Figure 3.21 Examples of wall separation at corners of buildings

3.1.13 Pounding

Several instances of damage due to buildings pounding against each other during the earthquake were observed. Figure 3.22 shows how the shorter building in the centre, which has different floor heights than the building to the left, damaged the column of the taller building at its top storey.

(a) Building overview **(b) Close-up of column** **(c) Close-up of column**

Figure 3.22 Example of building pounding damage

3.1.14 Special buildings

160 Manchester Street was a 7-storey office building that is reported to consist of load bearing masonry and was the most significant masonry building, at least in terms of height, in Christchurch (Figure 3.23). It is a registered heritage building and is a significant part of the fabric of the Christchurch city landscape. Unfortunately, the building suffered significant damage in the earthquake. The bottom two stories are reported to be reinforced concrete while the top five stories are reported to have load

bearing unreinforced masonry piers around the exterior of the building and a steel frame internally (columns spaced roughly at 5 m) with timber floors throughout (New Zealand Historic Places Trust, 2010). The masonry piers, having dimensions of approximately 1200 x 900 mm, were badly cracked at levels 3 and 4 (Figure 3.24). This damage was most likely due to the transition from concrete to masonry at level 3 and the fact that the adjoining 2-storey building located along the southern wall side stopped providing lateral support at that level. It appears that the lift core had received some strengthening previously, as well as the roof, perhaps in the late 1980s as reported by the New Zealand Historic Places Trust (2010). Close up photographs of the masonry piers at levels 3 and 4 show the primary damage that concerned the assessment teams (Figure 3.24). Further inspection by the assessment team exposed the internal face of one pier on the western face of the building to reveal that the external cracking continued through the entire pier thickness.

Figure 3.23 Manchester Courts building (view from NW)

(a) North wall piers, levels 3-4

(b) West wall piers, levels 4-5

Figure 3.24 Damage to masonry piers of Manchester Courts building at levels 3-5

Two days after the main earthquake, structural engineers met with Urban Search and Rescue Team leaders and city officials to determine a strategy for making the structure safe enough for building contractors and engineers to enter to determine more fully the extent of damage and the viability of repair. Four days after the main earthquake, the building had survived one M5.4 and three M5.1 aftershocks. After extensive deliberations the decision was taken to demolish the building.

St Elmo Court was also a 7-storey building that was 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, it appeared that the masonry piers attracted sufficient seismic in-plane forces to cause shear failure (refer Figure 3.25). However, once the masonry cracked the seismic loads were transferred to the concrete frame. Judging by the extent of cracking in the brickwork, it appeared that the storey drifts developed during the 4 September 2010 earthquake were less than 1%, implying that the concrete frame was not pushed to its maximum capacity (strength or drift). Following the 4 September 2010 earthquake the authors were not able to inspect the building from inside.

The building was demolished after the 22 February 2011 earthquake.

(a) Overview of building

(b) Close-up of damage to brickwork

Figure 3.25 Views of St Elmo Court building, 47 Hereford Street

3.1.15 Building damage due to ground deformation

Perhaps the most striking aspect overall of the 2010/2011 Canterbury earthquake swarm was the extensive amount of liquefaction and ground deformation that occurred. These phenomena were not seen to a significant extent in the Christchurch CBD region containing the highest density of URM buildings, but did impact on a number of timber framed structures with masonry veneer. As shown in Figure 3.26, several cases of extreme ground deformation that affected URM buildings were observed outside of the CBD, and there were numerous cases where large crack widths formed in residential timber framed structures having a masonry veneer (Figure 3.26(c)). There were also cases where ground liquefaction had resulted in masonry structures having sunk into the ground (Figure 3.26(d)).

(a) Damage to masonry veneer due to ground deformation

(b) Wide cracks due to ground deformation

(c) Masonry veneer damage to recently built residence.

(d) Damage due to liquefaction

Figure 3.26 Damage to buildings having masonry veneer over timber frame, due to ground deformation and liquefaction

3.1.16 **Summary**

On the few occasions that building owners or occupants were in attendance it was possible to gain access to the interior of URM buildings and often observe that some separation had occurred between the floor and/or roof diaphragms and the masonry walls (in the out-of-plane direction). This damage was not easy to detect from the outside of a building, so that the damage reported from building surveys in the first 72 hours could be assumed to be a lower bound estimate of structural damage to URM buildings.

On the other hand, there were many instances of buildings that were structurally sound themselves but had suffered damage or were yellow or red-tagged owing to 'falling hazards' from neighbouring buildings. In some instances it was clear that a parapet or chimney from a neighbouring building had fallen onto or through the roof, being the only damage to the structure. In other instances, a building abutting a taller building with damaged parapet or gable side walls or chimney was given a yellow card (no public access) due only to the falling hazard posed by the structure next door. These examples of 'collateral damage and risk', such as that posed by 160 Manchester Street, and the associated business interruption costs, make the financial impact of this earthquake much greater than just the cost of rebuilding.

