Variability of Shear Wave Velocity Structures in Launceston, Tasmania

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Abstract

Spatially averaged coherency spectra (SPAC) recorded at ten sites within the city centre of Launceston, Tasmania, are interpreted to evaluate the shear wave velocity (SWV) structure and its variation in and around the Tamar Valley running through the city. SWV profiles interpreted in North Launceston (Inveresk) suggest the presence of very low velocity sediments over shallow dolerite bedrock. The SWV profiles agree well with horizontal to vertical spectrum ratio (HVSR) recorded at all three sites. SWV profiles evaluated at two sites located above the deepest point of the Tamar Valley in Launceston City Centre prove the reliability of the SPAC method to work in a valley environment. SPAC observations recorded over the eastern flank of the Tamar Valley suggest a rapidly varying bedrock interface. SPAC observations recorded on top of the hill in West Launceston show low level of microtremor energy, poor coherency spectra, and absence of peak on HVSR observations; suggesting the presence of dolerite bedrock at the surface. The differences in the SWV profiles interpreted at Launceston explain the large range in the frequency of resonance observed in Launceston.

Keywords: spatially averaged coherency method, horizontal to vertical spectrum ratio, variability in SWV profile

1. INTRODUCTION

The single station horizontal to vertical spectrum ratio (HVSR) is used to estimate the frequency of resonance at specific sites in Launceston (Claprood and Asten, 2008). Studies proved that the reliability of site resonance predictions are improved when using single station microtremor methods in combination with array based microtremor survey methods to evaluate both the shear wave velocity structure and the frequency of resonance (Satoh et al, 2001; Asten et al, 2002; Chavez-Garcia et al, 2007).

Array based microtremor survey methods are used to evaluate the shear wave velocity (SWV) structure at specific sites. Pioneering work from Horike (1985) demonstrated that array based microtremor methods are useful and reliable tools for evaluating the shear wave velocity structure in urbanised area. An important hypothesis to consider when using microtremor survey methods is the assumption that the geology can be approximated by a layered earth, a very restrictive constraint when evaluating the SWV structure at specific sites.

This paper presents microtremor observations recorded at ten separate sites in the city of Launceston (Tasmania) using the array-based spatially averaged coherency (SPAC) method and the single station horizontal to vertical spectrum ratio (HVSR), and outlines the variability of the SWV profiles and frequencies of resonance within the city.

2. GEOPHYSICAL SETTINGS

Unpublished maps from Mineral Resources Tasmania, and the interpretation of gravity survey (Leaman, 1994) and previous microtremor surveys (Michael-Leiba, 1995; Claprood and Asten, 2009a) outline the rapid changes in surface geology within the city of Launceston. Figure 1 is a geological map of Launceston, and shows the location of ten sites of microtremor observations.

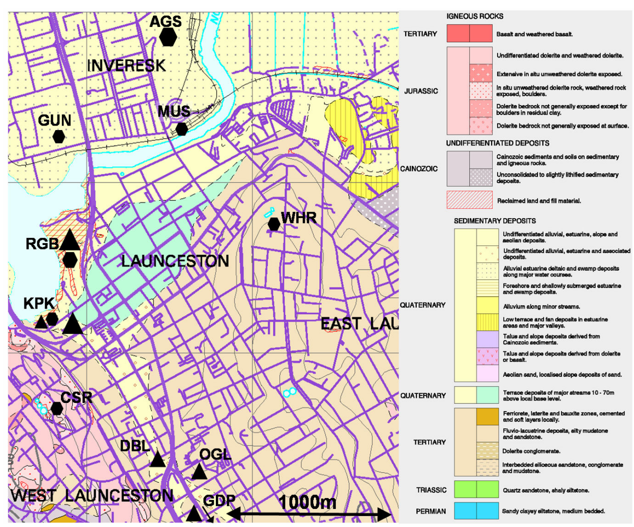
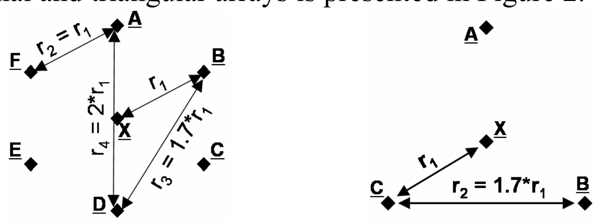


Figure 1. Surface geology map of Launceston (modified from Mineral Resources Tasmania). Location of SPAC microtremor observations during 2006 (hexagons) and 2007 (triangles) field surveys.

