Microtremor survey methods in the Tamar Valley, Launceston, Tasmania: Evidence of 2D resonance from microtremor observations.

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Abstract

We use the microtremor survey method to record ambient ground vibrations in Launceston, Tasmania. The presence of the Tertiary-age Tamar rift Valley, in-filled with soft sediments that vary rapidly in thickness from 0 to 250m over a few hundreds of meters, is thought to induce a 2D resonance pattern, amplifying the surface motions over the valley and in the urban area of Launceston. We combine the observations from the spatially averaged coherency (SPAC), and the horizontal to vertical spectrum ratio (HVSR) microtremor survey methods to identify and characterise site effects over the Tamar Valley.

We record array microtremor measurements (SPAC) to estimate the shear wave velocity profile at separate sites. Results show that sediment thicknesses vary significantly throughout Launceston. The top layer is composed of as much as 20m of very soft Quaternary alluvial sediments with a shear wave velocity from 50m/s to 125m/s. Velocities in the deeper Tertiary sediment fill of the Tamar valley, with thicknesses from 0 to 250m, vary from 400m/s to 750m/s. We present observations at 3 selected sites to study the resonance pattern. Two of these sites (*DBL* and *KPK*) are located inside the Tamar valley, while the third site (*GUN*) is located on assumed 1D geology. We decompose HVSR observations into axial and transverse components to the valley axis to identify the different modes of resonance of surface waves. At both *KPK* and *DBL* sites, we clearly differentiate the in-plane (*SV*) and anti-plane (*SH*) modes of resonance. This decomposition is not observed at *GUN*, where HVSR observations show a single peak at the frequency of resonance of a layered earth.

Keywords: microtremor, shear wave velocity profile, frequency of resonance, 2D resonance pattern.

1. INTRODUCTION

The microtremor survey method is traditionally used to evaluate the shear wave velocity (SWV) profile and the frequency of resonance of a site, with the imposed condition of a layered geology. An intricate pattern of resonance develops over complex geology and the hypothesis of a layered geology required for the use of traditional microtremor survey methods is no longer valid. The geology of Launceston is known to be quite complex, with the presence of the Tamar rift valley traversing the city in the NNW-SSE direction, in-filled with soft sediments from the Tertiary and Quaternary periods (Leaman, 1994).

We first combine information from a gravity survey (Leaman, 1994) and spatially averaged coherency (SPAC) microtremor observations from two field surveys in 2006 and 2007 to evaluate the SWV profiles at 3 separate sites in the city of Launceston (Figure 1).

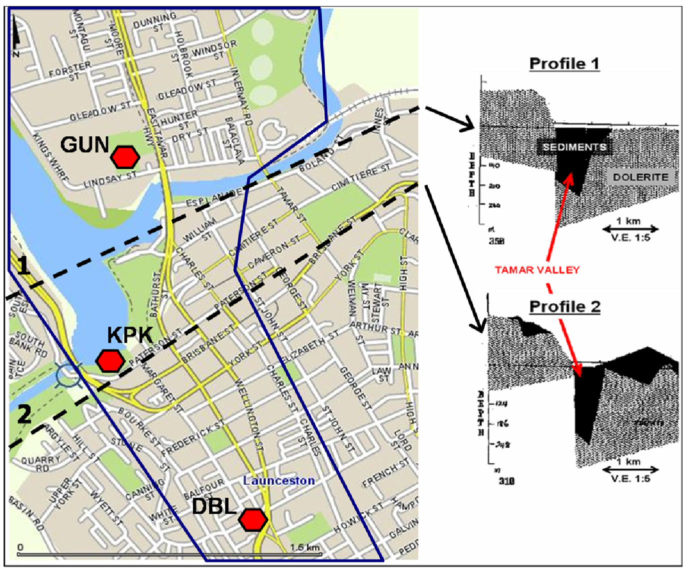

Figure 1. Left panel: Central Business District of Launceston, location of 3 sites of microtremor observations. Blue lines are the approximate outline of the Tamar valley. Right panel: Two gravity profiles from Leaman (1994).

The site *GUN* is allegedly located over a layered geology and is used as a reference site for the microtremor survey method. Using the information available from the gravity survey, we assume the sites *KPK* and *DBL* are located in the Tamar valley, where a 2D resonance pattern is expected to develop. In previous study, Claprood and Asten (2007) suggested the presence of 2D effects from microtremor observations. With the acquisition of lower frequency microtremor observations from the 2007 field survey, improving resolution at depth, we can identify the different modes of resonance developing in the Tamar valley.

