INTERBUILDING POUNDING DAMAGE OBSERVED IN THE 2010 DARFIELD EARTHQUAKE

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SUMMARY

Five days after the Darfield earthquake, a street survey of buildings with pounding damage was performed in Christchurch Central Business District (CBD). Pounding damage did not occur very often, and the level of damage observed was generally low. Moderate to severe pounding damage was observed only in some unreinforced masonry buildings. Outside the CBD one collapsed storey can be attributed to pounding.

The majority of pounding damage occurred in vertical structural elements. Adjacent stepped façades were also found to be susceptible. The damage patterns associated with pounding could have led to building collapse in more severe/longer duration shaking or major aftershocks. Pounding damage remains a serious concern for future strong earthquakes in New Zealand.

INTRODUCTION

Building pounding damage was specifically investigated in Christchurch's central business district (CBD) on Thursday September 9th, five days after the main earthquake event. Pounding damage was surveyed throughout the CBD, in an area roughly bordered by Gloucester St, Madras St, St Asaph St and Oxford Tce. A comprehensive survey could not be conducted due to building demolition, road cordons and available resources. However, typical exterior building pounding damage was examined and documented.

No prior surveys exist to indicate the potential for pounding damage in Christchurch; however in areas of the city with a high building density, there are many buildings with less than 3 mm separation. When building gaps were left, they were generally sufficient to prevent any building contact during the main earthquake. In this study, structures with less than 3 mm separation are defined as having zero separation. Consequently, almost all buildings found with pounding damage had zero building separation.

Few of the buildings in the CBD showed signs of pounding damage. Very crude estimates suggest roughly 5 % of surveyed buildings were affected by pounding in some manner. The figures presented in this paper are not an exhaustive account of all observed pounding damage, but have been selected to illustrate the both the typical and the exceptional pounding damage forms observed in the earthquake. Frequently the observed damage could also be attributed to other aspects of the building configuration. In particular, damage to parapets was not attributed to pounding unless other evidence was present. While the pounding damage was typically minor or absent (Figure 1), the damage patterns often demonstrated the initiation of mechanisms that would lead to building failure under further seismic activity. All moderate to serious pounding damage observed occurred in unreinforced masonry (URM) structures. Concrete

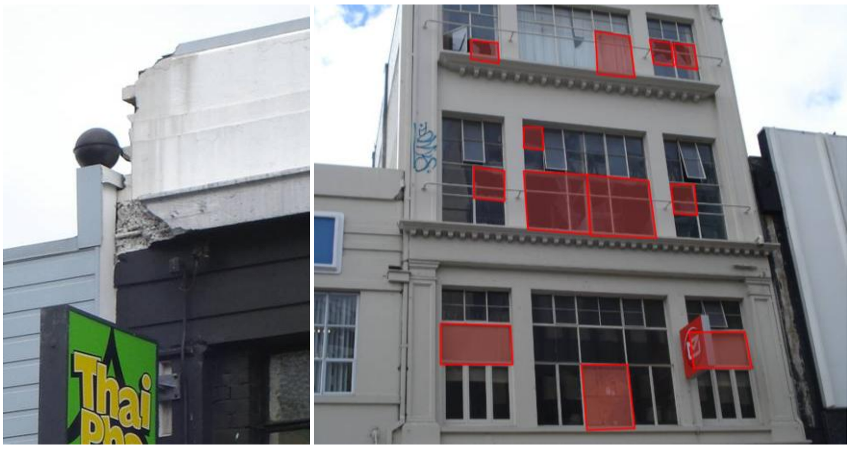

Figure 1: ***Minor pounding damage. Left: Spalled concrete at building interface. Right: Glazing damage (highlighted) predominately located at the third floor, which coincides with the roof of the adjacent buildings. Cracks are also present at the top of the left hand building.***

