MINISTRY OF BUSINESS, INNOVATION & EMPLOYMENT
HĪKINA WHAKATUTUKI

OPUS

Economic Benefits of Code Compliant Non-Structural Elements in New Buildings

Ministry of Business, Innovation & Employment






Contact Details

Jan Stanway

Opus International Consultants Ltd
Christchurch Office
12 Moorhouse Avenue
PO Box 1482
Christchurch 8140
New Zealand

Telephone: +64 3 363 5507

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Prepared by

Jan Stanway | Principal Structural Engineer
Bruce Curtain | National Technical Director - Architecture

Reviewed by

Jason Bretherton | Manager, Mechanical & Electrical Engineering, Design Centre South
Paul Campbell | National Technical Director – Building Structures

Approved for release by

Jonathan Hill | Group Manager Buildings, Design Centre South

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1. Executive Summary

This study examines the economic benefits to New Zealand of good seismic performance of non-structural elements in new non-residential buildings. It has been precipitated by notable failure of these elements in a series of seismic events including Christchurch, Cook Strait and most recently Kaikoura contributing a significant portion of the buildings damage, as well as the consequential business disruption and repair costs.

Review of the observations into the performance of non-structural elements in past earthquakes (Canterbury Earthquake Royal Commission, FEMA investigation of the 2014 South Napa earthquake, and review of the causes of non-structural damage in the Cook Strait Earthquake) has highlighted a recurring issue; that the majority of the damage to non-structural elements – ceilings, services, partitions, facades, etc. - was caused through lack of detailing and provision of appropriate clearances for seismic actions.

The performance requirements stated in the New Zealand Building Code (NZBC) along with relevant Standards for building services (NZS 4219) and sprinkler systems (NZS 4541) forms the basis to assess whether the installation of non-structural elements are code compliant. A Standard for the design of suspended ceilings exists (AS/NZS 2785). However, it is not cited as a means of complying with clause B1 of the Building Code. There are currently differing opinions of whether ceiling systems need to be designed to resist ultimate limit state design actions in accordance with NZS 1170.5.

For this study six different types of buildings were assessed to consider the construction value to install code compliant seismic bracing to partitions, ceilings, pipework, ducting, overhead equipment and sprinkler systems. The cost ranges from <1% of the construction value for a multi-storey car parking building with limited non-structural elements through to 9.5% of the overall construction value for a district hospital which is highly serviced with minimal ceiling space sizes. A typical office building was found to be 6.7%

The cost to design and coordinate the seismic restraints for non-structural elements (including ceilings and in-ceiling services) would be between 0.25% - 1% of the construction value. Senior quantity surveyors from the Fletcher Construction Company advise that they typically allow 2.5% of the overall construction value to design and coordinate non-structural elements during construction. The reason that the cost is greater when undertaken by the contractors during construction is because there is a greater amount of coordination required to work in and around an already completed design as provided by the detailed design documentation.

To provide a macro-economic context extrapolated out to the wider annual construction spend the value of code compliant seismic restraints for non-structural elements is in the order of an average of 5.4 % of the total construction value. In the context of the $40b insurance losses for the Christchurch earthquake event, damage to non-structural elements is believed to be a significantly higher proportion of material damage and consequential economic disruption compared with structural damage.

Whilst the cost to design and install seismic bracing to non-structural elements is relatively small compared to the overall cost of building projects, the actual performance of the building will be dependent on whether appropriate clearances are provided and restraints and services are installed as per the design documentation.

Discussions with the Insurance Council of New Zealand (ICNZ) highlighted the substantial economic losses in recent earthquakes due to poor performance of non-structural elements. While unable to be substantiated with specific data there is indicative evidence that business interruption plays a large, and potentially hidden, component of the economic loss. Our study reviewed the damage observed and it appears that had the installations been compliant with the requirements of relevant Standards and the New Zealand Building Code, the cost of repair and business interruption, would have been substantially less. A change in emphasis from building structural performance to both building and business resilience could alleviate substantial financial losses and wider economic disruption in future events.

While this report starts to quantify the cost for compliant restraints, the issue is a complex one across a diverse construction industry, and indications are that the New Zealand construction industry, needs to introduce design and coordination of non-structural elements, during the design phase followed up with independent inspections to confirm that the final installation meets the requirements of the relevant Standards. Indications are that if this occurs not only will the installations have considerably better performance during earthquakes, but the installation efficiencies will lead to reductions in both time and cost.

Ultimately the value proposition for good seismic performance of non-structural elements is enhanced building and business resilience - that is what delivers the wider benefit to the New Zealand economy in the long term.

Figure 1: Seismic Restraints of Services

2. Introduction

Non-structural elements suffered extensive damage in the Canterbury, Cook Strait and Kaikoura earthquakes. The economic costs of damage to these elements includes not only the physical repair works but also business interruption costs when the damage affects occupancy.

Observations following the Canterbury, Cook Strait and Kaikoura earthquakes has shown that new buildings that had code compliance certificates did not necessarily meet New Zealand Building Code requirements relating to non-structural elements. 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.

Non-structural elements within a building are typically defined as permanent items that are attached to and supported by the building primary structure. Non-structural elements normally include:

- Architectural features such as exterior cladding and glazing, ornamentations, ceilings, interior partitions and stairs,
- Mechanical elements and systems including air conditioning equipment, ducts, lifts, escalators, pumps and emergency generators,
- Electrical elements including transformers, switchgear, master control centres, lighting and cable trays,
- Fire protection systems including piping and tanks, and
- Plumbing systems and elements including piping, fixtures and equipment.

Figure 2: Seismic Restraint of Services and Ceilings

3. Scope of the Study

Opus has been engaged by the Ministry of Business, Innovation & Employment (MBIE) to undertake a study to better understand the economic costs and benefits of code compliant installations of non-structural elements. This study has focused on five non-structural elements - mechanical ducting, electrical cable reticulation, plumbing and sprinkler systems, partition walls and suspended ceilings. We have assessed the costs to appropriately design, construct and maintain the appropriate seismic restraints for these non-structural building elements.

The following describes the specific scope of the study:

1. Estimate the construction value to fabricate and install the seismic restraints of suspended ceilings, internal partition walls, HVAC equipment and ducting, pipework, and plumbing and sprinkler systems across a representative range of medium to high occupancy, non-residential buildings.

2. Compare the costs and benefits to design and coordinate code compliant seismic restraints for non-structural elements during the main documentation phase, to the current industry practice of providing a performance specification for the main contractor to design, coordinate and install all non-structural elements and their seismic restraints.

3. Estimate the maintenance and lifecycle costs associated with the seismic restraints for non-structural elements.

4. Review the processes, responsibilities and roles for the design and construction of seismic restraints for non-structural elements including literature review and performance of non-structural elements in past earthquakes.

5. Review the potential economic benefits arising from the installation of code compliant non-structural elements.

6. Whilst not specifically requested by MBIE, we also sought feedback from international subject matter experts and used the FEMA P-58 Seismic Performance Prediction Program (SP3) to predict damage and repair times to non-structural elements subjected to various levels of earthquake and compared this to observations following the Canterbury, Cook Strait and Kaikoura earthquakes.

Figure 3: Seismic Restraint of services

4. Performance Requirements for Code Compliant Non-Structural Elements

When reviewing the economic benefits of code compliant installations of non-structural elements it is necessary to not only consider the relevant Standards but to also consider the overarching performance requirements of the New Zealand Building Code. In the following section of this report we review the performance of non-structural elements during recent earthquakes and consider whether the failures that occurred were likely to have been caused by non-compliant installations and discuss the economic benefits that could have been achieved if the failures had not occurred.

4.1. New Zealand legislative performance requirements

The hierarchy of New Zealand building controls starts with the Building Act 2004, followed by the Building Regulations and the Building Code. The Building Code sets out the minimum performance requirements for buildings. It does not specify how to achieve this performance, rather it focuses on the outcomes for the building.

In order to issue a building consent, a building consent authority must accept an acceptable solution or verification method as evidence of compliance with the Building Code.

4.1.1. New Zealand Standards relevant to the design and installation 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 three non-specific design Standards that relate to the design and performance of non-structural elements. Two of the Standards, NZS 4219:2009 (Seismic performance of engineering systems in buildings) and NZS 4541:2013 (Automatic fire sprinkler systems) are cited in B1 -Acceptable Solutions and Verification Methods, whilst AS/NZS 2785:2000 (Suspended ceilings – Design and installation) is not. Currently there are no explicit provisions within Standards relating to the seismic restraint of internal partition walls, although designers can undertake a specific design using the New Zealand loadings standard NZS 1170.5 and relevant material Standards.

4.1.2. Performance criteria

Buildings designed using AS/NZS 1170 must comply with the following requirements for two limit states:

- Ultimate Limit State (ULS) Events – This is a "design level earthquake" at which the primary focus is life safety. Provided the performance of a building during a ULS event is such that no one within or adjacent to the building is harmed, the post-event condition of the building is not a design criteria. It is therefore acceptable that demolition or large scale repairs to a building can be expected. The principle of protecting life beyond the ultimate limit state design should be applied to all elements of a building that may be at risk if they fail in an earthquake.
- Serviceability Limit State (SLS) – This limit state corresponds to a smaller, or frequent seismic event, approximately 25%-35% of a ULS event. The performance criteria for an SLS event is that the design and construction must avoid damage to the structure and non-structural elements that

would prevent the building from being used as originally intended without repair after the SLS earthquake. This means immediate occupancy of a building is available, and that damage is limited to only minor damage to non-structural elements.

Amendment 1 to NZS 1170.5 was issued in August 2016. As this amendment has not yet been cited as a means of complying with the New Zealand Building Code this study has considered the provisions of NZS 1170.5 excluding Amendment 1 when considering code compliant non-structural elements.

For completeness we have noted the relevant changes to NZS 1170.5 included in Amendment 1 that will affect the seismic design of non-structural elements in the future:

- ULS for earthquake loading shall provide for (new clause) - Clause 2.1.4 (iv) – Avoidance of damage to non-structural systems necessary for building evacuation following earthquake that would render them inoperative
- Table 8.1 –Parts that do not need to be considered in P1, P2 and P3 (all to be designed to ULS with a Part Risk factor of 1.0) includes:
    - Note 2(a) A part that weighs less than 7.5kg **and** which, if it experienced a loss of gravity support or were to become decoupled from the structure, would fall less than 3m provided that the loss of gravity support does not lead to release of hazardous material. [*note in the current version of the code the Part Risk Factor is 0.9 and a part does not need to be designed to ULS if it weighs less than 10kg OR it can fall less than 3m*].

4.1.3. Performance requirements for non-structural elements

The table below shows a comparison between the performance requirements of the three key Standards which relate to the seismic restraints for non-structural elements. It is interesting to note the varying performance requirements between each Standard. NZS 4219 and NZS 4541 have some commonality regarding seismic design loads and interaction between elements, whilst the requirements of AS/NZS 2785 do not align well with the other Standards. The current fragmented nature of the requirements and interaction between ceilings, sprinkler systems and engineered systems does not support the coordination of these non-structural elements and as AS/NZS 2785 is not cited by the New Zealand Building Code as a verification method for the Building Code.

Table 1: Summary of New Zealand Standards for design of Non-Structural Elements

Standard	**NZS 4219 (Seismic Performance of engineering systems in buildings)**	**NZS 4541 (Automated fire sprinkler systems)**	**AS/NZS 2785 (Suspended ceilings – Design and Installation)** ***Not cited as a Verification Method***
Performance Requirements	P1, P2, P3, P4 and P5 categories as defined by NZS 1170.5. Performance requirements for ULS cases stated.	All sprinkler system elements shall be designed and installed so as to remain operational at ULS earthquake loads specified in NZS 1170.5	ULS performance – ceiling grid and its suspension system to be designed for ULS loads without causing impact with structure or other services and without causing ceiling tiles of 1.5kg or more to dislodge over occupied spaces or egress routes.
	All elements to be restrained so that system retains structural and operational integrity without requiring repairs after SLS1 earthquake	The sprinkler system shall not be damaged or impaired by the movement or failure of other features or elements of the building	SLS performance – Probability of loss of serviceability of the system is acceptably low and the ceiling maintains its intended performance level throughout its intended life
		Parts category P4 referenced.	Ceiling hangers shall be proportioned such that the failure or removal of a single hanger does not trigger a progressive collapse of the ceiling system

Design Requirements	**Specific design using NZS 1170.5 and non-specific design (prescriptive method to determine earthquake loads along with 2.5% drifts and prescriptive capacity of braces for given bolt fixings)**	**Piping support system based on an assessment using earthquake loadings of NZS 1170.5 (parts category P4), or piping support system to comply with prescriptive requirements**	**Earthquake design loads refer to NZS 4203.** **Current version of NZS 1170.5 is ambiguous as to whether or not ceiling systems need to be designed to resist ULS** loads or not**.**
	Specific design includes the design of all equipment, their restraints and their fixings to the primary structure such that they have adequate strength, stiffness and ductility in accordance with the provisions of the appropriate material standards	Clause 403.12.2 – All pipework shall be designed to resist repeated forces due to seismic acceleration of 1.0g acting on the mass of the pipework in any direction in addition to the gravity force.	ULS load combinations similar to NZS 1170.0 except gravity which is more onerous at 1.4G & 1.7U Both vertical and horizontal earthquake actions to be considered
Interaction between elements	Prescriptive clearances provided	Clause 5.2 Minimum clearance to building elements (walls, floors, beams, platforms and foundations) are provided.	Partitions shall be fixed to the primary ceiling framing in accordance with the ceiling manufacturer's requirements. Where the partition is face loaded, the top plate of the partition shall be braced within the ceiling plenum or partition continuous from floor to floor
	Equipment supported independently of suspended ceiling shall have a clearance of 25mm all round	Gaps may be sealed with flexible or frangible material (gypsum board is considered frangible).	Mechanical and electrical services shall be completed before installation of the suspension systems
	Plinths – prescriptive detail on connection of plinth to floor slab		Basic guidance provided for mechanical air terminal devices and downlights, all other services which are to be incorporated into the suspended ceiling shall be in accordance with AS 2946 or NZS 4219

5. Performance of Non-Structural Elements (NSE) in Past Earthquakes

The cost of repair work for damage and business interruption due to poor performance of non-structural elements in the Christchurch and Cook Strait earthquakes has been substantial, although difficult to quantify as the economic losses are not recorded separately by insurers, or the wider industry (refer to discussion in Section 5.1 of this report).

There were notable buildings located in Wellington that suffered disproportionate failures of non-structural elements during the Cook Strait earthquake sequence. The levels of earthquake shaking are believed to have been close to or slightly exceeded SLS design loads for IL2 buildings in Wellington. The damage sustained has put the spotlight on the potential for non-compliance of non-structural elements, the potential for large consequential damage (such as sprinkler failure), and the complexity and duration of repairs.

In this section we have reviewed the reasons why damage occurred to non-structural elements in recent earthquakes and considered if the installations were likely to have been compliant with the New Zealand Building Code. Where we believe the damage to the installation indicates non-compliance we have commented on the likely reduction in damage and economic losses had the installation been compliant.

