In Figure 3.11 we have, in addition, applied a stress drop scaling term as proposed by Atkinson and Boore (2006) to the McVerry *et al.* (2006) relationship. The stress drop scaling is based on the ratio of the expected stress drops of earthquakes across New Zealand to those expected from the more energetic Canterbury events (i.e., 10MPa/15MPa), giving a ratio of 1.5. Even with the enhanced stress drop, most of the observations within 10 km distance exceed the median value, indicating that other factors, such as directivity, are also important.

The sharp decrease in ground motions after about 10 km (resulting in an over-prediction of the ground-motions) is likely to be caused by a biased sampling of data in the near field toward locations subject to strong directivity, with that bias diminishing when including more distant stations and sampling over a much wider area outside of the directivity region.

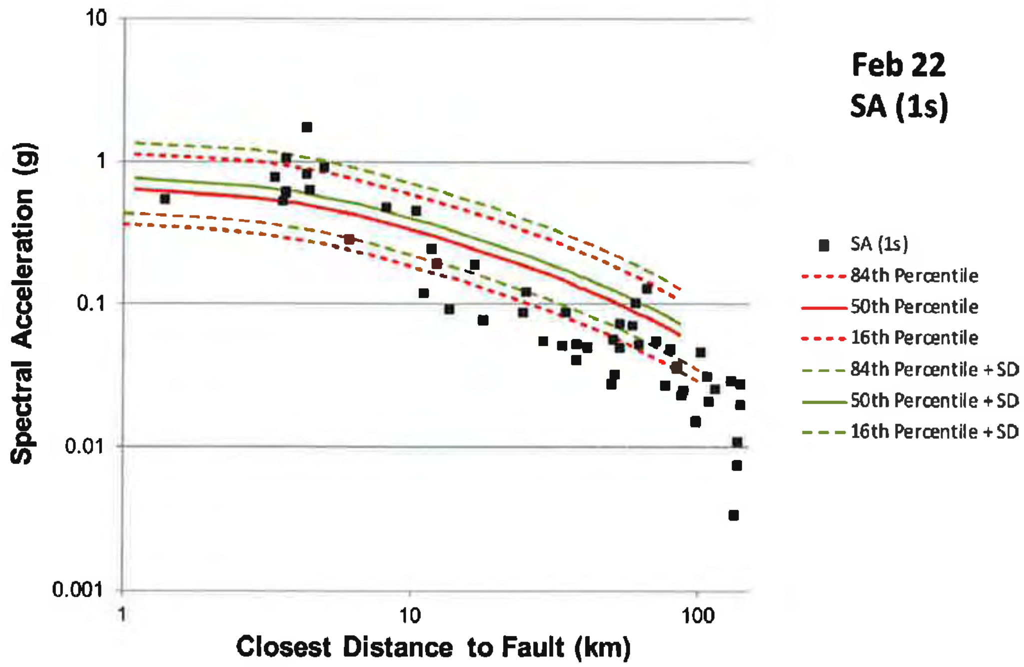

Figure 3.11 Observed spectral accelerations at 1.0 s during the Christchurch earthquake (black squares) compared to those predicted from the national attenuation model for deep or very soft soils (solid red line; McVerry *et al.*, 2006) assuming a crustal oblique-slip source. Also shown is the prediction with stress drop scaling (green solid line). For both predictions, the 16th and 84th percentile motions are also shown in the same color.

In Figure 3.12 we have plotted the median ground acceleration curves at 1.0 s for the 22 February event using the Atkinson and Boore (2006) and Abrahamson and Silva (2008) attenuation relationships. These relationships are known as Next Generation Attenuation (NGA) models and are applicable to parts of the Unites States, but are also likely to be appropriate for parts of New Zealand. Both curves are plotted using a reverse mechanism and assuming a seismic shear wave velocity, Vs30, of 230 m/s, a value determined from the average of two Christchurch GeoNet sites (Perrin, pers. Comm., 2011). For Abrahamson and Silva, we have used parameters based on data from two average sites in Christchurch. The behavior of the models is similar to the McVerry *et al.* (2006) model with under-predictions in the near field and over-predictions beyond 10 km. This confirms that this earthquake is anomalous in terms of the ground shaking produced, rather than this being a problem with New Zealand attenuation models.

