Simulation of site amplification effects at Heathcote Valley during the 2010-2011 Canterbury earthquakes

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1. Motivation

Heathcote Valley school strong motion station (HVSC) consistently recorded ground motions with higher intensities than nearby stations during the 2010-2011 Canterbury earthquakes. For example, as shown in Figure 1, for the 22 February 2011 Christchurch earthquake, peak ground acceleration at HVSC reached 1.4 g (horizontal) and 2 g (vertical), the largest ever recorded in New Zealand.

Strong amplification of ground motions is expected at Heathcote Valley due to: 1) the high impedance contrast at the soil-rock interface, and 2) the interference of incident and surface waves within the valley. However, both conventional empirical ground motion prediction equations (GMPE) and the physics-based large scale ground motions simulations (with empirical site response) are ineffective in predicting such amplification due to their respective inherent limitations.

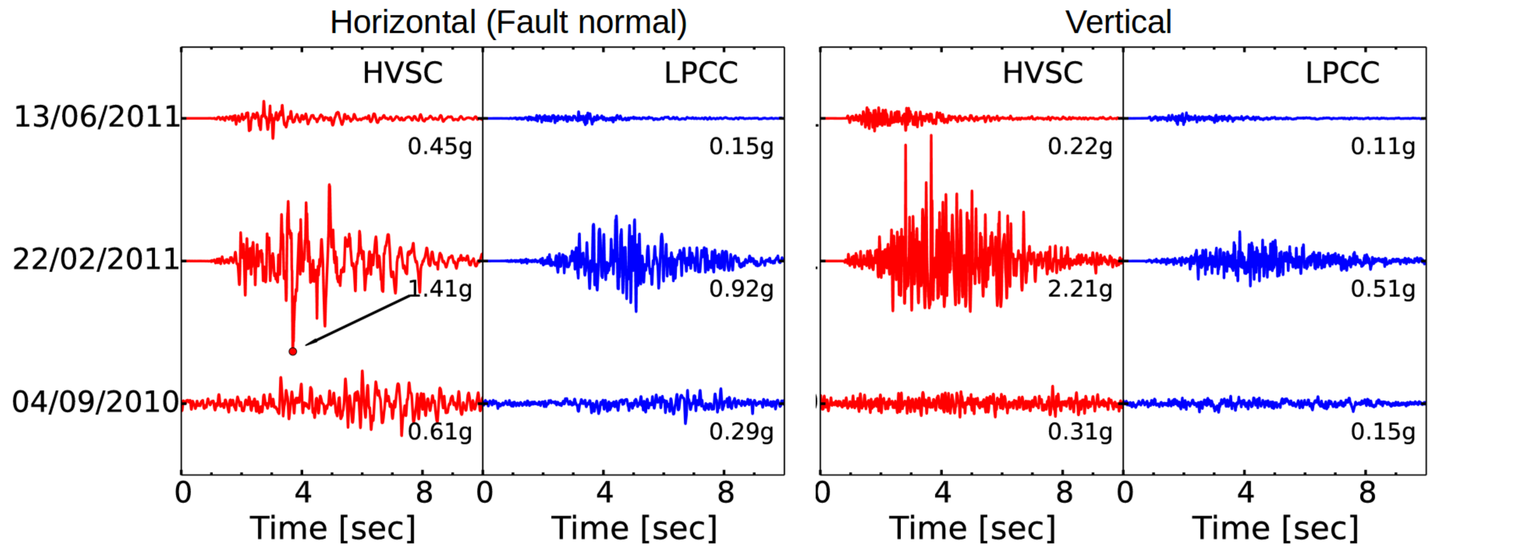

Figure 1: Ground motions recorded at Heathcote valley station (HVSC), compared with records at Lyttelton port company station (LPCC). LPCC is approximately 4km away from HVSC and is located on the Port Hills volcanics.

