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PERFORMANCE OF EARLY MASONRY, COB AND CONCRETE BUILDINGS IN THE 14 NOVEMBER 2016 KAIKOURA EARTHQUAKE

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ABSTRACT

The performance of historic buildings during the 14 November 2016 M_w7.8 Kaikoura, New Zealand earthquake is reported, focusing on early stone and clay brick masonry buildings, vintage concrete structures, cob cottages, and the non-structural masonry chimneys and veneers of buildings located in the upper part of the South Island (Marlborough and North Canterbury regions). To better document structural response, the intensity of horizontal and vertical ground motion from the nearest recording station is graphically placed alongside the assessed level of damage. In response to numerous strong earthquakes that have previously occurred in the area a large number of highly vulnerable buildings or non-structural building components were previously either seismically retrofitted or demolished, thereby reducing the level of damage and loss of life during the 2016 Kaikoura earthquake. Seismically retrofitted stone and clay brick masonry buildings and cob cottages exhibited good performance, while some vintage concrete structures and partially strengthened cob cottages suffered moderate to extensive levels of damage. A large stock of URM chimneys in Picton, Seddon and Rotherham were previously removed while in other locations chimneys presented a variety of responses. Rural masonry veneer dwellings located in Seddon and Waiau experienced high damage levels, typically resulting in out-of-plane collapse of the masonry veneer.

INTRODUCTION

The M_w7.8 Kaikoura earthquake struck North Canterbury, New Zealand, at 12:02:56 am local time on 14 November 2016 (11:02 on 13 November UTC) [1]. The epicentre (42°41'24.0"S 173°01'12.0"E) was located approximately 4.0 km south of Waiau, Canterbury and 100 km north of Christchurch, at a depth of approximately 15 km. Casualties were reported in Culverden and Kaikoura, with two deaths in Kaikoura and Mount Lyford [2]. Building damage was reported by the media mainly in the Waiau and Wellington areas [2]. In addition, 24 hours following the main earthquake the nearby area between Havelock and Blenheim was subjected to severe flooding due to heavy rainfall. A team of researchers was deployed into the field within 12 hours to document and record damage observations shortly after the earthquake event. 5% damped elastic acceleration response spectra for recording stations in Picton (QCCS), Blenheim (MGCS) and Waiau (WTMC) are illustrated in Figure 1. The observations reported herein are focused on the response of early buildings, and the response of unreinforced masonry (URM) chimneys and residential veneer construction located in the upper part of the South Island, New Zealand. The inspection of buildings was mainly focused on historic structures, most of which were listed in the New Zealand heritage register [3]. Previous reports on earthquake reconnaissance relating to similar building types and similar non-structural elements can be found in [4]–[10].

The upper South Island of New Zealand has previously experienced a number of strong earthquakes, with the 1848 Marlborough earthquake being the most destructive and the 2013 Lake Grassmere earthquake being the most recent [11]. The M_L7.4 Marlborough earthquake in 1848 damaged (and destroyed during the aftershocks) most of the URM structures and URM chimneys in Wellington and in the Marlborough region, which were then rebuilt in timber thereby largely contributing to reduce the level of damage and loss of life in the more powerful M_w8.2 Wairarapa (60 km east of Wellington) earthquake in 1855 [11]. More recently the area was struck by the M_w6.5 Cook Strait earthquake on 21 July 2013 that occurred approximately 25 km east of Seddon, and by the M_w6.6 earthquake on 16 August 2013 that occurred beneath Lake Grassmere, approximately 30 km south-east of Blenheim [10]. The rural communities of Seddon and Ward, both within 10 km of the Lake Grassmere earthquake rupture source, represented the worst hit regions in 2013 and experienced damage similar to that reported herein. Regarding the area located south of Kaikoura, historical earthquakes include the large M_w7.3 North Canterbury earthquake located in the Amuri District (now part of the Hurunui Territorial Authority of Canterbury, about 100 km north of Christchurch) in 1888 and the M_w6.9 Cheviot earthquake in 1901. The 1888 North Canterbury earthquake caused severe damage to cob and stone masonry buildings located in the Amuri District, as well as in Hokitika and Greymouth, and is thought to have originated on the Hope Fault which is part of the Marlborough Fault Zone [11]. As a result of these historic strong earthquakes, most of the vulnerable structures and non-structural components in the upper South Island region were previously either retrofitted or removed, resulting in less severe damage occurring during the 14 November 2016 Kaikoura earthquake than would have otherwise been expected.

