LESSONS LEARNED FROM THE 2010 CANTERBURY EARTHQUAKE AND AFTERSHOCKS, NEW ZEALAND

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ABSTRACT

A moderate M7.1 earthquake hit Canterbury on Saturday, 4 September, 2010 at 04:35:46 a.m. New Zealand time (GMT +12). It was expected to be the most damaging ground shake since the 1931 magnitude 7.8 Hawke's Bay earthquake. The epicentre was located approximately 45 km west of Christchurch, in a rural area at a depth of 10 km. There were followed by more than thousand aftershocks had been measured. An aftershock M6.3 was recorded at 12:51 pm on Tuesday, 22 February 2011. The epicentre of the aftershock was approximately 10 km south-east of the Christchurch Central Business District (CBD), near Lyttelton, at a similar depth to the initial earthquake and caused much more severe damage to CBD and residential areas nearby. Lessons learned from the Canterbury earthquake and its aftershocks are a timely reminder to Indonesian structural engineers of a number of things with respect to seismic design, construction practices and post disaster evaluation. These include: The importance of implementing the latest seismic loadings and design technology into new and existing structures without undue delay; The need to maintain effective Building Code enforcement and post-earthquake audit process, including the keeping of publicly transparent compliance records; The important role of the design engineer in observing and auditing the interpretation and implementation of the design; Vigilance to prevent improper substitution of materials and ill-considered design changes; The importance of ongoing continuing professional development and education for design, construction and building code enforcement officials. This paper also discusses the need of having a guide for conducting post-earthquake structural repairs as including a quick way to identify appropriate repair strategies.

KEYWORDS: *earthquake, post-earthquake repair, post-earthquake audit process, seismic loadings*.

INTRODUCTION

The garden city of Christchurch is the largest city in the South Island of New Zealand, with a population of around 376,700 people12. A moderate M7.1 ground shake (known as the Darfield earthquake) struck the east of the South Island at 4:35 am on Saturday, 4 September, 2010. The epicentre was located approximately 45 km west of Christchurch, at a depth of 10 km. There was no loss of life in this earthquake and only two serious injuries. This was the largest earthquake in New Zealand since the deadly M7.8 Hawke's Bay (east of North-Island) earthquake in 1931. There were over a thousand aftershocks which have been measured. The biggest aftershock was recorded at M6.3 at 12:51 pm on Tuesday, 22 February 2011. This epicentre of the latest aftershock was approximately 10 km south-east of the Christchurch Central Business District (CBD), near Lyttelton, at a similar depth to the initial earthquake (see Fig. 1). The damage to CBD buildings and residential areas in the eastern part of Christchurch was much greater than that of the last 4 September, 2010. Its shallowness, proximity to urban centre and the timing of this latest aftershock made this ground shake particularly devastating. This aftershock caused a death toll of 182 people and many people seriously injured as well as severe damage of a wide range of modern buildings, RC-buildings pre-1970 and heritage or older buildings.

SEISMICITY AND GROUND MOTIONS

New Zealand is located at the tectonic plate boundary between the Australian and Pacific Plates which passes through the South Island of New Zealand. Subduction at the north transitions into a continent-continent collision zone as shown in **Fig. 2**. The Australian and Pacific Plates converge obliquely at around 30-60 mm/year in New Zealand. The resultant collision zone between these plates is not in form of a line on a map, rather it is a distributed zone of active faults each with their own capability of generating large earthquakes throughout New Zealand.

It was found that a previously unknown fault had caused the earthquake. A fault beneath the Canterbury Plains capable of generating an earthquake of that size was a major surprise. Building design is based on the NZ Probabilistic Seismic Hazard Map, which is based on anticipated shaking from known faults. A significant question arises, about whether design standards should take more account of the possibility of such unknown faults.

There were many strong motion testing sites set up after the September earthquake that will provided very useful information about the earthquake for future assessment of seismicity in Christchurch. However it will take some time for the records to be properly calibrated and analysed. **Fig. 3** and **4** show the preliminary response spectra based on recordings in 4 September 2010 and 22 February 2011, for deep or soft soils, respectively compared to the NZS1170 spectra for sites close to the Christchurch CBD.

