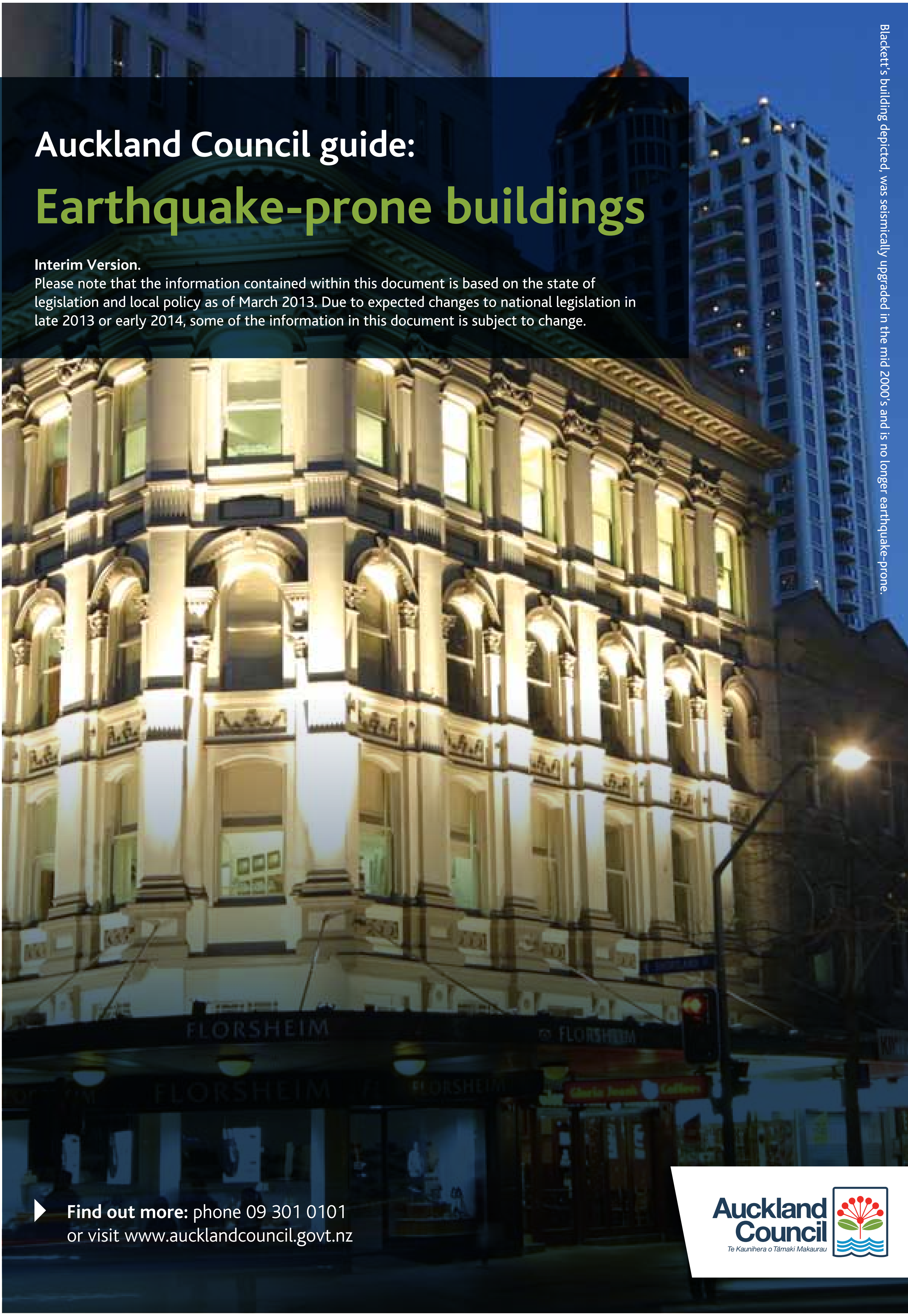
Auckland Council guide:

Earthquake-prone buildings

Interim Version.
Please note that the information contained within this document is based on the state of legislation and local policy as of March 2013. Due to expected changes to national legislation in late 2013 or early 2014, some of the information in this document is subject to change.



Blackett's building depicted, was seismically upgraded in the mid 2000's and is no longer earthquake-prone.

Find out more: phone 09 301 0101
or visit www.aucklandcouncil.govt.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau

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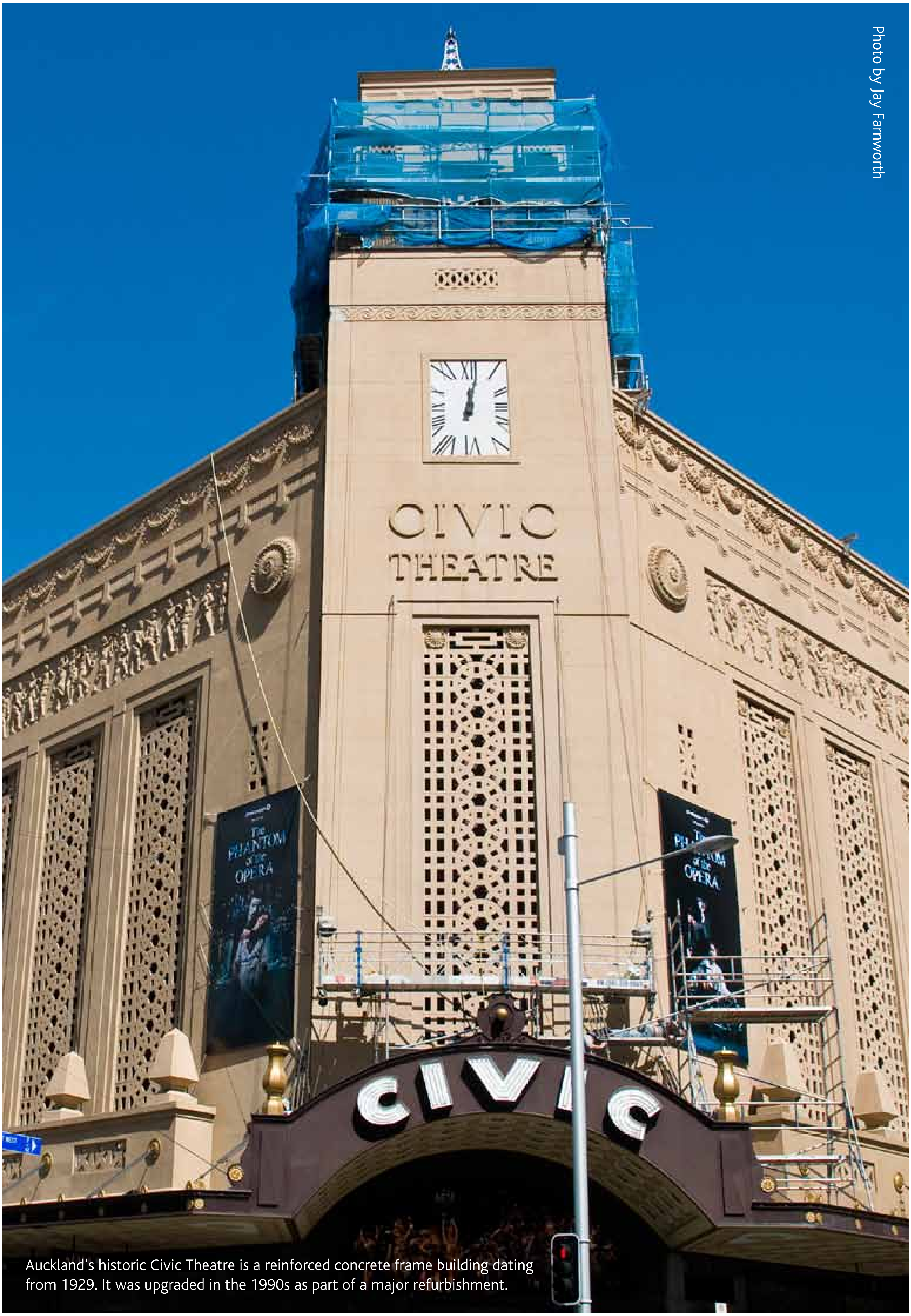

Photo by Jay Farnworth

Auckland's historic Civic Theatre is a reinforced concrete frame building dating from 1929. It was upgraded in the 1990s as part of a major refurbishment.

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This guide was prepared by Auckland Council as guidance information to supplement its earthquake-prone, dangerous and insanitary buildings policy 2011-2016. It is not a substitute for professional or legal advice, and should not be relied on as establishing compliance with the new zealand building code. It is not an acceptable solution under the building act, and may be updated from time to time.

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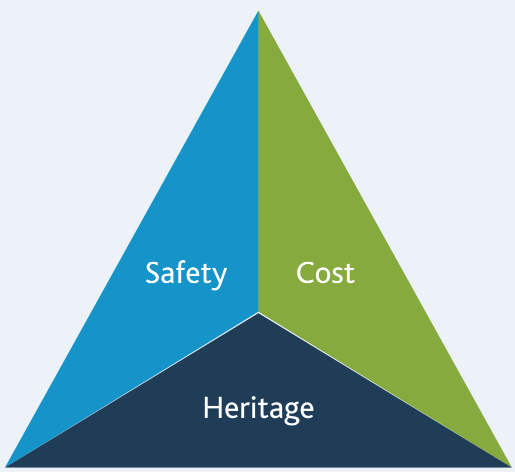
Introduction

New Zealand is positioned on the Pacific Rim of Fire, straddling a major fault between the Australasian and Pacific tectonic plates, meaning that we have to endure a greater risk of earthquakes than other parts of the world like Europe or the Eastern United States. While it is expected that the majority of these will occur in relative proximity to the Central/Alpine Fault, no area can be deemed completely seismically inactive.

In recognition of this fact, national legislation has changed to enhance our resilience to the effects of such an event, and the Building Act 2004 introduced the requirement for all Territorial Authorities to develop and implement a specific policy on Earthquake-Prone, Dangerous and Insanitary buildings.

The policies relating to earthquake-prone buildings (EPBs) are intended to determine how the assessment of a local council's buildings and private building stock will be carried out and in what priority order, strengthening requirements for any non-compliant buildings and the timeframes these buildings will need to be made compliant.



A key issue with such a policy is the impact of these requirements on the heritage buildings in an authority's region – those buildings that individually, or as a cluster, form part of our cultural heritage. It is recognised that, to obtain the best possible result in implementing such a policy, the authority and the community must strike a balance between the often-conflicting desires of public safety enhancement, heritage preservation and cost minimisation.