We use the SWV profiles to calculate an expected frequency of resonance at the three sites *GUN*, *KPK*, and *DBL* which would develop assuming a layered geology. Following the research of Bard and Bouchon (1985) on the propagation of surface waves across 2D valleys, we then compute the expected shifts in frequency for the different modes of resonance which would develop in the Tamar valley. We finally compare horizontal to vertical spectrum ratio (HVSR) microtremor observations with the expected frequencies of resonance computed from Bard and Bouchon’s model, using a methodology similar to Roten et al (2006).

2. SHEAR WAVE VELOCITY PROFILES

We use microtremor observations recorded during the 2006 and 2007 field surveys to evaluate the shear wave velocity profiles at Launceston, using the spatially averaged coherency (SPAC) method developed by Aki (1957). Microtremors recorded in 2006 were obtained with a centred hexagonal array of 7 Mark L28 - 4.5Hz geophones, while those recorded during the 2007 field survey were acquired with a centred triangular array of 4 Guralp CMG-3ESP – 0.0167Hz and 0.033Hz geophones for improved resolution at depth. We evaluate the shear wave velocity profile at every site separately for each SPAC array. We then combine the information obtained from all arrays to obtain the preferred SWV profile for every site, presented in Figure 2. We directly fit the coherency curves to the appropriate Bessel function by iterative forward modelling (Hermann, 2002) to obtain the SWV profiles as described in Claprood and Asten (2007), Asten (2006), and Asten et al (2004).

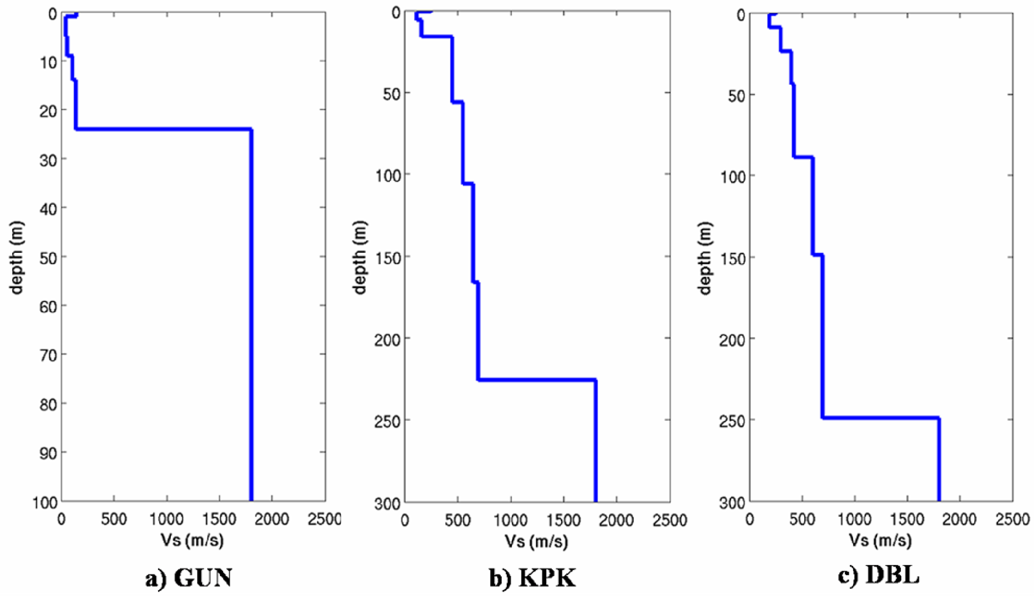

Figure 2. Shear wave velocity profiles at three separate sites a) GUN, b) KPK, and c) DBL. Important to note the scale difference in the depth axis for site *GUN* compared to sites *KPK* and *DBL*.

The preferred SWV profile at *GUN* suggests a shallow bedrock interface at approximately 25m, with sediments composed of a thin layer of filling, underlain by 10m of very low velocity (as low as 50m/s) alluvial sediments (clay and silt). 10m of more coherent silty clay to clayey sand is found between the alluvial sediments and the dolerite bedrock. Information from nearby borehole logs confirms SPAC interpretation.

At site *KPK*, we interpret the upper layers as being composed of clay and silt from the Quaternary period. They are underlain by a thick layer of low velocity (450-700m/s) sands from the Tertiary period. Two triangular SPAC arrays of 100m radius were used to locate the deep interface between the tertiary sediments and the dolerite, which is evaluated at 225m. This agrees well with the gravity survey from Leaman (1994) which suggested a maximum sediment thickness of 250m.