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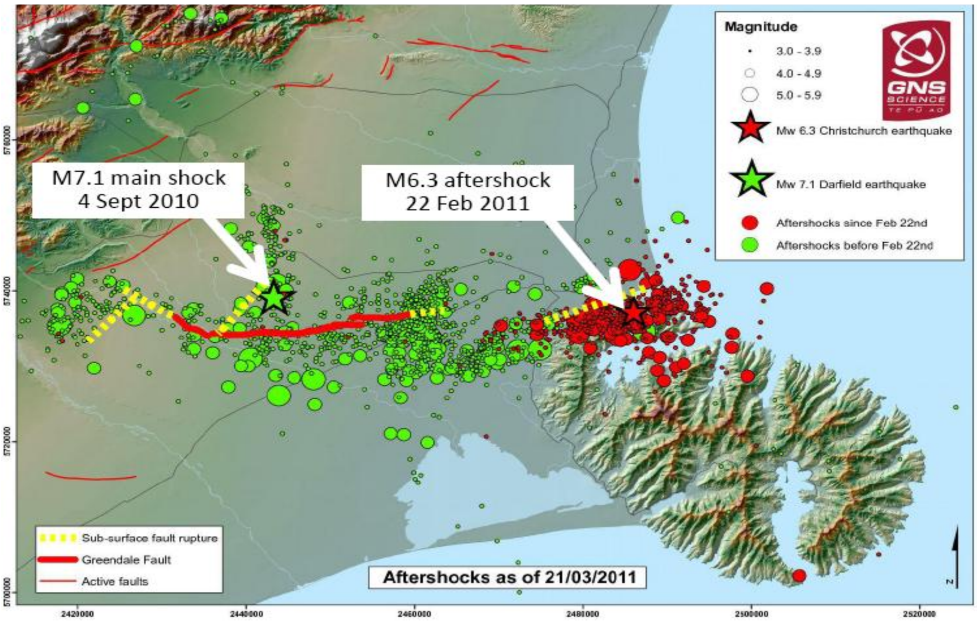

Fig. 1. Map showing the main shock, aftershocks, and fault ruptures[5]

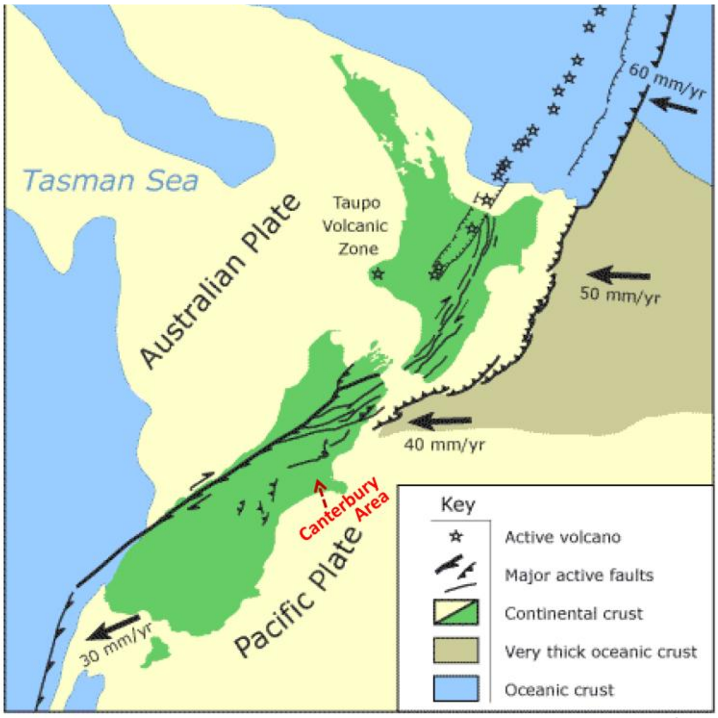

Fig. 2. The tectonic plate boundary in New Zealand region[13]

GEOTECHNICAL ASPECTS AND LIQUEFACTIONS

The over-riding impression of the main shock is one of serious liquefaction damage to homes as well as schools and other low rise buildings on soft soils and sand. Foundations are tilted, porches and rooms are broken away, and floors are pushed up or down and separated, leaving doors and walls out of kilter.