Aim of this guide

As a direct result of the series of earthquakes and aftershocks that struck Canterbury in 2010/2011, interest has increased significantly in how buildings across the country perform during earthquakes and how that performance can be improved.

Who should read this guide?

These days, it is no longer just seismic engineers who consider these issues. Many members of the public want to know which buildings are safe to enter or occupy. Building owners are keen to understand what cost-effective techniques they can best use to make their buildings more resilient and therefore attractive for tenants and the visiting members of the public.

Whether you are a building owner, tenant, agent or engineer and you have an interest in why your council is engaged in ensuring buildings are assessed for their seismic performance and requiring seismic retrofitting, this guide is for you.

This is not intended as a comprehensive guide, so it is recommended that you refer to the 'NZ Society of Earthquake Engineering Assessment and Improvement of the Structural Performance of Buildings in Earthquakes' document available from the NZSEE website for further engineering detail.

1.0 National seismicity

New Zealand sits across the margin between the Australasian and Pacific Plates, which are moving relative to each other by about 40mm/yr. In the North Island, the plates converge with each other and the Pacific Plate is driven beneath (subducted) the Australasian Plate. In the lower South Island, the opposite occurs and it is the Australasian Plate that is being subducted. In the upper South Island and Cook Strait area, the two plates slide past each other in what is termed a 'strike-slip' relationship.

As the plates move against each other, tension in the earth 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 Hawkes Bay and the 2010-2011 Canterbury events.

Figure 1.1: New Zealand showing plates and major fault systems (Environment Waikato).

Earthquakes have not constituted a major hazard to life and property in New Zealand as compared with many other seismically active regions, or if we consider earthquakes in relation to other types of accident. Altogether, 33 major earthquakes (magnitude 7 or greater) are known to have occurred since Europeans arried in New Zealand. The great Hawkes Bay earthquake of 1931 resulted directly or indirectly in 255 deaths; the 2011 Christchurch earthquake in 185 deaths; and a further 29 deaths have been recorded as as a result of other earthquakes since the year 1848.

As is only prudent, however, various precautions are taken against the effects of possible future earthquakes. Organisations ready to deal with earthquake and other kinds of disaster are sponsored in the main centres of population by the Ministry of Civil Defence.

To compare New Zealand with the rest of the Pacific, from 1918-1952, Gutenberg and Richter (for whom the common scale of earthquake magnitude was derived) measured major shallow earthquakes around the Pacific and found that Japan had the most at 39, followed by Chile with 23, New Zealand with 9, and finally California with 6. In total the whole world had about 500 such earthquakes during this period.

Studies of earthquakes and their effects are carried out by the Institute of Geological and Nuclear Sciences (GNS) in Lower Hutt. By about 1940, New Zealand's seismograph network was capable of locating all local earthquakes with magnitude 6 or greater; 23 shallow earthquakes with magnitudes in the range 6.0–6.9 occurred in the period 1940–60.

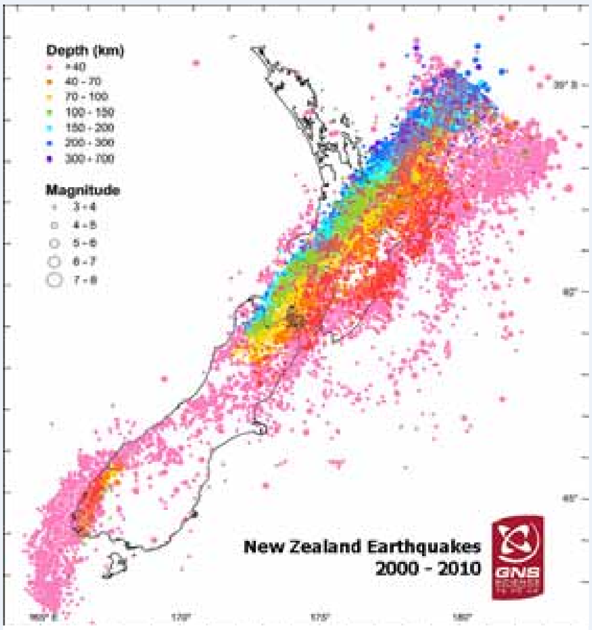


Figure 1.2: New Zealand showing locations and depth of seismic activity over period of 2000-2010 (GNS).

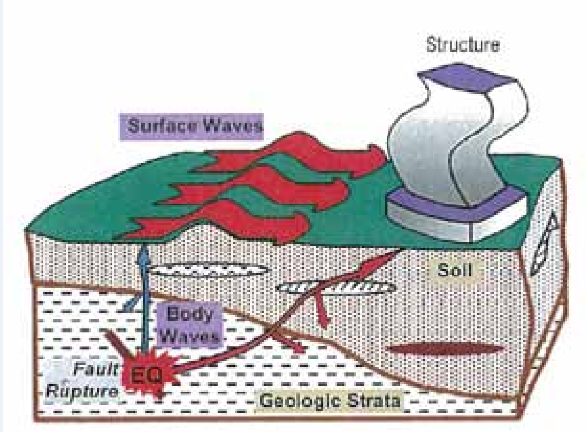


Figure 1.3: Arrival of seismic waves at a site.

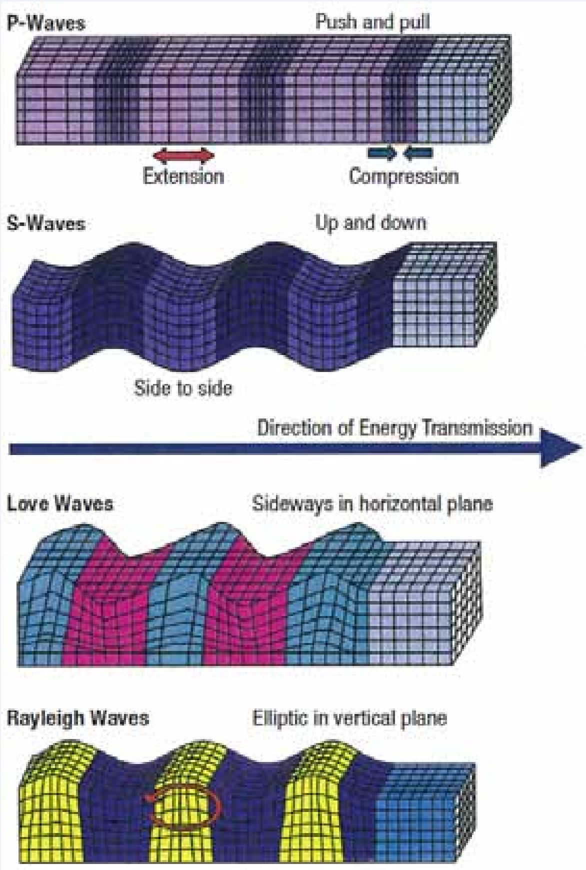


Figure 1.4: Motions caused by body and surface waves (Adapted from FEMA 99, Non-Technical Explanation of the NEHRP Recommended Provisions).

As shown in Figure 1.2, most earthquakes occur in two main areas, the eastern part of the North Island down to the top of the South Island, and Fiordland at the bottom of the South Island.

No part of New Zealand, with the possible exception of the district north of Whangarei, can be regarded as wholly exempt from shallow activity.

Deeper earthquakes are mostly confined to a narrow belt in the northern area, extending from the Bay of Plenty southwestwards to Tasman Bay.

Earthquake Waves

The energy released by an earthquake travels outwards from the epicentre in different sorts of waves. As they travel through the interior of the Earth they are termed 'body waves', and can be divided into compression waves (P-waves) that transmit energy like a row of train-cars shunting into each other, and shear waves (S-waves) that transmit energy in a rolling side-to-side motion like an ocean wave.

Once earthquake waves reach the surface, the remaining energy generates 'surface waves' that are slower than body waves, but are typically far more destructive. They take two main different forms, moving either side-to-side (Love waves) or in a vertical rolling motion (Rayleigh waves).

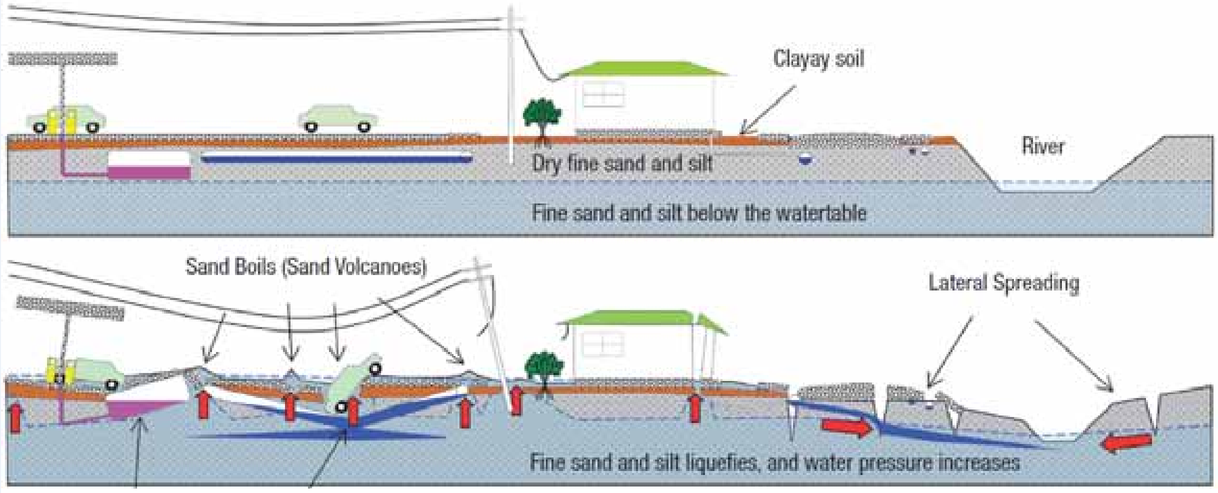


Figure 1.5: Before (Upper) and after (lower) potential effects of liquefaction on susceptible ground.

Aftershocks

These occur when the earth's surface moves again to adjust itself to the result of a main shock. They tend to decrease in intensity over time, but can persist for weeks, months or even years after the primary earthquake.

Liquefaction

This requires very specific ground shaking and soil conditions to happen. It occurs when waterlogged sediments experience earthquake shaking of enough intensity to cause the ground to become weak.

Sand Boils (Sand Volcanoes) consisting of sand, silt and water erupts upward under pressure through cracks and flows out onto the surface.

This can cause heavy structures, such as buildings and cars to sink, and light structures such as underground pipes and tanks, to rise up to the ground surface. Power poles are pulled over by their wires as they can't be supported in the liquefied ground, and underground cables are pulled apart.

