Strong Ground Motions Observed in the 22 February 2011 Christchurch Earthquake

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1. Background

On 22 February 2011 at 12:51pm local time, a moment magnitude Mw6.3 earthquake occurred beneath the city of Christchurch, New Zealand, causing an unparalleled level of damage and human causalities in the country's history. Compared to the preceding 4th September 2010 Mw7.1 Darfield earthquake, which occurred approximately 30km to the west of Christchurch, the close proximity of the 22 February event lead to ground motions of significantly higher amplitude in the densely populated regions of Christchurch. As a result of these significantly larger ground motions, structures in general, and commercial structures in the central business district in particular, were subjected to severe seismic demands and, combined with the event timing (12:51pm), structural collapses accounted for the majority of the 181 causalities.

Figure 1 illustrates the spatial distribution of ground motions observed as well as the surface projection of the inferred causative fault.

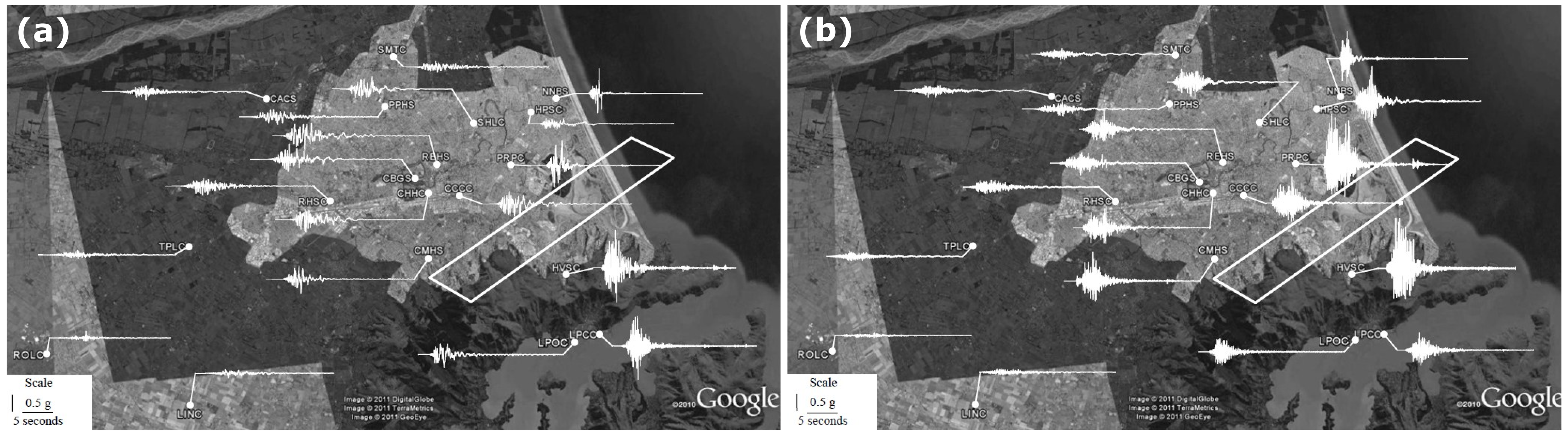

Figure 1: Spatial distribution of ground motions observed in Christchurch: (a) fault-normal; and (b) vertical components.

2. Response on rock and soil sites

Figure 2 illustrates the pseudo-acceleration response spectra observed at two sites in Lyttleton port located 1km apart with LPCC on rock and LPOC on a thin (~30m) colluvium layer of silt and clay. It can be seen that the horizontal ground motion at the LPOC site has significantly lower high frequency amplitudes and a longer predominant period. In contrast, it can be seen that there is relatively little difference between the vertical ground motion at LPCC and LPOC.

