Earthquake Prone Buildings – Guidance and Approaches

Auckland Council Guide

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Waitematā Local Board
Auckland Council

This guide is written for building owners, tenants and building managers who have been issued a council notice regarding the Potential Earthquake Prone status of their building. In addition, those who are interested in the earthquake assessment and retrofit process may also find this guide useful.

Foreword

Waitematā Local Board's vision is to create the world's most liveable city at the local level. The protection and promotion of our heritage and preserving historic character is vital to achieving that.

The Waitematā area is home to some of Auckland's most historic buildings. While many of those buildings are in the city centre, there are others around our area that it is critical we also protect, such as in New Zealand's first suburb, Parnell, and one of the world's largest collections of Victorian-era wooden buildings in Ponsonby/Grey Lynn. Age catches up with us all and heritage buildings are no different. The materials and construction methods used in days gone by mean that there are risks associated with those buildings. The likelihood of a damaging earthquake in Auckland is low but it cannot be ignored. Waitematā has heritage buildings that fall short of seismic performance standards and are consequently considered earthquake-prone.

Retrofitting to strengthen and protect structures can be confusing and costly, even causing some owners to consider demolition. But our community has told us that protecting, promoting and preserving heritage buildings to ensure their enjoyment now and in the future is important.

New Zealand's recent earthquake history has focused attention on the value of seismic resilience in protecting our heritage. Between 2011 and 2017 around 2000 potentially earthquake-prone buildings were identified in Auckland.

Council's approach to identification now follows legislation introduced in 2017. We are committed to the survival of our built heritage by ensuring it is structurally-sound, but we do not want seismic strengthening work to adversely affect the value of a building, nor should it compel an owner to resort to demolition for fear that strengthening work will be uneconomic.

That commitment has led to this overview of earthquake assessment processes. It outlines seismic strengthening requirements and common vulnerabilities for historic buildings, the retrofit process, and potential costs. We have aimed to make it as easy to read as possible while retaining the necessary technical detail.

Vernon Tava Board Member
Waitematā Local Board

Purpose of this document

The purpose of this document is to provide a high-level overview of the earthquake assessment process, the common earthquake vulnerabilities of historical buildings, common approaches to earthquake retrofit and the potential costs associated with those approaches. In the wake of devastating earthquakes in Canterbury and the risk of further earthquakes in other parts of New Zealand, the Government has made substantial changes to the seismic strengthening requirements in the Building Act. This guide has been prepared to help property owners in Auckland better understand their risks, and assist them with finding an appropriate way to both improve public safety and comply with new regulations that affect their properties.

This document has focused on a particular type of building that can be earthquake prone: a two storey unreinforced clay brick masonry (URM) building. Previous earthquakes have demonstrated the vulnerabilities of URM construction. And many URM buildings have not been strengthened to resist earthquake forces and may be vulnerable in future earthquakes. Two storey URM buildings are a common sight in Auckland's urban environment. They are usually older buildings, and often have historic heritage and character value that is appreciated by the wider community.

Although the focus in this document is on two storey URM buildings, the building characteristics, construction and retrofit techniques are often applicable to other historical building typologies.

Acknowledgements

This report was prepared by officers of Auckland Council in collaboration with EQ STRUC Group for Auckland Council, with funding and project oversight provided by the Waitemata Local Board.

Contact list

For further information on managing earthquake prone buildings under the current legislation or for technical advice on Historic Heritage and Character properties, contact the Council at 09 301 0101.

Disclaimer

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1.0 Auckland Seismology

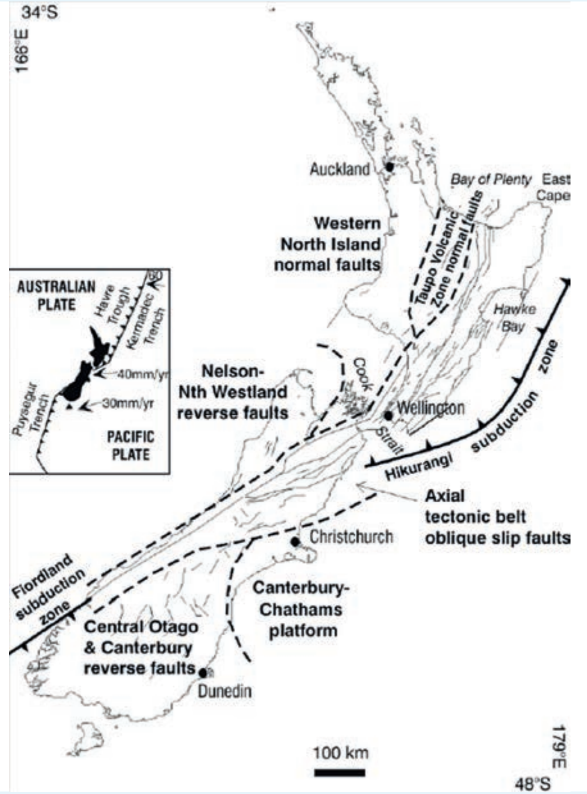


FIGURE 1: Plate movements and major fault systems (Image Courtesy of GNS Science).

New Zealand is situated across the margin between the Australasian and Pacific Plates, which are moving relative to each other by approximately 40mm/yr. In the North Island, the plates converge with each other and the Pacific Plate is driven under the Australasian Plate (i.e. subduction). In the lower South Island, the opposite occurs and it is the Australasian Plate that is being sub-ducted. In the upper South Island and Cook Strait area, the two plates slide past each other in what is termed a ‘strike-slip’ relationship (see **Figure 1**).

As the plates move against each other, excessive stress in the earth crust gradually builds up before eventually being released as earthquakes. Imperceptible seismic activity occurs across New Zealand (and the rest of the world) every day, but in the areas where movement is greatest along the major faults, larger earthquakes occur from time to time, such as the 1931 Hawke’s Bay and the 2010-2011 Canterbury earthquakes.

The Auckland region sits on the Australasian Plate approximately 300-500 km northwest of the active plate boundary running along the length of New Zealand. The landscape is made up predominantly of Cretaceous to Holocene sedimentary and volcanic rocks that overlay an older layer of Greywacke of Triassic to Early Cretaceous age (Edbrooke, 2011). Those faults that have been mapped in Auckland appear to be ancient and inactive, and many are thought to have originated when major geological changes occurred when New Zealand separated from Gondwana 80 million years ago (Kenny, Lindsay & Howe, 2011).

There are only a handful of active faults identified as potentially affecting the Auckland region. The closest being the Wairoa North Fault and the Kerepehi Fault (see **Figure 2**). Both of these faults are located in the southern part of the region and are thought to be capable of producing characteristic earthquakes of magnitudes greater than 6. However, the effects tend to be offset by the long return period of earthquakes generated by these faults (about every 12,600 to 20,000 years respectively).

From 2004 to 2014, 582 earthquakes exceeding magnitude 2 were detected in the Auckland and Northland region. Most earthquakes were less than magnitude 3 and were not felt, but one magnitude 4.5 earthquake, which occurred on 21 February 2007, was felt widely across the Auckland region. It was located in the Hauraki

Gulf, 6 km east of Orewa. This earthquake was part of a swarm of ten separate earthquakes that occurred within a 24-hour period. It caused

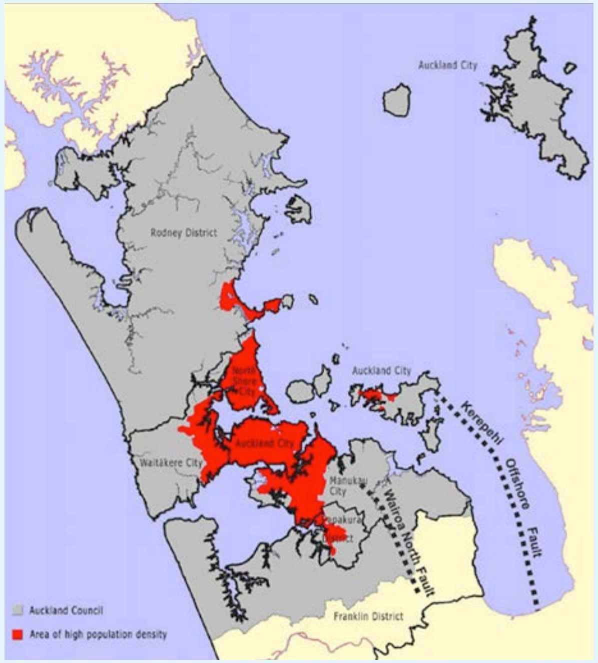


FIGURE 2: Relative locations of the Wairoa North and Kerepehi Faults (Image Courtesy of GNS Science)

minor damage to houses (particularly brick chimneys and walls) and their contents. A total insurance pay-out of $1.5 million was made, with 495 damage claims reported, primarily from residential properties in the former Rodney District and North Shore City. Auckland Council monitors these events and other factors in conjunction with GNS and other organisations, and the data obtained are used as indicators to help determine Auckland's earthquake risk.

Since the 1970s the New Zealand Building Code has placed strong emphasis on earthquake design of buildings by requiring buildings to be designed with earthquake resilience levels corresponding to the building use or importance. Most modern buildings are designed to withstand the regionalised peak ground accelerations generated by at least the 1 in 500 year return period earthquake. Fundamentally, the peak ground acceleration is used by engineers to establish the design earthquake forces on a structure in any given region of New Zealand. The regionalised ground acceleration value is modified during the design process to account for amplification caused by the local geology and the dynamic responses of the building.

As a recognition of Auckland's relatively low seismic activity, the peak acceleration for the 1 in 500 year return period earthquake Auckland is 0.13g and is significantly lower than other regions of New Zealand where the level of seismic activity is higher. Refer to **Table 1** for a comparison of Auckland design seismicity with other regions in New Zealand. In simple terms, a building in Wellington would be designed to resist an earthquake that is at least 3 times stronger than a similar building built on similar geology and subsoil conditions in Auckland.

Region	Peak ground acceleration	Relative earthquake demand requirement with all other conditions being equal
Auckland	0.13g	1.0x (basis of comparison)
Hamilton	0.16g	1.2x
Tauranga	0.20g	1.5x
New Plymouth	0.18g	1.4x
Napier	0.38g	2.9x
Wellington	0.40g	3.1x
Masterton	0.42g	3.2x
Greymouth	0.37g	2.8x
Christchurch	0.30g	2.3x
Dunedin	0.13g	1.0x
Invercargill	0.17g	1.3x

TABLE 1: Peak acceleration values for different cities within New Zealand.

[1] G-force stands for the force of gravity acting on a body. It is measured in g's, where 1g is equal to the force of gravity at the Earth's surface, which is 9.8 metres per second per second.

2.0 Earthquake Prone Building Legislation

2.1 Introduction

As of 1 July 2017 New Zealand has a national system for managing earthquake-prone buildings that has superseded all previous EPB policies held by Territorial Authorities. This system is consistent across the country and focuses on the most vulnerable buildings in terms of people's safety. It categorises New Zealand into three seismic risk areas and sets time frames for identifying and taking action to strengthen or remove earthquake-prone buildings.

