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IMPLICATIONS OF THE CANTERBURY EARTHQUAKE SEQUENCE FOR ADELAIDE, SOUTH AUSTRALIA

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ABSTRACT

The city of Christchurch has experienced over 10,000 aftershocks since the 4th of September 2010 earthquake of which approximately 50 have been greater than magnitude 5. The damage caused to URM buildings in Christchurch over this sequence of earthquakes has been well documented. Due to the similarity in age and construction of URM buildings in Adelaide, South Australia and Christchurch (they are sister cities, of similar age and heritage), an investigation was conducted to learn lessons for Adelaide based on the Christchurch experience. To this end, the number of URM buildings in the central business districts of both cities, the extent of seismic strengthening that exists in both cities, and the relative earthquake hazards for both cities were considered. This paper will report on these findings and recommend strategies that the city of Adelaide could consider to significantly reduce the seismic risk posed by URM buildings in future earthquake.

KEYWORDS: Adelaide, Canterbury, earthquake, seismic risk, unreinforced masonry

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 M5.4 1954 Adelaide (Australia) earthquake caused damage to an estimated 3,000 buildings and involved 30,000 insurance claims totalling 70 AUD million in today's value [1]. The damage was mainly confined to URM chimney damage and partial wall failures near the epicentre [2] (see Figure 1(a)).
- 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 [3] (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 [4]. An example of damage to URM buildings is shown in Figure 1(c).
- 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 [5].

Figure 1: Representative examples of damage to URM buildings in past New Zealand and Australian earthquakes: a) Damage to stone veneer house in the 1954 Adelaide Earthquake [2]; 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

The extensive damage to URM buildings in the 2010/2011 Canterbury earthquake swarm [6-10] has major implications for all other towns and cities of New Zealand and Australia. The earthquake sequence has had a major economic impact on New Zealand, with the rebuild being estimated to cost $20 billion, the equivalent of around 10 percent of Gross Domestic Product (GDP) [11]. As a comparison, the March 2011 earthquake and tsunami in Japan is estimated to have caused damage equivalent to around 3 to 4 percent of Japan's annual GDP.

To demonstrate the relevance of this damage to Australia 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.

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. New 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.

COMPARISON 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

Russell and Ingham [12] 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 [13].

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 [14]. The city was populated with mostly two and three storey buildings that were complementary in height to their neighbouring buildings

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 [11].

Figure 2 shows several examples of the similarities between the existing construction form in Adelaide City and that of Christchurch city before the 2010 Canterbury earthquake.

a

b

c

d

e

f

g

h

Figure 2: Representative examples URM buildings in Christchurch and Adelaide: a) Corner shops in Christchurch; b) Corner shops in Adelaide; c) Christchurch Theatre; d) Adelaide Arcade; e) Christchurch Mall; f) Adelaide Mall; g) Christchurch Cathedral; h) Bonython Hall, University 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 [15]. Sandy, silty soils along the coast, particularly around Port Adelaide, are thought to have a high potential for liquefaction [16]. 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 [15]. 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.

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 [17]. 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 [15].

Raw data obtained from Adelaide City Council shows that an estimated 35% of current buildings in Adelaide City were built before 1915 (see Figure 3). It is conceivable that almost all of these buildings and many of the buildings constructed after 1915 were made of unreinforced masonry material.

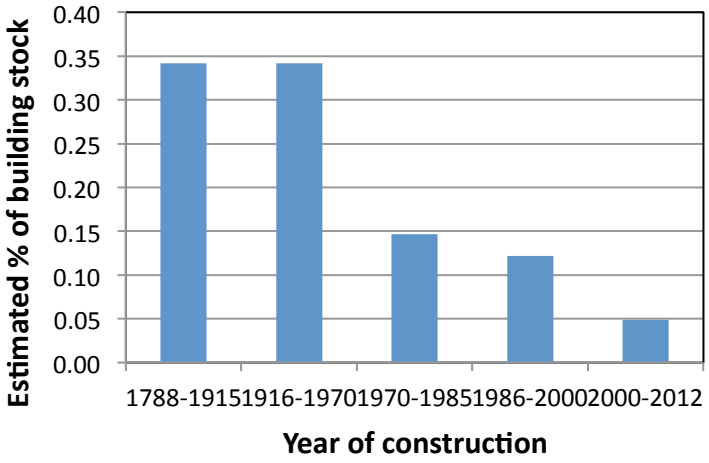

Figure 3: Approximate year of construction of buildings in Adelaide CBD

COMPARISON OF SEISMICITY

While New Zealand seismicity is mainly due to tectonic plate movements, earthquakes in Australia are characterised as intraplate earthquakes. New Zealand is located at the boundary of

the Australian and Pacific tectonic plates, which converge at a rate of 30-50 mm/yr depending on the location.

There are on average 2-3 earthquakes of M5 or greater occurring every year in Australia [18], while there are between 10 and 20 earthquakes of magnitude M5 or greater occurring every year in New Zealand. In the past 150 years, New Zealand has had approximately 15 earthquakes of magnitude 7 (M7) or greater, with centres less than 30 km deep. Although less seismically active, strong earthquakes are also frequent in Australia. In the past 100 years, 20 earthquakes of magnitude 6 (M6) or greater have occurred in continental Australia.