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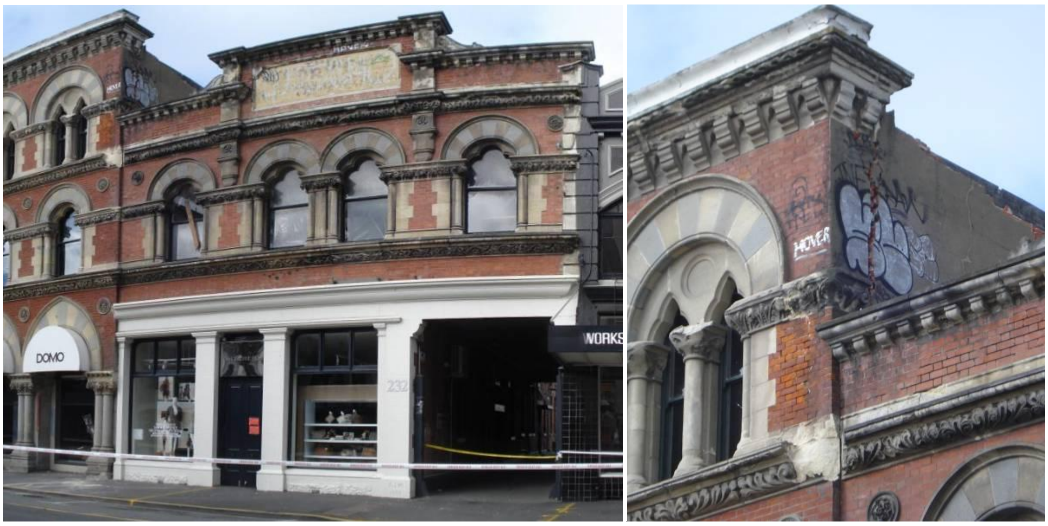

Figure 2: ***Loss of decorative cladding, and damage to masonry wall partly due to pounding. Right: Magnification of damage at the left building interface.***

buildings typically displayed only localised spalling damage.

Since the survey was limited to external damage, no account of intrabuilding pounding damage has been made. Issues such as pounding damage between seismic joints, or collision between structural elements of the same building were outside the scope of this survey. However, it is acknowledged that these effects did occur in the Darfield event.

GENERAL OBSERVATIONS

The observed damage was typically attributable to both pounding and URM construction. The central building in Figure 2 suffered damage from both adjacent buildings, including loss of decorative cladding on the left face. The damage to the masonry wall of the taller building is primarily attributable to the URM construction but pounding is likely to be a significant secondary factor. Parapet collapse also occurred along the length of this wall.

Adjacent buildings where one building has a façade setback suffered noticeable local pounding damage at the exposed corners (Figure 3). This configuration had not been previously identified as critical for pounding. Pounding damage of this type may be particularly severe if timber diaphragms are present in the protruding structure since they will provide little lateral support to the affected wall.

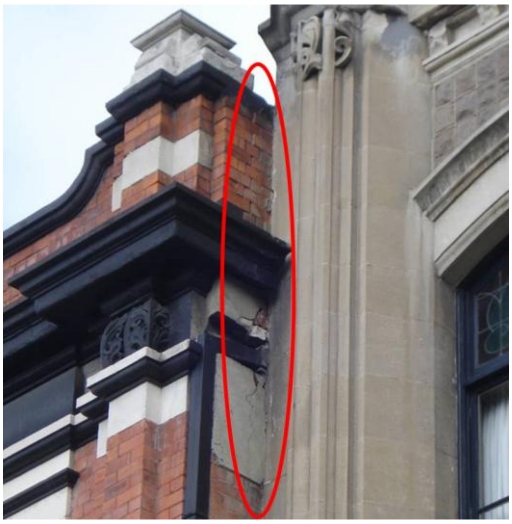

Figure 3: ***Damage to wall resulting from adjacent facade setback***

Buildings with observed pounding damage were typically two to four storeys tall. This is likely to be due to the large number of URM structures built within this storey range (Figure 4). Some image distortion is present in the left image in Figure 4, due to the combination of multiple photos.

