Section 6:

Demolition statistics and information on the cost of seismic improvement

This section provides information on building demolitions in Christchurch following the 2010/2011 Canterbury earthquake swarm, followed by details associated with the costs of seismic improvement of unreinforced masonry (URM) buildings. It is shown that the majority of demolished buildings were constructed of URM and that the cost of seismic improvement of the national URM building stock exceeds the current value of this building stock.

6.1 Christchurch building demolition statistic

A list of 224 buildings that have been demolished as a result of the 2010/2011 Canterbury earthquake swarm is presented in Appendix C. Figure 6.1 shows that 85% of these buildings were constructed of unreinforced masonry, clearly indicating that this class of building suffered the most extensive damage in the earthquakes.

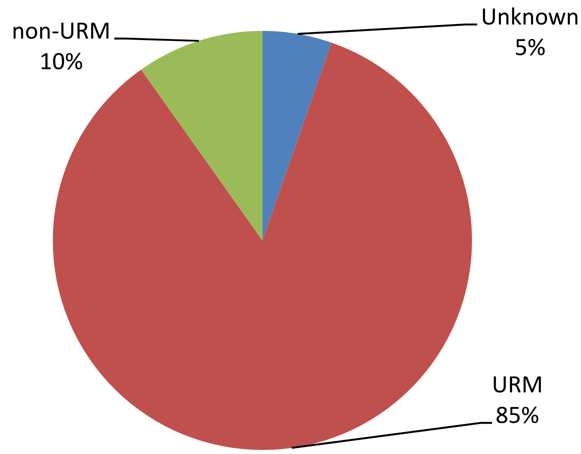

Figure 6.1 Distribution of construction types for 224 demolished buildings in Christchurch

The location of the demolished URM buildings is indicated on a map in Figure 6.2, with Figure 6.3 providing greater detail of the former location of these buildings within the Christchurch Central Business District (CBD).

