

FOUNDATION AND SUB-FLOOR BRACING ANALYSIS:
THE COST BENEFIT OF UPGRADING

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Abstract

The poor performance of residential foundations in past earthquakes, prompted a practical investigation to quantify the adequacy of Wellington timber dwellings' foundations, including the sub-floor bracing, sub-floor fixings and general condition of the foundation. The adequacy of a sample of 80 dwellings' foundations was assessed against the current "Light Timber Framed Construction Standard" NZS3604:1999. The NZS3604 standard was introduced in 1978 and has been subsequently tested by many New Zealand earthquakes, most significantly being the Edgecumbe earthquake in 1987. The observed damage to dwellings built to the then current NZS3604:1984, showed only negligible damage due to foundation inadequacies and as a result, the standard required only minor amendments. The most current 1999 edition of NZS3604 is therefore considered to have seismically appropriate detailing and provisions to withstand design earthquakes; so for the purposes of this study, NZS3604:1999 is assumed to be the residential benchmark for seismic adequacy.

The results from the study suggest that 39% of the sample had inadequate sub-floor bracing. Overall, 16% of the sample relied solely on the strength of ordinary piles, while 11% relied entirely on large concrete anchors. 76% of dwellings had some form of fixing deficiency, ranging from degradation to incorrect or non-existent fixings. The overall condition of the sample dwellings was compared with the House Condition Survey 2005. The results of this study showed that inadequacies identified in the House Condition Survey 2005, were also prevalent in the majority of sampled dwellings in the study, including non compliance with minimum height and sub-floor ventilation requirements. However, the House Condition Survey produced by BRANZ does not assess any rented accommodations and so the condition results may be underestimated. The study sample, however includes a proportion of rented dwellings, but may still be unrepresentative of the actual average dwelling, in terms of condition and range.

After identifying the common deficiencies both in the sample and also from similar studies, remedial measures were costed and applied to different foundation types based on the required strength and suitability to the existing foundation system. The remedies, to upgrade bracing, fixings and the general condition, including labour, ranged between \$15 per m² and \$60 per m². These costs were then projected to all Wellington City foundations, which totalled over \$250 Million. It was assumed that each dwelling should be remedied to comply with the standards in NZS3604:1999 and the remedies were applied based on the average condition of the sample. To understand the anticipated losses and therefore benefits of upgrading, the estimated damage cost to residential dwellings was calculated using an Earthquake Loss Modeller, which was supplied by the Institute of Geological and Nuclear Sciences. The cost was calculated by assuming an earthquake of Magnitude 7.5, at a depth of 7.5km centred on the Wellington fault line, around Kaiwharawhara. In order to formulate a cost saving, or economic benefit from

upgrading foundations, the cost of specific damage and collapse to residential dwellings was calculated to be \$2.1 Billion, assuming no remedial measures had been applied. The Mean Damage Ratio for each foundation type was then modified, based on similar earthquake damage projections based on the same Wellington earthquake scenario. Dwellings that had either significant configuration issues or were located in an area likely to experience higher earthquake shaking, were still anticipated to collapse despite applying sub-floor remedies. The cost of damage to dwellings following remedial measures was calculated at just over \$1.1 Billion. Therefore, the total savings were anticipated to be around \$950 Million. These results were considered as a ratio of cost over benefit which is used to understand whether the associated economic benefit is greater than the anticipated cost of remedy. The cost / benefit ratio for dwellings likely to collapse is less than 10% , while extensively damaged dwellings have a higher cost / benefit ratio of around 25%. The highest benefit was seen in Piled dwellings, where savings upwards of \$500 Million were projected. The economic saving due to the application of remedial measures has the potential to reduce pressure on the public sector including emergency management systems, hospitals and organisations involved with evacuations and erection of temporary shelters. In addition, there will also be a saving for both the public and private insurers, which will facilitate the quicker reconstruction of the post-earthquake society to pre-earthquake levels.

For the results of this study to be beneficial to New Zealanders, the information must be disseminated and implemented using proactive initiatives. These must be targeted at the homeowner in an easily understandable format, which is focussed on better performance and savings, rather than on the worst case scenario which has been shown to increase ambivalence and fatalistic mindsets within society.

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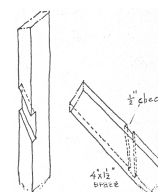
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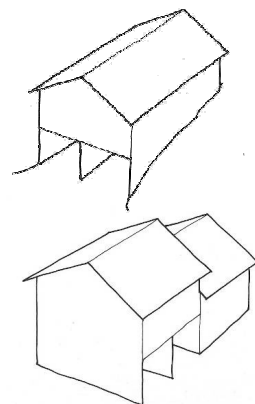
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- Anchors**_____ An Anchor is a large object with significant mass likely to resist lateral loading. These may include any concrete steps, porches, chimney bases or pathways that are in some way connected to a dwelling, either with fixings or by friction. Concrete slabs in dwelling additions may also be referred to as anchors.
- Anchor piles**_____ Piles which rely upon the soil bearing pressure and depth of footing to provide lateral resistance prescribed as 120BU. The depth and width of footing is greater than a cantilever pile.
- Braced Pile**_____ Two piles with a diagonal brace spanning from the lower part of one pile to the higher of the other. The braced pile system relies primarily on the strength of the brace in compression and the ductility of the fixings for lateral bracing, with prescribed resistance of 120BU.
- Bracing Line**_____ A line along or across a building, usually the bearer of joist directions, for controlling the distribution of bracing elements.
- Bracing Unit ["BU"]**_____ A unit measure used for the purposes of describing bracing capacity, where 20BU equals approximately 1kN.
- Cantilever piles**_____ Piles which rely on soil bearing pressure and timber bending strength for lateral resistance, with prescribed bracing potential of 60BU, in NZS3604:1999.
- Checked-in Bracing**_____ A timber member used to brace studs, usually checked into fanning and nailed into side of framing over every support.
- Cleared Ground Level ["CGL"]**_____ A level taken after topsoil is removed from site.
- Configuration Issues**_____ Issues regarding the design of a dwelling which will ultimately induce torsion and twisting under lateral loading. Configuration issues are the result of asymmetrical, discontinuous plans or elevations in a dwelling.
- Concrete Perimeter Wall**_____ A concrete wall which resists lateral loads in shear.
- Connections**_____ A connection refers to the whole *joint* between sub-floor elements, including the specific fixings and members being pinned together.
- Cut-Between-Brace**_____ A discontinuous timber member that diagonally spans between two studs, common in timber dwellings built before 1964 and used as a form of lateral bracing.
- Damage ratio**_____ The damage ratio is described as the cost of repairing an earthquake damaged building to the condition it was in before the earthquake, divided by the replacement cost of the building.
- Designed Bracing**_____ Bracing specified during the design process with a particular lateral strength capacity, stated in NZS3604:1999.
- Design load strength**_____ The capacity or characteristic strength of an element, within a particular limit state design which assumes that the failure mechanism is predicted.
- Direction "Along"**_____ Describes the load direction 'Along' the Bearer line or in the Longitudinal Lateral direction. This considers the force or load path directions travels parallel to the Bearers and perpendicular to the joists.
- Direction "Across"**_____ Describes the load direction 'Across' the Bearer line or in the Transverse Lateral direction. The load path or force is considered to travel parallel to the joists and perpendicular to the Bearers.
- DPC**_____ Damp Proof Course, a bituminous impregnated paper product laid between timber and concrete interfaces to limit timber rotting.
- DPM**_____ Damp Proof Membrane, usually black polythene sheeting used to limit water penetration into the sub-floor space or concrete slabs.



- Fixing**_____Refers to the actual element that is used in the connection of members, such as a nails, bolts or other proprietary elements.
- Footing**_____A concrete pad foundation under piles or vertical elements, which bears and distributes forces into the ground.
- Friction Co-efficient**_____A factor which is multiplied into the strength of a connection, which considers that friction contributes a proportion of strength in a connection depending on the specific interface material properties.
- Full Split Level**_____ Usually a two storey dwelling where the lower level has less floor area than the top level, and is usually been a renovation which has dug into the hillside under the dwelling, see image to right
- Half Split Level**_____A dwelling which has a proportion of the top half level above the lower, see image to right
- Herringbone strutting**_____Diagonal timbers used to limit joist overturning and forming an 'X' pattern and arranged in rows running at right angles to joists.
- House Condition Survey**_____ The current report ["HCS 2005"] released by BRANZ at 5 year intervals, which collates the specific condition and health of a sample of dwellings throughout New Zealand.
- Intensity**_____The relative ground movement in a specific area, zone or region, commonly scaled using felt intensity scales such as the Modified Mercalli scale.
- Irregular plan**_____A layout of a dwelling that is asymmetrical or irregular.
- Jack Studs**_____Jack studs are less than full height studs spanning vertically from plate to plate, usually used where normal piles or elements are too tall as prescribed by standards
- KiloNewton ["kN"]**_____The unit of measure to describe Force.
- Limit state design**_____The assumed strength of a material based on ultimate strength testing from the applicable manufacturers, after a Factor of Safety has been applied. The Factor of Safety relates to the type of building or dwelling and number of occupants the constructed building is likely to hold.
- Liquefaction**_____The reaction of shaking in soil which causes water to be suspended in soil with fine particles. This results in a loss of soil shear strength and slumping of structures above the soil.
- Magnitude**_____The size of the earthquake at the source and calculated from amplitude measurements, usually using the Richter scale to quantify the shaking.
- Mean Damage Ratio ["MDR"]**_____A calculated ratio for the damage of dwellings which defines the cost of the repair of the dwelling divided by the total cost of the dwelling. These are usually based on observed past losses and so are a mean product of the relative shaking and other parameters involved in shaking.
- Microzoning**_____The differing reactions of subsoils within a smaller area of the local geography.
- Moisture Content ["MC"]**_____Abbreviated term for 'Moisture Content' usually of timber.
- Non-Designed Bracing**_____Large heavy elements that provide lateral bracing potential despite not been designed as such.
- Notch scarfing**_____A joint between timber ends which is cut, so that notches accept each end of timber, in order to create a longer length of timber.



Notch _____ Cuts into upper timber members which slot over lower timber members.

NZS3604:1999 _____ The most current version of the Light Timber Framed Construction standard, which prescribes structural timber sizes, fixing methods and detailing light timber construction. All terms and definitions regarding timber construction used in the text can also be found in the definitions of NZS3604:1999.

Ordinary Piles _____ Piles that support only the vertical weight of a dwelling and have no prescribed lateral stability.

Period of a Dwelling _____ The frequency with which a dwelling will shake in an earthquake depending on the material weights in a dwelling. Also referred to the Frequency of Shaking, and Natural Resonant Frequency of a dwelling.

Redundancy _____ Strength capacity of elements which can be considered to contribute to the design strength of a dwelling, but may be removed without affecting the dwelling's overall bracing and strength capacities.

Remedial Measures _____ Solutions to problems in a foundation that will result in a foundation being assumed adequate when assessed against NZS3604:1999

Residential _____ Residential refers to one unit or dwelling, in which a family or individuals will sleep and generally inhabit.

Risk _____ Risk is the product of (natural) hazard and the resulting consequence. Risk can be rated for a specific local environment, a structure or to an individual.

Shallow Cantilevered Pile _____ A shallow founded pile with footing depth less than 450mm, allowable as a means of bracing until 1999, with an assumed bracing capacity of 12BU.

Soft Storey _____ A story in a dwelling which has load transfer issues due to either a lack of bracing, a larger stud height or heavier materials in the upper story increasing the loads to be transferred to the ground.

Splayed joint _____ A 45° to 30° angled joint used to connect timber ends, usually in bearers, to allow the increase in the overall combined length of timber.

Sleeper Plate _____ Historic term referring to a bearer, wall plate or other horizontally laid bearing member.

Standards _____ Standards refer to the formal construction codes, usually issued and controlled by a governing body with an overall interest or controlling influence over construction and building requirements.

Torsion _____ Torsion refers to the twisting of a structural member loaded by torque, or twisting couples, where one end turns about a longitudinal axis while the other is held fast or turned in the opposite direction.

'U nail' _____ A 4mm diameter U shaped nail with parallel ends. The nail is best to connect timber parallel members.

Ultimate strength _____ The maximum strength capacity that can be anticipated from an element, with no limit states applied.

Waling _____ A horizontal timber framing member secured to the face of vertical framing timbers to stiffen or tie the vertical framing or piles.

Water Staining _____ When water seeps into timber and a distinctive stain is left

'Z nail' _____ A 4mm diameter nail with ends designed to connect perpendicular timber members.

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Over the short history of New Zealand, the traditional timber dwelling has withstood many seismic events with little or no damage. However, the dwelling's strength has usually been attributed to the resistance and redundancy of the superstructure, as opposed to the foundations, which are often significantly weaker. Weak sub-floors in past earthquakes have resulted in dwellings slipping off foundations, or swaying substantially, which usually results in the collapse and subsequent demolition of a dwelling, rendering the residence uninhabitable. In addition, if a dwelling falls off the foundations and gas is connected to the dwelling with rigid connections, fire can cause further widespread destruction and increases the burden on emergency services. Most failures in the foundation area have been the result of construction negligence and also inadequate standards governing the construction of foundations. However, although these problems are often observed and documented, sub-floor bracing has continually had inadequate coverage and prescription in the formal New Zealand construction standards. Moreover, even though upgrading of the construction Standards results in a more robust, comprehensive document; certain existing dwellings with varying foundation types, still remain at significant risk from earthquake and often require sub-floor retrofit and upgrading to meet these new standards.

This study sets out information in a linear progression, which discusses historic foundation issues in regard to earthquakes, the reaction of different foundation types in earthquakes and how standards have altered to resolve these observed inadequacies. These commonly deficient areas are then analysed through a sample of 80 Wellington timber dwellings, focussing on the bracing, fixings, overall condition of foundations and adherence to the current standards. The last part of the study proposes appropriate remedial measures and calculates the strength of foundations before and after the application of these measures. Following this, the number of damaged and collapsed dwellings is predicted by using an Earthquake Loss Modeller, which statistically predicts the economic losses from an earthquake scenario centred in Wellington City. The associated earthquake repair costs and the overall costs and benefits to society will dictate how beneficial the upgrade of foundations will be and whether the remedial action is economically feasible. The final chapter concludes with a discussion of the dissemination of this information and the obligation of all concerned parties.

Throughout the text, a number of abbreviations regarding the connections and foundation types have been used to make reading the text simpler and clearer. The Pull Out Reference guide, which explains all of these terms, should be read in conjunction with the thesis and can be located at the end of the document. This thesis is also summarised in a paper presented at the 2007 New Zealand Society for Earthquake Engineering [NZSEE] conference (Irvine 2007).

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To understand how dwellings react under seismic loading, it is important to consider how the foundation interfaces and utilises the strength of the surrounding subsoils to resist lateral loads created by seismic activity. The subsoil characteristics of a particular site will often determine the severity of the shaking that a particular dwelling will experience during seismic induced loading. Therefore, different types of foundations have been designed to utilise these subsoil properties to compliment and therefore enhance the dwellings capacity to resist lateral loads. In order to understand how different foundations react or interact with the subsoil, it is first necessary to examine the science behind earthquakes and the way in which they are measured.

1.1 Earthquake Science

Earthquakes are caused by the sudden release of energy, or release of stress, built up from tectonic plate movement between the earth's crust and the interior of the earth (Dowrick 1977). Earthquakes are recorded and rated according to the intensity of shaking, which enables comparison between different earthquakes, prediction of further recurrences and timing of aftershocks. More than 200 active faults have been identified, many of which are within 10km of most New Zealand communities (Callan 2001).

1.1.1

Magnitude is the size of the earthquake event at its source and is indirectly related to the release of energy. Magnitude is calculated from amplitude measurements taken from seismographs in different geographic locations. Since 1850, New Zealand has experienced 14 shallow earthquakes of magnitude 7 or greater, which is an average of one every 10.5 years (EQC 2006c). Smaller earthquakes occur in a defined pattern, with 14,000 experienced in and around the landmass of New Zealand, of which up to 150 are big enough to be felt [Figure 1.1]. The Richter scale [M_L] is used to measure and compare the amount of energy released by earthquakes at their source.

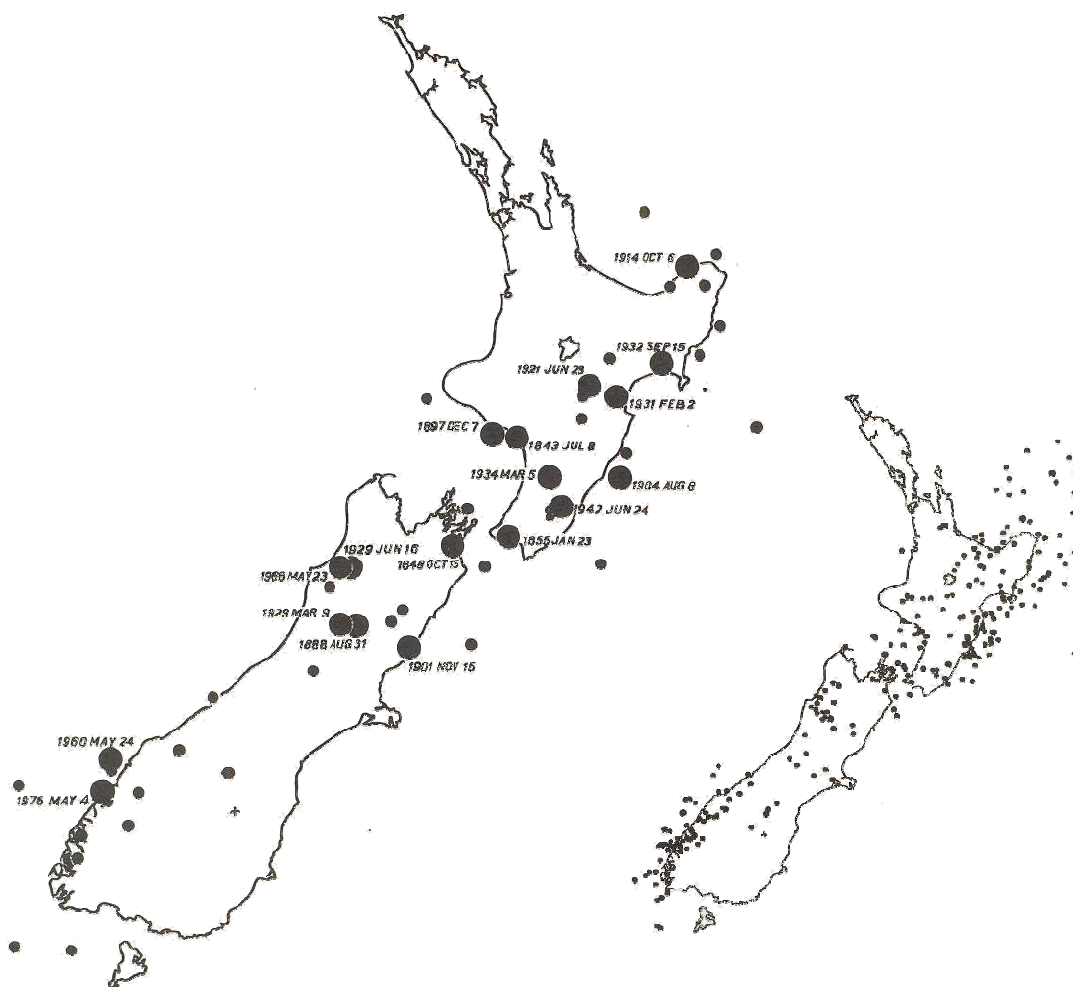


Figure 1-1 Significant large Earthquakes (Left) and smaller Earthquakes (Right) recorded throughout New Zealand (Source: Dowrick, 1977)

1.1.2

Intensity

Intensity is the relative ground movement at any specific site. The measurement of movement is rated with one of a number of “Felt Intensity Scales”, such as the Modified Mercalli scale or the MSK scale. Other intensity scales are also based on local peak acceleration and local peak ground velocity and usually assign a number to a given earthquake to describe the shock (Dowrick 1977). Currently the Modified Mercalli scale¹ [MM] is used to determine the relative destruction of built and natural environments (Eiby 1965). Measuring earthquakes via instruments, such as with the Richter scale, does not depict the earthquake destruction as accurately as felt intensity scales. Information from observed intensity scales in historic earthquakes formed the basis of the national earthquake zoning classes used to calculate earthquake bracing requirements in NZS3604:1999 [Figure 1.2].

¹ See Appendix A for the damage anticipated for each tier of the Modified Mercalli scale

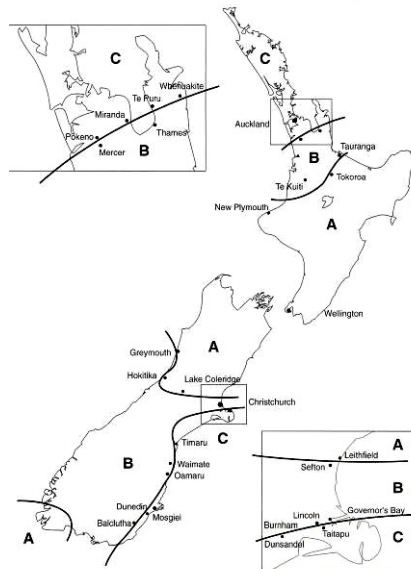


Figure 1-2 Calculated Earthquake Zones dividing New Zealand (Source: Winstones Wallboards Limited 2006)

There are three earthquake zones in New Zealand, the highest Zone A extends from below Tokoroa in the North Island to just above Christchurch in the South Island. Thus, an earthquake scenario in Wellington will also affect these areas, but to a lesser degree.

1.1.3 Earthquake Data Collection

Earthquake data is collected in and around New Zealand by the Geonet system (2005), which was developed and is maintained by the Institute of Geological and Nuclear Sciences [“GNS”], a Crown Research Institute. GNS is the government's principal earth systems and isotope science researcher and advisor. They provide an accurate non-subjective description of the earthquake and its specific location anywhere in New Zealand (Geological and Nuclear Sciences 2006). GNS assesses earthquake information, locates faults and provides related geographic data.

1.1.4 Fault Type

New Zealand is laced with faults travelling in an approximate northeast direction. Different fault types [Figure 1.3] determine the proportion of vertical and horizontal acceleration in an earthquake. Strike slip faults [Figure 1.3 d] tend to create purely horizontal accelerations, whereas Overthrust and Extensional faults [Figure 1.3 b and c] tend to force adjacent plates vertical with a given horizontal force. Overthrust faults are sometimes referred to as Blind thrust faults, which were experienced in the Northridge earthquake, California in 1994. The relative ratio of vertical to horizontal acceleration was given at 2 to 3 (Norton et al. 1994).

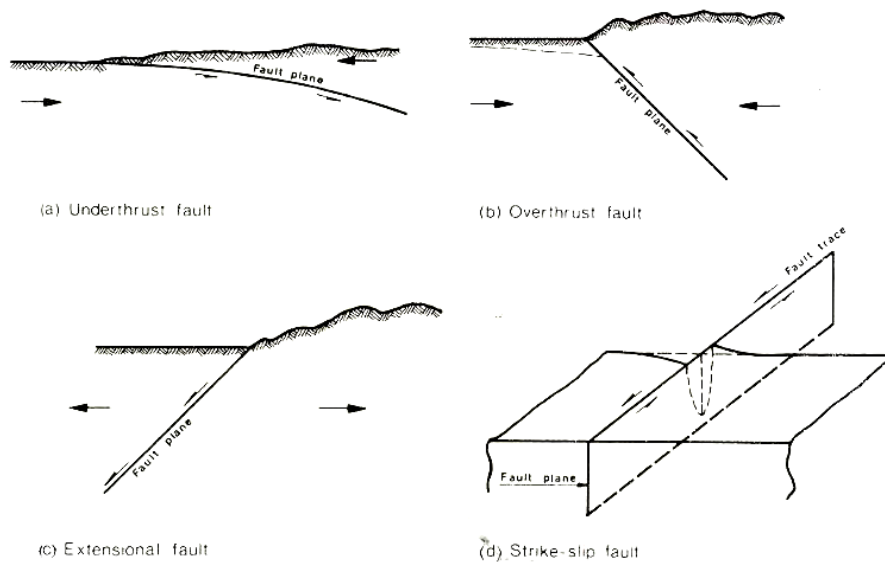


Figure 1-3 Different Fault types and Relative direction of Movement (Source: Dowrick 1977)

1.1.5

Location of a Dwelling

The geographic location of a dwelling affects how it reacts during earthquakes. The reaction depends on the specific combination of topography, the dwelling's configuration and the response of the subsoil. Figure 1.4 shows the different relative topographical scenarios, which may alter a dwelling's torsional response. Usually, the slope of the incline increases the likelihood of creating eccentricities within the foundation. Therefore, dwellings constructed in extreme topographical conditions may be more prone to damage due to induced torsion than those constructed on a gentle incline [refer Section 5.1]. However, the response of dwellings in gentle topography will depend largely on the response and characteristics of the subsoil.

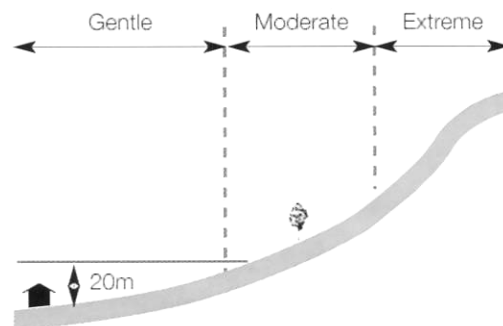


Figure 1-4 Topographical Scenarios used for the Study; Gentle, Moderate and Extreme (Source: Winstones Wallboards Limited 2006)

1.2 Subsoil Characteristics

Many foundation systems rely primarily on strength of soil surrounding foundation elements to dissipate energy from earthquakes. The strength of the soil at any site depends on the type of soil, the granular size and shape of the soil particles and the shear strength created between

these particles. The soil type varies from site to site, and potentially within a site [refer Section 1.2.3], however, the earthquake wave motion and number of different soil layers can also affect the reaction of the dwelling.

1.2.1 Topographical Siting and Geographic Occurrences

A dwelling's lateral stability under seismic loading depends on the soil strength and its reaction under vibration. The foundations will transfer any of the soil reactions to the dwelling. The integrity of the subsoil beneath the dwelling is always a product of the geologic formation of the land and can often be predicted by understanding the geography of New Zealand. Figure 1.5 shows geographies common throughout Wellington and New Zealand.

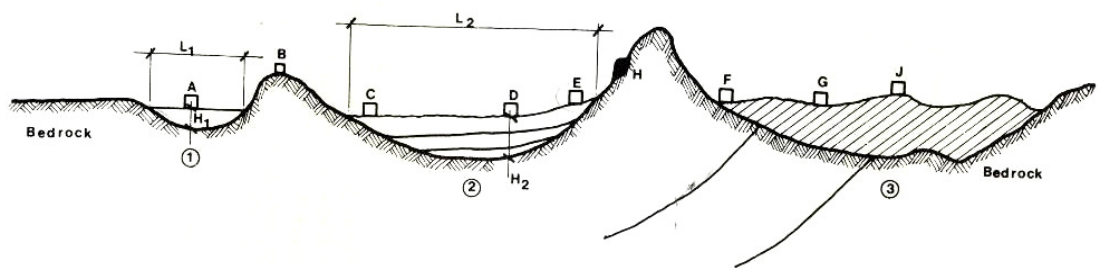


Figure 1-5 Different Soil types showing likely Soil Deposits (Source: Eiby 1980)

Some soil types, when combined with a high water table can cause liquefaction of the soil [Figure 1.5: image 1]. This causes subsidence and differential settlements of all types of foundations [Figure 1.6]. Liquefaction is the result of the reaction between settled sands or silts and water. The fine soils are vibrated to a point by the earthquake that they become suspended within the water (Dowrick 1977).

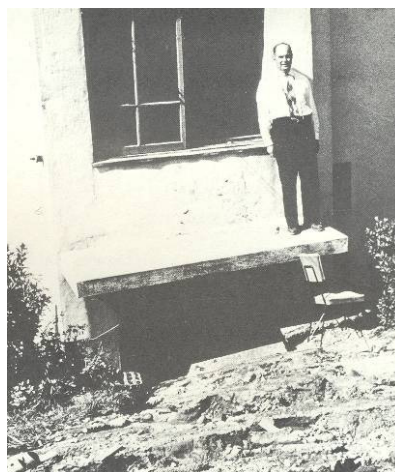


Figure 1-6 Liquefaction of Soils Sunk this Dwelling to the Ceiling of the Ground floor (Source: Eiby 1980)

Gravel, clays and dense sands are less likely to liquefy due to the relative size and weight of the granular particles. Dwellings founded in soils that have seasonal ground movements [Figure

1.5: image 2], such as expansive clays, can cause foundations to be strained and weakened by the constant expansion and shrinkage of the soil, possibly increasing the chances of severe damage in an earthquake. Larger earthquakes with the epicentre close to the surface [Figure 1.5: image 3], can cause fissures and cracks to appear in the land. Depending on the type of earthquake and direction of fault lines, vertical fissures can thrust divisions between adjacent land (Dowrick 1977). This was often seen in the 1971 San Fernando Earthquake (Jennings and Housner 1971) [Figure 1.7].

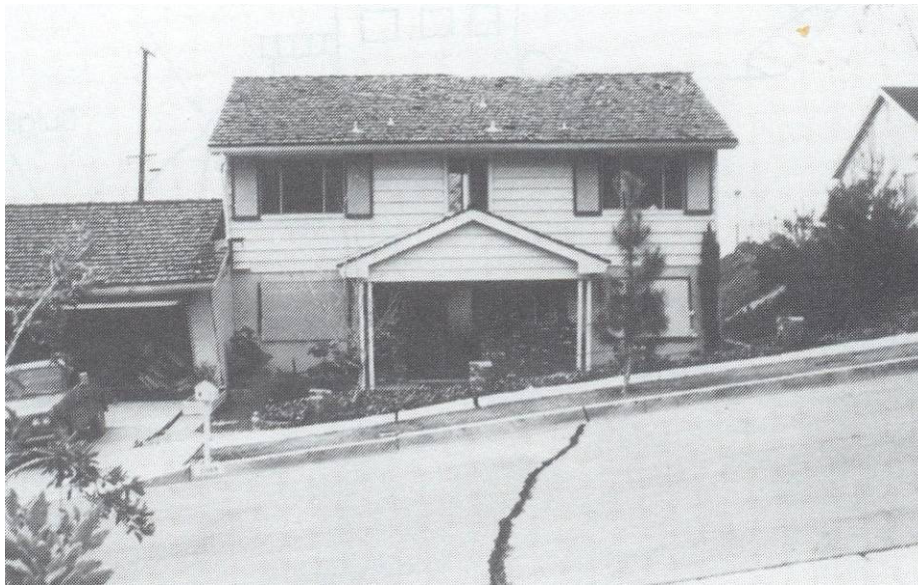


Figure 1-7 A Ground Fissure running into a Dwelling in San Fernando 1971 (Source: Jennings and Housner 1971)

1.2.2 _____ Reaction of Different Soils under Seismic Wave Motion

Different soil types resonate at largely different frequencies depending on the density, and thickness of soil deposits and the distance from the epicentre of the earthquake. Very soft soils and sands can amplify earthquake wave motion, while rock and other denser materials tend to dampen the earthquake's force at high frequencies (Dowrick 1977). Alluvial deposits, usually found around river mouths, banks or old river terraces, tend to absorb smaller earthquakes and amplify the larger earthquakes (Eiby 1980). A study following the Napier earthquake in 1931, showed that dwellings on solid rock experienced the most damage, followed by firm beach deposits and soft grounded dwellings. The findings imply that the impact of short period ground motion is lessened by soft ground when shaking is very strong and close to the epicentre (Dowrick et al. 1995). However, Hamilton et.al. (1969), on reconnaissance to the 1966 Gisborne earthquake, found that dwellings sited on rock generally experienced smaller accelerations and subsequently less damage. The wave motion in soil is a result of the refraction, reflection, focussing and scattering at the boundary condition between soils and the depth of soil over any bedrock (Dowrick 1977). Generally, soil vibration increases relative to the depth of the soil. Another situation that can cause additional damage in earthquakes is when

dwelling is constructed on two different soil types. These dwellings will likely suffer more damage than those constructed on a single soil type, due to differential shaking frequencies of the subsoils (Eiby 1980). This type of reaction within in one geographic location is often termed “microzoning”.

1.2.3 Microzoning

Microzoning is the observation of local soil variances which cause different vibrational responses to structures in relatively similar topographical and geographical locations. Microzoning is a combination of the interface effects of different soil layers creating different characteristics which make predicting the actual behaviour of structures sited on different soils difficult. Figure 1.8 shows two similar dwellings on similar sites, the dwelling on the right has slumped due to soil variances, where the one on the left has sustained only superficial damage.



Figure 1-8 Two similar Dwellings: The one on the Right slumped, while the other remains straight
(Source: Ruscoe 1988)

Statistical estimates of the likelihood of shaking have been documented (Smith 1976), to show that structures built on alluvium deposits, reclaimed land, soft sand or unconsolidated soils, require greater bracing consideration in the sub-floor areas. Iseismic maps of past earthquakes can depict shaking characteristics of smaller city areas, which allow for more accurate predictions of subsoil behaviour (Eiby 1965).

1.3 Structural Sub-floor Systems and the Soil Interface

During an earthquake, a dwelling will react to the thrust of the earthquake based on the weight and elasticity of the cladding and materials [Figure 1.9]. However, it is the sub-floor that transfers forces between both the superstructure and the soil. Thus, it is the interface characteristics between the foundation system and the ground that largely determines the overall response and damage to the superstructure. A BRANZ bulletin released after the 1987 Edgecumbe earthquake showed that regardless of the sub-floor bracing system strength; without a complementary soil and foundation system, the stability of the house was always affected (BRANZ 2003).

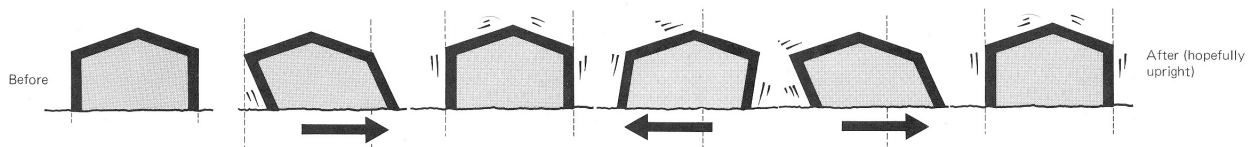


Figure 1-9 Response of a Dwelling under Seismic motion (Source: Cooney 1982)

1.3.1 *The Soil-Pile Interface*

Piled foundations work on the basis that the upper level of soil will determine the lateral resistance of the sub-floor, which will dampen the inertial forces transferred from the superstructure. A foundation which fails in ductile yielding is considered to be an acceptable energy dissipation mechanism, since the structure avoids abrupt collapse (Thurston 2001).

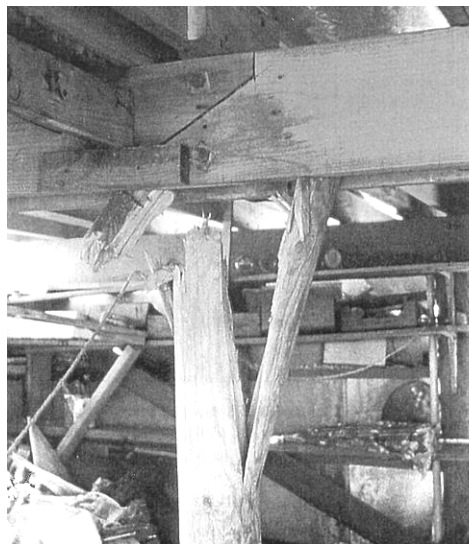


Figure 1-10 Brittle failure of a Pole to Bearer connection in a Pole house Foundation (Source: BRANZ 2003)

It has also been suggested that brittle elements, which normally exhibit elastic behaviour are good for lower magnitude earthquakes. However, they exhibit brittle, non ductile failure in larger earthquakes (Deam 1997). Essentially, an adequate foundation system and the designed ductility of the sub-floor fasteners, combined with soil ductility should not cause pile rupture or other timber fracturing failures (Thurston 1993).

1.3.2 Current Pile Bracing Systems

Cantilever piles and anchor piles, prescribed in NZS3604, require soil surrounding piles to have a 100kPa minimum bearing strength (Standards New Zealand 1999). However, tests done on braced-pile systems suggest that the strength of the system does not reflect the variability of the soil strength. Thurston (1993) suggests that most configurations still differ depending on the shear and ductile strength of the soil surrounding the piles. The basis of the current standard ensures that structural elements are provided with reserve strength capacity so that primary energy-dissipation systems, in this case the soil-pile interface, may be maintained.

Many piles in foundations will not have a specifically stated bracing capacity and rely solely on soil deformation to dampen seismic shaking. Bearing loads will be sustained either by earth friction on the sides of the piles, or bearing on the tip of the pile [Figure 1.11].

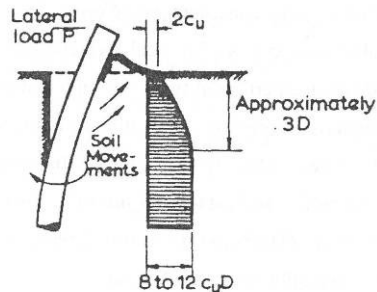


Figure 1-11 Pile Bending showing the Exaggerated Deformation of the Soil (Source: Burdon, Kueh, and McManus 2004)

However, since the footing is only shallow, the pile will not reach the inherent ultimate strength of the timber pile (Department of Agriculture 1974). In many cases the resistance may be achieved through the rocking motion of the foundation and the product of dead loads dampening this force. Other foundation systems also utilise the friction co-efficient of sliding between the foundation and the soil interface (Dowrick 1977).

Most other structural elements direct forces to the soil or use the soil bearing pressure to dissipate energy (Taylor 1976). Shear wall foundation systems use the compression of the soil at the extremities to withstand the overturning reaction, dampening the induced loads from the superstructure. Other shallow foundation systems gain lateral resistance from friction between the soil and the base of the foundation element.

1.4 Summary of Geological and Geographical Conditions

New Zealand is relatively seismically active with many fault lines and varying soil types. The type of soil within a seismic area will often affect the intensity of the shaking. Certain soft soils may liquefy under seismic loading, which will result in subsidence and differential settlement of the dwelling, while denser soils tend to dampen the seismic wave length through the material, thus limiting the amount of lateral load that the dwelling must withstand. Regardless of the subsoil's strength, all foundations rely on friction between the foundation base and the subsoil and also the resistance to rocking to resist lateral loads. Pile systems tend to use the ductility and compression strength of the surrounding subsoils, whereas concrete foundation wall systems utilise the friction between the soil and the foundation interface. Through earthquake science, we can gain an understanding of the interaction between soils and foundations under seismic loading. However, soil type is one of many factors which may impact on the performance of a foundation and its capacity to withstand seismic loading, Therefore it is necessary to examine the performance of dwellings and foundations in past earthquakes, to gain a better understanding of what additional factors impact on the performance of the sub-floor and the interaction with the particular topographical and subsoil conditions.

2

From observing the damage caused by past earthquakes, we can identify what factors affect the performance of certain foundation types and therefore predict the likely damage sustained to dwellings with similar foundation types and conditions. From colonialism until the present day, New Zealanders have used many different construction methods and materials to construct their dwellings, dictated by fashion, supply and necessity. As a result of earthquakes, these methods and materials have been reassessed or modified, which has led to the standardisation of dwelling and foundation construction in New Zealand. Similarly, overseas earthquakes provide lessons and solutions for common modern construction issues not yet tested by a New Zealand earthquake.

2.1 New Zealand Earthquake History

New Zealand experienced a number of large sporadic seismic events from early colonisation up to the mid 1980's, each resulting in significant damage and destruction to dwellings due to serious sub-floor defects. These earthquakes showed that light timber construction is suitable to resist earthquakes, however advances in construction techniques and building materials have yet to be tested by a large earthquake.

2.1.1

The main priority for early European settlers was the construction of shelter. The first primitive huts were constructed with sticks that were driven into the ground and tied at the top. Earthen floors were common and construction was largely influenced by the experiences of Maori (ten Broeke 1979). Primitive huts were constructed until further resources and materials were available to construct a proper dwelling in accordance with “European” standards. Colonialists used materials such as timber, masonry and adobe mud block to construct their dwellings. The strength of these materials and the construction methods were put to the test during two earthquakes in 1848 and 1855 centred in the lower North Island and recorded intensities of around MMX and MMXI+² [Figure 2.1].

² See felt observations of the Modified Mercalli Scale in Appendix A



Figure 2-1 Sketches of Damage to Unreinforced Masonry Structures in the 1848 Wairarapa Earthquake (Source: McSaveney 2007)

Early records show that dwellings which suffered the least damage, were those built of timber with timber weatherboards (Slade 1979). As a result, most new dwellings were rebuilt using timber. However, given that the construction of foundations was not standardised, the performance of the foundation often depended on the background of the carpenter and the topography of the land. Foundations were commonly constructed using pile blocks cut from stumps of trees, or other found objects [Figure 2.2]. Sometimes the joists and framing simply rested directly on the earth (ten Broeke 1979).



Figure 2-2 Pile systems, consisting of Tree Stumps (Source: Salmond 1986)

Following the 1855 earthquake, The Official Commission's report found that timber dwellings failed because they were either faulty in construction or had inadequate timber foundations that were rotted below floor level (Ward 1975 cited Slade 1979). Recommendations from the report prompted strength testing of timber as well as theories that pyramid shaped dwellings are the most suitable for resisting earthquakes. However, the recommendations in the report were not widely adopted.

The next 70 years were seismically uneventful aside from persistent minor shocks and tremors. Earthquakes were remembered as "*a matter of scientific interest, rather than a subject of alarm*" (Ford 1935 cited Slade 1979, p.10). Consequently, much of the information gained from the experience of constructing for seismic strength, in the mid 1800's was lost, confirming that

“no kind of panic subsides sooner than an earthquake panic” (Thomson 1859 cited Blake-Kelly 1965, p.35).

2.1.2

Earthquakes from 1929

On June 17, 1929, earthquakes in the West Nelson and Murchison areas reached a maximum intensity of MMXI and had a path of destruction that stretched from the Buller region in the South Island to Wellington in the North. The Department of Scientific and Industrial Research [“DSIR”] who reported on the aftermath, found that dwellings shifted from piles leaving them warped and twisted usually *“totally destroying the superstructure”* (Henderson 1937). The New Zealand Institute of Architects Investigation Committee report (1929) considered that the dominance and suitability of timber structures was confirmed by the performance of timber dwellings. However, other reports considered that many timber foundations were frequently inadequate, as dwellings had shifted off piles and were deposited on the ground causing damage to floors and to framing [Figure 2.3].



Figure 2-3 Destruction observed to affect a Dwelling in the West Nelson Earthquakes (Source: *McSaveney 2007*)

However, dwellings constructed using a continuous concrete foundation [refer Section 3.4] did not sustain any extensive damage. As a result, this form of construction was recommended for timber dwellings. Although, the DSIR earthquake Investigation Committee noted the extreme importance of bolting wall plates to the foundations for this form of foundation construction (Henderson 1937).

In 1931, the great Napier earthquake struck recording 7.75 on the Richter scale and rated MMXI from the destruction caused, which was similar to the 1929 Murchison earthquake destruction [Figure 2.4].



Figure 2-4 Overall Destruction to Residential structures in the 1931 Napier Earthquake (Source: Cooney 1982)

C. E. Dixon (1931) who released notes to The New Zealand National Review [refer Section 4.1.3] found that appropriate seismic detailing was lacking within the Building Industry and that “...the Hawke’s Bay earthquake... has [only] provided many excellent examples of failure to observe proven and accepted standards of design and construction”(Dixon 1931, p.6).

2.1.3 _____ Earthquakes from the 1960’s

Later great³ earthquakes, including the 1966 Gisborne earthquake, Seddon in 1966 and Inangahua in 1968, all continued to illustrate the limitations of the newly introduced construction legislation of the time, NZS 1900 [refer Section 4.1.6]. In the 1966 Gisborne earthquake, many older dwellings that had been re-piled, moved off their foundations through a lack of bracing and adequate connections to the sub-floor framing [Figure 2.5].



Figure 2-5 Dwelling moved off the Foundations from Lack of Bracing and Fixing of Sub-floor members to the Superstructure (Source: Shepherd, Bryant, and Carr 1970)

³ A Great earthquake is described as a Magnitude of M_L 8, a Major earthquake is M_L 7, a Strong/Large earthquake is M_L 6, and a Moderate earthquake is above M_L 5 (U.S. Geological Survey 2006).

Napier dwellings strengthened following the 1931 earthquake suffered negligible damage, however, many dwellings superficially repaired following the Napier earthquake showed additional damage at points of weakness (Hamilton et al. 1969).

The damage resulting from the Seddon earthquake, of April 1966, showed that foundations sited on silt sand and softer lower layers of coarse gravels were usually damaged. Generally, dwellings suffered damage due to a combination of site conditions, poor workmanship, and a lack of bracing and overall symmetry of wall bracing systems (Adams et al. 1970). Similar destruction was observed in the Inangahua Township, which is situated in a wet dense valley on the West coast of the South Island. The township suffered extensive damage due to the extreme climatic conditions of the region and a dilapidated housing stock [Figure 2.6]. Most dwellings still stood on their original free standing timber piles, with no lateral bracing and very shallow footings into the soil (Shepherd, Bryant, and Carr 1970).

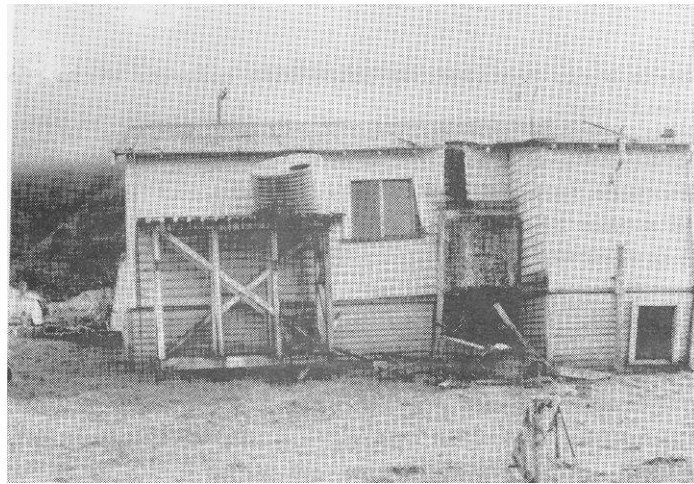


Figure 2-6 Severely Damaged Dwellings in 1968 Inangahua Earthquake (Source: Shepherd, Bryant, and Carr 1970)

Very few dwellings were anchored to foundations and in some cases no more than a single 4 inch nail had been used for anchorage between the piles and bearers. Some dwellings suffered from serious rot due to the close proximity of undrained ground. When dwellings were located on inclines and had unbraced jack studding; overturning of piles was a common failure mechanism (Shepherd, Bryant, and Carr 1970). Rescue efforts in the area were often delayed and limited due to the remote location. Any Bylaw revisions were minimal simply because the effect of the destruction was only experienced by small remote populace (Slade 1979).

2.1.4 The 1970's Building Boom

By the 1970's, New Zealand was experiencing a building boom and with it came many innovations in construction methods and materials. The Edgecumbe earthquake in 1987, showed that all dwellings built to the then current Standard NZS3604:1984 [refer Section 4.1.7] were not structurally damaged (Pender and Robertson 1987) [Figure 2.7].

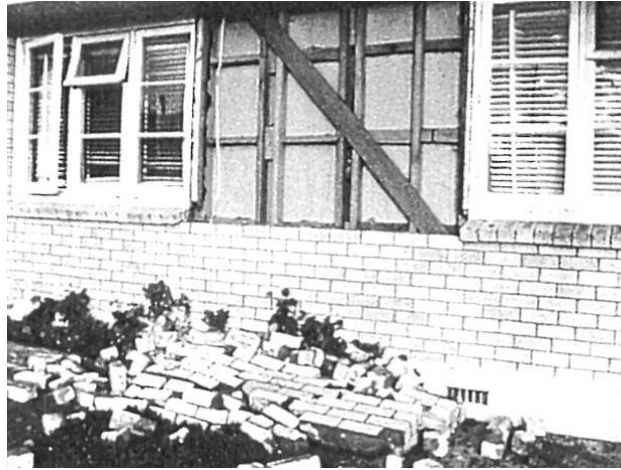


Figure 2-7 Superficial Damage of brick veneer to Full Foundation Wall Dwelling, note the Checked in Bracing of the Wall behind with no Damage (Source: BRANZ 2003)

Dwellings with intermittent concrete corner foundations [refer Section 3.3] performed well, however the soil condition often limited their lateral strength capacity. Dwellings with irregular plans often suffered shaking damage to the extremities, which was the result of induced torsional racking. Inadequacies were also observed for slab-on-ground foundations that had too few and undersized reinforcing bars connecting the floor slab to the perimeter foundation walls [refer Section 3.6]. These issues were addressed by the future revisions of NZS3604 (BRANZ 2003). Although the revision increased awareness of the importance of seismic restraint, existing dwellings built under older standards would still have inadequate fixings to the superstructure and substandard bracing.

2.2 Overseas Earthquakes with Specific Interest to New Zealand

Since New Zealand's last major earthquake in Edgecumbe, much research has been conducted into the performance and reaction of foundations in earthquakes. Research resulting from overseas earthquakes, such as San Fernando 1971, provides further insight into the limitations and restrictions in our own construction provisions. *"20 seconds of ground shaking elsewhere, can provide New Zealand with many lessons to aid further research"* (Park et al. 1995b, p.97).

Reconnaissance expeditions sent to survey the destruction following the 1971 San Fernando earthquake, found that much of the housing stock reacted poorly to the seismic activity. Split level dwellings, unbraced jackstudding and limited sub-floor bracing all contributed to the extent of destruction seen in the earthquake [Figure 2.8].



Figure 2-8 Damaged Split level Dwellings in 1971 San Fernando Earthquake, California (Source: Jennings and Housner 1971)

Generally, dwellings constructed before 1933, with no sub-floor bracing were severely damaged, while modern dwellings that complied with relevant codes and standards, suffered negligible damage. The 1994 earthquake in Northridge, California, illustrated the need for sufficient connections between the floor diaphragm and lateral sub-floor bracing elements and showed that much damage was attributable to torsionally eccentric dwellings. Again, the most common failure in the sub-floor area was the result of a lack of bracing. Conversely, dwellings on sloping sites utilising plywood sheathing on jackstuds performed well, resisting any of the effects of induced torsion (Norton et al. 1994).

The reconnaissance team sent to document the effects of the 1995 Great Hanshin-Awaji [Kobe] earthquake, observed the importance of incorporating ductile behaviour into the detailing of timber construction, utilising nail plates and external straps to tie the superstructure to foundations (Park et al. 1995b). Many dwellings with heavy roof and post and beam construction collapsed [Figure 2.9]. However, modern dwellings often remained standing, even though the soil surrounding the piles had subsided (The Engineered Wood Association 1995).



Figure 2-9 Traditional Post and Beam Dwelling collapsed in the 1995 Kobe Earthquake (Source: Park et al. 1995b)

2.3 Summary of Lessons from New Zealand Earthquakes

The post-European settlement history of earthquakes in New Zealand began with two large earthquakes in 1848 and 1855 in the Wairarapa region. Many unreinforced masonry dwellings collapsed, forcing the colonialists to rethink the European building practices. The 1931 Napier earthquake forced official recognition that construction detailing should be appropriate to withstand induced seismic forces. Later earthquakes, such as Seddon, Murchison and Inangahua, in the mid 1960's, continued to highlight issues such as insufficient bracing, inadequate connections of superstructure to foundations, and overall poorly maintained sub-floor areas. The 1987 Edgecumbe earthquake showed that revised construction methods attributed to the offset of extensive damage common in previous earthquakes. Also, new international architectural trends, such as the split level and the "L" shaped dwelling resulted in extensive damage at areas of discontinuity. Overall, it is evident that the revision of construction methods and materials, as well as changing lifestyle fashions has lead to the development of specific foundation types within New Zealand.

There are six major variations of foundation types commonly used in the construction of New Zealand dwellings. Whether or not a certain foundation type is specified, depends on a number of factors, including: the gradient of the site, subsoil, and weight of the superstructure above. These six variations have developed from three major systems; the piled system, the concrete foundation wall system and the concrete slab-on-ground system. Research following major earthquakes has exposed many inherent weaknesses of each of these systems and in particular where and how these foundations are likely to fail under seismic loading. Such research has led to the revision of construction standards regarding foundations and subsequent amendments which attempt to address some of these inherent weaknesses.

3.1 Internally Piled Foundation [IPF]

The Internally Piled Foundation is a completely piled foundation system with exterior piles supporting the superstructure and roof of the dwelling, while the interior piles support only the floor loading and internal walls. Figure 3.1 illustrates that the exterior piles usually have a jackstud system between exterior pile tops and the bottom plate. Other alternative constructions have bearers notched into the sides of exterior piles.

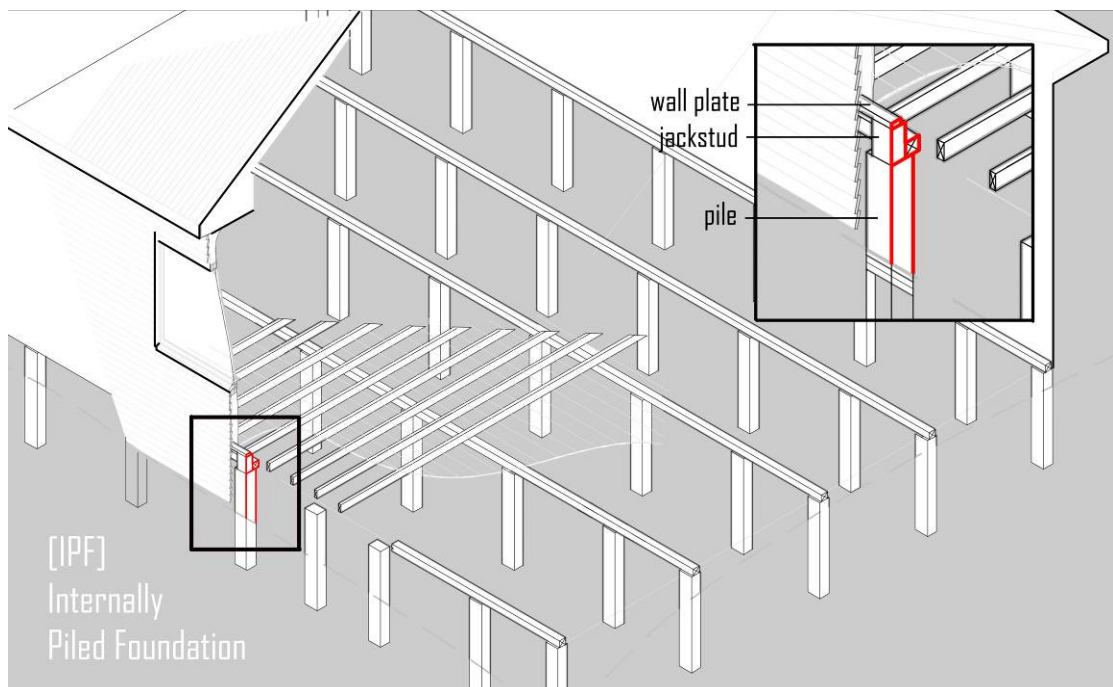


Figure 3-1 Detail of Internally Piled Foundation

This method of foundation construction is common in dwellings built around the turn of the 20th century (Harrap 1980), which may have derived from the construction of old stone cottages,

where the dwelling was enclosed prior to the timber floor being laid (ten Broeke 1979). All piles in these dwellings were usually timber, most often Totara or Puriri, due to the ease of splitting and relative rotting resilience compared with other timber species (Yate 1970 cited Salmond 1986).

3.1.1 Historic Bracing Capacity

The Internally Piled Foundation relies heavily on the strength of the soil surrounding the piles for lateral resistance. This strength, combined with the overturning resistance of squat piles are commonly the only form of lateral resistance. In past earthquakes, these dwellings often swayed sideways, especially if a dwelling had been repiled and replaced with only shallow pile footings [Figure 3.2]. Many dwellings of this age usually have weatherboards covering the sub-floor area, however this form of cladding cannot be assumed to provide any significant bracing potential.

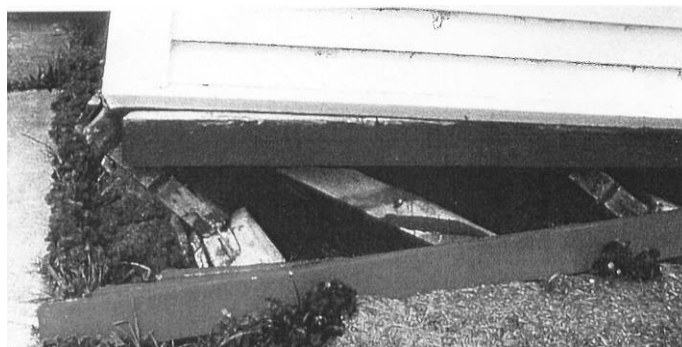


Figure 3-2 Corner of Foundation showing Piles swayed to one side (Source: BRANZ 2003)

3.1.2 Connections

The Internally Piled Foundation will transfer inertial loads from the superstructure and roof directly into the exterior perimeter piles. Since the joists and sometimes even the bearers are not connected to the exterior framing, it could be assumed that the internal piles will take a smaller proportion of the superstructure loading [Figure 3.3].

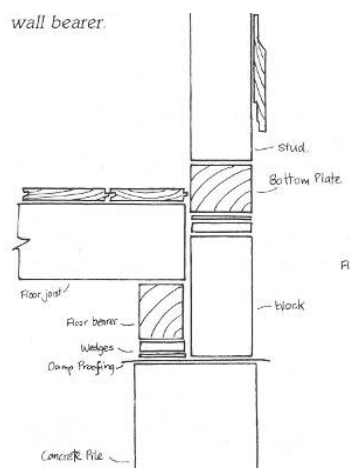


Figure 3-3 Detail of IPF Exterior Detailing (Source: Harrap 1980)

The interior piles will transfer dead and live loads from the floor and interior walls and some of the weight from the roof. The connections considered necessary for load transfer through sub-floor members include the Joist to Bearer [J-B] fixing, the Joist to Exterior Bearer [J-EB] and the Ordinary Pile to Bearer fixing [OP-B] [Figure 3.4]. These connections and the associated fixings will transfer all loads from the exterior shell of the dwelling and internal mass to the ground. The existence of a connection between the joist to exterior piles, may often depend on the age and specific construction of the foundation.

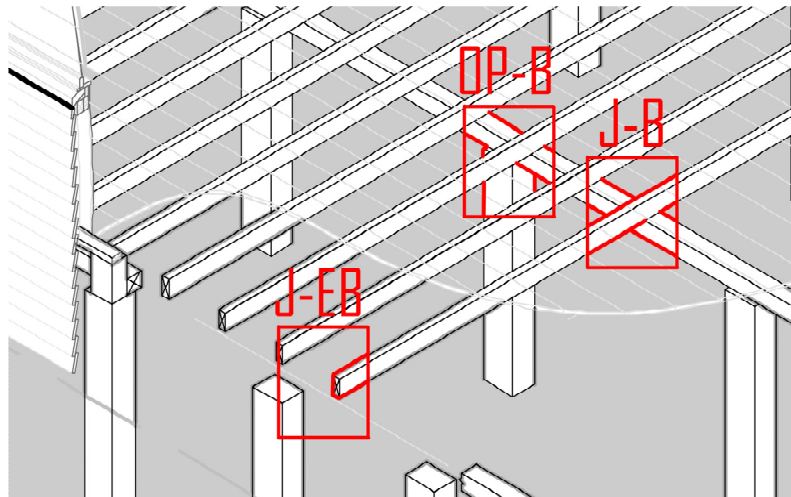


Figure 3-4 Connections in an IPF Foundation type

3.1.3

General Condition

The main factors contributing to the deterioration of Internally Piled Foundations are the result of a lack of clearance between sub-floor members and Cleared Ground Level [“CGL”], and a lack of ventilation combined with excessive moisture from the soil, which can seep into the sub-floor timbers (Cochran 1980). Many repiled dwellings have original piles still in load bearing positions which may be rotted, while others tend to have undersized joists or oversized timber member spans due to changes in the construction prescriptions (Cochran 1980). Subsequent repilings may have releveled the dwellings however, repiling alone may not increase the bracing capacity.

3.2 Full Piled Foundation _____[FPF]

The Full Piled Foundation is a piled foundation using concrete or timber piles to resist vertical loads. No special detailing given to the side or exterior pile lines [Figure 3.5]. The Full Piled Foundation is most common in dwellings built prior to 1940 and continues to be popular for modern dwellings especially where the topography is unsuitable for other foundation types.

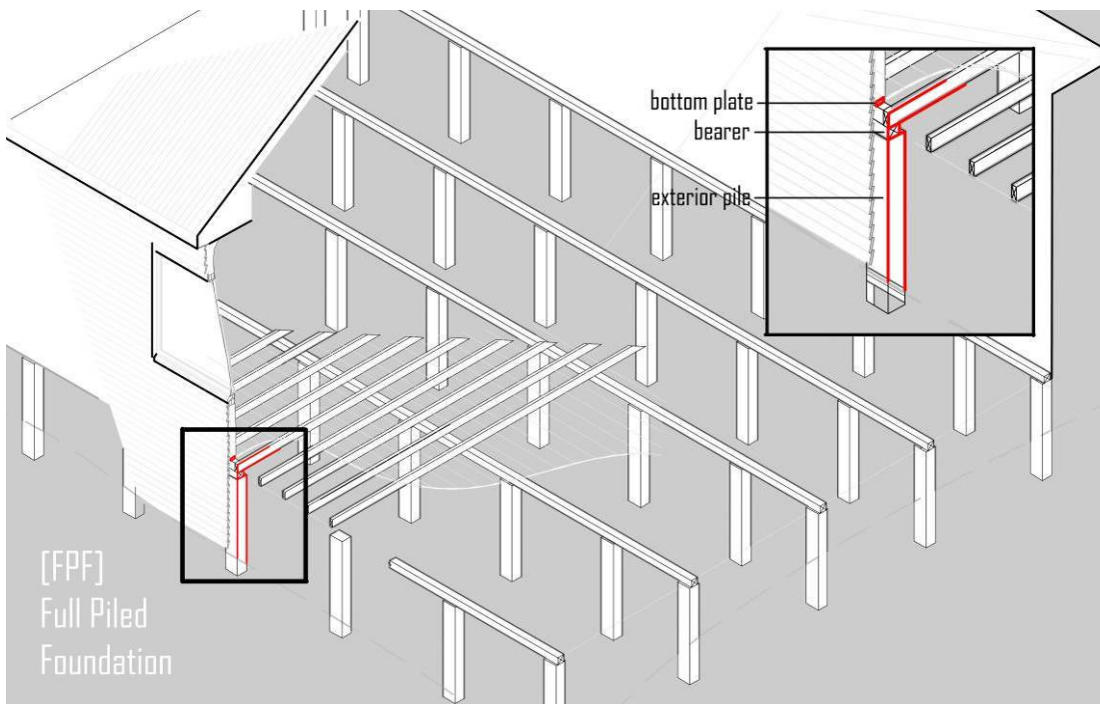


Figure 3-5 Detail of Full Piled Foundation

Many dwellings built prior to 1940 were constructed with native timber piles, which tend to decompose, where as concrete piles were used for dwellings built after the 1950's and in 1980's repilings. Other pile materials such as earthenware, ceramic piles or other found objects may have also been used during construction. Modern piled dwellings commonly use highly treated timber piles, which allow more reliable fixing methods to sub-floor framing.

3.2.1 Historic Bracing Capacity

Full Piled Foundation dwellings have tended to sway heavily on piles during earthquakes, utilising the ductility of soil surrounding the piles to dampen loads [refer Section 1.3]. As a result many dwellings with limited soil ductility, or shallow footings have resulted in sideways collapse, especially if no large concrete 'anchors' [refer Section 5.1.2] were integrally connected to the framing (Norton et al. 1994) [Figure 3.6].



Figure 3-6 Full Piled Foundation slipped off Foundations, with Concrete steps remaining in place
(Source: Cooney 1979)

If concrete ‘anchors’ were present and not fixed to the framing, smashing between the piles and concrete could also potentially occur. Observations of Full Piled Foundations with sheet bracing attached to exterior piles have shown good bracing performance in past earthquakes (Norton et al. 1994). Much of the extensive damage to dwellings during the 1989 Loma Prieta earthquake was attributable to pre 1940’s piled dwellings with unbraced exterior piles (Norton et al. 1994). Similarly, dwellings with walings or weatherboards on exterior piles also performed poorly.

3.2.2 *Connections*

The fixings between members on the interior and exterior of the foundation are typically the same as the Internally Piled Foundation, however the Joist to Exterior Bearer [J-EB] fixing will usually be the same as interior Joist to Bearer [J-B] fixings. The Pile to Bearer connection is perhaps the most important connection as this fixing transfers force from the superstructure to the ground [Figure 3.7].

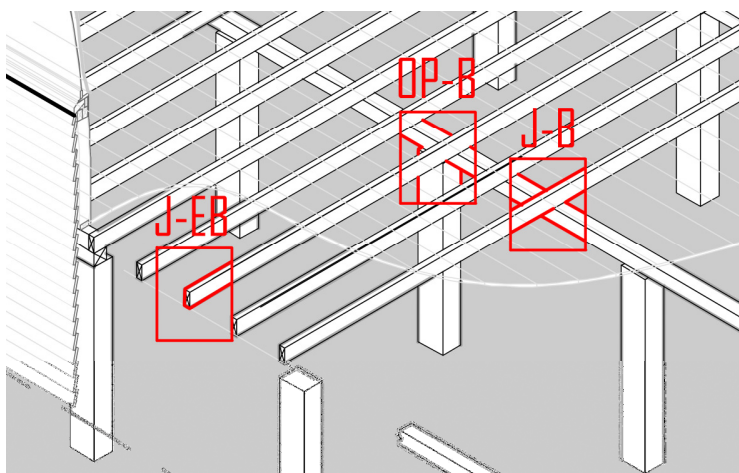


Figure 3-7 Connections in a FPF Foundation type

With adequate connections and a diaphragm over the entire floor area, it is assumed that the sub-floor will react as a single unit, however without adequate fixings, the dwelling can be seen to ‘slip’ off foundations, sometimes causing piles to punch up through the floor [Figure 3.8].



Figure 3-8 Example of Piles punching through Floor due to Sub-floor Framing slipping off Piles
(Source: BRANZ 2003)

As with the Internally Piled Foundation, piling issues such as differential settlement, non-vertical piles and other discrepancies can occur especially due to poor repiling techniques [refer Section 10.2.2]. Piling issues can cause differences in floor level and if the sub-floor timbers are left twisted in a moist condition, they can remain permanently deformed (Salmond 1986).

3.3 Partial Foundation Wall [PFW]

The Partial Foundation Wall, also known as an intermittent concrete foundation wall, has short lengths of concrete foundation wall, usually on the perimeter corners of the dwelling. This foundation type is most common between the 1940's and 1950's and is considered an adequate foundation type for resisting seismic loads (BRANZ 2003). The concrete section of the wall can span as much as four pile bays and is generally connected to sub-floor framing with bolts or reinforcing bars through a timber plate [Figure 3.9].

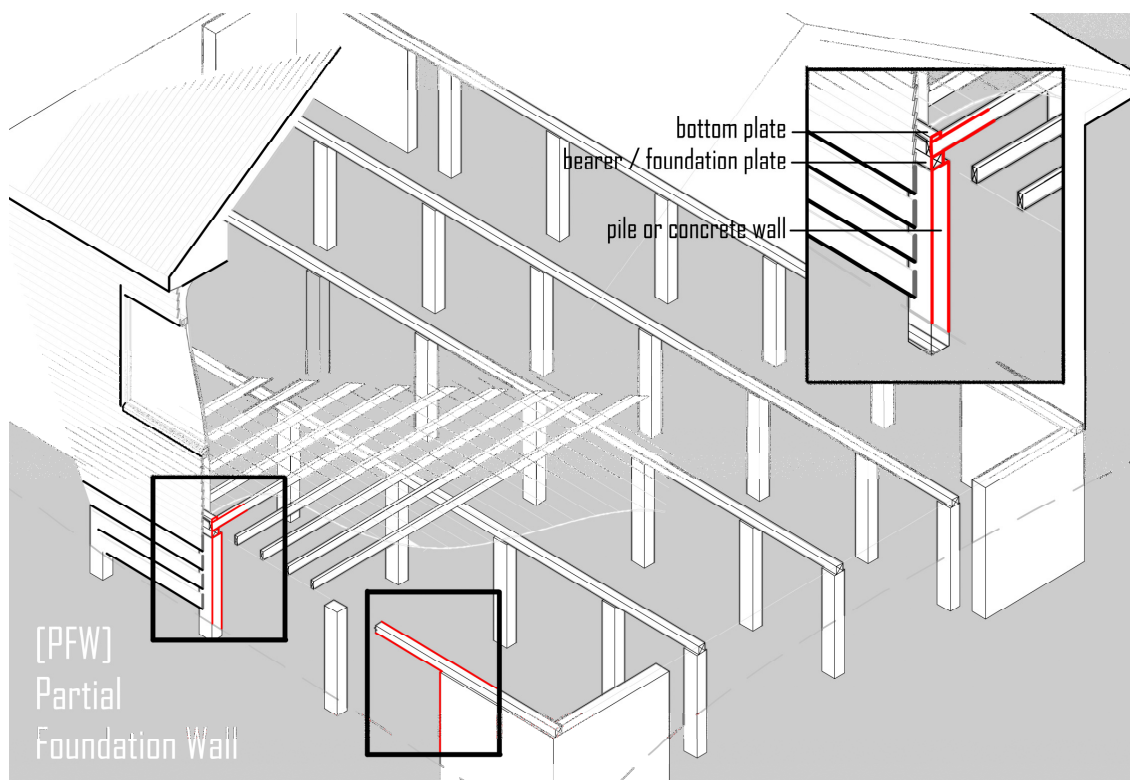


Figure 3-9 Detail of Partial Foundation Wall

The specification of this form of foundation was used predominantly during the 1939 and 1964 State House Specification (Schrader 2005), however tended to be used only where cost and availability of materials were limited (Slade 1979).

This foundation type has performed well in past earthquakes, with many examples escaping with only superficial damage to cladding (BRANZ 2003). Other foundation types that are also considered Partial Foundation Walls, are jackstudded sub-floor walls, where timber studs span between the wall bottom plate and the concrete foundation wall below. As evidenced in past earthquakes, unbraced jackstudding can cause full or partial collapse to the foundation and therefore requires sheet bracing fixed to the jackstudding (Norton et al. 1994) [Figure 3.10].



Figure 3-10 Jackstudded Sub-floor showing Brick Veneer Cladding broken off and Dwelling slumped to one side (Source: Jennings and Housner 1971)

The Partial Foundation Wall has its strongest elements in the exterior of the dwelling and therefore, the fixings to these bracing elements are crucial to resisting lateral loads. Exterior connections include the Plate to Foundation Wall [P-FW] and Bearer to Foundation Wall [B-FW]. The interior connections [Figure 3.11] are similar to piled foundations, and are similarly prescribed in the construction standards. Many examples of this foundation type have strong fixings in the bearer direction to the foundation wall, however lack strong fixings in the direction of the joists.

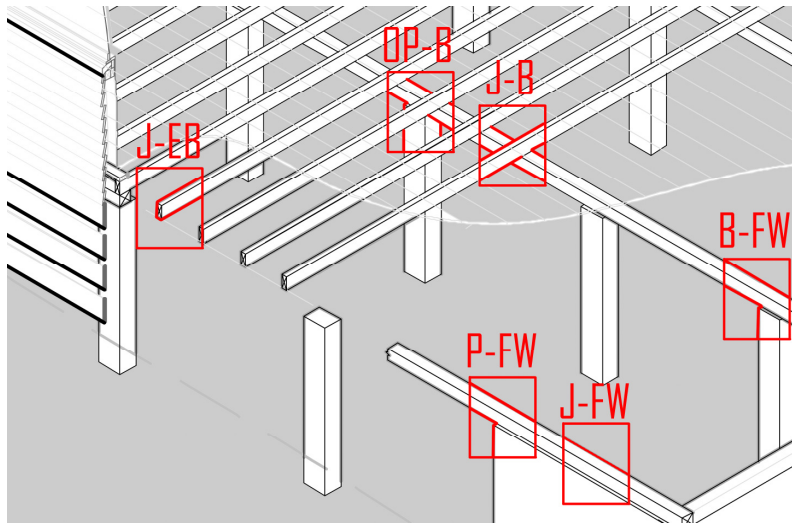


Figure 3-11 Connections in PFW Foundation type

3.3.3

General Condition

Since the Partial Foundation Wall requires strong fixings to connect framing to the bracing elements, these are required to be in an adequate condition for continued load transfer ability. In many situations this foundation has baseboards in the sub-floor, which usually provide adequate ventilation [Figure 3.12].

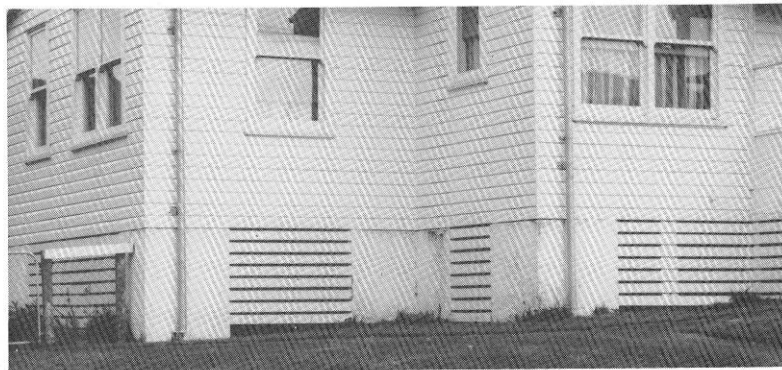


Figure 3-12 Partial Foundation Wall Dwelling showing open Baseboards for Ventilation (Source: Cooney 1982)

3.4 Full Foundation Wall _____ [FFW]

The Full Foundation Wall achieves its bracing potential from a reinforced concrete perimeter wall between the superstructure and the ground [Figure 3.13]. Lateral loads are directed from the super structure directly to the concrete foundation wall. The floor diaphragm transfers the lateral loads to the exterior concrete foundation walls.

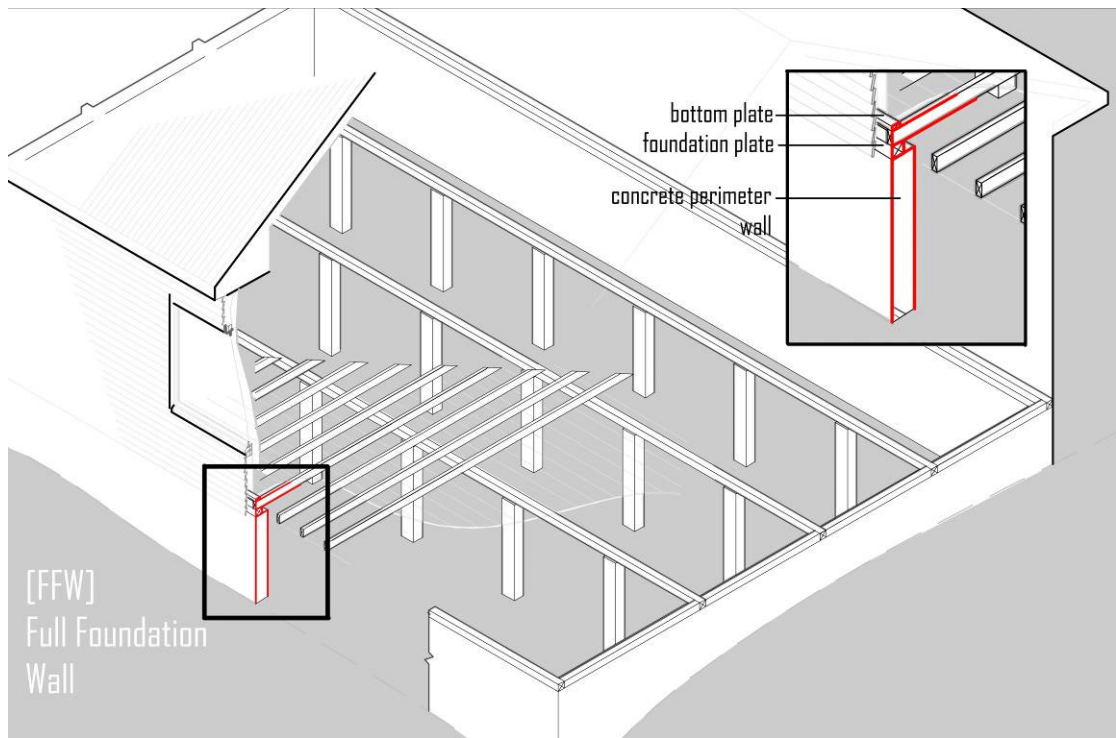


Figure 3-13 Detail of Full Foundation Wall

This method of construction found favour in post war New Zealand construction and was also promoted by the State Housing Scheme, whose focus was on strength and durability. Each dwelling would be constructed using quality labour and materials, and was designed to last up to 60 years (Schrader 2005).

3.4.1 *Historic Bracing Capacity*

The Full Foundation Wall was tested extensively by many earthquakes in the last 50 years, showing to sustain only light or moderate damage to the superstructure (Adams et al. 1970). Damage to the foundation area was usually limited to small cracks or subsidence (Pender and Robertson 1987) [Figure 3.14].



Figure 3-14 Superficial Damage to brick veneer on State Dwellings, however no damage to the Foundation Wall is evident (Source: Eiby 1980)

A Full Foundation Wall is necessary for dwellings with heavy wall and roof cladding, such as brick veneer and concrete roof tiles. Although these dwellings have more weight to resist in earthquakes, the bracing provided by the concrete ring foundation is usually more than adequate.

3.4.2 *Connections*

The Full Foundation Wall usually transfers loads from the superstructure directly to the concrete foundation wall. Since most of the weight in the dwelling is on the exterior of the dwelling, this is the most direct path for the inertial loads. The Plate to Foundation Wall [P-FW] is the most significant fixing in this foundation, transferring all of the collective forces from the interior of the sub-floor area into the concrete perimeter wall. This area has been seen to fail in past earthquakes, with some dwellings slipping off foundations due to limited or no fixing. This is especially significant in the South Island, as fixings between the Plate and Foundation wall may use only wire and staples, where a bolt or bar is usually required (Cooney and Fowkes 1981) [Figure 3.15].

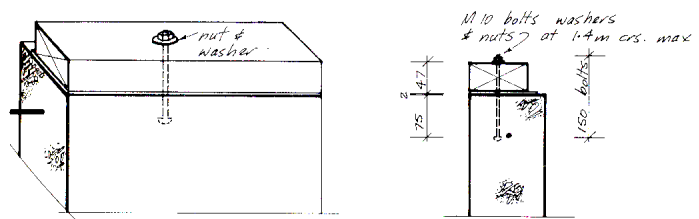


Figure 3-15 Bolted requirements for P-FW Connection between the Timber Plate and the Foundation wall (Source: Wilson 1997)

The floor diaphragm will transfer forces into the Joist to Bearer [J-B], which will then transfer floor loads to the exterior connections such as the Bearer [B-FW] and Joist to Foundation Wall [J-FW]. Loads will then be transferred by the Plate to the Foundation Wall [P-FW] fixing into the foundation plate [Figure 3.16].

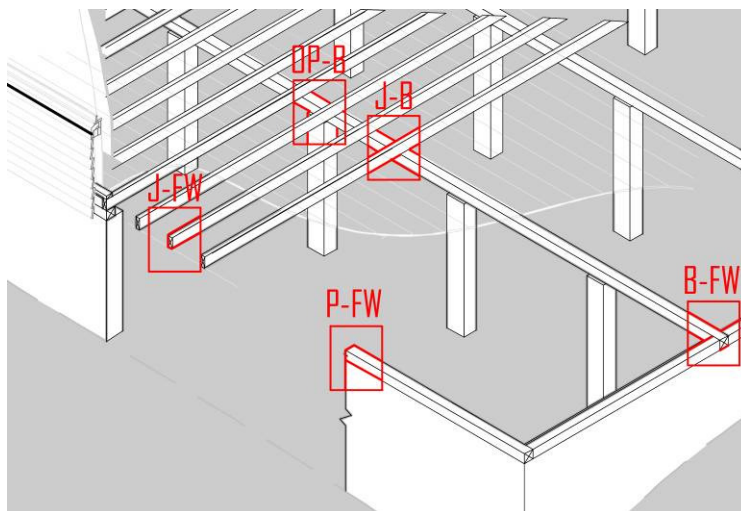


Figure 3-16 Connections in FFW Foundation type

In most Full Piled Foundations, the ventilation is usually adequate to expel moisture. However, modern dwellings with this type of foundation tend to have smaller openings and thus limited cross ventilation, which increases rapid degradation of sub-floor fixings and timbers.

3.5 Full Foundation Wall / Internal Piles [FFW/IP]

The Full Foundation Wall / Internal Piled dwelling is commonly constructed with a brick or block veneer from the ground to soffit level. The sub-floor wall is usually reinforced block and has integrally cast half-piles, on which the bearers sit. Early provisions for this type of foundation allowed the perimeter piles to be cast separately from the exterior wall, which meant that the sub-floor framing was simply sandwiched between either side of the foundation wall [Figure 3.17].

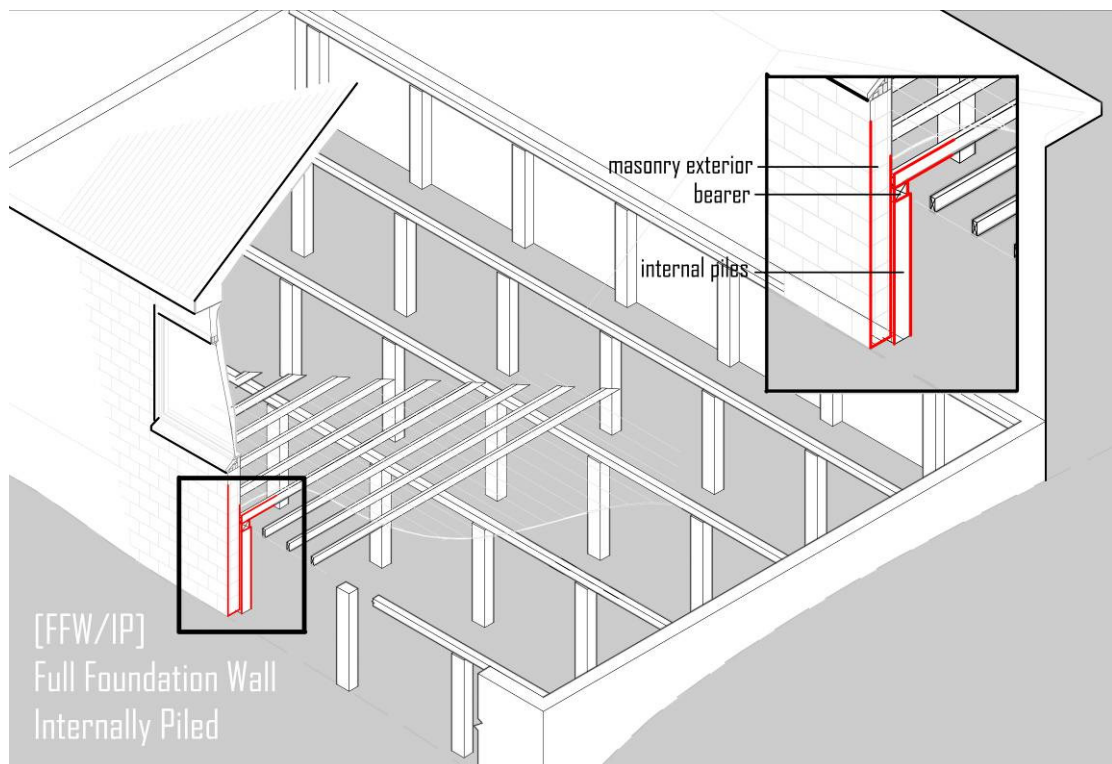


Figure 3-17 Detail of Full Foundation Wall / Internal Piled Foundation

This form of construction, prevalent in the 1970's and 1980's, is assumed to be as strong as the Full Foundation Wall, depending on the adequacy of reinforcing in the block sub-floor wall. However, out-of-plane bending of exterior walls, was seen in Edgumbe and was most probably due to the lack of integration between the dwelling superstructure and the sub-floor framing (BRANZ 2003) [Figure 3.18].



Figure 3-18 Wall separating from Exterior Foundation wall (Source: BRANZ 2003)

This type of damage could also cause cracking to appear in mortar lines and blocks if the movement was severe. However, this damage can usually be repaired and would not cause collapse of a dwelling [Figure 3.19].

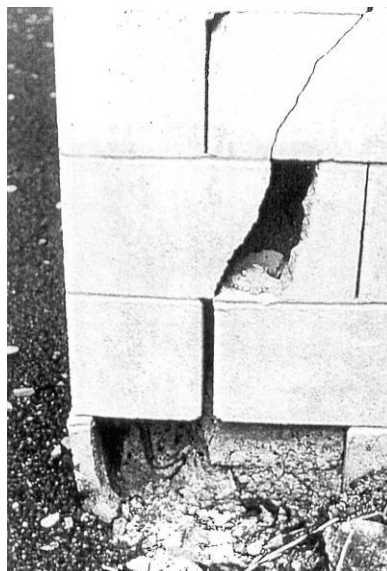


Figure 3-19 Extensive damage on the Lower Courses of Block in a Full Foundation Wall / Internal Piled Foundation (Source: BRANZ 2003)

3.5.2 **Connections**

In most Full Foundation Wall / Internal Piled foundations superstructure loads are usually transferred through the floor diaphragm and sub-floor timbers to be resisted by perpendicular bracing elements. If the exterior piles are not cast integrally, only friction will be assumed to resist all internal floor loading from sub-floor framing. Since fixings were not required between the exterior wall and internal framing members, the most important fixings tend to be the Joist to Bearer [J-B], the Joist to Foundation Wall [J-FW] and the Ordinary Pile to Bearer [OP-B] [Figure 3.20].

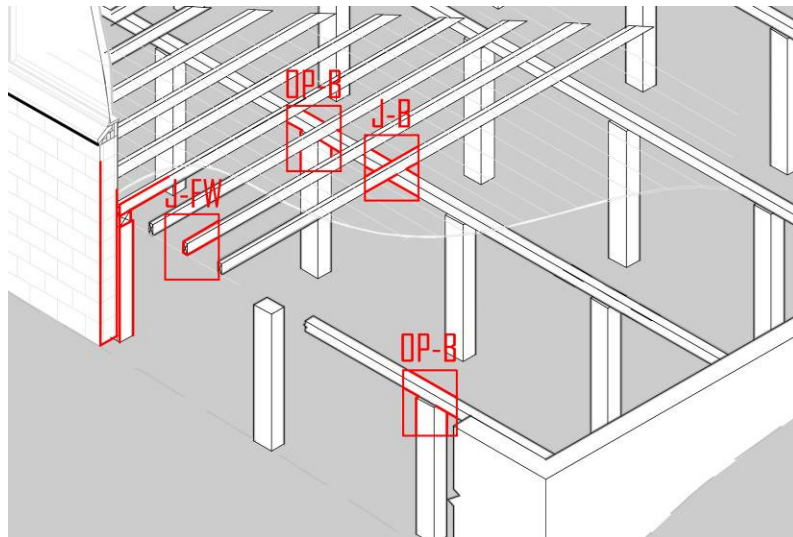


Figure 3-20 Connections in FFW/IP Foundation type

3.5.3 _____ *General Condition*

Since the Full Foundation Wall / Internal piled foundation is usually block or brick, maintenance following an earthquake will probably be necessary. Ventilation tends to be adequate, due to the provision of block sized openings. The main concern for this foundation type is the adequacy of reinforcing and the maintenance of the block work.

