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SHAKING AND GROUND FAILURE-INDUCED DAMAGE TO BUILDINGS BY THE 2010 AND 2011 CHRISTCHURCH EARTHQUAKES AND ITS LESSONS

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ABSTRACT

Two earthquakes with a magnitude of 7.0 occurred near Darfield on September 4, 2010 and with a magnitude of 6.3 occurred under Port Hills on February 22, 2011 in Canterbury region in the South Island of New Zealand. Although the 2010 earthquake was much stronger than the 2011 earthquake, the damage to structures by the 2011 earthquake was much heavier. Extensive ground liquefaction occurred in the city of Christchurch and Kaiapoi and heavy damage to buried lifelines and residential houses were caused. The light structures are uplifted while heavy structures sank into the ground. The earthquake caused substantial damage to historical masonry type building in the downtown of Christchurch City. In this article, the authors describe the shaking and ground failure-induced damage to buildings by the 2010 and 2011 Christchurch earthquakes and their lessons.

Key words: Christchurch Earthquakes, Building Damage, Shaking, Ground Failure.

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Introduction

Two earthquakes with magnitude 7.0 and 6.3 occurred near Darfield and Heathcote Valley in the Canterbury region in the South Island of New Zealand on September 4, 2010 and February 22, 2011 (Figure 1). The earthquakes were shallow and strong, and occurred within a populated region. Extensive ground liquefaction occurred in the city and suburbs of Christchurch and Kaiapoi, causing heavy damage to buried lifelines and residential houses. Although the second earthquake on February 22, 2011 had a magnitude of 6.3, the strong ground motions were higher and it caused much heavier damage to built environment. The ground liquefaction was much more widespread and liquefaction induced damage on buildings was much greater than that was caused by the September 4, 2010 earthquake.

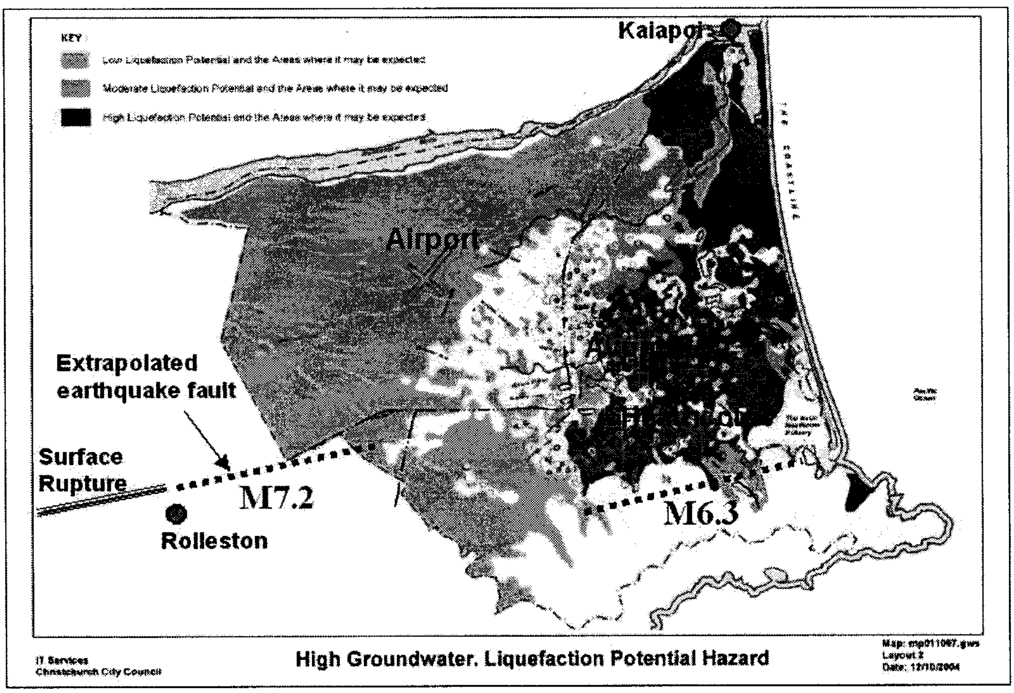

Figure 1 : Liquefaction hazard map and locations of earthquakes (modified from Christchurch City Council).

The authors firstly present briefly strong motions and their observations on the ground liquefaction and associated lateral spreading in both earthquakes. Then they describe the shaking and ground failure-induced damage to buildings by the 2010 and 2011 Christchurch earthquakes and their lessons.

