MBIE AND EQC

SURVEY OF SEISMIC RESTRAINT OF NON STRUCTURAL ELEMENTS IN EXISTING COMMERCIAL BUILDINGS

Report on Stage 2 – Full Study
Volume 1

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1.0 Executive Summary

Kevin O'Connor and Associates Limited (KOA) in association with Seismic Restraints NZ Ltd, Global Reach Associates and Future Impact Ltd have been engaged jointly by MBIE and EQC to carry out a *Survey of Seismic Restraint of Non-structural Elements in Existing Commercial Buildings*.

The objective of this survey is to assess the earthquake resilience and compliance of current stock of non-structural elements (NSEs, mechanical, electrical, plumbing, fire sprinkler and internal fit out) in a sample of commercial buildings in Wellington and Auckland in relation to the Building Act objectives and current building standards. We considered compliance with NZS4219, AS/NZS2785 and NZS4541. We inspected services suspended from slabs and within ceiling spaces as well as partition walls. The study did not include systems located in plantrooms, riser ducts and stairwells. The study did not include building facades.

We inspected a total of 41 floors in 20 commercial buildings in Wellington and Auckland. We focused on seismic braces and restraints, the adequacy and spacing of the restraints, all fixings and the suitability of structural elements fastened to.

Summary of Findings

- We observed only one life safety hazard which we deemed to be significant and verbally informed the building manager that it required attention
- The majority of the non-structural elements (NSEs) inspected do not have adequate restraint in accordance with the relevant standards
- Ceilings were the least compliant element; 89% require upgrading to comply with the standard
- Partitions walls, fire systems and HVAC units also scored poorly with typically 80% requiring upgrading
- Electrical and data systems scored best; only 26% required upgrading. However, these are light-weight elements and often do not require restraint in order to comply.
- The distance between restraints is often greater than permitted by the relevant NZ Standard
- The spacing between different elements is often less than permitted by the standard
- Many restraints are compromised by poor fixing at restraint, structure or both.
- Many NSEs are fixed to the underside of hollow-core floors with fixing types which are untested in New Zealand.

Full results are presented in the body of the report and the appendices.

We note that improvements to the restraint of ceilings and partitions would have the greatest effect on life safety; improving ceilings, partitions, fire sprinklers and plumbing systems would have the greatest effect on reducing potential consequential damage

We prepared rough order cost estimates to upgrade all restraints to comply as nearly as is reasonably practicable with the standard. The average estimated cost was \$64,000 per floor or \$68/m^2. The average upgrade costs were higher for Auckland than for Wellington.

We viewed a number of building files and found little evidence that restraint of NSEs is considered as part of the primary building design. Although compliance with relevant codes is included in specifications we did not find completion documentation showing the systems as installed did comply. It appears the design of restraints is most often carried out as part of a design and install contract.

Recommendations

Our recommendations are in section 10.0 below

This executive summary and summary of findings should be read in conjunction with the full report.

2.0 Introduction

2.1 Background

Non-structural elements (NSEs) form a significant proportion of the total cost of a building. Repairing non-structural elements after a damaging earthquake comprises a large part of the total cost of repair, especially in moderate earthquakes where there is minimal damage to primary structural elements. Damage to NSEs also has a significant effect on business disruption. Many observers commented that NSEs performed poorly in the recent Canterbury and Wellington (Seddon) earthquakes.

Whilst the above statements are widely promulgated they are based on anecdotal evidence only; there has been little study on the actual performance of non-structural elements in earthquakes in New Zealand.

MBIE have commissioned a number of studies in order to better understand the physical performance and economic implications of non-structural elements.

This report summarises and discusses our survey of the level of compliance of existing commercial building stock.

2.2 Purpose

The purpose of this survey is to assess the level of compliance of the seismic restraint of the mechanical, electrical, plumbing, fire sprinkler, ceiling and internal fit out in a sample of existing commercial buildings in Wellington and Auckland and to assess the scope and estimate the cost of upgrading the restraints to comply with current standards.

The objective of this study is to assist MBIE and EQC:

- To evaluate if existing design, installation and consenting practices comply with relevant standards and with the objectives and functional requirements of the Building Regulations
- To comment if the design and installation of seismic restraints is an integral part of current design practice for building services, ceilings and partition walls and if existing consenting and sign-off systems are effective.

We inspected a total of 41 floors in commercial buildings and report on the percentage of each type of non-structural element that comply with current standards and practise for seismic restraint. We emphasise that our reported percentage compliance is a relative measure and should not be taken as a direct indication of safety, likely damage or business disruption.

We considered the scope of works and rough order cost of upgrading the seismic restraint to meet current standards.

2.3 Our Engagement

Kevin O'Connor and Associates Limited (KOA) in association with Seismic Restraints NZ Ltd, Global Reach Associates and Future Impact Ltd were engaged jointly by the Ministry of Business Innovation and Environment (MBIE) and the Earthquake Commission (EQC) to carry out a Survey of the Seismic Restraint of Non-Structural Elements in Existing Commercial Buildings (originally entitled a Stocktake of Seismic Restraint of Non-structural Elements).

Refer to the MBIE & EQC Contact for Services dated 4 November 2015 for full details.

3.1 Two Stages of Project

In Stage 1 of this study we developed a methodology to inspect the NSE fitouts in commercial buildings and a consistent method of reporting our findings. We inspected four floors to test the methodology and presented the results.

In Stage 2 we amended the methodology following feedback and then inspected an additional 37 floors.

This report presents the results.

3.2 Selection of Buildings to Assess

We targeted commercial buildings of at least four floors, and generally of less than 60 years of age; we generally avoided ground floors and top floors as the services in these two areas are frequently not typical.

We inspected 20 floors in Wellington and 21 floors in Auckland, the majority of which meet the above criteria.

The identities of the specific buildings and floors inspected are confidential to respect the potentially sensitive commercial nature of our findings: we have not divulged the identities of the individual buildings to MBIE and EQC.

3.3 Data Collected on Site

We devised a spreadsheet to capture all the site data. We identified eight different common elements on commercial floors:

- Ceiling systems
- Partition walls
- Fire protection systems located in ceiling spaces
- Electrical and data systems located in ceiling spaces
- Light fittings
- Plumbing in ceiling spaces
- HVAC ducting in ceiling spaces
- HVAC units suspended in ceiling spaces.