3.6 Slab on ground _____ **[SLAB]**

The slab-on-ground foundation has revolutionised the construction of foundations in dwellings, reducing the cost and time required to build new houses and construct additions to dwellings since the mid 1980's. The slab-on-ground is assumed to 'float' on the soil, meaning that loads are distributed from the superstructure to the concrete slab and into thickened areas of the foundation [Figure 3.21]. Since the connection from the superstructure to the foundation is the most important for the transfer of forces, this area could be a problem for dwellings with inadequate or non-existent fixings that may be hidden behind internal linings. The slab construction often requires extensive reinforcing on internal corners or reinforcing mesh over the entire slab to stop cracking.

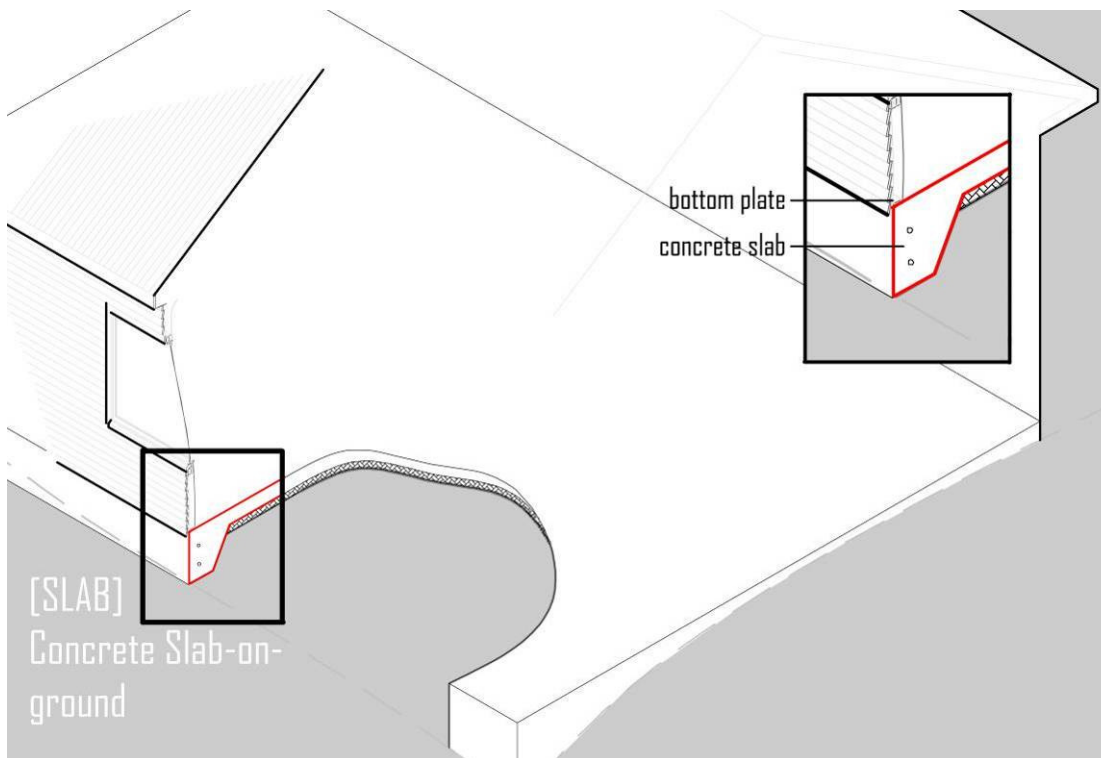


Figure 3-21 One variation of Detail for Slab on Ground Construction

Other modern foundations consist of concrete crib wall constructions, concrete column construction and other foundation constructions usually utilised only in extremely difficult situations and specifically designed by an engineer.

3.6.1 *Historic Bracing Capacity*

The strength of slab-on-ground construction has proven to be sound in past earthquakes (Cooney and Fowkes 1981). However, a common failure seen in Edgumbe was the top slab sliding relative to the lower wall, causing extensive damage to the foundation of the dwelling. A slab foundation now requires additional reinforcing between exterior perimeter walls and the poured slab (BRANZ 2003). Irregular plans for concrete slab foundations, also require additional reinforcement across assumed cracking lines or parts of distinct change in an asymmetric layout [Figure 3.22] (Standards New Zealand 1999).

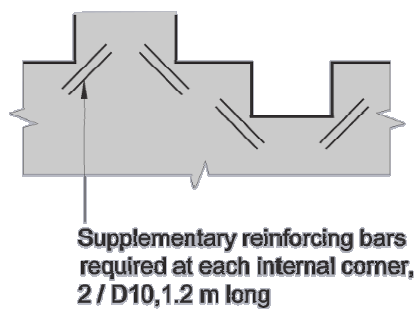


Figure 3-22 Supplementary Slab-on-Ground Bracing at Internal Corners (Courtesy: Standards New Zealand 1999)

Since a slab foundation floats on the ground, differential settlement can cause foundations to move, crack and possibly separate [Figure 3.23]. It is for this reason that slab constructions suit reasonably flat consistent sites and a gentle topography.



Figure 3-23 Slab on ground Dwelling showing the location of the Downpipe relative to the Drain after Sliding on top of the Ground (Source: BRANZ 2003)

3.6.2

General Condition

The general condition of slab foundations is largely dependant on the preparation and precautions taken prior to pouring the concrete slab. Any form of cracking in slabs is irreversible, as is any vertical or horizontal movement and differential displacement (Beattie 2001) [Figure 3.24].



Figure 3-24 Severe Cracking through a Concrete Slab (Source: BRANZ 2003)

Remedies for small cracking, is limited to exopy grout filling and reinforcing in the grout, larger cracks may be repaired with modern jacking and grout injecting techniques originally developed for industrial structures (Olshan Foundation Repair 2006). If these techniques are unsuitable or too expensive, the dwelling may be required to be condemned. Thus, the slab foundation should be correctly constructed in the first instance, otherwise the foundation is impractical to remedy if any damage occurs (Cooney 1982). Damp Proof Membrane should be laid over the whole

slab area to abate capillary water seepage into the concrete. Pole houses, which are an engineered foundation, may not achieve current requirements for bracing due to changes in construction standards (Cooney 1982).

3.7 The Domestic Architecture and Age of Foundations

The architecture of domestic dwellings is not easily defined, nor does one foundation type represent the age of one particular dwelling. However, certain trends exist which dictate the period in which each foundation type was built. Figure 3.25 shows the relationship between domestic dwelling fashions relative to the age of foundation type.

3.7.1 *Domestic Architectural History*

Older dwellings, around 1900 tended to be ornamental and built with many different native timbers, depending on the requirement and characteristics of the timber. Ornamentation usually depended on the craftsman and popular style of the time [Fig 3.25 A]. Transitional styles ranging from the Bay villa to the Bungalow, in the 1920's [Fig 3.25 B] resulted in a mix of residential architectural fashions (Stewart 1992).

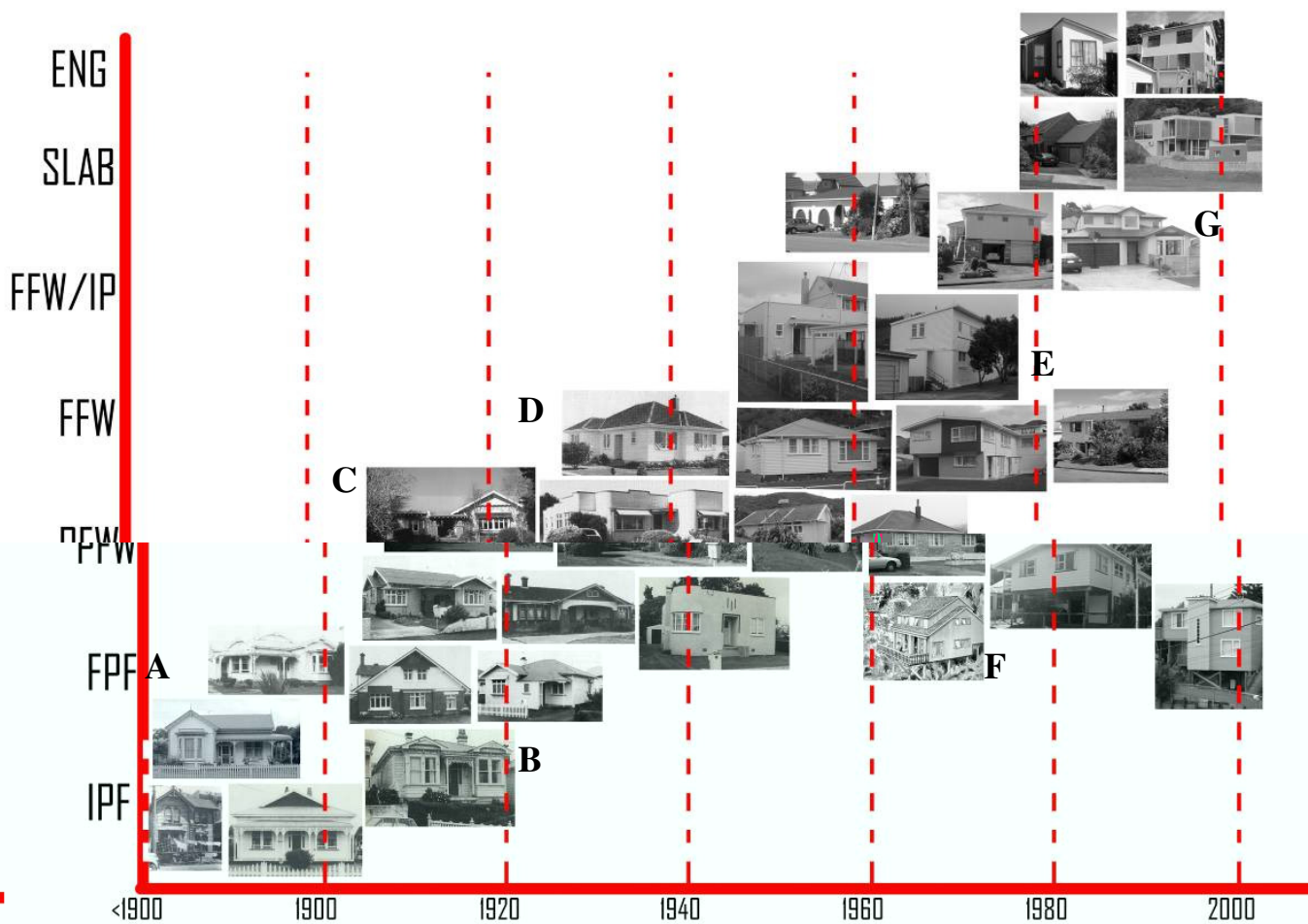


Figure 3-25 Domestic Architecture relating to Foundation type and age of the Style⁴.

⁴ Use the Pull-Out Reference Guide at the end of this document for reference to Foundation types

Pre 1940's dwellings were regular in plan and sufficient to resist earthquakes, however the piles often sank over time and the sub-floor was often not braced or well ventilated. Bungalow style influenced by Californian trends [Fig 3.25 C], often used brick in the design, either fully or partially (Saylor 1911). The Tudor and Georgian styles also used brick with reinforced concrete foundation walls to support the extra weight of the cladding (Raworth 1991). Dwellings built after the 1940's and 1950's, tended to utilise different non-traditional materials due to rations for the Second World War efforts. These were usually of a heavier nature and so dwellings required stronger foundations. This era was epitomised by the State House dwelling [Fig 3.25 D] and many non-state designed dwellings followed the same architectural fashion. Newer styles in the 1970's lead to integration of garages [Fig 3.25 E] into the dwelling envelope. Commonly adopted aesthetics of previous decades were abolished, favouring lifestyle combinations that have the potential to react poorly in earthquakes. The most critical combination is the rectangular split level ground floor dwelling with a garage at one end and excessive roof mass (Cooney and Fowkes 1981). Pole houses [Fig 3.25 F] popular in the 1970's allowed previously unbuildable gradients to be infilled with dwellings, pushing foundations into an engineering realm (Megget 1984). Minimal maintenance and low cost have contributed to the style of dwellings into the modern decades after 1990, with many dwellings aiming for visual durability utilising a myriad of new materials available today. These dwellings more commonly use slab and engineered foundations for strong, simple and quick solutions to the domestic construction boom [Fig 3.25 G].

3.8 Summary of Foundation Types

The six foundation types include two variations of piled foundations, three variations of the concrete and masonry foundation wall, and the slab-on-ground foundation. The piled foundations, common in older dwellings, usually perform poorly without lateral bracing to the exterior piles of the sub-floor. The concrete walled foundations have all shown adequate strength during past earthquakes, however inadequate connections between the superstructure and foundation usually resulted in the superstructure slipping off the foundations. Slab foundations are the strongest and fastest to construct, however if not adequately reinforced and prepared, they can cause irreparable cracks and splitting during an earthquake. Poorly maintained dwellings and unbraced dwellings usually react very poorly to the induced seismic loads in a large earthquake, and often result in the collapse or extensive damage to the dwelling. Each of these foundation type variations have developed during different periods of our construction history in compliance with either informal recommendations or formal historical construction standards.

4

Over the last century, the light timber frame construction standards have evolved from a set of informal recommendations to a modern comprehensive set of mandatory standards that cover all aspects of seismic detailing, sub-floor bracing requirements and construction in general. These standards have been revised over time, often in response to a seismic event or research findings regarding the adequacy of particular seismic detailing. A comparison of the revised standards identifies where requirements have significantly changed and whether a particular inherent weakness has been addressed. Often, older dwellings that were once considered adequate, will be deemed “inadequate” as a result of a revision. The overall policy behind revising standards is to mitigate the “collapse and irreparable damage” to dwellings and to minimise “injury or loss of life to people in and around the building”(Standards Association of New Zealand 1992). See *Light Timber Framed Construction History* [refer Appendix B1-B6]

4.1

4.1.1

Prior to the implementation of a formal national standard for construction, much of the detailing, design and interpretation of ‘adequate strength’ was determined by the builder. The builder was presumed to have the requisite knowledge of timbers, fixings and waterproofing and a high level of skill and accuracy to perform any construction task (ten Broeke 1979). As building practices and materials diversified, the specific knowledge tended to be lost, necessitating more stringent standards of construction.

4.1.2

In 1924, the New Zealand State Forest Service endorsed Circular 14. Circular 14 sets out recommendations from officials of the time, in relation to good timber construction practice and is considered to be New Zealand's first building regulation, albeit informal. It included information about timber construction, earthquake load calculations and the properties of timber specific to dwellings. Section II of Circular 14, relates to the "Minimum Requirements for Safe and Economical construction of Small Wooden Framed Buildings" and included six Articles, of which Article III was devoted entirely to foundations. It prescribes the dimensions and requirements of foundation walls and piers [piles], damp proof course and ventilation. Article I set out the requirements for the quality of timber to be "*thoroughly seasoned*" and "*foundation blocks, if of timber, shall be heart material*", which was common throughout early construction (New Zealand State Forest Service 1924). However, the only reference to seismic resistance

was that preference should be given to concrete foundation walls over piles. Circular 14 was always intended to be a set of recommendations and was consequently never enforced by local or regional governments (Slade 1979).

4.1.3 *Directions from Charles E. Dixon*

On March 15th 1931, a month after the Napier earthquake, Charles Dixon (1931) released an article in *The New Zealand National Review*, titled 'Earthquake Proves Superiority of Wooden Buildings', which drew on the experience of the Murchison Earthquake. It documented Dixon's observations, which included poor seismic detailing resulting in damage and the failure of the sub-floor area [Figure 4.1].

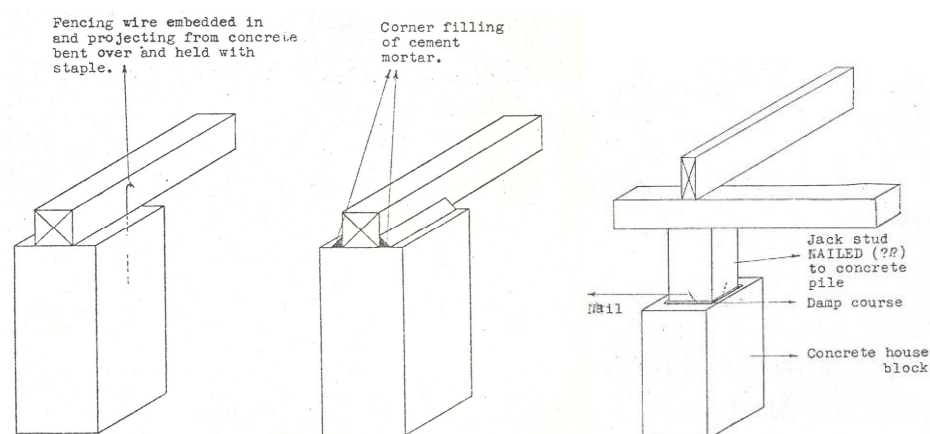


Figure 4-1 Drawn Details of Poor Seismic Detailing from *The National Review* article (Source: Dixon 1931)

Dixon explained that the top three reasons for total or partial failure of dwellings seen in Murchison and other earthquakes, was a lack of fixing of foundations to the superstructure, a lack of sub-floor framing or jack studding and inefficient bracing of walls, which caused racking of the sub-floor area. Dixon also noted that dwellings should use continuous concrete footings and all foundations should be constructed only on 'mother ground', thus allowing the subsoil to dampen earthquake forces. The article included drawings of good and poor construction practices and offered alternatives to non-standardised construction situations [Figure 4.2].

In 1936, the Labour Government formed the Housing Division as part of the Ministry of Works. A significant responsibility of the Housing Division was to release annual amended construction specifications to which all private contractors involved in constructing State Housing, were intended to follow. The 1936 State House Specifications required dwellings to have a Full Foundation Wall, for the reduction of termite infestation and to reduce movement in the expansive Auckland soils. Full Piled Foundations were also acceptable where termite infestation was considered less of a threat. Fixings were not specifically detailed so construction was still based on ‘good trade practice’ (Cooney 1979). The 1946 State House Specification required all dwellings to use Full Piled Foundations which significantly reduced the seismic strength of dwellings until 1947. At this time the Housing Division designated specific locations as being prone to termite infestation and reintroduced the Full Foundation Wall and the Partial Foundation Wall. Jack studding and bracing was permitted between 1948 and 1962, often being used in lieu of Full Foundation Walls when over 1.2m high. Checked-in bracing was also to replace all instances of Cut Between Bracing used in jackstudding previously (Slade 1979). Pinus Radiata replaced native timbers in 1951, which was seen as a limitation in the strength of timber members and connections (ten Broeke 1979) [refer Appendix B6].

The State Housing Specification in conjunction with N.Z.S.S. 95, governed all building practices, until NZS 1900 was introduced in 1964 (Standards Association of New Zealand 1964). The new Standard covered a number of areas, including the construction of timber residential dwellings and was very similar to N.Z.S.S. 95, except for the omission of waling requirements, which was interpreted to mean that they were not required in the sub-floor (Cooney 1979) [Figure 4.3].

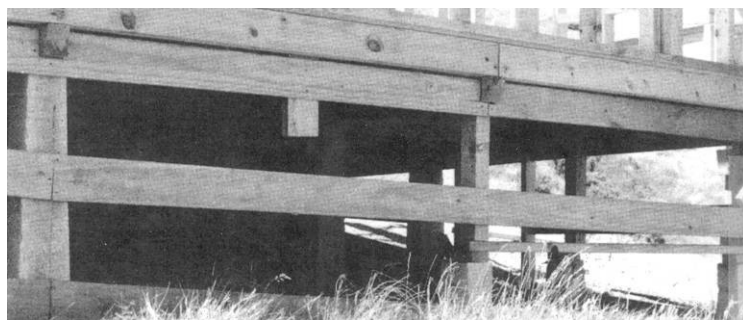


Figure 4-3 A Waling, which is used for Lateral Stability in some Dwellings (Source: Cooney 1979)

The sub-floor bracing provisions in NZS 1900 were seriously insufficient at a time when construction practices and technological advances required a strict framework of application. By the 1970's, standards that relied on ‘good trade practice’ for construction applications were seldom applicable. Using wording such as “Secure fixings” and “Securely braced”, were

meaningless without previous construction experience with the applicable materials (Cooney and Fowkes 1981). Therefore, a new Standard was required to further emphasise the need for an engineering focus in Timber Framed construction. This enabled easy application of construction methods and provided comprehensive reliable methods to apply to new structural applications.

4.1.7 Standard for Light Timber Framed Construction NZS3604: 1978

The new Standard, NZS3604, allowed greater flexibility for future construction methods, focussed less on traditional construction practices and in particular, took into account the actual loads which a dwelling is expected to withstand in an earthquake (Standards Association of New Zealand 1978). New Zealand was divided into different seismic zones and allowed provision to distinguish between dwellings with different roof masses and claddings. Different types of foundations and sub-floor framing systems were also illustrated, each with varying sub-floor bracing strengths. Foundation elements, which included meticulously detailed pile bracing systems drawn in a directly applicable format, were required to resist both vertical and horizontal forces, [Figure 4.4].

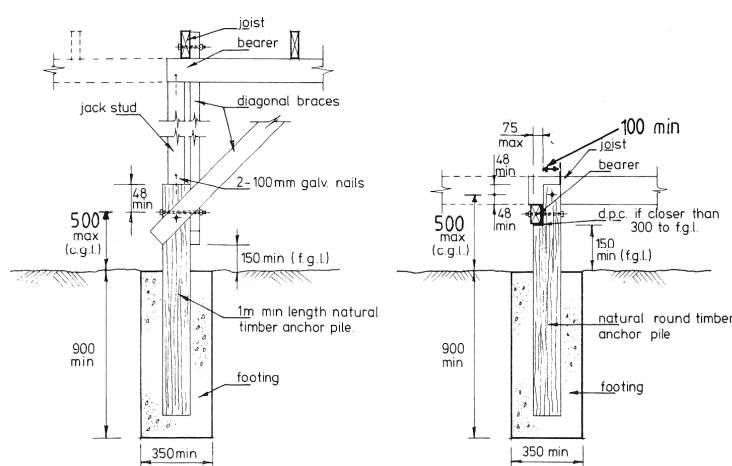


Figure 4-4 Anchor Pile Details with Specific drawn Information (Courtesy: Standards Association of New Zealand 1984)

NZS3604:1978 aimed at minimising damage to dwellings ensuring habitability after a major earthquake and followed a similar theory characterised in the loadings code NZS 4203 (Standards Association of New Zealand 1992). The subsequent revisions of NZS3604 attempted to integrate and cross reference separate but related building standards and other construction legislation which were gaining acceptance in New Zealand. Although the importance rests on compliance with the Standard, performance criteria for alternative construction methods could be introduced into each subsequent edition of NZS3604 (Cooney and Collins 1982).

4.1.8 Revised Edition NZS3604: 1984

The 1984 edition of NZS3604 included amendments regarding wind zones, exposures, and a re-evaluation of the requirements of sub-floor bracing. Sub-floor bracing was determined by the

dwelling parameters such as weight, height and roof pitch which then prescribed the number of Braces⁵ required per bracing line. The minimum requirement was two Braces per line up to a maximum of eight Braces per line. Sub-floor bracing was required on every external wall over 4m long, with a minimum of four Braces over the whole foundation (Standards Association of New Zealand 1984). However, selecting the correct sub-floor type was still difficult, and difficult to apply correctly to different onsite scenarios.

4.1.9 *Revised Edition NZS3604: 1990*

The 1990 edition of NZS3604 endeavoured to further simplify the complicated sub-floor bracing section, whilst retaining other fundamental requirements of the superseded Standard. The foundation bracing section collated foundation systems into 13 different foundation types, and listed variations for vertical and horizontal, internal and external resisting systems [Figure 4.5].

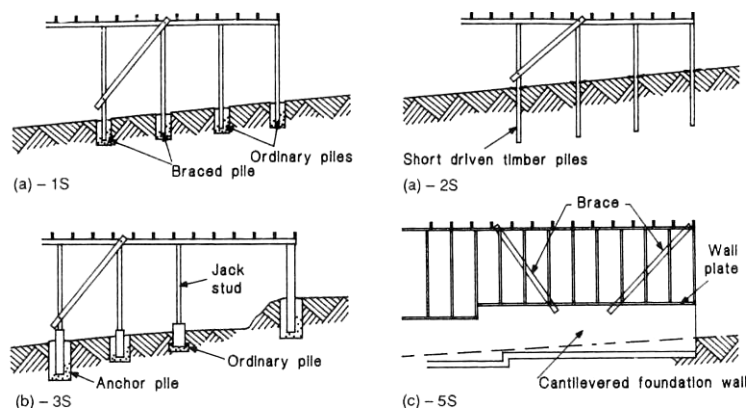


Figure 4-5 Four Examples of the Foundation Systems specified in NZS3604:1990 (Courtesy: Standards Association of New Zealand)

Sub-floor bracing elements were calculated to have specific Bracing Unit [“BU”] based on the strength of the system. To calculate the amount of bracing required, different combinations of dwelling weight and roof pitch were selected from a chart, which varied between 6.3 BU per m² up to 11.4 BU per m². More options for variations of foundation and user defined solutions were included in the amended Standard (Standards Association of New Zealand 1990).

4.1.10 *Revised Edition NZS3604: 1999*

Since the passing of the Building Acts 1991 and 2004, all new building work must comply with the Building Code (Department of Building and Housing 2006). The most recent revision of NZS3604 bridged gaps between the Building Code and the Code of Practice to acknowledge the changes in trade practices (Thurston and Park 2004). Bracing requirements in NZS3604 for the sub-floor area are significantly higher than in previous documents and poorly performing sub-floor bracing systems such as shallow cantilevered piles and cut-between-braces are no longer

⁵ See Appendix B 3.1 for the Specific requirements for a Brace as given by SANZ 1984.

permitted. Serviceability and durability requirements relating to different corrosion zones were adopted, which reflect the different environments throughout New Zealand. NZS3604 includes a user friendly colour coded indexing system to enhance usage for all possible user groups (Standards New Zealand 1999).

4.2 Vertical Load Resisting Systems

The historic standards have constantly altered to suit the understanding of what is deemed an appropriate structure to resist loads. The areas below may have changed over various standards depending on sawmilling technologies and affiliations within the forestry industries. These will be explored further in the analysis of the sample against NZS3604:1999 [refer Section 10]. Historic changes are collated in the *Light Timber Framed Construction History* [refer Appendix B1-B5]

4.2.1 Minimum Joist Span

The 125x50mm joist is assumed to be the most common framing member, as maximum joist spans are rarely used in practice. Larger joists are uncommon due to the sourcing of larger timber sizes and generally higher costs involved. The minimum joist span has changed only slightly in 1984 and remained constant over all standards, since most older standards were not altered as they were considered suitable for the application [Figure 4.6].

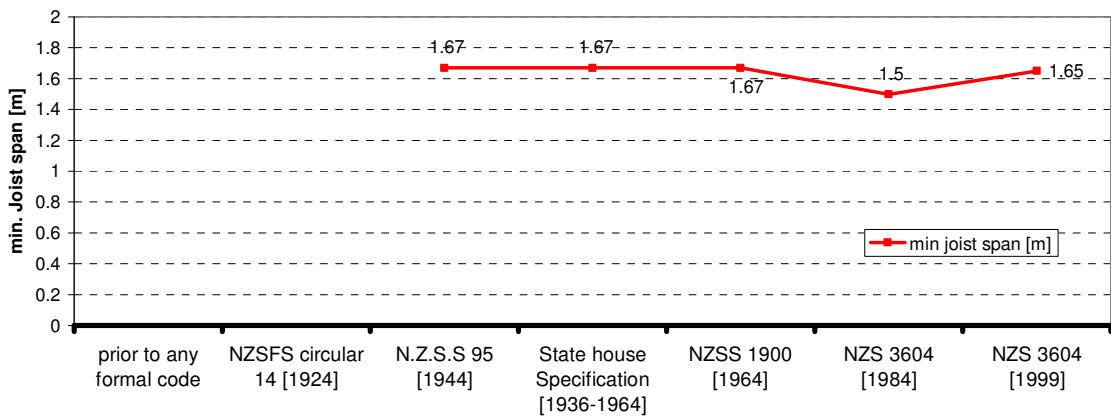


Figure 4-6 Minimum Joist span changes over all Major Standards

4.2.2 Bearer Span

The bearer span for a standard 100x75mm bearer has changed three times over the course of all the standards. The first was the conservative State House Specification, followed by NZS1900, which allowed up to 1.67m span [Figure 4.7].

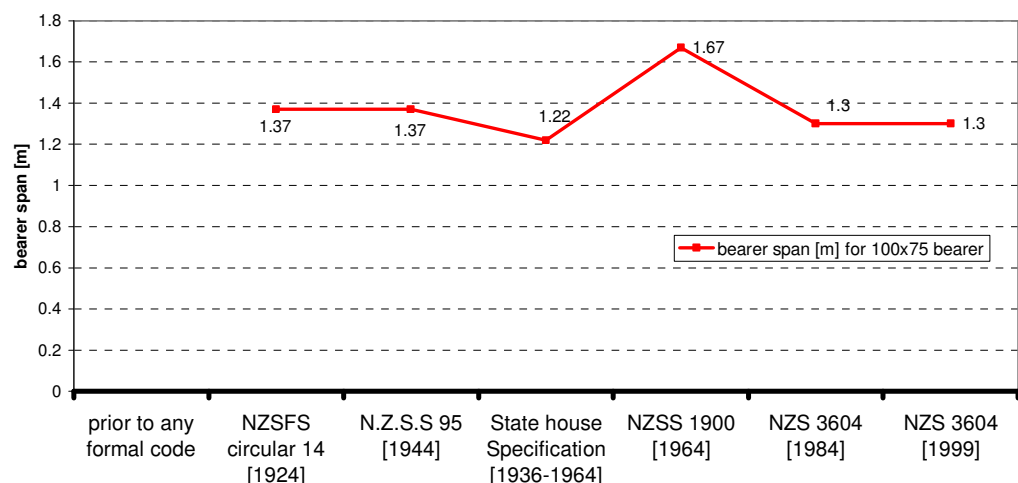


Figure 4-7 Bearer span for 100x75mm Member and changes over all Major Standards

4.2.3

Pile Height

Pile height allowances have increased constantly over the century to allow for new techniques such as pile driving of longer poles. A maximum length of 3m is allowed for non-driven standard timber piles in NZS3604 with an allowance of up to 3.6m for driven timber piles. All previous Standards had an allowable height of between 1.7 to 2m no matter whether the pile was driven or not [Figure 4.8].

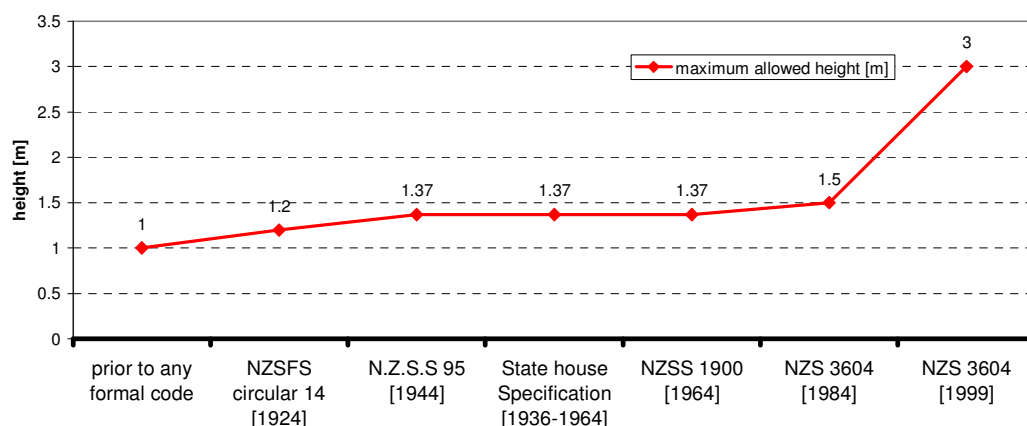


Figure 4-8 Non-driven Pile Height changes over all Major Standards

4.3 Fixing Provisions⁶

4.3.1

Joist to Bearer Fixing

[J-B]

Joist to Bearer fixings have received little attention in standards, up to 1964 prescriptions simply required the fixing to be fixed in a 'secure manner'. However, NZS3604 specifies that the fixing shall be two 100x3.75mm skew nails between the joist and bearer.

⁶ Use Pull-Out Reference Guide at end of this document for Connection abbreviations

4.3.2 Ordinary Pile to Bearer Fixing [DP-B]

The Ordinary Pile to Bearer connection has different fixing requirements depending on whether the pile is timber or concrete. 4mm wire and 4 staples are required to connect the bearer to concrete pile [Figure 4.9 left] and 2 Z and 2 skew nails are required for fixing to timber piles. However, until the release of NZS3604:1990 only 2 wire dogs between timber piles and bearer were required [Figure 4.9 right] (Standards Association of New Zealand). These requirements have not changed significantly since N.Z.S.S. 95 (Standards Association of New Zealand 1944).

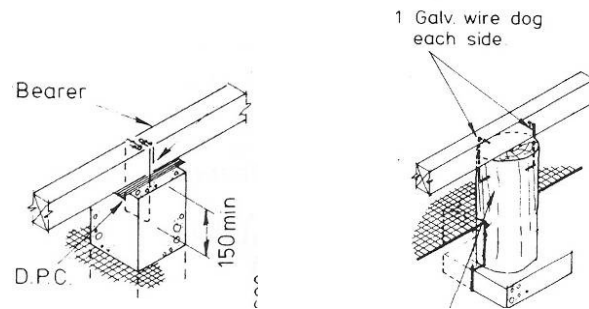


Figure 4-9 Ordinary Pile to Bearer fixing requirement for Concrete Piles [left] and Timber Piles [right] (Courtesy: Standards Association of New Zealand 1984)

4.3.3 Plate to Foundation Wall Fixing [P-FW]

The Wall Plate to Foundation Wall fixing requirement has been amended many times since the promulgation of formal standards. The Plate to Foundation Wall fixing usually consisted of 10mm reinforcing bars or embedded M10 bolts [Figure 4.10].

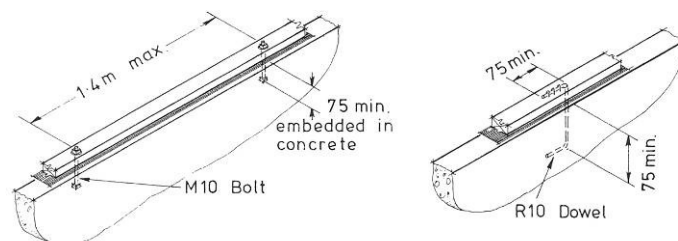


Figure 4-10 Plate to Foundation Wall showing two Variations of Fixings (Courtesy: Standards Association of New Zealand 1984)

All requirements from the 1924 standard specify fixing sizes and ranged from 5/8in. anchors to modern M12 bolted fixings. However, it is the spacing between the fixings that have altered most through all standards [Figure 4.11]. The current bolted spacing is the same as in previous standards, however, the reinforcing bar fixing now requires a 900mm spacing between fixings, due to observation of poor performance in past earthquakes.

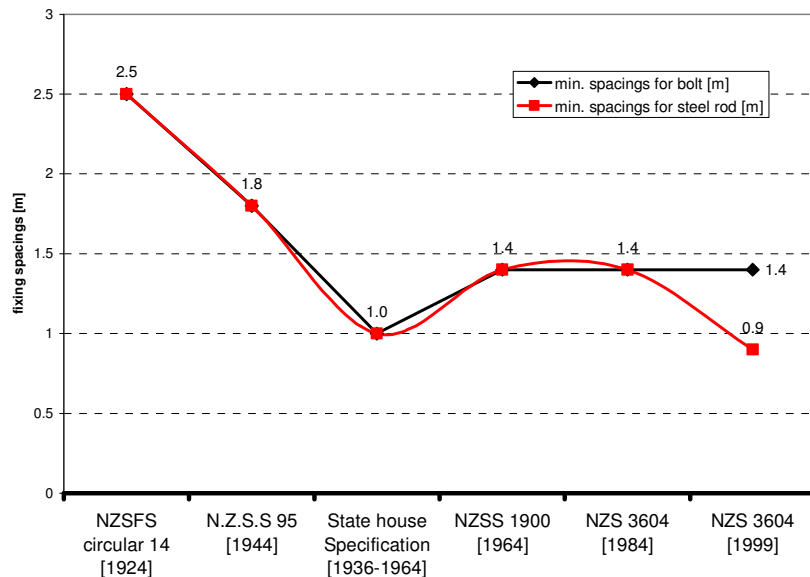


Figure 4-11 P-FW fixing over all Historic Standards

4.3.4 *Bearer to Bearer Fixing* *[B-B]*

The current Bearer to Bearer connection requires a 12kN fixing and is vital to the transfer of loads through the bearer line, otherwise the bearer end can slip off piled supports when not adequately fixed together. However, older standards up until 1964 require that the connection shall be “*halved or scarfed and well-nailed over adequate support*” (Standards Association of New Zealand 1964). Other standards state a similar situation with the Joist to Joist fixing [Figure 4.12], however, is less significant since the joists are connected to timber flooring.

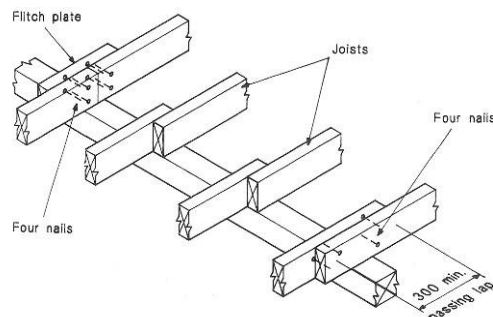


Figure 4-12 Standard Joist to Joist fixing Requirements (Courtesy: Standards Association of New Zealand 1990)

4.4 Other Non-Structural Provisions

4.4.1 *Sub-floor Ventilation*

The ventilation of a dwelling’s sub-floor is poorly complied with during the history of the Standards (Clark, Jones, and Page 2005). However, even the oldest recommendation published by the State Forest Service (1924) requires a ventilation opening of at least 7100mm² per m² of dwelling, exceeding current requirements two fold.

An observation that many older dwellings are built close to or even sitting on the ground, is not a direct reflection of what was prescribed in older standards [Figure 4.13]. Historic values show that a modern dwelling can be lower than in previous standards, where the opposite is generally observed onsite.

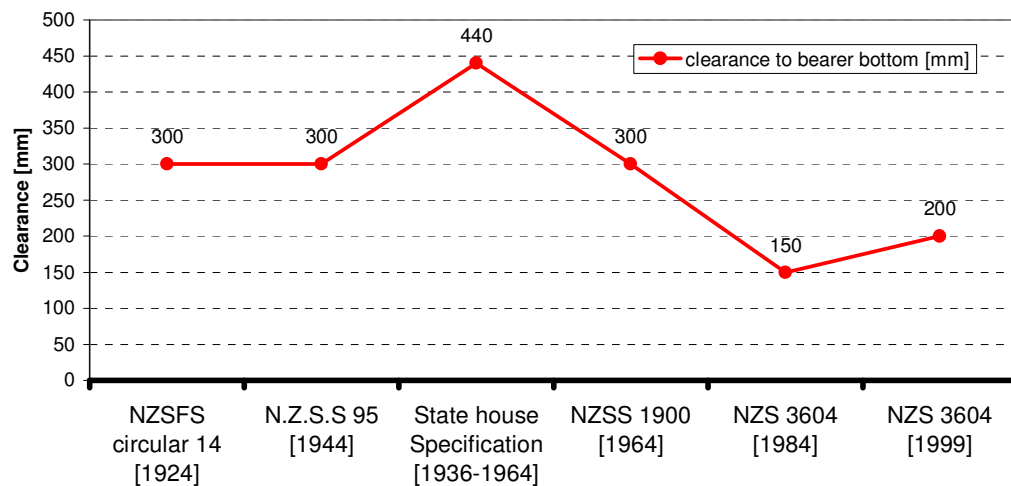


Figure 4-13 Clearance to Bearers over various Historic Standards

Timber such as Heart Puriri and Totara were common building timbers used for piles and sub-floor framing at the turn of the 20th century (ten Broeke 1979). However, timbers such as Pinus Radiata, were listed as appropriate for sub-floor applications up until NZS3604:1978. New requirements in NZS3602:2003 (Standards New Zealand), require treatment of wood based products which range from H1.2 for exterior framing up to H5 for piles (Black 2004).

4.5 The Light Timber Framed Construction History Summary

From assessing the development of construction standards, it is evident that New Zealand has been largely reactive as opposed to proactive with providing enforceable engineering based standards for foundation construction. The standards for light timber framed construction have evolved as a result of lessons learnt through earthquakes, such as Napier and Edgumbe, and in response to new construction methods and materials. From Circular 14 to NZS3604:1999, we can see the tightening of requirements and a move from a reliance on good trade practice, towards a set of concise objective standards. This formalisation of construction practice was prompted by early publications released by researchers, such as Charles Dixon whose research focussed on the 1929 Murchison earthquake. Many of Dixon's recommendations were formalised in New Zealand's first construction bylaw N.Z.S.S 95. Construction practice was not significantly altered until the launch of the State Housing Scheme in 1939, which resulted in strong seismically secure dwellings. Although, these specifications were not compulsory for the construction of private dwellings, the specifications were often adopted for private dwellings due to the popularity of the state house aesthetic. The current focus of NZS3604:1999 is to assess the individual components of a dwelling which contribute to the overall strength and performance of the seismic detailing. However, a dwelling can be designed within the parameters of NZS3604:1999, and still exhibit configuration issues which can result to poor seismic performance.

Current research often focuses on why and how foundations fail under seismic loading. Standards such as NZS3604:1999 provide a framework for foundation construction and prescribe how a foundation must be constructed. However, these Standards do not provide us with the rationale or science behind why the prescribed method will result in adequate performance under seismic loading. As evidenced in past earthquakes, timber members which are adequately fixed together into a single unit react well under seismic loading. However, difficulties can be encountered with inherent weaknesses of the timber and also the fixing interface. Therefore, it is important to understand and analyse the individual components of the sub-floor and how the configuration of a dwelling can impact on the performance and adequacy of a foundation under seismic loading.

5.1 The Cause and Effect of Configuration Issues

Configuration issues in dwellings are caused by either horizontal or vertical designs, alterations or additions that affect the symmetry and the response of a dwelling to earthquake shaking. Configuration issues have the potential to cause extensive damage or collapse, to areas of discontinuity, or areas at the extremities of the dwelling [Figure 5.1].

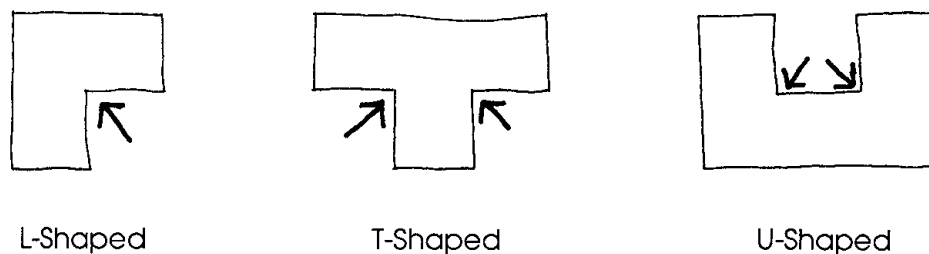


Figure 5-1 Irregular plan shapes likely to cause Configuration Issues (Source: Applied Technology Council 1989)

Dwellings with irregular shapes were seen to crush and bend significantly at these points of discontinuity in past earthquakes. The dwelling in Figure 5.2 shows significant crushing and smashing between the perpendicular wings of the dwelling (Adams et al. 1970).



Figure 5-2 Serious damage on the Interior Corner between Dissimilar parts of a Dwelling (Source BRANZ, 2003)

Configuration failure is the result of induced torsion, when the Centre of Resistance [“COR”] of the dwelling located in a different relative position from the Centre of Mass [“COM”]. In all dwellings, the mass will rotate about a COR, which is usually in the same location. If the dwelling is irregularly shaped, or the bracing is not symmetrical the COR is displaced against the COM and in an earthquake the mass will rotate about the COR. Torsion will be induced because of this discrepancy between the COR and COM under seismic loading, resulting in the extremities of the dwelling oscillating at different frequencies. This varying shaking may also cause damage at areas of discontinuity [Figure 5.3].

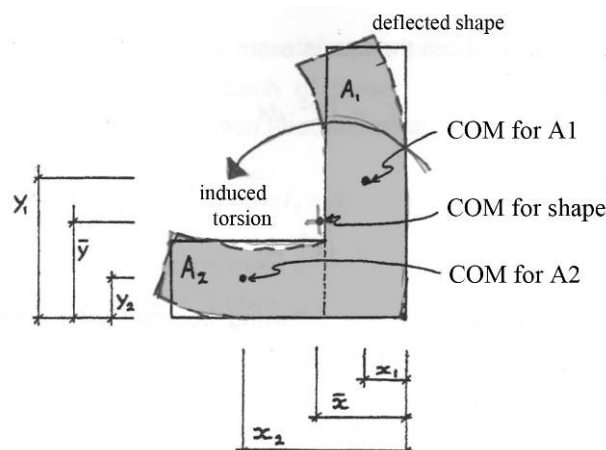


Figure 5-3 Dwelling COM rotating about the COR showing the Induced Torsional rotation and the resulting Deflected Shape

Induced torsion can also occur for dwellings elongated in plan more than 2.5 times the width (BRANZ 1984) and for dwellings with different vertical discontinuities between the COM and COR. Configuration issues cannot be easily remedied; although additional bracing at the points of weakness can reduce the effects of torsion. The best method of mitigating torsion is to consider the overall shape and resulting reaction under seismic loading of the dwelling during the initial design process.

Founding dwellings on dissimilar structural systems can cause differential response characteristics in the superstructure. Most timber dwellings have a fundamental period of response of around 0.1s to 0.6s, meaning that if one part of a dwelling is resonating at a particular frequency, the other will be required to have the same period of shaking to react as a single unit (Dowrick 1977). For this reason the transition between dissimilar structural elements can cause collapse and damage to a dwelling [Figure 5.4].



Figure 5-4 Damage to Dwellings with Differing Sub-floor systems (Source: Ruscoe 1988)

Dissimilar sub-floor structural systems can affect the period, drift and relative participation between parts of a dwelling. This causes sub-floor fixings to loosen, effectively increasing the period and possibly making the dwelling more susceptible to stronger forces (Standards Association of New Zealand 1992). The best method to mitigate damage is to avoid dissimilar sub-floor structural systems and use proper methods to transfer forces between different parts of a dwelling.

Anchors in the sub-floor area are often described as heavy elements either in the dwelling or the landscape that due to their mass, will not likely move during an earthquake. Anchors are usually concrete porches, steps, pathways or chimney bases [refer Section 6.2.3]. If anchors are integrated into the sub-floor framing of a dwelling, they can provide a significant amount of lateral resistance (Cooney and Collins 1982), however, if they are not adequately fixed, anchors can cause damage by knocking out or smashing against piles causing the dwelling to collapse to one side (Cooney and Fowkes 1981) [Figure 5.5].



Figure 5-5 Dwelling showing potential of Large Concrete Anchors: while the Dwelling slipped sideways off Piles, the Concrete Porch remains in Position (Source: BRANZ 2003)

5.1.3 Vertically Eccentric Foundations

The effects of configuration issues have been attributed to dwellings with horizontal eccentricities. However, many dwellings, especially after the 1970's have vertical eccentricities such as split levels and soft storeys that cause significant damage and collapse in an earthquake. Vertical eccentricities are similar to the horizontal eccentricities. Where the COM is vertically displaced compared with the COR, the difference causes torsion in a vertical as well as a horizontal direction.

5.1.3.1 Vertical Discontinuities by Design

The split level dwelling is vertically eccentric and causes discontinuities when transferring inertial loads from the superstructure to the ground [Figure 5.6]. This causes damage to the points of discontinuity, since no structural element exists to transfer the load to the ground (Jennings and Housner 1971).

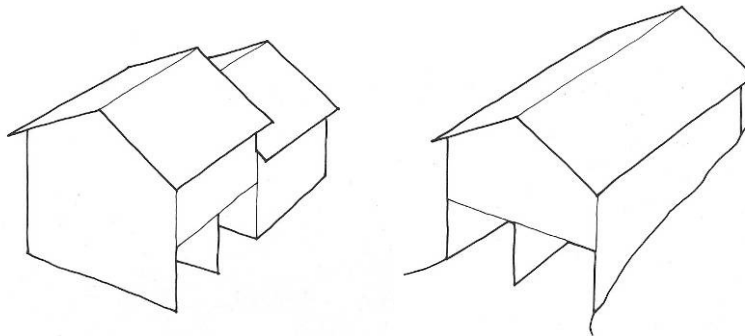


Figure 5-6 Split Level Dwelling with Side and Front access Garaging (Source: Cooney 1982)

Figure 5.7 shows dwellings that could not transfer loads from the upper level, resulting in damage to the lower section roof and walls.

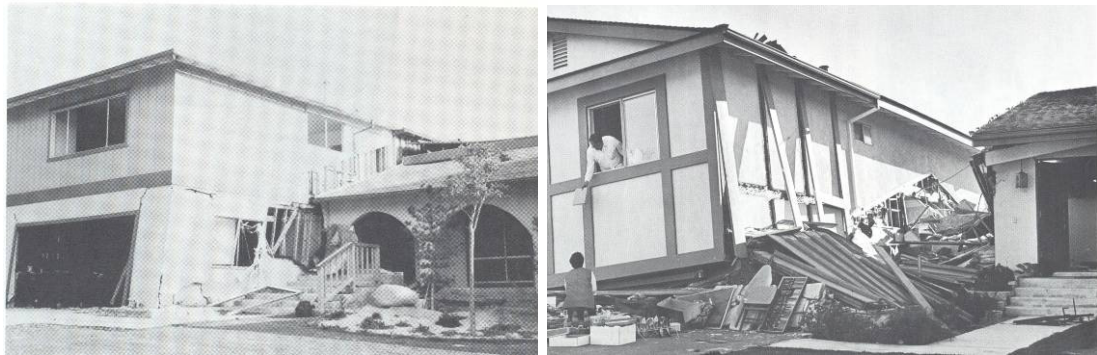


Figure 5-7 Failure of Garages with a Soft Storey Configuration (Sourced: Jennings and Housner 1971)

Another feature of the split level dwelling is the incorporated feature of internal garaging under the lower half level [Figure 5.7]. This is usually referred to as a soft storey, meaning that the lower level has less or differing bracing capacity than the upper storey and cannot transfer the induced loads from the weight of the storey above. This results in cracking or swaying or complete collapse. This failure also occurs more often if the upper storey is clad in a heavy material (Moss 1984).

5.1.3.2 *Vertical Eccentricities within Piled Dwellings*

The split level design uses differing levels usually in sloping topography. However, any dwelling that is founded on an incline with piled foundations is also at risk. Figure 5.8 shows a dwelling with short stiff piles to the top and longer more inherently flexible piles to the bottom of the incline. Under lateral loading, the stiff piles will move the least, whereas the flexible piles will move more readily. This will cause the dwelling to rotate about the stiffest elements, which will induce torsion, and will cause rotation around the middle of the uphill wall (Cooney 1979).

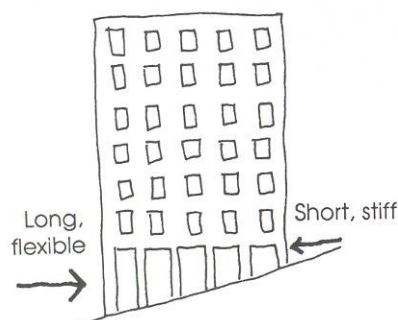


Figure 5-8 Vertical Eccentricities from Variable Pile Strength at either Ends of a Structure (Applied Technology Council 1989)

Similar configuration issues can be caused by the placement and location of braced elements in the sub-floor, which is still acceptable under the prescription of NZS3604. This can cause enough deflection to be beyond acceptable limits defined by NZS4203 (Thurston 2001).

5.2 Timber Properties, Strengths and Weaknesses

Timber has been used extensively throughout New Zealand's residential construction history, utilising properties such as damping, compressional ductility properties and relative stiffness to weight ratio. These properties make timber a valuable resource for constructing seismically durable dwellings. However, there are a number of properties in timber which can limit its strength, including the natural degradation cycle, inherent variability, and the length of seasoning or treatment required.

5.2.1 Natural Properties and Deficiencies

To analyse the natural properties of timber, it is pertinent to understand the structure of the wood cells. Wood cells are long slender hollow tubes aligned parallel to the longitudinal axis of the tree. The strength of wood is greatest when loaded parallel to the grain, however is considerably less when loaded perpendicular (Buchanan 2002). This longitudinal strength is gained from the matrix like configuration of the wood cells [Figure 5.9].

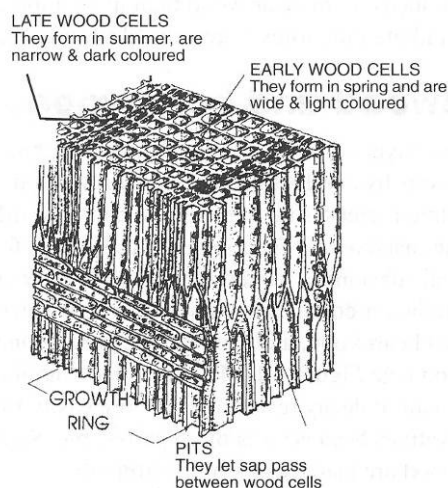


Figure 5-9 Celluloid make up of Parallel Lignin tubes in Timber (Source: Buchanan 2002)

Although the wood exhibits low strength and stiffness perpendicular to the grain, this area of flux allows a high potential for energy absorption. The lower weight, compared with other structural materials, allows a smaller inertial response, which generates excellent strength-to-weight and stiffness-to-weight ratios (Soltis, Gromala, and Tuomi 1980). Although the properties of wood are significant for structural applications, it still remains a natural product with natural flaws, knots and a rate of decay. For this reason the utilisation of timber in construction is strictly prescribed in NZS3604 and the New Zealand Building Code (Building Industry Authority 1992), stating that all “*building elements... shall have a low probability of causing loss to amenity due to undue deformation, vibratory response, degradation and other physical characteristics throughout their lives...*”. Variation can also occur between different

timber types, however this chapter focuses on Pinus Radiata, which is New Zealand's principle construction timber.

5.2.2 _____ ***Density***

The density of Pinus Radiata has a direct bearing on its strength and rate of decay, which can vary both within a tree and from tree to tree. Historically, denser native heart timbers such as Puriri or Totara have been used for piling applications specifically because they are slower to decay, than other softer timbers. It is assumed that dense wood is usually stronger, harder and stiffer than less dense wood and therefore has a greater capacity to hold fixings. However, fixing into a soft wood such as Pinus Radiata, utilises the high tension perpendicular to the grain, limiting splitting and other fixing deformities, which can be detrimental to resisting earthquake forces. (Buchanan 2002).

5.2.3 _____ ***Grading and Treatment***

Timber is graded to determine the strength of a particular timber member, which grades the end use of the specimen. NZS 3631:1988 covers the process of Visual Stress Grading and takes into consideration the amount of defects in the timber, whereas Machine Stress Grading [“MSG”] tests the load bearing capacity and modulus of elasticity. The grades, MSG 6, 8 and 10 [formally No.2, No.1 and Engineering grade framing] are used within the limits of NZS3604 for areas of specific use (Forestry Insights 2006). The treatment of timber is required for areas in the dwelling which may conceivably experience moisture damage. The common treatments in New Zealand are CCA⁷ or ACQ⁸, which, depending on the location and extent of treatment, rate from H1.2 up to H6⁹.

5.2.4 _____ ***Moisture Content and Seasoning***

Timber must be seasoned because of the porous nature of the timber fibres. Water is stored between the fibres, depending on the relative humidity of the surrounding air, which can permit the growth of mould and increase insect infestation. If unseasoned timber is integrated into a structure, the fluctuating moisture conditions can cause shrinkage which creates problems with fixings and longevity of the structure (Buchanan 1993). Shrinkage starts to occur when the moisture content falls below the Fibre Saturation Point, which is around 29% for Pinus Radiata (BRANZ 2001). The type and orientation of shrinkage is dependant on where the wood was grown in the tree and the method of cutting in the mill (Buchanan 1993) [Figure 5.10].

⁷ Copper-Chlorine-Arsenate

⁸ Amoniacal-Copper-Quaternary

⁹ The H treatment scale rates from H1 basic treatment, up to H6 which is usually for marine applications

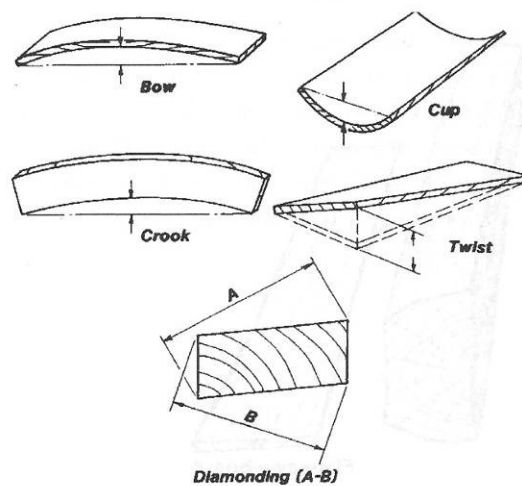


Figure 5-10 Warping and other Deformations resulting from varying Cutting Methods (Source: Buchanan 2002)

Thus, seasoning of timber prior to construction is essential to limit unnecessary deformation. An alternative to seasoning is to use kiln-dried timber, which has a predetermined moisture content and allows for quick construction without limiting any structural integrity (BRANZ 2001).

5.2.5 Timber Redundancy and Interconnected Characteristics

The performance of timber depends on the inherent characteristics of wood, however when fixed to form a structure, the redundancy and ductility of the combined members and fixings determines the overall strength of a structure (Buchanan 2002). Timber has a good reputation for being lightweight and structurally redundant, however it has little ductility in compression or tension and is likely to exhibit a brittle failure when loaded in tension or bending and shear. In order to achieve adequate ductility and the dissipation of energy through damping, structures must use ductile fixings that yield in a predetermined manner at a predictable strength (Buchanan 1984). Therefore, the seismic resistance of timber structures is a combination of ductile connectors, the timber strength and the extensive load sharing between the timber members (Webster 1984). Timber is more suited to short duration and impact loads (Buchanan 1993). The strength of timber can also be undermined when notching occurs in timber beams, with stress concentrations increasing with notch depth (Samer 1984) [Figure 5.11].

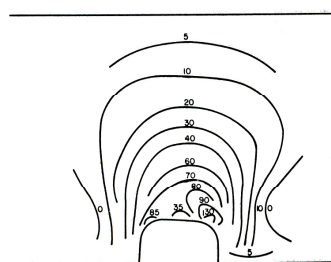


Figure 5-11 Vertical Stress contours surrounding a Notch in the underside of a Timber Specimen (Source: Samer 1984)

Overall, most structural failures during seismic activity occur at weak or incorrect connection details. Thus, to ensure a dwelling's behaviour remains predictable and capable of dissipating energy, adequate fixings are required which develop the full strength of the sawn timber through ductile yielding (Thurston 2001).

5.3 Where Nailed Fixings gain their Strength

Nailed fixing is the simplest method of connecting timber. The strength of a connection is dependant on the nail type and number of fixings, the withdrawal resistance, head restraint and angle of loading compared to the grain. Nails have distinct advantages of being inexpensive, small and provide good penetration. They exhibit ductile behaviour in bending and crushing between the wood and the fixing (Buchanan 2002) [Figure 5.12].

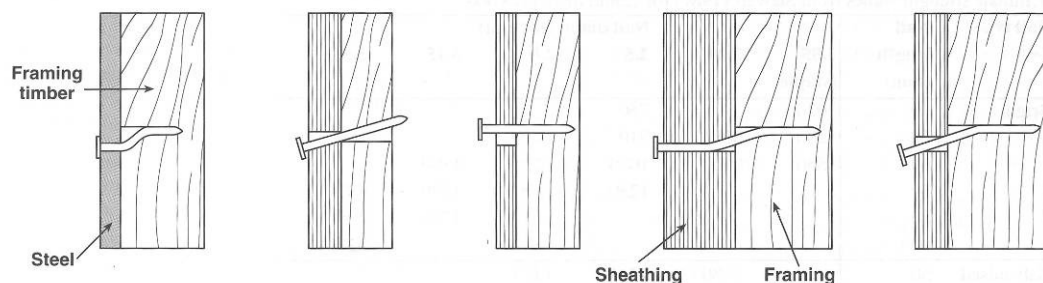


Figure 5-12 Different Failure modes of a Nail in Soft Timber with differing Cladding applications
(Source: Buchanan 2002)

5.3.1 Penetration

The penetration of a nail will determine the ultimate loading of a connection, however, the relationship is non-linear; a 10 nail diameter penetration is about 25% stronger than 4 nail diameters. The nail strength when loaded perpendicular to the grain is 60% of the strength compared to parallel loading. This ultimate loading causes nails to bend in shear and fail elastically and plastically, which results in local damage around the timber interface (Hunt 1984).

5.3.2 Withdrawal

The withdrawal resistance of nails is a product of the friction between the timber members and the fixing. Withdrawal strength is dependant on the surface texture of the nail, the moisture content of timber and load duration. Grooved nails are the best for withdrawal resistance especially in dry timber with delayed loading (Collins 1984). Timber joints with multiple nails creates a stronger interface connection, however, if a gap exists between the timber interfaces, the connection is around 10-48% weaker (Malhorta and Thomas 1984).

5.4 Where Bolted Fixings gain their Strength

Timber relies on ductile yielding connections however deviations which are common in practice, can affect structural strength compared to the requirements of the standards. Variations of fixings into wet and dry framing, variation in edge and end distances loaded parallel and perpendicular to the grain and washer and bolt hole sizes, can all affect the strength of bolted timber connections.

5.4.1 Bolt Hole Size

Although bolt size is found to have no significant effect on joint strength (Gerlich 1988), larger bolts were found to transmit more shear than a smaller diameter specimen (Fowkes and Harding 1986). Washer size only marginally affected some results, however, it was unlikely to affect the overall design loads calculated for a particular joint.

5.4.2 Parallel Loading

Bolted fixings loaded parallel to the grain show no difference between connections of 8 bolt Diameters [D] and 5D from the end, however anything less than 3D forced a shear key or plug of timber out of the face of the end grain (Fowkes and Harding 1986) [Figure 5.13: image 1]. Gerlich (1988) suggests that reducing end distance to 4D was the absolute limit for joint performance.

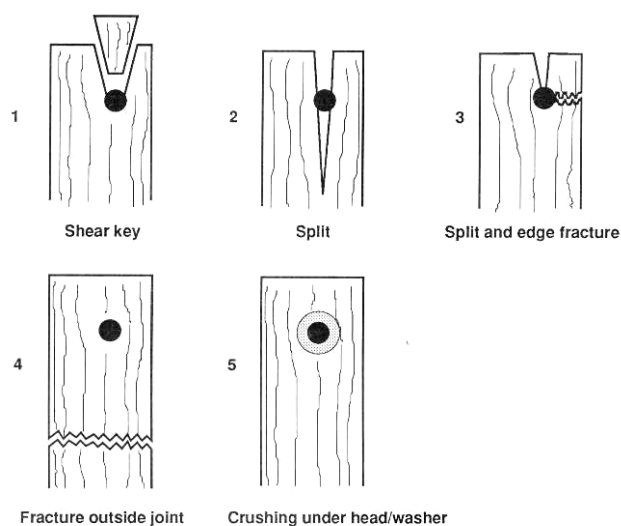


Figure 5-13 Failure modes under Loading Parallel to the Timber grain (Source: Gerlich 1988)

5.4.3 Perpendicular Loading

Loading Perpendicular to the grain reduces the strength values below prescribed standards (Gerlich 1988). Reducing edge distances increased overall displacements (Fowkes and Harding 1986) and shows splitting below the level of the horizontal line [Figure 5.14]. This shows that failure is irrespective of the bolt diameter (Gerlich 1988). Fowkes and Harding (1986) suggest

that the main mode of timber failure was the result of tension and bending. However, Spurr and Phillips (1984) suggest that all failure modes were pure tension failures, presumably due to the low tensile strength perpendicular to the grain and natural defects such as sloping grain.

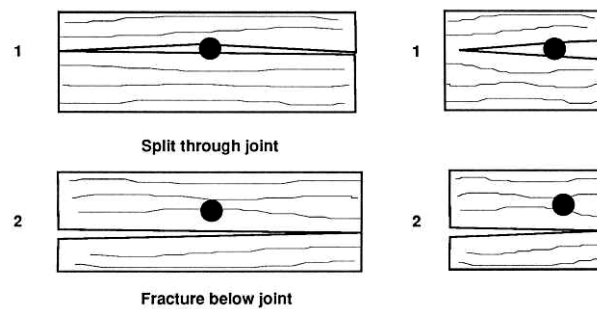


Figure 5-14 Failure modes under Loading Perpendicular to the Timber grain (Source: Gerlich 1988)

5.4.4 --- *Wet Timber*

In general, Fowkes and Harding (1986) found that the common onsite defect observed in practice combined wet timber, reduced washer size and reduced timber thicknesses, which resulted in reduced loading capacity and increased displacements. Overall, the general increase in moisture gave a decrease in overall strength and when connections were loaded parallel to the grain, specimens failed due to crushing under the washer.

5.5 The Benefit of Proprietary Fixings

5.5.1 --- *Nail Plates*

Nail plates have similar properties to multi nailing, however nail spacing and pull out failures can cause structural issues and allow little ductility (Buchanan 1984). However, nail plates or nail head restraint using plates create a significant strength increase, although larger displacements and local damage can decrease performance (Lowe and Edwards 1984). In general, the number of fixings is directly proportional to the redundancy within any structure (Moss 1984). Where connections have a total of four or fewer fasteners, the sum of the individual fastener should be assumed the total strength (Spurr and Phillips 1984).

5.5.2 --- *Rigid Connections*

Tooth-plate connectors between timber members [Figure 5.15] create a stiffer joint and contributes to more consistent behaviour, however, the ultimate load is similar to the bolted timber joint (Spurr and Phillips 1984).

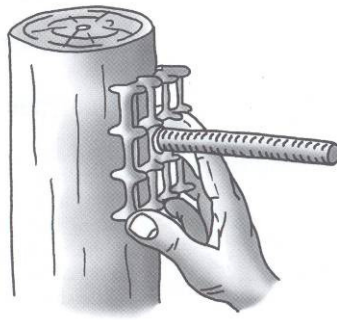


Figure 5-15 Tooth plate Connector used for Pole House Construction (Source: Jayanetti and Follett 2000)

Glued connections can also produce strong and relatively rigid joints, however exhibit no ductility. Thus the joint must remain in the elastic range to be sufficiently ductile and to avoid brittle failure (Buchanan 1984). Furthermore, Building Code regulations require a 50 year durability if used as part of a load resisting system.

5.6 The Sub-floor Condition and Maintenance Issues

The sub-floor condition has the potential to affect the overall structure due to a lack of ventilation and increase in sub-floor moisture. This can cause rot in timber, if ground clearance is insufficient and can cause degradation in fixings. These issues can force the structure to perform in an unpredictable and undesirable manner during seismic loading.

5.6.1 _____ Ventilation

The ventilation of the sub-floor area is pertinent to maintaining the strength of a foundation and maintaining a healthy dwelling. Non-ventilated enclosed sub-floor areas and high relative moisture levels can result in swelling, deterioration of surfaces, fungus growth and rotting within the timber member. This moisture may eventually cause odours and health risks associated with fungi spores and harmful bacterial growth. The source of moisture is usually from the ground, but can also originate from leaking pipes, ground water runoff or bathroom and kitchen exhaust units, which vent into the sub-floor. Any water that enters the sub-floor should be channelled out to avoid ponding. In many dwellings, ventilation should be increased to release airborne moisture (BRANZ 2005). The House Condition Survey 2005 (Clark, Jones, and Page 2005) suggests that 38% of dwellings require a 100% increase in ventilation area.

5.6.2 _____ Inward and Outward Services

Studies have shown that modern PVC sewerage systems with glued or rigid joints, or earthenware with rubber sleeves withstood sub-floor movements with little damage (Thurston 2001). Rigid grouted gully traps and toilet traps will not endure significant movement, with damage likely when movements are over 15mm (Thurston 1993).

The minimum clearance of sub-floor members to the ground has been included in the New Zealand standards of construction from the initiation of regulations, since water can seep up cladding into the structural timbers. A Damp Proof Membrane [“DPM”] in the form of Polythene sheets laid on the ground can reduce moisture build up in the sub-floor (Duncan and Vautier 1983) [Figure 5.16]. Damp Proof Course [“DPC”] should also be used between concrete and timber interfaces.



Figure 5-16 Polythene Sheet laid over Ground to aid in the Reduction of Moisture in the Sub-floor space (Source: BRANZ 2005)

Fluctuating moisture levels can cause premature corrosion of fixings and timber causing permanent deformations if the timber is loaded before drying (Duncan and Vautier 1983). Furthermore, when moisture content is high in treated timber, catalytic reactions can occur. A catalytic reaction is caused by having a small anode to large cathode area ratio, such as seen with metallic based treatments for timber and small fixings. The reaction will cause rapid degradation of some metals, which is exacerbated by the presence of water [Figure 5.17].

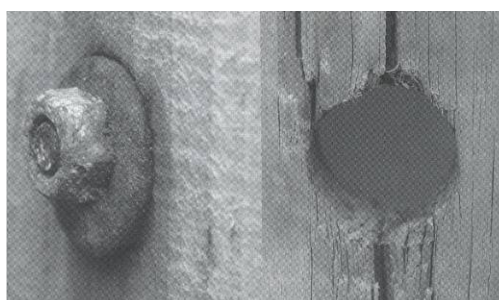


Figure 5-17 Prematurely degraded Bolted Connection resulting from Excessive Moisture and Catalytic Reactions (Source: BRANZ 2004)

Wet CCA or ACQ treated timber will corrode steel fasteners. Iron corrosion by-products may also catalyse a chemical degradation of timber which can cause excessive timber rot. Metal fasteners inserted into concrete can also cause premature rusting and corrosion due to the alkalinity of the cement, which also occurs for untreated zinc or aluminium surfaces. Sea salt and geothermal zones can also cause degradation not designed into the life of the structure (BRANZ 2004).

5.7 Summary of Typical Sub-floor Issues

Foundation failure and energy dissipation methods can be attributed to the configuration of all materials and fixings in foundations. Although timber is a natural product with inherent flaws and discrepancies, the strength-to-weight and stiffness-to-weight ratios are comparable to other structural materials. Nailed fixings into timber gain strength from withdrawal and penetration capacity and allow crushing in timber around the fixing to dissipate the induced forces. Bolted fixings similarly use the shear strength of the metal to transfer forces into surrounding timber. The fixing of timber into a structural configuration utilises the combined ductility of these fixings and interconnected nature of the structure to distribute forces through the timber framing. However, if the timber sub-floor structure is not vertically or horizontally regular, damage can occur at points of discontinuity.

All sub-floor spaces are susceptible to damage from moisture, poor ventilation and minimal clearance of timber members to the ground. These issues can exacerbate degradation of timber and metal fixings causing structural deficiencies, which contribute to inadequate foundations and subsequently result in poor performance under seismic induced loading.

The purpose of this project is to analyse and understand whether the current condition, bracing and fixings of foundations are adequate to withstand a large earthquake. Historically, New Zealand dwellings that were built to the standards prescribed in NZS3604:1999 have performed well under seismic loading. On this basis, the study assumes that the requirements of that standard, should be the starting point for determining the adequacy or otherwise of foundations. However, there may be other factors not specifically contemplated by the standards, which impact on the adequacy of a foundation, including; the specific or unique geological and geographical conditions of a site and any potential configuration issues.

6.1 Sample Location

As Wellington City is situated on a significant fault line and is densely populated, it is the ideal geographical area in which to conduct the study. The sample selection only assessed dwellings within the limits of the Wellington City Council, as defined in the District Plan (Wellington City Council 1991) [Figure 6.1]. It did not include any suburbs north of Tawa and Horokiwi or any of the Hutt Valley

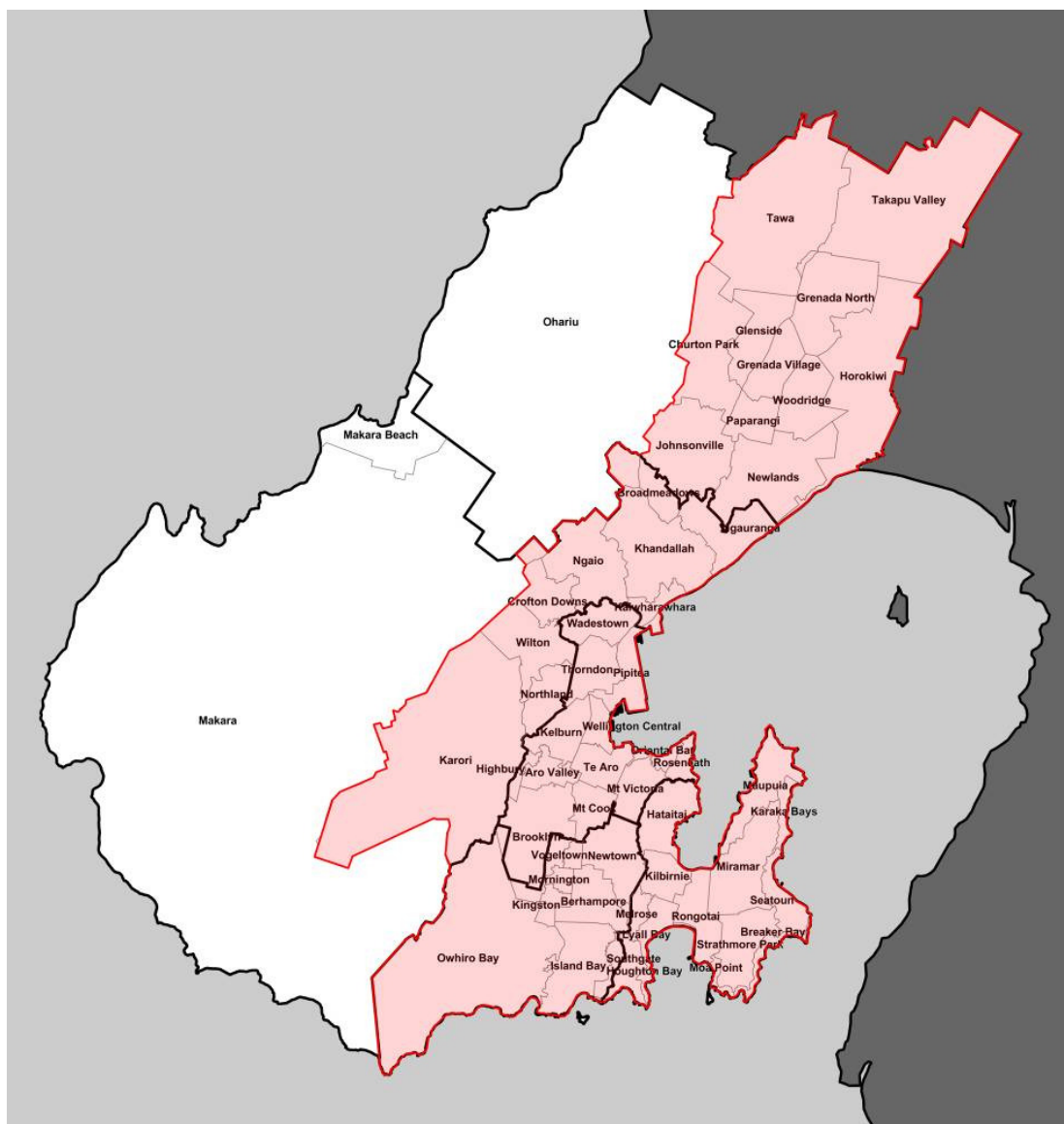


Figure 6-1 Map of Wellington limits for the Sample Survey

Wellington City exhibits many of the varying geological conditions which are likely to contribute to the overall damage to dwellings such as fault rupture, liquefaction, slope failure and increased shaking due to differing subsoil types. It is also considered to be the New Zealand city most at risk from a major earthquake.

Fault traces around the Wellington City region consist of seven distinct fault lines: The Wairarapa fault, Wellington fault, Ohariu, Shepards gulley, Pukerau, Wairau and Terawhiti faults [Figure 6.2]. Figure 6.3 shows the inscribed tracing over the suburb of Thorndon following up the highway and along Grant road. The fault rupture zone is expected to cause severe damage in this area, regardless of the foundation adequacy.

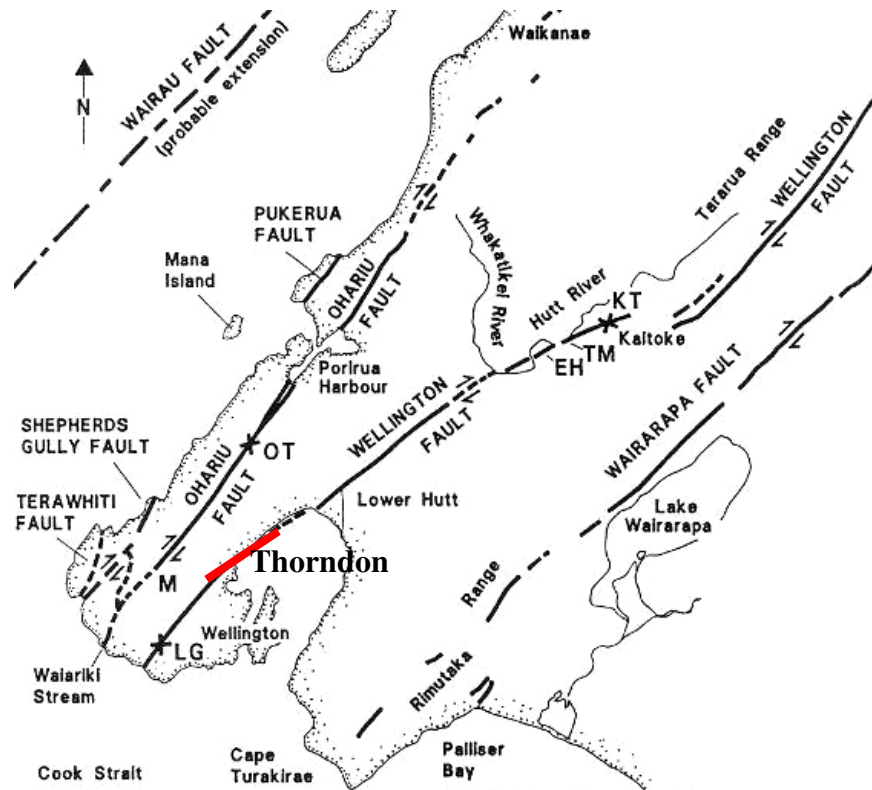


Figure 6-2 Wellington Faults (Source: Van Dissen and Berryman 1991)

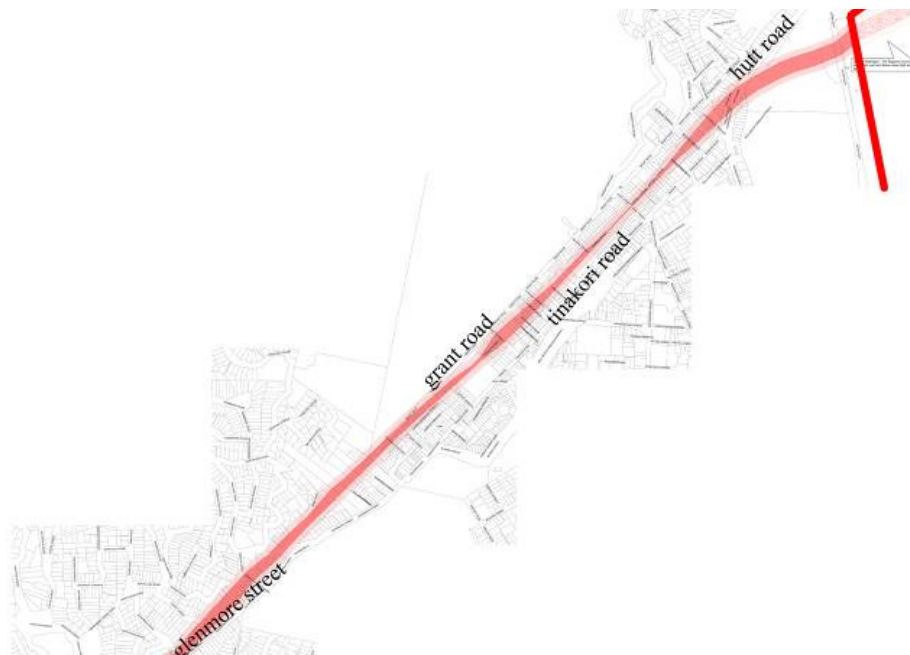


Figure 6-3 Fault Trace running through the Suburb of Thorndon in Wellington (Source: Wellington City Council Environment Division 1991)

Wellington City is built on varying soil types, made up of older tidal flats and other unconsolidated soils which may have the potential to liquefy. Hilly ground and steep land has the potential to slip, especially if the deposits on the land are stratified [Figure 6.4]. All subsequent maps are based on the soil types underlying the Wellington Suburbs.

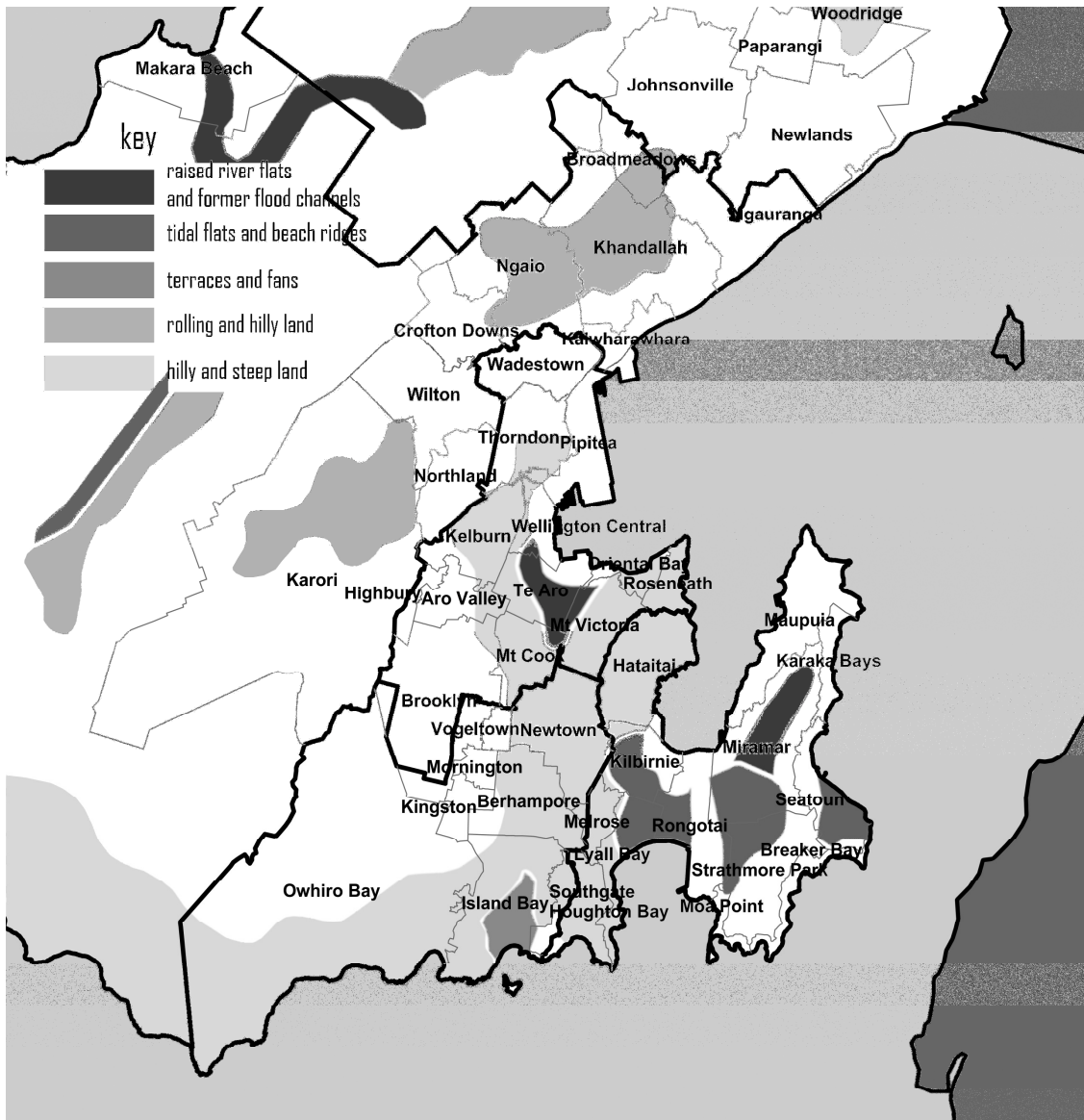


Figure 6-4 Soil areas under the Current Wellington Suburbs (Original Source: McConchie, Winchester and Willis 2000)

The Wellington District Plan has designated areas which are likely to experience greater shaking hazard, due to soil variability. This shaking is expected to range from MMXI¹⁰ in rock to MMX-XI in softer sediments throughout the Wellington Region (Davey and Shephard 1995). The areas of higher shaking [Figure 6.5], include surface rupture zones running through the Thorndon area [refer Section 6.1.1].

