PREVALENCE OF NEW ZEALAND'S UNREINFORCED MASONRY BUILDINGS

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SUMMARY

Unreinforced masonry (URM) buildings remain New Zealand's most earthquake prone class of building. New Zealand URM buildings are classified into typologies, based on their general structural configuration. Seven typologies are presented, and their relative prevalence, age and locations are identified.

There are estimated to be 3,750 URM buildings in existence in New Zealand, with 1,300 (35%) being estimated to be potentially earthquake prone and 2010 (52%) to be potentially earthquake risk, using the NZSEE Initial Evaluation Procedure. Trends in the age of these buildings show that construction activity increased from the early days of European settlement and reached a peak at about 1930, before subsequently declining sharply. The preponderance of the existing URM building stock was constructed prior to 1940, and as such, almost all URM buildings in New Zealand are between 80 and 130 years old (in 2010). Overall the URM building stock has a 2010 market value of approximately $NZ1.5 billion, and constitutes approximately 8% of the total building stock in terms of floor area.

Details are also provided regarding the development of New Zealand building codes and the associated provisions for assessing existing earthquake risk buildings, and provides some background to the history of the URM building stock in New Zealand.

HISTORY OF NEW ZEALAND URM

New Zealand's masonry construction heritage is comparatively young, spanning from 1833 until the present time – a period of less than 200 years. Consequently, a study of New Zealand's masonry building stock has a narrow scope in comparison with international norms (see for instance [1-3]). This comparatively narrow time period has the advantage of facilitating the documentation and reporting of New Zealand unreinforced masonry construction practice with a greater degree of accuracy than is often possible in countries with an older and more diverse history of masonry construction [4].

The Early Settlers

The first inhabitants of Aotearoa New Zealand were groups of Polynesian explorers who discovered and settled the islands in the period A.D. 800-1000 [5]. These people mostly did not develop a tradition of building in masonry, but instead built using timber, earth and most commonly raupo (bulrush). There are however, numerous stone-related archaeological sites in New Zealand attributed to Maori society, the majority of which are gardening walls or associated with fortifications. Examples of Maori construction are shown in Figure 1 and Figure 2.

Captain James Cook anchored off the coast of New Zealand on 9 October 1769. This event was followed by a gradual haphazard increase in the population of Europeans in New Zealand over the next 70 years, initially primarily associated with whaling, but also involving kauri timber extraction and gold mining. Jacobs [6] reports that the European population of New Zealand in 1830 was probably a little more than 300. By 1839 the number had risen to possibly 2000, and at the beginning of the 1850s there was 26,000 Europeans in New Zealand. These first European settlers found themselves without their familiar building materials, so initially emulated the style and construction of Maori dwellings [7]. For the most significant early buildings, such as churches and assembly buildings, architects from Australia or England were commissioned.

Captain William Hobson's arrival in Auckland in 1840 as the First Governor General of New Zealand marked the beginning of New Zealand as a British colony. Auckland's first years were modest, with the city providing the chief port of call for sailing ships in the Pacific Ocean, and providing the garrison for British troops and navy during the 1860s that were present due to tensions between Maori and Pakeha (European New Zealanders) over land ownership. The presence of the troops brought money to the city. However gold mining was eventually to provide greater prosperity for Auckland, with gold rushes in nearby Thames and the Coromandel [8].

Construction of this period was primarily of timber for residential and small commercial buildings (see Figure 3 and Figure 4), but masonry buildings did begin to appear close to the harbour (see Figure 5 and Figure 6). Oliver [9] reports that clay bricks were first manufactured in Auckland in 1852, with production of about 5,000 bricks per day. Timber was in plentiful supply and indeed it was not uncommon to just burn the timber where it stood rather than mill it, so it was only natural that outside the central city nearly all buildings were constructed of timber. By 1886 timber was being felled nationwide at the rate of several million feet a year, with

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timber extraction being the country's leading industry. Even within Auckland central city the construction of timber buildings was not restricted until the City of Auckland Building Act of 1856. A fire in central Auckland in 1858 provided further impetus for the transition from timber to clay brick masonry construction.

The lack of durable local building stone meant that the great majority of city buildings were constructed of clay brick with a stucco finish. Figure 7 and Figure 8 illustrate typical construction scenes (although dated from a slightly later period). In other parts of New Zealand there was a more plentiful supply of natural stone, with New Zealand's earliest masonry building having been constructed of stone in 1833 (see Figure 9). Figure 10 shows an example of early rural construction in parts of New Zealand were timber was scarce and natural stone was the primary construction material.

Evident in several of the above figures is a predisposition to emulate 'mother country' British architecture. To some extent this was due to the fact that there were very few architects in New Zealand prior to 1880, with buildings such as the 1865 Bank of New Zealand, the 1888 Auckland City Art Gallery and the 1911 Auckland Town Hall, all being designed by Melbourne based architects [10]. Figure 11 shows Auckland at a time where the majority of buildings were of timber, but a number of masonry buildings were becoming prominent. However Figure 12 shows that not all masonry buildings were well constructed. Hodgson [11] reports that inferior materials and uncertain ground conditions were not uncommon in building projects of this period. Hodgson also reports that the city went through a transformation during the 1870s when almost all timber buildings were replaced by masonry buildings, and Figure 13 and Figure 14 show that by 1910 the central city was composed almost entirely of unreinforced masonry buildings. Stacpoole and Beaven [12] have similarly reported that Auckland's early wooden buildings dating from the 1840s were badly in need of replacement by the 1860s.

Wairarapa and Murchison Earthquakes

The Wairarapa Earthquake occurred on Tuesday 23 January 1855 and had an estimated magnitude of M8.2 [13]. It is the largest earthquake to have occurred in New Zealand since the time of systematic European colonisation (see [14] for a catalogue of major New Zealand earthquakes from 1901-1993). The shock was felt across almost the entire country, was highly destructive in Wellington, and also caused severe damage in Whanganui and Kaikoura. Between seven and nine people were killed in the earthquake, and five others sustained injuries that required hospitalisation.

The M7.8 earthquake that struck Murchison on the 17th of June 1929 was felt throughout New Zealand [15]. Fortunately, the most intense shaking occurred in a mountainous and densely wooded area that was sparsely populated. Casualties were therefore comparatively light and the damage was mostly confined to the surrounding landscape, where the shaking triggered extensive landslides over thousands of square kilometres. Nonetheless, the shock impacted with damaging intensities as far away as Greymouth, Cape Farewell and Nelson (see Figure 15 and Figure 16). Fifteen people were killed in the Murchison Earthquake.

The 1931 Hawke's Bay Earthquake

As reported above, it was the combustibility of timber buildings that prompted the focus in Auckland towards building in clay brick unreinforced masonry, and occasionally in stone masonry. Early earthquakes in the Wellington region resulted in a slower adoption of masonry construction. This caution proved to be well justified. On the morning of 3 February 1931 the Hawke's Bay region of the eastern North Island was struck by an M7.8 earthquake that destroyed much of the city of Napier (see Figure 17 to Figure 20). Fires swept through the wreckage, destroying much of what was left. Eight nurses died when the reinforced concrete Napier nurses home collapsed, and perhaps the largest brick masonry building to collapse was the Napier Anglican Cathedral (see Figure 21 and Figure 22). The shaking resulted in damage from Taupo to Wellington, and left 30,000 people homeless (see Figure 23 and Figure 24). The official death toll was 256, and the event remains the worst disaster of any type to occur on New Zealand soil [16, 17].

NEW ZEALAND URM BUILDING STOCK

In order to ascertain the structural seismic response of both individual URM buildings and the aggregated URM building stock, it was recognised that several key attributes of these building required characterisation. Within the characterisation of URM buildings, the broadest and most important classification is that of the overall building configuration. The seismic performance of a URM building depends on its general size and shape, as a small, low-rise, square building will behave differently when subjected to seismic forces than a long, row-type, multi-storey building. In addition to this, retrofit interventions which may be appropriate for one type of building may not be appropriate for another, different, type of building [18]. While it is not envisaged that a "one size fits all" approach is viable for all URM buildings, for initial seismic assessments and vulnerability analyses, classification of buildings into typologies is a useful and necessary exercise. This also enables a broad understanding of the financial and economic factors associated with seismic assessment and improvement of potentially earthquake-prone buildings.

The word typology is used as a classification according to a general type, and in the sphere of architectural characterisation different groupings of buildings can be classified according to common features or elements. Numerous researchers have utilised the concept of classifying buildings according to typology for the purpose of seismic vulnerability assessment (see for example [4, 19, 20]). Tonks *et al.* [21] began a preliminary identification of building typologies in New Zealand, based on those identified in Italy by Binda [4]. Three typologies were identified, differing from those identified in Italy because of age and materials:

- Stand alone isolated secular or religious buildings and chimneys;
- Row residential buildings;
- Row commercial and retail buildings.