Once the shaking stops, the ground settles which squeezes water out of cracks or holes in the ground to cause flooding and the deposition of sand and silt.

Lateral Spreading is another related hazard where river banks move toward each other. with cracks opening along the banks. This cracking can extend back into properties leading to damage to nearby houses.

Tsunami

Caused by large ground movements like fault ruptures or underwater landslides, a tsunami is a large displacement of water that will travel as a wave until its energy is dissapated.

2.0 Auckland

The Auckland region sits on the Australasian Plate approximately 300-500km northwest of the active plate boundary running down the middle of the North Island. The landscape is made up predominantly of Cretaceous to Holocene sedimentary and volcanic rocks that overly an older basement of Greywacke of Triassic to Early Cretaceous age (Edbrooke, 2011). Those faults that have been mapped in Auckland appear to be ancient and inactive, many thought to have originated with the major geological changes wrought by New Zealand's separation from Gondwana 80 million years ago (Kenny, Lindsay & Howe, 2011).

Auckland is, at the present day, an area of low seismic activity, with a maximum peak ground acceleration of about 0.13G, compared to a value of 0.4G in Wellington.

There are only a handful of active faults identified as potentially affecting the Auckland region; the closest being the Drury Fault and the Wairoa North Fault. Both of these are located in the southern part of the region in the Hunua Ranges. Movement on these faults occurs about every 13,000 to 43,000 years. These faults are thought to be capable of producing earthquakes of magnitudes greater than 6.

Large faults located just beyond the Auckland boundary, such as the Kerepehi and Waikato Faults, could produce significant ground shaking in the southern part of the Auckland region.

From 2004 to 2008, 27 earthquakes exceeding magnitude 2 were detected in the Auckland 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, 6km east of Orewa. This earthquake was part of a swarm of ten separate earthquakes that occurred within a 24hour period. It caused minor damage to houses (particularly brick chimneys and walls) and their contents. A total insurance payout of $1.5 million was made, with 495 damage claims reported, primarily from residential properties in the former Rodney District and North Shore City.

In terms of minor earthquakes, on average, less than 10 are detected in the Auckland region each year. These are normally too small to be felt. Auckland Council monitors these events and other factors in conjunction with GNS and other organisations, and the data obtained from them is used as indicators to help us to determine Auckland's earthquake risk.

The damage caused by earthquakes depends on the location, depth and magnitude of the earthquake, the soil and rock types it's waves pass through, and the intensity of development. By collating data on these factors, we are able to develop an understanding of the potential effects if a significant earthquake were to occur.

In Auckland, the geology and ground conditions are generally hard volcanic rock or ancient mud and siltstones, which are not very susceptible to liquefaction. Localised areas that could be susceptible include reclaimed areas around the Ports of Auckland, floodplains of the Kumeu and Kaipara Rivers and the Manukau lowlands.

GNS Science have assessed Auckland's urban liquefaction potential and in their report concludes: "We expect neither liquefaction nor earthquake-induced landsliding to have significant impact on buildings in Auckland (a) because of the low levels of the intensities anticipated in future earthquakes and (b) because susceptible ground is uncommon in the built-up area."

2.1 Policy and scope

All Territorial Authorities in New Zealand are required by the Building Act 2004 to have developed and implemented a policy on determining which buildings might be prone to significant damage as the result of an earthquake.

For Auckland Council, the development and implementation of our new policy required an amalgamation of the previous policies of the legacy councils in the region, as well as an ongoing awareness of the lessons arising out of the events of the 2010/2011 Canterbury earthquakes. One of our key objectives is to collaborate with the community, and organisations with appropriate expertise to ensure that we are doing the best we can to strike the aforementioned balance of desires in a region that, while low in seismicity, could not afford to suffer the devastation experienced by our fellow citizens in Canterbury.

For the purpose of consistency, there exists a theoretical 'design-level earthquake' that as a standard all modern buildings must be built to endure. When assessing the performance of older buildings, they are deemed 'earthquake-prone' if ,during an earthquake of only one-third the intensity of that standard, they can be expected to suffer partial or complete collapse, causing injury or death to people or damage to another property.

In addition to the overall performance of the building, attention needs to be paid to those parts, such as heavy ornaments and parapets, which constitute a greater potential hazard in and of themselves.

Special attention will also be given to the intact survival of essential emergency egress routes, such as stairs and ramps, and the securing of secondary systems such as suspended ceilings and ventilation ducting. It is also recommended that building owners and occupiers ensure large or delicate pieces of office furniture be appropriately secured.

In Auckland, the task of carrying out these assessments is enormous, and the Seismic Performance Programme being led by Auckland Council is going to take many years to complete for the whole region.

The council will, over time, through continued engineering assessments and associated research, further develop its database of buildings of differing ages, materials, and structural types, to allow for a more appropriate targeting of resources to 'at-risk' structures and exemptions for those deemed to not be at-risk. The register of earthquake-prone buildings, as referred to by Auckland Council's policy, is a subset of that overall data.

For those interested in the state of a particular building, finalised assessments and relevant associated data will be available via Property Files.

Buildings excluded from Auckland's policy

The seismic forces for the design of buildings in Auckland have not changed much since earthquake design began with the introduction of NZS 95 in 1935. This was followed by NZS 1900, Chapter 8, then by NZS 4203 in 1976, by the Building Act 1991 and now the Building Act 2004.

Territorial authorities are at present not required to assess any building designed or strengthened to the 1976 NZS4203 and subsequent codes, unless they have a critical structural weakness. To be excluded from the process, building owners may have to provide evidence identifying the year of construction.

The reason for this is that, 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 by Auckland Council's 2011-2016 policy to undergo an assessment and potential upgrade.

2.2 Assessment

Three main types of assessment can be expected for Auckland's building stock.

1. Document review

In the first instance research is carried out through council records, city archives and private documentation (where available) to determine the history of the building and what (if any) previous upgrading may have occurred.

2. Initial Evaluation Procedure (IEP)

Developed by the New Zealand Society of Earthquake Engineering (NZSEE), the IEP provides an indication as to the seismic performance of the building relative to what the minimum strength a modern building would need to be constructed to for that region.

Where a building owner has already completed such an assessment or wishes to have one carried out sooner, Auckland Council is willing to accept independent IEP reports, provided the information is substantive and can be reconciled with any existing structural reports. This assessment must be completed and signed, complete with their registration number, by a Chartered Professional Engineer (CPEng).

To complete an IEP, certain characteristics of a building must be pulled from records and/or observed through a visual inspection.

These include:

- **year of building construction** - this determines to which structural design code the building was likely to have been constructed
- **structural frame type** - for instance, are the primary load-bearing elements of the building unreinforced brick, reinforced concrete, or timber
- **building height** - this affects the expected seismic period of the building; the time it takes for the building to sway back and forth during an earthquake
- **building form** - is it a regular square structure, or does it have irregular elements that may behave differently to each other in an earthquake?
- **relationship to neighbouring structures** - is it directly abutting or significantly different in height; is there a likelihood of pounding?

Regional seismic hazard factors and underlying geology also play an important part in calculations. Much of this data is obtained from regional hazard studies or geotechnical mapping by organisations such as GNS.

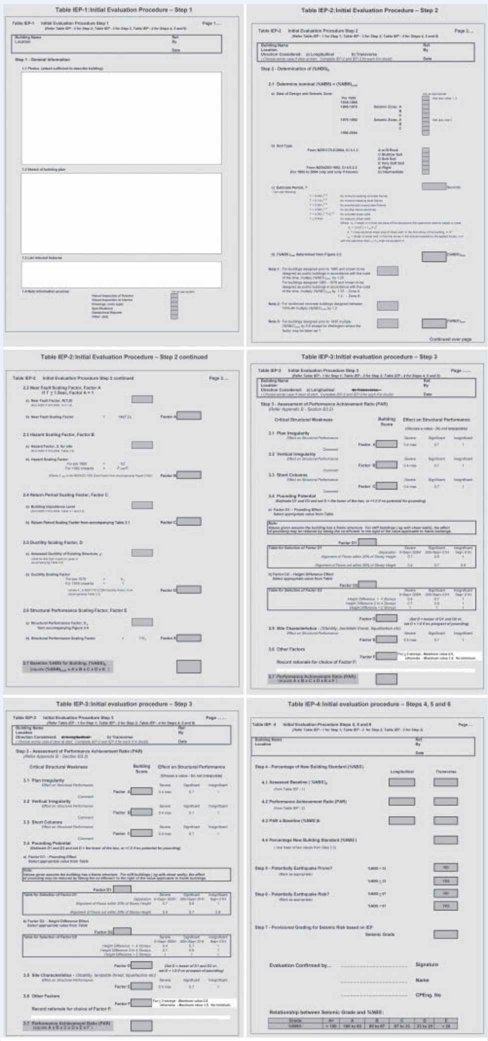


Table IEP-1: Initial Evaluation Procedure – Step 1
Table IEP-2: Initial Evaluation Procedure – Step 2
Table IEP-2: Initial Evaluation Procedure – Step 2 continued
Table IEP-3: Initial evaluation procedure – Step 3
Table IEP-3: Initial evaluation procedure – Step 3
Table IEP-4: Initial evaluation procedure – Steps 4, 5 and 6

Figure 2.1: Example of template IEP pages from the NZSEE.

The result of this assessment is a percentage score of the new building standard (%NBS), from which it is then possible to determine if a building is potentially earthquake-prone (less than 34%), and would therefore be required to take further action.

Auckland Council is expecting to carry out most of these assessments itself according to the following prioritised groupings:

- **Importance Level 4** buildings are those with special post-disaster functions. e.g. hospitals.
- **Importance Level 3** buildings are those that contain people in crowds or contents of high value to the community. e.g. schools.
- **Importance Level 2** buildings are those that make up the bulk of the city's built environment and are simply those that do not fall into the other categories. e.g. retail shops.
- **Heritage buildings** are those defined to be as such by the Auckland Council District Plans, by the NZ Historic Place Trust register or as other significant buildings or structures forming part of a Conservation Area or Special Character Area.

Further information on these Importance Levels and other information relevant to the IEP and seismic performance assessment can be found in the NZ standard 1170, which regulates the design of structures to resist earthquakes.

3. Detailed Engineering Evaluation (DEE)

A detailed engineering evaluation moves beyond the coarse indication of a buildings seismic performance as provided by an IEP. It instead provides a better understanding on how not only the overall building, but also its constituent elements will perform, identifying in particular any critical weaknesses that may need to be addressed.

There are numerous engineering methodologies for working through a detailed engineering evaluation, from finite element modelling to non-linear static push-over tests. Most of these analyses are significantly helped by the engineer having access to comprehensive data on the original construction of the building and any additional structural works that have been carried out during its lifespan. It is up to your engineer to determine what the most appropriate and cost-effective form of analysis will be for your particular building.