We referred to relevant New Zealand Standards:

- NZS 4219 Seismic Performance of Engineering Systems in Buildings
- AS/NZS 2785 Suspended Ceilings
- NZS 4541 Automatic Fire Sprinkler Systems
- NZS1170.5 Structural Design Actions - Earthquake.

We considered the prescriptive or non-specific pathways and requirements.

Basic Score

For each floor we identified if an element was present. We assessed, based on our experience and with reference to the above standards if that element requires independent seismic restraint. Examples of elements that we determine do not require independent restraint include lightweight elements (e.g. less than 1kg) soft ducting and elements suspended close to the slab soffit.

We allocate each element a basic score as follows:

- 0: No bracing visible
- 1: Inadequate Restraint: Bracing present but appears light or incomplete

- 2: Adequate Restraint: Bracing present and appears adequate
- 3: Compliant Restraint: Bracing present and a tagged or verified system.

Multipliers

We applied seven multipliers to each basic score, each scored from 0 to 1. A score of 1 indicates that that attribute is adequate and does not reduce the basic score. A score of less than 1 indicates that attribute is a weak link and reduces the score for that element. A score of 0 indicates a very serious flaw, meaning that restraint is ineffective.

The multipliers relate to the connections/fastener between the element and the brace, the bridging distance, the spacing of the braces, the fasteners used at the element and at the structure and the suitability of main structure being fastened to, the clearances and the condition of the restraint.

Consequence of Failure

We recorded the consequence of failure for both life safety and consequential damage. Each is scored as Low, Medium or High taking account of the inherent issues with that element and the adequacy of the restraints.

3.4 Inspecting Floors

Each site inspection was carried out by two staff members, who used judgement to agree on the appropriate score. Photographs are taken at each site.

All results are based on applying our experience to our brief observations. We did not measure the dimensions of the restraints; nor did we calculate the size of the restraints required.

3.5 Analysing Data

We devised a series of spreadsheets to analyse the data collected.

For each of the elements we selected the lowest *multiplier* to represent the weakest link in the chain. The ***basic score*** was then multiplied by the lowest multiplier to get the ***final score***. The final score is in the range of 0 to 3.

In some cases we assessed the *NZ Standard* (prescriptive) requirement was not suitable; it was either too onerous or too lenient for the element being restrained.

We considered eight elements, although not all elements are present on each floor. For each element that is present, we state if a restraint exists and if that restraint is *inadequate*, *adequate* or c*ompliant* and estimate the rough order cost estimate to upgrade the restraints.

We define a *compliant restraint* as one with sufficient manufacturers' markings on it that it can easily be verified as compliant. We would have also included any restraints with sufficient information on Council files to similarly verify, but did not find any of this category. We define an *adequate restraint* as one which we assess, by visual inspection is adequate and which has a final score of 1.0 or greater. Essentially these categories are two different paths to conclude the restraint is adequate. Where an element is present but due to its low weight or robust primary fixing (hanger) a separate restraint is not required by the code, we classify that as an *adequate restraint*. In the discussion below we group *adequate* and *compliant* restraints together.

An *inadequate restraint* is one with a final score of less than 1.0.

The analysis spreadsheet are included at Appendix D.

3.6 Property Files

We approached the Territorial Authorities (TAs) Wellington City Council and Auckland Council to obtain the property files. WCC were very helpful in allowing us access to files. We then reviewed the files looking for documents relating to the design and consenting of seismic restraints.

3.7 Age of Fitout

We attempted to record the age of each fitout but concluded it was too difficult to obtain an consistent date. Most building managers did not have records and many of the fitout tasks do not require building consent. Many new tenancy fitouts only involve partitions walls, data cables and in some cases HVAC ducting, fire systems detectors and light fittings; ceilings, HVAC units and plumbing are often carried over from the previous tenancy.

We concluded we had insufficient data to use age of fitout as a key parameter.

3.8 Cost Estimate

We prepared a rough order cost estimate to upgrade the restraints on each floor to comply with current standards. This is a rough order cost only; actual costs will vary due to access, working hours, product supply, contractor, council fees, professional fees, etc. GST is not included in the cost estimates.

4.1 Summary Tables - Combined

Combined (41 Floors inspected)

Element	No. Present	No. that require upgrading	Percentage to upgrade Combined	Percentage to upgrade Wellington	Percentage to upgrade Auckland	Difference, Larger	Comments
Ceilings	37	33	89%	89%	89%	0%	Difference not significant
Partition Walls	33	28	85%	84%	85%	1%	Difference not significant
Fire Protection Systems	27	23	85%	73%	100%	27% A	
Electrical and Data Systems	39	10	26%	45%	5%	40% W	
Light Fittings	40	21	53%	47%	57%	10% A	
Plumbing	31	17	55%	63%	47%	16% W	
HVAC Ducting	41	28	68%	60%	76%	16% A	
HVAC Units	19	15	79%	82%	75%	7% W	Difference not significant

Notes to Table

Upgrading means upgrading that element to comply with current standards as near as is reasonably practicable.

From the above table we can see that ceilings were present in 37 of the 41 buildings inspected. Of these, four were assessed to be adequate, i.e. comply with NZS2785 as near as is reasonably practicable, and 33 assessed to be inadequate. The detailed analysis spreadsheets in Appendices C and D provide further details.

Similarly we see that electrical and data systems do not comply with NZS4219 in ten of the 39 floors where they were present.

Combined (41 Floors inspected) Re-ordered – least compliant first

Element	No. Present	No. that require upgrading	Percentage to upgrade Combined	Percentage to upgrade Wellington	Percentage to upgrade Auckland		Comments
Ceilings	37	33	89%	89%	89%		
Partition Walls	33	28	85%	84%	85%		
Fire Protection Systems	27	23	85%	73%	100%		
HVAC Units	19	15	79%	82%	75%		
HVAC Ducting	41	28	68%	60%	76%		
Plumbing	31	17	55%	63%	47%		
Light Fittings	40	21	53%	47%	57%		
Electrical and Data Systems	39	10	26%	45%	5%		

This table shows the eight elements in order of compliance; least compliant at top.

