Australian Earthquake Engineering Society 2011 Conference, Nov 18-20,
Barossa Valley, South Australia

Performance of Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm and Implications for Australian Cities

Jason M. Ingham[1], Lisa Moon[2] and Michael C. Griffith[3]

1. Corresponding Author. Associate Professor, Department of Civil and Environmental Engineering, University of Auckland, New Zealand. Email: j.ingham@auckland.ac.nz

2. Doctoral Fellow, School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, South Australia 5005, Australia. Email: lmoon@civeng.adelaide.edu.au

3. Professor, School of Civil, Environmental and Mining Engineering, The University of Adelaide, Adelaide, South Australia 5005, Australia. Email: mcgrif@civeng.adelaide.edu.au

Abstract

Unreinforced masonry (URM) buildings have repeatedly been shown to perform poorly in large magnitude earthquakes, with both New Zealand and Australia having a history of past earthquakes that have resulted in fatalities due to collapsed URM buildings. A comparison is presented here of the URM building stock and the seismic vulnerability of Christchurch and Adelaide in order to demonstrate the relevance to Australian cities of observations in Christchurch resulting from the 2010/2011 Canterbury earthquake swarm.

It is shown that the materials, architecture and hence earthquake strength of URM buildings in both countries is comparable and that Adelaide and other cities of Australia have seismic vulnerability sufficient to cause major damage to their URM buildings should a design level earthquake occur. Such an earthquake is expected to cause major building damage, and fatalities should be expected.

Keywords: unreinforced masonry, architecture, earthquake, collapse

1 INTRODUCTION

It is well established that URM buildings perform poorly in large magnitude earthquakes, with a brief selection of relevant prior earthquakes that have caused major damage to URM buildings being detailed below:

- The M7.8 1931 Hawke's Bay (New Zealand) earthquake caused widespread devastation to URM buildings in the city of Napier (see Figure 1(a)), with 256 fatalities. This earthquake remains the worst disaster of any type to occur on New Zealand soil (Dowrick, 1998).

- The M5.6 1989 Newcastle (Australia) earthquake resulted in 13 fatalities and over 160 casualties. The earthquake damaged approximately 50,000 buildings (80% of these were homes) with unreinforced masonry buildings most widely affected (Page, 1991) (see Figure 1(b)).

- The M6.8 2007 Gisborne (New Zealand) earthquake caused damage to numerous unreinforced masonry buildings, including the collapse of 22 parapets (Davey and Blakie, 2010). An example of damage to URM buildings is shown in Figure 1(c).

- The M8.8 2010 Maule (Chile) earthquake caused extensive damage to older houses, churches and other buildings constructed of unreinforced masonry or adobe (EERI 2010).

- The M5.0 2010 Kalgoorlie-Boulder (Australia) earthquake occurred near the city of Kalgoorlie-Boulder, causing damage to historic buildings in Kalgoorlie-Boulder (see Figure 1(d)). There were no fatalities but two people were treated at Kalgoorlie Hospital for minor injuries resulting from the earthquake (Edwards et al., 2010).

The extensive damage to URM buildings in the 2010/2011 Canterbury earthquake swarm (Dizhur et al., 2010; Ingham et al., 2011; Ingham & Griffith, 2011a; Ingham & Griffith, 2011b; Ingham & Griffith, 2011c) has major implications for all other towns and cities of New Zealand, but also has direct relevance to Australian cities. To demonstrate this relevance a comparison is presented here between the cities of Christchurch and Adelaide, briefly focusing on the early settlement of each city, the architectural characteristics of the URM building stock of the two cities, and the reported seismic hazard of the two cities. From this comparison an assessment is made of the likely damage to URM buildings in Adelaide if an earthquake such as that having occurred in Christchurch on 22 February 2011 was to instead occur in the vicinity of Adelaide city.

1.1 Settlement of South Australia and New Zealand

European settlement of Australia and New Zealand dates from the arrival of the First Fleet into Port Jackson on Australia Day, 1788. The settlement was originally referred to as the colony of New South Wales, with New Zealand formed in 1840 as a new colony separating from the territory of New South Wales. In particular, South Australia was founded and settled in a similar manner to New Zealand, with both settlements being influenced by the ideas of Edward Gibbon Wakefield[1,2]. New

[1] See: http://en.wikipedia.org/wiki/Australia_-_New_Zealand_relations. Retrieved 23 August 2011.