Lateral displacements were measured in urban areas affected by lateral spreading during the 2010 main shock. Significant offset-right lateral generally ranged between 0.5 to 3.5 m, with variable vertical throw mostly less than 1 m in the areas investigated. As a result, a significant amount of damage was induced to the residential properties/houses and lifelines in these areas[10].

BUILDING PERFORMANCES

New Zealand significantly upgraded its building codes for seismic requirements in the 1970s. Buildings constructed before these stricter codes were in place sustained the most damage. Damage from the main shock is mostly restricted to old unreinforced masonry buildings, although many survived. Most modern concrete and steel buildings, and timber framed houses, had minimal structural damage.

The aftershock in February 2011, however caused thousands of buildings to be classified as unsafe, two total

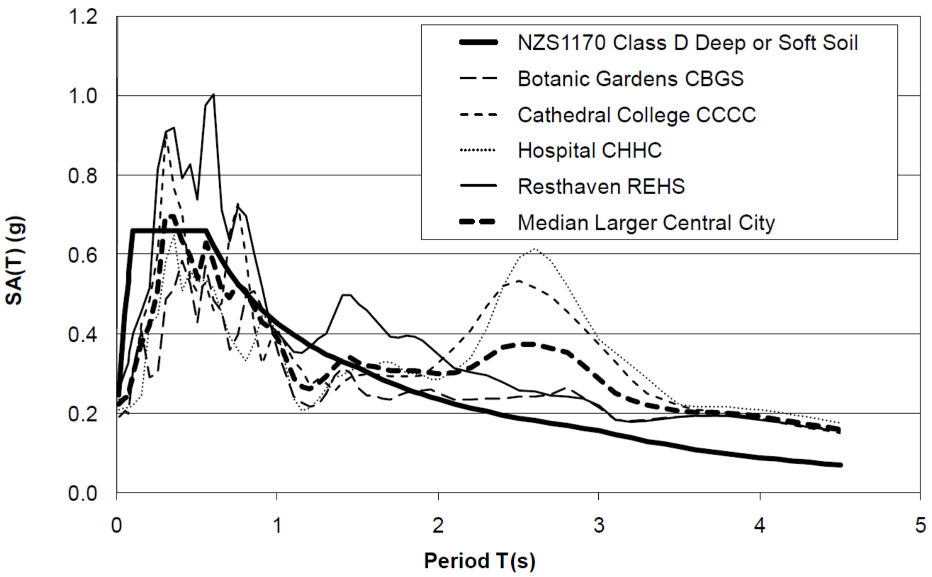

Fig. 3. Comparison of recorded in 4 September 2010 and NZS1170 spectra for sites close to the Christchurch CBD[8]

