

Implications of the 2010 Darfield (Christchurch, NZ) earthquake for Australia – are we ready?

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ABSTRACT

The 2010 Darfield earthquake is the largest earthquake on record to have occurred within 40 km of a major city and not cause any fatalities. In this paper the authors have reflected on their experiences in Christchurch following the earthquake with a view to what worked, what didn't, and what lessons can be learned from this for the benefit of Australian earthquake preparedness. Owing to the fact that most of the observed building damage occurred in Unreinforced Masonry (URM) construction, this paper focuses in particular on the authors' experience conducting rapid building damage assessment during the first 72 hours following the earthquake and more detailed examination of the performance of unreinforced masonry buildings with and without seismic retrofit interventions.

KEYWORDS

Unreinforced masonry, seismic retrofit, rapid damage assessment

INTRODUCTION

At 4.35 am on the morning of Saturday the 4th of September 2010 a magnitude 7.1 earthquake occurred approximately 40 km west of the city of Christchurch NZ at a depth of about 10 km (GNS 2010a), having an epicentre located near the town of Darfield. The ground motion had a peak ground acceleration of about 0.25g and a spectral acceleration in the plateau region of about 0.75g that corresponds well with the design spectra for a site class D soil site in Christchurch for spectral periods greater than 0.2 seconds. In general, the earthquake represented 67-100% of the ULS design event (Standards NZ 2004), depending upon the spectral period being considered (Figure 1), with reported damage consistent with MM8 on the Modified Mercalli intensity scale and it has been projected to be the 5th largest ever for insured losses (NZ Herald 2010).

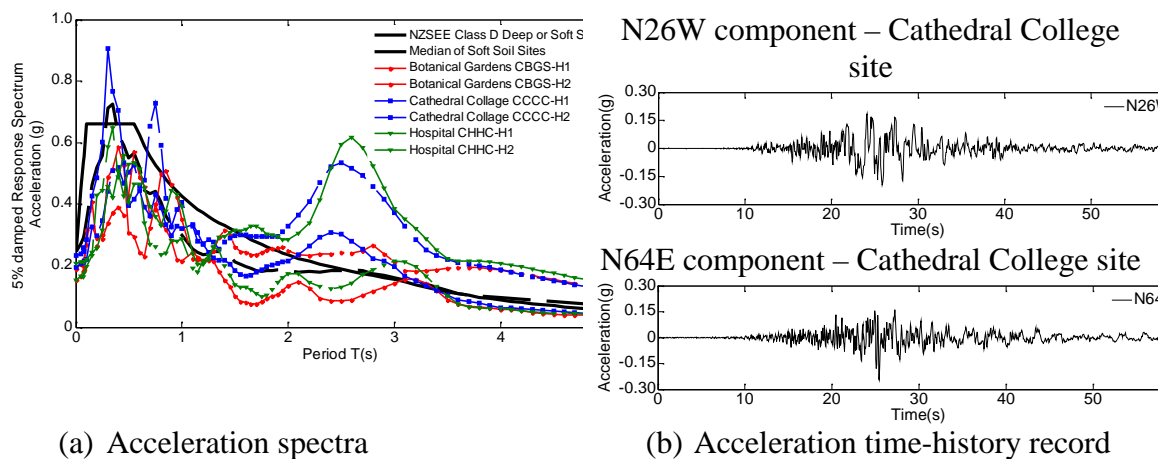


Figure 1. Details of earthquake ground motion (credit: GeoNet)

Immediately upon hearing news of the earthquake, the first two authors travelled to Christchurch uncertain as to how but hoping they could help with the immediate emergency response. In the end, their assistance was enthusiastically received and they spent three days assisting Christchurch City Council with rapid building damage assessment. Assisted by a team of PhD candidates from the Universities of Auckland and Adelaide, the authors were also able to document damage to URM buildings and in follow-up visits to further study some of the seismically retrofit URM buildings that performed well during the earthquake. The following sections of this paper report on the authors' experience during their first visit while engaged in the rapid building damage assessment phase of the emergency response, their observations of URM building response, and some lessons for Australia.