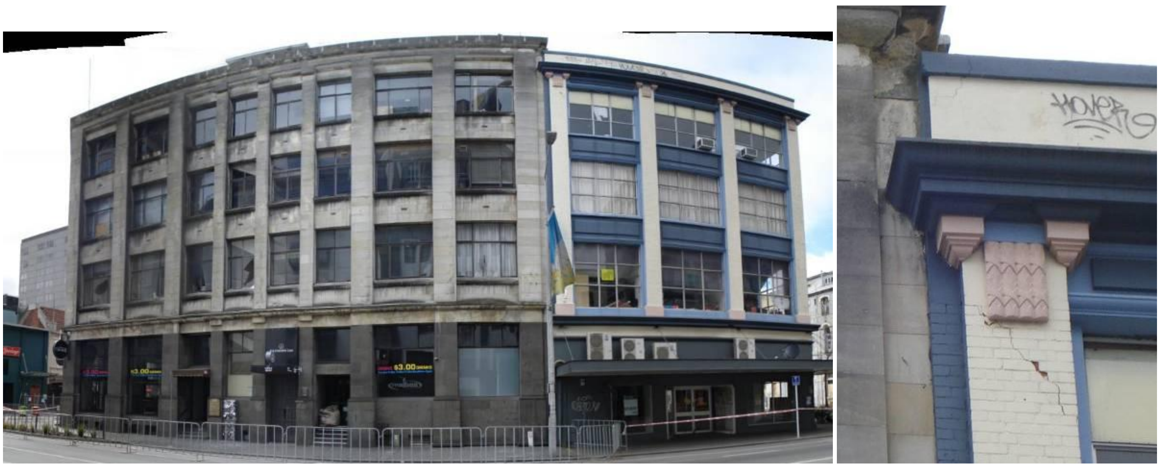

Figure 4: ***Pounding damage between two four storey structures Left: perspective image of building configuration. Right: Magnification of damage to top of right structure.***

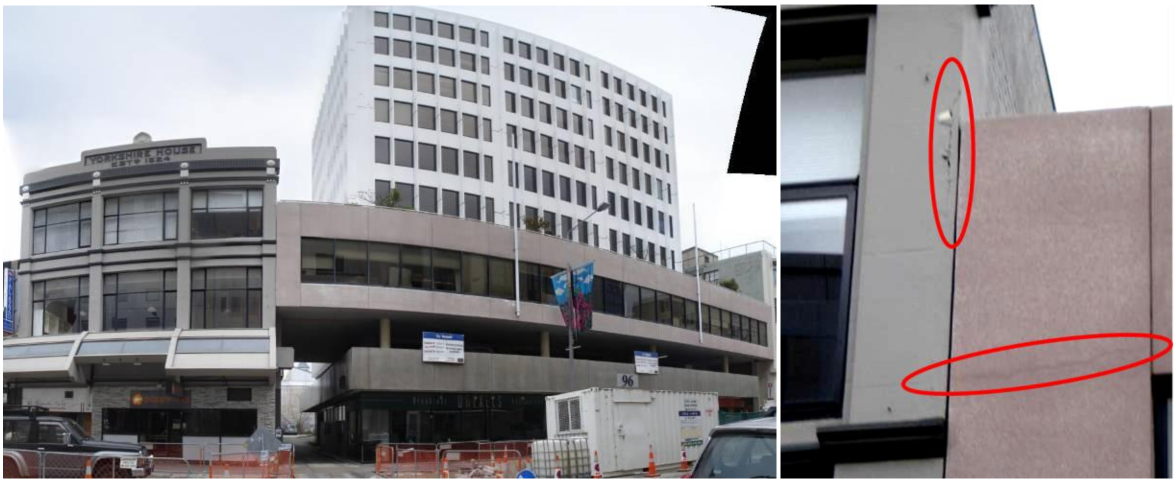

Figure 5: Minor damage resulting from pounding buildings of greatly differing heights. Left: perspective image of building configuration. Right: Magnification of damage at the building interface.

Adjacent buildings with greatly differing total heights displayed surprisingly little damage. Figure 5 shows the most severe damage observed between buildings differing by three or more storeys. While the level of damage is low, the location of this damage is critical. Both buildings have suffered damage to their vertical structural elements and not their horizontal elements. Since lateral loading is generally not considered at this location in any structure, and special detailing for inelastic behaviour due to such loading is unlikely to be present, this could potentially lead to brittle collapse in a larger event.

EXCEPTIONAL EXAMPLES OF POUNDING DAMAGE

The most pronounced pounding damage observed within the CBD was located on High St (Figure 6). Pounding occurred between two URM buildings of three and four storeys, respectively. No building separation was present. While the damage was severe, it was also relatively localised. Two factors have significantly contributed to the local failure: The brittle nature of the unreinforced masonry, and the position of the relatively strong window lintel. The location of the lintel immediately above the parapet of the adjacent building, and the relative strength of the lintel has created a highly brittle configuration. As a result, the top of the damaged masonry has displaced approximately 70 mm. Broken brick units have fallen into the resulting gap between the two buildings, which is likely to have contributed to this displacement. The lintel has also been damaged to a lesser extent. Other damage was also noted in the left hand building including partial failure of the wall not affected by pounding. However, this damage is attributed primarily to the building's URM construction.

