) |
| A1 | 0.25g | 0.75g | 5 | 50 |
| A2 | 0.50g | 1.00g | 10 | 100 |
| A3 | 0.75g | 1.50g | 15 | 150 |
| A4 | 1.00g | 2.00g | 20 | 200 |
| A5 | 1.50g | 3.00g | 30 | 300 |

** Refers to median peak floor acceleration for a standardized floor spectrum*
*** Only applicable to NSE for which failure would pose a life safety threat.*
*+ Fundamental period of NSE (interpolation/extrapolation permitted).*

By way of an example, if a stiff-strong RC wall structure was conceived as part of a conceptual design solution then, as a result of the low drift demands and high accelerations that would result, class D1 and class A3 non-structural elements may be appropriate for that building. Alternatively, if a flexible steel moment-resisting frame system was considered, then floor accelerations would be limited but drifts would be high so class D3 and class A1 non-structural elements may be appropriate.

It is proposed that the classification of acceleration and drift sensitive non-structural element systems will be developed via various pathways including experimental, analytical and historical performance evidence.

The classification system is expected to support the wider appreciation of the compatibility of various non-structural elements for the chosen primary structural option and enable a more considered cost comparison between alternative design scenarios (that include primary structure and non-structural elements) to be undertaken early in the project, and from this there is an opportunity to arrive at the best for project solution.

The classification system is also intended to support building inspection of existing buildings to help understand the current seismic risks and potential losses/business interruption, and simplistic building inspection of new builds by knowing what non-structural element classes the structural engineer has defined and then using examples of each classification type to inspect the installation.

Two-tier compliance pathway

A two-tier compliance pathway is proposed to align different design and procurement routes to the scale and complexity of the project.

The first compliance pathway is based on enhancing the existing industry practice where the design and coordination of non-structural elements is undertaken primarily by the contractor during construction. Feedback was received from contractors and sub-contractors that current ceiling void depths provided in New Zealand are too tight to accommodate late design and coordination of non-structural elements and hence it is intended that this compliance pathway would potentially include increased ceiling voids to say 1m deep in congested areas to reduce the complexity of the coordination and installation and increase the possibility of achieving a Code Compliant outcome without significant rework. The non-structural seismic classification system would be used by the design team to choose the appropriate categories for drift and acceleration sensitive components and these would be advised in the construction contract documentation.

The second compliance pathway is when the design and coordination of non-structural elements is undertaken as an integrated process within the main building design. There would be no minimum or maximum ceiling void depths as the required spatial volume for the non-structural elements would be assessed and confirmed to be sufficient throughout the design process. To support a competitive tender process spatial allocations can be provided within the design to enable a range of services, partitions and ceiling systems to be installed whilst minimizing the risk that the actual services, partitions and ceiling systems chosen by the contractor would require redesign or rework to achieve code compliance and the performance requirements for the building.

For both pathways, at the completion of the project an independent inspector (IQP) would be engaged to inspect and certify the installation has been constructed in accordance with the completed and coordinated design and achieves code compliance prior to the Code Compliance Certificate being issued.

## Independent Inspection and Certification Body

The establishment of a new Independent Quality Provider (IQP) and Certification Body (similar to the independent inspection and certification requirements currently used for Sprinkler Systems) would provide consistency of enforcement in relation to the seismic performance of non-structural elements to achieve Code Compliance and required building performance. All projects (alterations to existing buildings and new builds) would be inspected and signed off as being code compliant by an IQP and submitted to the Building

Consent Authority with the Request for Code Compliance Certificate documentation.

The IQP individuals would have considerable experience in the design, coordination and installation of non-structural elements.

### Updates to Standards

The performance requirements for the seismic design of fire sprinkler systems and suspended ceilings have recently been updated and now align with the seismic design actions standard (NZS 1170.5) and the New Zealand Standard for the seismic performance of engineering systems (NZS 4219).

Industry users of the current Standards for non-structural elements have advised there are gaps, inconsistencies and errors in the current Standards with regard to seismic restraint. It has also been demonstrated, within the research community, that current code provisions provide poor prediction of the acceleration demands (Sullivan et al., 2013) and drift limits (Sullivan et al., 2020) for non-structural elements.

The proposed non-structural seismic classification system discussed in the previous section will be developed based on research and testing results to confirm the acceleration and drift limits to the onset of damage, damage control limit state and life safety for various arrangements of non-structural elements and various detailing options.