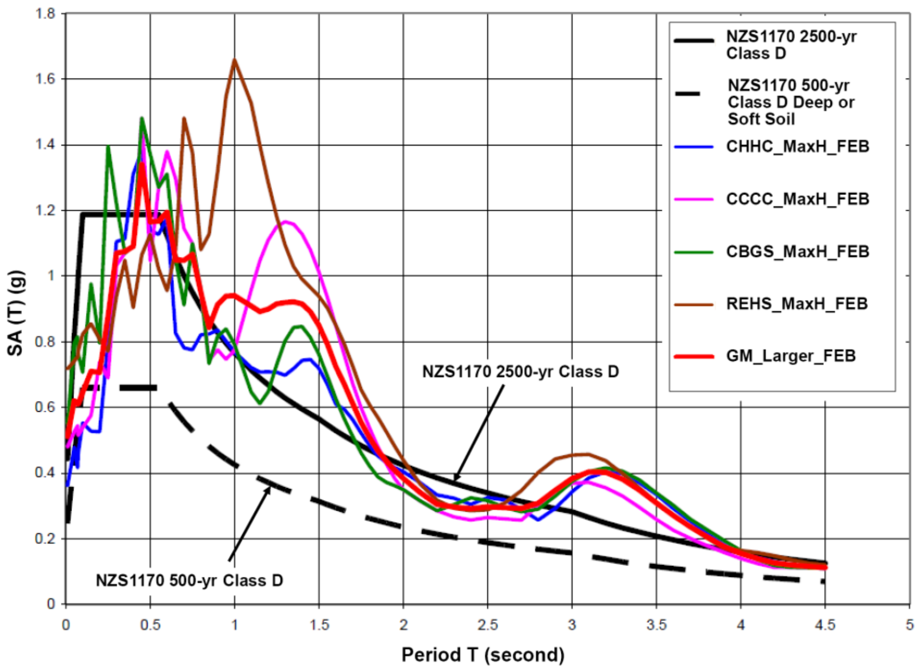

Fig. 4. Comparison of recorded in 22 February 2011 and NZS1170 spectra for sites close to the Christchurch CBD.

collapses of CBD buildings, liquefaction in many part of the eastern suburbs of the city and CBD, and inelastic response in a number of modern buildings.

Residential Buildings

Most houses in the vicinity are built using light timber framing, others use steel framing, solid wood, brick and masonry houses. During the 4 September 2010 earthquake, thousands of chimneys were claimed to have collapsed and resulted in damage of the surrounding roof structure (see **Fig. 5**), neighbouring properties and vehicles. Housing damage was typically limited to damage from liquefaction and related lateral spreading or settlement of foundations. Houses built in the last twenty years that are founded on unreinforced concrete slab on grade suffered significant damage where liquefaction occurred.

During the February 2011 aftershock severe structural damage of residential buildings occurred. Damage was caused by rock fall and also ground movements in the hilly Sumner area. Falling chimneys again caused damage to roofs. Vertical accelerations of this ground shake caused roof material to be shaken off. Further issues were damaged veneers, damage to linings, soft storey failures (see **Fig. 6**), lateral shift and subsidence near the river, damage to foundations due to liquefaction, slope movement and lateral shaking. Other houses constructed using steel framing, solid wood, brick and masonry were also severely damaged. Most pole houses performed well due to their flexibility.

