Dynamic Site Characterisation of the Nelson-Tasman Region

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ABSTRACT

This paper presents a study being undertaken to characterise the subsurface across Nelson and Tasman using active source surface wave testing, ambient wave field (passive) and H/V spectral ratio methods. Deep soil and gravels deposits are present in this area which may lead to amplification of ground shaking and basin effects. However, there is currently little information available on the dynamic properties of the deposits across the Nelson-Tasman region, and the potential site amplification effects. Existing subsoil information has been used to constrain the shear wave velocity profiles at a number of sites developed from surface wave testing, highlighting the high shear wave velocities in the regional gravel deposits. H/V spectral ratio measurements were employed in order to characterise the wider basin structure. However, based on current data and knowledge of the deeper regional geology, it is likely that there is often no strong impedance contrast at the bottom of the basin due to the significant depth and high shear wave velocity of dense claybound gravels overlying the bedrock. This means that H/V spectral ratio measurements may only be able to characterise the response of profiles above shallow impedance contrasts, not the overall soil profile.

1 INTRODUCTION

The Nelson-Tasman region is the north-western section of the South Island of New Zealand. The main centre, Nelson city, has a population of 46,000 and when combined with the wider Tasman area the region has a combined population of nearly 90,000 (Immigration NZ, 2016). The Nelson-Tasman region has two large shallow bays – Tasman Bay and Golden Bay, with a mountainous interior. Urban development is limited both spatially and in density, with only a small number of multi-story buildings present in the city business district. Nelson-Tasman Region is considered a 'moderately' seismic area, due to the proximity to the Alpine Fault and the local Waimea-Flaxmore Fault System.

Nelson-Tasman region is a rugged mountainous area formed of very hard rocks, some of which are among the oldest in New Zealand (GNS, 2016). The area comprises rugged, recently deglaciated Tasman Mountains in the west and the lower Richmond Range and other ranges in the east separated by the low-lying Moutere Depression. In the southeast, the Wairau valley separates the Richmond Range from the southern Nelson area and is characterised by relatively shallow water depths (Rattenbury et al., 1998).

The steep rocky mountain ranges that enclose the region have supplied huge volumes of gravel to the lower lying areas. Over time, the relatively flat areas of Nelson and Richmond have been formed on outwash gravels. There have also been a number of areas reclaimed in recent years with the use of hardfill and domestic rubbish to extend the natural foreshore area Figure 1.