The changes to design practice as a result of existing and future research, testing and the proposed non-structural classification system is expected to necessitate future updates to Standards. It may be appropriate for the seismic design provisions for non-structural elements to be brought into a one dedicated Standard, Verification Method or Building Code Clause, similar to ASCE-7/16 (2016), to ensure changes to seismic design practice is applied consistently to all non-structural elements. If the seismic design provisions and performance requirements for non-structural elements are retained in the individual component Standards there is potential for inconsistency and contradiction in the future.

If a new Standard, Verification Method or Building Code Clause was developed to cover the seismic design and performance of non-structural elements it would enable requirements that apply to all non-structural elements to be located in a single source document. This could include a consistent framework for mandatory independent inspection and reporting for non-structural elements and systems by an IQP. It is noted that this could be extended to involve annual inspection, reporting and certification linked to the issue of the annual Building Warrant of Fitness. A Building Warrant of Fitness involves an annual inspection and report on all specified systems that are crucial to the safety and health of a building and those who use it (for example emergency lighting systems).

### Introduce a New Clause in the New Zealand Building Code

In the future a new clause could be considered to be included in the New Zealand Building Code to cover all aspects of Non-Structural Elements and systems. A working title “B3 Non-structural Elements and Systems” is proposed.

This new clause would cover performance requirements, functional objectives and means of compliance for non-structural elements and could also include provisions for prefabricated building elements and products as well as the seismic design, integration and performance of non-structural elements in buildings.

The performance requirements section would expected to focus on serviceability/damage control performance with checks to ensure elements achieve life safety objectives. We propose a philosophy that uses a significantly enhanced ‘serviceability’ demand over current New Zealand Standards. We recommend this as there will be little to no additional cost for many non-structural elements to achieve this and the increase in performance of non-structural elements and subsequent resilience of our building stock would be significant.

### Conclusions

Recent New Zealand earthquakes (Canterbury, Seddon and Kaikōura), resulted in substantial economic losses and major disruptions to our businesses and communities. Much of the damage observed was to non-structural building elements. In response to this, the industry is considering what changes can be made to enhance the resilience of our built environment. This paper has reviewed and described a number of possible steps that could be made. If implemented, the changes proposed in this paper would significantly improve the seismic performance of buildings in New Zealand. Substantial co-benefits are also expected to be realized including:

- Improved community resilience as the changes penetrate further into our new and existing building stock,
- Improved productivity of the construction sector as the processes described in this paper are streamlined and expanded to encompass the building as a whole, resulting in projects routinely done once and done right,

- Improved quality control, through clear definition of roles and responsibilities and the introduction of an Independent Qualified Persons (IQP) body,
- Building owners, tenants and insurers will better understand the risk of building damage and downtime as a result of more frequent seismic events and take ownership for decision making and be prepared to invest in resilience.

## References

Arifin, F., Sullivan, T.J., Dhakal, R., 2020, *Experimental Investigation into the Seismic Fragility of a Commercial Glazing System*, Bulletin of the New Zealand Society for Earthquake Engineering, (Accepted for Publication).

Arifin, F., De Francesco, G., Sullivan, T.J., Dhakal, R.P., 2020. *Developing guidelines for the seismic assessment of glazing systems*. Annual Conference of NZ Society for Earthquake Engineering (NZSEE20), Wellington, 10pp.

ASCE 7-16, 2016, *Minimum Design Loads and Associated Criteria for Buildings and Other Structures*, American Society of Civil Engineers, United States of America.

AS/NZS 1170.0, 2002, *Structural Design Actions, Part 0: General Principles*, AS/NZS 1170.0:2002, Standards New Zealand, Wellington, NZ.

AS/NZS 2785, 2020, *Suspended Ceilings – Design and Installation AS/NZS 2785:2020*, Standards New Zealand, Wellington, NZ

Baird, A.; Ferner, H., 2017, *Damage to Non-structural elements in 2016 Kaikoura Earthquake*, Bulletin of the New Zealand Society of Earthquake Engineering, Vol. 50, No. 2, pp. 187-193.

Biggs, J. M., 1971, *Seismic response spectra for equipment design in nuclear power plants*, Proc. 1st int. conf. struct. mech. react. tech. Berlin, Paper K4/7.