Zealand participated as a member of the Federal Council of Australasia from 1885 but declined to accept the invitation to join the Commonwealth of Australia which was formed in 1901, remaining as a self-governing colony until becoming the Dominion of New Zealand in 1907.

(a) Overlooking Napier at the buildings destroyed by the 1931 earthquake and fires [Alexander Turnbull Library]

(b) Out-of-plane wall failure in the 1989 Newcastle earthquake

(c) Toppled parapet in the 2007 Gisborne earthquake

(d) Toppled parapet in Boulder after the 2010 Kalgoorlie-Boulder earthquake

Figure 1 Representative examples of damage to URM buildings in past New Zealand and Australian earthquakes

2 COMPARISON OF URM BUILDING STOCK

There are clear similarities in the characteristics of the URM building stock of New Zealand and Australia. Russell and Ingham (2008) reported on the architectural characteristics of the New Zealand URM building stock, with further details of the projected number and distribution of URM buildings throughout New Zealand presented in Russell and Ingham (2010).

---

[2] See: http://christchurchcitylibraries.com/heritage/earlychristchurch/edwardgibbonwakefield.asp. Retrieved 23 August 2011; and http://web.archive.org/web/20080730005101/http://www.samemory.sa.gov.au/site/page.cfm?u=758&c=3249. Retrieved 23 August 2011

2.1 URM Building Stock of Christchurch

Construction in early Christchurch was primarily of timber for residential and smaller commercial buildings until the late 1850s when prosperity from the wool trade allowed the transition from wood to stone and clay brick masonry for the construction of public buildings. The city's second town hall was built in stone in 1862-1863, the first stone building of Christ's College was constructed in 1863, and the stone Provincial Council Chambers was completed in 1864 (Wilson, 1984). The city was populated with mostly two and three storey buildings that were complementary in height to their neighbouring buildings.

Figure 2 Victorian Christchurch in 1885 (Coxhead, 1885)

Figure 2 and Figure 3 show photos of historical Christchurch from 1885 and 1910 respectively. By the 1920s wooden structures in the city were rare, and were seen as small irregular relics of the past.

Figure 3 New Zealand Express Company building, Christchurch's first 'skyscraper', photo circa 1910 (Brittenden Collection, 1910)

Post-earthquake inspection of Christchurch clay brick URM buildings has confirmed that the buildings are consistently constructed of relatively sound clay bricks, but that the mortar is often in poor condition, with strengths of approximately 1 MPa. Further details are provided in Ingham & Griffith (2011c).

2.2 URM Building Stock of Adelaide

Adelaide city is set on the Adelaide plain, with the Mt Lofty Ranges to the east and the south, and St Vincent's Gulf to the west (McDougall & Vines, 2006). Sandy, silty soils along the coast, particularly around Port Adelaide, are thought to have a high potential for liquefaction (Poulos et al., 1996).

The first buildings in the city of Adelaide, founded in 1836, were made from timber and mud. The discovery of easily accessible limestone and the prevalence of materials for making clay bricks and mortar, combined with the lack of suitable local timber for building, soon saw stone and masonry become the primary building material (McDougall & Vines, 2006). In the 1850s the Adelaide City Council banned timber construction due to the risk of fire. Other suitable stones for building were discovered at the base of the local hills, and these included Glen Osmond freestone, and the very popular bluestone. Bluestone buildings from the 1870s and 1880s account for roughly a third of Adelaide's current Heritage Listed buildings. Figure 4 shows Adelaide in the later part of the 19th Century, where all visible buildings are constructed from masonry.

(a) Victoria Square, Adelaide, around 1869, with the General Post Office visible on the left and the Town Hall visible in the centre (National Library of Australia)

(b) King William Street, Adelaide, 1889 (National Library of Australia)

Figure 4 Adelaide in the late 19th Century

Brick construction again became popular in about the 1890s, after the cost of dressed stone rose. Brick buildings of up to 4 stories remained the predominant type of construction until the development of steel framed and reinforced concrete buildings in the early part of the twentieth century, which allowed for the construction of taller buildings (Fisher, 1934). While Adelaide lost many of its original buildings to development in the 1950s and 1960s, many historic, unreinforced masonry buildings remain, contributing significantly to the character of the city (McDougall & Vines, 2006).