Fig. 5. Collapsed chimney of residential housing

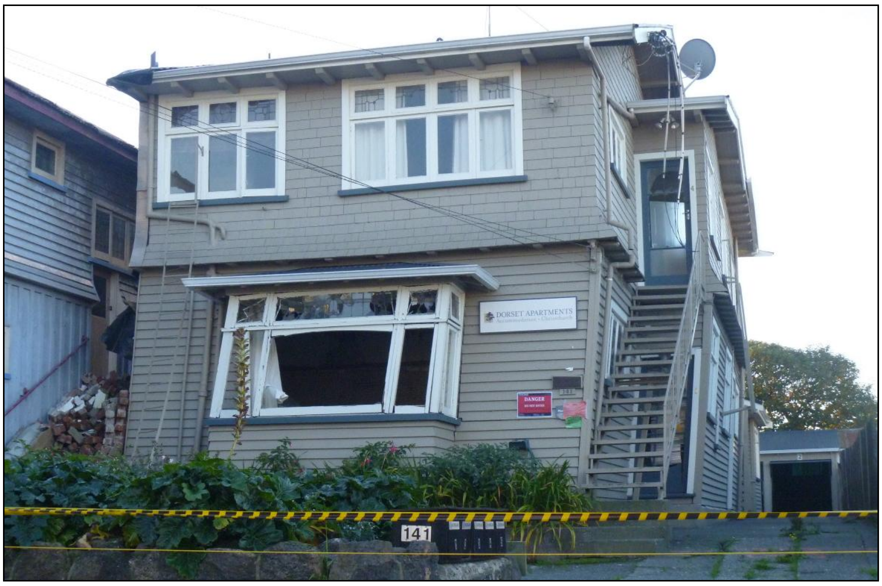

Fig. 6. Soft storey failure of timber housing

Heritage and Old Buildings

Recent research has suggested that there are approximately 850 unreinforced masonry (URM) buildings in the Canterbury area[11]. Most of these buildings consist of 1 or 2 storey and most of them are used for commercial occupancy. After the main shock 4 September 2010, URM buildings in Christchurch that had been re-strengthened earlier showed good performance. However to the contrary many of the ones that had not been strengthened experienced a lot of damage.

However, after the aftershock 22 February 2011, many URM structures, particularly in the Christchurch business districts, suffered more damage, and partial collapse due to their close proximity to the shaking (see **Fig. 7**). There was also considerable damage to other URM buildings which are historic or heritage structures. The Christchurch City Council and building owners will have to set priorities on which buildings must be saved and which may need to be demolished.

The retrofitted URM buildings basically showed that their steel strong back, textile reinforced mortar/shotcrete strengthening generally performed well. Reinforced concrete masonry (RCM) buildings suffered minor to moderate diagonal cracking failures primarily attributable to poor or absent grouting and poor rebar detailing. The city icon, Christchurch Cathedral which was built with stone material in 1881 and strengthened in 1997 has severely damaged.

Multi Storey Buildings

Based on the Building Safety Evaluation Statistics made after the 4 September 2010 event, it was found that in spite of non structural damage (facade, glazing, infills, partitions, ceilings, contents) around 90% of pre-1970s and post-1970s multistorey buildings had performed well. These buildings were constructed with various types of earthquake resistant structural systems, such as Reinforced Concrete (RC) Frames, RC Shear Walls, RC Frames with Masonry Infills. Pre-1970s RC buildings

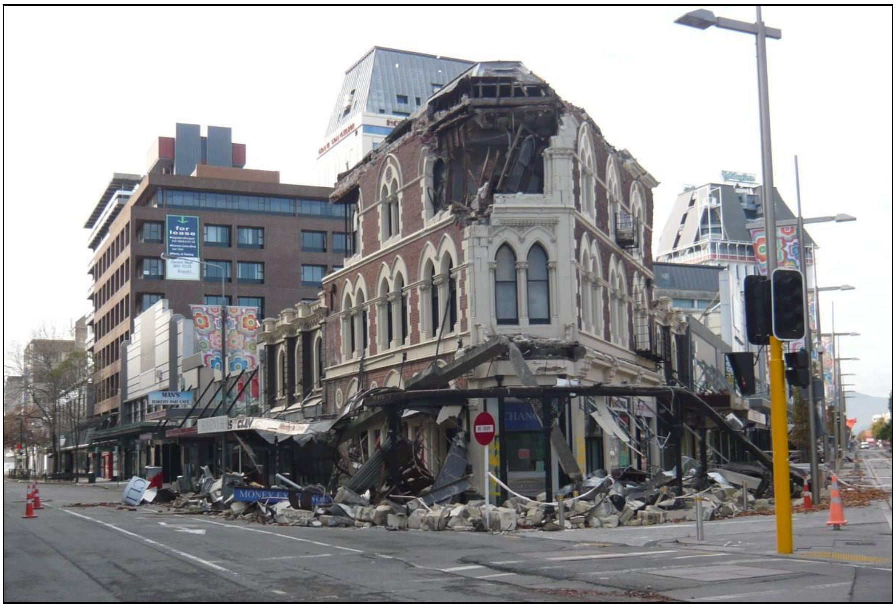

Fig. 7. Three storey URM building in the CBD severely damaged

Fig. 8. Shear failure column at post-1970 RC building

showed signs of early brittle failure modes, such as beam-column joint cracks and onset of infill wall failures. Several high-rise buildings showed low-to-moderate level of damage, consistent with the long-period demand of the ground shake.