It has since been identified that the New Zealand building stock warrants seven typologies, which are outlined in Table 1, and photographic examples are given in Figure 25. Buildings are separated according to storey height, and whether they are isolated, stand-alone buildings or a row building made up of multiple residences joined together in the same overall structure. A suggestion for the expected importance level of the structure is also given, according to AS/NZS 1170.0:2002 [22]. All identified URM buildings fall into importance level 2 or higher, with medium to high consequences for loss of human life. Within the identified typologies, further distinctions can be made. For example, Type A buildings can be divided into those which have a dividing wall down the centre (Type A1), and those which do not (Type A2). Type G buildings are generally monumental structures and those which do not fit easily into the other categories. Usually for such structures unique detailing is encountered, and unique analyses are necessary. Nevertheless there are useful sub-classifications which can also be made within this grouping.

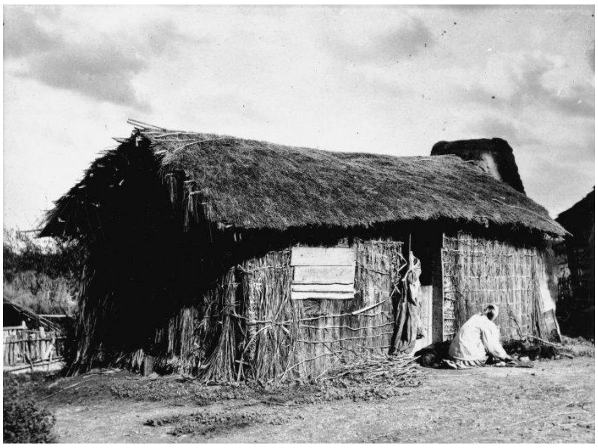


Figure 1: ***Raupo whare (house) at Wairau Pa, ca. 1880 [Alexander Turnbull Library].***

Figure 2: ***Raupo whare at Karaka Bay, Wellington, ca. 1895 [Alexander Turnbull Library].***

Figure 3: ***Shops on Queen Street, Auckland, 1859 [Alexander Turnbull Library].***

Figure 4: ***1866 view of the east side of Queen Street, Auckland, looking north [Alexander Turnbull Library].***

Figure 5: ***1866 View of the lower end, west side, of Queen Street, Auckland [Alexander Turnbull Library].***

Figure 6: ***Queen Street and Queen Street Wharf, Auckland, 1882 [Alexander Turnbull Library].***

Figure 7: *Group photograph of the construction workers, including bricklayers, that built the Stratford Public Hospital during 1906-1907 [Alexander Turnbull Library].*

Figure 8: *Brick building under construction, ca. 1920 [Alexander Turnbull Library].*

Figure 9: *The 1833 Stone Store at Kerikeri was built by the Church Missionary Society [Alexander Turnbull Library].*

Figure 10: *Two Chinese miners in front of a stone cottage in central Otago, ca. 1860 [Alexander Turnbull Library].*

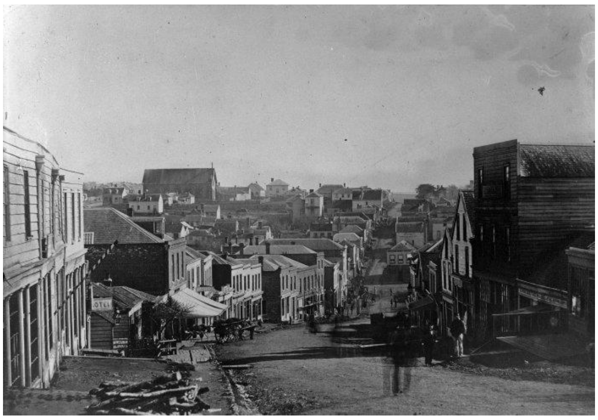


Figure 11: *Looking down Shortland Crescent, Auckland, ca. 1865. Construction is a mix of timber, brick masonry and stone masonry [Alexander Turnbull Library].*

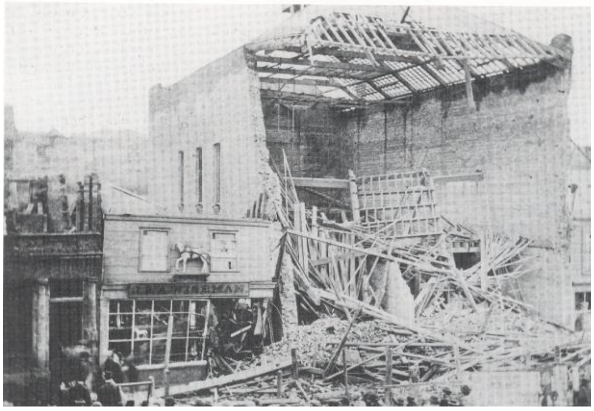


Figure 12: *Collapse of a new masonry auction market building, Queen Street, 1865 [Alexander Turnbull Library].*

Figure 13: *Looking along a row of commercial buildings on Queen Street, Auckland, ca. 1910 [Alexander Turnbull Library].*

Figure 14: *Lorne Street, Auckland, ca. 1910 [Price Collection, Alexander Turnbull Library].*

Figure 15: *General store damaged by the 1929 Murchison earthquake [Alexander Turnbull Library].*

Figure 16: *Damaged business premises after the earthquake of 17 June 1929 [Alexander Turnbull Library].*

Figure 17: *Overlooking Napier City, ca. 1900 [Alexander Turnbull Library].*

Figure 18: *Overlooking Napier at the buildings ruined by the 1931 earthquake and the fires [Alexander Turnbull Library].*

Figure 19: ***Hastings Street, Napier, ca. 1914 [Alexander Turnbull Library].***

Figure 20: ***View down Hastings Street, Napier after the earthquake 1931 [Alexander Turnbull Library].***

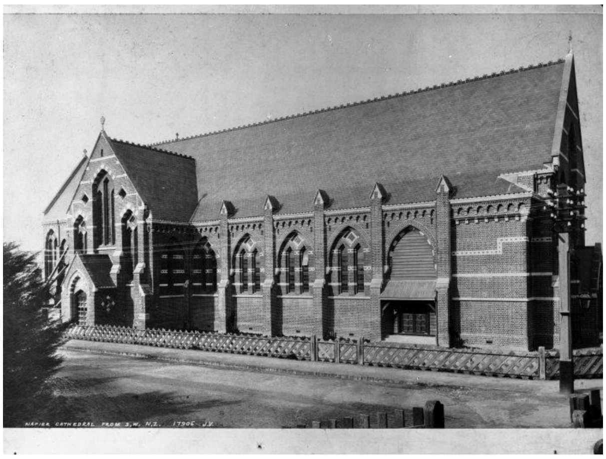


Figure 21: ***St John's Anglican Cathedral in Napier, ca. 1885 [Alexander Turnbull Library].***

Figure 22: ***Ruins of the Napier Anglican Cathedral after the 1931 Napier Earthquake [Alexander Turnbull Library].***

Figure 23: ***Aerial view of Napier after the 1931 earthquake, showing the refugee camp at Nelson Park in the centre [Alexander Turnbull Library].***

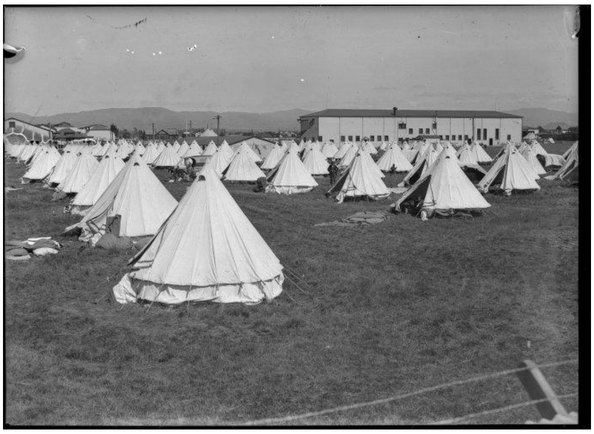


Figure 24: ***Rows of pitched tents in a field at a relief camp in Palmerston North for victims of the 1931 Hawke's Bay earthquake [Alexander Turnbull Library].***

Typology A building – one storey isolated.

Typology B building – one storey row.

Typology C building – two storey isolated.

Typology D building – two storey row.

Typology E building – three+ storey isolated.

Typology F building – three+ storey row.

Typology G building – religious.

Typology G building – institutional.

Figure 25: Photographic examples of New Zealand URM typologies.

Table 1: New Zealand URM typologies

Type	Description	Importance level (from NZS 1170.0)	Details
A	One storey, isolated	2, 4	One storey URM buildings. Examples include convenience stores in suburban areas, and small offices in a rural town.
B	One storey, row	2, 4	One storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in main commercial districts, especially along the main street in a small town.
C	Two storey, isolated	2, 4	Two storey URM buildings, often with an open front. Examples include small cinemas, a professional office in a rural town and post offices.
D	Two storey, row	2, 4	Two storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in commercial districts.
E	Three+ storey, isolated	2, 4	Three + storey URM buildings, for example office buildings in older parts of Auckland and Wellington.
F	Three+ storey, row	2, 4	Three + storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in industrial districts, especially close to a port (or historic port).
G	Institutional, Religious, Industrial	2, 3, 4	Churches (with steeples, bell towers etc), water towers, chimneys, warehouses. Prevalent throughout New Zealand.