Damage observations and photographs reported herein include a legend (see Figure 2) which graphically summarises the local intensity of the ground motion (horizontal and vertical Peak Ground Acceleration, PGA, provided by the nearest recording station whose name is identified by a 4-letter designation [1]) and the level of damage using a 5-point scale

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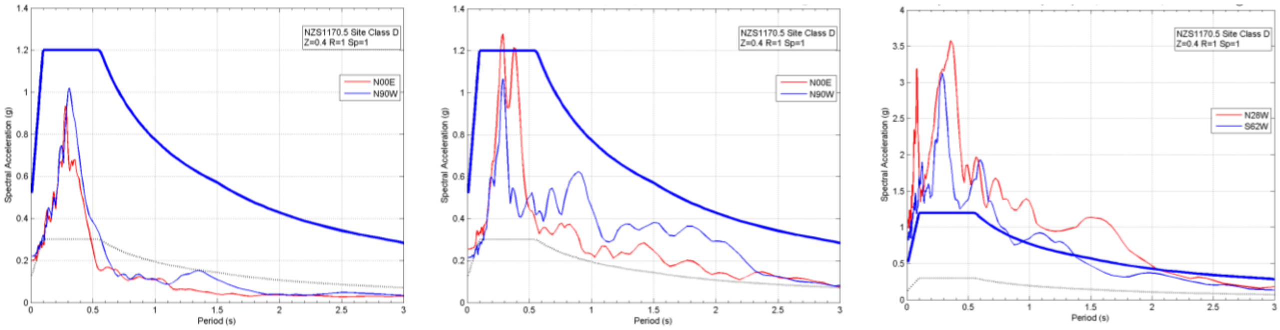
based on the authors' best judgement of overall damage sustained by the building and categorised in accordance with the European macroseismic scale, EMS 98 [12], and ATC-20 [13]. Using these graphics the authors do not mean to imply that shaking intensity directly relates to that specific level of damage, but merely to graphically summarise the recorded PGA value and the attributed damage level.



(a) Picton Queen Charlotte College (QCCS) hPGA=26.2%g; vPGA=10%g

(b) Blenheim Marlborough Girls College (MGCS) hPGA=26.9%g; vPGA=8.9%g

(c) Te Mara Farm Waiau (WTMC) hPGA=112.4%g; vPGA=321.6%g

Figure 1: 5% damped elastic acceleration response spectra (solid line – Ultimate Limit State (ULS), dotted line – 0.25xULS) [14].

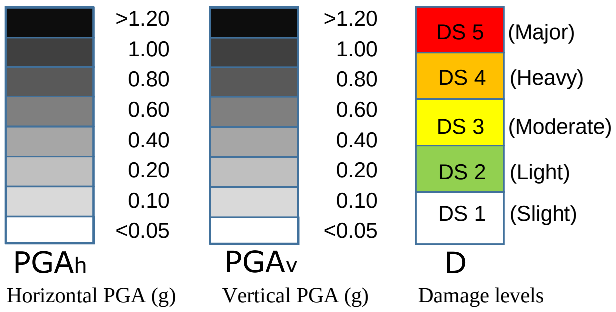


***Figure 2: Photograph legend (note that PGA values are based on the nearest ground motion recording station and might not be fully representative of the ground accelerations experienced at the site where the photographs were taken). Damage levels are based on authors' best judgement of overall damage sustained by the building with reference to EMS 98* [12] *and ATC-20* [13].**

STONE AND CLAY BRICK MASONRY BUILDINGS

During the 2016 Kaikoura earthquake reconnaissance five URM churches and four commercial URM buildings were inspected in detail. Most of these URM structures appeared to have been seismically retrofitted prior to the 2016 Kaikoura earthquake and based on a rapid inspection were found to have exhibited good performance during the earthquake shaking. Two churches were in Havelock, which is a town located approximately 170 km north of the epicentre, and experienced a horizontal PGA of 0.135g. St Peter's Church (see Figure 3a) was built in 1905, (Heritage List #1496) using stone masonry and appears to have been seismically retrofitted based on the presence of a concrete beam atop of the perimeter walls. No earthquake related damage was observed during close-up external inspection of St Peter's Church. The nearby Sacred Heart Church (see Figure 3b) was constructed using clay brick unreinforced masonry and no earthquake related damage was observed upon close exterior inspection and following consultation with the nearby residents.

St Joseph's is a large URM church that is located in Picton, approximately 180 km north of the epicentre (hPGA 0.262g). The foundation stone of the current URM structure was laid in 1917 on an elevated site, see Figure 4a. Following the 2010/2011 Canterbury earthquakes the Archdiocese took proactive measures to assess their property portfolio for earthquake safety [15], taking into consideration that many of the Archdiocese owned buildings are used by community groups and schools and that some buildings are heritage listed [3]. A Detailed Seismic Assessment (DSA) undertaken in 2012 revealed that the church was earthquake-prone (below 1/3 of the New Building Standards, NZS 1170.5, 2004), but the building has remained operational with an earthquake hazard notice being placed at the building entrance, which was identified at the time of the visit. From an external visual assessment no earthquake damage was identified. Strong cement mortar was used to lay the bricks in a running bond pattern and air-vents are present at the base and top of the walls, revealing the presence of a wall cavity. The masonry next to the buttresses appeared to be recently replaced and hence further investigations are required to understand if the buttresses were potentially rebuilt at a later stage. Pre-existing cracks were observed at the edges of the gables at the roof level, and weather deteriorated bricks are present at the base of the bell tower.