Less severe but still notable damage also occurred on Cashel St (Figure 7). Figure 7 shows the central two of four consecutive buildings with zero separation. Damage was confined to the interface between the two buildings. However significant masonry crushing is noted at the first floor. Some of the noted damage may be a result of the momentum transfer from the external buildings. No damage was observed at the top of the second floor. No other buildings in the CBD were observed to have this form of masonry crushing.

EXCEPTIONAL DAMAGED OBSERVED OUTSIDE THE CBD

Pounding damage was not restricted to Christchurch CBD, two notable examples located further afield are presented in Figure 8 and Figure 9. These buildings were observed in the eight days following the CBD survey, while undertaking other research. Figure 8 displays the local damage caused by a

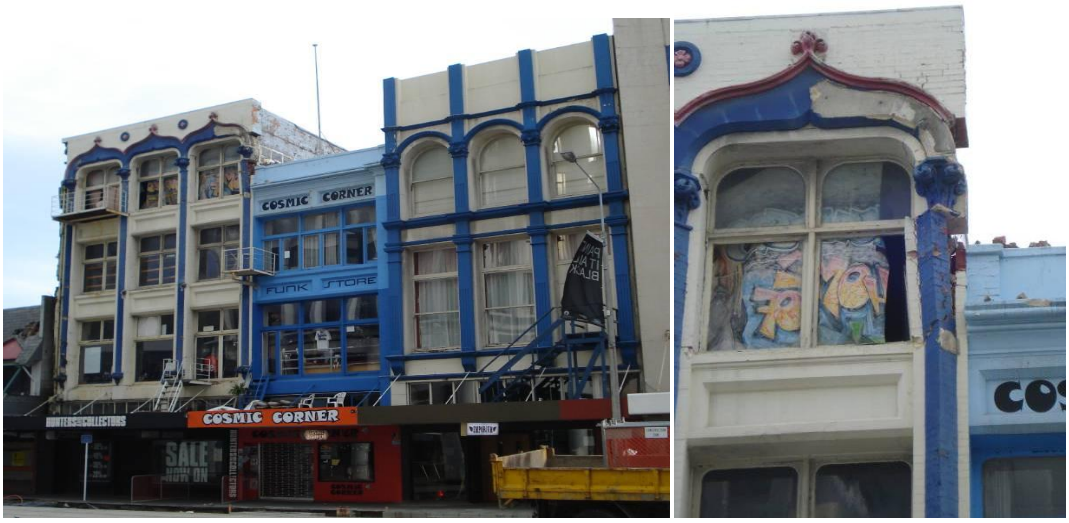

Figure 6: Top floor pounding. Pounding damage has been amplified by the relatively strong window lintel, localising the damage to the masonry below the lintel. Minor damage is present in the adjacent building's parapet. Left: Building configuration. Right: Magnification of damage.

