Twenty-five years of strengthening Wellington

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2010 NZSEE
Conference

ABSTRACT: Wellington’s inhabitants have long known that their region is highly seismically active. The first European settlers experienced dramatic demonstrations of the earth’s power and, for a time at least, adjusted their building styles to suit. The age of Wellington’s current building stock ranges from circa 1900 to the present day. Included within that range are many structures that are now adjudged earthquake prone.

Following the 1942 Wairarapa earthquakes some limited seismic retrofit/securing was undertaken, but it was not until the 1970s that central and local government began to systematically address the risks that the older, under-strength buildings posed to their inhabitants and to the commercial viability of Wellington. This coincided with a growing awareness of the need to conserve buildings that are significant from a heritage perspective.

Over the last 30 years Wellington’s structural engineers have developed and designed many seismic retrofit solutions. During that time, through experience and innovation, the structural-effectiveness, appropriateness and cost-effectiveness of the solutions have improved significantly. The retrofit portfolio and experiences of Dunning Thornton Consultants through this period illustrates the development of strengthening expertise.

The seismic engineering profession’s ability to further refine the application of effective retrofit and to lead its clients to a reduction in risk is essential for the ongoing commercial viability of Wellington.

1 INTRODUCTION - WELLINGTON’S SEISMIC HISTORY

According to Maori tradition, a great earthquake known as Haowhenua (land swallower or destroyer) joined Motukairangi (Miramar Island) to the mainland. This is thought to have occurred in the 15th century.

Wellington residents have long known that their environment places high demands on their building structures. The first organised European settlement occurred in 1840, and in that same year settlers in Petone experienced a fire which, presumably fanned by the wind, destroyed 14 cottages. This was followed the next morning by an earthquake, and then major flooding occurred a couple of days later.

Then, on 16 October 1848, during a storm, the settlement at Wellington suffered its first major earthquake which measured 7.8 on the Richter scale and had its epicentre in the Wairau Valley. Damage in Wellington was significant. Mary Taylor, an early settler, wrote “We have had…. lots of earthquakes until they are quite common place. Two fifths if not half the houses in Wellington were shaken down by the earthquake and the town is vastly improved as a consequence”.

Many of the buildings were rebuilt in timber. One settler who did not was Baron Charles von Alzdorf who rebuilt his wrecked two-storey hotel in Willis Street robustly in brick, claiming that this one would never be destroyed by earthquakes; that it was earthquake-proof!

Then, just a few years later at 9.11 pm on 23 January 1855, Wellington experienced a massive earthquake estimated to be 8.2 on the Richter scale, still the largest earthquake in NZ (since the beginning of European settlement). It was centred on the Wairarapa Fault where horizontal ground displacements of around 18 m have been measured.

In Wellington, there was considerable damage including the complete collapse of the Wellington Provincial Government offices. The population of Wellington at the time was 6000 and approximately 80% of chimneys fell down. Happily, and somewhat remarkably, there was only one death in Wellington. Baron Charles von Alzdorf perished when his ‘earthquake-proof’ hotel collapsed on him!

Subsequently, the earthquake was regarded as a positive event as it created flat land (always in short supply) in Wellington. Significantly also, it raised the seabed around the central city waterfront - enabling extensive reclamation. For the rest of the nineteenth century, construction was predominately in timber which helps to explain why Wellington has the second largest wooden building in the world, The Old Government Buildings, constructed during the 1870s. Construction in brick did not really recommence until the early 1900s following some major fires and sufficient time for the memories of earthquakes to grow dim. The great majority of Wellington’s unreinforced masonry (URM) building date from the period 1900-1930.

As elsewhere in NZ, the earthquakes in Murchison and Napier, together with 1935 legislation introducing seismic design consideration and the emerging technologies of structural steel and reinforced concrete, saw the use of brick as a structural element became rare by the end of the 1930s. Wellington has a number of significant, large, riveted steel buildings from the boom period of the 1920s, together with many low-rise reinforced concrete buildings dating from the 1930s and 1940s and early 50s designed (for the most part) with little understanding of seismic response or resistance. The moderate 1942 Wairarapa earthquakes reinforced views of the inadequacy of unreinforced masonry, but did not severely test the newer concrete buildings.

