DAMAGE TO NON-STRUCTURAL COMPONENTS AND CONTENTS IN 2010 DARFIELD EARTHQUAKE

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SUMMARY

This paper describes the performance of (or damage to) non-structural components and contents in buildings during the 4th September 2010 Darfield (Canterbury) earthquake and the subsequent aftershocks. Even in buildings with little damage to their structural systems, non-structural and content damages were significant; and these damages were reported to have increased during the aftershocks (especially those of magnitude 5 and higher). Most commonly damaged non-structural components were brick chimneys, parapets, ceilings, facades, internal walls and windows. The nature and extent of damages in each of these components are discussed in this paper with the help of typical damage photos taken after the earthquake. The extent of content damage in a building was dependent on its usage; typically buildings using racks/shelves for displaying commodities (such as library, departmental stores, liquor shops etc) suffered significantly greater loss from content damage than residential houses, office buildings and other types of commercial buildings.

INTRODUCTION

A significant portion of the estimated 4 billion dollars loss incurred in the 4th September 2010 Darfield (Canterbury) earthquake and the subsequent aftershocks can be attributed to the losses from damage to non-structural components (also termed as secondary structural elements) and contents. Although noticeable structural damage occurred only in a small proportion of the building stock, damage to non-structural components and contents was apparent in almost all buildings in this event. In many buildings, the extent of damage to non-structural components (such as chimneys, parapets, canopies, facades, partition walls, staircases, windows) was more than that to the structural components; except for old and unretrofitted unreinforced masonry (URM) buildings. This is in agreement with outcomes of previous seismic loss estimation studies [1, 2] which have concluded that in several buildings non-structural and content damage contribute a major share of the total loss in an earthquake.

Commonly observed damages to non-structural components and contents are described in this report with some typical damage photos taken after the earthquake. However, it is not to be misunderstood that the types of damage described herein occurred in all buildings. At this stage, it is not possible to provide a concise figure on percentage of buildings undergoing each type of damage. More information should come to light as the insurance claim details come in. Since there is an excess in home insurance policies, damage of very trivial nature is unlikely to be reported. However, owners of most surveyed houses have either lodged a building damage claim or are planning to do so after the aftershocks cease to occur. As structural damage has been minimal except for liquefaction effected areas and unretrofitted URM buildings, the majority of building/house damage claims are likely to be based on damage to non-structural components. This indicates that percentage of buildings that have undergone non-trivial damage to non-structural components is very high. The severity of non-structural damage was influenced by the age and type of building, whereas the extent of content damage depended mainly on the usage of the building.

CHIMNEYS

Damage to chimneys was very common in all areas of Christchurch in this earthquake. In general, brick chimneys damaged most severely (see Figure 1), whereas chimneys made of other materials (even brick chimneys that were plastered outside) damaged to a much lesser extent and light metal chimneys did not seem to have suffered any damage whatsoever. The damage to brick chimneys ranged from minor cracking to the collapse of the whole chimney. In many cases, falling down of the collapsed chimneys resulted in secondary damage to roofs; especially those made of tiles (see Figure 1). A crude survey indicated that more than half of brick chimneys damaged in residential buildings in Christchurch, and the extent of damage did not show any specific correlation with the age and type of the building.

PARAPETS

Brick parapets (not retrofitted for earthquakes) are common features in URM, confined masonry and concrete frame/wall buildings. The majority of parapets in buildings in Christchurch were damaged to different extent in this earthquake; parapet with no damage whatsoever was a rare sight. The damage included cracking, some bricks being dislodged and a segment of (in some cases the whole of) parapet falling down (see Figure 2). In several cases, the detached parapet blocks fell and damaged building parts in lower storeys and in a couple of locations squashed cars parked in the roadside underneath. Collapsed parapets in the roadside buildings could easily have caused injury/casualty if the earthquake had struck during the day.

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Figure 1: Typical chimney damage.

