Characterization of dynamic soil properties and stratigraphy at Heathcote Valley, New Zealand, for simulation of 3D valley effects

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1. Motivation and Objective

The 2011 Christchurch earthquake exhibited unusually intense ground motions. Peak ground acceleration recorded at Heathcote Valley School station (HVSC) exceeded 2g in vertical component, and 1.4g in horizontal component. Ground motions recorded at HVSC during the 2010-2011 Canterbury earthquake sequence also exhibited consistently higher intensities compared with nearby strong motion stations (see Figure 1). HVSC is located close to the edge of Heathcote valley, where the sediment thickness is approximately 10~20m, with shear wave velocity Vs≈350m/s.

- We suspect basin-diffracted Rayleigh waves played a significant role in amplifying the intensity of ground motions at Heathcote valley.
- It is also likely that the ground motion intensity was affected by topography effects; the station is located very close to the Heathcote portal of Lyttelton rail tunnel, which has very steep cut slopes about 8 meters high on each side.

The objective of this study is to develop a complete 3D representation of dynamic soil properties at Heathcote valley, necessary for detailed numerical simulation of 3D site effects observed in Heathcote valley.

- Shear wave velocities of surficial soils are characterized by synthesizing data from Seismic CPT (sCPT), seismic refraction, and multichannel analyses of surface wave (MASW).
- Sediment thickness is determined from CPT refusal depth and MASW survey result.

