Architectural characterisation and prevalence of New Zealand's unreinforced masonry building stock

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A.P. Russell & J. M. Ingham

The University of Auckland, Auckland, New Zealand.

ABSTRACT: Unreinforced masonry (URM) buildings remain New Zealand's most earthquake-prone structures. As part of an effort to develop retrofit solutions for upgrading the seismic performance of these structures, research into characterising the national building stock of URM buildings has been conducted.

This research classifies New Zealand URM buildings into typologies, based on their general structural configuration. Seven typologies are presented, and their relative prevalence, age and locations are identified. Based on these classifications, seismic vulnerability assessments will need to be conducted on a regional and national basis.

An estimate of the population and distribution, as well as the construction date, of existing URM structures in New Zealand is also presented. Effort is being developed to further improve the quality of data, in conjunction with exercises currently being conducted by local territorial authorities. The preponderance of these structures were constructed between 1920 and 1930.

1 INTRODUCTION

New Zealand's unreinforced masonry (URM) building stock was mainly constructed between about 1880 and 1950 (Stacpoole and Beaven 1972). Due to its poor resistance to seismic forces, the use of URM as a building material was explicitly outlawed in 1965 in most areas of New Zealand with the introduction of NZS 1900 (New Zealand Standards Institute 1965). Many URM buildings still exist in New Zealand. Of these, many are protected by the Historic Places Trust (Robinson and Bowman 2000), or if not actually protected (scheduled) are an important part of New Zealand's architectural heritage. Legislation has recently been introduced in New Zealand where earthquake-prone buildings (as defined in The Building Act 2004) must be improved to meet at least one-third the standard of a new building, or else removed (DBH 2004). Within this legislative framework the option of demolition may be more attractive to the building owner when compared to the investment associated with seismic retrofit of the structure. As many URM buildings form part of the country's heritage architecture, demolition in order to mitigate their seismic hazard is considered less favourable for this reason than building retrofit. Therefore it is important to identify and develop cost-effective seismic retrofit solutions. The first step in this process is evaluating the nature of New Zealand's URM building stock.

2 EARTHQUAKE PRONE BUILDING LEGISLATION

Territorial Authorities (TAs) in New Zealand are responsible for the consent process for the design of new buildings and the maintenance of existing buildings. The Building Act 2004 required TAs to adopt a policy on earthquake-prone buildings by the 31st of May 2006 (DBH 2004). The first step in the policy developed by each TA requires a preliminary assessment of their building stock to determine the number and types of buildings with the potential to be earthquake-prone. This involves both reviewing earthquake hazards within the TA district in accordance with NZS 1170.5:2004 (Standards New Zealand 2004) and considering the structural performance of the building stock in an earthquake taking account of age, construction, location and use in relation to the earthquake hazard in that district (DBH 2005).

3 NEW ZEALAND URM BUILDING TYPOLOGIES

Before economical and cost-effective retrofit solutions can be identified and developed for New Zealand's potentially earthquake prone URM heritage buildings, it is first necessary to accurately assess their seismic performance. But before the structural behaviour of URM buildings is ascertained and for a comprehensive understanding of the building stock, especially for TAs, the architectural characteristics must be defined. Within the architectural characterisation of URM buildings, the broadest and most important classification is that of the overall building configuration. The seismic performance of a URM structure depends on its general size and shape. 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 (Robinson and Bowman 2000).

There is a need for a consistent and systematic classification of existing URM structures in New Zealand. Territorial Authorities have an obligation under the New Zealand Building Act 2004 (DBH 2004) to gain a comprehensive understanding of their potentially earthquake-prone building stock. While it is not envisaged that a "one-size-fits-all" approach is viable for all URM buildings, for initial 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, Binda (2006), Erbay and Abrams (2007), Tomazevic and Lutman (2007)). The object of vulnerability assessments have usually been on case-studies, involving particular cities or parts of a city. Tonks et al. (2007) began a preliminary identification of building typologies in New Zealand, based on those identified in Italy by Binda (2006). 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. 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 (details can be found in Table 3.1 of that document and in Russell and Ingham (2008)) (Standards New Zealand 2002). All identified URM structures fall into importance level II or higher, with medium to high consequences for loss of human life. An estimated ranking of URM structures in terms of prevalence is also shown in Table 1.