4.2 Summary Tables – By City

Wellington Floors (20 inspected)

Element	No. Present	No. that require upgrading	Percentage that require upgrading	Average cost to upgrade per floor	Notes	High Life Hazard, Consequential Damage
Ceilings	19	17	89%	$16,799		3, 7
Partition Walls	19	16	84%	$2,970*	Excludes costs to fix to hollowcore	1, 4
Fire Protection Systems	15	11	73%	$9,158*	Excludes costs to fix to hollowcore	1, 6
Electrical and Data Systems	20	9	45%	$2,750*	Excludes costs to fix to hollowcore. Includes 2 with adequate scores.	0, 0
Light Fittings	19	9	47%	$3,726		0, 0
Plumbing	16	10	63%	$4,563*	Excludes costs to fix to hollowcore	1, 6
HVAC Ducting	20	12	60%	$3,074*	Excludes costs to fix to hollowcore	1, 0
HVAC Units	11	9	82%	$2,480	Excludes costs to fix to hollowcore	0, 0
TOTAL				$45,519		

Auckland Floors (21 inspected)

Element	No. Present	No. that require upgrading	Percentage that require upgrading	Average cost to upgrade per floor	Notes	High Life Hazard, Consequential Damage
Ceilings	18	16	89%	$19,522		4, 5
Partition Walls	14	12	85%	$4,452*	Excludes costs to fix to hollowcore	5, 10
Fire Protection Systems	12	12	100%	$17,104		0, 9
Electrical and Data Systems	19	1	5%	$9,600		0, 0
Light Fittings	21	12	57%	$8,532		0, 0
Plumbing	15	7	47%	$9,842		1, 3
HVAC Ducting	21	16	76%	$8,958	Includes 1 with adequate score	3, 6
HVAC Units	8	6	75%	$3,832		0, 3
TOTAL				$81,842		

Note: The Auckland average costs for Fire Systems, Plumbing and HVAC were skewed by building A4.4 with high costs for these elements. We have treated this as an outlier result and excluded it from the total cost estimates.

The rough order cost estimates have been built up from the individual floors; refer Appendices C and D.

5.0 Analysis of Costs

5.1 Introduction

We prepared rough order costs to upgrade all restraint on the floors to (or close to) the current requirements of the Standards noted above.

5.2 Costs

Our rough order cost estimates are as follows:

Element	Cost per Floor Wellington	Cost per Floor Auckland	Cost per Floor Average	Comment
Ceiling	$16,799	$19,522	$18,160	
Partition	$2,970*	$4,452*	$3,711*	
Fire Systems	$9,158*	$17,104	$13,131*	Auckland cost adjusted as above
Elect and Data	$2,750*	$9,600	$6,175*	
Light Fittings	$3,726	$8,532	$6,129	
Plumbing	$4,563*	$9,842	$7,203*	
HVAC in Ceilings	$3,074*	$8,958	$6,016*	
HVAC Unit	$2,480	$3,832	$3,156	
TOTAL	$45,519	$81,842	$63,681	Cost per Floor
Based on average of 995m² gross per floor	$46/m²			Cost per m²
Based on average of 872m² gross per floor		$94/m²		Cost per m²
Based on average of 934m² gross per floor			$68/m²	Cost per m²

5.3 Differences in Cost Estimates between Cities

In summary, buildings in Wellington require an average of $45,519 per floor to upgrade whilst buildings in Auckland cost $81,842 per floor, with the costs per square metre being $46 and $94 for the two cities. The averages estimated costs are $63,681 per floor and $68/m^2 based on an average of 934m^2 gross per floor.

As can be seen from the table, cost estimates per floor for Auckland are higher for all eight elements; this should be tempered by the following comments:

- The sample size is small.
- We noted more unrestrained NSEs, especially ceilings, in Auckland. Although we assessed some of these elements to be adequate without restraint there remained a high percentage assessed to require restraint. Not only were ceilings unbraced but many plumbing pipes, electrical and data cables, HVAC units and light fittings were supported directly by the ceiling grid or even ceiling tiles. Each of these elements require upgrading.
- Cost estimates exclude costs of fixings to hollow-core slabs; we noted a higher percentage of hollow-core slabs in Wellington compared to Auckland.

6.0 Discussion

6.1 General

In general, non-structural elements have a primary support system; where the mass supported is low or the primary support is robust, the primary support also constitutes an adequate restraint. In many cases the primary support is designed to carry gravity loads only and does not provide adequate lateral restraint and thus does not provide adequate resilience under earthquake loads.

Most of the non-structural elements inspected were restrained in some way, either by the primary support or by an independent restraint. However, many restraints appear either undersized or are let down by one or more weaknesses in the chain of restraint, e.g. a poor connection to the building structure or by interference with another element. The exception being the lightweight elements (electrical and data cables, plumbing) which were often simply laid in the ceiling grids.

We observed a higher percentage of independent restraints in Wellington compared to Auckland.

We found very little consent documentation for non-structural elements although many recent consent applications did include performance specification clauses requiring the contractor to design and build the supports and restraints in accordance with the relevant NZ Standards. However, it appears that despite the specification, many are not properly engineered and certainly not properly documented. We did not see any producer statements or similar documents clearly stating the elements had been installed in accordance with NZS 4219.

We observed only one significant life safety hazard and verbally informed the building manager that it required attention. However, we did note old-style heavy ceiling tiles in several buildings. We understand heavy tiles generally weigh between 3 and 7kg with a few obsolete types weighting up to 8.2kg (18 pounds) per tile for the larger sizes. We note that NZS1170.5, Table 8.1 states that in order to be considered as a part representing *a hazard to an individual life*, an element must weigh more than 10kg and be able to fall more than 3m. We did not observe any ceiling tiles in this category. We understand that as long as occupants either “get under their desks” or “drop, cover, hold” during an earthquake, tiles of less than 10kg are unlikely to be a life safety hazard. We suggest MBIE re-consider this assumption.

We did not observe any obvious “unauthorised penetrations” through structural elements during our inspections, although all team members have noted these at times during their careers. A number of unauthorised penetrations were reported in Christchurch after the earthquakes and some possibly contributed to significant building damage.

A significant number of non-structural elements are restrained back to unsuitably weak secondary elements (not part of the main structure). Several cases of this situation were recorded.

We did not specifically check if penetrations were adequately fire stopped.

