BUILDING
INNOVATION
PARTNERSHIP

Design, Construction and Seismic Performance of Non-Structural Elements

Reference Document

Quake Centre
Delivering Industry Solutions

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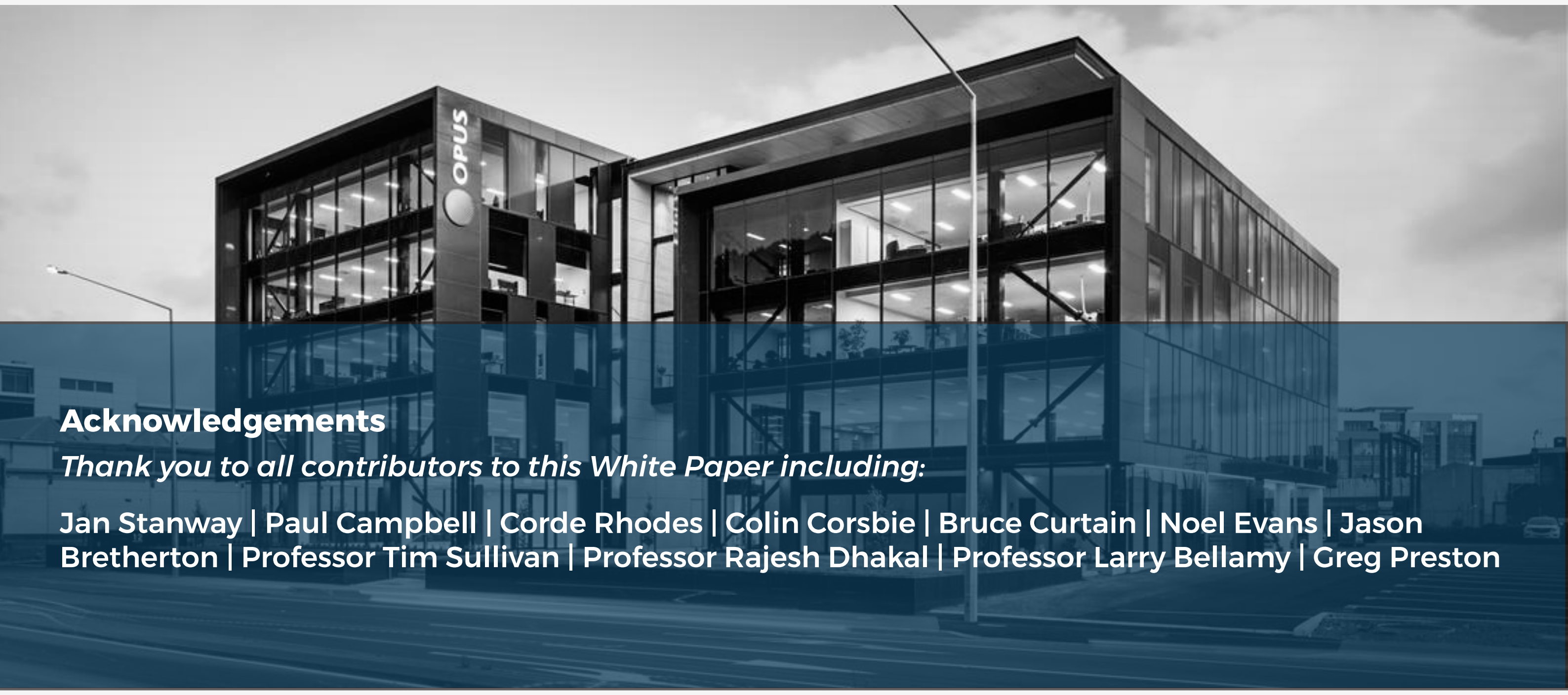

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Historically, a large effort and many resources have gone into improving our understanding of the seismic performance of the primary structure of buildings and development of improved methods of design and construction of buildings. This has resulted in modern buildings being much safer and resilient than was historically the case. Whilst this is a good thing, the seismic and general performance of non-structural elements in buildings has received much less historical attention. This is despite the fact non-structural components can make up eighty percent or more of the total asset value of a new building.

Many examples of failures of non-structural components in buildings were observed as a result of the Christchurch earthquakes of 2010-2011, Seddon earthquake in 2013, Kaikoura earthquake in 2016 and many other earthquakes around the world. This demonstrated that significant interruption to business and community occurs because of damaged or inoperable non-structural building elements. Depending upon severity, this can have a devastating effect on the national economy, in additional to the general well-being of a nation. This coupled with evidence the co-ordination and integration of the various forms of non-structural elements with each other, and the primary structure, is frequently less than needed to ensure efficient construction and asset management, strongly indicates the need for review and change. Whist this situation exists in many jurisdictions around the world, this paper focuses specifically on the relevance to New Zealand and the status of its design, construction, and regulations in relation to building structures.

This paper compiles a comprehensive review of the status of key challenges in the design, construction, and seismic performance of non-structural elements in buildings in NZ. It concludes with a series of seven wide ranging recommendations which if adopted, are expected to result in improved resilience, better built outcomes, and lower total out-turn costs. These outcomes would benefit asset owners, the building and construction industry and, importantly, the wider community of New Zealand with safer and resilient buildings.

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CHAIR: BUILDING INNOVATION PARTNERSHIP

FOREWORD

Terms of Reference

The Building Innovation Partnership (BIP) is an industry-led research programme that supports transformation in the building and construction industry. This seven-year programme (2018-2025) is supported by the Ministry of Business Innovation & Employment (MBIE) and industry and is based at Quake Centre hosted by the University of Canterbury.

The purpose of the Building Innovation Partnership (BIP) is to support transformation in the building industry so that New Zealand leads the world in digital design and construction methods, integrated asset management, material and manufacturing technologies and resilient construction systems.

The BIP programme is being delivered across three inter-linked themes, 1. Better Investment Decisions, 2. Enabling integrated Design, Construction and Operation and 3. Fit-for-Purpose Building Components. This report focuses on Theme 3 (Fit-for-Purpose Building Components) with direct links to the aims and outcomes of Themes 1 and 2.

This report is prepared for the Building Innovation Partnership to assist with understanding the current design, construction and seismic performance of non-structural elements in New Zealand. The report is expected to be used to inform initiatives and research that will provide improvements that result in a more productive and competitive building industry, more resilient and sustainable buildings, through the improvement of the procurement, coordination, design and construction methods of new and existing buildings throughout New Zealand.

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Executive Summary

1. Executive Summary

We live in a seismically active region of the world. Recent experience of the performance of our buildings in both the Canterbury and Kaikōura earthquakes has delivered stark lessons on seismic resilience. Most of our buildings, with a few noticeable exceptions, performed as our Codes intended them to do, with the primary purpose to safeguard people from injury caused by structural failure. However, many buildings had minor structural damage but were unable to be reused and re-occupied due to the damage and failure of non-structural elements. In these instances, the damage to non-structural elements caused major disruptions to businesses and our communities.

The research undertaken to prepare this white paper has shown clear connection between the issues causing pain in the industry with the significant damage and poor performance of non-structural elements in recent seismic events. It also highlights the future risk of extensive damage to non-structural elements in New Zealand's wider building stock when subjected to more frequent earthquake events (those events notionally above a moderate earthquake).

This white paper focuses on the challenges that the construction industry currently faces, our vision for the future and the changes we collectively need to embrace to ensure buildings achieve not only the Functional and Performance Requirements defined by legislation but also meet the expectations of asset owners, tenants and our communities.

The 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 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.

The procurement models push consultants and contractors to find ways to reduce their costs, which in many cases, results in an inferior outcome for the building owner. One method used by the industry to reduce costs is the use of product substitutions. Product substitutions do not always go through an approval process and can result in inferior products installed that are not identified due to a lack of independent review of non-structural element installations.

Currently, the design, coordination and construction of non-structural elements and their seismic restraints relies, in the most part, on self-regulation of the industry. Our research indicates that self-regulation is not working, and we are falling well short of the seismic performance expected of non-structural elements in our building stock.

In addition to the industry issues, university research has demonstrated gaps in technical knowledge both nationally and internationally especially with regard to how various non-structural elements respond and interact with other building components during seismic events.

Addressing the key issues as recommended by this paper (risk transfer, procurement, design, coordination, product substitutions, independent review and sign-off) will have significant co-benefits to the industry. Productivity of the construction industry will increase and consequently costs, and waste will decrease as the rework which plagues the industry decreases.

We believe that there is significant opportunity to improve the seismic performance of our buildings. This report outlines the vision for how our industry should work in the future, along with recommendations on how to get there.

Introduction

2. Introduction

Non-structural elements within a building are generally classified into three broad categories:

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

Non-structural elements usually account for around 80% of the costs of a building.

Non-structural elements suffered extensive damage in the Canterbury (Dhakal 2010), Cook Strait and Kaikoura earthquakes (Baird & Ferner 2017). Figure 1 illustrates a sample of some of the damage observed. The cost of repair work for damage and business interruption due to poor performance of non-structural elements in the Christchurch, Cook Strait and Kaikoura earthquakes has been substantial, although difficult to quantify as the economic losses are not fully documented by insurers, or the wider industry.

The New Zealand Insurance Council have advised that damage to internal fit outs have resulted in many 100% claims on insured Business Interruption Policies.

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

The damage also highlighted the potential for large consequential damage (such as sprinkler failure), and the complexity and duration of repairs which significantly impact business interruption.

Greater damage to non-structural elements has been realised in recent earthquakes than expected by building owners and insurers, especially in earthquake events which were significantly lower than the design level earthquake (defined as an earthquake with a 10% probability of exceedance in 50 years). It is now recognised that damage to non-structural elements is a bigger insurance problem than the building itself (Stanway & Curtain 2017).

Figure 2: Kaikoura earthquake (from Radio NZ/Susie Ferguson).