Structural/seismic knowledge and design expertise started their dramatic increase from the mid-to-late 1950s, led initially by the Ministry of Works, and then by the Universities and other researchers. Wellington’s history of development, coupled with its seismic exposure, its variable soil types, and a raising of the legislative bar, have left a significant legacy of strengthening to be undertaken.

2 LEGISLATION

The institutional and public understanding of the need to address a backlog of understrength structures through seismic retrofit dates from the 1970s. The Wellington City Council (WCC) have, for a long time, taken a proactive role in identifying at-risk buildings and in encouraging seismic retrofit.

In response to Section 624 of the Local Government Act 1974, the WCC carried out a review of non-residential URMs and classified them as Class A (less than 0.5 of NZS1900 Chapter 8 1965), Class B (between 50% and 100% of NZS1900 Chapter 8 1965) and Class C (in excess of the requirement of the 1965 code) during the late ‘70s. They followed this up in the 1980s and 1990s with a reasonably vigorously applied policy of notifying owners of URMs to strengthen, unoccupy or demolish their buildings. Strengthening targets of two-thirds of NZS1900 Chapter 8 were set - somewhat in excess of the implied requirement of 50% contained within Section 624.

During the 1990s, following the introduction of the 1991 Building Act, the strengthening target was raised to 100% of Chapter 8. Somewhat significantly, under the *Change of Use* provisions of the 1991 Building Act, WCC interpreted “comply, as near as reasonably practicable, to the same extent as if it were a new building” as being satisfied by meeting full compliance with NZS1900:Chapter 8 1965, until around 2002 when NZS4203 became the benchmark.

Following the introduction of the Building Act 2004, WCC introduced an Earthquake Prone Buildings Policy (EQP) outlining its approach to identify and confirm strengthening of at-risk buildings. The initial version included a matrix which considered Risk and Importance to determine a maximum time to strengthening of between 5 and 15 years. In 2009 that was increased to a time range of 10-20 years. WCC determined to review round 3800 buildings designed prior to 1976. Currently, around 50% of these buildings have had preliminary assessments (IEPs), and around 30-40% of those assessed have had been identified as being potentially earthquake-prone.

3 RESPONSE TO PERCEIVED RISK

Wellington's minor shakes serve to frequently remind her residents that they live in a seismically active zone. However, the response to the implied risk has varied significantly, particularly in their enthusiasm to retrofit. Incentives and disincentives for building owners to undertake seismic strengthening have been studied by others, and the resulting picture is a complex matrix. The main factors can be summarised as follows:

- Legislative requirements/enforcement – central and local government
- Financial factors – construction cost, insurance premiums, rentals before and after retrofit
- Perceived risk – to life/property/continuing operations
- Commercial opportunities – relative location, urban regeneration, residual structural value, sustainability
- Heritage preservation

Building owners can be categorised broadly into two types: 'Institutional' and 'Private/Commercial'. Institutional owners, particularly those that hold property and buildings indefinitely, typically take long-term views on risk and building value, and are proactive in undertaking retrofit and preservation of heritage. Examples include:

- Central Government – Parliament Buildings, Old Government Buildings
- Victoria University of Wellington – Hunter, Rankine Brown, Weir House
- WCC – Council Building, Town Hall, St James Theatre, Embassy Theatre, public multi-unit housing (with central government)

Private/Commercial owner response shows few trends, but it is clear that those retrofit projects that are regarded as successful (at least financially) are those that have, for the most part, combined seismic retrofit with more general refurbishment/change of use and lifting of perceived quality, and thus improved commercial return. This has happened where:

- There has been some form of urban renewal
- There has been a demand for refurbished space (retail/office)
- The building has some residual value: heritage, plot-ratio, original quality, location (e.g. Waterfront)
- The developer has been able to add storeys to the structure to improve the commercial return

This last incentive has been achieved with mixed results, both structurally and architecturally. One that is well regarded, at least from an architectural/heritage viewpoint, is the Te Puni Kokiri building.

Relatively few buildings have been just strengthened without some form of associated refurbishment; this is particularly apparent in older, semi-industrial zones that do not have the advantages of a desirable location.

