Section 5:

Set of representative buildings

In this section a recommendation is made for a set of unreinforced masonry (URM) buildings that are representative of the Christchurch URM building stock in terms of both their architectural characteristics and their observed earthquake performance. This section was prepared in response to the scope of the report as requested by the Royal Commission and outlined in section 1.1. Several iconic stone masonry buildings are first identified, recognising their historic significance to the people of Christchurch and their contribution to the character of the city. A selection of clay brick buildings is then presented for consideration, with attention first given to the performance of clay brick building that had been retrofitted, followed by details of several unretrofitted building that currently remain, and concluding with a selection of clay brick buildings that have since been demolished.

For each building a short description of the character and history of the building is provided, followed by a brief explanation for the reason why this building is recommended for consideration by the members of the Royal Commission as being representative of URM construction throughout New Zealand.

5.1 Stone masonry buildings

5.1.1 Christchurch Cathedral

The cornerstone of Christchurch Cathedral was laid on 16 December 1864, but financial problems saw the Cathedral's completion delayed between 1865 and 1873. In 1873 a new resident architect, New Zealander Benjamin Mountfort, took over the project and construction began again. The nave and tower were consecrated on 1 November 1881, but other parts of the Cathedral were not finished until 1904. The Cathedral underwent major renovations during 2006–2007, including the replacement of the original slate roof tiles. The February 2011 Christchurch earthquake destroyed the spire and part of the tower – and severely damaged the structure of the remaining building. The Cathedral had been damaged previously by earthquakes in 1881, 1888, 1901 and 2010[9].

Christchurch Cathedral occupies a position of prominence at the centre of the Christchurch Square which is in the centre of the CBD. For many people the damage to the Cathedral has been a defining image of the events in Christchurch since 4 September 2010. The Cathedral's masonry construction is complex, with dressed outer stone and a clay brick interior. Anchor plates that were installed in the gable end wall above the rose window (see Figure 5.1(a)) helped to secure the wall during the 22 February 2011 earthquake, presumably enabling those within the Cathedral at the time to safely exit through the front door. Unfortunately the rose window sustained damage on 13 June 2011. The building is recommended for attention largely for its historic significance, but also because it is currently anticipated that the Cathedral will be rebuilt. Structural improvements to the Cathedral prior to 4 September 2010 appear to have been effective, but clearly have not prevented substantial damage to the building. See Figure 3.30 and Figure 3.34 for further images of the Cathedral.

(a) Condition after 22 February 2011

(b) Condition after 13 June 2011

Figure 5.1 Damage to Christchurch Cathedral

5.1.2 Christchurch Basilica

The Cathedral of the Blessed Sacrament, commonly known as the Christchurch Basilica, was designed by architect Francis Petre. Construction started in 1901 and was complete by 1905. The Basilica was designed in the neo-classical style and is faced in Oamaru limestone. The solid walls are constructed of reinforced concrete and faced in stone. The roofs to both bell towers and the east dome are timber framed with a copper finish. The

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[9] This text is taken from: http://www.historic.org.nz/TheRegister/RegisterSearch/RegisterResults.aspx?RID=46

nave roof is timber framed and finished in terracotta tiles. The flat roofs east of the nave around the base of the dome are constructed of reinforced concrete. The building is held to be the finest renaissance style building in New Zealand and the most outstanding of all Petre's many designs[10].

The Basilica is a complex structure exhibiting characteristics of both unreinforced masonry and early concrete construction (see Figure 3.27(b)). The primary reason for identifying this building for attention is because of its distinctive architectural character as it is not particularly representative of a larger stock of buildings in New Zealand. Currently the principal concern regarding the stability of the Basilica is to deconstruct the dome because of the falling hazard posed by the damaged drum at the dome base (see Figure 5.2(a)). Damage to the Basilica's clock towers (see Figure 5.2(b)) suggests parallels with the collapse to the spire of the Christchurch Cathedral as shown in Figure 5.1.