Strong Ground motions

The focal mechanism solution for the 2010 Darfield earthquake implied that the earthquake was due to right-strike-slip faulting as observed in the field. The 2011 Christchurch or Port Hill earthquake was due to thrust fault. However, the 2011 earthquake did not result any distinct fault scarp. Figure 2 shows observed maximum ground acceleration for the two events together and compares the observations with some available empirical relations. As noted from this figure, the strong ground motions caused by the 2011 event were much higher than those caused by the 2010 event despite the magnitude of the 2011 was less than that of the 2010 event.

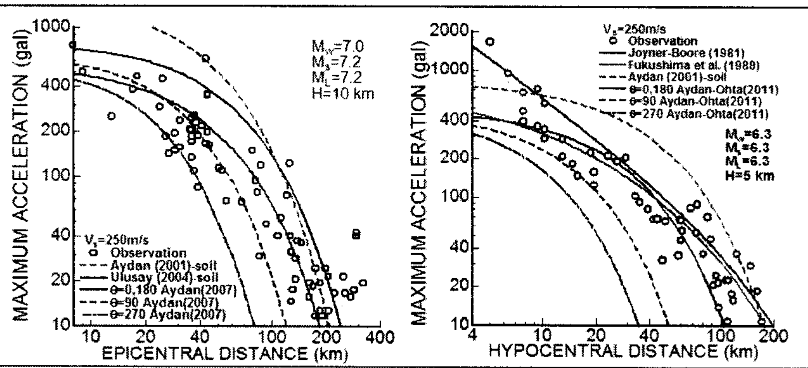

Figure 2 : Attenuation of maximum ground acceleration for the 2010 and 2011 earthquakes.

Ground Liquefaction and Lateral Spreading

One of the major characteristics of the 2010 earthquake is the extensive ground liquefaction over a wide-spread area. Extensive ground liquefaction was observed in the eastern suburbs of Avonside, and Shirley, and in Kaiapoi, Brooklands and the new suburb of Bexley (Figure 3). Due to the liquefaction induced ground settlement and lateral spreading, residential buildings and lifelines on liquefied ground suffered extensive damage. The effect of lateral spreading of liquefied ground was damaging even to reinforced concrete structures such as Canterbury Rowing Club Building and Sport Facilities in Porrit Park. Light structures were uplifted while heavy structures sank into the ground. The ground liquefaction also caused extensive damage to bridges. Furthermore, the lateral spreading induced failures of embankments and tidal gates. It is reported that ground liquefaction risk at the Pegasus Town site was identified in 2005 and the ground was remediated. These counter measures proved to be effective in Pegasus town and liquefaction was not reported there. The bridge on Bridge Street connecting South Brighton to Christchurch, suffered damage due to the settlement and rotation its abutments, as well as extensive cracking and settlement of the approach abutments due to ground liquefaction.

The 2011 earthquake caused more extensive ground liquefaction and associated lateral spreading in Christchurch City central business district, areas such as Mona Vale, Hagley Park, Heathcote, Opawa, Woolston, Ferry Mead, McCormacks Bay and Tai Tapu, in addition to Avonside, and Shirley, and in Kaiapoi, Brooklands and the new suburb of Bexley areas which liquefied in the 2010 Darfield earthquake (Figure 4). The lateral spreading along the Avon River was much more severe in the 2011 earthquake and the ground settlement was more extensive in Bexley. Although there was widespread liquefaction in Kaiapoi town, the effects of ground liquefaction and lateral spreading were much less than those caused by the 2010 earthquake. Residential buildings and lifelines on liquefied ground suffered extensive damage. The bridge on Bridge Street connecting South Brighton to Christchurch suffered more damage due to settlement and rotation of its abutments, as well as the extensive cracking and settlement of approach abutments due to ground liquefaction.

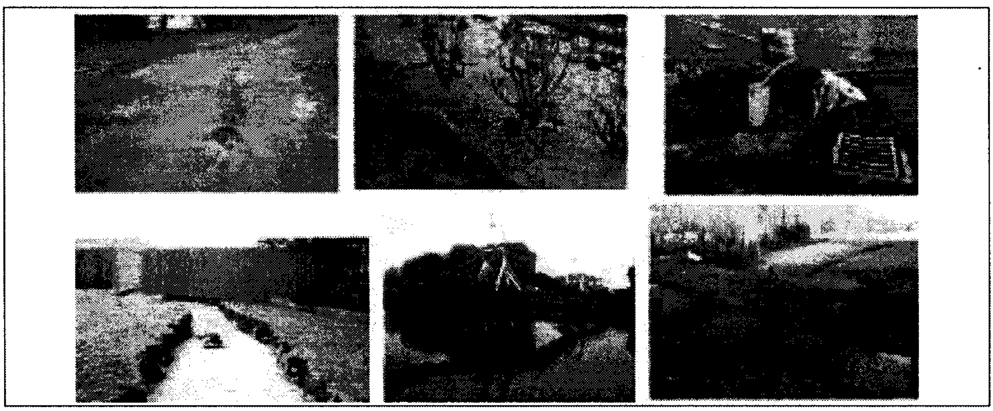

Figure 3 : Views of ground liquefaction at some localities caused by the 2010 earthquake.