Observations following the Canterbury, Cook Strait and Kaikoura earthquakes indicated that new buildings that had code compliance certificates did not necessarily meet New Zealand Building Code requirements relating to non-structural elements (Stanway & Curtain, 2017). This resulted in considerably more damage to non-structural elements than would be expected for compliant installations with the corresponding impacts on repair cost and operational disruption.

Given that the future of insurance in New Zealand is uncertain, building owners and tenants appear to be holding more risk than perhaps they realise.

This white paper provides a strategic review of the construction industry with regard to the seismic restraint of non-structural elements in new and existing buildings and goes on to propose possible solutions and research to support improvement to the performance in future earthquake events.

The information provided in this white paper has been sourced from literature research, university research, observations following recent NZ earthquake events and two industry workshops facilitated by WSP and Quake Centre in March 2019.

The workshops included participants from a wide cross section of the building construction industry, including:

- Government bodies holding significant property portfolios
- Developers
- MBIE
- Procurement Advisors
- Insurance Sector
- Building Consent Authorities
- Quantity Surveyors
- Project Managers
- Architects
- Structural Engineers
- Mechanical Engineers
- BIM specialists
- Research Organisations
- Main Contractors
- Ceiling and Partition Contractors
- Mechanical Services Contractors
- Seismic Restraint Specialists

Current Industry Position

3. Current Industry Position

The report has identified eight key issues which confront the sector and contribute to the observed poor performance of non-structural elements in recent seismic events:

- Risk
- Procurement methodologies
- Limitations in knowledge of code minimum performance requirements versus low damage and resilient options
- Lack of coordination between disciplines and sub-trades
- Construction and installation behaviours
- Lack of independent QA
- Gaps in regulation
- Lack of knowledge, skills and training throughout the industry

3.1 Risk

There appears to be a lack of understanding of risk combined with a desire to transfer and avoid risk in relation to the design, coordination, construction and performance of non-structural elements in the current construction industry. The interdependence of how risk is treated, and the final project outcome is highlighted in the key risks listed below:

a. Risk that the overall seismic performance of the building does not match clients and community performance expectations:

   - Clients do not generally understand the performance their buildings have achieved until a moderate or greater earthquake occurs. Recent earthquakes have shown that the public expectation of how code compliant buildings perform does not match reality (Hare, 2019).

   - In a design level earthquake there is a 10% probability that an earthquake will exceed the given level of earthquake shaking in 50 years. The New Zealand Building Code states that damage at this level of earthquake shaking is acceptable if life safety is protected. From a commercial perspective, the damage can be so significant that a complete rebuild of the non-structural elements can be required.

   - Risk that whilst buildings may have or achieve a Code Compliance Certificate, that many of the non-structural elements may not meet the requirements of the New Zealand Building Code. This results in an ongoing risk for building owners, tenants, users, consultants and contracting teams, that the building will not achieve the expected seismic performance in a future seismic event. There is also a risk that a future purchaser, tenant or user of a building, is unaware that the building may not be fully Code Compliant.

   - Risk that non-structural elements will be damaged in low to moderate seismic events and result in significant repair and business interruption costs. This was highlighted in recent earthquakes and most notably the damage to Wellington commercial buildings, resulting in many buildings claiming 100% of their business interruption insurance as a result of the 2013 Seddon earthquake, which only generated shaking in Wellington close to the serviceability limit state earthquake, i.e. 1 in-25-year event.

b. Unfair risk allocation

   - The current practice of using 'Design-Build' to procure the design and construction of non-structural elements, attempts to transfer the risk of design, coordination and construction of non-structural elements to the contracting teams.

- The contracting teams take on the risk that if appropriate coordination for all non-structural elements has not been undertaken from project inception, that significant additional costs and work-arounds may be required to achieve compliance with the New Zealand Building Code.

- The contracting teams are required to provide a fixed price to design and install non-structural elements within a short tender period. This is undertaken prior to completion of the design and comprehensive design coordination. There is a high risk to the contracting team that they have not allowed for all work required to complete the construction.

- Risk that individual sub-contractors allow for code compliant design and installation for their component of the building, but as the documentation is not fully coordinated and they have not had the opportunity to understand the building as a whole, they may have allowed for an installation that adversely affects the installation and seismic restraint of other non-structural elements.

- Sub-contractors try to manage their cost risk by choosing service routes that are easier to install and result in cheaper seismic restraints for them to complete their installation. This is done without full coordination and hence without due consideration of the potential significant effects for subcontractors still to do their installation.

- If the main design has created congested spaces/points there is a risk that it is not possible for the contracting teams to install the seismic restraint systems for all non-structural elements in a fully compliant manner.

c. Insurance Risk

   Based on the damage realised in recent earthquakes, there is a real risk that insurance companies and underwriters may reduce cover for damage to buildings the future.

d. H & S at Work Act 2015

   Should someone be harmed as a result of failure of non-structural elements there are risks that there may be significant legal responsibilities in terms of the Health and Safety at Work Act 2015 to building owners, tenants, designers and contracting teams.

e. Design & Coordination

   - Risk that insufficient budget is allowed in the project budget to appropriately design, coordinate, construct and inspect all non-structural elements.

   - Risk that insufficient time is allowed in design and construction programmes for the necessary coordination between elements of the building.

   - Currently the scope for design, coordination and seismic performance requirements are not well defined. Should a consultant or contractor attempt to reduce their scope to reduce their cost and risk, unless the risks associated with the reduced scope are understood by the tender evaluator, a cheaper price is more likely to win the work.

3.2 Procurement

There are currently two main forms of procurement of non-structural elements in New Zealand:

- Traditional
- “Hybrid” Design-Build

3.2.1 Traditional Procurement

The traditional procurement process for the design and construction of seismic restraints for non-structural elements in new buildings in New Zealand is summarised below:

a. Project context and building form developed. In this phase the Performance Objectives for the new building are confirmed and a high-level building form and project budget is developed, i.e. use and users for the building, number of storeys, approximate size of the building, and many other Performance Objectives. Non-structural elements are rarely considered in this phase.

b. The design team including architect, building services engineers, structural engineer, geotechnical engineer, civil engineers and specialist engineers e.g. acoustic engineers are procured using the Performance Objectives developed in the initial phase.

c. The design team are procured to design and document the building. This includes the architect documenting the building usually with basic details and performance specifications for the design and seismic restraint for internal partition walls, ceiling systems, glazing systems and facades. The building services team usually provides design intent drawings and schematics for the design and installation of the plant, equipment, ducts, pipework, cable trays, and sprinkler systems without many elements or routes confirmed. Limited coordination of the architectural and building services components occurs during the design phase. Final products, equipment, ducts, pipework etc is included in the tender documentation for the contractor to complete.

d. The current industry practice is for the design team to reference relevant Standards (NZS 4219, NZS 4541, AS/NZS 2785, AS/NZS 4600, NZS4223, AS/NZS 4284) in the Performance Specification with minimal or no seismic design, detailing or coordination between the various elements or the building as a whole.

e. The base build work is procured through the Main Contractor during tender and sub-contracted out to individual sub-contractors in the various sub-trades.

f. Main Contractor is responsible for the coordination of all non-structural elements including the seismic restraints.

g. Fit-out works are often procured separately (ceilings, partitions, HVAC and lighting) by the building tenant, and routinely there is no coordination between the fit out design team and the base build design team. Sometimes the design team is procured by the tenant, however they are not required to do this and is certainly not always the case.

3.2.2 Hybrid Version of Design-Build Procurement

The Contractors who attended the industry workshops noted that the New Zealand version of Design Build is what they term "Hybrid" model because it sits somewhere between pure Design Build and the Traditional Design-Tender-Construct procurement models.

The current practice for procurement using Design-Build in New Zealand is for the development of Principals Requirements which includes the concept/preliminary design documentation for the building form, key architectural elements, primary structural form, and building services as defined by the New Zealand Construction Industry Council.

3.2.3 Issues with current procurement models

Current procurement models allocate the majority of the risk for the design, coordination and installation of non-structural elements onto the construction team. Because the traditional procurement route does not provide a fully completed and coordinated design of all elements within the building prior to the procurement process engaging the Construction team, the main contractor and sub-contractors carry significant risk that they may not have fully understood the complexity of the installation. In particular this includes the challenge of finding sufficient room within the context of the form of the building that has been issued for tender, to adequately install, restrain and provide required clearances for the non-structural elements.

The ”Hybrid” procurement model provides base documentation where too many critical decisions have been made during the Principal’s Requirements phase that can severely restrict the ability of the Design-Build team to design and coordinate the design of non-structural elements within the context of the overall building and deliver a Code Compliant building.

Sub-contractors who attended the Industry Workshops advised their concerns that current procurement routes require them to provide a fixed price to complete the design and construction of their sub-trade, including seismic restraints, with no knowledge of the final design and required level of input required from them for coordination of all non-structural elements. Examples provided included risers which are simply a void in the building, where the mechanical contractor has to not only allow to price for the mechanical install, but they must also allow for a full structural frame to be constructed within the riser to enable seismic restraint and support of the mechanical, electrical and other services in the riser.

3.2.4 Procurement of Sub-Contractors

Designers, main contractors and sub-contractors all noted that those in the industry that have the knowledge of what is required to achieve Code Compliance will struggle to be competitive in the current market place, and very unlikely to win work if they price to design, coordinate, construction and inspect as required to achieve a compliant outcome.

Issues often arise that are outside the sub-trades area of control. To reduce their risk, it has been observed that some sub-trades employ site practices to get onto site as quickly as possible, sometimes ignore any agreed or documented routes, to ensure they get the most direct and cheapest route for their services. Product substitutions are also common.

Product substitutions do not always go through an approval process and can result in inferior products installed that are not identified due to a lack of independent review of non-structural element installations. In cases where product substitutions are offered for approval, anecdotal evidence is that either the substitution is offered with no cost, or as a cost saving, however approvers do not always understand the wider implications of knock on effects for other sub-trades, resulting in coordination issues, code compliance issues, increased costs and delays in the construction programme.

