Seismic Performance of Masonry Buildings in the Christchurch Earthquakes 2010-2011: A Progress Report

Lisa M. Moon[1], Dmytro Dizhur[2], Jason M. Ingham[3] & Michael C. Griffith[4]

1. Corresponding Author. PhD Candidate, School of Civil, Environmental & Mining Engineering, University of Adelaide, SA 5005.
   Email: lmoon@civeng.adelaide.edu.au

2. PhD Candidate, Department of Civil & Environmental Engineering, University of Auckland, New Zealand. Email: ddiz001@aucklanduni.ac.nz

3. Associate Professor, Department of Civil & Environmental Engineering, University of Auckland, New Zealand. Email: j.ingham@auckland.ac.nz

4. Professor, School of Civil, Environmental & Mining Engineering, University of Adelaide, SA 5005. Email: michael.griffith@adelaide.edu.au

Abstract

Following the Christchurch earthquake of 22 February 2011 a number of researchers were sent to Christchurch, New Zealand to document the damage to masonry buildings as part of "Project Masonry". Coordinated by the Universities of Auckland and Adelaide, researchers came from Australia, New Zealand, Canada, Italy, Portugal and the US. The types of masonry investigated were unreinforced clay brick masonry, unreinforced stone masonry, reinforced concrete masonry, residential masonry veneer and churches; masonry infill was not part of this study.

This paper focuses on the progress of the unreinforced masonry (URM) component of Project Masonry. To date the research team has completed raw data collection on over 600 URM buildings in the Christchurch area. The results from this study will be extremely relevant to Australian cities since URM buildings in New Zealand are similar to those in Australia.

Keywords: unreinforced masonry, Christchurch earthquakes, seismic retrofit

1. INTRODUCTION:

Since the M 7.1 Darfield earthquake on 4 September 2010 the region around Christchurch, New Zealand, has been subjected to over 10,000 earthquakes on previously unknown fault lines. The most catastrophic of these was the M 6.3 earthquake on 22 February 2011, which occurred close to the CBD. Furthermore, between September 2010 and August 2012 the region was shaken by about 50 earthquakes M 5.0 and above. Figure 1 shows the location of the 4 September 2010 and 22 February 2011 earthquakes and the location of all aftershocks M 3.0 or greater up to 11 July 2012. Figure 2 shows the magnitudes of all earthquakes from 4 September 2010 until August 2012. The peak ground accelerations induced in Christchurch due to the Darfield Earthquake were approximately equal to those of the design level earthquake, and the only visible shaking damage in the city was sustained by the most vulnerable known building type: URM buildings. On 22 February, despite the smaller earthquake magnitude, the accelerations induced in the CBD were up to three times greater than designed for and while all buildings types sustained some damage from this earthquake, URM buildings again suffered the most damage.

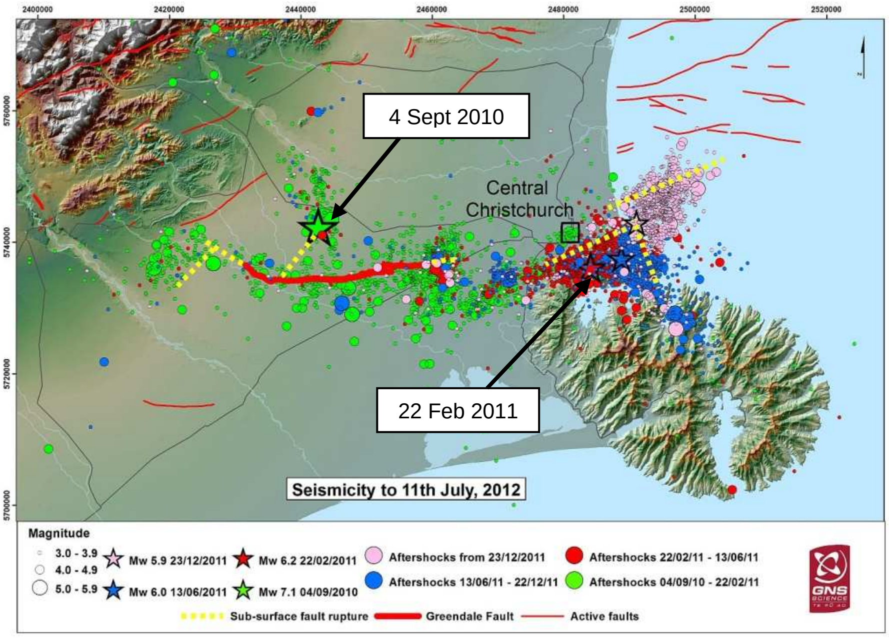


Figure 1 - Location of Major Earthquakes around Christchurch, NZ (GeoNet, 2012)