Some URM buildings had parapet bracing measures prior to the earthquake. In many cases, these parapets performed well in clear contrast to severe damage of nearby unbraced parapets in buildings with similar original construction. Even in buildings with the walls anchored to the roof/floor, parapets were found severely damaged (see Figure 2). This was particularly common in buildings where the height of parapet above the anchor line was significant. In a few cases, the parapets on the front elevation of buildings were braced but not on the side and back elevations which experienced severe damage. Also in many cases, damaged parapets were typically removed from tops of URM walls in the clean-up efforts, but the integrity of the connections of the walls to roofs were still compromised by the damage. As a result, tops of some remaining damaged walls will need to be further stabilized with reliable restraints before repairs commence. In some cases, severely damaged parapets collapsed during the aftershocks.

Figure 2: Typical parapet damage.

Figure 3: Typical canopy damage: (i) Supported canopy; (ii) Anchorage failure of suspended canopy; (iii) Cracked wall due to canopy anchorage.

CANOPIES

In several buildings, the canopy was damaged. A subjective approximation is that between 10% and 20% canopies were damaged. Some canopies which were secured to the building by ties (anchored to the wall) caused stress concentration around the anchorage, which resulted in cracks in the walls (see Figure 3). In some buildings, these anchors were unable to resist the extra force generated by the shaking, which caused punching shear failure of the walls around the anchor (see Figure 3). Needless to mention, this resulted in complete collapse of the canopy. In many cases the canopy was damaged because of the impact caused by falling parapets or facades from storeys above. Even canopies supported by light truss suffered damage in some cases (see Figure 3).

CEILINGS

In low-rise residential houses, ceilings generally consist of plasterboard nailed and/or glued to a light timber frame. In commercial buildings, ceilings consist of panels supported on a grid of aluminium beams that are hung though metal wires anchored to the floor above. In both cases, the ceiling systems are generally not engineered for seismic performance. Unlike in earthquake prone countries like USA and Japan, properly

Figure 4: Different types of damage to ceiling systems in residential and commercial buildings.

designed seismic braces were not used in the ceilings in the inspected buildings. Hence, it was not surprising that the ceilings were damaged in several buildings in this earthquake. In a crude approximation, 10%-15% of commercial/industrial buildings incurred ceiling damage to different extents.

The proportion of residential houses with ceiling damage was significantly less than in commercial/industrial buildings. In residential houses, the common form of ceiling damage was cracks (of varying length and width) on the plasterboard, crushed plasterboard particles falling on the floor and plasterboards being detached from the frame (due to punching though the nail or tearing off at the glue). On the other hand, in commercial buildings, the observed ceiling damage included dislodging of the panels, breaking of the panels, failure of the ceiling grid members and connections, failure of perimeter angles and damage of ceiling panels due to interaction with the services. Some photographs of typical ceiling damage are presented in Figure 4.

FAÇADES, INTERNAL LINING & PARTITION WALL

In most URM buildings, brick walls collapsed in the out-of-plane direction, but these are not included here as they are structural damage in URM structures. However, many other types of buildings such as timber framed, infill masonry and concrete framed buildings had damage to infill walls, partition walls and facades. Damage of masonry infill did occur in a few buildings but was not very common. The worst observed damage was to the St. Elmo Courts (see Figure 5), a brick-masonry infilled RC frame building constructed in 1930s. The building exhibited large shear cracking of the infill between windows. The cracks extended the full height of the building. Ceramic tiles attached to structural beams and columns were also fractured, especially around beam-column joints. Note that masonry infill in old buildings can easily be categorised as structural components and the aforementioned damage in St Elmo Courts could also be argued as structural damage.

Within the central city, the majority of facade damage was to medium height buildings with infill and exterior lightweight claddings. Damage to glass panes was visible from street throughout greater Christchurch, but this has been included in

Figure 5: Damage to non structural vertical elements.