It is made worse when contractors and sub-contractors know that checks and inspections are rare.

3.2.5 Impact of current procurement process

Interestingly whilst different industry groups attended the workshops, the participants agreed on the observed impacts of the current procurement models. These are listed below:

- There appears to be more focus to reduce CAPEX costs rather than a full consideration of whole of life costs with operational expenditure fully considered. In the context of non-structural elements, the whole of life costs needs to consider future changes to the non-structural elements. For example, a tenant fit out that requires a Building Consent in the future, may find that the Building Consent Authority (BCA) declines the fit out on the basis that the fit out will not comply with the New Zealand Building Code without major refit of a significant portion of the services and ceilings, it may even eventuate that due to limited ceiling void depths that future fit outs may not be able to achieve a Building Consent and Code Compliance.
- There is not a level playing field to deliver compliant solutions.
- Incorrect allocation of risk throughout the procurement process. Risk is currently assigned to the group that have the least ability to affect the outcome.

- Lack of trust throughout the industry.
- Opt-out strategies, to limit commercial risk of various players throughout the project.
- Procurement is weighted to the lowest price without regulation to ensure compliance can be achieved for the price submitted. When the BCA and owners/ tenants are faced with the completed building that is not Code Compliant, there are not many options available.
- The current procurement strategy encourages a "Race to the Bottom" for quality and compliance on the basis that it will achieve the cheapest capital cost.

3.3 Regulation

3.3.1 New Zealand Building Act and Code

The current NZ Building Act and Building Code focus on protecting life, not damage that affects a buildings ability to be used or accessed following a major seismic event.

The focus on protecting lives has created a Building Code that only requires building designers to ensure people can evacuate after a moderate earthquake.

The current Code has delivered buildings that are damaged during moderate earthquakes that renders buildings unusable for months or years.

3.3.2 Relevant Standards for Design of non-structural elements

All non-structural elements, whether they are covered by a Standard or not are required to meet the performance requirements of Building Code Clause B1, summarised below:

- Objective B1.1 - "Safeguard people from injury caused by structural failure, and to safeguard people from loss of amenity caused by structural behaviour".
- Functional Requirement B1.2 – "Buildings, building elements and site work shall withstand the combination of loads that they are likely to experience during construction or alteration and throughout their lives."
- Performance B1.3.1 – "Buildings, building elements and site work shall have a low probability of rupturing, becoming unstable, losing equilibrium, or collapsing during construction or alteration and throughout their lives."
- Performance B1.3.2. – "Buildings, building elements and site work shall have a low probability of causing loss of amenity through undue deformation, vibratory response, degradation, or other physical characteristics throughout their lives or during construction or alteration when the building is in use."

New Zealand has several Standards that relate to the design and performance of non-structural elements. The key Standards, NZS 4219:2009 (Seismic performance of engineering systems in buildings), NZS 4541:2013 (Automatic fire sprinkler systems), NZS 4223 (suite of glazing standards); AS/NZS 4284 (facades) are cited in B1 -Acceptable Solutions and Verification Methods, whilst AS/NZS 2785:2000 (Suspended ceilings – Design and installation) is not. AWCI have also published a Code of Practice for the design, installation and seismic restraint of suspended ceilings.

Currently there are no explicit provisions within Standards relating to the seismic restraint of internal partition walls, although designers can use the AWCI Code of Practice for the seismic design and installation of non-structural internal walls and partitions or undertake a specific design using the New Zealand loadings standard NZS 1170.5 and AS/NZS 4600.

Unfortunately, the various standards listed above do not align and, in some cases, contradict each other. Industry participants noted that NZS 4219 has gaps and requires an experienced competent engineer to complete the design using that Standard.

Further, a growing body of research, has demonstrated that current code provisions for non-structural elements, both in New Zealand and abroad, may be inadequate. Examples where current code provisions appear to require revision include:

a. The estimation of acceleration demands on non-structural elements. Sullivan et al. (2013) and others have demonstrated that current code provisions to compute floor accelerations at different levels of a building provide poor predictions of floor spectra demands, particularly for non-structural elements characterised by low levels of damping. 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.

b. Design provisions to account for non-linear deformation capacity of non-structural elements. There is little evidence from research or in-situ observations that the ductility reduction factors included in New Zealand and overseas codes are appropriate.

c. There is currently no guidance in the New Zealand Standards for the verification of drift sensitive non-structural components. Current practice is for the structural engineer responsible for the primary structure to evaluate drift demands and provide those in a design features report with the expectation that the various non-structural components are detailed to ensure that the drift demands can be achieved and meet the performance requirements for the different limit states. There is limited guidance for contractors on how to demonstrate compliance.

d. Proprietary guidelines and Standards for the design of different non-structural elements generally prescribe the maximum spacing of the seismic bracing for different components (e.g. NZS 4219), however the requirements do not distinguish between different component masses, size and inclination of the braces and the type of connections between the brace and the components or the supporting structure (e.g. floor).

During the industry workshops various participants noted that they often find that they cannot comply with the mandatory clearances stated in Table 15 of NZS4219. Some consultants and contractors noted that when faced with this issue they check the deflection of the various seismic restraints/frames using NZS1170.5 to confirm clearances between components are acceptable. This method does not consider the relative movement and deformation of individual components. This method is technically an Alternative Solution which does not appear to be well understood. It would require proof of evidence, including relevant research to confirm that the method used, and the resulting clearance is compliant and achieve the NZ Building Code Performance Objectives.

3.3.3 Performance Requirements for Non-structural elements

The current performance requirements for non-structural elements, is covered by the relevant Standards and the overarching performance requirements of the New Zealand Building Code (NZBC).

The New Zealand loadings code (NZS 1170.0) includes two serviceability limit state (SLS) performance requirements:

i. SLS1 for which "the structure and the non-structural components do not require repair" for earthquake loading with 1/25-year return period and

ii. SLS2 for buildings with special post disaster facilities that should maintain operational continuity for 1/500-year return period earthquake loading, and the parts and components section of NZS1170.5 which provides operational continuity (SLS2) return periods for IL2 and IL3 buildings.

As mentioned previously the SLS1 and ULS criteria only requires building designers to ensure people can evacuate after a moderate earthquake, damage criteria do not apply for earthquake shaking in excess of that defined by SLS1. A comparison of the various Standards used for the design of building services (NZS 4219), suspended ceilings (NZS 2785) and sprinkler systems (NZS 4541) highlights, however, varying performance requirements between the standards and the NZBC (Stanway & Curtain, 2017). It has also been highlighted that there are inconsistencies in the interpretation of the New Zealand earthquake loadings Standard NZS1170.5, and those inconsistencies are being applied in the design of non-structural elements (Ferner et al, 2016). The current fragmented nature of the performance requirements and interaction between partitions, ceilings, sprinkler systems and engineered systems does not support the coordination of these non-structural elements.

We understand that further clarity around interpretation of the performance requirements, particularly for the performance requirements for various non-structural elements, are to be included in future updates to NZS 1170.5 (Ferner et al, 2016).

3.3.4 Building Consent

Using a traditional procurement process a Building Consent is applied for prior to final design, coordination and documentation relating to non-structural elements being completed.

Some Building Consent Authorities (BCA's) require the seismic restraint for non-structural elements, and associated PS1, to be provided with the Building Consent application. This provides significant challenges with the current traditional procurement method. One route being used by the industry is to develop a small number of standard seismic restraint details and indicate their location on the indicative schematic architectural, electrical, mechanical and hydraulic drawings. This process is undertaken on the basis that when the contractor completes the design of the non-structural elements that changes to the seismic restraint details are inevitable and details and layouts for non-structural elements will be submitted to the BCA as a Building Consent Amendment.

The sub-contractors are often asked to provide PS1 for submission of the consent before they have started their sub-trade shop drawings and they noted that recently they have been asked to submit their PS1's as part of the Tender.

We understand some BCA's do not require documentation for the seismic restraint and coordination of non-structural elements as part of the Building Consent documentation, on the basis that many non-structural elements (building services, ceilings, partitions, facades) are 'Design-Build' elements yet to be designed.

3.3.5 Code Compliance Inspections and Certificates

The current situation is causing difficulties for BCA's to confirm compliance with the New Zealand Building Code when the seismic restraint of non-structural elements is consented by reference to performance specifications that refer to various clauses and Standards.

Based on discussions with BCA's, consultants, main contractors and subcontractors there is currently a wide variation of compliance that is achieved when a Code Compliance Certificate is issued. Industry participants noted that BCA's may focus on receiving a PS1 for Building Consent but do not always follow through and request PS4's. It appears that BCA's rely heavily on Contractor supplied PS3's and, when provided, consultants PS4's to confirm compliance with the minimum requirements of the NZ Building Code.

This is further complicated on commercial developments where the building owner/developer may only be responsible for the base building and the internal fit-outs are designed and managed by individual tenants. Even though multiple parties may be involved both the Base Building and the Internal Fit-out still need to be fully compliant with the NZ Building Code and Code Compliance Certificates are required for both.

Feedback from the industry workshops noted that the following are regularly encountered on projects:

- Insufficient ceiling void provided by the design team means that compliance with clearances as specified in Table 15 of NZS 4219 cannot be achieved.
- Congestion in ceiling spaces results in the

- installation not achieving the clearances between components as stated in relevant Standards.
- Seismic restraints not installed in accordance with the relevant Standards.
- No seismic restraints provided to components that should have them.
- Clashes between elements are not resolved.
- Rework has significant cost and time implications and avoided where possible, even if the result is not code compliant.
- Suppliers and installers have admitted, in confidence, they have knowingly installed seismic restraint systems for non-structural elements which do not fully comply with code requirement, but nevertheless they issue a PS3 Producer Statement certifying the installation is compliant. They noted that they do this because they are faced with 'an impossible' situation, where the work to achieve compliance would require significant rework by other sub-contractors when they are under pressure to complete the projects.