6.2 Most Compliant Elements

As can be seen from the summary tables, electrical and data systems (26% require upgrading), light fittings (53% require upgrading), plumbing (55% require upgrading) and HVAC ducting (68% require upgrading) were the most compliant elements. Electrical and data was the only element with less than 50% requiring upgrading. We emphasise that these percentages are derived from the study parameters and should not be considered as absolute; they are for comparative purposes only.

Our interpretation is as follows.

Many of the electrical and data systems and light fittings are relatively lightweight and these elements do not require a restraint that is independent of the primary support system; thus a typical tradesman’s installation is adequate. These lightweight elements are also relatively simple and economical to secure. Many are attached to tension wires.

In contrast, heavier elements do require independent restraint and although these exist in many cases, they have not been engineered and are undersized or let down by a weak link or lack of clearance.

Fire systems scored reasonably well and nearly all appeared to have been installed to good trade practice, suggesting the contractors installing these systems understand the importance of post-earthquake functionality and follow

NZS4219 and NZS 4541. However, as above, many fire system installations were let down by a weak link such as poor or unproven fasteners, excessive spacing between restraints and unrestrained range ends.

6.3 Ceilings

Ceilings were present in 37 of the 41 floors inspected and only four were assessed as adequate; two were adequately restrained and two were adequate without restraint. 24 had no restraint, nine had restraints that were assessed to be inadequate. The results for Wellington and Auckland were similar.

Although the majority of ceilings were given a basic score of either 1 (Bracing present but appears light or incomplete) or 2 (Bracing present and appears adequate), many weaknesses in the load paths resulted in low multipliers. Many ceilings were governed by poor fasteners at the element or poor fasteners at the structure. Additionally, many braces were spaced too far apart.

In Wellington where our sample had a much higher percentage of hollowcore floors than Auckland, many ceilings were fixed to the floor soffits with fixing types that have not been independently assessed.

We observed many heavy ceiling tiles, estimated to weight 3 to 5 kg per tile (max 7kg). These were mainly older fit-outs. Some floors had a combination of light weight ceiling tiles and older, heavier tiles. In at least one building, whilst the office ceiling tiles had been replaced with lightweight tiles, the original heavy-weight tiles had not been replaced in the exitways and stairwells, where falling tiles could cause significant disruption to evacuation.

6.4 Fastening to Hollowcore floor systems

Some of the structural floor systems which are widely used in modern commercial buildings are very difficult to securely fix to; hollowcore (e.g. Dycore) floors fall into this category. These precast concrete flooring systems consist of circular voids with only a thin shell of concrete and thicker ribs between the voids; however there is pre-tensioning strand in these ribs, thus leaving no suitable areas of soffit to fasten into. Although a number of fasteners claim to be suitable for these floors, we are unaware of any fastening systems which has been independently assessed for use with these floors. We understand ACI committee 355 is investigating post installed anchorages to concrete.

Where we noted bolts beginning to pull out of hollow slabs we scored the multiplier accordingly.

As there are no independently assessed fixing systems for fastening into this type of slab, we have not been able to estimate the cost of upgrading these elements.

We noted a higher percentage of hollow-core floors in Wellington compared to Auckland.

6.5 Partition Walls

Partition walls were present in 33 of the 41 floors inspected and only five were adequately restrained. 20 had no restraint, eight had restraints we assessed to be inadequate. The results for Wellington and Auckland were similar.

The causes on the low scores were; poor fasteners both at the element and at the structure and lack of clearance to other elements and structure. It is common practice for partition walls to simply be attached to the ceiling grid or even to ceiling tiles rather than being independently restrained. They are thus unbraced and are likely to interact with and damage the ceiling.

6.6 Fire Systems

Fire systems were present in 27 of the 41 floors inspected and only five were adequately restrained. 13 had no restraint, ten had restraints we assessed to be inadequate.

Of the 15 fire systems in Wellington, four were adequate and another nine had restraints assessed to be inadequate. In Auckland, 11 out of 12 fire systems were not restrained at all.

In general terms the fire systems (sprinkler systems) were given adequate basic scores which were then reduced by poor or unproven fasteners at the structure, excessive spacing of restraints, excessive length of unrestrained range ends and sub-standard clearance with other elements. Many range ends (branch pipes to a sprinkler) exceeded the maximum permissible unrestrained length from NZS4541. Another common problem was the lack of clearance with other NSEs, potentially leading to interference and damage in an earthquake.

It appears that sprinkler installers are attempting to comply with standards but require further guidance. The issue with fixing to the structure including hollow-core floors is discussed above.

6.7 Electrical and Data

Electrical and data systems were present in 39 of the 41 floors inspected. 28 were adequately restrained (or did not require independent restraint) and a further seven restrained but inadequately.

Most are attached to tension (catenary) wires; a few are within cable trays.

Due to the light-weight nature of these systems many do not require restraint in order to comply.

This is the only element where more than 50% were judged to be adequate. The only significant downgrading factor was poor fastenings between the cable tray brace and the structure.

We assessed that 45% of Wellington elements and 5% of Auckland elements required upgrading.

Many electrical systems in Auckland are adequate as installed on tension wires without independent restraint. Similar systems are often inadequate for the higher seismic loads in Wellington. Fixings to hollow-core floors, mainly in Wellington also contributed to the differences between the percentages of adequate restraints in the two cities.

6.8 Light Fittings

Light fittings were present in 40 of the 41 floors inspected (the other floor was undergoing a re-fit). Five were adequately restrained, 14 were compliant without restraint (generally because they were lightweight) and 21 had inadequate restraint.

The results for Wellington and Auckland were fairly similar.

Primary scores were reduced due to poor fixing at element.

We noted many lights supported directly off ceiling grids with no secondary bracing. This is generally adequate for lightweight fittings such as 600 x 600 light fittings only.

6.9 Plumbing

Plumbing pipework was present in 31of the 41 floors inspected. One floor was adequately restrained, 12 were compliant without restraint and 18 had inadequate restraint.

The results for Wellington and Auckland were fairly similar.

The basic scores were reduced by poor fixings at the structure, at the element and by insufficient clearance. Many uPVC pipes are simply laid upon the ceiling grid. Others are supported at wide spacing, leading to sagging of the pipes.