(a) Damage to drum at base of dome **(b) Damage to clock towers**

Figure 5.2 Damage to the Christchurch Basilica (images taken post-February 2011)

5.1.3 Canterbury Provincial Council Buildings

The foundation stone for the Canterbury Provincial Council Buildings was laid in January 1858. The first set of buildings were a two-storey timber building, forming an L shape along the Durham Street frontage, with the Timber Chamber, modelled on 14th and 16th century English manorial halls, being the meeting room for the Provincial Council. The Stone Chamber was the new meeting room for the council; it was larger than the Timber Chamber to cope with an increased size of the council. The Stone

[10] This text is reproduced with modifications from: http://www.historic.org.nz/TheRegister/RegisterSearch/RegisterResults.aspx?RID=47

Chamber's interior was described as provincial architect Benjamin Mountfort's most impressive achievement[11].

This set of buildings is recommended for further attention both because of the historic significance of the buildings and because the failure mode observed for the stone masonry construction (see Figure 5.3) is representative of failures observed in other stone masonry buildings, and in particular several stone masonry churches. See also Figure 3.35.

(a) Stone masonry collapse **(b) Collapse of the Stone Chamber**

Figure 5.3 Earthquake damage to the Canterbury Provincial Council Building (images taken post-February 2011)

5.1.4 Christchurch Arts Centre

> "The Arts Centre in Christchurch is a collection of fine Gothic Revival buildings, formerly used by the Canterbury University College (now the University of Canterbury) and two of the city's secondary schools. Construction on the buildings for the Canterbury University College, which later became the University of Canterbury, began with the building of the Clock Tower block. This building, which opened in 1877 and was designed by Benjamin Woolfield Mountfort, was the first building in New Zealand to be designed specifically for a university"[12].

The Christchurch Arts Centre complex is composed of stone masonry buildings that merit investigation because of the number of seismic retrofit technologies that have been previously installed within the complex. Three technologies in particular merit attention, being the innovative use of horizontal and vertical unbonded post-tensioning that appears from the exterior to have been highly successful in preventing damage (see Figure 5.4(a)), the use of wall-diaphragm anchor plates that in most cases have

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[11] This text is reproduced with modifications from: http://www.historic.org.nz/TheRegister/RegisterSearch/RegisterResults.aspx?RID=45

[12] This text is taken from: http://www.historic.org.nz/TheRegister/RegisterSearch/RegisterResults.aspx?RID=7301

effectively restrained the major part of gable end walls although some damage at the top of gables has occurred (see Figure 5.4(b)), and the use of surface bonded fibre reinforced polymers to the interior of the building. Documenting the successful performance (or otherwise) of these technologies will be useful when considering appropriate seismic improvement techniques for other iconic stone masonry buildings. See also Figure 3.32, Figure 3.38 and Figure 3.40.

(a) Good performance of stone masonry building with horizontal and vertical external post-tensioning

(b) Poor performance of stone masonry tower and top of gable

Figure 5.4 Mixed performance of the Christchurch Arts Centre (images taken post-February 2011)

5.1.5 Former City Malthouse

The Malthouse is a stone masonry building that was constructed in 1867-1872 (see Figure 5.5). The Malthouse is one of New Zealand's oldest buildings[13] has three levels, with a half basement, timber floor and roof diaphragms and an irregular floor plan. The building was used as a Malthouse until 1955, when it was converted to the Canterbury Children's Theatre. Between 1972 and 1984 the Malthouse went through several architectural renovations that included seismic retrofit. The roof was raised in two stages: the first stage involved raising half of the roof in 1992 and the second stage involving raising the remainder of the roof in 2003. Seismic retrofit of the Malthouse in 2003 was found to be insufficient and consequently the building's lateral load resisting system was again updated in 2008. The seismic retrofit involved injecting grout into the rubble masonry walls, strengthening the roof by introducing new steel trusses (see Figure 5.5(b)), strengthening of the floor diaphragms by replacing the plywood and introducing additional timber blocking (see Figure 5.5(c)), and installing new wall-diaphragm anchors. It was established from discussions with the manager that the cost of retrofit was approximately $NZ 750,000. The building appears to have performed well.