If the BCA's have knowledgeable staff that can be involved in the 'Final Inspection', they may pick up non-conformances. BCA staff that attended the industry workshops noted that in these instances it is incredibly difficult, fraught with tension, and usually results in compromises, particularly with pressure for project completion, as full compliance was impossible to achieve at such a late stage in the project.

3.4 Design

3.4.1 When and who does the design

For most projects, the design and coordination of the seismic restraints for non-structural elements is undertaken by the contracting teams.

In some instances, a basic structural design and seismic brace details may be developed by the structural engineer for tender and Building Consent purposes, with the Main Contractor completing the design, coordination, detailing and shop drawings. The final design usually has significant changes to the layout and seismic bracing details compared to the basic details and layouts provided at consent and tender.

3.4.2 Post installed anchors

A recent amendment to NZS 3101 requires post-installed anchors to be qualified and designed in accordance with the European Standards. Concrete substrates may compromise the strength capacity of a post-installed anchor, however fixing into composite steel-concrete slabs, double tee beams and hollow-core floor slabs is not covered within the scope of any current design standard.

The University of Auckland has commenced work to consider anchor capacities in these substrates and changes to NZS 3101 is expected in the future (Del Rey Castillo, 2019).

3.4.3 Ceiling Void Depths

The participants in the Industry Workshops advised that the depth of the ceiling void is one of the most significant decisions that will ultimately affect the complexity of the design, coordination and installation of all non-structural elements within the ceiling void including the ceiling and its support hangers and restraints. The smaller the ceiling void the greater the complexity of the interactions between components and the greater the challenge to achieve code compliance of the non-structural elements and good seismic perfomance.

The workshop participants advised that in the 1980's typical ceiling void heights were 1m and sub-trade zones were defined as shown in Figure 2.

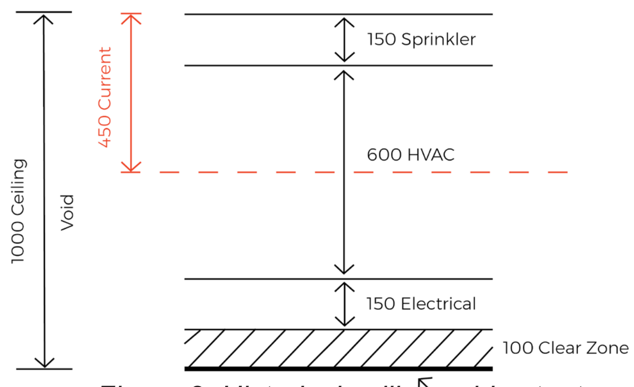


Figure 2: Historical ceiling void setout

It was noted that the arrangement shown in Figure 2 was not perfect, as having water pipes above electrical cables was not good practice, but the participants that worked in the industry at that time were unanimous that there was sufficient space in the ceilings to allow coordination as required on site. There was an understanding that if a sub-trade needed to move into another sub-trade zone it was the responsibility of the sub-trade to coordinate with the relevant adjacent sub-trade to confirm the solution. Issues were easily resolved on site.

The standardised ceiling void described above was reduced over time, as pressure on costs and the requirement to maximise Gross Lettable Area came to bear. It was found that in areas with overall building height restrictions, reducing the ceiling voids down to 450mm would not only reduce facade and structure costs, but it would add a floor to the building for the same overall building envelope for a five-storey building.

For building owners and tenants in buildings with reduced ceiling voids, they may not be aware of the complexity or costs involved to undertake changes to the services within small ceiling voids in the future.

3.4.4 Bracing technology

Typical seismic bracing solutions currently used in New Zealand include:

- Unistrut/Sikla Strut components to form support frame and bracing
- Diagonal tension wires used as braces (note no vertical bracing provided by this system)
- Thin gauge channel sections for bracing ceilings and partitions
- Structural steel trapeze frames
- Bracing for individual services
- Bracing for multiple services

3.4.5 NZ Testing capabilities

Single degree of freedom shake tables are available at the University of Canterbury, University of Auckland, BRANZ, WSP (Petone) and Holmes Solutions. However, current industry Standards and practice Performance Specifications for non-structural components and seismic restraints often require testing as a means of compliance with the Performance Objectives. The testing requirements can include dynamic performance criteria for non-structural elements that cannot be satisfied in New Zealand.

Some suppliers have been forced to have their testing undertaken overseas to prove their products meet the relevant Standards and specification clauses. Others have found the off-shore testing too difficult and instead choose to not undertake the required testing with follow up from the designer who provided the Performance Specification clauses rarely occurring.

3.4.6 Design Management

There are cases where the project manager acts as design manager. Design management requires extensive construction knowledge and experience. Industry workshop participants noted that it is not uncommon for the Design Manager to give approval, based on insufficient knowledge, for design changes on the client's behalf, on the understanding that the design change will result in a cost saving or have no effect, whereas in many instances this has caused extensive variations to the seismic restraint of non-structural elements.

3.5 Coordination

The level of coordination currently being completed in industry can be hap-hazard at times, and relies on the subcontractors to do their best, to "fit" everything in the space available. While there are better tools (3D BIM etc) to do coordination than previously available, it could be argued the process itself isn't as good as it was 20 years ago. The industry is not designing with buildability in mind, possibly due to limited of real life knowledge by less experienced tech-savvy designers.

Lack of coordination during design and installation leads to:

a. Clearance violations and clashes between components

b. Lack of room to install gravity and seismic restraints

c. Connection of gravity and seismic restraints to other non-structural elements which have not been designed for the loads.

These issues have been the cause of most of the damage observed in recent earthquakes (Stanway & Curtain, 2017).

There appears to be a combination of insufficient knowledge and an unwillingness to engage with, let alone coordinate, non-structural elements early in the design process. This is driving the coordination of non-structural elements to the late stages of the design process, usually as an after-thought prior to issue of documentation for Building Consent and tender. The main problem with the current situation is that the further into the design process the coordination of non-structural elements and the seismic restraints is left, the more complex the installation of the services and their seismic restraints becomes and the greater the risk that the resulting installation will not be fully compliant with the New Zealand Building Code.

Interestingly fire and acoustic requirements are well understood with clearly defined consultant scope of work. Engagement and coordination with these disciplines occurs early within the design process for all disciplines (services/fire/ceiling/facade/structure).

Coordination of seismic restraints for non-structural elements are not at the same point, this is possibly caused by the lack of understanding of what the scope requires and consequently issues with scope of engagement for consultant services and associated fees.

There is a belief that preparing documentation in a centralised 'BIM' model will provide a fully coordinated set of design documentation. A "coordinated" BIM model is rarely completed to a level that would allow seismic coordination of non-structural elements to be completed as it requires all elements to be fully modelled, which is not commonly done due to the cost and time needed to model to that higher level. It is complicated by the procurement process where the detailed design of many non-structural elements is not undertaken until the construction phase. Clash detection is meaningless if components are missing or are shown with indicative sizes and locations. Figure 3 below is a random image taken from a recent contractor's "coordinated" BIM model for an IL4 building. Note that construction and

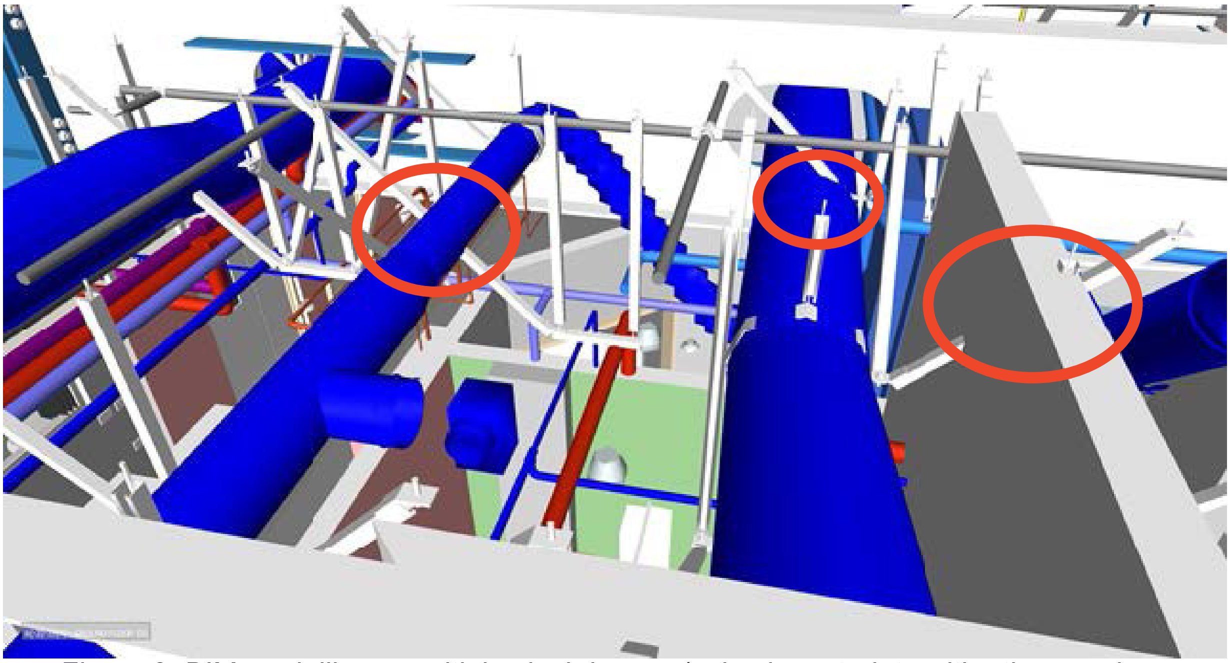


Figure 3: BIM modelling – multiple clash issues (seismic restraints with other services, partitions and ceilings)

installation of the non-structural elements was well advanced when this model was viewed. This shows the level of 'make-it-work" that is required by the subcontractors.