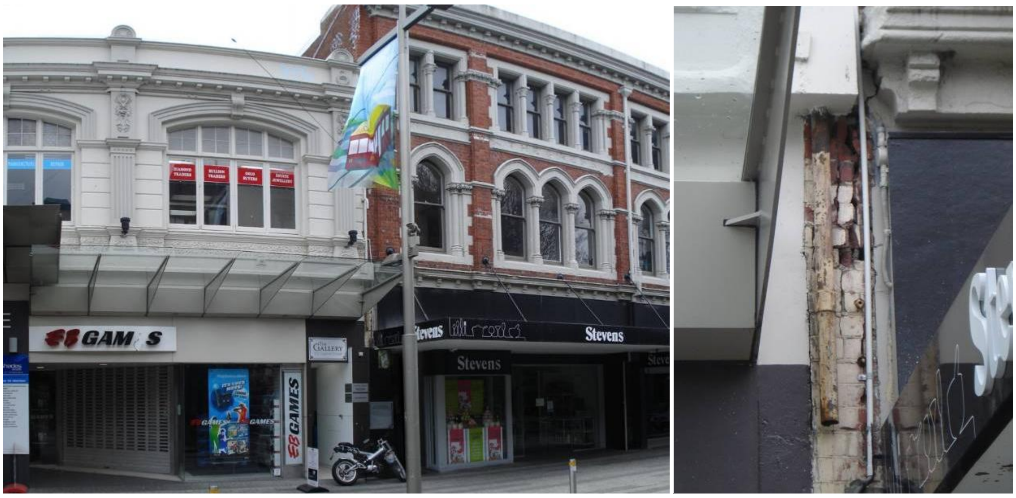

Figure 7: ***Local crushing of brick between buildings. Left: Building configuration. Right: Magnification of damage between buildings at the first floor.***

single fence in Woolston. The adjacent building to the left suffered no apparent damage. Figure 8 illustrates how a seemingly trivial addition to a building may have serious repercussions for the structural system. Figure 9 is also attributed to pounding, although the photo was taken after some demolition work was performed. The damage to the right structure has been amplified by the roof height of the left structure, which has acted as a localised hammer on the failed wall. Significant damage has resulted to both the first and second floor. Other damage is also found throughout the building, which is attributable to the URM construction. While major cracking was observed in the other external walls, none collapsed. Pounding is considered to have significantly contributed to the illustrated failure.

COMPARISON WITH PREVIOUSLY IDENTIFIED POUNDING HAZARDS

Previously, six building characteristics had been identified that increase the likelihood of pounding damage [1]. A brief comment is made on each of these characteristics below.

1. **Floor-to-column pounding**. Much of the observed pounding damage occurred between adjacent buildings with differing floor heights. This type of building configuration causes collisions between each building's floors and their neighbouring building's columns or walls (see Figure 4 - Figure 6, Figure 8, Figure 9). Buildings with floor-to-column pounding generally suffered more damage than buildings with matching floor heights (floor-to-floor pounding). However, some pounding damage was also observed from floor-to-floor pounding (Figure 2, Figure 7).

2. **Adjacent buildings with greatly differing mass**. Differing building mass was not considered to have caused any pounding damage in the Darfield event.

3. **Buildings with significantly differing total heights**. Only one case was observed where pounding damage was attributed total building height difference (Figure 5). As previously stated, this damage is minor.

4. **Similar buildings in a row with no separation**. Multiple buildings in series performed very well. Usually damage is expected on the buildings at either end of a row, however this was not observed in this earthquake. Damage to buildings within the row was sometimes observed when adjacent buildings had differing numbers of storeys.

5. **Building subject to torsional actions arising from pounding**. This characteristic has not been extensively investigated. Some torsional interaction may have occurred between the buildings in Figure 5 and Figure 9. However, the authors do not believe that torsion significantly contributed to pounding damage in this event.

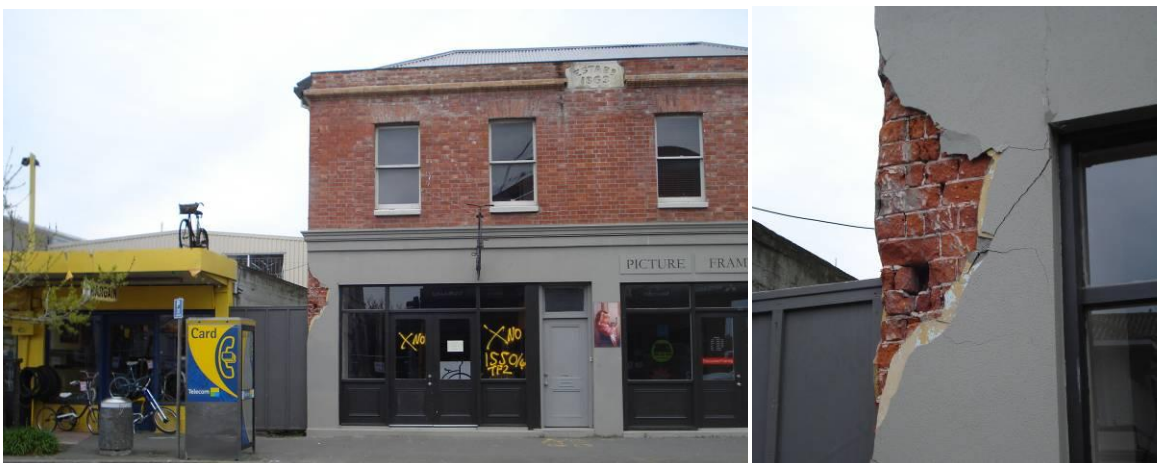

Figure 8: ***Pounding damage resulting from adjacent fence.***

6. **Buildings made of brittle materials**. URM was found to be the defining characteristic of pounding damage in this earthquake. All moderate to large pounding damage was found in URM buildings.