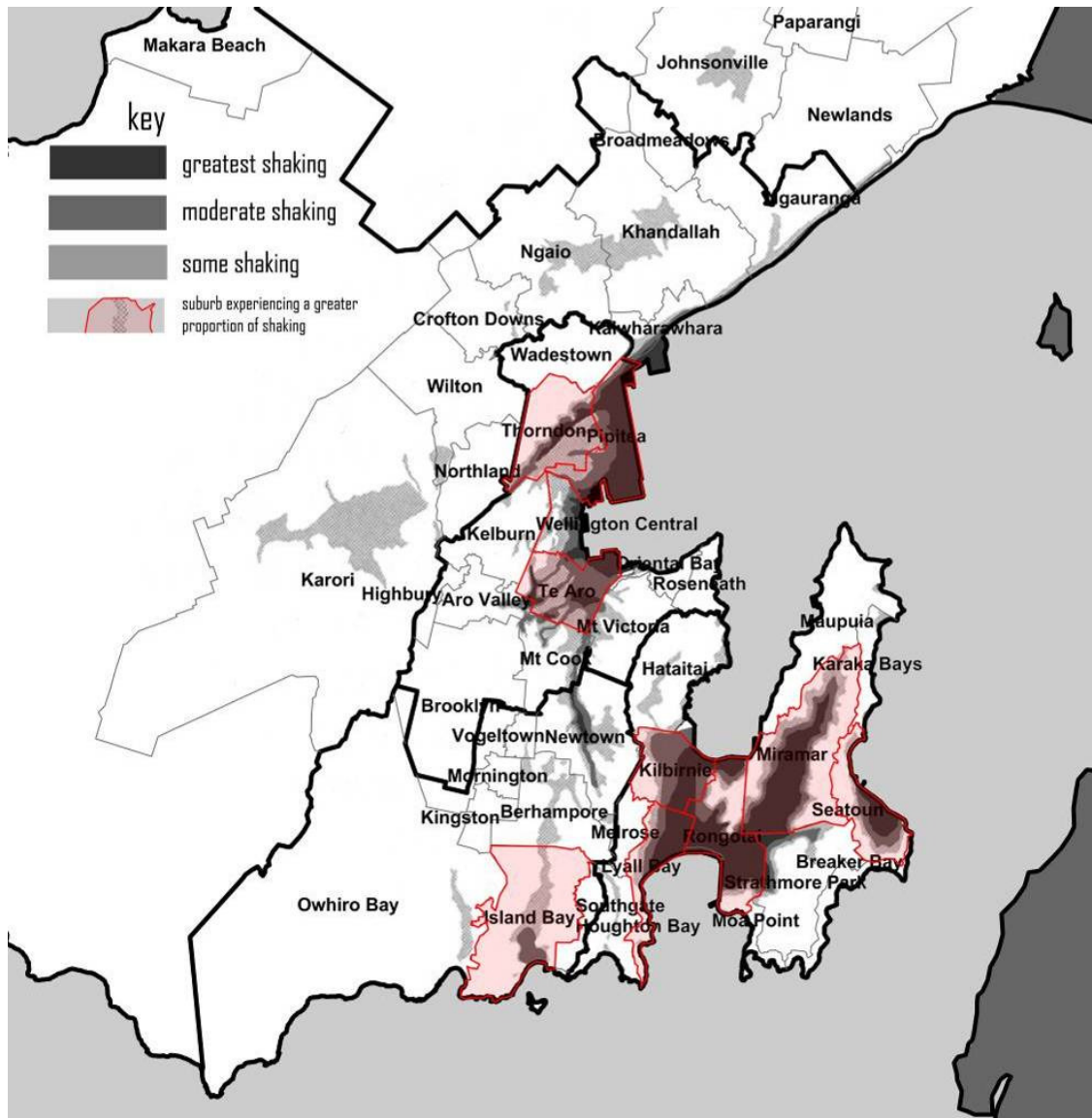


Figure 6-5 Areas of anticipated Severe Shaking within the Wellington City limits (Original Source: McConchie, Winchester and Willis 2000)

Extreme shaking will affect some suburbs more than others. Most of these areas relate to the soil types beneath the suburbs [refer Figure 6.4]. Flat areas that were underwater in previous centuries may be at higher risk from increased shaking and liquefaction.

¹⁰ For description of the anticipated destruction see Modified Mercalli scale refer **Appendix A**

The combination of sands and silts and a high water table is likely to result in a suburb having the potential to liquefy or with the potential to subside 500mm or more. Liquefaction can occur within 0-200m of any shoreline and in areas of extensive land reclamation [Figure 6.6]. Liquefaction usually results in the sinking of a foundation, due to loss of soil friction and cohesion, and can result in higher shaking damage than normal [refer Section 1.2.1].

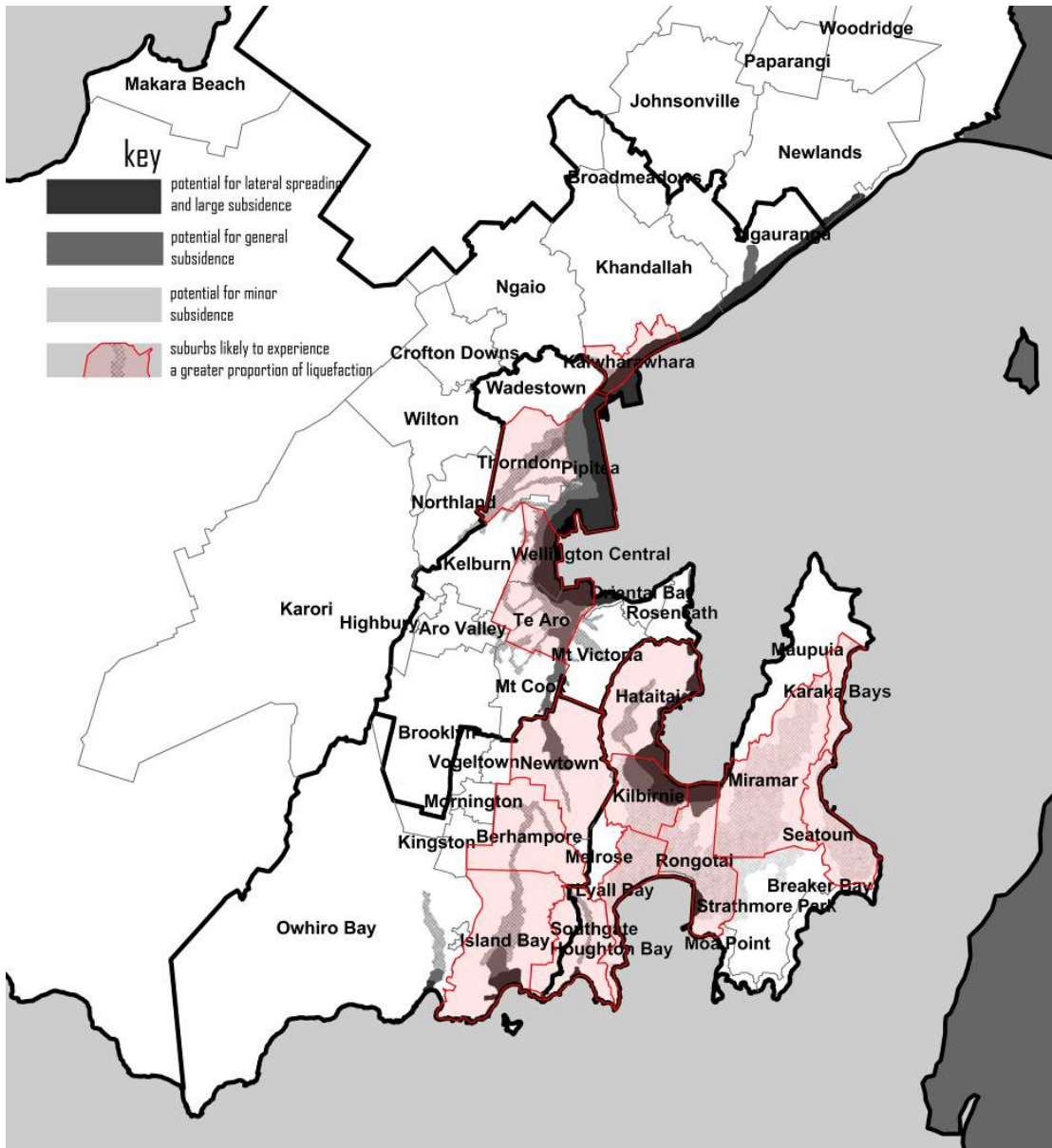


Figure 6-6 Areas of anticipated Liquefaction within the Wellington City limits (Original Source: McConchie, Winchester and Willis 2000)

Slope failure has the potential to cause building damage and casualty in an earthquake, due to the dwellings being swept from a slope, or debris landsliding over a dwelling. In both cases no remedial measures will limit this risk of dwelling damage, unless specifically engineered to resist such forces. Figure 6.7 shows areas that have a higher potential to landslide. However, slope failure is not strictly relevant for large proportions of the suburbs and usually only affects steeper unbuilt parts of the suburbs.

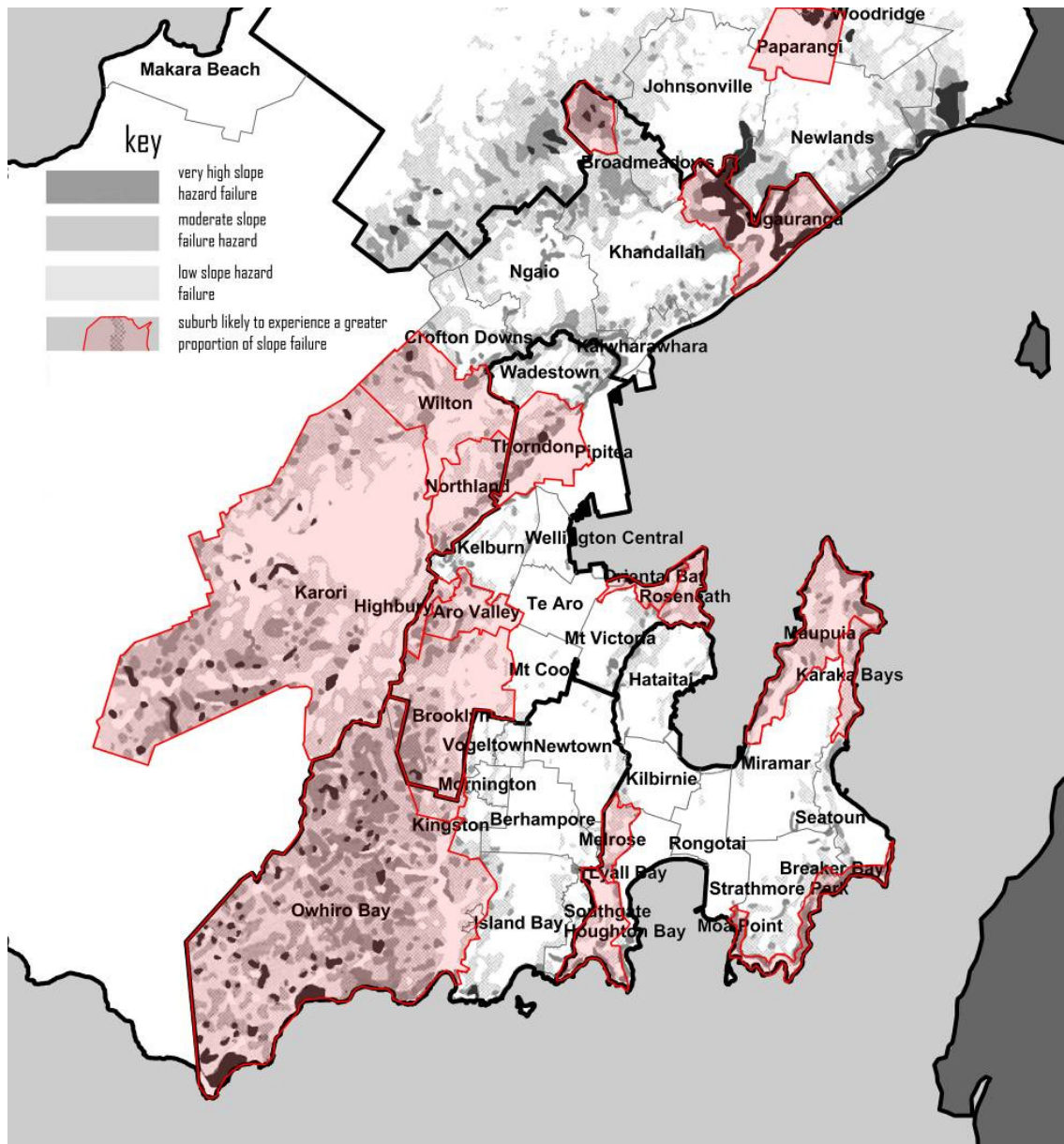


Figure 6-7 Areas of anticipated Slope Failure within the Wellington City limits (Original Source: McConchie, Winchester and Willis 2000)

Wellington's topography is diverse and an observation of the sample topography shows that 46% of dwellings are founded in gentle topography while only 20% are sited in extreme topography over a gradient of 1:3 [Figure 6.8].

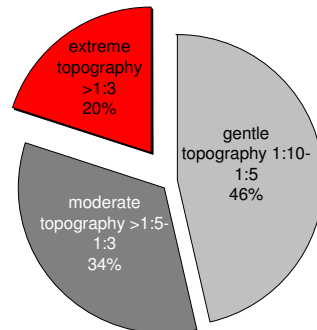


Figure 6-8 Percentage of Sample in differing Topographical situations

From the 1950s there has been a constant increase in infill land for dwelling construction and development [Figure 6.9]. Another trend showed that a constant number of dwellings have been built within 500m of the shoreline with small increases seen around the 1920's and 1990's [Figure 6.10]. The proximity to the shoreline will have an effect on fixings in current standards, which require higher fastener protection to limit rapid sub-floor fixing degradation (Standards New Zealand 1999).

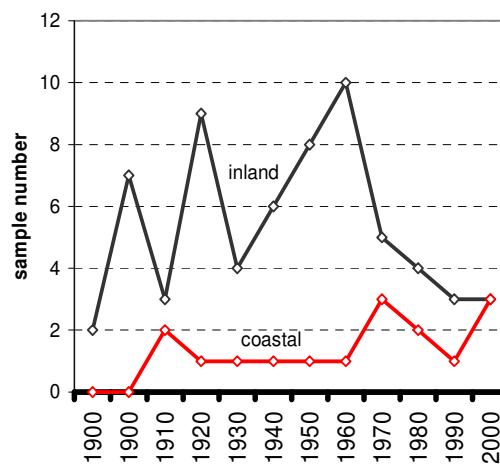
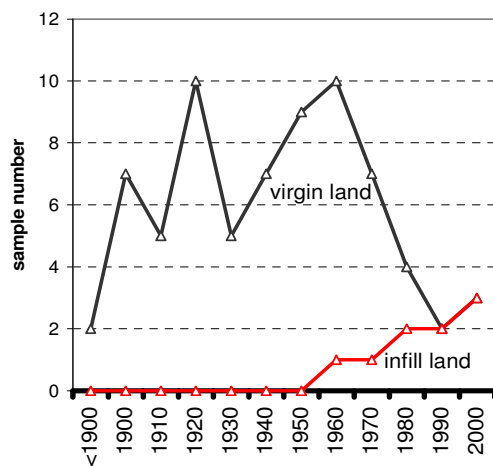


Figure 6-9 Trend of Dwellings constructed on Virgin or Infill Property

Figure 6-10 Trend of Dwellings built Inland or within 500m of the Shoreline

6.2 Sample Size and Selection

A sample of 100 dwellings was considered to be the maximum sample workload for the given scope of the project. The sample size in each decade is proportional to the number of dwellings built in that decade. This was required so the sample does not disproportionately favour one certain era of dwelling over another. The fluctuating building growth in each decade portrays eras of prosperity and also hardship, illustrating that a prosperous nation builds more dwellings, whereas a nation in recession tends to focus only on absolute necessities.

The statistical information regarding the number of dwellings from each decade up to the year 2000 was provided by the GNS database, which has been used for previous earthquake studies. Information regarding dwelling construction after 2000, was provided by Statistics New Zealand and was extrapolated into the GNS data set. The actual dwelling list, selection and randomisation was conducted by the Wellington City Council [“WCC”], using the rates database information (Wellington City Council 2006c). The Certificate of Title of the dwelling was sought from Land Information New Zealand and an address was matched with a name listed in the public telephone directory. The owners were sent a letter requesting permission to inspect their sub-floor [refer Appendix C1], which was followed by a telephone call one week later to arrange a time to make an onsite inspection.

Overall, a total of 115 people were contacted, with 80 people providing access to their foundations. The number of unresponsive or unwilling occupants was just over 30%, which was attributable mostly to landlords. Overall, rented properties made up 14% of the sample proportion, compared with the number of owner / occupied dwellings in the sample [Figure 6.11].

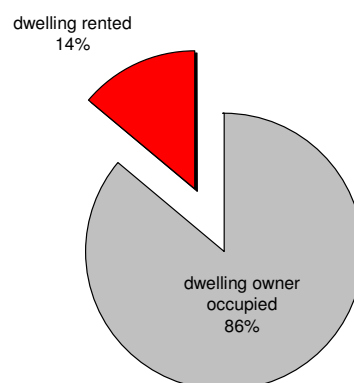


Figure 6-11 Percentage of Rented and Owner/Occupied Dwellings in the Total Sample

The rented sample of dwellings was disproportionate compared to statistics that suggest that currently around 25%-29% of dwellings are rented (Nigg 1995; McConchie 2000). This lower number of rented dwellings may simply be due to the fact that rented properties are historically less well maintained than owner/occupied dwellings. The landlord may not have wanted to disturb the tenants with issues relating to structural integrity or also may not have wanted to find largely hidden faults in the dwelling that may be expensive to remedy.

The house inspections were undertaken over a three month period during the Wellington winter. As they were all undertaken with a single inspector, methods of standardisation were not an

issue and were not required to be integrated into the survey. The survey considered 4 main areas, including the existing bracing potential, the connections and fixings between all framing members, the overall condition and an overall comparison against the current standard NZS3604:1999. An example of the onsite inspection data collection sheet can be seen in the *Onsite Inspection Form* [refer Appendix C2].

6.3 The Collection and Analysis of Bracing Adequacy

For the purposes of calculating bracing in the sub-floor, pile spacings and bearer lines, were considered to be lines of bracing, or where bracing may be applied [Figure 6.12]. To assess whether each dwelling had adequate bracing, the data collected onsite, was entered into a spreadsheet, which calculates the bracing requirements up to NZS3604:1999 (Winstones Wallboards Limited 2006).

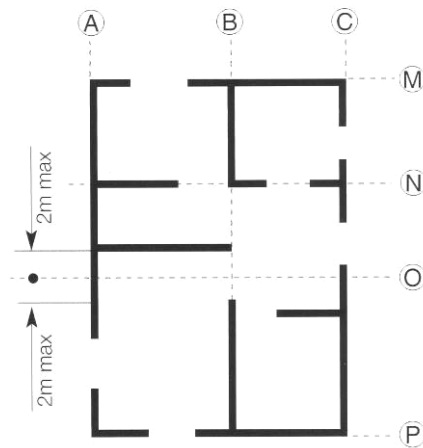


Figure 6-12 The method of Bracing Lines used for all Foundation Calculations (Source: Winstones Wallboards Limited 2006)

The spread sheet compared the dwelling weights and calculated bracing requirements with the existing bracing capacity. For each dwelling, an initial bracing capacity calculation was made and then another calculation was made with remedial bracing applied, in order to assess whether each dwelling had achieved the minimum bracing requirements. Bracing was considered in two ways; 'Designed' and 'Non-designed'. The 'Designed' bracing are elements specified in NZS3604:1999. The 'Non-designed' bracing included all structural and non-structural elements that are not specifically designed to resist lateral loads, but which could actually provide a proportion of bracing capacity.

6.3.1 Designed' Bracing

All elements in NZS3604:1999 with prescribed bracing potential were considered adequate to specifically withstand earthquakes. For concrete walled foundations, the bracing potential was based on the relative height to length ratio, which assumes that longer elements with less average height will be stronger than taller elements of similar length. A corresponding bracing

potential of between 42-300BU per metre was then obtained from NZS3604:1999 (Standards New Zealand) [Figure 6.13].

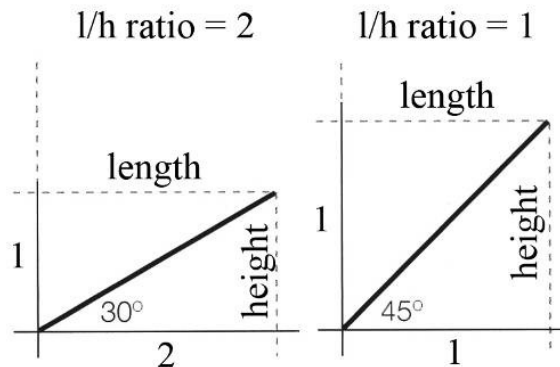


Figure 6-13 Concrete Foundation Wall and Sheet Bracing Length/Height ratio calculation

Sheet bracing potential was calculated using manufacturers tested strengths (Carter Holt Harvey 2005; James-Hardie Building Products 1994; Winstones Wallboards Limited 2006). Timber Cut-Between-Braces used in pairs between jackstudding were calculated as having strength relative to the compression strength of the timber depending on the location [Figure 6.14]. However, if only one brace was used, the strength would be considered as the withdrawal strength of the nails used to fix each end of the brace.

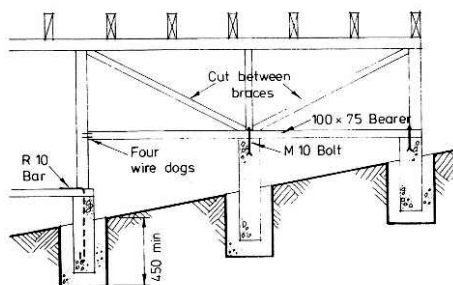


Figure 6-14 Detail of Cut Between Braces in Jackstudding (Courtesy: Standards Association of New Zealand 1984)

6.3.2

'Non-Designed' Bracing

Using plans and bracing schedules retrieved from the Wellington City Archives, piles were listed as being either Ordinary or Shallow Cantilever [Figure 6.15]. Ordinary piles, were considered to provide a small proportion of lateral resistance due to the friction interface between the soil and pile. This assumption must be valid otherwise a foundation would collapse under the slightest lateral force [refer Section 1.3.3]. Calculations of ordinary pile strength showed that a pile, depending on the volume and depth of the footing, was calculated to exhibit between 3-15BU per pile.

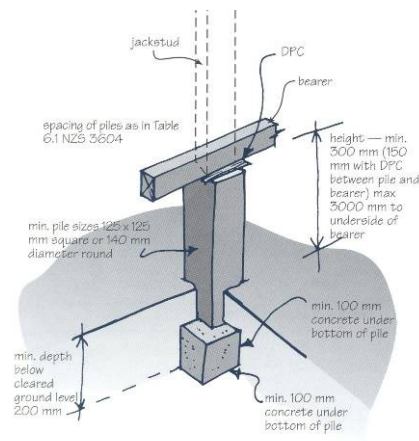


Figure 6-15 Ordinary Pile showing Minimum Depths and Footing sizes (Source: BRANZ 2000)

Other concrete volumes that can provide significant bracing potential to the sub-floor area are anchors such as porches, chimney bases and pathways [Figure 6.16]. The relative dimensions of these volumes were noted and used in bracing calculations.

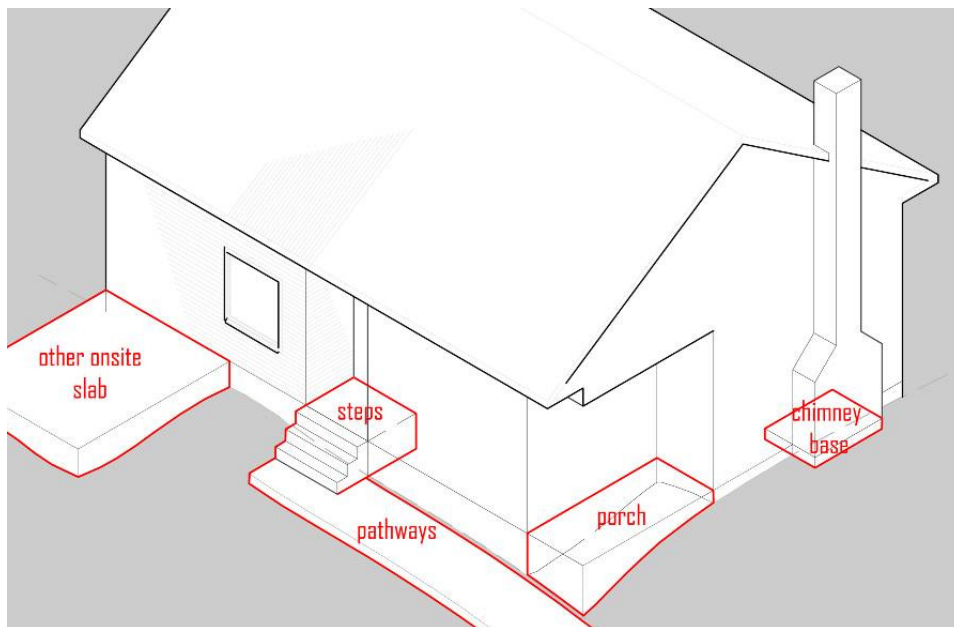


Figure 6-16 Bracing showing Different Non-designed Anchor types in a Foundation

6.4 The Onsite Analysis of the Load Path

The adequacy of connections and the load path in the sub-floor was assessed on three separate levels. The first level was a simple comparison against NZS3604:1999, to understand whether the fixing met the requirements of the standard [refer Section 10.2]. The second level assessed whether the fixing strength within a connection had enough capacity to transfer the calculated loads from the superstructure [refer Chapter 8]. The third level assessed the extent of degradation of the fixing [refer Section 9.4.1].

The overall methodology aims to understand where a specific foundation type may be at specific risk from weak fixings, and thus where additional fixing remedies should be applied. For the purposes of simplifying the load path to determine fixing adequacy, it was assumed that each pile will take an equal amount of gravity (vertical) load and lateral load from the superstructure. However, in reality it is understood that fixings under load bearing walls will be required to resist higher loads, depending on the foundation type, [Figure 6.17] [refer Sections 5.2 to 5.6].

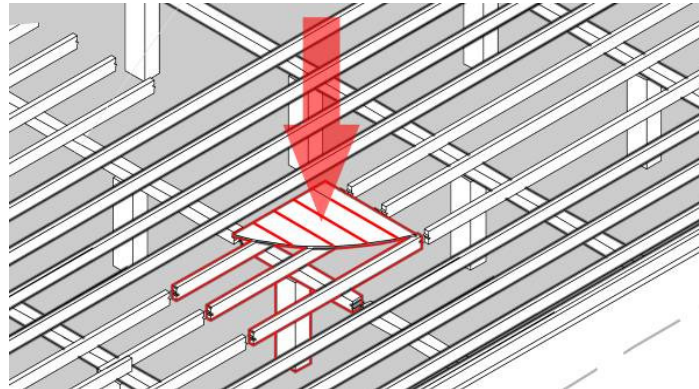


Figure 6-17 The Single Pile Methodology

The load was then assumed to be transferred through the framing members, and distributed equally along the length of the bearer [or joist depending on direction], to the bracing members and then to the ground [Figure 6.18].

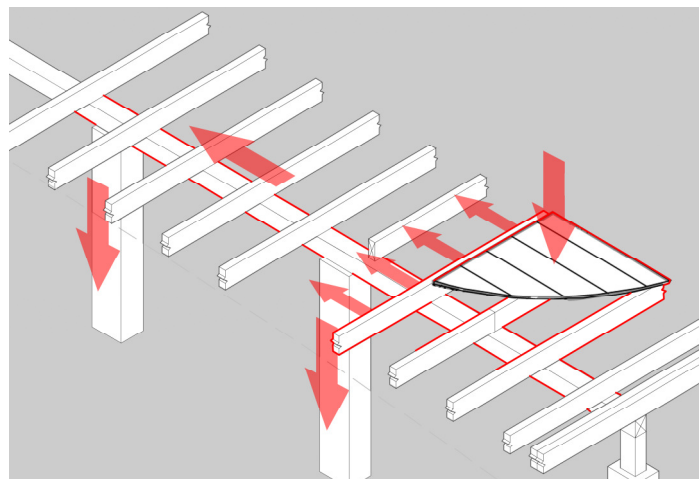


Figure 6-18 Method of Line Load Transfer through Framing to the Ground

Each connection was then assumed to take a proportion of load from the superstructure to the ground [Figure 6.19]. For dwellings with load concentrations at the perimeter of the dwelling, these loads were still anticipated to travel through the floor diaphragm and internal framing to transfer to exterior bracing elements over the whole foundation area. Using this methodology,

many of the internal piles may become structurally redundant compared with the bracing capacity of stronger bracing elements.

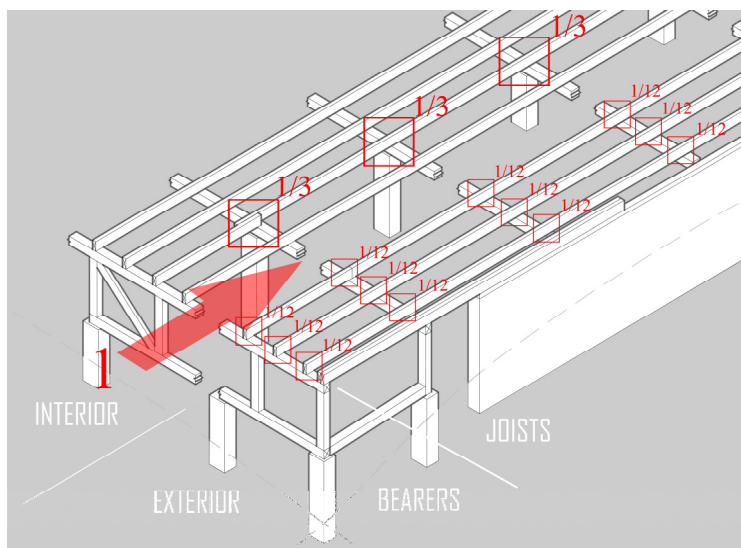


Figure 6-19 Proportion of Force relative to the Number of Connections in the Foundation

6.4.2 *Differences in Loading Direction*

In order to ensure bracing is adequate for lateral loads from any direction, both the longitudinal and transverse cases in the foundation must be considered. The Longitudinal lateral load was assumed to be in the direction of the bearer span, while the Transverse lateral loads were in the direction of the joist span [Figure 6.20]. This differs from the wind bracing analysis of superstructure, where direction is based on the longest face of a dwelling (Standards New Zealand 1999).

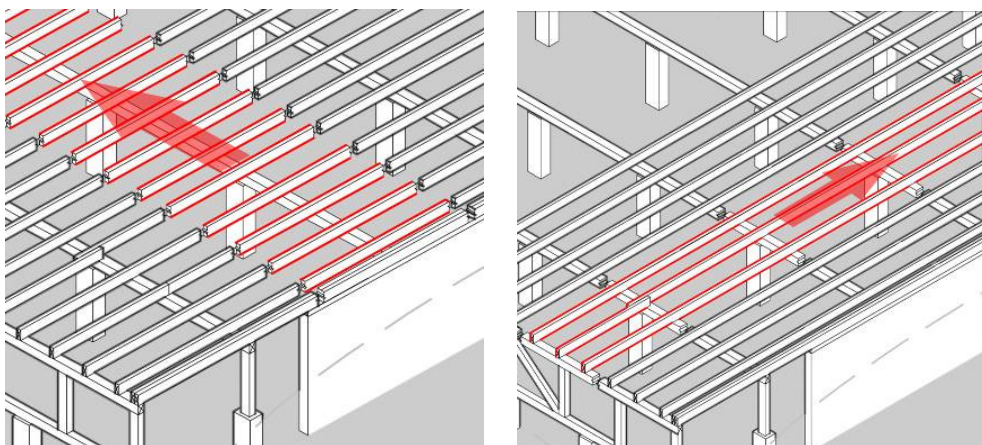


Figure 6-20 Longitudinal (left) and Transverse (right) Line Methodologies

6.4.3 *The Four Connection Locations*

The specific location of fixings was assessed to analyse where failure may occur. The weakest link methodology was used, which states that failure is most likely to occur in the weakest location. The four locations considered were the Interior and Exterior bracing lines [Figure 6.21] and the Joist and Bearer fixing locations [Figure 6.22].

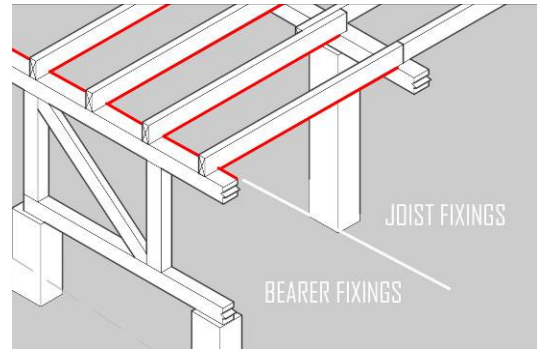
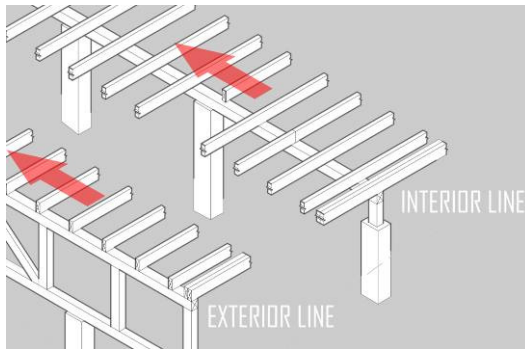


Figure 6-21 Exterior and Interior Frame lines

Figure 6-22 Joist fixings and Bearer Fixings showing the Location of each

Fixings were generally specific to a given location in the foundation, such as the ‘Interior Bearer’ fixings, which is the Ordinary Pile to Bearer connection [OP-B], and the ‘Exterior Bearer’ which may be a bolted Plate to Foundation Wall connection [P-FW]. The other connections affecting load transfer of a foundation are the interconnecting members.

6.4.4 *The ‘Interconnecting Members’*

An interconnecting member is defined as a timber member, which requires two or more lengths of timber to make up a line of structural framing [Figure 6.23]. These connections are the Bearer to Bearer and Joist to Joist connections, and can have load transfer issues when the appropriate fixing is not utilised. The load transfer methodology used assumes that a connection is considered inadequate, if the fixing cannot transfer force in tension from one end of a foundation to the other. Modern dwellings with sub-floors tend to have many of these connections over a line of framing, where as older dwellings tended to use longer lengths of timber.

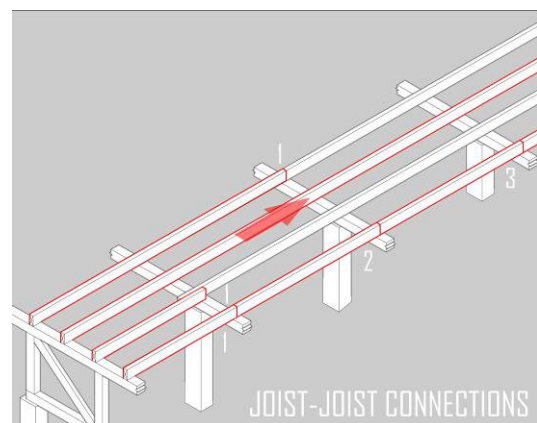
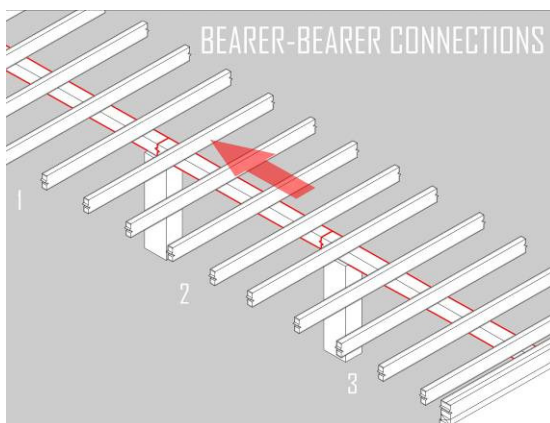


Figure 6-23 Bearer and Joist Interconnections between Members

6.4.5 *Fixings and Friction*

The different connections in a foundation have varying capacities and different methods of fixing. Some connections require nail fixing, where as other connections required to transfer

significantly larger loads, usually require an M12 bolt fixing. The characteristic fixing strengths were taken from manufacturer's literature, and were assumed to be the design strength for brief loads, rather than the ultimate strength of the fixing (Pryda New Zealand 2005; MiTek New Zealand Limited 2000). Thus, the assumption that a fixing was inadequate, may not mean that the fixing would experience brittle failure, however it assumes that the design capacity of the fixing may be exceeded and the connection may require additional fixings, over and above prescriptions in NZS3604:1999. Also calculated to contribute to the strength of each connection, was the friction between elements that are fixed together. Differing friction coefficients are observed when different surface textures interact. This can either increase or decrease the overall observed strength of a connection (Gorst and Williamson 2003). Four different scenarios were considered depending on the interface materials and the direction of loading [Figure 6.24]. Moreover, the addition of DPC was not predicted to significantly alter the friction characteristics between members, particularly when calculating load transfer.

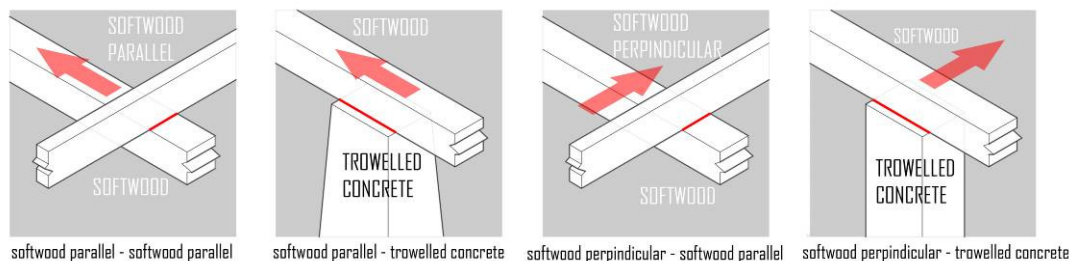


Figure 6-24 Differing Friction Material Interfaces seen in the Sample Connections

6.5 The Onsite Collection of Overall Condition Data of Dwellings

The information collected to assess the overall condition of a foundation used the weight of the dwelling, the deficiencies such as the pile defects, configuration issues and poor or missing structure to determine adequacy. Timber type and overall condition were also assessed, as well as the fixing degradation. Other historic issues such as ventilation, moisture and leaking services were assessed in order to analyse the relative condition of a foundation against other studies, most notably the New Zealand House Condition Survey 2005 produced by BRANZ (Clark, Jones, and Page 2005).

6.6 The Comparison against NZS3604:1999

The overall findings from all dwellings were compared with the prescriptions in NZS3604:1999. The three areas considered were the structural member compliance, the fixing provision compliance and the non-structural provision compliance [Figure 6.25]. The comparison of fixings and structural members from older construction standards could provide insights into whether foundations were constructed as prescribed, or when these prescriptions began to be enforced [refer Appendix B]. With these observations, it was possible to determine whether foundations were inadequate compared with the current or superseded standards.

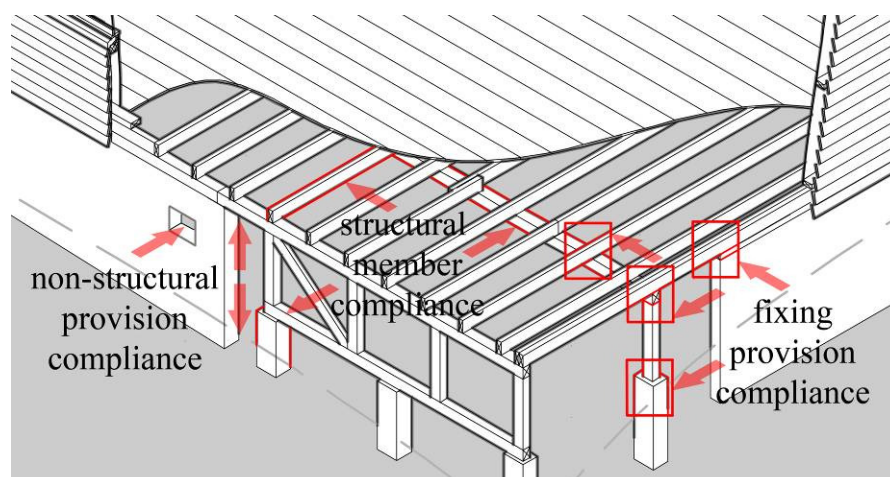


Figure 6-25 All Areas analysed in the Dwelling Comparison against NZS3604:1999

6.7 The Sample Totals and Preliminary Data

The fluctuations in dwelling construction rates over the century was provided by GNS, and showed increases in dwelling construction around 1920, 1950 and 1960, with new dwellings in the 2000 sample predicted to be of similar size after 2010 (Wellington City Council 2006b). The values in Figure 6.26, also show similar trends to the House Condition Survey 2005, however discrepancies of each age bracket possibly reflect the difference between overall New Zealand trends and trends specific to Wellington City only (Clark, Jones, and Page 2005).

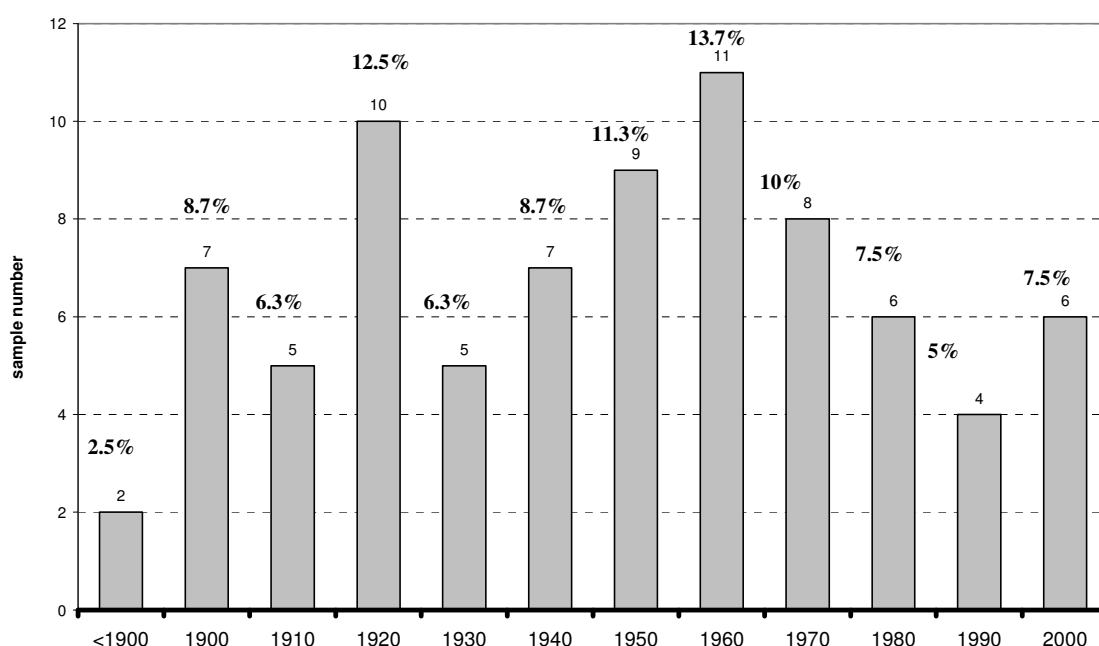


Figure 6-26 Sample Size and Proportion of different aged Dwellings over a Century of Construction

The age and total number of each type of foundation in each decade bracket is the most determinant factor, from which to present information on dwellings. The foundation type better identifies the strength of a sub-floor, as opposed to the architectural style or generalised age of a dwelling. Therefore, foundation type variables will be used to illustrate conclusions. Figure 6.27 shows the most common foundation type is the Full Piled Foundation, with 30% of the sample

dwelling, the Full Foundation Wall also makes up around 27% of the sample. Other foundations make up the remaining sample, including Slab-on-ground and engineered foundations making up around 16% of the sample.

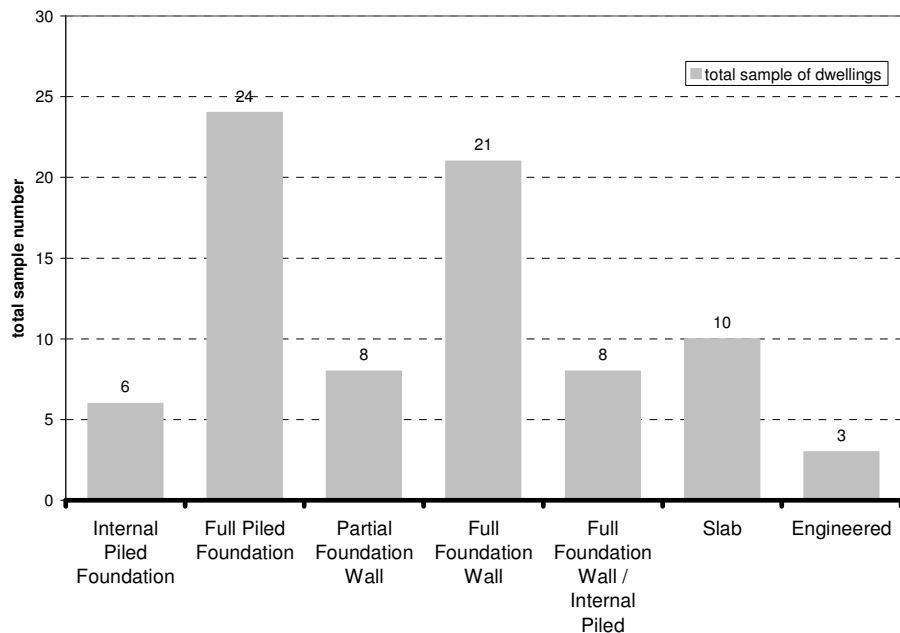


Figure 6-27 Numbers of Foundation type in the Total Sample

Comparing the total number of foundations over each age bracket and assessing what foundation type relates to each age, shows that the Full Piled Foundation and Internal Piled Foundation are the oldest, covering the majority of pre 1940's dwellings [Figure 6.28].

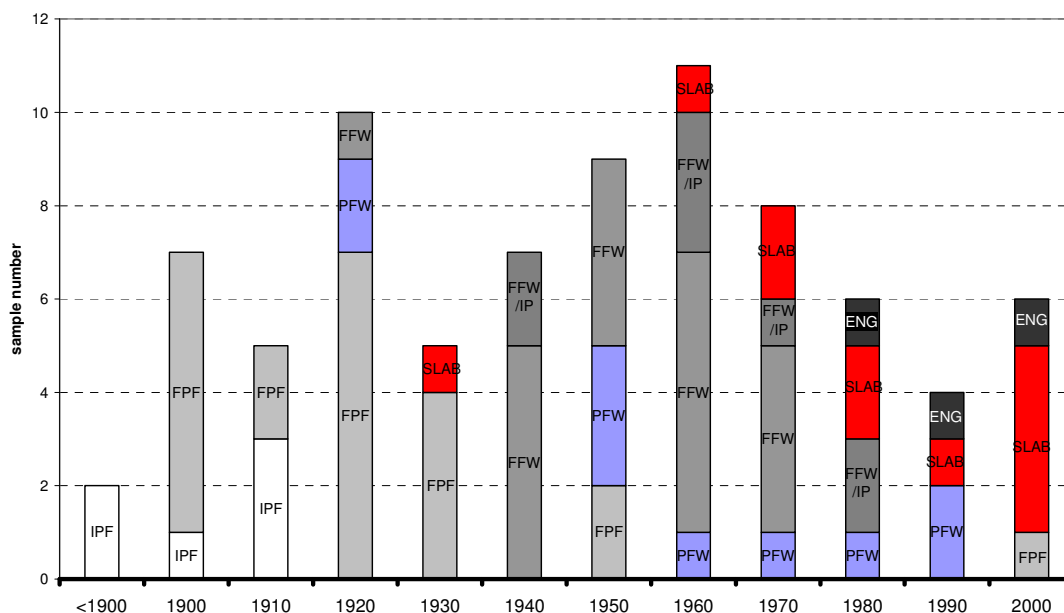


Figure 6-28 Foundation Sample spread compared with Year of Construction

After the 1940's an increase in Full and Partial Foundation Wall dwellings are common, followed by the emergence of slab foundations after the late 1960's. Engineered foundations start to feature after 1970's and include pole houses and other specific concrete founded dwellings. Slab and engineered foundations, which fall largely outside the observable scope of

NZS3604:1999, are assumed to have adequate strength, however are kept in all sample results to maintain the spread and calculations of the sample.

6.7.1 --- ***Variables of Comparison***

This study uses a number of variables to compare the statistics from dwellings in the most appropriate manner. For example, the overall condition of dwellings, will be presented in a time scale of construction, for simple comparison with other similar texts (Ref Clark, Jones, and Page 2005; Clark et al. 2000; Page, Sharman, and Bennett 1995). The connections and load path capacity will be assessed by comparing four different areas of the foundation and the corresponding fixing strength, [refer Section 6.2.2]. Bracing will be assessed against the foundation type [refer Sections 5.2 to 5.7] and the comparison against the NZS3604:1999, which will be split into corresponding groups relating to the time span of historic standards. Other variables assessed will be topography and dwelling by weight. At the end of each analysis, the overall results will be presented in an age and foundation type summary, to assess the appropriateness and extent of necessary remedial measures. The final Cost / Benefit [refer Chapter 14] will be assessed using the specific foundation types, as this will aid in the dissemination of specific information related to a particular dwelling.

6.8 Summary of the Project Methodology

To assess the adequacy of the bracing and the load path transferral, a logical process of load transfer and load division has been used. Through observations of the onsite elements, the fixings and bracing are given a physical capacity, based on manufacturers' material strength data. To understand whether these elements are adequate, the weight force of the superstructure is assumed to transfer through all connections and fixings. If the force to be transferred is more than the capacity of a single fixing, the area is assumed to be inadequate. Similarly, if the force to be transferred by bracing is more than the calculated capacity, the bracing is deemed to be inadequate. The overall condition of the sub-floor and the comparison against the current Standard NZS3604:1999 are simply statistical summaries of found observations, collated into age groups and foundation types. It is expected that the results of this project will be applicable throughout New Zealand given that Wellington exhibits many of the topographical and geographical conditions that contribute to the failure of dwellings in earthquakes. Therefore it is intended that the suggested remedies may be applicable and applied to all New Zealand dwellings of similar foundation type, provided that regional differences between the types of foundation, the materials and the construction method are taken into account.

NZS3604:1999 requires that dwellings be braced for earthquakes in proportion to the material weight of the dwelling and the anticipated live loading on the floors. Designed bracing is considered to be the sole way to efficiently and reliably transfer loads through the sub-floor. However, there are other elements in and around the foundation which contribute an appreciable amount of lateral resistance to the dwelling, such as concrete anchors and the lateral strength of ordinary piles. While such other elements have in past earthquakes assisted the performance and strength of a foundation, they are not considered to be reliable bracing mechanisms. However, this analysis considers the likely contribution of each of these non-designed bracing mechanisms in assessing the actual designed bracing performance for the purposes of determining the adequacy of the bracing based on NZS3604:1999.

7.1 Initial Bracing Calculations

The initial bracing calculations were a combination of all possible bracing elements observed onsite, which included the ‘Designed’ bracing elements, and the ‘Non-designed’ bracing elements. The bracing capacity required is calculated for each bracing line. The initial bracing shows that out of the total sample, 13% of dwellings are under bracing requirements prescribed in NZS3604:1999 [Figure 7.1]. Of this 13%, only 1 dwelling requires over 12kN, or two Braced piles per line [Figure 7.2]. It is clear from this evidence that a larger sample is necessary to validate and confirm certain trends, otherwise this could be seen as statistically insignificant and within the margins of error for the project.

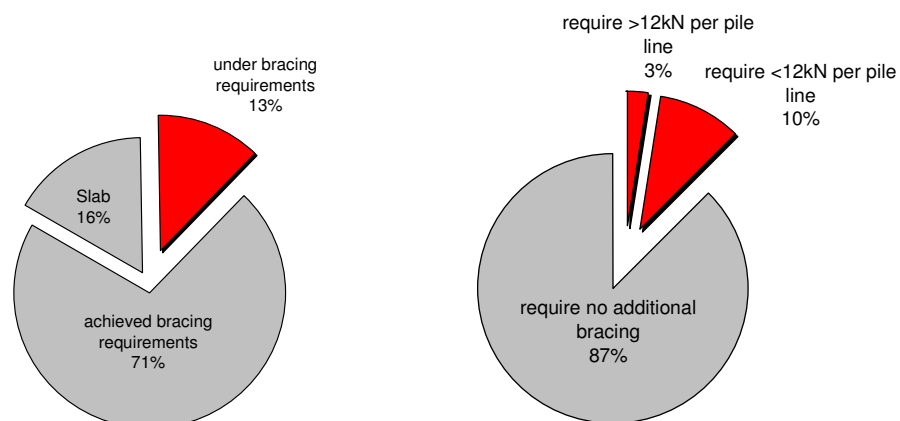


Figure 7-1 Percentage of Adequate and Inadequate Foundations including all Anchors
Figure 7-2 Percentage of Dwellings requiring Bracing under and over 12kN

From assessing the actual bracing deficiencies of the failed portion of dwellings, 9% of those that failed require more than three quarters of the total bracing prescription and 27% require over half of the bracing capacity [Figure 7.3].

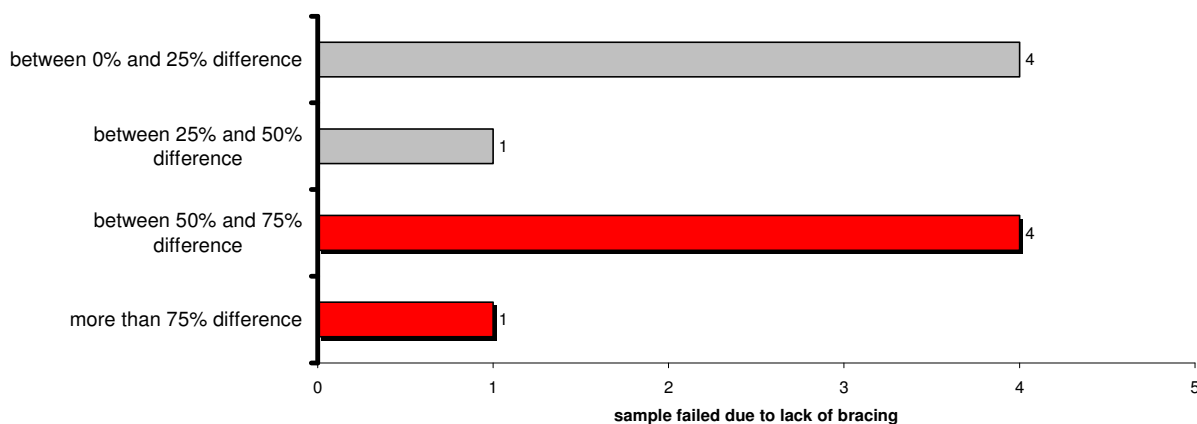


Figure 7-3 Range of Inadequate Bracing requirements of Failed Dwellings only

7.2 Bracing Reliance on Strength of Ordinary Piles

To assess the number of dwellings that rely entirely on the strength of unbraced piles, the bracing potential was calculated by taking into consideration the strength of designed bracing and the strength of ordinary piles only.

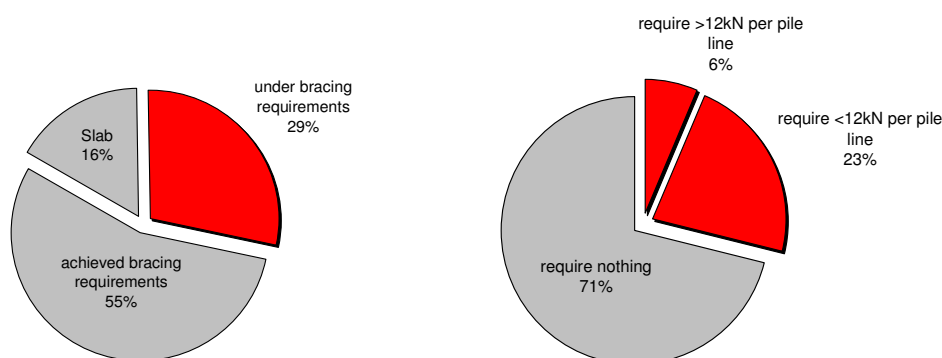


Figure 7-4 Percentage of Adequate and Inadequate Foundations Excluding all Anchors

Figure 7-5 Percentage of Dwellings requiring Bracing under and over 12kN

Overall, 29% of all dwellings are under the calculated bracing requirements [Figure 7.4]. Making up this total, 6% require at least 12kN per line to satisfy minimum restraint requirements [Figure 7.5]. Overall, the inadequate dwellings show an increase in bracing over 75% of requirements and also a large increase in dwellings requiring between 25-50% of bracing requirements [Figure 7.6].

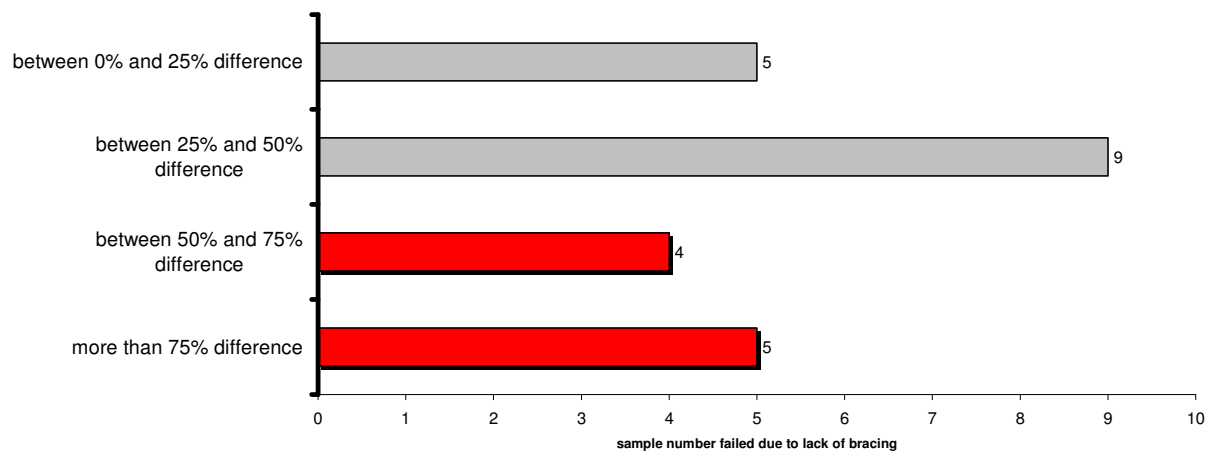


Figure 7-6 Range of Inadequate Bracing distribution Excluding all Anchors

Overall, 16% of dwellings rely to a reasonable extent on the strength and ductility between the ordinary piles and the soil. This is significant considering that this form of bracing was only included for theoretical purposes. Figure 7.7 shows the spread of pile strengths, and the relative average heights of piles per age.

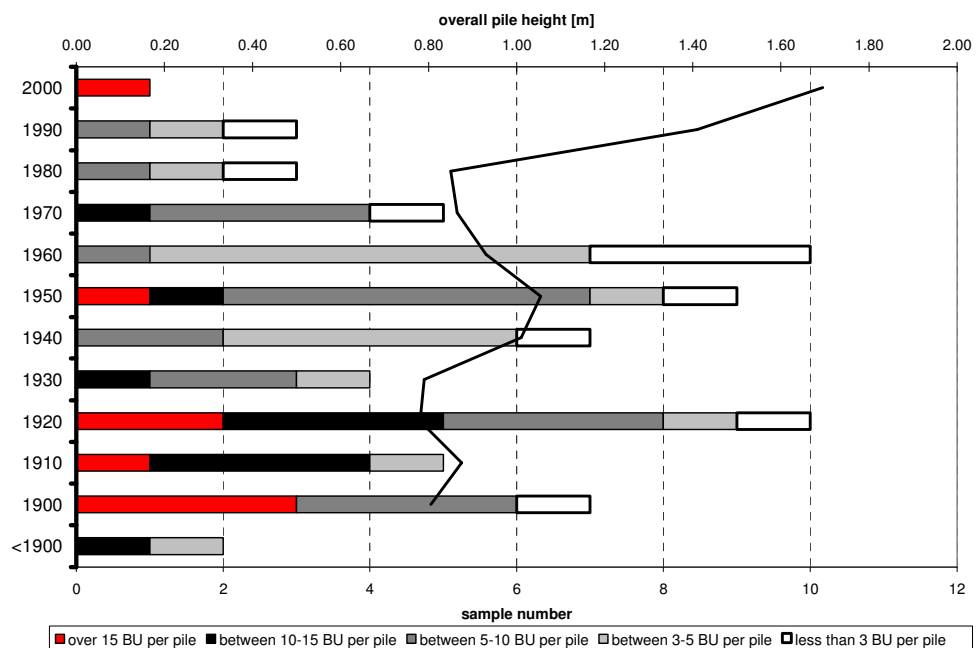


Figure 7-7 Range of Pile Strengths and Trend line of Overall Pile Heights

From Figure 7.7 it is evident that older dwellings tend to have bracing ratings for ordinary piles in the range of 10-15BU, however these values are so low that the force equates to less than 1kN. As a comparison, Figure 7.8 shows the types of piles in the sample including repiled dwellings. It is evident that dwellings repiled in the 1980's used concrete piles and tended to be deeper than the pre-existing piles, which correlates well with the bracing potential [Figure 7.7]. More modern timber repilings usually incorporate sub-floor bracing provisions, which are now required for Building Consent.

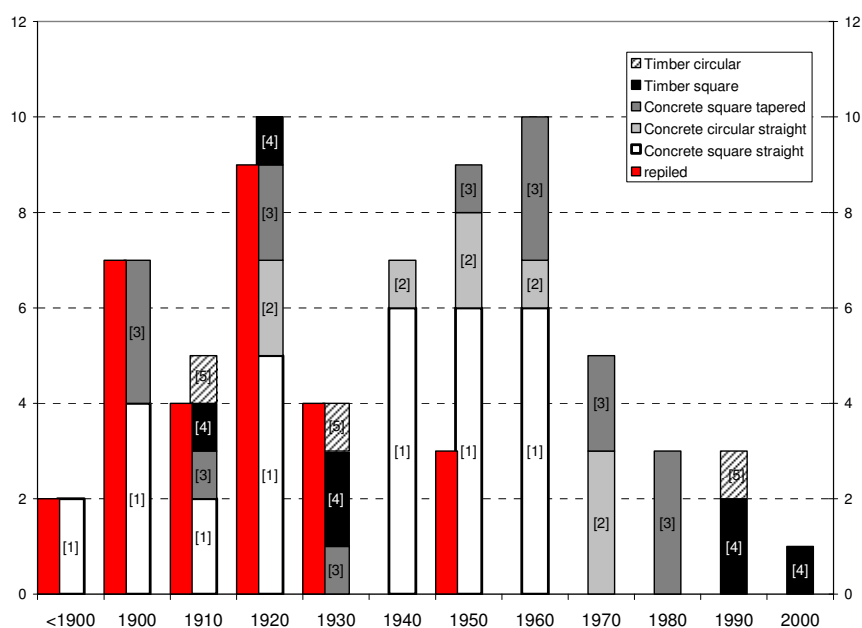


Figure 7-8 Type of Pile per Age of Dwelling including Replaced Dwellings

7.3 Bracing Reliance on Strength of Anchors

The study now focuses on the strength of designed bracing including the strength of surrounding anchors. The strength of the designed bracing was calculated by omitting the information pertaining to ordinary pile strength. Figure 7.9 shows that 24% of dwellings are under bracing requirements, which breaks down to 5% requiring over 12kN per bracing line.

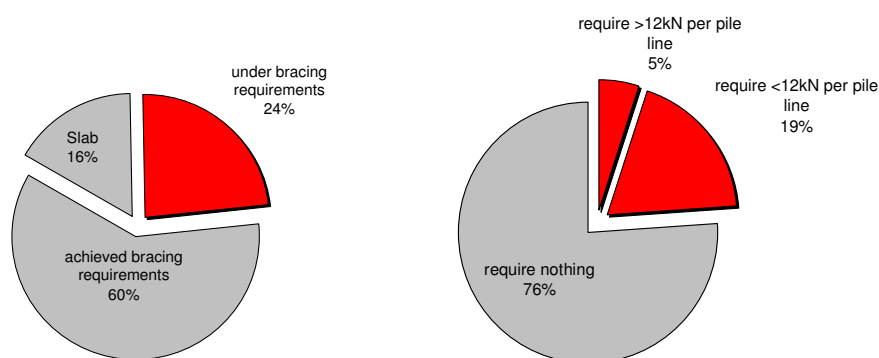


Figure 7-9 Percentage of Adequate and Inadequate Foundations Including Anchors but Excluding Ordinary Pile strength

Figure 7-10 Percentage of Dwellings requiring Bracing under and over 12kN

In comparison with the ordinary pile strength section [refer Section 7.2], less dwellings failed with the inclusion of anchors, meaning that anchors provide better support for the purposes of bracing. Figure 7.11 shows the number of dwellings requiring higher bracing is significantly less than in Figure 7.6, demonstrating that anchors provide more adequate lateral support than the strength of ordinary piles

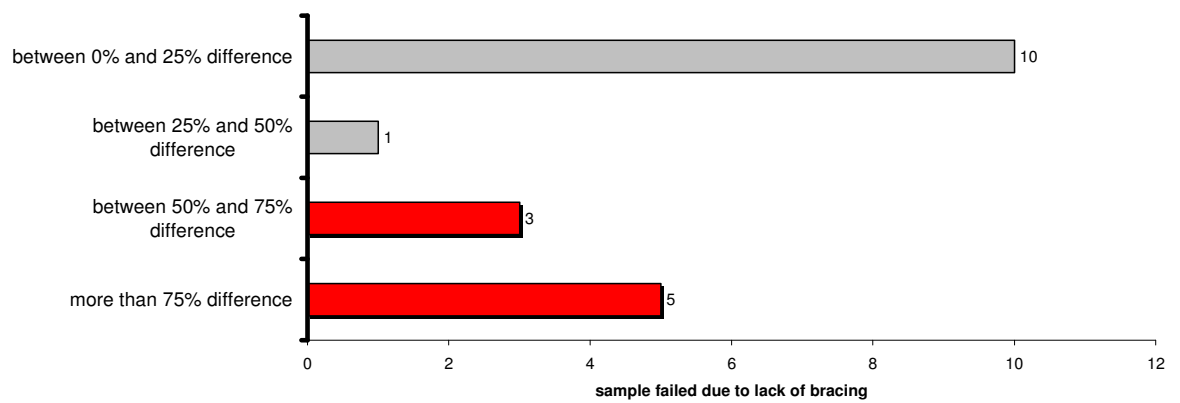


Figure 7-11 Range of Inadequate Bracing distribution Excluding Ordinary Pile strength

Concrete anchors are prevalent throughout the sample [Figure 7.12], the most common of which is the concrete slab. However, if the dwelling is founded on different sub-floor structural systems, configuration issues may cause significant damage at the junction between differing foundation systems [refer Section 5.1.1.].

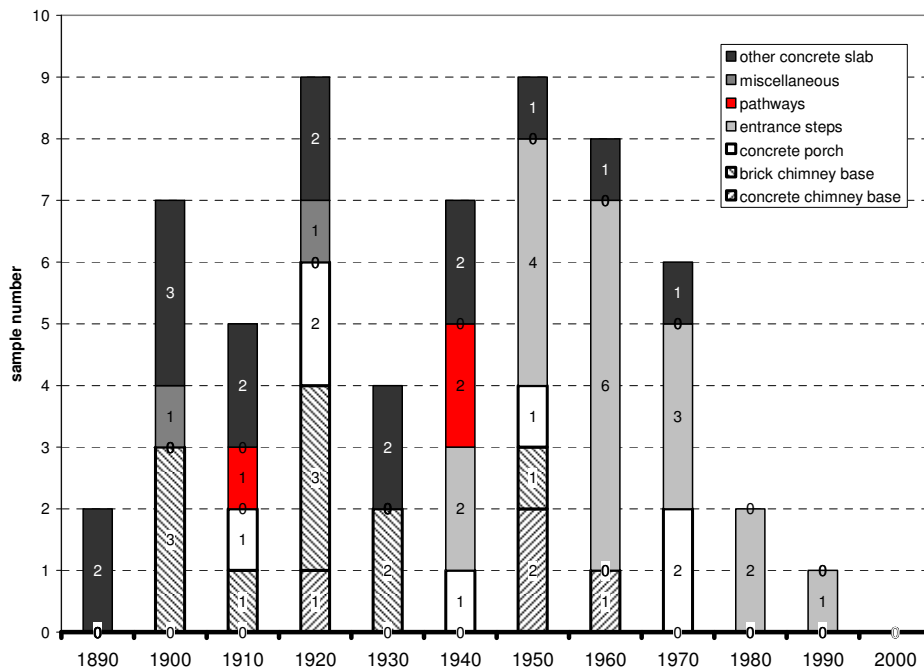


Figure 7-12 Distribution of Anchor type per Age of Dwelling

Common trends in the study illustrate that older dwellings constructed between 1900 and 1950 tend to have additions which are founded on concrete slabs, as well as concrete or brick chimney bases which provide lateral resistance. Entrance steps are common in dwellings constructed after 1940, which may be due to the popularity of the Full Foundation Wall construction method used in many State House developments.

7.4 Overall Bracing Deficiencies

The overall bracing deficiencies identified in this section of the study only include specifically designed bracing, such as concrete foundation walls and braced piles. This provides a true description of the lateral resistance of a foundation as per NZS3604, as many non-designed bracing elements may not have been considered structural elements during the initial design and construction process of a dwelling.

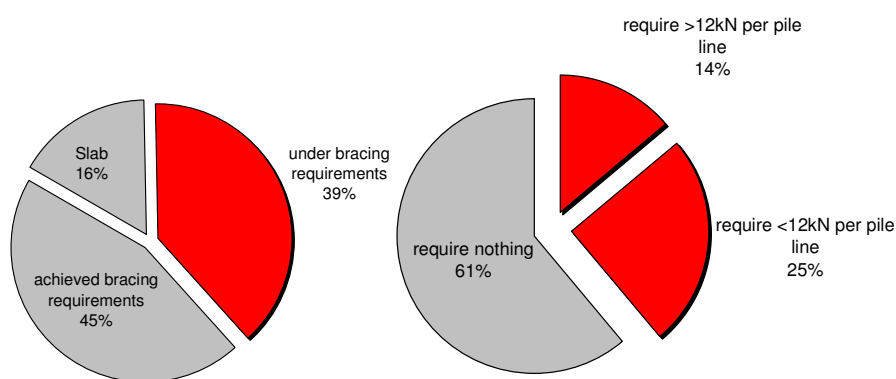


Figure 7-13 Percentage of Adequate and Inadequate Foundations Excluding all Non-Designed Bracing

Figure 7-14 Percentage of Dwellings requiring Bracing under and over 12kN

Figure 7.13 shows that 39% of dwellings are under bracing requirements given the specific parameters of each dwelling. Of that 39%, 14% required at least 12kN per pile line [Figure 7.14]. This compares favourably to the House Condition Survey 2005, which suggests that 36% of dwellings were observed to have inadequate bracing (Clark, Jones, and Page 2005, p.32). Figure 7.15, shows that 20% of the sample are at serious risk from lateral instability and required over 75% of the prescribed bracing.

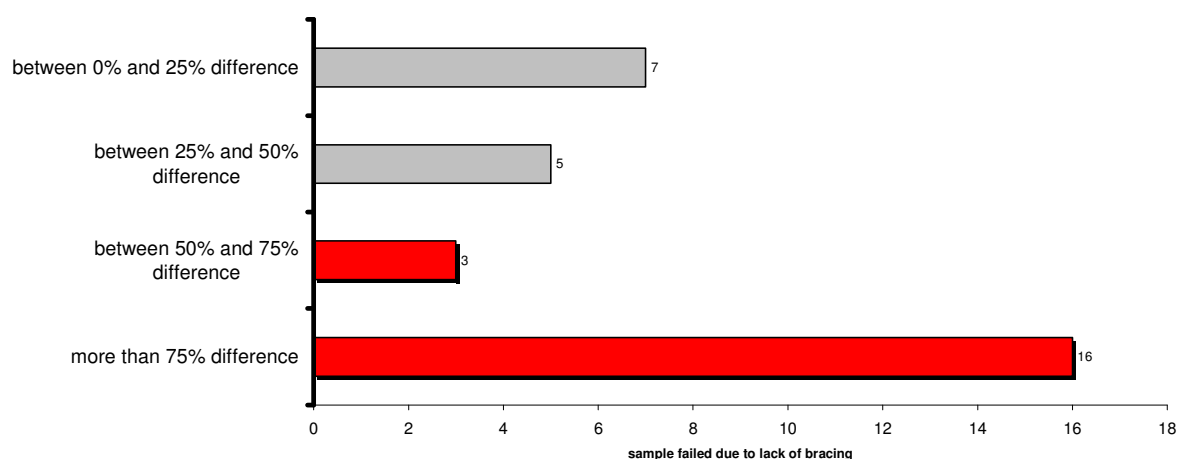


Figure 7-15 Range of Inadequate Bracing distribution Excluding all Non-Designed Bracing

The overall designed bracing in dwellings is dominated by concrete foundation walls which have a bracing capacity over 300BU per metre [Figure 7.16]. The graph shows the spread of primary bracing systems predominant in each dwelling age group. However, some of these

systems do not necessarily provide adequate bracing. In only two instances, is a concrete wall is less than 300BU/m, due to the relative height to length ratios in Partial Foundation Walls, common in the 1950's. Modern solutions used for bracing such as braced piles and anchor piles, are also seen in some older dwellings which have been repiled. The number of cantilever piles listed, reflects dwellings with significantly large footings, which are low to the ground. However, for the purposes of this study these are considered to be shallow cantilever piles since they are not specifically designed as cantilever piles.

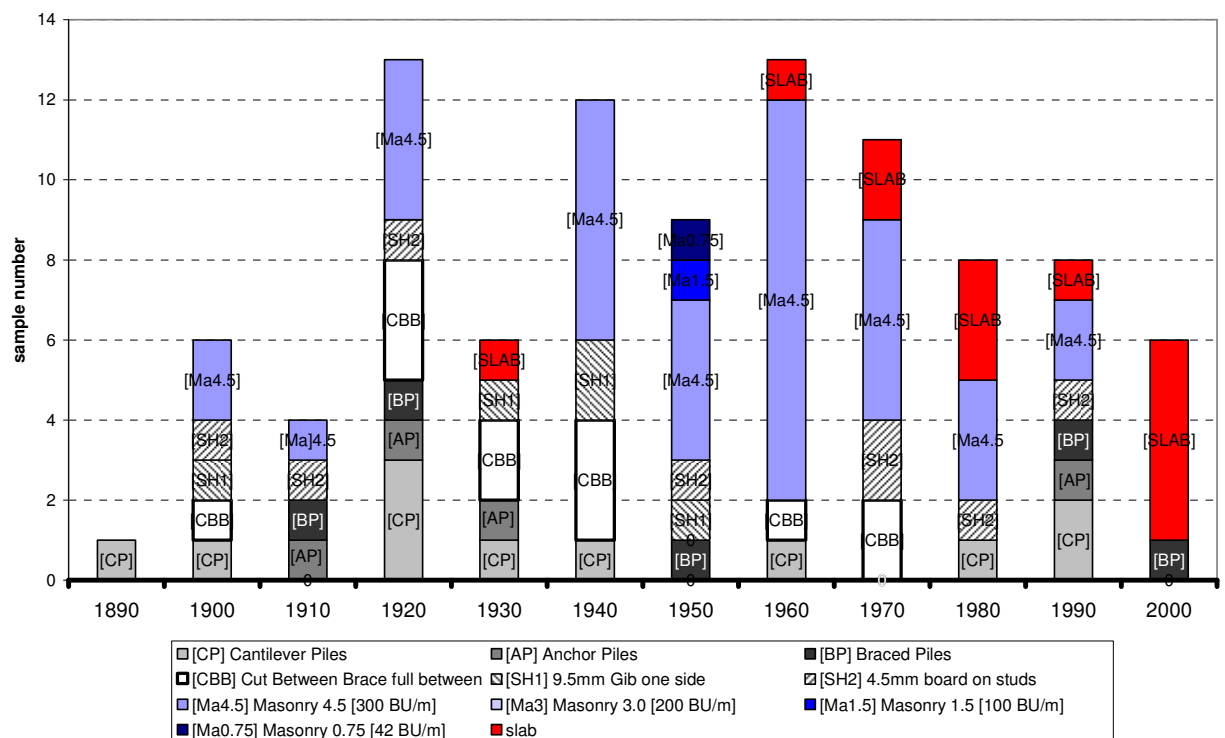


Figure 7-16 Designed Bracing type for Age of Dwelling

7.5 Bracing Totals in Comparison

The comparison of designed and non-designed bracing systems, shows that less dwellings require extensive bracing over 12kN per line, however many dwellings require between 0-12kN per bracing line. Figure 7.17 shows that some dwellings achieve moderate bracing from anchors, and less strength from ordinary piles. 20 dwellings were lacking bracing that could potentially result in extensive damage, and 11 dwellings were lacking bracing that would likely result in the overall collapse of a dwelling.

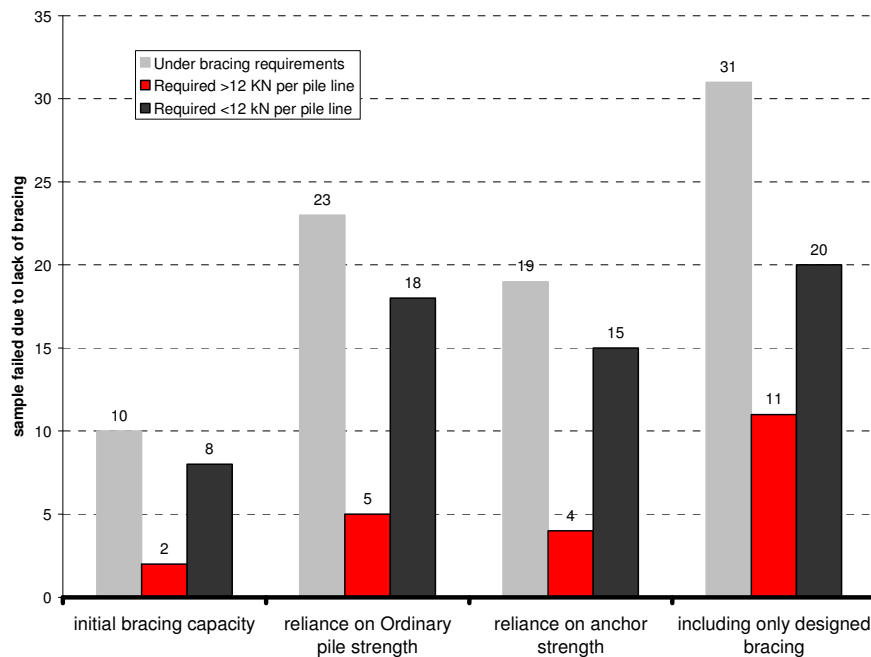


Figure 7-17 Total Sample failure for the 4 different Scenarios in Comparison

7.5.1 *The Transverse and Longitudinal Lateral Bracing*

The analysis of sub-floor bracing has so far only considered the longitudinal lateral [Along] direction, since given the length of a dwelling; this is the direction likely to have more bracing. However, the Transverse [Across] direction shows that 39% of dwellings still failed minimum bracing requirements [Figure 7.18], despite the differing direction.

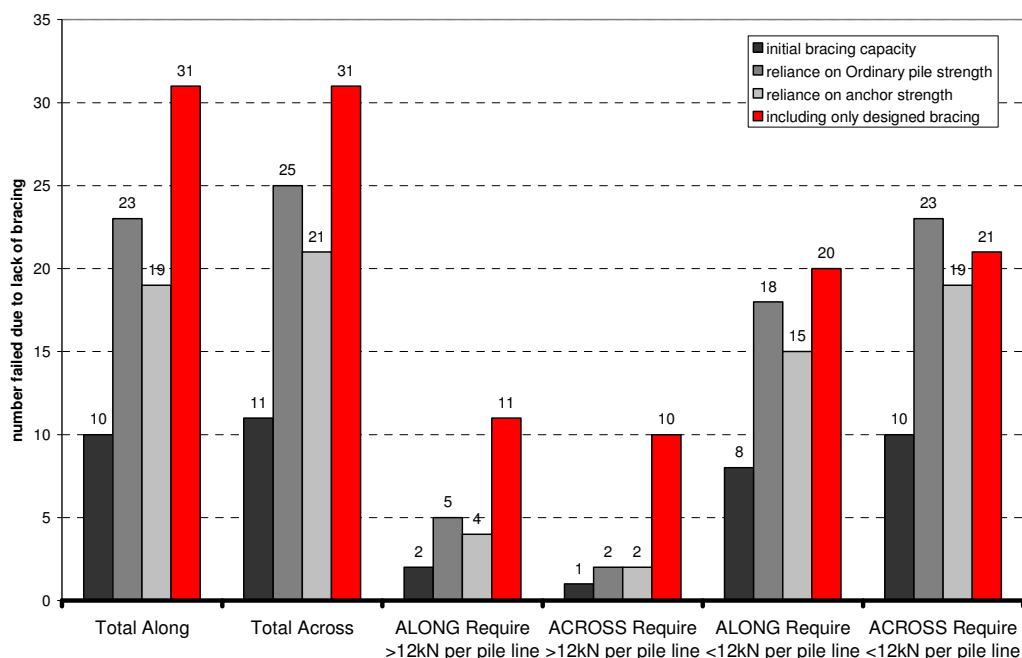


Figure 7-18 Comparison of all 4 scenarios for Along and Across directions

The transverse case in all scenarios shows a variation of 1-2%. This may be due to dwellings that were significantly squarer than more rectangular dwellings. The most significant area of difference is the dwellings requiring over 12kN per pile line, which may be higher due to the

increased number of bracing lines spanning transversely across a foundation compared with longitudinally along a foundation.

7.5.2 *Age of Dwelling under Bracing Requirements*

To further illustrate the type of dwelling likely to fail under lateral loading, Figure 7.19 compares the age of dwelling against the sample that failed relying on designed bracing only. The majority of all bracing inadequacies are in dwellings built prior to 1940, with some 1950's dwellings exhibiting limited bracing requirements. This is most likely due to the number of Partial Foundation Wall dwellings and Full Piled Foundations in these age groups [refer Section 6.7]. No dwellings from the 1940, 1970 or 1980's age brackets have inadequate bracing. This emphasises that dwellings older than 1940 tend to be more at risk than newer dwellings (State Insurance New Zealand 2007).

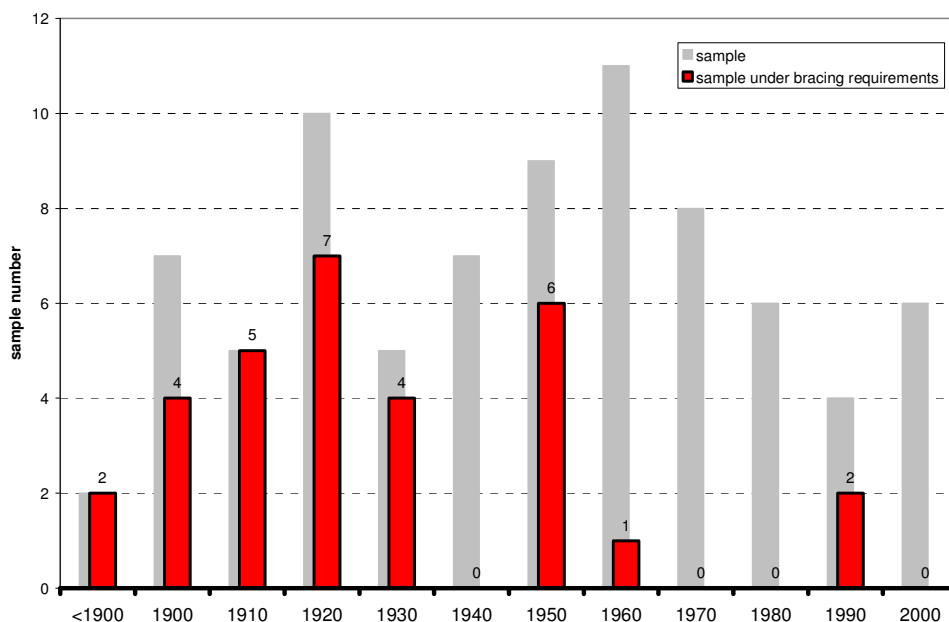


Figure 7-19 Total Sample failing including only Designed Bracing per Age of Dwelling

7.5.3 *Foundation Type under Bracing Requirements*

A comparison between the foundation types at risk and the total number of foundation types in each foundation bracket shows that the Internal Piled Foundation and the Full Piled Foundation have significant inadequacies compared with the overall sample [Figure 7.20].

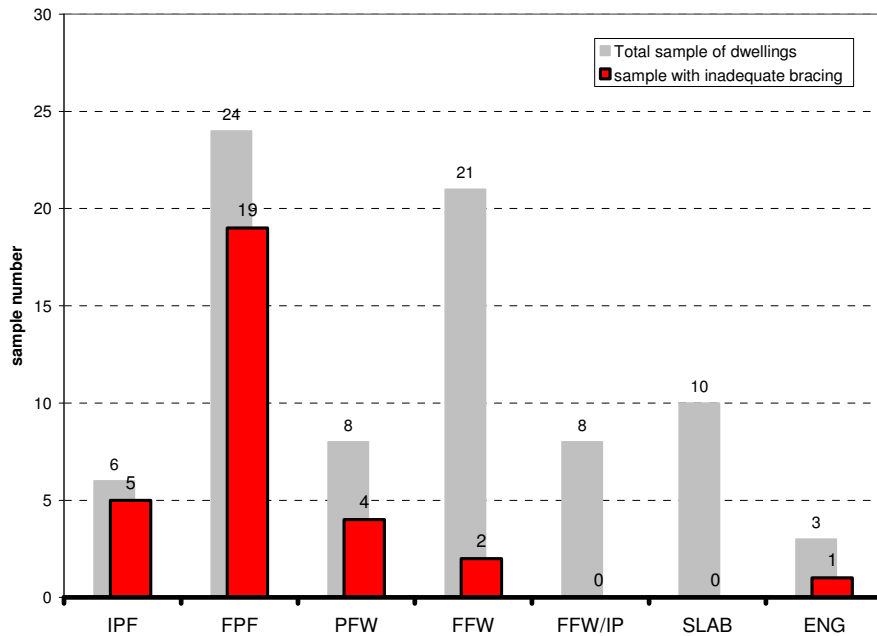


Figure 7-20 Total number of Dwellings failing Bracing Requirements per Foundation type

7.5.4 Remedial Bracing Requirements

Piled foundations are most at risk from extensive damage and collapse. Figure 7.21 shows that almost all Full Piled Foundations require more remedial bracing to fulfil minimum requirements. The Partial Foundation Wall sample shows some deficiencies with bracing, however since the concrete foundation wall may take a larger proportion of the load than what is calculated, this may only result in moderate damage as opposed to the total collapse of a dwelling.