RAPID BUILDING DAMAGE ASSESSMENT

In general, the observed damage to URM buildings in the 2010 Darfield Earthquake was consistent with observed damage to URM buildings in past New Zealand and Australian earthquakes (Davey and Blaikie 2010, Dowrick 1998, Page 1991) and in numerous earthquakes from other countries. As part of the emergency response to this earthquake, the authors spent 72 hours assisting Christchurch City Council with building damage assessments, tagging buildings with either a green, yellow or red placard depending, respectively, upon whether a building was safe for public use, had limited accessibility for tenants/occupants, or was not accessible (refer to Figure 2). Each assessment team

consisted nominally of a structural engineer, an emergency services technician (normally a fire services employee), and a city council employee. On the first day, an Urban Search and Rescue technician also accompanied each team. It took nearly three days to assess all the buildings in the Christchurch CBD, although the task was complicated by three magnitude 5⁺ aftershocks that occurred on the Monday night/Tuesday morning which necessitated review of many buildings to determine whether their status needed changing. Rapid building assessment was essential for the city to reopen as much of the CBD as soon as possible and allow the recovery process to commence. Many examples of earthquake damaged URM buildings were observed during this exercise, as well as many examples of seismic retrofits to URM buildings that had performed well.



Figure 2. Building assessment notices.

The results from the interrogation of damage assessment information are reported in Figure 3. Figure 3a reports the ‘useability’ assignment of the 595 URM buildings assessed. Figure 3b reports the level of damage for the same URM buildings. Despite the known vulnerability of URM buildings to earthquake loading, only 34% of the 595 assessed URM buildings were judged to have more than 10% damage.

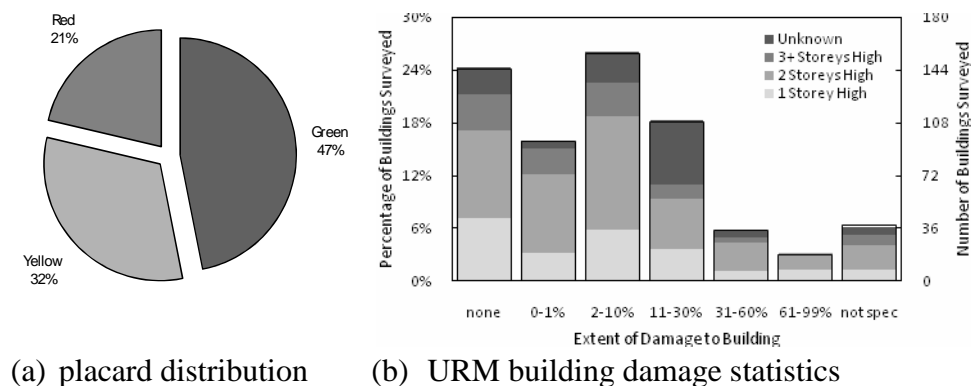


Figure 3. Damage statistics.

URM BUILDING RESPONSE

The architectural features of the URM building stock in the Canterbury region are consistent with the general form of URM buildings throughout both New Zealand and Australia (Russell and Ingham 2008; 2010). These buildings can be characterised as typically 2 or 3 stories in height, with 2 storey buildings being most common, and being either stand alone or row buildings, but with row buildings being most common (refer Figure 4). The most common occupancy type for the 595 URM buildings assessed was ‘commercial’ or ‘office buildings’, hence the majority of buildings were unoccupied at the time of the earthquake, significantly contributing to the lack of earthquake fatalities. A brief summary of the typical failure mechanisms are presented here. For a more

complete discussion of the behaviour of URM buildings during the 2010 Darfield earthquake, refer to Ingham and Griffith (2010).



Figure 4. Typical 2- and 3-storey URM buildings in Christchurch.