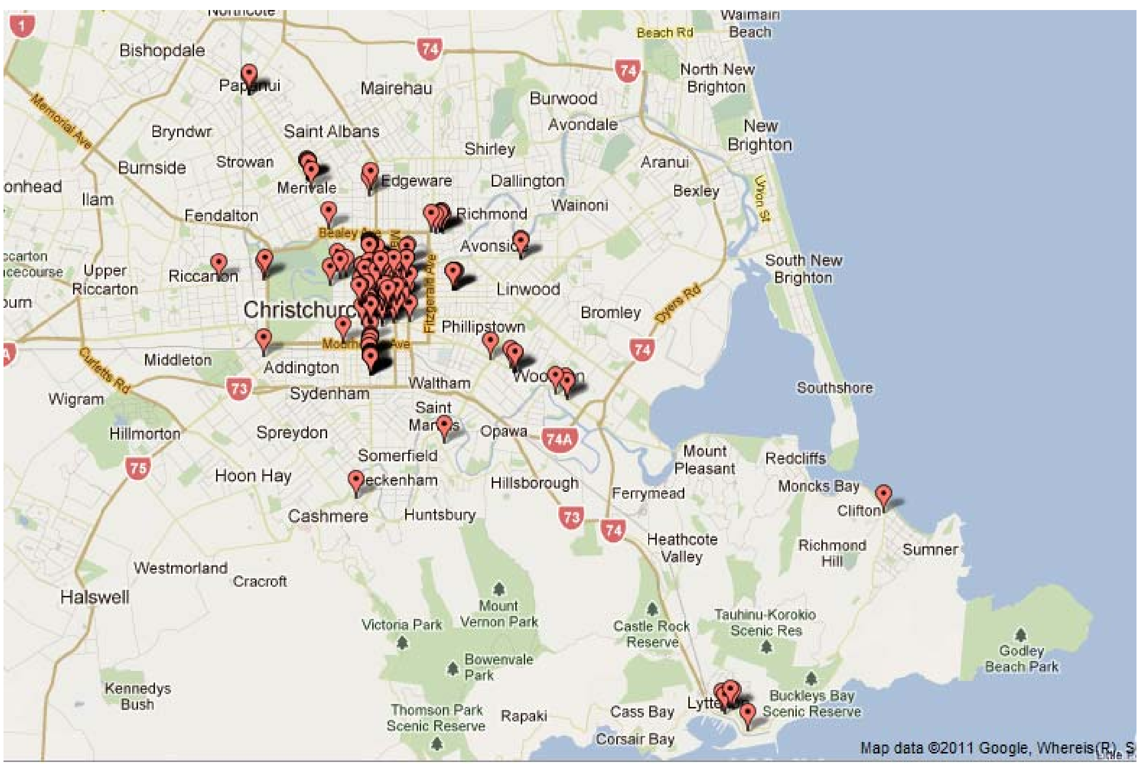

Figure 6.2 Overview of the location of demolished URM buildings (as at 25 July 2011)

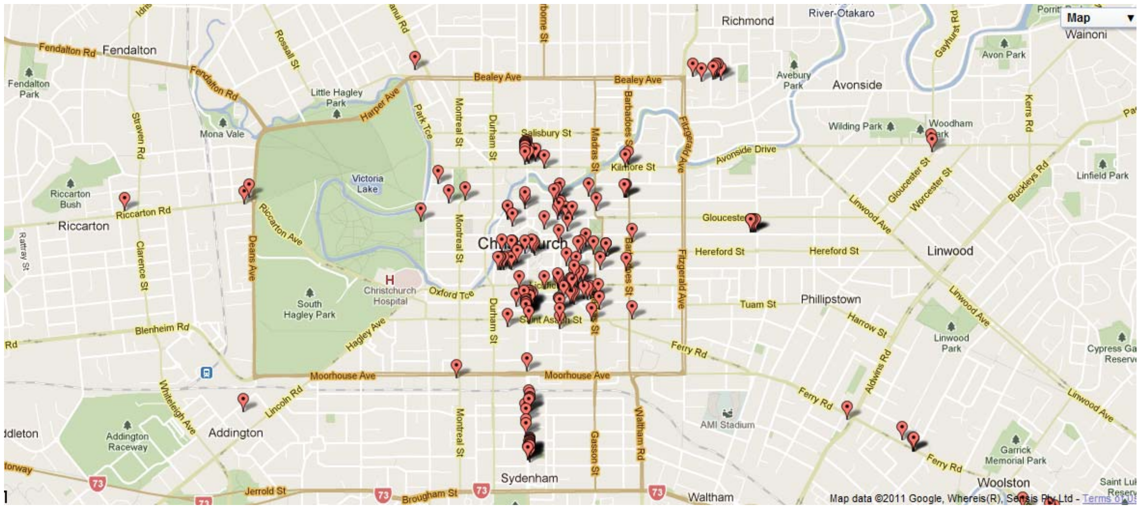

Figure 6.3 Location of demolished URM buildings in the Christchurch CBD (as at 25 July 2011)

Demolitions continue to occur and the data reported in Appendix C and Figure 6.1-Figure 6.3 are for the date up to 25 July 2011. This information will require updating as demolitions continue.

6.2 Costs of seismic improvements

Seismic retrofit cost is a significant factor affecting property owners' decisions to seismically rehabilitate their earthquake prone buildings (EPBs). Egbelakin et al. (2011) revealed that a high cost of retrofitting an EPB is a significant impediment affecting owners' decisions to rehabilitate their EPBs. The New Zealand study conducted by Egbelakin and colleagues revealed that 90% of the interviewees across all the cases studied disclosed that seismic retrofit cost is generally high and can become an economic burden on property owners. Hidden costs associated with retrofitting EPBs were regarded as one of the main contributors to the high cost of retrofitting EPBs (EERI, 2003), resulting in difficulty when attempting to accurately estimate the overall cost of retrofitting EPBs. Hidden costs relate to expenditure that cannot be estimated until the rehabilitation work commences or is completed (Bradley et al., 2008) and are characterised by several variations that depend on factors such as location, type of structure, building characteristics, rehabilitation scheme, the performance standard desired and other work(s) relating to the provisions in the building code that are triggered by the decision to retrofit. Both direct costs (seismic and non-seismic retrofit construction cost) and indirect costs (costs due to business disruption, loss of revenue) associated with seismic retrofit further complicate the cost estimation process (Bradley et al., 2008).