The bedrock at Launceston is dense, fractured and weathered dolerite of Jurassic age, which provides reduced seismic risk when outcropping (Leaman, 1994). Tertiary sands and clays of low density fill an ancient valley systems running beneath the city of Launceston, and are overlain by poorly consolidated Quaternary alluvial sediments (silts, gravels, fills) deposited in valley floors and other marshy areas near sea level. The interpretation of gravity survey by Leaman (1994) identified two NNW-SSE trending palaeo-valley systems below Launceston; the Trevallyn-Tamar (Tamar) and North Esk Palaeovalleys.

3. SPAC FIELD PROCEDURE

Two field surveys were completed to record microtremor observations in Launceston in 2006 and 2007 for evaluating shear wave velocity (SWV) profiles using the spatially averaged coherency (SPAC) method (Aki, 1957). SPAC observations from the 2006 field survey were recorded using centred hexagonal arrays of seven vertical component Mark L28 - 4.5Hz cut-off frequency sensors. HVSR observations were recorded at the centre of each array with a three-component Mark L4C - 1Hz cut-off frequency geophone. SPAC microtremor observations were recorded using centred triangular arrays of four three-component Guralp CMG-3ESP - 0.0167Hz or 0.033Hz cut-off frequency geophones in 2007 to gain sensitivity at low frequency (and at depth). HVSR observations were recorded simultaneously at all sensors of the array. The geometry of the centred hexagonal and triangular arrays is presented in Figure 2.



(a) (b)

Figure 2. Array geometries for SPAC observations in Launceston. (a) Centred hexagonal array (n = 6) with four inter-station separations r_1, r_2, r_3, and r_4. (b) Centred triangular array (n = 3) with two inter-station separations r_1 and r_2.

Spatially averaged coherency spectra are computed by averaging the observed coherency spectra over azimuth on all inter-station separations. The observed spatially averaged coherency spectrum *C(f)* is directly fit to the theoretical coherency spectrum (Bessel function of first kind and zero order J_0) by least-square optimisation (Herrmann, 2002) to evaluate the preferred shear wave velocity to depth profile under each array (Asten, 2003; Asten et al, 2004):

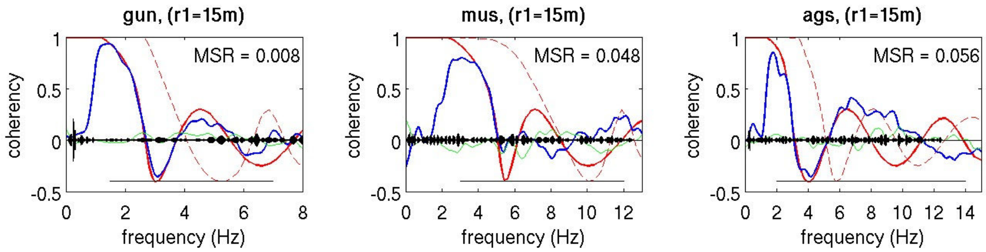
$$C(f) = J_0\left(\frac{2\pi f r}{V(f)}\right), \tag{1}$$

where f is the frequency, r the inter-station separation, and $V(f)$ is the S-wave velocity dispersion function of a layered earth model whose shear wave velocity profile is evaluated.

The observed coherency spectra recorded on inter-station separation r_1 at all ten sites in Launceston are presented in the next section. The mean square of residuals computed between the observed and theoretical coherency spectra (Bessel function J_0) over the selected frequency interval was used to assess the reliability of the SWV profile interpreted, following Claprood and Asten (2009b)'s methodology.

