USAR Engineering Response to the 2011 Christchurch Earthquake

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Abstract

This paper provides an overview of the 2011 Christchurch earthquake with particular reference to the Urban Search and Rescue operations. The USAR operations involved some 700 specialist personnel from New Zealand, Australia, Japan, USA, UK, China, Taiwan and Singapore, comprising Technicians, Engineers, Doctors, hazard experts and Police with search dogs. The USAR response lasted some four weeks and the paper describes the three distinct phases comprising; rescue, victim recovery and city/suburb safe operations. The Magnitude 6.3 Lyttelton earthquake struck within 10 kilometres of Christchurch CBD and caused massive damage to buildings and lifelines with some 184 confirmed deaths and a repair bill in the order of $15-20 billion dollars.

1. Earthquake Overview

The Magnitude 6.3 Lyttelton earthquake struck within 10 kilometres of central Christchurch at 12:51pm on Tuesday 22 February, 2011 and caused massive damage and 184 confirmed deaths. This event was a severe aftershock of the Mn7.1 Darfield earthquake that struck on 4 September 2010, some 40 kilometres from the city centre. The city of Christchurch with a population of 350,000 people and 140,000 homes is located on an alluvial plain with around a 50 metre depth of fine silts, sands and gravels and a very high water table. The Mn6.3 event was essentially a ‘bullseye’ event that violently shook the city with peak ground velocities in the order of 400 mm/second and very high vertical accelerations in the order of 1.0g. Such severe ground shaking on the soft saturated alluvial sediments caused widespread liquefaction and resulted in around 250,000 tonnes of silt deposited in the streets, widespread foundation damage, particularly to building located on pad footings or supported by shear friction piles. The liquefaction and soft soils both amplified the ground motion and in some cases weakened the building system as a result of differential settlement.

2. General Observations on the Performance of Buildings and Lifelines

2.1 Historic Buildings

Christchurch is an old colonial planned city dating back to the 1840s with a large number of low rise un-reinforced masonry buildings (URM) built in the period 1880-1930. These buildings added to the historic charm of Christchurch, but most had a lateral strength capacity less than 1/3 of current code requirements, which meant that the buildings were subject to loading six times greater than their strength. Consequently there was significant damage and collapse, both full and partial. A common form of partial collapse involved out-of–plane failure of the masonry walls, resulting in tonnes of bricks falling directly into the street or onto awnings, which in turn collapsed creating a significant risk for pedestrians.

The historic Christchurch Cathedral built in 1864 and located in the centre of the city suffered significant damage with the 60 metre tall masonry spire collapsing into the public square (Figure 1). At the time of collapse, it was feared that a number of people were trapped under the rubble, but fortunately this was found not to be the case, after extensive USAR searching.

The earthquake demonstrated the vulnerability of historic masonry structures that had not been retrofitted to modern standards for understandable financial reasons. Unfortunately, the earthquake destroyed the heritage, cost lives and had significant cost implications from both a business interruption and asset replacement perspective. Around 15% of the URM buildings needed to be demolished, 35% had severe damage, 35% moderate damage and 15% minor or no damage. Significantly, many of the retrofitted URM buildings that had walls secured to the floor and roof diaphragms to prevent out-of-plane failure, responded as a more robust system and performed well with only minor damage sustained.

2.2 Older Buildings 1930-1990

Most buildings of this era were reinforced concrete and reinforced masonry and many suffered significant damage, whilst some collapsed. The variation in performance can be attributed to a number of factors including; orientation, structural layout (plan and vertical), non-seismic detailing, axial load ratio on columns and walls, time of construction, foundation type, soil conditions, liquefaction effects and level of ground shaking experienced. Two notable reinforced concrete buildings collapsed; the Pyne Gould Corporation Building (PGC where 12 people died) and the Canterbury Television Building (CTV where more than 90 people perished).