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. For example, Type G1 buildings are religious buildings, Type G2 are warehouses and factories with very large tall sides and large open spaces inside. Further detail on each typology can be found in Russell and Ingham (2008).

Table 1: URM Building Typologies

Type	Description	Prevalence (rank)	Importance level (AS/NZS 1170.0)	Description
A	One storey, isolated buildings	4	II	One storey URM buildings. Examples include convenience stores in suburban areas, small offices in a rural town.
B	One storey, row buildings	3	II	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 buildings	2	II/III	Two storey URM buildings, often with an open front. Examples include small cinemas, a professional office in a rural town, post offices.
D	Two storey, row building	1	II	Two storey URM buildings with multiple occupancies, joined with common walls in a row. Typical in commercial districts.
E	Three + storey, isolated buildings	7	III/IV	Three + storey URM buildings, for example office buildings in older parts of Auckland and Wellington.
F	Three + storey, row buildings	6	III/IV	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 buildings	5	III/IV/V	Churches (with steeples, bell towers etc), water towers, chimneys, warehouses. Prevalent throughout New Zealand.

3.1 *Parameters for differentiating typologies*

3.1.1 *Storey Height*

URM building typologies are separated according to whether the buildings are one storey, two storey or three or more storeys. 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 (Abrams 2000), and diagonal shear failure is less likely. For walls without openings (or with small openings), and depending on the 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.

Another reason why buildings are distinguished according to storey height is because of the axial loads acting in the walls. One storey buildings with low axial loads are less likely to exhibit diagonal shear failure and are more likely to rock or slide. The bottom storey walls (with no window piercings) in a taller building are more likely to fail in shear because of the higher axial loads on them.

3.1.2 *Building Footprint*

The second primary characteristic for separating buildings into typologies is the building footprint. That means whether the structure is considered to be a stand-alone, isolated, (almost) square building, or a row building made up of multiple residences joined together with common walls. This 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 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 structure, the seismic resistance is greatly enhanced due to the increased stiffness in one direction.

Essentially square or round buildings with well distributed walls generally have a greater torsional resistance than buildings with less evenly distributed lateral force resisting walls (Robinson and Bowman 2000). Long row structures have different torsional properties than isolated buildings.

A significant difference between isolated and row buildings becomes evident at the time of upgrading the structure. An isolated structure usually contains few residences, perhaps two shops for example, or occasionally more. Row structures may contain many residents, even ten or more. An isolated structure is generally considered just that – a single structure. A row structure, despite behaving in an earthquake as a single interconnected structure, may be perceived as different buildings because of its multiple owners. It may be more difficult to perform remedial work on an entire row structure at one time compared with retrofit of an isolated structure. If retrofit interventions are implemented on only a part of a structure, such an intervention may be ineffective.

4 NEW ZEALAND BUILDING POPULATION AND DISTRIBUTION

As well as classifying buildings into typologies, it is useful for the purpose of understanding the nature of URM buildings in New Zealand to consider their prevalence and national distribution. Through the use of historic population data and a survey of commercial buildings in Auckland City, it was possible to ascertain a preliminary indication of the number of URM buildings thought to currently exist throughout New Zealand.

Two sources of data were utilised for estimating the number of URM buildings in existence around the country: the official population data of New Zealand from 1900 – 1940 (New Zealand Government 1890-1950), and a survey of potentially earthquake prone commercial buildings in Auckland City, undertaken by Auckland City Council in 2007.

