Dynamic site characterisation of the Hawke's Bay sedimentary basin using H/V and surface wave methods

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Summary

The Hawke's Bay region is subject to relatively high levels of seismicity, as evidenced by several large historical earthquakes. The most populated areas within the region have been founded upon a deep, soft sedimentary basin, which increases potential for ground motion amplification. To improve understanding of these basin effects and characterise the local soils, a seismic field testing programme was undertaken in the region. At 120+ sites, the horizontal-to-vertical spectral ratio (H/V) method was used to develop a map of fundamental site period (T_0) across the Hawke's Bay region. Surface wave (SW) testing methods were used to characterise the shear wave velocity (V_S) of the local soils. This new knowledge will inform regional seismic hazard studies and improve estimates of the level of damage across the region for a range of earthquake scenarios.

Background

- Hawke's Bay is a region of high seismicity, due to the presence of several nearby faults, including the offshore Hikurangi Margin.
- Several historical earthquake events with severe shaking have been noted in the region, such as the M_W7.9 1931 Hawke's Bay earthquake, which remains one of Aotearoa New Zealand's worst natural disasters; killing 256 people, injuring thousands more, and devastating the cities of Napier and Hastings.
- Much of the Napier and Hastings urban area lies upon the Heretaunga Plains sedimentary basin, which consists of thick deposits of Quaternary sediments.
- The dynamic response of soils in sedimentary basins are known to amplify ground motions and prolong shaking due to the entrapment and amplification of seismic waves and the generation of localised surface waves within the basin.

Experimental Methods

The H/V spectral ratio method was used to estimate the T_0 at 120+ sites on the Heretaunga Plains. Additionally, a combination of active and passive surface wave testing methods were used to develop deep V_S profiles at a farm site in Meeanee, just south of Napier. The testing locations are shown in Fig. 1.