At site *DBL*, we interpret the top 9m as low-velocity alluvial sediments (v_s=170 to 210m/s). It is underlain by 15m of soft sediments of velocity 300m/s, and thick tertiary sediments (400 to 700m/s). The boundary between the tertiary sediments and the bedrock is not resolved by SPAC alone. Horizontal to vertical spectrum ratio microtremor measurements (Claprood and Asten, 2007), and gravity survey by Leaman (1994) suggest a deep bedrock interface (~250m).

3. RESONANCE AND SITE EFFECTS AT LAUNCESTON

3.1 HVSR Methodology

The horizontal to vertical spectrum ratio (HVSR), popularised by Nakamura (1989), is used to evaluate the frequency of resonance of a layered geology (f_h). In a layered medium, the HVSR peak is empirically found to be a reliable estimation of the Rayleigh wave's ellipticity (Lachet and Bard, 1994; Tokimatsu, 1997; Scherbaum et al, 2003). HVSR provides a good estimate of the natural frequency of resonance of layered sediments.

We model the particle motion of the Rayleigh waves (R_o for fundamental mode), using the SWV profiles interpreted by SPAC and presented in Figure 2. This elliptical motion is proportional to the wave frequency and the elastic parameters of the earth. It tends to degenerate into a dominantly horizontal motion at the frequency of resonance (Asten et al, 2002). The peak on Rayleigh wave's ellipticity is used to determine the frequency of resonance of a layered site (Tokimatsu, 1997).

An intricate pattern of resonance develops across a valley in-filled with low velocity sediments. Waves bounce back and forth from the edges of the valley, creating interference and inducing a pattern of resonance different than expected over a layered geology. Different modes of resonance develop in a valley, shifting the frequency of resonance to higher frequencies when compared to its equivalent layered geology. Bard and Bouchon (1985) recognised the SH mode of resonance excited by the axial component of horizontal motion (parallel to the valley axis), and the SV and P modes of resonance excited by the transverse component of horizontal motion (perpendicular to the valley axis) together with the vertical component of motion. Field (1996) refers to the axial and transverse components as the parallel and perpendicular components relative to the valley axis. When decomposing the horizontal component of microtremor energy into the axial and transverse components relative to the valley axis, we can detect the SH and SV modes of resonance at the frequencies:

$$f_{mn}^{SH} = f_h \sqrt{(2m+1)^2 + (n+1)^2 \frac{h^2}{w^2}}, \tag{1}$$

$$f_{fund}^{SV} = f_h \sqrt{1 + \left(\frac{2.9h}{w}\right)^2}, \tag{2}$$

where f_h is the frequency of resonance of an equivalent layered earth, m and n are the number of nodes in the vertical and horizontal standing modes respectively, h is the depth of the basin, and w is the half-width of the basin. The basin half-width w is defined as the length over which the local sediment thickness is greater than half the maximum thickness (Steimen et al, 2003).

At each of the sites *GUN*, *KPK*, and *DBL*, we decompose the horizontal component of microtremor energy into axial and transverse components relative to the valley axis. We define the axial-HVSR as the ratio of the axial component of horizontal microtremor spectrum to the vertical microtremor spectrum; and the transverse-HVSR as the ratio of the transverse component of horizontal microtremor spectrum to the vertical microtremor spectrum.

We calculate the frequency of resonance f_h for the equivalent layered geology at all three sites from the SWV profiles displayed in Figure 2. At sites *KPK* and *DBL*, we then use equations (1) and (2) to compute the frequencies of resonance f^{SH} and f^{SV} expected to develop in the Tamar valley. Figure 3 presents a schematic of the sine-shaped valley and its equivalent layered earth. We then evaluate the axial-HVSR and transverse-HVSR at sites *GUN*, *KPK*, and *DBL* to identify the mode(s) of resonance (f_h, f^{SH}, f^{SV}) from microtremor observations at all three sites in Launceston.

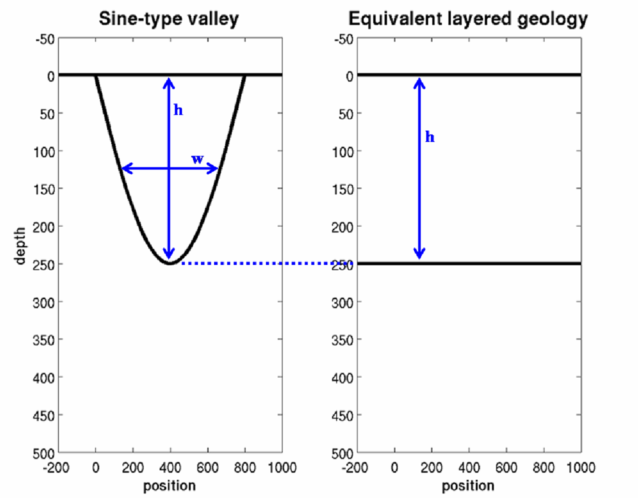

Figure 3. Sine-shaped valley and its equivalent layered geology.