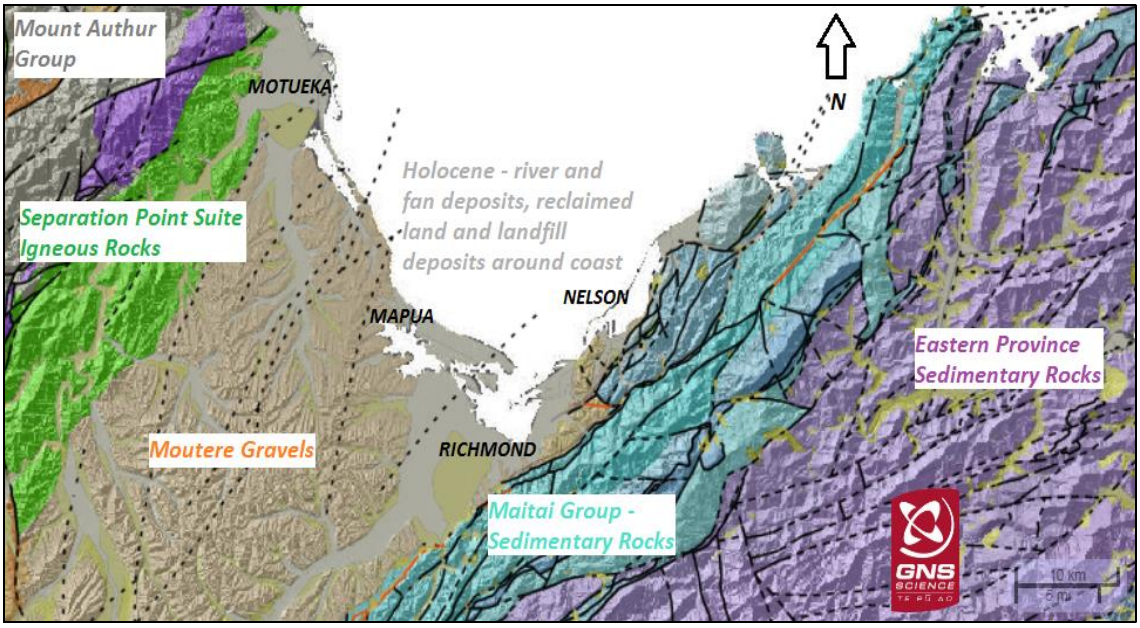

Figure 1: Overview of the Nelson-Tasman Region Geology (modified from Nelson Urban Area Geological Map, 1:250 000, New Zealand Geological Survey (2014) http://data.gns.cri.nz/geology/).

A large proportion of Nelson-Tasman is underlain by a very deep basin of dense gravel. The most prominent formations are the Moutere Gravels (Tasman) and Port Hills Gravels (Nelson) which are of a similar age and structure.

In Nelson city, the Port Hills Gravels are up to 500 m thick, and consist of granitic conglomerate grading upwards into conglomerate composed of clasts of volcanic Permian/Triassic rocks largely derived from the east of the Waimea Fault. Port Hills Gravel is comprised of heterogeneous clay and silt bound gravel with lenses of sandstone and occasional lignite seams and is intersected by a number of faults (Westerson, 2007).

The Moutere depression and surrounding areas of Tasman are generally underlain by Moutere Gravels. According to seismic reflection studies and interpretation of regional geology the Moutere Gravels extend thousands of meters below the ground surface, and are very dense (Lihou, 1992). Slightly weathered, well rounded quartzfeldspathic sandstone clasts in a brown weathered muddy sand matrix comprise the bulk of the Moutere Gravel. In the Moutere depression, an extensive area of Moutere Gravel is preserved. The gravels are described as uniform yellow-brown, clay-bound gravel, with deeply weathered clasts is almost entirely of Torlesse-derived sandstone and semi-schist (Rattenbury et al., 1998).

Although regional seismic reflection has provided an overview of the structure of the subsurface, there is very little knowledge of the dynamic characteristics of the regional deposits described previously. The primary aim for this study is to provide guidance and information on dynamic site parameters and seismic site classification in the Nelson Tasman region by developing shear wave velocity-depth relationships for regional deposits. Mapping of inferred NZS1170.5 (Standards New Zealand, 2004) site classes based on testing and analysis will also provide useful high-level guidance for seismic design.

The Nelson-Tasman site characterisation study is aimed at collecting information for site characterisation purposes using geophysical and traditional geotechnical techniques. Outputs will include site period estimates derived from H/V spectral ratio measurements and shear wave velocity profiles for a number of sites across the region.

2 DATA COLLECTION METHODOLOGY

A range of methods were used to collect data for the purposes of this project. This included collation of available traditional subsurface information as well as active-source and passive-source geophysical testing as detailed below. The processing and interpretation of the collected information was completed using best-practice methods.

2.1 Factual Geotechnical Database

Available subsurface data and geotechnical information was compiled to develop a reference dataset which would then be used to constrain and interpret the geophysical data collected. The use of factual geotechnical information as a means of constraining test data is an essential part of the geophysical site characterisation process.

2.2 Surface Wave Testing Methodology

Both active-source and passive-source surface wave testing methods were utilised to develop shear wave velocity profiles across the region. In this paper field investigation data was collected using a linear array for active source testing and a two-dimensional L array for passive source testing. Active source testing was performed using 24 geophones at 2 m spacing, with at least three separate source locations from the first receiver in the array (e.g. 5, 10, 20 m) to account for the effect of offset distance on the dispersion curve data, and from each end of the array to account for lateral heterogeneity. L-array testing was carried out using 24 geophones at 5 m spacing, creating an "L" shape with lengths of 60 m and 55 m. While not presented here, additional passive source surface wave testing has been carried out using circular arrays of broadband seismometers with diameters ranging from 50 m to 200 m. This will enable the characterisation of the shear wave velocity profile to much greater depths (up to 200 m).