The Building Act 2004 defines an earthquake prone building as one that would be likely to completely or in part collapse in a 'moderate earthquake' causing injury or death or damage to other property. The term 'moderate earthquake' is defined in regulations under the Act as one that would generate shaking, at the site of the building, that is of the same duration, but one-third as strong as what a new building at the same site would be designed for.

In practice, an earthquake-prone building is defined as one that is less than 34% of the new building standard, or NBS.

The definition of an earthquake-prone building takes into account a range of factors, including different levels of seismic risk around New Zealand. This means that the same non-earthquake prone building (i.e. 34%NBS or more) in Auckland where the seismic risk is lower may be considered as earthquake prone if the building was located in Wellington where there is relatively high seismic risk.

Further information on the national system can be found on the MBIE website: www.building.govt.nz/managing-buildings/managing-earthquake-prone-buildings/

2.2 Building Owner's Obligations

Once a building has been confirmed by Auckland Council as being earthquake prone, that building or parts thereof identified as earthquake prone will be required to be retrofitted to no less than 34% of the new building standard (34%NBS). Building owners are encouraged to retrofit buildings to a higher %NBS earthquake rating where practical.

Auckland Council recognises the varying financial and practical implications building owners will face. Note, however, that a higher %NBS rating may be required rather than encouraged by Auckland Council if other provisions of the Building Act 2004 are triggered, such as a change of use or substantial alterations.

Under the current earthquake prone building legislation owners of buildings in Auckland will have 35 years to strengthen their buildings from the time that the earthquake prone status is confirmed with the issue of an earthquake prone building notice (EPB notice) under Section 133AL of the Building Act. Further explanation of the earthquake prone building identification process can be found in Section 3.0.

2.3 NBS explained

Percent of New Building Standard, or NBS, is a percentage which describes the seismic capacity of the building relative to New Building Standards for a not less than 50 year design life, i.e.

$$\frac{\textit{Assessed capacity of the building}}{\textit{Design earthquake demand determined using the current building standard}} \times 100\% = \%\text{NBS}$$

The assessed capacity of the building and the design earthquake demands are based on the Ultimate Limit State (ULS). The functional requirements of ULS are focused on preventing structural collapse and ensuring safe egress out of the building following an earthquake.

Buildings are inherently complex and the seismic capacity of the various portions of a building may vary, resulting in different %NBS values for different building portions.

The overall %NBS of a building is dictated by the lowest-rated building portion or building component.

2.4 Failure to comply

Building owners are encouraged to plan and retrofit their earthquake prone buildings prior to the expiration of the 35 year timeframe. The benefits of early planning and retrofitting include: The public and the building occupants receive the benefits of the improved building safety. The ability to plan the seismic retrofit with any refurbishment of the building. Financial incentives from the building not being earthquake-prone.

At any point after a building is deemed earthquake-prone, Auckland Council may elect to restrict access and approaches to a building in accordance with Section 133AR of the Building Act 2004.

If seismic retrofit of an earthquake prone building has not occurred within the 35 years set for earthquake prone buildings in Auckland, council can restrict approach to the building under the authority granted to it by Section 133AR of the Building Act 2004. The approach restriction will likely take the form of hoardings and may also include warning signs and/or temporary restriction of the requirement for occupants of any type to vacate the building until such a time as work is carried out to address the hazard. In addition, Section 133AU may apply, where an owner who fails to comply can incur a maximum fine of $200,000, plus $20,000 for each day that the offence continues.

While the responsibility for dealing with earthquake prone buildings rests with owners of the affected buildings, Auckland Council may undertake improvement work in accordance with Section 133AS (where the owner fails to do so), and seek to recover the costs from owners. It should also be noted that the choice to demolish an earthquake-prone building does not take precedence over other regulatory requirements, and cannot be used to add weight to an argument for a resource consent.

The status quo of minimum 34% of the new building standard (NBS) will not change and building owner(s) n Auckland will have 35 years to strengthen their building under the legislation

3.0 Seismic Performance

The identification, assessment and retrofit of an earthquake prone building is a multi-staged process, involving inputs from Auckland Council, building owner(s) and building professionals. The flow chart on the following page is intended to provide a high level overview of the whole process.

3.1 Identification

Under the new national system, the classes of building that Auckland Council will continue to require assessments for are those built of unreinforced masonry and those of pre-1976 construction that are also three or more storeys high or 12 metres or greater in height. Especially in Auckland, buildings designed or strengthened to the code implemented after 1976 (NZS 4203:1976 and subsequent codes) are not required to have assessments, unless they have a critical structural weakness that the council is made aware of. The reason for this is because, from 1976 onwards, various other factors have been introduced to take account of the performance of modern structural forms that use varied materials with improved detailing standards. Therefore, all buildings designed to NZS 4203:1976 and later will not be required is to undergo an assessment and potential upgrade under the earthquake prone building legislation

Auckland Council has previously undertaken Initial Seismic Assessments (ISA) many of all pre-1976 commercial and multi-dwelling buildings. Developed by the New Zealand Society of Earthquake Engineering (NZSEE), the Initial Seismic Assessment process utilizes the Initial Evaluation Procedure (IEP) as a coarse screening tool, where the aim is to provide an indication on the seismic performance of the building in terms of a potential %NBS rating. It is important to note that financial decisions relating to the building should not be made solely on the basis of the ISA outcome. ISAs are largely based on visual observations of the building's exterior and

> It is important to note that the ISA is a coarse screening process and it is encouraged that financial decisions relating to the building should not be made solely on the basis of the ISA outcome.

reviews of original construction documentation that may be found in council records. Key parameters in an ISA assessment are: year of the building's construction, structural makeup of the building, structural configuration and geometric characteristics, and proximity to neighbouring structures.

Under the current methodology, the owner of any building identified as potentially earthquake-prone are sent a letter informing them as such. This letter gives an owner the option of accepting the designation or opting to undertake their own assessment. Buildings may be deemed potentially earthquake-prone due to existing seismic assessments held by Auckland Council, or if the Council has other reason to suspect the building may have a low performance rating (i.e. If a class of building becomes of concern to central government).

Where an owner opts to accept an earthquake-prone building rating or fails to respond to the letter within one month of it being posted, they are issued with an EPB notice that is to be placed on the building in a prominent location legible from the exterior. A record of the building and its rating is also uploaded to the national EPB Register for earthquake-prone buildings on the MBIE website. From the date of issue of that notice, an owner of a building in Auckland has 35 years in which to upgrade the building to at least 34% NBS or otherwise address the risk. Until it is no longer a risk, the notice and the MBIE website record remain in place.

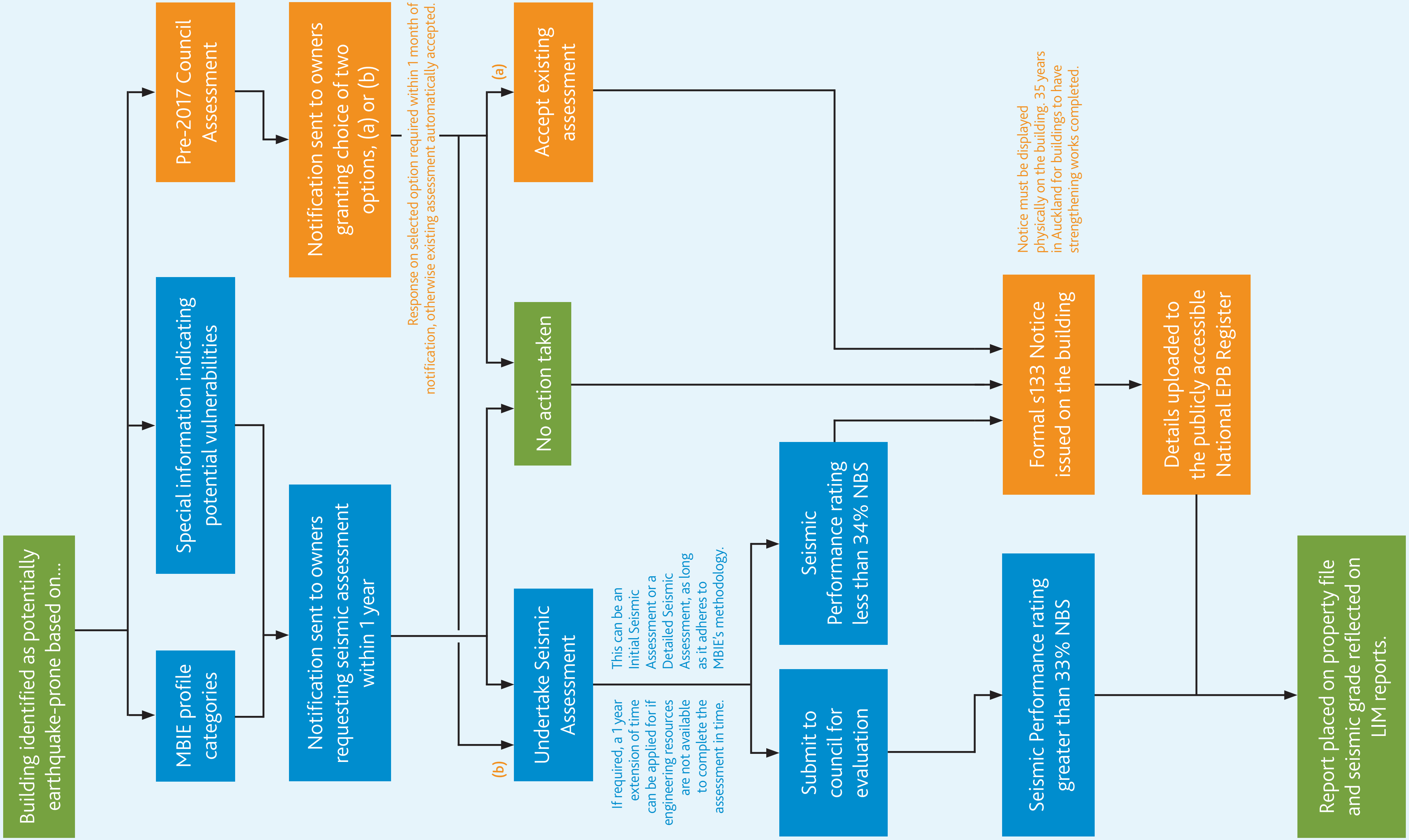


FIGURE 3: Flow chart illustrating the identification, assessment and retrofit process of earthquake prone buildings

If an owner chooses to engage their own engineer to conduct a new seismic performance assessment (ISA or DSA), they must do so within 12 months of the letter. Once a report is received, council staff will ensure it meets the prescribed methodology before making any changes to a building's seismic performance rating.

Information on the national system can be found on the MBIE website www.building.govt.nz/managing-buildings/managing-earthquake-prone-buildings/

3.2 Assessment

3.2.1 Independent Initial Seismic Assessment (ISA) Commissioned by the Building Owner

An independent initial seismic assessment commissioned by the building owner needs to be completed by a Chartered Professional Engineer (CPEng) and adhere to the methodology set by MBIE for these assessments. The differences in outcome between ISAs are commonly due to revisions of the ISA procedure, Council having limited information on the building at the time of the assessment, and limited access to the building to complete the visual inspection of the building.