Material Properties

The general observation from the debris of collapsed URM walls was that the kiln fired clay bricks were generally of sound condition, but that the mortar was in poor condition. In most cases the fallen debris had collapsed into individual bricks, rather than as larger chunks of masonry debris and the mortar readily crumbled when subjected to finger pressure (refer Figure 5). However, it appears that superior mortar was often used in the ornate parapet above the centre of the wall facing the street, as this segment of the collapsed parapet often remained intact as it collapsed.



(a) relatively 'clean' bricks



(b) weak mortar crumbles between fingers

Figure 5. Masonry rubble from collapsed wall.

Chimneys

Unsupported or unreinforced brick chimneys performed poorly in the earthquake (Figure 6), with numerous chimney collapses occurring in domestic as well as small commercial buildings and churches. Many examples of badly damaged chimneys that were precariously balanced on rooftops were also seen (Figure 6b) and it was reported that one week after the earthquake, 14,000 insurance claims involving chimney damage had been received, from a total of 50,000 claims (NewstalkZB 2010). Removal of damaged chimneys to minimise further risk placed significant demand on emergency services personnel (Figure 6c). In contrast, Figure 6d shows an example of a braced chimney that performed well.



(a) Two damaged chimneys and gable wall.



(b) Unstable damaged chimney



(c) Emergency services remove chimney.



(d) Braced chimney performed well

Figure 6. Examples of chimney performance during the Darfield earthquake.

Gable end wall failures

Many gable end failures were observed, often collapsing onto or through the roof of an adjacent building as seen in Figure 7. However, there were also many gable ends that survived; many more than might have been expected, with the majority having some form of visible restraints that tied back to the roof structure. These examples are shown and discussed later (refer Figures 15-17).



(a) 93 Manchester St



(b) 816 Colombo St

Figure 7. Examples of gable end wall failures.

Parapet failures

Numerous parapet failures were observed along building frontages and along their side walls, and for several URM buildings located on corners, the parapets collapsed on both perpendicular walls (refer Figure 8). Restraint of URM parapets against lateral loads has routinely been implemented in New Zealand since the 1940s, so whilst it is difficult to see these restraints unless roof access is available, it is believed that the majority of parapets that exhibited no damage in the earthquake were provided with suitable lateral restraint. In several cases, it appears that parapets were braced back to the perpendicular parapet, which proved unsuccessful.



(a) Multiple front wall parapet failures

(b) Corner of Sandyford and Colombo St.

Figure 8. Examples of typical parapet failures.

Anchorage failures

Falling parapets typically landed on awnings which overloaded the awning tie rods causing collapse (Figure 8). Most awning supports comprised a tension rod tied back into the building through the front wall of the building. In most cases the force on the rod exceeded the capacity of the masonry wall anchorage, causing a punching shear failure in the masonry wall identified by a crater in the masonry (refer Figure 8a).

Wall failures

Out-of-plane wall failures were typically the result of poor or no anchorage of the wall to its supporting timber (floor or roof) diaphragm. Several examples of wall failure are shown below. Figure 9(a) shows a corner building that had walls fail in the out-of-plane direction along both directions. Figure 9(b) shows a 3-storey building where walls in the upper two stories suffered out-of-plane failures. In both of these instances, it appears that the walls were not carrying significant vertical gravity loads, other than their self weight, since the remaining roof structures appear to be largely undamaged.

Cavity wall construction is generally believed to be much less common in New Zealand than is solid multi-leaf (or multi-wythe) construction. However, cavity wall construction can be extremely vulnerable to out of plane failure in earthquakes in situations where the cavity ties were poorly installed, or more commonly have corroded over time, as the wall is then comparatively slender and less stable than for solid construction. Figure 10 shows examples of cavity wall buildings that suffered out-of-plane wall failures. In most cases, cavity ties were present but were insufficient to prevent the outer leaf from failing.



(a) Corner Worcester and Manchester St.



(b) 118 Manchester Street

Figure 9. Examples of out-of-plane failures in solid masonry walls.