One way to overcome issues relating to seismic retrofit cost is to develop a strategy that will incorporate the seismic retrofit cost into a larger upgrade i.e. implementing seismic improvements during an on-going facility management program (EERI, 2003).

Teamwork during the conceptual design stage in a rehabilitation project can also reduce cost, as all stakeholders can discuss and evaluate cost cutting measures (EERI, 2000).

A motivating factor that could enhance property owners' decisions to invest in seismic retrofitting is the likelihood of cost recovery through increased rents or profits at the time of sale. However Egbelakin et al. (2011) found that cost recovery from retrofitted EPBs is difficult as the money expended on rehabilitation does not increase the market competiveness of the building. Egbelakin and colleagues specifically found that 92% of the owners of EPBs could not recoup any financial benefits from their investments on seismic retrofitting, with only 10% of the owners elucidated that although the investment is prohibitive at the time of retrofitting, implementing seismic retrofit could help to save cost associated with future rehabilitation and minimises business disruption due to possible changes in regulation. Likewise, Lindell & Perry (2004) highlighted that substantial financial aid and low-interest loans to owners of EPBs were significant motivators for improved seismic retrofit implementation.

6.3 Cost of seismic improvement of the national URM building stock

Christchurch City Council has published information on the projected cost of seismic improvement of URM buildings[16]. This document identifies that the cost to strengthen a typical URM building to 33% NBS is in the range of $350-450/m^2. As reproduced in Table 6.1, Christchurch City Council have also published data on the projected costs to strengthen 295 URM buildings to 33% NBS and to 67% NBS.

Table 6.1 Christchurch City Council Listed Buildings (25 March 2010)

Method of construction	Heritage Significance			TOTAL	Strengthening Cost (to 33%) (million)	Strengthening Cost (to 67%) (million)
	1	2	3			
	City Plan GP 1 and BPDP HPT Cat 1	City Plan GP 2	City Plan GP 3 and 4, BPDP HPT Cat 2 and Notable			
Unreinforced masonry	55	70	170	295	$137	$344
Reinforced concrete	1	7	21	29	$23	$57
Timber framed and other	18	19	126	163	$9	$22
TOTAL	74	96	317	487	$169	$421
Additional cost of fire and disabled access requirements					20%-100%	60%-160%

6.3.1 Approximate cost of seismic improvement of national URM building stock

The accurate determination of costs for the seismic improvement of the national URM building stock requires expertise in quantity surveying. The authors acknowledge that they have no such expertise, but nevertheless present the following analysis based upon

[16] **REVIEW OF EARTHQUAKE-PRONE, DANGEROUS AND INSANITARY BUILDINGS POLICY**: http://www1.ccc.govt.nz/council/proceedings/2010/march/regplanning4th/1.reviewofearthquakepronedangerousinsanitarybuildings.pdf

data presented at various locations throughout this report in order to trigger dialogue on the subject.

From Table 6.1 it may be determined that the cost of improving the identified Christchurch URM buildings to 33%NBS is M$137 and that the cost to instead improve these buildings to 67%NBS is M$344. Consequently it may be determined that the cost of improving to 67%NBS has a factor of 344/137 = 2.51.

Figure 2.11(b) shows that there are approximately 1376 URM buildings nationwide having a strength of less than 33% NBS and 2008 URM buildings nationwide having a strength of 34-67% NBS. It is recognised that there is uncertainty in these numbers and so therefore no attempt has been made to reduce the building count in accordance with the demolition data reported in section 6.1 and Appendix C. Section 2.4 reports that the URM buildings extracted from the QV database had a total floor area of 2,100,000 m^2. Consequently this data can be combined as shown in Table 6.2 to suggest an indicative cost of improving the national URM building stock to 67% NBS. In this analysis a typical cost of $450/$m^2$ to elevate to 33%NBS is assumed in order to partially compensate for inflation during the period March 2010 to July 2011.