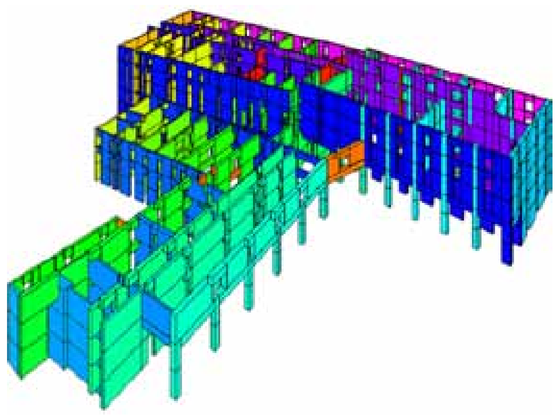


Figure 2.2: A finite element model used in some DEEs to calculate weak elements in a structure. (Image sourced from ASDEA, Italy)

To allow for updating of the Seismic Performance Database, any detailed assessment should provide an accurate measure of %NBS (New Building Standard), which will supersede any IEP scores held on file.

The detailed assessment will make use of appropriate materials standards and other New Zealand and/or overseas publications relevant to assessment of existing buildings for earthquake loadings. The owner is required to carry out the detailed assessment, not the council. Average known or measured strengths of materials may be used when assessing ultimate capacities of structural elements.

2.3 Notification and reporting

Council assessments

As each IEP is completed, the provisional result will be notified to the building owner, who will be provided with 3 months (4 months if this period falls over the Christmas break) to provide additional information to allow for review of the final IEP grading.

Information provided can come in the form of basic facts about the building that the council may not have been certain about (like the age of construction), or in the form of an independant engineering report.

As there are many buildings in the region to assess and this is expected to take up until December 2015, building owners are encouraged to obtain their own independant IEP reports on qualifying pre-1976 buildings sooner if possible. They also need to ensure that there are promptly sent through to the council for review and acceptance, and so that the work is not unecessarily replicated by the council.

Finalised reports

IEP and DEE grades (A, B, C etc.) will be available to the public via Land Information Memorandum (LIM) reports, while the reports themselves will be accessible via the Property File. Buildings assessed and indicated as not potentially earthquake-prone will also have their grades and reports stored to provide awareness of where assessment has been carried out.

When the council has satisfied itself that a building or a part is an earthquake-prone building, it will advise and liaise with the owner(s) regarding resolution of the buildings status.

NBS versus ULS

The reference to new building standard (NBS) is likely to be replaced with reference to ultimate limit state (ULS) in the near future as a better reflection of the nature of the assessment.

Formal notices

In accordance with s124 and s125 of the Building Act 2004, Auckland Council has the authority to attach a written notice to the building stating what work is required within a time stated in the notice, so as to reduce or remove a danger.

However, it should be noted that council would discuss options for action with owners before deciding whether a notice under s124 will be issued. The purpose of these discussions will be to develop an agreed approach for the building that achieves an overall positive outcome for council and the owner.

A notice may then be issued stating the particular parts for which the danger is to be reduced by strengthening to an ultimate capacity of at least 34% NBS, or be removed. The owners will then need to provide a formal proposal with respect to the work they will undertake. council can then formally accept the proposal.


Seismic performance report

Auckland Council

Figure 2.3: Template seismic performance report that is the council coversheet for all finalised engineering assessments.

If such a notice is issued, copies of the notice will be provided to the building owner, occupier, and every person who has an interest in the land, or is claiming an interest in the land at the time of the notice's issue. This will include the New Zealand Historic Places Trust if the building is a scheduled or registered heritage building. Once issued, the notice will be visible as part of council LIM reports for any new entities with an interest in the land.

Council will liaise with the owner to assess the progress of compliance with the notice and gain access to the building for the purpose of assessing any potential structural deterioration.

At the expiry of the time period set down in the notice, council will contact the owner and check the building to ascertain whether the notice has been complied with. Enforcement action is possible under the Act if the requirements of the notice have not been met within the stated time.

Reciept of reports

It is the responsibility of building owners to ensure their contact and mailing details are kept up to date with Auckland Council. Seismic performance assessments are conducted on entire buildings rather than individual units, and we send our reports to the primary listed contact. As there are cases where that primary contact is different to the leaseholder of the building, it is important that there is good communication between the parties in relation to this matter.

The register

The council keeps and updates a register of all potential EPBs for which an IEP, or DEE has been done. The register records details of the outcome of the assessments, the details of any notices which may have been issued and any strengthening which may have been done. In addition, the register also includes the details of any assessments that have shown buildings to not be earthquake-prone (or suspected of being) for the purpose of being comprehensive.

Information on the register will be made available via the following means; this includes all detailed information and calculations in connection with the IEP and DEE assessments.

The following information will be placed on the LIM for each building that has been assessed:

- address and legal description of land and building
- seismic performance grading (A, B, C, D or E) with an explanation of the grade
- statement that the building is on the council's register of potential earthquake-prone buildings if the provisional grade is a D or E where an IEP has been completed, or that it has been deemed earthquake prone following a detailed assessment with a %NBS score less than 34%
- notification where a s124 has been issued
- date by which strengthening is required
- statement that further details are available from the council, and that council has a cost recovery policy which will apply where it provides these details.

The following information will be accessible via the Property File:

- IEP report where one has been carried out
- DEE report where one has been carried out
- associated reports (geotechnical etc.) where provided. Please note that some of these may be deemed confidential and only available with the authorisation of the building owner or responsible agency.

2.4 Resolution

Seismic performance improvement

Once a building has been identified as earthquake-prone, that building or parts thereof identified as significant hazards will be required to be strengthened to no less than 34% of the new building standard (34%NBS).

The council will consider any reasonable approach proposed for improving the seismic performance of a building which is found to be earthquake-prone and a notice has been issued. The proposed work will be assessed on a case by case basis, taking into account the relevant principles and requirements set out in the Building Act 2004. Guidance on building assessment and strengthening is available from structural engineering firms and the NZSEE.

In recognition of the NZSEE recommendations and potential recommendations or legislative changes arising from the Canterbury Earthquake Royal Commission, Auckland Council recommends where practicable that all building owners issued with an EPB notice seek to upgrade to at least 67%NBS.

If in future an amendment to the Building Act requires or allows for a higher standard, Auckland Council reserves the right to immediately and to full effect, modify this policy to adopt a higher standard, provided the approval of council's governing body.

Any notice requiring upgrade will immediately by superceded by the new requirement, and any upgrade work to 34% will not preclude the issuing of a new notice to a higher level.

This superseding will not apply to buildings strengthened to 34% under the policies of legacy Territorial Authorities in the Auckland region (Waitakere City Council or Franklin District Council for example), except where a change to the definition of an Earthquake-Prone Building is made in national legislation.

The timeframe for upgrade starts from the date of council sign-off on the first Seismic Performance Report for the building.

- Importance Level 4 buildings – 10 years
- Importance Level 3 buildings – 10 years
- Importance Level 2 buildings – 20 years
- Heritage buildings – 30 years

Note: Where a heritage building also classifies as an Importance Level 3 or 4 building, the timeframe is 10 years. The Importance of the building would have to be reduced to 2 for it to qualify for the full 30 year timeframe.

Failure to comply

If mitigation of the hazard has not occurred in the timeframe set by the Auckland Council policy for an earthquake-prone building, council will isolate the building under the authority granted to it by Section 124 of the Building Act 2004.

This isolation will likely take the form of hoardings and the requirement for occupants of any type to vacate the building until such a time as work is carried out to address the hazard.

It should be noted that the choice to demolish an earthquake-prone building does not take precedence over other regulatory requirements, and in no way can be used to add weight to an argument for a resource consent or the like.

Legislative changes to timeframes

There is the strong possibility that legislative changes arising out of the Canterbury Earthquakes Royal Commission will see timeframes for hazard mitigation altered.

If this occurs, all timeframes will still be measured by the date of the first Seismic Performance Report for the building.

2.5 Heritage

Heritage buildings are those that, individually or as part of a collective community, hold historical value for our society. It is through their preservation that we remember our history and the personal stories that are interwoven with those structures.

Buildings of heritage value are classified in various ways; they are scheduled under the District Plan, are covered by a Conservation Area or Special Character Zone under the District Plan, registered under the Historic Places Act 1993, or known to be constructed before 1900.

Auckland Council believes that the ongoing survival of heritage buildings needs to be actively promoted. However, council does not want to see the strengthening work adversely affect the intrinsic value of these buildings. Where the detailed structural assessment confirms that the building is earthquake-prone, council will work with the owners to develop a mutually acceptable way forward. Again, consistent within this policy, where agreement cannot be reached, council will issue a notice under s124 of the Building Act 2004.

Special effort will be made to meet heritage objectives and may include the use of dispensations and waivers to avoid forcing work which has a significantly negative impact on heritage places, especially where the level of non-compliance is technical rather than significant, or where the level of risk can be adequately mitigated by a more flexible approach to levels of strengthening and to strengthening techniques under the Building Act 2004.

Strengthening work and techniques that respect and protect the heritage will be advocated. The timeframe for seismic upgrade of a recognised heritage structure may be extended to 30 years upon the agreement of Auckland Council Heritage.

Where a heritage building is damaged by an intervening event (such as fire) which renders the building earthquake-prone, dangerous or insanitary, any building work (other than demolition of all or part of the building) required by s124 notice to reduce or remove that danger will be in accordance with what is necessary to facilitate the preservation of the building's heritage value.

These provisions may include the retention of historic building material or components (such as brick or stone) for reconstruction purposes, and the recording of damaged elements or details, rather than the immediate removal of such materials and their disposal.

The Building Act also specifically recognises that heritage buildings may require a variation to such an approach if their particular heritage values are not to be compromised. It therefore makes provision for the council policy to deal with earthquake strengthening of such buildings in a systematically different manner and on a case-by-case basis. For instance, council can consider dispensations and waivers for issues of safety and sanitary conditions for heritage buildings and consider lateral or innovative approaches to achieve the desired level of compliance.

Figure 2.4: Auckland has a significant number of valued Heritage and character buildings that need to be maintained.

3.1 Structural performance

Decisions on whether to seismically retrofit a building, or to demolish and rebuild a replacement structure that complies with current earthquake strength criteria, depend upon the desired building performance as well as the associated costs. In this section, a generic retrofit strategy is described that begins with the most basic (and important) items to address with the primary aim of ensuring public safety.

