Section 3:

Observed performance of unreinforced masonry buildings in the 2010/2011 Canterbury earthquake swarm

As previously noted in section 1.4, there have been over 3690 earthquakes and aftershocks associated with what is referred to here as the '2010/2011 Canterbury earthquake swarm'. In this section, attention is specifically given to the damage caused by the 4th September 2010 'Darfield earthquake' (M7.1) and the 22nd February 2011 'Christchurch earthquake' (M6.3) to URM buildings within the Christchurch Central Business District (CBD), which is defined here as the area bounded by the four avenues (Bealey, Fitzgerald, Moorhouse and Deans) and Harper Avenue. Other experts will discuss the seismological aspects of these two earthquakes. However, for completeness it is noted that whilst the Darfield earthquake was greater in its Richter magnitude (M7.1), its epicentre was located much further away (approximately 40 km) from the Christchurch CBD than was the M6.3 'Christchurch earthquake' whose epicentre was only 10 km from the Christchurch CBD (refer to Figure 3.1).

3.1 Damage to URM buildings from the 4 September 2010 earthquake

Post-earthquake inspection of building performance led to 595 URM buildings being assessed. It is believed that the majority of un-assessed URM buildings were undamaged and were located outside the primary inspection zone associated with the CBD and arterial routes extending from the central city. General features of the 595 assessed URM buildings are reported in Figure 3.2, indicating that the majority of buildings were either 1 or 2 storey, consistent with prior findings by Russell & Ingham (2010) (see also Figure 2.9). Figure 3.2(c) shows that the most common occupancy type was commercial or office buildings, and hence the majority of buildings were unoccupied at the time of the 4 September 2010 earthquake, significantly contributing to the lack of direct earthquake fatalities. The survey forms contained a field to record the estimated gross floor area of the building, and thus the estimated building footprint could be determined once accounting for the number of stories (see Figure 3.2(b)). Unfortunately the data are incomplete as only 301 entries were recorded for the 595 separate buildings assessed. It is not possible to establish from the database whether individual entries belonged to a stand-alone or a row building.

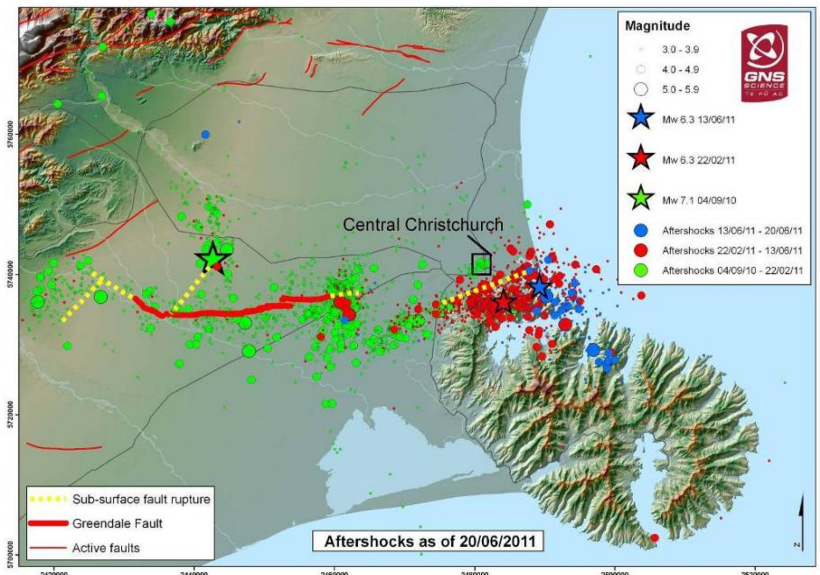
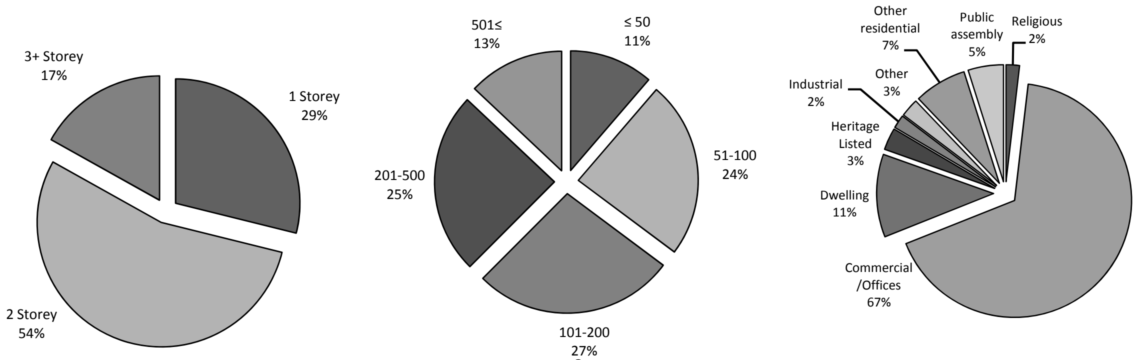