5.1. Economic costs of damage to non-structural elements in recent New Zealand earthquakes

5.1.1. Insurance claim overview

The Opus study team discussed the impact of damage to non-structural elements, and the consequential costs of business interruption and repair with John Lucas, Insurance Manager of the Insurance Council of New Zealand (ICNZ). The issue is complex and there is little specific, tangible economic data for the following reasons:

i) *A significant amount of damage and consequential losses, both material damage and disruption, would have been below the insurance policy excess and therefore these costs would be excluded from insurance cost reports.*

ii) *Insurances losses are often commercially sensitive and not fully reported other than in aggregated terms.*

iii) *Currently commercial insurance reporting includes capital asset losses and business interruption, etc. with no breakdown into individual products. It is therefore not possible to differentiate individual building elements, nor would it provide the full picture as per items 1 and 2 above.*

Mr Lucas advised that there is strong evidence that business interruption is potentially a much larger component of the total insured loss than material damage costs. In the context of the Christchurch earthquake sequence around 50% of the total $40B loss was covered by private insurers, therefore correspondingly the other 50% is covered by the government – a $20B cost to NZ tax payers. The challenge is therefore to understand the impact of non-structural element failure in the context of insurance costs and provide a mechanism to derive a value proposition between improved performance of non-structural elements verses insurance cover.

5.1.2. Global insurance context

It is important to understand the global context of the insurance market and how that effects the ability of New Zealand entities to access the earthquake cover. In particular the global volatility of the insurance market is a key risk to the New Zealand economy and in this way it can help us understand the risk/benefit profile of the seismic performance of non-structural elements.

The global pool of insurance funding is an investment vehicle, and therefore driven by a range of external economic and political factors and importantly not always determined by just insurance risk. Equally the contributions of New Zealand to the wider insurance pool are insignificantly small at around 0.01% / annum, relative to the recent insured losses which for New Zealand rate at number 2 in the world below the 2011 Tohoku earthquake in Japan.

In the Japanese context the insurance risk is deemed so high that self-insurance - through enhanced building performance - is in reality the only mechanism available as insurance cover is either unavailable or prohibitively expensive. This could reasonably become the case in New Zealand given the recent increase in seismicity.

At numerous points in New Zealand history the insurance market has dried up causing significant business issues for private entities, and thereby the wider economy and therefore governments as well. This volatility lead to government intervention with the establishment of State Insurance Office (1905 developed from Government Life Insurance in 1869), which was subsequently turned into a State Owned Enterprise (SOE) in 1963 and sold to IAG in 1990. At each point of volatility there was severe disruption to business and the wider economy in between. With trends towards privatisation and world-wide consolidation in the insurance industry New Zealand is, in reality, entirely reliant on the global re-insurance market to underpin the commercial and retail insurance industry.

More recently after each major seismic event there is often a minimum stand-down period of around 1-3 months before new insurance is available which has the effect of stalling normal economic activity. There are recent reports at the end of 2016 that international insurance modelling is suggesting a 40% increase in 'risk profile' for New Zealand, which will undoubtedly have an impact on premiums in the short term and conceivably even access to insurance altogether.

5.1.3. New Zealand insurance context – NBS vs business resilience

A great deal of focus since 2010/2011 has been on % NBS (Percentage of New Building Standard) ratings as the baseline indicator of a buildings structural performance. In the insurance context however business resilience is a better indicator of structural performance.

The performance of non-structural elements, which accounts for up to 70% of the buildings capital cost can have a bigger impact on operational disruption for businesses and tenants than failure of structural elements. Therefore as John Lucas from the Insurance Council has noted the insurance industry is particularly interested in shifting the debate from the baseline structural minimum 'preservation of life' to buildings and business resilience.

5.1.4. Capital asset insurance vs business interruption - example

An examination of business interruption / disruption in the context of non-structural element failure would provide a basis to explore the need for improved overall building performance. To highlight the escalating cost of business interruption losses verses capital asset losses we have compiled the following simplified hypothetical example. This is based on an escalating series of damage scenarios with a specific focus on damage to non-structural elements. As described in section 4.1.2 of this report the definition of serviceability limit state (SLS) is that the building remains operational following an SLS earthquake. This example reflects the actual situation observed following recent New Zealand earthquakes that damage to non-structural elements occurs at or close to the SLS earthquake:

i) Below SLS

ii) At or close to SLS (moderate non-structural elements damage)

iii) At or close to SLS (major non-structural elements damage)

iv) At ULS

A typical office building with an insured capital value of $10M may have 10 tenants with annual turnover of $1m each and run on cover for 2 years.

Table 2 – Hypothetical example of damage to NSE and effects of Business Interruption costs on the total losses.

Scenario	Damage to structure	Damage to NSE	Business Interruption	Capital Insured losses*	Business Interruption Losses**	Total Losses
Below SLS	Nil	minor	0-4 weeks	$100k	$800k	$900k
Close to SLS (moderate NSE damage)	Nil	50%	6 months	$3m	$5m	$8m
Close to SLS (major NSE damage)	Nil / Minor	100%	1 year	$7m	$10m	$17m
At ULS	100%	100%	2 year	$10m	$20m	$30m

Note: Assumes escalating non-structural elements damage up to total 70% including façade at scenario 3. **For simplicity assumes total business interruption.*

While this is a simplified example it demonstrates that for a major seismic event business interruption costs equal or exceed the capital asset losses of the physical a building. Notably even when business interruption insurance is not available for the first 3-4 weeks following an event, the above example shows that the disruption costs for business and tenants could easily out way the cost of damage to the physical building and fit out. This is a very real economic cost to those businesses themselves and the wider New Zealand economy.

5.1.5. *Economic benefits of good performance of non-structural elements*

The poor performance of non-structural elements is of much greater importance in the context of insurance risk when factored with business interruption and the wider un-calculated economic disruption. There are some key points to re-iterate around insurance:

- The potential for disproportionately large commercial insurance losses due to failure of non-structural elements, and
- the risk profile for New Zealand and the volatility of the wider global market for re-insurance means that New Zealand could quickly be in a position of either prohibitively high insurance premiums - or even no insurance at all.

At that point the options are either:

- passive insurance through enhanced building performance - particularly non-structural elements, or
- Insurer-of-last-resort i.e. central government.

Both scenarios have long-lasting negative economic impacts on New Zealand. Therefore there is clearly a value proposition for both business and wider macro-economic resilience in the context of insurance around the good seismic performance of non-structural elements.

5.2. 2010-2011 Canterbury earthquake sequence, New Zealand

5.2.1. *Description of the earthquake*

The most destructive earthquake of the Canterbury earthquake sequence was the Mw 6.2 earthquake which occurred on 22 February 2011. The resulting ground motions significantly exceeded the design level earthquake for commercial buildings in Christchurch (500-year return period) as documented by the New Zealand Standard for Earthquake Actions (NZS 1170.5).

5.2.2. *Non-structural damage due to Canterbury earthquakes*

Section 5.2 of Volume 2 of the Canterbury Earthquakes Royal Commission report describes the general observations of non-structural damage that occurred during the Canterbury earthquake sequence. The observations are summarised below:

5.2.2.1. Compromised egress routes

- There was evidence that doors jammed as a result of residual drift of buildings. Residual drift is a structural issue and would have significant cost implications.
- Emergency lighting failed in a number of buildings. In most instances this was caused by the lighting being attached to suspended ceilings which commonly failed. Failure of suspended ceiling systems supporting emergency lighting systems indicates that the ceilings were not compliant with the New Zealand Building Code. Had the ceilings remained intact it is probable that the emergency lighting attached to it would have remained operational. Failure of suspended ceilings would not only have a repair cost to install a new code compliant ceiling and re-install all services but it would also mean that the business would not have been able to continue operation.
- Lightweight fire separations failed because they were not detailed and installed to be able to accommodate the drift of the primary building structure. If the damage occurred at or below the serviceability limit state earthquake the partition would not have complied with the New Zealand Building Code. Damage to lightweight partitions tend to be more cosmetic and therefore incur minor business disruption through plastering and painting repairs.
- Shelving and contents fell into escape routes. Currently furniture and contents are not covered by the New Zealand Building Code. Depending on the size of furniture and the height and weight of contents, falling of these elements not only poses a threat of injury and compromises egress routes but there is potential repair costs and business interruption costs that should also be considered.

5.2.2.2. Falling hazards

Failures of suspended tile ceilings was widely reported. There were reports of suspended tile ceiling failures during the 23 December 2011 aftershock that had only just been replaced as a result of the September 2010 earthquake. Dhakal, MacRae and Hogg published a paper in the New Zealand Society for Earthquake Engineering (NZSEE) Volume 44, Number 4, December 2010 with the following observations regarding the performance of suspended ceiling systems:

- Most damage occurred at the perimeter of ceilings and increased with the size of the ceiling.
- The observed damage primarily occurred in ceilings with heavier ceiling tiles.
- Several ceiling failures resulted from lack of coordination with above ceiling services, bulkheads and partitions. NZS 4219 has clear guidance on coordination on the above ceiling services and minimum clearances between ceiling supports and services. We understand that the clearances and interactions did not, in many cases, comply with the requirements of NZS 4219.
- Poor installation practices in the case of ceilings, services and partitions appear to have caused more failures rather than errors in the design. The report noted that improved design guidelines are required for ceiling systems that take into account the interactions with partition walls.
- The economic benefits of well-coordinated above ceiling services and partitions with suspended ceilings such that the installation meets the requirements of NZS 4219 would have been significant in those buildings where failure of the suspended ceilings occurred.

Failure of the supports for HVAC systems. This indicates that the supports had not been designed and/or installed in accordance with NZS 4219 and therefore were not compliant with the New Zealand Building Code. Failure of the supports for HVAC systems would have not only incurred repair costs but continued operation of the business would not have been possible until the repairs could be effected.

Lighting systems, in particular those associated with suspended tile ceilings, but also longer channel lighting systems, regularly failed and fell into the rooms below. As noted for the failure of the HVAC supports, failure of lighting systems indicates that they had not been designed and/or installed in accordance with NZS 4219. Often the installation does not meet the requirements of NZS 4219 because the minimum clearances and coordination with other services and ceilings has not been appropriately considered.

There were many reports of damage to non-structural partition walls, however the Royal Commission was not aware of evidence that lightweight walls failed in a manner that created an immediate danger to people. The report noted the exception to this being lightweight wall damage that impeded exit routes.

Figure 4: Failure of ceilings and services in Christchurch commercial building

5.3. 2013 Cook Strait earthquake

5.3.1. Description of the earthquake

An earthquake of 6.5 Mw occurred in Cook Strait, on 21st July 2013 at 5:09pm. This earthquake was one of a sequence of earthquakes which started on Friday 19th July 2013. Ground motion data recorded in downtown Wellington indicate that the seismic loads on the building were well below the current design loads for commercial buildings with an Importance Level 2 (500-year return period), but potentially in excess of the serviceability limit state (25-year return period) design loads as defined for Wellington in NZS 1170.5.

5.3.2. Performance of non-structural elements

Damage to non-structural elements was observed in Wellington commercial buildings as a result of this earthquake. One notable building sustained significant damage due to non-structural elements including damage to a sprinkler head that led to significant flooding within the building which required the tenant to immediately vacate the building for months until repairs were completed.

Opus investigated the performance of non-structural elements in some commercial buildings in Wellington and noted that the observed failures of non-structure elements would have been avoided if properly restrained and separated in accordance with the relevant Standards. More detail on the observed failures are provided below:

- Suspended ceiling collapse
  - The extent and angle of diagonal bracing wires did not always comply with the stated design intent.
  - Support members and bracing wires of the ceiling system did not always meet the clearances to adjacent services members as required by NZS 4219 Clause 5.2.1.
  - Bracing wires were observed to have been connected to Unistrut which were intended to support major mechanical ductwork. This is contrary to AS/NZS 2785 Clause 4.5 which precludes ceiling wire connections to any services unless specifically designed.
  - Rigid sprinkler heads gouged holes in ceiling linings as the sprinkler and ceiling systems responded differently during the shaking.
- Collapse of building services equipment
  - Brace fixings installed with slotted holes. This is contrary to Clause 2.3.4 of NZS 4219 that requires equipment to be positively restrained and not rely on friction alone.

- Equipment suspended within ceiling voids was, in some cases, found to not comply with Clause 5.2.2 of NZS 4219 which requires flexible connections when services and ceilings are not supported together. Examples of non-compliance included unrestrained pipe branches connecting to unrestrained ventilation equipment, without a flexible connection.
- Mechanical equipment weighing in excess of 10kg was found to be unrestrained. This does not comply with Clause 5.9 of NZS 4219.

Figure 5: Lack of flexible connections to mechanical plant

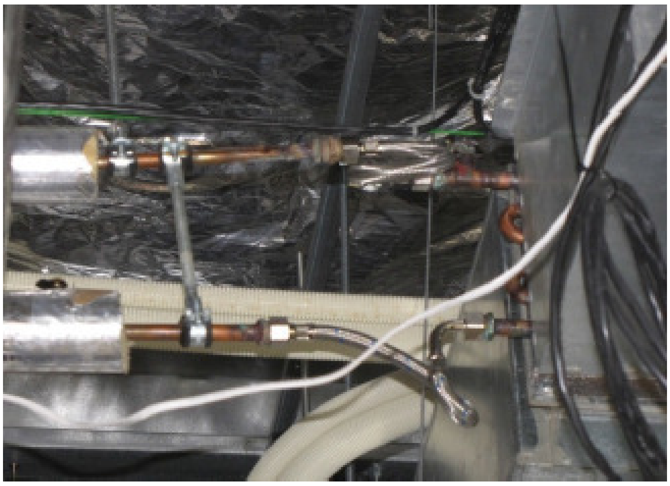


Figure 6: Use of flexible connections on mechanical plant to achieve compliant installation

- Hangers for mechanical ducting exceeded 200mm in length and the ducting was positioned within 150mm of a ceiling support hanger. This does not comply with Clause 5.9 and Table 15 of NZS 4219.
- Ventilation grilles and diffusers weighing in excess of 10kg were observed to be unrestrained. This does not comply with Clause 5.9 of NZS 4219 and leaves the equipment at significant risk of failure. The economic cost of failure of the diffuser needs to be considered in the context of what is around the diffuser/grille. The damage and associated repair costs is likely to be more than just the diffuser/grille itself, as the effect of this equipment swinging around is likely to cause damage and require repairs to nearby pipework, connections, equipment, ceiling hangers and other near-by services, and may also cause suspended ceilings and other equipment to fall and render the area unusable and cause interruption to business operations.

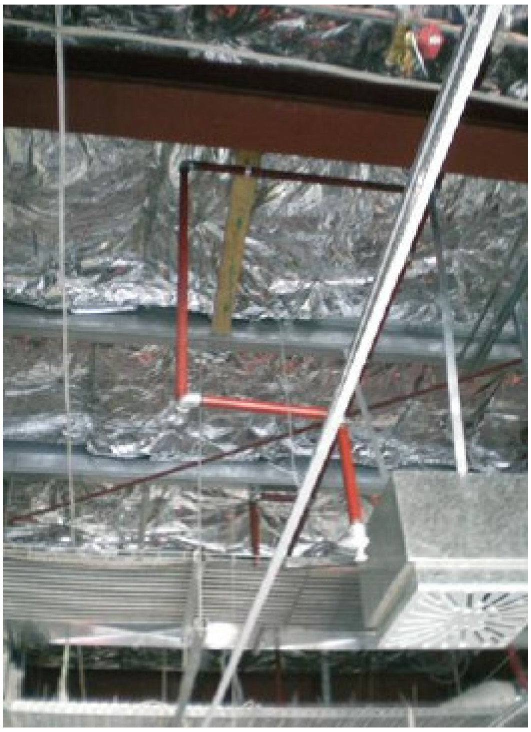


Figure 7: Unrestrained diffusers

- Luminaries dislodged from ceiling grids
  - Installations were observed where recessed luminaries did not appear to be positively fixed to the ceiling grid and therefore failed to comply with Clause 5.14 of NZS 4219. The weight of recessed luminaries can be significant and if they fall they risk injuring occupants below and causing business interruption.