The 5 storey PGC building was built in 1963 with a lift shaft near the rear of the building. The building experienced large drifts caused by local failure in the walls and torsional rotation, resulting in the limited ductile gravity frames and upper floor slabs progressively collapsing onto the intact first floor (Figure 2). Interestingly an adjacent 4 storey office building (Ernst and Young) survived with virtually no damage and the adjacent ‘Rotunda’ reinforced concrete dome structure survived by rocking on the poorly detailed, but lightly loaded columns.

The 6 storey CTV building was constructed in 1986 and relied on core walls surrounding the lift shaft on the north side and coupled shear walls on the south side. The whole building collapsed with only the lift shaft remaining standing and a fierce fire that started in the car park causing many of the deaths (Figure 3). The catastrophic progressive collapse of the building could be attributed to insufficient drift capacity caused by the high axial loads in the columns and shear walls combined with the very high horizontal and vertical ground motions experienced in the area.

2.3 Contemporary Buildings 1990+

Most contemporary buildings designed with the principles of capacity design and to more recent earthquake standards generally performed well. A common form of modern construction was the reinforced concrete special moment resisting frame building, which performed generally as planned with limited beam hinging and joints intact. An exception was the performance of the ‘non-structural’ precast stairs, which collapsed in a number of buildings, creating an unacceptable situation where people could not safely evacuate the building. The collapse of the staircases was attributed to insufficient movement gaps provided, which resulted in the staircases buckling in compression when the storey drift was excessive and then becoming unseated on the reverse cycle, resulting in gravity load collapse. A number of people were thought to have been trapped in such staircase collapses, particularly in the around 20 storey Forsythe Barr building where 10 flights of stairs had collapsed from around Level 5 to 15 (Figure 4). Fortunately, after extensive and difficult searching which involved removal of each of the 9 tonne precast stair units, no fatalities were discovered. Similar stair details were used in other buildings including the Grand Chancellor (partial stair collapse) and the Brannigan’s Bar building (damaged staircases).

2.4 Lifelines

Extensive damage was suffered to the services and lifelines of the city, principally caused by liquefaction and differential settlement. Electricity was returned to most of the city within 24 hours and to 90% of the city after 10 days. Telecommunication systems generally functioned well particularly the mobile system. The water and sewerage system performed poorly with extensive damage to the underground pipe network. The city was reliant on bottled drinking water for a number of weeks whilst the supply was restored and portable toilets and hand dug pits in the backyard became the substitute for the centralised sewerage system. Restoration of the water and sewerage systems to parts of the city is continuing six months after the earthquake, which adds additional hardship to the already strained community. The road system was badly damaged due to liquefaction causing extensive differential settlement and the deposit of a quarter of a million of tonnes of silt into the streets. The roads tended to have a ‘wavy’ profile caused by the settlement of the ground, which meant the roads were usable, but major rectification works will be required to reinstate the roads back to their original profiles. Most of the 320 bridges in the city remained operational despite the formation of small vertical gaps between the bridge and the abutment caused by differential settlement, although 13 bridges were closed due to structural and foundation problems. This was particularly evident around the Avon river where lateral spreading of the ground was clearly visible.

3. USAR Response

The response to the Christchurch earthquake was immediate with the three New Zealand USAR Task Forces deployed (TF1 Palmerston North, TF2 Christchurch, TF3 Auckland). This involved some 160 USAR technicians, 7 contracted USAR engineers and 15 trained USAR engineer support specialists. International fully self sufficient USAR teams quickly followed from the following countries: Australia (3 teams from Queensland, NSW and a national composite team), USA, UK, Japan, Taiwan, Singapore and China. The total number of USAR personnel was around 700 and all based in Latimer Square, a public park very close to the CBD (Figure 5). The USAR operations peaked over the first two weeks with operations concluding on Saturday 19 March, some four weeks after the earthquake. The USAR engineers deployed from NZ and Australia were all trained to Level 2 status with rubble pile experience. The USAR operations involved three distinct response phases; (i) search and rescue (ii) victim recovery and (iii) city/suburb safe, which are described in the following sections.