Bradley, B.A., Dhakal, R.P., Cubrinovski, M., MacRae, G., 2009. *Seismic loss estimation for efficient decision making*. Bulletin of the New Zealand Society of Earthquake Engineering, 42(2): 96-110, https://doi.org/10.5459/bnzsee.42.2.96-110

Building Innovation Partnership, 2020, *Design, Construction and Seismic Performance of Non-Structural Elements*, bipnz.org.nz, contact@bipnz.org.nz

Calvi, P.M. and Sullivan, T.J., 2014, *Estimating floor spectra in multiple degree of freedom systems*, Earthquakes and Structures, Vol.6, No.7.

Davies, R.D, Retamales, R., Mosqueda, G., and Filiatrault, A., 2011, *Experimental Seismic Evaluation, Model Parameterization, and Effects of Cold-Formed Steel-Framed Gypsum Partition Walls on the Seismic Performance of an Essential Facility Simulation of the Seismic Performance of Nonstructural Systems*, Edited by MCEER. Technical Report. Vol. MCEER-11-0. New York: University at Buffalo, State University of New York.

Del Rey Castillo, E, 2019, *Factors influencing the seismic design and evaluation of post-installed steel anchors in concrete*, 2019 Pacific Conference on Earthquake Engineering, April 2019.

Dhakal, R.P., 2010, *Damage to Non- Structural Components and Contents in 2010 Darfield Earthquake*, Bulletin of the New Zealand Society of Earthquake Engineering, Vol. 43, No. 4, pp. 404-411.

Dhakal, R.P., MacRae, G., Hogg, K., 2011. *Performance of ceilings in the February 2011 Christchurch earthquake*. Bulletin of the New Zealand Society of Earthquake Engineering, 44(4): 377-387, https://doi.org/10.5459/bnzsee.44.4.377-387

Dhakal, R.P., MacRae, G.A., Pourali, A., Paganotti, G., 2016a, *Seismic Fragility of Suspended Ceiling Systems Used in NZ Based on Component Tests*, Bulletin of the New Zealand Society for Earthquake Engineering, Special Issue on Seismic Performance of Non-structural elements (SPONSE), Vol. 49, No. 1, pp. 45-63.

Dhakal, R.P., Pourali, A., Saha, S., 2016b, *Simplified Seismic Loss Functions for Suspended Ceilings and Drywall Partitions*, Bulletin of the New Zealand Society for Earthquake Engineering, Special Issue on Seismic Performance of Non-structural elements (SPONSE), Vol. 49, No. 1, pp. 64-78.

Dhakal, R.P., Pourali, A., Saha, S., 2016. *Simplified seismic loss functions for suspended ceilings and drywall partitions*. Bulletin of the New Zealand Society for Earthquake Engineering, Special Issue on Seismic Performance of Non-Structural Elements (SPONSE), 49(1): 64-78, https://doi.org/10.5459/bnzsee.49.1.64-78

Dhakal, R.P., Pourali, A., Tasligedik, S., Yeow, T., Baird, A., MacRae, G., Pampanin, S., Palermo A., 2016c, *Seismic Performance of Non-Structural Components and Contents in Buildings: An Overview of NZ Research*, Earthquake

Engineering and Engineering Vibration, March 2016, Vol 15, No. 1.

Dhakal, R.P., Rashid, M., Bhatta, J., Sullivan, T.J., MacRae, G.A., Clifton, G.C., Jia, L.J., Xiang, P., 2019. *Shake Table Tests of Multiple Non-Structural Elements in a Low–Damage Structural Steel Building*. 4th International Workshop on Seismic Performance of Non-Structural Elements (SPONSE), 22-23 May, Pavia, Italy.

FEMA P-1024, 2015, *Performance of Buildings and Nonstructural Components in the 2014 South Napa Earthquake*, February 2015.

Geldenhuys, B., Szakats, G., Stuart, G., Burling, M., 2016, *Survey of seismic restraint of non-structural elements in existing commercial buildings – Report on Stage 2 – Full Study Volume 1*, November 2016, KOA, Wellington, New Zealand.

Haymes, K., Sullivan, T.J., Chandramohan, R., 2020, *A practice oriented method for estimating elastic floor response spectra*, Bulletin of the New Zealand Society for Earthquake Engineering, under review.