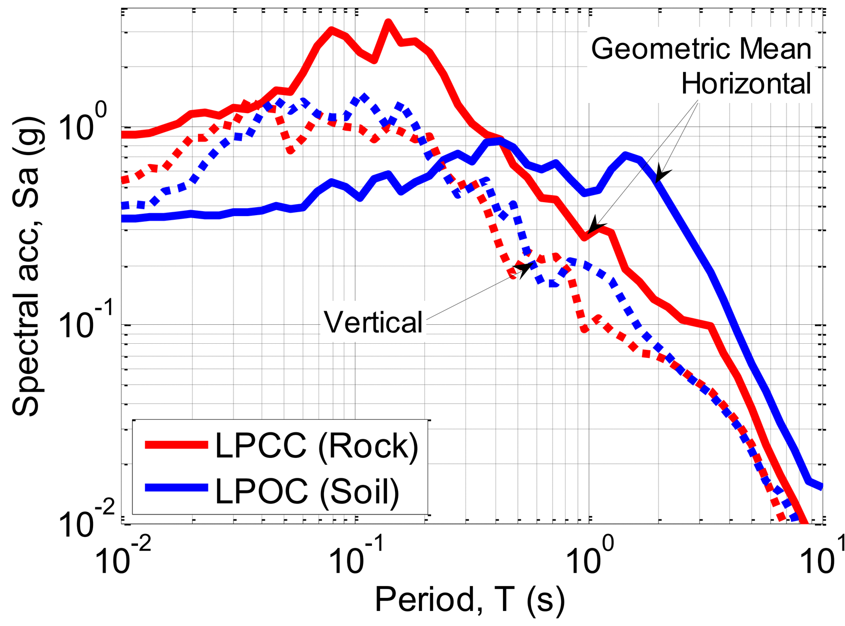

Figure 2: Comparison of response spectra at Lyttelton Port on rock and soil

3. Evidence of liquefaction

One of the major causes of damage in the Mw6.3 Christchurch earthquake resulted from the severity and spatial extent of liquefaction. The horizontal accelerations in Figure 1a show evidence of liquefaction phenomena in the central business district and eastern suburbs based on the manifested reduction in high frequency content of ground motion following several seconds of S wave arrivals, and the subsequent acceleration 'spikes', characteristic of strain hardening deformation during cyclic mobility

4. Basin generated surface waves

Figure 3a illustrates the deep geology of the Christchurch region along a plane trending south east to north west, as well as one possible ray path from the rupture in which seismic waves propagate up-dip and enter the sedimentary basin through its thickening edge leading to a waveguide effect. Figure 3b illustrates the pseudo-acceleration response spectra at Christchurch hospital (CHHC) as well as the predicted median response spectra for two different values of a proxy for basin depth. It can be seen that the spectral amplitudes at CHHC for periods greater than 0.3 seconds are under-predicted using this default basin depth of $Z_{1.0}$=300m (for site class D), while the predicted spectral amplitudes using a basin depth of $Z_{1.0}$=1000m are more in line with that observed.
Significant amplitude Rayleigh surface waves are also clearly evident in the vertical component of ground motion observed at larger source-to-site distances where body wave amplitudes are smaller (e.g. stations SMTC and CACS in Figure 1b).

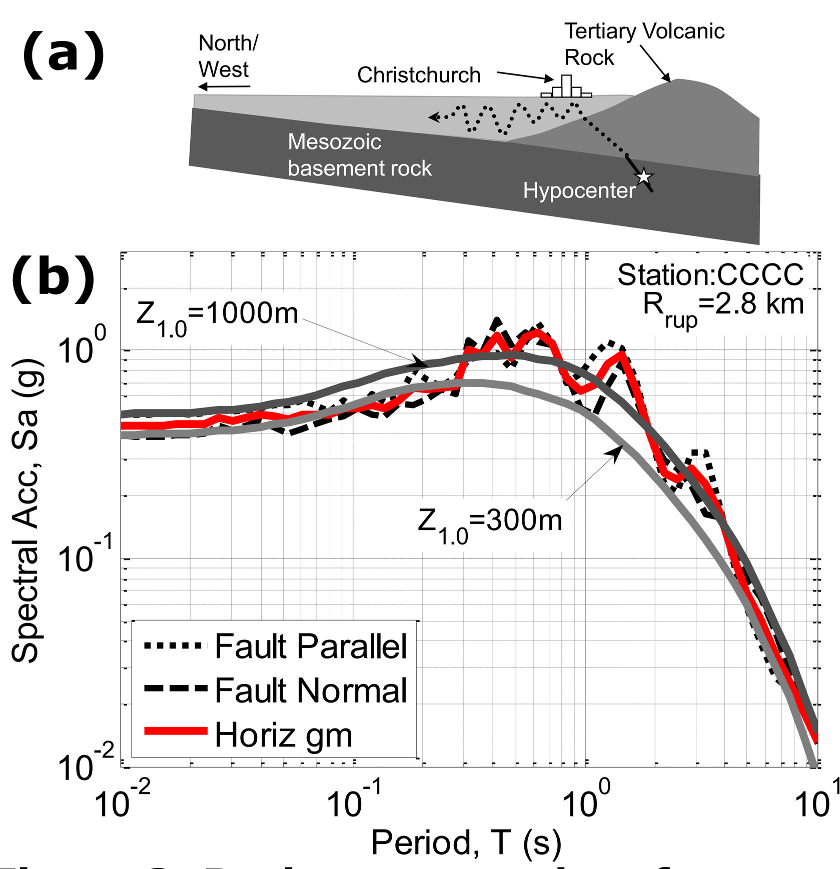

Figure 3: Basin-generated surface waves and effect on predicted response spectra

5. Near-source forward directivity

Because of the central location of the hypocenter and the misalignment of the direction of slip and rupture front, the surface area over which directivity effects are important is relatively small for this event (Bradley and Cubrinovski 2011). Figure 4 illustrates the velocity time history at Pages road (PRPC), one of the few observed ground motions where forward directivity effects can be seen in the fault-normal component.