3.1 USAR Phase One Response – Search and Rescue

USAR engineers provided support to the USAR teams to assist in rescuing trapped personnel in particular identifying the least dangerous access to potential void areas and providing advice on stabilisation measures with the collapsed structure. 70 trapped people were safely extricated from the collapsed buildings including 18 from the CTV building and 28 from the PGC building during the operations. USAR teams helped with the rescue of people from some office buildings where the precast stairs had collapsed and helicopter access from the roof was required. Unfortunately no live survivors were found after 24 hours; however USAR operations maintained their 24 hour search and rescue activities for 7 days following the earthquake before transitioning to the second phase.

3.2 USAR Phase Two Response – Victim search and recovery

USAR phase 2 operations involved searching every building, every floor and every room. Buildings searched were clearly identified with the international markings that denoted the USAR team, date, number of victims extricated and any hazards identified. At the commencement of phase 2 the official death toll stood at 146 with a further 180 people believed missing. Victim identification was slow and difficult, but ongoing positive forensic identification of remains led the realisation that many of those previously listed as missing had already been counted in the official death toll. The victim recovery in the CTV and PGC buildings was difficult and completed after around 7-10 days. Other difficult operations for the USAR teams involved searching for victims in the Christchurch Cathedral collapse, Grand Chancellor building staircase collapse and the Forsythe Barr building staircase collapse. In addition, USAR teams assisted with the design and erection of a flying buttress to support and secure the damaged western wall of the Christchurch Cathedral to allow search operations in the vicinity to continue.

Access to building records and detailed design drawings provided valuable information to USAR engineers during this and subsequent phases. For example, examination of the Copthorne Hotel drawings indicated two large column transfer beams had been used by the designers to provide an open column free ground floor foyer. A USAR team sent to investigate the transfer beam condition identified that despite the Hotel ceiling remaining intact, and there being no obvious external signs of distress, both beams were close to failure and temporary shoring was required to stabilise the structure.

3.3 USAR Phase Three Response – City Safe

Christchurch city was secured by the police and army with a cordon established creating a 2km by 2 km secure block with security passes required for access. The cordon was established to provide security against looting (all the shops were left open) and to prevent public access from a safety perspective. The USAR team assisted in making the city safer so that the cordon could be reduced in size over time. The city safe operations involved identifying and reporting hazards, supervising contractors where deconstruction had been approved to remove the hazard, removing debris from the streets and assisting strengthening some buildings where the structural support system had been damaged (Figure 6).

The most challenging aspect of this phase was managing the paperwork and ensuring the deconstruction process was well managed and the necessary approvals completed. The approval process involved a USAR engineer initiating a recommendation for the deconstruction of a dangerous building. This recommendation was processed by the City Council in consultation with the building owners and the historic society and within 24 hours a decision was finalised. Relevant services (electricity, gas and telecommunication) were contacted and a contractor engaged if deconstruction was approved through this process. USAR engineers were then involved in monitoring the deconstruction and providing a photographic record that the works had been completed. Requests from building owners for the removal of important items of contents prior to deconstruction were considered on their merits. In many instances, loose easily identifiable items such medical records, computer hard drives, and small precious objects were (when safe to do so) recovered by the deconstruction teams.

In some cases, USAR engineers worked with contract engineers to stabilise buildings where partial collapse of the building had occurred. For example, temporary strengthening works were developed and installed for the Copthorne Hotel and Grand Chancellor buildings together with constant monitoring to detect movement as an early warning mechanism. In the case of the Copthorne Hotel, a number of columns had partially collapsed in the basement which were stabilised by installing steel tubes around the column and filling the tubes with concrete (Figure 7). These works were completed by USAR teams in conjunction with external contractors for the steel fabrication and concrete supply and installation. The objective of such strengthening works was to secure the building from collapse, particularly from aftershocks, thereby making the surrounding space safer and to allow value engineering studies to be undertaken to assess the longer term future of the building (ie. building retrofit or demolition using conventional techniques).