Coordination requires a focus on the building, especially non-structural elements, as they not only equate to 80% of the capital cost of the building but are essential to the operation and use of the building. Full coordination from project inception is the key to achieving efficient construction and cost savings during construction but is currently not being done to a level where real benefits are being realised.

Examples of the types of issues being encountered are included below:

- There appears to be too much focus on reducing design programme which puts pressure on coordination during design.
- Decisions made on ceiling voids are often made without due consideration of the requirements for non-structural elements and their performance objectives.
- Interaction between services and walls/ partitions and ceilings is often an afterthought, possibly by the design team and more commonly the issues are only found during the late stages of construction, when it is very difficult to resolve and achieve code compliant clearances.
- Seismic loads for non-structural elements are not always allowed for in the structural design of the primary structure. This has resulted in complicated seismic restraints being designed to avoid the primary structure.
- Sub-trade installation maybe compliant when installed, but without necessary coordination the current situation is that one of the last sub-trades installation renders all previous installations non-compliant.

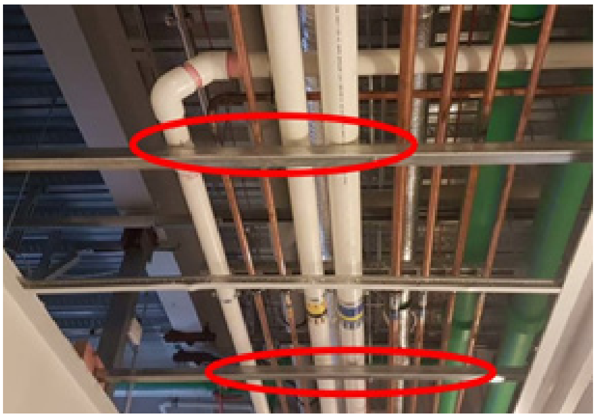
The photographs on the right have been taken recently in an IL4 building that is nearing completion. There are multiple clashes and issues that need to be resolved and are the result of a lack of appropriate coordination.

Figure 4

Figure 5

Figure 6

Figure 7



3.6 Strengthen/Retrofit/Restrain Deficient Non-Structural Elements in Existing Buildings

Working within existing structures has specific challenges, this is no different for the installation and restraint of non-structural elements. When working within existing structures, in many instances, the opportunity for the designer/coordinator of non-structural elements and their seismic restraints to influence the building layout to their benefit is limited. Lack of ceiling space is a common limitation, along with position of penetrations through structure and the inclusion of dedicated secondary structure, particularly in roof systems.

Although not exclusive to existing structures, the market availability of suitable fixing types for the underside of precast slab systems is problematic. Whether a building be a new build, or existing, seismically rated anchor fixings for use into hollow-core floors are not readily available. This leads to the development of specific solutions that may be costly or time consuming to install.

There is often confusion during refurbishments and retrofits when it comes to the treatment of existing non-structural elements and new non-structural elements. The issue of whether it is a requirement to restrain any existing unrestrained non-structural elements is normally covered off using justification similar to implementing new code requirements that are not retrospective, i.e. the existing unrestrained non-structural elements are not restrained as part of the retrofit works, which meets the requirements of Section 112 of the Building Act, that the building works have not made the building worse. The difference in these cases is that the requirement to restrain non-structural elements is not a new requirement, but one that was not well enforced in the past. If you consider the two main reasons for installing seismic restraints to non-structural elements, these loosely being a) meeting code requirements, and b) finishing with a more resilient building, then not restraining existing non-structural elements can mean the latter of these is not achieved.

3.7 Construction and Installation

Installation of seismic restraints relies on the element being fully coordinated within the context of the entire building before the restraint is installed. The actual design and installation for any single seismic restraint in isolation is straight forward. The complication comes from the large volume of restraints required, often within tight space constraints. The issue is not the seismic restraint of non-structural elements, it is a problem with the lack of coordination between architectural, structural and building services disciplines. This coordination issue has been highlighted by the poor seismic performance of non-structural elements.

Contractors comment "just because you can draw it, that doesn't mean you can build it" is true when it comes to seismic restraints. The contractor will try to do the best they can, however if the design is not complete, they can be forced to do their best with a result that the solution may not be compliant.

The type and difficulty of the project also influences the success of the installation of seismic restraints. Currently there are limited experienced contractors with the appropriate knowledge to install compliant project wide non-structural elements and seismic restraints for complicated and retrofit projects.

Contractors are reporting they want to construct and install a fully resolved design, however they are currently taking on design risk for seismic elements that is difficult to accurately assess and price at tender. There are instances where items need to be reconfigured 3+ times to get the installation right.

The current trend is for Design and Build of non-structural elements for "simple" projects, however this provides challenges for services heavy, projects with congestion or IL4 type projects. Where a consultant is novated to the main contractor, there has been cases where a loss of control of the design and delivery by the consultant team has occurred when the contractor choses to work in a non-collaborative way.

Main contractors often do not currently have seismic observer/certifier roles that cover all trades. This would require experienced people within their own team. This has a detrimental effect to the project's success and ability to make changes as the project in constructed. Clash issues during construction, particularly when redeveloping/extending/converting existing buildings, regularly occurs. These are currently not being well managed for non-structural elements.

3.8 QA

Participants at the industry workshops believe there is minimal industry recognition of the value of QA for the installation of NSE and their seismic restraints, reviewing clearances, and interaction between components. Where QA is undertaken it is ad-hoc and usually trade specific. There does not appear to be a building wide focus for QA.

There was agreement at the industry workshops that self-regulation is not working. There is a lack of on-site observation, by all parties, to verify what is required has been undertaken. It was noted that some are using the fact that no independent inspection occurs to check the use of inferior products (for example fixings that are not seismic approved), or not installing seismic braces in accordance with design and standards and reducing their fees accordingly to win the work.

3.9 Training

Seismic restraint of non-structural elements is relatively new and historically relied on ad-hoc solutions from the sub-contractors. The level of training currently occurring in the industry is limited. There have been some seismic courses offered by Engineering NZ over the last few years. The courses have targeted Mechanical and Structural engineers to improve their knowledge around demonstrating compliance for non-structural elements for building services (NZS 4219), suspended ceilings (NZS 2785), sprinkler systems (NZS 4541) and structural (NZS1170.5).

There are limited people specifically trained in the seismic design of non-structural elements. There is no professional recognition for seismic design of non-structural elements as a separate field in New Zealand.

There are structural engineers who use their knowledge to design seismic restraints for non-structural elements, however it is often a side role and they need considerable on-site experience to understand how the restraint design needs to be coordinated with other elements. Current regulations and standards are mis-aligned between different building systems which relies on competent engineers to make judgement calls to complete the seismic design.

Client understanding around the requirements and risks associated with the seismic restraint of non-structural elements is currently inadequate and often relies on the client looking to the Consultant or Project Manager to provide advice. The seismic performance and the costs involved to do the appropriate level of design, coordination and installation of seismic restraint of non-structural elements is not widely appreciated.

There does not appear to be consistent training for Building Consent Authorities to know what is compliant when it comes to non-structural elements.

Sub-Contractors have been looking to suppliers of seismic restraints to learn what needs to be done for their installations. Sub-Contractors have had training on their own specialised services, however it is apparent training on project wide “best practice” installation of non-structural elements is limited. There is no training for Contractors to provide a seismic observer role that covers all the trades. Site staff have limited knowledge about what is being installed and if it is compliant. There is a lack of on site observation (all parties) to verify the design is coordinated before installation begins and to verify that the installation is built in accordance with the design.

Vision for the Future

4. Vision for the Future

The desired industry position is one where fully informed clients make policy decisions regarding the desired seismic performance of non-structural elements that are based on fair and appropriate risk allocation, clear responsibilities, appropriate time and cost allowances for design and coordination and fully assured installation. Following major earthquake events non-structural elements would perform as per the design intent and meet the expectations of building owners, tenants and the wider community.

Productivity in the construction industry is streamlined and rework to address lack of coordination is not required.

4.1 Risk

The desired position would see clients fully informed of the risks and potential impacts associated with damage or failure of non-structural elements following a major seismic event. This may involve new policies and guidelines for performance standards, procurement, design, coordination, construction and independent inspection which would help clients and project teams to fully understand the risks associated with each phase of the project.

Informed clients may request a higher level of design that has a focus on functional recovery compared with minimum compliance with the New Zealand Building Code. Design consultants have a responsibility to fully inform clients regarding the building performance options available, the risks and impacts associated with failure of non-structural elements, and how the design of more resilient buildings will provide reduced time frames to re-occupancy and reuse the building following a major earthquake in addition to meeting the minimum life safety requirements of the NZ Building Code.

Ideally the design of the seismic restraints systems for non-structural elements would be identified as a separate discipline and deliverable in procurement that clearly identifies overall responsibility and individual responsibilities during the design, supply and installation processes. The specialist design consultant fees associated with this service are additional to the standard design consultant services and this would be highlighted in any Offer of Service and Consultant Engagement Agreement.

4.2 Procurement

To determine the best procurement methods for non-structural elements in each project first requires an increase in knowledge and skills throughout the industry, including clients, project managers, quantity surveyors, design consultants, main contractors and sub-contractors. This will result in a thorough understanding what it takes to achieve the performance requirements for non-structural elements as set by an informed client and from that the best procurement models to support this will be identified. This is likely to include the following:

- The relationships between clients, consultants and contractors is built on Trust.
- Procurement methods are well understood with knowledge regarding the potential impact of the procurement method on the final outcome including achieving a Code Compliant building at the completion of the project. Sufficient knowledge is held to enable the best procurement process to be identified for each project.
- The true cost for the detailed design, full coordination and installation of the non-structural elements to achieve code compliance is allowed for in the project budget from the project inception. Cost information made available from other high earthquake risk regions such as the west coast of the USA and Japan (reference required), and New Zealand (Stanway & Curtain, 2017) indicates the costs associated with the design and installation of compliant seismic restraint systems for non-structural elements is around 5%-7% overseas and 7%-10% of the overall construction cost in New Zealand.