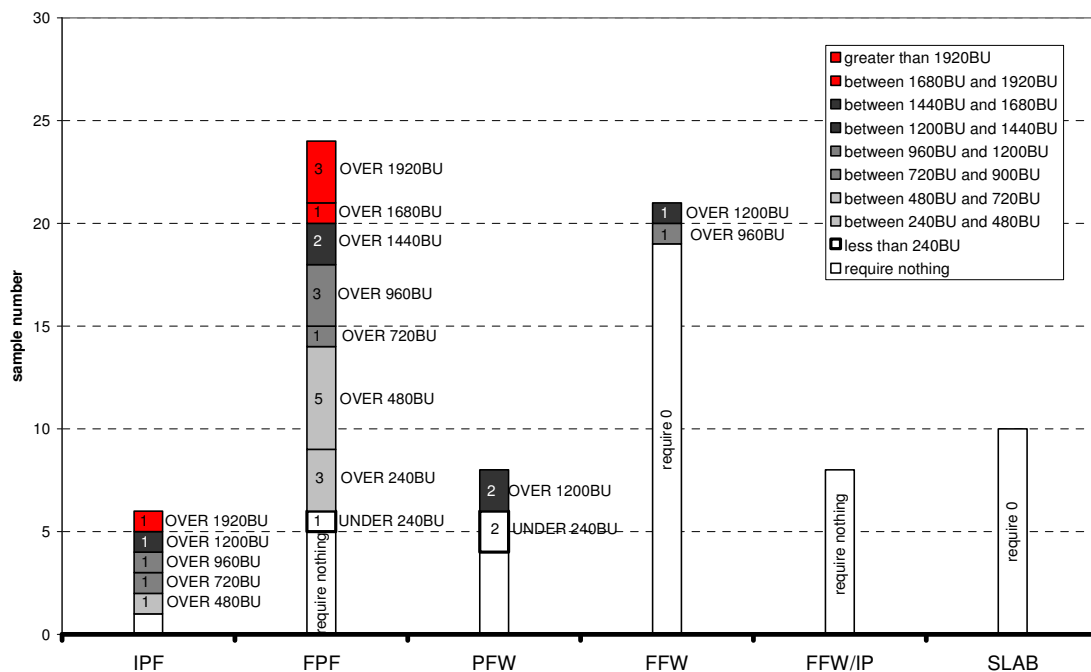


Figure 7-21 Total range of Bracing Units required per Foundation type

7.6 Summary of Bracing Deficiencies

The adequacy of bracing was assessed on four different levels. The first level considered all designed and non-designed bracing and showed that 71% of dwellings had sufficient sub-floor bracing capacity, with only 13% being under bracing requirements (with 16% considered Slab foundations). The second and third levels found that the ordinary pile strength was found to be the primary bracing mechanism for 16% of dwellings, whereas sole reliance on anchors for bracing, was seen in 11% of dwellings. Overall 39% of dwellings were under bracing requirements, when non-designed bracing was excluded from calculations. Table 7.1 shows that on average, 80% of piled dwellings had inadequate bracing with most requiring more than a 50% increase to be within minimum requirements. These values will be directly applied to calculate the extent of remedial bracing required and the overall cost of upgrading [refer Section 11.5].

Bracing	Sample Under requirements.	Under 50% bracing requirements	Over 50% bracing requirements	Sample requiring remedial Bracing
IPF	5	1	4	83%
FPF	19	5	14	79%
PFW	4	3	1	44%
FFW	2	2	0	10%
FFW/IP	0	0	0	0%

Table 7-1 Total Percentage of each Foundation type under Bracing Requirements

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NZS3604:1999 prescribes specific fixings for different areas of the foundation, depending on the anticipated load that the connection must transfer through framing to the bracing elements. The adequacy of these fixings will depend upon the lateral load capacity that they can withstand before exceeding design loading limits. In addition, it is important to not to neglect the reliance of the connection on friction to transfer loads between members. Current understanding of the Wellington fault assumes that there will be a proportion of vertical acceleration and friction between connections could be assumed to be close to zero.

8.1 Overall Load path of Connections

The load path through connections is assumed to travel from the flooring to the joists, through the bearers and to the bracing system. All foundations use different connections to transfer loads [Figure 8.1] [refer Chapter 3.0 and Section 6.4]. Each dwelling will be assessed for adequacy of load transfer, including interconnecting members, and also an assessment excluding friction between members in calculations.

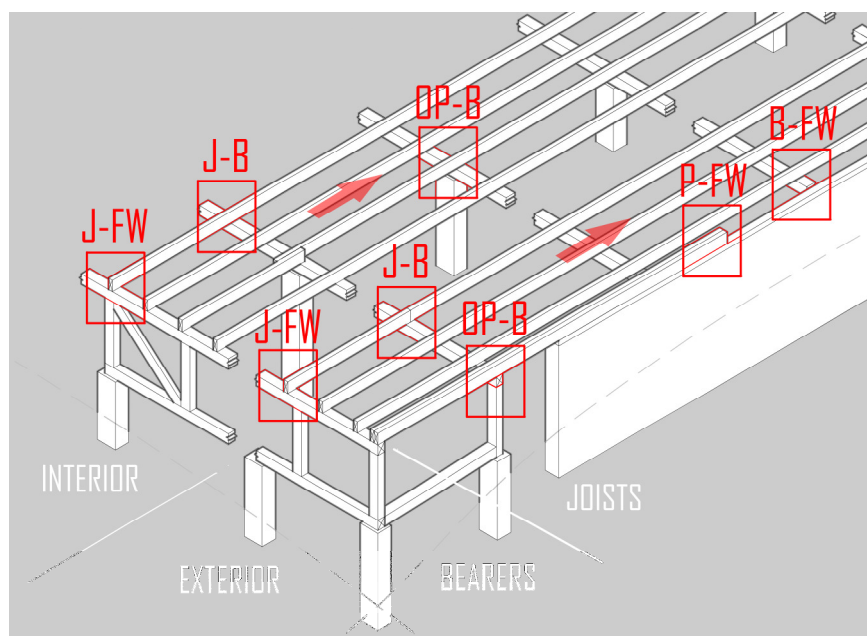


Figure 8-1 The Specific Connections relating to the Interior and Exterior, Bearer and Joist positions

8.1.1

Specific Location of Connection Failure

A connection is assumed to be inadequate, when the fixings and interface factors such as friction, do not have sufficient capacity to resist inertial forces, moving laterally from the superstructure. Figure 8.2 shows that over the four different locations [refer Section 6.4.3]

within the foundation, the Exterior Joist fixings have the largest fail rate at around 25%. The other three locations fail at an average rate of around 10-15%.

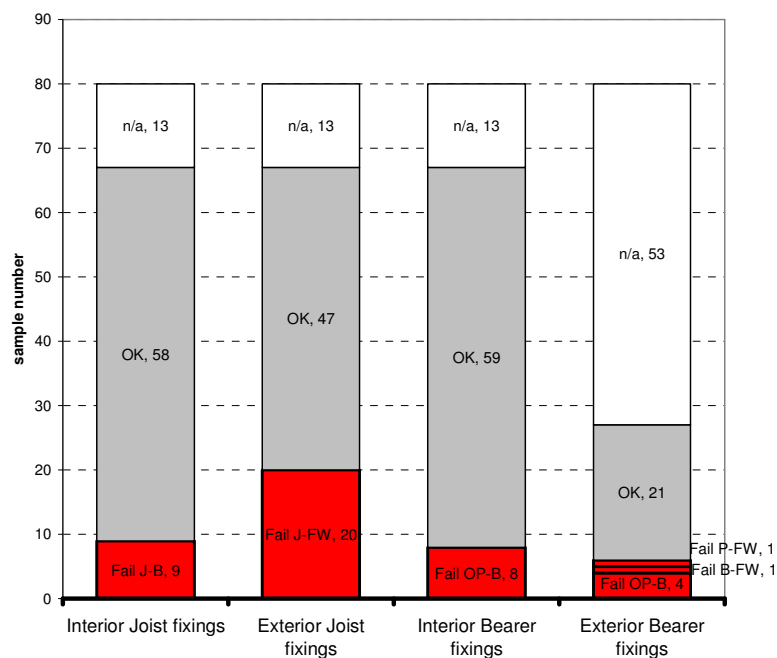


Figure 8-2 Specific location of Load Path discontinuity for the Four areas of Connection in the Sub-floor

Just over 7% of the sample exhibited inadequacies in the Exterior Bearer fixings. This is significant as these connections are crucial to transferring all loads from the superstructure to the exterior bracing elements in foundations, such as the Full Foundation Wall and Partial Foundation Wall.

8.1.2 *Including the Interconnecting Members*

The interconnecting members, usually the Joist to Joist [J-J] and Bearer to Bearer [B-B] connections, require an adequate fixing method to ensure loads are transferred along a line of sub-floor framing [refer Section 6.4.4]. If timber elements are not correctly fixed together, damage can occur because framing can slip off supporting piles. Figure 8.3, shows discrepancies in the Exterior Bearer fixings, where lines of the interconnecting members terminate. The major increase is specifically within the B-FW connection, which shows an increase of 26%, compared with Figure 8.2. A small increase is also seen in the Joist to Bearer connections, which may be the result of inadequate Joist to Joist fixings. However, joists are usually well fixed to the flooring or diaphragm meaning that displacement and fixing inadequacies are unlikely.

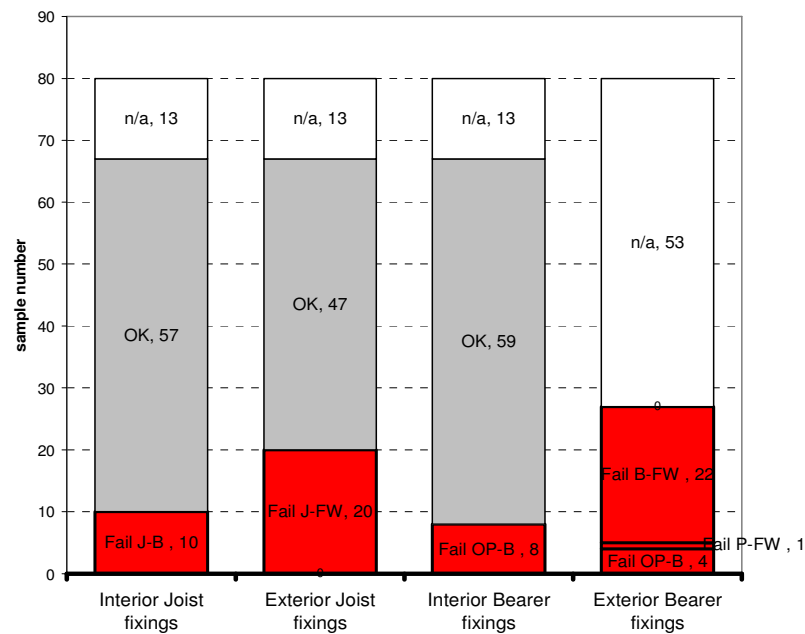


Figure 8-3 Specific location of Load Path discontinuity for the Four Locations in the Sub-floor, including the Interconnecting Members

8.2 Excluding Friction from the Analysis

The previous section for the calculation of connection adequacy, assumes that the interface between structural members, have the potential to resist a proportion of loading through friction [refer Section 6.4.5]. For the purposes of illustrating the effect of vertical acceleration in an earthquake, the coefficient of friction will be removed from calculations and assumed to be zero. This assumption is based on vertical acceleration ratios of between 50-100% of the horizontal acceleration, which are anticipated in a Wellington earthquake scenario (Cousins 2007). Foundation connections designed to NZS3604:1999 ignore any contribution from friction.

8.2.1 Specific Area of Connection Failure

The number of connections that rely specifically on friction between interface materials is significantly high. Figure 8.4 shows an overall increase for all connections in the sub-floor, when friction is removed. Almost twice the number of connections are considered inadequate. The most significant increase is seen in the OP-B connections and also the P-FW connections, which have a concrete-timber interface and a friction coefficient of over 1.

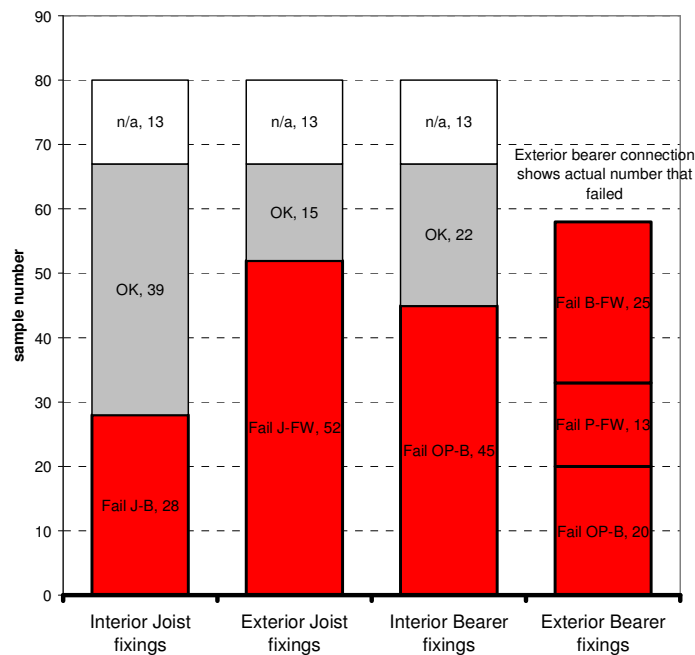


Figure 8-4 Number of Inadequate Connections Excluding Friction from the Calculations

8.2.2 Required Increase of Connection Resistance

The values in Figure 8.4 suggest that most connections require an increase in fixing, especially if vertical acceleration is a factor during an earthquake. Moreover, the extent of this increase for each connection and location needs to be expanded.

8.2.2.1 Interior Joist [J-B] Connection

The requirement for the J-B connections in Figure 8.5 shows that a large increase in capacity is necessary for dwellings constructed before 1930. Other areas require less extensive increases in fixing capacity of between 50-75%, which is predominantly in the 1940 to 1970 age bracket.

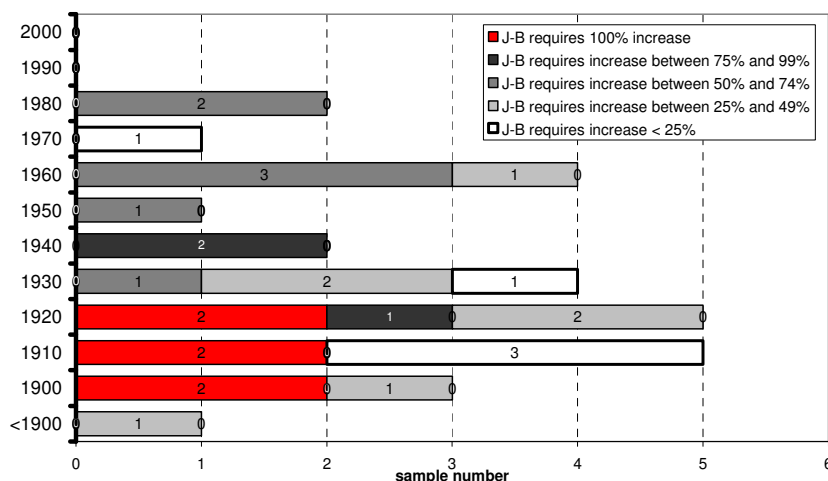


Figure 8-5 Interior Joist fixing [J-B] Requirement breakdown by Age of Dwelling

The Joist to Foundation Wall fixing shows that many dwellings constructed in the 1920's, 1940's and 1960's, require increased connection capacity [Figure 8.6]. This is possibly due to the larger proportion of heavier dwellings in these age groups [refer Section 9.1.3].

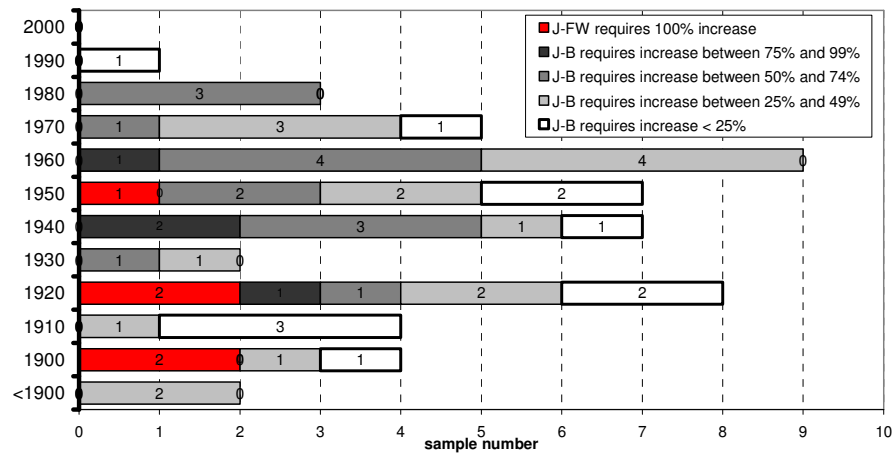


Figure 8-6 Exterior Joist fixing [J-FW] Requirement breakdown by Age of Dwelling

The Interior Bearer connection requirement, seen in Figure 8.7 shows that the Ordinary Pile to Bearer connection exhibits a severe lack of fixing capacity for dwellings constructed before 1930, which may reflect the poor repiling practices of this era [refer Section 9.2.2]. Some severely under strength connections are also seen in newer dwellings from the 1950 to 1970 age bracket, most probably from the degradation of fixings.

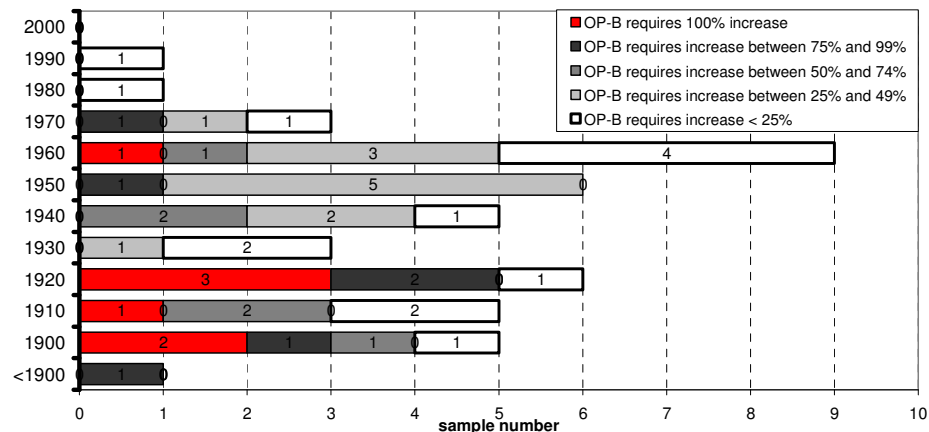


Figure 8-7 Interior Bearer fixing [OP-B] Requirement breakdown by Age group

The Exterior Bearer connection, including the P-FW and B-FW fixings, shows that the majority of dwellings ranging from 1940 to 1990, require over 75% of connection capacity requirements [Figure 8.8]. It is evident that if either of these connections fail, the dwelling may receive extensive damage or could potentially collapse.

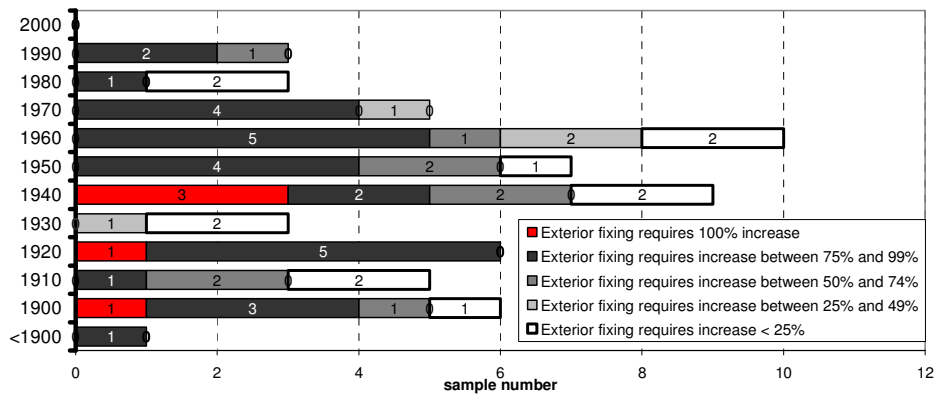


Figure 8-8 Exterior Bearer fixing Requirement breakdown by Age group

8.2.3 *Specific Connections Failed*

The graphs above show the extent and capacity required to upgrade connections in four areas of the foundation. However, to understand what remedial requirements are necessary, the existing inadequate fixings should be analysed. Connections with no fixings and no friction, failed in every instance, which made up 8% and 6% of the J-B and J-FW sample respectively [Figures 8.9 and 8.10]. However, 16% of the Interior Joist fixings, and 35% of Exterior Joist fixings were considered inadequate, despite being within the requirements of NZS3604:1999. This may be due to the reliance on friction, combined with higher weights from the superstructure.

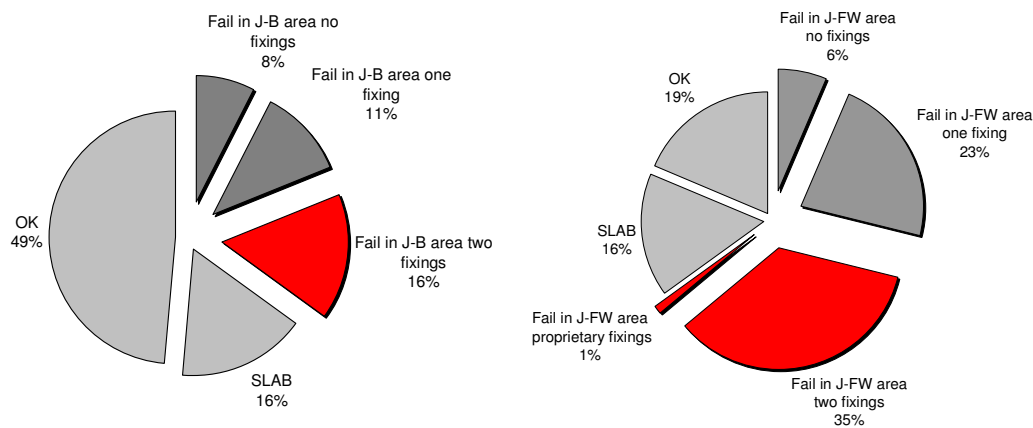


Figure 8-9 Inadequate fixing Method for Interior Joist fixings – Excluding Friction

Figure 8-10 Inadequate fixing Method for Exterior Joist fixings – Excluding Friction

The bearer connections show a similar trend of high inadequacies, whilst adhering to NZS3604:1999. Figure 8.11 shows that many of the wire and staple fixings are inadequate to transfer any loading. Figure 8.12 shows the opposite trend, where Exterior Bearer connections with correct fixings are adequate more often than connections that do not adhere to the standards.

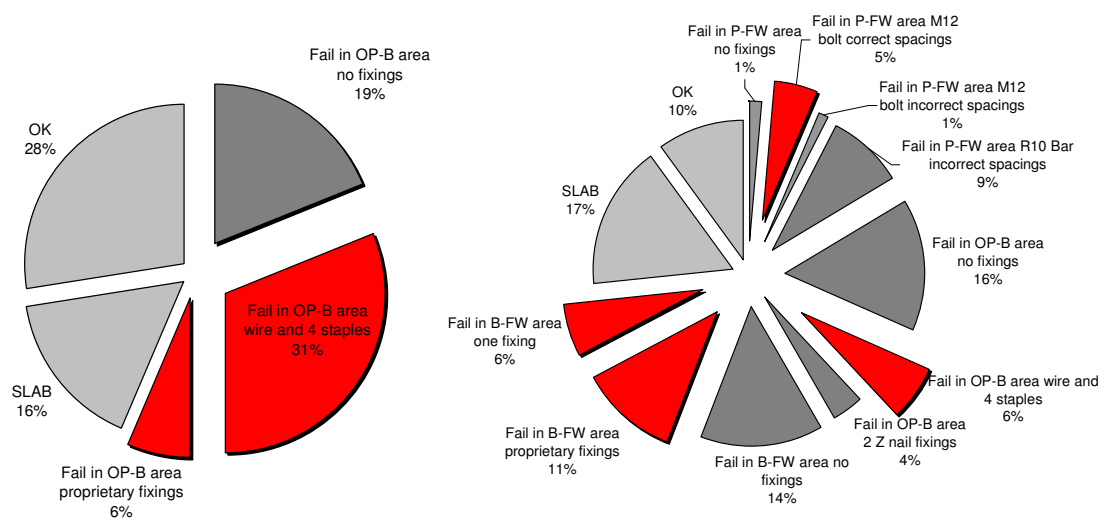


Figure 8-11 Inadequate fixing Method for Interior Bearer fixings – Excluding Friction
Figure 8-12 Inadequate fixing Method for Exterior Bearer fixings – Excluding Friction

8.3 Connection Capacity for Dwelling Weight

Dwellings with heavy wall and roof claddings tend to require connections and fixings to transfer more force. Figure 8.13 shows that the small number of dwellings surveyed over 5kPa [a unit area of force (kg per m²)] appear to have a significant increase in connection inadequacy given the proportion of dwellings in this weight bracket [refer Section 9.1.3].

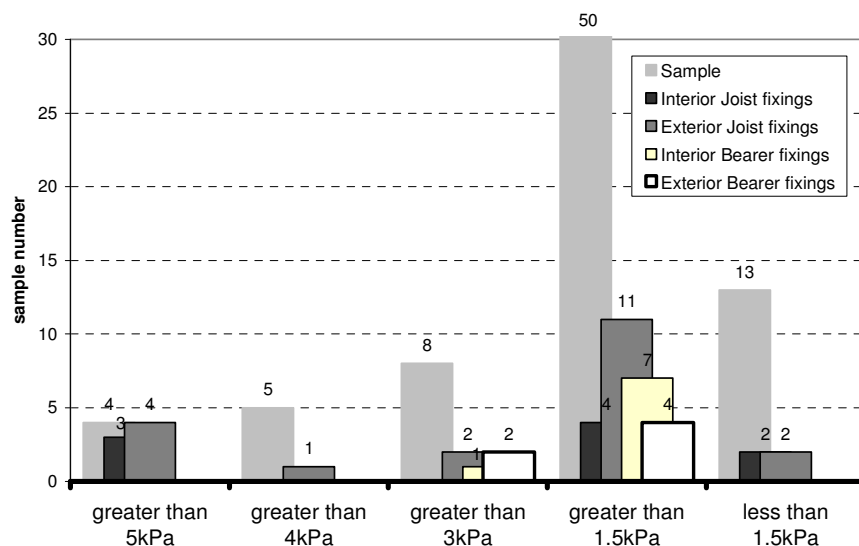


Figure 8-13 Dwelling Total Weight combined with Fixing transfer Deficiencies

8.4 Load Path Totals in Comparison

The totals seen in Figure 8.14, shows dwellings which are under requirements for load transfer when zero friction is assumed. Almost every foundation relies heavily on friction, to the point where load transfer would be extremely limited without it.

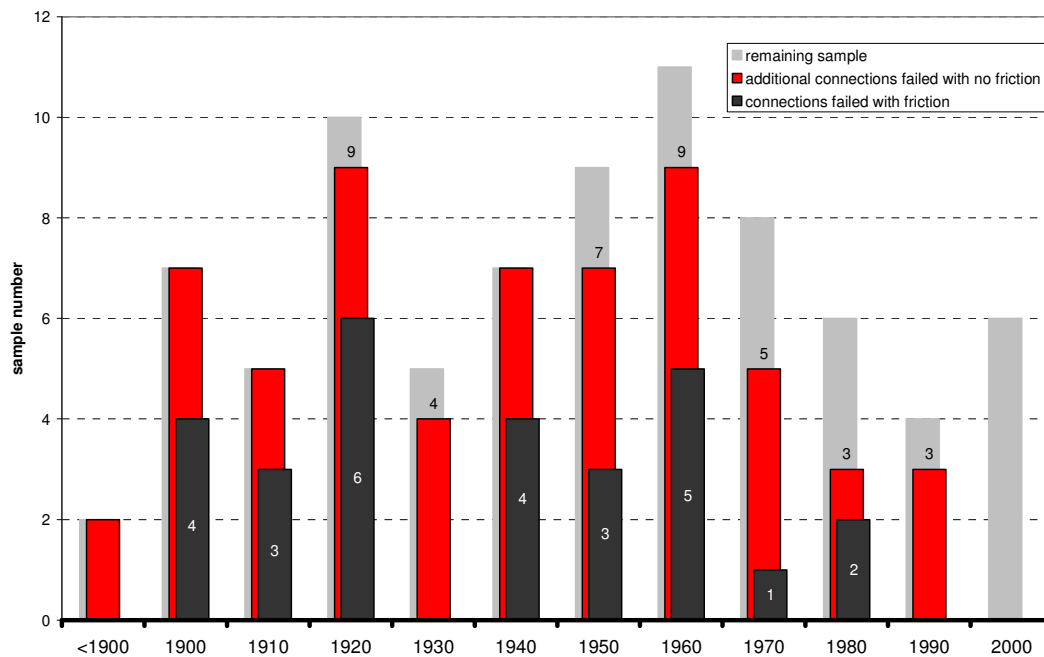


Figure 8-14 Connection failure Including and Excluding Friction compared with the Age of Dwelling for all Connections in the Sub-floor]

Dwellings constructed in the 1900-1910, 1930's and 1990's would normally have no load transfer issues. However, when friction is assumed to be zero, almost all of these dwellings are considered inadequate. The best performing age group for the overall load transfer ability are the 1970's and 1980's dwellings. These dwellings have reasonably low weight [refer Section 9.1.3] and both samples only have connection inadequacies in around half of the sample.

8.4.1 Load Path Capacity for Foundation Type

Assessing the load transfer for each foundation type shows that the Full Piled Foundation is the best performing foundation for connection capacity [Figure 8.15]. However, this is probably the result of lower weight dwellings and the reliance on a relatively large number of fixings in the foundation to transfer loads. Other foundations such as the Full Foundation Wall and Partial Foundation Wall have inadequate connections in around half of the sample and when friction is excluded, almost all connections are considered inadequate.

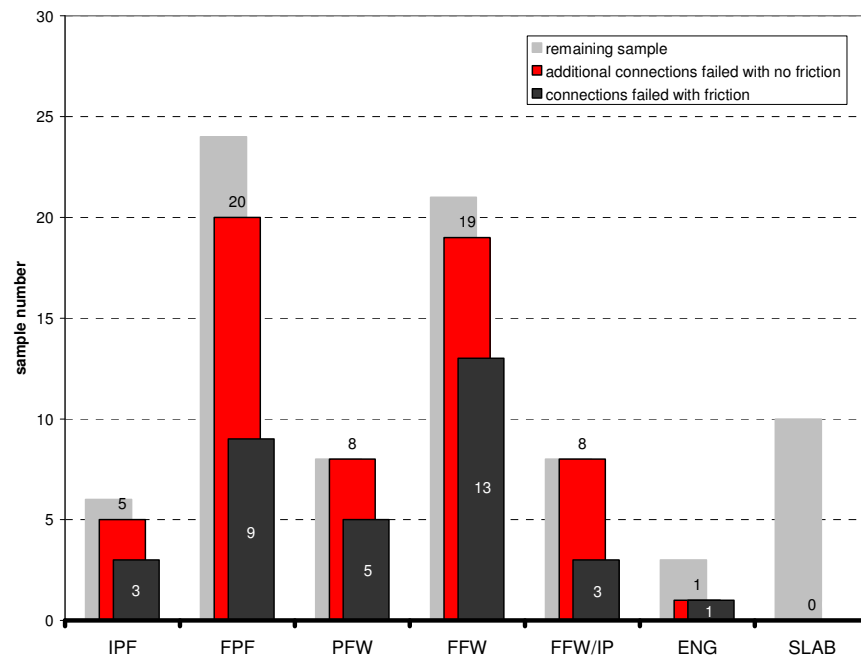


Figure 8-15 Connection failure Including and Excluding Friction compared with Foundation type

Figure 8.15 reiterates that much of the design capacity strength in a connection is the result of the interface friction between timber elements (Malhorta and Thomas 1984). Also, a number of the inadequate connections in the sample will be due to heavier dwellings transferring force to the ground; these connections may require stronger fixings above the prescriptions stated in NZS3604:1999.

8.5 Summary of Fixings and the Sub-Floor Load Path

The four areas in the foundation, which are the most significant for load transfer, were found to be inadequate between 8% and 25% of the time. The worst connection was the Exterior Joist fixings, which are required to transfer significantly higher loads to exterior bracing elements. An increase of 26% was seen in the Exterior Bearer fixings, when the inadequacies of the interconnecting members were included in calculations. When friction was assumed to be zero, as anticipated by a Wellington earthquake scenario (and by NZS3604:1999) to have a proportion of vertical acceleration, an increase of inadequacy of between 30% to 50% was seen in all four areas of the foundation. The most significant area of inadequacy was again the Exterior Joist fixings, which suggests that 35% of the sample was inadequate to transfer loads, despite having requirements as prescribed in NZS3604:1999. The Full Foundation Wall and Partial Foundation Wall had the highest significant proportion of inadequate connections with and without friction included in the calculations. However, this was assumed to be a direct consequence of heavier cladding materials, and the critical capacity of connections transferring higher loads into bracing elements. Remedial measures from the load path calculations, will recommend that fixings that were deemed inadequate, will require additional fixings above NZS3604:1999. Table 8.1, shows the rate of inadequate connections and fixings in the sample sub-floor, which will be used for application of remedial fixing measures.

Fixings	Interior Joist	Exterior Joist	Interior Bearer	Exterior Bearer		Interconnecting members		Total under reqs.
	J-B	J-FW	OP-B	B-FW	P-FW	B-B	J-J	
IPF	66%	66%	83%	n/a		83%	83%	76%
FPF	52%	66%	52%	n/a		85%	81%	67%
PFW	33%	100%	77%	88%	45%	100%	100%	78%
FFW	80%	90%	72%	68%	36%	86%	88%	73%
FFW/IP	88%	88%	55%	n/a		100%	100%	86%

Table 8-1 Total Percentage of each Foundation type requiring Connection Remedies

The overall condition of an existing foundation can affect the ability of structure, piles, fixings and connections to transfer lateral loads. NZ3604:1999 prescribes specific requirements for certain aspects of foundations, however, there is no actual provision for the overall condition of a foundation. This is largely due to the fact that the Standard focuses on construction of new foundations and not remedial measures to existing. However, the Standard does prescribe minimum requirements for ventilation and clearance of the timber structures from the ground aimed at mitigating sub-floor moisture, which can cause degradation of materials and fixings. The House Condition Survey 2005 [“HCS 2005”] (Clark, Jones, and Page 2005), considers all aspects of dwelling condition, including all sub-floor elements. The survey identifies areas which require immediate attention and has been used as a benchmark with which to compare the overall sub-floor condition of the project sample.

9.1 Dwelling Materials

The cladding and materials of dwellings were used to calculate the amount of force that the foundation must transfer to the ground. Certain materials depending on their physical properties and weight, resist movement better than others. Many of the materials selected for a dwelling will dictate the amount of damage that may result from an earthquake and also the overall anticipated cost to remedy that damage. For the purposes of comparison, the statistics in the HCS 2005 is used as the bench mark for sub-floor condition.

9.1.1

Exterior Wall Cladding

The exterior cladding of a dwelling makes up a significant part of the overall weight of a dwelling. Generally, the heavier the cladding, the more susceptible it is to movement (BRANZ 2003). Figure 9.1 shows that 64% of the dwellings have timber weatherboards, followed by more modern materials, such as cement board and stucco. Although the HCS 2005 values show less weatherboard dwellings and an increasing number of masonry and brick dwellings, the difference is probably due to the topography of Wellington and the unsuitability of heavier claddings.

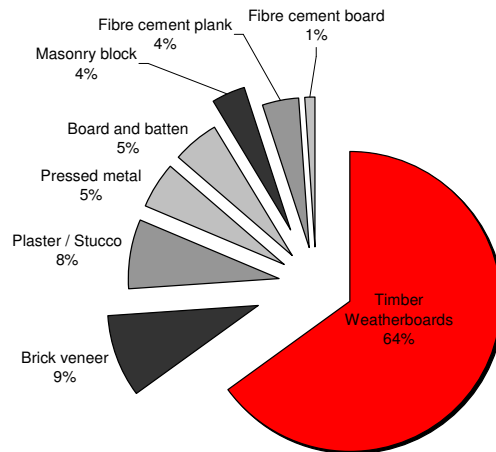


Figure 9-1 Percentage of Exterior Cladding spread in the Sample Dwellings

9.1.2

Roofing Material

The observation of roofing material types showed large numbers of pressed profile steel based products [Figure 9.2]. Concrete or masonry tiles made up 13% of the sample, compared with a high sample of 23% from the HCS 2005. Light roofing materials such as pressed metal sheeting and asbestos tiles pose no specific danger during earthquakes, however concrete tiles can fall through the ceiling during an earthquake and thus require metal ties to roofing battens (Cooney 1982).

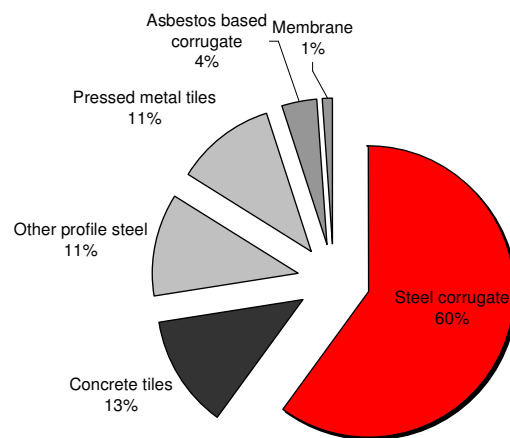


Figure 9-2 Percentage of Roofing Material spread in the Sample Dwellings

9.1.3

The Overall Combined Weight

The total weight of a dwelling varies depending on the surface area of the exterior wall cladding, roofing material, and the sub-floor cladding. The weight of the interior framing and wall linings are calculated using area and volume calculations based on archived records. Figure 9.3 illustrates that between 1940 and 1960, dwellings tended to be heavier due to changing fashions, which dictated the popularity of heavier elements such as masonry veneer and concrete tile roof. Older dwellings tended to be lighter since the palette of materials was more standardised up until the 1940's.

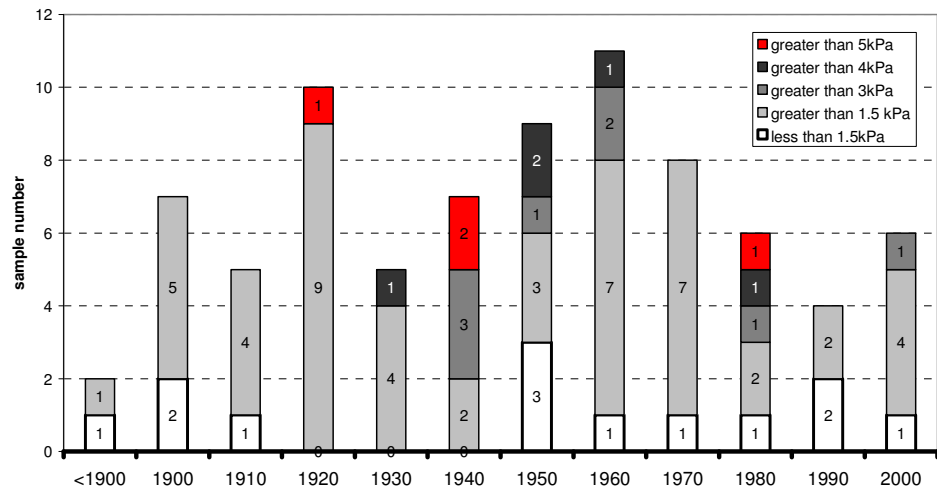


Figure 9-3 Combined Weights of Dwellings compared with the Age of Dwellings

Overall, Full Foundation Wall dwellings have a higher proportion of heavy dwellings over 3kPa [Figure 9.4]. Piled dwellings generally weigh less than 2kPa, which is due to the common use of steel corrugate roofing and timber weatherboards.

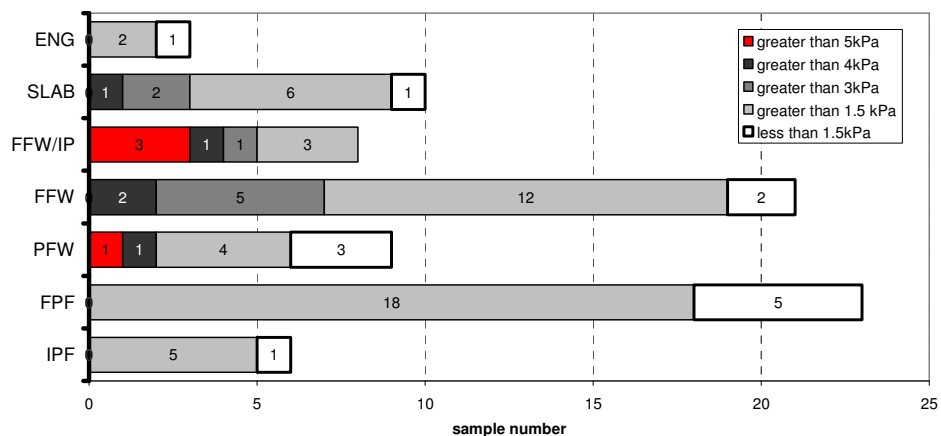


Figure 9-4 Foundation type compared with Force per Square Metre

9.2 General Structural Defects

Structural defects affecting the integrity of a sub-floor area can in most circumstances be remedied. However, issues that affect the dwelling's ability to resist an earthquake, such as configuration issues, may require additional consideration of the design. Structural defects observed onsite showed three main areas for concern: general structural deficiencies, pile deficiencies and configuration issues [Figure 9.5].

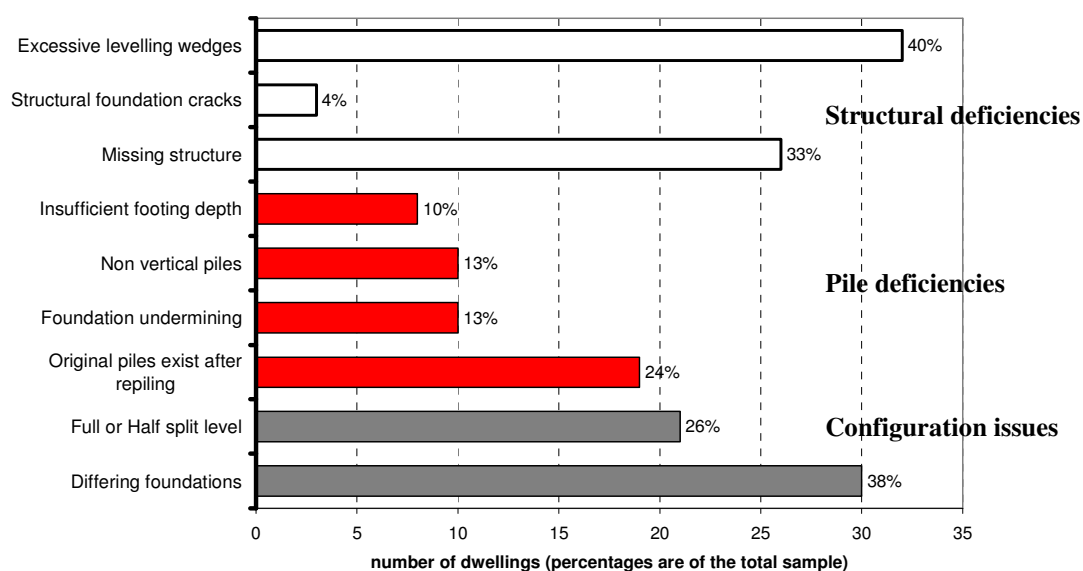


Figure 9-5 Major Sub-floor Defects likely to affect the Strength and Response of a Foundation

9.2.1

Structural Deficiencies

40% of dwellings are structurally deficient, due to the use of levelling wedges, deemed excessive in terms of the current standard (Standards New Zealand 1999, section 6.12.6) [Figure 9.6]. Many structural deficiencies can be remedied by simply replacing the offending element, such as replacing wedges, replacing missing structure and maintaining the lateral bracing systems. These should be part of common maintenance routine in a dwelling.

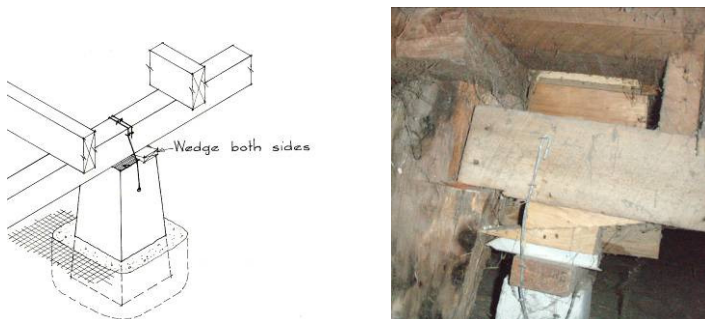


Figure 9-6 Limits of Prescribed Relevelling [left] (Source: Cochran 1980) and interpretations of the Extent of allowable Relevelling [right]

However, the HCS 2005 found that almost 80% of people rely on their own observations to prompt maintenance, which will create additional issues if the owner does not have a clear understanding of what actually requires maintaining. Statistics show that 96.6% of New Zealand homeowners do not perform any maintenance associated with foundations, which accounts for one of the highest outstanding base maintenance costs (Clark, Jones, and Page 2005, p.85).

Piles provide vertical load resistance in foundations, thus issues with piles can limit the structural integrity to resist these loads. Issues concerning the integrity of piles are prevalent in 10-25% of all dwellings. However, most of these issues occur in older dwellings that have been repiled. Figure 9.7 shows the different types of piles common throughout all periods of construction, of which 37% have been repiled.

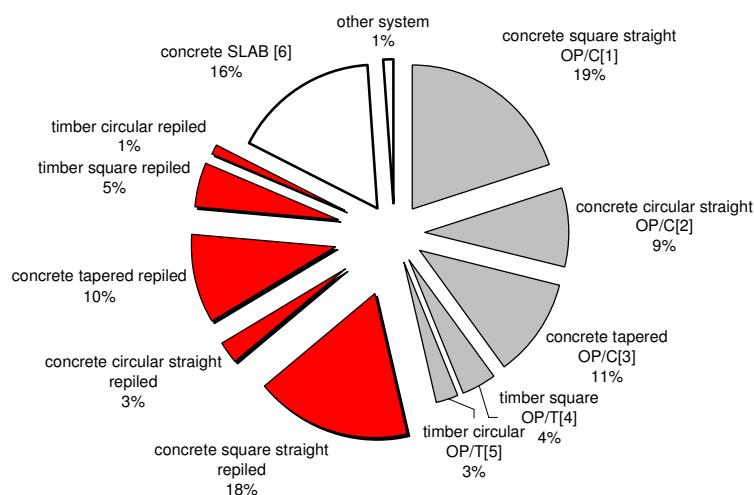


Figure 9-7 Pile type including Repiled Dwellings

Generally, dwellings are repiled around 60-80 years after the date of construction. The pile deficiencies observed include non-vertical piles, missing bearer ties and insufficient footing depth, which are all associated with poor repiling practice [refer Section 10.2]. The improvements in recent repiling practices have reduced the frequency of these deficiencies, in comparison to 1980's repiling practices. Figure 9.8 shows the percentage of repilings and when the repiling occurred.

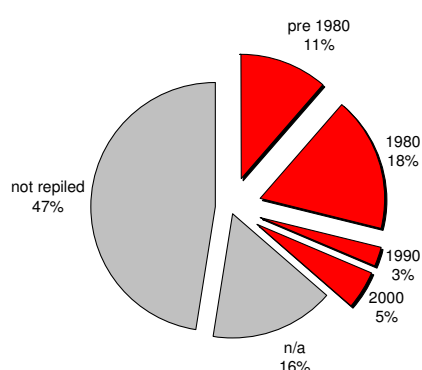


Figure 9-8 Repiled Dwellings and corresponding Decades of Retrofitting

When repiling is undertaken, soil must be cleared in order to reach cramped areas. Often this work is charged hourly, which can be an excessive expense for little gain for the owner. For this reason, many inaccessible and load bearing piles, are not replaced and remain in loaded positions in order to reduce costs. Due to the modifications to the Building Consent process, repiling requires a sub-floor bracing retrofit. The cramped conditions and the relative visual and

physical inaccessibility of the sub-floor make it difficult to conduct heavy labour and may be the main reason for poor workmanship.

9.2.3

Configuration Issues

Configuration issues in dwellings fall into two groups, differing foundations [a horizontal discontinuity], and split level dwellings [a vertical discontinuity]. Overall 25% of dwellings have a full or half split-level and 38% have differing foundations, [Figure 9.5]. Figure 9.9 shows that the Full Foundation Wall has the most split level issues and the Full Piled Foundation most often has differing foundations.

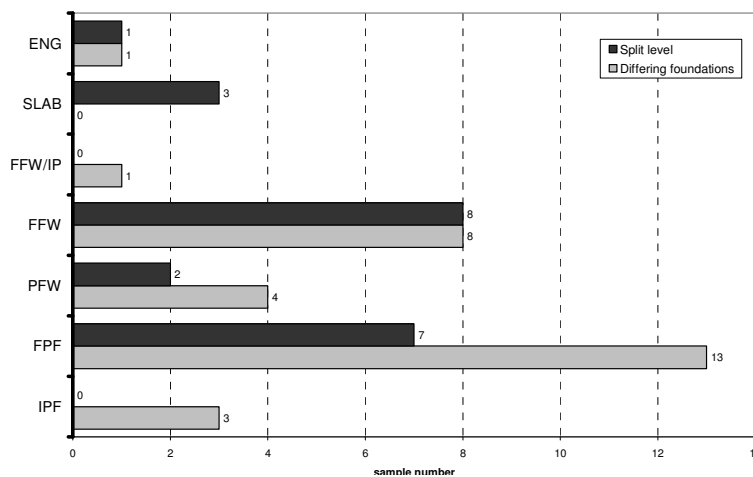


Figure 9-9 Configuration Issues for each Foundation type in the Sample

To understand whether configuration issues arise solely from topography or design, each foundation type is listed according to the slope of the ground over the site. The classification used here is based on the topography for wind loadings, either Gentle 1:10 to 1:5, Moderate 1:5 to 1:3 or Extreme over 1:3, as in NZS3604:1999 [Figure 9.10].

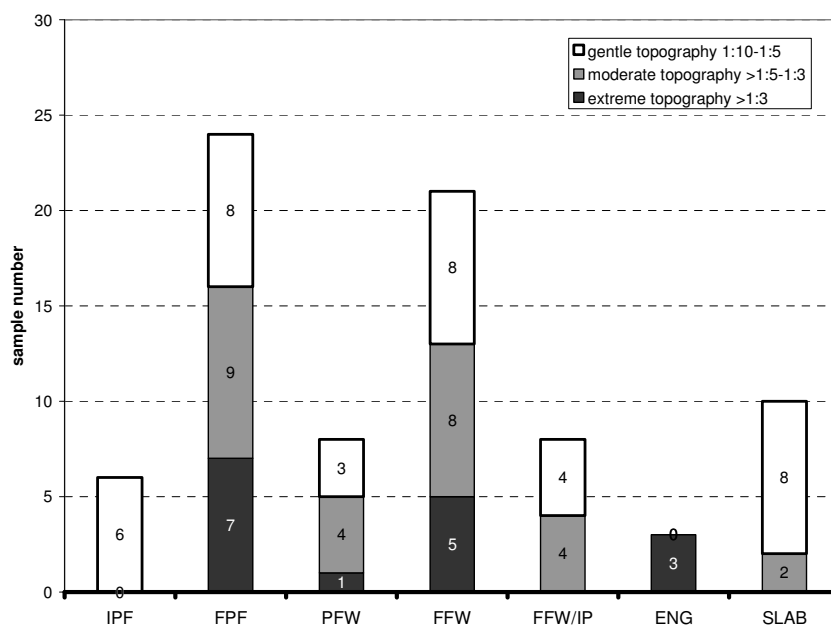


Figure 9-10 Foundation type for different Topographical Scenarios

Figure 9.10 shows that similar numbers of dwellings, which are located in an Extreme zone also have significant configuration issues, especially in Full Piled Foundation and Full Foundation Wall samples. This suggests that the design and resulting configuration issues are related to the slope on which the dwelling is situated.

9.3 Timber Condition

The timber in a foundation is required to transfer loads from the flooring to the piles and to the ground. Structural issues that affect a timber sub-floor usually arise from moisture related factors. Although the moisture content of timber was not analysed in the study, HCS 2005 found that around 40% of dwellings had a moisture content greater than the prescribed maximum of 18% (Clark, Jones, and Page 2005). This timber would likely show signs of water staining, rotting and degradation of fixings.

9.3.1

Timber Type

The timber used in a sub-floor depends on the age of the dwelling. Figure 9.11 shows the timber type for all ages of dwellings. Older dwellings tend to use native timbers according to the durability of the wood. However, durability in modern dwellings is more commonly specified using different timber treatment levels depending on the risk and likelihood of water damage to the timber.

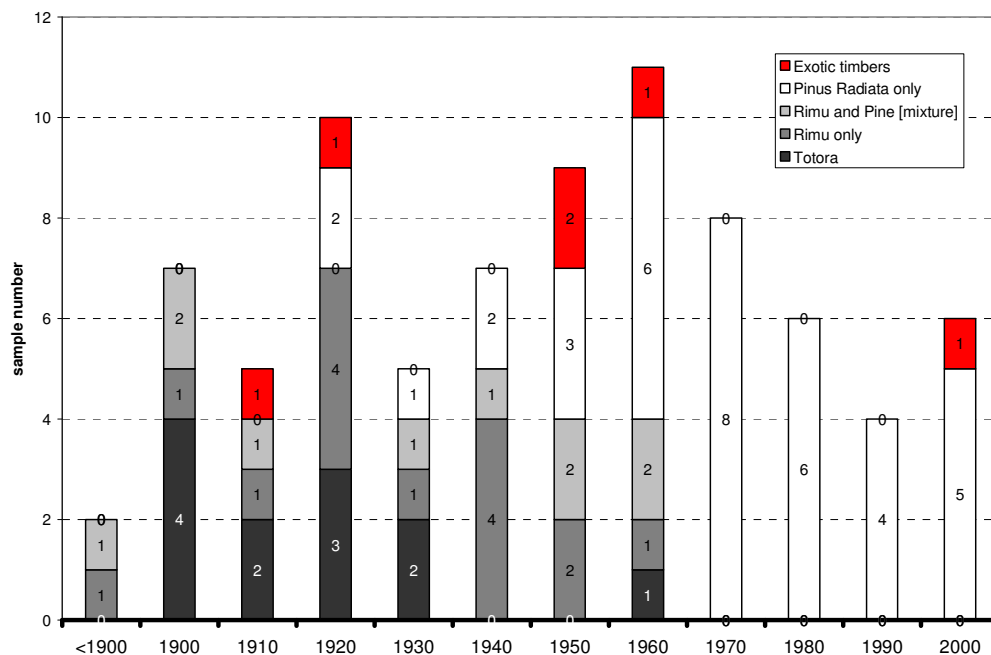


Figure 9-11 Timber type compared with Age of Dwelling

Moisture levels in timber can reduce the strength and durability of the timber and increase the potential for corrosion of fixings (Duncan and Vautier 1983). Figure 9.12 shows degradations in timber which have the potential to reduce strength. Splitting and other inherent timber issues accounted for 11% of discrepancies. Partial deterioration, which was the result of borer infestation, unsafe notching or structural members lying directly on the soil, accounted for 30% of the sample. However, this was usually not spread over the whole sub-floor and was often localised.

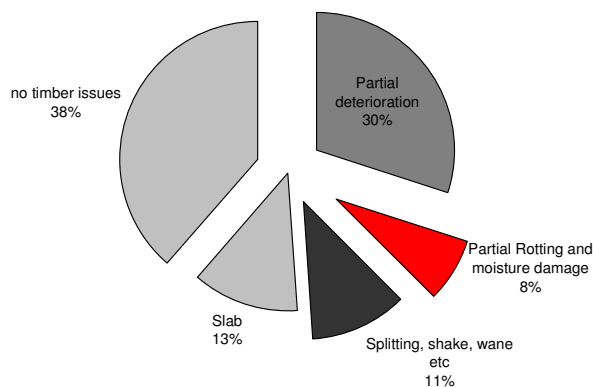


Figure 9-12 Damage observed in Sub-floor Timbers

Issues such as water damage and visible corrosion of fixings can affect the health of the timber sub-floor structure. A water stain can originate from when the timber has been wet in the past or recently and from either exterior or interior origins. If water stains occur near metal fixings, premature corrosion can occur. Figure 9.13 shows the number of foundations exhibiting corrosion, and new or old water staining on timber members.

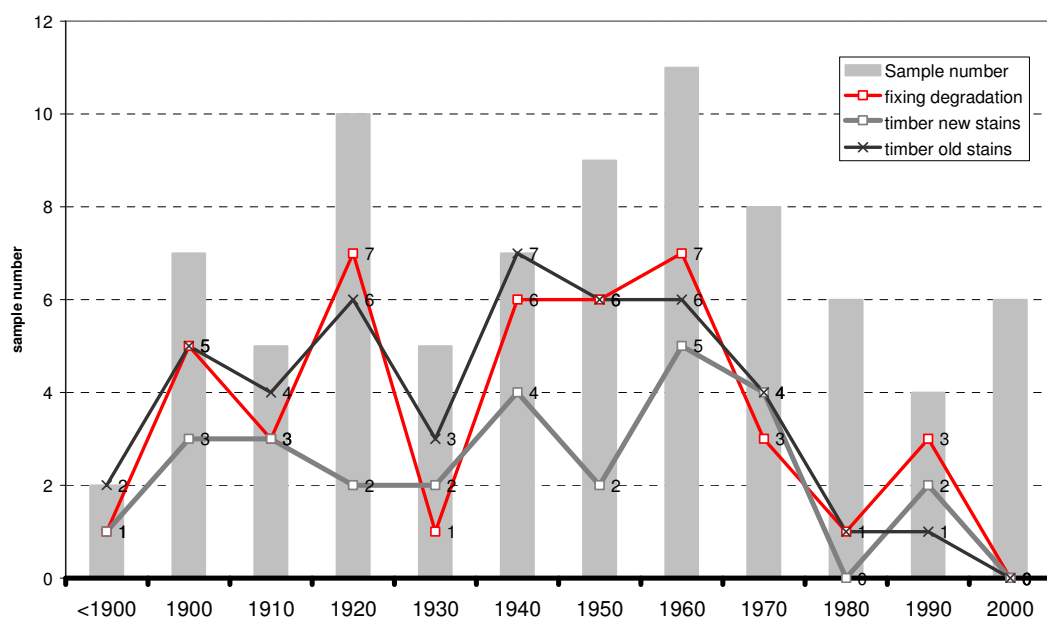


Figure 9-13 Sub-floor Timbers with signs of higher Moisture Content and Degradation

Most of the interior water stains originated from bathrooms, kitchens and other wet areas and were often the result of leaking pipes. If a leak is constant, replacement of sub-floor timbers and flooring could be necessary. Issues of excess moisture in the sub-floor can be seen in *The Observed Onsite Anomalies* [refer Appendix F].

9.4 Fixings

The fixings in a sub-floor are vital for the transfer of loads between different timber members. However, if the moisture levels are high and the fixings are allowed to corrode, the relative width of the metal fixing may decrease limiting the overall capacity and strength of a fixing.

9.4.1 *Fixing Degradation*

The deterioration of fixings is related to the sub-floor moisture levels; even with minimal airborne moisture, fixings are likely to deteriorate. Dwellings built around the turn of the century had no form of protection, such as galvanisation and consequently show excessive rusting, which also continues into modern dwellings. Figure 9.14 shows many dwellings with rusted fixings, however these degradations are often only localised, rather than extensive.

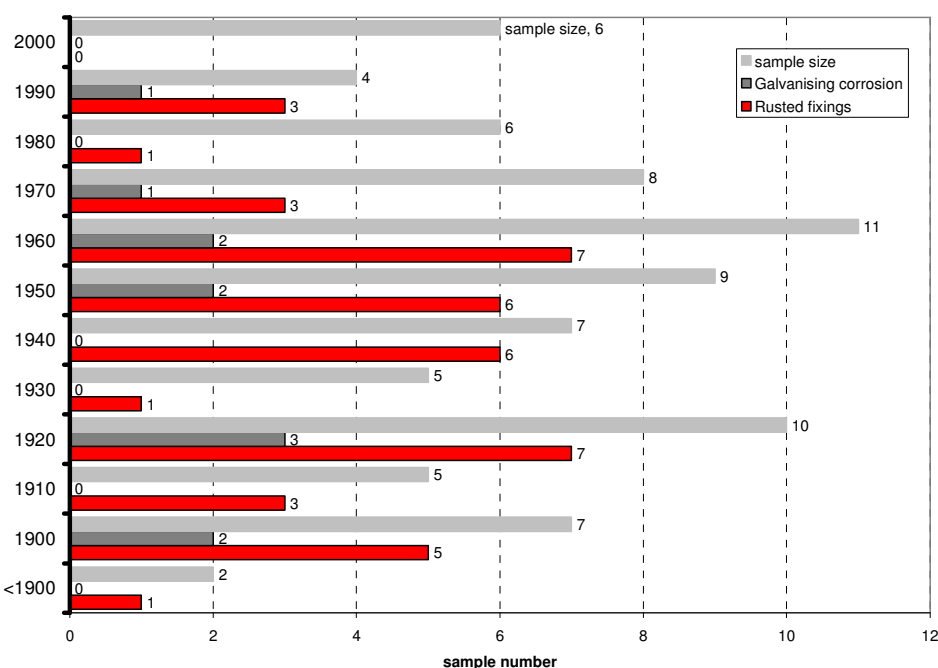


Figure 9-14 Fixing Degradation per Age of Dwelling

The HCS 2005 suggests that 17% of dwellings have corroding fixings and 16% show signs of white rust (Clark, Jones, and Page). Overall, 52% of dwellings have some form of rust likely to cause significant loss of strength. White rusting figures, were more in line with HCS 2005, suggesting that around 13% exhibited signs of zinc corrosion. The difference between the sample rusting figures and the HCS 2005 figures may be the result of wet soil seen in Wellington or the poor adherence to ventilation prescriptions.

9.5 Non-structural Sub-floor Maintenance

Non-structural maintenance refers to issues that will affect the integrity of the foundation, however may not be specifically structural. For this reason, many of these issues can be mitigated by the homeowner through general maintenance.

9.5.1

Ventilation

Subsequent House Condition Surveys have highlighted the lack of ventilation of sub-floor spaces (Page, Sharman, and Bennett 1995; Clark et al. 2000). Observations show that many dwellings built prior to 1940 have significant ventilation issues. The sample in Figure 9.15 shows that over 62% of dwellings built prior to 1940 require a 100% increase in ventilation to adhere to modern standards. This is significantly more than the current 38% stated in the HCS 2005 (Clark, Jones, and Page 2005, p.31)

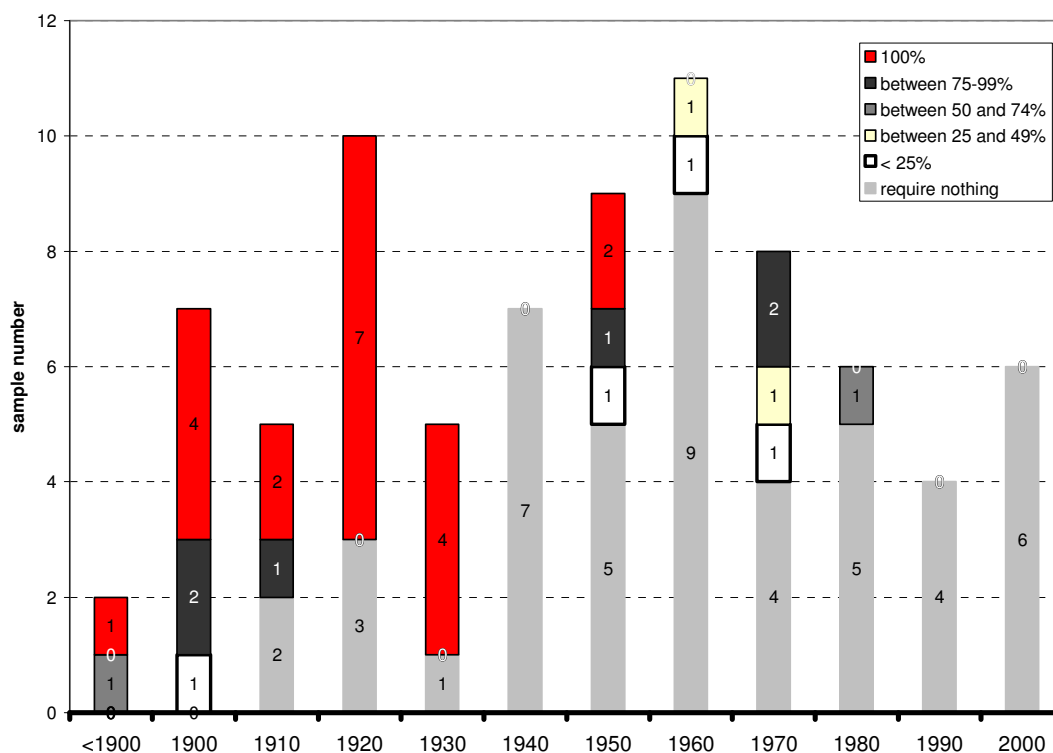


Figure 9-15 Number of Dwellings per Age of Dwelling requiring a Percentage of Ventilation increase

Areas which exacerbate ventilation issues are problems such as blocked vents, wet soil, no ground DPM or DPC between framing members, which can all exacerbate moisture related degradation [Figure 9.16]. In many cases these issues can be solved by covering the ground with an impervious layer of Damp Proof Membrane (polythene sheeting). This will prevent water becoming airborne and seeping into timber, causing degradation.

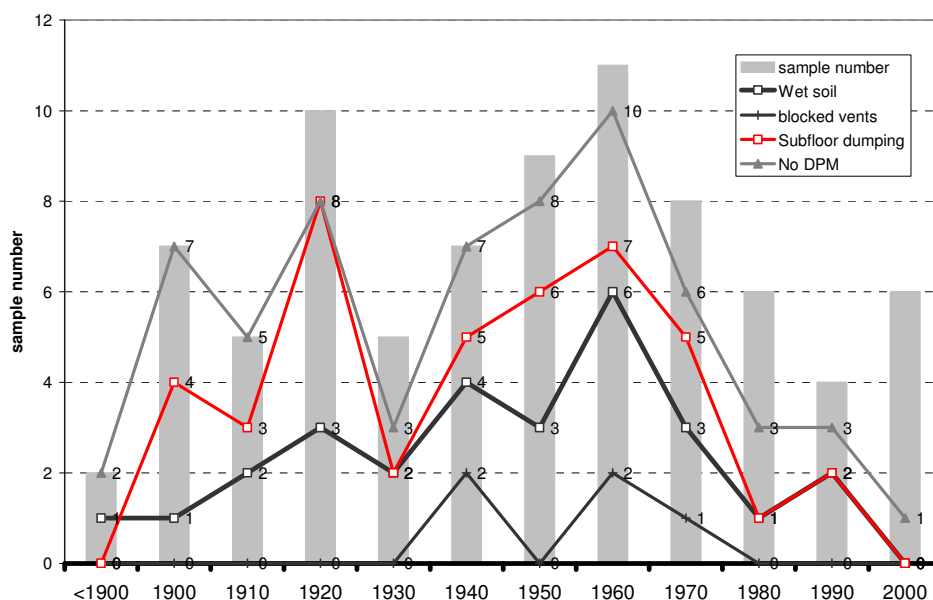


Figure 9-16 Wet Soil and relationship to Structural Degradation

The sources of moisture are primarily ground evaporation into the sub-floor space, and services, such as rain water down pipes. Other issues which limit the flow of air are blocked vents and sub-floor dumping, which includes large heating and ventilation equipment in the sub-floor. DPM is often used as an alternative to achieving minimum ventilation requirements, however only 10% of sampled dwellings, and 9% in the HCS 2005, used DPM (Clark, Jones, and Page).

9.5.2

Ground Clearance

Older dwellings do not generally have sufficient clearance from the soil. Many older dwellings were seen to be resting on the ground with piles completely submerged. This lack of clearance allows water to easily transfer into sub-floor timbers, potentially affecting the interior of the dwelling [Figure 9.17].

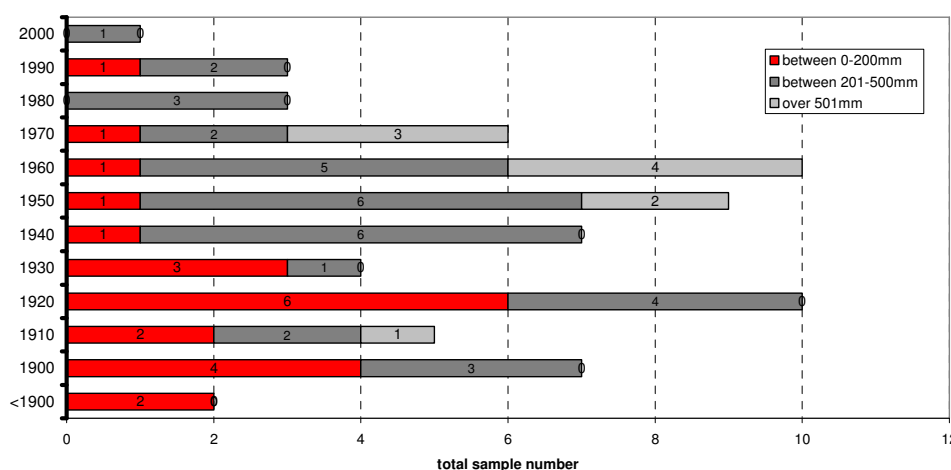


Figure 9-17 Minimum Bearer Clearance defined by Age of Dwelling

The trend shows the majority of dwellings constructed before 1940 tend to be between 0-200mm from CGL. The current minimum clearance set out in NZS3604:1999 is 150mm with DPC between pile and bearer.

Services entering a sub-floor can cause disruption to inhabitants following an earthquake especially if they are likely to cause further disruptions, such as fire or health hazards. 4% of dwellings had leaking inward services and 10% had leaking outward services. Leaking outward services include sewerage lines, and rainwater down pipes, which in some dwellings, emptied directly into the sub-floor space.

The gas connections differ between ages of dwellings and when the gas installation was made [Figure 9.18]. Older dwellings tend to have the piped connections laid on the ground with no flexible connections into the dwelling. Whereas newer dwellings may have gas meters connected to the exterior of the dwelling with piping directly into the wall. Flexible gas connections are of significance as when a dwelling moves in an earthquake, the rigid gas connection can rupture increasing fire ignitions.

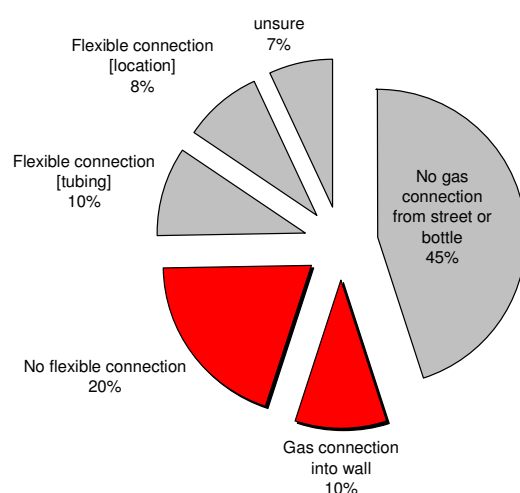


Figure 9-18 All Gas Connections in the Sample Dwellings

Almost half of the dwellings surveyed had no gas connections, usually because the suburb did not have reticulated gas, or the owner had chosen not to install it. Some owners had bottled gas; however, this was seen in only 4% of dwellings. The rigid connections account for nearly 20% of all gas connections surveyed, and connections directly into the wall of a dwelling, accounted for 10%. Most rigid connections tended to be either the very old or extremely new dwellings built after 2000.

9.6 The Overall Condition of Dwellings

The overall general condition of dwellings is the sum of all good and poor elements observed in the sub-floor space. It is assumed that as dwellings are upgraded, renovated or modernised, conditions will be comparable to a modern dwelling. The HCS 2005 suggests that the dwellings that are continually maintained and upgraded outweigh the dwellings which are falling into disrepair (Clark, Jones, and Page 2005). Of the sample observed, 55% had undertaken significant renovations or repiling and 9% were currently renovating at the time of inspection [Figure 9.19].

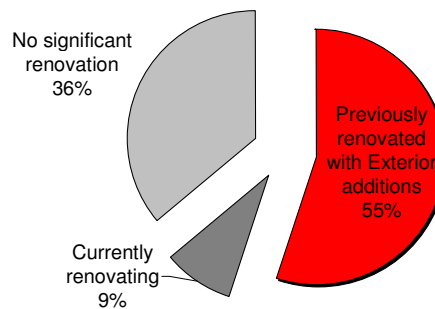


Figure 9-19 Percentage of Renovations to Dwellings in the Sample

This is significant as renovation usually entails structural alterations, which require retrofitting of the foundation area. Currently this is the only opportunity that the Territorial Authority has to demand upgrading of the sub-floor area. However, 36% of dwellings have never had any significant renovation, which means that the foundations are likely to be under the requirements of NZS3604:1999. The HCS 2005 observed that dwellings usually deteriorate up until they are 60 years old and are then renovated. Of all of the elements sampled in the HCS 2005, the floor elements showed the most fluctuation between dwelling ages [Figure 9.20].

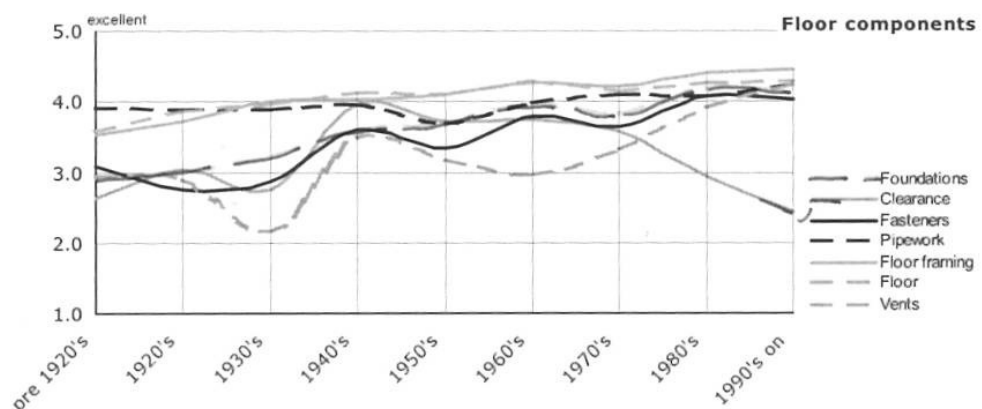


Figure 9-20 Floor Element Condition for Aged Dwellings (Source: Clark, Jones, and Page 2005)

The rating scale for overall condition considers all information from the above sections, including: structural and piled deficiencies, configuration issues, timber and fixing deterioration, ventilation, unprotected ground, dampness of soil, minimum bearer clearance below

requirements stated in NZS3604:1999, any dumping or storage in sub-floor space, which limits air circulation and poor or non-flexible gas connections. The rating scale assumes these issues may affect the structural performance or lateral instability of a foundation. Figure 9.21 shows the overall condition per age of dwelling, ranging from “Excellent” to “Poor” condition rating as in the HCS 2005.

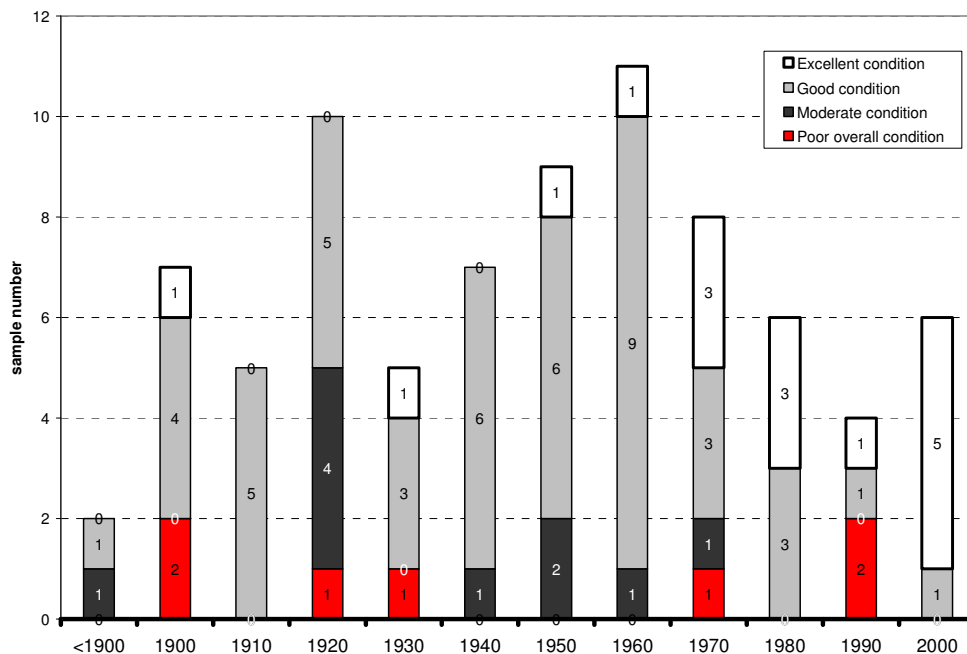


Figure 9-21 The Overall General Condition per Age of Dwelling

The dwellings with poor or below average rating, feature highest around dwellings constructed during the 1920's, with dwellings in an excellent condition featuring around the 1980's. The HCS 2005 suggests that 3% of dwellings were in a Poor condition, compared with 8% in the study, and 17% of dwellings were in an Excellent condition, compared with 20% in the study. The comparison of moderate and good conditions showed a similar relationship with the HCS 2005. Overall, the conditions of the sample dwellings compare well with the HCS 2005 and may suggest that the condition of the sample dwellings is similar to the average dwellings in New Zealand.

Comparing the overall condition and the foundation type, shows that Full Piled Foundation and Partial Foundation Wall tend to be in the poorest condition, with 40% below moderate condition. These will require some form of maintenance in the sub-floor area [Figure 9.22].

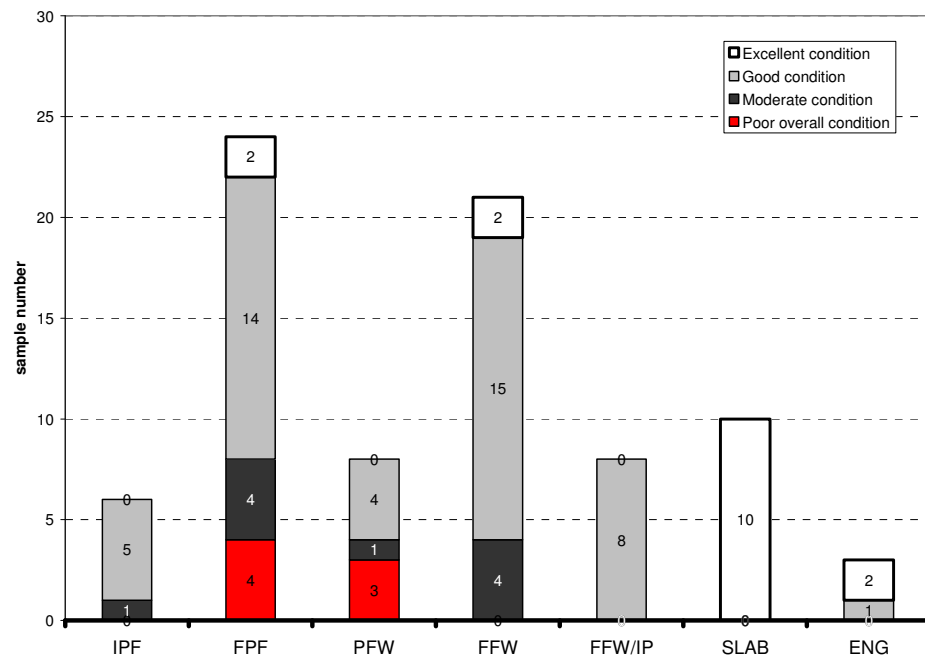


Figure 9-22 The Overall General Condition per Foundation type

9.7 Summary of the Overall Condition of Foundations

The sample size and observations in the study correlates well with observations made in the House Condition Survey 2005. This suggests that the study sample, although a significantly smaller proportion of dwellings, is generally similar to the dwelling conditions observed throughout New Zealand. The information observed in the rented proportion of sample dwellings reinforces anecdotal evidence that rented dwellings are usually in a worse condition than owner/occupied dwellings. Structural deficiencies, which can create unnecessary damage in an earthquake, were seen in around 30% of dwellings. Piled deficiencies, such as insufficient footing depth, non-vertical piles and foundation undermining were present in 10% of dwellings, with the majority being in repiled dwellings. Configuration issues were common in around 30% of dwellings, however, these issues are considered integral to the design of dwellings and cannot be easily remedied. Issues which can be remedied for the continuing health of a sub-floor are: ventilation, soil movement and upgrading of significant structural issues [Table 9.1]. These are the most important issues to take into account when considering the structural integrity and reaction of a foundation during an earthquake.

Conditions	Ventilation [see 9.5.1]	DPM [see 9.5.1]	Soil Clearance [see 9.5.2]	Soil Infill	Structural deficiencies
IPF	83%	100%	66%	0%	86%
FPF	82%	85%	50%	18%	75%
PFW	44%	100%	22%	0%	22%
FFW	22%	95%	0%	28%	22%
FFW/IP	12%	100%	0%	0%	0%

Table 9-1 Total percentages of Overall Conditions that require Remedy

As noted in the project methodology, this study assesses the sample for adequacy of foundations by using NZS3604:1999 as the benchmark for what is deemed to be an adequate foundation. The three main areas in which foundations should be adequate are: the compliance of structural members, compliance of fixings, and compliance of other non-structural requirements. It is important to note that NZS3604:1999 is the product of many superseded standards, which have been developed in accordance with earthquake science, technology and engineering scope. Therefore, any analysis of current foundation adequacy must take into account the previous standards and whether the historic requirements are still relevant in the application of NZS3604:1999.

10.1 The Structural Member Compliance

NZS3604:1999 prescribes the spacing, spans and sizing requirements of timber members. However, earlier chapters introduced the older standards and how these standards have changed during their revisions. The analysis of these standards against a sample of dwellings will uncover when and how these changes have affected construction practices. If under strength members have been used, the strength of the entire sub-floor may be affected. Therefore, this may also reveal whether dwellings that may be compliant with older standards, are still compliant with the current standards and strength requirements.

10.1.1

Joist Size and Joist Span

Figure 10.1 shows that the average minimum joist span of the sample varied depending on the standards to which it was built. This may be due to a lack of understanding of standards, as well as a continuation of old construction knowledge.

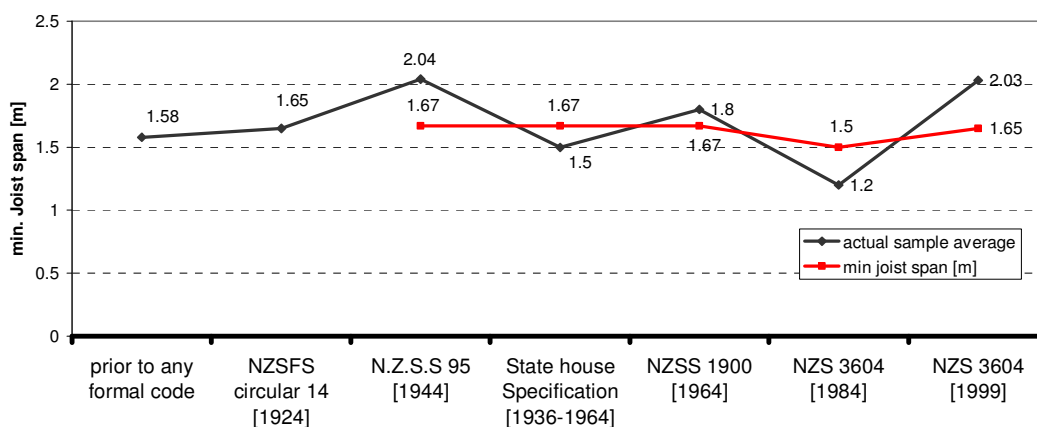


Figure 10-1 Joist Span over all Historic Standards

The bearer span for the typical 100x75mm bearer shows a similar trend as seen with the variations between older standards [Figure 10.2]. NZS3604 prescribes a 1.3m span, which correlates well to most bearers observed onsite. Dwellings constructed prior to 1944 had spans outside the prescribed limits of the standard. The most common size onsite was 100x75mm bearer. However, other sizes included 100x50mm for a similar span, up to a maximum of 250x50mm [refer Appendix D].

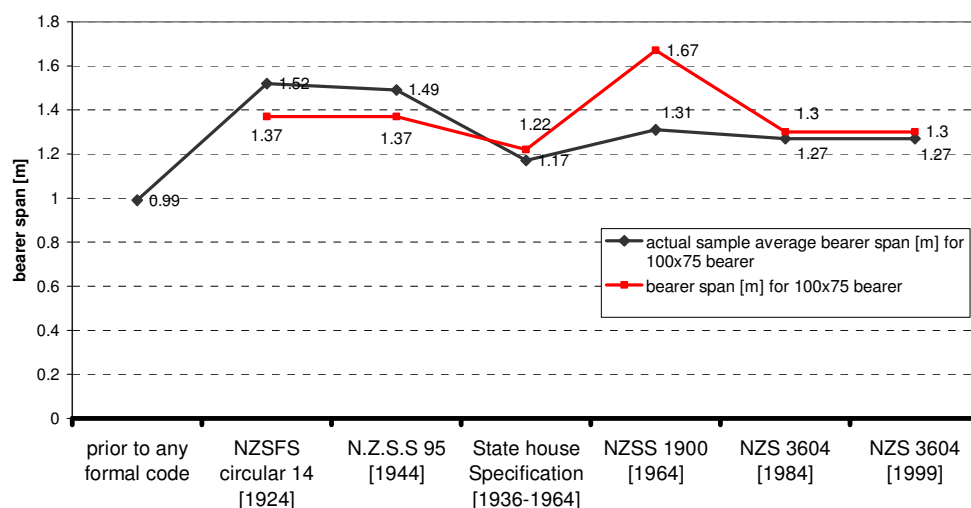


Figure 10-2 Bearer Span over all Historic Standards

The pile height and dimensions are an area which has received attention from every standard including Circular 14 in 1924. The vast majority of dwellings have adequate pile dimensions under the historic standards as well as NZS3604:1999. Moreover, the trend reflects the standards well, with all piles being below maximum heights [Figure 10.3].

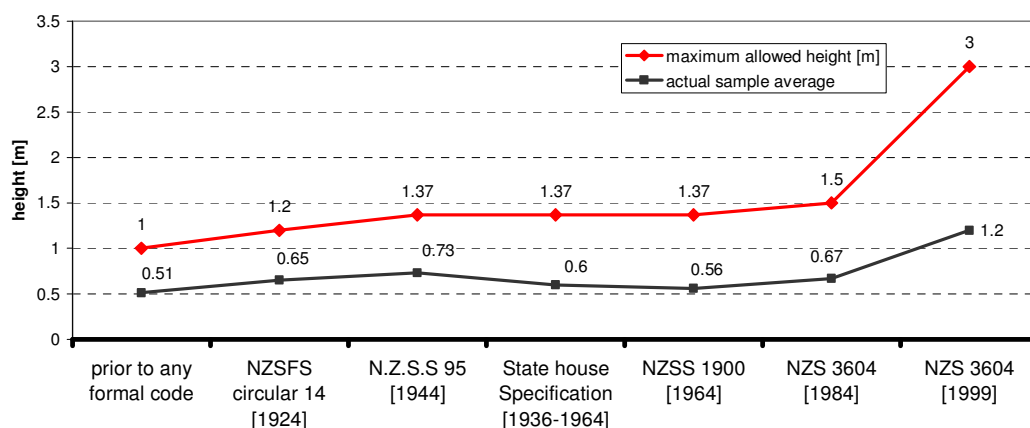


Figure 10-3 Pile Height over all Historic Standards

10.2 The Fixing Provision Compliance

The fixings for each dwelling were assessed for the direct compliance with NZS3604:1999. Initially they were assumed to be either pass or fail depending on the compliance, however many dwellings have fixings which are relevant to a certain historic standard, thus would be considered adequate when assessed against the superseded regulation. The fixings with the most variations are analysed, with the other observations listed in the *Data Collected Onsite* [refer Appendix D].