Figure 8: Unsecured recessed luminaires

- Freely suspended luminaires suspended on stay wires from ceiling tiles were observed. The use of vertical stay wires does not meet the requirements of NZS 4219 - Clause 5.14 as it allows the luminaire to move in an earthquake and impact with the building or other equipment. In some instances the support wires broke causing the luminaries to fall.

Figure 9: Typical suspended luminaire

- Electrical distribution cable trays without sufficient restraint damaging ceiling support wires and other services:
  - Large and heavy cable trays were observed in ceiling spaces. Often these cable trays were only supported by vertical hangers and were unrestrained laterally. Damage therefore occurred to ceiling support wires and other services as the cable trays swayed. This does not comply with Clause 5.11 or Table 15 of NZS 4219.
- Typically fire systems in recently constructed buildings were code compliant as as-built documentation is provided and an independent visual assessment is completed by an approved inspectorate (FPIS or AON) prior to code compliance certificates being issued. In some instances rigid droppers were observed to provide sprinkler distribution to in-ceiling sprinkler
  - Direct connection of sprinkler droppers to fixed cable tray and ductwork supports did not meet the code (NZS 4541) requirement that the sprinkler pipes and joints will not experience undue deflection. In particular failure was observed when the dropper arm was connected to heavily loaded unrestrained cable tray. The costs of consequential damage and business interruption due to failure of the sprinkler head is substantial with the potential for water damage that drains to multiple floors.

Figure 10: Relative movement of sprinkler and ceiling

5.4. 2014 South Napa earthquake, USA

5.4.1. Description of the earthquake

An earthquake of 6 Mw occurred in the Napa Valley, California, on 24th August 2014 at 3:30am. The peak ground accelerations at one strong motion station was recorded at PGA = 0.61g (north – south direction), 0.32g (east – west direction) and 0.24g (vertical acceleration).

5.4.2. Investigation into the performance of buildings and non-structural elements

The United States Federal Emergency Management Agency (FEMA) issued a report documenting the investigations and performance of buildings and non-structural elements in this earthquake. The report is titled FEMA P-1024 “Performance of Buildings and Non-structural Elements in the 2014 South Napa Earthquake”, dated February 2015. The data provided in this FEMA report primarily focused on the 68 buildings located within 300m of the strong motion recording station. The investigation was limited to buildings and did not include infrastructure, however the report noted that loss of water supply had the largest impact on building performance.

The loading and design code for all building elements are defined in the American Society of Civil Engineers Design Standard ASCE-7 “Minimum Design Loads for Buildings and Other Structures”. The performance requirements documented in ASCE-7 for the level and duration of shaking which occurred as a result of the South Napa earthquake for non-essential relatively modern structures is that they will be repairable or have sustained no-structural damage and potentially significant but repairable non-structural damage.

The following graph shows the distribution of commercial building damage according to the general damage classification. 80% of the buildings in the 300m radius of the strong motion recording station were observed to have some degree of non-structural damage, whilst 54% were observed to have some degree of structural damage.

Unfortunately the repair cost and business interruption costs caused by the damage has not been reported and given the limited coverage of insurance in the region there is no insurance body to obtain economic data from. We are still able to use the information obtained to understand the damage sustained and to consider whether restraint, provision of clearances and coordination of the non-structural elements in line with the requirements of the New Zealand Building Code and other relevant Standards would have reduced the damage and therefore the overall cost due to damage of non-structural elements.

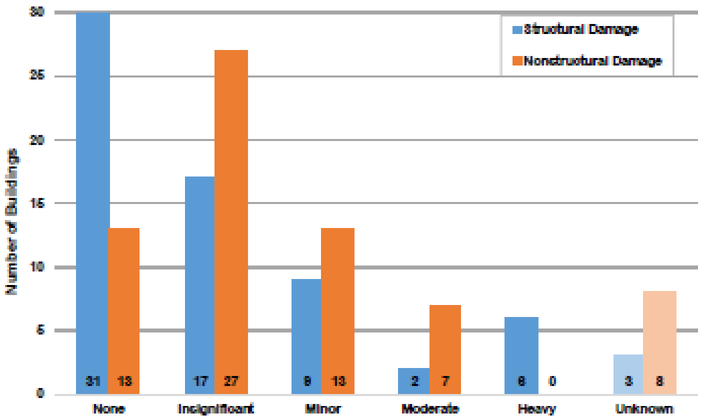


Figure 11: Distribution of building damage according to general classification

The FEMA report notes that buildings that were assigned UNSAFE placards provided limited access for observation of non-structural damage, and therefore those buildings with greater structural damage may well have had greater amounts of non-structural damage but because this could not be verified they have been categorised in the following graph as “unknown”.

5.4.3. *Functionality*

The investigation recorded the number of days to regain full functionality of the buildings that were inspected. In most cases, loss of functionality resulted from damage to contents, non-structural elements and systems or structural members. Full functionality was often assigned to buildings with business operation. In a few cases, proximity of the building to a damaged building delayed full functionality until the building was able to be shielded from fall hazards.

Less than one half of the buildings (44%) remained fully functional through the earthquake. Within one week of the earthquake, the necessary minor repairs were able to be made to many buildings, raising the percentage of fully functional buildings to 89%.

5.4.4. *Damage to non-structural elements*

The only fatality attributable to the earthquake was caused by a television. The report noted that the timing of the earthquake (3:30am) was the primary reason that only one fatality occurred along with the low number of serious injuries.

5.4.5. *Observed non-structural damage in commercial buildings*

The following list documents the observed damage to non-structural elements in commercial buildings that were located within 300m of the strong motion recording station.

1. Glazing, glazed curtain walls and storefront systems - Performance of these elements depended in a large part on the extent of storey drift sustained by the individual buildings.

2. Interior partitions - Partition damage was described as incidental with a very small number of buildings experiencing substantial partition damage.

3. Ceilings - Gypsum wallboard ceilings fastened directly to structural framing generally performed well. Some damage to suspended ceilings was common. The most common observed form of damage to suspended ceilings was fallen tiles. Failure of the ceiling grid was observed in several buildings.

4. Mechanical, electrical and plumbing (MEP) equipment - The performance of MEP equipment varied widely in the buildings investigated. There were failures of anchored equipment but based on the estimated age of the installations, they were not expected to have complied with current code provisions. MEP elements installed to recent standards generally performed well with the exception of pendant light fixtures.

5. Piping Systems - Piping systems were the source of a considerable portion of damage sustained in the earthquake. By far the most costly non-structural damage was caused by flooding from fire sprinkler systems. In cases where water release lasted for several hours, damage to a single pipe or sprinkler head was sufficient to flood substantial portions of the building and require building closure for several months.

5.4.6. *Summary of observed non-structural damage in hospital facilities*

Six hospitals were located near the epicentre of the earthquake (4 hospitals within 12km, 1 hospital within 15km and 1 hospital within 24km). In general the hospitals performed well and remained operational following the earthquake.

Non-structural damage to hospitals included damage to suspended acoustic tile ceilings, minor gypsum wallboard cracking, damage to storefront glazing systems, damage to exterior wall cladding, broken water pipes, movement of un-anchored equipment and furnishings and damage to expansion joint covers.

Both new and older hospital buildings experienced some non-structural damage which, in a larger earthquake with longer duration, could have impacted the continuity of service. In particular, damage to walls and ceilings in operating rooms was observed to have affected the ability to maintain the required positive air pressure and the required number of air changes, thus impacting the sterile environment.

The following photographs document the typical non-structural damage sustained in hospitals near to the earthquake epicentre.

Figure 12: Cracked gypsum board wall in hospital

Figure 13: Ceiling damage in hospital corridor link

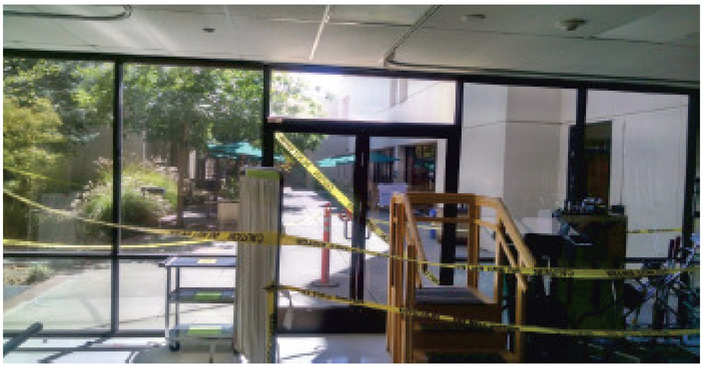


Figure 14: Damage to glazing leading to entrance being posted as "restricted use"

There was little or no structural damage to schools due to the Napa earthquake. Several schools did, however, experience non-structural damage to architectural, mechanical or electrical elements including suspended ceilings, light fixtures, equipment and furniture. Some of the elements (ceilings, mechanical and electrical elements) that fell from above could have been life threatening had the earthquake occurred during school hours.

The following photographs document the typical non-structural damage sustained in schools near to the earthquake epicentre.

Figure 15: Damaged light fixtures - commonly observed in school facilities

6. Cost of Code Compliant Non-Structural Elements (NSE)

6.1. Case study buildings

Fletcher Construction assessed the construction cost to fabricate and install code compliant seismic restraints for suspended ceilings, HVAC equipment and ducting, pipework and plumbing and fire sprinkler systems in six different types of buildings listed below.

- 1 storey fire station, Wairarapa (IL4)
- 1 storey school, Christchurch (IL2)
- 3 storey and 1 storey hospital, West Coast (Combination of IL3 and IL4)
- 2 storey library and service centre, Canterbury (IL3)
- 8 storey car parking building, Wellington (IL2)
- 4 storey office building, Auckland (IL3)

This range of building types provides a good selection for inclusion in this study as they focus on medium to high occupancy non-residential buildings which are either open to the public or are workplaces.

The costs to provide seismic restraints to various non-structural elements are reported in Table 3. A short description of each case study building is included below:

Fire Station – This is a relatively simple building, single storey, vehicle bay with adjacent administration and change areas. Floor area 503m^2. The services were well considered where they were required. The vehicle bay is relatively large with minimal services whilst the administration and change areas are serviced with simple systems. This results in a very low cost for seismic restraint of services.

School – This is a single storey building with a floor area of 2,592m^2. There is a reasonable amount of floor area for the extent of services provided. Due to the simplicity of the services design and the fact that the services were well co-ordinated, results in a relatively low cost seismic restraint solution.

Hospital – This building has a portion that is single storey and a portion that is one storey. The overall floor area is 11,260m^2. The building has a substantial extent of services in very congested spaces (ceiling voids etc.). This significantly increases the potential for service clashes. Access for installation is also reduced requiring a much higher degree of planning and supervision while restricting the restraint and bracing methods available. This results in lengthening of the installation duration. These factors significantly increase the seismic restraint and bracing costs. Early contractor involvement with both main contractor and sub-contractors would significantly reduce the cost of seismic restraint by avoiding clashes and combining service runs. The addition of a seismic restraint specialist would also assist in the design and planning, providing greater detail, increased cost certainty and lower installation costs.

Community Library – This building is a combination of double height single storey and double storey areas. The overall floor area is 1,123m^2. The services for this particular community library were reasonably extensive and there was limited space in a number of locations, resulting in a higher degree of bracing and congestion related conflicts between service disciplines. This has been reflected in the higher costs for the fabrication and installation of seismic restraints for non-structural elements for this facility.

Car parking building – This building is an 8 storey concrete car parking building with a floor area of 31,992m^2. Minimal services are required for car parking buildings and there are no ceilings to impede installation. The significant proportion of the cost relates to major plant/equipment restraint. These factors result in a very low cost for seismic restraint of services.

Office building – This particular building is 4 storeys, has a floor area of 6,413m^2 and has a generous floor to floor height and a good amount of space available to install the services and seismic restraints. The cost to provide code compliant seismic restraints sits between the simplistic systems associated with the school and fire station and the more complex and congested services included in the library and hospital projects.

6.1.1. Cost of seismic restraint of non-structural elements

Fletchers Construction estimated the cost to provide seismic restraints for services, partitions and ceilings (refer to Appendix A). Those costs are summarised in Table 3 below. The costs provided by Fletcher Construction are based on the information provided for each project. The level of detailed information relating to the seismic restraints varied for each project and assumptions have been made where detailed information was not available for each case study. Therefore the costings may not fully reflect the extent of a comprehensively designed seismic restraint solution to NZS 4219 in each instance.

The values stated are inclusive of main contractor and sub-contractor margin, but excludes GST, design and 3D modelling costs. No allowance has been made for seismic bracing of external site works.

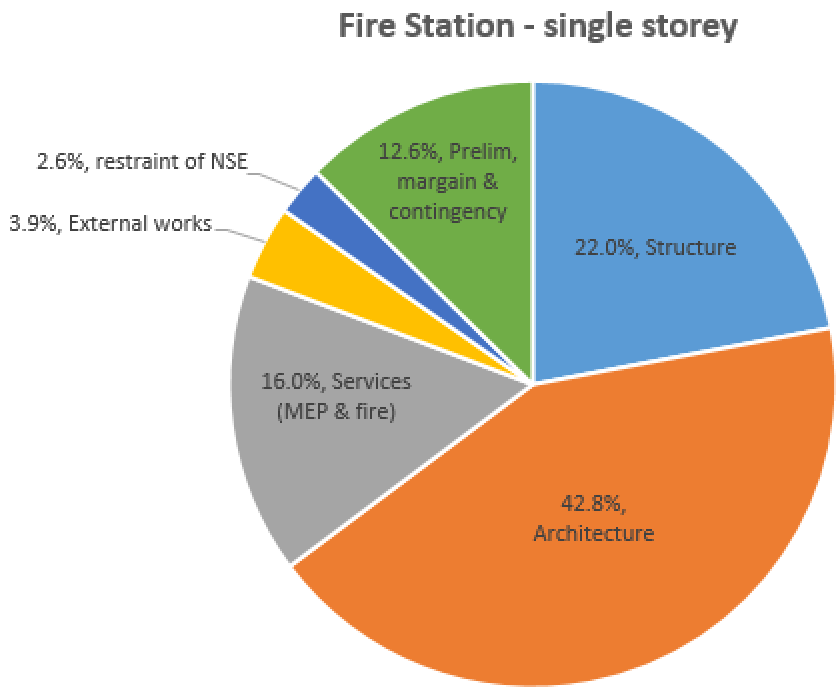
The actual case study for the office building involved retro-fitting seismic bracings into an existing building. For the purposes of this report the costs to provide seismic restraint into an entirely new build have been provided. As a useful comparison a cost estimate to provide the seismic bracing into the existing building has also been provided by Fletcher Construction and this has been included in the bottom of the table for information.