(a) St Peter's Church (1905, Heritage List #1496, likely to be seismically retrofitted)

(b) The Sacred Heart Church

Figure 3: Unreinforced stone and clay brick masonry churches in Havelock (hPGA 0.135g, vPGA 0.066g – HAVS).

Oxley's Hotel is located on the Picton waterfront and has a curved URM façade (Heritage List #5108) that was refurbished, strengthened and incorporated into the structure of a new building in 2004 after demolishing the original two-storey masonry hotel that was built between 1899 and 1902 [3]. No earthquake damage was noted during a close external inspection of the Oxley Hotel's URM façade, see Figure 4b. Within Picton the most extensive observed damage was the collapse of a single URM gable wall from a single storey URM retail building located on the main street of Picton, leading to the collapse of a canopy, see Figure 4c.

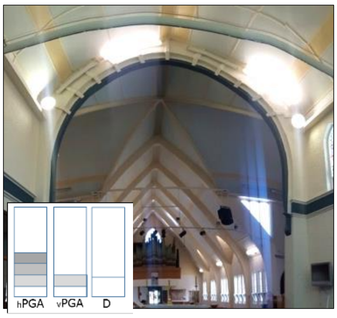
(a) St Joseph's Church (1917)

(b) Oxley's Hotel Façade (1899 to 1902, Heritage List #5108, retrofitted in 2004)

(c) Collapse of URM front façade and canopy (photo taken by Dr. J.Daniell)

Figure 4: Unreinforced clay brick masonry buildings in Picton (hPGA 0.262g, vPGA 0.100g – QCCS).

Central Blenheim is dominated by pre-1977 construction of two-storey buildings with open ground level retail spaces. Approximately 55 buildings were identified as earthquake prone with Initial Evaluation Procedures (IEP) undertaken in 2007, and since 2011 the owners of 22 buildings in Blenheim and Picton have received a notice to undertake retrofit intervention or demolition within the next 5-10 years [10]. All the URM buildings in central Blenheim appeared to have performed well during the Kaikoura earthquake (the peak recorded horizontal acceleration was 0.269g, QCCS). The Church of the Nativity in Blenheim is one of Blenheim's older buildings consisting of two distinct structural types, see Figure 5a. The transept and chancel were built in 1906 using clay brick URM with some reinforced buttresses and reinforced concrete bands whereas the nave, narthex and tower were built in 1959 of clay brick veneer over reinforced concrete and steel portal frames that replaced the old timber building, and the entire building is roofed with concrete tiles. An initial seismic assessment of the building was undertaken in 1976 and the building was seismically strengthened in the early 1980s [17] using reinforced concrete walls with a steel bracing system and vertical reinforcing bars embedded into the URM wall thickness. Based on a detailed internal and external inspection, no earthquake related damage was observed in the Church of the Nativity complex.



(a) The Church of Nativity (1906 and 1956, retrofitted in 1983) – internal view

(b) Bank of Australasia (1926, Heritage List #9301, retrofitted)

Figure 5: Unreinforced clay brick masonry buildings in Blenheim, (hPGA 0.269g, vPGA 0.089g – MGCS).

The Bank of Australasia is a listed heritage building (#9301, see Figure 5b) and is a two-storey commercial URM building constructed in 1926 and seismically retrofitted in 2005 using steel structural members. Based on a detailed internal and external inspection, no earthquake related damage was observed in the Bank of Australasia building. The Rapaura Community Church is in the surrounding area north of Blenheim and from an external inspection the building appeared to be clay-brick cavity masonry construction, with no earthquake related damage being identified, see Figure 6.

Figure 6: Unreinforced clay brick masonry church in Rapaura, (hPGA 0.269g, vPGA 0.089g – MGCS).

(a) Nurses' Hostel (1928-1929) with loadbearing cavity-URM walls on ground floor and timber framed walls on the upper level

(b) Close-up of the loadbearing URM cavity-walls, Nurses' Hostel

Figure 7: Unreinforced clay brick masonry buildings in Hanmer Springs, (hPGA 0.263g, vPGA 0.162g – HSES).

The historic Queen Mary Hospital in Hanmer Springs (hPGA 0.263g, vPGA 0.162g – HSES) was inspected in great detail, with no identified structural damage to the URM loadbearing walls. Significant damage was only observed in the URM chimneys, reported herein in a subsequent section. The vintage hospital complex is part of the Heritage List (#7583 and #7612) and includes the Soldiers' Block (1916) and the Chisholm Ward for female patients (1926) which are two single storey timber buildings with URM chimneys, and the Nurses' Hostel (1928-29, see Figure 7) which is a two storey building with loadbearing cavity-wall clay brick masonry on the ground floor and timber weatherboards on the first floor.