3.1 SPAC Observations in Inveresk

The geology in the northern area of Launceston (Figure 1, Inveresk), is composed of thin layers of very soft alluvial estuarine and swamp deposits. Three sites were visited during the 2006 field survey: sites GUN, MUS, and AGS, which observed coherency spectra are presented in Figure 3.



(a) (b) (c)

Figure 3. Observed coherency spectrum (COH) at sites (a) GUN, (b) MUS, and (c) AGS during 2006 field survey with centred hexagonal array. Blue: Observed spatially averaged COH at inter-sensor separation r_1. Solid and dashed red lines: Theoretical COH from preferred SWV profile, fundamental and 1^{st} higher modes respectively. Green line: Observed smoothed imaginary component of COH. Black bars: Observed roughened imaginary component of COH. MSR stands for Mean Square of Residuals. Straight line at bottom of each graph is the frequency interval where theoretical COH is fit to observed COH.

Low value of mean square of residuals at site GUN (MSR_{GUN} = 0.008) suggests the reliability of the SWV profile evaluated at site GUN. Poor fits are however observed at sites MUS and AGS (high MSR values, MSR_{MUS} = 0.048, MSR_{AGS} = 0.056). The non-uniformity of the alluvial sediments across the old railway yard at site MUS is suggested to explain the poor behaviour of the observed coherency. Due to poor penetration of surface waves across the thick low velocity sediments at site AGS, the bedrock interface was not resolved by SPAC alone, and was constrained by HVSR observations recorded at the centre of the array.

3.2 SPAC Observations in the Tamar Valley

Coherency spectra were recorded at 5 separate sites in the Tamar Valley during the 2007 field survey to analyse the potential of the SPAC method to interpret SWV profiles in a valley environment. The fit between observed and theoretical coherency spectra at all sites on inter-station separation r_1 from two centred triangular arrays (Figure 2b) are presented in Figure 4. Results demonstrate the spatially averaged coherency spectra recorded at all five sites can be used with reliability (0.002 <= MSR <= 0.021) to evaluate the SWV profile above soft sediments filling the Tamar Valley.

Bedrock interface was interpreted at a depth z = 250m at site DBL by fitting the coherency spectrum observed on a single pair of sensors oriented parallel to the valley axis to the theoretical coherency spectrum, by following the methodology proposed by Claprood et al (2009a) which validates the use of the SPAC method in a valley environment. The bedrock interface could not be located with SPAC observations alone at site KPK and was constrained by gravity data and HVSR observations. The bedrock is located at shallower depth at sites RGB and OGL, which sites were found to be located above the eastern flank of the valley. This was further demonstrated by a site resonance study on two HVSR profiles transverse to the Tamar Valley (Claprood et al, 2009b). Observed coherency spectra recorded at site GDP show poor resolution at depth, limiting the interpretation of SPAC observations recorded at this site.