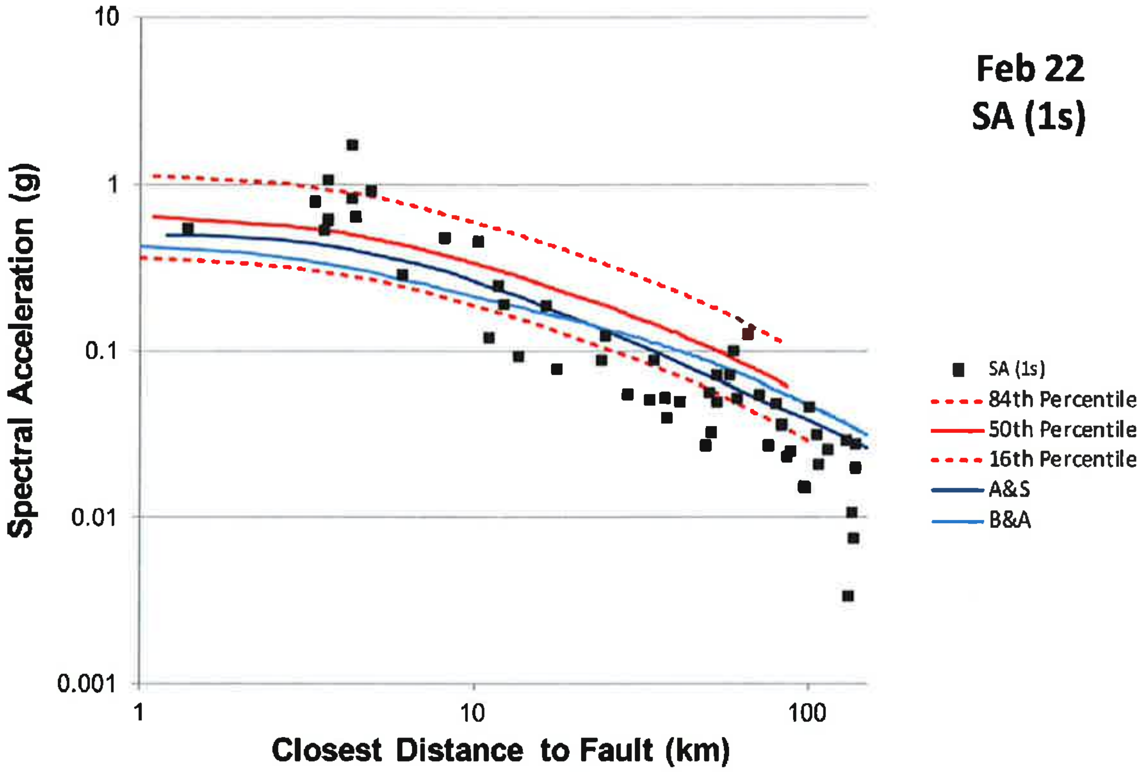

Figure 3.12 Observed spectral accelerations at 1.0 s during the Christchurch earthquake (black squares) compared to those predicted from the national attenuation model for deep or very soft soils (solid red line; McVerry *et al.*, 2006) assuming a crustal oblique-slip source. Also shown are the ground motion predictions from the Abrahamson and Silva (A&S; 2008) and Atkinson and Boore (B&A; 2006) relationships.

Fig. 3.13 compares earthquake response spectra (see textbox below) of recorded horizontal ground motions at four sites within ~1.5 km of the Christchurch CBD with spectra from the New Zealand design standard NZS1170. The New Zealand design standard sets guidelines for the levels of ground motion that are expected to occur at average intervals of 500 years, 1,000 years and 2,500 years for normal use, major use and post-disaster use structures, respectively. The comparison in Figure 3.13 shows that in the CBD, recorded earthquake response spectra (coloured lines) exceeded the 2,500 year return ground motions, especially at long periods, although they are generally somewhat less than these motions at short periods (<0.3–0.4 s). As in the 4 September earthquake, peaks in the response spectra at long periods are present, although at a slightly longer period (3 s) for the February earthquake. More detailed information can be found in Appendix 4).