Additional retrofit measures may be taken beyond these to further improve building performance in order to minimise damage to the building and contents, with the highest performance target conceivably being to have the building and its contents suffer no damage and be immediately functional following the considered earthquake event.

Elements of concern

Older buildings usually have a number of inherent structural features which make them prone to earthquake forces. Many of these features can often be addressed without significant alteration to the building, resulting in a relatively large increase in strength. The overarching problem is that New Zealand's URM building stock was simply not designed for earthquake loads and, whilst these buildings can be made to perform adequately in an earthquake, they lack a basic degree of connection between structural components to allow all parts of the building to act together.

Therefore, the basic philosophy followed here is to first secure non-structural parts of Unreinforced Brick Masonry (UBM) buildings that represent falling hazards to the public (eg, chimneys and parapets) followed by improving the connections between the structural elements (roof, floors and walls), strengthening of specific structural elements, and possibly adding new structural components to provide extra support for the masonry building.

Return wall separation

This failure mechanism is undesirable because it allows a wall over the entire building height to fall outwards. This failure mode can be prevented by the use of anchors installed along the vertical intersections between walls.

Figure 3.1: Failed parapet at the corner of a building.

Chimneys and parapets

Chimneys and parapets are parts of URM construction that project above the roof of the building. When subject to seismic actions, they can rock on their supports at the roof line and topple over. The simplest solution is to brace them back into the roof structure. Implementation of this bracing is usually comparatively straightforward and inexpensive.

Gable end walls

Gable end walls sit at the top of walls at the end of buildings with pitched-roofs. If this triangular portion of the wall is not adequately attached to the roof, the gable end section of the wall will rock and is vulnerable to outward collapse.

Figure 3.2: Failed gable end walls.

Figure 3.3: Out-of-plane wall failures in longitudinal and transverse directions.

Out-of-plane wall failure

Unreinforced masonry walls in particular are weak in 'out-of-plane' bending and therefore are susceptible to 'out-of-plane' failures dictated predominantly by their slenderness. Cavity walls that are missing wall ties, or have wall ties that are badly deteriorated, are especially vulnerable. Solid walls can also be vulnerable but they have the advantage of being less slender. The addition of wall-to-diaphragm anchors serves to reduce the vertical slenderness of a wall as well as make the building work together as a whole, rather than as independent parts.

In-plane wall failures (piers and spandrels)

When 'out-of-plane' failure mechanisms are prevented, the building is able to act as a complete entity and in-plane wall failure mechanisms can occur. It should be noted that, when in this condition, building strength is often not far off the full design strength requirements. Strengthening of piers and spandrels can result in further increases in overall building strength.

The seismic retrofit strategy for a building in this condition might be to improve the building's displacement capacity, rather than institute any further increase in strength.

This intervention could be achieved by locally reinforcing the masonry spandrels and/or piers. Alternatively, ductile steel or concrete frames can be inserted internally to provide the in-plane shear strength needed, whilst also becoming responsible for some or all of the gravity load carrying function of the masonry walls.

Floor and roof diaphragm failure

In some cases, the floor and roof diaphragms, which are typically constructed of timber, are excessively flexible. This flexibility may result in the walls that are connected to these diaphragms undergoing sufficiently large 'out-of-plane' deflections resulting in major wall damage and collapse.

Pounding failure

This failure mechanism only occurs in row type construction where there is insufficient space between adjacent buildings so that they pound into each other (when vibrating laterally) during an earthquake. Widespread examples of pounding damage to buildings were observed in the 2010/2011 Canterbury earthquakes.

Figure 3.4: In-plane wall failure of piers on the top floor of a building.

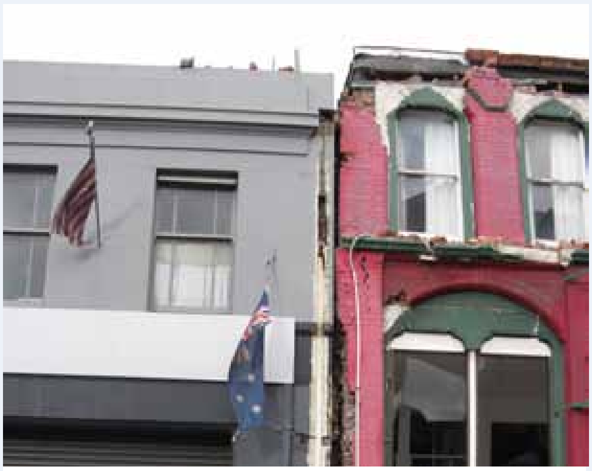


Figure 3.5: Pounding damage to two adjoining buildings.

3.2 Seismic retrofit solutions

Material stabilisation/maintenance

Aim: ongoing building maintenance should be undertaken to ensure that the masonry elements (walls, parapets, chimneys and facades), and the timber roof and floor elements, are in sound condition. Deterioration of the fundamental building elements compromises the ability of the 'as-is' connections between elements to share the seismic forces generated during an earthquake.

Figure 3.6: Severely degraded bricks and mortar due to the ingress of moisture into the wall.

The bricks (and particularly the mortar) used in UBM buildings deteriorate in the environment over time. Occasionally this deterioration will result in local failures and cracking which affects the overall effectiveness of the building. Various external actions such as dampness, subsidence, earthquakes and impacts can also cause cracking and damage in the masonry elements. Deterioration can often be remedied by reinstatement and repointing of mortar, but sometimes more substantial measures are required.

There are various techniques for the repair of cracks, securing of lintels and reinstatement of damage. Bonding agents such as grout or epoxy can be injected into the mortar and there are also several metal-based types of inserts, such as shaped dowels or reinforcing bars, which can be used to reinstate and strengthen the brickwork.

The visual impact of reinstatement and strengthening can be minimal if done carefully, and the result is potentially far superior to a cracked and broken façade. However, such measures are often irreversible and care needs to be taken with colour matching and the concealment of holes drilled for inserting rods.

Lintels and arches will sometimes require strengthening, particularly when these elements are constructed from UBM. One of the best ways to achieve this intervention is by using drilled and inserted rods which are grouted (or epoxy anchored) into place. These rods provide the requisite tensile strength to the structural element while posing little visual impact.

Parapets and other falling hazards

Aim: secure or remove falling hazards.

The greatest threat to public safety posed by UBM buildings is that of falling masonry. This hazard can be due to chimneys that fail by rocking (usually at the roofline) and fall through the building's roof or over the side of the building. Parapets that are not properly secured to the building can fail similarly. Because of their location along the front and sides of commercial buildings, and because they typically fall outwards towards the footpath/street, parapets pose a very high danger to the public. Gable end walls are another version of this out-of-plane failure mechanism and, similar to parapets, gable walls almost exclusively fall outwards.

Figure 3.7: Example of a secured gable end that survived earthquake loading and a companion failed gable end that was not secured.

Parapet failures

Many of these failures were seen during both the 4 September 2010 and 22 February 2011 earthquakes, where parapets not only fell towards the footpath/street, but they mostly fell onto the building's awning or canopy that projects above the pedestrian access, and resulted in collapse of that element as well. In cases of multi-storey (two or three) buildings with parapet failures, the parapets fell across the footpath and well into the street, crushing cars and buses, and in several instances, killing the occupants of those vehicles.

The basic strategy to eliminate these falling hazards is to fasten them to the rest of the structure, normally through the use of ties or anchors back to the roof structure.

UBM buildings will often feature numerous decorative elements built with brick and plaster which are important parts of the building's architectural character, such as parapets, chimneys, gable walls, and other, smaller, decorative features. In the past, some buildings have had these elements removed wholesale, rather than the elements being strengthened or secured. Parapets and chimneys are usually the first parts of a building to fail in an earthquake due to their low bending strength and high imposed accelerations.

Parapets in particular are comparatively simple to strengthen. Generally, a continuous steel section running horizontally along the length of the parapet, which is fixed back to the roof structure behind, is a suitable technique if a little crude. The back of a parapet is not often seen, which makes the visual impact of this method low. The steel section is bolted to the UBM which also allows good potential for reversibility.

Chimneys contribute to the architectural form of a building and often help define its roofscape and, as such, should be preserved if possible. The securing of chimneys is more complex than the securing of parapets and gables, but can usually be achieved by fixing them to the building diaphragms at each level and, either strengthening the projecting portion, or bracing it back to the roof structure with steel members similar to the methods used for parapet restraint, or fixing steel sections to the sides to provide flexural strength. A number of strengthening solutions are available for bonding to the surface of masonry elements and may be appropriate where the exterior has been plastered.

Other elements that constitute falling hazards, such as decorative plaster features on the face of a wall, can be effectively fixed with a single bolted connection. Less secure elements, such as plaster finials or balusters, can be secured with a single adhesive anchor connected to a strand of stainless steel wire, to mitigate the falling hazard. However, more complex strengthening work may be appropriate in some cases.

Wall strengthening to restrain 'out-of-plane' bending

Aim: prevent 'out-of-plane' failure of walls by increasing their flexural strength or reducing the vertical and horizontal distance between their supports.

UBM walls are weak when subjected to forces other than compression. Even when fully secured to floors at each level, 'out-of-plane' forces can cause significant wall bending that is governed by the ratio of the height between levels of support to the thickness of the wall. Some walls have sufficient thickness, or have cross-walls or buttresses, which enable them to withstand these out-of-plane forces without modification, however many walls will require seismic improvement. There are a number of approaches to combat this problem as later described in this guide.

One approach to this problem has been to fill the cavity with reinforcing steel and a cement grout. This has the dual benefits of bonding the outer leaf to the inner leaf and also forming a reasonably strong shear wall which is hidden from view. However, this approach fails to consider the purpose of a ventilated, drainable cavity. When a cavity is filled, not only is the ventilation route blocked, but water penetrating the outer leaf is transferred directly to the inner leaf via the grout fill, which results in moisture penetration into the building.

This moisture can directly cause the decay of timber components built into the structure. As a consequence, dry rot develops in timbers such as door and window frames and in skirtings, causing extensive damage.

Brick cavity walls – (Outer leaf fixing)

The outer leaf of a cavity wall is problematic as it is particularly susceptible to failure by peeling off outwards. The steel ties, which were often installed to connect this layer to the more robust wall behind, are subject to deterioration and sometimes missing, requiring attention during retrofits.

The current preferred approach to re-attaching the outer leaf is to use a series of proprietary corrosion resistant ties at regular centres which are drilled through the face layer and are epoxy anchored into the structure behind.

This technique is effectively a retrofit of the steel ties which have either deteriorated or were omitted in the original construction. The visual impact of these ties is minimal, although care needs to be taken when concealing drilled holes. These ties are irreversible, but their presence is visually negligible.