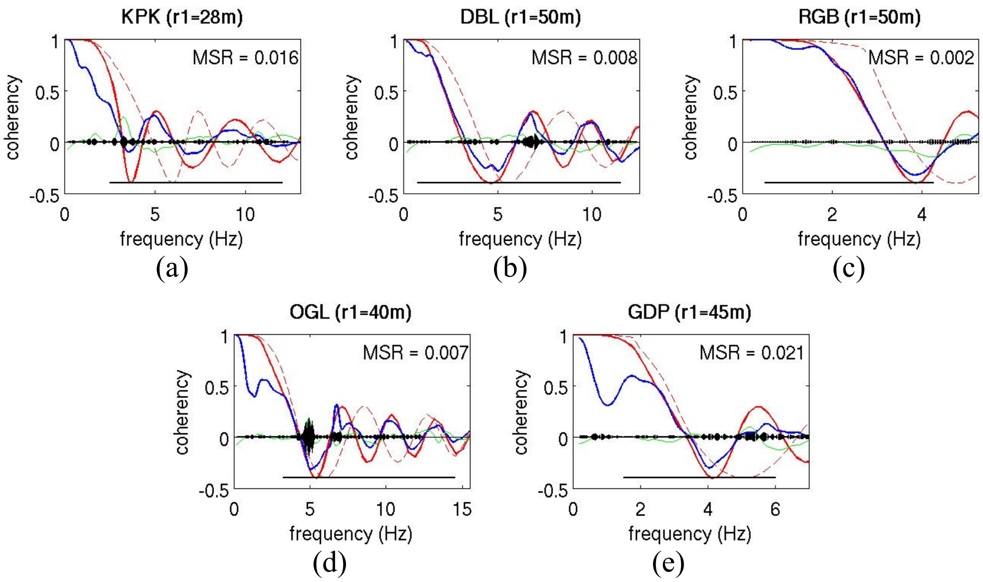


Figure 4. Observed coherency spectrum (COH) at sites (a) KPK, (b) DBL, (c) RGB, (d) OGL, and (e) GDP during 2007 field survey with centred triangular arrays. Same legend as Figure 3.

3.3 SPAC Observations outside Tamar Valley

Coherency spectra recorded at two additional sites during the 2006 field survey, west (site CSR) and east (site WHR) of the Tamar Valley, are presented in Figure 5.

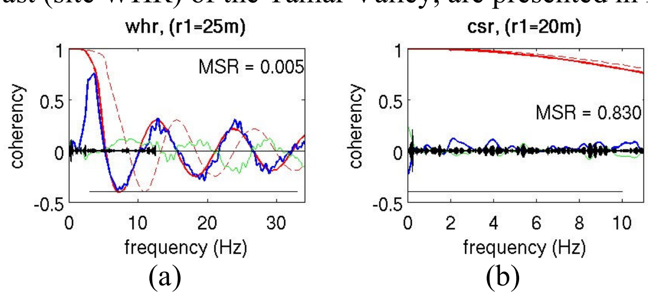


Figure 5. Observed coherency spectrum (COH) at sites (a) WHR and (b) CSR during 2006 field survey with centred hexagonal array. Same legend as Figure 3.

The fit at site WHR is excellent (MSR_{WHR} = 0.005) over an extended range of frequency (3 – 33Hz), which suggests good confidence in the SWV interpreted. However, poor agreement between the expected and observed frequencies of resonance at site WHR leads to contradictory conclusions concerning the depth to the bedrock interface at site WHR. The low level of microtremor energy at site CSR suggests the bedrock is outcropping at this site, which was expected from the surface geology map

(Figure 1) and the geographical location of site CSR, on significantly higher grounds than the Central Business District of Launceston.

4. SHEAR WAVE VELOCITY PROFILES

The preferred shear wave velocity profiles, interpreted by fitting the observed and theoretical coherency spectra at all ten sites (Figures 3 to 5), are presented in Figure 6. HVSR observations recorded at the centre of each array were used to constrain or validate the depth to bedrock at most sites.

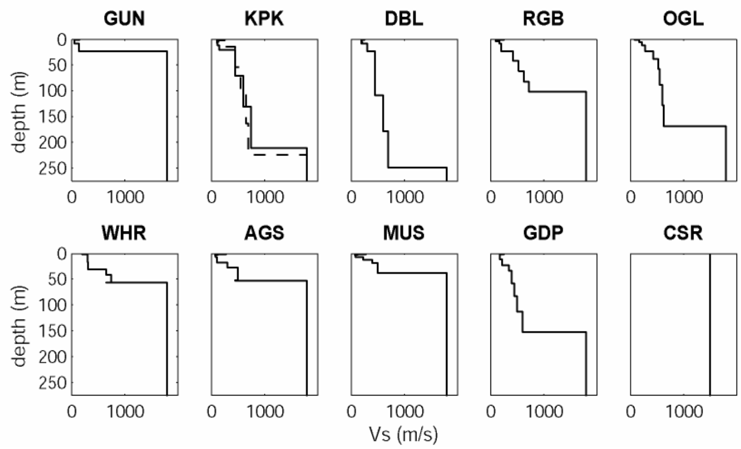


Figure 6. Preferred shear wave velocity (SWV) profiles at all ten sites in Launceston from interpretation of SPAC observations. Dashed SWV profile at site KPK is obtained from 100m radius centred triangular arrays (not presented).