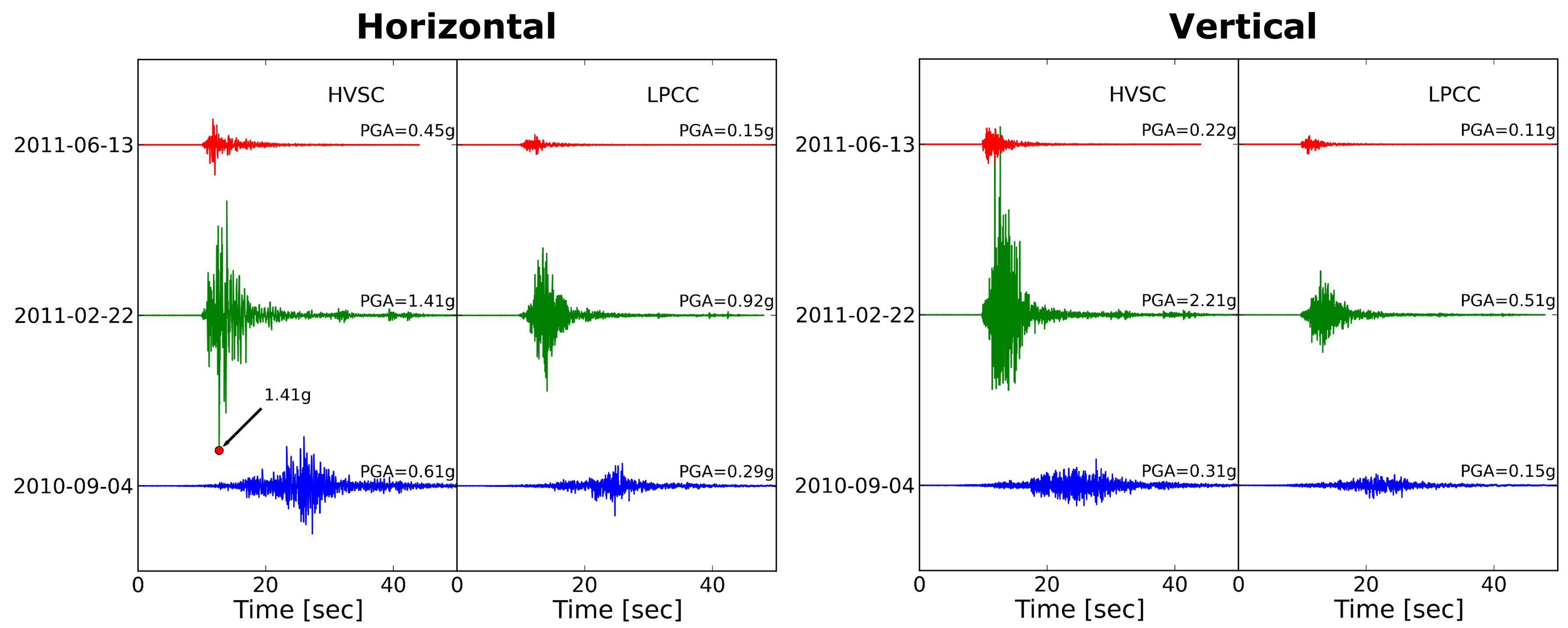

Figure 1: Ground motions recorded at Heathcote valley station (HVSC), compared with records at Lyttelton port company station (LPCC). LPCC is approximately 4km away from HVSC and is located on volcanic bedrock. Ground motions recorded at HVSC exhibited consistently higher intensities compared with LPCC and other nearby strong motion stations.