2. Site characterization & numerical model

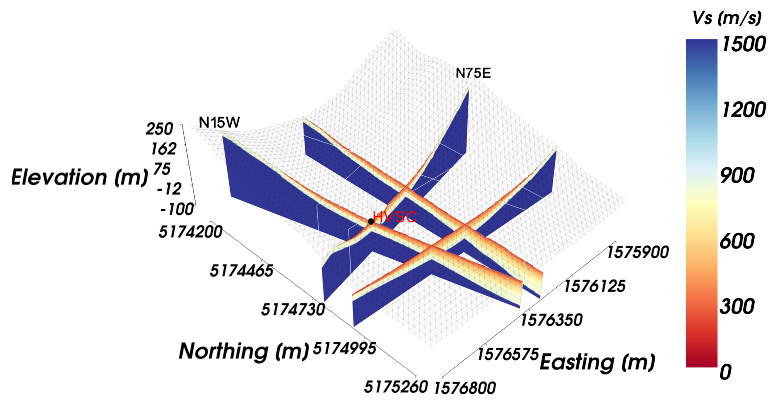

Figure 2: Fence diagram showing the 3D shear wave velocity model

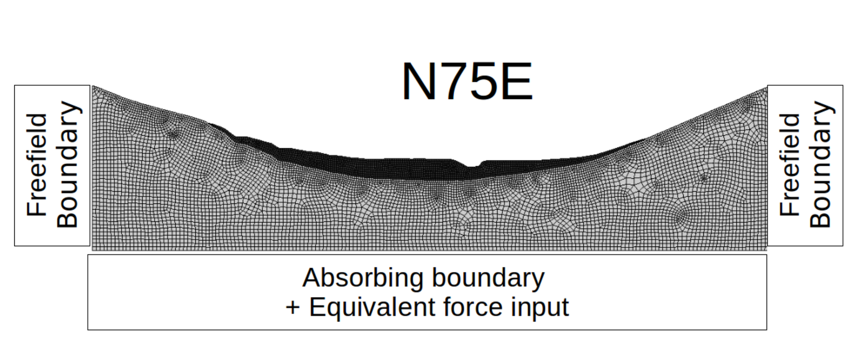

Figure 3: Two-dimensional mesh geometries and boundary conditions

- Fifteen seismic cone penetration tests; five multi-channel analysis of surface wave (MASW) surveys; fifteen H/V ambient vibration tests were conducted.
- Soils (aeolian and colluvial deposits) are modelled with V_S = 207 $Z^{0.25}$ and ϕ = 36 °; sediment thickness ranges from a few metres to 35 metres.
- Rock V_S = 1500 m/s; Weathered rock V_S = 800 m/s.
- A 3D shear wave velocity model (Figure 2) was created via spatial interpolation of test data.
- 2D finite element analysis using OpenSees (Mazzoni et al. 2007); pressure-dependent multi yield (Yang et al. 2003) soil model; linear elastic assumption for rocks.
- Absorbing boundary and equivalent force input at boundary nodes.
- Input motions were obtained by deconvolving and amplitude-correcting recorded motions at LPCC for the earthquake events listed in Table 1.

Table 1: Earthquake events used in the simulations

		HVSC			LPCC		
Event date	M_W	R_{rup} (km)	PGA (g)	PGV (cm/s)	R_{rup} (km)	PGA (g)	PGV (cm/s)
04/09/2010	7.1	20.8	0.61	29	22.4	0.29	19
19/10/2010	4.8	12.8	0.09	3.2	13.1	0.02	0.71
26/12/2010	4.7	4.7	0.11	2.9	7.7	0.02	0.65
22/02/2011	6.2	3.9	1.41	81	7	0.92	46
16/04/2011	5.0	7.3	0.68	32	5.2	0.29	8.5
13/06/2011 (a)	5.3	4.7	0.45	14	5.3	0.15	5.4
13/06/2011 (b)	6.0	3.6	0.91	55	5.8	0.64	33
21/06/2011	5.2	14.9	0.26	8.0	15.6	0.07	2.1
23/12/2011 (a)	5.8	9.9	0.31	12.7	11.4	0.24	7.6
23/12/2011 (b)	5.9	9.7	0.44	22	12.4	0.44	23