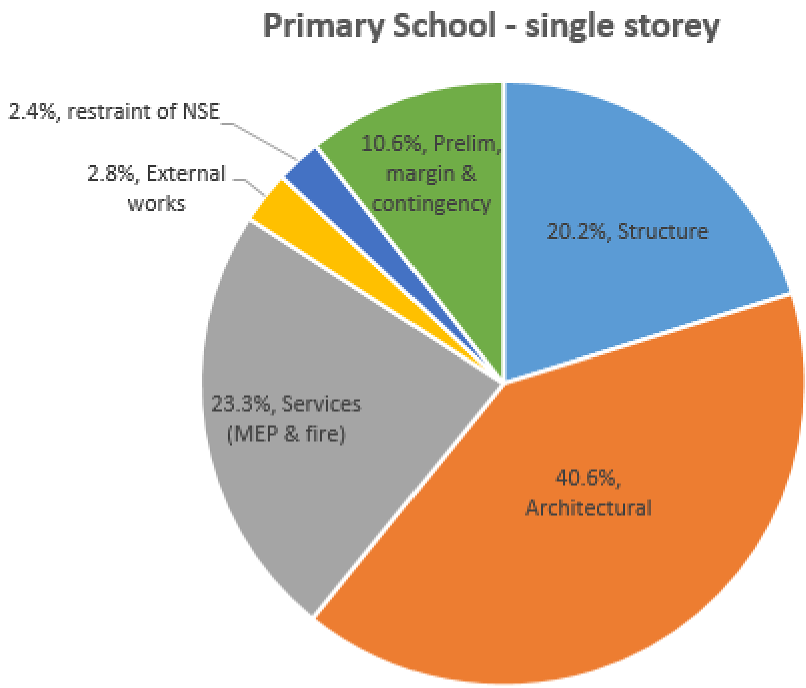
Table 3: Summary of costs for code compliant seismic restraints to non-structural elements

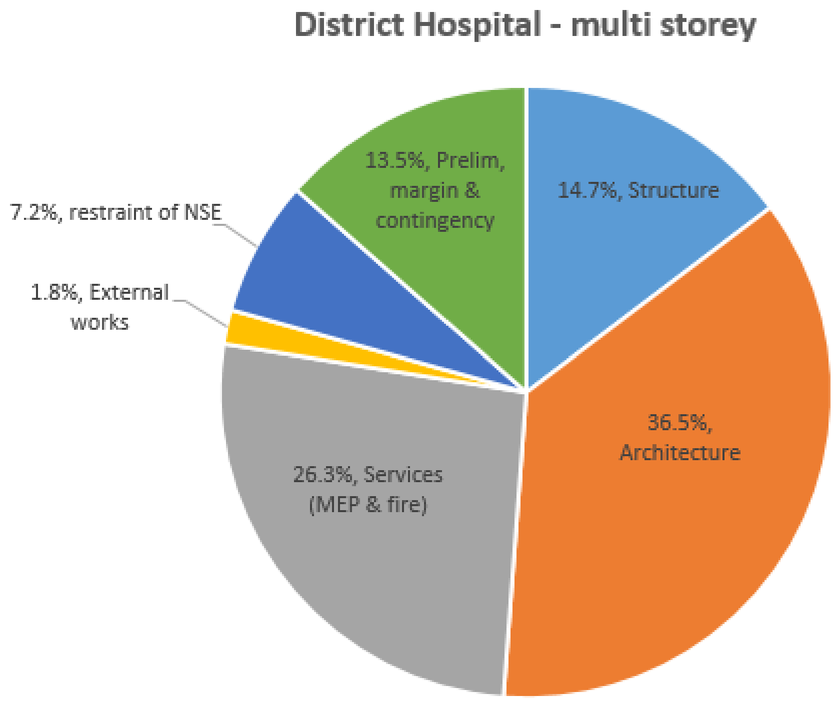
Building	**Total cost to restraint specified NSE** % of construction value	**Provision of code compliant seismic restraints for the listed NSE's**					
		HVAC equipment and ducting % of build cost	Pipework and plumbing % of build cost	Electrical equipment and distribution % of build cost	Fire Sprinkler systems % of build cost	Suspended Ceilings % of build cost	Partitions % of build cost
Fire station	2.6%	0.5%	0.2%	0.2%	0.1%	1.4%	0.2%
School	2.4%	0.4%	0.1%	0.1%	0.3%	1.3%	0.2%
Hospital	7.2%	3.3%	1.1%	1.3%	0.3%	0.7%	0.5%
Community library & service centre	9.9%	4.0%	1.3%	2.3%	0.4%	1.1%	0.8%
Carpark Building	0.3%	0.1%	0.1%	0.1%	0.0%	0.0%	0.0%
Office building – new build	5.7%	2.1%	0.4%	1.1%	0.3%	1.4%	0.4%
Office building - refurbishment	25.4%	7.5%	2.0%	7.1%	1.7	5.2%	1.9%

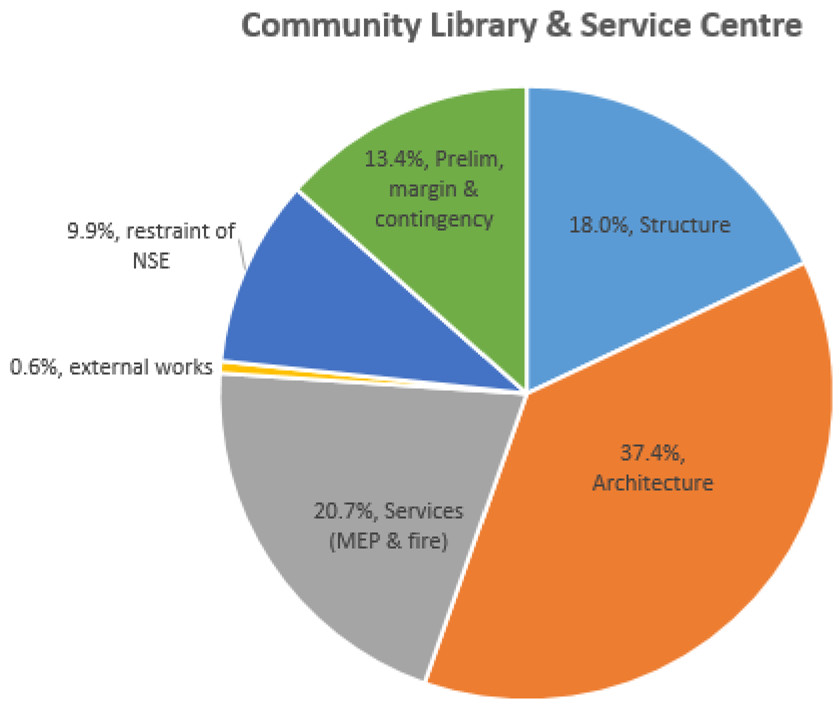
6.1.2. *Elemental breakdown of building costs*

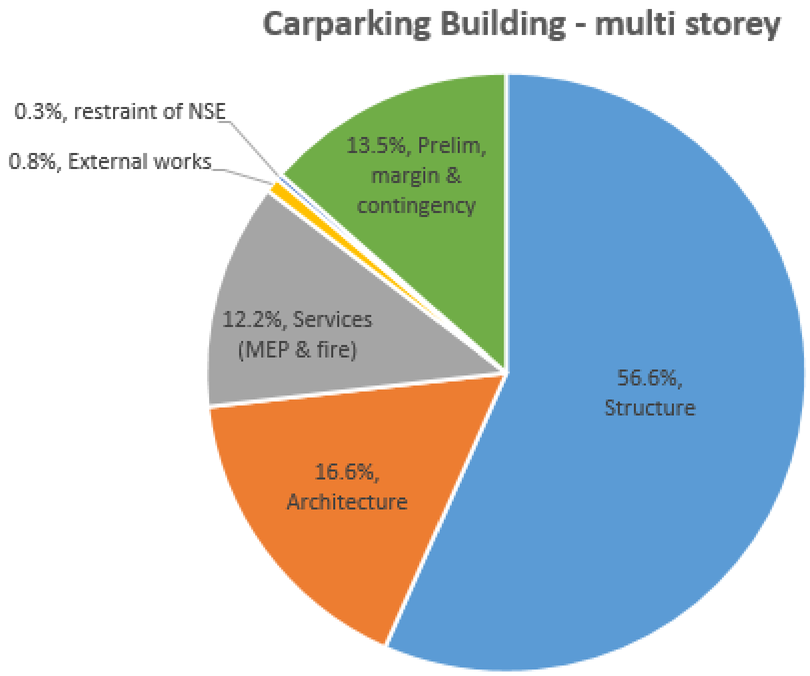
The following charts show the cost breakdown of building elements for each of the chosen study buildings. The dark blue pieces represents the cost to provide seismic restraints to the ceilings, partitions, mechanical, electrical, plumbing and pipework and sprinkler systems.

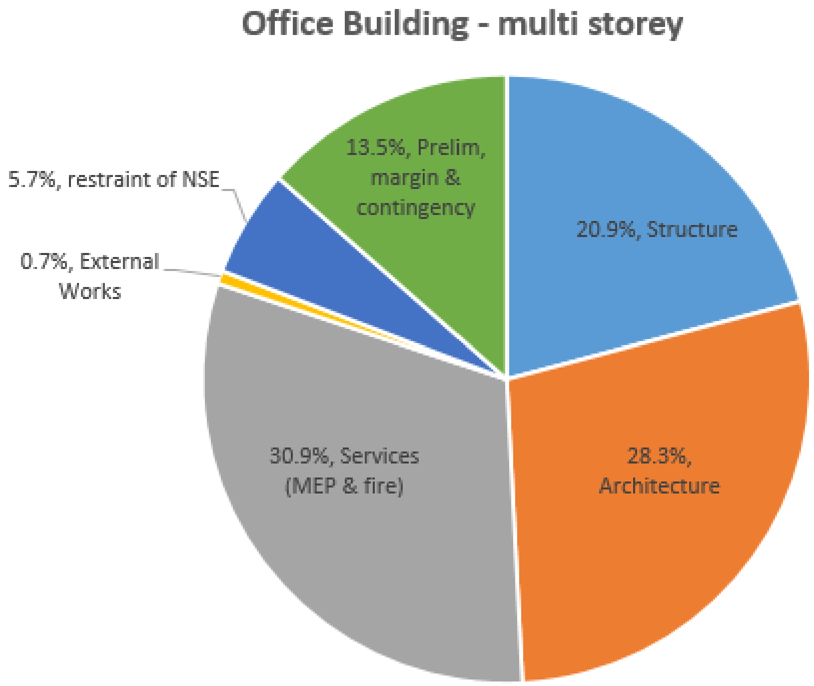





District Hospital - multi storey
13.5%, Prelim, margin & contingency
14.7%, Structure
7.2%, restraint of NSE
1.8%, External works
36.5%, Architecture
26.3%, Services (MEP & fire)


Community Library & Service Centre
13.4%, Prelim, margin & contingency
18.0%, Structure
9.9%, restraint of NSE
0.6%, external works
37.4%, Architecture
20.7%, Services (MEP & fire)


Carparking Building - multi storey
0.3%, restraint of NSE
0.8%, External works
13.5%, Prelim, margin & contingency
12.2%, Services (MEP & fire)
56.6%, Structure
16.6%, Architecture


Office Building - multi storey
5.7%, restraint of NSE
0.7%, External Works
13.5%, Prelim, margin & contingency
20.9%, Structure
30.9%, Services (MEP & fire)
28.3%, Architecture

6.1.3. Wider economic view

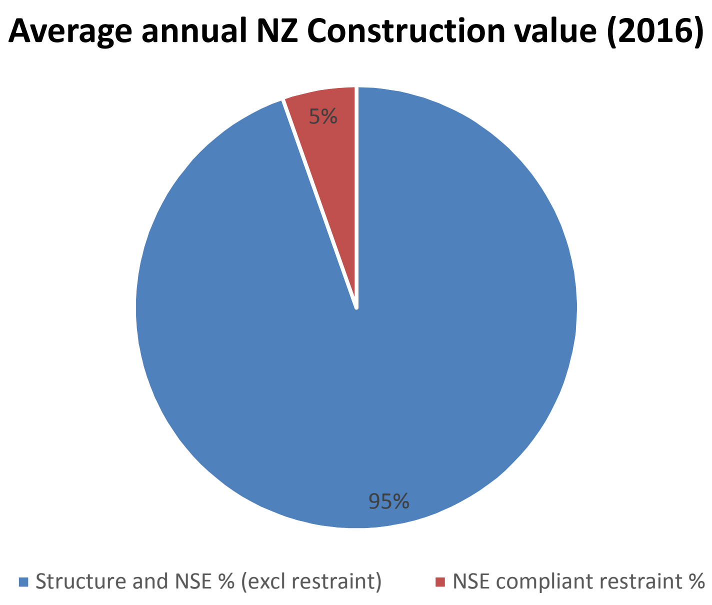
To evaluate the cost to install code compliant seismic restraints to non-structural elements in a wider construction industry economic context we have also compared the building costs against the most recent 'National Construction Pipeline report' dated July 2016 on the MBIE website. The construction activity to the end of 2016 is quoted as $15.1b in non-residential construction. Of that $5.7b is civil, $0.4b is sport, and $0.3b is heavy industry/energy which can be discounted for the purposes of this study (as they do not directly relate to the six case study buildings) leaving a total of $9.4b in non-residential building broken down as follows into types and then correlated against the NSE element building costs % for each study project:

Table 4 – National Construction Activity comparison against costs to provide code compliant seismic restraints for non-structural elements

Building type	Spend $(billion)/ annum	Match to NSE study project	Total cost to restrain specified NSE **% of build cost**	Macro NZ Construction industry 'cost' $(million)/ annum
Commercial	$5.1	Office Building, Auckland	5.7%	$290m
Education	$1.3	School, Christchurch	2.4%	$31m
Health	$0.6	Hospital, Westcoast	7.2%	$43m
Industry	$0.8	Car park, Wellington	0.3%	$2m
Multi Category	$0.9	Fire Station, Waipara Community Library, Chch	2.6% & 9.9%*	$56m
Sub-Total (buildings)	**$8.7b**			**$423m**

Note Assume average 6.25% NSE average cost for this 'multi-category'*

While the minor 'Heavy Industry / Energy' and 'Sports' categories are not covered in the table above these account for only $700m. For the remainder of the $8.7b of non-residential building construction in New Zealand the cost of NSE restraint can therefore be extrapolated be in the order of $423m or around an average of 4.9% of the total annual construction spend.



6.2. Factors affecting the cost of non-structural seismic bracing

Fletcher Construction provided the following feedback on the factors that they consider have the most effect on the costs to provide code compliant seismic restraints of non-structural elements (refer to Appendix A for a copy of the Fletcher Construction report).

The factors of influence vary from project to project and there is no “one size fits all” approach that can be adopted for seismic resilience of non-structural elements, however the way the construction industry as a whole approaches the issues faced by seismic bracing requirements (NZS 4219 and NZS 1170) can have a significant time and cost effect and should be introduced at a far earlier stage, with a deeper level of integration, than currently typically occurs. It is Fletcher Construction’s opinion that this will lead to installation efficiencies in both time and cost.