10.2.1 _____ Joist to Bearer [J-B] Fixing

The Joist to Bearer connection requires two 100 x 3.75mm skew nails from each side of the Joist to the Bearer. Figure 10.4 shows that 25% of fixings were poor, having less than two nails. This did not include any rating on the degradation in the fixing, which has already been discussed [refer Section 9.4].

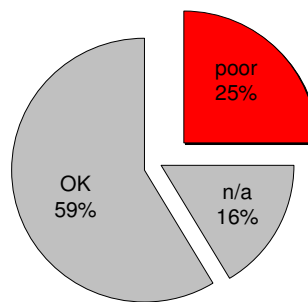


Figure 10-4 Joist to Bearer Non-Compliance with NZS3604:1999

10.2.1.1 _____ Fixing Compliance for the Age of Dwelling.

Figure 10.5 shows that for the Joist to Bearer connection, most dwellings built after 1960 achieved the minimum standard for compliance, while dwellings constructed before 1920 exhibit varying requirements with regard to what was deemed acceptable; shown by the number of variations of the same connection. The biggest proportion of dwellings that failed the requirements [as seen as darker shades] were constructed prior to 1950.

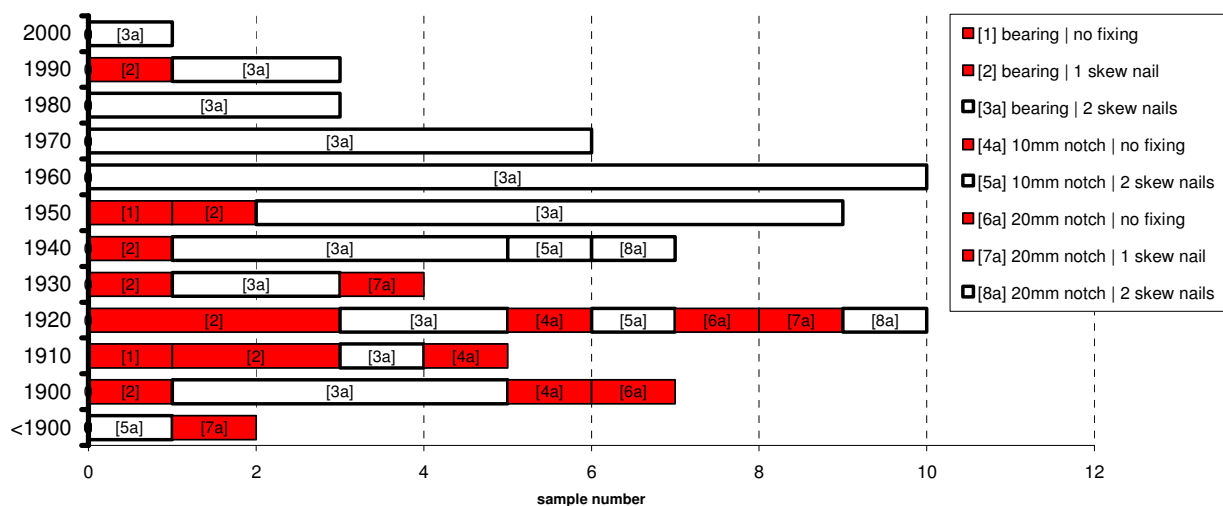


Figure 10-5 Joist to Bearer Connection Acceptable and Unacceptable under NZS3604:1999 per Age of Dwelling

Figure 10.6 shows the number of fixings that may be considered adequate compared with relevant historic standards. Standards in 1964 may have considered one skew nail as “*connected together in a secure manner*” (Standards Association of New Zealand 1964). Also, the connections which exhibited no nails, sometimes used notching to withstand movement and could be objectively considered as “*all floor joists securely fixed in position*” (Standards Association of New Zealand 1944, section 935(a)). Considering that nails were generally longer and the timber was usually denser and stronger than what is used today, these assumptions could be considered adequate. However, many standards were not in circulation when the fixings were used.

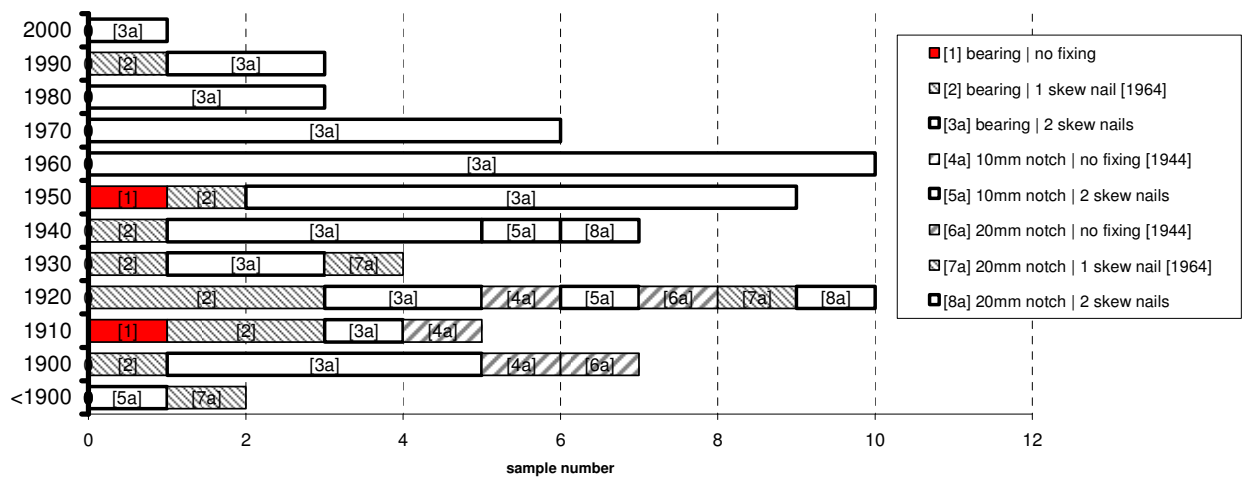


Figure 10-6 Changes in Construction Standards for Joist to Bearer Connections

It must be considered that past building expertise influenced the construction of dwellings, despite revisions in fixing practices. For the purposes of remedy, fixings below the current standard will still require new fixings.

The Ordinary Pile to Bearer connection is typically the most important connection between the ground and the superstructure of the dwelling. It is responsible for maintaining the vertical integrity of the foundation, even though this fixing can be incorrectly reinstated during repiling. Figure 10.7 shows that 35% of dwellings had poor fixings in the Ordinary Pile to Bearer area.

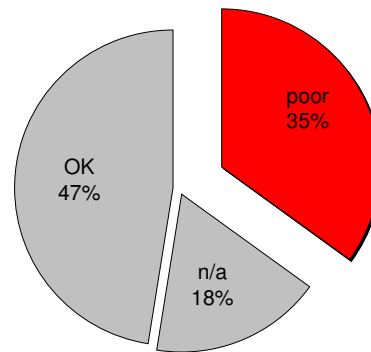


Figure 10-7 Ordinary Pile to Bearer Non-Compliance with NZS3604:1999

The compliance for the Ordinary Pile to Bearer fixing requires, either 4mm wire and 4 staples, or 2 Z nails and 2 skew nails for concrete and timber respectively. Figure 10.8 shows that dwellings predating 1930 have the most significant issues with this connection. Other newer dwellings have variations on the fixing, however they are still within the prescription of the standard.

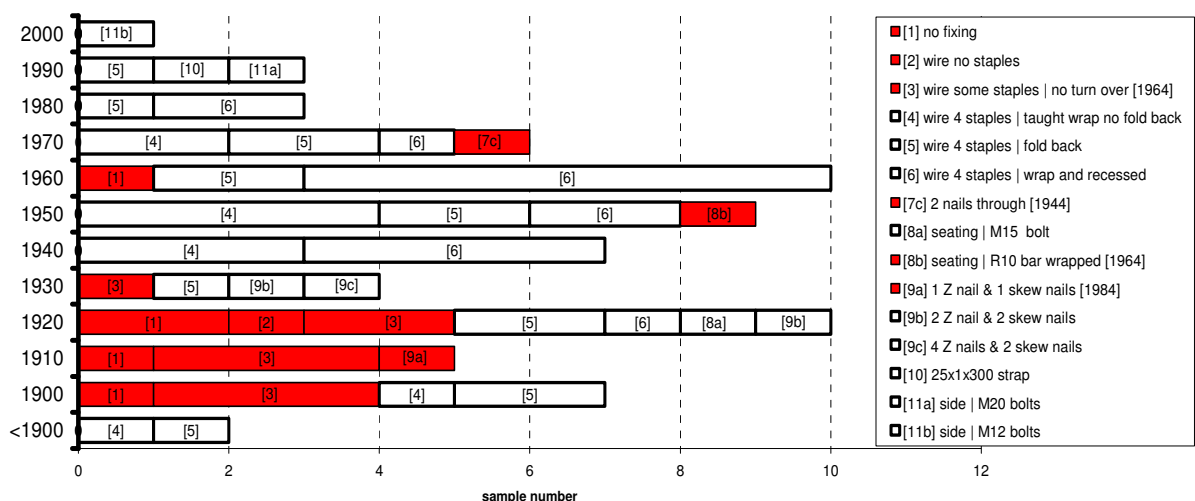


Figure 10-8 Ordinary Pile to Bearer Connection Acceptable and Unacceptable under NZS3604:1999 per Age of Dwelling

Using the data pertaining to repiled dwellings it is possible to gauge whether the issue of fixing variation and non-compliance is the result of the application. Figure 10.9 shows that almost half of the dwellings that had inadequate fixings have been repiled. These issues are usually the result of stapling errors or omitting parts of the fixing.

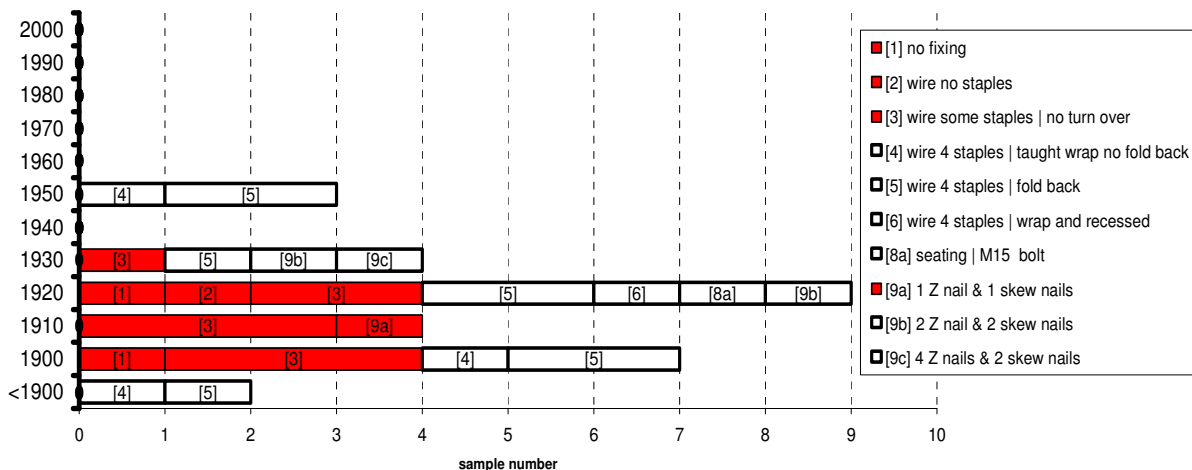


Figure 10-9 Ordinary Pile to Bearer Connection showing only Repiled Dwellings with Acceptable and Unacceptable Fixings under NZS3604:1999

Figure 10.10 shows that dwellings constructed before 1920 could be assumed to be adequate under NZS 1900. However, this standard did not exist at these times and most fixing variations in this area are the result of poor workmanship, especially since prescriptions for this fixing have not changed since the beginning of formal standards.

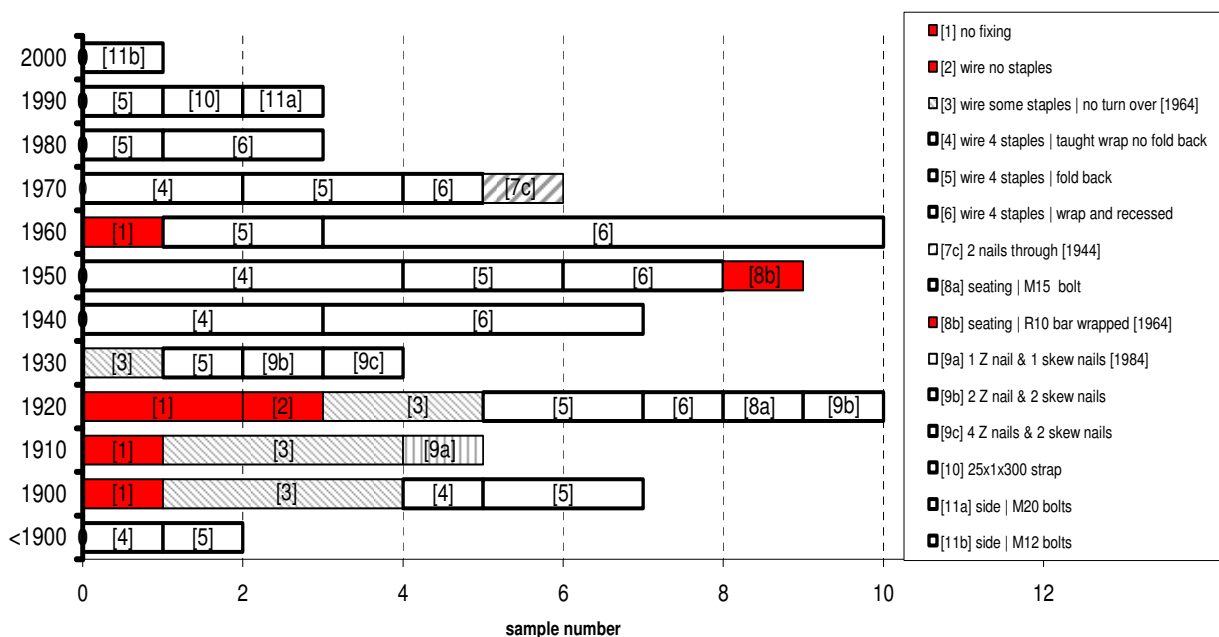


Figure 10-10 Changes in Construction Standards for Ordinary Pile to Bearer Connection

10.2.3 *Plate to Foundation Wall (P-FW) Fixing*

The Plate to Foundation Wall fixing is only required for dwellings with either a partial or full concrete foundation wall, which makes up almost half of the sample dwellings. Figure 10.11, shows that of these dwellings, 1/3 are under requirements of NZS3604 and 2/3 are considered adequate. The Plate to Foundation Wall has received attention in most standards, which usually reduced the spacing allowed between fixings [refer Section 4.3.3].

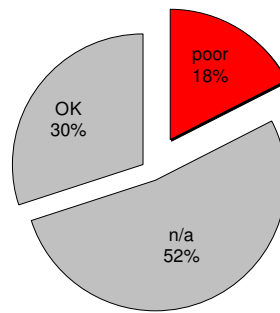


Figure 10-11 Plate to Foundation Wall Non-Compliance with NZS3604:1999

10.2.3.1 *Fixing Compliance for the Age of Dwelling.*

Due to changes in the historic standards and the overall variation of interpretation of requirements, spacings ranged from 900mm up to 1600mm. Figure 10.12 suggests that of the ‘bolted’ Plate to Foundation Wall fixings, all of the spacings are within the current prescriptions, however, the ‘reinforcing bar’ requirement shows that all of the connections are considered inadequate with only 3 dwellings in 1960 and 1970 being above current requirements.

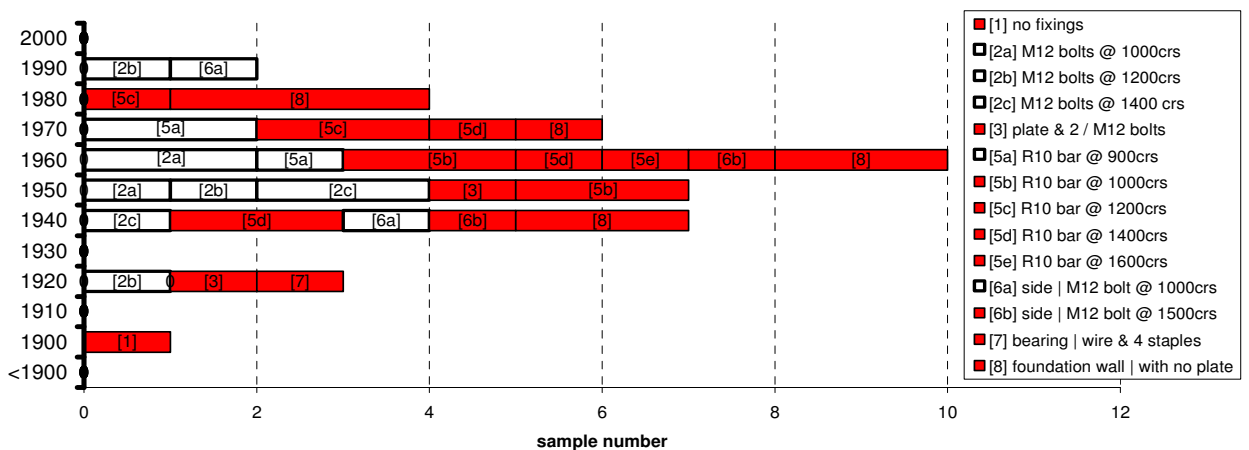


Figure 10-12 Plate to Foundation Wall Connection Acceptable and Unacceptable

Historic standards for the Plate to Foundation Wall fixing, illustrates the effect of superseding standards, affecting almost half of the dwellings [Figure 10.13].

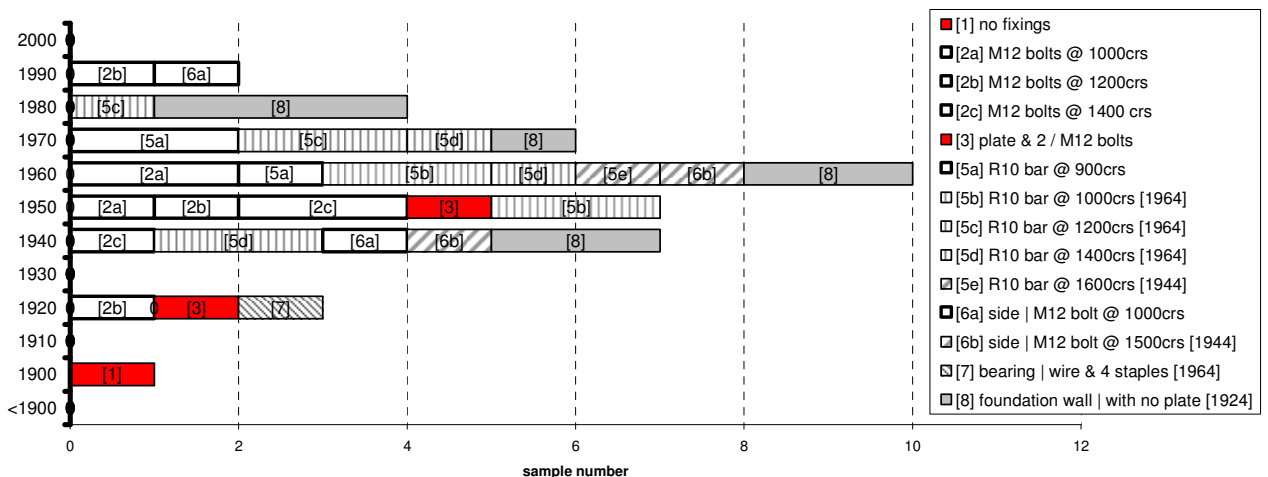


Figure 10-13 Changes in Construction Standards for Plate to Foundation Wall Connection

A significant proportion of dwellings constructed after 1964 have reinforcing rod spacings over 900mm. This variation in fixing spacings may be a result of either an incorrect interpretation of the standards or confusion with the bolted connection spacings. The fixing listed as foundation wall with no plate is in reference to FFW/IP dwellings. These dwellings have no plate and are usually only connected to the exterior foundation wall with friction.

10.2.4 *Bearer to Bearer (B-B) Fixing*

The Bearer to Bearer connection has had only minor coverage in all standards prior to NZS3604. Thus, in many cases wire and staples are used, where a 12kN fixing is required. Figure 10.14 shows that 69% of the sample dwellings had incorrect Bearer to Bearer fixings.

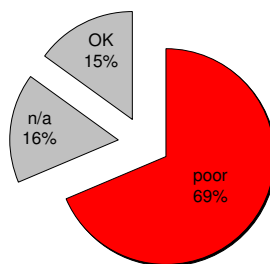


Figure 10-14 Bearer to Bearer Non-Compliance with NZS3604:1999

10.2.4.1 *Fixing Compliance for the Age of Dwelling.*

Figure 10.15 shows that over every foundation in the sample, only 4 dwellings have adequate fixings and only one has the required fixing stated in NZS3604:1999. Other fixings vary between butt joints and 45° splayed or notched face joints with nails penetrating both sides.

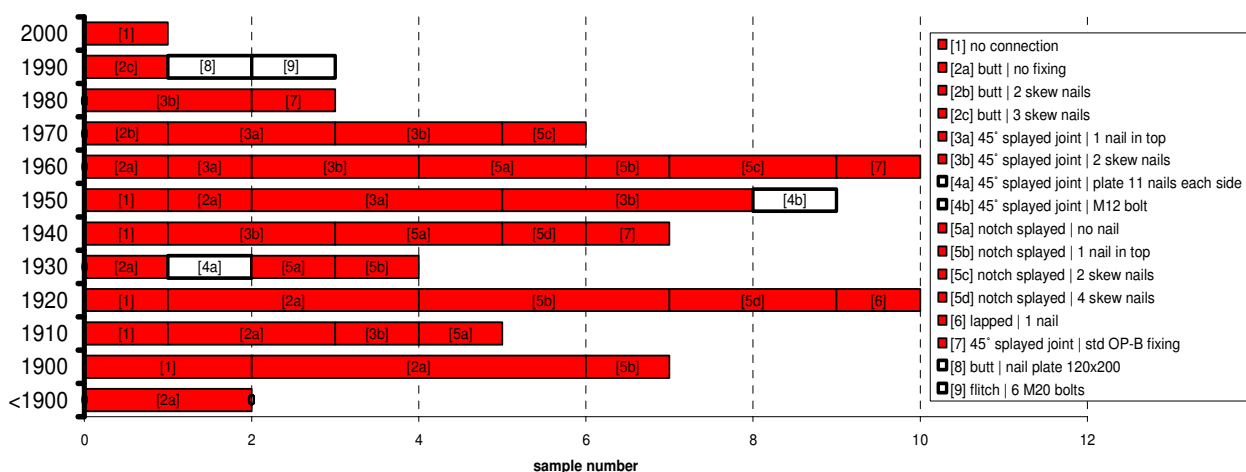


Figure 10-15 Bearer to Bearer connection Acceptable and Unacceptable

The variation of different Bearer to Bearer fixings is largely due to ambiguous requirements in older standards and interpretations regarding the strength of the connection [Figure 10.16]. Often a bearer lap with one nail was a common interpretation of the 1944 standard which stated “all joints in Bearers (plates) shall be halved or scarfed and well nailed and all joints shall be made over an adequate support”(Standards Association of New Zealand 1944, section 925(i)).

The connection “well nailed” is subjective and usually only meant one single nail penetrating the upper and lower diagonal face of interconnecting timbers. The 1964 standard generally increased the requirement for nail fixings twofold, however, these dwellings would still fail by current standards.

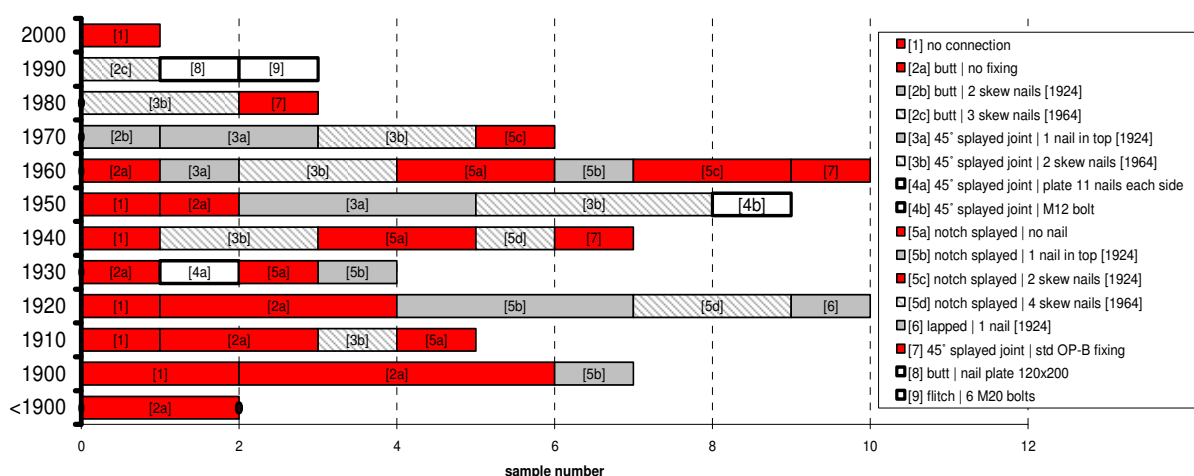


Figure 10-16 Bearer to Bearer Connection Acceptable and Unacceptable over different Standards

10.3 Non Structural Provision Compliances

The compliance with NZS3604 for the overall dwelling condition is limited to issues regarding moisture control and ventilation adequacy. The use of bituminous products for timber to concrete interfaces such as DPC, are included in most standards, however may not necessarily be applied.

10.3.1

Ventilation Provisions

Two factors decide the overall compliance with historic ventilation standards, the ventilation opening size relative to the area of dwelling and the spacings of the ventilation openings. Figure 10.17 shows that 43% of the sample dwellings had poor ventilation area compared with provisions stated in NZS3604:1999.

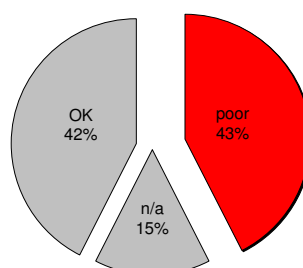


Figure 10-17 Proportion of Sample under Ventilation area requirements stated in NZS3604:1999

Figure 10.18 shows that the spread of poor ventilation occurs in dwellings constructed prior to 1940. However, some dwellings in the 1950-1970 age bracket also have issues with under

ventilated sub-floor areas. Overall, the best performing dwellings for ventilation adequacy were constructed between 1940 and 1960, which is colloquially known as the State House era.

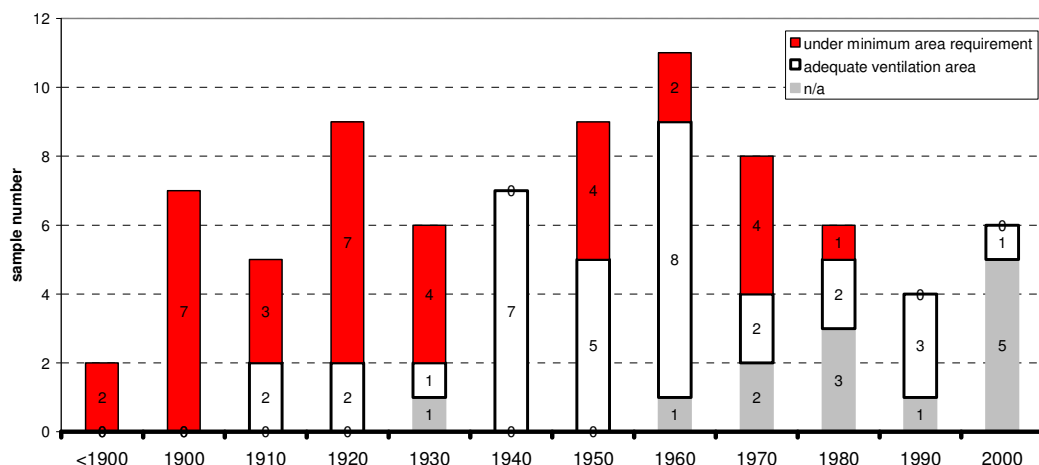


Figure 10-18 Area of Ventilation per Square metre of Dwelling per Age of Dwelling

The spacing of ventilation openings is a provision to ensure that no part of the sub-floor is further than 7.5m from any ventilation opening (BRANZ 2005). Figure 10.19 shows that the number of dwellings with incorrect spacings is significantly less than dwellings with insufficient ventilation per square metre, thus it is the ventilation exhaust size that may be the source of ventilation issues.

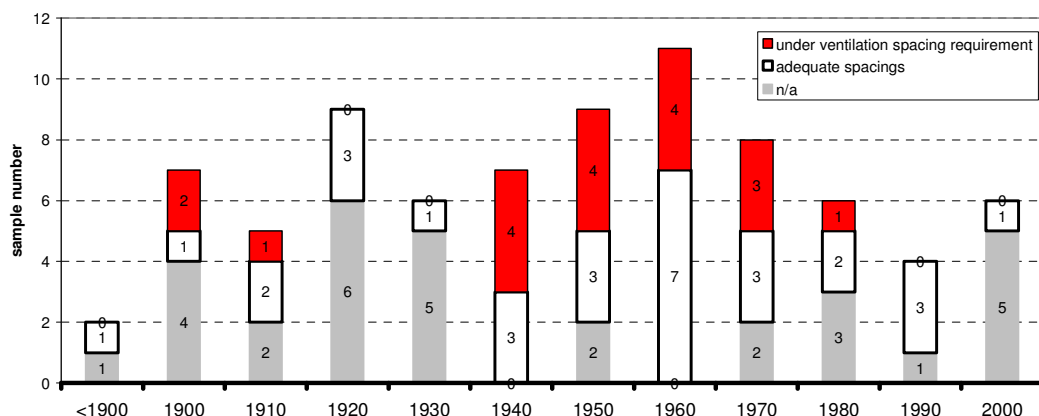


Figure 10-19 Spacing of Ventilation per Age of Dwelling

10.3.2

Bearer Clearance

The current minimum bearer clearance is 150mm with DPC between the pile top and Bearer. Figure 10.20 shows that a significant number of dwellings built prior to 1940 are under the minimum clearance requirements. Some dwellings in the newer ages are also under requirements, however, this is applicable only for a small proportion of the foundation rather than the whole sub-floor.

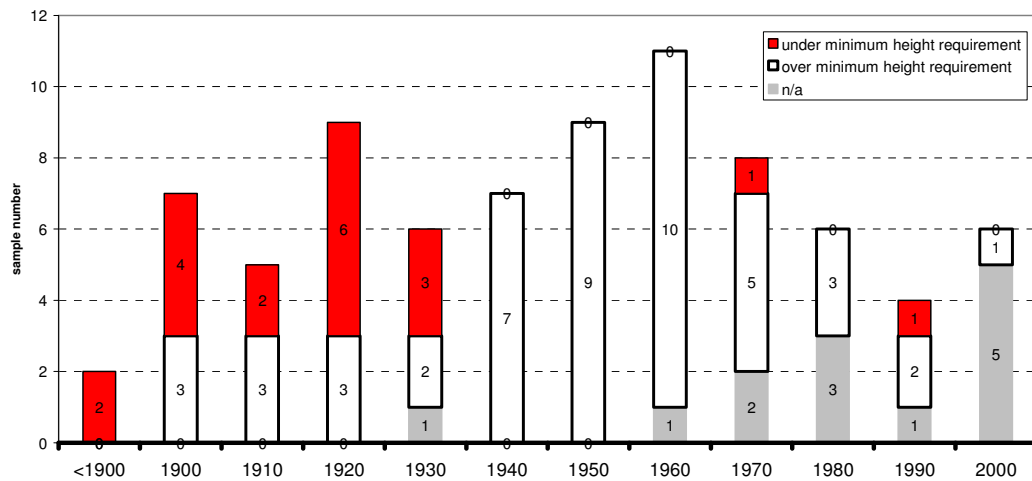


Figure 10-20 Minimum Pile Height up to Standard sizing stated in NZS3604:1999

10.4 Overall Compliance with NZS3604:1999

The compliance with all regulations specific to connections and other parts of the standard can be quantified as an overall compliance with all elements in the sub-floor including: the vertical load resisting system, the fixings and the other non-structural provisions. Figure 10.21 shows the total average compliance for each age group. These were calculated by taking all of the sub-floor provisions, including structural member compliance, fixing compliance and non-structural provision compliance, to determine an overall percentage of compliance per dwelling. This analysis assumed that all provisions had equal weighting and were all equally important for the long term seismic adequacy of a sub-floor.

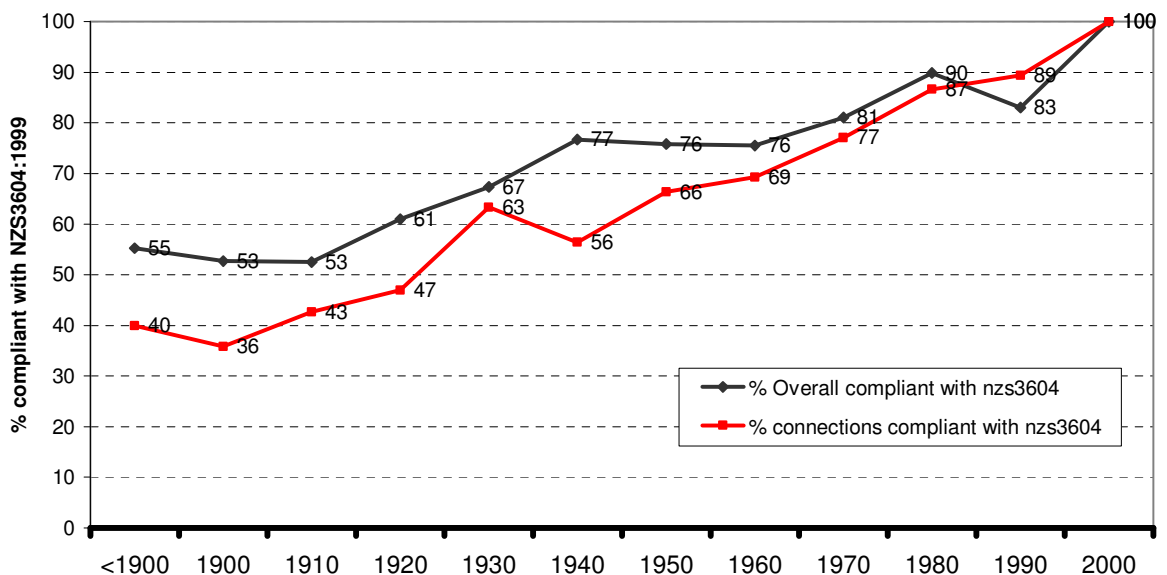


Figure 10-21 Percentage of Compliance against NZS3604:1999 per Age of Dwelling

The trend shows a constant increase up until a maximum compliance against NZS3604:1999 in the 2000 age bracket. The dip toward 1910 in the overall compliance may be reflective of building practices or vertical load resisting elements that differ significantly from the current

standards. Other features show a decline of overall compliance in the 1990 age bracket, which reflects poor sizing of timber members rather than inadequate fixing compliance. The overall connection compliance trend, shows that dwellings have worse fixing compliances compared with the overall trend, not including degradation of fixings. The 1930 dwellings show a significant increase in connection compliance, which may be reflective of modern repiling techniques and adherence to NZS3604:1999. Figure 10.22 shows a similar trend for foundation types.

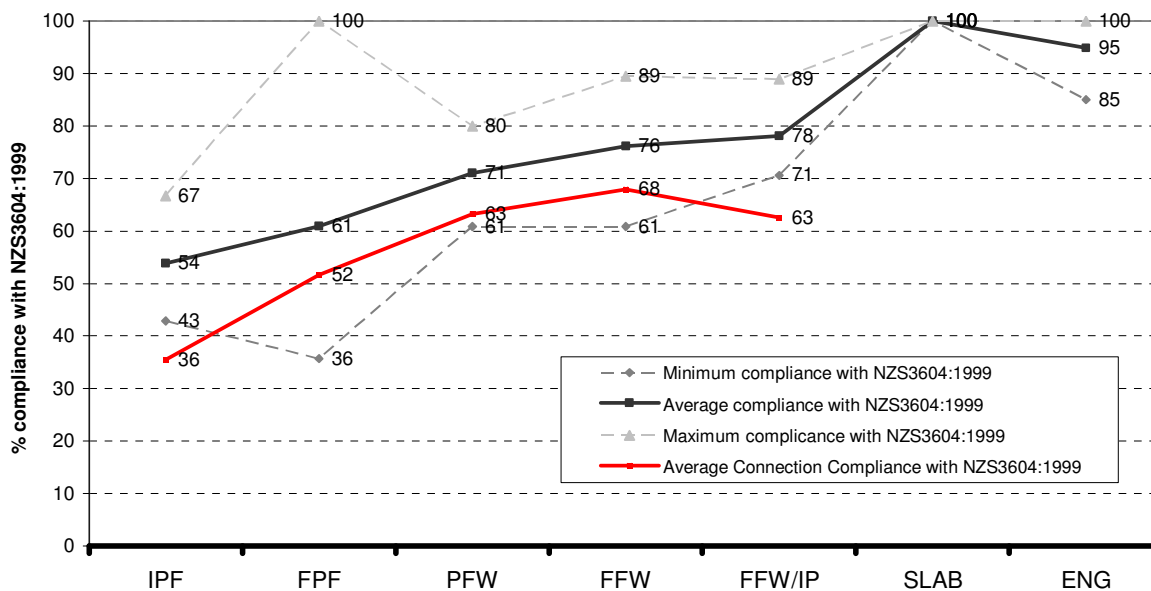


Figure 10-22 Percentage of Compliance against NZS3604:1999 per Foundation type

The trend for foundation types shows that Full Piled Foundations comply less often than newer foundation types constructed to NZS3604:1999 prescriptions. The Full Piled Foundation also exhibits the greatest spread between maximum and minimum compliances. Connections and fixings follow the same trend for compliance, however the Full Foundation Wall / Internal Piled dwelling shows a downward trend in compliance due to the lower number of fixings in the foundation and the greater emphasis on each fixing to comply.

10.5 Summary of Comparison with NZS3604:1999

Historic standards have generally been superseded in areas such as fixings, whereas structural and non structural provisions have not significantly altered since 1924. The structural members were generally within prescriptions of all historic standards, and therefore tend to be adequate in terms of NZS3604:1999. However, an analysis of fixing areas showed that; Joist to Bearer fixings were inadequate in 25% of the sample and the Bearer to Bearer fixings were inadequate in 69% of the sample. Furthermore, the Plate to Foundation Wall fixings were inadequate in 37% of applicable dwellings within the sample. While this connection has been updated and superseded through all historic standards, only three dwellings were inadequate in terms of all past and current standards. Non structural requirements, such as ventilation are historically not widely complied with. 42% of the dwellings sampled were under the ventilation requirements and 24% had inadequate ventilation spacings as required by NZS3604:1999. Dwellings generally constructed prior to 1940 had less clearance from CGL than prescribed, with many sitting directly on the ground. From assessing the sample, it is apparent that certain dwellings require different levels of remedies. Each remedy must be specific to the age and foundation type of the dwelling, as well as taking into account the level of compliance with NZS3604:1999.

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The purpose of this study is two fold, first the study will assess the current adequacy of foundations and second it will determine what remedial measures can be applied to each foundation type to ensure compliance with NZS3604:1999. The suitability of bracing remedies in particular, will depend on the existing bracing systems, specific parameters of the application for remedial bracing and the overall cost. Remedial fixing measures consist of three different types of fixing, depending on the location of and workable space around the connection. These are standard fixings, alternative fixings and proprietary fixings. Non structural requirements will be applied according to need up to requirements with NZS3604:1999.

11.1 Remedial Construction Limitations

The use of a particular remedy will depend upon how suited it is to the particular onsite conditions including the difficulty of application. Various fixings normal in new dwelling construction may require alternative methods of application due to cramped working spaces in the sub-floor. These parameters, excluding cost, will be used to determine whether a bracing system is adequate for a particular foundation type.

11.1.1

Tight Spaces

The space under dwellings is often cramped. This contributes to the constructability of a remedy. Certain labour tasks, such as digging and hammering will be very difficult in extremely tight spaces, especially where bearer clearance is minimal [refer Section 9.5.2]. Swinging a hammer with enough force, or having enough space for a power driven nail gun, could require up to 600mm of space around the target area (Mills 1985). However, these parameters depend upon the specific dwelling's age, location and foundation type.

11.1.2

Connections to Concrete

Concrete connections will be common in the sample dwellings, given that 70% of the sample dwellings have either concrete piles or a concrete foundation wall [refer Section 9.2.2]. For this reason the concrete to timber fixing shall be either a drilled hole with an M12 bolt or power driven nail fixing equivalent, with allowances for limited concrete strength. In many circumstances, framing is required around concrete piles for the adequate application of sheet bracing. Moreover in the concrete to timber situations, DPC is also necessary [refer Appendix E].

The location of bracing remedial measures need to consider the regular spread of existing and new bracing over the whole foundation so that remedial solutions do not affect the torsional or vibrational response of the dwelling (Thurston 2001) [refer Section 5.1]. NZS3604:1999 requires a minimum of 10BU per metre [0.5kN/m] on the exterior bracing lines of the dwelling, and a minimum of 70BU [3.5kN] total for each internal bracing line. All bracing must be spread evenly along each bracing line and should be parallel to external walls. The application of new bracing systems can be used to limit existing configuration issues due to differing foundation systems, however, careful placement is necessary not to exacerbate these issues any further (Potangaroa 1983).

The remedial bracing systems must be compatible and complement the existing bracing system. For example, if a Full Piled Foundation requires bracing, anchor piles or braced piles should be specified first, so as to limit issues created with differing foundation systems [refer Section 5.1.1]. This continuity of structure will mean that it is easier to predict how dwellings will react in earthquakes. This will eliminate inconsistent reactions, which can cause unpredictable damage at junctions between old and new systems (Beattie 2001).

11.2 Remedial Bracing Measures

Remedial bracing measures are considered to reduce the risk of moderate and extensive damage to dwellings and to reduce the number of uninhabitable dwellings following an earthquake by mitigating collapse. The solutions for remedial bracing measures include two piled bracing systems and two different sheet bracing solutions, which the study has found to be the best method of gaining the most lateral strength with minimum cost input. The application of each solution will depend on constructability factors and the specific bracing requirements of each foundation [refer Chapter 7], relating to each foundation type [refer Section 7.5.3]. Figure 11.1 shows the actual requirement of bracing ranging from under 120BU per line [6kN] up to 360BU [18kN] per line.

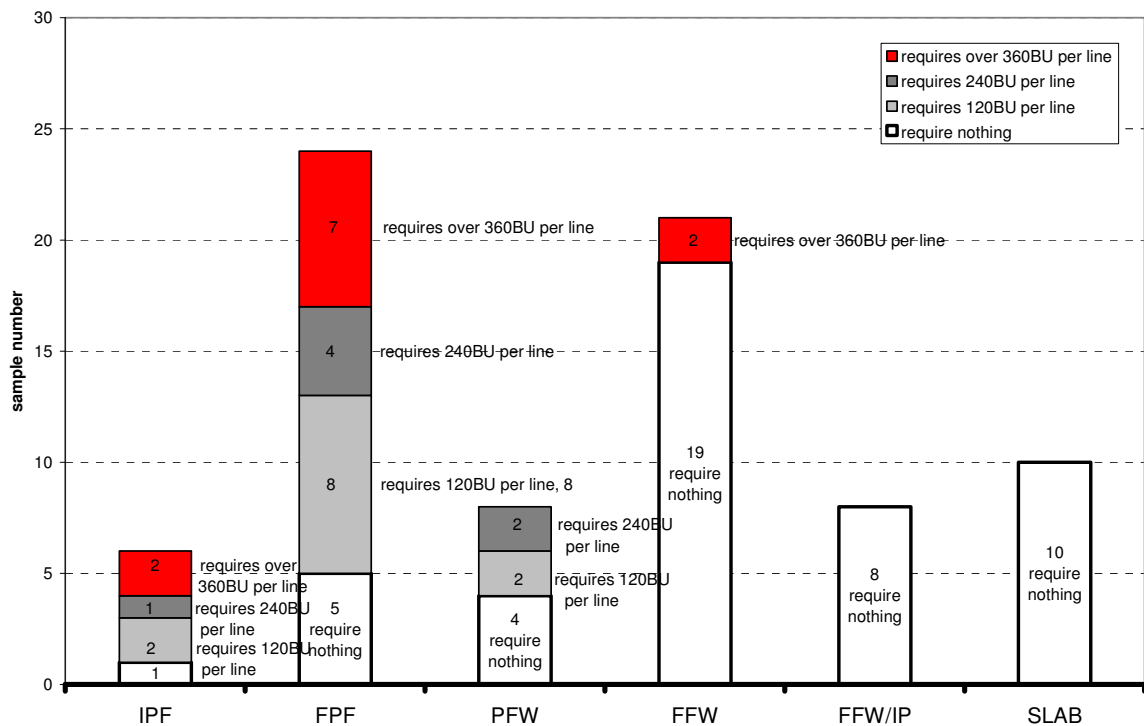


Figure 11-1 Requirements per Bearer line for each Dwelling

The total spread of bracing units over the whole sample shows that most of the bracing is required by the Full Piled Foundation and to a lesser extent the Internally Piled Foundation. Other foundations contribute in smaller parts to the higher end of the bracing units, however, this is most probably due to construction anomalies.

11.2.1 *The Piled Solutions*

Remedial piled solutions include the anchor pile solution, seen in Figure 11.2 and the braced pile solution in Figure 11.3, both of which are prescribed in NZS3604:1999 (Standards New Zealand). Both solutions offer a 6kN [120BU] bracing element and both have different physical limitations for application into existing dwellings.

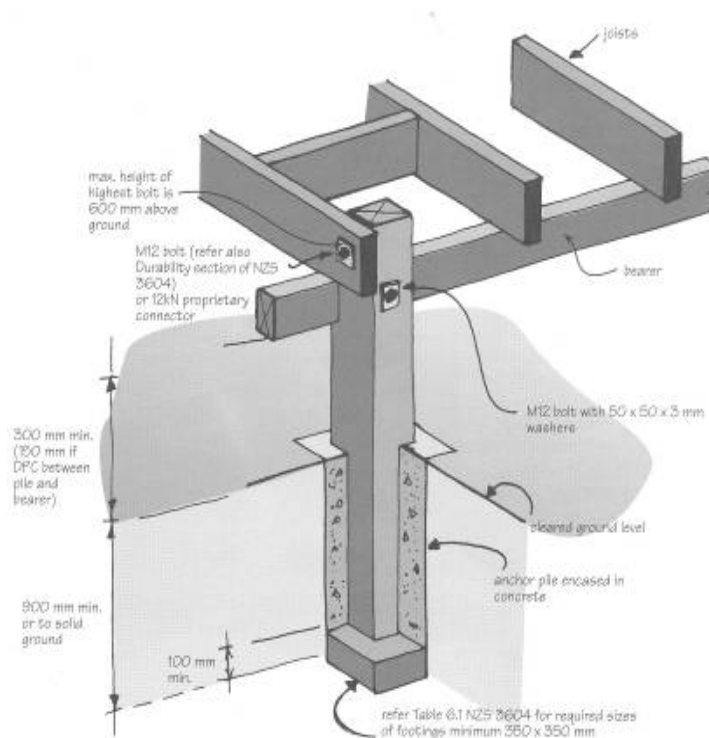


Figure 11-2 Anchor Pile Solution (Source: BRANZ 2000)

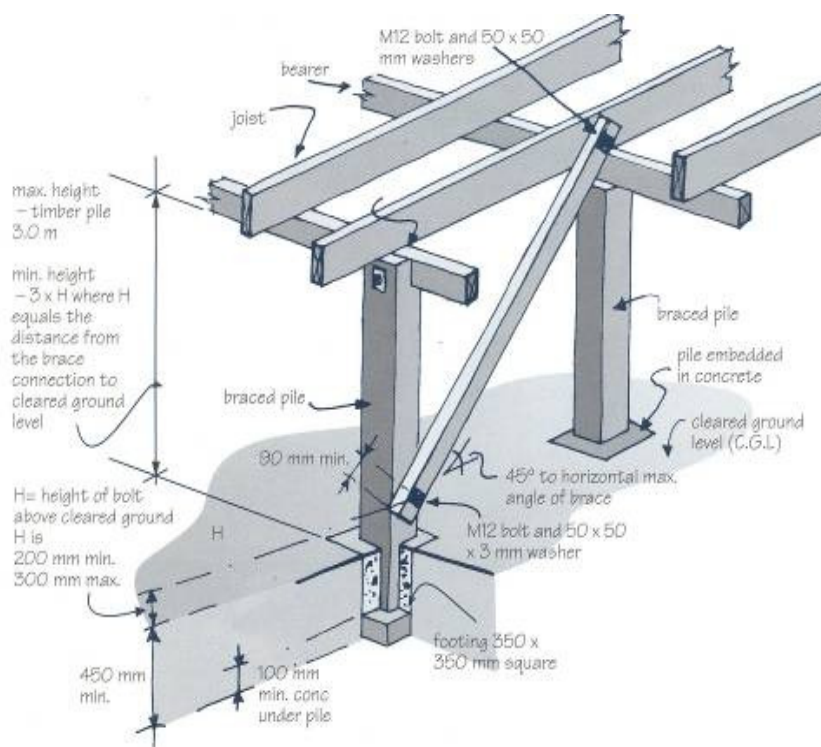


Figure 11-3 Braced Pile Solution, Braced from Pile to Joist (Source: BRANZ 2000)

11.2.1.1 *Height Limitations of Piled Applications*

The major limiting factor for the braced pile solution is the placement and height of the foundation. Figure 11.4 shows the average sample dwelling height in mm, with the maximum and minimum at either end. The braced pile solution requires a minimum of 450mm between bearers and CGL, so the solution will only apply to around one quarter of the sample.

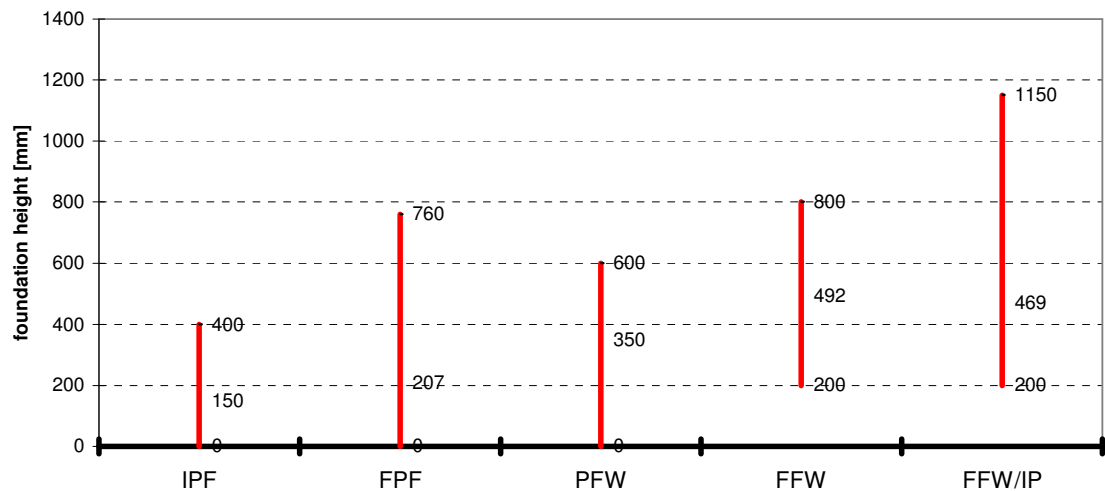


Figure 11-4 Average, Maximum and Minimum Foundation Heights from CGL by Foundation type

The minimum height for anchor piles is 150mm, which is also the overall minimum allowable sub-floor height. However, this distance is impractical for the purposes of digging a 900mm footing to install piles, unless the floor is cut and removed to excavate piles on the interior of the dwelling. Although this practice is common for repiling, it may be too destructive for remedial purposes [Figure 11.5].

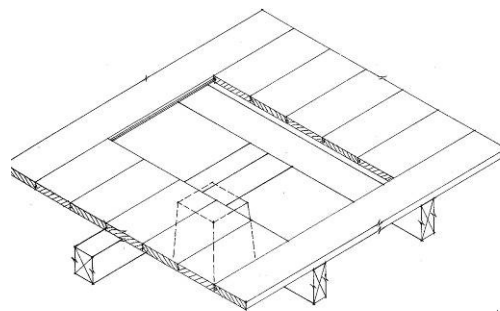


Figure 11-5 Repiling Practice of cutting Floor Boards to access Piles (Source: Cochran 1980)

Thus for the purposes of this study, anchor piles will be applied only to the exterior perimeter of dwellings. If the perimeter does not allow sufficient piles to brace the entire dwelling, another stronger bracing solution will be selected.

11.2.1.2

Piled Solution Costs

Costs for each bracing solution were quantified and costed by a qualified Quantity Surveyor, which suggested that the material and labour required to install one braced pile system is over twice as expensive as one anchor pile [refer Appendix E1.1 and E1.4]. Applying costing information to achieve the number of Bracing Units required per Bearer line in each dwelling, concludes that the braced pile solution should only be applied when height restrictions do not allow for anchor piles [refer Appendix B2.4]. Figure 11.6 shows that the Full Piled Foundation has a significant proportion of the sample requiring more than 3 piled solutions per bracing line.

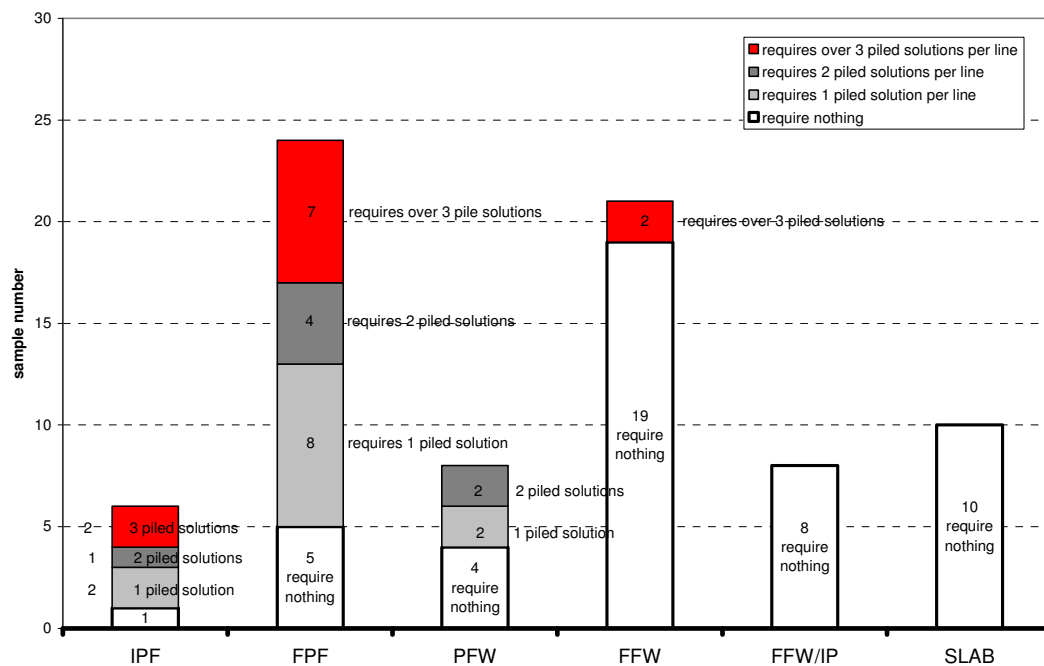


Figure 11-6 Piled Solution Bracing required per Foundation type

Based on the relative costs of each system [refer Appendix E], if a dwelling requires over 3 piled bracing solutions per bearer line, a more cost-effective solution should be utilised. Such systems include sheet bracing on exterior piles or concrete infill wall. The best solution for each foundation type based on costs will be compared and assessed at the end of the chapter [refer Section 11.5].

11.2.2 *The Sheet Bracing Solutions*

The sheet bracing solutions offer applications that gain their strength when the length of the bracing element is increased [refer Section 6.3.1]. Solutions include the application of sheeting material to exterior piles and the infill of concrete between exterior concrete piles, in accordance with the BRANZ remedial solutions in *Strengthening Houses against Earthquake: A Handbook of Remedial Measures* (Cooney 1982).

11.2.2.1 *Sheeting Material Selection*

The two versions for sheet bracing on exterior piles are plywood sheeting and cement based sheeting. The cement based sheet bracing on exterior piles, achieves a maximum bracing rating of 80BU per metre [4kN] (James-Hardie 1994). However, using 7mm Plywood on exterior piles can achieve up to a theoretical maximum of 175BU per metre [9kN] using height to length ratios suited for sub-floor walls (Carter Holt Harvey 2005) [refer Section 6.3.1]. Since the strength, ease of application, and finish to plywood is better than the cement based sheeting product, plywood will be utilised and costed for all sheet bracing applications [Figure 11.7].

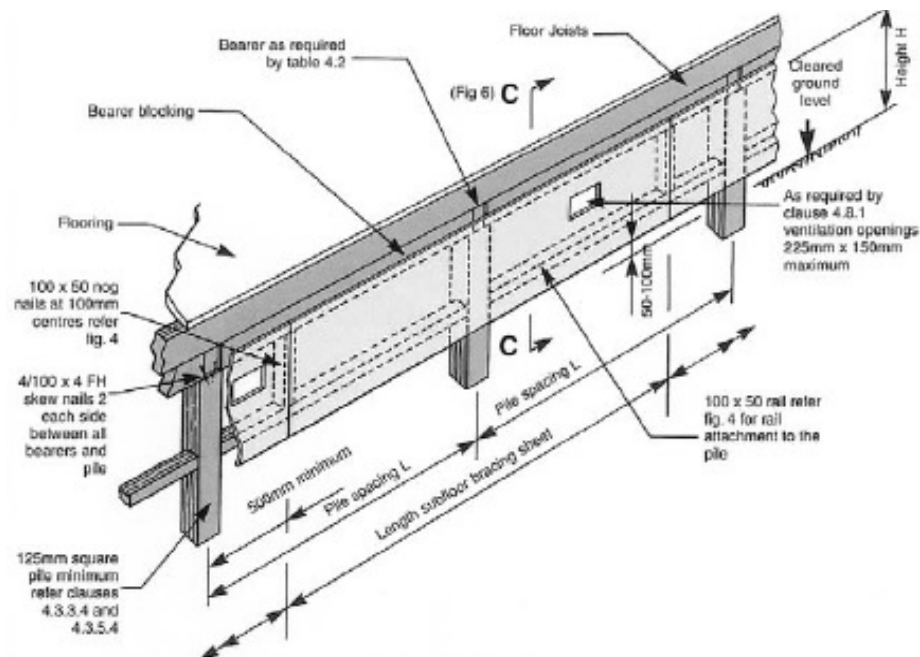


Figure 11-7 Sheet Bracing Remedial Solution (Source: James-Hardie 1994)

Sheet bracing on exterior concrete piles requires constructing framing between piles and fixing the perimeter directly to this framing. Thus, construction costs will be reduced if the exterior piles are timber. Manufacturers prescribe a strict minimum number of fixings to achieve the required bracing, as well as limitations on maximum and minimum sheet height and distance from CGL. Alternatively, the concrete infill wall solution (Cooney 1982) requires the bracing element to be integrally cast with existing footings, spanning between the two piles [Figure 11.8].

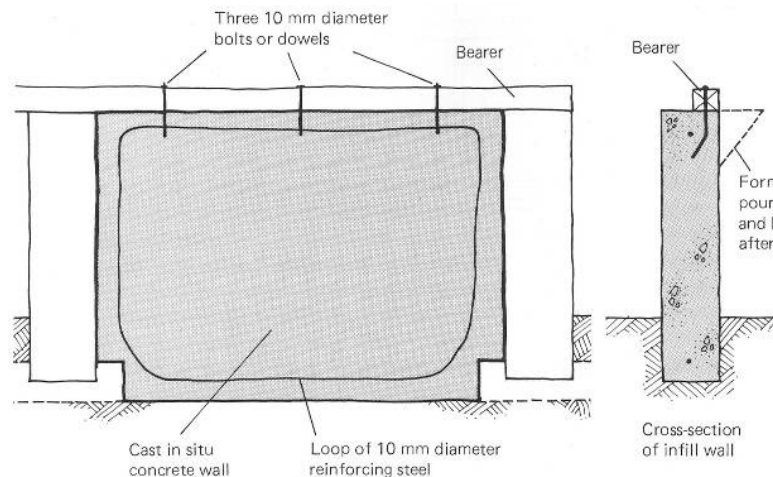


Figure 11-8 Concrete Infill Wall Remedial Solution (Source: Cooney 1982)

11.2.2.2

Maximum Bracing Capacities

The infill wall solution offers a minimum 42BU per metre for a short wall, up to a maximum bracing capacity of 300BU per metre, based on the parameters of a continuous concrete wall. However, due to the intermittent nature of the infill wall, and distance between piles, the solution may only obtain between 100-200BU per metre. It is often recommended that dwellings with concrete or clay tile roofs, and a floor area over 100sqm should have longer infill

walls preferably at the corners (Cooney 1982). Figure 11.9 shows the number of sample dwellings that require a proportion of the perimeter braced with plywood sheet bracing, to achieve the minimum bracing requirements.

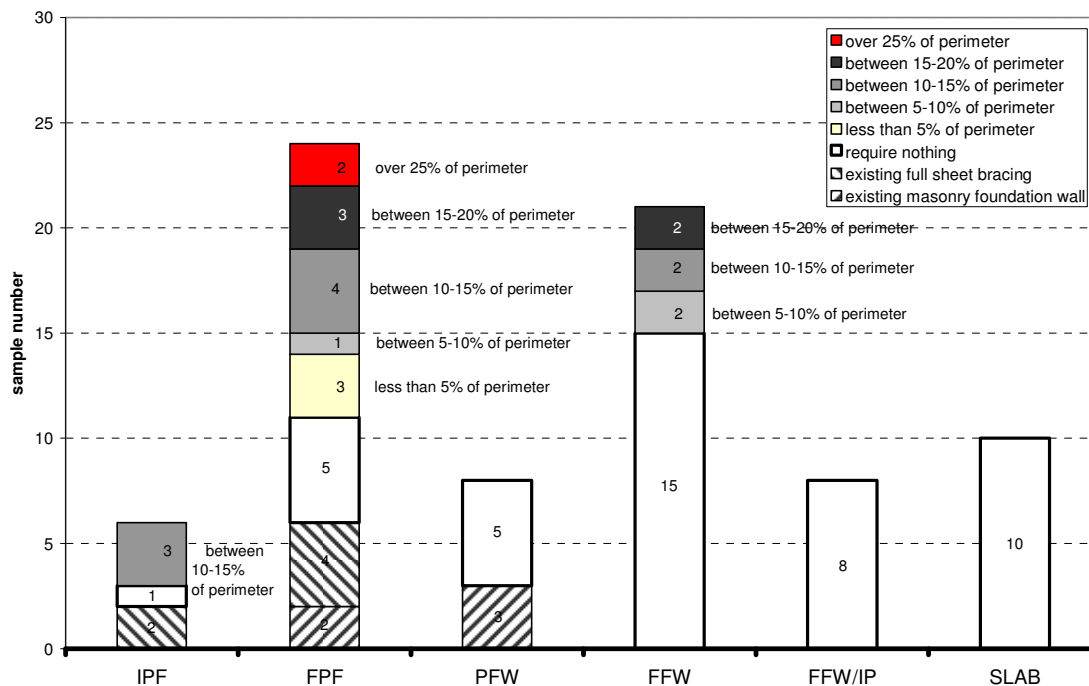


Figure 11-9 Percentage of Perimeter Plywood Sheet Bracing required per Foundation type

The plywood sheet solution can be applied to a large number of dwellings with Full Piled Foundation and Full Foundation Wall. However, since many piled dwellings are less than the minimum plywood sheet height requirement of 350mm, the infill concrete wall may be the only suitable option. Figure 11.10 shows the number of pile bays required to achieve the minimum bracing requirements for the concrete infill wall remedy.

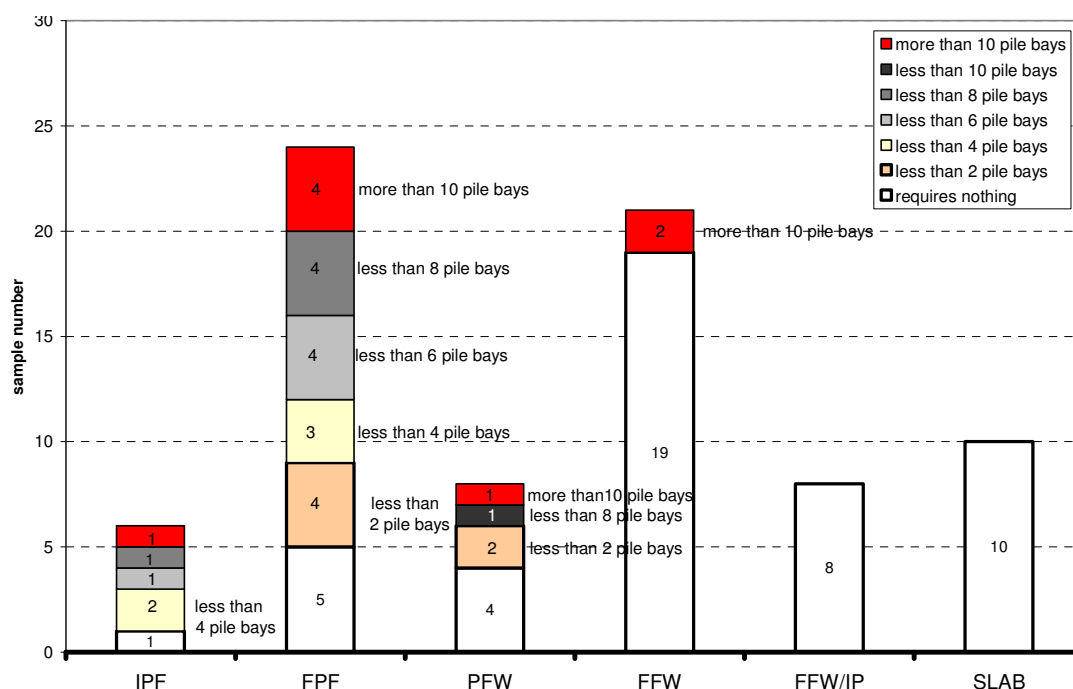


Figure 11-10 Number of Pile Bays of Infill wall required to meet Minimum Bracing Requirements

The infill wall bracing remedy requires upwards of 10 pile bays, compared with the sheeting maximum which is over 25% of the dwelling perimeter, or approximately 11 pile bays. The length to height ratio of the plywood sheet appears to provide favourable strength characteristics compared with the concrete solution. In this situation, the cost comparison will decide the outcome of the remedial bracing solution. Although, it is usually more economic, to use timber to resist vertical loads and concrete to resist horizontal loads (Potangaroa 1983); quantity surveying results suggest that the infill wall solution is over ten times the cost of a similar length plywood sheeting solution [refer Appendix E1.3].

11.3 Remedial Fixing and Connection Measures

The application of remedial connections and fixings is based on whether a fixing was deemed inadequate in the analysis [refer Section 8.5]. There are currently three fixing methods including the standard fixings from NZS3604:1999, alternative remedies for difficult applications, and proprietary fixings. A list of all fixings, the cost and labour involved is listed in *The Fixing Measures* [refer Appendix E2]. Fixings are applied on the assumption that each dwelling has an average number of inadequate fixings. This assumes that although the sample may have had some severely inadequate examples, the majority of dwellings showed an overall similar inadequacy. Therefore, the costing values will be conservative for all fixing cost estimates.

11.3.1 Standard Fixings

Standard fixings are fixings which are specifically prescribed in NZS3604:1999 and require no special consideration given to the method of application. The fixing will be assumed to have the strength of a similar fixing in a new dwelling, which includes the Ordinary Pile to Bearer [OP-B] fixing and other easily accessible connections such as the Bearer to Bearer [B-B] fixing [refer Section 10.2.4].

11.3.1.1 Ordinary Pile to Bearer [OP-B]

The Ordinary Pile to Bearer connection has two solutions depending on the materiality of the pile. 28% of the sample [refer Section 10.2.2.1], require remedial fixings to concrete piles. The cost of different pile fixing applications is around \$12.00 per unit installed [refer Appendix E2]. Figure 11.12 shows the fixing of a timber bearer to a timber pile, however depending on the joist size, the two skew nails may not be able to be driven [refer Section 11.1.1]. In this case the two nails should be replaced with 2 Z nails.

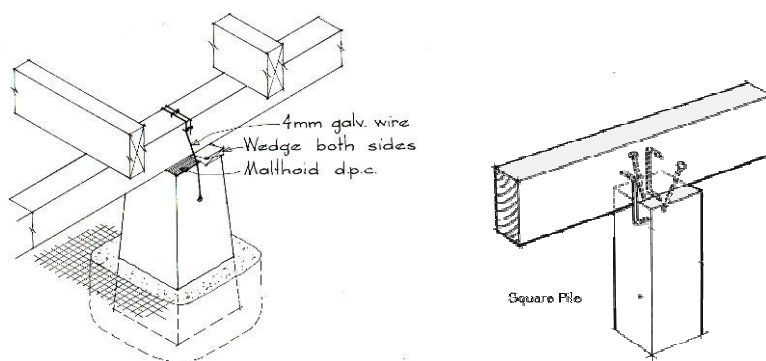


Figure 11-11 Fixing of Bearer to Concrete Ordinary Pile solution (Source: Cochran 1980)

Figure 11-12 Fixing of Bearer to Timber Ordinary Pile solution (Source: MiTek New Zealand Limited 2000)

11.3.2 Alternative Remedial Fixings

Alternative remedial fixings are different due to restrictions in constructability in the sub-floor space. The application of most alternative remedial fixings involves moving the point of fixing to a more appropriate location. The alternative solutions are sourced from *Strengthening Houses against Earthquakes: A handbook of Remedial Measures* (Cooney 1982). The cost of alternative fixings based on quantity surveying results in estimations of \$30.00 per unit installed [refer Appendix E2].

11.3.2.1 Plate to Foundation Wall [P-FW]

The Plate to Foundation Wall was inadequate in 18% of the sample [refer Section 10.2.3]. The P-FW connection to concrete requires a bolt or similar strength fixing, to connect a brace to the wall [Figure 11.13]. The plate may also require packing if the concrete wall is wider than the timber foundation wall plate.

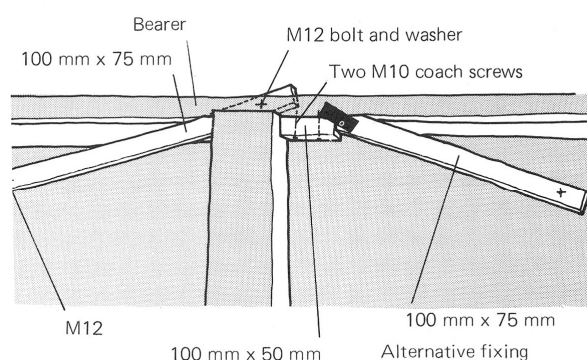


Figure 11-13 Remedial Connection for Plate to Foundation Wall (Source: Cooney 1982)

11.3.3 Proprietary Fixings

Proprietary fixings are used for purposes such as creating a 6kN or 12kN fixing, however the specific requirements differ between manufacturers. These fixings are used as integral parts of bracing systems, and are sold in 'kits' costing around \$30.00 to \$60.00 per unit installed, including labour. However, Stainless Steel fixings required for certain corrosive zones around

New Zealand, were not used for costing estimates, and usually cost more than standard galvanised fixings (Standards New Zealand 1999).

11.4 Remedial Condition Measures

The condition of a foundation takes into account the adequacy of the ventilation, the sub-floor timber clearance, moisture prevention and the general remedy for structural continuity. Remedies to these faults may not specifically aid in earthquake resistance, however, will prolong the life of the structural elements in a foundation, reducing the cost of maintenance and upgrade in the future. All remedial measures, the cost and the labour involved are considered in more detail in *The Overall Condition Measures* [refer Appendix E3].

11.4.1

Ventilation

Sub-floor ventilation requirements show that 42% of the sample requires an opening increase to limit further degradation of the sub-floor area [refer Section 9.5.1]. Creating ventilation opening involves cutting grills at regular intervals in a timber sub-floor, to satisfy the prescription of 3500mm² per metre (Standards New Zealand). Figure 11.14 shows the number of foundations requiring a percentage of ventilation increase.

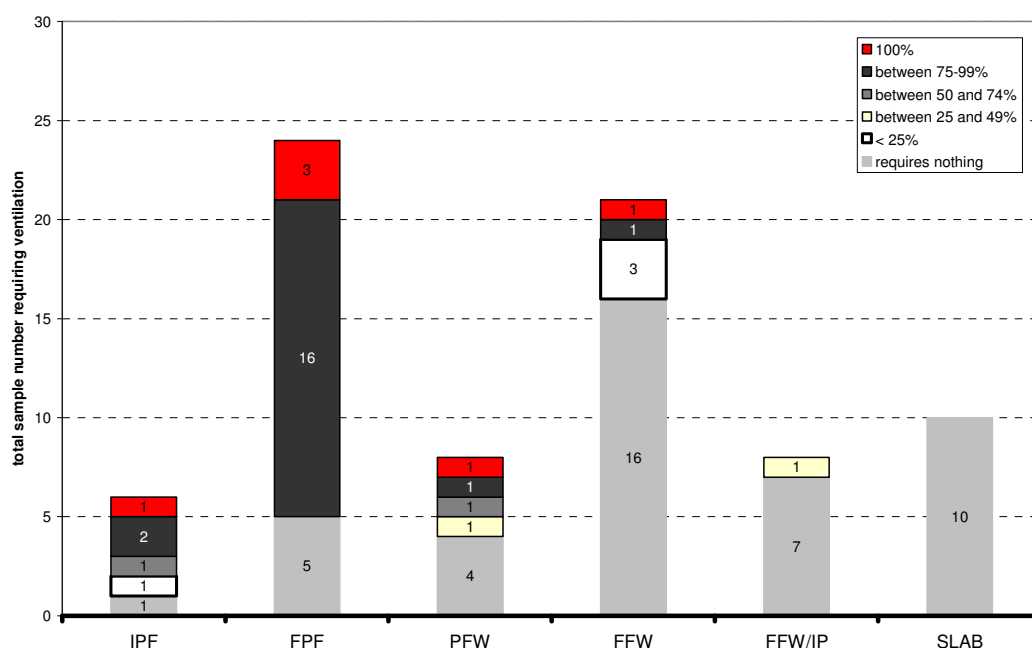


Figure 11-14 Percentage of Ventilation requirements per Foundation type

The sample is dominated by the Full Piled Foundation which requires an increase of over 75%, to bring the sub-floor up to current standards. The total cost of installing new ventilation grills is priced at around \$20.00 per unit installed. However, this remedy is not cost effective for Full concrete Foundation Walls and therefore, polythene sheeting priced at \$5.35 per square metre, is required to limit evaporated moisture in the sub-floor (BRANZ 2005).

The clearance of soil from beneath sub-floor timbers will reduce moisture content in timbers that have previously been sitting close or near to soil. Figure 11.15 illustrates that 27% of the sample require soil clearance which can cost upwards of \$175.00 per cubic metre, which is often required in older dwellings with piled foundations.

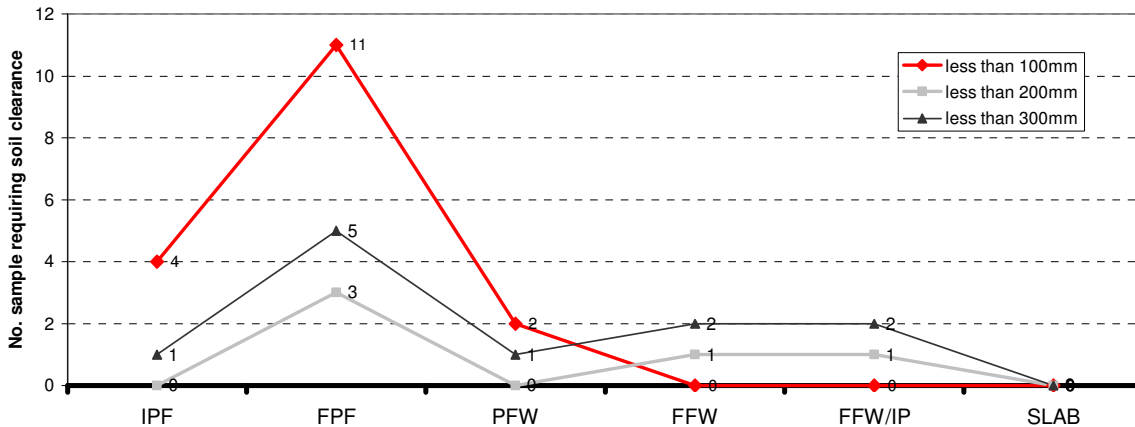


Figure 11-15 Soil Clearance required per Foundation type

The piled and structural deficiencies include undermining, non-vertical piles and insufficient footing depth. These issues account for around 10% of the sample [Figure 11.16]. Missing structure and excessive levelling wedges affect the biggest proportion of the sample at 33% and 40% respectively. These deficiencies are extreme cases of acceptable limits relevant to current standards, which may require propping, replacement and use of additional fixings. However, if not remedied these areas are the most likely to fail in an earthquake. Many soil issues can be remedied with concrete infill around piles, or removal and replacement of old inadequate piles.

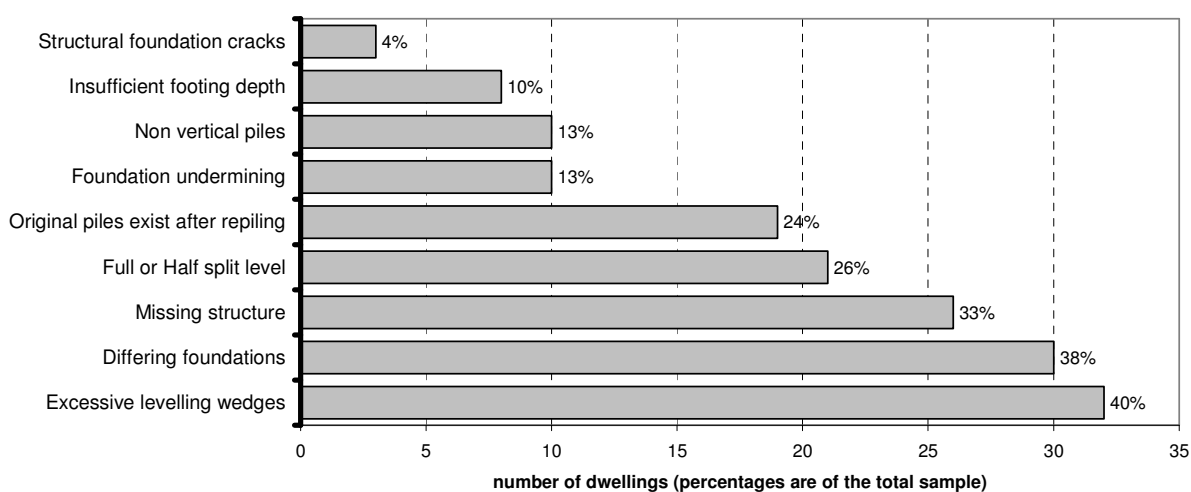


Figure 11-16 Issues which may cause Configuration Issues in the total Sample

11.5 Application of Remedy to Specific Foundation Types

11.5.1 Internally Piled Foundation [IPF]

The Internally Piled Foundation has one of the lowest bearer clearances out of all foundation samples and some of the highest bracing requirements in the sample [Table 11.1]. Overall, 83% require bracing [refer Section 7.5.2] and on average 76% of dwellings require remedial fixings [refer Section 8.5] to upgrade to current standards. The simplest and most appropriate bracing remedy for the IPF is the anchor pile, due to the low overall height of the sub-floors [refer Section 9.5.3]. The overall height of the foundation also indicates the necessity of higher soil removal costs. The total cost to remedy fixings, bracing and overall conditions is calculated at over \$6,500, including around \$5,000 in labour costs, based on January 2007 quantity surveying projections.

	IPF		Requirements totals						
% req. remedy		per unit	Avg #	Max #	Min #	Avg. Labour Cost \$	Avg. Material Cost \$	TOTAL \$	% of cost
83%	Bracing [see Table 7.1]								
Table 8.1	Anchor pile	120BU	10	18	3	\$1,750	\$1,025	\$2,775	42%
	Fixings [see Table 8.1]								
66%	J-B	1.5kN	84	123	47	\$462	\$168	\$630	
66%	J-FW	1.5kN	40	93	31	\$220	\$80	\$300	
83%	OP-B	3kN	57	78	45	\$427	\$114	\$541	
83%	B-B	12kN	5	8	1	\$60	\$60	\$120	
83%	J-J	6kN	24	41	16	\$264	\$96	\$360	
	Total Connection costs					\$1,434	\$518	\$1,952	29%
	Condition[see Table 9.1]								
83%	Ventilation	per unit	11	17	1	\$187	\$38	\$225	
100%	Polythene	m2	131	160	100	\$602	\$98	\$700	
66%	Soil Clearance	m3	5.6	8.5	3.5	\$980	\$0	\$980	
0%	Soil Infill	m3	0	0	0	\$0	\$0	\$0	
	Total General condition costs					\$1,770	\$137	\$1,906	29%
	TOTAL REMEDIAL COSTS					\$4,953	\$1,680	\$6,633	

Table 11-1 Total Breakdown for all Remedial Measures applied to Internally Piled Foundations Dwellings

The sample of Full Piled Foundations has a high number of dwellings with poor conditions and inadequate bracing. A total of 79% of the sample [refer Section 7.5.3] are under bracing requirements, and since the height of dwellings varies, two solutions for bracing are applicable. The sheet bracing solution costs significantly less than the piled solution, however it may require lifting of exterior cladding to fit the sheeting. Additional fixings are required on an average of 50% of dwellings, with a significantly higher proportion requiring interconnecting member fixings. The total cost for the foundation remedy using the sheet bracing solution is around \$5,000 for an average dwelling [Table 11.2].

	FPPF		Requirements						
% req. remedy		per unit	Avg. #	Max. #	Min. #	Avg. Labour Cost \$	Avg. Material Cost \$	TOTAL \$	% of costs
79%	Bracing [see Table 7.1]								
71%	Sheet bracing	175BU/m	7	19	1	\$560	\$604	\$1,164	24%
38%	Braced Pile	120BU	9	28	2	\$1,418	\$4,095	\$5,513	60%
	Fixings [see Table 8.1]								
52%	J-B	1.5kN	74	144	17	\$407	\$148	\$555	
66%	J-FW	1.5kN	49	95	22	\$269	\$98	\$367	
52%	OP-B	3kN	48	72	16	\$360	\$96	\$456	
85%	B-B	12kN	6	9	2	\$72	\$72	\$144	
81%	J-J	6kN	23	38	14	\$253	\$92	\$345	
	Total Connection costs					\$1,362	\$506	\$1,868	38%
	Condition [see Table 9.1]								
82%	Ventilation		18	30	8	\$306	\$63	\$369	
85%	Polythene		137	120	33	\$630	\$102	\$732	
50%	Soil Clearance		2.8	4.5	1.0	\$490	\$0	\$490	
18%	Soil Infill		1	4	0.5	\$75	\$210	\$285	
	Total General condition costs					\$1,501	\$376	\$1,877	38%
	TOTAL REMEDIAL COSTS		Sheet solution			\$3,423	\$1,486	\$4,909	
			Pile solution			\$4,280	\$4,977	\$9,257	

Table 11-2 Total Breakdown for all Remedial Measures applied to Full Piled Foundation Dwellings

11.5.3 Partial Foundation Wall

[PFW]

The Partial Foundation Wall sample requires bracing in only 50% of the sample [refer Section 7.5.3] and has two possible solutions for bracing; the Plywood sheet bracing and the concrete infill wall solution. The infill wall solution would integrate better with the existing bracing systems, however, the plywood sheet bracing costs almost 3 times less. The difference between the two solutions is around \$1,600 [Table 11.3]. The fixing measures for the Partial Foundation Wall are among the highest of all foundation types. The connections include the alternative fixing method for the Bearer to Foundation Wall [B-FW] and Plate to foundation Wall [P-FW] of which, both cost around \$40 to remedy. The ventilation requirement is less than other foundations, due to the typical open baseboards on non-concrete sections of the foundation. Overall, using the most economic sheet solution, the remedial measures cost almost \$5,200 per foundation.

	PFW		Requirements						
% req. remedy		per unit	Avg. #	Max. #	Min. #	Avg. Labour Cost \$	Avg. Material Cost \$	TOTAL \$	% of costs
50%	Bracing [see Table 7.1]								
100%	Infill wall	300BU/m	2	4.4	1	\$1,003	\$1,458	\$2,460	36%
100%	Sheet bracing	175BU/m	5	8	1	\$400	\$432	\$832	16%
	Fixings [see Table 8.1]								
33%	J-B	1.5kN	115	175	30	\$632	\$230	\$862	
100%	J-FW	1.5kN	45	83	31	\$247	\$90	\$337	
88%	B-FW	12kN	11	16	4	\$165	\$198	\$363	
45%	P-FW	12kN	13	15	12	\$196	\$273	\$469	
77%	OP-B	3kN	45	63	35	\$337	\$90	\$427	
100%	B-B	12kN	5	8	1	\$60	\$60	\$120	
100%	J-J	6kN	29	30	28	\$319	\$116	\$435	
	Total Connection costs					\$1,958	\$1,057	\$3,015	58%
	Condition [see Table 9.1]								
44%	Ventilation		15	30	6	\$255	\$52	\$307	
100%	Polythene		161	190	80	\$740	\$120	\$861	
22%	Soil Clearance		1.0	1.5	0.5	\$175	\$0	\$175	
0%	Soil Infill		0	0	0	\$0	\$0	\$0	
	Total General condition costs					\$1,171	\$173	\$1,344	26%
	TOTAL REMEDIAL COSTS		Infill wall solution			\$4,131	\$2,688	\$6,819	
			Sheet solution			\$3,528	\$1,662	\$5,190	

Table 11-3 Total Breakdown for all Remedial Measures applied to Partial Foundation Wall Dwellings

11.5.4 Full Foundation Wall

[FFW]

The Full Foundation Wall requires the least bracing remedies in the sample. However, dwellings that do require bracing should use an infill wall on the interior of the dwelling, or alternatively anchor piles. All fixings are relatively inadequate, except for the Plate to Foundation Wall [P-FW], which is only inadequate in 36% of the sample compared with NZS3604:1999 [refer Section 10.2.3]. Overall, the total cost for the remedy of the Full Foundation Wall is \$10,000 for the small number of dwellings that require remedial bracing. However, the majority of this foundation type only requires additional fixings and an upgrade in condition, which will cost just below \$3,300 [Table 11.4].