Figure 4 : Views of ground liquefaction at some localities caused by the 2011 earthquake.

Ground Shaking Induced Damage to Buildings

Many of the worst-affected buildings in both Christchurch and the surrounding districts by the 2010 Darfield earthquake were older unreinforced masonry buildings (Figure 5). The low story timber framed residential houses, except those on liquefied ground and new reinforced concrete or steel framed buildings, were almost intact. These buildings are characterized as typically 2- or 3-stories. However, 2- story buildings are most common. The causes of damage to unreinforced masonry buildings may be classified as (a) out-of-plane failure of walls, (b) parapet failures, (c)anchorage failures and (d) Chimney failures. It is estimated that 500 such buildings were damaged. 90 buildings in Christchurch Business District (CBD) were damaged. Some of retrofitted masonry buildings in the downtown of Christchurch performed well and there was almost no damage to such retrofitted masonry buildings. Nonstructural damage was due to partitions cracking, fall or toppling of ceiling tiles and lights in all types of buildings. Furthermore, glasses of windows with large span were broken.

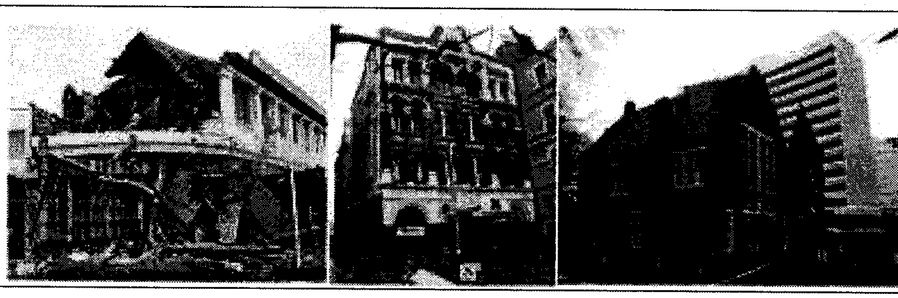

Figure 5 : Views of some of damaged masonry buildings.

The 2011 earthquake inflicted heavy damage to reinforced concrete and steel-framed structures besides masonry structures (Figure 6). Some buildings were damaged by rockfalls or rock slope failures. (Figure 7) Two reinforced concrete structures collapsed causing huge casualties (Figure 8). Partial damage during the 2010 Darfield earthquake and poor ground conditions are thought to be the main causes for these collapses

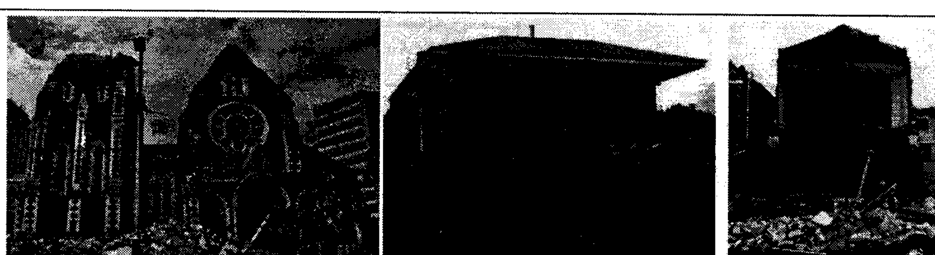

Figure 6 : Views of damage to some masonry buildings .

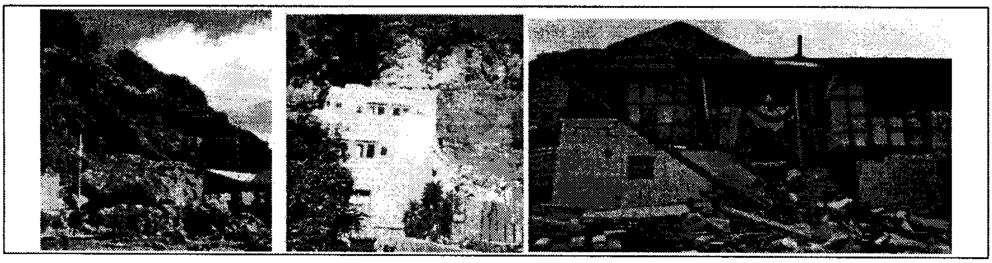

Figure 7 : Views of damage to buildings caused by rockfalls.