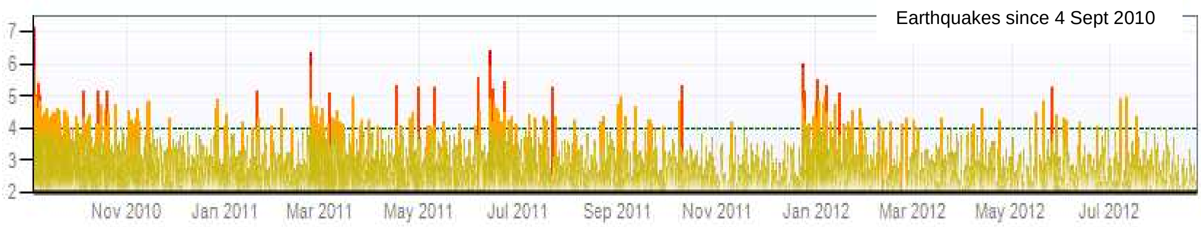


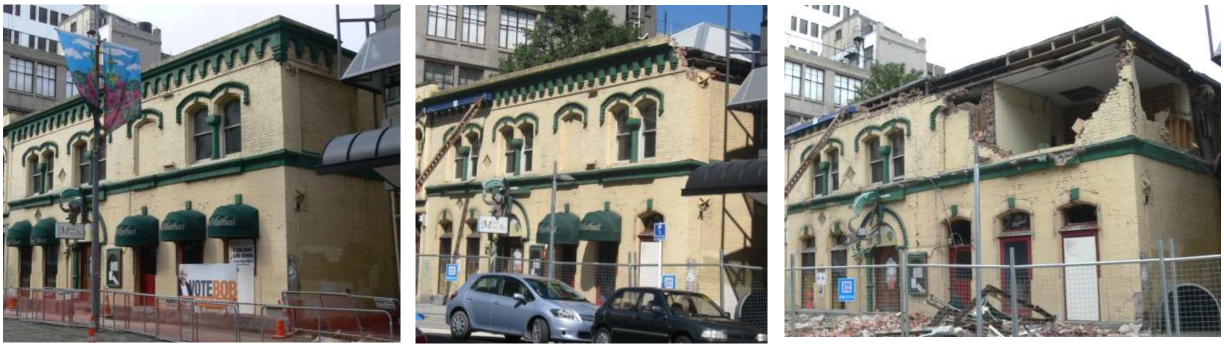
Figure 2 - Magnitudes of Canterbury Earthquake Sequence (Crowe, 2012)

Christchurch was famous for its many heritage and URM, buildings, so following the 22 February earthquake researchers were dispatched to Christchurch to document the damage to URM buildings. Later, researchers were also sent to focus study reinforced concrete masonry (RCM), residential masonry veneer, churches, and stone masonry.

2. BACKGROUND:

2011 marked the end of a long term study by the University of Auckland into the seismic assessment and retrofit of URM buildings in New Zealand, which also included a study on the standard typologies for URM buildings around the country (Retrofit Solutions, 2011). The study showed that the types of URM buildings around the country were of similar styles and ages, and that the building stock was relatively homogenous (Russell & Ingham, 2010). The URM buildings in Christchurch can therefore be considered representative of those across New Zealand, and therefore their seismic performance during the Christchurch Earthquake sequence is typical of how all New Zealand URM buildings would respond seismically. In some cases Christchurch URM buildings had also previously received various levels and forms of seismic retrofit. Therefore, studying the failure modes of these buildings and the effectiveness of retrofits can help predict what would happen to URM buildings in other New Zealand cities and how retrofits are likely to perform.