For example, Type G1 buildings are religious buildings and Type G2 are warehouses and factories with large tall sides and large open spaces inside. Further detail on each typology can be found in [23].

Parameters for Differentiating Typologies

Storey Height

URM building typologies are separated according to whether the buildings are one storey, two storey, or three or more storeys tall. While one and two storey buildings are approximately evenly distributed throughout the country, three and higher storey buildings are few in number and a single typology to classify all such buildings is sufficient. Buildings taller than three storeys are mainly located in the central business districts (CBD) of some of the largest cities, particularly Auckland, Wellington and Dunedin, as well as some port towns such as Timaru and Lyttleton in the South Island. Moreover, the difference in expected seismic behaviour between a three and four storey building is less significant than the difference between a one and two storey building, for example. This is particularly because three and higher storey buildings tend to be of masonry frame construction (on at least one face of the building, usually the front and back faces), in contrast to solid (with no window piercings) wall construction. As a broad generalisation, rocking of piers between windows and openings is the expected in-plane behaviour in masonry frames when subjected to lateral seismic forces [24], and diagonal shear failure is less likely. For walls without openings (or with small openings), and depending on the magnitude of axial load, the expected in-plane failure mode in an earthquake is likely to be either sliding shear failure, diagonal tension (shear) failure, or rocking of the wall itself.

Building Footprint

The second primary characteristic for separating buildings into typologies is the building footprint, which differentiates building based upon whether they are a stand-alone, isolated, (almost) square building, or a row building made up of multiple residences joined together with common walls. This differentiation accounts for Typologies A – F, whereas those buildings with a non-uniform ground footprint (for example, many URM churches) will fit into the Typology G classification. In row structures containing walls that are common between residences, pounding has the potential to cause collapse, especially when floor or ceiling diaphragms in adjacent residences are misaligned. Different heights for the lateral force transfer into the common wall can result in punching shear failure of the wall, or diaphragm detachment and collapse. The effects of pounding are greater in the presence of concrete floor diaphragms, compared with timber diaphragms. Conversely in the case of many residences of similar height within the building, the seismic resistance is greatly enhanced due to the increased stiffness in one direction. Essentially square buildings with well distributed walls generally have a greater torsional resistance than buildings with less evenly distributed lateral force resisting walls [18] and long row buildings have different torsional properties than isolated buildings. A significant difference between isolated and row buildings becomes evident at the time of upgrading the building. An isolated building usually contains few residences, perhaps two shops for example, or occasionally more. Row buildings may contain many residents, even ten or more. An isolated building is generally considered just that – a single building, whereas a row building, despite behaving in an earthquake as a single interconnected building, may be perceived as different buildings because it has multiple owners. It may be more difficult to perform remedial work on an entire row building at one time compared with retrofit of an isolated building. If retrofit interventions are implemented on only a part of a building, such an intervention may be ineffective.

NEW ZEALAND BUILDING POPULATION, DISTRIBUTION AND VULNERABILITY

For the purpose of understanding the scale and nature of the cumulative seismic risk posed by existing URM buildings in New Zealand it is useful to consider their prevalence and national distribution. Two independent methods with different primary data sources were used to estimate the number of URM buildings in existence throughout New Zealand in 2009. Data from Auckland City Council, Wellington City Council and Christchurch City Council, in conjunction with historic population data, were utilised to determine the distribution of URM buildings throughout the country and their associated construction dates. The purpose of the first procedure was to determine not only the aggregate number of URM buildings, but also an indication of their locations. The purpose of the

Table 2: Auckland City pre-1940 potentially earthquake prone buildings

	Pre-1900	1900-1910	1910-1920	1920-1930	1930-1940	Total	Percentage
URM	6	24	16	277	63	385	28.9%
Timber	3	21	16	341	90	417	35.3%
Brick infill	4	13	4	123	74	217	16.3%
Reinforced masonry	0	0	0	10	5	15	1.1%
Reinforced concrete	1	7	7	152	71	238	17.8%
Steel	0	0	0	5	3	8	0.6%
Total	15	65	45	907	304	1335	100%

second approach was to evaluate the financial value of existing URM buildings, using data provided from Quotable Value New Zealand Ltd (QV Ltd). This method also provided an estimate of the number of URM buildings. The validity of each approach was confirmed by their close agreement to determine the overall aggregate number of URM buildings in existence in New Zealand. The first method suggested that there are 3,880 URM buildings in New Zealand, while the second suggested that there are 3,590 URM buildings. Taking the mean of both values indicates that there are approximately 3,750 URM buildings in total existing in New Zealand in 2010.

Estimation of URM Population and Distribution

Several sources of data were utilised for estimating the number of URM buildings in existence throughout the country: the official population data of New Zealand between 1900 and 1940 [25], a survey of potentially earthquake prone commercial buildings in Auckland City, conducted by Auckland City Council in 2008 in conjunction with the authors, and data provided by Wellington City Council and Christchurch City Council.

In surveying potentially earthquake prone commercial buildings in Auckland City, a total of 1,335 buildings were identified to have been constructed before 1940. Although buildings with a construction date up to and including 2007 were surveyed, very few URM buildings were found to have been built in Auckland City after 1940. Therefore, only pre-1940 buildings were considered. Of the 1,335 buildings, 28.9% were URM, 35.3% were timber, 16.3% were comprised of reinforced concrete frame and brick infill, 1.1% were reinforced masonry, 17.8% were reinforced concrete frame or shear wall buildings and 0.6% were moment resisting steel or braced steel buildings. Using the associated construction date of each building the total sample was grouped according to decade. Pre-1900 was considered as a single grouping. Table 2 shows the number of buildings identified in the survey according to their construction date.

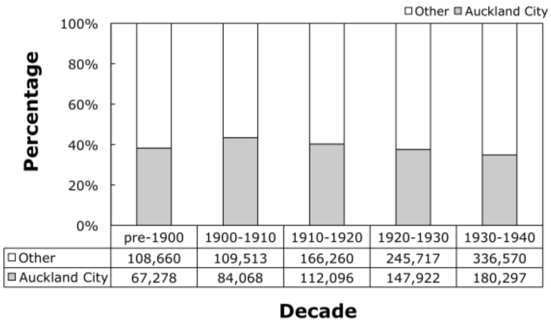


Figure 26: ***Proportion of population in the former Auckland Province living in the equivalent current Auckland City.***

In order to estimate the number of URM buildings in other parts of the country, the data from Auckland City Council were extrapolated using official population data. In the late 19th and early 20th Century, New Zealand was divided into the following provinces: Auckland, Taranaki, Hawkes Bay, Wellington, Marlborough, Nelson, Canterbury and Otago-and-Southland. Auckland Province was made up of the area of the North Island from Taupo and north (everywhere which currently celebrates Auckland Anniversary Day) [25]. Consequently, the area over which Auckland City Council has jurisdiction in 2009 is only a part of the former Auckland Province, and the current boundaries of this jurisdiction are equivalent to that of the Eden County up until 1940. This county historically included the boroughs of Auckland City, Mt Albert, Mt Eden, Newmarket, Parnell, Onehunga, Grey Lynn, One Tree Hill, and also Ellerslie Town District. The proportion of the population of the historic Auckland province which is made up by the current Auckland City was found using the population data from official New Zealand Year Books [25]. The average population of Auckland City and

Table 3: Population data and URM buildings for Auckland City and Auckland Province

	Pre-1900	1900-1910	1910-1920	1920-1930	1930-1940
Population of former Auckland Province	175,938	193,581	278,357	393,639	516,886
Population of equivalent current Auckland City	67,278	84,068	112,096	147,922	180,297
Proportion Auckland City/Province	38.2%	43.0%	41.1%	37.5%	35.2%
Actual current Auckland City URM buildings	6	24	16	277	63
Estimated current Auckland Province URM buildings	16	55	40	737	178
Estimated current URM buildings per 100,000 people	9.1	28.4	14.4	187.2	34.4

other parts of Auckland Province are shown in Figure 26.

Using the same proportional relationships shown in Figure 26, the number of currently existing URM buildings in the historic Auckland Province was estimated based on the number of currently existing URM buildings in Auckland City. For example, in the decade 1900–1910, Auckland City made up 43% of the population of Auckland Province. It is assumed that building prevalence was approximately proportional to population and that the rate of building demolition has been uniform throughout the former Auckland Province. There are 24 URM buildings identified from that decade now existing in Auckland City, and assuming these also make up 43% of the total number of buildings in the historic Auckland Province, then there are 55 existing URM buildings which were built between 1900 and 1910 in the whole of the equivalent Auckland Province today. Similarly, an indicative URM-buildings-per-capita ratio is determined. These data are summarised in Table 3, clearly showing that the majority of URM buildings were constructed in the decade 1920 – 1930.