3. Validation of the simulation

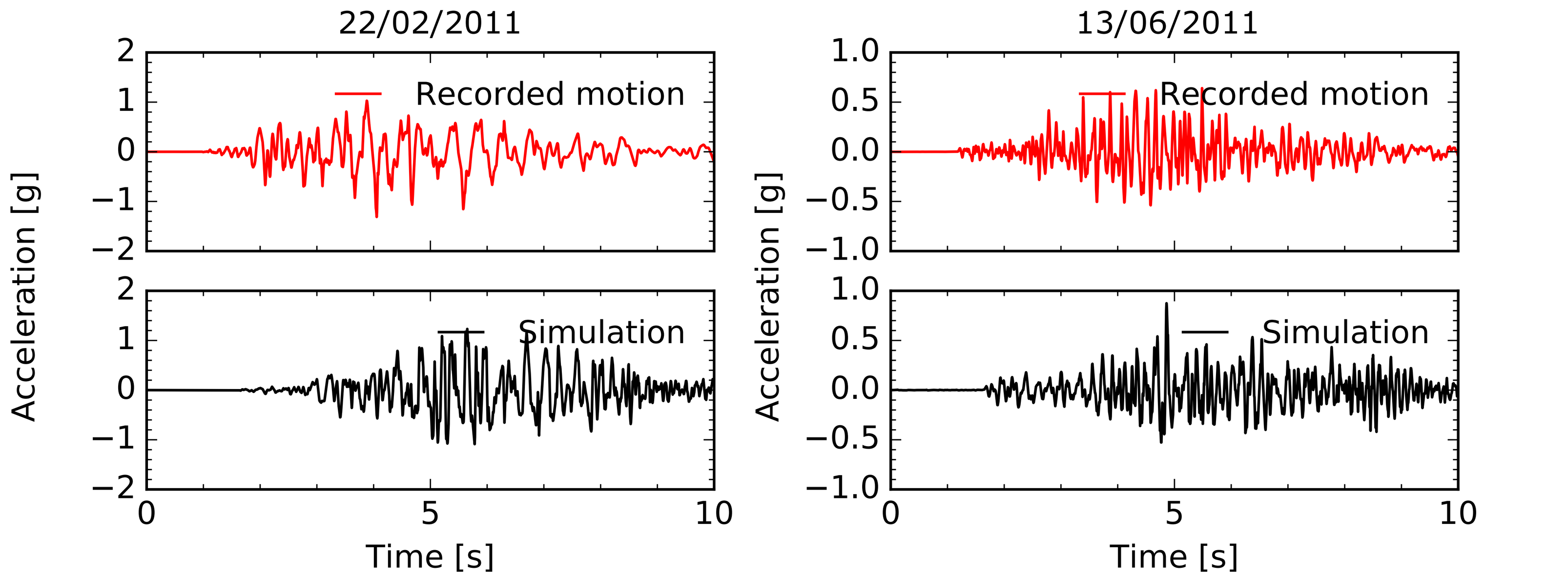

Figure 4: Comparison of horizontal (N75E) acceleration time series for earthquake events: 22/02/2011 and 13/06/2011