While a filled cavity may seem to be an excellent strengthening solution, it is the ventilation and drainage functionality of a cavity that is the overriding priority.

The filling of a cavity with a cement grout does not take into account the incompatibility between rigid cement mortars and grouts, and the weaker lime mortars that historic (mainly 19th Century and early 20th Century) buildings are constructed of. These materials are incompatible in terms of both strength and permeability, with the difference in permeability potentially leading to a number of detrimental effects on the original performance of the building fabric. The softer, permeable materials, such as bricks and the lime bedding mortar, will become prematurely sacrificial in the weathering process, as the cementitious materials trap water against the more porous, softer elements. As a result, extensive erosion of soft brickwork leads to the loss of original fabric due to the need for brick replacement.

Efflorescence can also develop in structures as a consequence of changing the way that moisture is transferred through a building, and by introducing cementitous grouts and mortars containing soluble salts. This efflorescence can cause extensive damage to both external brickwork and internal plaster finishes.

Inter-floor wall supports

A series of vertical steel sections can be bolted to the inside face of the wall at sufficient spacing to ensure that the width of wall between supports is capable of resisting the out-of-plane forces. These sections act in bending to transfer wall loads to the adjacent floor diaphragms, essentially breaking up a large planar wall into a number of buttressed segments. This simple method may be appropriate in, for example, an industrial building, where visible steel bolted to the walls is in keeping with the character of the building, or in other buildings where the steel can be made to be architecturally appealing.

In some other situations, it may be less appropriate but less intrusive, than other techniques. If there is existing internal framing with space behind for these columns, and no historic material is lost during installation, then it is a perfectly acceptable method. Sections generally fix to the historic material with bolts only, which allows a high degree of reversibility.

In the past, rather than only supporting the UBM walls for out-of-plane actions, these inter-floor wall support systems have been conceived as a method to support the floors in the event that the walls fail and collapse. A technique that is similar to the installation of vertical steel members, is to provide a horizontal steel member at the mid-height of the wall and brace this with diagonal struts up to the floor or ceiling diaphragm above.

This technique might be more suitable than the installation of vertical members if there is a cornice part way up the wall which needs to be conserved, or which can be used to disguise the steelwork. However, care needs to be taken to ensure that the struts are visually unobtrusive.

Both of these techniques can also be undertaken with the steel substituted with concrete, where this is more appropriate visually or, less commonly, with timber. Steel struts can also be recessed within the width of the wall. Recessing the members results in an irrecoverable loss of material and may result in other complications such as cracking, although recesses may be preferable if used beneath a plastered surface, as there it will not affect the interior space.

Concrete sections will have larger cross section geometries than will steel sections and will therefore be more intrusive. In addition, once cast, concrete is difficult to remove without significant damage, particularly from a porous and naturally coloured material like clay brick. The installation of in-situ concrete is a comparatively permanent measure, so any activity which requires concrete to be cast against brick should be given careful thought before being undertaken.

Figure 3.8: Internal strong backs to restrain out-of-plane wall failure

Post-tensioning

Post-tensioning is an extremely effective method for increasing the out-of-plane strength of UBM walls. The post-tensioning may be applied externally or be installed internally by drilling vertical cores through the middle of a UBM wall and then inserting steel rods into these cores. The rods may or may not be set in grout, and are then tensioned, which provides an additional compressive force in the wall. This loading modifies the stress behaviour of the UBM in bending (i.e. the result of out-of-plane loading).

Instead of bending instantly and causing tensile forces, to which UBM has little resistance, the wall remains in compression. This modification of the material properties also results in an increase in the shear strength of the wall, making post-tensioning an attractive strengthening solution.

Internal post-tensioning has little visual impact, although its installation may be unsuitable in some buildings, as access is required to the top of the wall, and walls need to be of a certain minimum thickness. Drilling cores involves some loss of historic material from the holes, though compared to some methods, this is a minor impact. If the bars are fully grouted in place, post-tensioning is essentially irreversible, although this does not necessarily have to be done.

The presence of post-tensioning bars is not likely to result in any negative effects to the historic material should their function no longer be required, provided care is taken with all core reinforcement to ensure that it is adequately protected from corrosion. This problem can be completely avoided by using plastic coated steel or FRP bars.

There are other methods of core reinforcement, with the most common being non-stressed steel bars set in grout, where the steel reinforcement only becomes stressed when the wall is loaded laterally. The visual impact and reversibility of these methods are the same as for fully grouted post-tensioning, although they are less effective structurally.

Floor and roof diaphragm stiffening

Aim: increase in-plane stiffness of horizontal diaphragms (floors and roof) so the seismic forces can be efficiently transferred to masonry shear walls.

Diaphragms are useful because they provide a layer through which lateral forces can be distributed from their source to remote resisting elements, and also act to bind the whole building together at each level. A building which acts as one rigid body rather than a number of flexible panels is far more likely to survive an earthquake. Tying floors to the outer walls is generally required regardless to ensure that joists are not dislodged.

Timber floor diaphragms consist of three main elements; chords, sheathing material and supplementary structure. To form a diaphragm in a typical UBM building, chords need to be established and mechanical fastenings added to take shear and tensile loads. Several secondary fastenings between the chord and the floor or roof may also be required depending on the technique used.

Some tensile ties will penetrate to the outside of the building and others will be drilled and epoxied in place. Existing historic sheathing may prove inadequate and require strengthening or an additional layer of more rigid material.

Ties to the outside of walls may require metal load spreaders which visually impact the exterior. Many New Zealand buildings display these, and they seem to have become somewhat accepted as part of the strengthening process. Nevertheless, care needs to be taken when considering their visual impact and invisible solutions may be preferable. Much of the additional required work can be hidden within the floor space, but if this is exposed or the connections are extensive, special attention will be required to preserve the visual character of the inter-floor space.

Figure 3.9: Internal post-tensioning bars used in the Birdcage hotel, Auckland.

Diaphragm strengthening may have some visual impact if new sheathing material is required. Historic flooring material is often a significant contributor to the character of a building and ought to be retained in view whenever possible. If the existing sheathing is inadequate, a ceiling diaphragm below, or stiffening the existing material, might be preferable to covering it. Another approach is to remove the existing sheathing and install a structural layer beneath it. This exercise requires extreme care; firstly because existing sheathing, particularly tongue and groove, is very easily damaged during removal; and secondly, care needs to be taken to restore the boards in the correct order.

Diaphragms which are formed using mechanical connections have a high degree of reversibility; where ties are epoxied into walls there is less reversibility, but minimal visual intrusion. Additional sheathing may damage or alter the nature of the historic timber below, making it less desirable as a solution, although this can be mitigated. Occasionally, pouring concrete over an existing timber floor is considered. This solution can greatly increase the stiffness of the building, but in turn increases its weight and therefore the forces acting upon it. Further, it completely changes the material of the floor and is not a reversible action, because even if it can be removed, the concrete would essentially destroy the character of the underlying timber. This procedure is therefore not recommended except in exceptional circumstances.

Roof diaphragms where the structure is exposed are slightly different, as the inclusion of a plywood diaphragm above timber sarking is generally acceptable if this area can be accessed, for example if the roofing is being replaced. This installation can also help to protect the sarking beneath. Roofs with suspended ceilings can be made to accommodate cross bracing, struts, and more innovative solutions, as they can be hidden within the ceiling space.

In instances where the roof provides little diaphragm action, or the forming of a diaphragm is uneconomical or impossible, a horizontal load resisting member at the level of the top of the walls can be used to provide stability to the walls under out-of-plane loads. However, this member needs to be fixed to stiff elements at regular intervals to transfer horizontal loads, and these stiff elements may need to be introduced to the building if other structural elements cannot perform this task.

Wall reinforcement (FRP and other materials)

There are a number of other methods that may be used to provide out-of-plane stability of unreinforced masonry walls, such as the use of strips of fibre reinforced polymer (FRP) fitted into vertical saw cuts in UBM. This technique is known as near surface mounting (NSM). NSM is a relatively recent technique which involves epoxying FRP into saw cuts in the surface of the UBM and covering the cut with a grout mixed with brick dust.

This technique would have some visual impact in naked brick, but little if done within an existing grout line, and none if installed in plastered walls being repointed. This technique can be a particularly effective and non-intrusive method of strengthening, although the finishing of this system is noticeable and work needs to be done to conceal the inserts.

Connection of structural elements

Aim: ensure adequate strength of roof-to-wall, floor-to-wall and wall-to-wall connections.

Good connectivity between the walls and the floor and roof diaphragms will ensure that the walls only deflect outwardly over the height of one storey of a building. This reduces the out-of-plane displacements that lead to wall collapse.

Figure 3.10: Steel strapping for floor stiffening.

Figure 3.11: Vertical Near Surface Mounted (NSM) Fibre Reinforced Polymer (FRP) strip strengthening of chimneys.

Similarly, good connectivity along the vertical intersection of walls meeting at corners of a building (or internal walls meeting with an external wall) will ensure that the building responds as a single structural system and not as separate, isolated components. Much better performance can be expected in an earthquake when the building responds as a single system.

A key problematic deficiency in UBM construction is inadequate connection of diaphragms to walls, as failure of these connections can potentially lead to global collapse of the building. The addition of a network of small ties can substantially increase the strength of the building by fixing the walls to the floor and roof diaphragms. These ties need to resist two actions: shear from the diaphragms trying to slide across the walls; and tension from the diaphragm and wall trying to separate. If these ties are missing, the walls will be acting as a cantilever from the ground level under lateral loads, and floors and roofs are far more likely to be dislodged from their supports, which is the most common mode of failure for UBM buildings in an earthquake.

The use of simple metal anchors to connect the walls to the floor and roof diaphragms is relatively straight forward and was observed in many buildings that survived both earthquakes. Recently, some proprietary systems have become available that use steel reinforcement to connect walls to the floor and roof diaphragms, and to provide wall-to-wall connection at corners and other wall intersections.

Typically, the reinforcement is placed in horizontally cored holes that pass through the entire building at each floor level and at the roof level. The reinforcement is then post-tensioned and grouted in order to clamp the walls to the floors and roof and to each other. In some applications, vertical reinforcement, sometimes with post-tensioning, is also used to increase the compressive stress in the wall which results in an improvement to the walls earthquake strength when subjected to horizontal loads.

Shear walls

Aim: provide additional storey/base shear strength; this could be through strengthening existing walls or by construction of additional shear walls.

Most UBM walls are required to transfer some degree of shear loading along their length. If a building has insufficient shear capacity in a particular direction, then capacity of existing walls can be increased instead of inserting additional structure.