In addition to the data provided from Auckland City Council and extrapolated to estimate the number of URM buildings in the historic Auckland Province, similar data were provided by Wellington City Council and Christchurch City Council. This enabled an assessment to be conducted of the prevalence of URM buildings in the historic Wellington Province and Canterbury Province respectively. The data were provided in a form which enabled a breakdown of construction dates in the same age brackets as for the Auckland Province. Based on official provincial populations of the time, the number of URM buildings currently remaining in the historic provinces of Taranaki, Marlborough, Nelson and Westland were also estimated assuming the same ratio of URM buildings per 100,000 people as in Auckland Province, as in the absence of specific data there is believed to be no evidence available to suggest that the ratio of URM buildings per 100,000 people in Auckland is not valid for these provinces. Based on evidence provided in [26], it was considered inappropriate to assume a similar buildings per capita ratio as in Auckland for the remaining provinces of Hawke’s Bay and Otago-and-Southland. When legislative guidance was introduced in 1968 [27] for assessing and upgrading earthquake prone buildings, Auckland and Wellington City Councils took a strong interest in strengthening URM buildings whilst Christchurch and Dunedin City Councils took a much more passive approach to implementing the legislation. Consequently, the rate of seismic retrofit and/or demolition and reconstruction in Auckland and Wellington was significantly different from that in Dunedin and Christchurch. Dunedin is the largest city in the former Otago-and-Southland Province and its rate of redevelopment was assumed to be characteristic of the whole province. Consequently, the number of buildings remaining in Otago-and-Southland was estimated using the buildings per 100,000 people ratio of Canterbury. The 1931 M7.1 earthquake in Hawke’s Bay destroyed a significant number of URM buildings in the Hawke’s Bay Province, especially in Napier. As a consequence of this and the resulting awareness of the vulnerability of URM buildings, the number of remaining buildings in Hawke’s Bay can be expected to be less than what would be estimated using the relationships outlined above. Nevertheless, there is no data available on the actual number of URM buildings in Hawke’s Bay, and because of this, the ratio of URM buildings per 100,000 people in Hawke’s Bay was estimated to be half that of Auckland’s. The estimated number of existing URM buildings in each province is shown in Table 4 and in Figure 27, and the construction date of URM buildings nationwide is shown in Figure 28, and are grouped according to the first year in each decade. This again shows that the majority of existing URM buildings nationwide derive from the decade 1920–1930.

It is acknowledged that the data presented here are useful primarily as an initial estimation only and may not accurately represent the number of URM buildings in other regions outside of Auckland, especially in smaller towns. The number of buildings from a particular decade in Auckland captures only those buildings which still exist, rather than all the buildings which were constructed in that time period, and the rate of demolition and redevelopment in Auckland City may

Table 4: Estimated provincial populations and number of URM buildings

Province		Pre-1900	1900-1910	1910-1920	1920-1930	1930-1940	Total
Auckland	Population	175,938	193,581	278,357	393,639	516,886	
	URM	16	55	40	737	178	1026
Taranaki	Population	34,486	45,973	48,546	63,273	76,968	
	URM	3	11	7	118	25	164
Hawke’s Bay	Population	37,139	46,906	51,569	65,037	77,652	
	URM	2	6	5	72	0	86
Wellington	Population	132,420	189,481	199,094	261,151	316,446	
	URM	27	127	169	243	111	677
Marlborough	Population	13,499	15,177	15,985	18,053	19,149	
	URM	1	3	2	27	6	47
Nelson	Population	33,142	45,493	48,463	49,153	59,481	
	URM	3	10	7	91	19	132
Westland	Population	15,042	15,194	15,714	14,655	18,676	
	URM	1	3	2	27	6	41
Canterbury	Population	145,058	166,257	173,443	206,462	234,399	
	URM	7	190	211	233	211	852
Otago and Southland	Population	174,664	156,668	191,130	206,835	224,069	
	URM	8	179	233	233	202	855
Total							3880

not be representative of the comparable rate in other parts of the country. Whereas in Auckland economic factors may have provided a stimulus for demolition of older URM buildings and development of newer structures, this may have not been the case in smaller towns. Smaller cities such as Wanganui, Timaru and Oamaru did not receive equivalent levels of investment and development in the 1960s and 1970s for economic reasons, and consequently many old buildings which would have otherwise been demolished in that time period still exist now [28]. Moreover, legislation governing the seismic performance of existing buildings may have resulted in different rates of development. For example, Blenheim is in a higher seismic zone (Z = 0.33) than New Plymouth (Z = 0.18) and if a building in Blenheim which was determined to be earthquake risk and subsequently demolished was instead situated in New Plymouth, because of the lower seismicity, it may have been found to not be earthquake risk. Finally, this is not an estimation of the number of earthquake prone buildings in New Zealand, apart from the inference that many URM buildings are likely to meet the criteria of being earthquake prone.

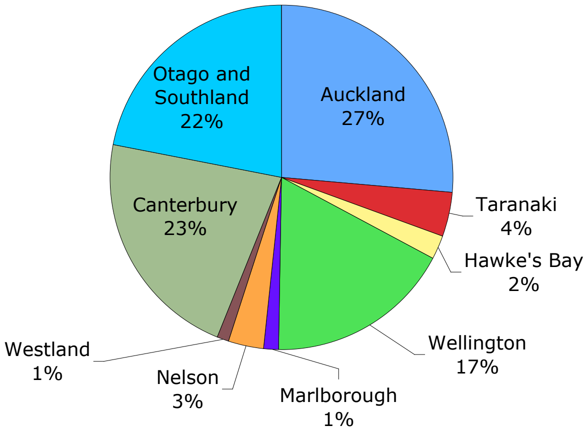


Figure 27: ***Estimated provincial populations of URM buildings.***

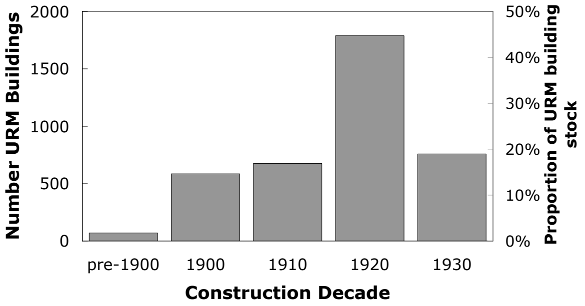


Figure 28: ***Construction decade of URM buildings in New Zealand.***

Estimation of URM Population and Value

In addition to the above estimate of the number of URM buildings in New Zealand, data on the New Zealand building stock were obtained from Property IQ, a part of Quotable Value Ltd (QV), which is a valuation and property information company in New Zealand. QV collects building information and conducts building valuations for rating purposes for most New Zealand Territorial Authorities. In the council valuation data, the building material and age (decade), among other data elements, is recorded. The building material refers to the wall cladding and is not a comment on the load carrying materials of the structure. It was assumed that no URM buildings were constructed in New Zealand after 1950 [12] and that buildings with a brick veneer but other materials for the load bearing parts of the structure (for example, timber frame buildings with a brick veneer) are recorded as "mixed materials" in the database. All entries for buildings constructed in New Zealand before 1950 and with "brick" recorded as the cladding description in the QV database were extracted. While it is acknowledged that a cladding description recorded as "brick" can include brick, brick veneer, adobe and rammed earth as the material type, it was considered that such an extraction of data would be a legitimate reflection of the URM building stock in New Zealand. The building data are recorded in three groupings as follows:

Table 5: Number of URM buildings from QV according to construction decade

Decade	URM Buildings
1870 – 1880	43
1880 – 1890	23
1890 – 1900	71
1900 – 1910	469
1910 – 1920	646
1920 – 1930	878
1930 – 1940	514
1940 – 1950	218
Mixed	726
Total	3590

Table 6: URM building stock according to storey height

Height	Number	Total Value	Average Value
1 storey	2526	$778,000,000	$308,000
2 storey	564	$256,000,000	$454,000
3 storey	163	$134,000,000	$822,000
4 storey	46	$54,000,000	$1,171,000
5+ storey	18	$20,000,000	$1,108,000
N/A	272	$259,000,000	$953,000
Total	3589	$1,501,000,000	

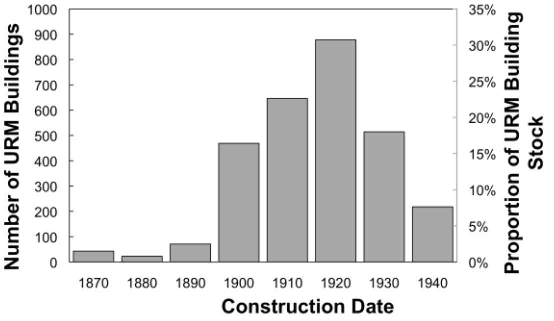
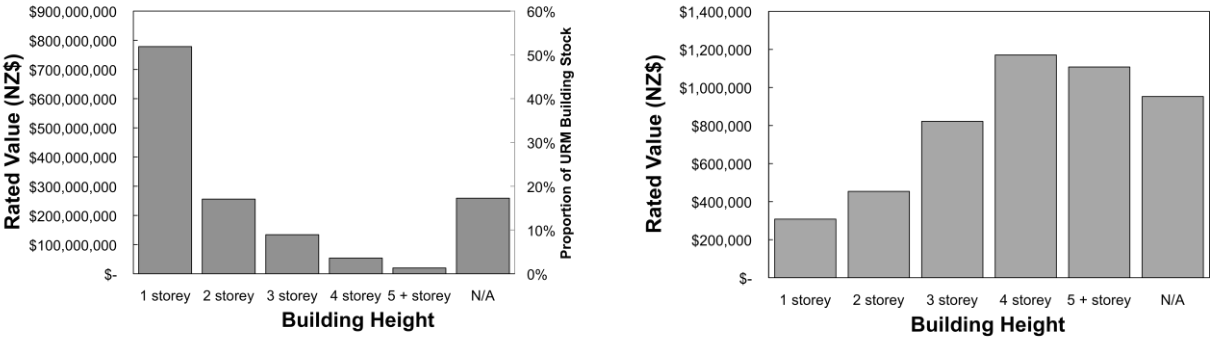


Figure 29: ***Number of URM buildings from QV according to construction decade.***



(a) Total value ***(b) Average value***

Figure 30: Valuation of URM building stock according to height.