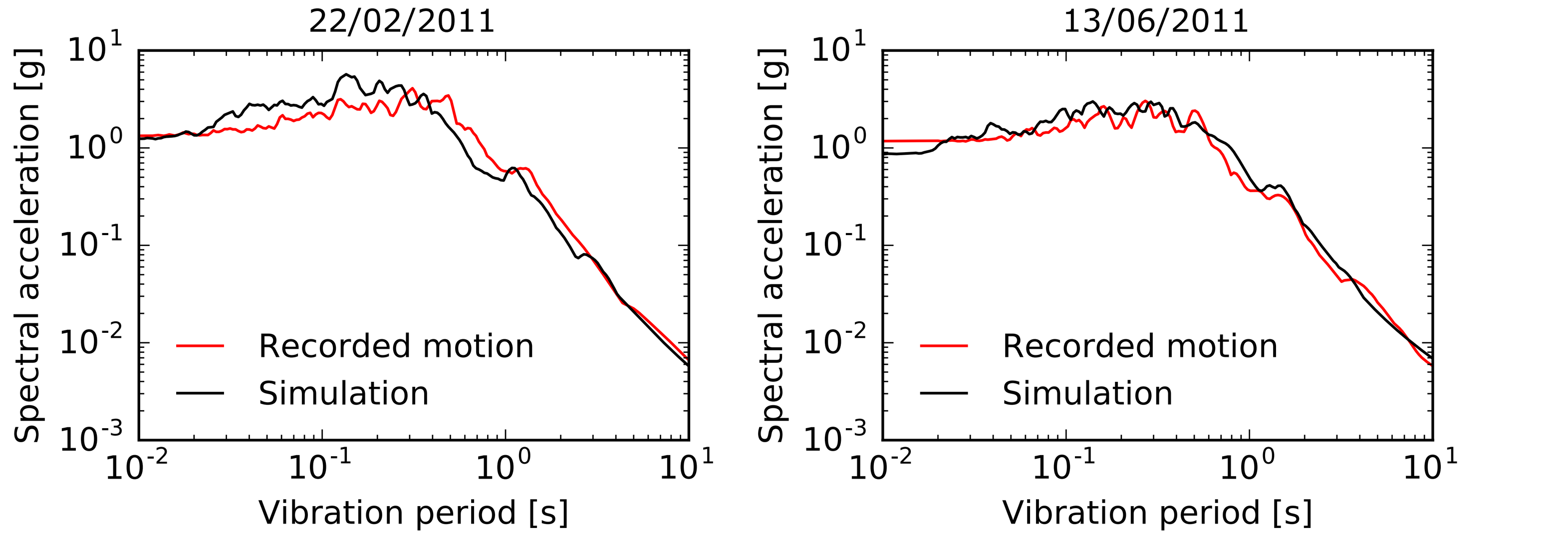

Figure 5: Comparison of horizontal (N75E) acceleration response spectra (SA) for earthquake events: 22/02/2011 and 13/06/2011