2.3 Assessment of similarities of URM building stock

Christchurch and Adelaide both have many URM and distinctive dressed stone buildings. As cities of approximately the same age, and sharing a Commonwealth background, the construction techniques used for the URM buildings were similar,

although the nature of the construction materials varied somewhat due to the use of local resources.

3 COMPARISON OF SEISMICITY

3.1 Seismicity of Christchurch

In Christchurch's founding years, the city and its surrounding boroughs were subjected to three medium sized earthquakes, and as many as seven smaller earthquakes that were centred closer to the north of the South Island (GeoNet, 2010). The earthquake of 5th June 1869 was the most damaging to the settlement of Christchurch, causing damage to chimneys, government buildings, churches and homes throughout the central city and the surrounding boroughs (Christchurch City Libraries, 2006). Twelve years later another earthquake was felt in Christchurch, but resulted in less damage than the previous 1869 earthquake (GeoNet, 2010). The only reported damage from the 1881 earthquake was that to the spire of the Cathedral, which was being constructed at the time.

The large earthquake that struck the Amuri District of Canterbury (about 100 km north of Christchurch) in 1888 is thought to have originated on the Hope Fault, which is part of the Marlborough Fault Zone (Stirling, 2008). A later earthquake in 1901 centred in Cheviot damaged the spire on the Cathedral for the third time in its short life and led to reconstruction of the spire in timber.

Although these earthquakes early in the development of Christchurch did result in some damage to buildings, and in particular to stone and clay brick masonry buildings, none of these earthquakes had an effect on the construction and design of buildings as did the 1931 Hawke's Bay earthquake (see Figure 1(a)).

3.2 Seismicity of Adelaide

Since being founded in 1836, several significant earthquakes have been felt, and caused damage, in Adelaide (PIRSA). In 1897 a 6.5 magnitude earthquake, with an epicentre just off the coast of Beachport in the south-east region of South Australia, struck south eastern Australia. Although over 300 km away minor damage was reported in Adelaide (Dyster, 1996). The 6.5 magnitude earthquake caused liquefaction and significant damage to nearby towns, and was followed by months of aftershocks (PIRSA). Just 5 years later, in 1902, there was a magnitude 6.0 earthquake near the town of Warooka, on Yorke Peninsula, located approximately 100 km to the west of Adelaide. Again this earthquake was widely felt in Adelaide and the rest of South Australia, and there was minor damage reported in Adelaide, including falling chimneys, plaster, and broken windows. Other earthquakes felt in the early days of Adelaide's settlement occurred in 1837, and again in 1883 (Dyster, 1996), with the former having occurred just one year into the founding of the city (Atlas SA).

It was in 1954 that Adelaide suffered its most damaging earthquake to date. A magnitude 5.4 earthquake occurred early on the morning of 1st March on the Eden-Burnside fault, which follows the Adelaide hills and runs from Adelaide's eastern suburbs to the southern suburbs (Geoscience Australia). The epicentre is believed to have been in the suburb of Darlington, approximately 15 km south of the city centre (Kerr-Grant, 1955). Damage was mainly confined to URM chimney damage and partial wall failures near the epicentre, but some houses near the epicentre were damaged beyond repair, and damage was reported to buildings in the city. Movement

on slopes resulted in much damage and ground disturbance in the hill suburb of Blackwood (Kerr-Grant, 1955). Fortunately there were no casualties, but insurance claims were made on 30,000 properties (Sinadinovski et al., 2006), totalling approximately AU$70 million in today's values (Sunday Mail, 2010). It is thought that this fault is still active and that further significant movement will occur along the fault in the near future (Sunday Mail, 2010). The estimated bill for a similar such event occurring today would be about $1 billion (Advertiser, 2009).

