Development of a Waikato Basin T_0 and depth model by the H/V spectral ratio method

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Summary

This paper presents the development of a preliminary model of the fundamental site period (T_0) across the Waikato Basin using the Horizontal-to-vertical (H/V) spectral ratio technique. We measured the ambient vibration of the ground at over 100 sites across the Waikato Basin, and produced a T_0 map by spatially interpolating T_0 obtained by the H/V spectral ratio technique. The measured site periods were over 5 seconds near Te Rapa and Gordonton, suggesting a deep sedimentary basin. This finding is also consistent with previous studies. We also found that most parts of the Waikato Basin, except very near the basin edge, have fundamental site periods longer than 0.6s, which means they should be categorised as site class D at a minimum, according to NZS1170.5: 2004. More site-specific assessments of shear wave velocity profiles will be able to identify site class E locations. Using the depths to the greywacke basement obtained from the existing petroleum logs in the region, we established a fundamental site frequency-depth correlation.

Motivation

- Waikato is known to have a deep soft sedimentary basin, which will likely increase the regional seismic hazard, but the quantitative data required to model the basin response is lacking.
- Despite the relatively low regional seismicity, the impact of a future large earthquake in the Waikato region would be high, considering the region has a population of 460,000, the fourth largest regional economy in New Zealand (Stats NZ, 2017), and critical national infrastructure systems, such as the Waikato expressway, high-pressure gas pipes, and high-voltage transmission lines.
- The ground motion data recorded in Hamilton in the 2018 M6.2 Taumarunui Earthquake were strongly amplified compared with a nearby rock station (TOZ) in Morrinsville, which demonstrates the role of the soft sedimentary basin in amplifying the observed ground motion.