[13] http://www.historic.org.nz/TheRegister/RegisterSearch/RegisterResults.aspx?RID=1902

(a) Exterior view

(b) Interior view

(c) Additional blocking at ground floor

(d) Wall-floor diaphragm connection

Figure 5.5 Former City Malthouse (images taken post-September 2010)

5.2 Retrofitted clay brick masonry buildings

In general, retrofitted URM buildings performed well in the 4 September 2010 earthquake, with minor or no earthquake damage observed. Partial or complete collapse of parapets and chimneys were amongst the most prevalent damage observed in retrofitted URM buildings, and was attributed to insufficient lateral support of these building components. Out-of-plane separation of the façade from the side walls was observed in some URM buildings, and was the result of insufficient wall-diaphragm anchorage. Most of these seismic retrofits were more severely tested in the 22 February 2011, with mixed success.

Most of the retrofitted URM buildings had significant heritage value based on their era of construction and aesthetic quality and therefore a carefully considered, minimally invasive retrofit solution had been preferred. The addition of a secondary structural system was found to be a common retrofit solution, with fewer buildings adopting alternative solutions such as steel strapping, the addition of surface bonded fibre reinforced polymer (FRP) sheets, and post-tensioning. Case study examples of the performance of retrofitted URM buildings that were inspected following the 4 September 2010 earthquake are briefly reported below.

5.2.1 The Smokehouse, 650 Ferry Road

The Smokehouse, located at 650 Ferry Road, is a two storey isolated clay brick URM building as shown in Figure 5.6. The building's construction date can be confirmed as pre-1930's, and the building has been categorised as a heritage building by the Christchurch City Council. The building's foot print is approximately square, having dimensions of 13 m along Ferry Road and 10 m along Catherine Street. The original mortar is a weak lime/cement mortar with large grain size sand. In places the original mortar was re-pointed with strong cement mortar.

(a) Exterior view **(b) Interior view showing added steel frames**

Figure 5.6 The Smokehouse, 650 Ferry Road (images taken post-September 2010)

The Smokehouse was seismically retrofitted in 2007 by introducing secondary moment resisting steel frames. This retrofit also included alterations to the internal layout, which involved partial removal of original external walls and replacement with moment resisting steel frames that created openings into the adjoining new section of the building (see Figure 5.6(b)), and also infilling one window at the second floor level. The retrofit design of the building won the New Zealand Architectural Award in 2008 for initiative in retention, restoration and extension of a significant building and its adaption to new uses[14]. The building appears to have performed well, with no significant signs of earthquake damage observed.

5.2.2 TSB Bank Building, 130 Hereford Street

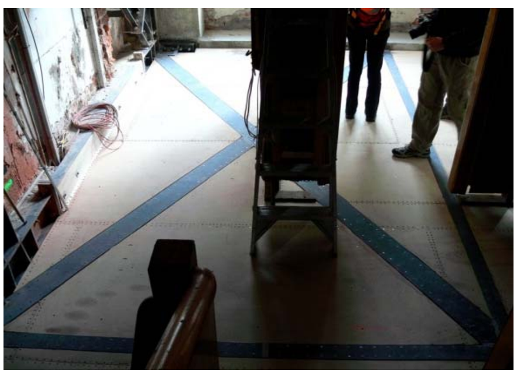
130 Hereford Street is a 1920's 3+ storey isolated URM building, currently owned and occupied by TSB Bank Limited. The original structural system consisted of URM load bearing clay brick walls, built in the Chicago style architecture as shown in Figure

[14] Smokehouse Restaurant. *Smokehouse*. 2009. Retrieved 28 October 2010. Available from: http://www.holysmoke.co.nz/.

5.7(a). The estimated footprint area of the building was approximately 450 m². The ground floor has been re-furbished and is occupied by the TSB Bank, whereas the upper levels required refurbishment at the time of the 4 September 2010 earthquake and therefore the retrofit structure was exposed at the time of inspection. A weak lime mortar (scratched with a finger nail) was used in construction. The bricks used were bright red burnt clay bricks, laid in a common bond pattern. The building has flexible timber diaphragms that consist of plywood sheathing resting over timber joists that are supported on the load bearing URM walls.