Adelaide's most recent earthquake was in April 2010, when a magnitude 3.8 event occurred in the hills town of Mt Barker, located approximately 40 kms from Adelaide (Geoscience Australia). No damage occurred but shaking was widely felt in Adelaide and as far away as Kangaroo Island (ABC News, 2010). State-wide, South Australia experiences about 200 earthquakes a year (Advertiser, 2009), with many of these earthquakes located along the Mt Lofty and Flinders Ranges (Kerr-Grant, 1955).

3.3 Assessment of similarities in seismicity

The cities of Christchurch and Adelaide have both experienced damage from numerous earthquakes during their short histories. As with Christchurch, none of the earthquakes that affected Adelaide had any significant effect on the design and construction of new buildings. Both cities are built in close proximity to fault lines that have a tendency to generate shallow earthquakes of less than 20 km depth. Although located near to the tectonic plate boundary and the Alpine Fault, the 2010/2011 Canterbury earthquake swarm occurred on shallow intra-plate faults. Both cities have potential for liquefaction.

Although the magnitude of the 1954 Adelaide earthquake (5.4) was significantly less than the magnitudes of the largest recent earthquakes in Christchurch, the Adelaide aftershock sequence lasted for months, with an aftershock occurring 6 months after the main event (Kerr-Grant, 1955). New springs were also reported following both events. In Christchurch, the statue of the Virgin Mary in the Catholic Cathedral rotated 180 degrees (Stuff.co.nz, 2011), while in 1954 in Adelaide a chimney on a central city bank and museum exhibits were also reported to have rotated (Kerr-Grant, 1955).

4 DAMAGE TO URM BUILDINGS IN THE 2010/2011 CANTERBURY EARTHQUAKE SWARM

There have been over 8400 earthquakes and aftershocks associated with what is referred to here as the '2010/2011 Canterbury earthquake swarm'[3]. This earthquake swarm has resulted in a number of different earthquakes and/or aftershocks that have caused damage, with the most notable events being on 4 September 2010, 26 December 2010, 22 February 2011 and 13 June 2011. In the 4 September 2011 earthquake almost all major structural damage occurred to URM buildings, with full details reported by Ingham and Griffith (2011b). Damage in the 22 February 2011 earthquake was far more severe, and with subsequent aftershocks has led to the demolition of at least 224 buildings (as of 25 July 2011), of which 85% were constructed of URM. A listing of these demolished building was reported by Ingham and Griffith (2011c) and the location of demolished URM buildings in the Christchurch Central Business District is shown in Figure 5.

[3] As of 23 August 2011. See http://www.christchurchquakemap.co.nz/

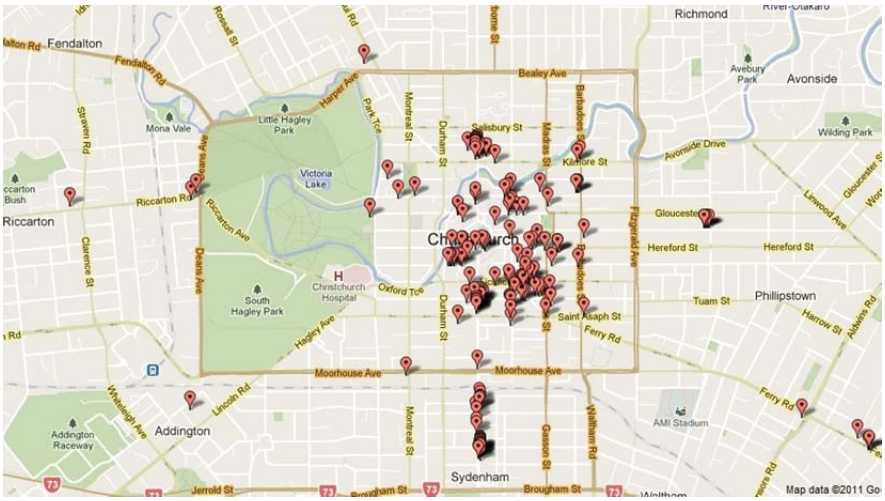

Figure 5 Location of demolished URM buildings in the Christchurch CBD (as at 25 July 2011)

4.1 Implications for Adelaide URM Building stock

Prior to the 2010/2011 Canterbury earthquake swarm it was estimated that there was approximately 3750 URM buildings in New Zealand, with approximately 36% of this stock having an earthquake strength of less than 33% New Building Standard[4] (%NBS) and a further 52% having between 33%-67%NBS.