VINTAGE CONCRETE STRUCTURES

Several vintage concrete buildings and monuments were inspected in the north part of the South Island. The former Public Trust Office Building (Heritage List #1530) was constructed in 1924 in the Art Deco style with a magnificent columned façade, and was turned into a bar and hotel in 1993, see Figure 9a. The only damage suffered to this building was related to horizontal cracks localised at the perpendicular walls next to the main building entrance. The Court House (1937, Heritage List #1509) and the War Memorial and Clock Tower (1928, Heritage List #243) are thought to be reinforced concrete structures with stone facing and no damage was identified, see Figure 9b-c. The Picton War Memorial had no observed damage, even to free-standing appendages, see Figure 8.

The level of building damage was more evident closer to the epicentre, for example in Wharanui that is 124 km north-east of the epicentre (70 km north of Kaikoura). The Saint Oswald's Church in Wharanui was built in 1927 by a neighbouring farming family, who used locally-sourced stone and a filled concrete core to construct the walls of the church. The church performed well during previous severe ground shaking that struck the area, including the 2013 Seddon and 2013 Lake Grassmere earthquakes [10]. However, during the 2016 Kaikoura earthquake the horizontal and vertical accelerations recorded were 1.278g and 1.271g respectively (WDFS – Ward, 10 km North), causing the collapse of one of the parapets above the tower and diagonal cracking and shear sliding cracks along the lateral walls as shown in Figure 10.

Figure 8: Vintage concrete structures in Picton (hPGA 0.262g, vPGA 0.100g – QCCS).

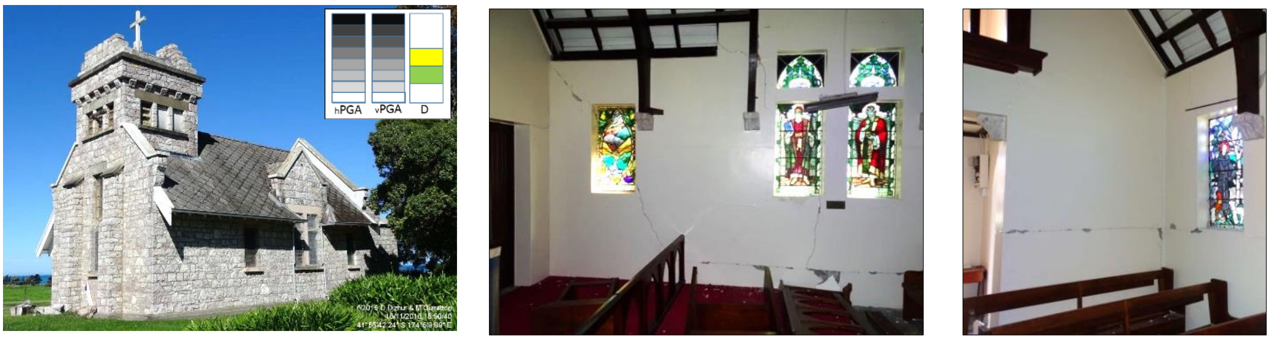
The highest level of building damage was observed in Waiau, 12 km north of the epicentre, where a strong vertical acceleration of 3.21g was locally recorded in addition to the horizontal 1.124g (WDFS). The red tagged All Saints Church was built in 1924 of local river boulders and a lightly reinforced concrete core and is a heritage listed building (#3690), Figure 11a. The strong ground motion caused tilting of the bell tower with significant settlement of the tower foundation as shown in Figure 11b-c and detachment and minor sliding movement of the church from the foundation. Diagonal shear cracks occurred in the chapel walls (see Figure 11d) and other cracks formed in the gables, probably due to wall-to-roof interactions and/or building irregularity.

(a) Former Public Trust Office Building (1924, Heritage List #1530).

(b) War Memorial and Clock Tower (1928, Heritage List #243)

(c) Court House (1937, Heritage List #1509)

Figure 9: Vintage concrete structures in Blenheim, (hPGA 0.269g, vPGA 0.089g – MGCS).

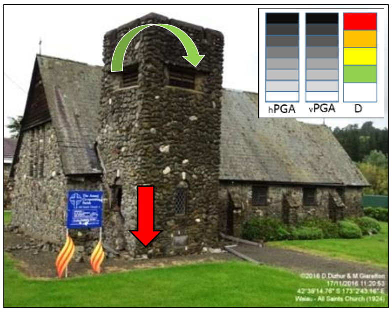


(a) St Oswald's Church (1927)

(b) Internal view with diagonal shear and shear sliding cracks

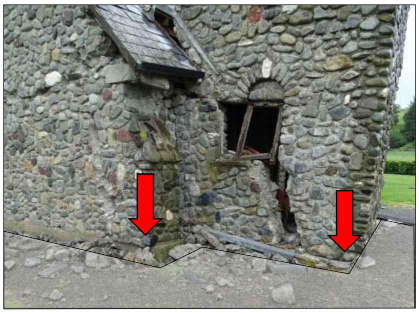
(c) Internal view with shear sliding cracks

Figure 10: Vintage concrete and stone church in Wharanui, (hPGA 1.278g, vPGA 1.271g – WDFS).