Khakurel, S., Yeow, T.Z., Chen, F., Wang, A., Saha, S.K., Dhakal, R.P., 2019. *Development of cladding contribution functions for seismic loss estimation*. Bulletin of the New Zealand Society for Earthquake Engineering, 52(1): 23-43, https://doi.org/10.5459/bnzsee.52.1.23-43

MacRae, G.A, Pampanin, S., Dhakal, R,P. and Palermo, A., 2012. *Review of Design and Installation Practices of Non-Structural Elements*, Project 42 Report for the Engineering Advisory Group, Department of Building and Housing. http://www.naturalhazards.org.nz/NHRP/Publications/Research-Publications/Short-Term-Recovery-Programme

MBIE, NZSEE, SESOC, EQC, NZGS, *The Seismic Assessment of Existing Buildings – Technical Guidelines for Engineering Assessments*, July 2017, Ministry of Business Innovation and Employment, New Zealand Society for Earthquake Engineering, Earthquake Commission, New Zealand Geotechnical Society, Wellington, New Zealand.

Muhammad, R., Dhakal, R.P., Sullivan, T., 2020. *Seismic Design of Acceleration-Sensitive Non-Structural Elements in New Zealand: State-of-Practice and Recommended Changes*. Bulletin of the New Zealand Society for Earthquake Engineering (Under Review)

Mulligan, J., Sullivan, T.J., Dhakal, R.P., 2020. *Experimental seismic performance of partly-sliding partition walls*. Journal of Earthquake Engineering, https://doi.org/10.1080/13632469.2020.1733139

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

NZS 4219:2009, *New Zealand Standard - Seismic Performance of Engineering Systems in Buildings*, Standards New Zealand, Wellington, NZ.

NZS 4541:2020, *New Zealand Standard - Automated Fire Sprinkler Systems*, Standards New Zealand, Wellington, NZ.

Pourali, A., 2018, *Seismic Performance of Suspended Ceilings*, PhD Thesis, University of Canterbury, NZ.

Pourali, A., Dhakal, R.P., MacRae, G.A., 2014. *Seismic performance of suspended ceilings: Critical review of current design practice*. New Zealand Society for Earthquake Engineering Annual Conference (NZSEE2014), 21-23 March, Auckland, 8 pages

Pourali, A., Dhakal, R.P., MacRae, G., Tasligedik, S., 2017. *Fully-floating suspended ceiling system: Experimental evaluation of structural feasibility and challenges*. Earthquake Spectra, 33(4): 1627-1654, https://doi.org/10.1193/092916EQS163M

Sassun, K., Sullivan, T.J., Morandi, P., Cardone, D., 2016, *Characterising the in-plane seismic performance of infill masonry*, Bulletin of the New Zealand Society for Earthquake Engineering, Vol. 49, No.1, pp.98-115.

Stanway, J., Curtain B., 2017, *Economic Benefits of Code Compliant Non-structural elements in New Buildings*, Opus Report Available from Ministry of Business Innovation & Employment, 52 pages.

Stanway, J., Sullivan, T.J., Dhakal, R., 2018, *Towards a New Delivery Approach to Improve the Performance of Non-Structural Elements in New Zealand*, 17th U.S.-Japan-New Zealand Workshop on the Improvement of Structural Engineering and Resilience, Queenstown, New Zealand, November 12-14, 2018

Sullivan, T.J., Calvi, P.M., Nascimbene, R., 2013, *Towards Improved Floor Spectra Estimates for Seismic Design*, Earthquakes and Structures, Vol.4, No.1.

Sullivan, T.J., Dhakal, R., Stanway, J., 2020, *A framework for the seismic rating of non-structural elements in buildings*, 17th World Conference on Earthquake Engineering, Sendai, Japan, new date pending due to Covid-19, 2021

Welch, D., Sullivan, T.J., 2017, *Illustrating a new possibility for the estimation of floor spectra in nonlinear multi-degree of freedom systems*, Proceedings 16th World Conference on Earthquake Engineering, Santiago, Chile, January 9th to 13th 2017, paper 2632.

Yeow, T., MacRae, G., Dhakal, R.P., Bradley, B., 2018. *Validating the sliding mechanics of office type furniture using shake-table experiments*. Bulletin of the New Zealand Society for Earthquake Engineering, 51(1): 1-11, https://doi.org/10.5459/bnzsee.51.1.1-11