- Separate buildings, which have a single age and a single rating valuation for the whole building.
- Parent/child entries, which are buildings with multiple ownership records. For example, a building with offices and apartments above will have one parent and multiple children for each use. In this case only the parent record was analysed.
- Orphans, which are records for buildings where the children of the parent structure are recorded but the territorial authority has stopped maintaining the parent record. In this case the orphans have the same roll and valuation number so can be grouped to determine the parent record.

These records were analysed according to construction date, building height and financial value. Table 5 shows the decade in which each URM building was built. Brick buildings with mixed age are entered on the QV database as pre-1950, but their exact age is indeterminate from the data recorded. The number of URM buildings with a confirmed construction date are shown in Figure 29, and are grouped according to the first year in each decade.

Figure 29 clearly shows a trend where the number of URM buildings initially increased until the end of the 1920s, and subsequently declined. This follows the increasing rate of European immigration and associated infrastructure development in New Zealand in the early 20th Century, until the 1931 M7.8 Hawke’s Bay earthquake, after which URM was no longer considered a favourable building material.

Table 6 summarises the number, total value and average value of URM buildings according to storey height. In the QV database the Building Floor Area and the Building Site Cover are recorded, and an estimate of the number of storeys can be obtained by dividing the Building Floor Area by the Building Site Cover, as the number of storeys is not directly recorded.

The Building Floor Area is the useable floor area and does not include the roof area. In some entries, either the Building Floor Area or the Building Site Cover is not recorded, and in this case the number of storeys is shown as N/A. It could not be determined from the data whether a structure was an isolated or row structure, so interrogation of the data according to the typologies presented above was not possible. It could be suggested that “parent” structures with multiple “children” may constitute a row structure with multiple occupancies inside the structure, but this only considers ownership of the structure and does not take into account the shape of the building footprint. It must also be noted that, using this definition, one storey buildings could not with certainty be classified as typology A or B, as outlined above.

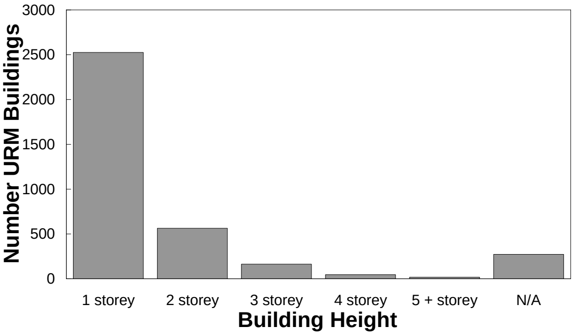


Figure 31: Number of URM buildings according to storey height.

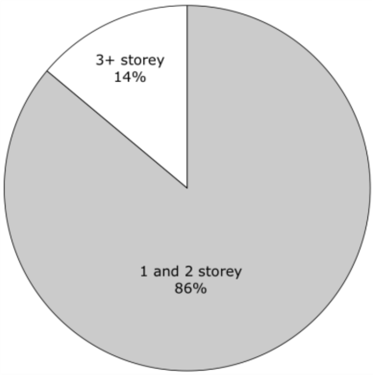


Figure 32: Number of "low rise" (1 and 2 storey) buildings as a proportion of all New Zealand URM buildings.

To put the New Zealand URM building stock in the context of the overall New Zealand building stock, the floor area provides a useful tool. A report prepared for the Department of Internal Affairs in 2002 [29, 30] showed that the total floor area of buildings in 32 cities and towns throughout New Zealand was approximately 27,200,000 m^2. The total floor area of URM buildings extracted from the QV database was approximately 2,100,000 m^2, suggesting that URM buildings make up approximately 8% of the total New Zealand commercial building stock in terms of floor area.

For all entries the Land Value and the Improvements Value are recorded. The value of the improvements refers to the value of any structure on the site, and is independent of the value of the land on which the building is situated. All data entries were revised between July 2005 and September 2008, and all buildings are valued in New Zealand Dollars (NZ$) as at the date of valuation.

The aggregate of the financial value and the average value of each building height are shown in Figure 30, and Figure 31 shows the number of URM buildings according to storey height. There was a small number of buildings where the number of storeys was estimated as 5 or 6, and these were grouped as 5+ storeys.

As shown in Table 6, New Zealand has in existence nearly 3,600 URM buildings, with a collective financial value (in 2009) of approximately NZ$1.5 billion. The majority of the URM building stock consists of one-storey buildings, with the caveat on how this was determined noted above. It is clear from Figure 30 that as the building height increases, the average value of the building also increases. Because the number of one-storey buildings is by far the greatest, the aggregate value of that building height is also the greatest, despite the comparatively low average value of each building. Thus it appears that the New Zealand URM building stock is largely made up of smaller, lower value buildings, and that in particular, the combination of one- and two-storey URM buildings constitutes 86% of the entire New Zealand URM building stock (see Figure 32). One-storey buildings make up 70% of all buildings, but only 51% of the total value of all URM buildings, and conversely buildings taller than one-storey make up only 30% of the number of buildings, but 49% of the value. The average value of the building should determine the investment associated with seismic assessment and retrofit, and thus it may be concluded that while there are comparatively fewer larger buildings, the investment associated with their seismic assessment and retrofit can be justifiably higher. Similarly, low-rise buildings may require simplified and repeatable assessment methods and retrofit interventions.

Finally, it must be recognised that many buildings have a worth greater than their financial valuation, including an architectural, historic or heritage value to the community, which can be difficult to quantify [31, 32].

Estimated Vulnerability of URM Buildings

Following determination of the number of URM buildings and their approximate regional distribution, the analysis can be extended to determine the expected vulnerability of the URM building population. As part of the NZSEE Guidelines “Assessment and Improvement of the Structural Performance of Buildings in Earthquakes” [33], an initial evaluation procedure (IEP) is provided as a coarse screening method for determining a building’s expected performance in an earthquake. The purpose of the IEP is to make an initial assessment of the performance of an existing building against the standard required for a new building, i.e., to determine the “Percentage New Building Standard” (%NBS). A %NBS of 33 or less means that the building is assessed as potentially earthquake prone in terms of the Building Act [34] and a more detailed evaluation will then typically be required. A %NBS of greater than 33 means that the building is regarded as outside the requirements of the Act, and no further action will be required by law, although it may still be considered as representing an unacceptable risk and seismic improvement may still be recommended (defined by NZSEE as potentially “earthquake risk”). A %NBS of 67 or greater means that the building is not considered to be a significant earthquake risk. NZSEE [33] notes that “A %NBS of 33 or less should only be taken as an indication that the building is potentially earthquake prone and a detailed assessment may well show that a higher level of performance is achievable. The slight skewing of the IEP towards conservatism should give confidence that a building assessed as having a %NBS greater than 33 by the IEP is unlikely to be shown, by later detailed assessment, to be earthquake prone” (see [33], chap. 3).

In collaboration with Auckland City Council during 2008, 58 buildings in Auckland City were assessed using the IEP. The %NBS of a building is determined by multiplying the “Performance Achievement Ratio” (PAR) (see [33] for details) by the Baseline $\%NBS_b$. For determining the $\%NBS_b$ for URM buildings, the following assumptions can reasonably be made in the context of the IEP (see [35]):

- The construction date is pre-1935
- The period $T \leq 0.4s$
- The ductility factor, $\mu = 1.5$
- Most URM buildings have an importance level 2
- “Very soft soils” can be excluded.

Taking these assumptions into account, the only factor in determining the $\%NBS_b$ which varies between provinces is the seismicity at the site where the building is located. This is determined by the Hazard Factor, Z, which for each province was evaluated by averaging the Hazard Factors from the locations in that province (see [36]). The PAR is a measure of an individual building’s expected performance, independent of location, and primarily takes into account critical structural weaknesses, such as plan and vertical irregularity and pounding potential. It was determined from the analysis of the 58 buildings that the distribution of PARs in the sample was approximately normally distributed with a mean ($\bar{x}$) of 1.6 and standard deviation (s) of 0.41. If it assumed that the PAR of all URM buildings in the country is also normally distributed, with the same mean and standard deviation as calculated for the sample population in Auckland City, the distribution of %NBS for all URM buildings in each former province in New Zealand can be estimated as follows,

$$s_{\%NBS} = \%NBS_b \times s_{PAR}$$
$$\bar{x}_{\%NBS} = \%NBS_b \times \bar{x}_{PAR}$$

For each province the Hazard Factor, $\%NBS_b$, and mean and standard deviation %NBS are shown in Table 7.