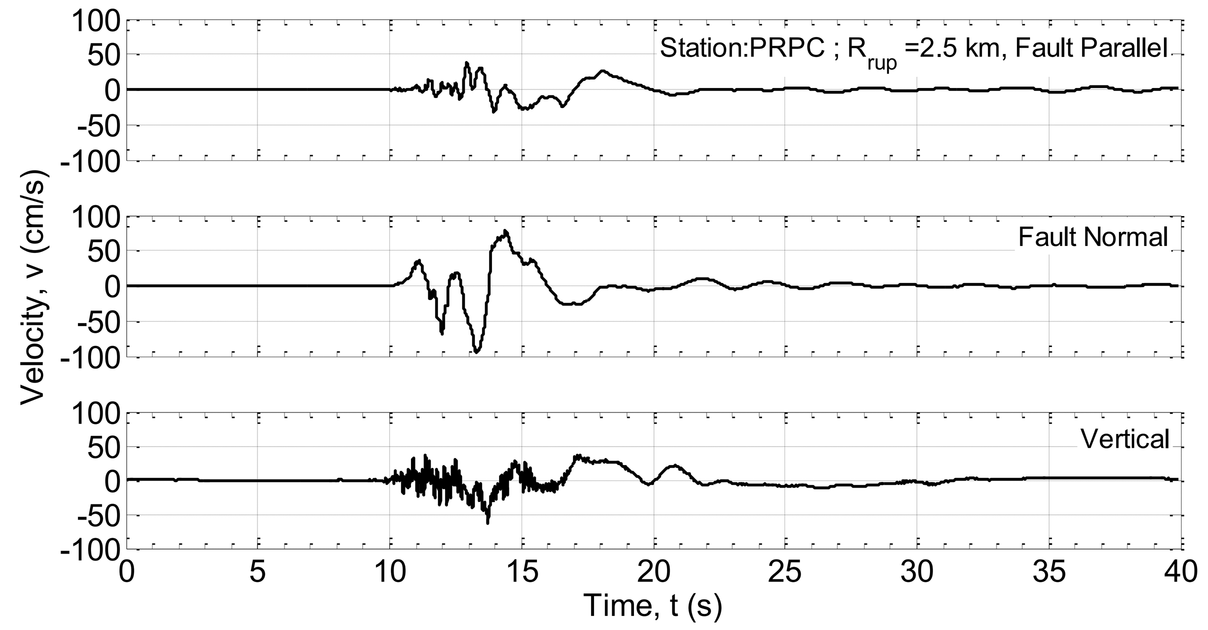

Figure 4: Near-source forward directivity observed at Pages Road (PRPC)

6. Vertical ground motion

As illustrated in Figure 1b significant vertical accelerations were observed with 0.6g exceeded at 7 stations. Vertical PGAs of 2.21g and 1.88g were observed at Heathcote Valley (HVSC) and Pages Road (PRPC), respectively, where the separation of soil layers limiting the maximum negative PGA to -1g can be seen (the so-called "Trampoline-effect").

Figure 5 illustrates the ratio of peak vertical acceleration and peak horizontal acceleration at the near-source strong motion sites where it can be seen that ratios of up to 4.8 were observed. The vertical-to-horizontal PGA ratios show a rapid decay with source-to-site distance and compare favourably with the Bozorgnia and Campbell empirical model for source-to-site distances beyond 5km, but significantly under-predict the ratios at closer distances. The large vertical-to-horizontal PGA ratios observed for R_{rup}<5km are interpreted to be the result of a steep fault dip as well as significant non-linear soil behaviour (including liquefaction) which generally results in more of a reduction in peak horizontal accelerations than peak vertical accelerations.