3.2 HVSR Observations at Launceston

We present in Figure 4 the observed horizontal to vertical spectrum ratios recorded at sites *GUN*, *KPK*, and *DBL*. The ellipticity curves are computed from the SWV profiles obtained by SPAC (Figure 2).

3.2.1 Site GUN

The peaks on observed HVSR and modelled ellipticity curve agree well for *GUN*, with a frequency of resonance f_h = 1.08Hz. We note no significant difference between the axial-HVSR and the transverse-HVSR, both presenting a peak at the frequency of resonance evaluated by the modelled ellipticity. This suggests that HVSR can adequately estimate resonance pattern when using microtremor survey method over a layered geology.

3.2.2 Site KPK

We see discrepancies between the observed HVSR and the modelled ellipticity at site *KPK*. We observe different behaviours in the observed axial-HVSR and transverse-HVSR. The axial-HVSR peak is observed at approximately 0.90Hz, while the transverse-HVSR peak is observed at 1.16Hz, both at significantly higher frequency than the expected frequency of resonance computed on the modelled ellipticity (0.72Hz) assuming a layered geology.

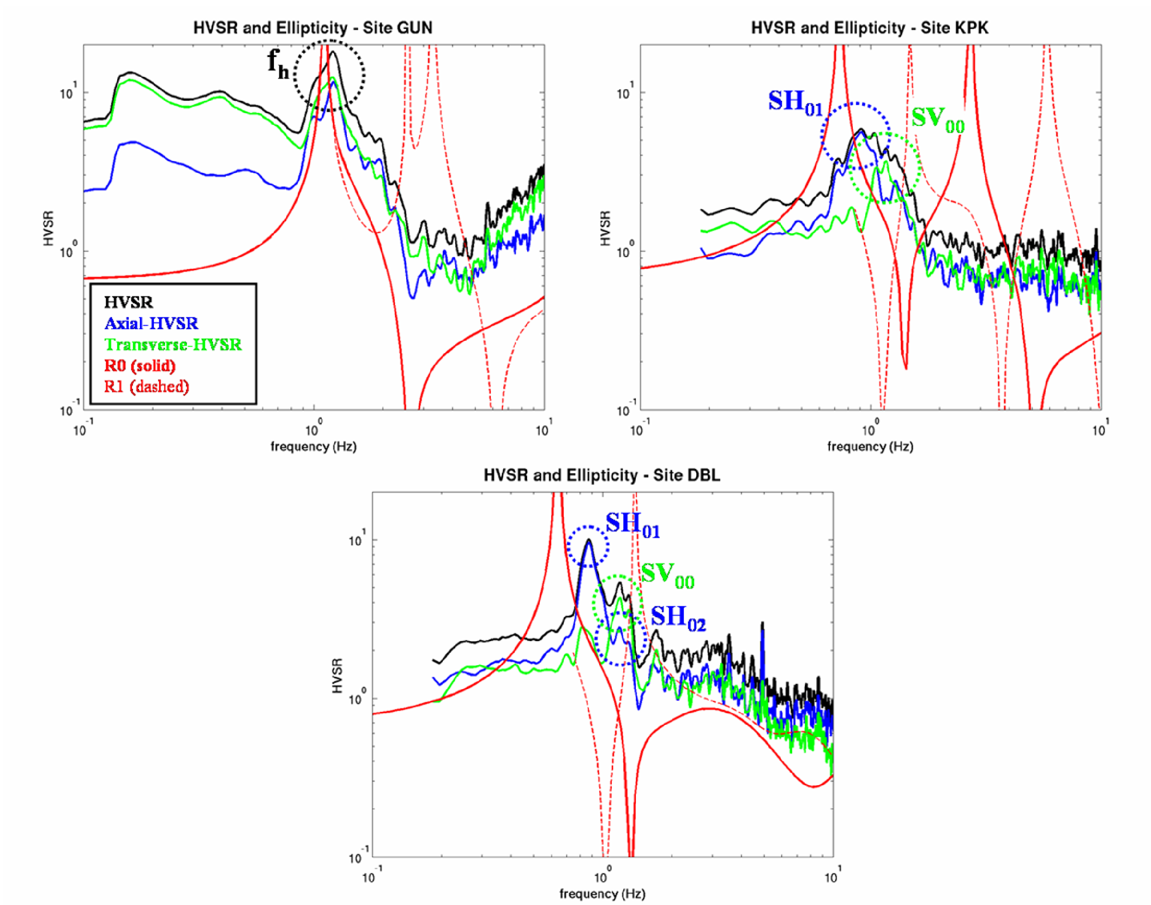

Figure 4. Observed HVSR at *GUN*, *KPK*, and *DBL* compared with modelled ellipticity from SWV profiles evaluated by SPAC. Black curves is total HVSR, blue curve is axial-HSVR, green curve is transverse-HVSR, solid thick red curve is fundamental ellipticity R_0, dashed red curve is first higher mode ellipticity R_1.

3.2.3 Site DBL

As observed at site *KPK*, there is a discrepancy between the observed HVSR and the modelled ellipticity site *DBL*. We again notice differences in behaviour between the axial-HVSR and transverse-HVSR. Two axial-HVSR peaks are observed at approximately 0.90Hz and 1.20Hz, while one transverse-HVSR peak is observed at 1.18Hz. Both peaks are located at significantly higher frequency than the expected frequency of resonance computed on the modelled ellipticity (0.63Hz) assuming a layered geology.

We propose the hypothesis that 2D effects generated by the Tamar valley explain the higher than expected frequencies of resonance observed on microtremor observations at sites *KPK* and *DBL*. We compute the frequencies of resonance of the modes of resonance *SH* and *SV* using Bard and Bouchon's model (equations 1 and 2) from the modelled frequency of resonance f_h of their equivalent layered earth. The depth h and half-width w of the Tamar valley were obtained from SPAC observations and gravity survey from Leaman (1994). We present the modelled and observed frequencies of resonance obtained at all sites in Table 1.