2. Site Overview and Test Locations

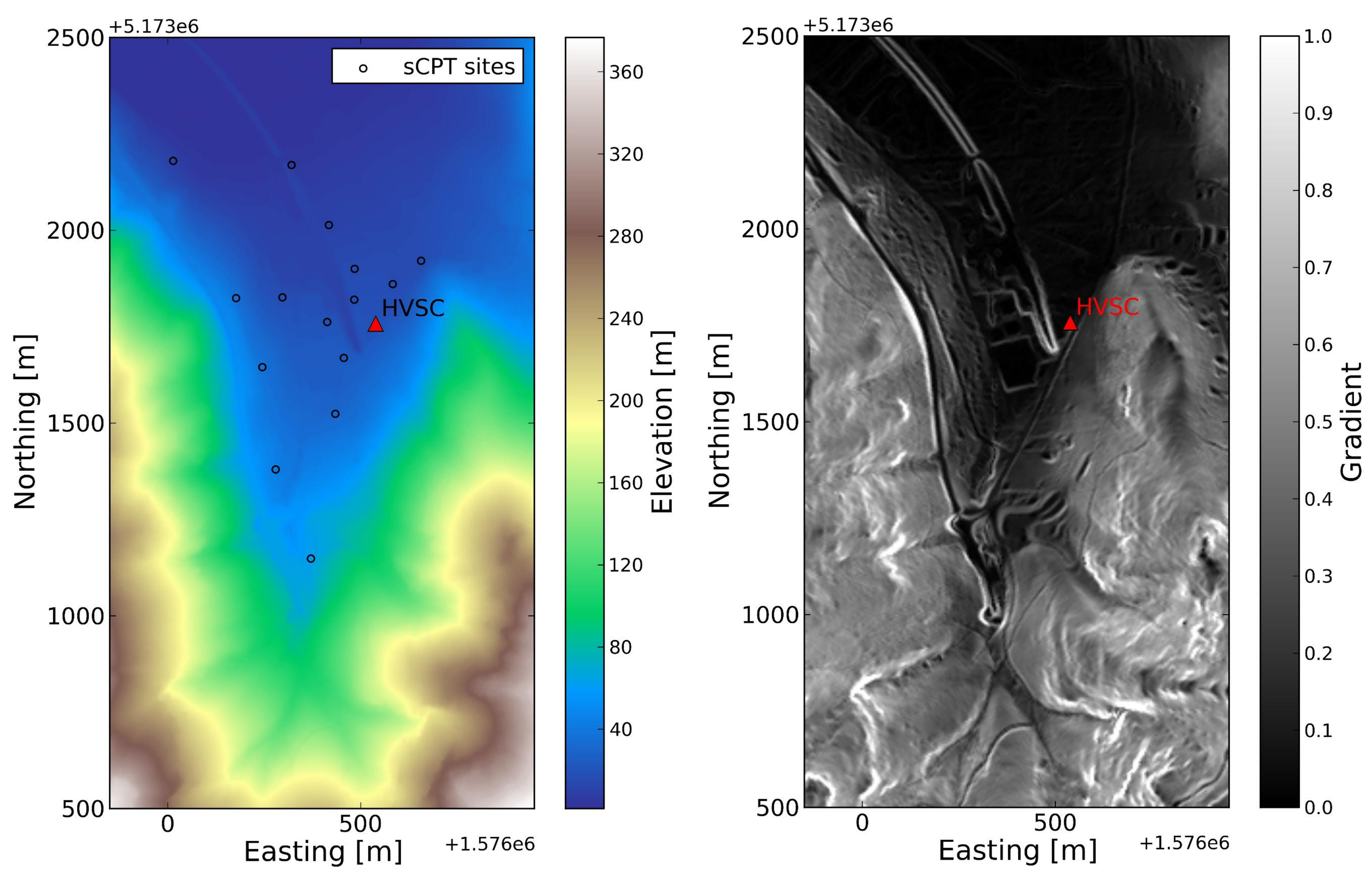

Figure 2: Maps showing the Lidar based digital elevation model (DEM, left) and the gradient (right) of the Heathcote valley. sCPT test sites are located with black circles. Location of HVSC is shown with a red triangle.

Figure 2 illustrates the topography of Heathcote valley and locations of sCPT test sites. It is a V-shaped valley facing north, surrounded by volcanic foothills located at Port Hills, Christchurch.

Loess is predominant in surficial soils in the Port Hills area, and it has shear wave velocity Vs≈350m/s. Thickness of surficial soil varies from a few meters to 35 meters at Heathcote valley.

HVSC is located near the edge of the valley, as shown in Figure 2, and is just 50 meters behind a 8 meter high steep cut slope, formed during a rail tunnel construction. A 2D schematic of the valley cross section at HVSC is shown in Figure 3.

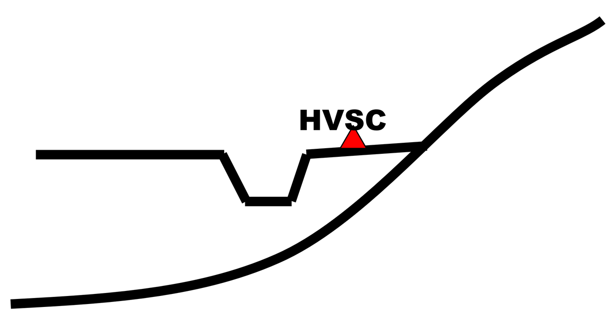

Figure 3: A 2D schematic of valley cross section at HVSC.

3. Seismic CPT

Fugro Geotechnical (NZ) performed 15 sCPT soundings at Heathcote valley. Locations of the soundings are plotted with black circles in Figure 2. During the survey, we continued the penetration until refusal, at which point the tip resistance (q_c) usually exceeded 40MPa.

Thickness of sedimentary layers obtained from sCPT ranged from a few meters near the edge of valley to 35 meters at the deepest location. The thickness of sediments obtained from CPT, corroborated by MASW survey is spatially interpolated using a Kriging algorithm to estimate the surface of the weathered rock (Vs=800~1500m/s), which underlies the surficial sediments.

Figure 4 shows the shear wave velocity profiles obtained from sCPT, along with the mean and standard deviation of all profiles. We found that the velocity of the loess in this area strongly depends on the confining pressure, a typical characteristic of granular material. This pressure dependence can be approximated by a power law equation shown as a red dashed line in Figure 4.