Applying the mean number of URM buildings estimated from both methods above (3,750 URM buildings in total) to the normal distribution of %NBS scores, an estimate of all the %NBS scores for each of the provinces can be evaluated, as shown in Figure 33. From Figure 33 the number of URM buildings in each province with an estimated %NBS below 33, between 33 and 67, and above 67 can be evaluated. Thus the number of URM buildings in each province which are

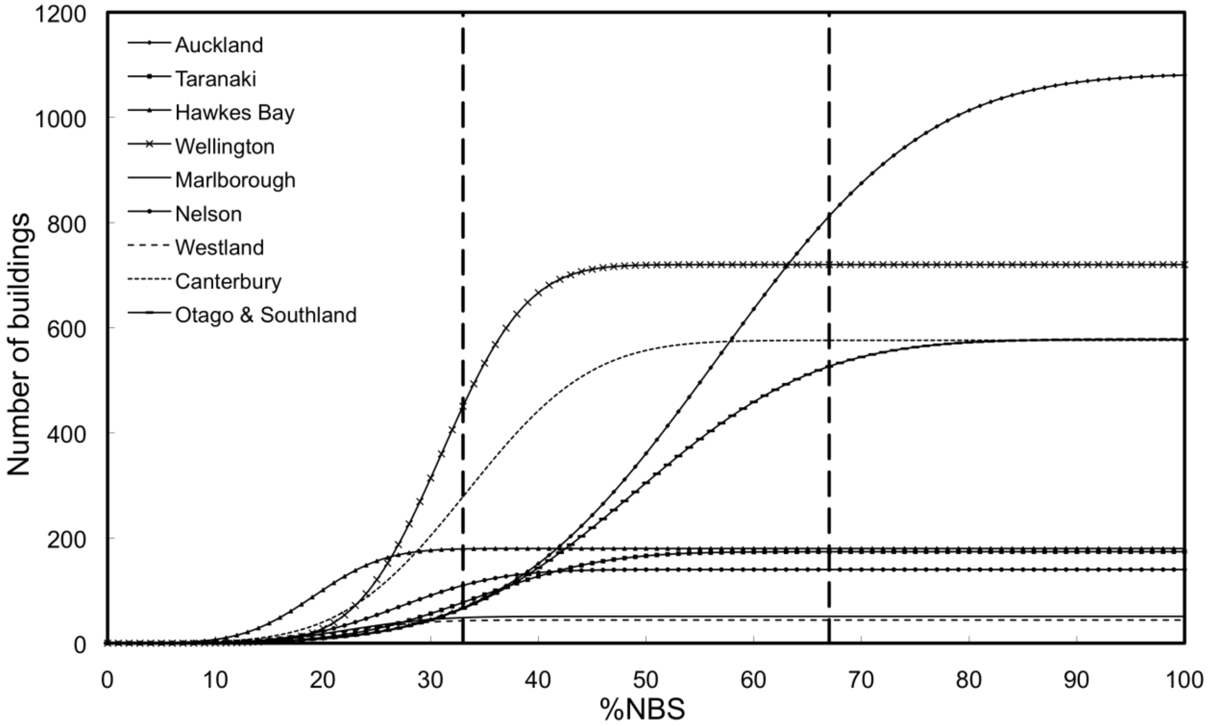


Figure 33: ***Estimated %NBS of URM buildings in Provinces throughout New Zealand.***

Table 7: Baseline %NBS$_b$ for provinces

Province	Z	%NBS$_b$	$\bar{x}_{(\%NBS)}$	$s_{(\%NBS)}$
Auckland	0.13	37.5	60.0	15.4
Taranaki	0.22	22.7	36.3	9.3
Hawke's Bay	0.39	12.7	20.3	5.2
Wellington	0.40	15.2	24.3	6.2
Marlborough	0.32	15.5	24.8	6.4
Nelson	0.27	18.0	28.8	7.4
Westland	0.34	14.5	23.2	5.9
Canterbury	0.22	22.1	35.4	9.1
Otago and Southland	0.15	32.5	52.0	13.3

potentially earthquake prone, potentially earthquake risk and unlikely to be significant, respectively, can be estimated. This is shown in Table 8 and aggregated to determine the estimated overall number of URM buildings in these categories throughout all New Zealand, as shown in Figure 34 and Figure 35. From these results (Figure 33 – Figure 35 and Table 8), it can be seen that up to 35% of URM buildings currently existing in New Zealand could be potentially earthquake prone, and additionally up to 52% could be potentially earthquake risk, such that approximately only 13% of existing URM buildings can be expected to not be a significant earthquake risk. Most of these buildings are in regions of higher seismicity, which is the most critical factor in the vulnerability of URM buildings. Bothara *et al.* [37] noted from assessments conducted in Wellington, that "most unreinforced masonry buildings have been confirmed as potentially earthquake prone." This statement is in agreement with the results presented here, in which 92% of URM buildings located in Wellington are estimated to be potentially earthquake prone.

Additionally, 52% of all New Zealand URM buildings are estimated as being not earthquake prone as defined by The Building Act 2004, but can be expected to perform at a level less than 67% of the standard of a new building. NZSEE recommends that buildings with < 67%NBS should be seriously considered for improvement of their structural seismic performance. Thus up to 87% of all URM buildings in New Zealand could require seismic improvement, according to the criteria set by NZSEE [33].

It must be recognised that the analysis presented here is essentially qualitative in nature and can be expected to overestimate the number of poorly performing URM buildings, primarily because of the conservative nature of the IEP. Nevertheless, as an informative estimate of the nature of the vulnerability of New Zealand's URM building stock, this analysis is considered robust. Additionally, this analysis does not take into account the number of buildings which have already been seismically improved, which Thornton [38] notes is not insignificant.

Table 8: Estimated number of potentially earthquake prone and earthquake risk URM buildings

Province	Potentially earthquake prone		Potentially earthquake risk		Unlikely to be significant risk	
Auckland	41	3%	628	31%	357	74%
Taranaki	59	4%	105	5%	0	0%
Hawke's Bay	85	6%	1	0%	0	0%
Wellington	622	45%	55	3%	0	0%
Marlborough	42	3%	5	0%	0	0%
Nelson	94	7%	37	2%	0	0%
Westland	39	3%	2	0%	0	0%
Canterbury	338	24%	513	26%	0	0%
Otago and Southland	66	5%	664	33%	126	26%
Total	1386	36%	2010	52%	483	12%

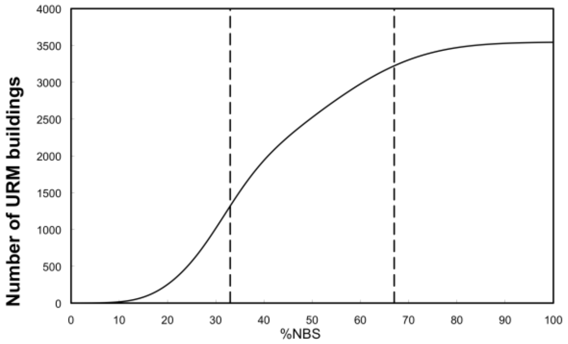


Figure 34: Estimated %NBS of URM buildings New Zealand.