Some commercial/private buildings that illustrate these trends include:

- Odlins, Shed 21, Shed22
    - *Waterfront location, bulk and height that could not be replaced under current planning rules.*
- Sheds 13, 21 & 22
    - *Waterfront location, recognised heritage value, change of use.*
- 44 & 56 Victoria Street, 29-31 Willis Street (Chews Precinct)
    - *Urban regeneration, residual structural value, heritage value, change of use.*
- 2-12 Allen Street, The Exchange Allen/Blair Street, 1-5 Blair Street
    - *Urban regeneration, change of use, heritage*
- 1 Marion Street, 123 Cuba Street, Ballroom Cafe
    - *Strengthening only, some heritage value.*

It can also be noted that in a locally depressed area (and one not undergoing urban regeneration), lack of seismic robustness does not particularly affect the value of the building/property. However, the same cannot be held true in an area with higher property values. In these locations, the building's value can be more significantly affected by its seismic status.

The introduction of the 2004 Building Act and the resulting WCC Strengthening Policy has increased the catchment of earthquake-prone buildings, effectively to include 1935 – 1976 concrete and steel-framed buildings. Again, reactive trends are difficult to categorise particularly as the global financial crisis has had an effect on commercial building occupancy and property values. One noticeable reaction has been the concerns raised amongst the owners of multi-unit residential buildings (apartments).

A significant number of older apartment buildings have been identified as being potentially earthquake-prone and this has had an immediate effect on the turnover of ownership. Illustrating perhaps the general public's preoccupation with value rather than risk, potential purchasers have been concerned to know their potential share of the strengthening cost. This is leading a number of communal owners (Body Corporates and the like) to commission strengthening design sufficient at least to reliably establish the cost of strengthening.

An emerging development is that the WCC have recently started sending building owners, occupiers, mortgage holders and other stakeholders, formal notice of their building's earthquake-prone status; these notices to be publicly displayed. Just what the effect of these notices will be on values, rents and occupancy levels (and hence the imperative to retrofit) should become better identified in the near future.

4 ENGINEERING RESPONSE

Just as the Wellington environment is demanding on its structures, so it is on its structural engineers and building designers. With its active seismic status and location astride a number of tectonic faults, gale force winds, corrosive salt-laden atmosphere, steep hillsides, variable geotechnical conditions and exposure to tsunami, it is a challenging and rewarding location in which to practise structural engineering.

Structural engineers have, for the most part, responded well to the challenges and, not withstanding its lack of a traditional engineering university, Wellington has developed somewhat of a reputation as a centre of excellence for seismic engineering. While its position above a number of active faults makes this a necessity, it is also no doubt due in part to the presence of the central government, the proactive attitude of the WCC, and the presence (at least until the 1980s) of the Ministry of Works and other government engineers.

The expertise is now carried on locally by private practitioners with support from crown entities such as GNS Science and BRANZ and, of course, with research at Canterbury and Auckland Universities.

Seismic retrofit of significance first occurred in Wellington following the 1942 Wairarapa Earthquake. It involved primary mitigation by securing and by removal of decorative pediments, parapets, chimneys, cupola and the like that had been damaged or had been demonstrated to be unsafe during the shaking that occurred in June and August. Much of the damaged brickwork was simply repaired. Reports state that Bricklayers from all over New Zealand came to help.

Damage resulting from 1942 Wairarapa Earthquake:

Alexander Turnbull Library- Dominion Post Collection

EP Science- Earthquakes 1940 & 50s.

Some more useful structural mitigation was also carried out, primarily securing walls to diaphragms, addition of band beams and the like.

Seismic retrofit as we better know it began in the late seventies following the introduction of Section 624 of the Local Government Act and coincided with an awakening of public interest in the preservation of heritage buildings. During the 1970s and early 1980s a number of significant heritage buildings were demolished with little public comment but, by the end of the 1980s, local government (spurred on by the excesses of the 1980s property/building boom) had a clear mandate to consider heritage - at least when contemplating demolition.

An example of this was the Hunter Building of Victoria University of Wellington (VUW). Declared earthquake prone in 1974, it was progressively emptied in preparation for demolition. In 1977 the *Friends of Hunter,* through petition and public subscription, convinced the university council to strengthen rather than demolish. It required a very substantial investment and was not completed until 1993.

Another reasonably high-profile retrofit project was the installation of concentric bracing into the DIC building in Lambton Quay in 1979. In retrospect it was not considered a success either commercially (it reportedly contributed to the failure of its department store owners) or structurally (the resulting structure has been adjudged earthquake prone under current Building Act requirements).