The following points are an outline of the key aspects that an ISA should include:

- The Engineer should ask the building owner to provide a copy of the Property File or obtain a copy on behalf of the building owner. The Engineer should then complete a careful review of the information within the property file relating to the building structure, such as legacy consent plans and consented structural modifications.
- The Engineer should complete a visual inspection of the building's exterior and interior. Particular attention should be given by the engineer to identify and inspect any structural modifications and visible critical structural weaknesses.
- A written report should be provided by the engineer accompanying the ISA calculations. The report should outline observations from the assessment and from the review of the property file. In addition, the report should highlight the potential critical structural weaknesses, aspects that can affect the earthquake performance of the building, and recommendations for further review if required.
- A summary of the engineering assessment must be provided to the council in the format prescribed by the 'Engineering Assessment Guidelines'.

3.2.2 Detailed Seismic Assessment (DSA)

Detailed seismic assessments (DSA) are often the subsequent step following an ISA. But the two forms of assessments are independent and it is possible to conduct a DSA without completing an ISA. The DSA is intended to provide an in-depth understanding of how the constituent elements of a building will perform during an earthquake, identifying in particular any critical structural weaknesses that may need to be addressed.

As part of the DSA process, the Engineer will make use of appropriate standards, assessment guidelines, New Zealand and/or international research and non-invasive and invasive techniques to obtain information on the as-built arrangement of the building and to complete the assessment. The outcome of the DSA is significantly dependent upon the access to detailed information on the construction of the building, such as plans, specifications and design information, and information on modifications that had been carried out since the building's construction. The information is generally available from Auckland Council, however additional information may be available from other sources. The method of assessment is dependent on the quality of information available and the complexity of the building. For example, simpler forms of analysis procedure may suffice for a low rise structurally regular building and more sophisticated analysis procedures may be necessary to increase the confidence level of the assessment for a for complex and irregular building, see **Figure 4** illustrating the relationships.

It is up to the Engineer to determine the most appropriate form of analysis. As a general guide, a good DSA should incorporate the following aspects:

- Desktop review of the relevant plans, calculations, specifications and previous consents on the building. Review of previous heritage assessments and conservation plan and other useful reports on the building provided by the client or obtained from other sources;

- Detailed inspection of the primary and secondary building structure, connections and services;

- Where structural information is lacking, conduct non-invasive and invasive investigations to help establish the as-built arrangement of the building and mechanical properties of the constituent materials;

- Quantitative analysis of the building to determine %NBS for various building portions and identify any critical structural weaknesses that could affect the earthquake performance of the building;

- Assessment of secondary structural and non-structural features within the building where failure during an earthquake could pose risks to human safety and affect the safe egress from the building;

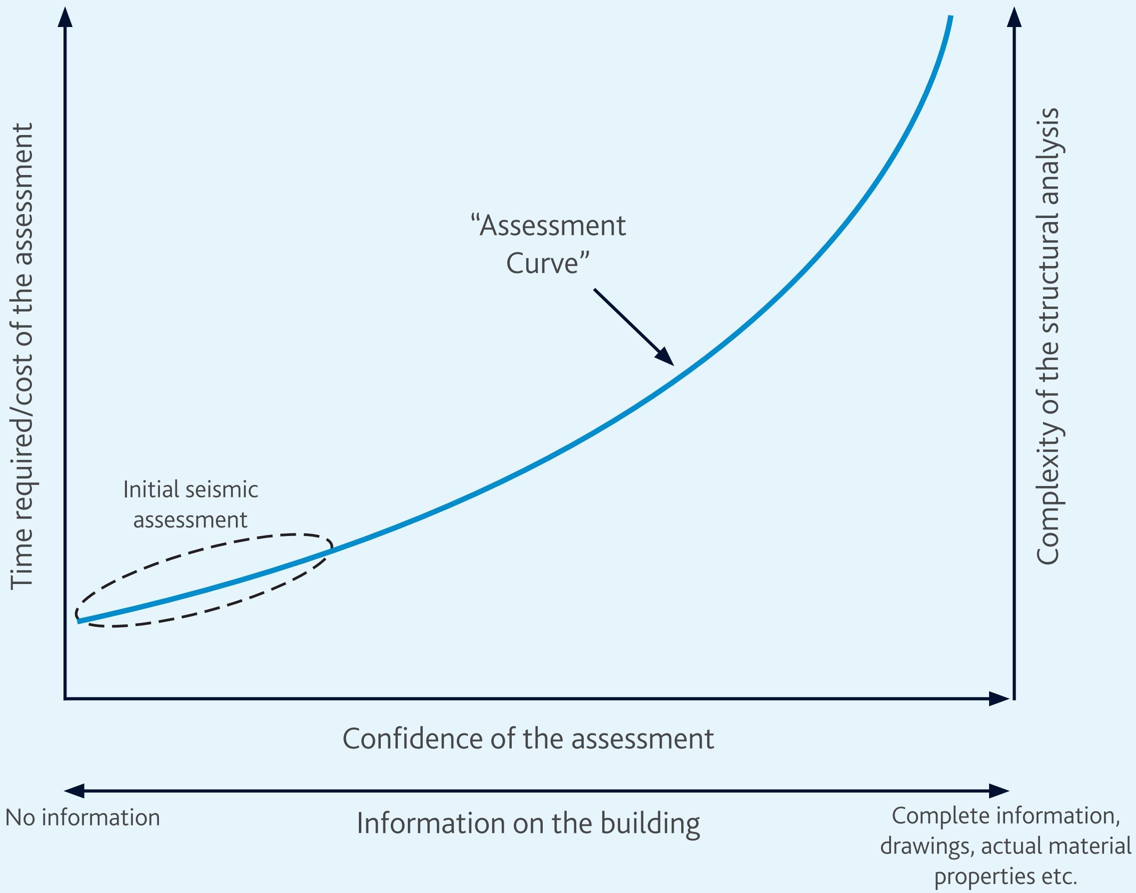


FIGURE 4: Graph illustrating the relationship between the confidence of the assessment, time/cost and complexity of the analysis

- Report outlining the findings from the investigations, analysis outcome, conclusion and recommendation. The recommendations should outline the scope of seismic retrofit identified during the DSA process and outline any uncertainties encountered during the assessment that is worth further investigation.

The following table is a brief comparison of the key differences between the ISA and DSA:

	Initial Seismic Assessment (ISA)	Detailed Seismic Assessment (DSA)
Assessment methodology	Qualitative assessment. ISA is intended to provide a potential %NBS rating.	Quantitative assessment. Various building components that contribute to the seismic performance of the building are analysed and given a %NBS rating.
Knowledge of the building required to complete the assessment	Assessment can be completed based on visual inspection of the building and without detailed information on the building structure.	Accurate and detailed information of the building is critical to the assessment. DSA cannot be completed based solely on visual inspection of the building. The engineer must have a comprehensive understanding of the building structure and aspects of the building that can affect the earthquake performance of the building.
Assessment outcome	A single %NBS number representing the potential seismic rating of the ENTIRE building.	Seismic ratings are provided for various portions of the building that contribute to the earthquake performance of the building. The final %NBS rating is based on the lowest-rated portion of the building.
Advantages	• The assessment is relatively quick and cost effective to complete. • The assessment is a reasonable tool for the identification of buildings that warrant further assessment. • Identification of obvious critical structural weaknesses.	• Aspects of the building directly affecting the earthquake rating are clearly identified, such as quantifying the effects of the critical structural weaknesses. • The assessment outcome could be used by the building owner with the assistance of their engineer to understand the financial implications of the seismic retrofit. • The assessment outcome and report will be useful to any future seismic retrofit of the building.
Disadvantages	• Low level of confidence on the assessment outcomes. Provides a single rating for the building. I.e. it is difficult to determine from the results if the rating applies to the whole building or only a portion of the building. • The assessment has limited value for building owners who wish to undergo the seismic retrofit process.	• DSA requires significantly more effort and time to complete. This is directly reflected in the cost and time required to complete a DSA. • DSA are not a suitable tool when there is a large number of buildings to assess, as is the case for Auckland Council.

TABLE 2: Comparison of the ISA and DSA process.

3.3 Other factors that can influence the %NBS rating

The direct factors that can influence the earthquake rating of a building include variables such as the reinforcement in the structural elements, the configuration of the building walls, depth and size of the foundations, etc. However, there are other indirect factors not related to the construction of the building that can influence the %NBS rating, such as the use of the building, the type of soil on which the building is founded and the configuration of any neighbouring structures.

In certain cases, building owners may benefit from investigating these factors in order to improve the %NBS rating of the building without seismic retrofit works. The subsequent sections provide brief explanations on how these other factors can influence the %NBS rating.

3.3.1 Building Importance Level

Most buildings in New Zealand are designed based on a 50 year service life for the 1 in 500 year return period earthquake. However, in recognition of the different building uses, service life, and the value a building may have in the community, different Importance Levels can be assigned during design to take these factors into consideration.

The Importance level will affect the return period of the design earthquake event for the building amongst other things. A higher Importance Level increases the return period of the design earthquake and the design requirement on the building. Vice versa, a lower importance level reduces the return period of the design earthquake and the design requirement. For example, a building was originally designed and used as a theatre and assessed as an Importance Level 3 building with regards to its earthquake performance. However after some consideration, the building owner feel that the original use is no longer viable and decides to redevelop the building into general retail and offices through a change of use that is into an Importance Level 2 building. The change will result in a 30% reduction in the earthquake demand, which will have a positive effect on the building's %NBS rating without doing any seismic retrofit.

Where applicable, reducing the Building Importance Level through the Change of Use process can result in significant reductions in the earthquake demand. This will have a positive effect on the building's %NBS rating without any seismic retrofit.

Presented in **Table 3** is a summary of the Importance Level definitions and the earthquake design requirement with respect to the 1 in 500 year earthquake event.

Importance level	Examples	Relative design requirements based on return periods
1	Fences, masts, in ground swimming pools, farm buildings, small scale structures with total floor areas of less than $30m^2$	1 in100 year event or **50%** of the 1 in 500 year event
2	Family homes, car park buildings, most low-rise commercial buildings	1 in 500 year event
3	Structures that may contain people in crowds such as shopping malls, theatres, assembly buildings, apartments, large commercial buildings, schools	1 in 1000 year event or **130%** of the 1 in 500 year event
4	Structures with post disaster functions such as hospitals, fire stations, police stations	1 in 2500 year event or **180%** of the 1 in 500 year event
5	Special structures such as dams, power plants etc	Site specific considerations are required

TABLE 3: Building Importance Levels and adjustment factors

3.3.2 Site Soil Class

The 'fundamental' earthquake acceleration for Auckland is 0.13g. Coupled with various other factors, the earthquake acceleration is used by engineers to estimate the earthquake demand on new buildings and the earthquake demand on existing buildings for assessment purposes.