Much of the plumbing observed in ceilings is lightweight small diameter pipework. Whilst damaged plumbing can lead to consequential damage and business disruption it is rarely a life safety issue.

6.10 HVAC Ducts

HVAC ducts were present in all 41 floors inspected. 11 used soft ducting which under NZS4219 does not require restraint. Three had adequate restraint and 27 had inadequate restraint. The results for Wellington and Auckland were similar.

Scores were reduced by poor fixings at the structure, restraints spaced too far apart by inadequate clearances and by poor fixings at elements

We comment that the Standards seem quite onerous for HVAC ductwork considering it is light weight, generally close to the ceiling and often soft sided, i.e. unlikely to cause injury to people or damage other NSEs.

We observed steel sheet ducting in a variety of sizes; the larger sizes are relatively heavy and we noted lack of clearance with ceilings, fire systems and plumbing with potential for interaction and damage. In contrast, soft ducting is light weight and is unlikely to damage other elements even when the clearances do not comply with the standard.

We noted several HVAC diffusers supported directly off ceiling grids with no independent support or restraint.

6.11 HVAC Units

HVAC units were present in 19 of the 41 floors inspected. Five had adequate restraint and 14 had inadequate restraint.

The results for Wellington and Auckland were similar.

The major reason for reducing scores was poor fixings at the structure, meaning only two were assessed to be adequate.

6.12 Weaknesses in Restraints

As described above, we allocated each restraint an initial score and then applied a multiplier to each component within the restraint. Multipliers had a maximum value of 1; i.e. they could not increase scores, only reduce them. The multipliers were based on visual assessment and a knowledge of the prescriptive solutions from the standards; we did not measure sizes or calculate strengths. The multipliers with greatest effect on the final score were:

- Poor fastener at structure
- Poor fastener at element
- Restraints spaced too far apart
- Insufficient clearance between element and other element or structure.

Many fasteners appeared to be undersized for the seismic forces they should be designed to carry. The issues with common flooring types are discussed above. Similarly, many restraints were placed too far apart, indicating to us that the restraints had not been engineered, rather installed by a tradesman without engineering design or reference to the prescriptive standards.

It is more difficult to draw conclusions on the clearance issues. Obviously space to run services is limited leading to crowding of elements. However, it may be that the prescribed clearances are unnecessarily large and these could be reduced in future standards.

We did not observe any cases where NSEs are fastened back to inadequate structure (although team members have noted this in the past); all were fixed to substantial structure.

In crowded ceiling spaces we noted several NSEs supported and restrained by light braces which appear to have been designed for one NSE only, with the other elements simply laid over the top.

6.13 Differences between Wellington and Auckland

In general terms we noted more unrestrained NSEs in Auckland. Although we assessed some of these elements to be adequate without restraint there remained a high percentage assessed to require restraint. This is carried through into the higher average costs to upgrade in Auckland.

We noted a higher percentage of hollow-core floors in Wellington; we do not know if this is a general case or whether it is a result of the small sample size.

6.14 Photographs

A selection of photographs is provided at Appendix A.

7.0 Consequences of Failure

7.1 Introduction

We record the consequence of failure for both life safety and consequential damage. The inspector selects Low, Medium of High for each case based on his judgement. There is more than one aspect to life safety: a heavy item can cause direct harm; a toppled or fallen item can block egress routes, a broken sprinkler pipe means the system is no longer effective and a missing or un-lighted egress sign can lead to confusion during building evacuation. Leaking gas from a ruptured gas line is another potential life safety, hazard although we did not observe any gas lines in the building floors inspected.

Consequential damage is an indication of damage caused to other elements rather than the element being scored. A broken water pipe or sprinkler pipe causes significant disruption and damage.

7.2 Life Safety

Taking into account both the number of adequate restraints and the effect on life safety, our analysis showed that ceilings and partitions are the elements that need the most attention, followed by plumbing and fire sprinkler systems.

We followed the NZS1170.5 definition of an individual component weighting more than 10kg and able to fall more than 3 metres.

Although fire safety systems and electrical systems do have a major effect on life safety, as discussed above, we observed a higher proportion of adequate restraints for these systems.

Where HVAC units are located in ceilings, these are heavy and are a potential hazard. However, a reasonable portion of those observed were adequately supported.

As discussed in 6.3 above, although ceilings are not deemed to be a life safety hazard, there is evidence that collapse of ceilings and light fittings can trigger panic as well as disruption to exitways.

7.3 Consequential Damage

Taking into account both the number of adequate restraints and the effect on consequential damage, our analysis showed that ceilings, partitions and plumbing are the elements that need the most attention.

Failure of ceilings systems would in many cases lead to damage to light fittings as well as electrical and data systems and in some cases plumbing and HVAC ducting, often simply because the ceiling supports these other elements. Ceiling failure also tends to cause alarm and even panic among the floor occupants.

In most cases, partition walls and ceilings are fastened together and failure of one would cause damage to the other.

As with plumbing, fire sprinkler systems have the potential to cause very significant consequential damage. Whilst many failed the adequacy test most fire systems were restrained in some way and thus were deemed less likely to cause consequential damage. As noted in 6.12 above, excessive length of unrestrained range ends is a common weakness.

Interaction of different NSEs due to inadequate clearance can lead to consequential damage; for example failure of HVAC ducting can lead to damage to sprinkler systems.

8.1 Introduction

To investigate industry practice and consenting processes we looked at available property files. We approached the Territorial Authorities (TAs) Wellington City Council and Auckland Council to obtain the property files. WCC were very helpful in allowing us access to files. We then reviewed the files looking for documents relating to the design and consenting of seismic restraints.

Whilst the files contained both architectural and structural drawings, they did not include any details of installation, support or seismic restraints of NSEs. For some recent buildings we found clauses stating that services must in installed in accordance with NZS4219 but we did not sight any documents such as producer statements or installers' certificates to prove that the restraints were correctly installed or verified. Structural loading calculations viewed did generally include an allowance for services but did not include any specific designs or details for supports or restraints. It appears the design of restraints is most often carried out as part of a design and install contract for each individual service.

8.2 Standards

NZS4219, NZS4541 and NZS2785 are all focussed on new build; they do not adequately acknowledge refurbishment. For example in many cases it is not possible to meet clearance requirements in existing ceiling spaces and some of the standard solutions are not practical in refurbishments. This issue should be considered in the next revision of the Standards.