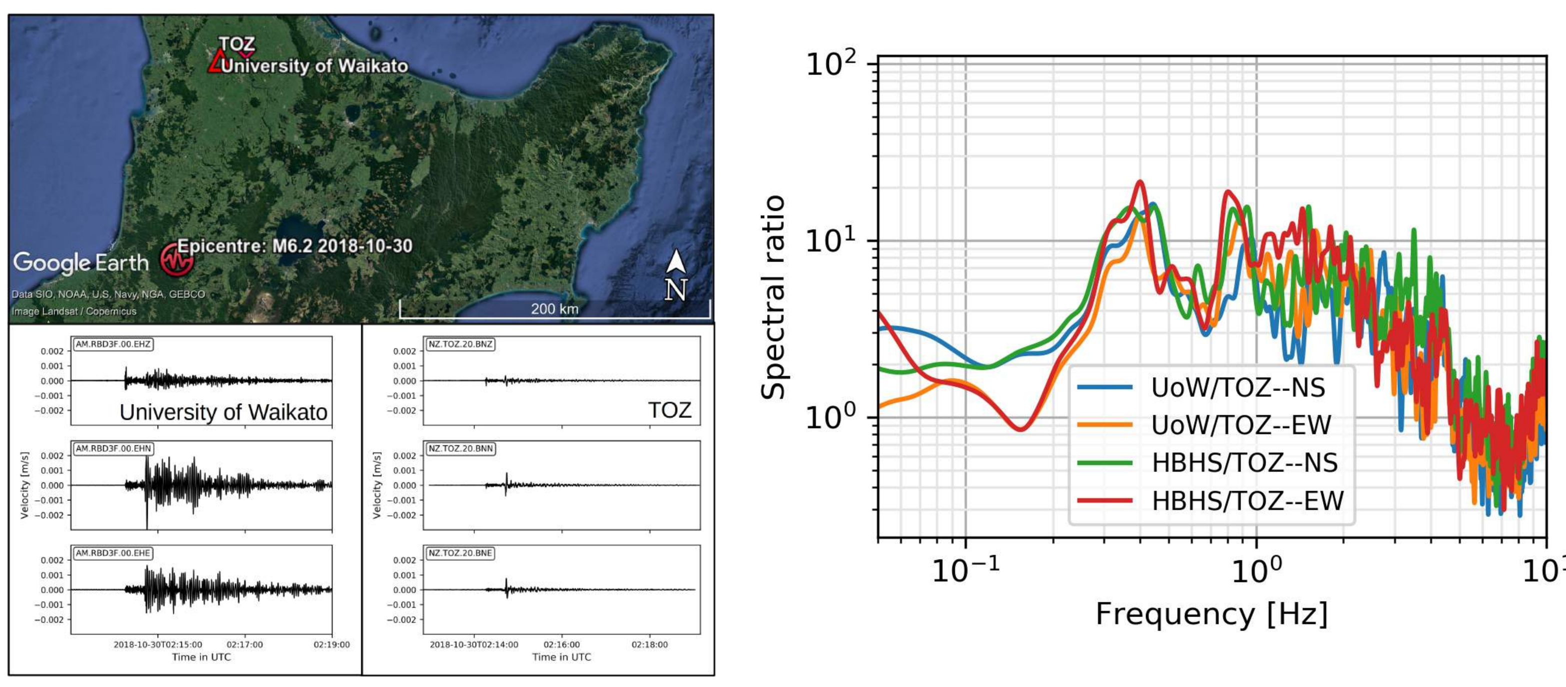

Figure 1: Comparision of ground motion recorded in Hamilton (UoW and HBHS; soft sites) and in Morrinsville (TOZ; a rock site), in time and frequency-domain.

H/V spectral ratios

- Ambient vibration data were processed using Geopsy (www.geopsy.org), to compute the H/V spectral ratios (Nakamura, 1989), which is known to have the fundamental mode frequency consistent with the 1D response function of the site.
- The majority of sites show a very clear fundamental mode peak with a large amplitude, indicative of a large impedance contrast. Also, in most cases, the lowest frequency (longest period) peak in the H/V ratio showed the largest amplitude. The lowest frequency peaks in the H/V spectral ratios likely correspond to fundamental mode vibration of the entire soil profile down to the basement rock (greywacke).
- H/V spectral ratios at some sites also feature multiple H/V peaks, and there are a few possible situations in the Waikato region for such multiple peaks in the H/V ratio, such as the impedance contrast between the Tauranga Group and the Waitemata Group or the impedance contrast between the Pirongia volcanic formation and the younger quaternary sediments.
- To create a map of T_0 across the Waikato Basin, we spatially interpolated the fundamental period of tested sites using the Natural Neighbor algorithm (Sibson, 1981).

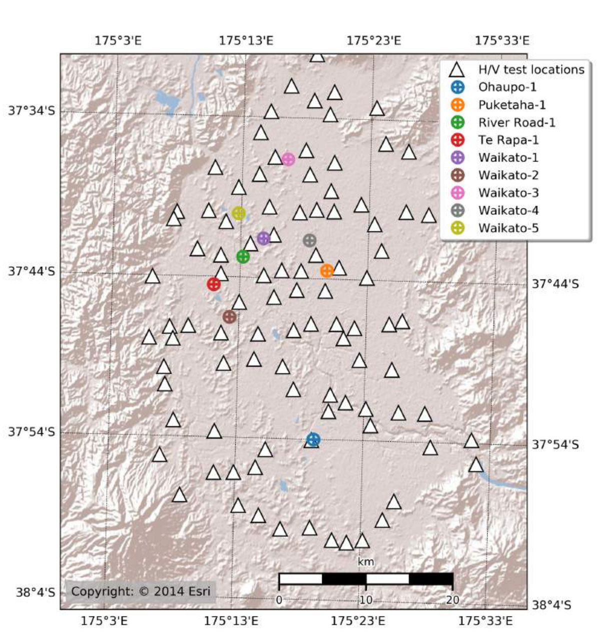

Figure 2: Shaded relief map showing the extent of the Waikato basin. Sun cross symbols show the locations of the petroleum exploration boreholes and the H/V test sites are marked with triangles.