% req. remedy	FFW		Requirements			Avg. Labour cost \$	Avg. Material cost \$	TOTAL \$	% of costs
		per unit	Avg. #	Max. #	Min. #				
10%	Bracing [see Table 7.1]								
100%	Anchor Pile	120BU	11	11	10	\$1,733	\$5,005	\$6,738	67%
100%	Infill wall	300BU/m	4.1	4.3	3.8	\$2,055	\$2,988	\$5,043	61%
	Fixing [see Table 8.1]								
80%	J-B	1.5kN	43	102	13	\$236.50	\$86.00	\$322.50	
90%	J-FW	1.5kN	49	80	25	\$269.50	\$98.00	\$367.50	
68%	B-FW	12kN	7	14	2	\$105.00	\$126.00	\$231.00	
36%	P-FW	12kN	16	21	13	\$241.60	\$336.00	\$577.60	
72%	OP-B	3kN	23	36	6	\$172.50	\$46.00	\$218.50	
86%	B-B	12kN	4	7	1	\$48.00	\$48.00	\$96.00	
81%	J-J	6kN	24	40	13	\$264.00	\$96.00	\$360.00	
	Total Connection costs					\$1,337	\$836	\$2,173	26%
	Condition [see Table 9.1]								
22%	Ventilation		9	21	1	\$153.00	\$31.50	\$184.50	
95%	Polythene		148	210	70	\$680.80	\$111.00	\$791.80	
0%	Soil Clearance		0	0	0	\$0.00	\$0.00	\$0.00	
28%	Soil Infill		0.5	1	0.25	\$37.50	\$105.00	\$142.50	
	Total General condition costs					\$871	\$248	\$1,119	13%
	TOTAL REMEDIAL COSTS		Pile solution			\$3,941	\$6,089	\$10,029	
			Infill wall solution			\$4,264	\$4,071	\$8,335	

Table 11-4 Total Breakdown for all Remedial Measures applied to Full Foundation Wall Dwellings

11.5.5 Full Perimeter Foundation / Internally Piled [FFW/IP]

The Full Foundation Wall / Internal Piled Foundation has no remedial bracing requirement, however does lack fixings required by the current standards. Since no bracing is required, the Full Foundation Wall / Internal Piled dwelling has the lowest remedial cost of just under \$2,700 for all remedies [Table 11.5].

% req. remedy	FFW/IP		Requirements			Avg. Labour Cost \$	Avg. Material Cost \$	TOTAL \$	% of costs
		per unit	Avg. #	Max. #	Min. #				
0%	Bracing [see Table 7.1]								
	n/a		0	0	0	\$0.00	\$0.00	\$0.00	0%
	Fixings [see Table 8.1]								
88%	J-B	1.5kN	72	196	31	\$396.00	\$144.00	\$540.00	
88%	J-FW [J-B edge]	1.5kN	39	49	29	\$214.50	\$78.00	\$292.50	
55%	OP-B	3kN	45	72	36	\$337.50	\$90.00	\$427.50	
100%	B-B	12kN	5	9	4	\$60.00	\$60.00	\$120.00	
100%	J-J	6kN	19	28	15	\$209.00	\$76.00	\$285.00	
	Total Connection costs					\$1,217	\$448	\$1,665	62%
	Conditions [see Table 9.1]								
12%	Ventilation		11	11	11	\$187.00	\$38.50	\$225.50	
100%	Polythene		149	200	60	\$685.40	\$111.75	\$797.15	
0%	Soil Clearance		0	0	0	\$0.00	\$0.00	\$0.00	
0%	Soil Infill		0	0	0	\$0.00	\$0.00	\$0.00	
	Total General condition costs					\$872	\$150	\$1,023	38%
	TOTAL REMEDIAL COSTS					\$2,089	\$598	\$2,688	

Table 11-5 Total Breakdown for all Remedial Measures applied to Full Foundation Wall/Internally Piled Dwellings

11.6 Summary of Remedial Measures

The remedial measures are applied and costed by a qualified Quantity Surveyor on the basis of average maximum requirement for each foundation, and correct as at January 2007. The total remedial costs are therefore a reflection of the average dwelling, remedied up to NZS3604:1999. The Internally Piled Foundation costs \$6,600 to upgrade the average dwelling, which includes remedial bracing measures in 83% of the dwellings. The Full Piled Foundation exhibits similar costs at around \$5,000, however, uses less expensive sheet bracing for the 79% of dwellings under bracing requirements. The Partial Foundation Wall and Full Foundation Wall both require less bracing than the piled foundations, but should use the complimentary infill concrete wall bracing systems for lateral loading. Overall, the Partial Foundation Wall and Full Foundation Wall dwellings, which require bracing, cost around \$7,000 to \$8,000 per foundation. For those dwellings with adequate bracing, this is reduced to between \$3,000 and \$4,000 respectively. The Full Foundation Wall /Internal Piled dwelling has adequate bracing, thus the total average costs for remedial measures are approximately \$2,600 per foundation. These totals can be combined and used for direct cost/benefit analysis of each foundation, to understand whether the application of remedial measures is economically feasible.

12 **The Wellington Earthquake Condition**

There has been an increased focus on the consequences of an earthquake centred in or around Wellington for a number of years. It is widely believed that Wellington is overdue for a large earthquake, which is expected to result in many deaths, injuries and collapse of dwellings. The collection of Wellington statistics in this chapter, will be used in the cost/benefit analysis, which will include anticipated damage rates and the Mean Damage Ratios for different foundation types. An earthquake prediction will be calculated using a computer based Earthquake Loss Modeller, which determines the number of damaged dwellings and the costs to repair and reinstate dwellings. It has been argued that if authorities place more emphasis on the importance of adequate foundations, improvements could potentially mitigate the collapse and extensive damage to dwellings which will ultimately lead to a lower mortality rate and increase the likely habitability of dwellings post earthquake.

12.1 The Wellington Statistics

The statistics used and applied in this section are based on official information obtained through the WCC directories and archives. Values stated in the Earthquake Loss Modeller and calculations are also derived from similar sources. They will be applied in the following Chapter [refer Chapter 13].

12.1.1 ***The Wellington Population***

Wellington has differing populations from day to night, due to the number of commuters from near by cities and outlying areas. The total daytime population is estimated from 2005 Census totals, at 207,556 people, while the night time total is around 180,262. The difference between day and night is 27,295 (Cousins 2005). For the purposes of definition of the limits of Wellington city, the Wellington suburbs do not include any of the Porirua or Hutt Valley districts [refer Section 6.1]. For later comparison of costs and benefits, totals for the whole Wellington region will be used, including Porirua and the Hutt Valley with a combined population of 461,460.

12.1.2 ***The Wellington Dwellings***

Statistics provided by the WCC and the Valuation New Zealand [“VNZ”] Database, show that Wellington City constitutes approximately 65,400 dwellings, assuming constant growth (Wellington City Council 2006b). Using the combined area of dwellings throughout the city [9,092,359sqm] (Cousins 2005), it is calculated that the average dwelling is approximately

139sqm. This value is in line with historic predictions made in 1995 following similar growth patterns (Davey and Shephard 1995). Using this prediction and the population data, it is understood that the average family dwelling will house approximately 3.17 persons.

12.1.3 *The Wellington Suburbs and Growth*

The suburbs of Wellington have had different rates of inhabitation in different eras throughout the short history of the city. The foundation types are always relative to the type and age of dwelling in the suburbs. The suburban limits are based on current planning maps obtained from archives for District Planning purposes. However, historical amalgamations of older boroughs and districts within Wellington, means that the accuracy of older suburb growth cannot be assumed to be completely correct. The historical dynamics of Wellington growth suggests that distinct patterns exist based on the introduction of public and private transportation and with the creation of tunnels and better access to suburbs. These trends suggest that suburbs reach a maximum density and then taper off [Figure 12.1] (Morrison 2000). These patterns and the age of suburbs allow predictions into the number and type of foundations anticipated in each suburb, as each foundation type can be related to a distinct period in history [refer Section 3.7].

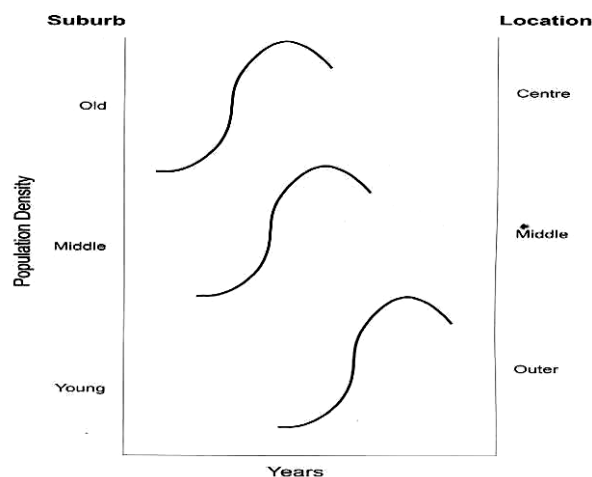


Figure 12-1 Indicative relative Suburb Growth compared against Density and Location (Source: Morrison 2000)

Infrastructure, such as the tram systems, allowed outer suburbs to be accessed and inhabited in the first half of the 20th Century (Stewart 1999). Thus, suburbs created in unison tend to have similar dwellings and most commonly, more regular foundation systems. This data is based on archived information of building activity and also pictorial analysis of more established suburbs such as Hataitai (Howman and Lindsay 1982), Brooklyn (Vickers and Fitchett 1998) and Kelburn (anon 1975). Infill housing and subdivision is also becoming more prevalent, resulting in atypical foundations not related to the age of a suburb. Growth in more rural districts or remote undeveloped locations have been excluded from the study, assuming that these areas have grown out of necessity and do not reflect typical suburban growth pattern [Figure 12.2].

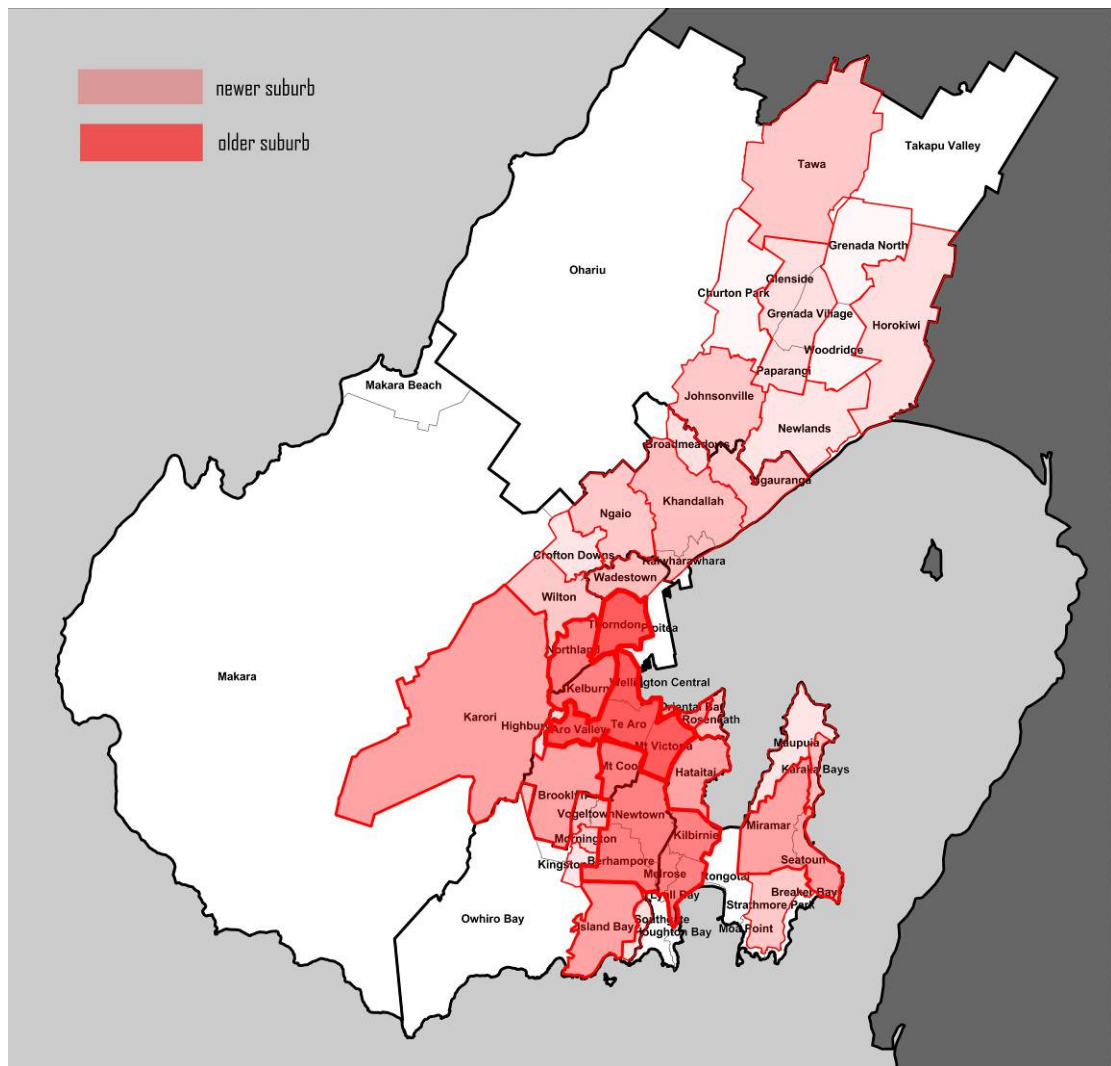


Figure 12-2 Wellington Suburbs showing Decade Growth Patterns

12.2 The Earthquake Scenario

The Wellington fault line is the assumed trace that will cause the most destruction to Wellington City. The epicentre of the earthquake is assumed to be close to Kaiwharawhara and will extend from Cook Strait, north-eastward, through Wellington, up to the Tararua ranges and further north. Rupture of the southern fault is one of the most serious natural hazard scenarios in Wellington (Van Dissen and Berryman 1991), and is the basis of the study scenario stated below.

“The large earthquake centred on the Wellington-Hutt valley segment of the Wellington fault. Rupture of this segment is expected to be associated with an earthquake having a Magnitude in the range of 7.2 to 7.8 with an assumed mean of 7.5, centred at a depth of less than 30km and with up to 5m horizontal and 1m vertical displacement. The return period of such an earthquake is 600years.” (Davey and Shephard 1995, p.8)

Studies into the prehistoric faults in the Wellington region showed that many earthquakes ruptured at regular intervals at large magnitudes. This information presupposes a similar recurrence and the likely interval of large future earthquakes (Van Dissen and Berryman 1991). Figure 12.3 shows a section through the main faults running through Wellington with relative horizontal separations and anticipated vertical shifts.

Figure 12-3 A Section of the Main Faults in Wellington showing the direction of Faulting (*Source: McConchie 2000*)

The study uses an Earthquake Loss Modeller [“the Loss Modeller”], to predict the total losses before and after the earthquake scenario described above. The Loss Modeller, produced by GNS and Jim Cousins (2005), predicts the number of casualties, total economic loss to residential dwellings and commercial properties for any given city, based on earthquake data such as the magnitude, location and epicentre depth. Damage Ratios and values used by the Loss Modeller are based on “*reasonable probabilistic fits to Earthquake Commission losses for the period 1990 to 2003*”(Cousins 2005).

Although the influence of topography on seismic shaking is specific to the location of a dwelling, certain suburbs will be more at risk from collapse depending on the slope, soil type and magnitude of the earthquake. Suburb data provides information on the potential for shaking due to unconsolidated soils, the probability of slope failure and potential for fault rupture (McConchie, Winchester and Willis 2000) [refer Section 6.1].

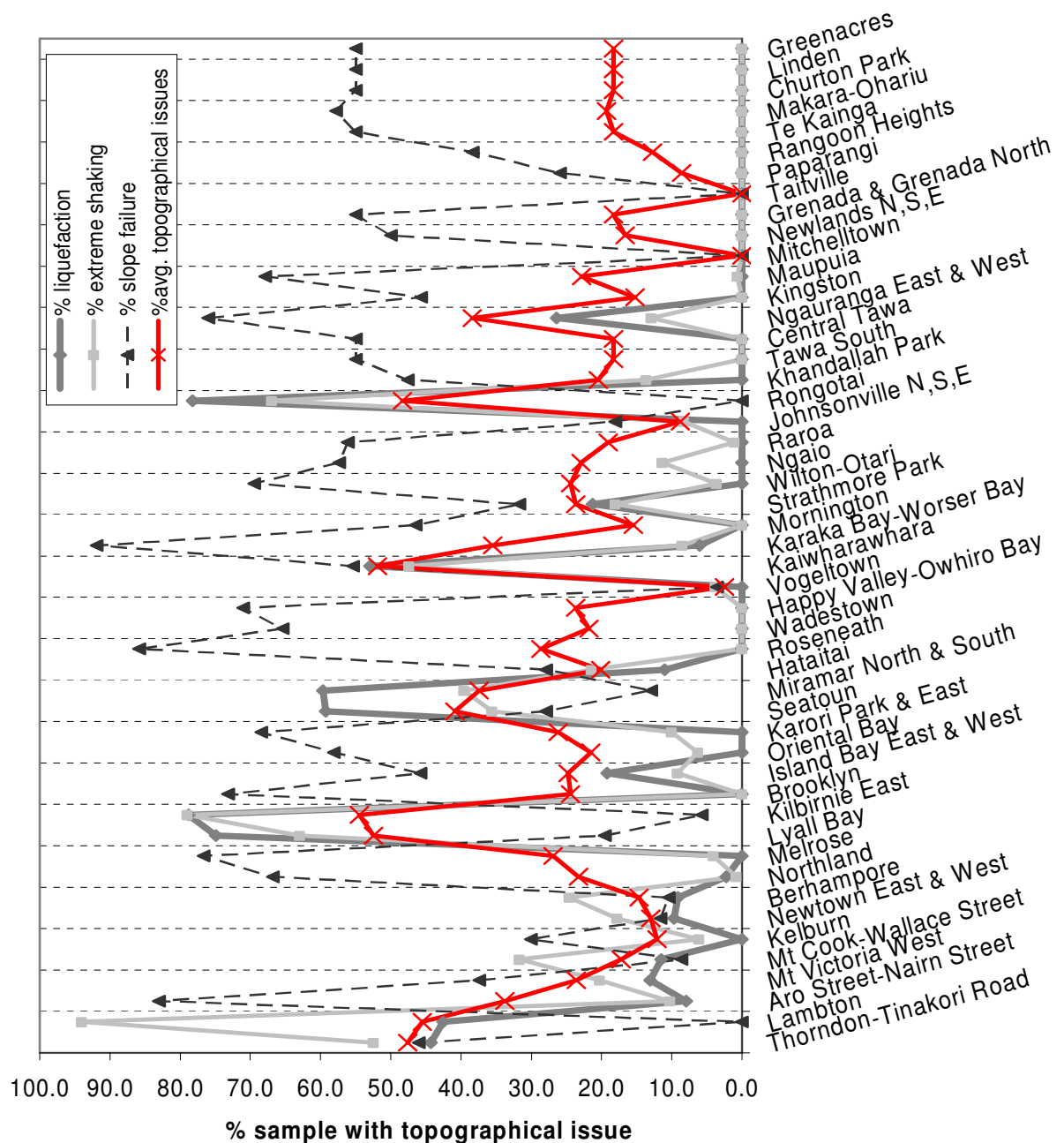


Figure 12-4 The Topography likely to affect the Collapse and Damage of Foundations

Figure 12.4 shows the likelihood of reaction for Wellington suburbs, which was sourced from the following texts: Dynamic Wellington (McConchie 2000), Risk Assessment Study Area 1: Wellington City (Davey and Shephard 1995), the Wellington Earthquake Lifelines Group prediction (1995) and WCC District plan maps (Wellington City Council Environment Division 1991). The figures predict the number of dwellings likely to experience varying states of damage or collapse. However, many of the geographically related failures cannot be controlled through foundation remedy. This is especially true for fault rupture (Parliamentary Commissioner for the Environment 2006) slope failure, and also to a certain extent liquefaction reactions. Table 12.1 shows the foundation type reaction, based on location observations and the likelihood of each foundation type experiencing different geographical failures.

Foundation type	Extreme >1:3	Moderate >1:5-1:3	Gentle 1:10-1:5	Slope failure	Liquefaction	Extreme shaking
IPF	0	0	6	0%	10%	6%
FPF	7	9	8	28%	13%	16%
PFW	1	4	3	4%	5%	7%
FFW	5	8	8	20%	13%	15%
FFW/IP	0	4	4	0%	7%	8%
ENG	3	0	0	12%	0%	0%
SLAB	0	2	8	0%	13%	9%
Unbuilt areas	n/a	n/a	n/a	35%	39%	40%
TOTALS	16	27	37	100%	100%	100%

Table 12-1 Topographical issues relating to different Foundation types

12.2.3 *The Reaction of Wellington Dwellings*

Dwellings with configuration issues, are more likely to experience collapse and sustain moderate or extensive damage, based on observations of past earthquakes [refer Section 5.1]. Since remedial measures cannot realistically resolve configuration issues, it is assumed that remedial measures will not significantly mitigate damage to these dwellings. Totals for collapsed dwellings, with configuration issues and located in areas likely to experience more damage are listed in Table 12.2. These values will be used to calculate total earthquake damage costs.

Foundation type	failure due to configuration issues %	failure due to topography issues %
Internal Piled	9.57%	5.17%
Full Piled	5.11%	19.19%
Partial Wall	13.23%	5.19%
Full Wall	36.87%	16.17%
Full Wall/Intern.	15.14%	4.70%
SLAB	16.24%	7.52%
ENG	4.13%	4.06%
AVERAGE	14.33%	8.86%

Table 12-2 Percentage of each Foundation type with Configuration issues

Figure 12.5 shows the number of dwellings in each suburb with differing foundations or split level issues, which contribute to overall configuration issues. All values in the tables above were obtained by calculating percentages of suburb areas at risk from different topographical reactions. This information was obtained from previous studies of Wellington City (Davey & Shephard 1995).

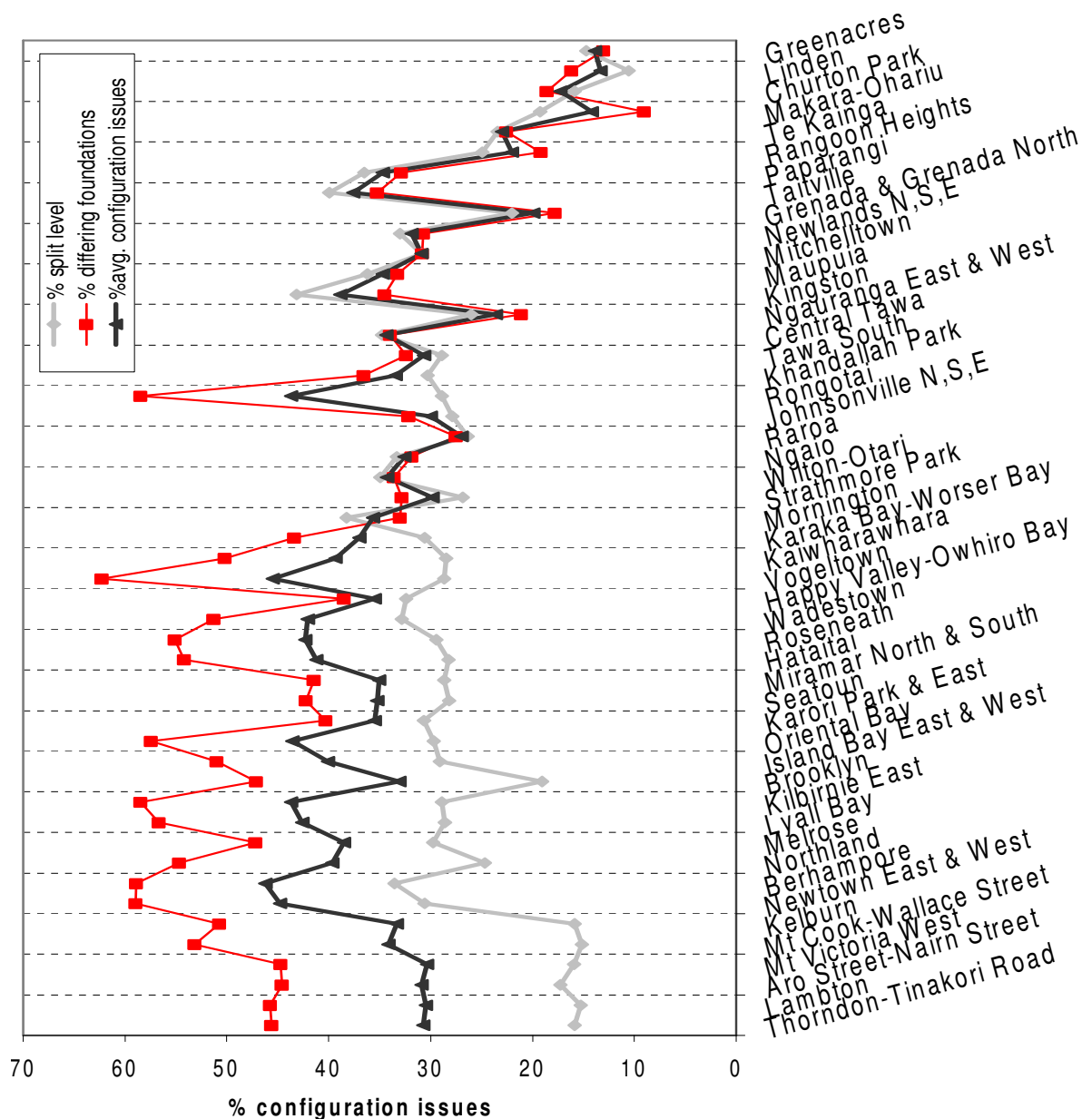


Figure 12-5 Configuration issues likely to result in Collapse or Damage to Foundations

12.3 The Damage States and Mean Damage Ratios

A damage state is a measure of the amount of damage a dwelling will experience in a certain intensity earthquake. It is assumed that any discrepancy with transference of loads has the potential to cause major structural damage (BRANZ 2000). Thus, dwellings with similar cladding and foundations are likely to react in a similar manner. Past earthquake repair costs to dwellings, can provide an insight into the Mean Damage Ratio [“MDR”], which is the ratio of the cost of repairs divided by the dwelling replacement cost. All MDR’s are based on historical data gathered from past earthquakes, usually obtained by insurance agencies wanting to quantify their losses. For the purposes of this study, five distinct damage states are used to distinguish between damage costs and what damage remedial measures may mitigate.

12.3.1 _____ ***No or Negligible Damage***

The negligible damage state is simply superficial damage costing less than the excess required by the Earthquake Commission [“EQC”], which is between \$200-\$500 (Earthquake Commission 2006b). Only cleanup of fallen and broken objects will be required, which can be undertaken by the occupants. 12% of dwellings will experience no serious damage and therefore costs will only reflect personal possession claims (Davey and Shephard 1995).

12.3.2 _____ ***Light Damage***

Light damage states results in small plaster or gypsum board cracks, especially at corners of doors and window openings and wall to ceiling interfaces [Figure 12.6]. Small cracks will appear in masonry chimneys and brick veneers, usually along mortar lines, which may require remedy to remain watertight.



Figure 12-6 Small Cracks seen at Edges and Interfaces of Gypsum Board (Source: Earthquake Commission 2003)

The MDR for light damage is assumed to affect dwellings superficially and cost around 1.5% of the total dwelling replacement cost, which could potentially affect up to 55% of dwellings (Davey and Shephard 1995). Dwellings are likely to remain habitable, however, no sub-floor remedy is anticipated to significantly mitigate any light damage.

12.3.3 _____ ***Moderate Structural Damage***

Moderate damage excludes irreparable structural damage, however inadequate and substandard fixings are anticipated to cause sub-floor elements to move creating large displacements and cracks in plaster at corners of door and window openings. This damage will require repair, especially where cracks in bracing wall panels could limit the potential to resist future loading. Moderate damage may increase the risk of moderate injury from falling fixtures and could warrant a limited entry to be posted [refer Section 13.6.3]. The dwelling is likely to remain habitable and may cost around 20% of the total dwelling replacement cost. Moderate damage will be seen in dwellings with inadequate fixings and adequate bracing, especially in concrete or masonry foundation walled dwellings [Figure 12.7].



Figure 12-7 Small Cracks seen in Concrete Perimeter Wall, as a result of Inadequate Sub-floor Bracing Resistance (Source: Earthquake Commission 2003)

12.3.4 Extensive Structural Damage

This study assesses damage due to excessive movement in the foundation area. Extensive damage may be the result of many other factors, but these are outside the scope of this study, which solely addresses foundation problems. It is assumed that if the foundation has poor connections and inadequate bracing, the superstructure will most likely suffer. Internal framing may be damaged with large diagonal cracks appearing across bracing panels. Permanent lateral movement of the floors and roof is anticipated, as well as splitting of timber framing, slipping and serious cracks in foundations [Figure 12.8].

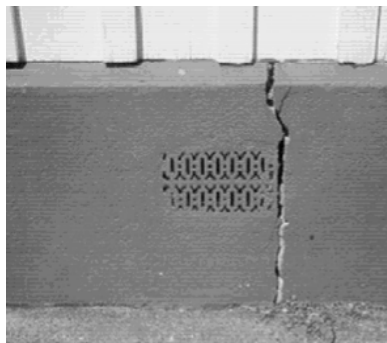


Figure 12-8 Serious Foundation Wall Cracks attributable to Extensive Structural Damage (Source: Earthquake Commission 2003)

Extensively damaged dwellings will have serious structural damage to vertical and lateral support mechanisms, which will likely result in a “no entry” posting [refer Section 13.6.3]. Partial collapse of dwellings with configuration issues will cause serious injuries to occupants and people around the dwelling. Therefore, extensive damage is considered more likely to occur in dwellings which have a combination of less than 50% sub-floor bracing capacity and inadequate fixings within the sub-floor. Extensive damage is predicted to affect around 10% of dwellings and have a MDR of around 45%. Many dwellings will require structural and economic feasibility investigations to determine whether repair or demolition should be undertaken.

While the structure should be designed not to exceed the ultimate limit state design criteria, it is unrealistic and uneconomic to design a structure to withstand the biggest earthquakes (Deam 1997). Thus, collapsed dwellings are those which have experienced a full failure of the lateral load resisting system. Many structures may have large permanent lateral displacements and be in imminent danger of collapse due to the superstructure slipping from the foundations. Dwellings with serious configuration issues [refer Section 5.1], or in locations at higher risk from extreme shaking, liquefaction and slope failure [refer Section 6.1] will be assumed to collapse. Thus, the location of the dwelling will partially dictate the collapse of dwellings. Dwellings with over 50% bracing inadequacies combined with fixing inadequacies are likely to collapse and will affect around 2% of dwellings. Collapsed dwellings will require demolition and replacement of the entire dwelling and will likely result in a high number of serious injuries and deaths to occupants.

12.3.6 The Damage Estimates and Mean Damage Ratios for each Damage State

Each damage state and the likely cause of each damage state are based on historical reactions seen in past earthquakes [Table 12.3]. Therefore dwellings with the combination of foundation defects seen below will be assumed to attain each corresponding damage state. It is also assumed that the location of the dwelling will also contribute to the reaction and the damage state of the dwelling.

Damage State	Poor General Condition	Inadequate Fixings	Less than 50% Bracing Required	Over 50 % Bracing Required
Collapse	n/a	X		X
Extensive	n/a	X	X	
Moderate	n/a	X		
Light	X	n/a	n/a	n/a

Table 12-3 The Cause of different Damage States

The MDR's used for all dwelling repair costs can be seen in Table 12.4, these values were obtained from suburb data from the Loss Modeller and adapted for each foundation type. These values were generally obtained by extrapolating the average dwelling replacement cost (which is loosely attached to the age of a dwelling) through each of the damage state costs.

Foundation type	Internal Piled Foundation	Full Piled Foundation	Partial Foundation Wall	Full Foundation Wall	Full Foundation Wall/Internal Piles
Collapse	1	1	1	1	1
Extensive	0.465	0.495	0.422	0.403	0.416
Moderate	0.195	0.207	0.177	0.169	0.174
Light	0.017	0.018	0.016	0.015	0.016
Average MDR	0.226	0.240	0.205	0.196	0.202

Table 12-4 MDR's used for different Damage States in the Sample

The MDR only describes the anticipated cost of repair if a dwelling experiences damage, and does not describe the actual risk of damage to each foundation. Overall, MDR's must be assumed to have maximum and minimum limits so that the overall cost / benefit ratios can remain conservative and do not portray one single estimate only [refer Section 13.5.2].

12.4 The Earthquake Statistics

The statistics for the earthquake scenario assumes a number of factors which were built into the Loss Modeller and were predicted based on projected growth information provided by the WCC (Wellington City Council 2006b). For maximum residential casualties, the earthquake scenario will be assumed to occur at night. All dollar values in the proceeding sections are accurate as at September 2005, when the Loss Modeller was released and are in New Zealand Dollars. Costings for the remedial measures [refer Chapter 11] were made in January 2007, thus the 16 month difference may have discrepancies due to inflation in building costs, however this will favour the conservatism of the cost / benefit ratio calculations.

12.4.1 Wellington City Values

- \$18,606,000,000 dollars for total replacement value of all homes in Wellington city suburb limits, as at 2005.
- This assumes the average dwelling price is around \$316,000, based on the value of the dwelling only, not including land [refer Section 13.2.1].
- Population day at home 39,303 people [approx. minimum of 12,400 dwellings inhabited during the day]
- Population night at home 169,718 people [approx. minimum of 53,200 dwellings inhabited at night]
- In total 58,860 dwellings with varying foundations are in the Wellington residential housing stock (Wellington City Council 2006b), of which 90% are assumed timber framed (Cousins 2005).

12.4.2 _____ *The Wellington City Disaster Scenario*

- \$4,200,000,000 of damage to residential dwellings
- In the day time scenario 930 dead and 1290 moderately to seriously injured, the night scenario shows 120 dead and 535 moderately to seriously injured.
- MM 10.8 maximum shaking and MM 9.7 minimum shaking observed, with an average assumed shaking of MM10.3.
- Assuming all dwellings cost equal amounts to reinstate or rebuild, the total loss and damage to timber dwellings is \$3.78 Billion.
- The total cost for the earthquake damage compared with total residential dwelling asset in New Zealand is around 22%.

12.4.3 _____ *Vulnerability of Collapse and Damage to Dwellings*

The collapse proportion for timber dwellings is around 2% of the total. This assumes that approximately 1177 dwellings will collapse, due to topographical and configurational issues only [refer Section 12.2.3]. The number of dwellings that will likely collapse per suburb is shown in Figure 12.10 and damage in Figure 12.11. The total maximum dwelling collapse in any one suburb is 62, with the mean at around 24 dwellings per suburb. The number of dwellings likely to experience moderate to extensive damage seen in Figure 12.11 shows that similar trends exist, however, the overall number of dwellings affected increases to around 40 times the number of collapsed dwellings. In newer suburbs, it can be seen that foundation types that have become increasingly popular, show a high proportion of collapse and damage. Values in Figures 10 and 11 were obtained from the Earthquake Loss Modeller, when total earthquake statistics for Wellington City are broken down to suburb area units.

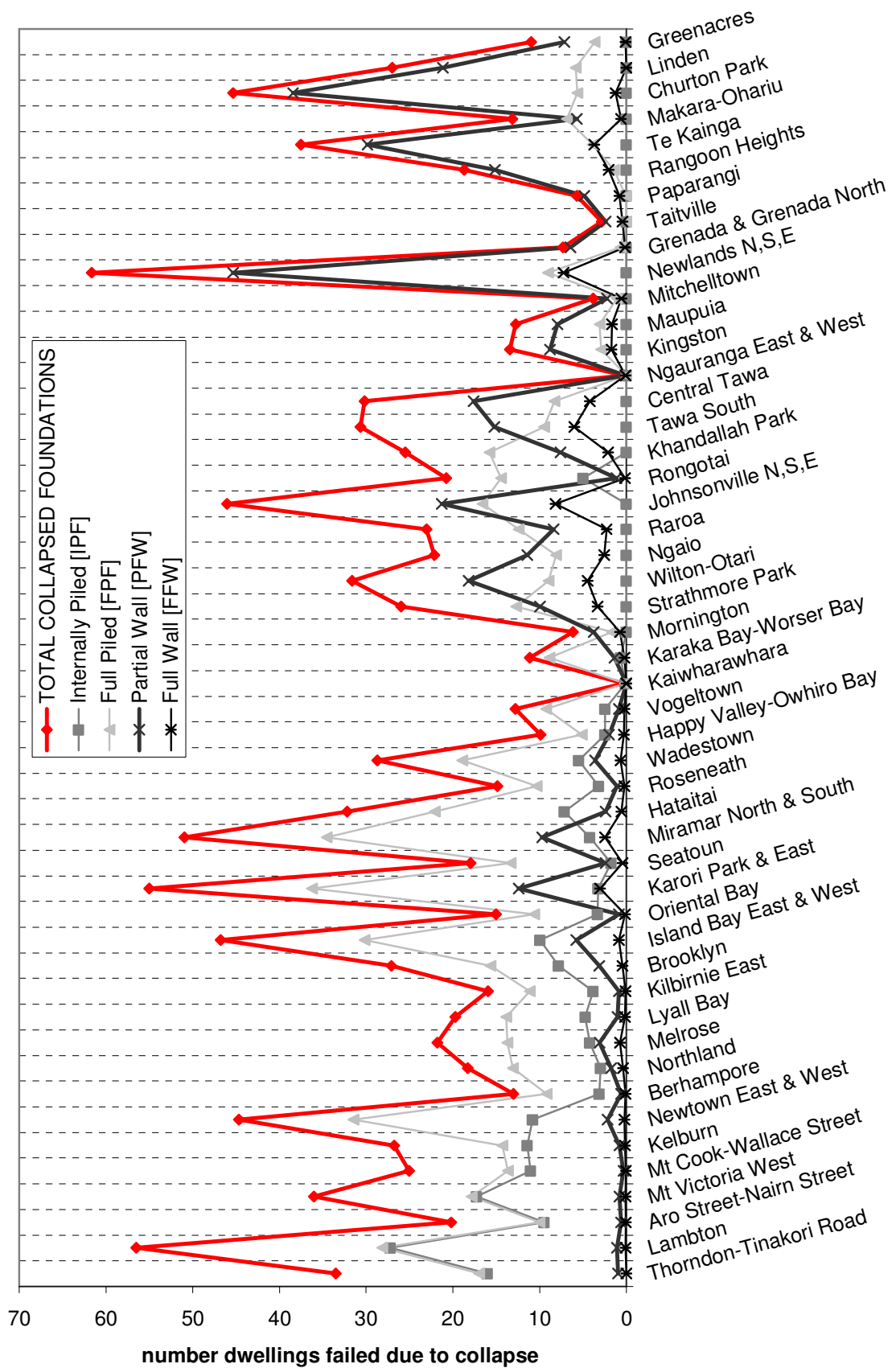


Figure 12-9 Number of Dwellings Collapsed per Foundation type

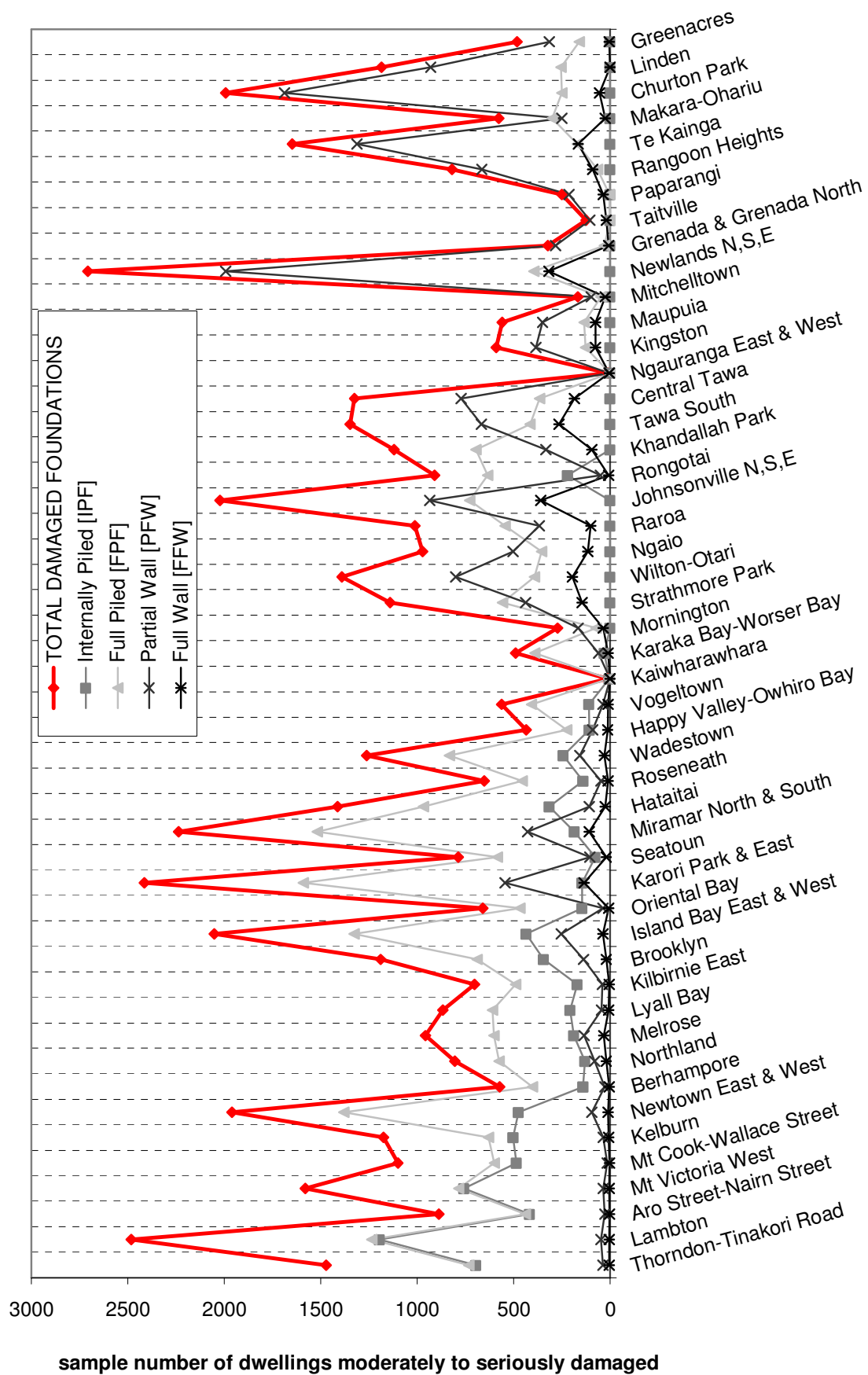


Figure 12-10 Number of Dwellings Damaged per Foundation type

Overall the cost of repair is based on the MDR's in Table 12.4, using an average dwelling value and the total number of dwellings affected, it is assumed that around 85% of Wellington dwellings will sustain some form of damage ranging from light damage to collapse. The repair costs can be calculated by working backwards from the MDR and the average dwelling value [Table 12.5].

- Collapsed dwellings are assumed to cost the value of the dwelling replacement, which is around \$315,000, this will affect around 1200 dwellings in total, however the cost of this insurance is not totally covered by the EQC [refer Section 13.2.6].
- Extensive damage is assumed to cost on average \$144,000 to repair each dwelling, affecting just under 6,000 dwellings.
- Moderate damage is assumed to cost around \$60,000 to repair each dwelling and will affect 21% of dwellings, or just over 12,000 dwellings.
- Light damage, which cannot be mitigated is assumed to cost around \$5,500 to repair each dwelling and will affect the largest amount of dwellings, at around 32,000.
- In total over 50,000 dwellings will experience some degree of damage costing a total of \$2,100 Million assuming all repair costs are around the mean for every dwelling.

	Damage type	% chance of each damage state	No. dwellings in each damage state	Max. assumed loss from damage	MDR for each damage state	MDR % of each damage state
100	Collapse	2.0%	1177	\$316,000	1.000	100.0%
75	Extensive	9.5%	5592	\$144,000	0.456	45.6%
50	Moderate	21.2%	12478	\$60,500	0.191	19.1%
25	Light	55.1%	32432	\$5,500	0.017	1.7%
0	None	12.2%	7181	\$0	0.000	0.0%
		100.0%	58860		0.21	

Table 12-5 Damage States relating to the Sample Dwellings

12.5 The Wellington Regional Scenario

So far the earthquake scenario has concentrated solely on Wellington City, however, other parts of New Zealand will also be affected by a large earthquake in the Capital. The *Wellington regional* scenario includes all of the Hutt Valley including Upper Hutt City, Lower Hutt, Petone, as well as Porirua, Kapiti coast and all of the Wairarapa districts including Masterton, Carterton and the South Wairarapa.

- MM 10.8 maximum shaking and MM 6.3 minimum shaking will be observed.

- From a total housing stock asset of \$43.9 Billion, \$6.2 Billion damage will be to residential dwellings, which shows that the majority of damage still occurs within the Wellington City limits.
- Total damage assets equates to around 14% of the total housing stock.
- From a total population base of 461,000 people, day and night, 1200 people are predicted dead, with 1690 moderately to seriously injured.

12.5.1 The National Scenario

When predicting the damage costs for the whole of New Zealand, values are taken to be similar to the Wellington regional scenario. Areas around the Wellington fault may experience shaking, including the Manawatu, Marlborough and Tasman regions, all experiencing shaking in the vicinity of intensity shaking MM7.5 [Figure 12.12].

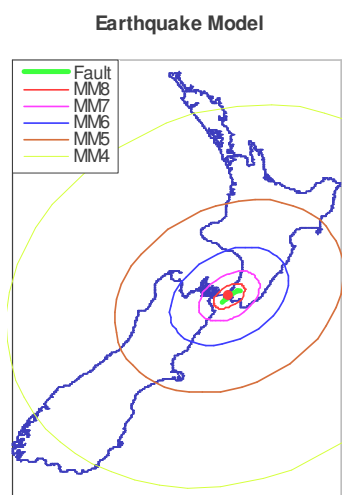


Figure 12-11 Shaking Intensity [Modified Mercalli] in the Vicinity of Wellington

- \$375 Billion total residential housing stock assets, with a total \$6.2 Billion cost of damage. Of the total housing stock, this equates to 1.65% of the total housing assets.
- 4,110,000 people total in New Zealand, 1200 people presumed dead with 1690 people moderately to seriously injured.

The totals for the New Zealand scenario are assumed to be negligible assuming that the earthquake may be felt, however, may not relate to significant volumes of claims for the damage affecting dwellings.

12.6 Summary of the Wellington Earthquake Condition

The Wellington earthquake scenario predicts that dwellings will experience an average MM10.3 intensity shaking, cause \$4.2 Billion worth of damage to the residential sector and cause the death and injury to over 2000 people. Collapsed dwellings will total nearly 1200, which will often be the result of inadequate bracing, combined with geographical and configuration issues. The Mean Damage Ratios used to calculate the repair costs are based on past earthquake observations and range from dwellings sustaining only Light damage, up to dwellings with extensive damage, which could potentially cost up to half of the dwelling's value to reinstate. Using these values, it is possible to calculate the direct economic benefit of applying foundation remedial measures and how much the homeowner could be anticipated to save by applying remedial measures.

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13

13.1 Specific Individual Costs

13.1 Specific Individual Costs

13.1.1

13.1.1

13.1.1

Foundation type	Bracing	Connections	General condition	Remedial cost for avg. dwelling	Total remedial cost \$ per m ²
Internal Piled	\$2,775	\$1,952	\$1,906	\$6,633	\$47.72
Full Piled	\$1,164	\$1,868	\$1,877	\$4,909	\$35.32
Partial Wall	\$832	\$3,015	\$1,344	\$5,190	\$37.34
Full Wall	\$5,034	\$2,173	\$1,119	\$8,326	\$59.90
Full Wall/Intern.	\$0	\$1,165	\$1,023	\$2,188	\$15.74
SLAB	\$0	\$0	\$0	\$0	\$0.00
ENG	\$0	\$0	\$0	\$0	\$0.00

Table 13-1 Remedial Costs per Dwelling for all Foundation types

The overall comparison of foundation types in Figure 13.1, shows the comparison of all remedies for all foundations, including the labour and materials.

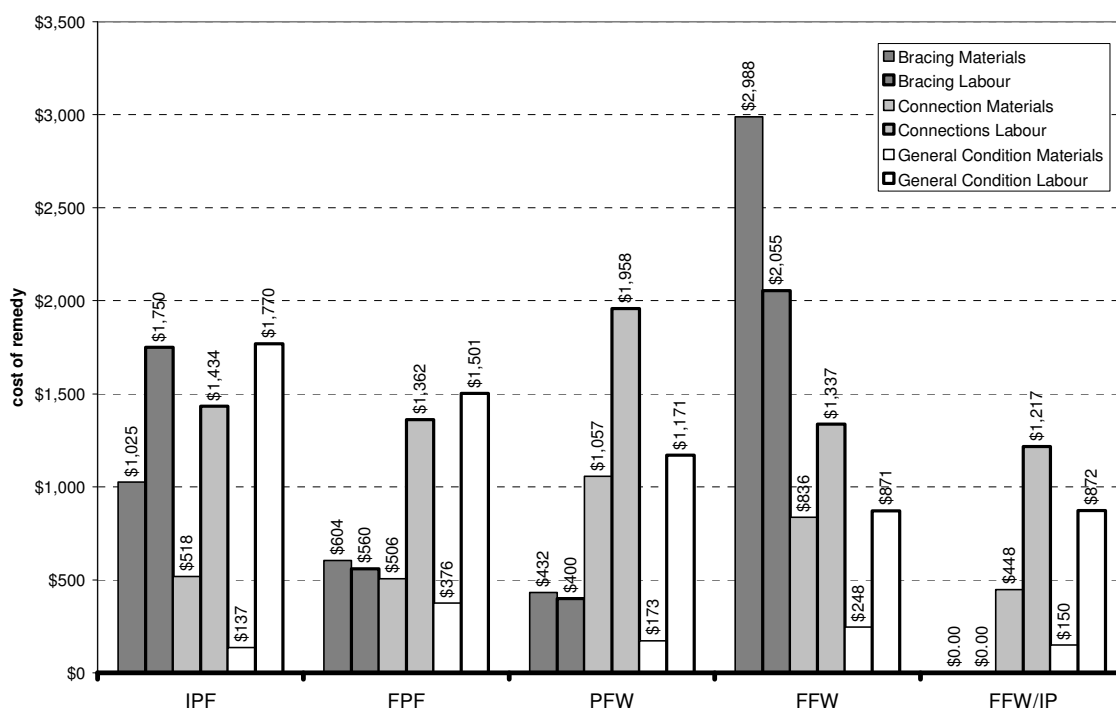


Figure 13-1 Cost Comparison for average Labour and average Materials for each Foundation type

It can be seen that labour costs tend to dominate all remedial totals. Since all costs are the maximum for the average dwelling, thus, it can be anticipated that many dwellings will not require this level of remedial measure and remedies may cost significantly less. In all cases, the remedial action undertaken on foundations can be directly related to personal cost, mitigation of injury and increase in habitability of dwellings following an earthquake [refer Section 13.6].

13.1.2 *Total Combined Costs for each Foundation Type*

The total costs of remedial measures in Wellington City are quantified by using the total cost of remedial measures in Table 13.1 and multiplying by the total number of each foundation type requiring remedy in Wellington City. This is then split into the total overall cost of remedy for damaged and collapsed dwellings [Table 13.2]. These costs are the maximum total from all

dwelling, despite whether a dwelling does not require bracing or fixings up to the maximum values.

Foundation type	Total remedial costs for Damage \$M	Total remedial costs for Collapse \$M	Total cost \$M
Internal Piled	\$25.1	\$1.6	\$26.8
Full Piled	\$74.3	\$4.3	\$78.6
Partial Wall	\$26.2	\$0.3	\$26.5
Full Wall	\$105.1	\$0.0	\$105.1
Full Wall/Intern.	\$11.0	\$0.0	\$11.0
SLAB	\$0.0	\$0.0	\$0.0
ENG	\$0.0	\$0.0	\$0.0
TOTALS	\$241.9	\$6.2	\$248.1

Table 13-2 Total Remedial Costs for all Foundation types

The total cost of remedial measures is around \$248 Million, which assumes that the cost of remedying dwellings against collapse is only \$6.2 Million. The Cost / Benefit section will show that this value is small compared with the total replacement costs [refer Section 13.2.5]. All foundation types have different remedial requirements, however, the actual requirement of remedy should also reflect the associated risks of damage resulting from an earthquake.

13.1.3 *The Cost of Risk*

Preparedness is higher among citizens who perceive that they are likely to suffer negative consequences because of an earthquake (McClure 2006). Therefore, the strategies to increase preparedness should encourage citizens to understand the risk from earthquakes and apply it to themselves, rather than focussing on the actual probability of an earthquake striking. Thus, the cost of risk can be understood to be the product of all inadequacies in the sub-floor that may lead to a specific damage state. This means that dwellings with poor bracing and poor fixings, are more likely to experience collapse, compared to dwellings with only inadequate fixings. Thus, certain dwellings will have a higher risk of failure in an earthquake. Table 13.3 shows that older foundation types will have higher combined risk of different damage states than newer foundation types. Values in Table 13.3 were obtained from the analysis of the different foundation types and the risk of attaining each damage state [refer Section 12.3.6].

Foundation type	Risk of Collapse	Risk of Extensive Damage	Risk of Moderate Damage	Overall Combined Risk of Failure
Internal Piled	67%	71%	76%	81%
Full Piled	58%	63%	67%	68%
Partial Wall	13%	45%	78%	54%
Full Wall	0%	37%	73%	39%
Full Wall/Intern.	0%	43%	86%	38%
SLAB	0%	n/a	n/a	n/a
ENG	0%	n/a	n/a	n/a

Table 13-3 Total Perceived Risk from different Damage States for each Foundation type

13.1.4 *The Likelihood of Damage and Collapse*

The likelihood of damage is the product of a percentage of dwellings in each foundation type that will experience each damage state. This is different from the perceived risk, which is a percentage of the likely damage within each foundation type. Table 13.4 shows the overall spread of anticipated damage for each foundation type. Each percentage relates to the percentage of all Wellington dwellings and was extrapolated from statistics in the Earthquake Loss Modeller and the Earthquake Risk Assessment (Davey & Shephard 1995).

Foundation type	Negligible damage	Light damage	Moderate damage	Extensive damage	Collapse	% of each foundation type over the sample
Internal Piled	0.92%	4.13%	1.59%	0.71%	0.15%	7.50%
Full Piled	3.66%	16.53%	6.36%	2.85%	0.60%	30.00%
Partial Wall	1.22%	5.51%	2.12%	0.95%	0.20%	10.00%
Full Wall	3.05%	13.78%	5.30%	2.38%	0.50%	25.00%
Full Wall/Intern.	1.22%	5.51%	2.12%	0.95%	0.20%	10.00%
SLAB	1.68%	7.58%	2.92%	1.31%	0.28%	13.75%
ENG	0.46%	2.07%	0.80%	0.36%	0.08%	3.75%
TOTALS	12.2%	55.1%	21.2%	9.5%	2.0%	100.0%

Table 13-4 Percentage breakdown the likelihood of Damage States relating to Foundation type; all percentages relate to the percentage of the Overall Sample

However, the totals above must be combined with the perceived risk of damage for each foundation type, in order to reflect the actual situation of foundation failure that has been experienced in past earthquakes. Using the percentages of risk in Table 13.3 and the total percentage of dwellings at risk from each damage in Table 13.4, the total number of damaged timber dwellings can be calculated [Table 13.5].

Foundation type	No. dwellings with Light damage	No. dwellings with Moderate damage	No. dwellings with Extensive damage	No. dwellings Collapsed	Total No. timber dwellings Damaged
Internal Piled	2432	971	656	249	4308
Full Piled	9729	3423	1186	863	15201
Partial Wall	5285	1328	850	65	7528
Full Wall	8108	3108	1087	0	12303
Full Wall/Intern.	3243	1464	833	0	5540
SLAB	4459	1716	769	0	6944
ENG	1216	468	210	0	1894
TOTALS	32432	12478	5592	1177	53718

Table 13-5 Number of Dwellings in each Foundation type likely to experience different Damage States with Overlaid Risk factors, refer Table 13.3

Damage resulting from an earthquake is reasonably subjective and it cannot be completely ascertained whether each damage state is completely separate from the next. However, it is assumed that certain remedial actions will mitigate some damage states more than others [refer Chapter 12.3].

13.2 The Individual's Benefits of Domestic Damage Reduction

The remedial measure costs calculated above, when applied to the maximum number of sample dwellings in Wellington, can provide an insight into the cost of initial damage and overall economic saving to the individual and society. The price of dwellings must be assessed for each foundation type to provide a reasonable market value for different dwelling types, in this manner all benefits to the homeowner can be considered in monetary terms.

13.2.1 The Cost of Damage to Residential Timber Assets

The timber residential housing stock at risk from damage and collapse, predicted by the Loss Modeller (Cousins 2005) is calculated to be around \$3.8 Billion for Wellington City. The total overall cost of damage to residential dwellings, compared with the overall cost of the Wellington housing stock is approximately 22%. Figure 13.2 shows the average percentage of damage cost to dwellings in Wellington suburbs at a constant radius from the epicentre of the earthquake¹².

¹² Assumed to centre around Kaiwharawhara with a Magnitude of 7.5 at a depth of approximately 30km. [refer Section 12.2]



Figure 13-2 Percentage of total Suburban Assets at Risk from Earthquake at a Radiating Distance from the Epicentre of the Earthquake

This shows that although the average damage cost is around 22% of the total dwelling value for all suburbs, some dwellings could be as high as 30% or as low as 12%. Figure 13.3 shows the trend of the value of a dwelling, against the trend for increases in floor area of dwellings throughout the 20th century.

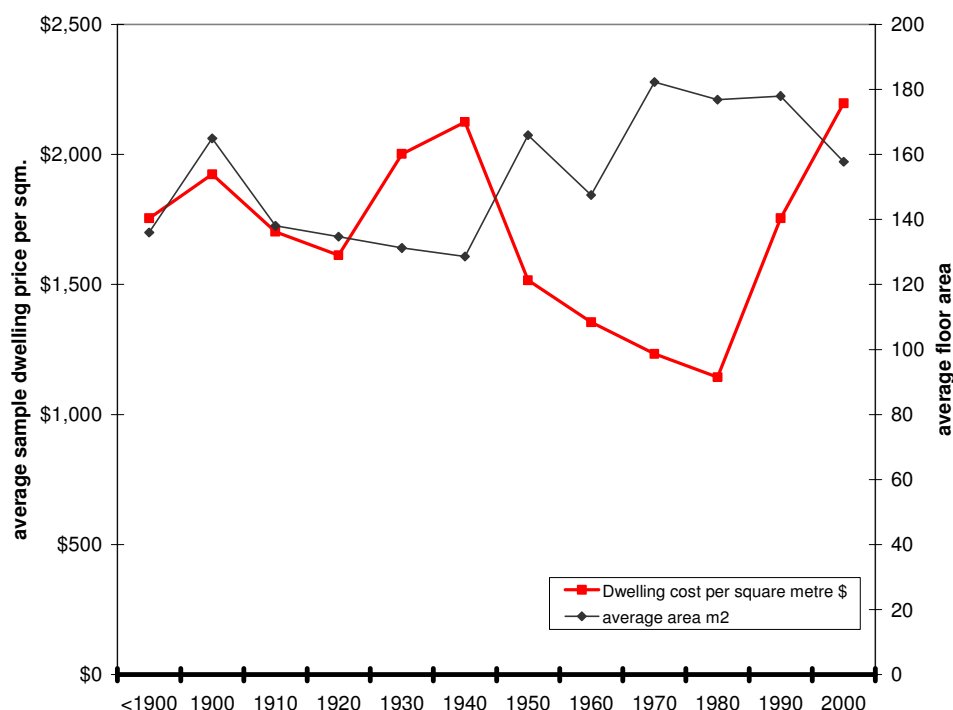


Figure 13-3 Average Dwelling Price per Square metre compared with the Trend of Dwelling area over all Age groups

Information for dwelling values are standardised to 2006 information obtained from the WCC's rates database (2006c), not including dwelling land price and dwelling valuation escalation. This database shows that the average dwelling's value ranges from between \$195,000 for 1970's dwellings up to \$339,000 for modern dwellings built in 2000. These values are also reflective of values in the Rawlinson's guide to pricing index as at 2005, of between \$1500-\$1750 per m² (Rawlinsons 2005). An observation from the graph suggests that although a price of a dwelling can be calculated on the floor area, this does not account for the significance of historic building retention and protection. Dwellings from the oldest decades would perhaps cost more than newer dwellings to be built to the previous quality, however may not receive such attention following an earthquake (State Insurance New Zealand 2007).

13.2.2 *Timber Dwelling damage Before Applied Remedial Measures*

Using the Mean Damage Ratios from Table 12.3 and the total dwelling values obtained from the Sample, the total anticipated repair costs prior to remedial measures can be calculated. Table 13.6 suggests that the averages for light, moderate and extensive damage are around \$5,000, \$60,000 and \$145,000 for all dwellings in each damage state respectively, based on 2006 prices.

Foundation type	Cost by dwelling foundation type \$	Average cost of Repair for Light Damage \$	Average cost of Repair for Moderate Damage \$	Average cost of Repair for Extensive Damage \$	Average cost of Replacement for Collapse \$
Internal Piled	\$322,236	\$5,478	\$61,547	\$146,940	\$322,236
Full Piled	\$342,686	\$5,826	\$65,453	\$156,265	\$342,686
Partial Wall	\$292,492	\$4,972	\$55,866	\$133,376	\$292,492
Full Wall	\$279,601	\$4,753	\$53,404	\$127,498	\$279,601
Full Wall/Intern.	\$288,153	\$4,899	\$55,037	\$131,398	\$288,153
SLAB	\$332,399	\$5,651	\$63,488	\$151,574	\$332,399
ENG	\$354,460	\$6,026	\$67,702	\$161,634	\$354,460
	AVERAGE	AVG \$5,372	AVG \$60,357	AVG \$144,098	AVG \$316,004

Table 13-6 Average Repair Costs for each Damage State

Using the number of dwellings in each damage state, seen in Table 13.5, and multiplying by the total anticipated repair cost, the total cost of damage can be calculated [Table 13.7].

Foundation type	Light damage repair cost \$M	Moderate damage repair cost \$M	Extensive damage repair cost \$M	Collapse damage cost \$M	Total cost \$M
Internal Piled	\$13.3	\$59.7	\$89.2	\$64.1	\$226
Full Piled	\$56.7	\$224.0	\$351.8	\$259.6	\$892
Partial Wall	\$16.1	\$74.2	\$76.5	\$41.1	\$208
Full Wall	\$38.5	\$166.0	\$108.7	\$22.3	\$336
Full Wall/Intern.	\$15.9	\$80.6	\$43.1	\$0.0	\$140
SLAB	\$25.2	\$108.9	\$116.5	\$0.0	\$251
ENG	\$7.3	\$31.7	\$33.9	\$0.0	\$73
TOTALS	\$173	\$745	\$820	\$387	\$2,125

Table 13-7 Total Cost of Damage for each Damage bracket Before Application of Remedial Measures

The total cost of dwelling reinstatement to pre-earthquake levels calculates an approximate cost of \$2.1 Billion. The majority of damage is seen in the extensive damage repair, followed by the moderate damage, both totalling around \$800 Million. However, to understand the benefits of remedial action, the costs of damage reduction, after application of remedial measures, need to be tallied using the same methodology.

13.2.3 Timber Dwelling Damage after Applied Remedial Measures

All dwellings assumed to have remedial actions applied based on the risk tallies seen in Table 13.3, are totalled for each damage state [Tables 13.8 to 13.11]. The number of dwellings collapsed before and after remedies has been calculated by changing the MDR's of each damage state in the Loss Modeller and considering the percentage of dwellings likely to collapse due to foundation defects [refer Section 12.3.6] and reaction of the dwelling in the topography [refer Section 12.2.2].

Foundation type	% sample under necessary bracing reqs. [see Table 7.1]	% of total sample Collapsed due to insufficient bracing	No. timber dwellings Collapsed before remedy	No. timber dwellings Collapsed after remedy	Total cost of reinstatement to assets \$M
Internal Piled	67%	21.2%	249	37	\$11.8
Full Piled	58%	73.3%	863	210	\$71.9
Partial Wall	13%	5.5%	65	12	\$3.5
Full Wall	0%	0.0%	0	0	\$0.0
Full Wall/Intern.	0%	0.0%	0	0	\$0.0
SLAB	0%	0.0%	0	0	\$0.0
ENG	0%	0.0%	0	0	\$0.0
TOTALS		100%	1177	258	\$87.2

Table 13-8 Data relating to Collapse to different Foundation types

The total cost of repair following application of remedy is around \$88 Million for collapsed dwellings, which shows that around 258 dwellings collapse due to issues that could not be remedied. This is a saving of around 23%. Table 13.9 shows the totals for the extensive damage after remedial measures are applied.

Foundation type	% sample under connection and bracing reqs. A	% of total sample with extensive damage from no connections or bracing B	no. timber dwellings with extensive damage before remedy	Total No. timber dwellings with extensive damage after remedy	Total cost of reinstatement to assets \$M
Internal Piled	61%	14.22%	656	97	\$14.2
Full Piled	55%	25.72%	1186	288	\$45.0
Partial Wall	68%	18.44%	850	157	\$20.9
Full Wall	57%	23.57%	1087	577	\$73.5
Full Wall/Intern.	69%	18.06%	833	165	\$21.7
SLAB	0%	0.00%	769	769	\$116.6
ENG	0%	0.00%	210	210	\$33.9
TOTALS		100.00%	5592	2263	\$325.9

Table 13-9 Data relating to Extensive Damage to different Foundation types

The totals for extensive damage are based on a combination of a lack of bracing, under 50% of requirements [refer Section 7.6] and lack of fixings [refer Section 8.5]. This total seen in column A is then multiplied by the total number of foundations in each sample to produce values in column B. The result is a total damage after remedy of over \$300 Million. The values for moderate damage are based on a similar approach, however, this assumes that foundations with a lack of sub-floor fixings and adequate bracing will only experience moderate damage [Table 13.10]. A damage factor of 0.5 is required to maintain conservative assumptions that despite applying remedial fixing measures, many dwellings will not react any differently to an earthquake.

Foundation type	% sample under necessary connection reqs.	% of total sample damaged from inadequate connections	no. timber dwellings with moderate damage before remedy	No. dwellings failed due to Topo and Config. issues	Incl. Damage factor of 0.5	Total No. timber dwellings with Moderate damage after remedy	Total cost of reinstatement to assets \$M
Internal Piled	76%	9.43%	971	138	468	606	\$37.3
Full Piled	67%	33.25%	3423	910	1872	2781	\$182.1
Partial Wall	78%	12.90%	1328	230	624	854	\$47.7
Full Wall	73%	30.19%	3108	834	1560	2394	\$127.8
Full Wall/Intern.	86%	14.23%	1464	172	624	796	\$43.8
SLAB	0%	0.00%	1716	408	858	1266	\$80.3
ENG	0%	0.00%	468	38	234	272	\$18.4
TOTALS		100.00%	12478	2729	6239	8969	\$537.5

Table 13-10 Data relating to Moderate Damage to different Foundation types

Damage mitigation with remedial measures saves upwards of \$200 Million. Table 13.11 shows the number of dwellings sustaining light damage. This total remains unchanged, however dwellings from other damage states are assumed to now sustain light damage, an increase which can be seen in column C.

Foundation type	No. timber dwellings with Light damage before remedy	No. timber dwellings with only Light damage due to remedial action	New Total No. dwellings with Light damage C	Total cost of reinstatement to assets \$M
Internal Piled	2432	660	3092	\$16.9
Full Piled	9730	2093	11822	\$68.9
Partial Wall	3243	848	4091	\$20.3
Full Wall	8108	1671	9779	\$46.5
Full Wall/Intern.	3243	946	4189	\$20.5
SLAB	4459	450	4909	\$27.7
ENG	1216	195	1412	\$8.5
TOTALS	32432	6863	39295	\$209.4

Table 13-11 Data relating to Light Damage to different Foundation types

13.2.4 Cost Mitigation with Remedial Action

Overall the total number of dwellings sustaining damage is reduced by around 20%. However, the majority of dwelling damage now relates to light damage, which was not considered to be altered with the remedy of the sub-floor. Table 13.12, shows the number of dwellings affected after remedial action, most significant is the collapse ratio, which is reduced to around 78%, [refer Table 13.5].

Foundation type	No. dwellings with Light damage ¹³	No. dwellings with Moderate damage	No. dwellings with Extensive damage	Total No. dwellings Collapsed	Total No. timber dwellings Damaged and Collapsed
Internal Piled	2432	606	97	37	3172
Full Piled	9730	2781	288	210	13009
Partial Wall	3243	854	157	12	4266
Full Wall	8108	2394	577	0	11079
Full Wall/Intern.	3243	796	165	0	4204
SLAB	4459	1266	769	0	6494
ENG	1216	272	210	0	1698
TOTALS	32432	8969	2263	258	43922

Table 13-12 Number of Dwellings Damaged and Collapsed with Remedial Measures applied

Table 13.13 calculates that the total cost of damage after remedial measures are applied is over \$1.1 Billion. The totals showing the most significant change are the collapse and extensive damage totals, both showing cost savings of between 60% and 80% [refer Table 13.7].

Foundation type	Light damage repair cost \$M	Moderate damage repair cost \$M	Extensive damage repair cost \$M	total Collapse damage cost \$M	Total cost \$M
Internal Piled	\$16.9	\$37.3	\$14.2	\$11.8	\$80.2
Full Piled	\$68.9	\$182.1	\$45.0	\$71.9	\$367.9
Partial Wall	\$20.3	\$47.7	\$20.9	\$3.5	\$92.4
Full Wall	\$46.5	\$127.8	\$73.5	\$0.0	\$247.8
Full Wall/Intern.	\$20.5	\$43.8	\$21.7	\$0.0	\$86.0
SLAB	\$27.7	\$80.3	\$116.6	\$0.0	\$224.6
ENG	\$8.5	\$18.4	\$33.9	\$0.0	\$60.8
TOTALS	\$209.4	\$537.5	\$325.9	\$87.2	\$1,159

Table 13-13 Total Repair Costs for Dwellings over all Damage States with Remedial Measures applied

13.2.5 The Total Costs of Remedial Action

The totals in comparison demonstrate that by applying remedies of around \$250 Million, savings will total almost \$1 Billion, with significant savings seen particularly in the Full Piled Foundation, at around \$500 Million [Table 13.14]. The Full Foundation Wall can be seen to cost more for remedial action than what is saved, however this is based on all dwellings having applied bracing remedies.

¹³ This total does not include totals from other damage states that may now show light damage as opposed to previous extensive or moderate damage states.

Foundation type	TOTAL No. Dwellings affected before remedy	TOTAL Assets at risk of damage and Collapse before Remedy \$M [Table 13.11]	TOTAL No. Dwellings affected after remedy	TOTAL Assets at risk of damage and Collapse after Remedy \$M [Table 13.17]	Total Cost of Remedial action \$M	Total Saving from the application of remedies \$M
Internal Piled	4209	\$226	3172	\$80	\$26.8	\$146
Full Piled	16161	\$892	13009	\$368	\$78.6	\$524
Partial Wall	5285	\$208	4266	\$92	\$26.5	\$116
Full Wall	12149	\$336	11079	\$248	\$105.1	\$88
Full Wall/Intern.	5036	\$140	4204	\$86	\$11.0	\$54
SLAB	6944	\$251	6494	\$225	\$0.0	\$26
ENG	1894	\$73	1698	\$61	\$0.0	\$12
TOTALS	51678	\$2,125	43922	\$1,159	\$248	\$966

Table 13-14 Statistics Before and After Application of Remedial Measures

The total reduction in damage will limit evacuations and increase the number of habitable dwellings following an earthquake, which could significantly aid the speed and efficiency of post-earthquake repair, as well as limit the anticipated demand on resources from the residential sector.

13.2.6 The Cost of Rebuilding after an Earthquake

The post earthquake construction period can cause increased demand for construction material, labour, machinery and other local resources leading to inflation. The amount of inflation varies over the earthquake repair period and differs between building materials according to the supply and the source. Figure 13.4 shows the totals before and after remedial measures are applied, with 30% inflation (Wellington Earthquake Lifelines Group 1995; Davey and Shephard 1995) [refer Table 13.7 and Table 13.13]. This 30% inflation is based on conservative past estimates, however for short periods following a disaster, inflation has been known to be as high as 75% (Walker 1995).

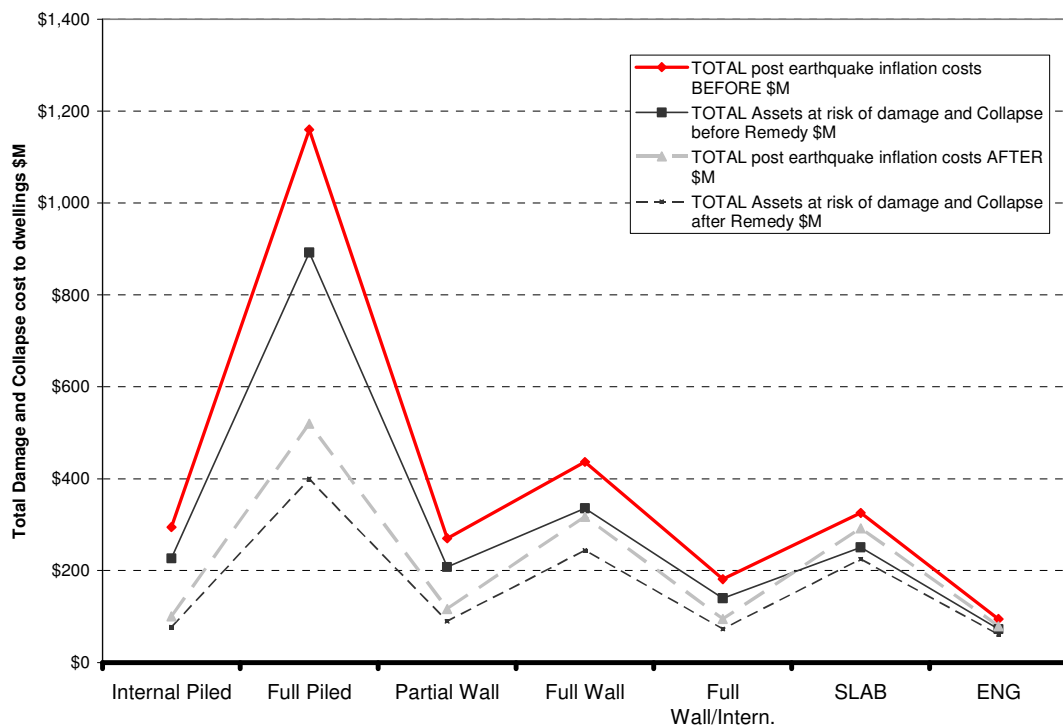


Figure 13-4 Total Cost of Damage and Collapse to Dwellings including Inflation

13.2.7

The Other Residential Costs

New Zealand dwellings are insured by EQC for damage and collapse up to a maximum of \$100,000 plus Goods and Services Tax (GST). Personal possessions are insured up to \$20,000 + GST, depending on whether dwelling is insured against fire (Earthquake Commission 2006b). The EQC currently has a total fund of NZ\$4.73 Billion¹⁴ backed up by reinsurance from overseas groups and a Government Guarantee that will fund the maximum foreseeable losses, which anticipates payouts of over 100,000 claims. The Government Guarantee states that that EQC will always be able to meet its obligations, regardless of the circumstances (Earthquake Commission 2006a) Given the initial figure of \$3.78 Billion damage to residential dwellings [refer Section 12.4.2], and subtracting the total repair costs of \$2.1 Billion before remedy, the remainder can be attributed to costs such as contents and land surrounding the dwelling up to 8m (EQC 2000). Figure 13.5 shows that almost \$890 Million will not be paid by the EQC, but will be paid either by the private insurer or the homeowner. Estimates suggest that the contents damage will cost around 50% (Hopkins 1995) and up to around 2/3 of the dwelling damage costs (Birss 1985), which is approximately correct for the costs seen below.

¹⁴ As at January 2007 from (Earthquake Commission 2006a)

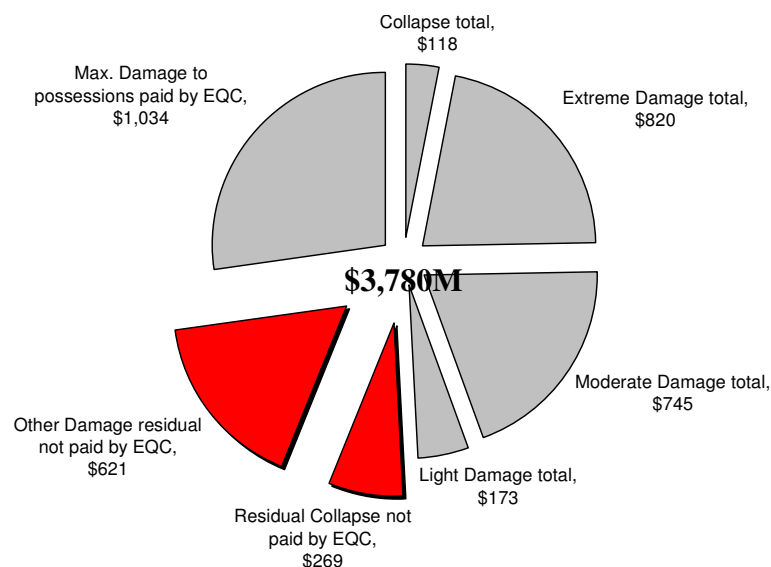


Figure 13-5 Total Cost of Residential Timber Dwelling and associated Damage not potentially covered by EQC *Before* Remedy

Following the application of remedies, Figure 13.6 shows that the total not covered by the EQC fund is only \$60 Million. This means that the private insurer and homeowner will incur less costs allowing money to be spent elsewhere in the post-earthquake economy.

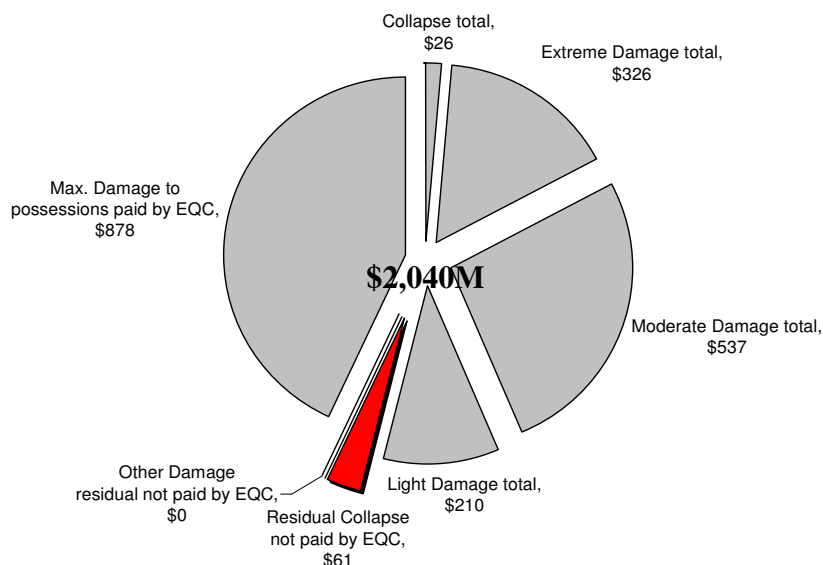


Figure 13-6 Total Cost of Residential Timber Dwellings and associated Damage not potentially covered by EQC *After* Remedy]

13.3 The Greater Societies' Economic Benefits

The totals above suggest that for a disaster centred in Wellington, many dwellings will be affected in some manner. However, the scenario does not reflect the effect on the greater Wellington Region nor the greater New Zealand.

The Wellington Region cannot be neglected when assessing an earthquake hitting the capital, especially considering that parts of the Hutt Valley are closer and more prone to damage than Wellington's outer suburbs. Figure 13.7 shows that the damage costs are maximum in Wellington City and taper to a constant damage cost of around \$10 Million from Lower Hutt up to Kaptiti, with certain suburbs in Lower Hutt showing higher costs than certain Wellington suburbs. Significantly smaller costs are seen in the Masterton, Carterton and South Wairarapa areas. The damage cost mitigation by applying remedial measures is significantly less than the Wellington City scenario, showing an overall saving of around half, from \$6.2 Billion to around \$3.6 Billion.

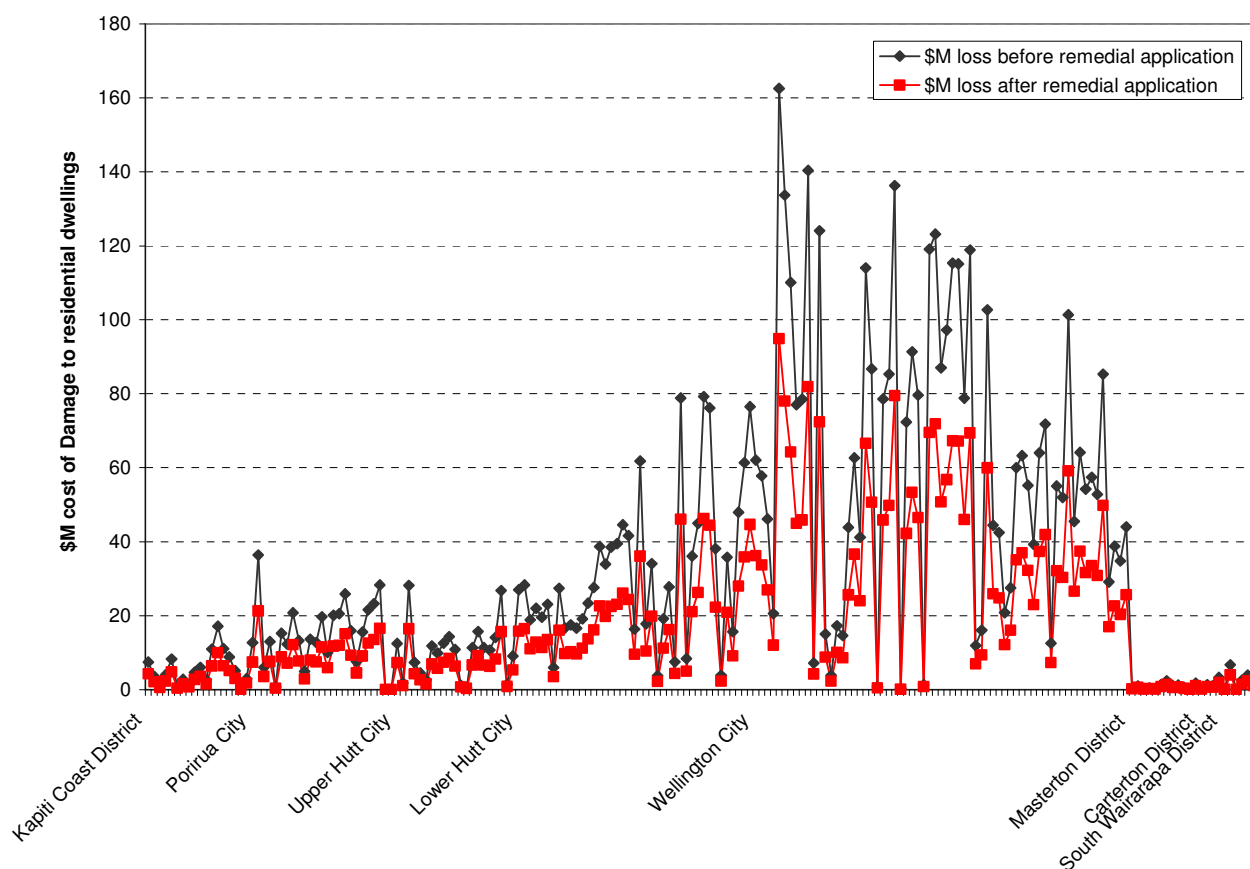


Figure 13-7 Economic Loss to Dwellings over the Wellington Region

13.3.2 The Effect on the Whole of New Zealand

The differences between the Wellington regional and national scenarios only differ slightly, however, not enough to alter loss modeller data related to cost damages. Figure 13.8 shows a small increase in costs in the West Coast area and also the Tasman Region. This damage is typical of past earthquakes, which have struck the top of South Island and spread serious damage into Wellington and West Coast [South Island] regions, such as the Murchison earthquakes [refer Section 1.1.3]. The national damage costs do not alter the overall costs,

although it is anticipated that the volume of claims for light damage and personal possessions would increase dramatically.

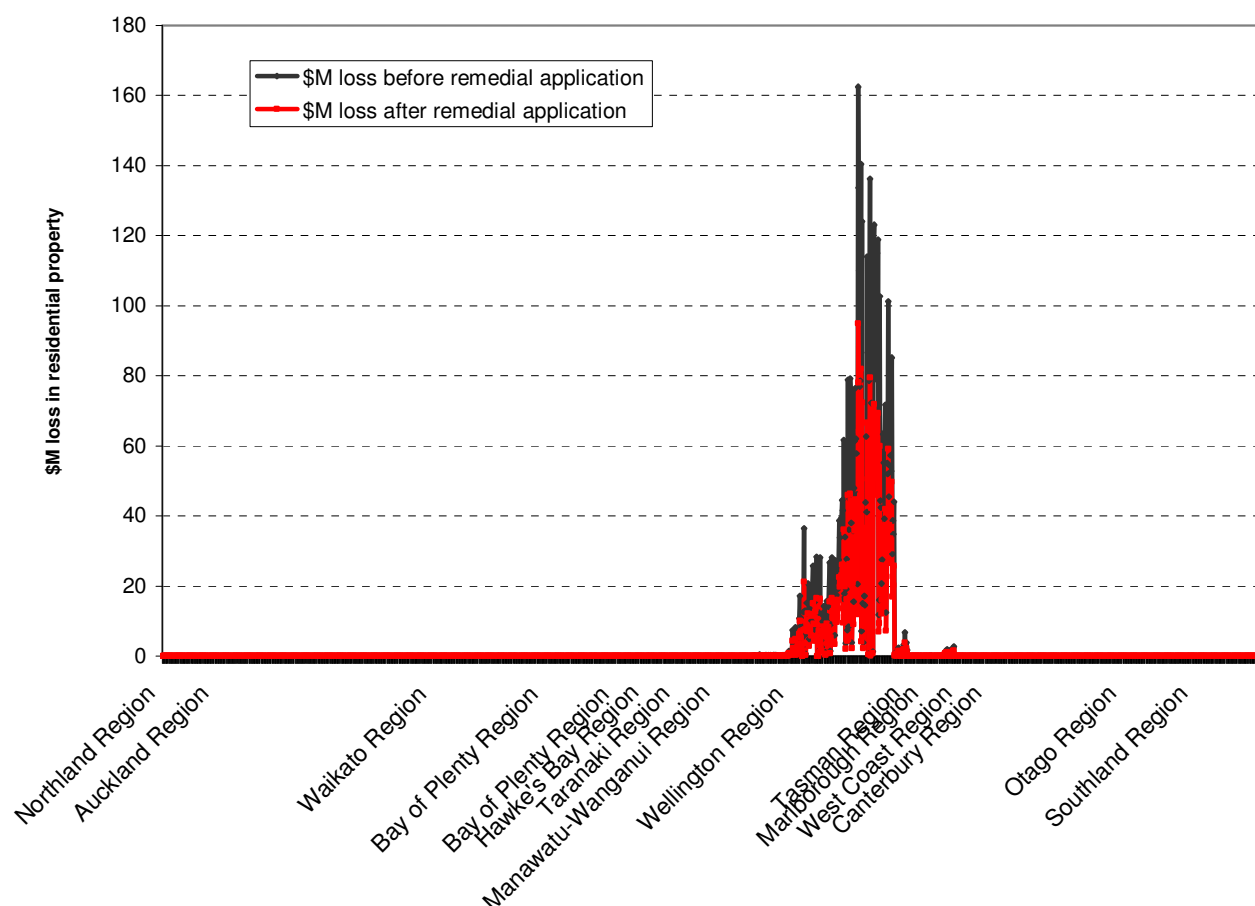


Figure 13-8 Economic Loss to Dwellings over the whole of New Zealand

13.4 Pre- or Post-Earthquake Prevention?

The difference between pre and post-earthquake repair is that post-earthquake repair can be more expensive due to price escalation and may take longer due to shortages and limitations of resource. The study has so far assumed that pre-earthquake repairs are more effective than post-earthquake repair. However, it is pertinent to understand the scope of work involved in post-earthquake repair measures. In many circumstances the post-earthquake repair of dwellings is considerably more difficult than constructing a new dwelling. Two stages of post earthquake repair are necessary; the temporary shoring followed by permanent repair, however superficial repairs can also occur, which disguises structural damage without reinstating the actual underlying problem.