One of the other factors that can influence the earthquake demand is the geology which the building is founded on. Currently there are five general classes of soils with different influences on the earthquake demand and the soil classes range from hard rock to very soft soils. Rock type soils generally represent more favourable soil conditions for earthquake forces whereas softer soils are less favourable in terms of earthquake demand on buildings.

As an example, the earthquake demand for soft soil is 12% to 87% higher than rock type soils, which means that the same building constructed on softer soils is likely to receive a lower %NBS than the same building constructed on rock.

> Rock type soils generally represent more favourable soil conditions for earthquake forces whereas softer soils are less favourable in terms of earthquake demand on buildings.

Generally, site specific geotechnical studies are the only method to identify the site soil class which a building is founded on and it is often beneficial that such a study be included as part of the DSA and earthquake retrofit design. The information can be used to eliminate the assumptions made on soil class and ground conditions, which could significantly improve the outcome from the assessment and/or help reduce the scope of the earthquake retrofit.

3.4 Implementation of the seismic retrofit

The implementation phase involves the detailed design of the seismic retrofit, obtaining consents from Auckland Council, and construction of the retrofit. A Detailed Seismic Assessment is normally completed prior to the detailed design of the seismic retrofit stage. However, building owners who wish to streamline the process could combine the DSA and earthquake retrofit design and potentially save both time and cost compared to carrying out both activities in sequence. The flow chart in **Figure 5** is a brief illustration of the implementation process starting with the detailed design of the earthquake retrofit. **Figure 5** also illustrates the inputs from various parties that are often involved in the process.

3.4.1 Row Buildings

General principles of structural performance along with observations made of damage to structures in the Canterbury Earthquake sequence mean that buildings must be considered in their entirety when undertaking seismic upgrades. Choosing to upgrade only one unit within a larger building is unlikely to achieve the desired performance increase, and may even cause greater damage to the building as a whole.

In the case of buildings that have been subdivided along firewall separations especially, this means that different building owners will need to cooperate to achieve a workable outcome. Auckland Council will treat any building as a single structure unless a clear seismic separation can be proven, and the retrofit of individual units will not increase the overall seismic performance rating for that building until the weakest element is brought up to the sufficient standard.

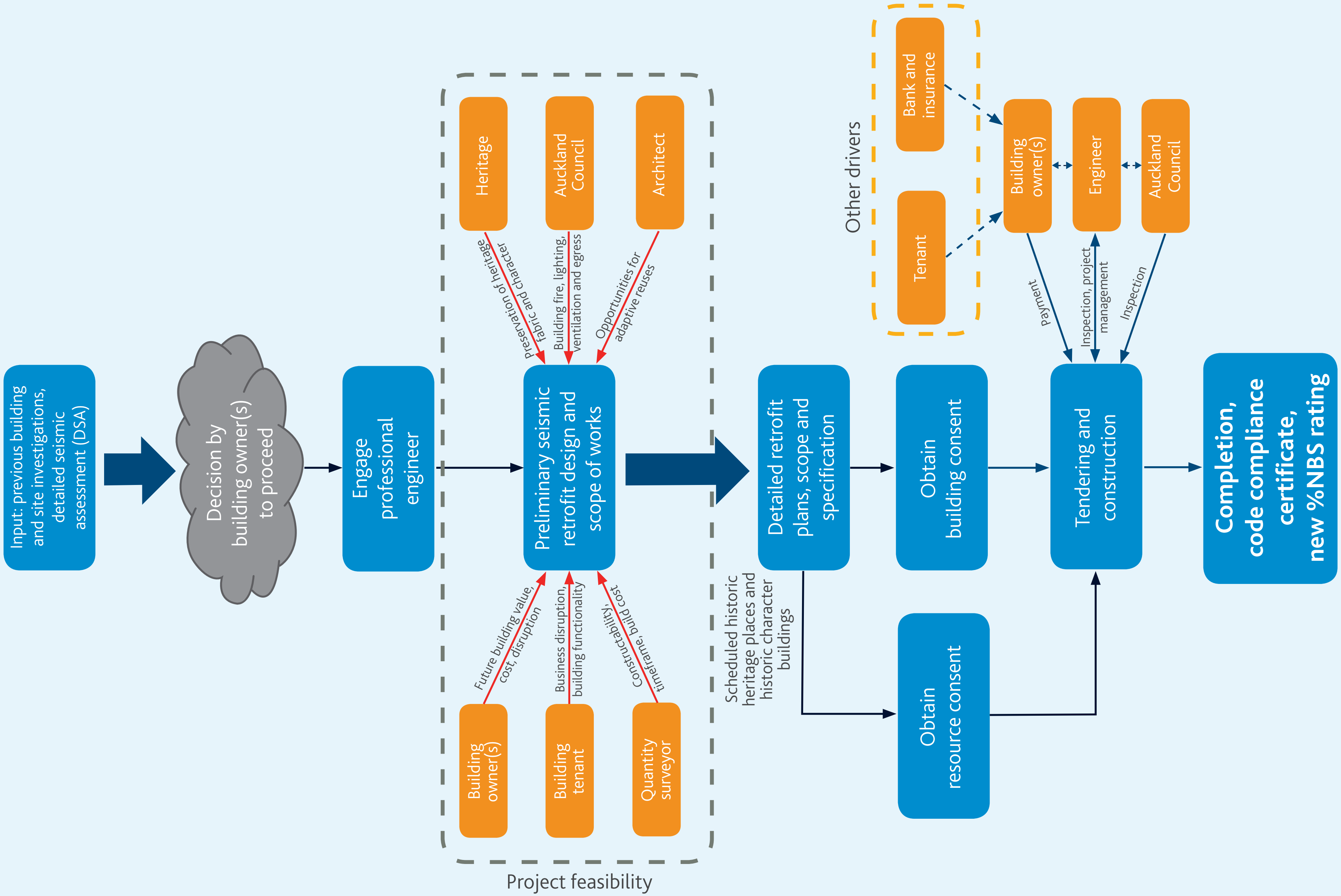


FIGURE 5: Flow chart of the earthquake retrofit process and inputs from the various stakeholders.

3.5 Professional Services Cost

The cost of acquiring professionals to take a building through the assessment, design and implementation processes is highly variable and is generally established on a case by case basis. The costs are typically dependent on the complexity of the building, any changes to the configuration of the building, and other market drivers at the time.

As an indicative guide, **Table 4** presents professional services fees (excluding taxes) based on the floor area per storey and the number of storeys for the DSA and the seismic retrofit design. The indicative fees are gross approximations of the engineering, architectural and sub-consultant fees up to the Building Consent stage. Additional consultant fees are likely to be incurred during construction, especially if a project manager is employed to look after the construction.

The indicative rates do not include other costs such as Auckland Council Building Consent charges, additional design fees associated with building improvements and additional fees associated with an independent heritage impact assessment. The indicative rates in **Table 4** do not distinguish between the 34%NBS and 67%NBS levels as similar efforts are often required during DSA and the retrofit design regardless of the intended %NBS.

		Number of storeys			
	Area per storey	**1**	**2**	**3**	**4**
Assessment	**100m²**	$90	$65	$65	$60
	200m²	$70	$45	$35	$30
	300m²	$60	$40	$30	$25
	400m²	$50	$35	$25	$20
	500m²	$45	$30	$25	$20
Design and Consent	**100m²**	$140	$110	$90	$90
	200m²	$100	$70	$65	$60
	300m²	$80	$60	$50	$45
	400m²	$70	$50	$40	$35
	500m²	$60	$45	$35	$30

TABLE 4: Indicative professional service fee for DSA and seismic retrofit design ($\$/m^2$).

3.5.1 Example

Estimate the Detailed Seismic Assessment and retrofit design costs for a 2 storey building with an average area of 300m² per floor level.

Step 1
– Determine the indicative $\$/m^2$ from **Table 4** based on the average floor area per storey:

		Number of storeys			
	Area per storey	**1**	**2**	**3**	**4**
Assessment	**100m²**	$90	$65	$65	$60
	200m²	$70	$45	$35	$30
	300m²	$60	$40	$30	$25
	400m²	$50	$35	$25	$20
	500m²	$45	$30	$25	$20
Design and Consent	**100m²**	$140	$110	$90	$90
	200m²	$100	$70	$65	$60
	300m²	$80	$60	$50	$45
	400m²	$70	$50	$40	$35
	500m²	$60	$45	$35	$30

The indicative rate for a DSA is $\$40/m^2$
The indicative rate for the detailed design up to the consent stage is $\$60/m^2$

Step 2
– Calculate the indicative DSA and retrofit design costs using the indicative rates from Step 1:

DSA
2 storeys × 300m² per storey × $\$40/m^2$
= $24,000

Detailed Retrofit Design
2 storeys × 300m² per storey × $\$60/m^2$
= $36,000

2 The indicative rates are based on 2014 sources and are subject to future revisions as more data becomes available.

4.0 Earthquake Building Performance

In New Zealand, unreinforced clay brick masonry (URM) was the most popular form of commercial construction between the 1880s and 1930s and many URM buildings still exist today. A high proportion of the remaining URM buildings have not been retrofit to resist earthquake forces and make up a large portion of the earthquake prone buildings in the Auckland region. For this reason, the typical construction, earthquake performance and retrofit of historical URM buildings are discussed herein.

4.1 Typical construction

The earlier buildings in New Zealand were designed and constructed without significant understanding and consideration of earthquakes and it was not until the 1931 Hawke's Bay earthquake that engineers and architects started to gain an understanding and appreciation of the need to design buildings to withstand earthquakes. As technologies and knowledge of New Zealand's seismicity improved, so did the earthquake design requirements of buildings.

The earlier buildings are typically very robust at resisting gravity forces (i.e. vertical weights), however are often vulnerable when subjected to earthquake-induced lateral forces. **Figure 6** is an illustration of an exemplar two storey URM building. Such building typology is common among many of Auckland's developed suburban hubs. Although many other typologies and types of construction exist, such as single storey and multiple storey URM buildings, reinforced concrete buildings with URM in-filled walls and the like, there are many structural characteristics which are common across all typologies.

4.2 Evaluation of earthquake performance

The response and stability of early structures when subjected to lateral earthquake forces is a complex subject. However, in simple terms, the earthquake performance (and rating) of a building is generally evaluated based on a hierarchy of risk. At the top of the hierarchy are structural weaknesses that pose the biggest concerns to human safety during an earthquake and at the bottom of the hierarchy are structural weaknesses that pose the least concern.

Examples of structural weakness at the top of the hierarchy are elements of the building that could potentially fall and collapse during a small to moderate earthquake, causing injury to people and damage to other properties.

One of the common issues associated with these elements is the lack of connections and restraints into other building elements, such as unrestrained parapets, decorative ornaments, and chimneys which are prone to toppling during an earthquake.