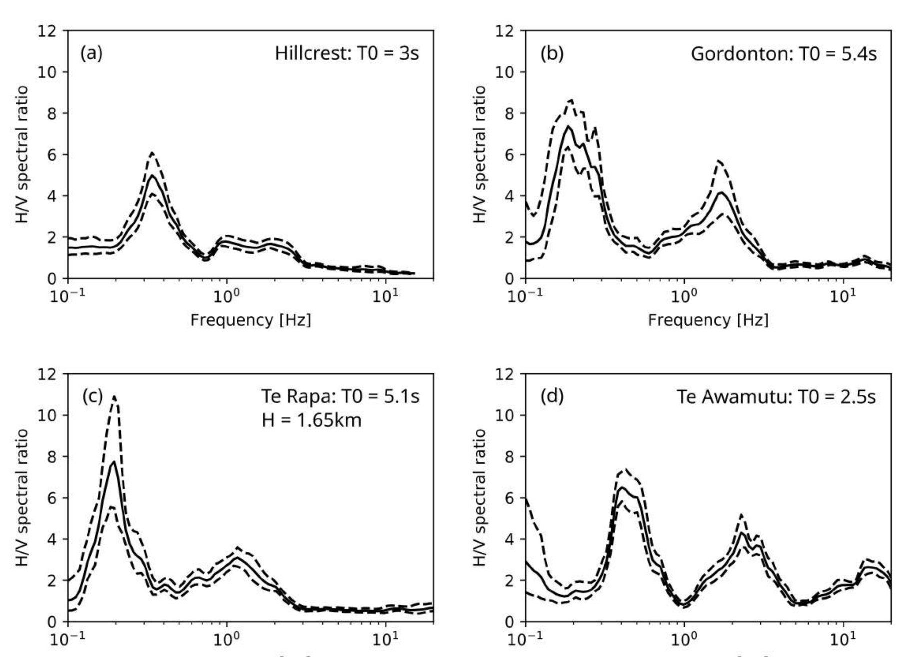

Figure 3: Examples of H/V spectral ratios obtained in the Waikato Basin. Nearly all sites show a clear fundamental mode of vibration with large amplitude ratios.

T_0 model for the Waikato basin

- Over 100 tests were conducted around the Waikato basin. The white triangles in Figure 4 mark those locations. Also shown in the figure are the locations of existing petroleum logs (www.nzpam.govt.nz), at which the depths to the greywacke basement is known.
- We found that the site periods in the basin is as long as 5.4 seconds. The longest periods were found near Te rapa, north-west of Hamilton and near Gordonton to the north-east; we also found that the site periods change rapidly near the areas of longest site periods.
- According to the New Zealand structural design standard for earthquake actions (NZS1170.5: 2004), the majority of the Waikato basin is classified as the site class D.