(a) All Saints Church (1924, Heritage List [#3690](#), red tagged)

(b) Tilting of the bell tower



(c) Close-up of significant bearing failure of the tower foundation

(d) In-plane damage

(e) Waiau Lodge Hotel (1910, red tagged)

(f) Cracking around window openings

(g) Horizontal cracking showing evidence of pier rocking

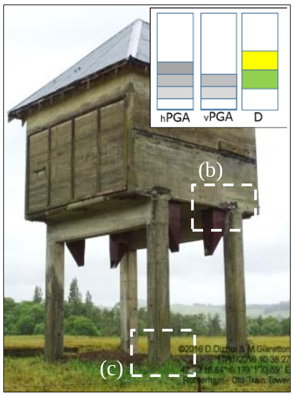
(h) Fireplace collapse (photo taken by S. Squires)

Figure 11: Vintage concrete buildings in Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

The Waiau Lodge Hotel is a concrete two-storey building constructed in 1910 that was severely damaged, see Figure 11e. All three URM chimneys fell through the roof, severely damaging the adjoining rooms (see Figure 11h), and in-plane diagonal cracks around openings and pier rocking damage was observed on the front and back façades (see Figure 11f-g).

Knox Presbyterian Church in Cheviot was built in 1952 using a similar construction method as used in the All Saints Church Waiau: stone gathered from near the Hurunui River and a lightly reinforced concrete core. Cheviot is located along State Highway 1, 17 km east of the epicentre, and the area experienced a significantly lower peak horizontal acceleration (0.288g) than in Waiau, resulting in no visible damage being detected during a detailed external inspection of the church structure. Another vintage concrete structure that was investigated was the Old Train Tower located in Rotherham and probably constructed between 1914 and 1919 when the railway connecting Waiau to Culver den (aka Waiau Branch) was built. A large concrete store stands above two tall concrete portals, which experienced heavy damage at the column bases and at the beam-column joints, as shown in Figure 13. The Waiau Branch railway closed in 1978.

Figure 12: Vintage concrete church in Cheviot (hPGA 0.288g, vPGA 0.09g – CECS).



(a) Old Train Tower (probably 1910s)

(b) Hinging of the column-to-beam joints

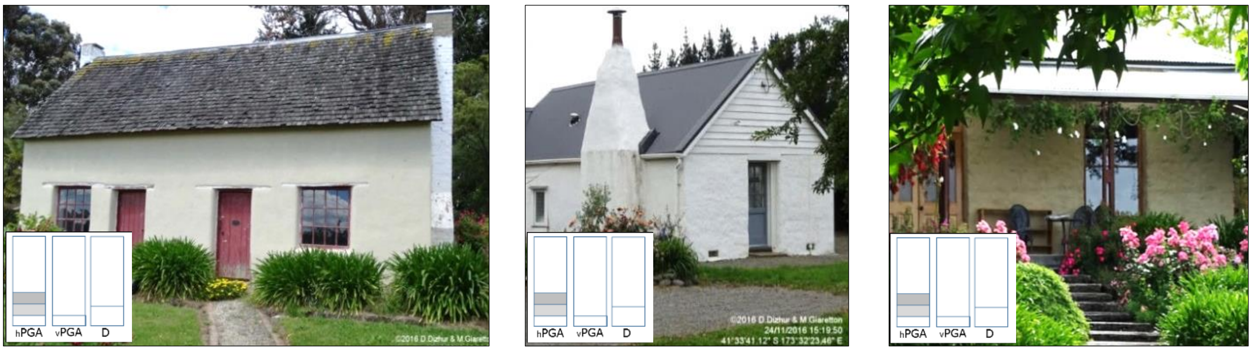
(c) Column base cracking detail

Figure 13: Vintage concrete structures in Rotherham (hPGA 0.280g).

COB COTTAGES

Cob was a common building material in early 19th-century Marlborough south of the Wairau River, partly because of a lack of readily accessible timber. The technique involved the use of clay subsoil combined with aggregates (straw and tussock) and water to make a material that was placed directly without formwork onto foundations to make massive earth walls. Five cob cottages, all part of the Heritage List, were inspected in Blenheim, Waiau and Rotherham.