There are various methods for achieving this strength increase which generally involve the application of an additional layer of material bonded to the surface of UBM to increase its strength, although there are some measures which involve altering the wall itself, such as post-tensioning, as described above. Most of these measures involve a plane of extra independent structure being applied over the surface of the UBM, effectively forming new shear walls, which are described below.

The presence of openings in a shear wall renders that section less stiff than the surrounding full height walls, meaning that the wall above and below, or between closely spaced openings, will likely be the first areas to fail in the event of an earthquake. Infilling the openings will eliminate this problem by making the wall continuous, and has been advocated as a valid solution in the past.

Problems with altering the character of the building and matching brick and mortar colours mean that this approach should only be used as a last resort and even then preferably not in visible areas. Infilling openings is likely to be somewhat reversible if done with brick (but not completely), and visual impact will depend on the location.

If in-filled with concrete, the work will be less reversible and the ductile behaviour of the wall may be affected due to incompatible stiffnesses. Localised steel cross bracing near openings is another technique which can prove effective, but again this system is likely to be highly visible and should only be undertaken when it does not detract from the character of the building.

Shear walls are used to increase the strength of existing UBM walls or are added as new elements. Materials which resist shear loads can be added to the surface of the UBM; these might include gypsum plasterboard, particle board, plywood, or plate steel, and are generally fixed to the UBM wall with bolts via a supplementary structure. This approach leads to the surface of the UBM wall generally being covered which may interfere with decorative elements on walls and openings, although this interference can be alleviated by using stronger materials such as plate or strap steel. They can also increase the thickness of the wall, which is not particularly desirable as it can reduce the scale and area of the interior.

For these reasons shear walls can be visually detrimental if used indiscriminately. Stand alone shear walls, which are independent of UBM walls, can be introduced, although these can be detrimental for similar reasons. Despite these negatives, shear walls are a practical and efficient method for strengthening and are commonly used. All of these materials can be easily removed in the future, which makes them good solutions for shear walls in two to three storey buildings with moderate horizontal loads.

The shotcreting of shear walls was a common strengthening technique during the 1980s. This technique involves spraying concrete onto the surface of a UBM wall to essentially cast a new wall against the existing wall. This technique provides plenty of additional strength to the wall, both in-plane and out-of-plane, but is now largely regarded as unacceptable unless absolutely necessary.

The technique causes a significant increase in wall thickness and it is very difficult to remove the concrete, and even more so to restore the wall behind to any semblance of its character prior to concreting. Furthermore, the installation of shotcrete generally requires the building to be gutted, which results in the loss of much heritage material and creates an essentially new interior.

Another technique for forming strengthened shear walls is the addition of surface bonded fibre reinforced polymer sheets. These sheets do not require the same invasive installation as shotcrete walls, but generally are equally permanent, and have potentially limited application, although new technology may soon change this. If it is possible to provide out-of-plane strength using FRP inserts, coupled with an FRP surface layer for shear, then this solution could be far superior to shotcrete from an architectural perspective. A key consideration with the use of sheets of FRP is that it is impermeable, which can lead to problems with water trapped within the building resulting in damp and mould issues, and potential de-bonding of the epoxy.

Figure 3.12: Shotcrete applied to a former URM building.

Insertion of internal frames

Aim: provide alternative structural system to resist the seismic loads.

Moment frames

Moment frames are a common method of gaining additional horizontal resistance which can also be used as a local strengthening solution. The advantage of this system is that it is comprised of beams and columns, so is fully customisable, and there is space between the vertical and horizontal elements. Moment frames allow full visual and physical access between each side of the frame, and minimal spatial disruption. In building façades with numerous openings, some form of moment frame can often be fitted to the masonry piers on the inside or outside (or both) depending on the effect on the architectural character.

Moment frames can be a particularly effective solution, especially where the frame is tailored to the character of the building. Care needs to be taken with steel frames in particular to ensure stiffness compatibility with the existing structure. Steel is a ductile material, but UBM is not, meaning that under earthquake loads the added stiffness of the steel might not come into effect until a load is reached where the UBM has already been extensively cracked.

Moment frames can be an excellent strengthening technique, either to supplement an existing wall or as a new, stand alone element. If a steel frame is erected against an existing wall where weakness exists, the frame needs to be fixed either directly to the UBM using bolted connections into the wall or to the diaphragm. Installing concrete frames is a more complex undertaking, as these will often be constructed by thickening existing piers, although a concrete frame which is separate from the existing structure is possible. In both situations, it is important that architectural character is retained, and historic material conserved. Some considerate and artful design strategies may need to be undertaken to achieve this.

Steel moment frames have a high degree of reversibility, as again they rely on mechanical connections and relatively small ties to connect to the existing structure. Concrete frames are generally far less reversible, but can sometimes be better concealed when this is a requirement. Some recent buildings have very effectively used precast concrete load-resisting elements which are separate from the UBM walls, solving the problem of reversibility.

Braced frames

Braced frames are available in various configurations: concentric, tension only concentric, eccentric, and 'K' bracing. The key functional difference between braced frames and moment frames is that due to the diagonal braces, braced frames prevent physical continuity between spaces on either side of the frame. Braced frames are also generally constructed from steel rather than concrete, and are much more rigid than moment frames.

Braced frames are a very efficient method of transferring horizontal forces but have significant setbacks. Their use in façade walls is usually precluded by the presence of windows, as diagonal braces crossing window openings are generally considered to be poor design. It is also difficult to get a braced frame to conform to an existing architectural character; however they can be used to very good effect within secondary spaces, and can be made to fit architecturally in some situations with careful consideration. Generally speaking, steel braced frames have a good degree of reversibility and can provide excellent strengthening when used appropriately.

Removal of mass and/or geometric/stiffness irregularities

Aim: reduce the seismic forces through reduction of structural mass or structural irregularities.

Another approach to seismic improvement of UBM buildings derives from the building's weight. Seismic actions are directly proportional to the mass of the building, so if mass is reduced, so are the forces acting upon the building. A lighter building requires less lateral strength and therefore less additional strengthening. Reducing the mass of a building may seem at face value to be a sensible approach; however past experience has shown this to not be so. The mass must be removed from somewhere, and the higher up the mass is, the stronger the forces upon it and the more difficult it is to strengthen, so the top of the building is the first place which has been looked at.

Historically this logic has led to the ad-hoc removal of decorative elements such as parapets, gables, chimneys, and occasionally whole towers. These elements will almost always significantly contribute to heritage value and character, and their retention is essential to preserving these attributes. Indeed, it is often desirable to replace these features if they have been removed from buildings and still exist. While reduction of weight may be achieved in more minor ways, such as removal of internal UBM partitions or the removal of plant loads, the wholesale removal of decorative elements is strongly discouraged.

Figure 3.13: Eccentrically braced steel frame core.

4.0 Frequently-asked questions

What is the risk of an earthquake in Auckland?

The risk of an earthquake in Auckland is low. On average, less than 10 earthquakes occur in the Auckland region each year. These are often too small to be felt.

Auckland is a low-risk seismic zone. Why are buildings subject to earthquake assessment?

The Building Act 2004 requires all councils to develop and implement a specific earthquake-prone, dangerous and insanitary building policy. Residential properties (unless they have two or more stories and contain three or more household units) are not subject to the earthquake-prone provisions of the Building Act. While there is a general expectation that major earthquakes will likely occur in relative proximity to the Central/ Alpine Fault in New Zealand, no area should be considered completely seismically inactive.

What are the seismic performance measurements for buildings?

Refer to Figure 4.1

When is a building earthquake-prone?

A building is earthquake-prone when it is less than 34% of current building standards. Auckland Council has identified pre-1976 buildings in the region and contracted engineers will undertake assessments (known as an IEP) on these buildings by 2015. Buildings finally assessed as earthquake-prone are added to council's earthquake-prone register.

What is an IEP?

The Initial Evaluation Procedure (IEP) is a preliminary exercise undertaken by a chartered professional engineer who reviews any available building consent plans and undertakes a site visit. It is a standardised procedure developed and used by the New Zealand Society for Earthquake Engineering members to identify if a building is potentially earthquake prone.

What do I do if I own a pre-1976 home?

Information about how you can strengthen your pre-1976 home can be found on the Earthquake Commission website.

I want to find out if my building is earthquake-prone before the council does an IEP assessment on it. What can I do?

Owners can engage a chartered professional engineer to undertake a seismic assessment of buildings at their own cost. Reports should be sent to the council for consideration once assessments are undertaken.

Can I respond to the council's seismic assessment of my building?

Yes. Owners are provided a copy of the engineer's assessment (IEP) and have three months to respond in agreement or to provide more information for consideration. An owner may choose to engage an independent structural engineer to undertake an IEP or a more detailed engineer evaluation. Auckland Council will consider additional information and may reevaluate seismic assessments as a result. Owners will be advised of final assessments and details will be included on the building's LIM report.

What happens if my building is earthquake-prone?

If a building is assessed as earthquake-prone, council will advise timeframes in which owners must remedy the earthquake-prone state of building. Building owners are responsible for all costs associated with upgrading their buildings. Any upgrade work or demolition will require a building consent.

Where can I find support advice to help me upgrade my earthquake-prone building?

Owners of earthquake-prone buildings should contact the Auckland Council's Building Control department to discuss options for strengthening and timeframes.

What is the timeframe for strengthening work?

Auckland Council's earthquake-prone building policy states the timeframe for strengthening work is 10-30 years, depending on the priority of services of the building and if it is a heritage building. Council will work with owners and tenants to develop realistic timelines for strengthening programmes. Auckland Council's earthquake-prone building policy is available on the council website.

How much will it cost to strengthen my building?

The exact cost of any required work is on a case-by-case basis and is dependent on the engineer's evaluation of the building. The timeframes outlined in council's earthquake-prone building policy provides scope for costs to be programmed and spread over time.

Can I buy or sell an earthquake-prone building?

Yes. The LIM report will record if a building has earthquake-prone status. The new owner will be responsible for the building seismic upgrades within the specified timeframe. Interested buyers need to do their own investigations and seek expert advice.

If my building has a heritage classification, will it need to be upgraded?

The council's earthquake-prone building policy applies to heritage buildings in the same way as it does to any other building. We encourage owners to discuss options with the NZ Historic Places Trust, and to make every effort to meet Auckland Council's heritage objectives. For more information, visit the NZ Heritage Places Trust website.

Will council place a red sticker on an earthquake-prone building?

No. The IEP assessment of each earthquake-prone building will appear on the property's LIM report. Council is intent instead to work with building owners to achieve practical and positive outcomes.