Table 1. Modelled frequencies of resonance from ellipticity curves f_h for equivalent layered geology, corrected by Bard and Bouchon's model (SH_{mn}, SV_{00}) for a valley; and observed frequencies of resonance on HVSR at *GUN*, *KPK*, and *DBL*.

Mode of resonance	Modelled frequencies of resonance	Observed frequencies of resonance on HVSR
	GUN	
f_h	1.08 Hz	1.10 Hz
	KPK (h = 230m, w = 500m)	
f_h	0.72 Hz	Not observed
SH_{00}	0.79 Hz	Not observed
SH_{01}	0.98 Hz	0.90 Hz
SH_{02}	1.23 Hz	Not observed
SV_{00}	1.20 Hz	1.16 Hz
	DBL (h = 250m, w = 450m)	
f_h	0.63 Hz	Not observed
SH_{00}	0.72 Hz	Not observed
SH_{01}	0.94 Hz	0.90 Hz
SH_{02}	1.22 Hz	1.20 Hz
SV_{00}	1.19 Hz	1.18 Hz

We observe from Table 1 that the frequency of resonance evaluated by ellipticity at *GUN* agrees well with the frequency of resonance observed on HVSR. This is good indication the site *GUN* is located above a layered geology. We observe that the two peaks observed at site *KPK* on the axial-HVSR and transverse-HVSR agree well with the modes of resonance SH_{01} and SV_{00} calculated from equations 1 and 2 of Bard and Bouchon's model. Similarly, the observed axial-HVSR and transverse-HVSR peaks agree well with the modes of resonance SH_{01}, SH_{02}, and SV_{00} at site *DBL*. The use of different dimensions at *KPK* and *DBL* was suggested by the depth of the Tertiary sediments interface from SPAC analysis, and by the gravity survey from Leaman (1994) which indicate widening of the valley in the North (site *KPK*).

4. CONCLUSIONS

We demonstrate that the array microtremor survey method SPAC and the single station microtremor method HVSR can be combined to evaluate the frequencies of resonance developing over a layered earth and in a valley. Our results clearly demonstrate the observed HVSR peak agrees well with the modelled frequency of resonance computed on the ellipticity curve at site *GUN*, located on a layered geology. By decomposing the horizontal microtremor energy into its axial and transverse components to the valley axis, we show two HVSR curves from which we detect the modes of resonance *SH* and *SV* known to develop across a valley. Observations at sites *KPK* and *DBL* confirm the presence of a 2D resonance pattern in the Tamar valley, with the axial-HVSR and transverse-HVSR peaks agreeing well with the expected frequencies of resonance computed from Bard and Bouchon's model.

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