- The design programmes include appropriate allowance for detailed coordination of non-structural elements, within the context of the building as a whole.
- It is recommended that a dedicated Seismic Consultant is engaged on every project. The seismic consultant would be responsible for design, coordination and PS4 for the installation of all trades including ceiling and facade.
- It is suggested that procurement models are adopted that provide an even playing field for all tenderers' and the appropriate tender price to be submitted. The following procurement models are recommended:
  - A traditional procurement process where the design is fully developed and coordinated prior to tender or building consent or,
  - Procurement process where the sub-contractors are involved in the design and coordination from the early stages of the project, or,
  - A full Design Build procurement model where the design is not developed prior to issuing for tender.
  - Clients may consider options for procurement including incentives and innovation from the contractor through early contractor engagement, collaborative working alliance or via negotiated contracts on an "open book basis".

4.3 Regulation

It appears that alternative compliance pathways are required. Possible strategies and updates that could be considered are discussed below.

4.3.1 Updates to the Loadings Standard NZS 1170.5

Updates to the New Zealand Loadings Standard could include the following:

a. Definition of those non-structural elements that have low damping and provide new calculation methods to provide better prediction of acceleration demands for non- structural elements (Sullivan et al, 2013).

b. Further research and testing to inform provisions for realistic ductility reduction factors for various non-structural elements.

c. Provide provisions to verify that drift sensitive components will achieve the limit state performance objectives.

d. The introduction of a range of acceleration and drift limits for different non-structural element typologies with Code Clauses that state that without any testing or research, all components can be assumed to satisfy Class A1 and D1 (see below for suggested typologies), and then set out pathways to demonstrate compliance to other performance class ratings.

<u>Suggested acceleration-sensitive component damage limits which can resist the stated floor acceleration **without** damage:</u>

Class A1: 0.25g
Class A2: 0.50g
Class A3: 0.75g
Class A4: 1.0g
Class A5: 1.50g

<u>Suggested drift-sensitive component damage limits which can resist the stated storey drift demand **without** damage:</u>

Class D1: 0.25% storey drift
Class D2: 0.50% storey drift
Class D3: 1.00% storey drift
Class D4: 2.00% storey drift

We recommend a single standard for the seismic design of non-structural elements. The new standard, Acceptable Solution or Verification Method will include research developments to address existing gaps and contradictions identified within the existing standards by the industry steering group.

4.3.2 Alternative compliance pathways

The New Zealand Building Code Clause B1 was developed with a focus on protecting life safety and limited consideration of damage that reduces use or the function of the building. B1 was not developed with a focus on damage or functionality of non-structural elements. This review has highlighted viable solutions that would include adding alternative compliance pathways specifically for non-structural elements. Suggestions on these alternative compliance pathways are described below.

a. The use of approved standards/ Acceptable Solution

For structures with a ceiling void at least 1m deep:

This compliance pathway would be based on approved standards, that would likely include increased ceiling voids to a minimum depth of 1m deep. Using this compliance pathway Building Consent can be approved with a specimen design and standard approved details for seismic restraint of non-structural elements. The design and coordination of non-structural elements would be completed by the contractor and sub-contractors during the construction phase and covered by a Building Consent Amendment. An independent inspector to be engaged to inspect the installation during construction and certify the completed installation achieves the Performance Requirements stated in the contract (with minimum compliance being NZ Building Code Compliance). The proposed enforcement would be similar to an FPIS inspector and certification which would be required to be submitted with the documentation for Code Compliance Certificate.

b. Customised design for non-structural elements/ Verification Method.

Building Consent will only be approved if the design is fully complete (with no specimen design or performance specifications for non-structural elements inside the building envelope), and proof that the design has been fully coordinated. A PS1 would be required from an engineer responsible for the design and coordination of all non-structural elements. A PS4 confirming that all non-structural elements and their seismic restraints have been installed in accordance with the design documentation will be required, as well as an independent inspection and certification from a qualified third-party inspector.

c. Introduce experimental testing as a compliance pathway for equipment and restraint systems. This will require development of loading protocols that reflect real-world loading scenarios on non-structural elements.

d. Development of industry appraisals for components and systems, like BRANZ appraisals for building components.

4.4 Design

In the future, the seismic restraint design discipline for non-structural elements would be "respected" and understood in the industry like fire and acoustic disciplines.

It is recommended that the design of seismic restraint systems for non-structural elements becomes a specialist design discipline that has an over-arching function comprising all non-structural elements incorporated in that building. Ideally clients would consider engaging a single design consultant entity for non-structural elements, either directly or through the principal design consultant, or within the construction team, who has the responsibility for the design, documentation, coordination, construction observation, and certification of the seismic restraint systems.

4.4.1 Design Process

The desired design process for non-structural components and their seismic restraints is for this to be undertaken during the main design phase and be fully coordinated with all aspects of the design. This would require the design programme to have greater duration to allow for the design process to progress in a more linear progression to allow for significantly greater level of coordination.

We recommend that the seismic design of NSE completed in phase with the other disciplines for concept design. Beyond concept design the seismic consultant reviews design development and coordination through each phase but will undertake the design and coordination of the seismic restraints a phase behind, i.e. preliminary seismic design for NSE starts when structure, architecture and building services deliver preliminary design model and documentation. Detailed design for seismic restraint of NSE will be completed after all other disciplines have completed detailed design. The project would not be issued for tender until full coordination of all components has been confirmed and the seismic restraint of NSE has been completed and scheduled.

The ideal scenario for co-ordinating and designing the restraint of non-structural elements would include the Building Services and Architecture engaged to design and document to minimum LOD350 (or the equivalent level of detail where BIM is not used for a project). This would allow for the design of specific seismic restraints and co-ordination of these elements, with a significant reduction of decision making on site, and result in a meaningful consenting process where the final design elements are included in the consent applications.

Holistic design options would be considered whereby the primary structural design accounts for non-structural seismic loads, combined services including gravity supports and wall/ceiling seismic loads. This would prevent duplication and provide clear load paths back to the primary structure for all elements.

In future, the ceiling voids would be sized following detailed engagement and coordination with the various disciplines/ subcontractors responsible for the design and installation of the non-structural elements.

4.4.2 Testing capabilities

At least one high performance testing facility in New Zealand would be developed that can undertake experimental testing of non-structural components, to meet international testing requirements such as those prescribed in AC156.

4.4.3 Industry Guidance Documentation

In addition to revising the Standards as discussed in Section 4.3.1 it is recommended that industry guidance documentation is developed including design guidance, construction details for different elements and combinations of elements.

It is expected that if the industry guidance documentation are developed by both technical experts and supplier, sub-contractor experts, that they are likely to be recognised and used by the industry and regularly updated.

4.5 Coordination

The best outcome for the industry is that all non-structural elements are fully coordinated prior to construction commencing. The design would be buildable and cognisant of all the other building elements. Based on industry feedback, we recommend that every project has a single point of responsibility for the design and coordination of all non-structural elements.

For complex projects, BIM 3D would be used to ensure compliant design is completed prior to the start of construction. A high level of coordination would be carried out with the inclusion of subcontractors ensuring everything "fits" in the space available. In addition, a seismic coordinator role would be established to ensure the design is coordinated between all design parties.

For straight forward projects the seismic design for non-structural elements would be achieved by following clearly written consistent Standards such as building services (NZS 4219), suspended ceilings (NZS 2785), sprinkler systems (NZS 4541) and structural (NZS1170.5) with the support of Industry Guidance Documentation and appropriate ceiling void depths.

Clients and project managers will understand the importance of seismic coordination when considering procurement, budget, programme and value engineering situations where quantity surveyors and contractors propose a saving through substitution.

4.6 Strengthen/Retrofit/Restrain Deficient Non-Structural Elements in Existing Buildings

Ideally clients in the future will have an overall higher appreciation of the benefit of restraining non-structural elements in general and understand that achieving a successful outcome requires a higher level of expertise than is currently applied. This would also involve conversations with clients regarding the risk associated with existing portions of the building that are not being retrofitted and the client's expectation of seismic performance and time to regain functionality of the building as a whole following varying levels of earthquakes.

Ideally all services, existing or new, would be fully restrained and code compliant regardless of when they were installed. This would ensure that overall building resilience is achieved. This could be undertaken through a modification to Section 112 (Alterations) and Section 115 (Change of Use) of the Building Act where upgrade of the fire and accessibility to as near as reasonably practicable is triggered for alterations and change of use, to include upgrade of seismic restraint to non-structural elements. It is acknowledged that this may prove costly, but at the very least clients should be informed of the risks and implications of not undertaking these works.

With regard to space constraints within existing structures, there are limitations on what can be done to improve the ease of the installation of non-structural elements and the associated restraints. Well considered co-ordination and an allowance within the project for a specialist restraint designer with extensive knowledge is expected to provide the best outcome. Based on reduced ceiling voids provided in the last 20 to 30 years, coordination and full design would be required to ensure the retrofit meets or comes as close as reasonably practicable to meeting the performance requirements.

While some good, versatile proprietary systems are available (e.g. unistrut), simple, seismically rated anchor fixings are required to be tested and certified for use in various floor systems that are being used now and those that were used in the past.

As a minimum we recommend that in all IL4 buildings (continued operation post disaster) and IL3 buildings (crowds and contents of high value to the community), that all non-structural elements are assessed and upgraded to achieve minimum building code compliance.

4.7 Construction and Installation

In the ideal situation the seismic design of non-structural elements will be fully completed with thorough coordination prior to the construction team pricing the work.

The correct installation of seismic restraints relies on the design being completed with thorough coordination before the restraint is installed. The contractor needs to know what to install and where to install it. They can then determine the most efficient way to do it working with other sub-contractors to ensure the restraint is installed correctly the first time.