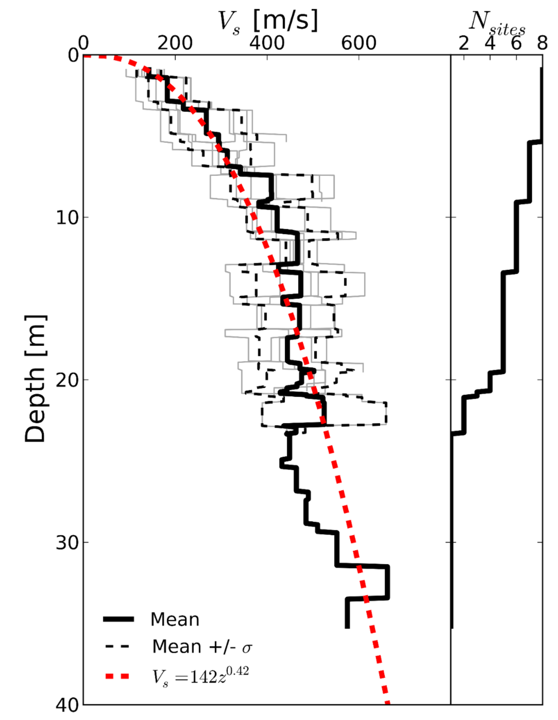

Figure 4: Shear wave velocity profiles, its mean, and standard deviation, obtained from sCPT tests. Red dashed line shows a power law equation fitted to data

4. Seismic Refraction and MASW

We performed seismic refraction surveys and multi-mode MASW at multiple sites in Heathcote valley, using 24 horizontal and 24 vertical geophones and a 5kg sledge hammer.

Figure 5 shows a typical Rayleigh wave dispersion curve. Most surveys exhibited multiple modes in the dispersion curve with strong contributions from higher modes, requiring simultaneous inversion of multiple modes.

Figure 6 shows a comparison of the shear wave velocity profiles obtained from sCPT, seismic refraction, and MASW. Velocity profiles from different test methods generally agreed well. Most importantly, MASW was able to identify the thickness of the surficial soils, whereas it was difficult to resolve deeper than 15 meters with the seismic refraction survey due to the rapid increase of shear wave velocity as a function of depth.

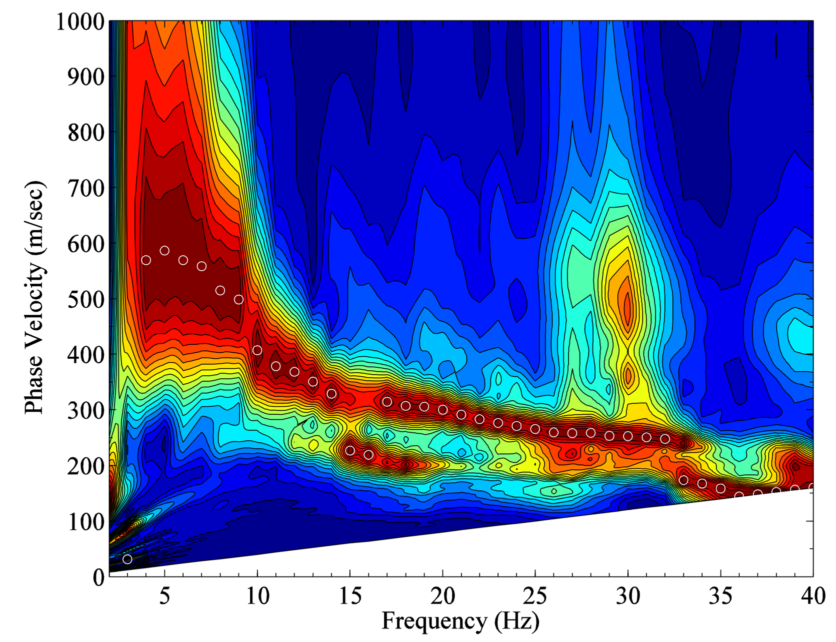

Figure 5: A typical Rayleigh wave dispersion curve at Heathcote valley. Most survey exhibit multi-mode dispersion with strong higher modes.