13.4.1 Temporary Repair and Shoring

Re-levelling, propping walls and sliding dwellings back onto piles are typical requirements for post-earthquake repair. However, most extensive foundation repair measures first require shoring [Figure 13.9]. These remedies are temporary and are required to maintain an acceptable

level of interim public safety (Ian Smith & Partners NZ and Earthquake and War Damage Commission 1992). Further work is required to repair the structure and lateral capacity of the dwelling.



Figure 13-9 Propping of a Damaged Dwelling (Source: Ian Smith & Partners NZ and Earthquake and War Damage Commission 1992)

13.4.2

Permanent Repair

Permanent repair involves redistributing forces, correcting fixing defects and replacing structural members in the damaged dwelling (United Nations Department of Economic and Social Affairs 1977). However, these repairs usually require heavier engineering than what is required for pre-earthquake remedial solutions and usually involve many labour hours to overhaul foundations, which may also never attain the same level of trueness. The costs of repair for many common light damage issues have been quantified in the Earthquake Damage Assessment Catalogue published by the EQC (Earthquake Commission 2003). This catalogue helps ensure cost assessment of damage is consistent among all assessors of earthquake damage. The EQC also keeps costs a building cost database to help with assessment of the type of damage and relative costs (Earthquake Commission 2007).

13.4.3

Superficial Repair

Post-earthquake repair can sometimes involve the ‘patch-up’ of damage without actual remedy to the structural integrity. This type of historic ‘patch up’ was a common occurrence in Gisborne 1966, where buildings which were ‘restored’ as early as 1931 from the Napier earthquake, subsequently collapsed due to a lack of resistance (Hamilton et al. 1969). Patch ups are most often seen on block work and brick work, where mortar lines have cracked and entire walls are too expensive to reinstate or reinforce (United Nations Department of Economic and Social Affairs 1977). These issues are often superficially patched up to avoid the distress and anxiety that may arise from the public perception of the strength of the repaired dwelling. Thus,

for the purposes of this study, pre-earthquake remedial measures are considered more feasible, more economic and will require less resources when a shortage can be anticipated.

13.5 The Overall Cost / Benefit

A cost / benefit analysis is sometimes referred to a risk-benefit analysis, which is focussed on economic savings as a ratio of an outlay of capital costs. This ratio provides an insight into the amount that can be saved after an earthquake compared with the costs of remedial measures applied prior to an earthquake. However, it is important to express that large benefits do not always entail large costs. Prior to the 1989 Loma Prieta earthquake, businesses that fitted computer restraints were the biggest predictor of whether a business survived or not. Those businesses that had no computer restraints lost data and often went bankrupt as a consequence (McClure 2006).

13.5.1 *The Range of Repair Costs*

The range of estimated repair costs is used to find a reasonable estimate of damage ratios. Figure 13.10 suggests the relationship and difference between the minimum, maximum and average MDR for each damage state, which shows that the largest discrepancy is in the Moderate and Extensive damage states. These values were obtained from averaging all of the damage MDR's for all foundation types in order to show a probable maximum and probable minimum MDR. These MDR's can then be multiplied through dwelling replacement costs to find the range of cost / benefit ratios that can be realistically anticipated.

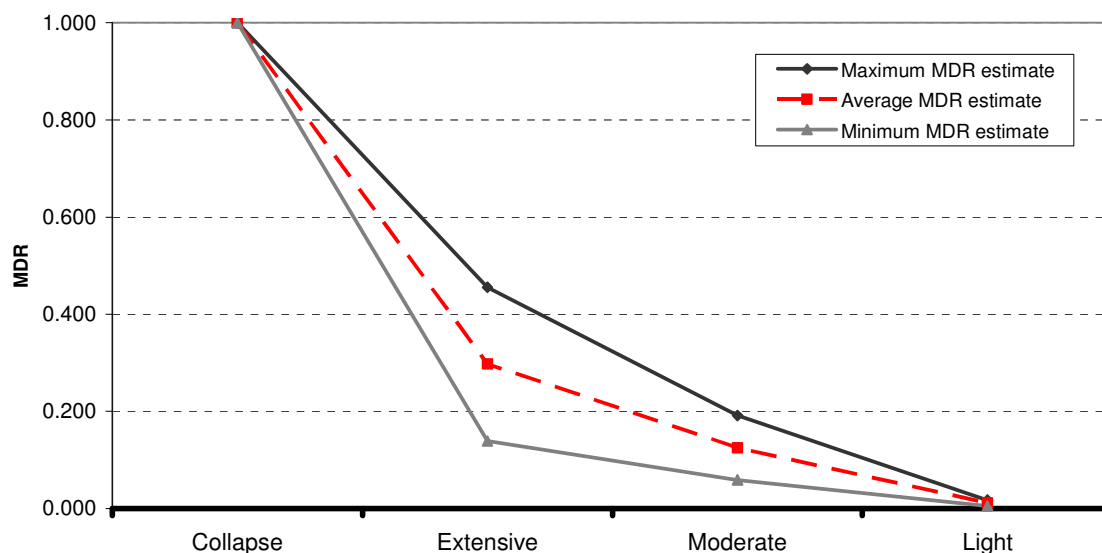


Figure 13-10 Maximum, Minimum and Average MDR over all Damage States

The values obtained provide a conservative estimate of the probable losses despite any assumptions made in previous sections, although all assumptions made thus far have always overestimated costs and remedial measures, rather than underestimated. Table 13.15 shows that

the difference in maximum and minimum costs alters significantly for all states, with maximum probable differences of \$100K.

Dwelling Damage type	Max. loss from damage BEFORE Remedy	MDR % of each damage state	Min. loss from damage AFTER Remedy	MDR % of each damage state	AVERAGE loss to dwellings after Remedy	AVERAGE MDR % for each damage state
Collapse	\$316,000	100.0%	\$316,000	100.0%	\$316,000	100.0%
Extensive	\$144,000	45.6%	\$44,000	13.9%	\$94,000	29.7%
Moderate	\$60,480	19.1%	\$18,480	5.8%	\$39,480	12.5%
Light	\$5,498	1.7%	\$1,680	0.5%	\$3,589	1.1%

Table 13-15 Maximum and Minimum Cost of Repair for a High and Low Estimate for each Damage State¹⁵

13.5.2 *The Best Estimate Cost / Benefit Ratio*

The cost / benefit total suggests a ratio of around 0.05 for all foundation types likely to experience collapse or extensive damage [Table 13.16]. A ratio of less than one, suggests that it is economically feasible to undertake remedial measures, where as a total over one would suggest that the cost of remedy is over and above anticipated repair costs for a dwelling. The negative number in the light damage bracket suggests that no remedial measure will abate any of this type of damage.

Foundation type	Light damage cost / benefit	Moderate damage cost / benefit	Extensive damage cost / benefit	Collapse cost / benefit
Internal Piled	-8.93	0.55	0.07	0.05
Full Piled	-7.84	0.88	0.06	0.04
Partial Wall	-7.99	0.49	0.09	0.04
Full Wall	-17.00	1.36	0.46	0.00
Full Wall/Intern.	-3.06	0.15	0.07	0.00
SLAB	0.00	0.00	0.00	0.00
ENG	0.00	0.00	0.00	0.00

Table 13-16 Overall Cost / Benefit Ratios using Average MDR Values

Using the range of anticipated maximum and minimum repair costs, the cost / benefit ratios can be calculated. These values are only made for moderate and extensive damage, as these areas are most likely to show discrepancies [Table 13.17]. Light damage totals are considered outside the scope of remedial measures and the collapse costs are always only reflective of dwelling replacement costs. The range of ratios is significant for moderate damage, however is still low for extensive damage costs ratios.

¹⁵ All costs based on 2005 estimates from the Earthquake Loss Modeller and using 2007 Quantity Surveying estimates for application of remedial measures.

Foundation type	Minimum Moderate damage cost / benefit	Maximum Moderate damage cost / benefit	Minimum Extensive damage cost / benefit	Maximum Extensive damage cost / benefit	Overall Average cost/ benefit ratio
Internal Piled	0.55	0.91	0.07	0.11	0.29
Full Piled	0.88	1.44	0.06	0.19	0.44
Partial Wall	0.49	0.80	0.09	0.10	0.26
Full Wall	1.36	2.24	0.46	0.59	0.78
Full Wall/Intern.	0.15	0.24	0.07	0.08	0.09
SLAB	0.00	0.00	0.00	0.00	0.00
ENG	0.00	0.00	0.00	0.00	0.00

Table 13-17 Maximum and Minimum Cost / Benefit Values for Moderate and Extensive Damage

Using the observations made from previous earthquakes, which states that it is advisable to make pre-earthquake structural repairs only if the cost of remedy is less than 30% of the cost of repair or replacement; the Internal Piled Foundations, Partial Wall Foundations and Full Foundation Wall/Internally Piled dwellings should all be remedied (United Nations Department of Economic and Social Affairs 1977). However, the Full Piled Foundation shows minimal mitigation from Moderate damage, due to the size, range and variability of dwelling value and significantly higher repair costs [refer Section 13.2.2]. Thus, a Full Piled Foundation would benefit from remedial measures to mitigate Extensive damage and Collapse, which considering the number of dwellings with this type of foundation under bracing requirements, is perhaps a more significant saving than other foundation types [refer Section 13.1.4]. Rearranging the values to produce a benefit / cost ratio shows the direct saving for money spent. Table 13.18 shows that for collapsed dwellings, the benefit is around 20 times the capital cost. Overall, the average value is around 11 times for all damage and collapse states. The Full Piled Foundation shows that benefits are higher for collapsed dwellings, with fewer benefits for extensive damage and no potential saving against moderate damage. However, this is consistent with cost / benefit totals, which show that more superficial damage states tend to procure less overall benefits.

Foundation type	Mean Moderate damage benefit / cost ratio	Mean Extensive damage benefit / cost ratio	Collapse benefit / cost ratio	Average benefit / cost ratio
Internal Piled	1.45	11.89	20.71	11.35
Full Piled	0.92	6.86	26.42	11.40
Partial Wall	1.64	12.83	22.99	12.49
Full Wall	0.59	2.25	0.00	0.95
Full Wall/Intern.	5.42	28.87	0.00	11.43
SLAB	0.00	0.00	0.00	0.00
ENG	0.00	0.00	0.00	0.00

Table 13-18 Overall Benefit / Cost Ratios using Average MDR Values

To analyse this information further, if a dwelling has an expected life of approximately 50 years, and an earthquake has a 50% chance of hitting Wellington in the next 50 years [assuming an earthquake with a 100 year return period], then the average benefit / cost ratio for all high damage states is approximately 6 for all foundation types, except those with very low average benefit / cost ratios. This methodology assumes that since earthquakes in New Zealand are reasonably common and the housing stock is not extremely dilapidated, the cost / benefit, on average, is approximately 0.5 for a 50 year earthquake return period. Naturally, this information has direct benefits that are not strictly economic, which can be seen to aid throughout the post-earthquake clean-up.

13.6 The Post-Earthquake Clean-up

Haas, Kates and Bowden (1977) describe three different phases of post earthquake recovery. The first is the restoration or “Patch up” of existing physical and social system damage, which usually involves the implementation of emergency management systems and initial evaluation of the damage. The second phase is the “Replacement / Reconstruction”, which entails the rehabilitation of capital stocks to pre-earthquake levels. This has been known to last from months to years, depending on the economy of resources, material stocks and availability of labour force in the vicinity of the damaged region. The final phase is the “Commemorative phase”, where effort is focussed towards promoting economic growth and the mitigation of any future damage in the event of recurrence (Haas, Kates and Bowden 1977 cited Nigg 1995). The factors that may be mitigated by increasing awareness and application of remedial measures of foundations will be shown to lessen the post-earthquake stress and burden of the residential sector on the economy.

Hazard mitigation is the process of recovery planning, developing evacuation plans and saving lives, which are solely dependant on the number of dwellings that will collapse or sustain extensive damage. The system of emergency management from the WCC explains that three recoveries of society must exist, the economic recovery, the physical recovery and the social recovery. Figure 13.11 suggests that of these three recoveries, all preparations are equally important and extremely vital to the quick recovery of Wellington City to pre-earthquake levels.

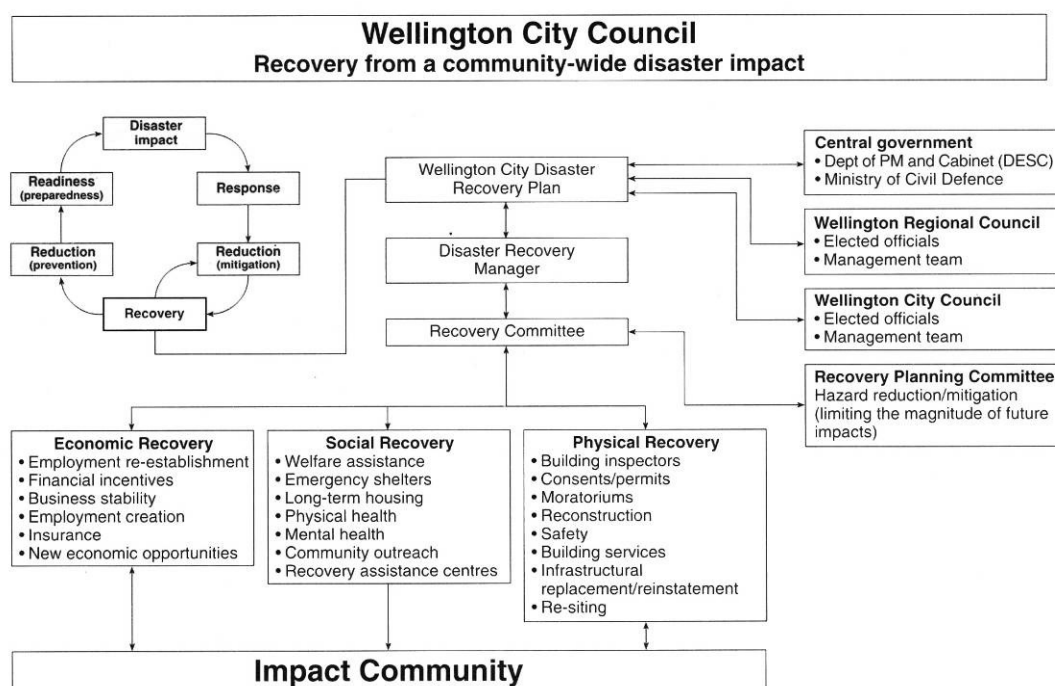


Figure 13-11 The Wellington Overall System of Emergency Management (Source: Britton 1994)

Studies into the post-earthquake restructuring and reinstatement of Wellington, suggests that New Zealand has enough labour, material and plant resources to aid in a maximum four year clean up period. However, certain shortfalls, such as temporary housing of the additional labour force may become evident over this period (Lanigan 1995). However, evidence following the 1995 Kobe earthquake, suggests that up to 20% of businesses failed (Wellington Earthquake Lifelines Group 1995), which can directly increase unemployment and inhibit the growth of post-earthquake society (Nigg 1995).

13.6.2 *Evacuation, Shelter and Aid*

So far, the costs and benefits to society have been termed as expressions of financial savings, however, this neglects the cost of human life resulting from disaster. When 'costs' are measured in volume of evacuations or number of temporary shelters required, then these costs can be reasonably difficult to predict and quantify (Cooney and Fowkes 1981). The remedy of foundations will reduce the volume of dwellings that may be destroyed by an earthquake and therefore, the number of people that require temporary shelter and immediate medical attention [Figure 13.12]. These values were obtained from assuming that for every collapsed dwelling, an average of 3 people will require evacuation (as a collapsed dwelling is uninhabitable). Certain extensive damage in the foundation area, will also require immediate evacuation [refer Section 12.3 and Section 13.6.3].

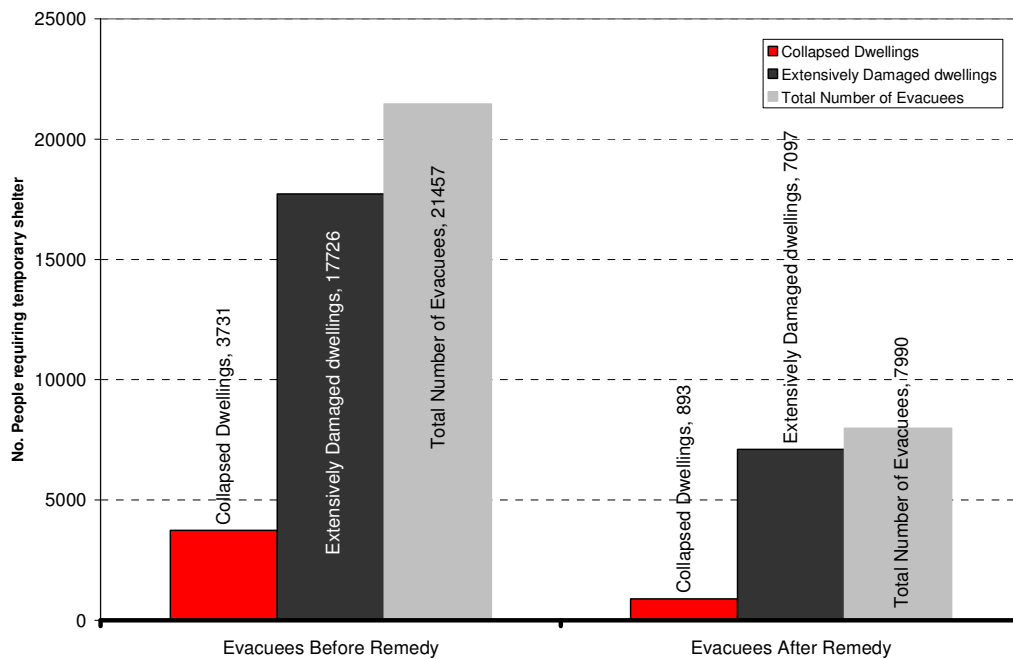


Figure 13-12 Number of Evacuees Before and After applying Remedial Measures

The evacuation process described in the National Civil Defence Emergency Management Plan Order (2005) stipulates that evacuation can either be pre or post disaster, by voluntary or mandatory order, however mandatory orders are only made when dwellings are evaluated as inhabitable or unsafe [refer Section 13.6.3]. However, evacuations may cause post-traumatic stress disorder, depression, and other physical ailments, which can remain long after the disaster impact. These psychological effects can affect different cultures and socioeconomic groups differently (Mileti 1995). The Kobe earthquake showed that, “*many people walked unemotionally around the wreckage to work, carrying their day’s water supply on their backs*” (Park 1995a, p.207). Whereas following the 1971 San Fernando earthquake, people were usually concerned with saving themselves, neighbours and their property (Applied Technology Council 1989). Therefore, evacuation orders must be made in consideration of whether the risk of staying is greater than the risk of evacuating and the resulting psychological distress involved (Ministry of Civil Defence and Emergency Management 2005). Based on the Loss Modeller estimate of the number of dwellings collapsed before and after the scenario earthquake, Figure 13.13 forecasts both a lower mortality rate and injury toll.

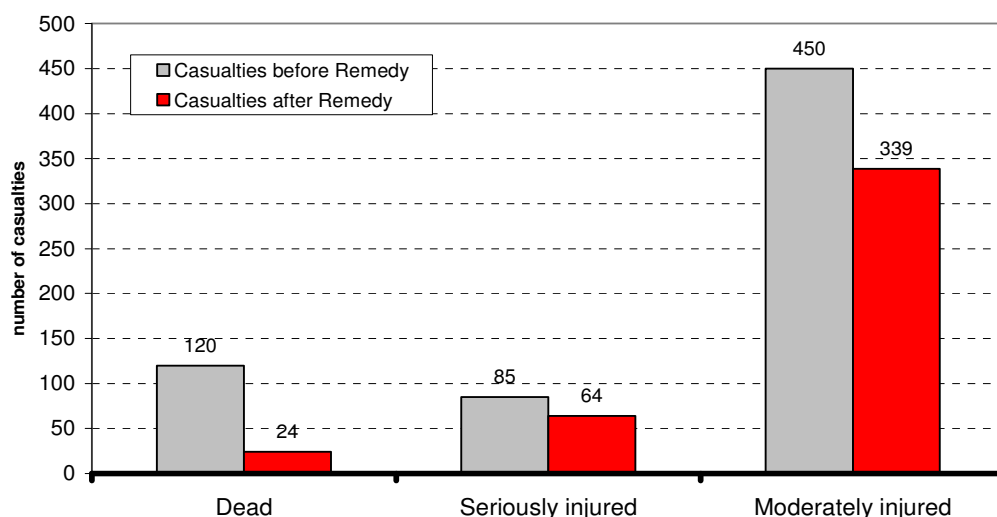


Figure 13-13 Number of Casualties and Deaths Before and After applying Remedial Measures for a Night time Earthquake Scenario, from Loss Modeller estimates

13.6.3 Post-Earthquake Dwelling Evaluation

After temporary shoring of a dwelling from further damage [refer Section 13.4.1], evaluations are required to assess the structural integrity of dwellings. The Building Code (1992) requires foundations to have negligible permanent offset after a seismic event, including some damage but not total collapse. Thus, dwellings will be evaluated as either having minor damage, no apparent instability hazard, moderate foundation damage or severe settlement. The damage evaluation guideline, based on the Applied Technology Council document (1989), and adapted to New Zealand dwellings by the EQC (Earthquake Commission EQC 2000), outlines obvious indicators for assessing structural strength, habitability and entry criteria. If a dwelling is posted as “no entry”, there may be moderate foundation damage, severe settlement or severe swaying of foundations. “Limited entry” indicates that a dwelling will have no instability hazard, moderate foundation cracks and moderate settlement, which allows occupants to retrieve their belongings. For a dwelling to remain “habitable”, only minor settlement, cracking and local uplifts are allowable (National Fire Protection Association 1991).

13.6.4 Insurance Issues

In the event of damage to a dwelling, it is the owner’s responsibility to organise repair or reinstatement of the dwelling. A number of issues seen in past earthquakes include a lack of information regarding how the dwelling would be repaired and non-forthcoming insurance payments (Ruscoe 1988), where quick and efficient rationally focussed methods of actions are of essence (UN 1977). Delays will be common if a decision must be made regarding the remedy or demolition of a dwelling (Middleton 1995). Many examples of undue condemnation have been observed due to overzealous demolition crews, often referred to as the “*Second earthquake*” (United Nations Department of Economic and Social Affairs 1977). This will be compounded if the dwelling has particular historical significance (Lanigan 1995). Moreover,

many occupants have remained in significantly damaged dwellings for over six months awaiting insurance payments and for the availability of contractors and quotes. This is further compounded, since commercial properties are given priority over residential dwellings; which prioritises development of the post-earthquake economy (Ian Smith & Partners NZ and Earthquake and War Damage Commission 1992). Another issue for insurance agencies is the legitimacy of certain insurance claims. Since repair costs are reimbursed by the EQC, this can sometimes be seen as an opportunity to blame unmaintained foundation damage on earthquakes and therefore repair and maintain dwellings free of charge (Henri 1995). Instances in the past have also shown an increase in the rate of arson, in order to receive full insurance payment under the separate fire insurance policy (National Fire Protection Association 1991). However, this may not be such an issue in New Zealand, as fire and earthquake insurance is usually covered in a single insurance package.

13.6.5 _____ The Media Involvement and the Dissemination of Information

Following an earthquake, the public require a constant flow of factual and practical assistance, in order to dispel fears or concerns regarding the earthquake. The televised news media usually tends to focus on areas of the most damage, which may misrepresent the magnitude and severity of the disaster. Research suggests that this type of coverage is counterproductive and increases people's anxiety beyond useful levels (Finnis 2004). If these images were decreased and images of buildings and dwellings which stood firm because of sound construction, adjustments may be made to better prepare for earthquakes (McClure 2006).

13.7 Societal Benefits Summary

Overall, the cost of remedial measures for all foundations in Wellington City is anticipated to total around \$250 Million, which includes the upgrade of bracing, fixings and condition of foundations up to the standards of NZS3604:1999. It was calculated that without applied foundation remedies, the total earthquake repair bill would total around \$2.1 Billion and may affect to a certain degree up to 53,000 dwellings. After calculations with remedial measures applied, a saving of around \$1 Billion is anticipated from the post-earthquake repair bill. Most significant is the saving for piled dwellings, which anticipates a saving of over \$500 Million from the mitigation of extensive damage and collapse of dwellings. The cost / benefit ratio for extensive damage and collapsed dwellings shows values between 0.1 and 0.04, meaning that for every dollar spent now, \$20 will be saved in post earthquake repair costs. This will result in less pressure on materials and resources and will mitigate the extent of post-earthquake construction inflation. More dwellings will remain habitable through the upgrade of foundations, which could save around 13,000 evacuations and limit the total number of deaths and injuries from severe shaking and falling objects. This will in turn limit the initial pressures on emergency management systems, minimise the total number of immediate claims lodged with the EQC and allow a faster economic and social recovery in the short and long term over the whole of New Zealand. However, the method of dissemination of this information will dictate the overall uptake of recommendations. The adequacy of the marketing campaign and the systems put in place, should allow the easy and simple application of remedial measures for existing foundations in residential dwellings.

14 _____ The Societal Infrastructure: Where does Responsibility Begin?

Understanding how information regarding earthquakes and in particular foundation securement is disseminated to the public, can provide an insight into the type, quality and scope of available media. This information may aid the development of public focussed remedies or other presentation media for the instigation of remedial action in the sub-floor area. The producers or developers of this information need to be aware of the benefits to the community, companies and therefore the economy, in providing the public with information that covers all aspects of earthquake preparedness, including what remedial measures can be applied both to the structure of dwellings and inside the home. It is unrealistic to believe that all dwellings can be saved from extensive earthquake damage. However, many failings need not occur, and simple actions or amendments to current legislation may save a community and therefore New Zealand from excessive earthquake repair costs that will be necessary to rebuild communities, the economy, and infrastructure to pre-earthquake standards.

14.1 The Current Dissemination of Preparation Information

Since the presentation of information is so pertinent to the uptake of remedial measures, an analysis of the current strategies could provide insight into the state of current information dissemination to the public. Government funded organisations such as the Ministry of Civil Defence and the EQC usually follow similar patterns of advertising, often sporadically promoting defences against natural disaster.

14.1.1 _____ *The Ministry of Civil Defence*

The Civil Defence campaign “Get ready, Get thru” initiated with television advertisements and familiar celebrity faces, describes that New Zealand can become a disaster zone from any number of natural disasters at any time (Ministry of Civil Defence and Emergency Management 2006). The television advertisements prompts viewers to visit the website, which reintroduces people to images of the emergency scenarios seen in the television advertisements [Figure 14.1].



Figure 14-1 Imagery from Ministry of Civil Defence Campaign, “Get Ready Get Thru” (Source: Ministry of Civil Defence and Emergency Management 2006)

Although the campaign covers preparation for all disasters, it does not inform the public that certain preventative actions can be undertaken to limit damage and therefore disaster. The Earthquake Commission (EQC) campaign is more descriptive of the requirements specifically for earthquakes, however still has limitations attached.

14.1.2 _____ *The Earthquake Commission’s Information*

The EQC’s role in the community is two fold, education and disaster preparation and management. The EQC’s 2001 ‘Fix, Fasten, Forget’ disaster preparation campaign was lead by television advertisements enticing people to make simple moves to ‘Quake-safe’ the interior of the home. The campaign had positive effects with an increase in preparedness, however compliance was low especially for non multi-useful items strictly for earthquake preparedness (Finnis 2004). Analysis following the campaign showed that the two main reasons for not preparing, was that it was ‘pointless’ or it was ‘too much effort’ (Finnis 2004). The EQC’s newer campaign, entitled “EQ-IQ”, is initiated by a series of television advertisements of fences running through majestic landscapes of New Zealand and into the common place we all live [Figure 14.2].



Figure 14-2 Imagery from the “EQ-IQ” Campaign, showing the Common place we all live and the Fault line Threat that is always Apparent

The information again prompts the viewer to visit online information that provides more in depth earthquake information. The online links lead to ‘Quake-Safeing’ information which is again focussed on how to secure the contents of your home. While this website does have the potential for dissemination of official information before and after an earthquake, including foundation remedial measures, this forum may introduce liability issues regarding the proper application of remedies [refer Section 14.2.4]. The current section on foundation securement and the sub-floor is quoted below [Figure 14.3] (Earthquake Commission 2006c).

“Check that your house is bolted to its foundations and that it is properly braced; if not: Wire, bolt or bracket Bearers to piles. Nail strong plywood sheets to the inside of the framing in the sub-floor space. Nail strong plywood sheets to brace and clad outside piles. Infill with concrete (preferably) or nail panels between outside piles on all corners to help reduce twisting motions”.

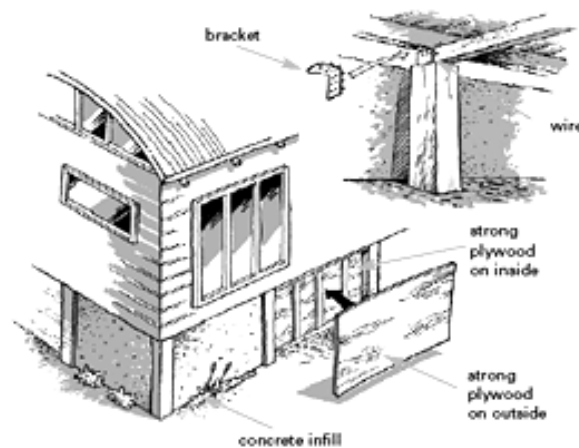


Figure 14-3 Excerpt from the EQ-IQ Website – “Other Actions/foundations” (Source: Earthquake Commission 2006c)

The requirements such as “properly braced” and “strong plywood” are ambiguous and allow little insight into the actual restraints required. No action can be expected from oversimplified prompts from imagery and related text, such as seen above.

14.1.3 Other Sources of Information

Without having the experience of an earthquake first hand, it can be difficult to understand the impact, effect and damage to structures. Perhaps one of the best sources of first hand information portraying the force of an earthquake is the simulated shaking house exhibit on regular display at Te Papa, Wellington. The simulation recreates the earthquake felt at the 1987 Edgecumbe earthquake and provides first hand demonstration of the forces a dwelling must withstand [Figure 14.4]. This exhibit is surrounded by “Quake-Safeing” techniques and information as seen on the EQC website.



Figure 14-4 Te Papa display showing the Small Shack driven with Thrust Actions to Simulate the 1987 Edgecumbe Earthquake

Overall, television is considered the preferred medium to *receive* hazard mitigation information, and the internet, as well as advice from family, is preferred when *seeking* information, where as brochures are the preferred media for *reference* (Finnis 2004). Therefore, educational books aimed at the younger generation can aid in the facilitation of informing older members of families who may not be aware of new earthquake information. Other texts tend to describe why and how structures failed. Thus, the availability of such information can inform and remind people that damage to dwellings and foundations is related to specific design features. It is more useful to inform people that mitigation of these defects can reduce damage, rather than offering no solution at all (Mileti & Darlington 1995 cited Finnis 2004).

14.1.4 Overseas Documents

In 1990, a 24 page publication inserted into the Sunday paper was released to the public of San Francisco, which emphasised the likelihood of an earthquake in the region, what people should do to prepare and how to reduce damage. The article also included scientific explanations of why an earthquake is likely, descriptions of how scientists make their predictions and finally where to get more information (U.S. Geological Survey: Earthquake Hazards Program 2003). Researchers assessed levels of preparedness before and after the release of the publication and found a significant preparation increase on high frequency items such as food and water, from 44% to 75% and fixing latches to cupboards from 10% to 16% (Mileti & Darlington 1995 cited Finnis 2004).



Figure 14-5 Imagery from the San Francisco Publication (Source: U.S. Geological Survey: Earthquake Hazards Program 2003)

The research suggests that this release of information had significant positive effects for earthquake preparation. Given the success of this type of article, New Zealand could produce a similar document focussing on specific areas such as the sub floor, bracing and overall dwelling safety. However, despite the spread of information, it is always ultimately the homeowner's decision to prepare.

14.2 The Homeowner's Decision to Prepare

The totally unexpected, nearly instantaneous devastation of one's property has a unique psychological impact on people (Dowrick 1995), however it is the homeowners responsibility to implement preparedness actions, rather than relying on response from Local Authorities or the Government. Public messages and campaigns need to describe the boundaries between public and private responsibilities, so that pre-planning and preparation may mitigate danger and destruction. Since past earthquakes have shown that the physical effects of earthquakes are highly predictable (Yanev 1974), preplanning methods simply require consideration by the public.

14.2.1 _____ *The Psychology of Preparation*

Despite the information provided to the public, the preparation for disasters is based on the psychological perceptions of risk. In most circumstances the best method to prompt action, is to frame risk in terms of threat. Personal safety to homeowners can be enough to convince people to undertake preparatory action. Other messages can choose to negatively frame the economic risk to individuals, including emphasising the long delays and recovery time to repair one's dwelling following an earthquake, despite EQC insurances [refer Section 14.3]. Suggestions such as: "*If an earthquake strikes your house, contents and memories may be destroyed if you do not remedy your sub-floor*", may have more effect than simply saying "*Applying foundation remedies could save your home, contents and memories*". However, many people do not see the risk as being relevant to themselves, for example a Chicago study asked citizens, "*if an atomic bomb was to hit the city and killed 97% of citizens, what would you be doing?*" More than 90% predicted that they would be helping burying the dead and only 2% said they thought they would be dead (Burton, Kates and White 1993 cited McClure 2006). The study suggests that in general, societies are not mentally or physically prepared for a disaster, and believe it is

more likely to affect people other than themselves. This unrealistic optimism¹⁶ can be reduced by alerting people about earthquake hazards that have happened to other people in similar settings. It is commonly understood that people who have lived in a hazard prone area or have been personally affected by a similar disaster, expect the relevant disasters more and are better prepared, than people who usually cope with the threat of disaster by denying its likelihood (McClure 2006). Although current attention has been toward risks such as Tsunami, flooding and rising sea levels, 70% of New Zealanders believed that an earthquake is the most likely hazard (Finnis 2004). Higher expectations exist in Wellington; with around 88% believing an earthquake will strike in the next five years (Gough 2000). Another reason people do not prepare for earthquakes is that too many risks exist which entice expenditure. Thus, the remedial measure must be depicted in a manner which shows the usefulness in multiple risk situations or alternatively makes the remedy obligatory or absolutely vital to survival. However, this may be an issue for landlords who can anticipate no benefit for any implementation of remedial measures (McConchie 2000).

Essential actions that will prioritise mitigation of injury and death are usually the first areas of implementation for a household. Evacuation and survival kits provide an easy way to prepare [refer Section 14.4.3]. However, ranking actions with potentially greater benefits relative to the cost, may provide a better understanding to the homeowner of the intention of preparation rather than presenting a long unranked list of 30 items that must be done to prepare for earthquakes. For example, fixing a dwelling to the foundations is likely to prevent a dwelling collapsing in an earthquake, however, fixing shelf contents restraints is likely to prevent objects falling from the shelf. It would seem that the benefits of preventing the dwelling falling from its foundation would far exceed the benefits of preventing objects falling from shelves, even though the costs are similar [refer Section 14.2.3]. All of this information can be overwhelming to a person, especially since certain remedial actions involve large costs for seemingly low-risk event. Therefore, prioritisation ranking should be made with consideration for the overall anticipated benefits as opposed to the initial costs.

An area that has received recent publicity by the EQC's 'Quake-Safe' initiative, is securing dwelling contents against movement [refer Section 14.1.2]. Securement of tall objects can prevent personal injury by limiting flinging, sliding or overturning of heavy objects. Securement of small irreplaceable items can be as simple as using Velcro strips or brackets. Applying costs and savings to the homeowner is straightforward, as it is easy to understand the physics behind

an object toppling over. This is supported by studies which conclude that more people are injured by non-structural hazards than from dwelling collapse or damage (Charleson 1995). However, internal contents securement only solves issues which are visually apparent, and perhaps superficial, it does not mitigate the source of the problem, which is at the sub-floor level. Moreover, Table 14.1 shows that the application of internal restraints and sub-floor restraints have similar costs, but benefits which could potentially differ by an order of magnitude. This comparison is made to compare costs and it is still anticipated that contents will be damaged with a remedied sub-floor.

Household Item	Specific name		Cost	Install	Sub-floor Remedy	Cost	Install
Microwave	Stainless steel braces	2	\$52	?	Bracing	\$604	\$560
Oven	Refrigerator strap	1	\$60	?	Fixings	\$506	\$1,362
Computer Monitor	Monitor Pull	1	\$20	?	J-B	\$148	\$407
Refridgerator	Refrigerator strap	1	\$60	?	J-FW	\$98	\$269
Computer	Versa Buckle	1	\$18	?	OP-B	\$96	\$360
Television	TV fastening kit	1	\$30	?	B-B	\$72	\$72
Hot Water Cylinder	Water cylinder kit	1	\$18	?	J-J	\$92	\$253
Washmachine / Dryer	Washer/Dryer Strap	2	\$52	?	Condition	\$376	\$1,501
VCR / DVD / Stereo	Versa Buckle stereo	3	\$54	?	Ventilation	\$63	\$306
Books on shelving	Boing bar	10	\$200	?	Polythene	\$102	\$630
Bookshelves etc	Out of Sight furn.strap	10	\$200	?	Clearance	\$0	\$490
Cupboard doors	Q-lock 3/4"	20	\$240	?	Soil Infill	\$210	\$75
Refridgerator door	Refrigerator door strap	1	\$10	?			
Wall mounted pictures	Picture fastening kit	5	\$60	?			
Miscellaneous	Quakehold putty	5	\$50	?			
Miscellaneous	Quake tape	2	\$80	?			
TOTAL			\$1,204	?	TOTAL	\$1,486	\$3,423

Table 14-1 Comparative Costs for Interior Seismic Restraints and Piled dwelling Remedial Measures

On the surface, the material costs from the New Zealand distributor of interior restraints (Q-Safety Inc. 2001) is comparable to the material costs of sub-floor remedies for an average Full Piled Foundation, however the labour for applying the interior restraints is unspecified. Although most of the fixings are simple, the correct installation of the products could potentially cause liability issues [refer Section 14.2.4]. A new focus should perhaps be to convince people that securing a dwelling from slipping off foundations may be as simple and as 'inexpensive' as applying fasteners to the interior of the home, and will be far more beneficial during and following an earthquake.

14.2.4 DIY-[Li]Ability

In terms of the public, the most common preparations are most often low cost or low effort (McClure 2006). Items that relate to structural integrity or that require expertise tend to be lower on the list, despite the high overall benefits. The uptake of sub-floor remedial measures after the

Earthquake Hazards Program (1990), [refer Section 14.1.4] showed a 3% increase of wall bracing and a 5% increase in bolting of dwellings to foundations. As seen in the previous section, if sub-floor remedies are applied by the individual, significant costs can be saved. However, issues with liability can be created when non-professionals apply structural remedies and damage occurs. Internal content suppliers state that they are not liable for any damage caused by the failure or incorrect installation of products, nor are the accurate strengths of the products guaranteed (Q-Safety Inc. 2001). Thus, the DIY application of sub-floor remedies, which can be purchased at the hardware store, could potentially cause similar liability issues relating to the collapse of a dwelling. The solution may be as simple as informing trades people and homeowners of the proper application of remedies. Considering that much of the additional strengthening costs to dwellings were often paid by the owners following an earthquake (Hamilton et. al. 1969), the liability should perhaps fall on the dwelling owner who takes no action to implement remedial measures to secure their dwelling.

14.2.5 _____ ***Is Upgrading Foundations simply Maintenance?***

The values in the House Condition Survey (Clark, Jones, and Page 2005), suggest that on average \$1,300 is spent per annum, for general maintenance of dwellings. 16% to 49% of the sample were observed to have poor sub-floor condition ranging from inadequate ground clearance, poor ventilation, inadequate bracing and missing connections. Although these issues require serious attention, almost every other element within the dwelling including doors, guttering and household fittings received more maintenance during that period (Clark, Jones, and Page 2005). This may be the result of a lack of knowledge or simply that the foundation is out-of-sight so does not receive reasonable attention. This is especially true for renovated dwellings, which seldom receive attention in the sub-floor area due to the anticipated expense involved. Many issues with moisture in dwellings, is the direct result of poor sub-floor ventilation. A modern solution is to apply active ventilation systems. However, a more cost effective solution would be passive polythene sheeting in the sub-floor to eliminate the moisture at the source. Unfortunately, no one is actively marketing this solution so it is not apparent to the homeowner. If foundations were seen as an important area to maintain, the public may be more open to applying remedial measures and to use annual maintenance funds, for structural rather than simply aesthetic purposes.

14.3 Private and Public Insurance

New Zealand has an extensive disaster fund that will allow a large number of claims to be settled following an earthquake. However, many people currently rely on this as an alternative to higher private insurance. The private insurer needs to apply more financial incentives to necessitate upgrading and maintaining of foundations which are currently at risk.

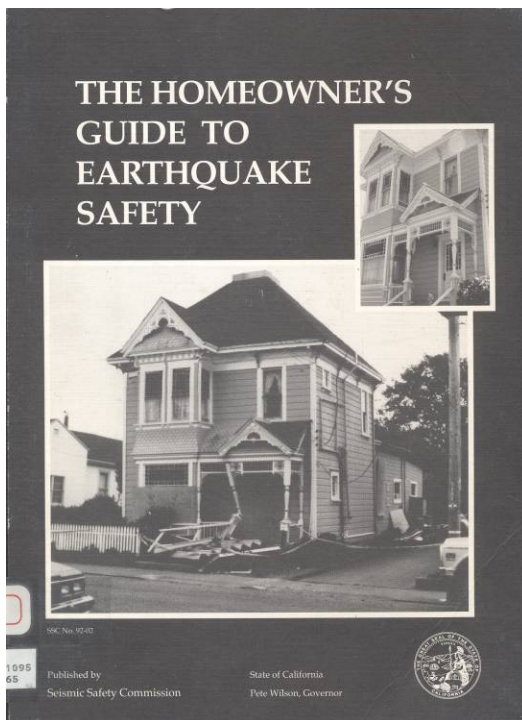
The EQC is a Crown Entity, set up under the Earthquake Commission Act (1993). Its role is to administer an insurance scheme that protects participating properties against damage resulting from certain disasters (Earthquake Commission 2006b). EQCover is a scheme, which was introduced in 1995 to handle and cover residential dwelling, land and possession claims, up to a capped amount [refer Section 13.2.6]. Excesses apply for certain damage limits to mitigate unnecessary claims and instances of fraud from the public following a disaster (Middleton 1995). Past earthquakes have shown that around 70% of residential structures had defects that were likely to affect the strength of a dwelling to resist an earthquake. However, the EQC makes no distinction between these dwellings and usually accepts claims no matter the pre-existing condition (Henri 1995). Also worth noting is that currently the biggest disincentive to remedy foundations for earthquakes, is actually the security of having EQC insurance, which insures against natural disasters.

Currently the EQC requires that homeowners have private insurance in order to claim damages following a disaster. The personal insurance policy in New Zealand will normally cover the contents, as well as the sudden loss or damage to a dwelling. Most insurance agencies require that pre-1935 dwellings be ‘modernised’, meaning that the dwelling requires upgrading of the electrical, roofing, internal lining or foundations, up to current standards. However, no specific definition is made between differently clad dwellings, or dwellings with inadequate sub-floor bracing (State Insurance New Zealand 2007). Thus, insurance premiums do not reflect the different risks posed by varying damage states to dwellings. Overseas insurance agencies take precautions for seismic restraint when assessing the insurance premiums the homeowner will have to make. Cooney and Fowkes (1981) suggest that Californians therefore have more incentive due to risk related insurance policies. A similar ‘incentive based’ risk could be adopted in New Zealand, to ensure people build and maintain dwellings appropriate to the seismic condition.

14.4 Local and National Legislative Changes

Current building legislation has had an overhaul to reflect the modern requirements for different materials that are prevalent in construction today. These changes have a new focus towards durability, treatment against degradation and structural decay, as well as provision for thorough inspection of work throughout the process of construction. Although these regulations may make current building practices more standardised, no legislation exists that requires that older residential dwellings be maintained.

Altering the existing building legislation, seems to require a strong understanding of the problem at hand, the backing of a prominent Member of Parliament, and the unified opinions of a handful of appropriately qualified professionals. If the change is in the best interests of the entire country and the Government can save money, then new regulations seem prudent. However, current views held on the processes for rebuilding after an earthquake suggest that the consent procedures under the Resource Management Act ["RMA"] and Building Act will not operate effectively under emergency conditions (Feast 1995). It should be suggested that if legislation existed which gave priority to preventative remedial action for dwellings; damage and subsequent rebuilding claims lodged to the Territorial Authority ["TA"] would be minimised. Similar experiences in California have prompted law changes which require elements such as the Hot Water Cylinder to be fixed to the wall. Also required when selling a dwelling in California is a disclosure booklet [Figure 14.6], which informs the purchaser of any known faults or seismic deficiencies. The seller must list all earthquake weaknesses and potential hazards and disclose whether the dwellings is within earthquake fault rupture zones (Seismic Safety Commission 1992). The effect is that awareness of seismic restraint and anticipated insurance premiums [refer Section 14.3.2] can sometimes affect the saleability of a dwelling. Therefore, incentives exist to seismically upgrade dwellings to achieve an appropriate dwelling sale price.



RESIDENTIAL EARTHQUAKE HAZARDS REPORT

Refer to Section 8897 et seq., California Government Code

Name _____ Assessor's Parcel No. _____

Street Address _____ Year Built _____

City and County _____ Zip Code _____

Answer these questions to the best of your knowledge. If you do not have actual knowledge as to whether the weakness exists or not, answer "Don't Know." If your house does not have the feature, answer "Doesn't Apply." The page numbers in the right-hand column indicate where in this guide you can find information on each of these features.

	Yes	No	Doesn't Apply	Don't Know	See Page
1. Is the water heater braced, strapped, or anchored to resist falling during an earthquake?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	6
2. Is the house anchored or bolted to the foundation?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	7
3. If the house has cripple walls: <ul style="list-style-type: none"> * Are the exterior cripple walls braced? * If the exterior foundation consists of unconnected concrete piers and posts, have they been strengthened? 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	8 9
4. If the exterior foundation, or part of it, is made of unreinforced masonry, has it been strengthened?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	10
5. If the house is built on a hillside, answer the following: <ul style="list-style-type: none"> * Are the exterior tall foundation walls braced? * Were the tall posts or columns either built to resist earthquakes or have they been strengthened? 	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	11 11
6. If the exterior walls of the house, or part of them, are made of unreinforced masonry, have they been strengthened?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	12
7. If the house has a living area over the garage, was the wall around the garage door opening either built to resist earthquakes or has it been strengthened?	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	13

If any of the questions are answered "No," the house is likely to have an earthquake weakness. Questions answered "Don't Know" may indicate a need for further evaluation. If you corrected one or more of these weaknesses, describe the work on a separate page.

As Seller of the property described herein, I have answered the questions above to the best of my knowledge in an effort to fully disclose any potential earthquake weaknesses it may have.

EXECUTED BY

(Seller) _____ (Seller) _____ Date _____

I acknowledge receipt of this form, completed and signed by the Seller. I understand that if the Seller has answered "No" to one or more questions, or if Seller has indicated a lack of knowledge, there may be one or more earthquake weaknesses in this house.

(Buyer) _____ (Buyer) _____ Date _____

This earthquake disclosure is made in addition to the standard real estate transfer disclosure statement also required by law.

Keep your copy of this form for future reference.

Figure 14-6 The Seismic Safety Commission's Legal Document under Californian Law (Source: Seismic Safety Commission 1992)

The Local Authorities are in charge of administering the District and Regional Plans created by the RMA, which govern the acceptable use of land and resources within the region. Currently the TA administers a Building Warrant of Fitness, which requires that active emergency response systems be maintained (Department of Building and Housing 2006). However, the Building Warrant of Fitness is not a residential dwelling requirement, so if a dwelling is undergoing extension or alteration and requires a Building Consent, many checks are integrated to ensure residential dwellings are up to current standards. Unfortunately this means that only dwellings that are currently being upgraded will ever be checked against the current standards. The *Earthquake Prone Buildings Policy*, being instituted by the WCC requires at risk buildings with less than 33% of the required loading capacity, as stated in NZS1170.5:2004, to be upgraded or demolished. This does not apply to buildings that are mainly for residential purposes, unless the structure is two or more storeys or holds over three household units (Wellington City Council 2006a). The process of ensuring residential safety from earthquake should be a joint effort between the homeowner and the TA. However, using schemes which unduly force homeowners to implement remedial measures will not be popular for either party. Perhaps incentives for individuals with at risk foundations, could be given Building Consent waivers when upgrading the sub-floor, which may entice people to upgrade as well as maintain the sub-floor area.

BRANZ produces a number of articles pertaining to the upkeep and maintenance of dwellings and uncovers new areas of interest that arise with changing legislation and superseding standards. However, this information is generally applicable to those involved in the building industry, rather than the public. Many businesses which focus specifically on the public preparedness have been created out of a need for emergency focussed kits, such as Survival Kits and home Seismic Restraints Kits. The businesses prepare “kits” that would normally require hours of preparation [Figure 14.7].



Figure 14-7 Prepared Survival Kits with Survival necessities for 4 People up to 3days

Since most non-engineered residential foundations are to be designed within the limits NZS3604, and much of the public are unaware of the requirements of this standard, a kit could be produced that allows the homeowner to apply simple fixings to all of the members of a foundation. Kits already on the market, such as the Pryda and LumberLok 12kN pile systems, offer a starting point, from which more versions of kits could be developed [Figure 14.8].



Figure 14-8 Pryda 12kN Pile kit, showing all Components included to create one 12kN Connection

Another service could be also marketed that offers an ‘earthquake foundation check’ of all important foundation details for seismic restraint, which may or may not include undertaking the remedies. This type a seismic check is currently available from an engineer. However, a seismic check is usually not a priority when purchasing or selling a dwelling, nor does the Engineer apply the remedial measures.

14.5 Societal Benefits Summary

The dissemination of information regarding the upgrade of foundations is currently supported by Government run organisations such as the EQC and the Civil Defence. Other programs focussed at informing the public of the risks of earthquake and what can be done to prepare, usually occur where people are receptive to learning such as museums and newspapers. However, no matter the advertising, it is ultimately the homeowner's decision to prepare for an earthquake. The focus for the homeowner usually requires an understanding of what information is most relevant, what action is most important to undertake first, and whether or not any remedial action is actually required; all of which are based heavily on the psychology of disaster preparation. Thus, it is in the best interests for private and national insurance programs, as well as Local and National Authorities to ensure that people have the adequate incentives to limit damage to the home and to adequately prepare the foundation area for earthquakes. These incentives could be in the form of legislation change, residential earthquake checks or other incentives which will not seem oppressive or demanding resulting in Authorities being ruled out of favour by the domestic housing sector. Third party businesses involved in making earthquake preparation easy, perhaps find a middle ground for the situation, where they provide a simple kit which is available to apply to the earthquake preparation requirement. Overall, New Zealand society requires a proactive rather than a reactive stance for the application and dissemination of information regarding the necessity of foundation remedial measures. It is only in a proactive society, ranging from authorities to communities, that we will mitigate the unnecessary damage of dwellings, caused by weak and inadequate foundations.

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A sample of 80 dwellings was used to observe the capacity of Wellington foundations to determine whether sub-floor bracing and conditions are adequate for resisting earthquakes. Although this sample could be considered only a small sample (less than 0.2%) to extrapolate any reliable evidence, the thesis procures a methodology and procedure on which to base further research. Therefore, for this study to develop into a robust survey, the sample size will need be significantly expanded. Overall, six foundation types were observed in the study sample including two variations on piled sub-floors, three variations of the concrete and masonry sub-floor foundation wall, and the slab-on-ground foundation. All foundation types were assessed for bracing and fixing capacity, the general condition and compliance with NZS3604:1999.

The bracing adequacy of different foundation types was assessed assuming certain foundations gain their strength from non-designed bracing such as ordinary piles and large concrete anchors. Observations illustrated that ordinary piles were the primary bracing mechanism for 16% of dwellings, and concrete anchors in 11% of dwellings. Most piled dwellings had inadequate bracing with around 80% requiring a bracing increase of more than half to be within minimum prescriptions. Concrete foundation wall dwellings were generally adequate, despite commonly utilising heavier cladding materials. Overall, 39% of dwellings were under bracing requirements, when non-designed bracing was excluded from calculations.

Fixings and load transference were inadequate in between 8 to 25% of dwellings. This was further exacerbated when friction was assumed to be zero, which is an anticipated scenario in an earthquake with proportions of vertical acceleration. An increase of inadequacy of between 30% and 50% was seen in all areas of the foundation. The most significant area of inadequacy was the Exterior Joist fixings, which suggests that 35% of the sample were inadequate to transfer loads, despite meeting the requirements prescribed in NZS3604:1999.

Correlation was found between the condition of sample dwellings and the House Condition Survey 2005, which quantifies the condition of a large sample of New Zealand dwellings. This reinforced that piling deficiencies, such as insufficient footing depth, non-vertical piles and foundation undermining were common issues, especially in repiled dwellings. Dwellings commonly had insufficient ventilation capacity and were outside prescriptions for heights between the ground and sub-floor timbers, especially in older dwellings. These same trends were also problematic when assessing foundations against the current standard provisions NZS3604:1999.

The structural members in the sample foundations were generally within prescriptions of all historic standards, and therefore adequate in terms of NZS3604:1999. However, a specific analysis of the fixings showed serious inadequacies in over 70% of dwellings. The most significant area, which has previously resulted in dwellings slipping from foundations, was the Plate to Foundation Wall fixing which were inadequate in 37% of all applicable dwellings. These inadequacies were seen as the product of constantly changing historic prescriptions. Overall, only three dwellings were inadequate in terms of all past and current standards. As suggested by anecdotal evidence, older dwellings constructed prior to 1940 had less clearance from CGL than prescribed and 42% of all dwellings were under the ventilation requirements, despite adequate provisions in all historic standards. From the assessment, certain dwellings required different levels of remedy and so solutions were applied on the basis of average maximum requirement for each foundation type.

The total remedial costs were priced by a qualified Quantity Surveyor and totalled between \$2,500 and \$8,000 per foundation, depending on the level of remedy and compatibility with existing bracing systems. These remedies were then projected to all foundations in Wellington City, totalling approximately \$250 Million to upgrade bracing, fixings and to remedy structural deficiencies up to NZS3604:1999. In order to quantify the benefits of applying remedies, the costs of destruction from an MM10.3 intensity earthquake scenario in Wellington City were calculated using an Earthquake Loss Modeller supplied by Institute of Geological and Nuclear Sciences. It was calculated that without applied foundation remedies, the total earthquake repair bill would be around \$2.1 Billion, and would affect around 53,000 dwellings and injure over 2,000 people. Mean Damage Ratios within the Loss Modeller were then adjusted based on similar earthquake loss modelling studies to reflect the applied remedial foundation measures.

After calculations with remedial measures applied, savings of over \$1 Billion was anticipated from post-earthquake repair estimates. The piled foundation, most commonly used in dwellings built prior to 1940, were found to benefit most from applying remedial measures, saving over \$500 Million in total. Remedies were calculated to achieve a cost / benefit ratio of between 4% and 10% for extensively damaged and collapsed dwellings, meaning that remedial measures are significantly less than post-earthquake construction repair costs.

This saving results in a number of benefits, both economic and non-economic. More dwellings will remain habitable, which may potentially save around 13,000 evacuations and limit the mortality and injury rate. This will in turn limit the initial pressures on emergency management systems, minimise the total number of immediate claims lodged with the EQC, mitigate construction cost inflation and allow a faster economic and social recovery in the short and long term over the whole of New Zealand. However, it is the form of dissemination of this

information that will ultimately dictate the uptake and application into the domestic sector. Overall, New Zealand society requires proactive rather than reactive actions for the application and dissemination of information regarding the necessity of an adequate sub-floor. It is only in a proactive society, ranging from the highest authorities to our communities, that we will mitigate the unnecessary damage caused by the destructive combination of a large earthquake and inadequate foundations.

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Modified Mercalli Scale *Appendix A*

Light Timber Framed Construction History *Appendix B*

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The Observed Onsite Anomalies *Appendix F*

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Appendix A. Modified Mercalli Scale

The information contained in this section was used in conjunction with the EQC Damage Assessment Catalogue, to determine what affect an earthquake would have on different sub-floor systems. The damage listed as “Building Type I”, refers to the table at the end of Appendix A. Information regarding the intensities are cited from the following texts: (Eiby 1980, EQC 2000)

1	MMI	Observed only instrumentally Not felt except by a very few under especially favourable circumstances. <hr/> <i>Specific damage</i> No damage to fixtures or structures
2	MMII	Can be bearly felt near epicentre Felt only by a few persons at rest, especially on top storeys of buildings, delicately suspended objects may swing. <hr/> <i>Specific damage</i> No damage to fixtures or structures
3	MMIII	Barely felt, no damage reported Felt quite noticeably indoors, especially on the upper floors of buildings, but many people do not recognise it as an earthquake, Standing motor-cars may rock slightly, Vibration like th passing of a truck. Duration estimated. <hr/> <i>Specific damage</i> No damage to fixtures or structures
4	MMIV	Felt a few miles from epicentre During the day, felt indoors by many, outdoors by few. At night some awakened, dishes, windows, doors disturbed, walls make cracking sound. Sensation like heavy truck striking the building. Standing motor-cars rock noticeably. <hr/> <i>Specific damage</i> No damage to fixtures or structures
5	MMV	Causes damage Felt by nearly everyone; many awakened. Some dishes, windows etc., broken; a few instances of cracked plaster; unstable objects overturned. Disturbances of poles, trees and other tall objects sometimes noticed. Pendulum clocks may stop. <hr/> <i>Specific damage</i> A few earthenware toilets cracked
6	MMVI	Moderately destructive, some severe damage

felt by all; many frightened and run outdoors. Some heavy furniture moved; a few instances of fallen plaster or damaged chimneys. Damage slight.

Specific damage

Unstable furniture overturned
Slight damage to Type 1 buildings
Some stucco and cement plaster falls
Suspended ceilings damaged
Type 1 Windows damaged
Chimney damage

7

MMVII

Everybody runs outdoors.
Damage negligible in buildings of good design and construction; slight to moderate in well-built ordinary structures; considerable damage in poorly built or badly designed structures; some chimneys broken. Noticed by persons driving motor-cars.

Specific damage

Unreinforced brick and stone walls collapse
Type 1 buildings cracked and damaged
Type 2 buildings unbraced parapets and architectural ornament falls
Roofing tiles dislodged especially ridge tiles
Unreinforced chimneys broken

8

MMVIII

Damage slight in specially designed buildings and considerable in ordinary substantial buildings with partial collapse in poorly built structures. Panel walls thrown out of frame structures, fall of chimneys, factory stacks, columns, monuments, walls. Heavy furniture overturned. Sand and mud ejected in small amounts. Changes in well waer. Disturbs persons driving motor cars.

Specific damage

Buildings type 2 damaged some seriously
Buildings type 3 damaged in some cases
A few post 1980 brick veneers damaged
Weak piles damaged
Dwellings not secured to foundations may move slightly

9

MMIX

Damage considerable in specially designed structure; well designed frame structures thrown out of plumb; great in substantial buildings, with partial collapse. Buildings shifted off foundations. Ground cracked conspicuously. Underground pipes broken.

Specific damage

Very poor unreinforced masonry dwellings destroyed.
Building type 2 heavily damaged
Building type 3 damaged
Houses not secured to foundations slip off

Brick veneers fall and expose timber framing

10 **MMX** Some well built wooden structures destroyed; most masonry frame structures destroyed with foundations; ground badly cracked. Rails bent. Landslides considerable from river banks and slopes. Shifted sand and mud. Water splashed over banks.

Specific damage

Most unreinforced masonry structures destroyed

Building type 2 destroyed

Building type 3 seriously damaged

Many buildings type 4 have moderate damage or permanent distortion.

11 **MMXI** Few if any (masonry) structures remain standing. Bridges destroyed. Broad fissures in ground. Underground pipe lines completely out of services. Earth slumps and landslips in soft ground. Rails bent greatly.

12 **MMXII** Damage total. Waves seen on ground surfaces. Line of sight and level destroyed. Objects thrown upwards into the air.

Buildings and Bridges	
Type I	Weak materials such as mud brick and rammed earth; poor mortar; low standards of workmanship (masonry D in other MM scales).
Type II	Average to good workmanship and materials; some including reinforcement, but not designed to resist earthquake (masonry B and C in other MM scales).
Type III	Buildings designed and built to resist earthquakes to normal use standards, i.e. no special damage limiting measures taken (mid-1930s to c. 1970 for concrete and to c. 1980 for other materials).
Type IV	Since c. 1970 for concrete and c. 1980 for other materials, the loadings and materials codes have combined to ensure fewer collapses and less damage than in earlier structures. This arises from features such as: (i) "capacity design" procedure, (ii) use of elements (such as improved bracing or structural walls) which reduce racking (i.e. drift), (iii) high ductility, (iv) higher strength.
Windows	
Type I	Large display windows, especially shop windows.
Type II	Ordinary sash or casement windows.

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Appendix B. _____ Light Timber Framed Construction History

The changing construction codes and regulations describe a story of the history of modern construction methods through five different areas B1- B5. The provisions describe where amendments have been made and the regulations which affect the sub-floor area. An approximate 20 year lapse exists between all major construction standards. Modern amendment dates have been included for NZS3604 as the new amendments describes certain limitations of the superseded regulation, especially in the sub-floor area. The State Specification is included in section B6 as this was not an official document, All measurements given as bracketed conversions from imperial to metric are rounded to the nearest decimal or approximation in metres or millimetres as appropriate.

Appendix B1 Structural Member Compliance

B1.1 Joists

1999 [under NZS3604:1999]

Currently joists and since the introduction of the code, joists can be a minimum of 100x40mm which allows a span of 1.65m @ 400 spacings and 1.20m @ 600mm spacings. The longest span for a joist is 5.75m for 300x50mm joist @ 400crs. All spans can be increased by 10% over 2 or more spans. The minimum bearing on a joist is 32mm.

1984 [under NZS3604:1984]

Sizes ranging from 100x40mm allows joist span up to 1.5m @ 600mm crs and the 150x50 to have a span up to 2.4m @ 600mm crs.

1964 [under NZSS 1900:1964]

All floor joists shall be of sufficient strength to carry the loads required. The loading standard was 40lb/sq.ft and a joist of 4x2[100x50] could span 5.5ft.[1.67m] , 6x2 [150x50] span was 9ft [2.7m], 8x2 [200x50]span 12ft [3.65], 10x2[250x50] span 15ft [4.5m]and 12x3 [300x75] 20ft.[6.1m] joists under bearing partitions shall be doubled or separated not more than 4in.

1944 [under N.Z.S.S. 95]

All loadings were for 40lb/sqft [2.75kPa] or 60lb/sqft [4kPa] so will be over estimated compared with residential values of today. However all joists were at spacings of 18in. [450mm]. 4x2in. [100x50] joists could span 5'6" [1.67m] and the 12x2in. [300x50mm] joist could span almost 19ft [5.8m]. These values are modest compared with today's values.

1924 [under NZSFS Circular 14]

Joists shall be of sufficient strength to safely carry the loads 40lb/sqft [2.75kPa] live load, self weight and any dead load they are to carry. Joist spacing shall not be more than 18in [450mm] centre-to-centre.

B1.2 Bearers

1999 [under NZS3604:1999]

Currently the accepted range of spans for Bearers is 1300mm up to 2000mm for two or more spans. The loaded dimension of the Bearer is a limiting factor and this spacing directly informs the sizes and span of the joists above. The minimum size of a Bearer is 100x75mm while the maximum, spanning 2m is 200x75mm. Bearer sizes can be altered if they run parallel to a load-bearing walls, are no more than 200mm from that wall, support a heavy roof and have a loaded dimension greater than 4m then sizes can be reduced: for 1.3m span 125x75mm, 1.65m span 150x75mm and 2m 200x75mm.

1978 [under NZS3604:1978]

All Bearer spans must be continuous over two or more spans.

Bearers can span 1.3, 1.65 or 2.0m, which affects the span of the joists. The minimum size for a Bearer is 100x75mm and can span 1.3m with a maximum span of joists being 1.85m. The maximum size is 200x75 with a span of 1.3m and allows for a joist span of 5.95m. Packing beneath Bearers should be avoided if possible.

1964 _____ [under NZSS 1900:1964]

Bearers are dependant on spacings of piles and are allowed to span 4'6" [1.37m], 5'6" [1.67m], 6'6" [2m] the allowable loading for 40lb/sqft [2.75kPa] and 60lb/sqft [4kPa] is applicable. The span of the joists also has a effect on the Bearer size. For a joist span of 10'6" [3.2m] the Bearer is 4x3in. [100x75] up can span up to 5'6" [1.67m]. For a Bearer 5x3in. [125x75] up to a max of 15ft [4.57m]. For 5'6" piles crs and 5'6" joist span the Bearer is 4x3in. [100x75]. For pile crs up to 9ft [2.7m] the Bearer needs to be 5x3in. [125x75]. The pile spacings for 6'6" [2m] and joist span of 5'6" [1.67] the size was 5x3in. [100x75].

1944 _____ [under N.Z.S.S. 95]

Intermediate Bearers supporting joists shall be thicker than 3in. [75mm]. For buildings with more than one storey, the thickness shall be increased to 4in. [100mm]. When span of joist is less than 10'6" [3.2m], all Bearers shall be 4x3in. [100x75].

1924 _____ [under NZSFS Circular 14]

No specific provisions for sizes or spacings set, except for timber to be of a minimum strength to resist dead loads and live loads.

B1.3 _____ ***Ordinary Piles***

1999 _____ [under NZS3604:1999]

Piles shall be sunk at least the thickness of the footing or a minimum of 200mm below cleared ground level. There shall be a minimum of 100mm below the pile which will be sufficiently embedded in the footing. Piles may be up to 3m high for all. Spacing of piles shall not exceed the span of the Bearer.

Piles not cast integrally with the footing shall be embedded in the footing until there is a minimum of 100mm below the pile bottom.

[Concrete]_____ Concrete piles shall be parallel sided of 200mm or 200mm bottom and 150 top for tapered piles. Concrete masonry piles shall have a minimum dimension of 190mm.

[Timber]_____ round Timber piles shall be 140mm minimum diameter, square sawn piles shall be a minimum 125x125mm.

1984 _____ [under NZS3604:1984]

Minimum depths for foundations shall be 150mm in rock, 450mm in expansive clay and 300mm in other materials. All piles shall be no longer than 3.6m.

[Concrete]_____ Concrete or masonry piles shall be a minimum of 150mm above ground and a maximum of 1.5m. Concrete piles shall be minimum of 200mm for parallel sides and minimum 150mm top for tapered piles. Masonry piles shall be a minimum of 190mm. Concrete pile strength can be reduced up to 10MPa if they are ordinary or support jackstuds. All piles shall be reinforced with one R10 bar located centrally and have a footing 100mm thick.

[Timber]_____ Timber piles shall be the same as concrete piles except not cut off closer than 300mm from ground level, this can be reduced to 150mm where DPC is used.

Timber piles may be up to 3m high if supporting Bearers, however timber piles supporting jackstuds shall be a maximum of 600mm. Timber piles shall be a minimum 140x140mm and be placed on a concrete footing 200mm thick.

1964 _____ [under NZSS 1900:1964]

The engineer may permit the use of timber piles or blocks if the required use of concrete or masonry would cause undue hardship.

Piles [concrete] shall not extend less than 6in or 4'6"ft [1.37m] above ground level. And not spaced greater than 4'6" [1.37m] centre to centre.

Sectional areas for loadings up to 60lb/sq.ft [4kPa] buildings not more than 10ft [3m] in height 36sqin [0.02sqm]. single storey building 64sqin [0.04sqm] external walls and bearing partitions 100sqin. [0.06sqm]. An increase of 10% allowed for spans of joists over 7ft [2.1m].

[Concrete]_____tapered concrete piles are allowed of 64sqin [0.04sqm] and tapered from 8in [200mm] at bottom to 6in.[150mm] at top provided they are more than 2'6" [760mm] long and with reinforcement of steel rod of 3/8in [10mm].

1944 _____ [under N.Z.S.S. 95]

Timber piles and concrete piles were to be 8x8in. [200x200mm] for a single storey dwelling or 10x10in. [250x250mm] for a two storey dwelling. A 10% increase in sectional area of the piles was necessary when pile row spacings are greater than 7ft [2.1m]. Spacing of piles shall be maximum 4'5" [1.4m] centre-to-centre unless the sectional area of the Bearer is increased.

Piles under bearing walls shall be sunk equal to their projection but not more than 18in. [460mm]. Rammed earth shall be consolidated around them. Piles must be 6" [150mm] minimum above finished ground surface up to a maximum of 4'6"ft [1.4m].

1924 _____ [under NZSFS Circular 14]

Ordinary piles shall consist of unreinforced concrete or brick piers or continuous foundations of brick, stone or concrete, or of approved timber blocks. All foundations shall extend below the frost line, at least 12in [300mm] below cleared ground level. Piles and blocks under the bottom plate shall not be spaced more than 36in. [915mm] apart and shall not exceed 4ft [1.2m] in height. For single storey dwellings the foundation blocks shall be minimum 7x7in. [175x175mm] and minimum 8x8in. [200x200mm] for two storey dwellings.

B1.4 _____ ***Jackstuds***

1999 _____ [under NZS3604:1999]

Jack studs can be a maximum of 3m high depending on nominal size and joist spans. The height allowed decreases with span of joists above. Sizes supporting floors above range from 100x75mm to 100x100mm.

Foundation walls are treated as walls within a storey for stud framing. Framing must be greater than 50mm thick and be double stud under Bearers laid perpendicular.

1984 _____ [under NZS3604:1984]

Two cut between braces were considered a single 'Brace', when referring to jackstuds. All jackstuds must be a minimum of 50mm thick and their maximum height is dependant on Bearer span, joist span and supporting storeys. The minimum size is 100x75mm up to 100x100mm. The maximum height allowable is 3.0m.

1964 _____ [under NZSS 1900:1964]

Where the lowest or ground floor joists are more than 4'6" [1.4m] above ground they shall be supported with studs plates and braces as specified for bearing walls or with a reinforced concrete wall at least 5in. [125mm] thick. Where a single storey building under external walls and classification for live loading does not exceed 40lb/sqft [2.75kPa] the Bearers may be supported on 4x3in. [100x75mm] jackstuds standing on piles and secured in an approved manner. This system is not applicable for pile spacings greater than 4'6" [1.4m] or where the joist span is in excess of 6ft [1.8m].

1944 _____ [under N.Z.S.S. 95]

Where the lowest joists need to be above 1.4m, jackstuds shall be constructed. These shall be constructed with studs, plates and braces, as specified for load-bearing walls.

1924 _____ [under NZSFS Circular 14]

Jack-studs shall be a minimum of 4x3in. [100x75mm] and braced when over 4' [1.2m] in height.

B1.5 Slab-on-ground

1999 [under NZS3604:1999]

The new code states that reinforcing between the slab and exterior foundation wall should be D10bars @ 600mm crs. This reinforcing should be continued and bent around the reinforcing in the foundation wall. The maximum dimension is 18m in either direction. The minimum thickness of slab varies with the type of vapour barrier used. The minimum is 75mm for rubber emulsion barrier and 100mm for bitumous sheet or polyethylene sheet. Reinforcing under loadbearing walls is required, as well as reinforcing mesh for varying situations. Shrinkage control joints are required to be a quarter of the slab thickness and cut within 24-48 hours of pouring depending on the season.

1984 [under NZS3604:1984]

The finished floor level shall be 150mm to unprotected ground or 100mm to permanent paving. Concrete shall be 17.5MPa at 28 days standard cured. Slabs shall have a continuous vapour barrier between ground and floor surface.

Foundation walls supporting slab-on-ground shall be assumed supporting the ground floor and require minimum one D12 bar at the top of the wall.

Foundation walls constructed separately from ground slab shall be tied to the ground slab with R6 bars @ 600mm crs. lapped not less than 300mm with slab reinforcing and anchored into the foundation wall.

1964 [under NZSS 1900:1964]

Noted is a section stating that where a solid concrete floor is laid on the ground, it shall have a moisture barrier or Damp Proof Course incorporated in the construction, this construction is not necessary where human inhabitation is not intended.

1944 [under N.Z.S.S. 95]

No specific provisions set

Appendix B2 *Lateral load resisting member Compliance*

B2.1 *Concrete Foundation wall*

1999

[under NZS3604:1999]

This system may be full perimeter or intermittent on corners, the only restriction is the connection to the framing. Footing to be minimum of 200mm or solid bearing and must not retain more than 300mm of soil. Footing is to be a minimum of 150mm thick and continuous beneath all openings. Maximum height of concrete wall is not to be more than 2m above the height of the footing. The height above finished ground level shall be 225mm. Wall thickness is dependant on height of building and varies to block sizes if concrete masonry is used. The wall width for a single storey is 130mm. with a minimum of 1 D12 reinforcing bar in the footing. The footing width shall be the half the height. The maximum rating obtainable is 300BU/m.

1978

[under NZS3604:1978]

Shall be of reinforced concrete or reinforced masonry. All concrete foundation walls shall be supported against horizontal loads by a floor diaphragm, a wide footing or floor joists directly supported by a wall plate. No lateral support is required for walls less than 2m long. Footings shall reinforced concrete and be continuous under all openings. Foundation walls shall not be less than 225mm above CGL and a maximum of 2m above bottom of footing. Reinforced concrete shall be 130mm thick for one storey and 150mm for two storeys.

Concrete shall be reinforced with one D10 bar at the top of 1.2m wall. When wall is 2m high D10 bars are necessary at 600crs in both directions, or 665 welded steel mesh.

Reinforced masonry shall be 140mm for single and 190mm for two storey buildings.

The height of a single-wythe clay masonry(brick) foundation wall shall not exceed 1.3m if constructed with bonded piers supporting the wall. If the construction includes piers with reinforced concrete this height may be extended to 2m.

1964

[under NZSS 1900:1964]

Foundation walls shall consist of concrete or masonry: walls, piers or columns, foundation blocks or piles or a combination of these. Where a single corner extends more than 4ft above ground level a continuous concrete wall, suitably reinforced, shall be erected not less than 4'6"[1.37m] in each direction. All foundations shall extend at least 12in [300mm] below ground. Walls that exceed 6ft [1.8m] in height shall be considered as walls of single storey masonry. Where foundation walls are more than 3ft [0.9m] above footings, the reinforcing shall be supplemented with 3/8in [9.5mm] rods at 15in crs [380mm] vertically and horizontally.

Nothing prohibits the infilling of space between masonry or concrete piles. In each case these shall not be more than 4ft [1.2m] height in concrete not less than 3.5in [90mm] thick.

1944

[under N.Z.S.S. 95]

All unreinforced brick and stone foundation walls one and two storey structures shall be 8.5in [215mm] thick. For reinforced concrete this value shall be 5in [127mm] with reinforcing bar in the top. 1/2in [13mm] reinforcing was also required in the footing.

When any foundation wall reached over 3ft [0.9m], extra 3/8in [9.5mm] reinforcing bars were required at 15in. crs [380mm] vertically and horizontally.

A foundation wall was also required when the bottom plate was higher than 4'6" [1.4m] from the ground. It must also extend horizontally for a minimum of 4'6"[1.4] from the

corner. If the wall is taller than 4'6" [1.4m] a concrete jackstud wall should be constructed minimum 5in. [130mm] thick.

Where the foundation is above 4ft [1.2m] at any one corner, the foundation shall be suitably reinforced Continuous concrete at each corner, extending no less than 4'6" [1.4m] along each adjacent wall.

1936 _____ *[under 1931 Building Regulations Committee]*

Foundations on the outside shall be sunk not less than 18in [450mm] and earth consolidated around them. Continuous external walls shall have not less than two 3/4 in. [19mm] dia. steel rods embedded near top and near bottom

1924 _____ *[under NZSFS Circular 14]*

Foundation walls of brick, concrete block or coursed stone shall be at least the width of the bottom plate 4in [100mm]. The unsupported height shall not exceed 10 times their least dimension [~1m].

B2.2 _____ Sheet bracing on Framed Sub-floor walls

1999 _____ *[under NZS3604:1999]*

Wall framing shall be the same dimensions as the studs above. The bottom plate must be supported on a foundation wall or on piles.

1984 _____ *[under NZS3604:1984]*

A sub-floor sheet brace shall consist of a 2.4m length of framing covered with a sheet material from a Bearer or plate to a wall plate or Bearer directly supported by a foundation wall, ordinary piles or a complete row of cantilever piles. The board must be a minimum 6mm ply or other wood-based product with a density of more than 880kg/cubicmetre. Each sheet was to be wider than 900mm, be fixed no less than 10mm from the sheet edge and fixed to all contacted framing members.

1964 _____ *[under NZSS 1900:1964]*

Where piles under external walls extend more than 2.5ft from ground, piles shall have horizontal walings of not less than 4x1.5in. [100x40mm] at least 6in. [150mm] from ground level. These walings shall be attached with 1/2in. [M12] bolts. Sheathing shall be nailed at edges 3/8in. [10mm] from the edge and also nailed at intermediate supports not more than 12in. [300mm].

1944 _____ *[under N.Z.S.S. 95]*

If piles extend on average more than 2'6" [760mm] above the ground, horizontal walings of 8x1.5in. [200x40mm] or equivalent shall be fixed to the exterior piles. These shall be firmly attached with 1/2in. [M12] bolts if piles are concrete, stone or brick or with nails if piles are timber.

1924 _____ *[under NZSFS Circular 14]*

No specific provisions set

B2.3 _____ Braced piles

1999 _____ *[under NZS3604:1999]*

Piles must be embedded in a 450mm deep footing, Concrete piles shall not exceed 1.5m. This ensures that an adequate angle of brace is obtained to resist lateral loads. Only one brace may be connected to the top of any one pile. The brace shall be between 10° and 45° to the horizontal, 6° may be used if brace connected to joist or Bearer. The brace shall be one length of timber with a maximum of 5m for a 100x100 brace. Other sizes are permitted for a lesser span. 6 kN connections are also required

for joists directly surrounding brace connection. Connection must be 12kN from Bearer to pile top or side. This system provides an EQ bracing of 120BU and a Wind bracing of 160BU.

1984 _____ *[under NZS3604:1984]*

Braced piles shall be embedded in concrete 450mm below CGL. The brace shall be between 0° and 45° and can be attached to a joist, Bearer or blocking joist. The lower end of the brace shall be minimum 150mm from FGL and connected to a braced or anchor pile or foundation wall. The brace can be two pieces of timber provided they are well nailed. The brace can be a maximum of 5m and shall be 100x100mm, or 100x75mm if less than 3m. If nailed together and not exceeding 4.5m can be 100x50mm.

1964 _____ *[under NZSS 1900:1964]*

A brace of not less than 3in thick times the width of the plate shall be fixed between walings and the plate in the space between the two end piles of each external wall.

1944 _____ *[under N.Z.S.S. 95]*

Not essentially described as a braced pile, however section 916(e) suggests that a brace not less than 3x4in. [75x100mm] in thickness, shall be fixed between the plate and the Waling in the space between the two end piles at each external wall. Similar braces shall be inserted in rows of internal piles at 16ft [4.8m] intervals.

1936 _____ *[under 1931 Building Regulations Committee]*

Piles greater than 18in. [450mm] shall have a longitudinal waling of 4x1.5in [100x40mm] bolted with 1/2in. [M12] bolts or well spiked to wooden piles on each side of piles. The end bays shall have 4x3in. [100x75] diagonal brace between the bottom plate and these walings. Braces greater than 30ft [9.1m] require two intermediate braces. If the base boards are 1 1/4in [30mm] or more in thickness outer walings may be omitted.

1924 _____ *[under NZSFS Circular 14]*

No specific provisions set

B2.4 Cantilever piles

1999 _____ *[under NZS3604:1999]*

Requires 6kN connection to Bearer. Cantilever piles must be driven piles under the NZS3604 clauses for driving piles. The minimum depth is 900mm through gravel and 1200mm through other types of soil. Pile tops shall not be more than 1.2m from ground, other wise it cannot be assumed a cantilever pile. No pile shall be more than 3.6m in length. One cantilever pile achieves an EQ bracing of 30BU and a Wind of 70BU, which is approximately 1.5kN and 3.5kN respectively.

1984 _____ *[under NZS3604:1984]*

One cantilever pile was considered a single 'Brace'.

Each line of horizontal support, supporting a Bearer shall consist of a complete row of cantilever piles, except under an external wall. They shall be a maximum of 600mm high, and embedded in concrete 450mm below CGL. Short driven timber piles can be 900mm through gravel or 1200mm through other soil types. No Pile top shall be higher than 1.2m.

Up until 1990, Shallow Cantilever piles were allowed, which had a footing less than 450mm deep. The Shallow Cantilever pile provided 12BU of bracing.

1964 _____ *[under NZSS 1900:1964]*

No specific provision set

1944 _____ [under N.Z.S.S. 95]

Under the provision of braced piles, the waling and brace could be omitted if the piles are concrete and do not extend further than 3'5" [1050mm] above ground. The system must have a concrete footing 6in [150mm] deep and integrally cast with a 18in. [450mm] square concrete pile for all piles in the sub-floor. Essentially this construction assumed this system could resist lateral loading and thus is considered as a cantilever pile system.

1924 _____ [under NZSFS Circular 14]

No specific provisions set

B2.5 _____ **Anchor piles**

1999 _____ [under NZS3604:1999]

Minimum depth of footing is 900mm from cleared ground and the pile shall have a minimum plan size of 350x350mm. The maximum height is 600mm to the highest connection. Connection to the Bearer and / or joist should be 12kN. The width of the pile at the Bearer connection is to be 100mm minimum. No Bearer connections can occur over an anchor pile. This system provides an EQ bracing of 120BU and a Wind bracing of 160BU.

1984 _____ [under NZS3604:1984]

One Anchor pile was considered a single 'Brace'.

The brace shall be a maximum of 520mm high to the top of fixings for braces. A steel angle may be placed centrally in concrete anchor piles to allow for fixings. Concrete shall embed the pile up to 900mm below CGL.

1964 _____ [under NZSS 1900:1964]

No specific provision set

Appendix B3 *Other Structural Provision Compliance*

B3.1 *Bracing Provisions*

1999 *[under NZS3604:1999]*

Bracing shall run in two directions and at not more than 6m spacings. Internal bracing lines must have a minimum of 70BU's. 10 times external wall length minimum for external bracing lines. Braces at angles other than 90° shall be proportionate to the angle. Eg 45° shall provide 70% of full bracing of straight wall.

1990 *[under NZS3604:1990]*

Sub-floor Bracing should be selected from a list of 13 types, ranging from braced piles, jackstuds, or foundation wall systems. All of the bracing types were provided with specific bracing units, which are significantly lower than in modern provisions. The standard specified the internal and external vertical systems and also internal and external horizontal systems. The selection of earthquake bracing depended on the same factors as in 1984, however also required was minimum of 10Bracing Units per metre for exterior walls and 70 minimum bracing units for all internal lines. The standard also included Bracing Units for shallow cantilever piles and diagonal cut in bracing.

1984 *[under NZS3604:1984]*

The provision for sub-floor braces was based on the length of the line for horizontal support [or length of dwelling], the combination of weight of the roof and cladding, number of storeys and the pitch of the roof. The earthquake zone [A, B, C] and wind zone differentiated between areas in New Zealand. Bracing was given in requirements per line, ranging from a minimum of 2 up to a maximum of 8 "Braces" per line. The "brace" consisted of one of the following:

- A diagonal timber brace cut between jackstuds, two of which are required, the brace is required to be between 0-45 degrees and slope in opposite directions
- A sub-floor sheet brace consisting of a 2.4m length of 6mm plywood, which extends the full height from Bearer or plate to a wall plate.
- A pair of masonry piles at not more than 1.5m crs, or not less than 1m crs, connected by a RC top beam not more than 1m above a RC footing, supporting a masonry infill panel.
- A 1.5m length of continuous foundation wall carried up to the wall plate.
- An anchor pile directly supporting a Bearer or joist.

1978 *[under NZS3604:1978]*

Inclusion of earthquake and wind zones, however wind zones were only included in the 1984 revision. Sub-floor provisions were generally oversimplified.

1944 *[under N.Z.S.S. 95]*

No specific requirement for bracing is required depending on the dwelling parameters, except to say that all sub-floor spaces shall follow instructions seen in Outer walings may be omitted if, base boards are 1.25in. [32mm] or more in thickness, or if concrete piles do not exceed 3'6" [1m] in height and with a footing of 6in. [150mm] or more. Alternatively, if the space between piles is filled with brick or stone, or concrete 3.5in. [90mm] with reinforcing, footings and bonding, no walings are required.

1936 *[under 1931 Building Regulations Committee]*

All corners of external walls shall be diagonally braced in the horizontal direction

1924 _____ *[under NZSFS Circular 14]*

Foundations of wooden framed buildings shall, where possible, use brick or concrete piers or continuous foundations of brick, stone or concrete.

B3.2 _____ ***Lateral support for joists***

1999 _____ *[under NZS3604:1999]*

Lateral support of joists shall be provided at the ends of joists with a continuous boundary joist 25mm thick and of the same height as the joists, and at any location of joist ends at not more than 1.8m crs. Blocking can be in the form of solid blocking 40mm thick and the same depth as the joists or herringbone strutting.

1984 _____ *[under NZS3604:1984]*

At the ends of joists, a continuous boundary joist 25mm thick and to the same depth. Or solid strutting at 1.8m crs.

Any joist being 4 or more times their depth shall provide strutting at the mid point of any span exceeding 2.5m. Or herringbone strutting 40x40mm.

1964 _____ *[under NZSS 1900:1964]*

All joists spanning more than 8ft [2.4m] shall be stiffened with herringbone strutting or bridging at right angles to joists.

1944 _____ *[under N.Z.S.S. 95]*

All joists spanning more than 8ft [2.4m] shall be stiffened with herringbone strutting or dwanging at right angles to the joists for their full depth. The distance separating rows of strutting shall not exceed 8ft [2.4m].

1924 _____ *[under NZSFS Circular 14]*

All joists exceeding a 10ft [3m] span shall be properly blocked with the distance between bridging not exceeding 10ft [2.4m]. Blocking must be a minimum of 2x1.5in. [50x40mm].

B3.3 _____ ***Concrete Strength***

1999 _____ *[under NZS3604:1999]*

All concrete piles shall be of 17.5MPa. Ordinary concrete piles shall be reinforced with one D10 bar centrally placed for piles over 750mm high.