There would be benefit to Contractor's developing a seismic observer role and/or client appointed Clerk of Works type role for complex projects that covers all the trades. Part of the responsibility of this role would be to ensure the restraints are coordinated prior to construction, changes during construction are understood for knock-on effects and ultimately the installation will achieve the seismic performance objectives of the building.

4.8 QA

To achieve a quality outcome, independent inspectors would be developed and engaged on every project. Their role would be to inspect and certify that the installation of all non-structural elements achieves the Performance Objectives as set out by the design documentation.

Ideally one discipline would be responsible for the design, coordination and installation of all non-structural elements, that, and in the context of the overall building/facility, achieve the Performance Objectives for the building. We recommend that a single engineer of record signs the PS1 and PS4.

4.9 Training

Industry training needs to be widely available to all parties including Client, Council, Consultant, Project Manager, PQS, Contractor and sub-contractors. In the future the seismic restraint for non-structural elements field would be well understood in the industry, similar to fire and acoustic disciplines. Specialist designers (Independent Qualified Persons (IQP) specifically trained in seismic restraint design of non-structural elements) would be widely available to provide advice and share their knowledge to the industry and junior colleagues.

Increased training and knowledge across the board would ensure holistic design for future projects was considered. With greater training and understanding, the importance for fully coordinated designs would be understood between all disciplines. There would be training to provide standardised and combined seismic restraints for all trades.

How Do We Get There?

5. How do we get there?

5.1 Risk

For Clients to fully understand the risks associated with the seismic restraint of non-structural elements, the risks to their respective organisations, employees/tenants, and the risks to their building assets, the preparation and dissemination of detailed information on this issue, combined with industry wide education, is essential. This will enable Clients to make informed decisions and choices on how they can best manage these risks in the future.

For many organisations attracting input from the key policy decision makers can prove difficult because it can easily be viewed as solely a technical issue rather than an organisation resilience issue. Thus, information transfer and education may need to be targeted through organisation resilience gatherings and associations. The NZ Insurance Council is aware of the risks and issues and its representatives make a convincing case for policy decision makers to better inform themselves of the issues and risks they face. The just launched NZ Construction Sector Accord could also be a conduit as an example where greater collaboration across the industry would have direct benefits to NZ.

While client decision makers need to be informed to define appropriate policies for the seismic restraint of non-structural elements, client property and project managers also need to be fully aware of the options available and understand the technical issues involved and the risks their client could be exposed to. Probity needs to be reconsidered. There needs to be a shift away from 'cheapest is best' attitudes, and a focus on moral principles, honesty and decency which can all be upheld without the single focus on lowest cost.

If clients want enhanced performance and resilience for their buildings, they would need to discuss options with knowledgeable consultants. The way forward needs to be by information sharing and education.

Many consultants, contractors and subcontractors are already aware of the needs and measures to reduce the risks of non-structural elements, but the issues need to be consistently discussed on all projects. At present the inputs can be random and uncoordinated.

How non-structural elements risk issues are discussed and shared can only be improved when all participants are aware and have imposed or agreed on an arrangement in which non-structural elements issues are aired, discussed and responsibilities identified.

5.2 Procurement

Contractors and sub-contractors have advised they want to price and construct fully resolved designs. They no longer want to take on the coordination risk that is difficult to accurately assess and price at tender. Good coordination has been hard to manage with the "hybrid" design and build procurement models used recently in New Zealand. Providing traditional design or full Design and Build would provide the environment to achieve a fully coordinated design.

The skills and capability within the New Zealand design and construction market needs to be improved to provide a platform upon which good procurement outcomes can be realised. This is discussed further in Section 5.9, Training. Until the industry matures and the knowledge and skill base improve, the following key procurement initiatives are expected to improve procurement and outcomes in general in the short term:

a. A single entity is made responsible for the design, coordination and installation, via PS1 and PS4 for all non-structural elements.

b. A Clerk of Works is engaged during the construction phase.

c. QS industry to work closely with the design and construction industry to provide industry guidance for the following costs:

   - Fee increase for all disciplines to

allow for fully coordinated design

- Fee allowance for designated Seismic Consultant
- Understanding the true cost of the depth of ceiling voids, noting that small ceiling voids increase the complexity and cost of the installation, seismic restraint and maintenance of non-structural elements.

d. Industry to provide Guidance Documentation that explains the issues for building consent, tender and construction if the procurement process only allows for specimen designs for non-structural elements at tender and building consent phase.

e. Industry to provide Guidance Documentation for appropriate fees and time frames for design and coordination.

f. Key sub-trades are procured following conceptual design to enable the design to be completed and fully coordinated prior to tender to Main Contractor's. Sub-trades named as nominated sub-contractors.

5.3 Regulation

Regulation is unlikely to be able to be implemented within a short duration. In the meantime, industry guidance documentation would likely provide more consistency in the industry in the short term.

It is possible that new Clauses could be introduced into section B of the NZBC, for example "B3 – Non-structural Elements and Systems" that could address potential simplified compliance pathways (refer to Section 4.3.3a) however possible time frames through which any changes could be introduced into the industry are uncertain.

Building Consent Authorities (BCA) require support by way of training and guidance documentation to provide consistent approach to documentation review, site inspections and the requirements for Code Compliance.

If an Independent Quality Provider body is developed they would support the BCA's in their inspection and certification role.

5.4 Design

Feedback from the industry workshops is that the thing that will make the single biggest improvement to the seismic restraint and compliance of non-structural elements is for the design of non-structural elements to be considered and fully designed and coordinated from the commencement of the project. This will require changes to current procurement, design programmes, design fees and QS estimates.

The suppliers and installers are generally aware of the needs for the seismic restraints and clearance requirements for non-structural elements, but they are often compromised by budget issues, lack of space and up-front coordination. What they require is communication, direction and appropriate monitoring of their activities.

Sub-contractors need to be involved as much as main contractors in communications on non-structural elements, despite that, in some contextual arrangements that may appear difficult.

There was consistent agreement at the industry workshops that a key way to get more consistency in the industry is to prepare industry guidance documentation that sets out the design process, clearance requirements, a range of appropriate restraint types for different applications along with some 'standard' details. It is expected that if industry steering groups are involved that the guidance will be recognised and used across the industry.

5.5 Coordination

Recommendations from industry workshops was to establish a seismic coordinator role to take responsibility for the design and coordination between all design parties.

Seismic design for non-structural elements historically has been left to the end whereby limited time has been available to complete a fully coordinated design. Considering non-structural elements early in the design process would allow greater influence for coordination for all elements including primary structure and key architectural details. This process requires adequate time frames within the delivery programme for robust documentation checking and coordination.

On complex projects full coordination is likely to require BIM 3D to ensure a well-coordinated and compliant design is completed prior to the start of construction. It would require a high level of coordination with input from suppliers/subcontractors ensuring everything "fits" in the space available. Where value engineering is required, the effect to non-structural elements and seismic restraints would be considered with implications raised and considered before the design change was adopted.

There is no such thing as a perfect set of fully coordinated construction drawings as issues reveal themselves during construction particularly when redeveloping, extending or converting existing buildings. It is important that the construction monitoring fee for the designated seismic coordination allows adequate contingency for increased site hours, if needed, for site attendance to review that what was designed and coordinated is actually being built.

5.6 Strengthen/Retrofit/Restrain Deficient Non-Structural Elements in Existing Buildings

The first step that is required is awareness by building owners, building authorities, and insurers that non-structural elements are an identifiable risk in existing buildings.

As with Earthquake Prone Building's building owners and tenants can, and should, be encouraged to understand the risks and upgrade the seismic restraint of non-structural element's particularly in IL4 and IL 3 buildings. The insurance industry is already aware of the costs associated with damage to non-structural element's and it is a commercial reality that it is likely to lead to changes in New Zealand commercial building insurance.

Significant value is expected to be realised if an experienced non-structural designer and coordinator is engaged at the project inception to consider the most efficient way to effectively install and restrain new components and upgrade the seismic restraint of existing components. Project level consideration is required from all disciplines to navigate the inherent complexity of successfully coordinating non-structural elements and the associated seismic restraints into existing buildings.

In addition research will investigate known non-compliance issues in existing building and provide recommendations for effectively retrofitting the deficient non-structural element systems in the majority of existing buildings.

5.7 Construction and Installation

The contracting teams have advised that they want to install a design that is compliant. They would achieve that by having clear, buildable drawings that show what to install and where to install it. For this to occur, the seismic design for non-structural elements restraints would be fully designed and coordinated before construction commences. The restraints would only be installed one time, as the contractor would push back if the design was not complete prior to starting an installation. Robust QA processes will be implemented by the contractor to ensure the restraints were installed as per the coordinated design documentation.

Contractors could use 3D models during construction to assist with installation and understanding where and how the various trades interact between the each other. The model would also be used by the contractor team to plan installation and timing for each trade.

Looking forward, contractors could develop a site based seismic observer role (which could be mandatory on complex projects) that covers all trades. There is also strong support to re-establish a client engaged Clerk of Works role specifically for the non-structural elements and their seismic restraint. These initiatives alongside review by the engineer on record, are expected to ensure installations achieve Code Compliance and project specific Performance Objectives and provide a forum for the site staff to highlight non-complaint issues.

Moving forward the seismic design for non-structural elements will be clear to price and easy to follow by the client and QS. The contractor would fully understand their contractual obligations regarding seismic restraint of non-structural elements by having experienced people in their team or subcontracting to a specialist in the field of non-structural elements.

5.8 QA

5.8.1 Live QA process

A change in the behaviour of designers and the construction teams is required and this could be supported by a live QA process where as soon as defects/clashes/non-conformance are identified work in that area shall stop until it is resolved with consideration of the implications of the proposed resolution and how it may affect all components. Current practice is to ignore the defects and continue the design/construction. This means that the issues and extent of non-compliance compounds significantly. The current behaviour is likely driven by risk aversion and addressing risk and procurement methods are likely to help provide an environment where a live QA process could thrive.