While poor resolution from microtremor observations limits the interpretation at sites presented in the bottom row of Figure 6, the SWV structures interpreted at all ten sites, however, still clearly demonstrate the variability in geology in and around the Tamar Valley in Launceston. The ten sites investigated in Launceston are all located within a two kilometre radius from the city centre. SWV profiles presented in Figure 6 express the extreme variability of the geology at Launceston where the depth to bedrock interface varies from 250m at site DBL to 0m (outcropping) at site CSR.

5. RESONANCE IN LAUNCESTON

Horizontal to Vertical Spectrum Ratios (Nakamura, 1989) are recorded at the centre of each array to evaluate the frequency of resonance in and around the Tamar Valley in Launceston, and to compare with the Rayleigh wave ellipticity curves computed from the preferred SWV profiles interpreted from SPAC observations. HVSR profiles presented in Figure 7 outline the significant variations in the frequency of resonance within the city of Launceston. While the frequency of resonance evaluated from HVSR observations agrees with the expected frequency of resonance computed from the preferred SWV profile at some sites (GUN, MUS, AGS, RGB, OGL), it does not agree at the remaining sites. Claprood and Asten (2008) suggested a 2D pattern of resonance develops across the Tamar Valley and shift the frequency of resonance to higher frequency at sites DBL and KPK, hypothesis further supported by numerical simulations (Claprood et al, 2009b).

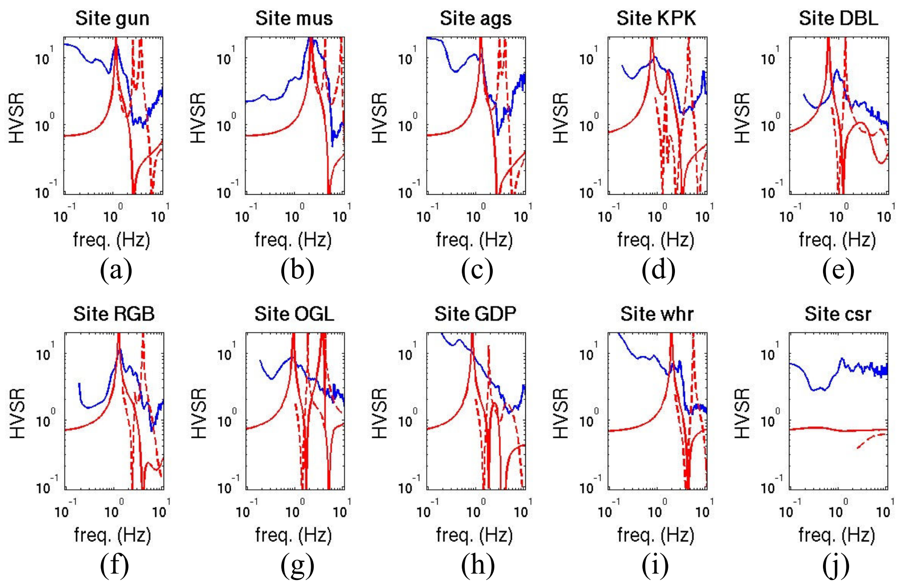


Figure 7. HVSR profiles at all ten sites. Blue curves: Observed HVSR at centre sensor of all arrays. Red curves: Rayleigh wave ellipticity curves computed from preferred shear wave velocity profiles interpreted from SPAC observations, fundamental (solid) and first higher (dashed) modes.

6. CONCLUSION

Microtremor observations recorded at ten separate sites in Launceston outline the rapid variations in geology with location in the city. The interpretation of single station HVSR and array-based SPAC microtremor observations agree at most sites in Launceston, suggesting both methods are effective at conducting site resonance studies over layered geology (Inveresk, Figure 1). The disagreement between SPAC and HVSR observations at some sites within the Tamar Valley suggest the importance to consider local geology effects when conducting site resonance studies in complex geology environments, as misleading conclusions can be made when using the approximation of a layered earth geology.

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