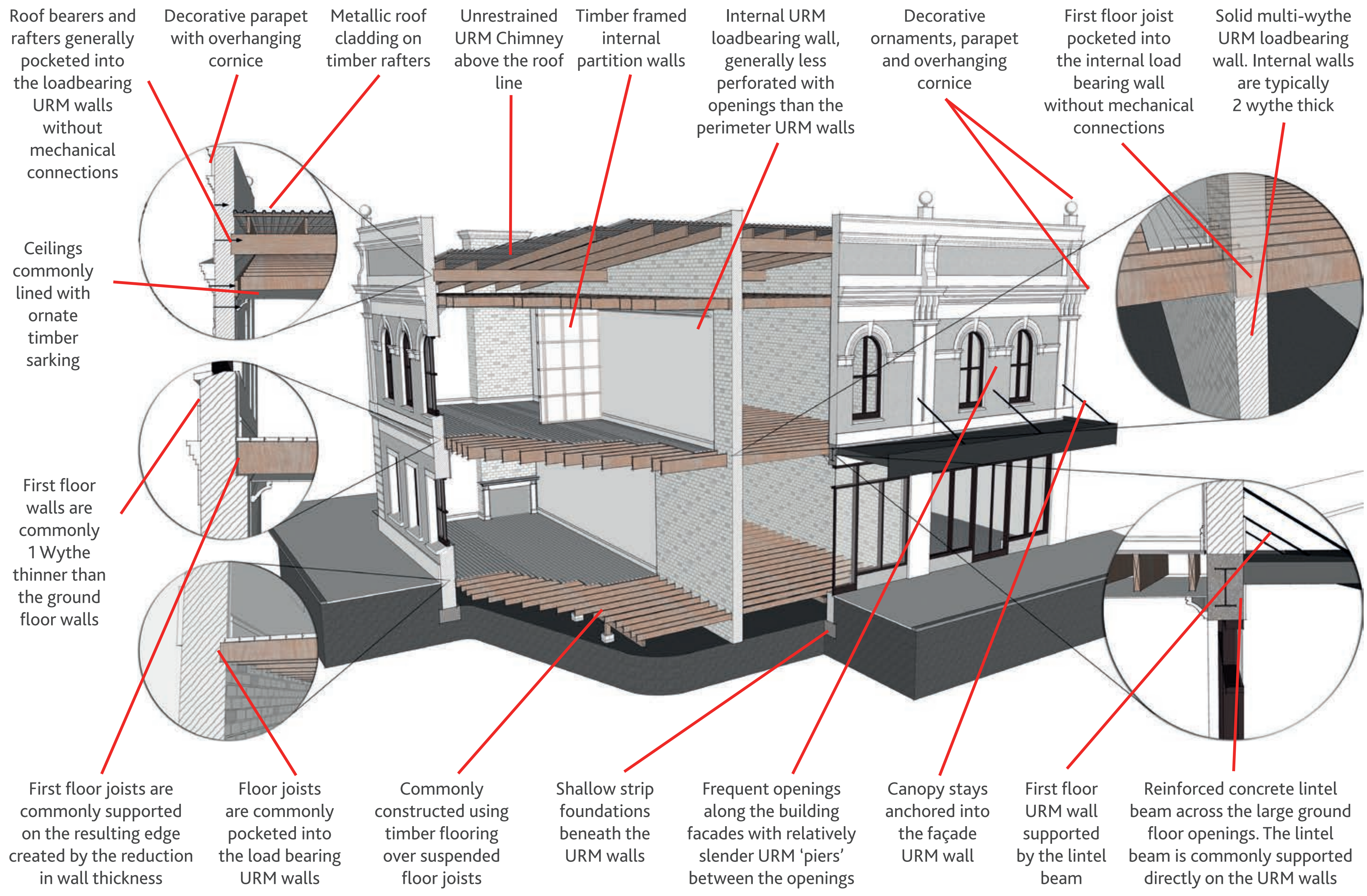


FIGURE 6: Typical construction of a two storey historical URM structure.

At the other end of the hierarchy are building elements that do not pose an immediate threat to human safety and egress from the building during an earthquake. An example may be the lack of lateral capacity in a URM wall. During an earthquake, the URM wall may sustain significant damage and crack, but retain its ability to sustain gravity loads and not result in the collapse of elements that the wall is supporting.

Therefore, a hierarchical approach should be taken when it comes to improving the earthquake performance of a building and priorities should be given to addressing structural weakness at the top of the hierarchy.

A hierarchical approach should be taken when it comes to improving the earthquake performance of a building and priorities should be given to addressing structural weakness at the top of the hierarchy.

4.3 Gravity load-resisting system

Gravity load resisting elements are structural features responsible for sustaining vertical weights above. Examples of such features are: loadbearing walls, floor joists, lintel beams, etc. The main gravity load resisting system of a typical URM building are the perimeter and internal loadbearing walls and the floor and roof systems. The floor and roof systems are generally constructed using timber and are lightweight in comparison to the URM loadbearing walls.

Other internal partition walls are commonly constructed using timber or single leaf URM and are generally non-load bearing. However, the top floor internal partition walls are commonly used to support the internal ceiling, but it is rare for the roof rafters and roof bearers to be supported directly on the internal partition walls. This type of construction is robust at resisting gravity forces for the following reasons:

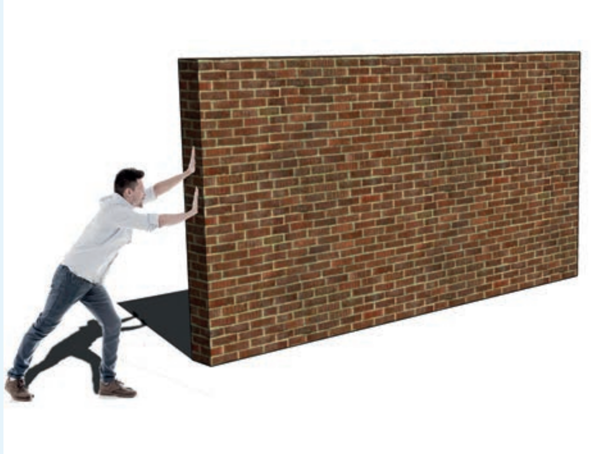
- Generally squat building profile (large plan area relative to building height) and simple load path for gravity loads
- Gravity forces are mostly resisted by URM walls which are constructed using multiple wythes of URM, instead of a comparatively slender column and beam type arrangement as in a more modern building
- The load bearing URM walls tend to be thicker in the lower levels, which inherently provide more stability at the base and more capacity to resist gravity forces
- Unreinforced masonry is very strong in compression and ideally suited to resisting gravity loads. However, it is poor in tension, which is a characteristic with similarities to concrete.

4.4 Lateral load-resisting system (earthquake)

The lateral load resisting (i.e. bracing) elements of historical URM buildings are generally reliant on the loadbearing URM walls, and to account for the unpredictability of earthquakes, the building needs to have sufficient lateral strength in both orthogonal directions (i.e. across and along).

Geometry dictates that URM walls are much stronger and more stable when the direction of lateral force is parallel to the horizontal span of the wall (commonly referred to as the in-plane direction by engineers). When the direction of force is perpendicular to the wall (commonly referred to as the out-of-plane direction by engineers), the stability of the wall is greatly diminished. These principles are illustrated in **Figure 7**.

(a) Schematic of a wall responding out-of-plane.



(b) Schematic of a wall responding in-plane

FIGURE 7: Illustrations of URM walls when subjected to in-plane and out-of-plane lateral forces.

As illustrated in **Figure 6**, the floor and roof structures generally rest upon the loadbearing URM walls without mechanical connections. In addition, parapets, chimneys and other decorative ornaments frequently featured above the roof line of historical URM structures are rarely restrained. This form of construction causes the loadbearing URM walls, parapets and chimneys to be particularly prone to toppling (i.e. out-of-plane failures) when there are components of the earthquake forces that are oriented perpendicular to the wall.

This type of failure was the most common and one of the most damaging failure modes of URM structures during the recent Canterbury earthquakes and in previous New Zealand and international earthquakes. Preventing the out-of-plane collapse of loadbearing URM walls, parapets and chimneys is regarded as a priority on the hierarchy of structural weaknesses. Wall collapse could have other implications such as collapse of the roof and floor structures due to the loss of gravity support.

Preventing the out-of-plane collapse of loadbearing URM walls, parapets and chimneys is regarded as a priority on the hierarchy of structural weaknesses. Wall collapse could have other implications such as collapse of the roof and floor structures.

Other common earthquake vulnerabilities borne out of the characteristics of historical URM buildings include the poor geometric distribution and the lack of lateral load resisting walls, lack of stiffness in the floor and roof diaphragms and the general lack of connectivity between the various structural elements. These common vulnerabilities are explained in the following **Table**.

Other common vulnerabilities	Explanation
Poor geometric distribution of lateral load resisting walls	As illustrated in **Figure 6**, URM buildings frequently feature large ground floor street-facing entrances, open plan interior, facades with regular window openings and relatively unperforated internal loadbearing URM partition walls between the tenancies. Based on this configuration, the majority of the lateral load resisting URM walls are positioned across the building and the building is laterally stronger in the cross direction. Consequently, the earthquake performance of the building is likely to be much better if all the earthquake forces are aligned and are acting across the building.
Lack of floor and roof stiffness, poor connectivity between structural elements	During an earthquake, the floors and roofs of the building essentially act as 'lids to the building' by providing out-of-plane restraints to the URM walls and transferring the inertia forces into the in-plane URM walls. Often, due to the construction, age and condition of the flooring, ceiling and framing, the floor and roof structures are poorly connected to the walls and lack the sufficient stiffness required to function as the load transferring diaphragm during an earthquake. Therefore, stiffening and improving the connections of the floors and roof is often required.

TABLE 5: Other common structural weaknesses in URM buildings.

Figures 8 and **Figure 9** are illustrations of the exemplar two storey URM building with the inherent structural weaknesses discussed in this section. The illustrations represent the commonly observed failure modes of historical URM buildings with respect to the idealised unidirectional earthquakes. In addition, photographic evidence from the previous earthquakes are also presented in conjunction with the illustrations.