The two-storey Riverlands Cob Cottage ([#1471](#), see Figure 14a) was constructed between 1854 and 1868 and served variously as a farm cottage, shearers' quarters, school, a store room, and a hay shed. The 400 mm thick walls are of a puddled clay and chopped tussock mixture reinforced with horse manure containing 'undigested' chaff. Restoration was undertaken between 1961 and 1965 by the Marlborough Historical Society and Historic Places Trust that included placing concrete blocks at the base of the walls which enabled the cottage to survive past earthquakes but attracted moisture which has weakened the cob walls [18]. Strengthening of the cottage was undertaken in 2013, involving strengthening of the foundation to meet the requirements of the building code and to address the problem of rising damp, consolidation of the walls using strong lime-based plaster on both interior and exterior surfaces to protect the material, and repair and securing of the URM chimneys that were damaged during the 2013 earthquakes. No further damage was observed in the Riverlands Cob Cottage following the 2016 Kaikoura earthquake, as for the other cob houses in the area surrounding Blenheim (Wairau Valley and Renwick, see Figure 14b-c). Conversely, the Waiau Cob Cottage museum was heavily damaged by the Kaikoura earthquake and received a red placard, see Figure 15**.** The cottage was built in 1866 using clay, straw and tussock (#3682) and appeared to be well preserved prior to the earthquake and to have been partially seismically strengthened. Evidence of the use of textile reinforced mortars was identified only on the south-west wall, which also presented cracks and localised detachment of the textile net. In all perimeter walls cracks were displayed around windows, roof and corners suggesting the potential initiation of an out-of-plane failure mechanism but without leading to collapse. Diagonal cracking and extensive detachment of the recent thick plaster was also observed. The URM clay brick chimneys located in the timber portion of the cottage had collapsed, see Figure 15a, while the timber church behind the cottage did not sustain any damage, see background of Figure 15b. Minor damage was also found in the Watters Cob Cottage in Rotherham, see Figure 16. The Watters cottage was originally built in 1885 (#3691) by John Watters who migrate from Ireland and lived in the building until 1961. The cottage was originally built with 500 mm thick cob walls and a thatched roof and was restored by the Hurunui District Council and New Zealand Historic Places Trust between 1991 and 1998, now being a testimony of the living conditions of many families in the late 19th century. During the 2016 Kaikoura earthquake the URM clay brick chimney collapsed (see Figure 16a) and localised cracks developed at the roof-to-wall and wall-to-wall connections, as shown in Figure 16b.



(a) Riverlands Cob Cottage (1854-1868, Heritage List #1471)

(b) Wairau Valley COB House (1860s, Heritage List #1472)

(c) Renwick COB House (Heritage List #2922)

Figure 14: Cob cottages in area surrounding Blenheim (hPGA 0.175g, vPGA 0.048g – BWRS).

(a) Damage to the Cob Cottage museum (1866, Heritage List #3682, red tagged)

(b) Evidence of Textile Reinforced Mortar (TRM) used as a retrofit intervention

Figure 15: Cob cottage in Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

(a) Damage to the Watters Cob Cottage (1885, Heritage List #3691)

(b) Internal view showing return wall separation

Figure 16: Cob cottage in Rotherham (hPGA 0.280g).

NON-STRUCTURAL URM COMPONENTS

Past earthquakes in New Zealand [4], [9], [10] have repeatedly caused damage to URM domestic chimneys and masonry veneers. For many residents of the upper South Island, in particular for Waiau and Seddon inhabitants, the most significant effect of the 14 November 2016 Kaikoura earthquake was a toppled chimney, either punching through the roof of the house or landing alongside the house, or the more destructive out-of-plane collapse of the masonry veneers. Below are selected photographs of representative damage, with the observed damage summarised in Table 1.

Table 1: Summary of damage to non-structural components (location ordered from north to south).

		Chimney		Veneers	
Location	**hPGA, vPGA**	**Level of damage**	**Type of damage**	**Level of damage**	**Type of damage**
Picton	0.262g, 0.100g	Limited *	None visible, Cracking and torsion at the Railway Station	n/a	None visible
Blenheim	0.269g, 0.089g	Moderate	Cracking at roofline, Toppling (1)	n/a	None visible
Seddon	0.759g, 0.196g	Limited *	Detachment of the stack	Moderate to extensive	Initiation of out-of-plane, Collapses
Clarence	0.430g, n/a	Extensive	Toppling	n/a	None visible
Hanmer Springs	0.263g, 0.162g	Moderate	Mortar disintegration, Toppling	n/a	None visible
Rotherham	0.280g, n/a	Limited	Detachment of the stack	n/a	None visible
Waiau	1.124g, 3.216g	Extensive	Toppling	Extensive	Collapses

* Appeared that most unreinforced masonry chimneys had been previously removed or lowered to roofline

URM Chimneys

Limited damage to URM chimneys was observed in Picton, Seddon and Rotherham, where most chimneys appeared to have been previously removed or lowered to the roofline, likely to have occurred following the 2013 Seddon and 2013 Lake Grassmere earthquakes [10] or after earlier large earthquakes [11], see Figure 18. Removal of the URM chimney appeared to be the only mitigation intervention adopted prior to the 2016 Kaikoura earthquake and no braced or strapped URM chimneys were identified in the area. In Blenheim, Hanmer Springs, Clarence, and Waiau the damage level was moderate to extensive and the type of damage included the following:

- Cracking at the roofline and rocking, see Figure 18,
- Mortar disintegration and dislodged bricks, see Figure 20,
- Toppling, see Figure 21,
- Detachment of the stack, see Figure 22.