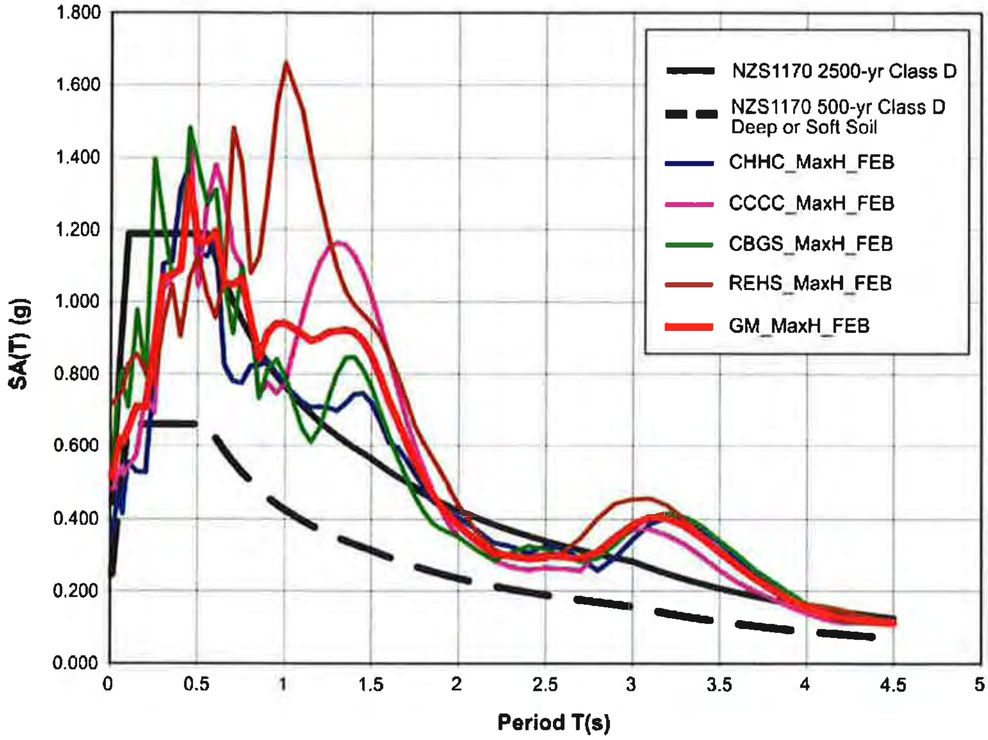

Figure 3.13 Comparison of recorded (5% damped) acceleration response spectra for four sites within ~1.5 km of the CBD (coloured lines) and corresponding spectra from the New Zealand design standard NZS1170 for deep or soft soil sites (black lines). The solid red line is the average of the four central sites; dashed and solid black lines are the NZS1170 spectra expected for 500 and 2,500 year return periods respectively.

Earthquake response spectra

When designing buildings to be resistant to earthquake motions, engineers must take into account the amplitude of seismic waves at different periods (or frequencies). Different types and sizes of buildings respond to the earthquake motions in different ways, and every building has its own resonant behaviour, i.e. it responds most strongly when the input ground shaking is strong at the natural period of the building. Very roughly, a one-storey building will respond most strongly to ground accelerations with a 0.1 second period, a ten-storey building to 1 second accelerations (i.e. 10 times the period of a 1-storey building), and a 20-storey building to 2 second accelerations, etc.

To create an earthquake response spectrum, a large set of very simple building models with different resonant periods and a specified level of damping are exposed to a complete earthquake recording, and the peak responses of the models are estimated, and plotted as a function of their period. Note that, for building design, engineers generally use the spectra of horizontal (rather than vertical) ground motions.

A number of factors are thought to have contributed to the high accelerations experienced in Christchurch city during the 22 February event (Fry *et al.* 2011a; Reyners 2011). Firstly, because the earthquake was close to the city and at a shallow depth, ground shaking was high compared to September, as the energy of seismic waves reduces very rapidly away from where the fault rupture occurred. Secondly, the energy magnitude (Me) of the Christchurch earthquake was 6.75 (compared to the moment magnitude of 6.2), indicating that, as for the 4 September Darfield earthquake, this was a high stress drop event that