UNREINFORCED CLAY BRICK MASONRY BUILDINGS

Unreinforced masonry buildings are an important part of New Zealand's heritage architecture. A survey of the damage to these buildings following the 22 February 2011 earthquake highlighted the importance of seismic retrofitting.

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Starting in March 2011, the damage to unreinforced stone and clay brick masonry (URM) buildings in the Christchurch area was assessed and the seismic performance documented. Over 650 unreinforced clay brick masonry buildings were inspected and 90 unreinforced stone masonry buildings identified, many on the Historic Places Trust register of heritage buildings. A damage statistics database was compiled by combining safety placarding results and post-earthquake inspections.

The majority of structures, and particularly those in the Gothic Revival style, are characterised by external structural masonry walls connected to an internal frame structure of cast iron or steel columns and timber beams or to internal masonry walls that support flexible timber floor diaphragms and timber roof trusses.

Majority of demolitions URM

Between 22 February and 25 July 2011, almost 200 URM buildings were demolished – approximately 85% of demolitions during this time. Few of the remaining URM buildings are currently fit to be occupied.

Brick and mortar samples collected from Christchurch URM buildings following the 4 September 2010 and 22 February 2011 earthquakes showed the typically lime mortar had a low compressive strength and could be crumbled by finger pressure.

Performance of anchor connections

The connections between the flexible timber diaphragm and the URM walls are critical to the building's seismic performance. These connections often consist of steel anchors installed during construction or added later. Anchors are also used for parapet bracing and veneer restraint.

Punching shear failure was by far the most common failure type, with bricks or mortar around the anchor failing (see Figure 1). In some cases, whole bricks or sections of masonry remained attached to the anchor. Successful anchor performance did not necessarily prevent out-of-plane wall failure where there was one or two-way bending (see Figure 2).

Wall damage and failures

In a large number of cases in the Christchurch central business district (CBD), in-plane damage was on the north and south-facing walls, while out-of-plane damage was on the east and west walls. This indicates shaking in the CBD was predominantly east–west (see Figure 3).

The higher seismic forces generated by the 22 February 2011 earthquake caused greater and more widespread damage to Christchurch's URM building stock than the 4 September 2010 earthquake. Building damage also got worse with the continuing earthquakes and aftershocks (see Figure 4).

Chimney, parapet and gable failures were evident, along with return-wall separation and out-of-plane failure.

OUT-OF-PLANE WALL FAILURE

Out-of-plane wall failures were common following the 22 February 2011 aftershock, with many 2-storey buildings losing their entire front façades or upper storey walls (see Figure 5).

The two primary types of out-of-plane wall failure are:

- vertical bending of the wall (or one-way bending), which tends to occur in longer walls or walls without side supports
- two-way bending, which requires support of at least one vertical edge of a wall.

The failure may be a cantilever type with the entire top section of a wall collapsing. When the top section is well connected to the diaphragm, failure may occur in vertical or two-way bending.

Figure 1: Punching shear failure of roof rafter anchor plates. This type of damage was widespread.

Figure 2: Row of successful wall-diaphragm anchors, despite the wall failure beneath.

Figure 3: Looking at the southeast corner of this building, the in-plane shear cracking is only visible on the south face indicating the predominant shaking was east–west.

MORE CAVITY CONSTRUCTION

Cavity construction was believed to be less common in New Zealand URM than interconnected multi-leaf walls. However, cavity construction was found in almost half of the URM buildings surveyed in Christchurch.

In cavity construction, an air gap is left between wythes or leaves of brick, allowing the outer veneer layer to 'peel' separately. A single layer of outer brick veneer is the most common type of cavity construction, with the inner section being two or more leaves thick, although double leaves on each side of the cavity were observed.

Figure 4: Sequence of damage to a wall following the series of earthquake events.

Leaves on either side of a cavity are typically held together by regularly spaced metal cavity ties. Some cavity ties in failed cavity walls were rusted.