Considerable knowledge and judgement is required in order to apply NZS1170.5 Section 8 Parts and Components and NZS4219. As a result there is a wide variety of interpretations and differences in how these Standards are applied. This issue should be considered in the next revision of the Standards and/or guidance should be provided in order to improve consistency of application.

In terms of the prescriptive or acceptable solutions, fewer examples with wider application may prove to be easier for installers and therefore more economical in the long run.

8.3 Industry Practice

There appears to be a wide variety of competence and willingness in the industry to comply with the Standards. Although this study covered installations of varying ages we assess we did not collect sufficient data to comment if installation practice has improved over time. We recommend that some newly constructed buildings also be surveyed; this will assist in identifying where improvements have been made and where improvements to the construction process are still required.

8.4 Tagged Compliance

We observed only one restraint system permanently marked with the compliance standard. We recommend a system of tagging compliant components be considered in a future revision of NZS4219.

8.5 Regulatory Process

There does not appear to be consistency between consenting authorities in what they require in terms of design and construction documentation for NSEs.

8.6 Coordination with Other Building Issues

There appears to be situations where NSEs are not well co-ordinated with each other, for example elements are closer than minimum clearance allow, or are simply laid onto of each other. We also noted but did not record details of other construction issues such as poor fire stopping where services pass through walls.

9.0 Conclusions

We inspected a total of 41 floors in 20 commercial buildings in Wellington and Auckland. We focused on seismic braces and restraints, the adequacy and spacing of the restraints, all fixings and the suitability of structural elements fastened to.

Summary of Findings

- We observed only one life safety hazard which we deemed to be significant and verbally informed the building manager that it required attention
- The majority of the non-structural elements (NSEs) inspected do not have adequate restraint in accordance with the relevant standards
- Ceilings were the least compliant element; 89% require upgrading to comply with the standard
- Partitions walls, fire systems and HVAC units also scored poorly with typically 80% requiring upgrading
- Electrical and data systems scored best; only 26% required upgrading. However, these are light-weight elements and often do not require restraint in order to comply.
- The distance between restraints is often greater than permitted by the relevant NZ Standard
- The spacing between different elements is often less than permitted by the standard
- Many restraints are compromised by poor fixing at restraint, structure or both.
- Many NSEs are fixed to the underside of hollow-core floors with fixing types which are untested in New Zealand.

We note that improvements to the restraint of ceilings and partitions would have the greatest effect on life safety; improving ceilings, partitions, fire sprinklers and plumbing systems would have the greatest effect on reducing potential consequential damage

We prepared rough order cost estimates to upgrade all restraints to comply as nearly as is reasonably practicable with the standard. The average estimated cost was $64,000 per floor or $68/m^2. The average upgrade costs were higher for Auckland than for Wellington.

We viewed a number of building files and found little evidence that restraint of NSEs is considered as part of the primary building design. Although compliance with relevant codes is included in specifications we did not find completion documentation showing the systems as installed did comply. It appears the design of restraints is most often carried out as part of a design and install contract.

10.0 Recommendations

Our recommendations are:

10.1 Research Recommendations

10.1.1 We recommend that more research be carried out into suitable fasteners for use in hollow-core and similar flooring systems. We understand that research into suitable, reliable fixings has commenced but have not yet seen any results. This is of high importance due to the large number of existing buildings utilising this type of floor.

10.1.2 We recommend that existing and older current fastener types also be tested. Some may prove to be more reliable than currently assumed.

10.1.3 Depending on the outcome of these tests we recommend the development of a new fastener be instigated.

10.1.4 We recommend that whenever a significant failure of NSEs occurs, wherever possible the exact cause of the failure should be investigated and the results publicised to interested parties. For example it is widely known that a moderate earthquake caused failure of piped systems in a Wellington building, leading to serious disruption. However, it has not been widely publicised which component of the support system actually failed, possibly due to the owners' confidentially requirements.

10.1.5 We recommend that this study be expanded to include 10 existing buildings (20 floors) in the South Island.

10.1.6 We recommend that this study be expanded to include 10 newly-constructed buildings (20 floors) from Christchurch. This will provide a better indication of current practice.

10.1.7 We recommend the suitability of existing Standards and practices for refurbishment be investigated.

10.1.8 We recommend the results of this study be compared with actual data collected from NSE failures, particularly in the Canterbury Earthquakes.

10.2 Specific Recommendations

10.2.1 We recommend that building owners consider removing all one-way heavy plaster tile ceilings and replacing with modern light-weight ceilings

10.2.2 We noted many ceiling systems support data cables, plumbing, HVAC ducting and light fittings. We recommend that ceiling systems be rated for a defined load per square metre

10.2.3 We recommend training courses be developed to upskill both designers and installers of NSE systems

10.2.4 We recommend NZS1170.5 Part 8 be revised to improve clarity or guidelines developed to improve consistency of interpretation

10.2.5 We recommend that improved guidelines for partition wall installation be prepared.

10.2.6 We recommend a system of tagging compliant components be considered in a future revision of NZS4219.

10.3 Improvements to Methodology

We assess the methodology developed was fit for purpose having used it to inspect 41 floors we recommend a few developments if it is to be used again. The detailed methodology is included in Appendix B.

10.3.1 Inspectors should clearly record both the primary support and the independent restraint

10.3.2 Clearly state if element is satisfactory without secondary restraint

10.3.3 Area of each floor be accurately recorded

10.3.4 The analysis spreadsheets should be revised and simplified.

11.0 Limitations Statement

Kevin O'Connor & Associates Limited (KOA) and its sub-consultants has undertaken this study and applied their professional judgement with the usual standard of care and skill normally exercised by professional engineers in similar circumstances. No other express or implied warranty is made as to the professional advice in this report. We have inspected samples of restraints on each floor; we have not carried out a comprehensive inspection of all components.

KOA has no liability to the Client (or anyone else) should it transpire that any building is constructed of materials and/or is a design different from those materials investigated or tested and/or different from those in the plans and specifications.