The history and development of the structural engineering practice Dunning Thornton Consultants (DTC) has, to some extent, followed the development of the practice of seismic retrofit in Wellington. Founded in 1979, it has been involved in over 70 strengthening projects.

5 CHANGING TECHNOLOGIES

In the following section the paper reviews the development of retrofit technologies, illustrated principally by DTC's Wellington projects.

It is appropriate to consider retrofit in a number of categories.

5.1 Low Rise URM

Like most NZ towns and cities, Wellington has many one and two-storey commercial buildings. Although now largely removed from the central business district, there are plenty still to be found in Te Aro, and outlying suburban centres. Typically of unreinforced brick side walls, timber floors and with an open retail frontage, these buildings generally have little transverse strength or stiffness. They also generally have little by way of floor-to-wall ties.

Early strengthening concentrated on:

- Installing primary transverse frames – concrete moment resisting frames (MRFs) or steel, rectangular, portal frames. The eccentrically braced 'K' frame came to prominence during the 1980s, and this soon became a frame of choice because of its relative affordability and stiffness. Generally not preferred by the architectural/heritage community, we now try our best not to place them in the shop-front window.

Eccentric Chevron Bracing (K-Frames)

Reinforced Concrete MRFs

- Fixing floor and roof diaphragms to the brick walls (and the new transverse frames). This inevitably involved many low-capacity fixings between a perimeter member (steel angle or timber ribbon plate) and both the brickwork and the timber joists. Different solutions were required for parallel and perpendicular joists, and were developed from first principles and common sense.

Diaphragm/wall connections

- Providing out-of-plane strength to the brickwalls, typically by way of steel mullions, particularly for upper-storey walls carrying small gravity loads.

Out-of-plane strengthening

Added shear walls

Where brick walls were found to have insufficient in-plane strength, they have been strengthened typically with sprayed concrete and/or additional walls or stiff frames.

As floor plate size increases, it is common to improve diaphragm strength-typically either with steel flat bracing or by the addition of sheet bracing above or below the floor. Alternatively diaphragm spans are reduced by the introduction of additional frames or cores.

Examples include:

- Kaiwharawhara Road Depot
- Nicolini's, 26 Courtenay Place
- School Road Warehouse, Kaiwharawhara
- The Exchange Complex, Allen/Blair Streets
- 29 Willis Street
- 1 Marion Street

The Exchange Complex

29 Willis Street

Steel MRF

More recent retrofit technologies have included vertical post-tensioning to improve both in-plane and out-of-plane performance, the use of Fibre Reinforced Polymer (FRP), and the use of controlled-deflection yielding devices.

Examples include:

- 202 Thorndon Quay
- Shed 13, Wellington Waterfront
- Chest Hospital/SPCA

Shed 13

Chest Hospital (SPCA)

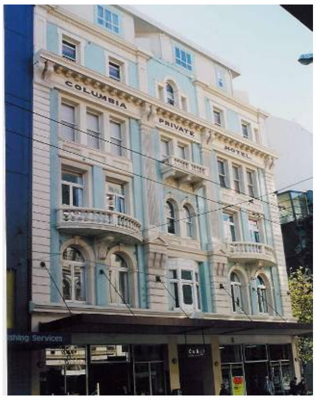
5.2 Medium Rise URM

Unreinforced masonry buildings were constructed up to around 6 storeys, mostly prior to 1920. Smaller footprint buildings were retrofitted in a similar manner to the low-rise URMs. The dependability of modelling flexible diaphragms in irregular structures provides some uncertainty in effectively retrofitting these buildings.

Examples include:

Columbia Hotel (apartments)

Odlins (floors replaced with concrete)



Columbia	*Odlins*

5.3 Public Assembly Buildings

Public assembly buildings are characterised by having high-stud, large-volume spaces (auditoriums) with infrequent diaphragms and high-occupancy risk. Typically, the structures have substantive mullions (columns) on grids, but inadequate transverse frames and little or no diaphragm strength at roof level. Retrofit solutions have included introduction of transverse frames (typically shear walls) together with new/additional diaphragm bracing at ceiling level.

Examples include:

Basilica of the Sacred Heart 1985

St James Theatre 1997

Embassy Theatre 2002-2010

Basilica	*St James Theatre*	*Embassy Theatre*

5.4 Steel Framed Buildings

Wellington's developers have found steel-framed construction attractive for multi-storey buildings - principally during three periods over the last 100 years. Before that, though, New Zealand's first steel-framed building, The Public Trust, was (perhaps prophetically), designed by San Francisco architects. The year? 1905!