6.2.1. Location of building

The costs to provide code compliant seismic restraint to services and ceilings are highly dependent on the extent of services and whether or not the services spaces are congested or not. The location of the building has a minor effect on the overall costs to provide a code compliant installation.

6.2.2. Early design and early contractor involvement

The primary factor with the most potential to reduce the cost of seismic bracing of non-structural elements is early and detailed design of the services and their layout and detailed co-ordination with structural and architectural elements.

It is recognised that undertaking the design and coordination of seismic bracing for non-structural elements will be new to many consultants. During the initial period, it is likely that the design team will benefit from working in conjunction with a main contractor and sub-contractors to ensure that primary and secondary services are taken into account and installation experience is incorporated into the design. This integration of the design and construction teams should happen at the earliest opportunity, with close and complete co-operation to realise the maximum time and cost efficiencies.

Many of the other factors that affect cost are fixed (i.e. building use, building Importance Level, consent requirements etc.).

6.2.3. Extent of services and available space

The extent of services in relation to the space available requires careful co-ordination between design disciplines. Insufficient space can lead to conflicts between services, seismic support, structure and architectural envelope (partitions, ceilings etc.). This in turn affects ceiling layouts, maintenance access and penetrations. In many cases there are external factors that may restrict the increasing of the ceiling void space (floor to ceiling and building height restrictions) or require a significant number of services (i.e. hospitals). This space restriction also affects access for installation and increases installation durations.

The distance of services from the structure can significantly increase the cost of seismic bracing. The closer the services are fixed to the structure the lower the seismic forces will be and this results in a reduction in the bracing that will be required. Larger ceiling voids may reduce the cost of services bracing but can, to a lesser degree, increase the cost of bracing the ceiling itself.

6.2.4. Design and method of construction

The building layout and method of construction will affect the seismic bracing installation duration and costs. This may include the type of structure, inter-storey height, pre-fabrication or the use of base isolation (to reduce load requirements). The use of in-slab ducts or raised access floors may also reduce the requirements for bracing but will obviously impact on the floor to ceiling heights.

The type of services may be restricted by budgets to include older technologies that are larger, heavier or less resilient and therefore require a greater degree of bracing.

Any reduction in the penetrations through fire walls or acoustic separation will positively affect the cost of fire protection and acoustic attenuation.

6.2.5. *Floor System*

The specific details of the primary building structure to which the seismic restraints will be fixed has an impact on the design and cost effectiveness of the seismic restraint system. Whilst the selection of a floor system (hollow core, Comflor etc.) is unlikely to be governed by the seismic restraint requirements for services and ceilings, the choice of flooring system can have a large effect on the restraint details and the cost of the seismic restraints, e.g. hollow core floors are more difficult and costly to fix restraints to than a Comflor floor.

6.2.6. *Roof system*

Additional primary structure may be required to provide support for larger items of plant supported by the roof. The cost of this additional primary structure would increase the overall cost to seismically restraint the equipment. This could occur when trying to provide seismic restraints too larger items of plant hung off a light steel or timber framed roof.

6.2.7. *Building use*

The use of a building (hospital, school, government building etc.) will determine the extent of services and therefore the associated seismic bracing cost. This would also include the selection of the building importance level (IL), which may require a higher degree of support/restraint.

6.2.8. *Retrofit of seismic restraint in existing buildings*

The retrospective bracing for non-structural elements is a major issue as access to provide secure fixing back to the structure will, in most, if not all cases, require the isolation, removal and re-fixing, testing and commissioning of a large proportion of services. Where retrofitting is considered for services intensive buildings such as hospitals, these issues are increased. The cost and duration is further compounded should the existing building be occupied and a phased approach adopted adding even more time and cost.

Where retrospective seismic bracing is undertaken, there may also be subsequent effects on infection control (e.g. asbestos), regulatory changes requiring fire and other service systems to be upgraded, structural impacts due to penetration size increases and additional fire or acoustic attenuation, removal of plasterboard ceilings, wall linings and flooring etc.

Depending on the extent of architectural refurbishment and the extent of services specified for replacement the overall $/m2 can rise sharply, with a corresponding decrease in the % construction cost of seismic restraints.

All of these factors combine to make retrofit of seismic bracing in existing buildings a huge task that can be very expensive with long install durations not to mention the downtime of decanting spaces and relocating occupants. Fletcher Construction advise that the cost to retrospectively install seismic bracing to existing buildings will typically be in range of 15 – 30% of the overall construction value.

These factors make retro fitting costs and durations very much a building by building case but in all instances, the associated costs will be substantially more than the cost of the seismic bracing itself.

6.3. Cost to design and coordinate non-structural seismic bracing

The cost to design the seismic bracing, undertake appropriate 3D modelling to include all primary structure, architecture, services, supports and seismic restraints of non-structural elements using BIM, and to inspect installation works to ensure the completed works are in accordance with NZS 4219, NZS 4541 and AS/NZS 2785 would be in the order of 0.25% to 1% of the total construction value.

Fletcher Construction advised that the cost and risk allowed by contractors to undertake the design and coordination of the seismic restraints of non-structural elements is around 2.5% of the total construction value.

6.4. Cost to consent non-structural seismic bracing

Current industry practice is to require the contractor to construct the ceilings to AS/NZS 2785, services to NZS 4219 and fire sprinkler systems to NZS 4541. Building consents are currently issued on this basis and code compliance certificates are issued on the basis that the contractor supplies a PS3 for the project.

The current industry practice makes it difficult for building consent authorities to confirm compliance of the seismic restraint details as they are not provided with any details or coordinated documentation as part of the consent process. It is our understanding that there will not be any additional cost to building owners to submit building consent documentation that includes the coordination and seismic restraint of non-structural elements. However there may be additional costs for building consent authorities to provide suitably qualified resources to review the additional documentation and undertake independent site inspections. Quantifying the potential additional costs of consent checking is outside the scope of this study, however we note Building consent authorities recover costs, so they do not ultimately pay for design reviews and additional checks, these costs will be passed back to the owner in consent fees.

6.5. Cost to maintain non-structural seismic bracing

As discussed in section 8 of this report, the maintenance and lifecycle costs associated with seismic bracing of non-structural elements is anticipated to be minimal as the seismic braces are expected to have been properly installed and remain in place for the life of the partitions, ceilings, plant and equipment they relate to, and that no change would be necessary for the life of the asset.

7. Estimation of Losses Due to Seismic Damage of Non-Structural Elements

7.1. FEMA P-58 Project

The United States Federal Emergency Management Agency (FEMA) is tasked with reducing the ever-increasing cost that disasters inflict upon the USA.

The US codes are prescriptive in nature and are intended to provide a life-safety level of protection when a design level event, such as an earthquake occurs. FEMA recognised that during a design level earthquake, a code-designed building could achieve the intended goal of preventing loss of life or life threatening injury to building occupants, but could sustain extensive structural and non-structural damage, and be out of service for an extended period of time, and in some cases, the damage may be uneconomic to repair, leaving demolition as the best economic option. This issue was also observed following the Canterbury and Cook Strait earthquake sequences.

In 2006 FEMA contracted with the Applied Technology Council (ATC) and initiated a project to develop a seismic performance assessment methodology and called the project FEMA P-58.

The product of the FEMA P-58 project was the development of a methodology for seismic performance and assessment of individual buildings that properly accounts for the uncertainty to accurately predict the response of buildings and provides a consistent language to communicate performance of buildings in ways that better relate to the decision making stakeholders.

One of the outputs of the FEMA P-58 project was the development of two tools to perform the probabilistic computations and estimation of losses; PACT and SP3 (Seismic Performance Prediction Program). Both PACT and SP3 assess the probabilistic seismic performance of individual buildings based on their unique site, structural and non-structural elements and occupancy density characteristics. The output of the PACT and SP3 assessment is an estimation of building performance measured in terms of the probability of incurring casualties, repair and replacement costs and repair time.

7.2. Estimation of loss and downtime due to seismic damage of non-structural elements

The SP3 programme has been developed by the Haselton Baker Risk Group. The output from an SP3 model includes an estimate of the percentage loss of non-structural elements and an estimate of the downtime to business caused by various seismic events as chosen by the user. The percentage loss output is the cost to repair the element being assessed (e.g. structural elements, ceilings or other non-structural elements) against the cost to repair the entire building.

In order to make the model as accurate as possible, specific known information is input. The following building specific information was input into the SP3 program:

- Floor area
- Storey heights
- Lateral load resisting structural system
- Seismic hazard using NZS 1170.5 spectral accelerations for SLS and ULS events, and the PGA's for these levels of earthquake
- Period of the structure
- Detailed information regarding non-structural elements including types and quantities of internal partitions, ceilings, HVAC, water, sewer and electrical services. This information is in the form of

"fragilities" where performance data for the particular building elements available within the programme.

- Information relating to engineers inspections, the ability to mobilise contactors, whether or not building consents will be required and how the repairs/replacement works will be funded (insurance).

The models created as part of this research focused on the non-structural elements only. In order to identify the approximate benefit, or not, of installing code compliant restrained non-structural elements, two models were created for each building. The two models are identical for all items other than the fragilities added to represent the non-structural elements. Here, the SP3 programme offers fragilities for non-structural elements that are either braced or unbraced. One model was created with all the non-structural elements braced, and another with all these elements unbraced.

In order to give meaningful results, it was also important to identify an appropriate level seismic event. The SP3 programme allows different levels of seismic events within each model. The exact loading parameters, such as return period (frequency of the seismic events), is also influenced by the Importance Level (IL) of the buildings. The buildings modelled in this study range from IL2 for the office, school and carpark, IL3 for the library and IL4 for the hospital and fire station.

When damage is presented as a percentage loss, as it is in the SP3 output, it is expected that a ULS event will show 100% loss and an SLS event close to 0% loss.

In order to gain meaningful output from the SP3 programme, an additional seismic event was added. This was the 1/100 year event. This represented a seismic event roughly half way between an SLS event and a ULS event, depending on the Importance Level of the building. We see this as the level of seismicity where restraint to non-structural elements can be most effective, as the building will be expected to have a level of damage higher than the SLS event (0%), but less than the ULS (100%). It is at this level of seismicity that a building with higher robustness and resilience will experience a lower level of damage and have a higher rate of continued occupancy and functionality. The performance of the non-structural elements is critical to the ongoing occupancy of a building at this level of seismicity. It would be expected that there would be no structural damage during a 1/100 year event, but non-structural elements without seismic restraints would be vulnerable. Further detail regarding the limitations and features of SP3 are included in Appendix C.

The output from the modelling using SP3 is summarised in Appendix C. The results predict similar damage and business interruption to non-structural elements both with and without seismic restraint. Observations from both the Canterbury and Cook Strait earthquakes suggest that the percentage loss and business downtime is significantly higher if the services and ceilings are not seismically restrained. We therefore believe that, at this time, the SP3 program under predicts the losses to non-structural elements that are not seismically restrained. The SP3 tool has the backing of FEMA and the US Resiliency Council and their aim is to continue to develop this and other tools to provide more specific and accurate predictions of losses and business downtime. For these reasons the results presented in Appendix C should be taken as indicative only. Despite any potential shortcomings of the SP3 program at this time, we see value in presenting it as part of this study and for the New Zealand construction industry. The programme has the potential to be part of future discussions regarding the prediction of performance of buildings as a whole (including non-structural elements) to earthquake shaking.

8. Maintenance and Lifecycle Considerations

8.1. Maintenance considerations

On the basis that the seismic restraints (supports and bracing elements) have been properly installed and are appropriate for the application (i.e. material selection and/or corrosion protection suitable for the installation environment), the maintenance costs associated with the seismic restraints are expected to be negligible. It is anticipated that the seismic restraints would remain in place for the life of the plant and equipment that they relate to and that no changes would be necessary for the life of the asset.

Where the equipment is subjected to regular movement or vibration while in use (as opposed to irregular movement due to a seismic event) then the following considerations would apply:

- All flexible or moving parts (soft mounts, hinges, couplings etc.) would require regular checking and lubrication as part of the routine servicing for the item of plant or equipment. These costs would be minimal.
- Snubber mounts used on skid mounted equipment such as generators may need routine checking for deformation and/or damage, to ensure that they remain effective and are not subject to failure under normal use or in seismic events.

8.2. Lifecycle considerations

Referring to published industry guidelines used for building services installations, and using HVAC or electrical installations as examples, there is significant variability in the anticipated life expectancies of plant and equipment. This may vary from a little as 10-15 years for some lighting and controls equipment, to 20-30 years for major plant items such as chillers and motors or pumps, to 30 plus years for boilers, transformers and ductwork.

Should changes in equipment be required (to correspond with end of life failure or perhaps maintenance obsolescence), then a well-considered design and installation would be expected to include sufficient flexibility such that equipment could be changed out without having major impacts or effects on the surrounding installation. Minor modifications of mounts and corresponding restraints would be required to suit the new equipment as well as any transitions and connections into the existing installation. The impact of this is expected to only be a small percentage of the overall upgrade or re-fit cost.

For ceilings and partitions the lifecycle is typically driven by tenancy alterations and churn than end of life considerations of the materials and systems. From a tax perspective for the tenant depreciation of the asset cost is across 7 years. Typical tenancies are based on 6 year renewal cycles. With a workplace shift to more flexible, open-plan work environments spaces and away from cellular offices there is even less change being required, other than to meeting rooms required for acoustic privacy. For more complex specialist functions, such as hospitals, non-structural elements are part of the wider refurbishment costs and again the inertia for change means this might only be every 20-30 years when major functional change drives spatial reconfiguration. In this context lifecycle considerations are negligible for non-structural elements and in particular the seismic restraints.

Similarly other service items such as pipework is typically limited to kitchens and bathrooms as part of a landlord/tenant provision around in discrete, dedicated zones to allow code compliant falls to drainage systems, or in fire sprinkler systems. Functional and spatial change is again the most common driver for alterations to systems rather than lifecycle considerations.

9. Current New Zealand Industry Practice

9.1. Current procurement process

The current procurement process for the design of seismic restraints of non-structural elements in New Zealand follows the Construction Industry Council (CIC) Guidelines (note that a new version of the CIC Guidelines were issued in August 2016, but as procurement using the new guidelines has not yet been tested, this study refers to the previous 2008 Guidelines).

The current procurement process is summarised below based on the design team being procured to prepare tender and building consent documentation, followed by tender award and construction:

- Architect provides performance specification requirements in relation to suspended ceiling bracing. Requirements to meet AS/NZS 2785 without details or explanation.
- Architect provides performance specification requirements for bracing of internal partition walls
- Building Services (mechanical, electrical and fire engineers) provide performance specifications for the design and installation of seismic restraints of building services plant, pipework and equipment.
- The CIC guidelines make reference to the architect/coordinating consultant to verify all structural elements and dimensions against structural drawings, the mechanical services are to verify the structural support locations of the mechanical equipment has been compared with the structural documentation and the structural scope includes design coordination of key elements with other disciplines. The current industry practice is for the design team to provide performance specifications that reference NZS 4219, NZS 4541 and AS/NZS 2785 but no design or coordination is undertaken.
- Main contractor responsible for the design and coordination of seismic restraints for suspended ceilings, partitions, HVAC ductwork and equipment, electrical cable trays and equipment and sprinkler systems. The work is procured during tender and sub-contracted out to individual sub-contractors working in the various sub-trades.
- Main contractor responsible for the coordination of all seismic restraints of non-structural elements and the main structure as documented by the design team. Often this coordination is ad-hoc and each subcontractor undertakes their work independently of the other trades and full coordination is not achieved.