Damage to old window panels | Spider glazing damage | Damage to window and wall

Figure 6: Typical damage to windows.

the next section under "windows damage", which could also have been categorized as facades. Many residential houses exhibited warping of their joinery without any cracks visible in the glass. The other type of facade damage consisted predominantly of brick facades falling out due to poor connection with the structure. In the partition walls and internal linings, it was very common to see cracks initiating from door and window corners (see Figure 5). Some cases of observed façade, wall, lining, tile damage are shown in the photos in Figure 5. As shown in the photos, ceramic tiles on the walls (and floor in some cases) also suffered damage.

In many buildings, the aftershocks (especially; the 5.1 magnitude crustal aftershock which originated in Lyttleton, less than 10 km from Christchurch, on the early morning of Wednesday 8 September) caused additional damage to non-structural components. It was reported that new cracks on walls and internal linings appeared and the existing cracks widened and extended during the aftershocks. Being a near source and very shallow earthquake, this aftershock had a higher dominant frequency than the main event, which is closer to the natural frequency of the low rise residential building stock. Understandably, this aftershock caused noticeable damage to these buildings.

WINDOWS

Broken glass panels in windows were observed in several buildings. The worst of the glass panel damage was focussed in the central city, where the majority of Christchurch's taller and historic buildings are located. Window panels cracked in the main shock were reported to have broken in the aftershocks in some buildings. As the window framing system used in the old buildings was rigid and did not allow relative glass displacement, most broken glass panes were observed in this type of window frames. On the other hand, modern aluminium frame windows have deformable rubber sealing which allow the glass panels to displace to some extent. Hence, very few broken glass panels were observed in this type of window. Although spider glazing is a modern system, damage to this type of glazing was observed; for example in the Westpac building in the city centre (see Fig 6). In all cases, the window glass damage posed a falling hazard for pedestrians. Some typical window damages are shown in Fig 6.

RACKS AND SHELVES

Racks and shelves are common in industrial, commercial and office buildings. Apart from liquefaction affected areas, industrial establishments typically suffered little damage to non-structural elements and suffered no interruption to their business services. One notable exception was damage to storage rack systems and the subsequent loss of stock. The damage to the rack systems varied. Complete collapse occurred to heavily loaded, relatively light gauge racks. It was reported by storeowners that more things fell from racks that were secured to the floor but not to the walls than the racks that were not secured to the floor. This might have been due to lower forces in the unsecured racks as a result of rocking and sliding. In some cases, it has also been found that inadequate provision of bolts in one segment of racking system resulted in twisting of the whole rack (see Figure 7). In some cases, cracks were found in the infill wall panel where the racks were anchored (see Figure 7). A sampling of the observed racking damage is shown in Figure 7.

In offices, unsecured book shelves fell to the floor. In libraries, even the shelves that were tied together collapsed (see Figure 7). It was found that the ties in this case were not strong enough and failed to resist the tilting tendency of the shelves. Shelves tied to the wall and tied with each other using strong ties were intact.

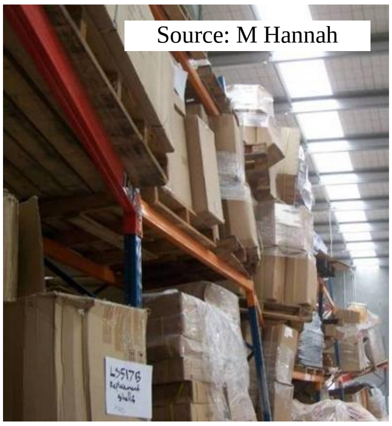
CONTENTS

The earthquake was strong enough to cause things fall down from their elevated position in almost every building in Christchurch. The extent of content damage varied greatly depending on the location of the building and the use of the building. In residential houses, the common contents that were damaged include racks, cutlery, vases, photo frames, arts, decorative pieces and aquarium. In a small number of houses; television sets were reported to have fallen off from the cabinets. Contents were reported to have damaged also in the aftershocks; especially the Wednesday (8th September) morning's 5.1 magnitude aftershock appeared to have caused content damage amounting to more than half of that in the main earthquake in some houses/shops. More than half of the surveyed residential households were not planning to lodge an insurance claim for content damage which means that the content damage was less than the excess of their content insurance policy (typically 250 dollars).