3.2 Damage to stone masonry buildings from the 22 February 2011 earthquake

Statistics regarding the damage to clay brick URM buildings from the 22 February 2011 Christchurch earthquake are still being compiled. It is expected that these statistics will be included in the final report to the Commission[6]. Consequently this section exclusively addresses unreinforced stone masonry buildings, including a comparison of damage reported following the 4 September 2010 and the 22 February 2011 earthquake.

The damage assessment inspections that were undertaken in September 2010 and again in April and May 2011 identified 90 unreinforced stone masonry buildings in Christchurch, many of which are included on the Historic Places Trust register of heritage buildings. Most of these stone masonry buildings were constructed between 1850 and 1930 and are masterpieces by important architects of the period, such as Benjamin Mountfort, Cecil Woods and John Goddard Collins, and are excellent examples of the Gothic Revival style. Significant examples include the Canterbury Provincial Council Buildings (see also section 5.1.3) and the former Canterbury University College, which is now referred to as the Christchurch Arts Centre (see also section 5.1.4). Besides their architectural value, these buildings represent the history of a relatively young country and for this reason resources should be directed towards their preservation and seismic improvement.

Most of the buildings considered in the study are now used for a variety of public functions, ranging from churches to public offices, schools and colleges, and incorporating both commercial and cultural activities.

The stone masonry buildings in Christchurch have similar characteristics both in terms of architectural features and in the details of their construction. This observation derives primarily from the fact that most of these structures were built over a comparatively short time period and were designed mostly by the same architects or architectural firms.

The vast majority of structures, and in particular those constructed in the Gothic Revival style, are characterized by structural peripheral masonry walls that may be connected, depending on the size of the building, to an internal frame structure constituted of cast

[6] Whilst final statistics are not available for damage to clay brick masonry buildings in earthquakes that occurred after 4 September 2010, it is clear from observations during the field survey work conducted since 22 February 2011 that the failure modes in later events were similar, with damage in the 22 February 2011 earthquake being both more prevalent and more severe in nature.

iron or steel columns and timber beams or to internal masonry walls that support flexible timber floor diaphragms and timber roof trusses. However, there are a few commercial buildings in the Christchurch CBD that are characterized by slender stone masonry piers in the front façade with the other perimeter walls constructed of multiple leaves of clay brick. These buildings are typically 2 or 3 stories in height, with 2 storey buildings being most common, and may be either stand alone or row buildings. The wall sections can be of different types:

- Three leaf masonry walls, with dressed or undressed basalt or lava flow stone units on the outer leaves (wythes) while the internal core consists of rubble masonry fill (Figure 3.27(a));
- Three leaf masonry walls, with the outer layers in Oamaru sandstone and with a poured concrete core, such as for the Catholic Cathedral of the Blessed Sacrament (Figure 3.27(b) and section 5.1.2);
- Two leaf walls, with the front façade layer being of dressed stone, either dressed basalt or bluestone blocks, or undressed lava flow units, and the back leaf constituted by one or two layers of clay bricks, usually with a common bond pattern, with the possible presence of a cavity or of poured concrete between the inner and outer leaves (Figure 3.27(c)).

(a) Cramner Court - 3 leaves with rubble fill.

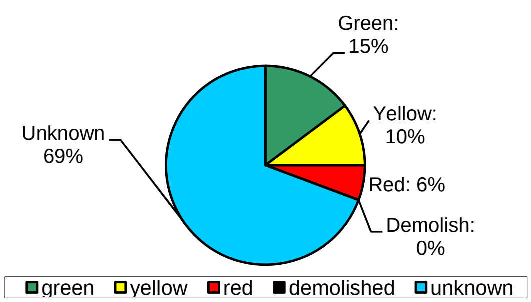
(b) Cathedral of the Blessed Sacrament - Oamaru stone with poured concrete.

(c) St. Luke's Anglican Church - stone front façade with clay bricks back layers.

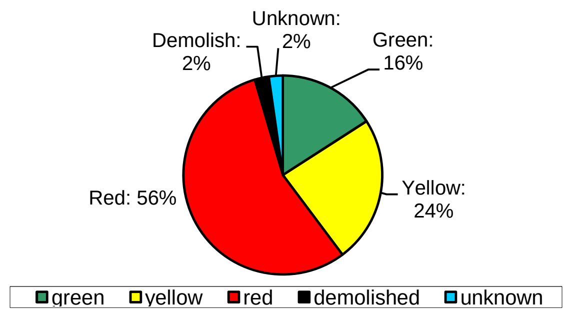
Figure 3.27 Representative examples of wall cross-sections for Christchurch stone masonry buildings

3.2.1 Post-earthquake assessment and building damage statistics

The seismic performance of stone masonry buildings was partially identified by considering the safety assessment data that was collected following the earthquakes that occurred in September 2010 and February 2011. Figure 3.28 shows the distribution of building safety assessments after the 4 September 2010 and 22 February 2011 earthquakes, respectively. From this figure it can be seen that there was a significant escalation of damage due to the continuing earthquake activity in the Christchurch region. Figure 3.29 gives a further breakdown of this data for the two major earthquakes on the basis of building usage. As noted earlier, green placards were assigned to structures that were deemed to be safe to re-enter and required no further intervention; yellow placards were applied to buildings whose accessibility was restricted due to minor damage; and red placards were applied to buildings that were considered unsafe and likely to have a moderate to severe level of damage. At the time of the study reported here, several buildings had been demolished already because of the hazard associated with their damage state. As shown in Figure 3.28, only 16% of the stone masonry buildings surveyed were assigned a green placard after the 22 February 2011 earthquake whereas approximately 50% (15% green compared with 16% yellow and red) had green placards after the 4 September 2010 earthquake.