3.4 USAR Phase Three Response – Suburb Safe

USAR teams also assisted with making the suburbs safer including providing advice on slope and hillside stability, providing advice on road closures from potential rock falls, structural inspections of houses and engineering safety advice.

Many areas entered by the teams up to two weeks after the earthquake had seen no prior contact with anyone in authority. People encountered were often simply looking for reassurance, whilst others were in desperate need of practical assistance. Faced with this, USAR teams departed from their usual search and rescue role, and successfully utilised their shoring and engineering skills to temporarily stabilise a number of residences and commercial properties.

During this phase, interaction with the general public was a positive and rewarding experience for the rescue teams. It also became apparent that the general public has a very limited understanding of hazards in their immediate environment, particularly those associated with structural failure, slope stability and soil retaining structures. Often the practical advice given was simply to establish an effective exclusion zone until further assistance was available.

A number of temporary barriers were constructed using stacked shipping containers. Such barriers were able to be quickly installed and provided effective defence against debris strike to populated areas should adjoining structures be considered at risk of collapse.

4. Conclusions

The Mn6.3 ‘bullseye’ Lyttelton earthquake transformed Christchurch from a city of great charm to a scene reminiscent of a war zone, with widespread damage and collapse of buildings, homes and lifeline services. The earthquake claimed 184 lives, destroyed many buildings and caused significant business interruption with an overall reconstruction cost in the order of $20 billion. Around 700 USAR specialists from around the world assisted in three phases of response operations involving; (i) search and rescue, (ii) victim search and recovery and (iii) city and suburb safe. A lasting impression of the USAR operations was the resilience and caring spirit of the Christchurch community in the face of this disaster of epic proportions.

5. Acknowledgements

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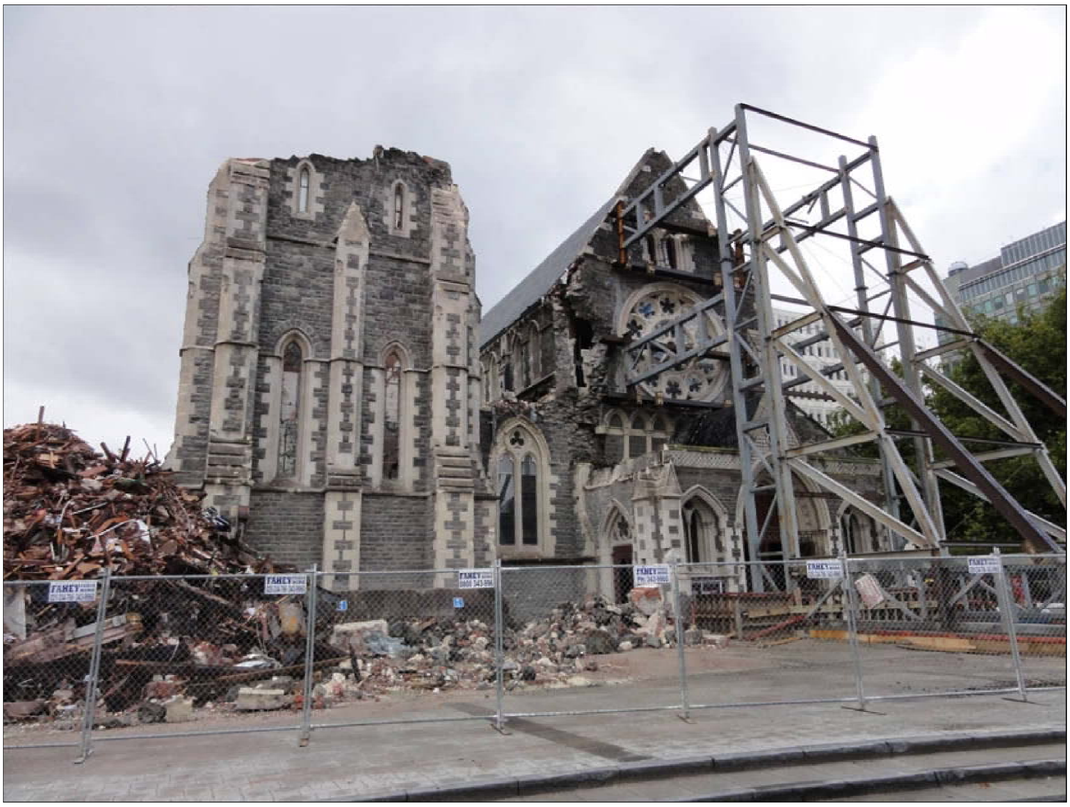