In industrial buildings, content damage was almost none (except for damage to racks in some industrial buildings as mentioned earlier) because the heavy machineries and equipments expectedly did not fall down from their positions. In offices, despite several things (including documents) fell down, there was not much that could not be reused. Office equipments (such as printer, photocopiers) are generally not secured to the floor with any seismic restraints; however, they mostly remained operational after the earthquake. On the other

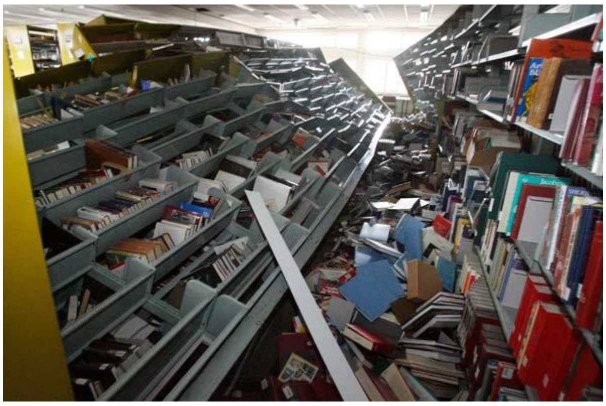
Crack developed in the wall behind the rack at the anchor

Twisted racks due to insufficient bolt in a segment



Damaged racks at a storage facility

Collapsed racks at a metal fabricator warehouse



Damage to book shelves in university library

Figure 7: Typical damage to racks and shelves.

extreme, content damage was a major contributor to the total loss in commercial buildings.

Depending on the type of business, the extent of content damage varied greatly. In a poultry farm, it was reported that 3,000 chickens were killed and thousands of eggs were broken. In many shops, things put inside the freezer got spoilt because of power disruption, which lasted from a few hours in most suburbs of Christchurch to a few days in some. As expected, there was little content lost in shops selling garments, shoes, beds, flowers, furniture and all other business which did not display items in racks. Similarly, some businesses providing services also did not incur much content loss. Nevertheless, businesses selling everyday commodities suffered severe content damage. Flooding on the floor from broken bottles was a common sight in department stores, liquor shops, bars and restaurants (see Figure 8). Pharmacies, gift shops, and several other businesses which display fragile items in racks also reported extensive content damage. Some typical photos of content damage are shown in Figure 8.

EXAMPLES OF GOOD PRACTICES

The extent of damaged contents varied greatly depending on the type of display racks. For example, there was no content damage whatsoever in a shop selling fragile items such as trophies, glassware, plaques, frames etc. A lot of these delicate things were hung on wall, displayed on racks secured to the wall and standalone racks, still nothing fell and broke. It was found that the racks secured to the walls had an angle at the front edge, which stopped things from falling down despite being displaced from their original position. Even at other locations, lips and rods at the edge of shelves (see Figure 9) performed quite well, reportedly preventing the sliding or toppling of many contents. The standalone display racks were

Furniture and artifacts damage in a church.

Liquor damage in a store.

Cabinet and book damage in an office.

Damaged contents in a warehouse.

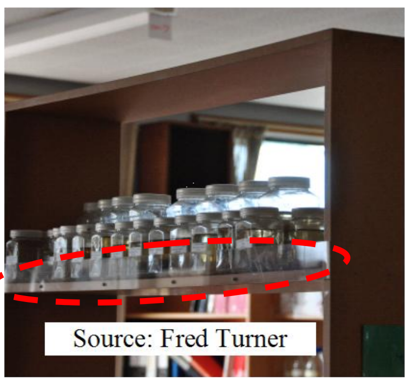
Figure 8: Contents damage.