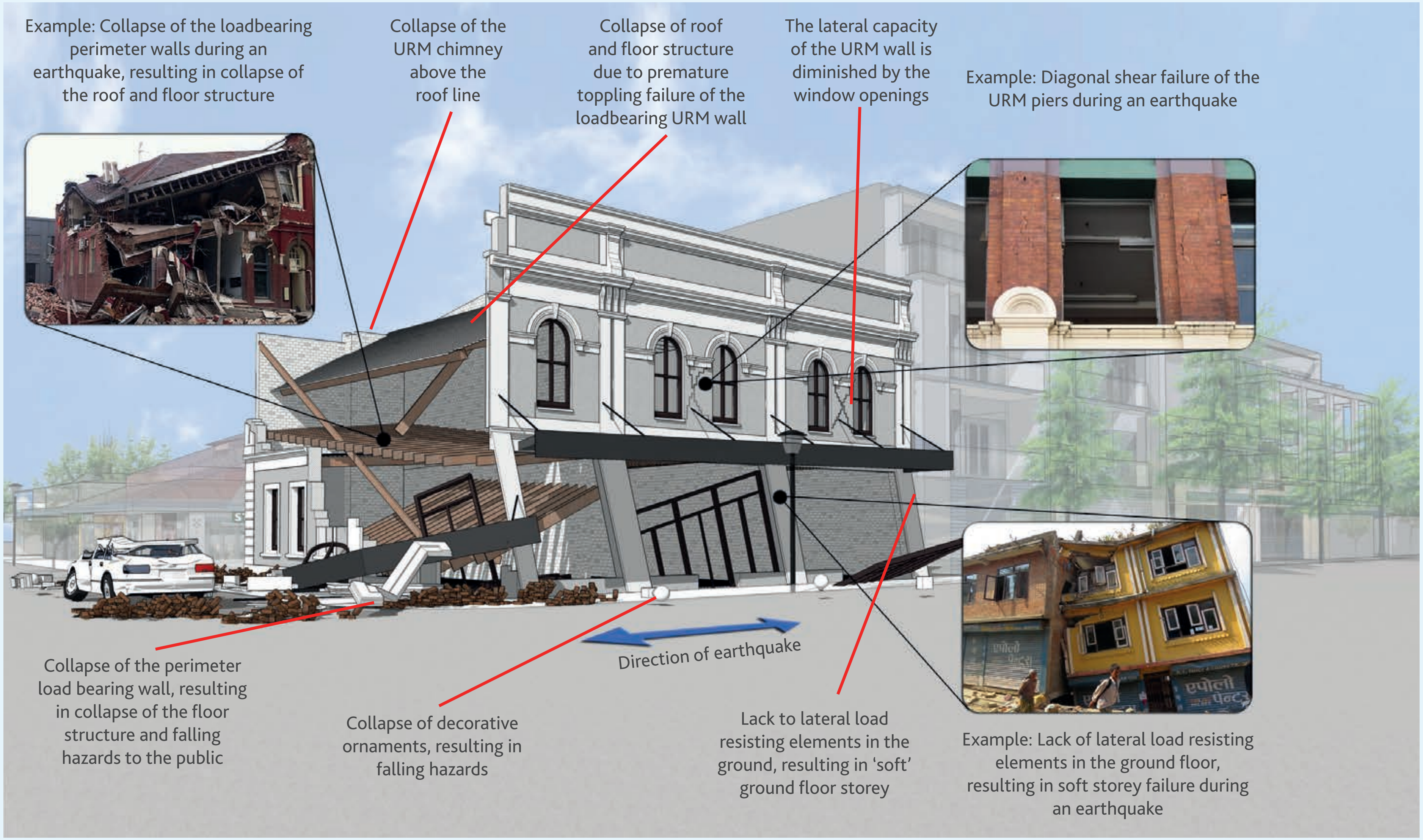


FIGURE 8: Earthquake forces acting along the building

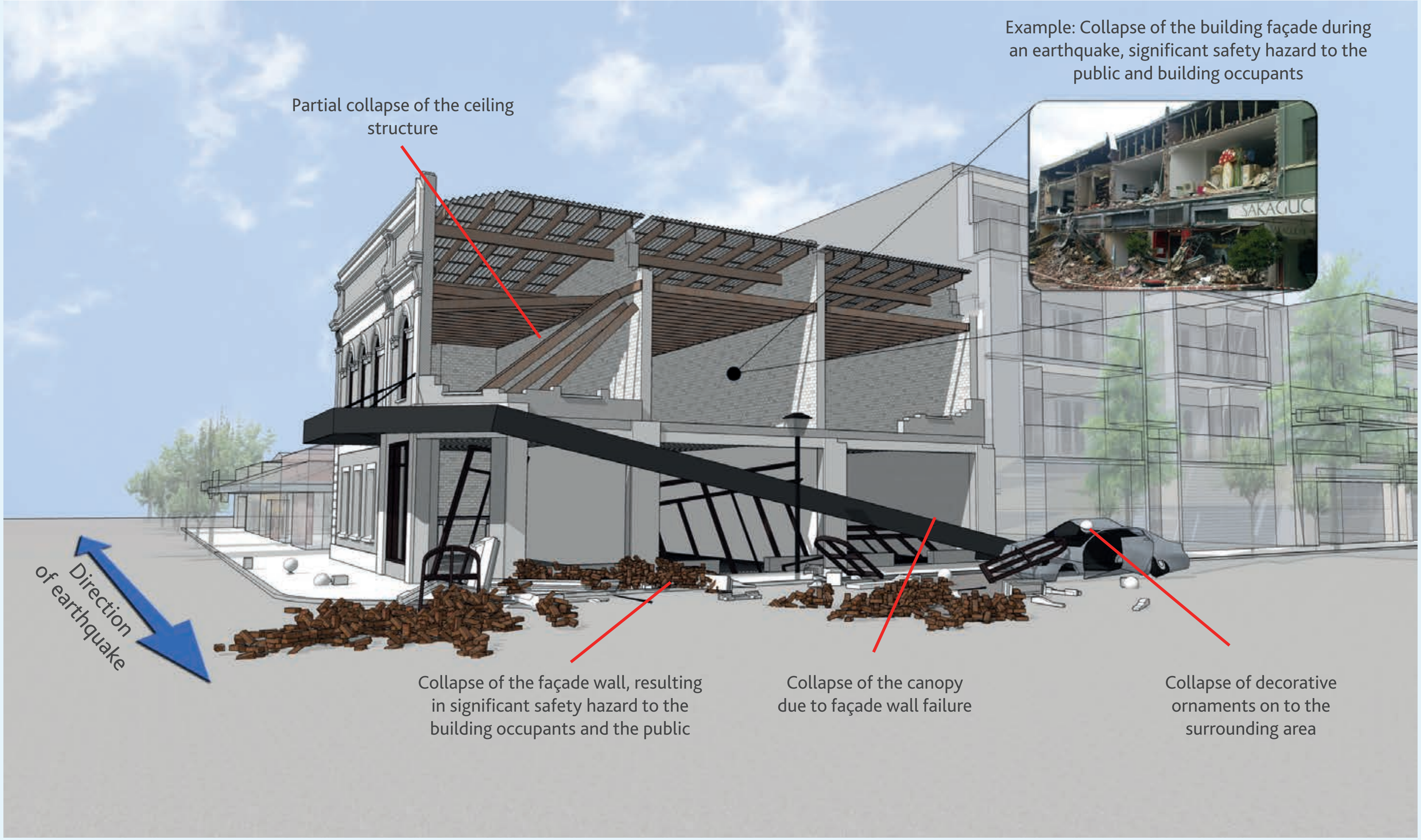


FIGURE 9: Earthquake forces acting along the building

5.0 Earthquake Retrofit Solutions

5.1 Seismic retrofit hierarchy

Examples from the Canterbury earthquakes and international earthquakes have shown that it is possible to retrofit and improve the performance of existing buildings against the effects of strong earthquake ground motions. There are a range of options available and the eventual solution or combination of solutions is a balance between the level of acceptable risk, financial constraints and preservation of heritage.

In a constrained environment, a hierarchical approach should be adopted for seismic retrofits. Priorities should be given to retrofitting building elements that have the highest risk to human safety during an earthquake:

Retrofit hierarchy

1. Protection against potential fall hazard during an earthquake. For example, securing parapets, decorative ornaments, chimneys, gable walls and other building elements that are located at height.

2. Improve the stability of walls during an earthquake against toppling type failures. This can be achieved by adding reinforcing materials to the walls and/or by installing mechanical connections between the walls and the roof and floor structures.

3. Ensure there are adequate connections between all the structural elements so the building responds as a cohesive unit instead of as individual parts during an earthquake. For example, this can be achieved by stiffening diaphragms, installing additional connections between structural elements and at building junctions.

4. Improve the building configuration issues such as poor distribution and/or lack of lateral load resisting elements. For example, this can be achieved by installing new structural frames and walls to supplement the existing structure at areas where the building is lacking lateral strength.

Presented in **Figures 10** and **Figure 11** are one combination of the available solutions to improve the earthquake performance of the exemplar building against the possible failure modes illustrated in **Figure 8** and **Figure 9**. Building retrofits belonging to the categories in the hierarchy listed above are also annotated in **Figure 10** and **Figure 11**.

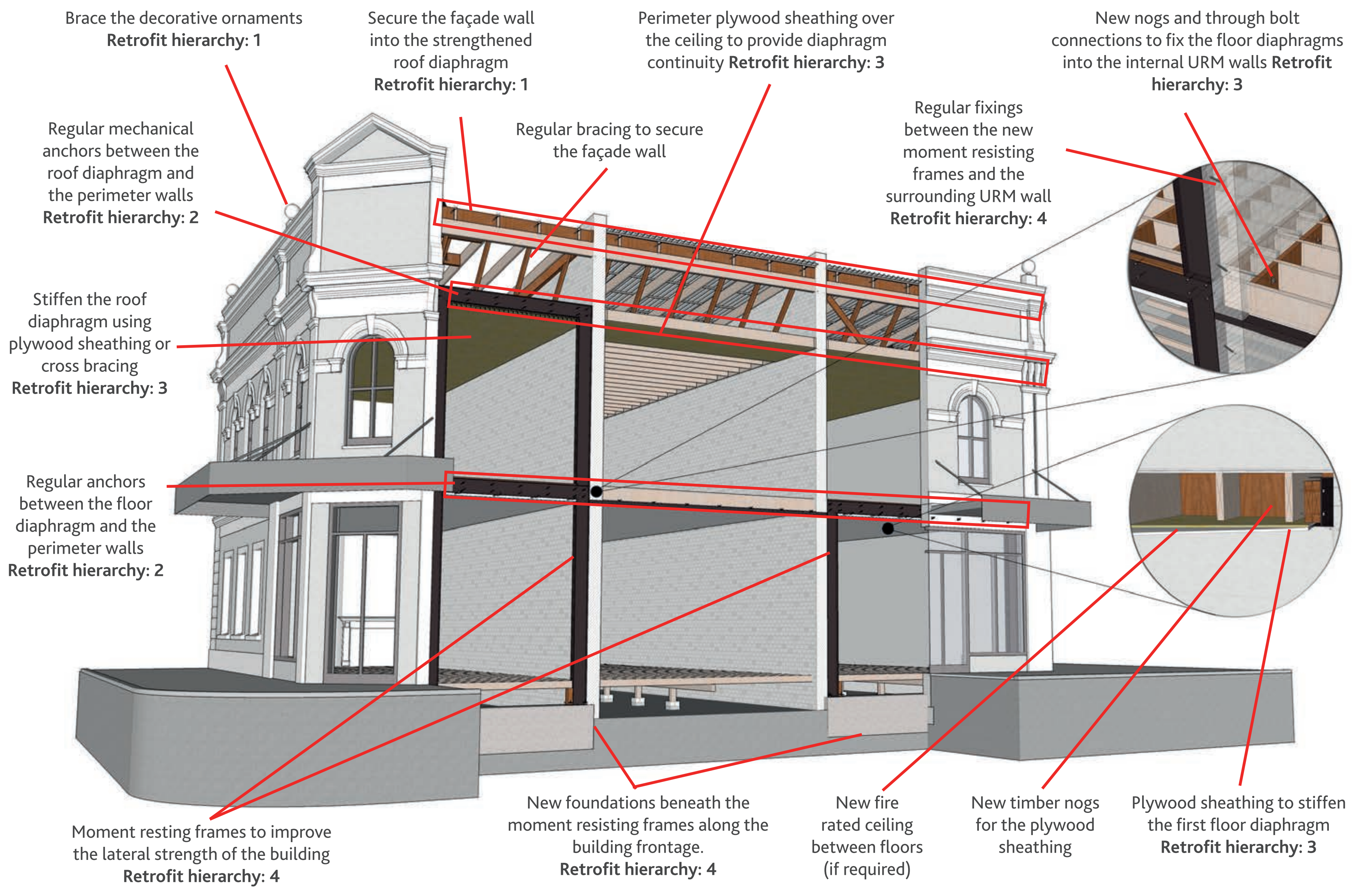


FIGURE 10: Earthquake retrofit of the exemplar two storey URM building.