Figure 3.1 Epicentre locations for Sept 2010 and Feb 2011 earthquakes (from http://www.geonet.org.nz/canterbury-quakes/)



(a) Storey height (595 entries) **(b) Footprint area (m^2; 301 entries)** **(c) Occupancy type (595 entries)**

Figure 3.2 Building characteristics derived from interrogation of the inspection database (September 2010)

3.1.1 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 (refer to Figure 3.3(a)). When rubbing the mortar that was adhered to bricks it was routinely found that the mortar readily crumbled when subjected to finger pressure (refer Figure 3.3(b)), suggesting that the mortar compression strength was very low. 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 the parapet collapsed (refer Figure 3.4).

(a) Masonry rubble showing 'clean' bricks **(b) Weak mortar crumbles between fingers**

Figure 3.3 Masonry rubble from collapsed wall

3.1.2 Building damage statistics

In general, the observed damage to URM buildings in the 2010 Darfield Earthquake was consistent with the expected seismic performance of this building form, and consistent with observed damage to URM buildings both in past New Zealand and Australian earthquakes 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. Many examples of earthquake damage were observed during this exercise, as well as many examples of seismic retrofits to URM buildings that had performed well.

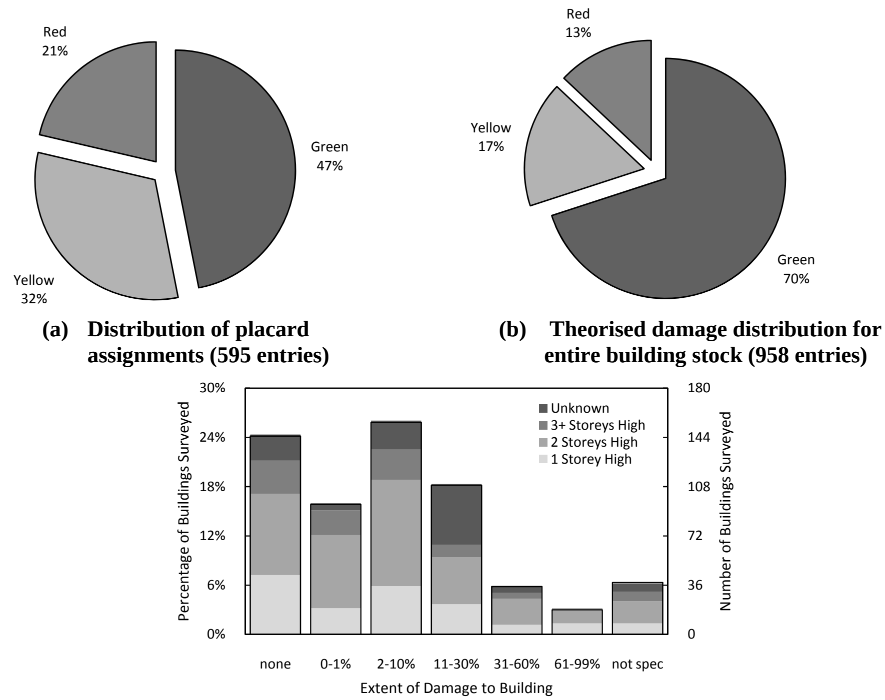
(a) Solid section of masonry gable

(b) Solid section of parapet

Figure 3.4 Large sections of masonry intact after fall from buildings

The results of the damage assessment are reported in Figure 3.5. Figure 3.5(a) reports the 'useability' assignment of the 595 URM buildings assessed. In consultation with staff of Christchurch City Council it was assumed that the remainder of the URM buildings thought to exist in Christchurch probably had a green tag usability rating, and so a theorised damage distribution for the entire URM building stock of Christchurch is shown in Figure 3.5(b).

Figure 3.5(c) reports the level of damage in percentage terms for the 595 buildings that were surveyed by the Rapid Building Assessment teams. The values recorded by the teams for each building surveyed were simply estimates (excluding contents damage). Despite the known vulnerability of URM buildings to earthquake loading, 395 of the 595 buildings (66%) were rated as having 10% damage or less, with only 162 (34%) of the buildings assessed as having more than 10% damage. It was also possible to study the distribution of damage dependent on storey height (Figure 3.5(c)), with the data indicating no definitive trend and a comparatively uniform level of damage assigned to buildings in each height category.



(a) Distribution of placard assignments (595 entries)