In some cases wall-diaphragm anchors remained visible in the diaphragm after the wall had failed, again indicating that failure had occurred due to bed joint shear in the masonry (refer Figure 11). Figure 11(b) shows a situation where a diaphragm anchor had been embedded within the wall. It can be seen that the anchor successfully prevented the restrained wall from failing, but was not able to prevent toppling of the masonry above the anchor.



Figure 10. Examples of out-of-plane failures in cavity walls.



(a) Gable wall failure despite anchor



(b) Wall anchor still intact

Figure 11. Wall-to-diaphragm anchor details.

Return wall separation

Many buildings exhibited substantial cracking between their front wall and side (return) walls. This damage is not necessarily a catastrophic problem if stiff horizontal diaphragms are well connected to the walls in both directions, but where there is not good diaphragm connectivity, there is the potential for complete out-of-plane collapse of one or both walls. Figure 12 shows some examples where major cracking was observed between the side return walls and the front parapet and wall without collapse.

Other mechanisms

Several walls exhibited some damage to in-plane deformation where the cracks were mostly seen to pass vertically through the lintels over door or window openings. There were also several examples of URM buildings with different storey heights ‘pounding’ against each other. However, these mechanisms were not widely observed.



Figure 12. Examples of wall separation at corners of buildings.

Special buildings

160 Manchester Street is a 7-storey, heritage listed (NZ Historic Places Trust 2010), URM office building that was built in 1905 (Figure 13). The building suffered significant damage to its masonry piers at levels 3 and 4. After much debate, the city council gave approval to demolish the building as it poses a significant falling hazard to the dozen or so businesses and buildings within the 70 m radius ‘fall zone’.



(a) Overview of building



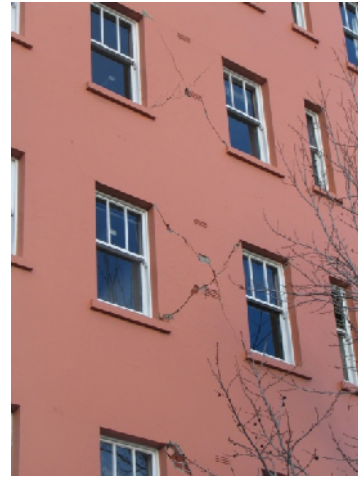
(b) North wall pier, level 3.

Figure 13. Manchester Courts building.

St Elmo Chambers is also a 7-storey building, reported to be a reinforced concrete frame building with external clay brick masonry piers. Owing to the absence of control joints between the masonry and concrete frame, the masonry piers attracted sufficient seismic in-plane forces to cause shear failure (refer Figure 14). Judging by the extent of cracking in the brickwork, it appears that the storey drifts were less than 1%, implying that the concrete frame was not pushed to its maximum capacity (strength or drift).



(a) Overview of building



(b) damaged brickwork

Figure 14. Views of St Elmo Chambers building in Montreal Street.

SEISMIC RETROFIT EXAMPLES

Because of the high level of earthquake hazard in New Zealand, the country has required URM buildings to be seismically assessed and retrofit where necessary. Consequently there are many examples of seismic retrofit interventions on URM buildings in Christchurch that were successful. A selection of these are reported in detail in Dizhur et al (2010). In the following section of this paper, examples of some of the most commonly observed schemes are described.

Successful wall anchorage

A significant feature of the earthquake was the number of occasions where wall-to-diaphragm (floor or roof) anchors performed well. Photographs showing this are presented in Figures 15-16. A typical wall-to-diaphragm anchor typically consists of a long 20 mm bolt with a large circular disk of about 150-200 mm diameter between the wall exterior and nut that clamped the disk to the wall.