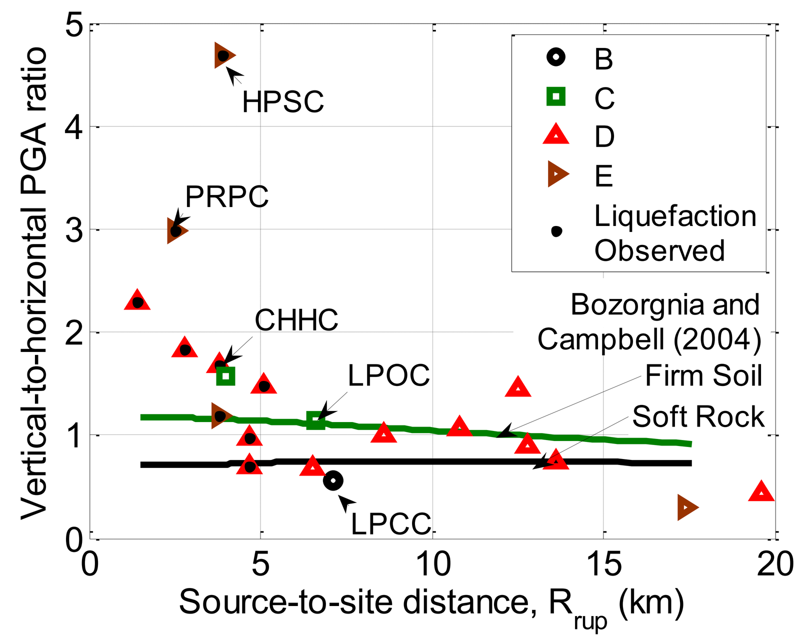

Figure 5: Observed vertical-to-horizontal PGAs

7. Ground motion intensity in the central business district (CBD) and importance of local site effects

Figure 6a illustrates that the ground motion at four stations located in the CBD are relatively similar, particularly at long vibration periods. It can also be seen that the ground motion intensity exceeded the design spectra over the majority of vibration periods.

Figure 6b illustrates the pseudo-acceleration response spectra observed at Papanui (PPHS) in the Christchurch and 4th September 2010 Mw7.1 Darfield earthquakes. The similarity in response spectral shapes for T<2s are very similar, despite the different source locations of these two events, illustrating the importance of local site response.

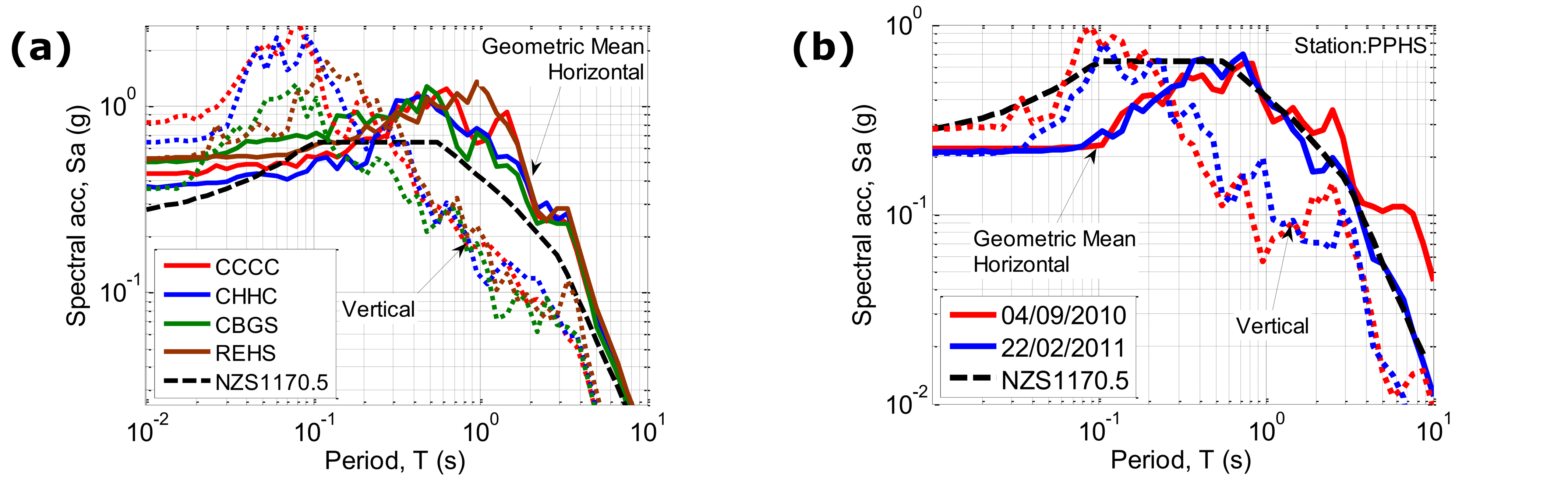

Figure 6: Pseudo-acceleration response spectra: (a) observed at four stations in the CBD; and (b) at Papanui (PPHS) during the Mw6.3 Christchurch and Mw7.1 Darfield earthquakes

8. References

Bradley BA and Cubrinovski M (2011) Near-source strong ground motions observed in the 22 February Christchurch Earthquake. ***Seismological Research Letters*** (submitted).