The first proliferation of steel buildings occurred during the boom period of the 1920s; this was followed by various government sponsored structures during the 1930 depression. Secondly, during the 1960s and 70s-culminating in the BNZ (now State Insurance) tower when militant industrial action by boiler makers effectively curtailed construction in steel for some time. Thirdly, from the late 1980s to the present day, steel has gained a larger share of the Wellington construction market.

DTC have an ongoing involvement with three of the oldest examples. The Public Trust Building, historically a gem, is currently receiving careful analysis. The Hope Gibbons Building in Taranaki Street and the Harbour City Centre (formerly DIC) in Lambton Quay, both designed and constructed in the mid 1920s. These structures are characterised by minimal beam-column moment connections and minimal encasement reinforcement.

The Harbour City Centre was strengthened in the 1970s with concentric, steel, chevron bracing which leaves it earthquake-prone by current standards. Consent-ready design proposes axial hysteretic dampers to be inserted into the braces to provide dependable compression/tension yielding.

Analysis of the Hope Gibbons building suggests that member sizes are adequate if the connections can be improved.

Interestingly, the government-designed steel-framed buildings that followed the 1931 Napier Earthquake included considerably greater beam-column moment connection. (e.g, The Government Life Insurance Building – now Tower).

Hope Gibbons

Harbour City Centre (DIC)

Testing of axial hysteretic damper

5.5 Concrete Buildings

Concrete buildings that require retrofit typically originate between 1930 and 1976. Strengthening undertaken prior to 2000 was relatively rare as they were not covered by the earthquake-prone legislation. They were however ‘caught’ by change-of-use requirements in the 1990s.

The inadequacies of concrete buildings are quite different to URMs; diaphragm strength, diaphragm/frame connections and out-of-plane capacity are typically not of primary concern. For the concrete structure, seismic inadequacy arises primary from lack of ductility and inappropriate hierarchy of strength with some general strength inadequacy of the primary yielding elements.

The retrofitter’s arsenal is extensive and includes:

- Addition of steel bracing (notably, eccentric chevron bracing)
- Addition of shear walls or concrete MRFs.
- Conversion of perimeter infill concrete panels to shear-wall elements
- FRP to improve flexural strength, confinement and shear strength
- Selective weakening to reduce torsion and to lengthen period
- Use of the ‘Pagoda’ column (or shear wall) to force a desirable collapse mechanism

DTC has used these methods in a variety of applications. A selection follows:

Buckle Street Museum (now Massey) circa 1930, strengthened 1999. A high stud with a complex form and window-less walls on the upper floor had resulted in an inherent soft storey. Large shear walls were introduced at ground floor to match the upper floor stiffness and to protect the lower level perforated façade.

Te Puni Kokiri (was State Insurance) circa 1938, strengthened 1997. A large proportion of concrete ‘infill’ walls would have dominated the response of the frames. The walls were strengthened to enable them to perform effectively as shear walls.

The Poultry Building, 56 Victoria Street circa 1927, strengthened 2005. A corner building with concrete infill wall panels, it was prone to a torsional response. The concrete walls were strengthened and a bay of eccentric chevron bracing was introduced to counteract the torsional action.

Buckle St Museum (Massey University Wellington Campus)

Te Puni Kokiri

The Poultry Building

The National Mutual Building, 44 Victoria Street circa 1960 strengthened 2005. Designed at the beginning of the modern era (in relation to seismic design), the structure was reasonably well detailed and has robust shear walls in the longitudinal direction. Transversely, short column and overstrength beams resulted in the possibility of a column-sway mechanism. A stairwell wall was strengthened to act as a 'pergoda' column, to give confidence of a resulting beam-sway mechanism. FRP was wrapped around the short columns to give reliable ductile performance.

119-125 Ghuznee Street – This was a low-rise concrete building with brick infill panels. Strengthening involved selective weakening of the brickwork together with FRP wrap to beams and columns to improve frame performance sufficient to allow a change of use.

178 Willis Street circa 1963, strengthened 2002. This multi-level office building had an existing concrete shear core with inadequate shear strength. Sprayed concrete jacketing of the core improved performance to allow a change of use.