The 22 February 2011 aftershock, however caused an early 1960's and a late 1980's RC buildings to totally collapse (PGC and CTV Buildings). There were also found among both pre- and post-1970s RC buildings: beam plastic hinges and slab damage; beam shear failures; short column failures at building setback level; punching shear of RC flat slabs; multiple shear failures at columns (see **Fig. 8**); cracks in beam-column joints; foundation beam failures; buckled boundary reinforcing bars; shear or flexural damage in columns and walls.

Construction of modern steel buildings in Christchurch generally performed well after the main shock and also the aftershock 22 February 2011. However, one eccentrically braced frames developed link fractures due to poor detailing; concentrically braced frames fractures were observed in connections unable to develop the brace gross-section yield strength; and multiple industrial steel storage racks collapsed.

In precast concrete buildings, there were beam elongation and precast floors damages; welded slotted connection failures due to workmanship errors; anchorage pull out failures; loss of bearing support/shear transfer; collapsed precast stairs, etc. As expected the base isolated Christchurch hospital only experienced minimal damage and remained operational.

EMERGENCY RESPONSE AND COORDINATION

The emergency responses after both the 4 September 2010 as well as the 22 February 2011 events were effective. Well planned arrangements were set-up across local authorities, lifeline utility operators, engineering consultancies, and national agencies. Christchurch City, and Waimakariri and Selwyn Districts, all declared a State of Local Emergency for their districts under the Civil Defense Emergency Management Act 2002[8]. The Urban Search and Rescue (USAR) teams immediately commenced rescue operations. The search and rescue operation officially ended nine days after the 22 February 2011 aftershock and they then moved their focus from rescue to recovery, once the probability of finding survivors was gone.

Building assessments began within 12 hours after the shocks, using the "Building Safety Evaluation during a State of Emergency" process refined during the 2009 NZSEE mission to Padang, Indonesia[1]. The building inspection teams involving professional structural engineers and building officials were divided into several operations. One operation focused on the residential suburbs while another operation focused on the commercial/residential buildings within the Christchurch Central Business District (CBD). Level 1 Rapid Assessment (placarding) of the CBD area started on the fourth day and some private engineering consultancies were tasked to carry out Level 2 Assessment of specific buildings where they had an existing client-consultancy relationship.

Physical and virtual clearing houses were established after the earthquakes by the Natural Hazards Research Platform (for registered users), NZSEE (for both public and for registered users), AEES, and EERI., in the first few weeks comprised an impressive collaboration and free exchange of information between scientists, engineers, government officials, and International visitors.

FINAL REMARKS

The M7.1 main shock and also M6.3 aftershock which hit Canterbury area in a 5 month period of time is a punctual reminder to Indonesian structural engineers of a number of things with respect to seismic design and construction practice of structures. These include:

a. The importance of implementing the latest seismic loadings and design technology into new structures and existing essential buildings without undue delay. Non-ductile detailing, for instance can be catastrophic and must therefore be retrofitted. So-called gravity only elements do not exist in reality. They need to be design to accommodate the inelastic displacements developed in the buildings primary seismic resisting system. Precast concrete connections are critical and therefore need to be designed and implemented with extreme care.

b. It is important to the community who occupy buildings for the authorities to maintain an effective Building Code enforcement and audit process, including the keeping of publicly transparent compliance records. Good seismic resisting structures require good design, good materials, and good construction. Therefore the role of the design engineer in observing and auditing the interpretation and implementation of the design is essential, to prevent improper substitution of materials and ill-considered design changes during construction.

c. There is an urgent need for ongoing continuing professional development and education for designers, construction engineers and building code enforcement officials, to develop and maintain their technical competency.

d. There is an urgent need to develop a guide for conducting post-earthquake structural assessments and repairs, including a quick way to identify appropriate repair strategies.

e. It is important to urgently implement effective and cooperative emergency response schemes involving all relevant agencies. Seismic drills for response agencies need to occur regularly.

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