I am making substantial renovations to my pre-1976 building. Do I have to obtain an IEP and strengthen it at this time?

Not necessarily - only if a building consent is required for the renovation. Council will consider the potential risk of the building's age, use, and value of alterations at consent stage. Proposed alterations exceeding 25 per cent of the building value will always require a building consent and an IEP. A resource consent may also be required. More information is available on the council website or by calling.

I am changing the use of my building. Does the policy affect me?

Yes. A change of use requires any building to be upgraded to comply "as nearly as is reasonably practicable" with the current Building Code, regardless of its earthquake prone status. For more information, visit the Ministry of Business, Innovation and Employment website.

I strengthened my building prior to 2004. Does the policy affect me?

Yes, if confirmed as earthquake-prone, the building will need strengthening to comply as nearly as is reasonably practicable with the current Building Code.

Will the policy affect insurance?

Yes, if the building is earthquake-prone. Insurance policies usually require disclosure of information contained on the property LIM report regarding a building's earthquake-prone status. Buildings owners should contact their insurer for further information.

What is happening in regards to the Canterbury Earthquakes Royal Commission of Inquiry?

The Government is currently considering the Royal Commission's recommendations. If, as a result, there are any proposed legislative changes, these will likely occur in 2013-2014. Already, the Ministry of Business, Innovation and Employment (MBIE) has begun reviewing earthquake-prone building policies. Details are on their website.

Should I take any action as a result of the Royal Commission findings to date?

The Royal Commission's interim report recommends that owners of unreinforced masonry buildings should begin bracing parapets, installing roof ties and securing external falling hazards (e.g. chimneys) "as soon as practicable."

What is Auckland Council doing to ensure the region is prepared for an earthquake?

Auckland is prepared with a well-developed civil defence structure that involves emergency services, local and central government, utility companies, health boards and welfare agencies. We regularly check our response systems through exercises and real life situations. For more information about Auckland Council civil defence and emergency management, visit the website www.aucklandcivildefence.org.nz

Grade	A+ Excellent	A Good	B Good	C Potential Earthquake risk	D Potential Earthquake prone	E Potential Earthquake Prone
%NBS	>100	80-100	67-79	34-66	20-34	<20

Figure 4.1: Comparison between seismic grade and new building standard (NBS) score.

5.0 Glossary of terms

Section 122 of the Building Act 2004: meaning of earthquake-prone building

(1) A building is earthquake-prone for the purposes of this Act if, having regard to its condition and to the ground on which it is built and, because of its construction,

(a) Will have its ultimate capacity exceeded in a moderate earthquake (as defined in the regulations); and

(b) Would be likely to collapse causing-

(i) Injury or death to persons in the building or to persons on any other property; or

(ii) Damage to any other property.

(2) Subsection (1) does not apply to a building that is used wholly or mainly for residential purposes unless the building-

(a) Comprises 2 or more storeys; and

(b) Contains 3 or more household units

Balusters – vertical posts between the handrail and stair treads or stair stringer (side of stair). In simple terms, it's a post, or series of posts, to support a handrail. A series of balusters is referred to as a balustrade.

Base-isolation – is a series of super shock absorbers introduced into the foundations of a building to help absorb the energy and ground shaking generated by an earthquake.

Buttress – a brick, concrete or steel structural component designed to provide lateral (side-to-side) support. A buttress doesn't necessarily need to extend to the full height of the wall it is supporting.

Cantilever – a vertical or horizontal beam fixed at one end and unsupported at the other. For example, a gate post set down and concreted into the ground to a depth of 900mm that sticks above the ground 1200mm is a simple cantilevered member.

Cavity wall – a wall constructed with two separate thicknesses, with a space between, and tied together with metal wall ties. Many older buildings with cavity walls do not have wall ties and are generally only fixed at the top and bottom of the wall.

Cementitious – a product with a cement base. For example, a cementitious grout is cement in a liquid state for filling crevices or cavities or for forming a key for jointing together new or old concrete or brickwork. Modern grouts are chemical based (not cement) and are used in specialist situations.

Cross-bracing/struts – structural components made of either steel, timber or sheet material that provide a floor, wall, ceiling or roof added structural resilience. Cross- bracing is usually placed diagonally across the element it is located in.

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 – a structural element that transmits in-plane diaphragm forces typically from wind or earthquakes, to and from shear walls or frames. Floors often act as diaphragms.

Ductile or ductility – a measure of how easily a solid material (such as steel) deforms under stress without breaking. In earthquake engineering terms, ductile structures are designed to absorb earthquake energy without collapsing.

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.

Efflorescence – a white, powdery, crystalline deposit found on concrete, brickwork, masonry or on plasterwork caused by the evaporation and crystallization of alkaline salts which may be contained in the building material.

Epoxy – a chemical additive/adhesive made from synthetic polymers containing epoxide groups.

Fault – a fracture in the Earth's crust where the blocks on either side have moved relative to one another in a direction parallel to the fracture.

Finials – pointed ornamental pieces of timber, concrete, steel or other material, fixed vertically at the roof apex – particularly on the gable ends of the roof or on a church spire. Some can be very ornate and are there for decorative purposes.

Flexure strength – the ability of a structural component to bend under a load – for example, a beam when a load is applied to the top of the beam.

FRP bars – reinforcing bars of fibre-reinforced polymers.

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

Intensity – a measure of how strongly an earthquake affects the surface, based on its observable effects on people, buildings and the environment. Intensity is usually ranked using the 12 point Modified Mercalli Intensity (MMI) scale.

K-bracing – steel bracing shaped like the letter 'K' introduced to provide additional earthquake resilience to a structure.

Liquefaction – the process in which water saturated sediment loses its strength and acts as a fluid.

Load spreaders – steel or cast-iron plates seen on the outside face of a masonry building, with threaded tie rods and large nuts protruding through the centre of the plates. Load-spreading plates are usually located at floor and ceiling levels. They help spread the load by way of the threaded steel tie rods running through the plates on the face of the external walls.

Magnitude – a measure of the energy released by an earthquake at its source. Magnitude is commonly determined from shaking recorded on a seismograph. Each unit of magnitude on the scale represents a substantial increase in energy. For example, a magnitude 5 earthquake releases 30 times more energy than a magnitude 4 earthquake.

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.

Moment frame – a box-shaped steel frame provided with special moment connections or joints that helps a building to flex as necessary to retain the buildings structural integrity. There are various types of moment frame and the type used is dependent on the building and its design.

Mortar – a plastic mix of binding material between brick courses (layers). Modern mortar is usually a mixture of sand, cement and water (and sometimes additives to make it work better). The mortar in old brick work was made with lime, sand and water (lime mortar) and fails when the structure is exposed to the effects of a moderate earthquake.

New Building Standard (NBS) – the minimum structural performance standard that must be met by a new building based on present day design codes.

Near Surface Mounted (NSM) – when reinforcement is retrofitted by cutting grooves or chases into the surface of the brickwork or masonry and by inserting reinforcement that is embedded in cement or an epoxy mix.

Out-of-plane – when a brick, masonry or concrete wall is subjecte to forces acting on the face of a wall and normally at right angles. For example, a brick wall that moves out of the perpendicular or buckles and bulges through the length and height of the wall because of the forces generated by the earthquake on the wall.

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; they form part of an internal guttering system and they prevent roofing or other materials sliding off the roof onto adjoining property – for example, where the building abuts the public street.

Post-tensioning – a method for strengthening a concrete floor, wall or beam and even laminated timber structural components. For example, tensile steel wires or rods are run vertically through prepared holes in brick or masonry at specified intervals along the wall. The wires or rods are then tightened (tension is applied) by a hydraulic jack. Once the required tension is applied on the wire or rod, it is fixed (usually wedged) and grout is pumped into the hole to make sure the wire or rod is protected.

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

Shotcrete – concrete designed to be applied to a brick, masonry or concrete wall to improve itsstrength and/or fire-resistance rating. Shotcrete is applied by a high pressure hose with a hardened nozzle using compressed air to deliver the concrete to the appropriate position. The concrete can be reinforced with steel mesh pre-fixed to the wall to be Shotcreted. The Shotcrete can also have carbon fibres and other additives included into the mix to improve the strength of the finished mix and to make it easier to apply to the wall in layers.

Spandrel – the portion of a wall below a window from the sill to the floor level and/or the head of the window directly below. As well as serving an aesthetic function, spandrels can help prevent the vertical spread of fire up the external face of the building.

UBM - 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 reinforcing. This type of construction is not permitted under modern building codes which typically require reinforcement of building elements. UBM was a construction method mainly used in the early 20th century. Buildings constructed with unreinforced masonry are generally found to be earthquake-prone and need to be strengthened.

URM – another acronym for unreinforced masonry, meaning exactly the same thing as UBM.

6.0 Further information

Auckland Council

The unitary authority responsible for the city of Auckland and its greater region.

Website: www.aucklandcouncil.govt.nz
Phone: 09 301 0101

Auckland Council - Civil Defence

The department of Auckland Council responsible for enhancing the resiliency of the regional populace to disasters and coordinating recovery if necessary.

Website: www.aucklandcivildefence.org.nz

BRANZ

Technical guidance documents

Website: www.branz.co.nz

Canterbury Earthquakes Royal Commission

Information and recommendations from the Royal Commission inquiry into the Canterbury seismic events of 2011-2012 and their impacts.

Website: www.canterbury.royalcommission.govt.nz

Earthquake Commission (EQC)

Central government agency responsible for assisting with post-disaster recovery.

Website: www.eqc.govt.nz
Phone: 0800 326 243

Institute of Geological and Nuclear Sciences (GNS)

Geoscience research and hazard information publications.

Website: www.gns.cri.nz

Ministry of Business and Innovation & Employment (MoBIE)

Central government department responsible, amongst other things, for matters related to buildings and the reduction of risks posed to them by environmental hazards.

Website: www.dbh.govt.nz/building-index
Phone: 0800 242 243

NZ Historic Places Trust (NZHPT)

National society for the recording and preservation of New Zealand's historic structures and places.

Website: www.historic.org.nz
Phone: 09 307 9920 (Northern Regional Office)

NZ Society of Earthquake Engineering (NZSEE)

Engineering society focused on the development of the field of earthquake engineering, and creators of the IEP assessment tool.

Website: www.nzsee.org.nz

NZ Standards

Technical standards documents, including those specifically required for IEP assessments.

Website: www.standards.co.nz

Wellington City Council

Useful guides including one on how to go about assessing and upgrading a residential house.

Website: www.wellington.govt.nz

Find out more: phone 09 301 0101
or visit www.aucklandcouncil.govt.nz

Auckland Council
Te Kaunihera o Tāmaki Makaurau