(a) Exterior view

(b) steel brace frame



(c) floor diaphragm strengthening

(d) gable strengthening

(e) roof diaphragm strengthening

Figure 5.7 130 Hereford Street (images taken post-September 2010)

The building was seismically retrofitted by the new owner (TSB Bank) in 2009, which involved the introduction of secondary frames. The facade is strengthened by concrete columns and beams at the floor levels (forming a concrete frame) and the side walls are strengthened using steel frames with diagonal braces that are anchored into the masonry as shown in Figure 5.8 and Figure 5.7(b). The floor diaphragms on levels 2 and 3 were stiffened with plywood sheets and 'X' pattern steel plates, with screw fixings spaced at approximately 20 mm to connect the plates to the timber diaphragm as show in Figure 5.7(c). Figure 5.7(d) shows strengthening of the gable, consisting of steel frames secured with adhesive anchor bolts, and Figure 5.7(e) shows the roof diaphragm strengthening using steel tie rods. The walls are supported by newly added concrete beams at the basement level, further resting over old concrete basement walls.

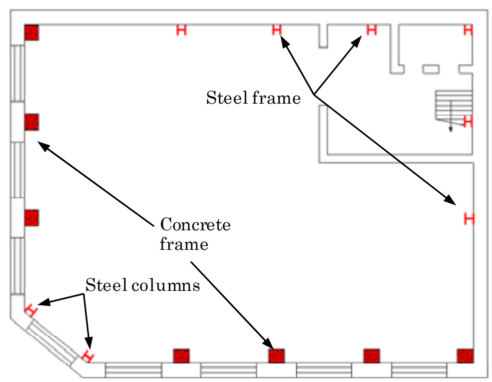


Figure 5.8 Floor plan of TSB Bank Building, showing retrofit

5.2.3 X Base Backpackers, 56 Cathedral Square

This four storey URM building located in the northeast corner of Cathedral Square was constructed in 1902 (see Figure 5.9(a)). The building, formerly known as the Lyttelton Times building and now occupied by X Base Backpackers, is the last in a row of multi-storey buildings on Gloucester Street and butts up to the original Canterbury Press building. The building's exterior aesthetics are similar to the nineteenth century Chicago high-rise buildings (i.e., Romanesque style), with heavy vertical URM piers ending in round headed arches on the front façade and two leaf thick solid brick URM walls on the periphery. The facade of the building is shown in Figure 5.9(a). The building was registered as a category I heritage building with the New Zealand Historic Places Trust in 1997 and therefore an application for its demolition was declined and the building was instead purchased by the Christchurch Heritage Trust. The building was constructed using bright red burnt clay bricks, laid in a common bond pattern. From preliminary scratch tests it was established that a weak lime/cement mortar was used in construction, with variation in the mortar strength in upper floors.

(a) Exterior view

(b) 'X' steel brace fixed into wall

(c) Interior steel frames

(d) Parapet restraints

(e) Façade separation

(f) Cracking through the spandrel on ground level

Figure 5.9 X Base Backpackers, 56 Cathedral Square (images taken post-September 2010)

The X Base Backpackers building was seismically retrofitted in 2001 using steel moment resisting frames. The moment frames, as seen from the fourth floor of the building, are shown in Figure 5.9(c). As part of the seismic retrofit scheme, the parapets were tied back to the roof structure using hollow steel circular sections (see Figure 5.9(d)). In a recent inspection of the building, steel straps anchored to the side walls in an X pattern were also observed (shown in Figure 5.9(b)) and were possibly part of an earlier retrofit scheme.

5.2.4 **Vast Furniture / Freedom Interiors, 242 Moorhouse Avenue**

Vast Furniture / Freedom Interiors (shown in Figure 5.10) is a single storey masonry building, with its roof supported on strong steel trusses that were laterally braced by connecting steel section trusses. Masonry materials observed were bright red clay bricks and a weak lime mortar, with URM laid in a common bond pattern.

(a) wall-diaphragm anchor punching

(b) wall strengthening using steel sections

(c) interior of the building (location where anchor plate pull out occurred)

Figure 5.10 242 Moorhouse Avenue (images taken post-September 2010)

The trusses are further supported on steel portal frames, but the frames had more modern welded joints than the old fashioned riveted joints used in trusses, which suggests that the portal frames were added later to the building as a seismic retrofit solution (see Figure 5.10(b) and (c)).

During the 4 September 2010 earthquake the parapets collapsed out-of-plane and the wall-diaphragm anchors pulled out from the wall, with the anchors punching through the brickwork and creating localized wall damage (refer to Figure 5.10(a)). The building was cordoned off as falling hazards had been identified during post-earthquake evaluation but the internal retail area remained open.