Figure 1 Christchurch Cathedral Collapse

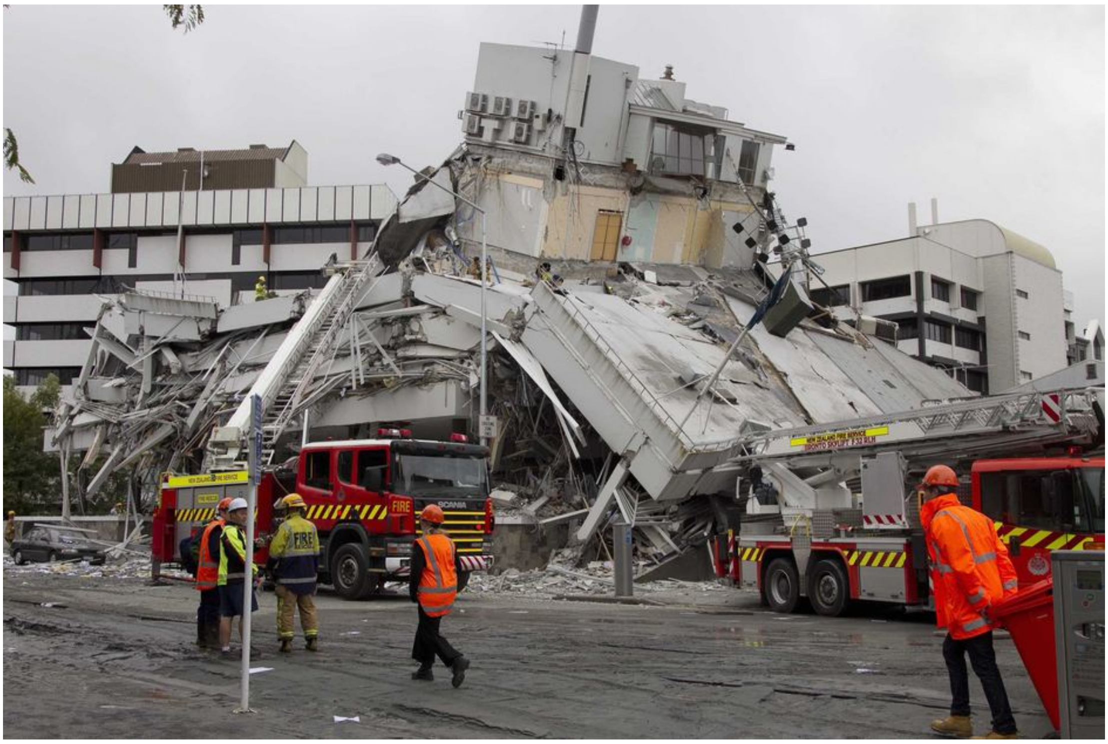

Figure 2 Pyne Gould Building Collapse

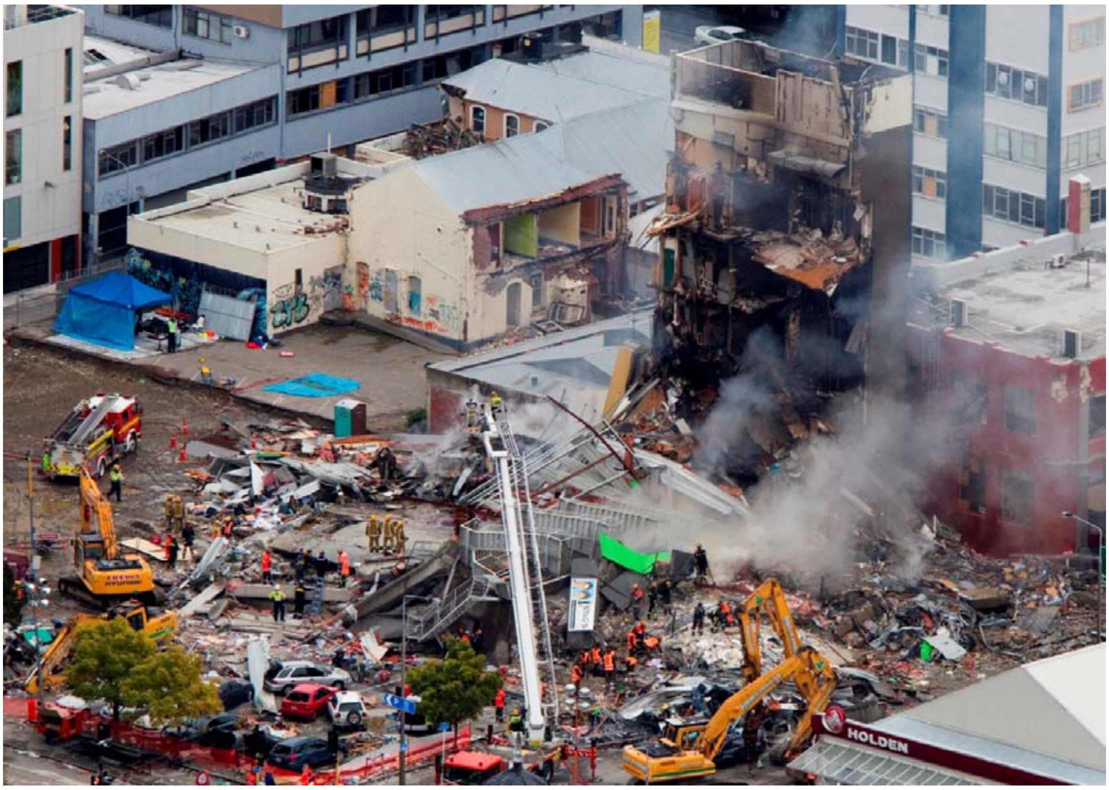