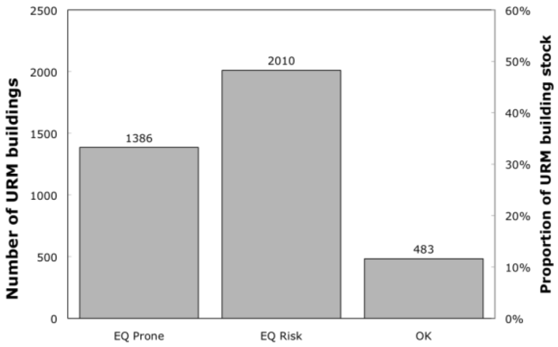
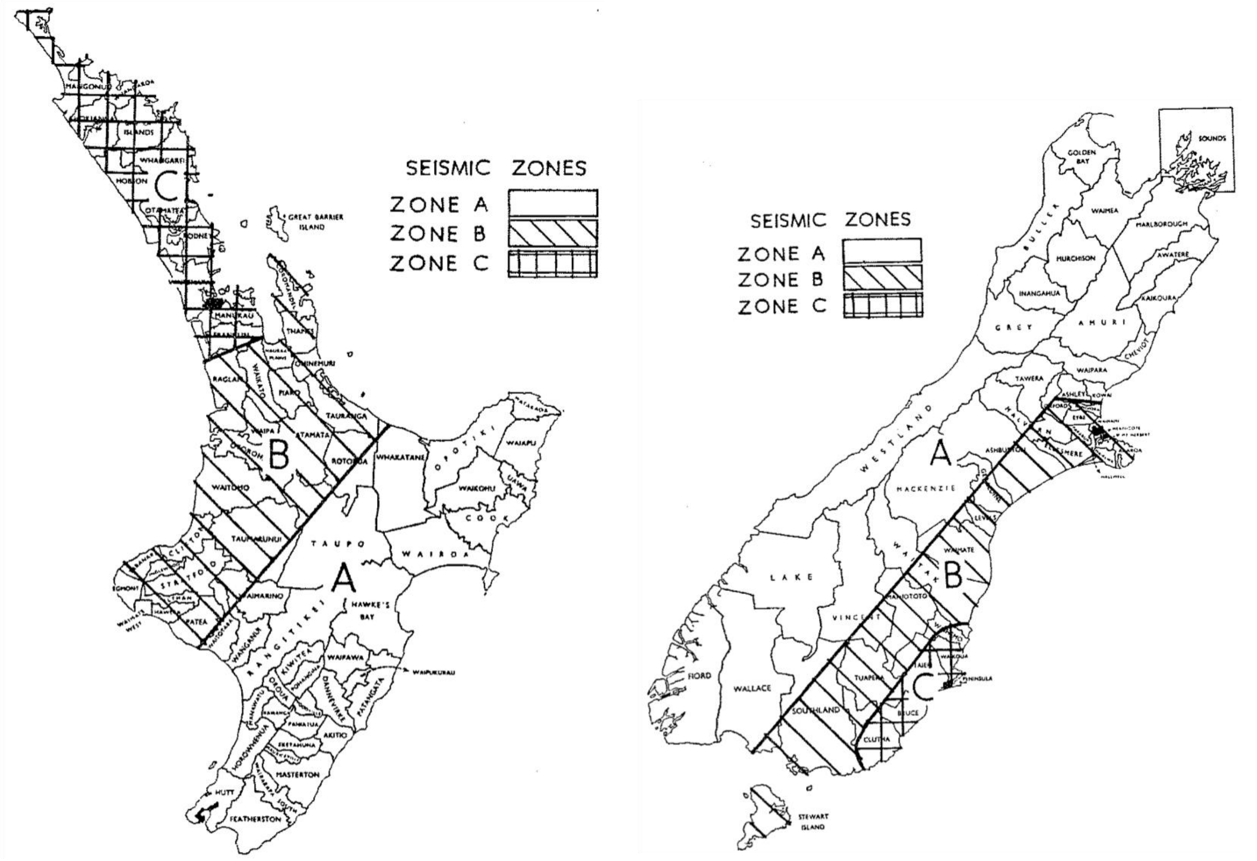


Figure 35: National estimate of potentially earthquake prone and earthquake risk URM buildings.

NEW ZEALAND BUILDING CODES

The construction of URM buildings in New Zealand peaked in the decade between 1920 and 1930 and subsequently declined (see Figure 28 and Figure 29), with one of the most important factors in this decline being the economic conditions of the time. The Great Depression in the 1930s and the outbreak of World War II significantly slowed progress in the construction sector, and few large buildings of any material were constructed in the period between 1935 and 1955 [12, 39]. Equally important in the history of URM buildings in New Zealand was the 1931 M7.8 Hawkes Bay Earthquake, and the changes in building provisions which it precipitated. The destruction of many URM buildings in Napier graphically illustrated that URM construction provided insufficient strength to resist lateral forces induced in an earthquake due to its brittle nature and inability to dissipate energy. Later in 1931, in response to that earthquake, the Building Regulations Committee presented a report to the Parliament of New Zealand entitled "Draft General Building By-Law" [40]. This was the first step towards requiring seismic provisions in the design and construction of new buildings. In 1935, this report evolved into NZSS no. 95, published by the newly formed New Zealand Standards Institute, and required a horizontal acceleration for design of 0.1g, and this requirement applied to the whole of New Zealand [41]. NZSS no. 95 also suggested that buildings for public gatherings should have frames constructed of reinforced concrete or steel. The By-Law was not enforceable, but it is understood that it was widely used especially in the larger centres of Auckland, Napier, Wellington, Christchurch and Dunedin [39]. The provisions of NZSS no. 95 were confined to new buildings only, but the draft report acknowledged that strengthening of existing buildings should also be considered, and that alterations to existing buildings were required to comply [42]. In 1939 and 1955 new editions of this By-Law were published, and apart from suggesting in 1955 that the seismic coefficient vary linearly from zero at the base to 0.12 at the top of the building (formerly the seismic coefficient was uniform up the height of the building), there were few significant changes [43]. It was not until 1965 that much of the recent research at the time into seismic design was incorporated into legislation. The New Zealand Standard Model Building By-Law NZSS 1900 Chapter 8:1965 explicitly prohibited the use of URM: (a) in Zone A; (b) of more than one storey or 15 ft (4.6 m) eaves height in Zone B; (c) of more than two storeys or 25 ft (7.6 m) eaves height in Zone C. These zones refer to the seismic zonation at the time, which have subsequently changed and evolved. Zone A consisted of regions of the highest seismic risk and Zone C consisted of regions of the lowest seismic risk [44]. Details of the seismic zonation in NZSS 1900 are shown in Figure 36. Again, the provisions of this By-Law did not apply automatically and had to be adopted by local authorities.

The 1965 code required that buildings be designed and built with "adequate ductility", although further details were not given. The next version of the loadings code was published in 1976 as NZS 4203 [45], and was a major advance on the 1965 code. Most importantly, the 1976 loadings code was used in conjunction with revised material codes: steel, reinforced concrete, timber and *reinforced* masonry, which all required



(a) North Island (b) South Island

Figure 36: Map of seismic zones [from NZSS 1900 Chapter 8:1965].

specific detailing for ductility. Thus after the publication of this code in 1976, unreinforced masonry was explicitly prohibited as a building material throughout the whole of New Zealand.

The use of URM was implicitly discouraged through legislation from as early as 1935, and although it was still allowed in some forms after 1965, observations of existing building stock show its minimal use from 1935 onwards, especially for larger buildings. This is thought to be significantly attributable to the exceptionally rigorous quality of design and construction by the Ministry of Works at the time [39, 46]. Although two storey URM buildings were permitted in Auckland (Zone C) after 1965, only three existing URM buildings in Auckland City constructed after 1940 have been identified. All three are single storey and they were constructed in 1950, 1953 and 1955.

PROVISIONS FOR THE SEISMIC UPGRADE OF EXISTING BUILDINGS

As building codes were being developed for the design of new buildings, attention was also given to the performance of existing buildings in earthquakes. The first time this was addressed in legislation was Amendment 301A to the 1968 Municipal Corporations Act [27]. This Act allowed territorial authorities, usually being boroughs, cities or district councils, to categorise themselves as earthquake risk areas and thus to apply to the government to take up powers to classify earthquake prone buildings and require owners to reduce or remove the danger. Buildings (or parts thereof) of high earthquake risk were defined as being those of unreinforced concrete or unreinforced masonry with insufficient capacity to resist earthquake forces that were 50% of the magnitude of those forces defined by NZS 1900 Chapter 8:1965. If the building was assessed as being “potentially dangerous in an earthquake”, the council could then require the owner of the building within the time specified in the notice to remove the danger, either by securing the building to the satisfaction of the council, or if the council so required, by demolishing the building. Most major cities and towns took up the legislation, and as an indication of the effect of this Act, between 1968 and 2003 Wellington City Council achieved strengthening or demolition of 500 out of 700 buildings identified as earthquake prone [47]. Auckland City Council, in spite of having a low seismicity, took a strong interest in the legislation and this led to considerable activity in strengthening buildings (see [48]), In Christchurch, a moderately high seismic zone, the City Council implemented the legislation, but adopted a more passive approach, generally waiting for significant developments to trigger the requirements. In Dunedin, now seen to be of low seismic risk, little was done in response to the 1968 legislation although strengthening of schools, public buildings and some commercial premises was achieved. As a result, Dunedin has a high percentage of URM buildings compared with many other cities in New Zealand [26]. Megget [39] and Thornton [38] state that much of the strengthening in Wellington was accomplished with extra shear walls, diagonal bracing or buttressing and the tying of structural floors and walls together, and that many brittle hazards such as parapets and clock towers had been removed after the two damaging 1942 South Wairarapa earthquakes (M7 & M7.1) which were felt strongly in Wellington. Hopkins et al. [47] noted that “there was criticism at the loss of many older heritage buildings and at the use of intrusive retrofitting measures which were not harmonious with the architectural fabric of the building [49]. At the same time, this did provide an opportunity in many cases for the land on which the old building was situated to be better utilised with new, larger and more efficiently designed structures."