Engineers from the Universities of Auckland and Adelaide spent time in Christchurch studying the damage to URM buildings following the 4 September 2010 earthquake, and this has been reported by Dizhur et al (2010), Griffith et al (2010) and Ingham & Griffith (2011a). This meant that not only were the team familiar with the Christchurch URM building stock but that they also had a record of damage to these buildings from before the 22 February earthquake and could therefore better understand what additional damage was caused by the February earthquake. Figure 3 shows an example of progressive damage to a URM building in Christchurch. Figure 3 (a) shows the building fenced off after the 2010 Darfield earthquake; Figure 3 (b) shows the same building five months later with part of the parapet fallen and the front wall braced on the left; and Figure 3 (c), taken four days after the 22 February earthquake and six days after Figure 3 (b), shows the loss of the front parapet and out-of-plane failures of upper walls.



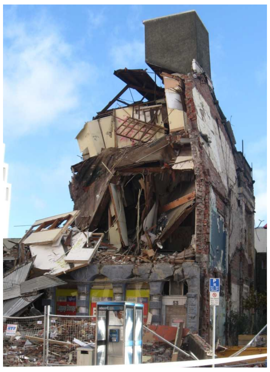
a) 1 October 2010 b) 20 February 2011 c) 26 February 2011

Figure 3 - Progression of damage from September 2010 until February 2011

3. PROJECT MASONRY:

3.1 Project Goals

The primary aim of Project Masonry is to document the characteristics of and damage to retrofitted and unretrofitted masonry buildings in and around Christchurch. A unique database will be created for the URM building stock in Christchurch, including building characteristics, damage levels and damage modes sustained in each major earthquake, any seismic retrofits present and the performance of such retrofits. Figure 4 (a) shows damage to a typical unretrofitted building and Figure 4 (b) shows a URM building retrofit, both observed in Christchurch CBD following 22 February 2011 earthquake.



a) Unretrofitted URM building

b) URM building with visible retrofit

Figure 4 - Typical URM building (a) and URM building retrofit (b) in Christchurch CBD following 22nd February 2011 earthquake

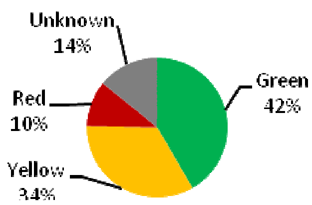
In order to gather the information for the database the team spent several months on the ground in Christchurch documenting the damage first-hand. Council records, engineering reports, aerial photographs and Google Street View have also been used where it was not possible to record data from direct observation,.

Upon completion the database will be used to generate fragility curves for both retrofitted and unretrofitted URM buildings. There are currently no fragility curves for retrofitted URM buildings, and those that do exist for URM buildings are based on a small data set. New Zealand URM buildings have been shown by Russell et al (2006) to be similar to those in Australia and the USA, so the fragility curves derived here will have wide application.

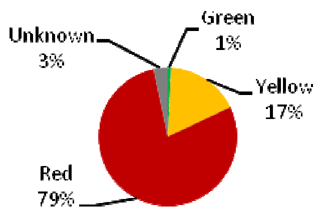
The database will also be interrogated to look for any trends between building typologies and types of damage modes and damage levels, and to determine the frequencies of different damage modes. It will be a record of the progression of damage to all the city's URM buildings, most of which have already been demolished. Furthermore, the database will be used in assessing the effectiveness of all URM building retrofits, and where deficiencies may be found improvements may be suggested.

3.2 Project Progress

Following the Darfield earthquake there were 389 non-residential URM buildings in the Christchurch CBD. By the time of the 22 February earthquake 21 of these buildings had been demolished leaving 368. Civil defence rapid damage assessments for these buildings are shown in Figure 5. It can be seen that in September 2010 only 10% of URM buildings were deemed too unsafe to enter (Red), while following 22 February this had risen to nearly 80%; only 1% of URM buildings were assessed as safe to be entered after February (Green).



a) September 2010 (389 buildings)



b) February 2011 (368 buildings)

Figure 5 - Usability rating of URM buildings in Christchurch CBD following a) 4 September 2010 and b) 22 February 2011 earthquakes

Of the 368 URM buildings left in the Christchurch CBD in February 2011, 62% were confirmed to have received some form of seismic retrofitting. Figure 6 shows the damage levels of buildings for different levels of retrofit and shows that only buildings strengthened to 67% of new buildings strength (NBS) or greater showed significantly lower levels of damage that unretrofitted buildings.