5.2.5 Environment Court Ministry of Justice, 282-286 Durham Street North

The Environment Court building is a one storey isolated URM building that was constructed in the 1890's. The building was originally constructed as an art gallery, with street facades divided into a series of bays and decorated with patterned cornices. A wooden truss supports a gable roof and rests on load bearing URM walls. Due to the building's historic value it is identified as a Category I historic place on the New Zealand Historic Places Trust register.

(a) Armagh street view

(b) Strap detail around openings

Figure 5.11 282-286 Durham Street North (images taken post-September 2010)

The building was seismically retrofitted in 1972 by the Justice Department. The seismic retrofitting scheme involved the addition of cross walls and strapping of the building with steel plates, as shown in Figure 5.11.

5.2.6 Shirley Community Centre, 10 Shirley Road

Shirley Community Centre is a single storey URM building that was constructed in 1915 to be the Shirley Primary School. The building has a hipped roof and was constructed in the Georgian style with large and regular fenestrations. This historic building was registered under the Historic Places Act in 1993. The perimeter cavity walls consist of two leaf thick solid red clay brick masonry with a single veneer yellow brick layer on the exterior surface.

(a) FRP sheet strengthening, image taken 2009 (BBR Contech, 2010)

(b) FRP strengthening after 4 September 2010 earthquake, no visible cracking

Figure 5.12 Shirley Community Centre

Seven individual wall areas were strengthened with surface bonded FRP sheets using Sikawrap 100G (the application of FRP retrofit is shown in Figure 5.12(a)) in the locations shown in Figure 5.13. FRP rod anchors were installed to bond the applied

Sikawrap 100G sheet to the concrete foundation beams (BBR Contech, 2010). The out-of-plane stability to the perimeter wall was provided by using steel hollow sections as strong backs fixed to the URM walls. To ensure sufficient lateral load resistance in the North-South direction a concrete shear wall was also added at the location shown in Figure 5.13. The veneer brick layer was secured to the main wall using helical veneer ties at regular spacing.

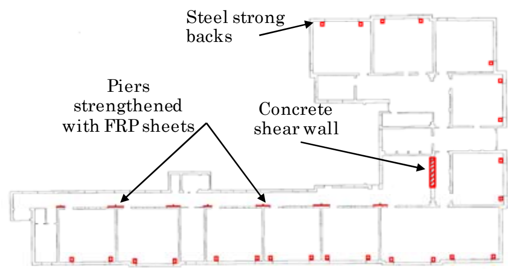


Figure 5.13 Floor plan of Shirley Community centre showing retrofit

5.2.7 Review of performance of retrofitted clay brick URM buildings

The above details were documented following the 4 September 2010 earthquake, where most retrofitted clay brick buildings performed well. The subsequent performance of these buildings is briefly summarised in Table 5.1.

Table 5.1 Performance of retrofitted clay brick URM buildings

Building and address	**Assessed earthquake performance**
The Smokehouse, 650 Ferry Road	**All:** No significant damage. See Figure 5.6.
TSB Bank, 130 Hereford Street	**September:** Some cracks in the basement walls. Retrofit appeared to perform well. See Figure 5.7. **December:** Unknown. **February:** Gable failure on the east side, but again the retrofit appeared to have performed well. **June:** No further significant damage.
X Base Backpackers, 56 Cathedral Square	**September:** Some cracking at top of front facade. Timber shoring placed at top of parapet (visible in Figure 5.9(a)). **December:** Unknown. **February:** Front facade was in process of being repaired, and was covered in scaffolding. Observed damage includes failure of the north east corner at top floor (rear of the building), extensive cracking of front facade (particularly in spandrels). Parapet strengthening appeared to work well, apart from where walls failed. Diagonal shear cracking and failure of some walls of top storey rooms, not visible from the street. X steel straps appear to have kept the walls from collapsing. **June:** Unknown. This building has recently been demolished.
Vast Furniture, 242 Moorhouse Ave	**September:** Partial punching shear of wall-diaphragm anchor, parapet collapse. See Figure 5.10.