9.1.1. Advantages of current procurement process

1. Reduced risks to design team associated with the design and coordination of the seismic restraint of non-structural elements. The risk is passed onto main contractor which in turn is passed onto the various sub-contractors. Ultimately any risk lies with the building occupants.

2. Reduced design programme from commencement of project to delivery of the detailed design documentation, because the design team does not undertake the coordination of the seismic restraints of non-structural elements. This means that the documentation is ready to be issued for tender earlier than if the seismic restraints of non-structural elements were fully designed and coordinated by the design team.

9.1.2. Disadvantages of current procurement process

1. Increased risk to Construction value. Estimated by Fletcher Construction to be around 2.5% of project value.

2. While the design consultant fees may be lower, the fees to design and coordinate the seismic restraints for non-structural elements are included in the contractor’s tender price. Additional fees occur as the contractor allows to design, coordinate and deal with the expected clashes and issues on site during the installation of the seismic restraint of non-structural elements.

3. Increased time is required for shop drawing coordination and working with design consultants to accommodate the seismic restraint loads with the existing structure.

4. BIM coordination undertaken post tender will add 2.5% to 3.5% of the total services contract to update the BIM model and be fully coordinated with the design documentation. Often the fit-out works (ceilings, partitions, HVAC and lighting) is undertaken in a separate contract between the tenant and potentially a different main contractor. This makes the coordination of the seismic restraints with the base build even more difficult.

5. As NZS 4219 is a performance standard it is not possible to inspect an installation for compliance with this standard. It is only possible to inspect an installation for compliance with the design if the inspector has a detailed knowledge of the design of elements that are near to or interact with each element.

6. The supply of structural design information for the design of seismic restraints for non-structural elements, e.g. building displacements and seismic coefficients, varies between consultants.

7. The design of the seismic restraint of non-structural elements is a key design input and the current industry practice is to defer this design work to the contractor during the construction phase. This procurement strategy creates a large risk for the building owner/tenant as any work found to be non-compliant is a potential business interruption risk which could result in an insurance risk. If seismic restraints to NZS 4219, NZS4541 and AS/NZS2875 are not considered until the construction phase, Fletcher Construction has advised that compromise is often required, as clashes will occur and on-site coordination is difficult to manage.

8. Timing of the subcontractor installations on site often influences the outcome. It is typical for the first subcontractor to complete their install with no coordination with other services requiring all subsequent installations to work around those services already installed.

9. It is difficult for building consent authorities to confirm compliance with the Building Code when the seismic restraint of non-structural elements is provided by reference to a performance specification only.

10. The design team is not responsible for undertaking inspections to confirm that the installed seismic restraints of non-structural elements meets the performance specifications. This means that there is effectively no independent QA of the installation for code compliance.

9.2. Non-Compliance of non-structural elements

There is significant anecdotal, and physical evidence, for non-compliance of non-structural elements in commercial and civil buildings throughout New Zealand as observed during inspections following the Canterbury and Cook Strait earthquakes. In particular suspended ceiling systems, in-ceiling services and their coordination through both the design and installation phases are an area where considerable improvement is required to meet the current legislation.

There appears to be a number of embedded factors within the construction industry resulting in this outcome. These appear across all delivery phases and combine to provide the potential for non-compliance.

9.2.1. Design phase

- Commercial pressures to reduce floor to floor heights to save overall build costs directly impact on the in-ceiling services voids making compliance with seismic bracing requirements difficult, if not impossible.
- The value proposition of early design and coordination of non-structural elements is not fully understood by clients as it is usually buried in construction value.

- When establishing project budgets, the cost and complexity of seismic bracing for non-structural elements is not well understood by the quantity surveyor in traditional cost/m^2 rates or elemental breakdowns.
- Siloed services design, seismic bracing design and subcontractor design and procurement occurs.
- Seismic design is often performance specified and therefore passed down to individual subcontractors who do not appear to always have the skills or competency to deliver, as it requires complex technical coordination across multiple trades.
- The sprinkler design standard, NZS4541, sits outside the current ceilings standard AS/NZS2785 and are often designed and installed in isolation. The outcome is that the holistic coordination requirements with ceilings and other services is often not taken into account. Often disjointed programmes between landlord (base-build) and tenant (fit out) lead to assumptions or lack of design coordination. Subsequent tenant fit out can add significant complexity to already congested ceiling voids.

9.2.2. Consenting

- With performance specified systems, building consent authorities are not able to assess the compliance of seismic bracing systems for non-structural elements at time of consent.
- There is general lack of understanding in the industry as a whole as to what code compliant solutions look like, and what they cost to design and install.
- Observations of buildings following Canterbury and Cook Strait earthquakes found a number of recently completed buildings that had non-compliant non-structural elements. It is assumed that these buildings have received a code compliance certificate and therefore the process is at least sometimes not delivering code compliance outcomes.

Figure 16: Non-compliant installation of overhead mechanical plant (no lateral restraint provided) – building completed and received Code Compliance Certificate 2015

- Lack of construction coordination of multiple sub trades by the main contractor. This is particularly important when there is meant to be performance specified designs by specialist sub-contractors.
- Lack of understanding in the industry as a whole as to what code compliant solutions look like and the cost to design and install.
- Non-compliance is not picked up through building consent inspections during construction
- Lack of approved and coordinated drawing documentation which makes construction observation difficult and subjective. Non-compliance is often not picked up by contractors and consultants defects processes, as the level of coordination is complex and there also is a general lack of understanding of what a compliant installation looks like.

The factors outlined above can have cumulative effects and therefore can create situations where the non-compliance of non-structural elements is the default outcome.

We note that in the NZ market there are now emerging specialist sub-consultants or sub-contractors specifically taking on the role of delivering coordinated seismic bracing for non-structural elements. We are also seeing a few clients recognising the value of early design and documentation of seismic bracing of non-structural elements at consent and tender phases, by specifically commissioning design teams to complete this work.

While these are positive signs at this stage they tend to be limited to high-value, complex projects and do not represent any deep penetration into the bulk of the delivery of new building stock in NZ. At the present time the challenge for regulators and the New Zealand construction industry is therefore to bring all new build projects up to the minimum compliance status.

10. Improving the Seismic Performance of Non-Structural Elements

10.1. US lessons learnt regarding the seismic performance of non-structural elements

We have included the experience of the United States in dealing with the issue of improving the seismic performance of non-structural elements as a way to illustrate how others are trying to solve the issues.

Robert Bachman was our key contact to provide an insight into the current industry practice in the United States of America and the lessons learned by the USA on how to improve the performance of non-structural elements.

Mr Bachman has over 47 years' experience in the design, analysis, construction, evaluation and repair of commercial and heavy industrial facilities located domestically and internationally. He is a nationally recognised expert in the field of earthquake engineering and has played a leading role in the development of seismic provisions for United States national standards and building codes during the past 20 years. He has been involved with the design, installation and United States code activities relating to non-structural elements for over 25 years including being the team leader for the Performance of non-structural elements team of the FEMA P-58 project (Seismic Performance Assessment of Buildings).

A number of initiatives have been undertaken in the United States to improve the seismic performance of non-structural elements. Mr Bachman provided a brief summary of these as outlined below:

10.1.1. Codes and standards

Over time the USA have tried to improve and tweak codes and standards. They revised ASCE-7 "Minimum Design Loads for Buildings and Other Structures", which includes Chapter 13 dedicated to the seismic performance of non-structural elements. However, following this update they noted that the industry did not change.

To effect a change in the industry they needed to update the national industry standards to align with the changes to ASCE-7 (e.g. sprinkler standards, ceiling standards etc.).

They found that an excellent way to improve performance of non-structural elements was to undertake shake table testing of various construction details to determine the capacity and performance of various details then issue prescriptive details for the industry to implement.

10.1.2. Fire sprinkler systems

There has been a significant development in the US in recent years where flexible sprinkler hoses are being used for the final drop. It is also noted that flexible droppers are now being implemented more commonly in New Zealand following observations and lessons learnt from the Canterbury earthquakes.

The US building industry has just recently specified the gaps and clearances to items that can damage sprinkler systems.

10.1.3. Ceiling systems

The US has tried to implement improvements to ceilings systems. Testing confirmed that suspended ceilings fail around the edges, this is in alignment with the observations of ceiling failures as recorded in Volume 2 of the Canterbury Royal Commission Report. The USA tried to implement wider ledger angles but the industry has not adopted this due to the aesthetics. Shake table tests found that adding screws etc. can make a significant improvement in performance. Mr Bachman advised that it has been his experience that in order for the industry to implement improvements in detailing, the details need to be prescriptive or they are simply ignored.

10.1.4. Coordination of documentation

The US has recognised that there are both cost savings and energy savings during construction by providing fully coordinated documentation. The industry in the US has made good progress on this over the last ten years, which has led to good cooperation between the various sub-trades and designers resulting in minimal conflicts on site (or where conflicts do occur this is seriously questioned as it should not have occurred), and more efficient construction. However, Mr Bachman advised there is still a long ways to go.

Mr Bachman advised that the coordination during the design documentation is being supplemented and improved by the greater uptake of BIM to fully coordinate all elements of building projects including non-structural elements.

Some projects in the USA that are using BIM are now at the point that they do not use post-installed anchors to connect fixings and braces for non-structural elements, instead cast-in anchors are being used, as the coordination of where the various elements are going to be located has been completed well in advance of the installation of these elements.

10.1.5. Enforcement

The gold standard for coordination and implementation of non-structural elements in the USA are for critical facilities in the defence, nuclear and hospital industries. These industries have very strict criteria and enforcement for critical facilities. Prior to commencement of construction in these industries the design documentation would have been through many independent checks and proven to meet criteria.

Throughout the US the fire sprinkler systems are enforced by the Fire Marshalls. Therefore the installation of these systems is typically good. Mr Bachman noted it works well because it is a specialist field with specialist contractors and inspectors and they work strictly to the NFPA-13 code.

10.1.6. FEMA recommendations to improve the performance of non-structural elements

FEMA recognised that there was a lack of data on the performance of non-structural element during real earthquakes. Consequently they instigated an investigation into the performance of non-structural elements following the August 2014 Napa earthquake and issued FEMA report P-1024 “Performance of Buildings and Non-structural Components in the 2014 South Napa Earthquake”, dated February 2015. Based on observations, the report included a summary of ways to improve the seismic performance of non-structural elements to reduce both repair and business interruption costs:

i) Where sprinkler heads are connected to ceilings, use of flexible piping between the branch line and the sprinkler head may reduce the potential for damage caused by flooding.

ii) The interaction of fire sprinkler piping with other mechanical, electrical and plumbing elements requires further study. The importance of maintaining clearances with other obstructions is critical and standard requirements needs to be maintained.

iii) The adequacy of the code provisions relating to pendant lighting fixtures should be examined.

iv) The adequacy of code requirements to protect glazing from damage should be investigated, particularly for moment frames that experience significant amounts of drift during an earthquake.

v) Some furnishings and contents are not regulated by building code provisions but pose seismic safety risk. The public should be made aware of the risks and voluntary installation of seismic restraints should be encouraged.

vi) Installation of mechanical, electrical and plumbing equipment is often completed without inspection by building officials or design professionals. Approaches for requiring equipment inspections during construction should be investigated.

vii) Architects, mechanical engineers, plumbing engineers, electrical engineers, fire protection engineers, information technology consultants and others associated with non-structural elements should be trained to better understand the seismic performance implication of improperly designed or installed non-structural elements.

viii) The performance of gypsum wallboard partitions should be studied to better understand their vulnerability and to recommend detailing that would reduce the potential for costly damage.

ix) *Detailing of cladding and linings in hospitals should be able to accommodate building drifts without unacceptable damage. Acceptable performance criteria should be defined based on requirements for maintaining sterile environments.*

10.2. Coordination of non-structural elements using BIM

In Australia it is now expected that all major projects use BIM in their design and delivery particularly in regards to design and virtual construction coordination. In April 2016 the UK BIM mandate came into effect which requires organisations to adhere to government issued BIM principles and protocols to be able to work on central government projects.

The use of BIM during design amongst the small and medium businesses and projects seems to be increasing. However, the wide spread acceptance of "handing on" BIMs and associated information to be utilised during construction and management of the asset, is yet to occur. The limiting factor in most cases would appear to be the lack of investment in training, the technology required, concerns over intellectual property and perceived increased project liability.

There is also a growing understanding that the amount of information required for operations and management is minimal compared to the construction phase. It is not necessary to capture all asset data within the BIM model for it to provide significant benefits in the coordination of non-structural elements, their support and seismic restraints.

A significant barrier to harnessing the value of BIM is the lack of a cohesive and fit-for-purpose data scheme that meets the needs of designers, constructors, the supply chain and ultimately building owners and facility managers. What the industry ultimately needs is a set of common standards and deliverables that can be easily understood and readily implemented.

Coordination of ceilings, partitions, structure, mechanical plant and ductwork, electrical cable runs, hydraulic and sprinkler pipework routes using a 3D BIM model enables the designers to consider clashes and clearance issues well before the design is completed. Whilst this will increase the time and cost to prepare the detailed design documentation, the Fletcher Construction Company advised that they typically allow 2.5% of the total construction value to design and coordinate the seismic restraint of non-structural elements noting that there are often clashes during construction that require significant rework and cost. Fletcher expect significant savings in physical works costs and construction build times when Contractors are provided fully coordinated design documentation, including seismic restraints of the non-structural elements.

10.3. Improvement of seismic performance of non-structural elements

Whilst the insurance industry is unable to provide actual costs of repair works and business interruption cost due to damage of non-structural elements in the recent New Zealand earthquakes, there is substantial anecdotal and physical evidence to confirm that the economic costs have been huge. Our study has reviewed the damage observed and it appears that had the installations complied with the requirements of relevant Standards and the New Zealand building code, the cost of repair and business interruption, particularly damage due to the Cook Strait earthquake, would have been substantially less.

Discussions with Mr Bachman, leading building services team members from the Fletcher Construction Company and observations by Opus engineers following recent New Zealand earthquakes the following items are likely to make a significant improvement to the seismic performance of non-structural elements in New Zealand and consequently reduce the economic costs of damage due to non-structural elements in future seismic events:

1. Full design and coordination of non-structural elements and their seismic restraint in the main design documentation.

2. Enforcement – inspections following recent major earthquakes in New Zealand has found that typically fire systems in recently constructed buildings were found to be code compliant. It is likely that this is due to the requirement for as-built drawings of the system and an independent visual assessment completed by an approved inspectorate (FPIS or AON) prior to code compliance

certificates being issued. The requirement to undertake these inspections are mandated in NZS 4541 (Automatic fire sprinkler systems). Enforcement regimes for other non-structural elements would be expected to significantly improve the rate of code compliance for new buildings.

11. Recommendations for Further Study

This study into the economic benefits of code compliant seismic performance of non-structural elements has highlighted a number of areas where we recommend further study is undertaken. These are listed below:

1. Further study is recommended to consider both the benefits and challenges that are likely to be encountered to change industry practice to include the detailed design and coordination of the restraints for non-structural elements into the main design documentation. It is acknowledged that the current industry practice is for a lot of in ceiling services equipment and runs to be determined during the construction phase, and it will be a significant challenge to modify the industry to enable the design of the seismic restraints to be completed prior to tendering. We recommend that the study considers the expected increase in design fees and design programmes against the reduced contractor priced risk, and the competency of building consent authorities to review and potentially inspect the installations.