Although Adelaide has a slightly lower seismic risk than New Zealand, it can be inferred that Adelaide's historic URM building stock is also likely to be well below current design standards. Therefore, in the event that an earthquake occurred in the Adelaide region having a similar magnitude to the earthquake that struck Christchurch on 22 February 2011, similar levels of damage should be expected, with associated fatalities and injuries.

5 CONCLUSIONS

The early development of Christchurch mirrored construction practices in early Australian cities, with this similarity demonstrated herein by comparing Christchurch and early Adelaide. It is shown that a shared Commonwealth background led to the construction of unreinforced masonry buildings in both cities that have similar architecture and employed similar construction techniques, and hence this building stock has analogous earthquake strength. Furthermore, both cities have a past history of experiencing repeated earthquakes and associated aftershock sequences, and both cities have liquefaction potential. Consequently it is concluded that the cities share a common hazard associated with the earthquake risk from un-improved unreinforced masonry buildings and that events in Christchurch have relevance for Adelaide, and by extension have relevance to other Australian cities also.

Christchurch city has been severely hit by the 2010/2011 Canterbury earthquake swarm. Damaged buildings in the central city continue to be demolished, but it is clear that the greatest level of damage occurred to unreinforced masonry buildings. Observed failure modes were consistent with those routinely documented in past

[4] A number that scores the expected earthquake performance of a building compared to that of an equivalent new building correctly designed to current standards and located at the same site

earthquakes, and it is clear that Australian cities have much to learn from recent experiences in Christchurch.

6 ACKNOWLEDGEMENTS

Alistair Russell, Dmytro Dizhur, Ronald Lumantarna, Cass Goodwin and Charlotte Knox are former or current postgraduate students from the University of Auckland who have assisted in the data collection that forms the background to the reported study. Paul Somerville is particularly thanked for his assistance with information on the seismic vulnerability of Adelaide city and the surrounding region.

7 REFERENCES

ABC News. (2010). 'Adelaide hit by earth tremor'. 17th April 2010 http://www.abc.net.au/news/2010-04-17/adelaide-hit-by-earth-tremor/399538, Retrieved September 2011

Advertiser, (2009). 'No one can predict when the next earthquake will strike Adelaide'. 15th February 2009. http://www.adelaidenow.com.au/news/south-australia/bigger-quake-to-come-says-expert/story-e6frea83-1225854750895, Retrieved August 2011.

Atlas South Australia. 'Natural Hazards'. http://www.atlas.sa.gov.au/go/resources/atlas-of-south-australia-1986/environment-resources/natural-hazards. Retrieved August 2011

Brittenden Collection (1910). View south-east from the Cathedral tower, C.C. 1199.

Coxhead, F. A. (1885). Victorian Christchurch, C. 182.

Davey, R. A., and Blaikie, E. L. (2010). 'Predicted and observed performance of masonry parapets in the 2007 Gisborne earthquake', 2010 Annual Conference of the New Zealand Society for Earthquake Engineering, Wellington, March 26-28; http://db.nzsee.org.nz/2010/Paper07.pdf

Dizhur, D., Ismail, N., Knox, C., Lumantarna, R., Ingham, J. M. (2010). 'Performance of Unreinforced and Retrofitted Masonry Buildings during the 2010 Darfield Earthquake', *Bulletin of the New Zealand Society for Earthquake Engineering*, 43(4), Dec., 321-339.

Dowrick, D. (1998). 'Damage and Intensities in the Magnitude 7.8 1931 Hawke's Bay, New Zealand, Earthquake'. *Bulletin of the New Zealand Society for Earthquake Engineering*, 30(2), 133-158.

Dyster, T. (1996). 'Strong shock of earthquake – The story of the four greatest earthquakes in the history of South Australia', Mines and Energy South Australia, Report Book 95/47, Adelaide

Edwards, M., Griffith, M., Wehner, M., Lam, N., Corby, N., Jakab, M. and Habili, N. (2010). 'The Kalgoorlie Earthquake of the 20th April 2010: Preliminary Damage Survey Outcomes'. Proceedings of the Australian Earthquake Engineering Society Conference, Perth.