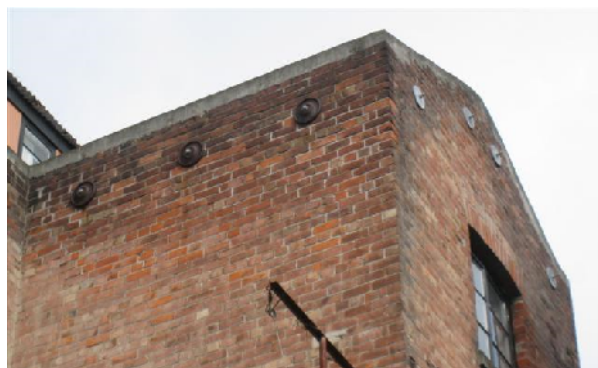
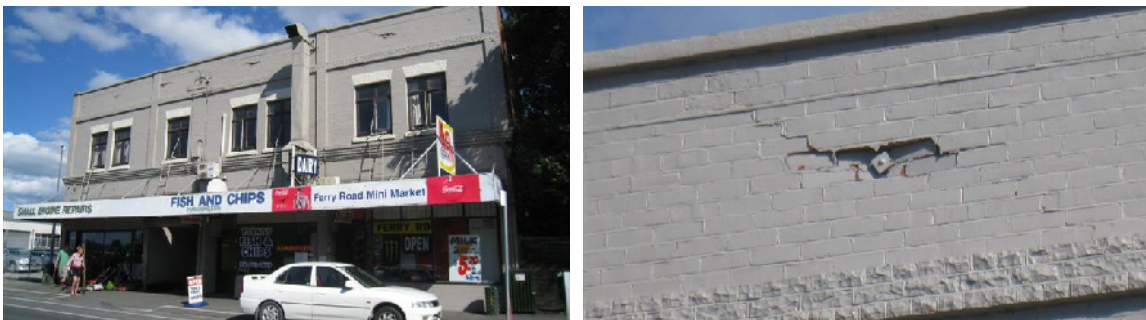


Figure 15. Successful gable end wall and side wall anchorages.



Figure 16. Successful wall-floor and wall-roof diaphragm anchorages.

Another interesting feature of this earthquake is the observation of walls that only partly failed, allowing for identification of the specific failure mode at its onset. An excellent example is a 2-storey URM building on Ferry Road (see Figure 17) where the front, street facing, wall of the building had started to fail out-of-plane despite the presence of wall-roof diaphragm anchors. As shown, the anchors were on the verge of pulling through the masonry wall. Internal inspection of the building revealed that the front wall had separated from the long side walls of the building and moved approximately 50 mm towards the road with respect to the ceiling/roof diaphragm.



(a) Building overview

(b) Detail of partial anchorage failure

Figure 17. Onset of wall-roof anchorage failure.

Diaphragm stiffening

Diaphragm stiffness has a significant effect on the behaviour of a building during earthquakes, as observed at the Malthouse Theatre (Figure 18). Prior to the earthquake, the stone masonry building from 1867 underwent an extensive seismic retrofit involving stiffening of floor and roof diaphragms and connecting it to the external walls.



Figure 18 – Malthouse Theatre



Figure 19 – Steel frame in roof

The roof diaphragm was stiffened through the addition of an internal steel frame (Figure 19). The frame was attached to the original timber roof trusses, and connected to the external walls. The floors were stiffened through the addition of blocking between joists (Figure 20a), and steel plates were added to connect some of the joists to the masonry walls (Figure 20b). Externally, diaphragm ties were visible on all sides at floor levels indicating that the floors had been anchored to the walls (Figure 20c).



(a) blocking of joists



(b) joist-wall connection



(c) diaphragm anchors – external view

Figure 20 – strengthening of floor diaphragm and wall anchors

Corner Connectors

In some buildings steel plates were observed connecting the front and side walls. Such ties prevent building facades collapsing as well as increasing the in plane and out of plane capacity of both walls. While it is not clear whether the two examples shown in Figure 21 were installed before or after the recent earthquake, the technique has the potential to improve the seismic performance of the buildings by ensuring greater interaction between return walls.



Figure 21 – Examples of corner ties

Lessons for Australia

Given the similarity in pre-1950 constructed URM buildings in Australia and New Zealand, there are some valuable lessons for Australia in what transpired in

Christchurch during and immediately after the 4 September 2010 Darfield earthquake. Some of these observations are listed here.