Figure 3 Canterbury Television Building collapse

Figure 4 Forsythe Barr Building Staircase collapse

Figure 5 USAR camp Latimer Square

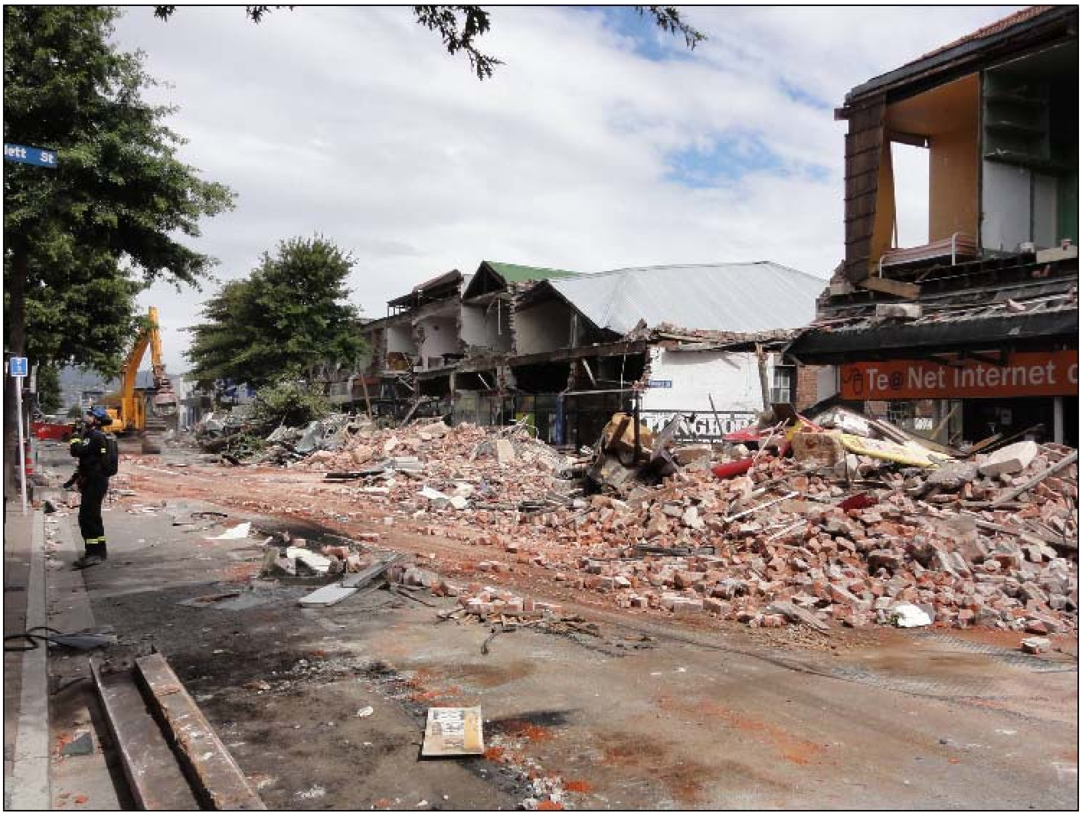