1984 _____ *[under NZS3604:1984]*

All concrete piles shall be 17.5MPa.

1964 _____ *[under NZSS 1900:1964]*

Concrete specified by chapter 9.3 of the code and stated ordinary, high, special or low grade concrete. The rations and bags of aggregate are very specific and ordinary grade can have between 2000psi [13.8MPa] and 2500psi [17.2MPa] crushing strength of a 12x6in [300x150mm] cylinder at 28 days standing. High grade was from 2000psi [14MPa] up to 3500 psi [24MPa].

1944 _____ *[under N.Z.S.S. 95]*

All concrete is to be mixes of 1:1:2 shall have a 2925psi [20MPa] at 28 days and ratio of 1:2:4 at 2250psi [15MPa] rating

1924 _____ *[under NZSFS Circular 14]*

All concrete and timber strengths were presented in the form of a density measure (Pounds per cubic foot). Concrete, stone and gravel was to be 2400Kg/m³. The list also

included many native timbers and their adequate densities ranging from 560kg/m³ for Kauri to 736kg/m³ for Black Beech.

B3.4 **Pile Footing**

1999 *[under NZS3604:1999]*

Timber requires a 200mm thick footing and concrete piles a 100mm footing. Cantilever and braced pile footings are as stated in their respective sections. Footing plan sizes are dependant on loading and spans of Bearers, joists and number of storeys. They also alter depending on a circular or square pile. The plan sizes range from 200x200mm for minimum joist and Bearer span to 575x575mm for a 3 storey large span dwelling.

1984 *[under NZS3604:1984]*

Bearing of all foundations shall be upon solid bottom or where a certificate of suitability has been issued in terms of NZS 4431. All soil shall have a minimum bearing pressure of 100kPa. Footings dimensions vary from circular or square dimensions and depend on the span of joists and Bearers and likely loading. Timber piles footing shall have a minimum depth of 200mm and concrete 100mm. Each pile shall be cast integrally with the footing. Ordinary piles and braced piles need only stability from footing, and concrete or masonry piles require 300mm.

1964 *[under NZSS 1900:1964]*

Where pile is greater than 64sq.in. [200x200mm] a footing is required. This may be done by increasing the base only or in the precast piles by setting in a pad of concrete before it has set. Such a pad shall not be less than 4in. [100mm] in depth or double the projection beyond the face of the pile, which ever is greater.

1944 *[under N.Z.S.S. 95]*

All footings for concrete, stone and brick shall be of concrete and have a bearing area to safely support the loads imposed as determined by the soil condition. No provision was set for timber piles other than having rammed earth consolidated around them once erected.

1924 *[under NZSFS Circular 14]*

All foundations shall be placed upon a solid and approved bottom.

B3.5 **Configuration**

1999 *[under NZS3604:1999]*

Piles in rows of 6m cannot be more than twice the height of any other pile, otherwise torsion may be induced.

1984 *[under NZS3604:1984]*

Pile tops should be laid out to suit the sub-floor framing. A minimum of 4 braces in each direction placed symmetrically at the extremities of the building.

1964 *[under NZSS 1900:1964]*

No portion of any timber building shall exceed 35ft [10.6m] in height

1944 *[under N.Z.S.S. 95]*

Pile rows can be a maximum of 7ft [2.1m] apart without increasing the pile sectional areas.

1924 *[under NZSFS Circular 14]*

No specific provisions set

B4.1

Floor connection to Joists

1999

[under NZS3604:1999]

Assumed in two ways: with floor diaphragm or timber floor boards. In most cases it is assumed that forces from the floor transfer into the joists well.

1978

[under NZS3604:1978]

Floor boards shall be fixed to each joist, nails shall be well punched. Nails used for secret nailing shall be punched to allow full entry of tongue into groove.

Sheet material shall be fastened along edge to framing or blocking and to every intermediate framing member, fastenings shall be 10mm from sheet edge and at 150mm crs. Nails shall be 2.5 times the finished thickness.

1964

[under NZSS 1900:1964]

All timber shall be connected with nails at least 2.5 times the finished thickness of the attached material. All flooring shall be connected to joists with not less than 2 nails per piece, secret nailing can be fixed to each joist with one nail only.

1944

[under N.Z.S.S. 95]

All flooring shall be fixed with nails at least 2.5 times the floor thickness and fixed with no less than 2 nails per piece of flooring

1924

[under NZSFS Circular 14]

No specific provisions set

B4.2

Joist to Joist [J-J]

1999

[under NZS3604:1999]

Joists can be flitched with a minimum 32mm bearing and the flitch plate extending 150mm over each joist 4/100x3.75mm nails into each joist from the flitch plate. Lapped connections require a 150mm lap and 4/100x3.75mm skew nails, 2 each side of the connection. Butt joints require a 32mm minimum bearing and each joist end requires 2/100x3.75mm nails to each support and 1/100x3.75mm nail to the top of connection.

1984

[under NZS3604:1984]

Joints can be made over supports, where they have a minimum of 32mm bearing. Lapped joints shall not be less than 150mm each side and nailed together with two 100x3.75mm nails each side. Or butted and flitched with piece of timber extending 150mm on each side of joist, nailed to both lengths from both sides with two 100x3.75mm nails. Or a similar 5kN connection.

1964

[under NZSS 1900:1964]

Jointing over a support and passings of at least 12in. [300mm] to every third pair and well nailed from both sides with nails to pass through both timbers. Butt joints are allowed with a bearing of 2in. [50mm] and flitched every third pair and similarly nailed or otherwise secured.

1944

[under N.Z.S.S. 95]

Provision for the connection of joists was given but not specifically. It states that joists shall be jointed over supports and lapped at least 12in. [300mm], butt jointing was also permitted but only with a minimum of 2in. [50mm] bearing.

1924 _____ [under NZSFS Circular 14]

The ends of joists shall be lapped at least 12in. [300mm] over adequate bearing and securely nailed. Butt joints shall be connected with steel straps or dogs.

B4.3 _____ **Joist to Bearer [J-B]**

1999 _____ [under NZS3604:1999]

Fixings shall be 2/100x3.75mm skew nails.

1984 _____ [under NZS3604:1984]

Two 100x3.75mm skew nails.

1964 _____ [under NZSS 1900:1964]

The wooden framework of all buildings shall be connected together in a secure manner.

1944 _____ [under N.Z.S.S. 95]

The only note relating to this connection states that all floor joists shall be securely fixed in position.

1924 _____ [under NZSFS Circular 14]

No specific provisions set

B4.4 _____ **Wall bottom plate to boundary joists**

1999 _____ [under NZS3604:1999]

Into timber the bottom plate should be fixed with 2/100x3.75mm nails at 600mm crs. Internal fixings can be with only a single nail at 600mm crs.

1978 _____ [under NZS3604:1978]

The connection of boundary joists to the wall plate shall be 12/100mm nails or 6 each side for the length of one side which is 1.5m.

The bottom plate to the floor framing on external and bracing elements and 2 nails at 600crs.

B4.4 _____ **Wall plate to Foundation Wall [P-FW]**

1999 _____ [under NZS3604:1999]

In modern codes this requires either an M12 bolt and washer into concrete not less than 75mm and placed at 1.4m crs or R10 dowel bent at 90 degrees with 75mm concrete embedment at 900mm crs. All connections should be within at least 300mm of ends and corners.

1984 _____ [under NZS3604:1984]

M10 bolts with minimum depth of 75mm into concrete. Or R10 dowels bent 90° and projecting to allow the steel dowel to be clinched over the timber. Spacings for both shall be no more than 1.4m crs and when within 300mm of ends or at corners, two such fixings shall be used.

1964 _____ [under NZSS 1900:1964]

Secured with bolts not less than 3/8in. [10mm] diameter embedded at least 3in. [75mm] into wall or by 3/8in. [10mm] diameter steel dowel hooked at the end and bedded at least 6in. [150mm] into the wall. Dowels shall project 3in. [75mm] above the plate and ends clinched over and stapled.

Or no. 8 S.W.G. [4mm] galvanised wire may be looped and embedded at least 6in. [150mm] into the concrete and the ends folded over the plates and securely stapled, spacings at not more than 4'6"ft [1.4m].

1944 _____ [under N.Z.S.S. 95]

Any beams or joists which are attached to a foundation wall or plate on a foundation wall are required to be securely anchored with steel tie bolt not less than 5/8in. [M16] diameter or with steel straps. Connections were to be at intervals of less than 6ft [1.8m].

1936 _____ [under 1931 Building Regulations Committee]

All bottom plates bolted to foundation wall at not less than 4ft [1.2m] spacings. Dowels and dog-bolts should be used for timber piles.

1924 _____ [under NZSFS Circular 14]

All ends of Bearers and joists entering or resting on masonry walls shall be fixed with steel anchors of minimum 1.5x1/4in [40x6.35mm] attached to the lower half of the member.

B4.5 _____ ***Bearer/Joist to Foundation Wall (B or J-FW)***

1999 _____ [under NZS3604:1999]

The Bearer running perpendicular to the foundation wall should be seated or rebated and bolted with an M12 bolt and washer with a minimum embedment of 75mm and at maximum spacings of 1.4m. The Bearer may also sit on a pier cast with the wall. The bolt must be embedded at least 150mm into the pier.

Joists connected to foundation wall shall be 2/100x3.75mm skew nails, if the joist runs parallel with the wall the connection shall be 12/100x3.75mm skew nails per 1.5m length.

1984 _____ [under NZS3604:1984]

Bearers shall be bolted to foundation wall with an M12 bolt set 150mm into concrete wall. Or rebated into foundation wall and nailed with 4 skew 100x3.75mm nails to plates butted perpendicular to Bearer. Or each Bearer supported by a pier no less than 150x150mm and cast integrally with foundation wall. The Bearer shall be bolted to pier with an M12 bolt 150mm into pier.

1964 _____ [under NZSS 1900:1964]

All joists shall be securely spiked to the outer walls. Depending on the construction of the dwelling.

1944 _____ [under N.Z.S.S. 95]

No specific provision

1924 _____ [under NZSFS Circular 14]

Every beam shall have at least 100mm bearing area. Each Bearer/joist shall be securely tied to masonry walls with tie-bolts or straps not exceeding 10ft [3m] intervals.

B4.6 _____ ***Bearer to Bearer (B-B)***

1999 _____ [under NZS3604:1999]

Joints in Bearers should only be made directly over supports but not over braced or anchor piles. The minimum bearing for a butt joint is 45mm and 90mm in all other cases. The connection should be 12kN or 2 / 6kN connections to each side.

1984 _____ *[under NZS3604:1984]*

Joints shall be made over supports and shall not occur where Bearer is fixed over a braced pile. The connection shall have a capacity of 7.0kN and can be either butted or flitched on each side. Butt joint shall have one 3.5kN nail plate each side and four 100mm nails each side. Flitch joints require a 600mm ex. 100x50mm section nailed from bottom with four 100mm nails each end of Bearer and two nails from ex.100x50 section into pile.

1964 _____ *[under NZSS 1900:1964]*

All joints in plates and Bearers shall be halved or scarfed and well nailed over an adequate support.

1944 _____ *[under N.Z.S.S. 95]*

All joints in Bearers (plates) shall be halved or scarfed and well nailed. All joints shall be made over an adequate support.

1924 _____ *[under NZSFS Circular 14]*

All joist or beam shall be securely nailed or anchored in the same manner as the wall construction

B4.7 _____ Ordinary Pile to Bearer (OP-B)

1999 _____ *[under NZS3604:1999]*

Connections differ for concrete and timber piles.

[Concrete] _____ Concrete shall have 4mm galvanised wire through the pile to the Bearer, the wire needs 4 staples total; two before the hook and two driven over both of the hooks.

[Timber] _____ Timber requires 2 wire dogs and 2/100 x 3.75 nails driven into the piles.

1984 _____ *[under NZS3604:1984]*

4mm galvanised steel wire and 4 staples or two 4.9mm galvanised wire dogs

1964 _____ *[under NZSS 1900:1964]*

Shall be fixed to concrete piles as in the foundation wall. Or no. 8 S.W.G. [4mm] galvanised wire may be looped and embedded at least 6in. [150mm] into the concrete and the ends folded over the plates and securely stapled at spacings at not more than 4'6" [1.4m]

1944 _____ *[under N.Z.S.S. 95]*

[Concrete] _____ Bearers shall be secured to the concrete piles with two strands of galvanised no.8 (8 Standard.Weight.Gauge) [4mm] wire looped and embedded at least 6in. [150mm] into the concrete. The wire should extend sufficiently to be stapled securely.

[Timber] _____ Connections of timber piles to Bearers shall be with one 6in. [150mm] nail driven through Bearer and two 4in. [100mm] skew nails

1924 _____ *[under NZSFS Circular 14]*

No specific provisions set

B4.8 Ordinary Pile to Jackstud [OP-JS]

1999 [under NZS3604:1999]
[Concrete] Concrete same as from ordinary pile to Bearer
[Timber] Timber jack studs require 4/100 x 3.75 nails driven skew into the timber piles. DPC required if within 150mm from the ground.
Connection to foundation walls shall be as stated in foundation wall connection requirements.

1984 [under NZS3604:1984]
4mm galvanised steel wire stapled or two 4.9mm galvanised wire dogs
1964 [under NZSS 1900:1964]
No specific provision set

B4.9 Jackstud to Bearer [JS-B]

1999 [under NZS3604:1999]
The only requirement is 2/100x3.75mm skew nails to the Bearer.

1984 [under NZS3604:1984]
No specific provision set.

B4.10 Braced pile top to Bearer/Joist [12kN]

1999 [under NZS3604:1999]
The connection from the Bearer to the pile top should be a 12kN connection, usually an M12 bolt to the side, or other connection to the top.....see fixing guides by lumberlok etc.
The diagonal timber brace shall be connected at each end with an M12 bolt, 90mm from the end and passing through the centre. The lower end should not be more than 300mm from CGL, however the end of the brace must be a minimum of 150mm from CGL. The diagonal brace top can also be connected to the Bearer or joist with a similar 12kN connection.

1984 [under NZS3604:1984]
[Concrete] For concrete pile, One 10mm Steel dowel bent over
[Timber] For timber an M10 bolt or alternative 12kN capacity.
No provision for additional connection of joists to Bearers. If a brace passes an intermediate pile or jackstud, it must be connected with an M12 bolt. In all other connections the brace shall be fixed with an M12 bolt at least 84mm from the end. Any alternative fixings shall have a 17kN capacity.

1978 [under NZS3604:1978]
The cut between braced needed 2/75x3.35mm nails skewed.

B4.11 Cantilever pile to Bearer/Joist [6kN]

1999 [under NZS3604:1999]
The connection shall have a capacity of 6kN. Alternatively an M12 bolt with scarfed pile top can also be used, providing that at least 70mm of pile top remains for

connection. The floor joists closest to the pile top shall have a 6kN capacity in both directions.

1984 _____ *[under NZS3604:1984]*

[Bearer] _____ 4 galvanised wire dogs, 2 each side of Bearer and 4/100x3.75mm galvanised nails through Bearer into pile or vice versa.

Or one 12mm galvanised bolt.

Or 2/25x1mm steel galvanised straps with 30x3.15mm galvanised nails 4 into pile and 2 into Bearer and 4/100x3.75mm galvanised nails through Bearer into pile or vice versa.

Or 2 galvanised wire dogs and 4mm galvanised wire.

[Joist] _____ Connection of joist to Bearer only needed in first example, 2 galvanised wire dogs, one each side of Bearer. This is only required on one joist adjacent to the pile.

1978 _____ *[under NZS3604:1978]*

4/100x3.75mm galvanised nails and 4mm galvanised wire or 2 galvanised wire dogs

B4.12 _____ ***Anchor pile to Bearer/Joist [12kN]***

1999 _____ *[under NZS3604:1999]*

The connection shall have a capacity of 12kN. And can be either an M12 bolt or 12mm threaded rod connected to the Bearer or to the joist directly.

1984 _____ *[under NZS3604:1984]*

An M12 bolt and 50x50x3mm washer providing 12kN in tension and compression.

Appendix B5 *Non-Structural Provision Compliance*

B5.1 *Water barrier*

1999 *[under NZS3604:1999]*

Vapour barriers are required under floor slabs on ground to a limit of 90 MNs/g all gaps and objects likely to penetrate the barrier should be removed. Ground cover is also necessary if adequate ventilation cannot be provided. A barrier of 50MNs/g should be provided. DPC is essential under all places where timber comes in contact with concrete or masonry. It is also required under any contacting framing if within 150mm of the ground.

1984 *[under NZS3604:1984]*

DPC must be used for timber piles when less than 300mm from CGL, the DPC must over lap timbers by at least 6mm.

1964 *[under NZSS 1900:1964]*

All timber in contact with concrete or masonry shall be protected by an approved Damp-Proof Course or other approved method.

1944 *[under N.Z.S.S. 95]*

An approved Damp Proof Course was necessary where timber beams and joists were resting on brick, stone or concrete walls.

1924 *[under NZSFS Circular 14]*

A damp-proof course was necessary to be laid on top of masonry beneath the level of the lowest timbers and above the ground next to foundations. The DPC shall be of lead sheet 5.95kg/m³ or, 1/2in. [12mm] asphalt, or slates covered in cement.

B5.2 *Ventilation*

1999 *[under NZS3604:1999]*

Ventilation is set at 3500sq.mm per 1sq.m of floor area. Alternatives include 20mm slots between baseboards, a 50mm gap between wall plates and boundary joists or any other regularly spaced openings that will provide ventilation. Where this ventilation cannot be provided then a vapour barrier must be used. This equates to a vent of 50x70mm for every 1sqm of floor area.

1984 *[under NZS3604:1984]*

Not less than 3500sq.mm per sqm of floor area, shall be distributed around the entire perimeter of external walls. Ventilation intervals at maximum 1.8m crs and at least 750mm from any corner.

1964 *[under NZSS 1900:1964]*

Ventilation shall be provided through a number of openings in the foundation walls and shall be 1/2sq.in. of unobstructed air space per sqft of ground floor area [roughly 3580sqmm per sqm of floor area]. This may be provided through special ventilators spaced every 6ft [1.8m] and not more than 2'6"ft [760mm] from each corner.

1944 *[under N.Z.S.S. 95]*

The minimum ventilation was to be 1/2 sq.in per sq.ft of dwelling [3600sq.mm per 1sq.m of floor area]. Vents may be used but must be spaced at maximum 6ft [1.8m crs.] and must be no more than 2'6"ft [760mm] from any corner.

1924

[under NZSFS Circular 14]

Cross ventilation shall be provided for the space enclosed by foundation walls equal to 1 sq.in. per 1 sq.ft of floor area [7160sq.mm per 1sq.m of floor area].

B5.3

Timber treatment

1999

[under NZS3604:1999]

All timber piles should be treated to H5 of MP 3640. The timber shall not be cut for fixings less than 150mm to finished ground level.

1984

[under NZS3604:1984]

All timber preservative treatment shall be approved as suitable for their end use.

1964

[under NZSS 1900:1964]

All timber shall be thoroughly seasoned in accordance with recognised principles either by air seasoning or kiln drying. Inclusion of Macrocarpa and Tanekaha all of heart.

Inclusion of timbers permeable sapwood of named timbers and Pinus Radiata, Corsica pine, Tawa, Taraire, Kahikatea, Douglas fir, Larch and Beech silver provided that they are treated to the approval of the timber preservation authority and used in all sub-floor areas or where exposed to ground atmosphere.

1944

[under N.Z.S.S. 95]

All foundation bracing and piles are to be of heart timber of Totara, Red beech, Hard beech, Silver pine, or other timbers that may be approved. Floor joists shall be heart Totara, Kauri, Matai, Rimu, Miro, Hard beech, Red beech or other timbers that may be approved.

Timber may not be heart if they have been effectively treated with an approved wood preservative by an approved process. If flooring is more than 4ft [1.2m] from the ground joists can be as in other parts of the framing.

Another clause stated that areas with a mean annual rainfall of less than 2'6''ft [760mm], non-heart Rimu may be used untreated if no white outer sap timber is included.

Ends of joists and Bearers resting on concrete, stone or brick walls should be treated with Creosote or other wood preservative.

1924

[under NZSFS Circular 14]

Foundation blocks, if of timber, shall be of heart material of Totara, Silver pine, Puriri, Hinau, Maire, Rimu, Maire, Red beech and other approved imported timbers. Other specifications for timbers close to the ground are also stated and listed for their inherent resilience.

All beams and joists resting on concrete, stone or brick shall have ventilation around their ends and be heavily treated with Creosote or other approved wood preservative.

B5.4

Timber Moisture Content

1999

[under NZS3604:1999]

Timber MC is specified in NZS3603 and shall be a maximum of 18%

1984

[under NZS3604:1984]

All timber moisture content shall be approved as suitable for their end use.

1964

[under NZSS 1900:1964]

Allowable stresses apply to timber which is surface-seasoned to an average sectional moisture content of 30% or less before it is fully loaded.

1944 _____ *[under N.Z.S.S. 95]*

All timber other than framing timber shall be thoroughly seasoned in accordance with recognised principles of Air-seasoning or Kiln-drying. Framing timber was to be thoroughly dry prior to enclosing the structure.

1924 _____ *[under NZSFS Circular 14]*

All timber was to have 15% Moisture Content based on the oven-dried weight of the wood. All timber used for construction shall be thoroughly seasoned, meaning bought to a point which it is in equilibrium with the atmosphere in which it is to be used.

B5.5 _____ ***Clearance***

1999 _____ *[under NZS3604:1999]*

All pile heights following are above cleared ground level, meaning above any non structural top soil. Any structural member must be minimum 150mm from the ground with DPC, and any cladding must be at least 200mm vertically from adjacent ground and 450mm horizontally from any ground.

1984 _____ *[under NZS3604:1984]*

Remains unchanged

1978 _____ *[under NZS3604:1978]*

A minimum of 450mm horizontal space and 150mm of vertical space between foundation timbers shall be maintained between the outside wall and ground. The crawl space must be min. 450mm high.

1964 _____ *[under NZSS 1900:1964]*

The minimum clearance between the bottom of the lowest sub-floor member and the ground shall be a minimum 12in. [300mm] at any point and no obstruction to prevent ready access to any part of the foundation for the purposes of inspection.

1944 _____ *[under N.Z.S.S. 95]*

The minimum dimension between the ground and the Bearers (sleeper plates) was 12in. [300mm].

1924 _____ *[under NZSFS Circular 14]*

All framing shall have a minimum clearance of 12in. [300mm].

All timber within 18in. [450mm] of ground level must be of heart or sap material of Kauri, Matai, Rimu, Miro, Hinau, Red Beech, Silver Beech, and other approved imported timbers.

Appendix B6 *State House Specification and Amendments*

State Specification changes related to the Sub-floor area and the year each amendment was made. Information was sourced from: (ten Broeke 1979, Ministry of Housing, 1937, Archives New Zealand File 1937)

Original State house Specification 1939 *[Original State House Specification]*

Foundations will be of entirely of Concrete foundation walls brick veneer will be taken down in front of concrete, one third will be of wood and the remaining two thirds will be of brick veneer. Sleeper plates will be heart Totara, 5x2in. [125x50mm] at 4ft spans [1.2m]. Joists will be 5x2in max. [125x50mm] and have 6ft spans at 18in crs [450mm crs]. All foundation piles will be of concrete and have 14"x14"x 6" concrete pads for loaded pads. All floors will be T&G back grooved 4x1in. [100x25mm] Rimu. All studding if applicable to be 450mm crs. Special attention must be paid to ventilation under all floors and to external walls and shall use vents measuring 13x10in. [330x250mm] at 6ft crs [1.8m].

1942 *[State House amendment]*

Double joists required under load bearing walls, usually when incorporating a concrete roof, treated timber allowed in sub-floor.

1945 *[State House amendment]*

Concrete mix improved for all foundation work, as well as piles to extend 9in. [230mm] below CGL

1946 *[State House amendment]*

Topsoil was required to be cleared on site, and new use of piles in exterior walls as well as open baseboards on exterior piles.

1947 *[State House amendment]*

Continuous concrete walls required in termite infested areas, piles and concrete otherwise allowed if corner wall of any part of foundation is over 4ft [1.2m] from CGL

1948 *[State House amendment]*

Foundation height increased to 1ft4in. [400mm] to lowest member, however if pile height is over 4ft [1.2m] 4x3in. [75x100mm] jack framing is to be used.

1951 *[State House amendment]*

Use of Radiata Pine was allowed, which was seen as an area which weakened nailing capacities

1953 *[State House amendment]*

Minimum sub-floor clearance allowed is 12in. [300mm]

1960 *[State House amendment]*

Minimum height increased to 17in. [430mm] foundation height for termite areas.

1962 *[State House amendment]*

Piled foundations again allowed in termite areas. Continuous concrete wall required on sloping sites if over 4ft6in. [1.4m] in height

1964 *[State House amendment]*

Jackstud bracing changed from 4x3in. [100x75mm] cut between bracing to checked in 6x1in. [150x25mm] brace.

To the Owner of 666 Albany Avenue, Melrose

Dear John and Mary Smith,

We are currently undertaking a research project at Victoria University of Wellington for the Earthquake Commission focussing on the 'Structural Adequacy of House Foundations during and after Earthquakes'. We have selected your house from a random list generated by the Wellington City Council.

This research is important to the city of Wellington and to New Zealand, as it is currently understood that many dwellings foundations built in during various decades have specific structural deficiencies that are likely to cause failure in a major earthquake. Many houses seen in the last large earthquake at Edgecumbe (1987) failed from weak foundations, however many houses built after the introduction of the modern Light Timber Frame design code, survived with only superficial damage to walls and foundations.

Therefore, we wish to have access to the foundations of your dwelling in order to assess the general condition of the foundation, the adequacy of the bracing and to conduct a general structural analysis of your foundations against the current New Zealand Light Timber Frame design code. The results will then be used to create a database of the general condition of houses against their age. The specific results relating to certain foundation types will be used to calculate the price of upgrading to meet the standards set out in the Light Timber Frame design code.

In return for your time, we will provide you with the general status of your foundations that will describe any deficiencies found. It will also describe details of any extra bracing requirements. Even though this analysis is not a specific engineering report, it may be useful in identifying any deficiencies or inadequacies with your foundations. This information will allow you to take remedial measures for securing your house so it remains habitable following an earthquake.

Although the overall results of this research will be publicly available, under no circumstances will identifying information be released regarding your property.

James Irvine, who will be conducting the analysis, will contact you in the next week regarding the visit.

Thank you for your time

Dr Geoff Thomas
Senior Lecturer

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Part A		to		get plans?	OY ON	why		Photo #
Kilometre reading		km	to	end		km	total	
Age of house	<1900	1900-1910	1910-1920	1920-1930	1930-1940	1940-1950	1950-1960	1960-1970
	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>	<input type="checkbox"/>
Address	Sample #	Number	Street				Suburb	
<i>Owners questions</i>						<i>date and time</i>		
Type of living	<input type="checkbox"/> owner / occupier		<input type="checkbox"/> rented		<input type="checkbox"/> unsure			
Do you have gas	<i>do you know where?</i>							
Stud Height (m)	<input type="checkbox"/> 2.4	<input type="checkbox"/> 2.7	<input type="checkbox"/> 3.0					
No. Floors	<input type="checkbox"/> 1	<input type="checkbox"/> 2	<input type="checkbox"/> 3	<input type="checkbox"/> more				
Gas comes from	<input type="checkbox"/> street		<input type="checkbox"/> bottle		<input type="checkbox"/> unsure		<input type="checkbox"/> no gas	
Owner's knowledge	<i>list any number of additions, changes, etc</i>							
Has it been Re-piled?	<input type="checkbox"/> Y <input type="checkbox"/> N <i>details / when?</i>							
Inaccessible foundations	<input type="checkbox"/> Y <input type="checkbox"/> N <i>details</i>							
General arch. description	<i>alterations, structural additions</i>							

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Part B

Photo #

Connected dwelling

no units

☐ N/A

☐ 1

☐ 2

☐ 3+

☐ end

☐ middle

mirrored?

☐ N/A

☐ Y ☐ N

describe?

same area?

☐ N/A

☐ Y ☐ N

describe?

Building Height to Eaves
[apex](m)

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ 8

☐ 9

☐ 10+

Roof Height above Eaves (m)

☐ 1

☐ 2

☐ 3

☐ 4

☐ 5

☐ 6

☐ 7

☐ 8

Cladding Weight Upper

☐ N/A

☐ light

☐ heavy

material?

Cladding Weight lower

☐ light

☐ heavy

material?

Cladding Weight subfloor

☐ None

☐ light

☐ heavy

material?

Discontinuous plan elevation

☐ Y ☐ N

describe?

Roof Weight

☐ light

☐ heavy

material?

Roof Pitch (degrees)

☐ 0-25

☐ 25-45

☐ 45-60

Room in Roof Space

☐ Y ☐ N

Building Length (m)

m

add

add

add

Building Width (m)

m

add

add

add

Differing foundations

☐ Y ☐ N

where?

Split level

☐ Y ☐ N

where?

Slab-on-Ground

☐ Y ☐ N

where?

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also

across

legend

O

ordinary pile

cantilever/anchor. pile

 BP

IIIIIIIIIIIIIIIIIIII F.wall

signi

Significant framing

O T

Timber

O

Concrete

C1

1 Investigation

C2

2 Investigation

C3

3 Investigation

Mode of failure assumption

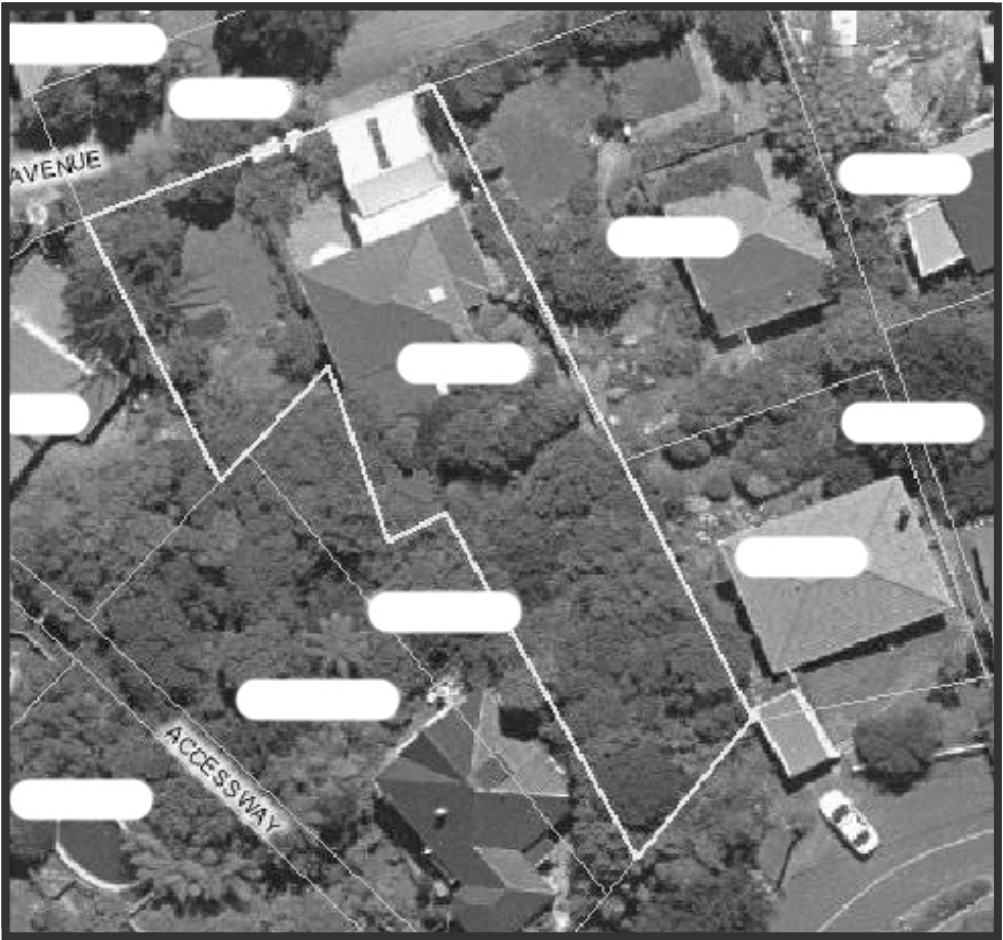
Photo #

to

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Topography	<input type="checkbox"/> gentle 1:10 - 1:5 <input type="checkbox"/> moderate >1:5 - 1:3 <input type="checkbox"/> extreme >1:3			
Terrain	<input type="checkbox"/> inland <input type="checkbox"/> coastal			
exposure	<input type="checkbox"/> sheltered <input type="checkbox"/> exposed			
soil type any signs	<input type="checkbox"/> rock	<input type="checkbox"/> sand	<input type="checkbox"/> clay	<input type="checkbox"/> loose soil visible

Site layout and significant features



north

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Part C1

3 corners strategy

photos

to

Photo #

Corner

C1

Position

describe

photos

Horizontal

Joists

size

spacing

Bearers

size

spacing

Vertical

Ordinary Piles

size

Timber

concrete

height

Conc. Found. Wall

Width

Jackstuds

Height

size

Joist-Joist

Joist-Bearer

Bearer to Bearer

Bearer / Joist to edge foundation wall

Plate to foundation Wall / Jackstud[T/C] [top]

Jackstud to Bearer / Plate [bottom]

Ordinary pile to Bearer

Ordinary pile to Jackstud

12kN or 6kN BP/AP/CP

Likely Bracing

Anchor Piles

Cantilever Piles

Braced Piles

massive anchors

Typical exterior details

photo

Typical interior details

photo

fixing

height

width

material

DPC

joists

framing

deteriorate

spans

Anomalies

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Part C2

3 corners strategy

photos

to

Photo #

Corner

C2

Position

describe

photos

Horizontal

Joists

size

	x		mm	also			
--	---	--	----	------	--	--	--

spacing

<input type="checkbox"/> 400	<input type="checkbox"/> 450	<input type="checkbox"/> 600	<input type="checkbox"/> other?				
------------------------------	------------------------------	------------------------------	---------------------------------	--	--	--	--

Bearers

size

	x		mm	also			
--	---	--	----	------	--	--	--

spacing

<input type="checkbox"/> 1300	<input type="checkbox"/> 1650	<input type="checkbox"/> 2000	<input type="checkbox"/> other?				
-------------------------------	-------------------------------	-------------------------------	---------------------------------	--	--	--	--

Vertical

Ordinary Piles

size

Timber

<input type="checkbox"/> circular	<input type="checkbox"/> square		mm				
-----------------------------------	---------------------------------	--	----	--	--	--	--

concrete

<input type="checkbox"/> circular	<input type="checkbox"/> square		mm	<input type="checkbox"/> tapered		up to		
-----------------------------------	---------------------------------	--	----	----------------------------------	--	-------	--	--

height

	mm	also		mm			
--	----	------	--	----	--	--	--

Conc. Found. Wall

Width

	mm	height		mm			
--	----	--------	--	----	--	--	--

Jackstuds

Height

	mm	Length		m	Spacing		m
--	----	--------	--	---	---------	--	---

size

	mm	x		mm	Footing?		
--	----	---	--	----	----------	--	--

Joist-Joist

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	<input type="checkbox"/> butt	<input type="checkbox"/> lapped	<input type="checkbox"/> flitch	describe		
------------------------------	---------------------------------------	-------------------------------	---------------------------------	---------------------------------	----------	--	--

Joist-Bearer

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

Bearer to Bearer

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

Bearer / Joist to edge foundation wall

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

Plate to foundation Wall / Jackstud[T/C] [top]

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

Jackstud to Bearer / Plate [bottom]

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible					
------------------------------	---------------------------------------	--	--	--	--	--

Ordinary pile to Bearer

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	<input type="checkbox"/> top	<input type="checkbox"/> side	describe			
------------------------------	---------------------------------------	------------------------------	-------------------------------	----------	--	--	--

Ordinary pile to Jackstud

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

12kN or 6kN BP/AP/CP

<input type="checkbox"/> N/A	<input type="checkbox"/> none visible	describe				
------------------------------	---------------------------------------	----------	--	--	--	--

Likely Bracing

Anchor Piles

☐ none

☐ y

describe

Cantilever Piles

☐ none

☐ y

Braced Piles

☐ none

☐ y

massive anchors

☐ Y ☐ N

☐ chimney ☐ porch ☐ old steps ☐ verandah ☐ other

connected? ☐ Y ☐ N

Typical exterior details

photo

Typical interior details

photo

fixing

height

width

material

DPC

joists

framing

deteriorate

spans

Anomalies

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Part D										Photo #	
Ventilation		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?		number					
		ventialtion size		mm		x		mm at spacings			
placement		<input type="checkbox"/> not on all sides		<input type="checkbox"/> more than 1.8 crs		<input type="checkbox"/> not within .75m of corner					
blockage		<input type="checkbox"/> vegetation		<input type="checkbox"/> pathways etc		<input type="checkbox"/> other					
Moisture											
visible signs		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
		source?		o interior		o exterior					
soil wet		<input type="checkbox"/> Y <input type="checkbox"/> N		where?							
ponding		<input type="checkbox"/> Y <input type="checkbox"/> N		where?							
channelled?		<input type="checkbox"/> Y <input type="checkbox"/> N		where?							
degraded connections		<input type="checkbox"/> Y <input type="checkbox"/> N		<input type="checkbox"/> ZnO		<input type="checkbox"/> FeO		o other			
		describe?									
degraded timber		<input type="checkbox"/> Y <input type="checkbox"/> N		what?							
cladding deterioration		<input type="checkbox"/> Y <input type="checkbox"/> N		where?							
		minimum clearance				mm					
DPC visible		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
Timber											
type		<input type="checkbox"/> Native		<input type="checkbox"/> pine		<input type="checkbox"/> treated					
wet timber		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
timber condition		<input type="checkbox"/> good		<input type="checkbox"/> some deterioration		<input type="checkbox"/> some rotting		<input type="checkbox"/> alot deteriorated			
clearance to Bearers		minmium				mm		maximum		mm	
lateral support		<input type="checkbox"/> block		<input type="checkbox"/> herringbone							
repiling wedges		<input type="checkbox"/> Y <input type="checkbox"/> N		fixed in place?		<input type="checkbox"/> Y <input type="checkbox"/> N					
Soil condition											
unprotected ground		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
other discrepancies											
Sub-floor dumping		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
missing structure		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
retaining structures		<input type="checkbox"/> Y <input type="checkbox"/> N		describe?							
Gas plumbing											
material		<input type="checkbox"/> PE		<input type="checkbox"/> uPVC		<input type="checkbox"/> iron		<input type="checkbox"/> copper		<input type="checkbox"/> lead	

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Appendix D. _____ Data Collected Onsite Relating to all Dwellings

Joists					Appendix B1.1	
#	Sizes	#	Spacings	#	Spans	
8	100x50	14	400mm	12	< 1m	
37	125x50	37	450mm	14	1.3m	
9	150x50	12	500mm	7	1.5m	
3	200x50	4	600mm	7	1.7m	
7	250x50	13	slab	13	2m	
3	300x50			9	2.5m	
				3	3m	
				2	over 3m	
Bearers					Appendix B1.2	
#	Sizes	#	Spans			
42	100x75	3	<1m			
5	100x100	16	1.3m			
9	125x50	15	1.65m			
3	150x50	15	2m			
2	150x100	14	3m			
2	150x75	4	over 4m			
3	200x75					
1	250x50					
Piles					Appendix B1.3	
#	Types	#	Sizes			
16	concrete square straight OP/C[1]	2	100x100			
7	concrete circular straight OP/C[2]	8	130x130			
9	concrete tapered OP/C[3]	3	150x150			
3	timber square OP/T[4]	38	200x200			
2	timber circular OP/T[5]	3	250x250			
14	concrete square straight repiled					
2	concrete circular straight repiled					
8	concrete tapered repiled					
4	timber square repiled					
1	timber circular repiled					
10	concrete SLAB [6]					
4	other system					
Jackstuds					Appendix B1.4	
#	Sizes	#	Spacings	#	Height	
11	100x50	2	500mm	4	<500mm	
14	100x75	26	600mm	13	<1000mm	
5	100x100	2	1000mm	9	<1500mm	
1	125x50			7	>1500mm	

Joist to Joist		[J-J]	Appendix B4.2	
#	Fixing observed	Description		
9	J-J[1]	none visible / no connection		<i>not acceptable</i>
4	J-J[2a]	<u>lapped apart</u>		<i>not acceptable</i>
8	J-J[2b]	<u>lapped no fixings</u>		<i>not acceptable</i>
5	J-J[3a]	lapped 1 nails through		<i>not acceptable</i>
18	J-J[3b]	lapped 2-3 nails through		<i>not acceptable</i>
12	J-J[3c]	<u>lapped 4-6 nails through</u>		<i>acceptable</i>
1	J-J[3d]	lapped 8 nails through		<i>acceptable</i>
0	J-J[4]	<u>lapped 2 skew nails in end grain</u>		<i>not acceptable</i>
2	J-J[5a]	<u>butt no fixings</u>		<i>not acceptable</i>
4	J-J[5b]	butt 1 skew nail each end		<i>not acceptable</i>
1	J-J[5c]	butt 2 skew nails each end		<i>not acceptable</i>
13	n	n/a		
Joist to Bearer		[J-B]	Appendix B4.3	
#	Fixing observed	Description		
2	J-B[1]	bearing no fixing		<i>not acceptable</i>
10	J-B[2]	bearing 1 skew nail		<i>not acceptable</i>
42	J-B[3a]	bearing 2 skew nails		<i>acceptable</i>
0	J-B[3b]	bearing 2 skew nails packing		<i>acceptable</i>
0	J-B[3c]	bearing 2 skew nails DPC		<i>acceptable</i>
3	J-B[4a]	10mm notch no fixing	ALONG	<i>not acceptable</i>
0	J-B[4b]		ACROSS	
3	J-B[5a]	10mm notch 2 skew nails	ALONG	<i>acceptable</i>
0	J-B[5b]		ACROSS	<i>acceptable</i>
2	J-B[6a]	20mm notch no fixing	ALONG	<i>not acceptable</i>
0	J-B[6b]		ACROSS	<i>not acceptable</i>
3	J-B[7a]	20mm notch 1 skew nail	ALONG	<i>not acceptable</i>
0	J-B[7b]		ACROSS	<i>not acceptable</i>
2	J-B[8a]	20mm notch 2 skew nails	ALONG	<i>acceptable</i>
0	J-B[8b]		ACROSS	<i>acceptable</i>
13	n	n/a		
Plate to foundation wall		[P-FW]	Appendix B4.4	
#	Fixing observed	Description		
1	P-FW[1]	bearing no fixings		<i>not acceptable</i>
3	P-FW[2a]	bearing M12 bolts @ 1000crs		<i>acceptable</i>
3	P-FW[2b]	bearing M12 bolts @ 1200crs		<i>acceptable</i>
3	P-FW[2c]	bearing M12 bolts @ 1400 crs		<i>acceptable</i>
0	P-FW[2d]	<u>bearing M12 bolts @ 2000 crs</u>		<i>not acceptable</i>
2	P-FW[3]	bearing plate & 2 / M12 bolts		<i>not acceptable</i>
0	P-FW[4]	<u>no bearing plate & 2 / M8 bolts</u>		<i>not acceptable</i>
3	P-FW[5a]	bearing R10 bar @ 900crs		<i>acceptable</i>
4	P-FW[5b]	bearing R10 bar @ 1000crs		<i>not acceptable</i>
3	P-FW[5c]	bearing R10 bar @ 1200crs		<i>not acceptable</i>
3	P-FW[5d]	bearing R10 bar @ 1400crs		<i>not acceptable</i>
1	P-FW[5e]	bearing R10 bar @ 1600crs		<i>not acceptable</i>
2	P-FW[6a]	side M12 bolt @ 1000crs		<i>acceptable</i>
2	P-FW[6b]	side M12 bolt @ 1500crs		<i>not acceptable</i>
1	P-FW[7]	bearing wire & 4 staples		<i>not acceptable</i>

9	P-FW[8]	foundation wall with no plate		<i>not acceptable</i>
40	n	n/a		
Bearer to foundation wall or edge plate [B-FW]			Appendix B4.5	
#	Fixing observed	Description		
8	B-FW [1]	bearing no fixings		<i>not acceptable</i>
2	B-FW [2]	bearing 1 skew nail		<i>not acceptable</i>
8	B-FW [3]	bearing 2 skew nails		<i>not acceptable</i>
0	B-FW [4]	bearing 2 Z nails		<i>not acceptable</i>
0	B-FW [5]	plate 2 M8 bolts each end		<i>not acceptable</i>
2	B-FW [6a]	bearing M12 bolt through		<i>acceptable</i>
6	B-FW [6b]	bearing R10 bar through		<i>acceptable</i>
5	B-FW [7]	bearing wire & 4 staples		<i>not acceptable</i>
1	B-FW [8]	120x200 nail plate		<i>not acceptable</i>
48	n	n/a		
Joist to foundation wall /plate [J-FW]			Appendix B4.5	
#	Fixing observed	Description		
5	J-FW [1]	bearing no fixings		<i>not acceptable</i>
19	J-FW [2]	bearing 1 skew nail		<i>not acceptable</i>
38	J-FW [3]	bearing 2 skew nails		<i>acceptable</i>
2	J-FW[4]	bearing 1 skew nail per 500mm		<i>not acceptable</i>
3	J-FW[5]	side joist hanger		<i>acceptable</i>
13	n	n/a		
Bearer to Bearer [B-B]			Appendix B4.6	
#	Fixing observed	Description		
7	B-B[1]	none visible / no connection		<i>not acceptable</i>
14	B-B[2a]	butt no fixing		<i>not acceptable</i>
1	B-B[2b]	butt 2 skew nails		<i>not acceptable</i>
1	B-B[2c]	butt 3 skew nails		<i>not acceptable</i>
6	B-B[3a]	45° splayed joint 1 nail in top std. OP-B fixing		<i>not acceptable</i>
12	B-B[3b]	45° splayed joint 2 skew nails std. OP-B fixing		<i>not acceptable</i>
1	B-B[4a]	45° splayed joint plate 11 nails each side 4 skew nails		<i>acceptable</i>
1	B-B[4b]	45° splayed joint M12 bolt		<i>acceptable</i>
6	B-B[5a]	notch splayed no nail		<i>not acceptable</i>
6	B-B[5b]	notch splayed 1 nail in top		<i>not acceptable</i>
3	B-B[5c]	notch splayed 2 skew nails		<i>not acceptable</i>
3	B-B[5d]	notch splayed 4 skew nails		<i>not acceptable</i>
1	B-B[6]	lapped 1 nail		<i>not acceptable</i>
3	B-B[7]	45° splayed joint std OP-B fixing		<i>not acceptable</i>
1	B-B[8]	butt nail plate 120x200		<i>acceptable</i>
1	B-B[9]	Flitch 6 M20 bolts 5 skew nails		<i>acceptable</i>
13	n	n/a		
Ordinary pile to Bearer [OP-B]			Appendix B4.7	
#	Fixing observed	Description		
5	OP-B[1]	seating no fixing		<i>not acceptable</i>
1	OP-B[2]	seating 4mm galv.wire no staples		<i>not acceptable</i>
9	OP-B[3]	seating 4mm galv.wire staples no turn over		<i>not acceptable</i>

11		OP-B[4]	seating 4mm galv.wire 4 staples taught wrap no fold back	<i>acceptable</i>
14		OP-B[5]	seating 4mm galv.wire 4 staples fold back	<i>acceptable</i>
17		OP-B[6]	seating 4mm galv.wire 4 staples wrap and recessed	<i>acceptable</i>
0		OP-B[7a]	side 1 nail	<i>not acceptable</i>
0		OP-B[7b]	side 2 nails	<i>not acceptable</i>
1		OP-B[7c]	bearing 2 nails through	<i>not acceptable</i>
1		OP-B[8a]	seating M15 bolt	<i>acceptable</i>
1		OP-B[8b]	seating R10 bar wrapped	<i>not acceptable</i>
1		OP-B[9a]	seating 1 Z nail & 1 skew nails	<i>not acceptable</i>
2		OP-B[9b]	seating 2 Z nail & 2 skew nails	<i>acceptable</i>
1		OP-B[9c]	seating 4 Z nails & 2 skew nails	<i>acceptable</i>
1		OP-B[10]	25x1x300 strap	<i>acceptable</i>
1		OP-B[11a]	side M20 bolts	<i>acceptable</i>
1		OP-B[11b]	side M12 bolts	<i>acceptable</i>
13		n	n/a	
Wall plate to Jackstud [WP-JS]				
#		Fixing observed	Description	
2		WP-JS [1]	10mm notch no nails	<i>not acceptable</i>
1		WP-JS [2]	5mm notch 1 skew nail	<i>not acceptable</i>
4		WP-JS [3]	bearing 1 skew nail	<i>not acceptable</i>
9		WP-JS [4]	bearing 2 skew nails	<i>acceptable</i>
2		WP-JS [5]	bearing 2 skew side nails & 1 top	<i>acceptable</i>
4		WP-JS [6]	bearing 4 skew nails	<i>acceptable</i>
58		n		
Jackstud to Bearer [JS-B] Appendix B4.9				
#		Fixing observed	Description	
1		JS-B[1]	10mm notch 1 skew nail	<i>not acceptable</i>
0		JS-B[2]	10mm notch 2 skew nails	<i>acceptable</i>
13		JS-B[3]	bearing 2 skew nails one side	<i>acceptable</i>
4		JS-B[4]	notch 2 skew nails both sides	<i>acceptable</i>
4		JS-B[5]	bearing 4 skew nails	<i>acceptable</i>
58		n	n/a	

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Appendix E. _____ Remedy Parameters

The remedial measures were costed by a qualified Quantity Surveyor on a unit basis for the material and labour cost. All costs below were calculated on different basis' depending on the application and type of remedy. Fixings are usually per unit installed and calculated on a single unit installation only, removal of soil and infill of concrete were calculated on a cubic metre basis. The information in Appendix E was the information supplied to the Quantity Surveyor, on which to base all material and labours costs. All dollar figures are in NZ dollars and calculated as at January 2007.

E1.1

Braced Pile Solution

The Braced pile solution is a system of where a timber brace spans between the pile bottom and joists or Bearers at the top.

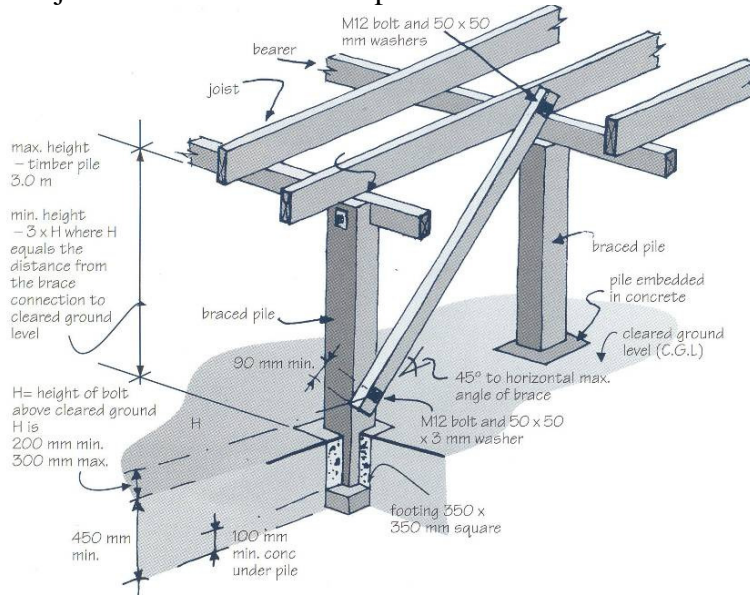


Figure E1 Braced Pile Solution, Braced from Pile to Joist (Source: BRANZ 2000)

E1.1.1

Labour

\$175.50 per pile system

- Excavate soil around two piles
- Remove existing concrete piles and discard
- Extend existing hole to a minimum 450mm below ground
- Install two 125x125mm H5 timber piles **[cut to size]**
- Pour concrete footing
- Apply 12kN fixing from pile top to Bearer [see image below]
- Apply M12 bolt [12kN fixing] to both ends of 100x100mm H1.2 timber brace **[cut to size]**. [incl. 50x50x3mm washer one side]
- Apply 6kN fixings to 2 joists near brace ends.
- Repeat as necessary in foundation
- Clean up

E1.1.2

Material costs

\$455.00

- 2 / 125x125mm H5 timber pile **[minimum overall height 900mm and maximum height 1600mm]**
- 100x100mm H3 timber brace [maximum length 3m]
- 2 / M12 bolts galvanised including 50x50x3mm square washer
- 2 / 12kN fixings from pile top to Bearer **[refer 12kN fixing in connections section]**
- 0.050m³ concrete per pile [assume two piles]
- 2 / 6kN fixings between joist and Bearer **[refer 6kN fixing in connections section]**

E1.2

Sheet Bracing Solution

The sheet bracing is 7mm treated DD plywood applied to the exterior of piles with ventilation grills applied at appropriate centres. The piles if not timber [which is almost always the case] require timber framing to infill around the piles before any sheet bracing is applied. For the purposes of clarity, always assume an average case for foundation heights of 600mm [up to top side of joists]. Pile spacings will have two cases of 1.3m and 2m

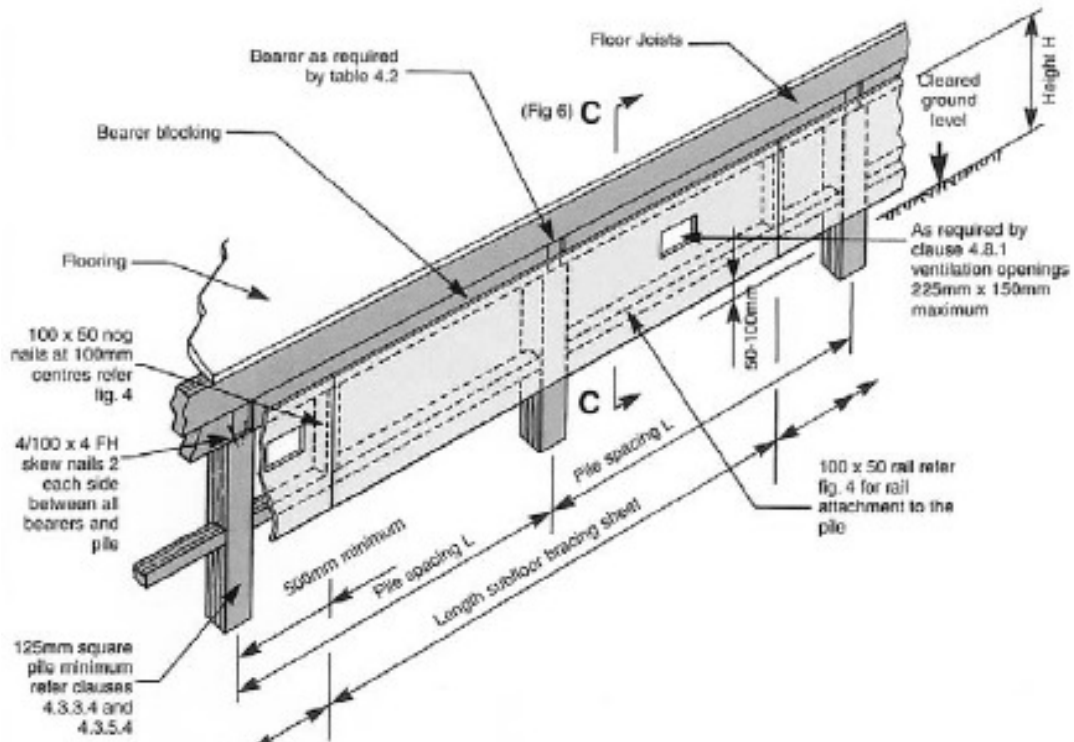


Figure E2 Sheet Bracing Remedial Solution (Source: James-Hardie 1994)

E1.2.1

Labour

\$80.00 per linear metre

- Fill lower chord and sides between concrete piles with 100x50mm H3 timber framing [assuming a 1.3 to 2m pile spacing]
- Fix framing members to piles with ramset or similar power driven fixtures at 300mm centres [assume 3 such connections per pile side]
- Allow additional framing where sheet ends meet [see image below]
- Remove lowest 2 weather boards to reveal joist or wall plate ends
- Cut sheet width to appropriate height [assuming average sheet of 600mm]
- Fix sheet bracing with 30x2.5mm galvanised clouts at 150mm centres around the sheet edge [assume 30 nails for 1.3m pile spacings and 40 nails for 2m spacings]
- Fix ventilation grills [see ventilation in General Condition above]
- Repeat as necessary around perimeter
- Clean up

<i>El.2.2</i>	<i>Material costs</i>	<i>\$86.35 per linear metre</i>
	<ul style="list-style-type: none"> ▪ H3 100x50 timber framing [assume 3m for 1.3m pile spacings and 3.5m for 2m pile spacings] ▪ 7mm exterior grade DD H3 treated plywood [maximum length 2.0 m] ▪ Ramset or similar power driven nail [6 per pile bay] ▪ 10 / 100x3.75mm nails for other framing applications ▪ 30 / 30x2.5mm galvanised nails for 1.3m pile spacings and 40 / 30x2.5mm galvanised nails for 2m spacings ▪ <i>Ventilation materials</i> 	
<i>El.2.3</i>	<i>Total costs</i>	<i>\$166.35 per linear metre</i>

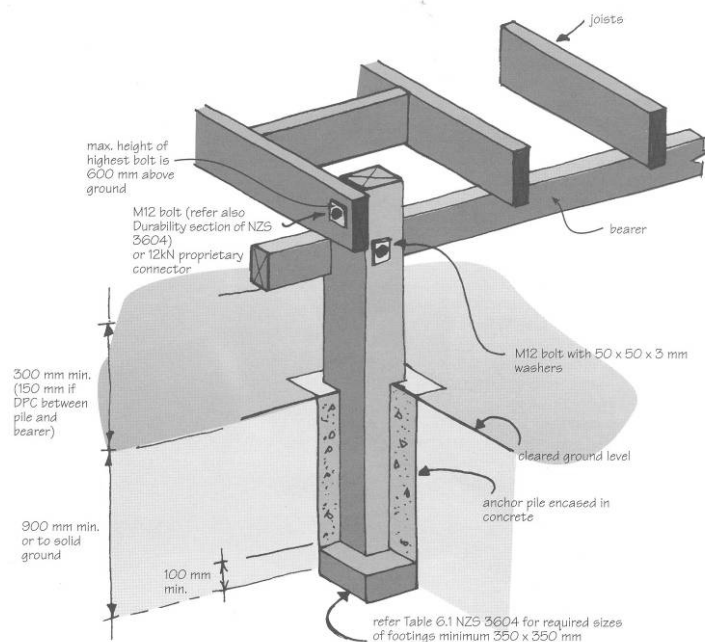
The infill concrete wall is essentially a fabricated concrete wall spanning between two concrete piles and fixed to the timber framing members through fixings set in the concrete. Wall height will always be assumed an average of 900mm with pile spacings will be assumed as before, 1.3m and 2m spacings. The concrete infill wall will assume a maximum of 200mm width.

Figure E3 Concrete Infill Wall Remedial Solution (*Source: Cooney 1982*)

- El.3.2 Material costs \$728.75 per linear metre*

- | | | |
|---------------|--------------------|-----------------------------------|
| <i>E1.3.3</i> | <i>Total costs</i> | <i>\$1230.00 per linear metre</i> |
|---------------|--------------------|-----------------------------------|

The anchor pile is bracing measure covered in NZS3604 and is essentially a pile with a deep large footing, utilising the soil shear strength to dampen earthquake loads. It is best used in a reasonably open situation as the footing depth is 900mm.



E1.4.1 Labour \$175.00 per pile system

- E-5

- Apply M12bolt fixing from pile side to Bearer side [see image below]
- Apply 6kN fixings to 2 joists near brace ends.
- *Repeat as necessary in foundation*
- Clean up

El.4.2 Material costs \$102.50 per pile system

- 1 / 125x125mm H5 timber pile [**maximum overall height 1500mm**]
- 1 / M12 bolts galvanised including 50x50x3mm square washer from pile side to Bearer side
- 0.080m3 concrete per pile
- 2 / 6kN fixings between joist and Bearer [**refer 6kN fixing in connections section**]

El.4.3 Total costs \$277.50 per pile system

Appendix E2 *The Fixing Measures*

All costs for all remedial measures are based on using galvanised fixings unless specifically stated. It is estimated that if Stainless Steel fixings are required, the cost would be slightly more.

E2.1 Joist to Bearer

The joist to Bearer requires 2 Z nails

<i>E2.1.1</i>	<i>Labour</i>	<i>\$5.50 per unit</i>
	<ul style="list-style-type: none"> Fix 2 Z or U nails in either side of joist to Bearer Clean up 	
<i>E2.1.2</i>	<i>Material costs</i>	<i>\$2.00 per unit</i>
	<ul style="list-style-type: none"> 2 / Z or U nails 	
<i>E2.1.3</i>	<i>Total costs</i>	<i>\$7.50 per unit</i>

E2.2 General Strap

The joist to Bearer either requires 2 Z nails

<i>E2.2.1</i>	<i>Labour</i>	<i>\$12.00 per unit</i>
	<ul style="list-style-type: none"> Place 25x400mm strap in place Fix 6 / 30x3.15mm galvanised nails each end. Clean up 	
<i>E2.2.2</i>	<i>Material costs</i>	<i>\$5.00 per unit</i>
	<ul style="list-style-type: none"> 1/ 25x400m m galvanised strap 12 / 30x3.15mm galvanised nails 	
<i>E2.2.3</i>	<i>Total costs</i>	<i>\$17.00 per unit</i>

E2.3 Plate to Foundation Wall

<i>E2.3.1</i>	<i>Labour</i>	<i>\$15.10 per unit</i>
	<ul style="list-style-type: none"> Cut 100x75mm H3 treated timber to 1m length Drill masonry hole through foundation wall [approx 12mm] Drill 12mm hole in timber plate above Fix M12 bolt through timber plate to 100x75mm member. Fix lower end to masonry wall with 12mm masonry “dynabolt” or grip bolt or similar. 	
<i>E2.3.2</i>	<i>Material costs</i>	<i>\$21.00 per unit</i>
	<ul style="list-style-type: none"> 100x75mm H3 treated timber @ 1m length 	

- 1 / M12 bolt with 50x50x3mm galvanised square washer.
- 1 “Dynabolt” or similar

E2.3.3 *Total costs* *\$36.10 per unit*

E2.3.4 *Image*

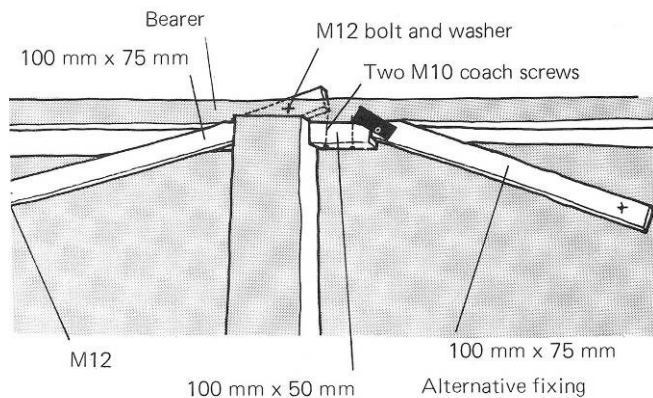


Figure E5 Remedial Connection for Plate to Foundation Wall (Source: Cooney 1982)

E2.4 6kN Connection – Version 1

E2.4.1 *Labour* *\$11.25 per unit*

- Hold galvanised cleat in place
- Nail with 10 / 45x3.15mm galvanised nails per cleat, 5 in lower and 5 in upper member
- Repeat for other side
- Clean up

E2.4.2 *Material costs* *\$8.75 per unit*

- 2 diagonally folded cleats,
- 20 / 45x3.15mm galvanised nails

E2.4.3 *Total costs* *\$20.00 per unit*

E2.4.4 *Image*

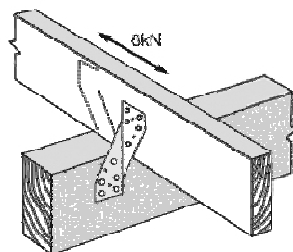


Figure E6 6kN Fixing of Bearer to Joist (Source: Pryda New Zealand 2005)

E2.5 6kN Connection – Version 2

E2.5.1 *Labour* *\$18.75 per unit*

- Scarf pile top to meet Bearer bottom edge
- Fix 4 / U nails, 2 each side

- Fix 2 / 100x3.75mm skew nails from the Bearer to the pile and 2 / 100x3.75mm skew nails from the underside of the Bearer [see **image below**]
- Repeat as necessary
- Clean up

E2.5.2 Material costs \$4.00 per unit

- 4 U nails
- 4 / 100x3.75mm galvanised nails

E2.5.3 Total costs \$22.75 per unit

E2.5.4 Image

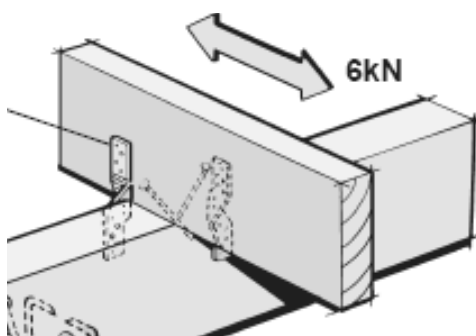


Figure E7 6kN Fixing of Bearer to Joist (Source: MiTek New Zealand Limited 2000)

E2.6 12kN Connection - Version 1

E2.6.1 Labour \$15.00 per unit

- Hold galvanised cleat in place
- Nail with 6 / 45x3.15mm galvanised nails per cleat, 3 in lower and 3 in upper member
- Repeat on all corners [**max 4**]
- Fix 2 / 100x3.75mm skew nails from the pile to the underside of the Bearer [see **image below**]
- Repeat as necessary
- Clean up

E2.6.2 Material costs \$18.00 per unit

- 2 / 100x3.75mm galvanised nails.
- 4 galvanised cleats.
- 24 / 45x3.15mm galvanised nails.

E2.6.3 Total costs \$33.00 per unit

E2.6.4 Image

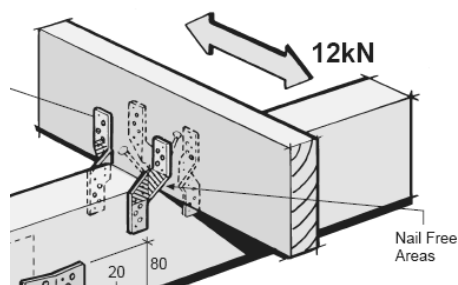


Figure E8 Fixing of 12kN fixing from Bearer to Joist (Source: MiTek New Zealand Limited 2000)

E2.7 12kN Connection - Version 2

E2.7.1	Labour	\$20.00 per unit
	<ul style="list-style-type: none"> ▪ Scarf pile top to meet Bearer bottom edge ▪ Fix 2 / stainless steel nail plates, 2 each side with 16 nails per plate, 8 into the Bearer and 8 into the pile top. ▪ Fix 4 / 100x3.75mm skew nails from the pile to the underside of the Bearer, two each side[see image below] ▪ Repeat as necessary ▪ Clean up 	
E2.7.2	Material costs	\$46.00 per unit
	<ul style="list-style-type: none"> ▪ 4 / 100x3.75mm galvanised nails. ▪ 2 / 190x100x1mm nail on plates ▪ 32 / 45x3.15mm galvanised nails. 	
E2.7.3	Total costs	\$66.00 per unit
E2.7.4	Image	

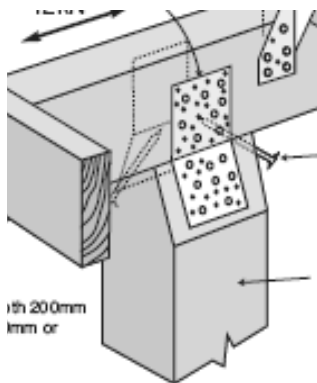


Figure E9 12kN Fixing of Bearer to pile (Source: Pryda New Zealand 2005)

E2.8 12kN Connection - Version 3

E2.8.1	Labour	\$5.00 per unit
	<ul style="list-style-type: none"> ▪ Drill 12mm diameter hols through two members ▪ Insert bolt and tighten ▪ Clean up 	

<i>E2.8.2</i>	<i>Material costs</i>	<i>\$9.00 per unit</i>
<ul style="list-style-type: none"> Min. 200mm M12 bolt and 50x50x3mm galvanised washer 		

<i>E2.8.3</i>	<i>Total costs</i>	<i>\$14.00 per unit</i>
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E2.9 Bearer to Bearer

<i>E2.9.1</i>	<i>Labour</i>	<i>\$12.00 per unit</i>
<ul style="list-style-type: none"> Place nail plate in position and hammer down all prongs into the timber. Repeat for opposite side. Clean up 		

<i>E2.9.2</i>	<i>Material costs</i>	<i>\$12.00 per unit</i>
<ul style="list-style-type: none"> 2 / 190x116mm nail on plates or similar 		

<i>E2.9.3</i>	<i>Total costs</i>	<i>\$24.00 per unit</i>
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<i>E2.9.4</i>	<i>Image</i>
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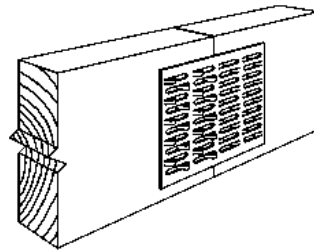


Figure E10 6kN Nail plate fixing (Source: Pryda New Zealand 2005)

E2.10 Ordinary Pile to Bearer - Version 1

The timber version of the connections requires a slightly different approach.

<i>E2.10.1</i>	<i>Labour</i>	<i>\$10.00 per unit</i>
<ul style="list-style-type: none"> Fix 2 / Z nails either side of joist to Bearer, one each side Fix 2 / 100x3.75mm galvanised nails from Joist to Bearer. Clean up 		

<i>E2.10.2</i>	<i>Material costs</i>	<i>\$2.00 per unit</i>
<ul style="list-style-type: none"> 2 / Z or U nails 2 / 100x3.75mm galvanised nails 		

<i>E2.10.3</i>	<i>Total costs</i>	<i>\$12.00 per unit</i>
<i>E2.10.4</i>	<i>Image</i>	

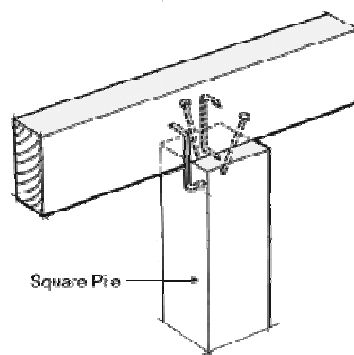


Figure E11 Ordinary pile to Bearer fixing for Timber pile (Source: Pryda New Zealand 2005)

E2.11 Ordinary Pile to Bearer - Version 2

The second version is a connection from concrete to a timber Bearer

<i>E2.11.1</i>	<i>Labour</i>	<i>\$7.50 per unit</i>
	<ul style="list-style-type: none"> Place 4mm galvanised wire through [existing] hole in concrete pile and wrap over top of Bearer. Staple 2 / 20mm staples over ends of wire Fold ends of wire back over each staple and staple again Clean up 	
<i>E2.11.2</i>	<i>Material costs</i>	<i>\$2.00 per unit</i>
	<ul style="list-style-type: none"> 500mm 4mm galvanised wire 4 20mm galvanised staples 	
<i>E2.11.3</i>	<i>Total costs</i>	<i>\$9.50 per unit</i>
<i>E2.11.4</i>	<i>Image</i>	

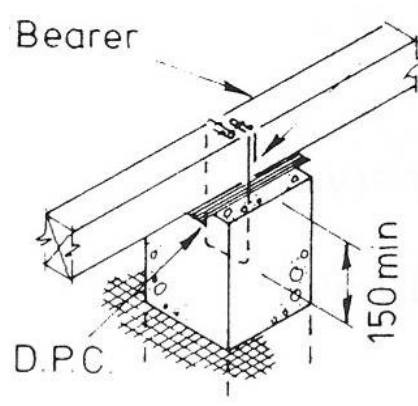


Figure E12 Ordinary pile to Bearer fixing for Concrete pile (Courtesy: Standards New Zealand 1990)

E3.1 Ventilation

The remedy for ventilation is the cost of forming new holes in timber sheeting foundation sub-floor walls, and fitting an appropriate steels grill, approximately 50x70mm opening per sqm of dwelling area. The total costs are per unit installed.

<i>E3.1.1</i>	<i>Labour</i>	<i>\$17.00 per unit</i>
	<ul style="list-style-type: none"> ▪ Cut new rectangular hole in timber exterior sheeting. At least 50x70mm. ▪ Fit ventilation grill with appropriate fixings. ▪ <i>Repeat if required for other points around the foundation.</i> ▪ Clean up 	
<i>E3.1.2</i>	<i>Material costs</i>	<i>\$3.50 per unit</i>
	<ul style="list-style-type: none"> ▪ Standard ventilation grill and fixings. Minimum 50x70mm 	
<i>E3.1.3</i>	<i>Total costs</i>	<i>\$20.50 per installation of unit</i>

E3.2 Polythene Sheeting

Polythene sheeting [**usually in strips in roll format**] is laid in strips over the ground with no gaps and lapped at joints. All edges should be folded up at foundation walls. This stops rising moisture in the foundation and can be an alternative to ventilation. The polythene only requires to be weighted down with stones or other heavy objects around the edges and at corners

<i>E3.2.1</i>	<i>Labour</i>	<i>\$4.60 per m²</i>
	<ul style="list-style-type: none"> ▪ Lay strips of polythene sheeting in strips ▪ Cut around piles and other objects for total coverage ▪ <i>Repeat until foundation is covered completely</i> ▪ Weight corners and other intermediate points ▪ Clean up 	
<i>E3.2.2</i>	<i>Material costs</i>	<i>\$0.75 per m²</i>
	<ul style="list-style-type: none"> ▪ Polythene sheeting in rolls at a standard width [usually 2m] ▪ Stones or other found objects around site. 	
<i>E3.2.3</i>	<i>Total costs</i>	<i>\$5.35 per m²</i>

E3.3 Soil Clearance

The clearance of soil from under Bearers and joists can be calculated on a per cubic metre of soil removed. The maximum removal of soil will be

enough to crawl through. The minimum around Bearers is 150mm [as stated in NZS3604:1999]

<i>E3.3.1</i>	<i>Labour</i>	<i>\$175.00 per m³ removed</i>
	<ul style="list-style-type: none"> ▪ Remove soil around Bearers to a minimum level of 150mm ▪ [Hand excavation is probably necessary] ▪ <i>Repeat until all Bearers and foundation structure is uncovered completely</i> ▪ Remove soil from onsite 	

<i>E3.3.2</i>	<i>Material costs</i>	<i>\$0.00</i>
	No cost for materials	

<i>E3.3.3</i>	<i>Total costs</i>	<i>\$175.00 per m³ removed</i>
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E3.4 Soil Infill

The infill of concrete into places where excavation has occurred, requires infilling for the purposes of reinstating the structural integrity of the soil in the foundation. This shall be calculated on a per cubic metre basis.

<i>E3.4.1</i>	<i>Labour</i>	<i>\$75.00 per m³ infill</i>
	<ul style="list-style-type: none"> ▪ Mix concrete ▪ Fill holes with concrete [on cubic metre basis] ▪ [will only be possible where standing labour is possible] ▪ <i>Repeat until all holes and trenches are filled</i> 	

<i>E3.4.2</i>	<i>Material costs</i>	<i>\$210.00 per m³</i>
	<ul style="list-style-type: none"> ▪ Aggregate ▪ Cement 	

<i>E3.4.3</i>	<i>Total costs</i>	<i>\$285.00 per m³</i>
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Appendix F. _____ The Observed Onsite Anomalies

Appendix F1_____ *The Onsite Construction Anomalies*

The defects shown describe situations where the construction differs from what is stated in the current [and most historical] editions of NZS3604. In most cases the detail is the fault of a contractor or is the product of miscalculations. The entire appendix describes different connections and elements.

Fl.1 *Discontinuous Horizontal Elements*

The connection between joists is not quite adequate to reach the Bearer and is wedged into place with a timber wedge.



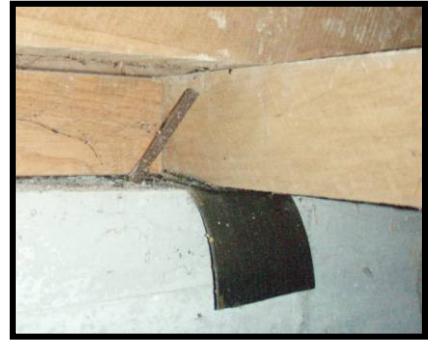
The split level in this 1950's renovated dwelling has a drop of 400mm and rusted connections between elements.



The reinforcing bar extending from the foundation wall to the wall plate has been set in the wrong place and nailed to the side of the plate



A similar connection between the bearer and foundation wall shows the reinforcing bar missing the bearer end. Under lateral movement this bearer end could potentially move from the foundation.



The Bearer to Bearer connection in this 1970's dwelling, describes a notched discontinuous Bearer secured with wire and nails. This detail is replicated over every Bearer to pile span. Note the curve of each side describing that the Bearer is under significant load.



The Bearer to Bearer connection here shows a significant gap between members. The bearing of the Bearer on the left side indicates that this end could slip off the pile under lateral movement.



Another Bearer to Bearer connection showing one side secured appropriately to the pile below. The other side of the Bearer shows no connection to the pile.



This image shows the repiling methods and makeshift Bearers to support the floor. This occurred a number of times throughout the foundation. Note the significant bending the timber member is under.



The Bearer here is notched over the pile in order to make the correct level for the joists. Although this may have been simpler initially, the strength over this notch could limit the Bearer strength.



A similar issue has occurred when installing pipe work in this 1920's cottage. The joist has been cut to at least half the size and allows the easy penetration of moisture through the cut section.

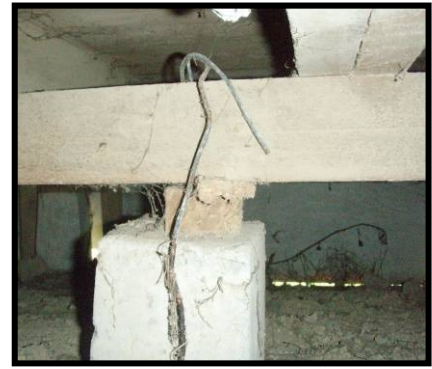


Fl.2 _____ ***Discontinuous Vertical Elements***

The connection between the pile and the Bearer has pulled through the staple, possibly from previous lateral movement. This enforces the need to wrap the wire over the staples.



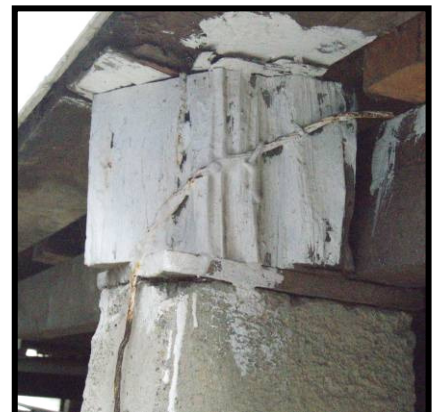
This connection, possibly a repiling, has the 4mm wire, however forgets to include the staples in the connection.



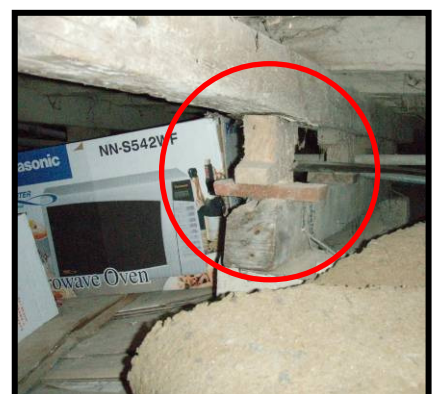
The connection here simply neglects all connections all together. The member laid on its short edge has the potential to roll off under lateral loading.



The connection here, typically seen in an Internally Piled Foundation has been repiled and kept the pile top under the load bearing exterior wall. Note the white paint to abate further rusting.



Excessive packing is evident in this image after the dwelling has been repiled. All of the elements lack any connection with each other and will simply keep the floor level until future movement occurs.



Excessive packing shown here will exhibit similar problems as before. Note this dwelling has also been repiled.



Bricks and other site debris are common packers between piles and Bearers, however they are also used to make certain sections of the floor level with each other.

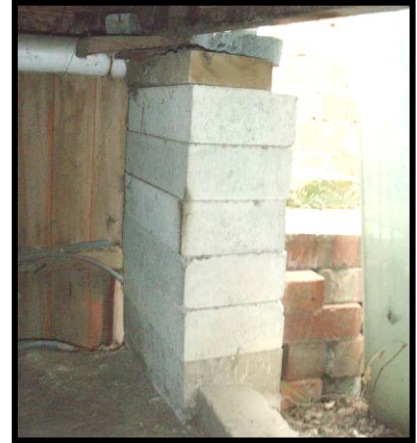


Appendix F2 _____ The Observed Overall Condition defects

The order of this appendix relates to the general condition section. See Chapter 10

F2.1 _____ *Piles*

The pile seen here is fabricated from small concrete slabs laid on top of each other and packed at the top. Although the foundation of this block is satisfactory, the method of jointing and lack of reinforcing may cause issues under lateral loading.



The non vertical piles are possibly too large for the application and have thus been set into the ground skewed. The dwelling was extremely low to the ground and this piling was installed during a 1980's repiling.



The pile seen here has most probably been used before in construction. The old footing now sits at least 200mm above the soil. No indication is given to the original height of the pile, however the old footing probably makes up a significant proportion of the depth in the new footing.



The pile shown here is on a load bearing wall and was not replaced during repiling of the dwelling. Subsequently the bottom has rotted and the soil eroded away leaving the pile stump hanging in the air. This was seen in a 1920's dwelling.



The undermining seen here has the potential to cause collapse. The soil in this dwelling has been pulled away to allow for expansion in the lower of the dwelling. This is a common issue where homeowners want to expand their dwellings.



F2.2

Fixings

The rusted R10 bar fixing exploded with rust shows that in some circumstances the DPC is not enough to abate moisture penetration and serious degradation of fixings. Note also the serious water staining on the timber and building paper behind.

This connection was in a 1970's dwelling.




Excessive white rusting on proprietary engineered angle bracket. Although the rusting is at the sides the corrosion will continue into the centre and to the fixings. This may be a result of excessive airborne moisture as the fixing was at least 1m from any soil and at the top of a 2m square H5 pile. This fixing was in a 1990's dwelling.



A close-up photograph of a wall with a wood-grain pattern. A red circle highlights a small, rectangular, textured object, possibly a piece of tape or a small plaque, attached to the wall. The object has a mottled, brownish appearance. Below the highlighted area, there is a small, white, rectangular object, possibly a piece of paper or a small plaque, also attached to the wall.

A close-up photograph of a light-colored wooden beam. A vertical crack runs through the center of the beam. Two circular knots are visible on the beam's surface, one above and one below the crack. The beam is supported by a wooden post below it.



A close-up photograph of a wire electrode assembly. A red circle highlights the contact area between the electrode and the sample, showing a small, dark, irregular spot on the electrode tip.

The transition between old and new sections of the dwelling can cause issues. The added foundation is sometimes not fixed to the older section. In this particular image the Bearers and joists also swap direction at the threshold. This issue can cause the different parts to resonate at different frequencies under lateral loading almost always resulting in a split between old and new.



This concrete foundation wall [part of an addition] has been poured over timber boxing to leave a hole where solid concrete should be. The dwelling was built in the 1960's with additions made in the 1980's.



The foundation wall in this image has been poorly constructed and shows signs of poor vibration, and poor placement of reinforcing. The reinforcing bar is subsequently exposed and has the potential to rust and crack the foundation. This was seen in a 1970's dwelling.



The movement of this dwelling against the surrounding pathways has caused cracking between the foundation and the superstructure. If not remedied water could enter causing structural issues.

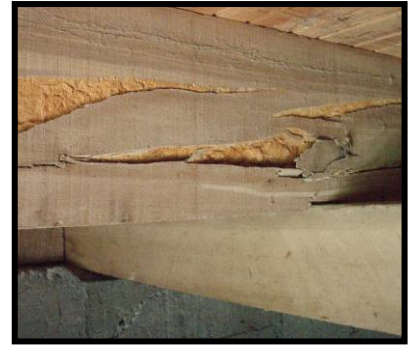


F2.4 ***Timber Defects***

The timber shown here depicts the remains of the timber wall plate and the jackstud after a number of years surrounded by running water and moist conditions. The gully traps was overflowing with too many pipes and was overgrown with moss. The water was running into the foundation causing serious decay of the 1970's foundation.



The joist here shows a serious check in the side splitting the exterior surface of the member. This may have the potential to cause significant loss of shear strength in the joist. This was seen in a 1960's dwelling.



The check split in the timber runs the length of the Bearer in this 1980's Statehouse. This also has the potential to limit the shear strength capacity of the timber. Also note the inventive use of excess fibreboard for Bearer packing purposes.



The cut seen in this 1910's villa is most probably the product of many renovations and service intrusions. The cut in the Bearer will significantly limit the Bearer bending strength and has the potential to split at the cut under loading.



Typical rotting in foundation timbers, however this describes what happens when no DPC is present allowing water to seep into the timber.



This water mark is common where timber meets concrete piles, especially if no DPC is present. The water can exacerbate corrosion in fixings and rot timber from the interior. This issues is common to many dwellings of all ages, this one from before 1900.



F2.5

Soil Condition

The soil seen in this image is soft and loose after repiling. The polystyrene is seen scattered over the ground. Water under the foundation ponds in the loose powdery soil and cannot escape.



The soil wall seen in this image is semi soild 1.4m clay self retaining wall. The piles and foundation structure is within 600mm from the wall. This digging was undertaken on the 1970's dwelling in order to add a flat downstairs but was never completed.



F2.5

Ventilation

The ventilation here is blocked by a concrete path and vegetation growing around the edge. The sub-floor space was extremely damp to touch and musty due to poor ventilation. The water runoff from the concrete most probably ran into the sub-floor space



The recently installed ventilation opening for small grill is poorly made and is not adequate for the entire space.



Sub-floor dumping leads to lack of ventilation circulation and can cause other issues, including mould growth, timber decay and metal corrosion.



F2.6

Services

The services running from all parts of the dwelling come to one single gulley trap. All connections are cemented in to avoid the blocked gulley trap from overflowing into the foundation. This was the cause of the serious decay seen in the timber defects section.



The runoff from a broken pipe has caused the building paper to rot and disintegrate. Although the paper exists to stop moisture, excessive water can cause it to fail. This was observed in a 1990's dwelling.



The broken services pipe in this 1970's rented dwelling has caused the ground and other surrounding elements to grow fungi.



The contractor introducing piping into this 1900's villa has used the existing wiring to hold up the pipe work.



A broken water pipe spraying water onto sub-floor fraing has caused this 1970's dwelling to have saturated timber, destroyed connections, and has caused the building paper to disintegrate and cause the growth of fungi. This issue has likely existed for months and will have caused moisture issues in living areas.



A more common sight in retrofitted dwellings is the integration of a mechanical heating or ventilation system. These systems block sub-floor circulation with bulky tubes and machinery. This example shows the destruction of bracing elements to make the path for the ducting.



Water pipe leaking has caused the particle board to swell and turn mushy. Prolonged periods of water spray can destroy the integrity of such timber sheeting products.



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