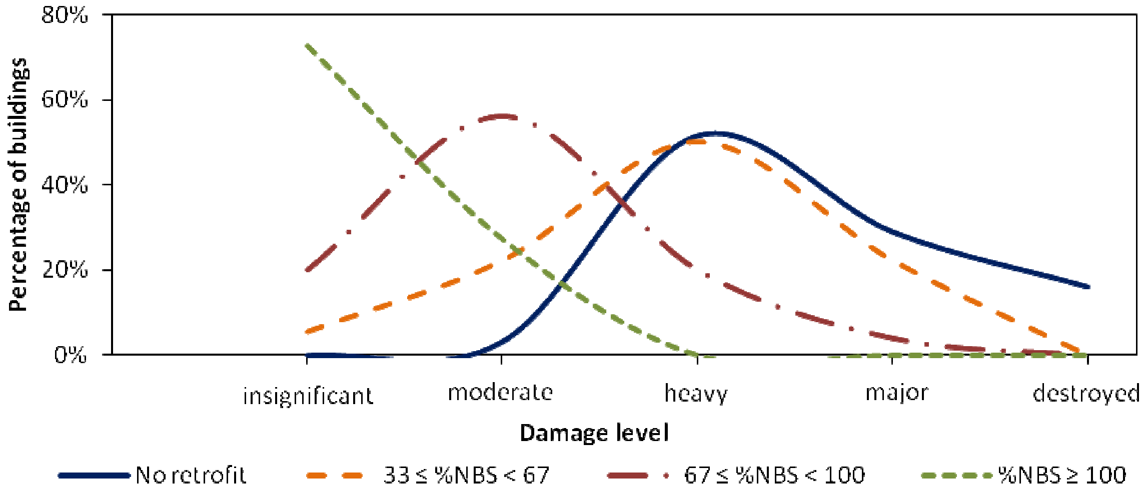


Figure 6 - Effects of retrofit level on damage level

3.3 Further details

Further details and preliminary results for Project Masonry have been reported by Dizhur et al (2011). More details on the performance of URM in the Christchurch earthquake sequence have been reported by Dizhur et al (2010), Griffith et al (2010), Ingham & Griffith (2011a, 2011b and 2011c), Ingham et al (2011) and Moon et al (2011). Further details on the performance of stone masonry has been reported by Senaldi et al (2011), further details on the performance of Churches has been reported by Leite et al (2012) and further details on the performance of residential brick veneer has been reported by Dizhur et al (2012a, 2012b). Additional information and further details on the performance of RCM and of stone masonry will be published in the near future.

4. REMAINING WORK:

The next stage of Project Masonry is to complete the URM database, and make it available to the international research community. From the completed database and additional information fragility functions for the Christchurch URM buildings will be developed.

It is likely the team will have the opportunity to return to Christchurch to collect further information on retrofits previously made to URM buildings. This information, together with the database of damage and the data already collected on seismic retrofits, will enable further evaluation of the performance of all types of seismic retrofits. This will enable the team to assess the effectiveness of all URM building retrofits and where deficiencies are found suggest improvements. Figure 7 shows a successfully retrofitted Christchurch masonry building in May 2011.

Figure 7 - Successfully retrofitted Christchurch URM building (May 2011)

5. SUMMARY AND CONCLUSIONS:

Project Masonry will result in the creation of a unique database which can be used by the public, recording the progression of damage to and characteristics of Christchurch's many masonry buildings. The database will allow researchers to see the frequency of different damage modes, and to look for trends in building types and damage types. It will enable the team to develop fragility curves and scrutinise the performance and effectiveness of different retrofit techniques. Although the database is not complete preliminary results have been widely reported, and already it has been shown that buildings must be strengthened to at least 67% of the code requirements for new buildings in order to significantly reduce the likelihood of suffering major damage.

6. ACKNOWLEDGEMENTS:

The New Zealand Natural Hazards Research Platform is thanked for providing funding for the collection of perishable data in Christchurch. The University of Adelaide and University of Auckland are thanked for their ongoing support.