Central Park Apartments circa 1966, strengthening2010. This tower/podium structure has inadequate transfer diaphragms and inadequate transverse strength in the podia. Selected weakening, separating the tower from the podia, significantly reduces demand on the podia structures and through period lengthening also reduces demand on the tower itself.

National Mutual

178 Willis Street

Central Park Apartments

Weir House Student Hostel, circa 1933, strengthening 2010. Originally designed in brick, constructed as concrete (following Napier Earthquake) with punched perimeter shear walls and reinforced concrete gravity frames. Internal, non-loadbearing terracotta partitions posed a potential hazard to the occupants. Insitu flexural testing, utilising airbags (together with the addition of some new concrete shear walls), established adequate performance.

5.6 Base-Isolation

Three important heritage buildings have been base-isolated in Wellington (Parliament, Old BNZ group and the Maritime Museum [*design by Holmes Consulting Group*]) Base isolation has proven to be a key retrofit technology when conditions, location and budget permit.

6 HERITAGE RETROFIT

Seismic retrofit of heritage buildings and structures provides a dilemma for the structural engineer. Surely, if a building merits conservation, then it warrants protection indefinitely, implying a higher than normal importance factor. This is at odds with objectives of minimal intervention and frequent calls for reduced performance requirements for heritage structure.

The solution (and compromise) is to firstly get the best from the existing structure and secondly to either hide any new structures from view or to add structure in such a way that it is complementary and yet is obviously added (and hence removable). Most of the strengthening projects that DTC have been involved with have had a heritage component. Notable examples include:

- St James Theatre
- Embassy Theatre
- Sheds 13, 20, 21, Wellington Waterfront
- Odlins
- Massey University, Wellington Campus
- Old National Mutual Building
- Sacred Heart Cathedral

8 THE WAY FORWARD

There is no doubt that one of the outcomes of the 2004 Building Act's, Earthquake Prone provisions has been to provide work for Wellington structural engineers. For many building owners the implications are still not clear, and will not become so until all the at-risk buildings are assessed and strengthening requirements costed. This may take three to five years.

The enthusiasm of owners to undertake actual strengthening is extremely varied and is likely to hinge on financial necessity rather than perception of risk, particularly for many private and commercial owners.

Crucially, some owners appear to have a modus operandi of shopping around between consultants to find those recommending the lowest target strength i.e. to achieve 34% NBS (New Building Standard). It is my view that this is damaging to the profession and to Wellington. Engineering consultants should be acting co-operatively, recommending cost-effective solutions (measured on a whole of life basis) and leading their clients and the public at large to realise the benefits of appropriate retrofit.

While NZSEE and WCC both recommend strengthening to 67% NBS, the lack of a legislated targeted strength beyond 34% NBS is perhaps unfortunate from engineering and risk perspectives. What is clear is that for the next few years at least, considerable engineering effect is going to be expended to establish whether structures exceed 34% NBS. The availability of new assessment and analysis tools are making that process more reliable.

Similarly, the emergence of new retrofit technologies, both through academic research and through innovative practitioner application, should ensure that the output of the retrofit designer becomes more productive and effective. Generally, there is a sense that with the seismic retrofit research currently being undertaken at Auckland and Canterbury universities, practitioners will soon have most the analytical and technological tools that will be required to complete the strengthening that will be required over the next 20 years. A notable exception is a reliable and time-effective analysis tool to model pounding. Cross-boundary pounding is a problem, politically (to regulators), commercially (to owners), and to engineers. While research is underway, the practitioner perception is that useful solutions are some way off.

All in all Wellington structural engineering consultants are going to be concerned with retrofit for quite some time.

9 CONCLUSION

Wellington is a seismic city, something its residents have been aware of from the earliest times. While its modern buildings may provide a high level of confidence of satisfactory seismic performance, its older buildings fall well short of current standards.

Over the last 30 years, seismic retrofit has slowly become recognised as a necessity and Wellington's structural engineers have developed and designed many seismic retrofit solutions. During this period, through experience and innovation, the structural-effectiveness, appropriateness and cost-effectiveness of the solutions has improved significantly.

The seismic engineering profession's ability to further refine the application of effective retrofit and to lead their clients to a reduction in risk is essential for the ongoing commercial viability of Wellington. It will take the resolve of regulators, the commitment of its building owners, and the skill and experience of its retrofit design community to provide a satisfactory level of seismic robustness for Wellington City.

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