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

Figure 2.8 Photographic examples of New Zealand URM typologies (figure continues on next page)

Typology G building – religious

Typology G building – institutional

Figure 2.8 Photographic examples of New Zealand URM typologies

2.2.1 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. This comparative similarity is 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 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 buildings 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 (Robinson & Bowman, 2000) 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. 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.

2.3 New Zealand URM building population and 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 (see Appendix B). In order to establish the financial value of existing URM buildings, data provided from Quotable Value New Zealand Ltd (QV Ltd) were used. This latter 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 were 3867 URM buildings in New Zealand (see Table 2.2), while the second method suggested that there are 3589 URM buildings (see Table 2.3). Taking the mean of both values indicates that there were approximately 3750 URM buildings in total existing in New Zealand in mid-2010[4].

---

[4] The reported analyses to determine the approximate number of URM buildings in New Zealand was performed prior to the 4th September 2010 Darfield earthquake. Recognising both the continual slow demolition of URM buildings nationwide and more recently the rapid number of URM buildings demolished in Christchurch, it was determined that the presented analyses were sufficiently accurate for the purpose of this exercise.

Table 2.2 Estimated provincial populations and number of URM buildings (see Appendix B for further details)

Province		Pre-1900	1901-1910	1911-1920	1921-1930	1931-1940	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	85
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	39
Nelson	Population	33,142	45,493	48,463	49,153	59,481	
	URM	3	10	7	91	19	130
Westland	Population	15,042	15,194	15,714	14,655	18,676	
	URM	1	3	2	27	6	39
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 URM Building population by decade		68	584	676	1781	758	3867

2.4 Value of the New Zealand URM building stock

Table 2.3 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.

Table 2.3 URM building stock according to storey height[5]

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	

[5] 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 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.

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 (Hopkins, 2002; Hopkins & Stuart, 2003) 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.

Figure 2.9 Number of URM buildings according to storey height

As shown in Table 2.3, New Zealand has in existence nearly 3600 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 Table 2.3 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 2.9). 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 (Goodwin, 2008; Goodwin et al., 2009).

2.5 Seismic Vulnerability of the New Zealand URM Building stock

Following determination of the number of URM buildings and their approximate regional distribution, the analysis was 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" (NZSEE, 2006), 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 (New Zealand Parliament, 2004) 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 (2006) 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 NZSEE (2006), 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 NZSEE (2006) 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 Stevens & Wheeler, 2008):

- The construction date is pre-1935
- The period $T \leq 0.4$s
- 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 Standards New Zealand, 2004). 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 2.4.

Table 2.4 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

Applying the mean number of URM buildings estimated from both analysis methods discussed in section 27 (3750 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 2.10. From Figure 2.10 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 potentially earthquake prone, potentially earthquake risk and unlikely to be significant, respectively, can be estimated. This data is shown in Table 2.5 and aggregated to determine the estimated overall number of URM buildings in these categories throughout all New Zealand, as shown in Figure 2.11. From these results (Figure 2.10, Figure 2.11, and Table 2.5), 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. (2008) 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.

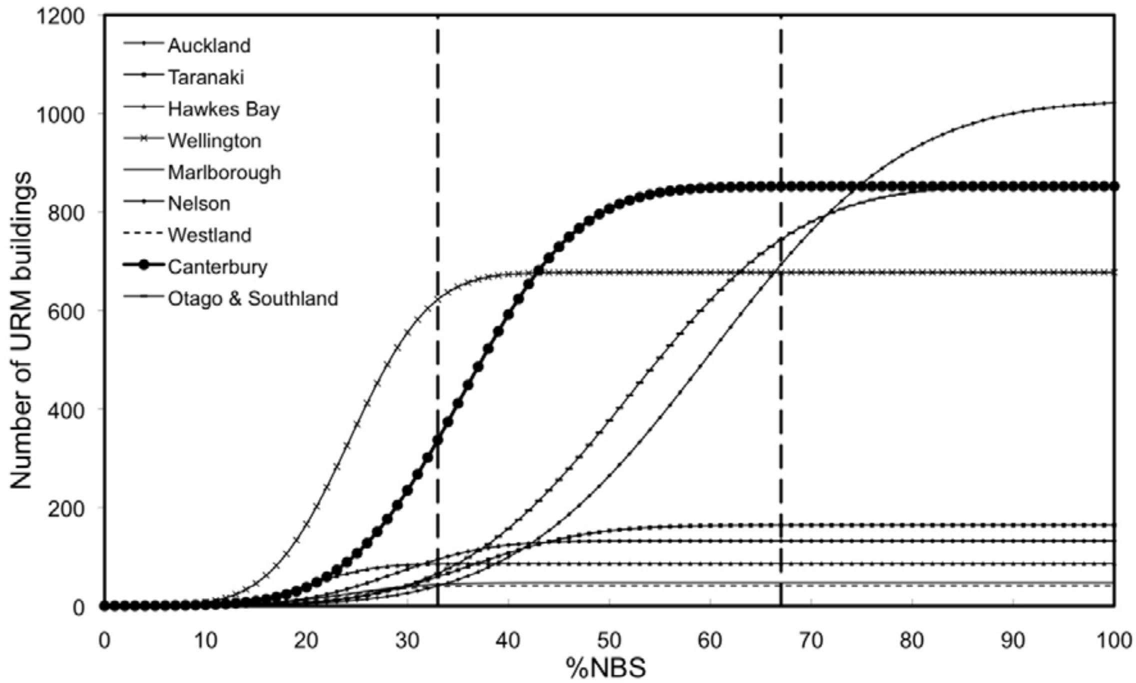

Figure 2.10 Estimated %NBS of URM buildings in Provinces throughout New Zealand

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 (2006).

Table 2.5 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	4%	628	61%	357	35%
Taranaki	59	36%	105	64%	0	0%
Hawke's Bay	84	99%	1	1%	0	0%
Wellington	622	92%	55	8%	0	0%
Marlborough	35	90%	4	10%	0	0%
Nelson	93	72%	37	28%	0	0%
Westland	37	95%	2	5%	0	0%
Canterbury	339	40%	513	60%	0	0%
Otago and Southland	66	8%	663	78%	126	15%
Total	1376	36%	2008	52%	483	12%