7. REFERENCES:

Crowe, C. (2012). Canterbury Quake Live, http://www.canterburyquakelive.co.nz/ retrieved on 24th August 2012.

Dizhur, D., Ismail, N., Knox, C., Lumantarna, R. and Ingham, J.M. (2010). Performance of unreinforced and retrofitted masonry buildings during the 2010 Darfield Earthquake, Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 43, No 4, pp 321-339.

Dizhur, D., Ingham, J.M., Moon, L., Griffith, M.C., Schultz, A., Senaldi, I., Magenes, G., Dickie, J., Lissel, S., Centreno, J., Ventura, C., Leite, J. and Lourenco, P. (2011). Performance of masonry buildings and churches in the 22 February 2011 Christchurch earthquake. Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 44, No 4, pp 279-296.

Dizhur, D., Moon, L. And Ingham, J.M. (2012a). Observed performance of residential masonry veneer construction in the 2010/2011 Canterbury earthquake sequence, 15th International Brick and Block Masonry Conference, Florianopolis, Brazil.

Dizhur, D., Moon, L. And Ingham, J.M. (2012b). Observed performance of residential masonry veneer construction in the 2010/2011 Canterbury earthquake sequence, Earthquake Spectra, accepted pending revisions.

GeoNet (2012). Canterbury Quakes, http://www.geonet.org.nz/canterbury-quakes/ retrieved on 22nd August 2012.

Griffith, M., Ingham, J. and Moon, L. (2010). Implications of the 2010 Darfield (Christchurch, NZ) earthquake for Australia – are we ready? 2010 Australian Earthquake Engineering Society Conference, Perth, Western Australia.

Ingham, J., and Griffith, M.C. (2011a). Performance of unreinforced masonry buildings during the 2010 Darfield (Christchurch, NZ) earthquake. Australian Journal of Structural Engineering, Vol 11, No 3, pp 207-224.

Ingham, J.M., and Griffith, M.C. (2011b). The performance of unreinforced masonry buildings in the 2010/2011 Canterbury earthquake swarm. Report for Canterbury Earthquakes Royal Commission of Inquiry, Christchurch. Available online at http://canterbury.royalcommission.govt.nz/documents-by-key/20110920.46

Ingham, J.M., and Griffith, M.C. (2011c). The performance of earthquake strengthened URM buildings in the Christchurch CBD in the 22 February 2011 earthquake. Report for Canterbury Earthquakes Royal Commission of Inquiry, Christchurch. Available online at http://canterbury.royalcommission.govt.nz/documents-by-key/20111026.569

Ingham, J.M., Moon, L. and Griffith, M.C. (2011). Performance of masonry buildings in the 2010/2011 Canterbury earthquake swarm and implications for Australian Cities. 2011 Australian Earthquake Engineering Society Conference, Barossa Valley, South Australia.

Leite, J., Ingham, J.M. and Lourenco, P.B. (2012). Statistical assessment of damage to churches affected by the 2010-2011 Canterbury (New Zealand) earthquake sequence, Journal of Earthquake Engineering, accepted

Moon, L., Dizhur, D., Griffith, M.C., and Ingham, J.M. (2011). Performance of unreinforced clay brick masonry buildings during the 22nd February 2011 Christchurch earthquake, SESOC Journal, Vol 24, No 2, pp 59-84.

Retrofit Solutions (2011). Seismic Retrofit Solutions http://www.retrofitsolutions.org.nz/ retrieved on 24th August 2012.

Russell, A.P., Ingham, J. and Griffith, M.C. (2006). Comparing New Zealand's unreinforced masonry details with those of other seismically active countries. 7th International Masonry Conference, London, UK.

Russell, A.P. and Ingham, J.M. (2010). Prevalence of New Zealand's unreinforced masonry buildings. Bulletin of the New Zealand National Society for Earthquake Engineering, Vol 43, No 3, pp 182-200.

Senaldi, I., Magenes, G. and Ingham, J. (2011). Performance of Unreinforced Stone Masonry Buildings during the 2010/2011 Canterbury Earthquake Swarm and Retrofit Techniques for their Seismic Improvement, SESOC Journal, Vol 24, No 2, pp 44-57.