IN-PLANE WALL FAILURES

Damage in the plane of URM walls was widely observed including:

- diagonal shear cracking in piers, spandrels and walls
- shear sliding on mortar or between storeys (see Figure 6)
- in-plane rocking of piers and toe crushing.

Diaphragm deformations

Evidence of timber diaphragm movement was seen in many buildings, and the effect varied from cracked plaster to complete wall failure.

In some, excessive movement of the diaphragm pushed the building's side walls beyond their out-of-plane deflection capacity, resulting in the collapse of the wall.

Pounding and liquefaction

Pounding was commonly seen in closely spaced buildings in the CBD. In many cases, pounding appears to have been the loading condition principally responsible for in-plane wall failures (see Figure 7).

The 4 September 2011 earthquake and aftershocks also caused significant building damage from ground deformations due to liquefaction, primarily in the eastern suburbs, and lateral spreading near rivers.

Retrofitted buildings

The performance of retrofitted URM buildings varied greatly. A few showed little visible sign of earthquake damage, but others were severely damaged. Insufficient connections was one of the main contributors to failure. Poor construction quality of anchorages epoxied into the masonry was also frequently observed.

In most cases, installed retrofits prevented entire building collapse, allowing building occupants to safely escape.

Some of the more common types of retrofit observed in Christchurch were:

- steel strong-backs, which help prevent out-of-plane failure of URM walls (see Figure 8)
- steel moment frames, which increase the lateral capacity of a building (see Figure 9) →

Figure 5: Out-of-plane failure of second storey parapet and façade.

Figure 6: The corner detail shows this upper storey has slid by 200 mm.

Figure 7: Pounding between two buildings causing diagonal shear cracking in URM building.

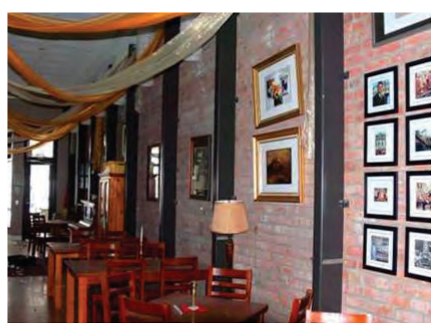

Figure 8: Steel strong-backs provide out-of-plane support for URM walls.

- application of shotcrete, which increases the in-plane and out-of-plane strength of the walls (see Figure 10).

Retrofits that generally performed well were:

- well designed to reduce torsional effects and tied the masonry together
- steel strong-backs and steel moment frames.

Buildings that had been well maintained over their life generally performed better. Having a weathertight envelope reduced water damage to the masonry and timber diaphragms.

The veneer of the building in Figure 11 was retrofitted by inserting high-strength twisted stainless steel rods to tie the veneer to the main walls. In the aftershock on 22 February 2011, these rods showed signs of movement, with the rod cover being pushed out or becoming completed dislodged, suggesting differential movement between the leaves on either side of the cavity. The outer leaf of the wall collapsed during the 13 June 2011 earthquake.

Lessons for other cities

Although it is too late to save many of Christchurch's historic URM buildings, the lessons learnt during and after the Canterbury earthquake swarm of 2010/2011 can be applied to URM buildings throughout the rest of New Zealand and around the world. Well designed and constructed seismic retrofits of entire buildings greatly improves their performance during earthquakes.

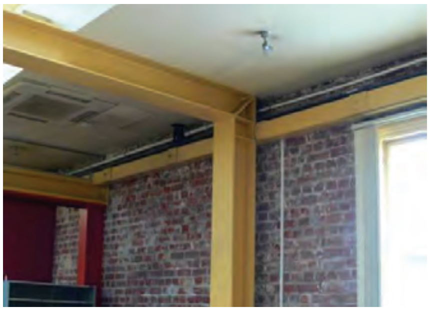

Figure 9: Internal view of steel moment frame.

Figure 10: Retrofit with shotcrete on the rear of a building.

Figure 11: Although this URM had been retrofitted with high-strength twisted stainless steel ties, it failed during the 13 June 2011 earthquake.