(b) Theorised damage distribution for entire building stock (958 entries)

(c) Extent of building damage

Figure 3.5 Damage statistics for the 4 September 2010 earthquake

3.1.3 **Chimneys**

Unsupported or unreinforced brick chimneys performed poorly in the earthquake (Figure 3.6), with numerous chimney collapses occurring in domestic as well as small commercial buildings and some churches. Many examples of badly damaged chimneys that were precariously balanced on rooftops were also seen (Figure 3.6(b)) 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). Emergency services personnel were in significant demand, being deployed to remove damaged chimneys in order to minimize further risk and eliminate these 'falling hazards' (Figure 3.6(c)). In contrast, Figure 3.6(d) shows an example of a braced chimney that performed well. Note that Figure 3.6(b) shows further evidence of the poor performance of mortar during the earthquake.

(a) Two damaged chimneys and gable wall

(b) Unstable damaged chimney

(c) Emergency service workers remove chimney

(d) Braced chimney performed well

Figure 3.6 Examples of chimney performance during the Darfield earthquake

3.1.4 Gable end wall failures

Many gable end wall failures were observed, often collapsing onto or through the roof of an adjacent building (refer to Figure 3.6(a) and Figure 3.7). 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 Figure 3.14 and Figure 3.15).

(a) 93 Manchester St

(b) 816 Colombo St

(c) Montreal-Armagh street corner

(d) Kilmore-Montreal street corner

Figure 3.7 Examples of gable end wall failures

3.1.5 Parapet failures

Numerous parapet failures were observed along both the building frontage and along their side walls. For several URM buildings located on the corners of intersections, the parapets collapsed on both perpendicular walls (refer Figure 3.8). Restraint of URM parapets against lateral loads has routinely been implemented 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 Street

(c) Side wall parapet collapse onto roof.

(d) Corner Columbo and Tuam Street

Figure 3.8 Examples of typical parapet failures

3.1.6 Anchorage failures

Falling parapets typically landed on awnings, resulting in an overloading of the braces that supported these awnings, leading to collapse. Most awning supports in Christchurch involved a tension rod tied back into the building through the front wall of the building. Many of these connections appear to consist of a long, roughly 25 mm diameter rod, with a rectangular steel plate (about 5 mm thick) at the wall end that is about 50 mm wide x 450 mm long and fastened to the rod and positioned either inside the brick wall or in the centre of a masonry pier or wall. 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 3.9(a)).