BUILDING CONFIGURATIONS WITHOUT OBVIOUS POUNDING DAMAGE

Numerous building configurations where pounding may be expected due to their close relative proximity actually showed no external damage when inspected. This may be attributed to the low spectral response for buildings with short natural periods. In particular, 3 – 4 storey wall structures were not generally greatly excited. However, taller buildings are understood to have been excited to approximately design basis earthquake levels. Lack of pounding damage in taller buildings can be partially attributed to the low number of tall buildings immediately neighbouring other tall buildings in Christchurch CBD, and the presence of seismic separation between tall building's towers and their surrounding podiums. Other factors affecting pounding damage include the direction of the strong motion shaking, and the relatively short duration of large intensity excitation. Based upon these factors, New Zealand buildings with similar configurations to those illustrated in this paper can expect moderate to severe pounding damage in a large earthquake event. Such levels of pounding damage have been observed in previous earthquakes worldwide [2, 3].

CONCLUSIONS

Predominantly minor pounding damage has been observed in Christchurch CBD. Moderate to severe pounding damage was observed only in URM buildings. The observed pounding damage was less than what could be expected given Christchurch's existing building stock and the intensity of the excitation.

However when evidence of pounding was observed, the damage patterns illustrate how pounding could lead to building collapse. The observed damage almost exclusively occurred in vertical structural elements. From this survey, the authors have observed one collapsed storey that can be reasonably attributed to pounding. Adjacent stepped façades are also identified as a building configuration that is particularly susceptible to pounding damage. Pounding damage remains a serious concern for future earthquakes in New Zealand, especially for earthquakes exceeding the excitation of the Darfield event, or any pounding involving unreinforced masonry buildings.

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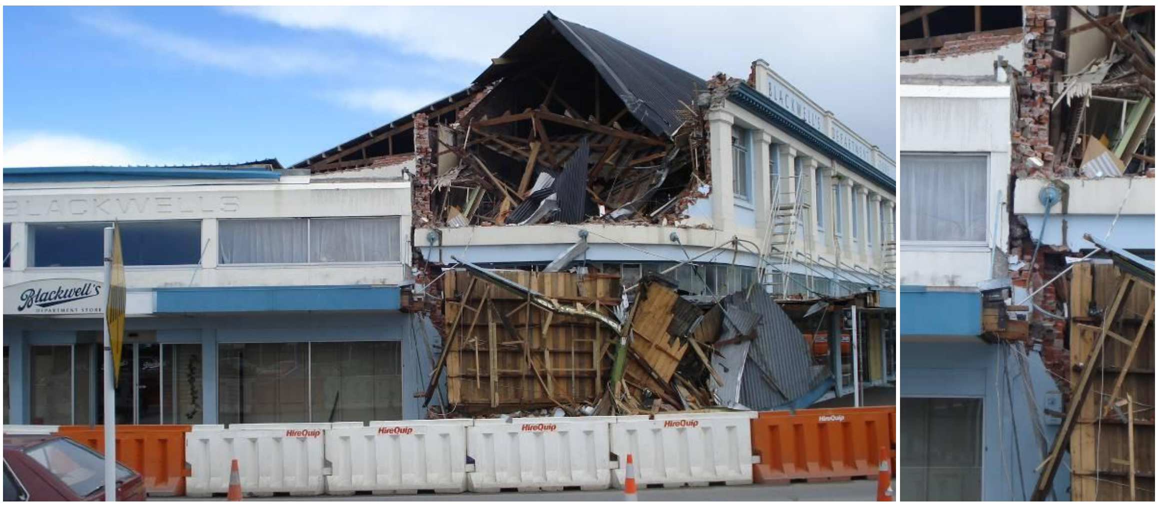

Figure 9: ***Damaged masonry structure in Kaiapoi. Right: Magnification of damaged building interface.***