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 [19]. 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. Twelve years later another earthquake was felt in Christchurch, but resulted in less damage than the previous 1869 earthquake [19]. 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. 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.

The population centre of Adelaide has the highest earthquake risk of any capital city in Australia [20] with an effective peak ground acceleration coefficient given in the Australian earthquake loading code of 0.1g for the 1-in-500 year event (refer Figure 4). Since being founded in 1836, several significant earthquakes have been felt, and caused damage, in Adelaide [21]. 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 [22]. The 6.5 magnitude earthquake caused liquefaction and significant damage to nearby towns, and was followed by months of aftershocks [21]. 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 [22], with the former having occurred just one year into the founding of the city [23].

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 [24]. The epicentre is believed to have been in the suburb of Darlington, approximately 15 km south of the city centre [2]. 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 [2]. Fortunately there were no casualties, but insurance claims were made on 30,000 properties [25], totalling approximately AU$70 million in today's values [1]. It is thought that this fault is still active and that further significant movement will occur along the fault in the near future [1]. The estimated bill for a similar such event occurring today would be about $1 billion [26].

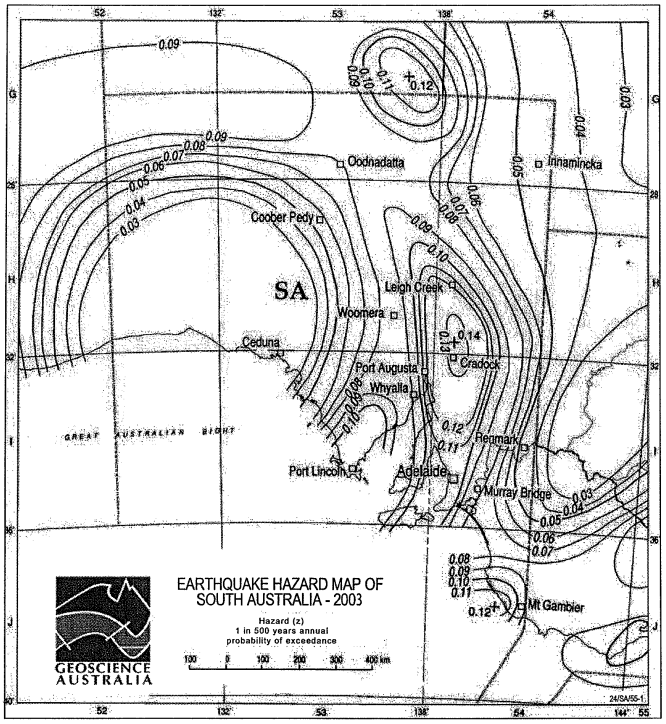

Figure 4. Earthquake hazard map for South Australia (SA 2003).

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 [24]. No damage occurred but shaking was widely felt in Adelaide and as far away as Kangaroo Island [27]. State-wide, South Australia experiences about 200 earthquakes a year [26], with many of these earthquakes located along the Mt Lofty and Flinders Ranges [2].

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 [2]. New springs were also reported following both events. In Christchurch, the statue of the Virgin Mary in the

Catholic Cathedral rotated 180 degrees [28], while in 1954 in Adelaide a chimney on a central city bank and museum exhibits were also reported to have rotated [2].

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'[1]. 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 [9]. 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 [10] and the location of demolished URM buildings in the Christchurch Central Business District is shown in Figure 5.

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

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[2] (%NBS) and a further 52% having between 33%-67%NBS.

Although Adelaide has a slightly lower earthquake hazard than Christchurch, Adelaide has a significantly larger number of URM buildings and almost no seismic strengthening has been undertaken. It can also be inferred that Adelaide's historic URM building stock that forms an estimated 35% of CBD buildings is 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, even greater levels of damage than that which occurred in Christchurch should be expected, with associated fatalities and injuries.

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

[2] 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

In addition to the seismic risk associated with the commercial and government URM buildings in Adelaide CBD, the majority of domestic construction in inner suburbs is also made of cavity brick walls and have unsecured brick chimneys. These buildings contribute further to the seismic risk associated with the existing URM construction in Adelaide.

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. Australia has a larger number of URM buildings and unlike New Zealand almost no seismic retrofitting has been undertaken. Consequently it is concluded that some Australian cities, and in particular Adelaide, has a similar or even greater risk associated with the seismic vulnerability of un-improved unreinforced masonry buildings. It is concluded that the events in Christchurch have relevance for Adelaide, and by extension have relevance to other Australian cities.

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 earthquakes and provide an opportunity for Australian cities to learn from recent experiences in Christchurch. Hence, it is concluded that there is a need to conduct such studies to get a realistic evaluation of the seismic risk of cities such as Adelaide so that resources can be allocated as appropriate to reduce the vulnerability of existing buildings.

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