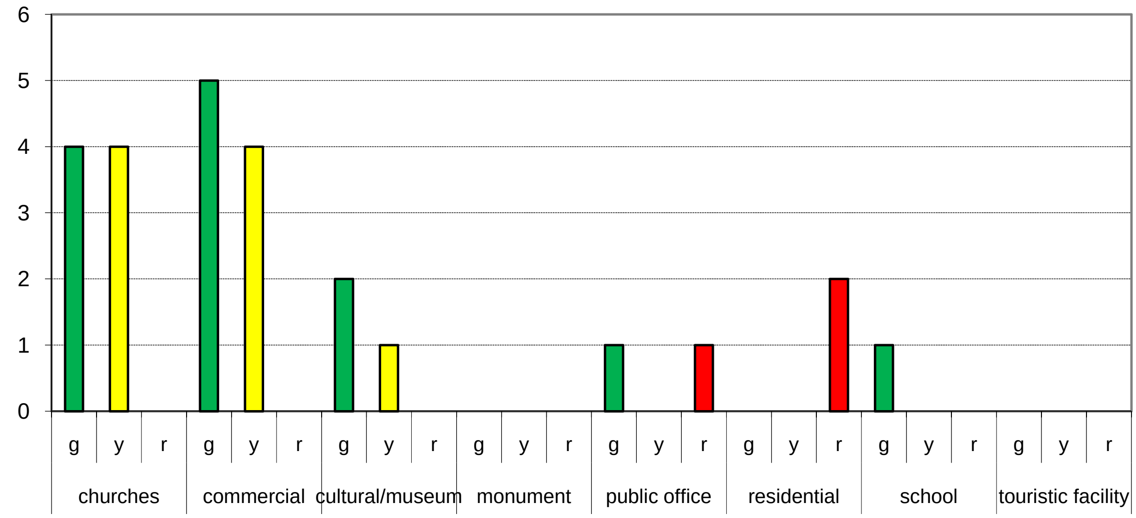


(a) After September 2010

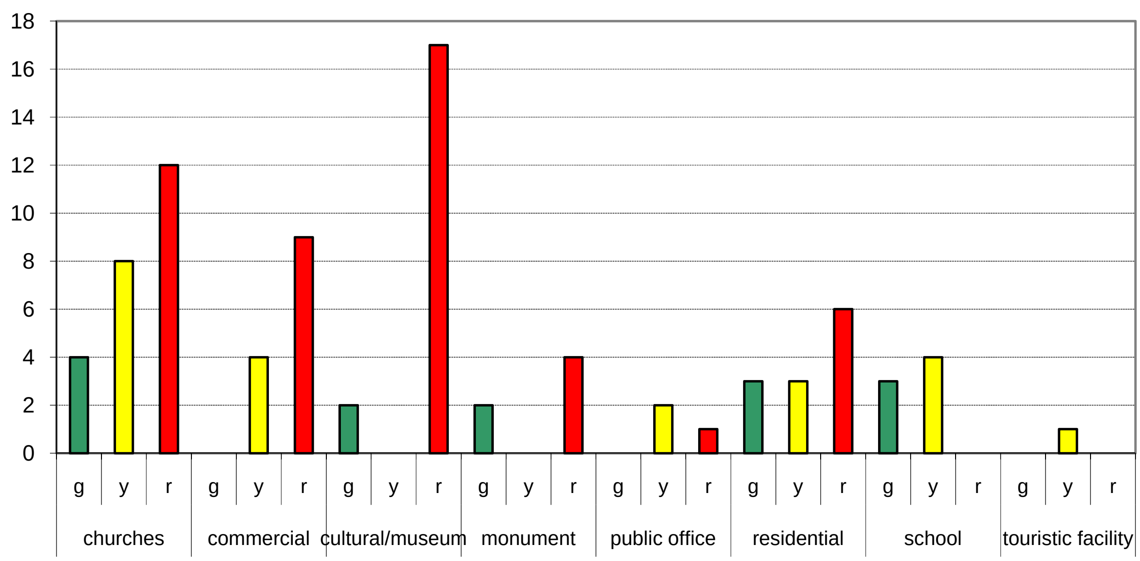


(b) Data updated 07 June 2011

Figure 3.28: Distribution of safety evaluation placarding applied to stone masonry buildings



(a) after September 2010



(b) after February 2011

Figure 3.29 Distribution of safety evaluation placarding applied to stone masonry buildings differentiated by building usage