Numerous examples existed of chimney cracked at the roofline, and displaced and skewed chimney stacks after rocking due to the intense and long duration shaking, see Figure 18.

In a few cases residents were quick to remove damaged chimneys that remained standing and cover the stack, in order to eliminate the risk due to aftershocks or strong winds. At the Picton Railway Station there is a fireplace located in the middle of the timber building, where the chimney stack was cracked above the smoke chamber and had rotated, resulting in damage to the ceiling and the flashing, see Figure 17a. The roof coating around the chimney was also damaged and the free-standing chimney portion above the roof appeared to have displaced, see Figure 17b.

At the Queen Mary Hospital in Hanmer Springs most of the chimneys exhibited weak mortar disintegration and dislodged bricks, resulting in badly damaged but standing URM chimneys that represented a significant falling hazard, see Figure 20. Extensive cracking and collapse of the top part of the stack occurred in an historic free-standing fireplace located in the countryside, 16 km west of Seddon, see Figure 21d. Several falling chimneys had punched through the roof, as well as a number of chimneys or chimney stacks that had toppled outside the building perimeter also being observed. Examples are illustrated in Figure 21 and Figure 22.

Despite the extent of damage described above and the large number of chimneys previously removed or lowered at the roofline, there were several cases of undamaged tall chimneys as shown in Figure 23.

(a) Indoor view (b) External view

Figure 17: Historic URM chimney at the Picton Railway Station (1902, Heritage List #5392).




(a) Picton (b) Picton (c) Seddon (d) Seddon

Figure 18: Examples of URM chimneys that had been removed and/or lowered to the roofline.

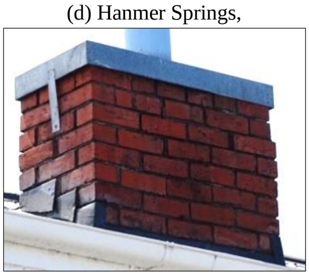



(a) Blenheim, rocking at base (b) Hanmer Springs, sliding (c) Hanmer Springs, rotation at base (d) Kekerengu (19 km north of Clarence), rotation

Figure 19: Examples of horizontal cracking at the chimney base with rocking (a) and sliding (b) or rotation (c, d).




(d) Hanmer Springs,

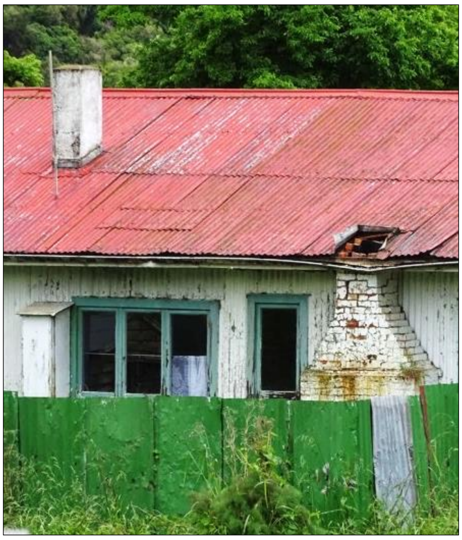


(a) Hanmer Springs (b) Hanmer Springs (c) Hanmer Springs (e) Blenheim

Figure 20: Examples of mortar disintegration and dislodged bricks for chimneys in Hanmer Springs at the historic Queen Mary Hospital and in Blenheim.

(a) Clarence

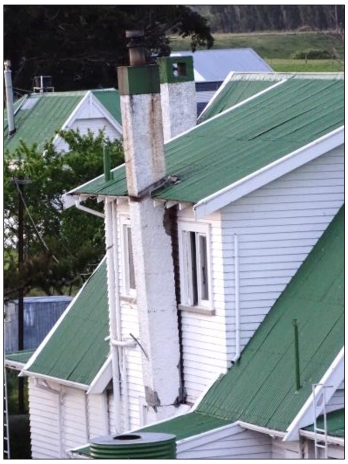
(b) Blenheim



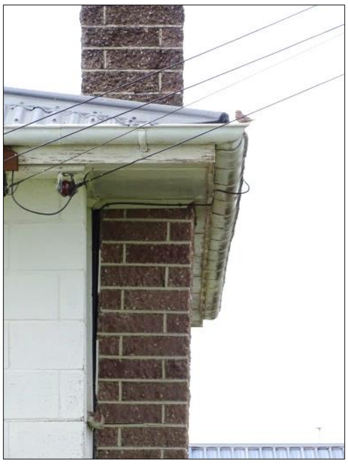
(c) Oaro

(d) Standalone historic URM chimney, located 16 km west of Seddon

Figure 21: Examples of chimney toppling above the roofline.