Dispersion data from each array were combined to form composite dispersion curves for each processing method. The Rayleigh-wave dispersion data was inverted using a multi-mode inversion along with the neighbourhood algorithm in Geopsy (Wathelet, 2008). To provide the best representation of the shear wave velocity profile at each site layering characteristics from subsurface investigation data was used to constrain the surface wave inversion parameters. This is a key step in the development of profiles that are representative of the actual site conditions, as without this constraint there will be an increase in the uncertainty of shear wave velocity profiles that are developed (Wood et al., 2015). Rather than providing a single, deterministic Vs profile for each site, these inversions provide a suite of profiles that fit the experimental data equally well.

2.3 H/V Spectral Ratio Methodology

To estimate the site period (T_0) at each location, the ratios of the horizontal-to-vertical Fourier amplitude spectra (FAS) of recorded ambient noise were used (i.e., H/V spectral ratios) (Nakamura, 1989). Broadband 3-component seismometers (Nanometrics Trillium Compact, 20 second period) were used at individual test locations at sites including council owned parks and road-reserves. The seismometers were either embedded in the ground and packed securely into place, or placed on a levelling cradle used to ensure the sensor has a firm connection with the ground. H/V data were processed using the software Geopsy (www.geopsy.org). Time windows that were overly noisy were removed, with the remaining windows used to develop the spectral average at each location. The geometric mean of the horizontal-component Fourier spectra were used to develop the H/V spectral ratios, and a Konno & Ohmachi (1998) smoothing function with a smoothing constant of b=40 was applied. The H/V spectral ratios from a range of time window lengths were compared during processing to determine the influence of window lengths on the estimated spectral peak(s) and to estimate the uncertainty associated with the spectral peak(s).

The data presented in this paper used a window length of 100 seconds with no overlap and a 5% cosine taper.

The H/V spectral peak(/s) from ambient noise recordings in this region were expected to correspond to: (1) the site period for the entire soil profile down to basement rock (a significant impedance contrast); or (2) the site period of shallow sandy soils above a shallow impedance contrasts.

2.4 Site Classification Metrics

In this paper we present the shear wave velocity profile and direct site period measurements. The site period (T_0) is the fundamental period of vibration of the overall soil profile above bedrock at a particular location. In the most simple sense, this can be related to the shear wave velocity by the equation below (the quarter wavelength method):

$$T_0 = \frac{4H}{V_{s,avg}}$$

where:

H is the thickness of the soil deposit above bedrock or above the identified impedance contrast at a given site.

V s, avg is the time averaged shear wave velocity profile calculated using the following equation

$$V_{s,avg} = \frac{\sum_i h_i}{\sum_i \frac{h_i}{V_{si}}}$$

where h_i is the thickness of the soil layer (i) and V_{si} is the shear wave velocity of layer (i). A more rigorous estimate of the site period can be made using the small strain transfer function between the bottom and top of the profile, with the maximum peak in the transfer function corresponding to the site period (e.g. Kramer, 1996).

3 RESULTS

Four sites have been selected to illustrate the type of outputs that this project will deliver for a number of sites across the region. The four locations are (with simplified mapped geology according to Rattenbury et al. (1998)): Tahunanui Fields (Tahunanui sands, underlain by Port Hills gravels), Greenmeadows Park (Stoke Fan Gravels underlain by Port Hills Gravels), Saxton’s Fields (Stoke Fan Gravels, underlain by Moutere Gravels) and Ben Cooper Park (Stoke Fan Gravels, underlain by Moutere Gravels).

The map in Figure 2 shows the relative locations of the example sites, and also provides a summary of H/V spectral ratio data recorded using broadband seismometers. The peak frequency (i.e. inverse of fundamental period) is relatively clear for most of the sites, but it is noted that there is a relatively weak peak measured at Greenmeadows Park, with a H/V ratio of around 2. At Ben Cooper Park two close peaks are identified. All peaks are less than 0.3 seconds, suggesting that they represent the response of a shallow soil profile rather than the overall profile to bedrock.