2. Further study is recommended to consider the viability and possible benefits of implementing enforcement regimes to inspect non-structural element installations prior to issue of the code compliance certificate. We would recommend that the study considers, but not limited to, how enforcement might be included within the building consent process and/or the provision of requirements for an independent inspectorate signoff similar to what is done for fire services installations by AON and FPIS.

3. Further study is recommended to review the current Standards relating to non-structural elements. We recommend that the study considers the following:

    - Assess the benefits of combining NZS 4219, NZS 4541 and AS/NZS 2785 into one Standard which references NZS 1170.5 with consistent performance requirements and cited by the Building Code acceptable solutions and verification methods. We believe it would be worth considering ASCE-7-10 in particular Section 13 of this standard which is dedicated to the performance of non-structural elements.

    - Consider the best way to provide design clarity and seismic restraint detailing for lightweight partitions that can be cited by the New Zealand Building Code. Providing support to partition walls, is usually accomplished by extending the partition walls full height with connections at top and bottom or to restrain the top of partial height stud walls by the ceiling or more commonly with diagonal braces or wires independent of the ceiling. Although important for controlling damage due to inter-storey drift[1], there are currently no standardised requirements governing the detailing of the head of the non-loadbearing partition wall. It is noted that whilst damage to partition walls is rarely drift damage to internal partition walls may compromise the fire rating of internal fire walls. In this situation the functionality and operation of the building would be affected

    - Consider the design of ceilings and provide guidance to the industry confirming the requirements for designing ceilings. Consider the potential to update AS/NZS 2785 and have it cited as a verification method for clause B1 of the New Zealand Building Code. The study should seek clarity to confirm when ceilings need to be designed to ULS and when design to SLS only (operational continuity) is acceptable.

4. We recommend that further study is undertaken to establish business interruption costs to put the findings of this piece of work in the wider economic context.

[1] Interstorey drift is the horizontal movement of the floor of a building relative to the floor above during earthquake shaking.

12. Conclusions

This study assessed that the design fees to design and coordinate non-structural elements (in particular ceilings and in-ceiling services) would be between 0.25% - 1% of the construction value. Senior quantity surveyors from the Fletcher Construction Company advise that they allow 2.5% of the overall construction value to design and coordinate non-structural elements during construction. The reason that the cost is greater when undertaken by the contractors during construction is because there is a greater amount of coordination required to work in and around the already completed design as provided by the design team.

Six different buildings were assessed to consider the construction value to install seismic bracing to partitions, ceilings, pipework, ducting, overhead equipment and sprinkler systems. The cost ranges from <1% of the construction value for a multi-storey car parking building with limited non-structural elements through to 9.5% of the overall construction value for a district hospital which is highly serviced with minimal ceiling space sizes.

Review of the observations into the performance of non-structural elements in past earthquakes (Canterbury Earthquake Royal Commission, FEMA investigation of the 2014 South Napa earthquake, and review of the causes of non-structural damage in the Cook Strait Earthquake) has highlighted a recurring issue; that the majority of the damage to non-structural elements was caused through lack of detailing and provision of appropriate clearances for seismic actions.

Discussions with the Insurance Council of New Zealand (ICNZ) highlighted the substantial economic losses in recent earthquakes due to poor performance of non-structural elements. While unable to be substantiated with specific data there is indicative evidence that business interruption plays a large, and potentially hidden, component. A change in emphasis from building structural performance to both building and business resilience could alleviate substantial financial losses and wider economic disruption in future events.

The benefits of providing code compliant non-structural elements were considered in this study and in most cases the damage sustained to non-structural elements in recent earthquakes could have been significantly reduced if they had been appropriately seismically restrained and clearances and effects of the entire system considered. The result would have been reduced business interruption costs, reduced repair costs, less replacement of building materials and therefore reduced environmental impacts, and while not easily quantifiable, it is known that there are also less social and health effects when people can quickly return to their place of work and continue their employment following major seismic events.

Whilst the cost to design and install seismic bracing to non-structural elements is relatively small compared to the overall cost of building projects, the actual performance of the building will be dependent on whether appropriate clearances are provided and restraints and services are installed as per the design documentation. Feedback received from a recognised industry leader from the US and senior buildings services staff from the Fletcher Construction Company Ltd indicates that the New Zealand construction industry, as a whole, needs to introduce design and coordination of non-structural elements including the seismic bracing, during the design phase and followed up with independent inspections to confirm that the final installation meets the requirements of the relevant Standards. Indications are that if this occurs not only will the installations have considerably better performance during earthquakes, but the installation efficiencies will lead to reductions in both time and cost.

13. Limitations

Our professional services are performed 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 Ministry of Business, Innovation & Employment to assist with the understanding the economic costs and benefits associated with the design, construction, consenting and installation of non-structural elements in new buildings for earthquake actions in order to comply with the current New Zealand Building Code.

This report is not intended for any other party or purpose.

14. References

1. NZS 4219:2009 "New Zealand Standard – Seismic Performance of Engineering Systems in Buildings".

2. NZS 4541:2013 "New Zealand Standard – Automated Fire Sprinkler Systems".

3. AS/NZS 2785:2000 "Suspended Ceilings – Design and Installation".

4. ASCE 7-10 "Minimum Design Loads for Buildings and Other Structures".

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

6. FEMA 461 "Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Non-structural Elements". This document describes the shake table test procedures for non-structural elements.

7. ISO 13033:2013 "Bases for design of structures – Loads, forces and other actions – Seismic actions on non-structural elements for building actions". This standard has developed the seismic design requirements for non-structural elements for building applications. Input from New Zealand was led by Roger Shelton from BRANZ. The philosophy behind this standard was that each country would determine how to implement this document into their country.

8. FEMA-E74 "Reducing the Risks of Non-structural Earthquake Damage – A Practical Guide". This is a good implementation document that includes background, summaries of what damage occurs to various elements, and provides suggestions for design details for common situations.

9. FEMA-412 "Installing seismic restraints for mechanical equipment"; FEMA-413 "Installing seismic restraints for electrical equipment"; FEMA-P414 "Installing Seismic Restraints for Duct and Pipe". These codes of practice have been produced for the trades. They include prescriptive details on how to install. The focus being on simple to understand documentation for sub-contractors.

10. NFPA-13 "Standard for the Installation of Sprinkler Systems".

11. FEMA P-58-1 "Seismic Performance Assessment of Buildings – Volume 1 Methodology", September 2012.

APPENDIX A – Fletcher Construction Value Report

Fletcher

15th March 2017

BUILDING + INTERIORS

Christchurch
58 Hazeldean Road, Addington
Christchurch 8024
PO Box 141, Christchurch 8140
New Zealand
Tel +64 3 374 0140 Fax +64 3 374 0145
www.fletcherconstruction.co.nz

Opus International Consultants Limited
12 Moorhouse Avenue
Christchurch
8011

Attn: Jan Stanway

Dear Jan,

Re: Seismic Services Bracing and Restraint Costings

Introduction

We have been asked to review a number of projects and provide indicative estimates for the seismic restraint and bracing to the services and non-structural installations. In addition to these costings we have also provided commentary on factors effecting seismic restraint and bracing costs.

The cost ranges provided below are based on the information provided for each project, however, we note that the level of detailed information varies for each project and therefore the costings may not fully reflect the extent of a comprehensively designed seismic solution to NZS4219 in each instance. The values stated are inclusive of main contractor and sub-contractor margin, but exclusive of GST, design costs and BIM/3D modelling costs. No allowance has been made for external site works seismic bracing restraints or retrospective installations to existing buildings.

There are various factors that can significantly influence the cost of NZS4219 compliance which are discussed in the section below. Assumptions have been made where detailed information is not available for each case study.

The following tables identify approximate costs for seismic restraint and bracing to a variety typical of building types.

Estimated Seismic Costs per Building Type

Project	**Estimated Cost Range**	**Median Cost**				
		Mechanical	Electrical	Hydraulic	Fire	Sus Clgs
Fire Station Wairarapa	28,000 – 37,600	6,700	2,400	3,200	1,200	19,350
School Christchurch	140,000 – 182,600	26,700	7,300	9,200	18,800	99,770
Hospital West Coast	4,120,000 – 4,463,000	2,125,000	871,000	678,500	184,000	433,125
Community Library Christchurch	340,400 – 390,500	159,000	94,000	53,500	16,000	43,239
Carpark Building Wellington	85,700 – 94,500	28,000	40,000	19,000	3,100	0
Office Building Auckland	985,000 – 1,253,000	357,500	339,000	94,000	82,000	246,900

Seismic Bracing and Restraint as a Percentage of Total Construction Cost

Project Details		Total Construction Cost Median $/m²	Construction Cost (Non-Seismic) Median $/m²	Seismic Cost Median $/m²	Seismic % of Total Cost
Fire Station Wairarapa	503 m²	2,495	2,420	75	3%
School Christchurch	2,592 m²	2,766	2,695	71	3%
Hospital West Coast	11,260 m²	5,732	5,335	397	7%
Community Library Christchurch	1,123 m²	3,538	3,190	348	10%
Car Park Building Wellington	31,992 m²	883	880	3	1%
Office Building (Refurb) Auckland	6,413 m²	746	550	196	26%

Fire Station – Wairarapa (503m²)
The services design appears to have considered the seismic design in some detail although full information has not been provided. The combination of a considered design and the building use and extent of services results in a very low cost for seismic restraint and bracing for services.

School – Christchurch (2,592m²)
There is a reasonable amount of space available given the extent of services required for this project. This coupled with the construction and co-ordinated services design results in a relatively low requirement for services restraint and a low cost solution.

Hospital – West Coast (11,260m²)
The substantial extent of services required results in a very congested services space (ceiling voids etc), which significantly increases potential service clashes. Access for installation is also reduced requiring a much higher degree of planning and supervision whilst restricting the restraint and bracing methods that can be installed and lengthening the installation durations. These factors combined with the requirement for secondary services to be detailed increases the seismic restraint and bracing costs significantly.

Early contractor involvement with both main contractor and sub-contractors would significantly reduce the cost of seismic restraint by avoiding clashes and combining service runs, by including specific services detail for primary and secondary services. The addition of a seismic specialist would also assist in the design and planning, providing greater detail, increased cost certainty and lower installation costs.

Community Library – Christchurch (1,123m²)
Services for this building are reasonably extensive given building type together with limited space in a number of locations, which may result in a higher degree of bracing and congestion related conflicts between service disciplines. It was not possible to determine specific solution details which could influence the cost for seismic bracing to services in this building.

Carpark Building – Wellington (31,992m²)
The costs for this cover only the multi-storey carpark. The services requirement for this type of building together with some of the design principles adopted indicate a very low seismic restraint cost with a significant proportion of the cost relating to major plant/equipment restraint.

Office Building – Auckland (6,413m²)
This project involves retro-fit bracing to an existing building. Retrospectively installing seismic bracing has inherent risks as many of the services may need to be removed and re-fitted to facilitate access for seismic bracing, which would increase the cost and duration of installation significantly. The cost for retrospective seismic bracing to non-structural elements is huge and impacts on both architectural and structural disciplines. There is also potential asbestos and other contamination risks that have not been accounted for in our costings.

The costings provided assume the services seismic bracing install as part of a new build installation.

Factors Effecting Non-Structural Seismic Bracing
There are a number of factors that have a significant effect on the costs associated with seismic bracing to services and other non-structural trades. These elements of design and construction have the potential to effect other elements of the building including architecture, structure and of course services.

Early Design and Early Contractor Involvement
The primary factor with the most potential to reduce the cost of seismic bracing is early and detailed design of the services and their layout and detailed co-ordination with structural and architectural elements. For maximum benefit this should be done in conjunction with main contractor and sub-contractors to ensure that primary and secondary services are taken into account and installation experience can be incorporated into the design. Many of the other factors that affect cost are fixed (ie building use, Importance Level, consent requirements etc).

This integration of the design and construction teams should happen at the earliest opportunity, with close and complete co-operation to realise the maximum time and cost efficiencies.

Extent of Services & Available Space
The extent of services in relation to the space available requires careful co-ordination between design disciplines. Insufficient space can lead to conflicts between services, seismic support, structure and architectural envelope (partitions, ceilings etc). This in turn affects ceiling layouts, maintenance access and penetrations. In many cases there are external factors that may restrict increasing the ceiling void space (floor to ceiling and building height restrictions) or require a significant number of services (ie hospitals). This also affects access for installation and increases installation durations.

The distance of services from the structure can significantly increase the cost of seismic bracing. The closer services and other non-structural elements can be fixed to the structure the lower the degree of bracing and restraint. Larger ceiling voids may reduce the cost of services bracing but could to a lesser degree increase the cost of bracing the ceiling itself.

Design & Method of Construction
The building layout and method of construction will affect the seismic bracing installation duration and costs. This may include the type of structure, inter-storey height, pre-fabrication or the use of base isolation (to reduce load requirements). The use of in-slab ducts or raised access floors may reduce the requirement for bracing but will obviously impact on the floor to ceiling heights.

The type of services may be restricted by budget to include older technologies that are bigger, heavier or less resilient and therefore require a greater degree of bracing.

Any reduction in penetrations through fire walls or acoustic separation will affect the cost of passive fire protection and acoustic attenuation.

Retrospective Bracing

The retrospective bracing for non-structural elements is a massive issue as access to provide secure fixing back to the structure will, in most if not all cases, require the isolation, removal and re-fixing, testing and commissioning of a large proportion of services. Where retro fitting is considered for services intensive buildings such as hospitals, these issues are increased. The cost and duration is further compounded should the existing building be occupied and a phased approach adopted adding even more time and cost.

Where retrospective seismic bracing is undertaken there will also be subsequent effects on infection control, regulatory changes requiring fire and other service systems to be upgraded, structural impacts due to penetration size increases and additional fire or acoustic attenuation, removal of plasterboard ceilings, wall linings and flooring etc.

All of these factors make retro fitting a massive task resulting in massive costs and install durations not to mention the downtime of decanting spaces and relocating occupants. These factors make retro fitting costs and durations very much a building by building case but in all instances, the associated costs will be substantially more than the cost of the seismic bracing itself.

Building Use, Building Importance Level & Seismic Resilience

The use of a building (hospital, school, government building etc) will determine the extent of services and therefore the associated seismic bracing cost. This could also include the building importance level (IL) which may require a higher degree of support/restraint.

Clause A3 of the Building Code defines building importance levels (IL) as follows:-

- **Level 1:** Structures presenting a low degree of hazard to life or property, such as walkways, outbuildings, fences and walls.
- **Level 2:** Normal structures and structures not covered by other categories, such as timber-framed houses, car parking buildings or office buildings.
- **Level 3:** Structures that may contain crowds, have contents of high value to the community or pose a risk to large numbers of people in close proximity, such as conference centres, stadiums and airport terminals.
- **Level 4:** Buildings that must be operational immediately after an earthquake or other disastrous event, such as emergency shelters and hospital operating theatres, triage centres and other critical post-disaster infrastructure.
- **Level 5:** Structures whose failure poses a catastrophic risk to a large area or a large number of people, such as dams, nuclear facilities or biological containment centres.