(a) Clarence



(b) Seddon

(c) Clarence

(d) Waiau, veneer chimney

(e) Waiau

(f) Clarence, concrete stack

Figure 22: Examples of out-of-plane (a-c) detachment or (d-f) collapse of the chimney stack.

(a) Blenheim (b) Hanmer Springs (c) Rotherham

Figure 23: Examples of tall non-damaged URM chimneys.

Masonry Veneers

Clay brick and concrete block masonry is used in New Zealand as an anchored wall veneer for its durability, resistance to fire and moisture, and for aesthetic reasons. Observations made following previous earthquakes [5][6][9] have highlighted that masonry veneer systems may exhibit poor performance when subjected to lateral loads. A comprehensive background and description of veneer details and tie types is presented in [9]. Following the 2016 Kaikoura earthquake, moderate to extensive damage to masonry veneers was observed in localised areas, mainly in Seddon and Waiau. The damage was typically attributed to a combination of differential movement between the masonry veneer and the timber framing and the poor anchorage of ties connecting the masonry veneer to the timber wall framing, see Figure 24 and Figure 25**.** Differential movement between the timber structure and veneer induced both in-plane cracking (Figure 26) and the initiation of out-of-plane damage and collapse relative to the direction of shaking (Figure 27 and Figure 28). Such behaviour was also observed in hollow concrete block (Figure 29**)** and more modern masonry veneer systems (Figure 30 and Figure 31).

(a) Damaged veneer dwelling (b) Heavy solid veneer cladding blocks (c) Pull-out of ties

Figure 24: Significant damage to a masonry veneer dwelling in Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

(a) Out-of-plane collapse (b) Close-up of damaged area (c) Close-up of ties

Figure 25: Out-of-plane collapse of masonry veneer in Seddon (hPGA 0.759g, vPGA 0.196g – SEDS).

(a) Dislodgement of the veneer blocks, Seddon (b) Corner damage, Waiau

Figure 26: Examples of in-plane damage to veneer.

(a) Detachment and initiation of out-of-plane collapse, Seddon (b) One-way bending collapse of large veneer panels, Waiau

Figure 27: Examples of out-of-plane damage to veneer.

Figure 28: Examples of in-plane and out-of-plane damage to masonry veneer dwelling, Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

(a) Out-of-plane collapse

(b) Extensive cracking and dislodged blocks

Figure 29: Examples of in-plane and out-of-plane damage to hollow concrete block masonry veneer dwelling, Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

(a) Recently constructed veneer building

(b) Out-of-plane collapse

(c) Buckling of ties

Figure 30: Example of damaged modern masonry veneer dwelling, Seddon (hPGA 0.759g, vPGA 0.196g – SEDS).

Figure 31: Example of damaged modern masonry veneer dwelling, Waiau (hPGA 1.124g, vPGA 3.216g – WTMC).

SUMMARY AND FINAL OBSERVATIONS

On 14 November 2016 a M_w7.8 earthquake struck the upper South Island and Wellington, with the epicentre located approximately 4.0 km south of Waiau, Canterbury (100 km north of Christchurch). The Wellington, Marlborough and Canterbury regions have previously experienced a number of strong earthquakes since the mid-19th Century, including the most destructive 1848 Marlborough earthquake (M_L7.4), the most powerful 1855 Wairarapa earthquake (M_w8.2), and the most recent 2013 Lake Grassmere earthquake (M_w6.6). As a result of these strong historic earthquakes, most of the vulnerable structures and non-structural components in the upper South Island region affected by the 2016 Kaikoura earthquake had been previously retrofitted or removed, resulting in less severe damage during the 2016 Kaikoura earthquake than may have otherwise been anticipated. Despite this observation, Waiau and Seddon represented the worst affected areas with high levels of damage observed in early buildings (vintage concrete structures and cob cottages) and masonry veneer dwellings. Most of the remaining URM stone and clay brick masonry buildings in Havelock, Picton and Blenheim appeared to have been seismically retrofitted prior to the 2016 Kaikoura earthquake and no damage to these structures was observed.

A large number of URM chimneys had been removed or lowered to the roofline following past earthquakes, in particular in Picton, Seddon and Rotherham, and no braced or strapped original URM chimneys were identified in the area during the post-earthquake reconnaissance. URM chimneys located in Blenheim, Hanmer Springs, Clarance, and Waiau experienced moderate to extensive damage which included cracking at the roofline and rocking, mortar disintegration and brick dislodgment, toppling of the chimney portion above the roof, and/or detachment of the stack.

In-field observations presented herein were collected immediately after the main earthquake with the aim to document and record the response of early existing buildings (stone and clay brick masonry buildings, vintage concrete structures, cob cottages), URM chimneys and residential masonry veneer construction located in the upper part of the South Island, New Zealand. It is hoped that despite the localised damage, this earthquake has provided a timely reminder for building owners to undertake action to increase the earthquake resilience of their buildings.

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