Figure 8 : Views of damage to reinforced concrete buildings in Christchurch.

Ground Liquefaction Induced Damage to Buildings

Ground liquefaction caused by the 2010 Darfield earthquake resulted in heavy damage to residential buildings in Kaiapoi and Bexley areas along Avon River in Dallington district (Figures 9 and 10). The lateral spreading caused damage to buildings. The details of ground liquefaction by two earthquakes are given elsewhere [1-3].

Figure 9 : Views of ground liquefaction observed at several localities during the 2010 Darfield earthquake.

Figure 10 : Views of damage to buildings caused by ground liquefaction during the 2010 earthquake.

Ground liquefaction caused by the 2011 earthquake occurred in the most-vulnerable areas along Avon River and Heathcote valley as predicted by the hazard map of the Christchurch City Council (Figure 1). The effect of ground liquefaction in Christchurch was much heavier than that caused by the 2010 Darfield earthquake. (Figures 11 and 12). The lateral spreading caused damage to buildings. Furthermore, the ground liquefaction in downtown of Christchurch caused tilting of some high-rise buildings and played major role in the collapse of two reinforced concrete buildings.

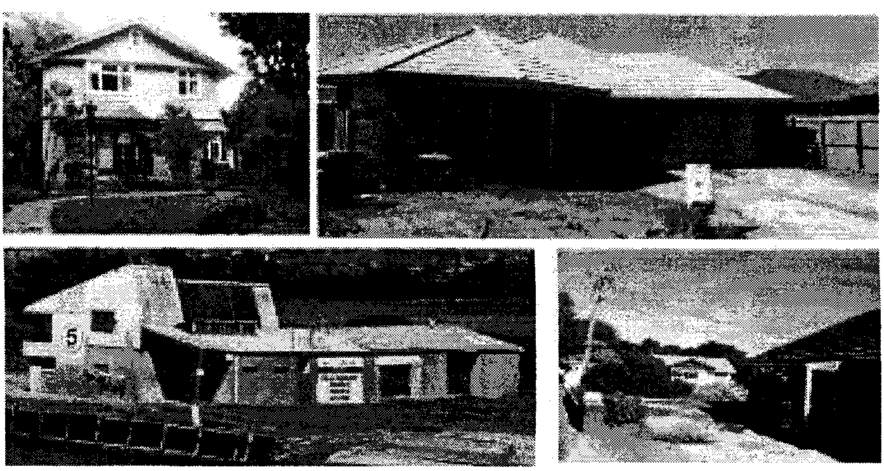

Figure 11 : Views of ground liquefaction observed at several localities during the 2011 earthquake

Conclusions

The conclusions, which may be drawn from the previous sections, are as follows.

1) The strong ground motions caused by the 2011 earthquake were much higher than those by the 2010 earthquake despite the magnitude of the 2011 earthquake was less than that of the 2010 earthquake. This may be related to the depth, distance and faulting characteristics.
2) The building damage was much heavier during the 2011 earthquake as compared with that during the 2010 earthquake. The higher strong ground motions observed during the 2011 earthquake should be one of the main reasons for heavy damage.
3) The effect of lateral spreading did not cause the collapse of buildings during the 2010 Darfield earthquake. However, some reinforced concrete buildings were heavily damaged in downtown Christchurch due to ground liquefaction and the loss of bearing capacity during the 2011 Christchurch earthquake.

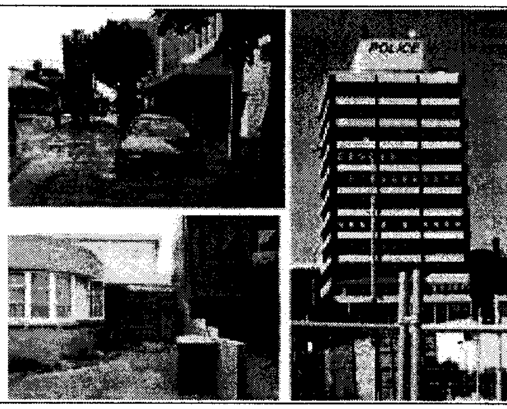

Figure 12 : Views of ground liquefaction observed at several localities during 2011 earthquake.

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