- USAR support - Within 1 hour the Christchurch-based USAR Task Force had mobilised and within 24 hours had verified that nobody was left trapped in any of the collapsed or partially collapsed buildings within the earthquake affected region. The Auckland and Palmerston North/Wellington USAR Task Forces were mostly on the ground assisting within 12 hours of the event and over the next two weeks 145 USAR Task Force members were activated. In addition, thirteen USAR Engineers had responded to the crisis by Saturday evening and over the following two weeks worked 60 person days assisting the three NZ USAR Task Forces to secure unsafe structures.
- In addition to USAR, the emergency services personnel (eg, fire, police, ambulance) and city officials were well prepared, knew what to do and how to do it. By Sunday morning, barely 24 hours after the earthquake, disaster management officials had set up the incident command centre in the City's new Art Gallery building, had allocated appropriately qualified and attired volunteers to rapid building damage assessment teams and were briefing the teams on their assignments, protocols, and agreed safety procedures.
- Significantly, the Christchurch City local government had no state or provincial government to liaise with, they dealt directly with the national government and disaster managers. This interaction appears to have gone off quite smoothly and effectively. Will Australia's extra tier of government allow such efficient mobilisation of resources such as inter-state USAR team assistance?
- All the paperwork (eg, assessment forms and building assessment placards) was ready to go. Would anyone in your local council, or state, know where to find a rapid building damage assessment form?
- The NZSEE/IPENZ/CPEng structural engineers were knowledgeable and sufficient numbers were available as volunteers for damage assessment from day one to enable all buildings in the CBD to be covered within 48 hours. Are sufficient numbers of suitably qualified structural engineers available in most Australian cities?
- As noted earlier, the earthquake occurred early in the morning so most of the worst damaged buildings had no occupants. Hence, there were no lives lost as a direct consequence of the earthquake – an amazing statistic given the earthquake's size and proximity to Christchurch. Nevertheless, had this occurred during business hours the storey would have been dramatically different.
- Strong government policy to seismically 'strengthen' earthquake prone buildings. This is evidenced by policies at both the local and national level (Christchurch City Council 2010, NZ Parliament 2004, NZSEE 2006). This has ensured a relatively widespread take-up of seismic retrofit for URM buildings. This clearly has not occurred in Australia to the degree that it has in NZ.
- As noted earlier in the paper, there were many examples of retrofit schemes that worked – diaphragm stiffening, wall-to-diaphragm connections, chimney and parapet tie-backs. The most common forms of damage involved out-of-plane failure mechanisms in URM buildings and chimneys in all forms of construction.

- Besides helping to minimise structural damage, seismic retrofit had the benefits of reducing damage to stock and minimising business interruption costs. It is expected that for many businesses the interruption to income, damage to premises and loss of stock associated with the earthquake will be significant. With the evolution of new materials and the development of new, alternative retrofit techniques, many more (NZ) building owners will be undertaking seismic retrofit in the near future. How about in Australia?

Notwithstanding all of the ‘successes’ observed by the authors, there were a number of ‘problems’, or areas, where the emergency response could be further improved.

- Getting consistency between the many damage assessment teams is a challenge. Managers must make it clear whether they want the teams to be assessing risk with regard to the usual ‘design magnitude earthquake’ for ultimate limit strength design or only for the anticipated aftershock magnitude events.
- It was also unclear as to how to assign damage ratios – some examples could have been useful and would have helped with consistency.
- Management of the ‘data’ collected on assessment forms and communicating that information back to the teams (through daily briefing sessions?) could help reduce confusion in the field where it was observed that some teams were duplicating assessments of other teams. Interfacing the assessment data with other council databases such as “where the URM buildings were located’ and ‘which URM buildings have been retrofit’ could be done to target stretched resources to the most likely to be damaged structures first.

On balance, the local Christchurch and National Disaster Management Teams did an outstanding job in coordinating the formal emergency services capability as well as substantial volunteer manpower to respond quickly and effectively to the earthquake. Australia should take every opportunity to learn from this event and ensure that when a major Australian city is struck by a similar size earthquake that we can respond and recover as well as Christchurch.

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