"A major drawback of the 1968 legislation, which endured until 2004, surviving intact with the passage of the Building Act 1991, was that the definition of an earthquake prone building and the required level to which such buildings should be improved remained tied to the 1965 code. Most territorial authorities called for strengthening to one-half or two-thirds of the 1965 code, and many buildings which were strengthened to these requirements were subsequently found to fall well short of the requirements of later design standards for new buildings" [47]. (Wellington City Council found that in January 2008, of 97 buildings which had been previously strengthened, 61 (63%) were subsequently identified as potentially earthquake prone [35, 37]). This situation was recognised by the New Zealand Society for Earthquake Engineering (NZSEE), who were also concerned about the performance of more modern buildings, particularly after the observed poor performance of similarly aged buildings in earthquakes in Northridge, California (1994) and Kobe, Japan (1995). NZSEE pushed for new, more up-to-date and wide-ranging legislation. This was supported by the Building Industry Authority, later to become part of the Department of Building and Housing, and a new Building Act came into effect in August 2004 [34]. This brought in new changes as to what constituted an "Earthquake Prone Building". In particular, the definition of an earthquake prone building was tied to the current design standard of the time, and no longer to the design standard of any particular year. The legislation allowed any territorial authority that is satisfied that a building is earthquake prone to require the owner to take action to reduce or remove the danger. Each territorial authority was required to have a policy on earthquake prone buildings, and to consult publicly on this policy before its adoption. Policies were required to address the approach and priorities and to state what special provisions would be made for heritage buildings. The 2004 legislation applied to all types of buildings except small residential ones, (residential buildings were excluded unless they comprised 2 or more storeys *and* contained 3 or more household units).

As soon as the 1968 legislation came into effect to attempt to mitigate the effects of earthquake prone buildings, the New Zealand National Society for Earthquake Engineering set up a steering committee to provide a code of practice in an effort to assist local authorities to implement the legislation. Since the first draft code of practice published by the NZNSEE [50], several successive publications have been produced, each extending on the previous version. These guidelines have been instrumental in helping engineers and territorial authorities to assess the expected seismic performance of existing buildings consistent with the requirements of the legislation. Guidelines for assessing and upgrading earthquake risk buildings were published as a bulletin article in 1972 [50] and then separately published the following year, which became colloquially known as the "Brown Book" [51]. This document provided guidelines for surveying earthquake risk buildings and for the identification of particularly hazardous buildings and features, and was found to be helpful in many respects. It did not establish or recommend strength levels to which earthquake prone buildings should be upgraded, and thus standards varied from one area to another. It was implicit that strengthening be to more than half the standard required in Chapter 8 of the 1965 NZSS Model Building By-Law.

In 1982, NZSEE established a study group to examine and rationalise the use of these guidelines and to produce further guidelines and recommendations. This activity culminated in the publication in 1985 of what became known as the "1985 Red Book" [52]. Again, this document was primarily of a technical nature and the responsibilities of what to do with buildings still rested with local authorities. The publication was intended to promote a consistent approach throughout New Zealand for the strengthening of earthquake risk buildings and included a recommended level to which buildings should be strengthened plus the time scale to complete the requirements. The basic objective was to establish a reasonably consistent reduction of the overall risk to life which the country's stock of earthquake risk buildings represented. Based on overseas experiences, particularly in Los Angeles in Southern California, a philosophy was accepted of providing owners of earthquake risk buildings with the option of interim securing to gain limited extension of useful life, after which the building should be strengthened to provide indefinite future life. The design of interim securing systems was to be based on minimum seismic coefficients which represented two-thirds of those specified in NZSS 1900, Chapter 8 [44]. For "permanent" strengthening measures, it was recommended that the building be strengthened to the standard of a new building, but with the design lateral forces reduced depending on the occupancy classification and type of strengthening system. This publication was widely used by territorial authorities and designers.

In 1992 the NZNSEE again set up a study group to review the 1985 publication, and this resulted in another publication, which similarly became colloquially known as the "1995 Red Book" [53]. This document extended the approach and content of its predecessor and took into account the changing circumstances, technical developments and improved knowledge of the behaviour of URM buildings in earthquakes. In particular, earthquake risk buildings in that document were taken to include all unreinforced masonry buildings, and not just those which were defined as "earthquake prone" in terms of the Building Act of the time, which still referred back to the 1965 code. Another key difference from the 1985 Red Book was that a single stage approach to strengthening was suggested, in contrast to the two stage securing and strengthening procedure of the 1985 document. The guidelines also highlighted the differences in analysis for unsecured buildings in comparison to a building which has positive connections between floor, roof and wall elements, and cantilever elements secured or removed. Greater emphasis was placed on the assessment of the likely performance of URM buildings in their original form and with interim securing only in place, as distinct from the performance of the building with any strengthening work which was subsequently found to be necessary. Furthermore, material strengths were given in ultimate limit state format. Historic or heritage buildings were not given any specific or separate treatment, and the guidelines stated that "the issues of risk versus the practicalities of strengthening associated with historic buildings require evaluation on a case-by-case basis. The principal problem with such buildings is that the greater the level of lateral forces that is specified for strengthening, the greater the risk of damaging the fabric that is to be preserved" [53].

After the introduction of a new Building Act in 2004 [34] the Department of Building and Housing supported NZSEE in producing a set of guidelines, "Assessment and Improvement of the Structural Performance of Buildings in Earthquakes" [33]. This was a major review and extension of previous guidelines, to account for the wider scope of the proposed new legislation. Prior to enacting The Building Act 2004, the term 'earthquake risk building' related only to URM buildings, but now an earthquake prone building could be of any material; steel, concrete, timber or masonry. The level of risk posed by buildings constructed as recently as the 1970s was more widely appreciated, in particular the inadequate performance of reinforced concrete structures due to deficient detailing. Definitions of "earthquake prone" and "earthquake risk" also changed. Essentially, earthquake prone buildings were defined as those with one-third or less of the capacity of a new building. While The Building Act itself still focussed on buildings of high risk (earthquake prone buildings), NZSEE considered earthquake risk buildings to be any building which is not capable of meeting the performance objectives and requirements set out in its guidelines, and earthquake prone buildings formed a subset of this. Moreover, NZSEE expressed a philosophical change, in acknowledgment of the wide range of options for improving the performance of structures that are found to have high earthquake risk. Some of these options involve only the removal or separation of components, and others affect a relatively small number of members. In line with performance-based design thinking, the term "strengthening" was replaced with "improving the structural performance of", highlighting the fact that such solutions as base isolation were not "strengthening" but were an effective way of improving structural performance.

The 2006 guidelines [33] provided both an initial evaluation procedure (IEP) and a detailed analysis procedure. The IEP can be used for a quick and preliminary evaluation of existing buildings, and takes into account the building form, natural period of vibration, critical structural weaknesses (vertical irregularity, horizontal irregularity, short columns and potential for building-to-building impact) and the design era of the building. Based on this analysis, if a territorial authority determines a building to be earthquake prone, the owner may then be required to take action to reduce or remove the danger, depending on the territorial authority's policy and associated timeline. The level required to reduce or remove the danger is not specified in The Building Act or its associated regulations. The Department of Building and Housing suggested that territorial authorities adopt as part of their policies that buildings be improved to a level "as near as is reasonably practical to that of a new building". Most territorial authorities took the view that they could not require strengthening beyond one-third of new building standard, but a significant number included requirements to strengthen to two-thirds of new building standard, in line with NZSEE recommendations. In developing policies on earthquake prone buildings, most territorial authorities recognised the need for special treatment and dialogue with owners when heritage buildings were affected. It is believed by the Department of Building and Housing that "the legislation has required each local community to put earthquake risk reduction on its agenda, and has left the local community to develop appropriate policies that reflect local conditions and perceptions of earthquake risk" [47].

CONCLUSIONS

New Zealand is a comparatively young country, with formalised European settlement commencing in 1840. The first masonry building in New Zealand was constructed in 1833, with unreinforced clay brick masonry having been a predominant construction material for all non-residential structures until the devastating 1931 Hawke's Bay earthquake.

Seven typologies have been identified to categorise configurations in the New Zealand URM building stock. Distinctions between typologies are made on the basis of building height and the geometry of the building's ground floor footprint.

Through two independent methods an estimation of the number of URM buildings in New Zealand has been established. Both approaches suggest that there are between approximately 3,750 URM buildings in existence in New Zealand currently, with the majority being low rise one and two storey buildings. Trends in the age of these buildings show that construction activity increased from the early days of European settlement and reached a peak at about 1930, before subsequently declining sharply. Few URM buildings have been observed throughout the country with a construction date later than 1950, and the preponderance of the existing URM building stock was constructed prior to 1940. Thus, almost all URM buildings in New Zealand are between 80 and 130 years old (in 2009). The stock of URM buildings in New Zealand was estimated to make up approximately 8% of the overall stock of all commercial buildings, in terms of floor area. Overall the URM building stock has a value of approximately $NZ1.5 billion. Collectively the value of smaller buildings is higher than the value of larger buildings, but individually the larger buildings have greater financial value. This suggests that for seismic assessment and retrofit, less time and money should be invested in smaller buildings individually, but collectively these buildings will form the majority of the seismic improvement work which remains to be undertaken to make the New Zealand URM building stock less vulnerable to earthquakes.

An estimate of the vulnerability of all 3,750 New Zealand URM buildings suggested that up to 1,300 (35%) of these buildings could be assessed as potentially earthquake prone, and an additional 2,010 (52%) could be assessed as earthquake risk using the NZSEE Initial Evaluation Procedure (IEP). Consequently, up to 87% of all New Zealand URM buildings could be found to require improvements to their seismic structural performance.

It has also been shown that significant attention has been given to the assessment and improvement of existing URM buildings for many years, particularly by the New Zealand Society for Earthquake Engineering.

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