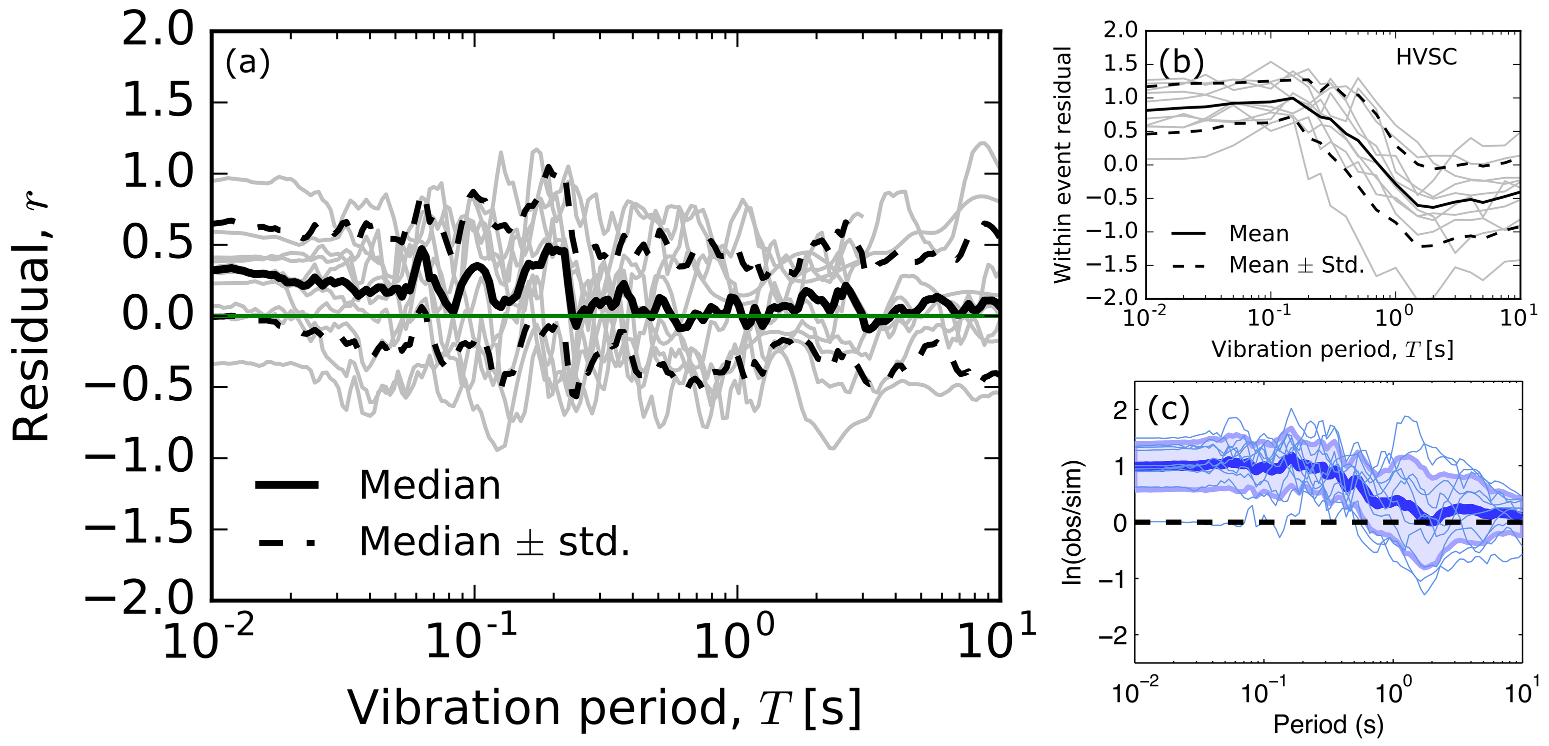

Figure 6: SA residual from (a) the 2D site-specific response simulation, (b) an empirical GMPE, and (c) the large-scale broadband ground motion simulation (with empirical site response).

- Simulated ground motions are compared with recorded motions for ten earthquake events in 2010-2011 (Table 1) and they show an overall good agreement.
- Figure 6 shows that the 2D Heathcote Valley site response model (Figure 6a) performs much better (mean residual is closer to zero) than both the empirical model (Figure 6b) and the large-scale ground motion simulation with empirical site response (Figure 6c).
- A large uncertainty in long vibration periods (in Figure 6a) indicates a large uncertainty in the estimated input motions, because these vibration periods are unaffected by the shallow site effects.
- We expect that the model performance in short periods (T<0.3s) would be further improved with consideration of more complex model (e.g. modeling of 3D basin geometry and pore water pressure effect).