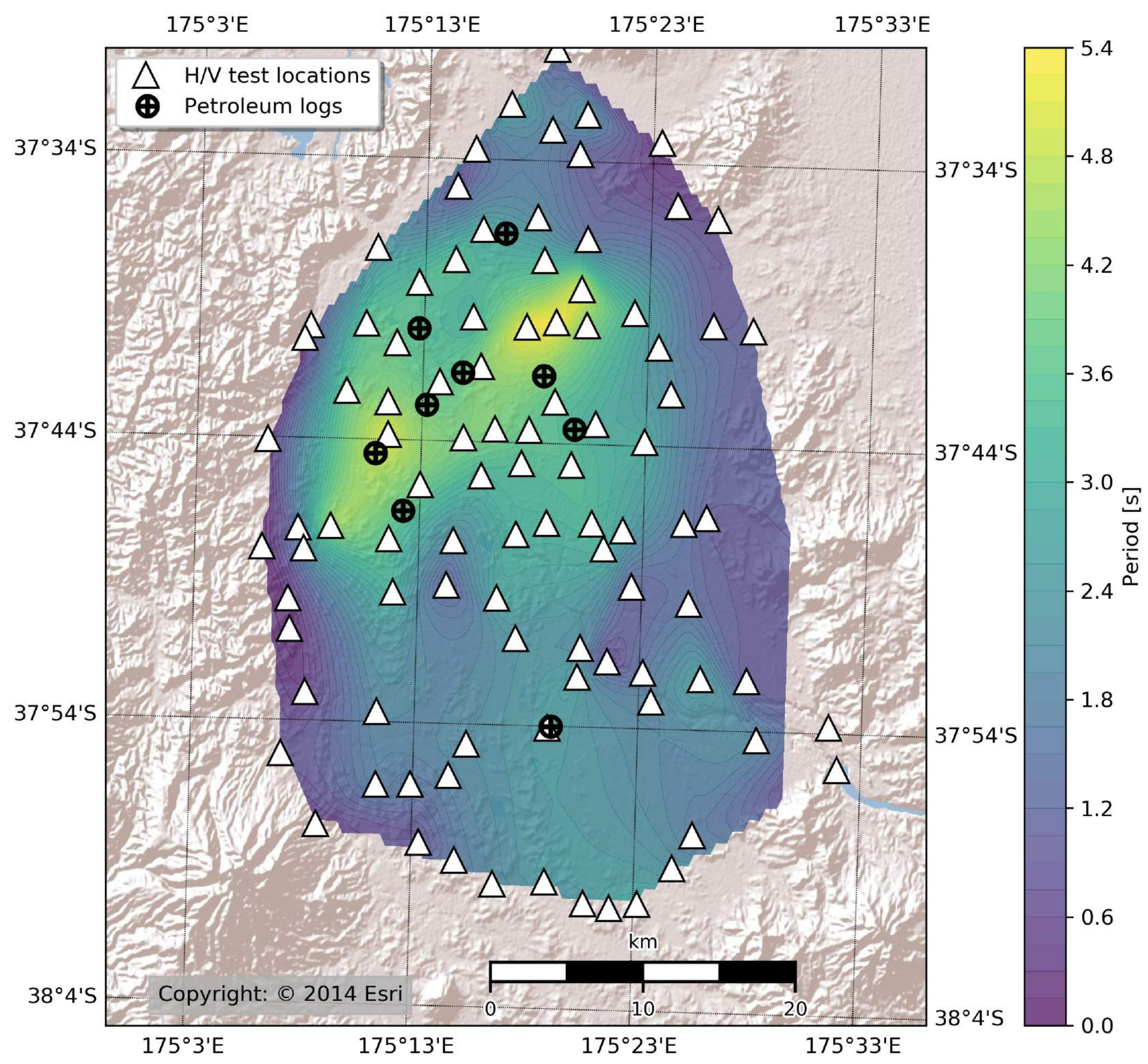

Figure 4: T_0 model of the Waikato basin developed by spatially interpolating the fundamental site periods obtained from the H/V spectral ratios.

Depth - f_0 correlation

- Using the H/V test data and the basin depth obtained by the previous petroleum logs, we developed an empirical model to predict the basin depth, H, as shown in Figure 5.
- We compared our model with two overseas studies (Parolai et al., 2002; Ibs-von Seht and Wohlenberg, 1999). We found that both of the overseas models are somewhat consistent with our data, but Parolai's model is more similar to the model we derived.
- All of the observed basin depths (from petroleum logs) used in our regression analysis are deeper than 250m, meaning that the current model is not well constrained where the basin is shallower than 250m.

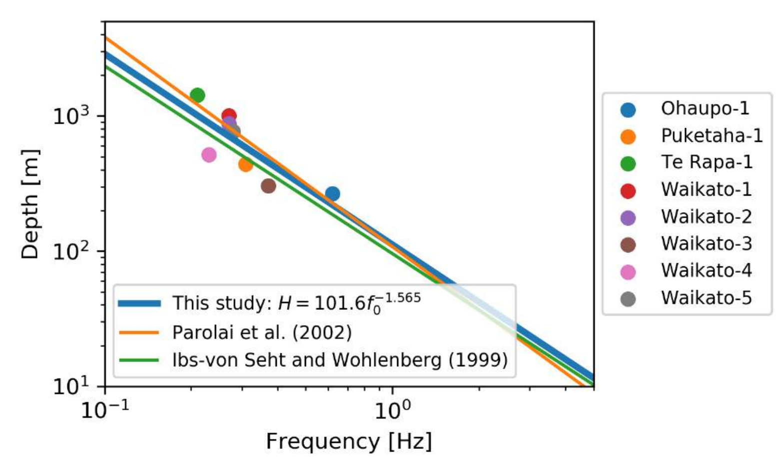

Figure 5: H-f_0 model developed using the measured f_0 and H.

Table 1: Thickness and depths from the ground surface to the base of stratigraphic groups found in Waikato Basin petroleum boreholes, modified from Edbrooke et al., (2009). NP stands for 'not present'.

Name	Tauranga Group Thickness, H_{TG} (m)	Waitemata Group Thickness, H_{WG} (m)	Te Kuiti Group Thickness, H_{TKG} (m)	Total depth to basement, H_T (m)	H_{TG}/H_T
Puketaha-1	439	NP	NP	439	1.0
Te Rapa-1	610	829	210	1649	0.37
Waikato-1	485	510	30	1025	0.47
Waikato-2	453	437	125	1015	0.45
Waikato-3	200	104	NP	304	0.66
Waikato-4	518	NP	42	560	0.93
Waikato-5	265	512	228	1005	0.26

Key findings

- During the 2018 Taumarunui earthquake, two separate stations closely located in Hamilton recorded significant differences in ground shaking. This is likely due to the amplification and reverberation caused by the response of the sedimentary basin.
- Near Te Rapa and Gordonton the site periods were over 5 seconds. It is expected that those are the points where the basement rock is deepest; we also found that most sites in the Waikato basin should be categorised as the site class D at a minimum, according to the NZS1170.5: 2004.
- We developed an empirical model, which estimates the bedrock depth using the obtained fundamental site frequency.

Acknowledgements

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