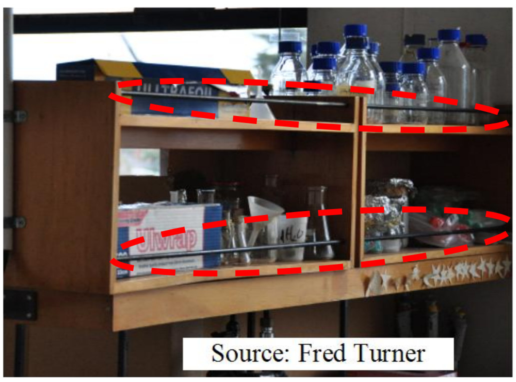
provided with rollers at the base, which acted like base isolation and prevented the rack from rocking which would have caused the things to fall down. The racks on the roller moved a small distance, but the carpet on the floor restricted the rack from rolling haphazardly. However, racks on rollers may be very unstable in uncarpeted floors.

Similarly, there was generally no damage to racks that were anchored to walls. It was learnt from a liquor shop that a rack with a bigger footprint had a much smaller likelihood of bottles falling down than smaller racks. In the University library, book shelves connected to each other by a small tie toppled whereas shelves anchored to the wall and/or interconnected by a stronger tie remained intact. Some typical cases of good storage practice leading to reduced risk of content damage are shown in Figure 9.

LESSONS LEARNT

- Brick chimneys are very vulnerable and should not be used in new constructions. Even in existing buildings, brick chimneys should ideally be properly braced or replaced. Bracing is challenging as the chimneys tend to be very heavy and any bracing will have to anchor to very light wood roof framing members. A viable option may be to remove the chimneys down to the roof line,





Wall-anchored rack with no damage **Lips and bars at the edges of racks protecting the contents from falling down**

Figure 9: Examples of good storage practice.

provide a concrete confining cap at the roof line, anchor to the roof at that point and replace with a properly engineered light chimney above the roof line.

- Unsecured parapets are highly susceptible to severe damage, potentially leading to collapse in earthquakes. They should be braced to the buildings to prevent collapse.
- Windows with tight frames and without any deformable sealing (as in old windows) are very vulnerable to glass breaking in earthquakes. The modern windows with aluminium frames and rubber sealing performed very well.
- The members used in truss/grids/frames to support and/or brace non-structural components such as canopies, ceilings, racks, shelves should be properly designed to resist the effect of seismic actions.
- Racks and shelves should be properly anchored to walls wherever possible. In some cases, the racks with insufficient anchorage performed poorly than unanchored racks. However, this should not be taken as a justification to put unanchored racks on the floor. A properly designed racking system that is also adequately anchored will provide the best performance in relation to life safety and protection of contents. It is important for new facilities to use seismically engineered rack systems which would consider the wall anchorage as a boundary condition of the system.
- Wherever feasible, wider racks should be used instead of thin/slender racks.
- Angles, lips or rods at the edges of racks are very effective in preventing the contents from falling.

RESEARCH NEEDS

- Bracing scheme for existing brick chimneys and come up with seismic resistant chimney system (probably already exists in the form of modern metal chimneys, but this needs to be verified/enforced).
- Methods to stabilize facades, parapets and canopies in existing buildings.
- Seismic performance assessment and methods to improve seismic performance of common ceiling systems used in NZ.
- Investigate suspended ceiling seismic bracing systems currently in use (if any) and their relative performance. Ceiling performance can improve if some simple and prescriptive installation and seismic bracing details are utilized.
- Analysis of insurance claims on non-structural and content damage.
- Methods to improve seismic performance of racks and shelves. In particular, the current NZ racking design guidelines need to be compared with the observations from this earthquake, potentially leading to amendment of the guidelines.

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REFERENCES

1. Bradley, B., Dhakal, R. P., Cubrinovski, M., MacRae, G. and Lee, D., (2009), “Seismic Loss Estimation for Efficient Decision Making”, *Bulletin of the New Zealand Society for Earthquake Engineering*, Vol. **42**, No. 2, pp 97-110.
2. Dhakal, R.P., Mander, J.B. and Xu, L. (2010), “Seismic Financial Loss Estimation of Steel Moment Frame Buildings”. *Journal of the International Review of Civil Engineering (IRECE)*, Vol. **1**, No. 2, pp 130-142.