Table 6.2 Projected cost of seismically improving the national URM building stock to 67% NBS

Current strength (% NBS)	Number	Total Floor Area (1,000,000 m^2)	Cost ($/$m^2$)	M$
0-33	1376	0.748	1129.5	844.9
34-67	2008	1.090	450	1231.2
>68	483	0.262	-	-
Total	3867	2.100		2076.1

Note that the estimated value to improve the national URM building stock to 67% NBS is approximately $2.1 billion. This number can be compared with the estimated value of these buildings of approximately $1.5 billion, as reported in Table 2.3.

Section 7:

Recommendations and closing remarks

7.1 Recommendations

1. Identify all unreinforced clay and stone masonry building stock in New Zealand[17].
   - Unreinforced masonry buildings consistently perform poorly in large earthquakes. Previously, not all territorial authorities have had a register of URM buildings located within their jurisdiction. In order to ensure that all URM buildings in New Zealand do not pose a safety risk to the public, it is essential that the presence and location of these buildings are known.
2. Successful retrofits showed that it is possible to make strengthened URM buildings survive severe earthquake ground motion.
3. There are several logical stages of building performance improvement that should be considered. The number of stages involved for seismic retrofitting of a building will depend upon how well the building owner and/or officials and occupants want the building to behave.
   - 1st stage: ensure public safety by eliminating falling hazards. This is done by securing/strengthening URM building elements that are located at height (eg, chimneys, parapets, ornaments, gable ends).
   - 2nd stage: strengthen masonry walls to prevent out-of-plane failures. This can be done by adding reinforcing materials to the walls and by installing connections between the walls and the roof and floor systems at every level of

[17] In all cases the term URM is used in this section to refer to unreinforced masonry buildings constructed of both clay brick and of stone, or of a combination of the two masonry materials.

the building so that walls no longer respond as vertical cantilevers secured only at their base.

- 3rd stage: ensure adequate connection between all structural elements of the building so that it responds as a cohesive unit rather than individual, isolated building components. In some situations it may be necessary to stiffen the roof and floor diaphragms, flexurally strengthen the masonry walls, and provide strengthening at the intersection between perpendicular walls.
- 4th stage: if further capacity is required to survive earthquake loading, then the in-plane shear strength of masonry walls can be increased or high-level interventions can be introduced, such as the insertion of steel and/or reinforced concrete frames to supplement or take over the seismic resisting role from the original unreinforced masonry structure.

4. The authors propose that all URM buildings should go through the first two stages of building improvement so that the targeted structural elements have their strength elevated to match that required for equivalent structural elements in a new building located at the same site. For 3rd and 4th stage improvements, building strengthening should aim for 100% of the requirement for new buildings but as a minimum, 67% might be acceptable.
5. Recommendation 4 should be a national requirement, rather than being left to territorial authorities to draft and monitor their own individual policies.
6. There is a need for more widespread technical capability for seismic assessment (analysis) and design of URM buildings in the New Zealand engineering community.
7. In view of the uncertainties regarding the seismic strength of existing URM buildings, it is recommended that field testing be conducted on some of the URM buildings in Christchurch that are scheduled for demolition.
8. Budgeting constraints will likely limit the extent to which URM buildings can be seismically upgraded. Therefore priority should be given to ensuring public safety by implementing Recommendation 3: Stage 1 and Stage 2 as soon as possible for all URM buildings.

7.2 Closing Remarks

1. There were no surprises amongst the collapse mechanisms observed in URM buildings.
2. Current building standards are appropriate and are representative of 'world's best practice'.
3. The amplitude of ground shaking experienced by URM buildings in Christchurch was well in excess of that prescribed by the current design spectra for Christchurch buildings located on soft soils. Nevertheless, well considered, conceived and implemented seismic retrofits of URM buildings performed well, even when the building experienced ground motion that was well in excess of the design level for Christchurch.
4. The URM building damage statistics were significantly worse after the 22nd February 2011 earthquake than they were after the 4th September 2010

earthquake due to the severity of local ground motions in the CBD during the 22 February earthquake.

5. The estimated cost to upgrade all 3867 URM buildings in New Zealand to a minimum of 67% of the NBS is roughly $2.1 billion, which is more than the estimated total value of the URM building stock of $1.5 billion. However, a multi-stage retrofit improvement program has been recommended and it is anticipated that the cost of implementing stage 1 and stage 2 improvements will not be excessive and should be within the budget capability of most building owners.

Section 8:

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