	December: Unknown. **February:** Wall-diaphragm anchors punched through further, but no collapse. **June:** No further significant damage externally visible.
Environmental Court, 282-286 Durham Street North	**September:** No apparent damage. See Figure 5.11. **December:** Unknown. **February:** Although the retrofit behaved well the building has suffered some damage, particularly around the entrance. **June:** No further damage.
Shirley Community Centre, 10 Shirley Rd	**September:** No visible damage. See Figure 5.12. **December:** Unknown. **February:** Differential movement between cavity wall layers causing veneer ties to become visible. Liquefaction and differential movement around the grounds. Some cracks extended from ground into the building. Movement of the roof diaphragm visible. In-plane cracking of external walls. **June:** Out-of-plane collapse of external veneer layer.

5.3 Unretrofitted clay brick buildings

5.3.1 127-139 Manchester Street

127-139 Manchester Street is a 3 storey clay brick URM "L" shaped row building that was originally constructed circa 1905 and is listed by the Christchurch City Council as a protected building[15]. The building consists of 7 'bays' along Manchester Street, each having an approximate length of 5 m, with an overall building height of approximately 12 m as shown in Figure 5.14.

(a) 135-139 Manchester Street, out-of-plane facade collapse

(b) 139 Manchester Street, through steel anchors and rotten timber roof diaphragm

Figure 5.14 Damage to clay brick URM building at 135-139 Manchester Street (images taken post-September 2010)

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[15] Christchurch City Council. "Protected Buildings, Places and Objects in Christchurch City Coucil". Retrieved 25 October 2010. Available from: http://ketechristchurch.peoplesnetworknz.info/canterbury_earthquake_2010/topics/show/172-list-of-protectedbuildings-places-and-objects-in-christchurch-citycouncil.

The first storey load bearing walls of the building are solid and four leaves thick and the upper storey walls are solid two leaves thick clay brick masonry. The front facade wall of the building is two leaves thick for the upper level and three leaves thick for the first level. All brickwork was constructed in the English bond pattern. Internal non-load bearing partition walls were constructed using timber studs with lath and plaster type finish. The ground floor was modified using a combination of concrete and timber supporting structure in order to provide larger open shop front space. Canopies extended along Manchester Street above the ground level and were tied back into the piers of the first level using steel rods. Decorative, balustrade type parapets extending approximately 1 m above the roof level were positioned around the street frontage perimeter.

The corner bay of the building (139 Manchester Street) was in a deteriorated condition and had been poorly maintained, with visible water damage and rot of the timber floor and roof diaphragms being evident. The floor joists and roof rafters were oriented in the North-South direction for the building portion along Manchester Street. The end gable was connected to the roof structure using only two through anchors with round end plates.

The building sustained considerable damage during the 4 September 2010 earthquake, mainly concentrated at the end bay (139 Manchester Street) where the front facade entirely collapsed out-of-plane (see Figure 5.14). The entire building sustained damage from collapsed parapets, apart from two bays (135 and 137 Manchester Street) where the parapets remained on the building. From visual observations and physical assessment of the collapsed masonry the mortar was found to be in a moist condition and the mortar that was adhered to the bricks readily crumbled when subjected to finger pressure (see Figure 3.3), suggesting that the mortar compression strength was low (<2 MPa). The collapsed facade wall revealed extensive water damage to the timber structure, with rotten floor joists and roof rafters. Also, it was observed that there were large patches of moist masonry on the interior surface of the building, especially around the roof area (there was no precipitation during the period following the earthquake and prior to building inspection).

It appears that the through steel anchors at the gable did not provide sufficient restraint to the masonry, with the brickwork being pulled around the steel anchor plates. Furthermore, from images prior to the earthquake it is evident that there were significant cracks through the spandrel and the parapet over the top corner window of 139 Manchester Street. Falling parapets landed on the canopies, resulting in an overloading of the supporting tension braces that led to canopy collapse. The connections appeared to consist of a long, roughly 25 mm diameter rod, with a rectangular steel plate (approximately 5 mm thick) at the wall end that was approximately 50 mm wide x 450 mm long and fastened to the rod, and was anchored either on the interior surface or within the centre of the masonry pier or wall. The force on the rod exceeded the capacity of the masonry, causing a punching shear failure in the masonry wall (see Figure 5.15).