For each shear wave velocity test location, 1000 theoretical shear wave velocity profiles were derived which best represented the measured dispersion curve. The 1000 best shear wave velocity profiles for each site have been plotted with depth in Figure 3 and 4. At each site, the ‘Lowest Misfit Profile’ is the shear wave velocity profile from the inversion process that best fits the experimental data and is shown in bold on each plot. A typical trend at each site is an increase in the range of shear wave velocities as depth increases.

As indicated previously, the period identified by the H/V spectral ratio method likely corresponds to the response of a shallow soil profile above an impedance contrast. Using the shear wave velocity profiles, we are able to identify potential shallow impedance contrasts and calculate the site period using the two methods described previously. The impedance contrast depth adopted for each site and the resulting site period for the quarter wavelength, transfer function and H/V spectral ratio method are reported in Table 1.

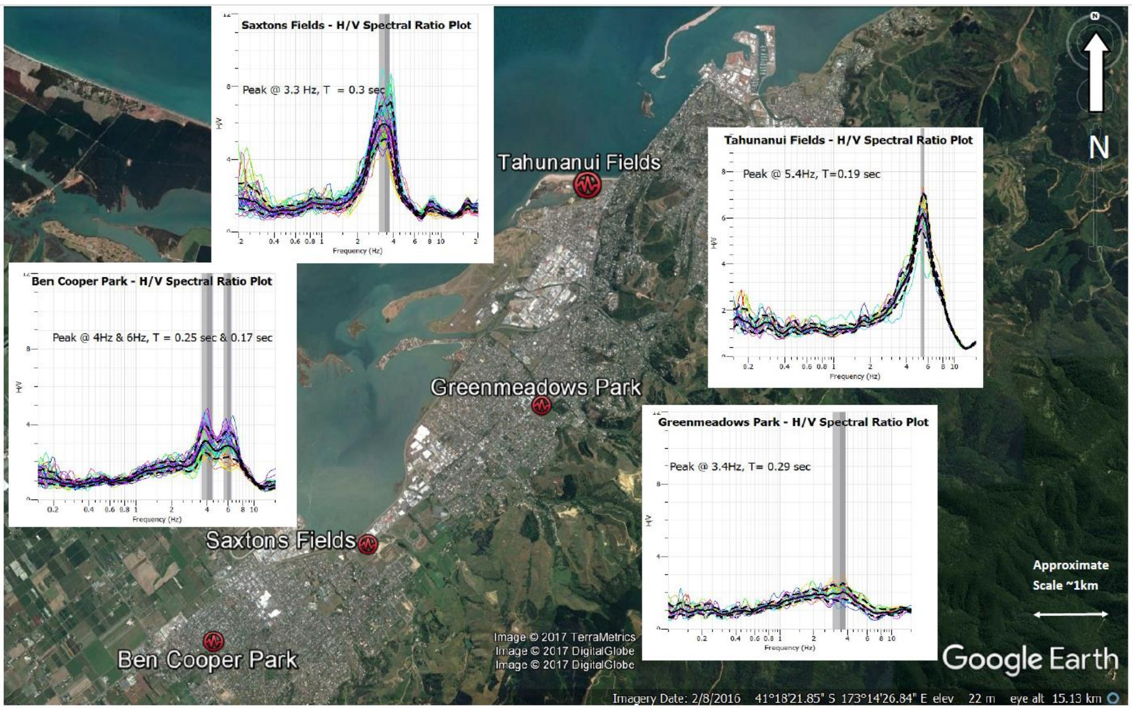

Figure 2: Locations Nelson-Tasman sites considered for comparison

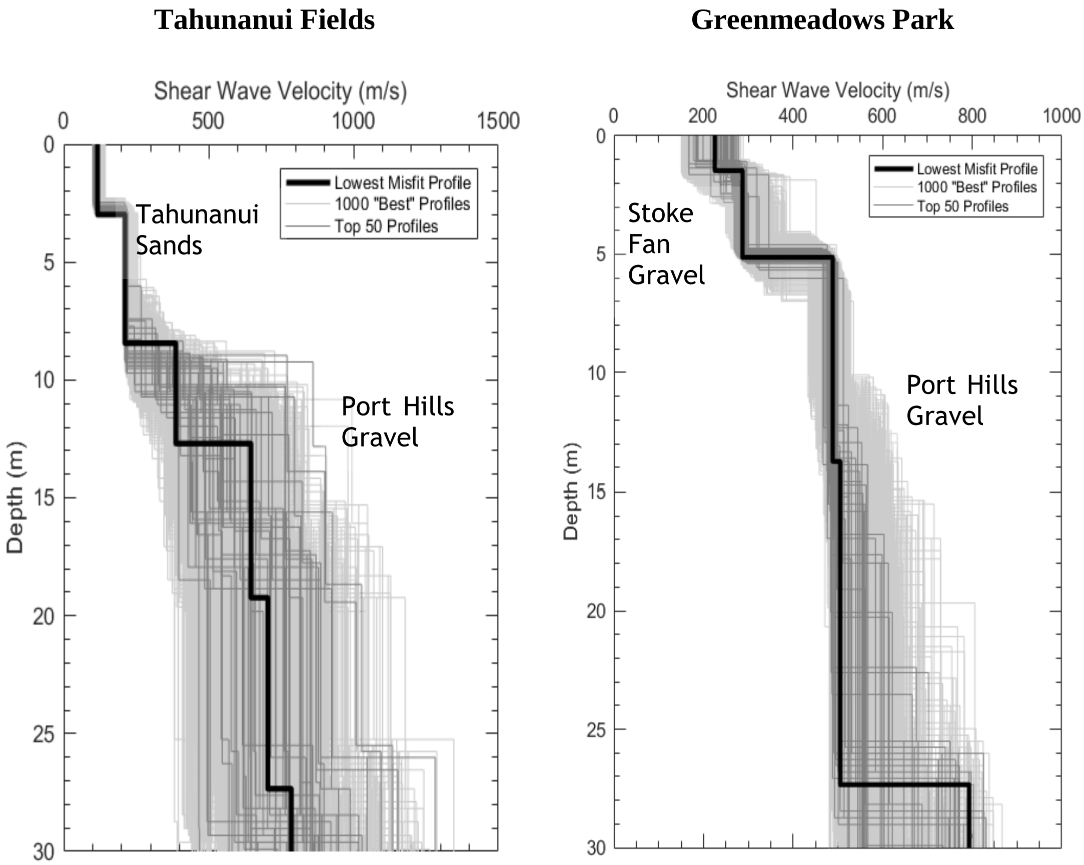

Figure 3: Shear-wave velocity top 1000 profiles ('best-fit' profile shown on bold) and transfer functions for each site, derived from 'best fit' Vs profile