4. 2D vs 1D simulation

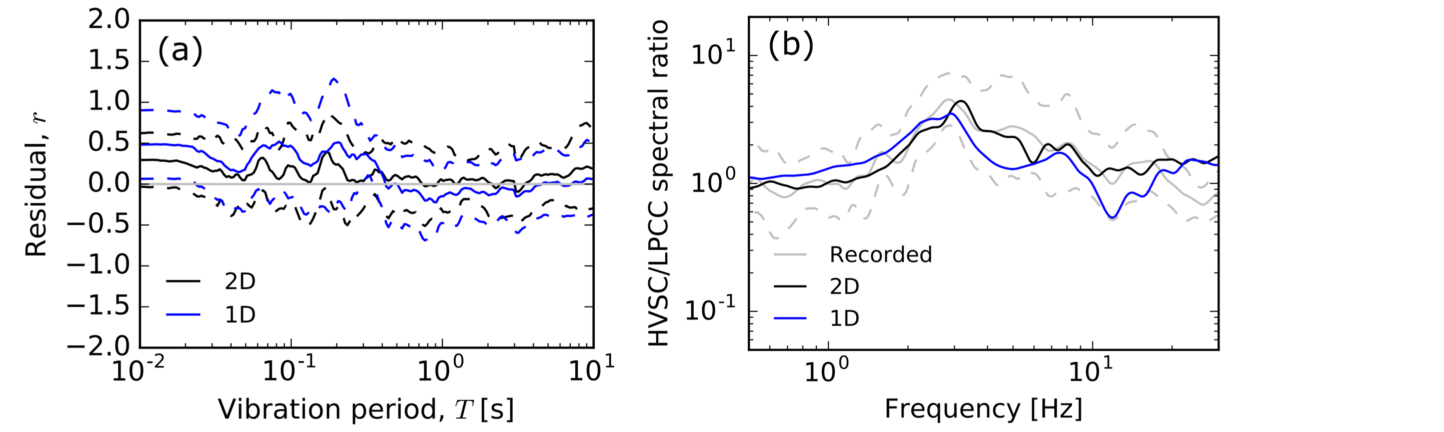

Figure 7: Comparison of (a) SA residuals and (b) HVSC/LPCC spectral ratios from 2D and 1D simulations.

- 1D simulations overestimate long period motions (T > 0.5s or f < 2Hz): Topography effect ?
- 2D simulations and the recorded motions show higher amplification than 1D simulations in short periods (T < 0.5s or f > 2Hz), likely caused by the Rayleigh waves generated near the basin edge.

5. Effects of non-linear soil response

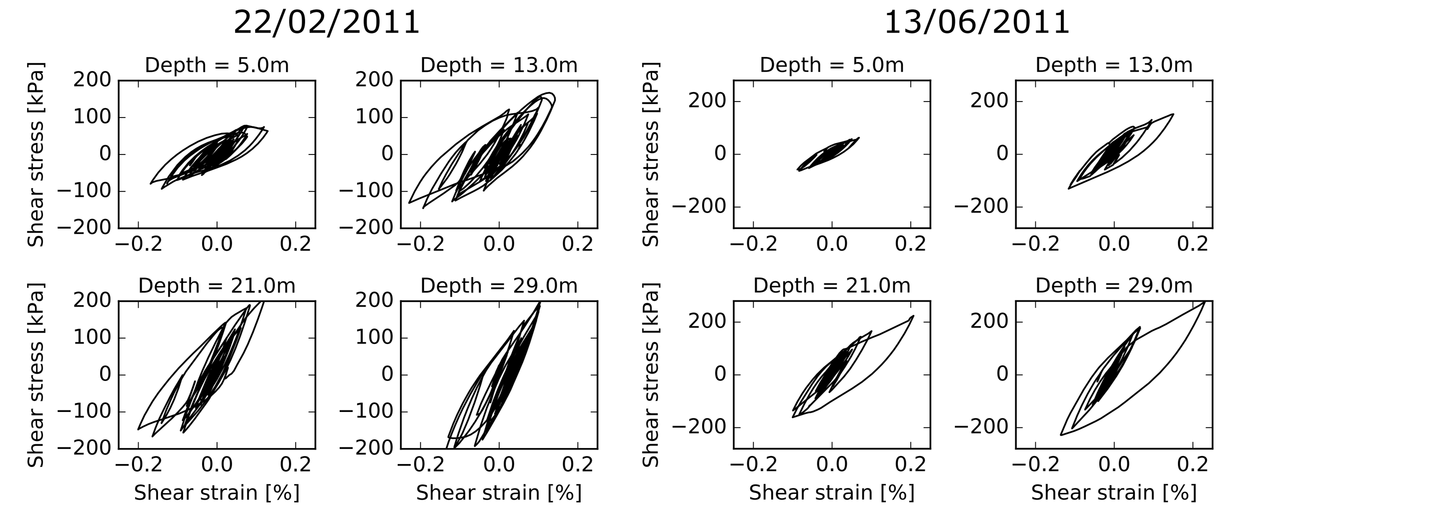

Figure 8: Shear stress-strain curves of soil elements for events: 22/02/2011 and 13/06/2011.