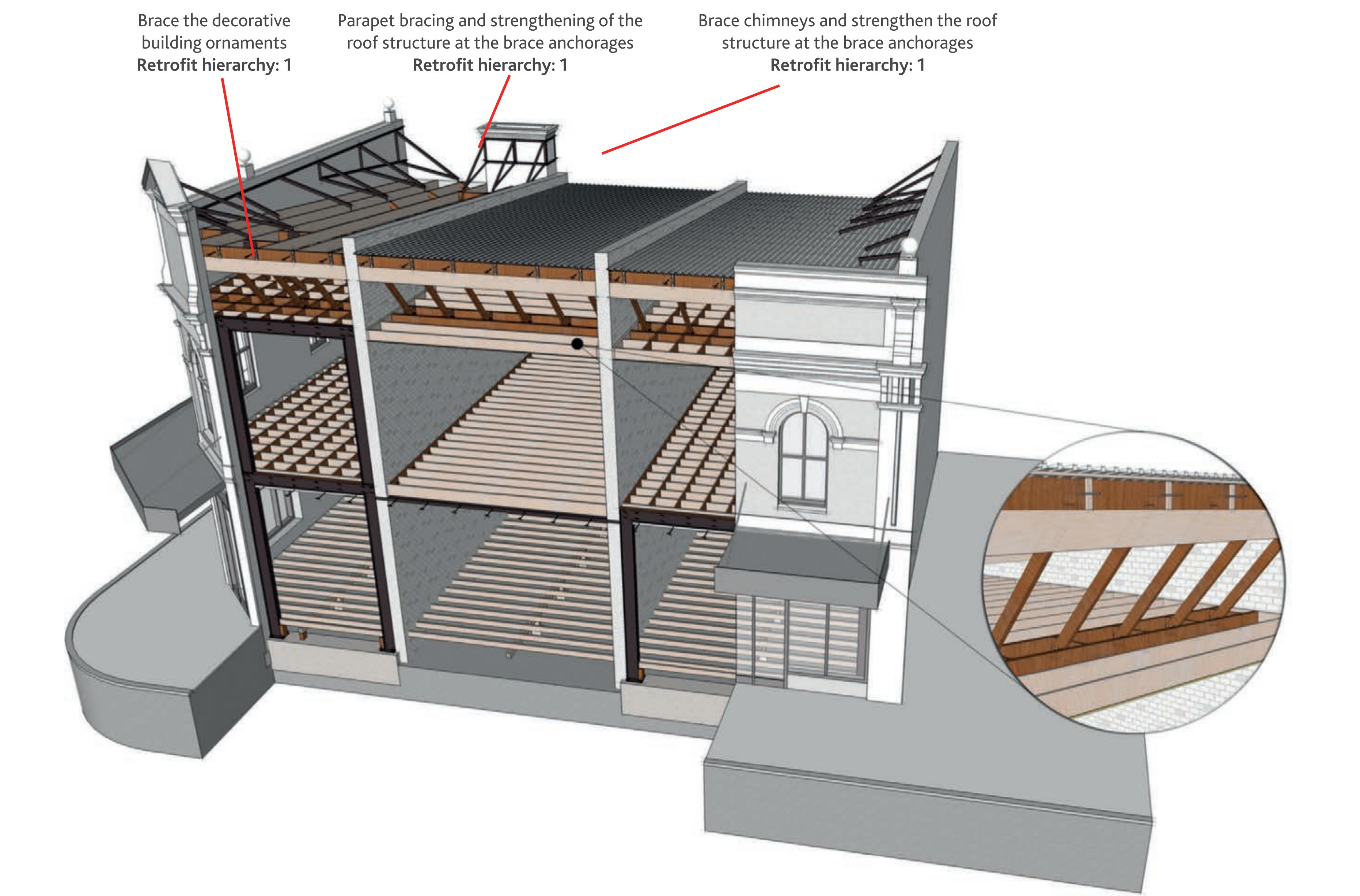


FIGURE 11: Earthquake retrofit of the exemplar two storey URM building.

5.2 Other retrofit techniques

The following sections and illustrations are examples of other retrofit techniques which may be applicable to certain building features. It is important to evaluate each retrofit technique against the building feature and remember that not all the techniques are applicable in every situation.

5.2.1 Fibre Reinforced Polymer (FRP) Retrofit of Walls

This technique is commonly used to improve the tensile strength of URM walls and to improve the performance of URM walls in the out-of-plane direction. This generally involves embedding FRP strips into thin cuts made in the masonry with the FRP strips acting as 'reinforcing' strands within the wall. For thicker walls, the FRP strips are embedded on both the inside and outside faces of the wall and it is also important that the ends of the FRP strips are well anchored, such as being embedded into the concrete bond beams at the floor levels.

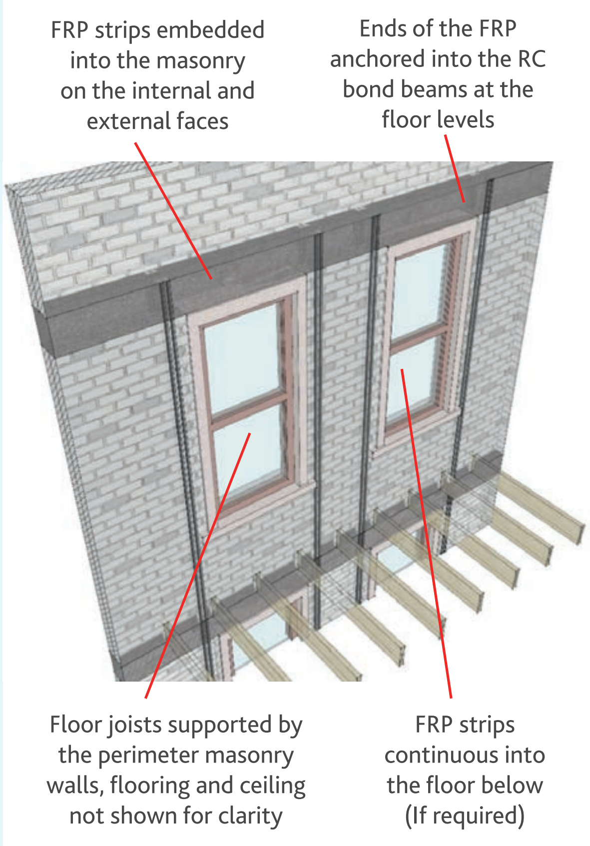


FIGURE 12: Example of FRP retrofit of URM walls.

5.2.2 Overlay with Engineered Cementitious Composite (ECC)

The technique is commonly used to improve the lateral and out-of-plane performances of URM walls when used in conjunction with other retrofits. The technique involves preparing the wall surface and overlaying the surface of the URM wall with a thin layer of ECC. The ECC is generally applied to the internal face of the wall as wall preparation will require stripping of the decorative features. The method of application has similarities to the application of shotcrete.

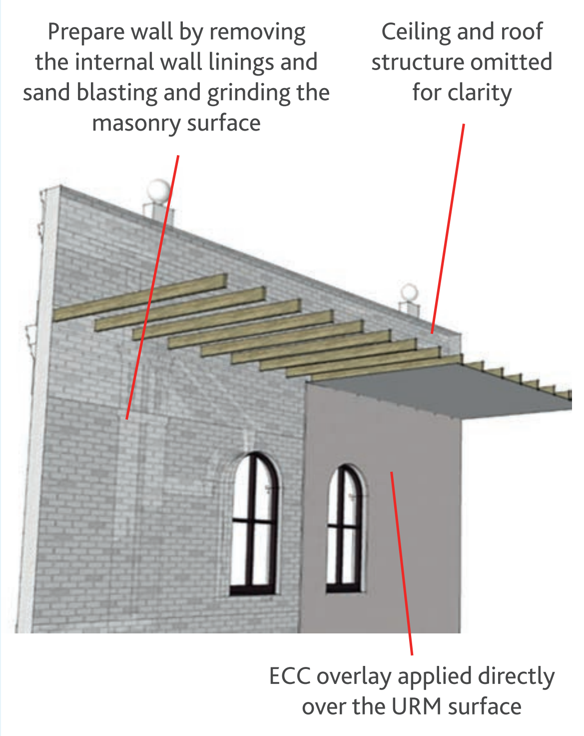


FIGURE 13: Example of ECC retrofit of URM wall.

5.2.3 Securing of the URM Layers in a Cavity Wall

Cavity wall construction is commonly encountered in URM buildings and buildings featuring URM in-filled walls. Cavity wall construction was used to provide heat and moisture insulation but it was observed in the Canterbury earthquakes that this type of construction performed significantly worse in comparison to solid URM wall construction.

There are a number of proprietary solutions designed to replace the original cavity ties within the URM wall. The technique generally involves drilling in new corrosion resistant cavity ties at regular centres between the URM layers.

5.2.4 Fibre Reinforced Polymer (FRP) Retrofit of URM Chimneys

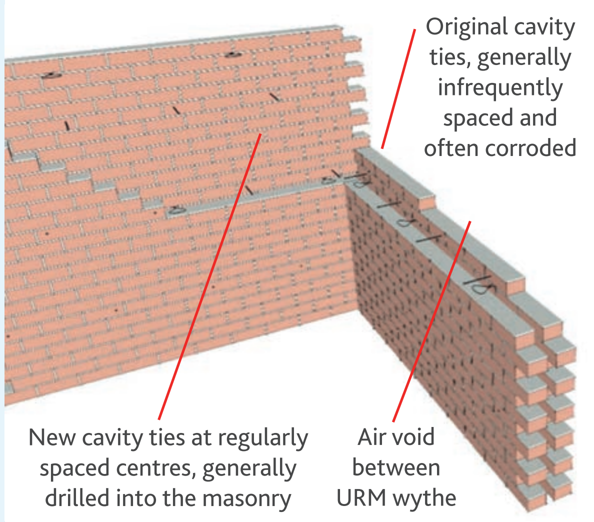


FIGURE 14: Example of cavity tie installation.