12.0 Appendix A – Photographs

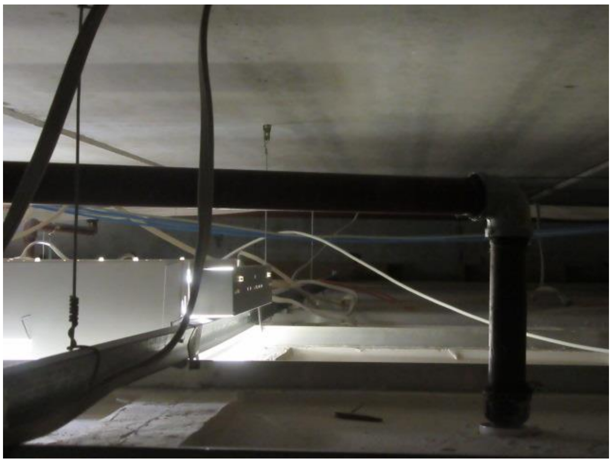
6mm Dynabolt pulling out of Hollowcore concrete slab

Ceiling bracing. Weakest element is 3.6mm aluminium rivet fastening to grid. Dynabolts in Hollowcore also failing

Fire sprinkler within 150mm of slab, unrestrained light (not supported independently), soft ducting unrestrained over 3m length.

Electrical wires laid directly on ceiling.

No ceiling bracing present. Cables leading down into unrestrained partition wall and unrestrained soft ducting in background.



Fire Range End not supported independently; supported by ceiling only. Light fitting not supported or restrained independently.


6mm Dynabolt pulling out of Hollowcore concrete slab


Duct hanger rivet fail

Typical partition wall to ceiling fastener


Interaction between ducting and fire sprinklers likely.


Range supported by cable tie, unbraced

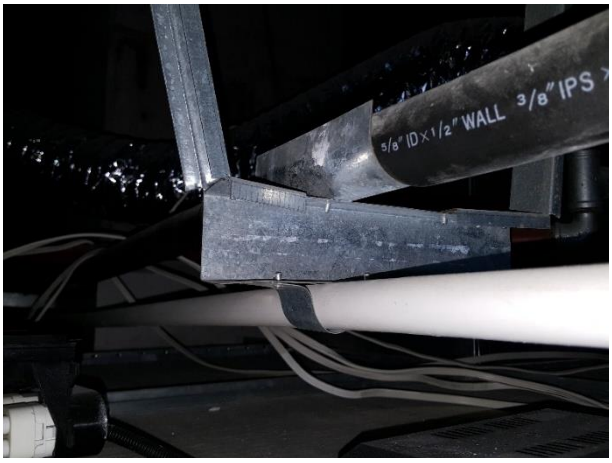

Grid ceiling to rondo ceiling not fastened

Unsupported or braced range end

Large lighting not independently supported

Water tank on a swing could interact with sprinkler

Long range ends unrestrained or hung



DIY at it's finest

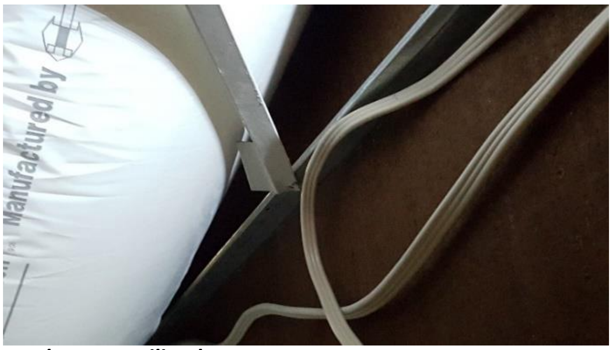
Air handling bracing let down by clearance, angle and general poor methodology

Ceiling bracket appears to have been shot to hollowcore

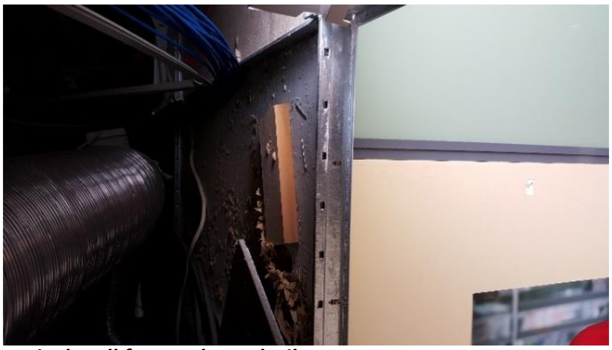
Large ducting could interact with ceiling hangers

Typical wall to ceiling fasten. This appears to have sheared.

Failing in hollowcore, previous drift evident



Inadequate ceiling brace



Typical wall fasten through tile to MDF

Partition wall bracing let down by fasteners 2

Partition wall bracing let down by fasteners

Pipework trapeze; inadequate clearance to fire

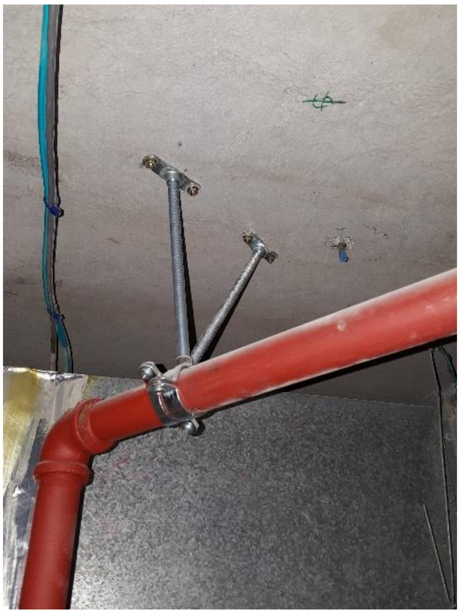
Partition wall poorly braced

Range ends not braced, Light not braced Pipe work not braced or supported.

Partition wall to plaster ceiling fastening

Ceiling bracing let down by weak fastener at element, note poor angle of fire brace in back ground

Partition bracing, no clearance around penetration suspect fasten



Ceiling bracing let down by weak fastener at element, note poor angle of fire brace in back ground

Ceiling bracing let down by weak fastener at element, note poor angle of fire brace in back ground

Track-lok bracing of partition walls

Grid fastened around lights

Flexible range

13.0 Appendix B – Methodology

13.1 Overview

The methodology consists of:

- An assessment template for the inspection procedure, complete with brief guidance notes
- An analysis methodology
- A table for presenting the results.