Figure 6 URM damage and debris in streets

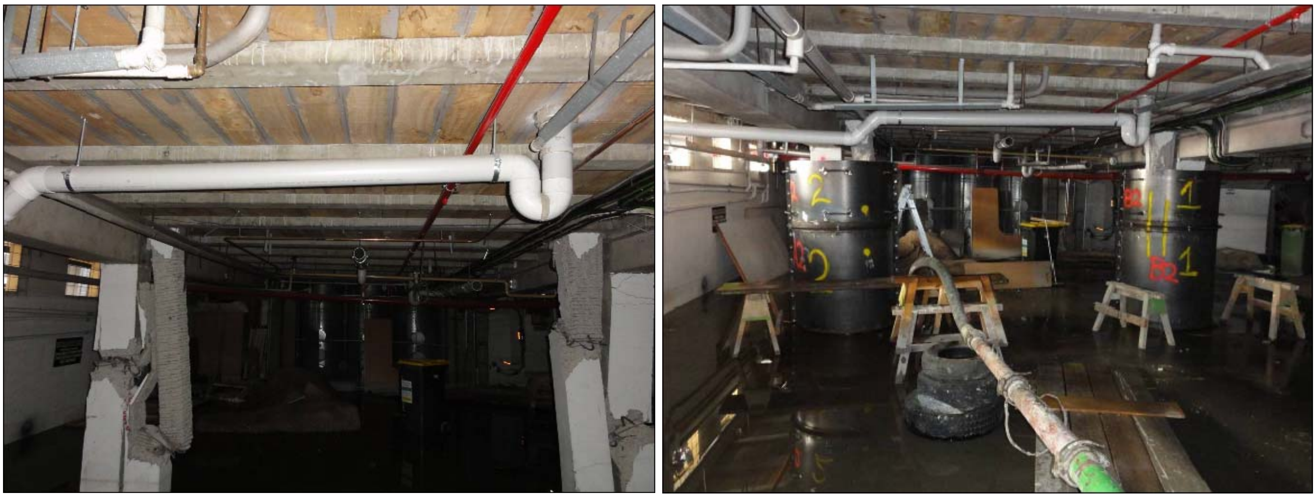

Figure 7 Retrofit repairs of partially collapsed columns