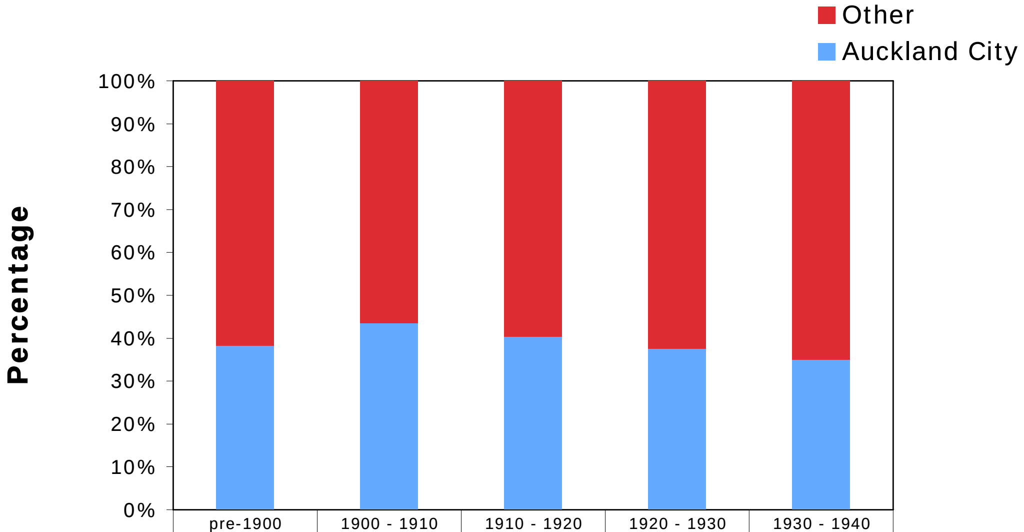
In surveying potentially earthquake prone buildings in Auckland City, a total of 1500 buildings were identified to have been constructed before 1940. Although buildings with a construction date up to and including 2007 were surveyed, very few URM structures were found to have been built in Auckland City after 1940. Therefore, for the purpose of this exercise, only pre-1940 structures were considered. Of the 1500 buildings, the construction material of 51.5 % was unknown, and of the remaining 48.5 %, 27.5 % were URM, 16.7 % were timber and 4.3 % were of reinforced concrete frame and brick infill. Using the associated construction date of each building the total sample was grouped according to decade. Pre 1900 was considered as a single grouping, and the other groups were 1900 – 1910, 1910 – 1920, 1920 – 1930 and 1930 – 1940.

Although in Auckland City the construction material of only half of the building population has been positively identified, the principle of estimating the number of URM buildings can be illustrated. As more data becomes available, the accuracy will increase. This data collection process is currently ongoing. Table 2 shows the number of buildings identified in the survey according to their construction date. It is estimated that up to half of the unknown buildings are built of URM.

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

	Pre-1900	1900-1910	1910-1920	1920-1930	1930-1940	Total	Percentage
URM	8	29	19	304	49	767	27.5 %
Timber	2	14	10	199	24	409	16.7 %
Brick infill	3	8	0	25	28	249	4.3 %
Unknown	4	23	22	490	228	64	51.5 %
Total	17	74	51	1018	329	1489	100 %

In order to estimate the number of URM buildings in other parts of the country, the data from Auckland City Council can be extrapolated using official population data. In the early 20th Century, New Zealand was divided into the following provinces: Auckland, Taranaki, Hawke's Bay, Wellington, Marlborough, Nelson, Canterbury and Otago-and-Southland. Auckland province was made up of the area of the country Taupo and north (everywhere which currently celebrates Auckland Anniversary Day) (New Zealand Government 1890-1950). The current boundaries of the area under the jurisdiction of Auckland City Council are equivalent to that of the Eden County up until 1940. This 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 can be found using the population data from official New Zealand Year Books. (New Zealand Government 1890-1950). The average population of Auckland City and other parts of Auckland Province are shown in Figure 1.



	pre-1900	1900 - 1910	1910 - 1920	1920 - 1930	1930 - 1940
Other	108,660	109,513	166,260	245,717	336,570
Auckland City	67,278	84,068	112,096	147,922	180,297

Figure 1: Proportion of population in Auckland Province

Using these same proportional relationships, the number of existing URM buildings in the historic Auckland Province can be estimated based on the number of positively identified 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 is approximately proportional to population. There are 29 positively identified URM buildings from that decade in Auckland City, and assuming these also make up 43 % of the total number of buildings in the historic Auckland Province, then there are 67 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 can be determined. This data is summarised in Table 3.

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 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 %
Auckland City URM buildings	8	29	19	304	49
Auckland Province URM buildings	21	67	46	810	139
Buildings per 100,000 people	11.9	34.6	16.5	205.8	26.9

Based on official provincial populations of the time, the number of buildings in the other provinces of New Zealand can also be estimated as shown in Table 4. The determination of these results assumes that the ratio of URM buildings per 100,000 people in Auckland is also valid for the other provinces of New Zealand.