The methodology is intended to allow different inspectors to achieve similar results.

13.2 Collecting Data on Site

We devised a spreadsheet to capture all the site data. It can be used as a paper form or on a tablet.

We inspected eight different non-structural elements; on commercial floors; ceilings, partition walls, fire systems, electrical and data, light fittings, plumbing, HVAC ducting and HVAC units.

We refer to relevant standards including NZS 4219 Engineering Systems, NZS 2785 Suspended Ceilings and NZS 4541 Fire Sprinkler Systems. We consider the prescriptive or non-specific pathways and requirements. General concepts and prescriptive restraints from NZS 4104 Restraint of Building Contents are also useful.

Basic Score

For each floor we identified if an element was present. We assessed, based on our experience and with reference to the above standards if that element requires independent seismic restraint. Examples of elements that we assess do not require independent restraint include lightweight elements (e.g. less than 1kg) soft ducting and elements suspended close to the slab soffit.

Using our knowledge of the above standards, we then allocate each element a basic score as follows:

- 0: No bracing visible
- 1: Bracing present but appears light or incomplete
- 2: Bracing present and appears adequate
- 3: Bracing present and a tagged or verified system.

Multipliers

Next, each individual item was assessed in regard to the connections/fastener between the element and the brace, the bridging distance, the spacing of the braces, the fasteners used at the element and at the structure and the suitability of main structure being fastened to. We also scored the clearances and the condition of the fastener. There are seven multipliers for each element.

Each of the above *multipliers* was scored between 0 and 1.

Consequence of Failure

We recorded the consequence of failure for both life safety and consequential damage. The inspector selects Low, Medium or High for each case based on judgement taking account of both the inherent issues with that element and the adequacy of the restraints. There is more than one aspect to life safety: a heavy item can cause direct harm; a toppled or fallen item can block egress routes, a broken sprinkler pipe means the system is no longer effective and a missing or un-lighted egress sign can cause confusion during building evacuation.

13.3 Selection of Buildings to Assess

We targeted commercial buildings of at least four floors, and generally of less than 60 years of age. We approached building owners, managers and tenants to request access. Wherever possible we requested floors with one or a small number of tenants to simplify access arrangements. We accepted most floors offered: where a choice was offered, we generally avoided ground floors and top floors as the services in these two areas are frequently not typical. We only inspected floors where access into the ceiling space was possible and preferably where there was more than one access point to the ceiling (or where the services were exposed).

In the end although some of the floors inspected did not fully meet our original criteria, we assess they all represent typical commercial building floors.

The identities of the specific buildings and floors inspected are confidential to respect the potentially sensitive commercial nature of our findings: we have not divulged the identities of the individual buildings to MBIE and EQC.

13.4 Inspecting Floors

Each site inspection was carried out by two staff members. They discussed their findings and agreed on the most appropriate score. During inspections all of the data was recorded, either by hand on a spreadsheet or using a tablet computer. Several photographs are taken at each site.

All results are based on applying our experience to our brief observations. We did not measure the dimensions of the restraints; nor did we calculate the size of the restraints required.

13.5 Analysing Data

The data collected was analysed as follows.

For each of the elements we selected the lowest *multiplier* to represent the weakest link in the chain. The basic score was then multiplied by the lowest multiplier to get the final score. The final score is in the range of 0 to 3.

In addition, we noted for each element the number of multipliers that equal 0 and the number that equal 1. This is useful in assessing the cost to upgrade to full compliance.

After Stage 1 we developed the analysis, largely to improve the readability of the results and to minimise any ambiguity.

We also added one additional criteria. Whereas initially we had a column *Restraint required?* We now have two columns, *Restraint Required – Assessed?* and *Restraint Required by NZ Standard?* We added this extra column as in a number of situations we assessed the prescriptive solution from the NZ Standard did not result in a suitable recommendation, being too onerous in some cases and too lenient in others. In most cases the column entry is identical.

For each building floor there are 8 elements, although not all elements are present in each case. For each element that is present, we state if a restraint exists and if that restraint is *inadequate*, *adequate* or c*ompliant*. We also include a rough order cost estimate to upgrade that element.

We define a *compliant restraint* as one with sufficient manufacturers' markings on it that it can easily be verified as compliant. We would have also included any restraints with sufficient information on Council files to similarly verify, but did not find any of this category. We define an *adequate restraint* as one which we assess, by visual inspection is adequate and which has a final score of 1.0 or greater. Essentially these categories are two different paths to conclude the restraint is adequate. Where an element is present but due to its low weight or robust primary fixing (hanger) a separate restraint is not required by the code, we classify that as an *adequate restraint*.

An *inadequate restraint* is one with a final score of less than 1.0.

The overall summary table for each city summarises the 8 elements for the 20 floors. In the text we group *adequate* and *compliant* restraints together.

13.6 Property Files

After selecting buildings and specific floors for inspection, we approached the Territorial Authorities (TAs) Wellington City Council and Auckland Council to obtain the property files. WCC were very helpful in allowing us access to files. We then perused the files looking for documents relating to the design and consenting of seismic restraints.

We obtained the property files for all Wellington buildings. We had difficulty in obtaining files from Auckland Council; after considering the information obtained from the Wellington files (lack of useful data) we concluded that additional file information was not likely to add to our results.

13.7 Cost Estimate

We prepared a rough order cost estimate to upgrade the restraints on each floor to comply with the standards. This is a rough order cost only; actual costs will vary due to access, working hours, product supply, contractor, council fees, professional fees, etc. GST is not included in the cost estimates.

14.0 Appendix C – Analysis Summary Sheets

Wellington Summary (W T4)
Wellington by Element (W T3)
Auckland Summary (A T4)
Auckland by Element (A t3)
Notes to Summary tables

15.0 Appendix C – Analysis Sheets (In Volume 2)

Wellington Analysis Sheet 1 (W T1)
Wellington Analysis Sheet 2 (W T2)
Auckland Analysis Sheet 1 (A T1)
Auckland Analysis Sheet 2 (A T2)
Analysis Table Notes

16.0 Appendix D – Inspection Sheets (In Volume 2)

Survey Spreadsheet Template
Auckland Inspection Sheets (21)
Wellington inspection Sheets (20)