The required level of seismic resilience increases with each level of importance and the associated cost increases beyond Level 3 are substantial.

The factors of influence vary from project to project as there is definitely no “one size fits all” approach that can be adopted for seismic resilience, however, the way the construction industry as a whole approaches the issues faced by seismic bracing requirements (NZS4219 and NZS1170) can have a significant time and cost effect and should be introduced at a far earlier stage, with a deeper level of integration, than currently typically occurs, which in turn will lead to installation efficiencies in both time and cost.

Clarifications and Departures

1. The costings have been prepared based on the information provided. No allowance has been made for any errors or omissions in the design information provided (if any).
2. Seismic bracing and restraint costs have been estimated for the services and ceiling elements only. Any seismic requirement to brace internal partitions, fixtures, fittings or other building elements are specifically excluded.
3. The values indicated are median construction costs for generic/typical building types across New Zealand without any adjustment or allowance for regional variance, regardless of the project location and are not specific to the project examples referenced.
4. All of the buildings compared in this study have been assumed to be Importance Level 3 (IL3).
5. The TVNZ building services scope appears to miss a number of floors.

6. No allowance has been made for design, BIM/3D modelling or shop drawings.
7. Assumptions to the method and extent of bracing have been made for each case study, unless specifically identified on the design details provided.
8. No allowance has been made for retrospective installations to existing structures.
9. Pricing is based on current construction costs as at 4th quarter 2016. No allowance has been made for escalation or uplifts due to currency exchange rates.
10. Availability of sufficient labour, plant and materials has been assumed.
11. GST is excluded, however, main contractor and sub-contractor margin is deemed to be included in the costs provided.
12. Penetrations are deemed to be included, however, the cost of structural upgrades, fire and acoustic provisions associated with same are specifically excluded.
13. Suspended ceiling bracing costs are extra over the cost of installing ceilings
14. Suspended ceilings assumed to full area of each building (as this is based on the specific design/specification for individual projects and will therefore can vary greatly)
15. Whilst areas have been given for each case study project, the factors effecting seismic bracing (as described above) dictate that cost per square metre calculations may provide misleading budgets if applied without consideration of project specific factors.
16. All costs are in New Zealand dollars (NZ$).

Yours faithfully
The Fletcher Construction Company Limited

Robert Noble
Commercial Manager

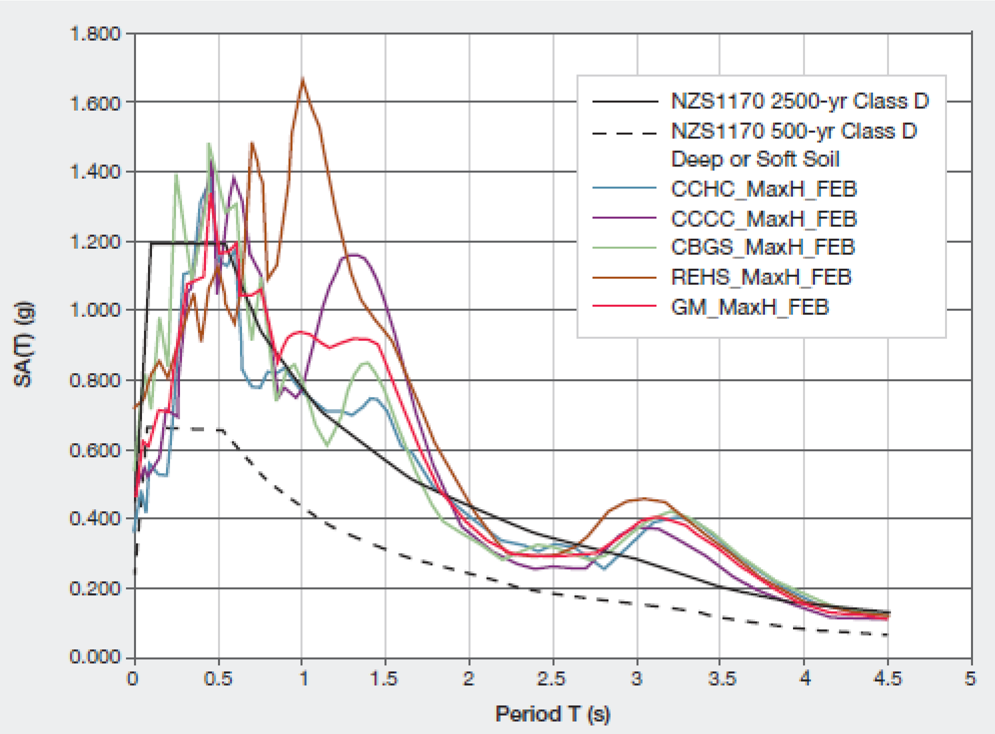
APPENDIX B – Canterbury Earthquake Sequence

Description of the earthquake sequence

On 4 September 2010, at 4.35am, an earthquake of 7.1 Mw struck the Canterbury region. The epicentre was around 40km west of Christchurch. The peak ground acceleration recorded at the Greendale seismic station reach 1.26g and peak ground accelerations up to 0.3g were recorded in Christchurch. In central Christchurch the ground motions were (depending on the period of the structure) comparable with that anticipated for a design 500-year return period earthquake for Christchurch.

There was a series of shallow aftershocks on 26 December 2010 beginning with a Mw 4.7 earthquake at 10.30am with an epicentre 1.8km north-west of Christ Church Cathedral. The maximum peak ground acceleration of 0.4g was measured at the Christchurch Botanic Gardens.

The most destructive earthquake of the Canterbury earthquake sequence was the Mw 6.2 earthquake which occurred at 12.51pm on 22 February 2011 with an epicentre under the Port Hills. The resulting horizontal ground motions reached 1.7g in the Heathcote Valley near the epicentre and up to 0.8g in the CBD. Vertical accelerations of 2.2g were recorded in the Heathcote Valley. The ground motions significantly exceeded the design 500-year return period earthquake for Christchurch as can be seen in the following figure.



Recorded response spectra in Christchurch CBD compared with NZS 1170.5 for deep soil sites

APPENDIX C – SP3 Results (Seismic Performance Prediction Program)

Limitations and use of SP3

The SP3 programme has some limitations and features that reflect differences between the US construction industry to the New Zealand construction industry. Some of these items are:

- Not all the building elements in the sample buildings have fragility information available within the programme. For example, there are no cable trays within the SP3 programme. There are therefore some elements missing from the models created.
- Some of the fragilities available represent US industry standard elements that differ from those equivalent elements used in New Zealand. There are therefore some elements within the models that may be expected to behave differently from the equivalent element in New Zealand. Examples of these include cast iron plumbing elements listed within SP3 that would be PVC in New Zealand.
- The SP3 programme give specific dollar values for the repair of the buildings. These are presented in US dollars and is based on rates and costs from the US industry. The SP3 programme also gives the repair costs as a percentage of the total cost. It would be complex and likely inaccurate to compare construction value between New Zealand and the US, along with allowing for an exchange rate. Based on this, the specific dollar values given by SP3 have been overlooked as an accurate estimate within the New Zealand market. Following discussions with the SP3 programme developers, it was deemed appropriate, however, to take the percentages provided as being applicable to both the US industry and the New Zealand industry.

Once populated with the above mentioned information, the models for each of the buildings, with elements braced and unbraced, is run such that outputs can be analysed. The programme provides output which includes an estimate of the percentage loss of non-structural elements and an estimate of the downtime to business caused by the seismic events input into the models.

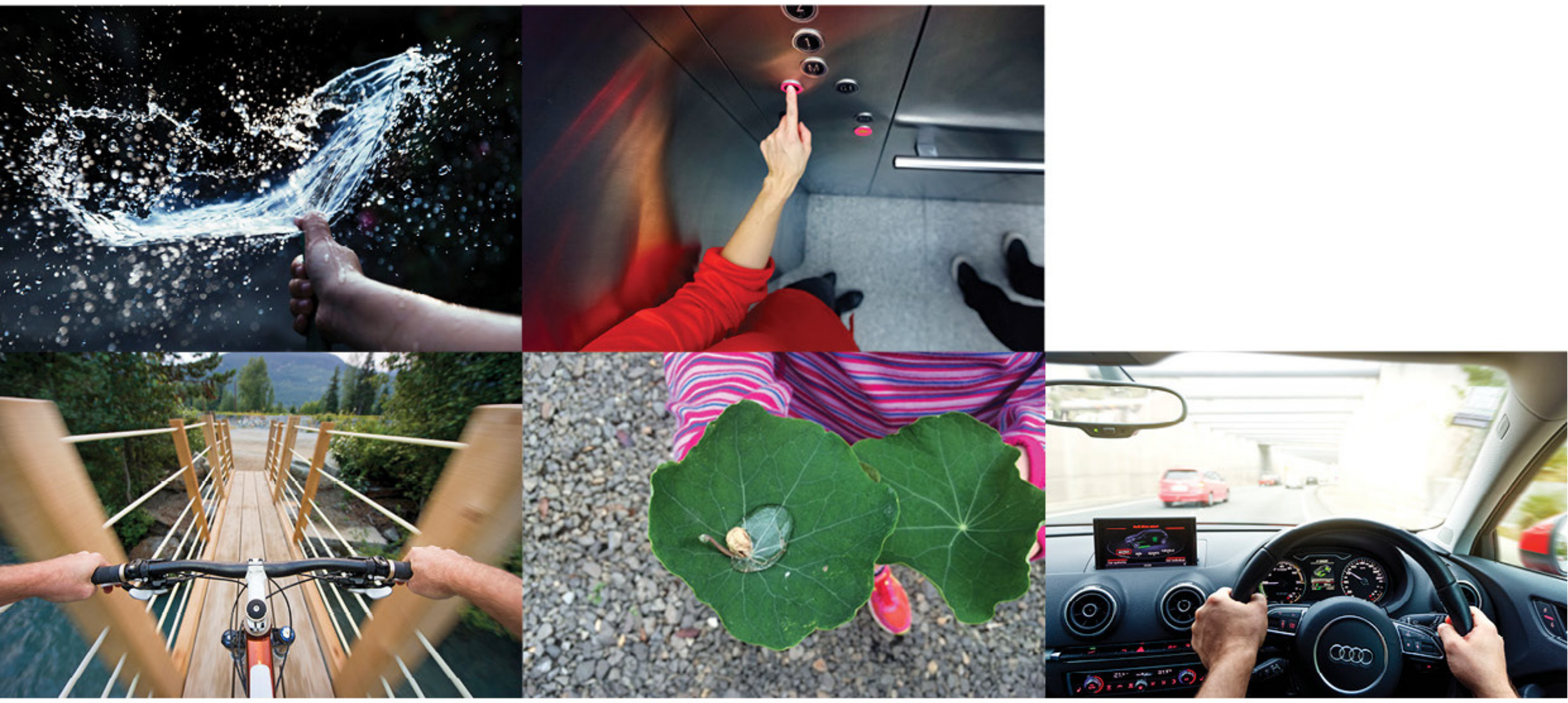
The percentage loss is the cost of repairing certain elements (e.g. structural elements, non-structural elements) against the cost to repair the building overall, at the certain levels of seismicity.

It is noted that some of the results below show a repair cost greater than 100% of the total cost of the building. These estimations represent instances where it would be more costly to carry out the repair of damaged structural and non-structural elements, than it would to completely demolish and rebuild the building.

Summary of output from SP3 models

Building	Seismic Restraint for Non-structural elements provided?	Intensity Level	Contribution of Building Elements to Mean Loss						Estimated Downtime Due to Damage (Days)
			Total Losses	Partition Walls	Ceilings	Plumbing and HVAC	Other Non-Structural Elements	Sum of Non-Structural Elements	
4 Storey Office building. Auckland	No seismic restraints	SLS 1	0%	0%	0%	0%	0%	0%	0
		100 year	0.3%	0.3%	0%	0%	0%	0.3%	2
		ULS	1.0%	0.9%	0%	0%	0.1%	1.0%	6
	Seismic restraints for NSE included	SLS 1	0%	0%	0%	0%	0%	0%	0
		100 year	0.3%	0.3%	0%	0%	0%	0.3%	2
		ULS	1.0%	0.9%	0%	0%	0.1%	1.0%	6

Building	Seismic Restraint for Non-structural elements provided?	Intensity Level	Contribution of Building Elements to Mean Loss						Estimated Downtime Due to Damage (Days)
1 storey school. Canterbury	No seismic restraints	SLS 1	0.7%	0.7%	0%	0%	0%	0.7%	2
		100 year	3%	1.6%	0.8%	0%	0%	2.4%	8
		ULS	45%	1.5%	1.%	0%	0%	2.5%	99
	Seismic restraints for NSE included	SLS 1	0.7%	0.7%	0%	0%	0%	0.7%	2
		100 year	3%	1.6%	0.5%	0%	0%	2.1%	7
		ULS	46%	1.4%	1%	0%	0%	2.4%	101
2 storey library. Canterbury	No seismic restraints	SLS 1	0.4%	0.2%	0.1%	0.1%	0%	0.4%	2
		100 year	4.0%	0.9%	0.3%	0.7%	0%	1.9%	18
		ULS	69%	0.7%	0.1%	0.3%	0%	1.1%	196
	Seismic restraints for NSE included	SLS 1	0.3%	0.2%	0.1%	0%	0%	0.3%	1
		100 year	3.1%	0.9%	0.2%	0%	0%	1.1%	15
		ULS	68%	0.7%	0.1%	0%	0%	0.8%	195
1 storey fire station. Wairarapa	No seismic restraints	SLS 1	22%	0%	4.6%	0%	0%	4.6%	27
		SLS 2	71%	0%	17%	0.2%	0%	17%	89
		100year	65%	0%	16%	0.2%	0%	16%	82
		ULS	90%	0%	15%	0.3%	0%	15%	131
	Seismic restraints for NSE included	SLS 1	20%	0%	2.9%	0%	0%	2.9%	24
		SLS 2	69%	0%	15%	0.3%	0%	15%	87
		100year	63%	0%	14%	0.2%	0%	14%	79
		ULS	90%	0%	14%	0.4%	0%	14%	131
8 storey car parking building. Wellington	No seismic restraints	SLS 1	3.4%	0%	0%	0%	0%	0%	26
		100 year	31%	0%	0%	0%	0%	0%	188
		ULS	109%	0%	0%	0%	0%	0%	516
	Seismic restraints for NSE included	SLS 1	3%	0%	0%	0%	0%	0%	23
		100 year	33%	0%	0%	0%	0%	0%	195
		ULS	106%	0%	0%	0%	0%	0%	512
3 Storey / 1 storey hospital. West Coast	No seismic restraints	SLS 1	1.7%	0%	0.8%	1%	0%	1.8%	7
		SLS 2	34%	0%	2.1%	2.3%	0%	4.4%	106
		100year	26%	0%	2.3%	2.4%	0%	4.7%	89
		ULS	120%	0%	0%	0.1%	0%	0.1%	261
	Seismic restraints for NSE included	SLS 1	0.1%	0%	0.1%	0%	0%	0.1%	1
		SLS 2	32%	0%	1.3%	0.1%	0%	1.4%	97
		100year	20%	0%	1.3%	0.1%	0%	1.4%	76
		ULS	120%	0%	0%	0%	0%	0%	263



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