EERI. (2010). 'The Mw 8.8 Chile Earthquake of February 27, 2010', Earthquake Engineering Research Institute Newsletter, June 2010, http://www.eeri.org/site/images/eeri_newsletter/2010_pdf/Chile10_insert.pdf; Retrieved 16 Sept 2010.

Fisher, N.C., (1934), 'Building Progress in Adelaide", The Advertiser, 24th January 1934, p. 26, Adelaide.

GeoNet. (2010). M 7.1, Darfield (Canterbury), September 4 2010. Retrieved on 12th July 2011. Available from: http://www.geonet.org.nz/earthquake/historic-earthquakes/top-nz/quake-13.html

Geoscience Australia. 'Earthquakes @ Geoscience Australia'. http://www.ga.gov.au/earthquakes/home.do, accessed August 2011

Ingham, J. M., Biggs, D. T., Moon, L. M. (2011). 'How did unreinforced masonry buildings perform in the February 2011 Christchurch earthquake', *The Structural Engineer*, 89(6), March, 14-18.

Ingham, J. M., Griffith, M. C. (2011a). 'Damage to unreinforced masonry structures by seismic activity' *The Structural Engineer*, 89(3), February, 14-15.

Ingham, J. M., Griffith, M. C. (2011b). 'Performance of unreinforced masonry buildings during the 2010 Darfield (Christchurch, NZ) earthquake, *Australian Journal of Structural Engineering, 11, 3,* 207-224.

Ingham, J. M., Griffith, M. C. (2011c). 'The Performance of Unreinforced Masonry Buildings in the 2010/2011 Canterbury Earthquake Swarm', Commissioned report to the Royal Commission of Inquiry into Building Failure Caused by the Canterbury Earthquake, http://canterbury.royalcommission.govt.nz/Technical-Report---The-Performance-of-Unreinforced-Masonry-Buildings-in-the-2010-2011-Canterbury-Earthquake-Swarm

Kerr-Grant, C. (1955). 'The Adelaide earthquake of 1st March, 1954'. Transactions of the Royal Society of South Australia, 79, pp. 185.

McDougall & Vines, (2006). 'The city of Adelaide – a thematic history', McDougall and Vines, Conservation and Heritage Consultants, Norwood, Australia

Page, A. (1991). 'The Newcastle earthquake – behaviour of masonry structures', Masonry International, Journal of the British Masonry Society, 5(1), 11-18.

PIRSA (Primary Industries and Resources, South Australia). 'PIRSA Minerals: Earthquakes'. http://www.pir.sa.gov.au/minerals/earthquakes, accessed August 2011

Poulos, H. G., Love, D. N. & Grounds R. W. (1996) 'Seismic zonation of the Adelaide area'. 7th Australian and New Zealand Conference on Geomechanics,. Adelaide, Australia, July.

Russell, A. P., & Ingham, J. M. (2008). 'Architectural Trends in the Characterisation of Unreinforced Masonry in New Zealand', 14th International Brick and Block Masonry Conference (14IBMAC), Sydney, Australia. 17 - 20 February.

Russell, A. P., & Ingham, J. M. (2010). "Prevalence of New Zealand's Unreinforced Masonry Buildings", Bulletin of the New Zealand Society for Earthquake Engineering, 43(3), 182-201.

Sinadinovski, C., Greenhaigh, S., & Love, D. (2006). 'Historical earthquakes: a case study for the Adelaide 1954 earthquake', Proceedings of the Australian

Earthquake Engineering Society Conference, Perth, Australia, 24 – 26 November

Stuff.co.nz. (2011). ‘Catholicism’s Canterbury spiritual home in doubt’. 10th March 2010 http://www.stuff.co.nz/national/christchurch-earthquake/4750684/Catholicisms-Canterbury-spiritual-home-in-doubt, accessed September 2011

Sunday Mail, 2010 ‘Bigger quake to come, says expert’. 19th April, 2010 http://www.adelaidenow.com.au/news/south-australia/bigger-quake-to-come-says-expert/story-e6frea83-1225854750895, accessed August 2011.

Wilson, J. (1984). Lost Christchurch. Springston, New Zealand: Te Waihora Press.