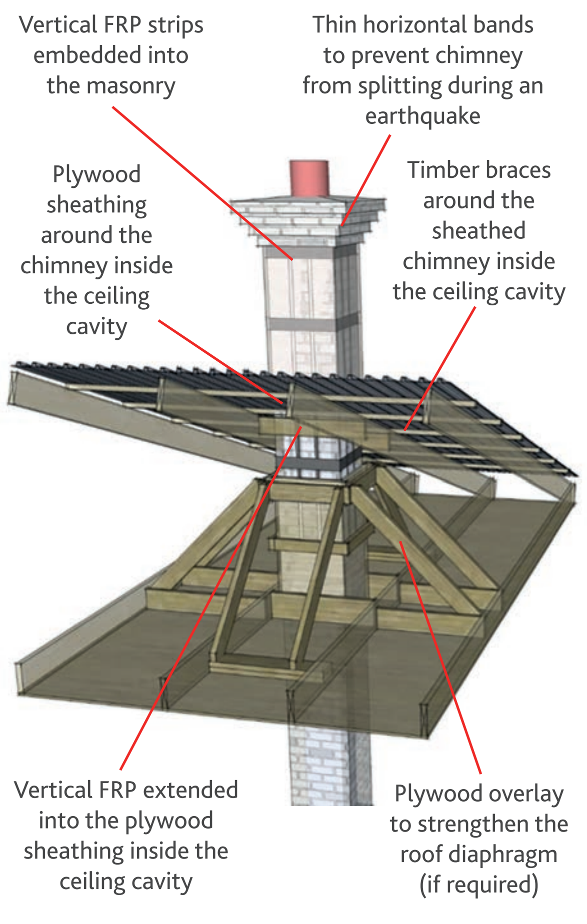


FIGURE 15: Example of FRP retrofit of URM chimneys.

FRP strips can be embedded into thin cuts made in the URM chimney to improve its stability during an earthquake. This is an alternative option to external bracing and is less visually invasive. Once the FRP strips are embedded, the decorative plaster can be reinstated or the brick dust can be collected during the cutting process and used to patch over and conceal the cut.

5.2.5 Roof Diaphragm Retrofit with Tension Braces

Stiffening of the diaphragms using steel tension braces is an alternative option to the plywood overlay option shown in **Figure 10** and **Figure 11**. The design typically utilises the existing roof system and involves the addition of supplementary members and connections to create a load path between the various lateral load resisting walls within a building.

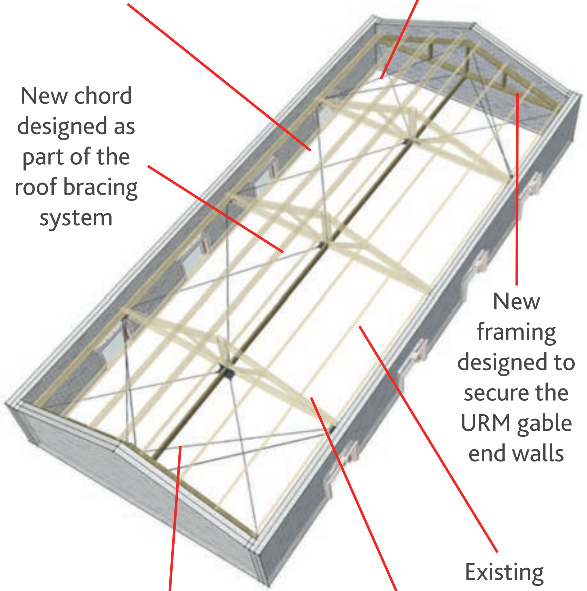


FIGURE 16: Example of roof diaphragm retrofit with tension braces.

5.3 Earthquake retrofit costs

The construction of earthquake retrofits is highly variable between different buildings and the cost is dependent on a range of factors, including the configuration of the building, height of the building, interior fit-out and use of heritage-sensitive alternatives.

Presented in **Table 6** and **Table 7** are indicative square metre rates of earthquake retrofit construction costs. Costs associated with reinstatement of the affected areas and meeting building compliances have been incorporated into the rates. However, additional costs associated with significant building improvement and upgrade (such as sprinkler systems, additional egress points, new lifts, interior fitout) are not accounted for.

The total indicative construction cost is calculated by multiplying the rates in the tables against the number of storeys and the square metre floor area per storey.

The increases in cost of seismic retrofit are generally not proportionate to increases in the target %NBS. This is due to the fixed cost component of construction such as mobilisation and reinstatement of the affected areas. As shown in the example, the difference in construction cost is approximately $100,000 between the 34%NBS and the 67%NBS estimates.

	Number of storeys			
Area per storey	**1**	**2**	**3**	**4**
100m²	$800	$1000	$1050	$1250
200m²	$600	$700	$700	$750
300m²	$500	$700	$600	$550
400m²	$500	$700	$550	$500
500m²	$400	$600	$550	$450

TABLE 6: Indicative m² rate for retrofitting to 67%NBS. Based on 2014 statistics.

	Number of storeys			
Area per storey	**1**	**2**	**3**	**4**
100m²	$800	$700	$700	$600
200m²	$500	$500	$450	$450
300m²	$400	$450	$400	$400
400m²	$400	$400	$400	$350
500m²	$300	$350	$350	$350

TABLE 7: Indicative m² rate for retrofitting to 34%NBS. Based on 2014 statistics.

Other factors that could influence the indicative rates include the following:

	Adjustment Factors		
	Less than $250k	$250k - $500k	Greater than $500k
Poor building condition e.g. large areas of mortar repointing, concrete repairs and timber replacement	+30%	+25%	+25%
Difficult access to site such as building without side access along a main road	+5%	+8%	+8%
Building features cavity URM wall construction where there is an air cavity between the inner and outer URM leaves	+12%	+15%	+15%
Tall parapets (greater than 1.5m), gable end walls and multiple chimneys above the roof line	+7%	+5%	+4%
Reinforced concrete floor diaphragms with perimeter beams cast into the loadbearing walls	-15%	-20%	-25%

5.3.1 Example

As a comparison, estimate the 34%NBS and 67%NBS earthquake retrofit cost of a two storey URM building where the average area is 250m² per storey. The building features cavity URM wall construction and the floors are constructed using reinforced concrete with perimeter beams at each floor level of the building.

Step 1 – Determine the indicative square metre rate from **Table 4**:

34%NBS:

	Number of storeys			
Storey area	1	2	3	4
100m²	$800	$700	$700	$600
200m²	$500	$500	$450	$450
300m²	$400	$450	$400	$400
400m²	$400	$400	$400	$350
500m²	$300	$350	$350	$350

	Number of storeys			
Storey area	1	2	3	4
100m²	$800	$700	$700	$600
200m²	$500	$500	$450	$450
300m²	$400	$450	$400	$400
400m²	$400	$400	$400	$350
500m²	$300	$350	$350	$350

Indicative costs based on 2014 statistics.

67%NBS:

	Number of storeys			
Storey area	1	2	3	4
100m²	$800	$1000	$1050	$1250
200m²	$600	$700	$700	$750
300m²	$500	$700	$600	$550
400m²	$500	$700	$550	$500
500m²	$400	$600	$550	$450

	Number of storeys			
Storey area	1	2	3	4
100m²	$800	$1000	$1050	$1250
200m²	$600	$700	$700	$750
300m²	$500	$700	$600	$550
400m²	$500	$700	$550	$500
500m²	$400	$600	$550	$450

Step 2 – Calculate the indicative retrofit cost using the indicative rate from Step 1:

34%NBS:

2 storeys × 250 m2 per storey × $475/m² = $237,500

67%NBS:

2 storeys × 250 m2 per storey × $700/m² = $350,000

Step 3 – Apply adjustment factors based on the % in **Table 6**:

34%NBS:

Adjustment factor for cavity walls:
$237,500 × 12% = $28,500

Adjustment factor for reinforced concrete floor slabs:
$237,500 × -15% = -$35,625

Indicative costs based on 2014 statistics.

67%NBS:

Adjustment factor for cavity walls:
$350,000 × 15% = $52,500

Adjustment factor for reinforced concrete floor slabs:
$350,000 × -20% = -$70,000

Step 4 – Calculated the total indicative retrofit cost:

34%NBS:

$237,500 + $28,500 - $35,625 = **$230,375**

67%NBS:

$350,000 + $52,500 - $70,000 = **$332,500**

6.0 Glossary of Terms

Cavity wall – a wall constructed with two separate thicknesses, with an air void in between, and tied together with metal wall ties. Many older buildings with cavity walls have irregular spaced wall ties that are often corroded.

Chord – a top or bottom member of a wall, beam or roof truss that the vertical wall or horizontal floor bracing members are attached to. In a seismically retrofitted building, the chords could be in timber or steel.

Diaphragm – commonly the floors and roof within the building. Diaphragms are "horizontal beams" that help to distribute earthquake and wind forces between the lateral load resisting elements within a building.

Earthquake-prone building – a building is earthquake-prone if, due to its condition, the ground on which it is built, and the way it was constructed, it could be structurally undermined in a moderate earthquake and would likely collapse causing injury or death to people in the building or on nearby property or cause damage to any other property. This is commonly understood as the building meeting less than 34 per cent of the New Building Standard (NBS) requirements.

Gable end – the triangular area of brickwork, masonry, timber and weatherboards or sheet material forming the outside wall between the sides of the end of a roof and the line of the eaves.

In-plane – when a brick, masonry or concrete wall is subjected to forces acting parallel to the direction of the wall.

Moderate earthquake – an earthquake that would generate shaking at the site of a building that is of the same duration as, but that is one-third as strong as, the earthquake shaking (determined by normal measures of acceleration, velocity and displacement) that would be used to design a new building at the same site if it were designed on 1 July 2017.

Moment frame – frame structure that features special connections between the beams and columns designed to provide lateral bracing to the building.

% New Building Standard (%NBS) – the ratio of the ultimate capacity of a building as a whole or of an individual member/element and the ultimate limit state shaking demand for a similar new building on the same site, expressed as a percentage.

Out-of-plane – when a brick, masonry or concrete wall is subjected to forces acting on the face of a wall and normally at right angles.

Parapets – the parts of an external wall that extend above the eaves' gutter line. They are functional as well as decorative. They provide fire-protection to the adjoining building and they form part of an internal guttering system.

Shear wall – a structural wall which, because of its position and shape, makes a contribution to the lateral strength of a building. There can be more than one shear wall in the design of a building.

URM – an acronym for unreinforced brick masonry, which is a term used to describe bricks secured by mortar and/or concrete used in the construction of a building without any form of steel reinforcement, timber or cane. This type of construction is not permitted under modern building codes which typically require reinforcement of building elements. URM was a construction method mainly used in the early 20th century. Buildings constructed with unreinforced masonry are generally earthquake-prone and usually need to be retrofitted.

Wythe – a continuous vertical section of masonry one unit in thickness. A wythe may be independent of, or interlocked with, the adjoining wythe(s).

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