Saxtons Fields **Ben Cooper Park**

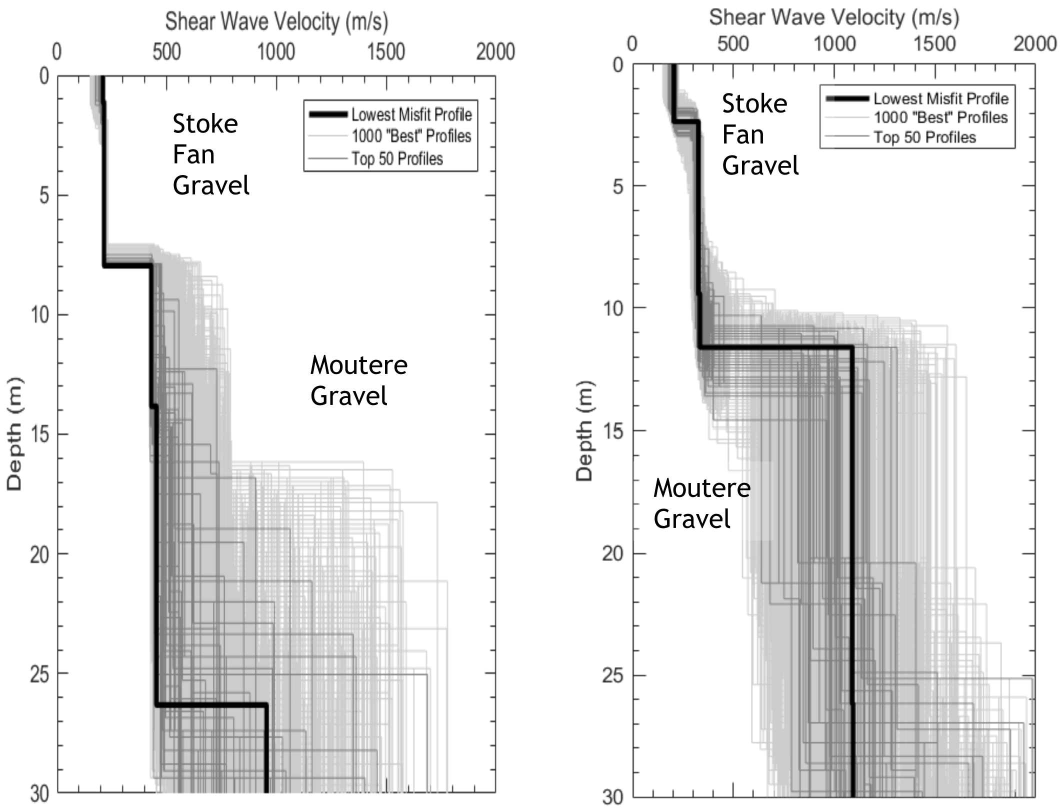

Figure 4: Shear-wave velocity top 1000 profiles ('best-fit' profile shown on bold) and transfer functions for each site, derived from 'best fit' Vs profile

Table 1: Site Period Method Comparison for Nelson-Tasman Sites Analysed

Site Name	Depth to impedance contrast	Transfer Function Method	Quarter Wavelength Method	H/V Spectral Ratio Method
Tahunanui Fields	13 m	0.19 sec	0.20 sec	0.19 sec
Greenmeadows Park	23 m	0.23 sec	0.24 sec	0.29 sec
Saxton Fields	26 m	0.25 sec	0.28 sec	0.30 sec
Ben Cooper Park	12 m	0.14 sec	0.15 sec	0.17 sec & 0.25 sec

The estimates of the shallow profile period for each site using the three different methods show some variation, but in general there is good agreement between methods. As the shear wave velocity profiles show an increase with depth the simple quarter wavelength method provides a fairly good representation of the shallow profile period. This is most significant for Greenmeadows Park and Saxton Fields, possibly because the depth to the inferred impedance contrast is deeper than that identified at Tahunanui Fields and Ben Cooper Park. The increase in measured shear wave velocity is also more gradual with a weaker impedance contrast at Greenmeadows and Saxton Fields, making it more difficult for the applied methods to clearly define the period of the shallow profile for a given site. Analysis of the passive source circular array test data will help to constrain these effects.

4 DISCUSSION

Compared to testing completed in other regions across New Zealand with broadband seismometers the measured H/V spectral ratio peaks had significantly shorter period and less clearly defined. It is inferred that this is due to the lack of strong impedance contrast at basement depth in the Nelson-Tasman geology, and seems to be supported by the large velocities measured in the clay bound gravel deposits.

The shear wave velocities derived from the inversion process are in the order of 600 – 1200 m/s for Moutere Gravels and Port Hills Gravels at shallow depths of around 15 m to 20 m below ground level. Such high shear wave velocity is normally associated with bedrock with an Unconfined Compressive Strength (UCS) of more than 1 MPa. A shear wave velocity of 800 – 1200 m/s is reported by the 'Caltrans/NEHRP soil profile types' (Wair et al. 2012) to be within the considered range of Vs30 for rock. The Moutere Gravels and Port Hills Gravels are generally a clay bound gravel, are very dense and stiff, but are unlikely to be a cemented conglomerate rock until around 30 m below ground level for Port Hills Gravel or more than 100 m depth for Moutere Gravels (Wopereis, 2017). Therefore, some revision of what we consider to be 'rock' in the guidelines for assessing seismic site class may need to be considered, particularly for regions such as Nelson-Tasman which have very deep and dense gravel deposits.

5 CONCLUSION

The information presented in this paper summarises the data from four considered sites across the Nelson-Tasman region. Discrepancies shown between the resulting site period estimates are likely to be partly caused by the lack of strong impedance contrast in the region. Consideration of the definition of 'seismic bedrock' (i.e. the defined rock underlying a surficial soil profile) needs to be explored further for sites with deep gravel basins overlying deep rock.

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