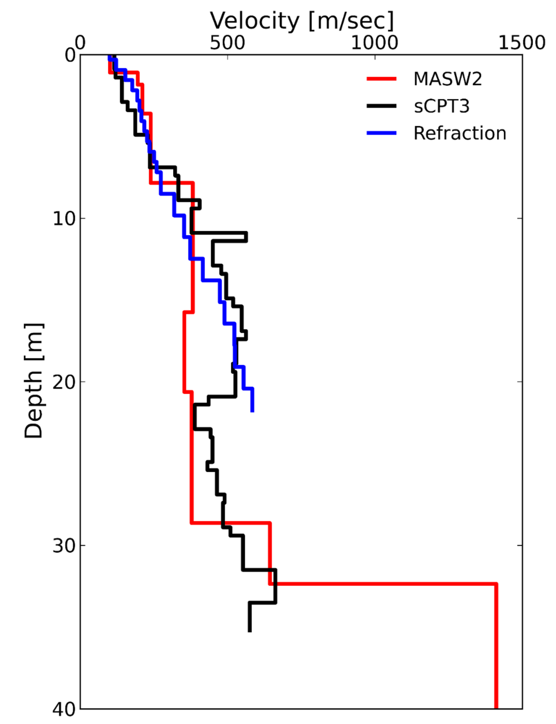

Figure 6: Comparison of shear wave velocity profiles from various tests. Rock depth estimated from MASW agrees well with CPT refusal depth.

5. Current State and Work in Progress

We synthesized data obtained from sCPT, seismic refraction and MASW, for developing a 3D representation of dynamic soil properties and the rock topography at Heathcote valley.

Figure 7 shows a contour plot of sediment depth, determined by spatial interpolation (Kriging) of discrete datapoints, obtained by sCPT and MASW. Subplots on top and on the left of the main plot show cross sections of the valley with filled contours of shear wave velocity. Currently, the shear wave velocity of soil is approximated by a simple power law equation shown in Figure 4. The boundary of rock outcrop is delineated utilizing the DEM and satellite imagery, as shown in black solid line in Figure 7.

We have planned additional seismic refraction and MASW, to improve the spatial coverage of our data. We plan to approximate inelastic constitutive behavior of soil based on its elastic properties, obtained from seismic testings, and shear strength estimated from CPT resistance readings.

While currently the velocity is approximated by a simple power law equation, we plan to improve our model by considering the spatial variability of observed velocities.

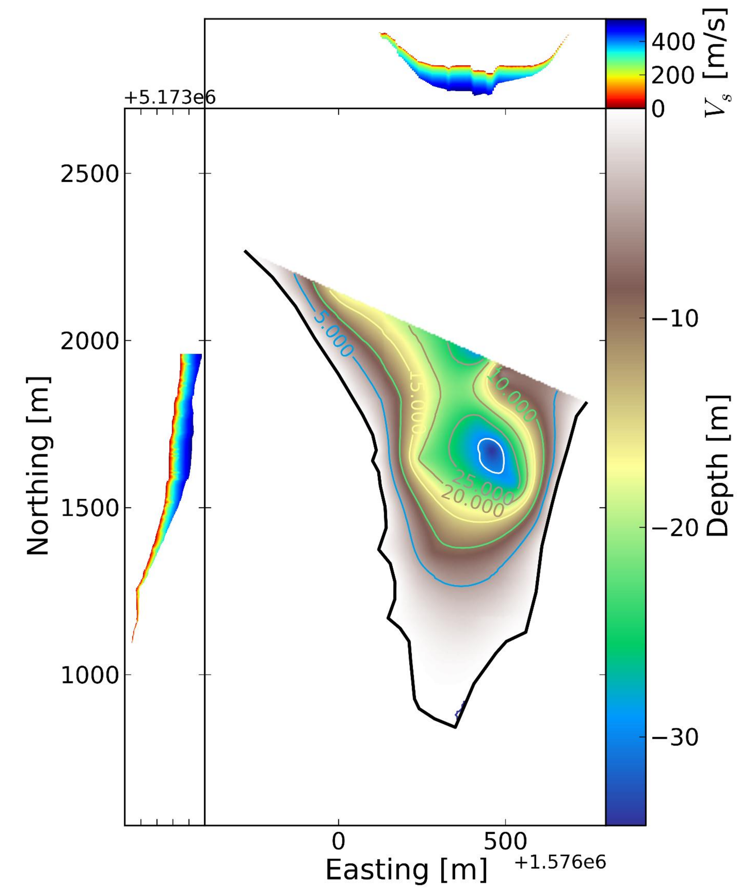

Figure 7: A contour map showing the sediment depth obtained by spatial interpolation of test data. Subplots on top and on the left of the main plot show cross sections of the valley and the velocity approximated by a power law equation.