Table 4: 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	21	67	46	810	139	1083
Taranaki	Population	34,486	45,973	48,546	63,273	76,968	
	URM	4	13	8	129	20	174
Hawke's Bay	Population	37,139	46,906	51,569	65,037	77,652	
	URM	5	13	9	133	20	180
Wellington	Population	132,420	189,481	199,094	261,151	316,446	
	URM	17	54	35	533	81	720
Marlborough	Population	13,499	15,177	15,985	18,053	19,149	
	URM	2	4	3	37	5	51
Nelson	Population	33,142	45,493	48,463	49,153	59,481	
	URM	4	13	8	100	15	140
Westland	Population	15,042	15,194	15,714	14,655	18,676	
	URM	2	4	3	30	5	44
Canterbury	Population	145,058	166,275	173,443	206,462	234,399	
	URM	18	47	30	421	60	576
Otago and Southland	Population	174,664	156,688	191,130	206,835	224,069	
	URM	22	44	33	422	57	578
Total							3546

It is acknowledged that the data presented above is indicative only and may not accurately represent the number of URM buildings in other parts of New Zealand, especially in smaller towns. The number of buildings from a particular decade in Auckland captures only those buildings which still exist, not all the buildings which were constructed in that time period. The rate of demolition and redevelopment in Auckland City may not represent that rate in other parts of the country and hence the number of existing buildings. Smaller towns in New Zealand may have experienced different economic conditions than larger centres. Whereas in Auckland economic factors may have provided a drive for demolition of older URM structures and development of newer structures, this may not have been the case in smaller towns. It is also acknowledged that while the identified building per capita ratio may be robust (or at least approximate) for other larger centres in New Zealand, further research is required into the prevalence of URM buildings in smaller towns.

Although further refinement of the prevalence of URM structures is required (even for Auckland City), trends from the above data can still be inferred, for example, trends in construction date. The following section outlines some of the influences on the construction dates of URM structures in New Zealand.

4.1 *New Zealand Building Codes and URM Construction Date*

From the above data, it can be seen that construction of URM buildings in New Zealand peaked in the decade between 1920 and 1930 and subsequently declined. One of the most important factors in this decline was the economic conditions of the time. The Great Depression in the 1930s and the outbreak of World War II slowed progress in the construction sector significantly, and few large buildings of any material were constructed in the period between 1935 and 1955.

Equally as important in the history of URM structures in New Zealand was the 1931 M7.8 Hawke's Bay Earthquake, and the changes in building provisions which it precipitated. The total destruction of almost all 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 Parliament entitled "Draft General Building By-Law" (Cull 1931). This realistically was the first step towards requiring seismic provisions in the design and construction of new buildings. In 1935, this evolved into NZSS no. 95, published by the newly formed New Zealand Standards Association, and required a horizontal acceleration for design of 0.1g. It 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 (Megget 2006). In 1939 and 1955 new editions of this By-Law were published, although with few significant changes. It was not until 1965 that much of the recent research at the time into seismic design was made 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 in Zone B; (c) of more than two storeys in Zone C. These zones refer to the seismic zonation at the time. Zone A was regions of the highest seismic risk and Zone C was regions of the lowest seismic risk (New Zealand Standards Institute 1965). Although two storey URM structures were still permitted in Auckland (Zone C) after 1965, only three existing URM structures in Auckland City constructed after 1940 have been identified. All three are single storey and they were constructed in 1950, 1953 and 1955.

The use of URM was implicitly discouraged (yet not prohibited) 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 (Johnson 1963; Megget 2006).

5 CONCLUSIONS

The overall configuration of a building influences its performance in an earthquake. Seven typologies have been identified to categorise configurations in the New Zealand URM building stock. Separations between typologies are made on the basis of building height and the geometry of the building's ground footprint. Assessment and analysis of the structural performance of buildings within these typologies will enable targeted and cost-effective retrofit solutions to be implemented for the retention of New Zealand's heritage URM buildings. Few URM buildings have been observed throughout the country that are newer than 1950, and the preponderance of existing URM building stock was constructed prior to 1935.

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