5.8.2 Independent Inspectors

Development of an independent inspectorate that has licensed inspectors who, following site inspection confirm the building/facility complies with the New Zealand Building Code and project specific Performance Objectives, can sign and issue a Certificate.

All applications for Code Compliance Certificates in buildings that have non-structural elements should require an independent inspection and certification. There is precedent for this process, which is required in NZS 4541 for fire protection systems and is a requirement for the certificate to be submitted to the Building Consent Authority prior to a Code Compliance Certificate being issued for that building.

5.8.3 Industry appraisals

Development of industry appraisals for non-structural components and systems installed in buildings. This is expected to provide similar outputs for industry to use as is currently undertaken and issued by BRANZ for building products.

5.9 Training

The Industry currently directs the responsibility for seismic design and coordination of non-structural elements down to the sub-contractors. For complex projects this has resulted in non-complaint installations due to lack of appropriate budgets, understanding and training by the sub-contractors.

Industry training to support consultants and contracting teams alike is needed. Services engineers training would include understanding what seismic-friendly design looks like. Whilst training of structural engineers could include how services equipment (mechanical vibration and thermal expansion) and ceiling/wall partitions behave in an earthquake.

Regular Industry conferences and training sessions would ideally be provided for seismic design of non-structural elements. Increased exposure in university and polytechnic courses could be provided to build a knowledge base about good holistic building design that incorporates non-structural elements would improve behaviours around the importance of seismic coordination across all the trades.

Building WOF training could be updated to include seismic audits in the BWOF certification.

If the Clerk of Works role is re-established as recommended in Section 5.7, it would require informal training through extensive design and site experience as to the requirements and issues to be considered for the installation of non-structural elements and their seismic restraints.

Recommendations

6. Recommendations

We challenge the industry to work together with a common goal of putting people and future generations wellbeing at the heart of what we do. There is no one part of the industry that is the cause of the current challenges that are facing the industry, it is a product of a systematic failure of the industry. We believe there is a significant opportunity to improve the seismic performance of non-structural elements and our buildings as a whole. To do this we recommend that a system wide change is implemented, that will deliver buildings that meets the needs and expectations of our communities.

1 | Training, Guidance Documentation and Code of Practice

Industry training would be widely available 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, owners on what the new system is and what it delivers.

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 (Independent Qualified Persons, IQP) specifically trained in the seismic performance of non-structural elements, would be widely available to provide advice and share their knowledge to the industry and junior colleagues.

In consultation with stakeholders a suite of industry guidance documentation will be developed. These will include:

- Overarching document that provides 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) functional recovery of buildings and iii) collapse prevention. This guidance documentation would benefit designers, contractors, building owners and tenants as it will provide, in plain English, 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 include clarity on what work to existing non-structural elements constitutes an Alteration to the building, in accordance with section 112 of the Building Act.
- Guidance document which describes procurement methodologies, risk allocation and the resulting risk to building owner. Recommended procurement methods will be described as well as discussion on procurement methods that are not recommended.
- Technical guidance document. This is expected to provide sufficient detail that in time it could become a future verification method in the New Zealand Building Code. It would include the two-tier compliance pathway recommended in this report as well as include approved standard details and anchor types for support and seismic restraint of non-structural elements.
- Guidance document for the inspection of non-structural elements and systems. The document will have two sections, the first for inspection and assessment of existing systems and the second which will provide information for independent inspection of new non-structural elements. The sections will include chapters for various non-structural elements.
- Following release of the guidance documentation, feedback will be taken on board and a Code of Practice will be developed. The Code of Practice would likely be the first step towards a new New Zealand Building Code Clause.

2 | Define roles and responsibilities

Work with the industry to define the roles and responsibilities of owners, tenants, architects, building services engineers, structural engineers, seismic coordinators, contractors and sub-contractors with regard to the design and coordination of non-structural elements and systems.

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

3 | Carry out research and testing

There is a need for the development of at least one high performance testing facility in New Zealand that can undertake experimental testing of non-structural components under dynamic/high speed cyclic loading.

Further to this university research has demonstrated gaps in technical knowledge, both nationally and internationally, especially regarding how various non-structural elements respond and interact with other building components during seismic events. Research will investigate these issues further and provide recommendations for changes to design practice and effective retrofit of deficient non-structural systems in existing buildings.

The research will support the introduction of a range of acceleration and drift limits for different non-structural element types and restraint systems.

The research programme will support the development of a new New Zealand Standard/ Verification Method for the seismic design of non-structural elements.

4 | Introduce an independent quality provider and certification body

A new Independent Quality Provider (IQP) and Certification Body will be established, which would be similar to the independent inspection and certification requirements currently used for Sprinkler Systems with a broader responsibility of ensuring QA of all NSEs. All projects 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 will have considerable experience in the design, coordination and installation of non-structural elements. Given the wide range of components and sub-trades in buildings it may require more than one IQP to provide the necessary knowledge base to complete inspections and certification of complex buildings.

5 | Introduce a new Building Code

Instead of a fragmented regulatory system, introduce a new clause that covers all aspects of seismic performance for all Non-Structural Elements. A working title “B3 Non-structural Elements and Systems” is proposed. It is envisaged that this new clause will cover objective, functional and performance requirements like the other clauses of the Building Code.

The performance requirements section would be based on functional recovery with checks to confirm the elements achieve life safety objectives. We propose a philosophy that uses a significantly enhanced ‘serviceability’ load over current New Zealand Standards. We recommend this as there will be little to no additional cost for many NSE elements and the increase in performance and resilience of non-structural elements will be significant.

By having this new clause all stakeholders will be required to use the same ‘single source of truth’.

The Code of Practice developed as part of Recommendation 1, is expected to be the first towards a new Building Code Clause for non-structural elements.

6 | Withdraw the seismic provisions from current NZ Standards and associated industry guidance for non-structural elements and replace with one NZ Standard or verification method

The performance requirements in the current NZ Standards for seismic design of fire sprinkler systems, suspended ceilings and buildings services do not align and, in some cases, contradict each other. Industry users of the current non-structural Standards, have advised there are gaps and errors in the current Standards with regard to seismic restraint and it has been demonstrated, within the research community, that current code provisions provide poor prediction of the acceleration demands and drift limits for non-structural elements.

The new Standard or verification method would provide a consistent framework for mandatory independent inspection, reporting certification for non-structural elements and systems. This would involve inspection and certification by an IQP which would be required to be submitted with the application for Code Compliance Certificate. Currently NZS 4541 extends the IQP involvement to annual inspection, reporting and certification linked to the issue of the annual BWOF.

The new Standard will include definitions of what constitutes maintenance work and what constitutes an alteration in terms of the Building Act. If work to existing non-structural elements and systems is deemed an alteration, or new components are being installed, the works would need to be assessed by an engineer experienced in the design and coordination of non-structural elements and systems, to ensure that appropriate design is undertaken and at the completion the building will comply with section 112 of the Building Act. An IQP will inspect and certify.

7 | Introduce two tier compliance pathway

The recommended addition to the NZ Building Code 'B3 Elements', would include a two-tier compliance pathway, VM1 and VM2. The detail of the two-tier compliance pathway is expected to be tested and updated to reflect industry input following use of the Industry Guidance Documentation described in Recommendation 1 of this report, but is expected to include:

<u>VM1 – Use of Approved Standards</u>

Building consents would be approved with a specimen design, approved standard seismic restraint details, along with a performance specification for non-structural elements. This compliance pathway provides for design and coordination by the main contractor, various subtrades and consultants during construction and would require a Building Consent Amendment once the design for all non-structural elements has been completed and fully coordinated. This Verification Method is likely to include increased ceiling voids to a minimum depth of 1m to reduce the complexity of installation of non-structural elements and their seismic restraints in constrained locations. 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.

<u>VM2 – Customised design for non-structural elements and systems</u>

Design and coordination of all non-structural elements within ceiling voids, risers etc are fully complete (to LOD350 or equivalent level of detail when BIM is not used on a project) and submitted for Building Consent. There would be no minimum or maximum depth of ceiling void, but the depth chosen must be confirmed through full design and coordination. An independent inspector (IQP) will inspect the installation of the non-structural elements and provide certification that the installation is completed in accordance with the coordinated design and achieves code compliance prior to the Code Compliance Certificate being issued.

Conclusion

7. Conclusion

If implemented the seven recommended changes will significantly improve the seismic performance of buildings in New Zealand and substantial co-benefits will be realised 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 report 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.

> ***“The issues facing the construction industry won’t go away through tinkering with codes, demanding cheaper costs or scattering enforcement or resilience through random projects.***
>
> ***We need to be bold and take the step change that is needed. Taking action will challenge the industry, it won’t be easy.***
>
> ***We need to work together to achieve the productivity and performance outcomes so that our building stock of the future will meet the expectations of our communities, iwi, owners and tenants.”***

Research Acknowledgment

8. Research Acknowledgment

This report is an output from Quake Centre's Building Innovation Partnership (BIP) programme, which is jointly funded by industry and the Ministry of Business Innovation & Employment (MBIE). Under the contract the University of Canterbury's Quake Centre has with MBIE, this report forms partial completion of Theme 3 Fit-for-Purpose Building Components, resulting in improved seismic performance through Research Aims 1.9 (new data of engineering relevance on the seismic performance of non-structural elements), 1.11 (new low-damage technologies for non-structural building components) and 1.12 (new technologies and approaches for the effective retrofit of non-structural components).

Limitations

9. Limitations

The opinions provided in this report are based on research and industry workshops and are provided using a degree of care and skill normally exercised, under similar circumstances, by reputable professional consultants practicing in this field at this time.

This report is prepared for the Building Innovation Partnership lead by Quake Centre to assist with understanding the current industry position and outcomes being realised for the seismic restraint of non- structural elements. The report is expected to be used to inform initiatives and research that will provide improvements to the seismic performance of non-structural elements in New Zealand.

This report is not intended for any other party or purpose

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