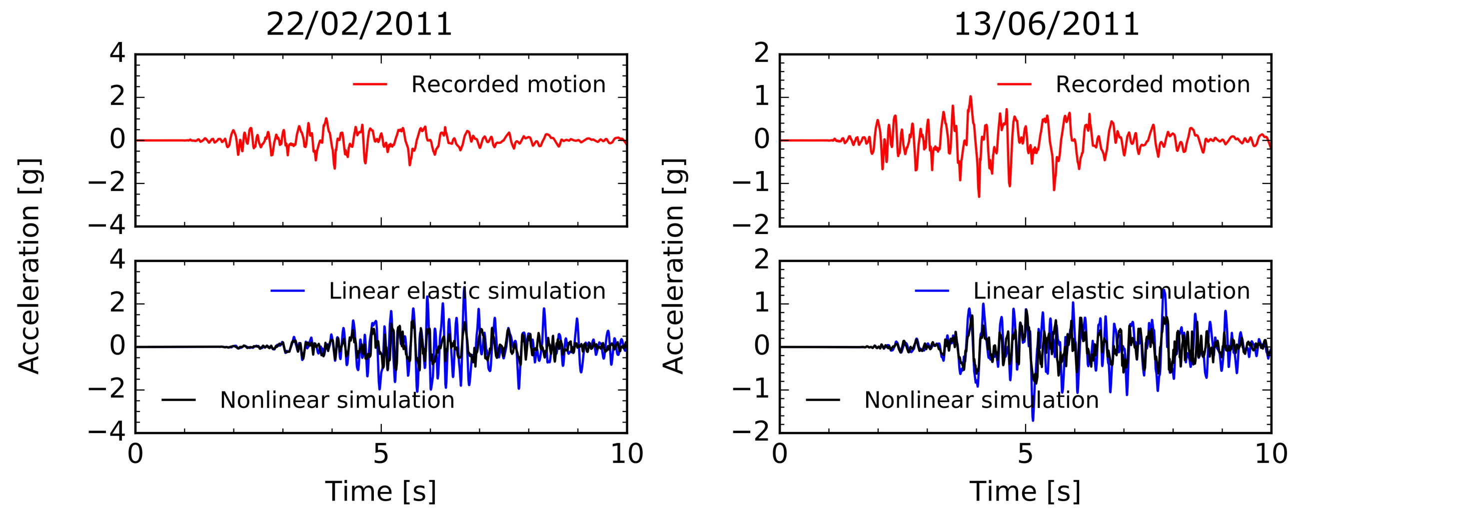

Figure 9: Comparison of acceleration time series from linear elastic and non-linear analyses for events: 22/02/2011, and 13/06/2011

- Significant amount of energy is dissipated via the hysteretic response of soils during strong ground shaking events.
- The simple linear elastic model therefore can lead to significant overestimation of ground motion amplification during strong ground shaking events, caused by the waves trapped within the soil layer.

6. Conclusion and future work

This poster demonstrates the capability of site-specific response analyses in predicting the ground motion intensity by presenting a case study of Heathcote Valley during the 2010-2011 Canterbury earthquakes. The site specific model shows much improved prediction of ground motions in comparison with an empirical GMPE and a large scale ground motion simulation. Simulations also demonstrate the significance of the basin edge effects, the topography effects, and the soil non-linear response in the ground motion intensity at Heathcote Valley.

In the near future, we plan to directly couple the site-specific response analyses with input motions from large scale ground motions simulations, and a detailed investigation into the role of dynamic soil response on strong asymmetric vertical accelerations.