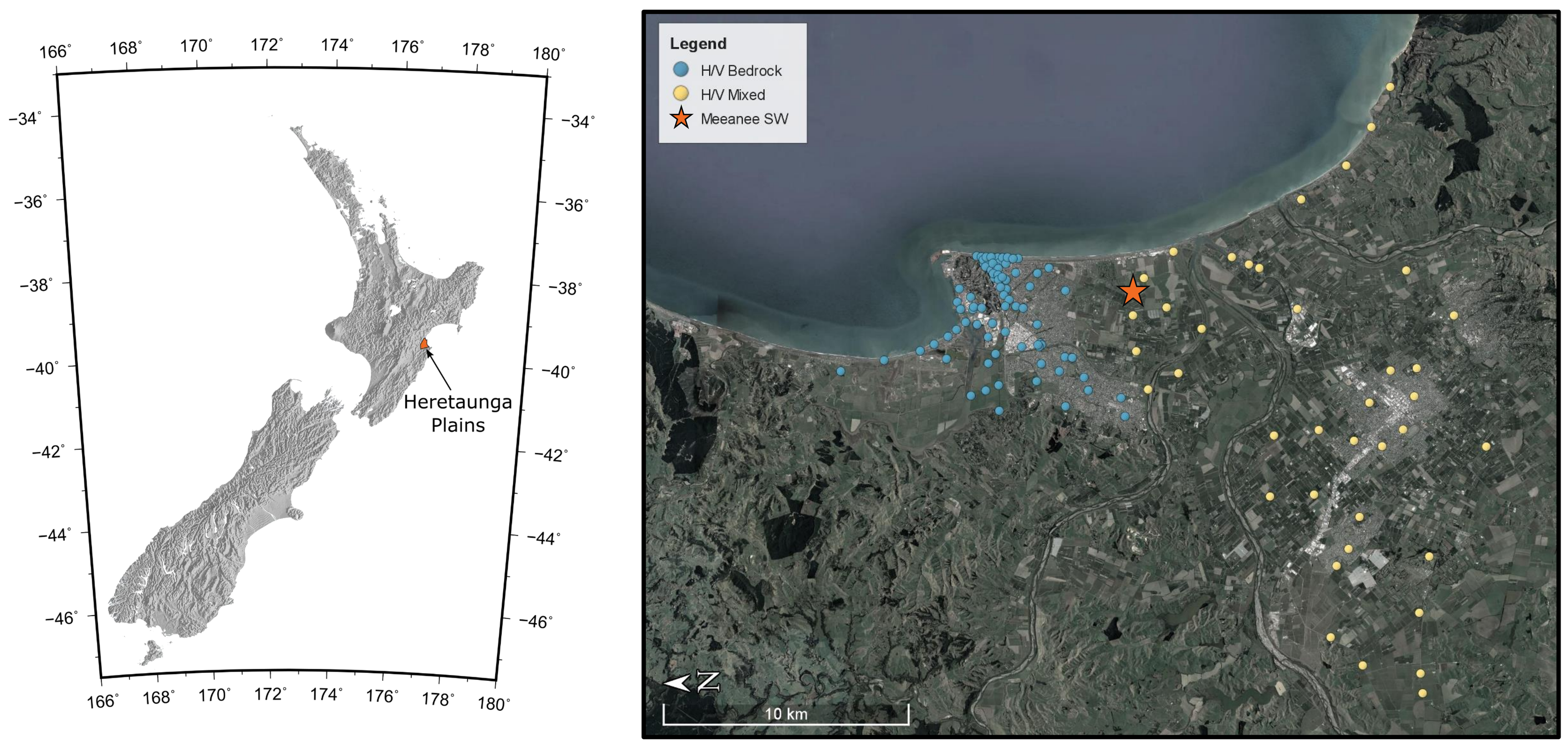

Figure 1: (left) Location of the Heretaunga Plains (Hawke's Bay) in New Zealand (right) H/V and SW testing locations on the Heretaunga Plains

H/V testing: Ambient vibration records were collected using three-component broadband seismometers and sampled at 100 Hz. Record lengths were varied depending upon anticipated depth of the sedimentary basin. At locations near hills, the record length was 30 min. In the middle of the basin, the records were at least 60 min long. The records were broken into 60 to 180 sec long windows and transformed into the frequency domain. Peaks in the H/V spectral ratio data were related back to geologic knowledge of the region and used to infer the site periods associated with different impedance contrasts (e.g., bedrock).

Surface wave testing: Data from active- and passive-source SW testing methods were to develop a combined experimental Raleigh-wave dispersion curve (DC). The geometry of the sensor arrays is shown in Fig. 2

Active-source:

- Linear array of 24 4.5-Hz vertical geophones spaced 2 m apart
- 12 lbs (5.44 kg) sledgehammer source at 5, 10, and 20 m offsets

Passive-source:

- Three circular arrays (50, 200, and 500 m diameter) of eight broadband seismometers
- Ambient vibration record lengths of 30, 60, and 60 minutes, respectively

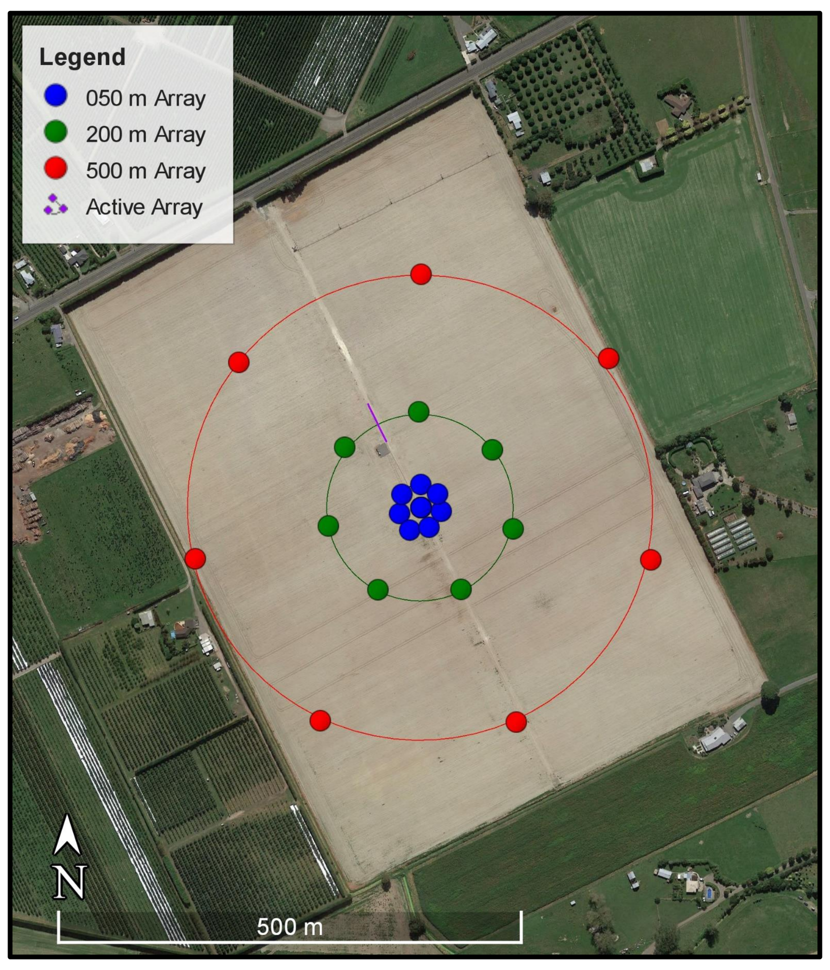

Figure 2: SW testing array geometry at Meeanee site

Results and Discussion

H/V testing: The majority of sites had a single peak in the H/V data, however, the impedance contrast that this peak represented varied across the region. In some areas, this peak likely represented the impedance contrast between the base of the soil profile and the basement rock (Fig. 3a). In other areas, where a softer surface layer was present, this peak represented a shallow impedance contrast (Fig. 3b) of a soft layer overlying a stiffer layer (e.g., gravel)

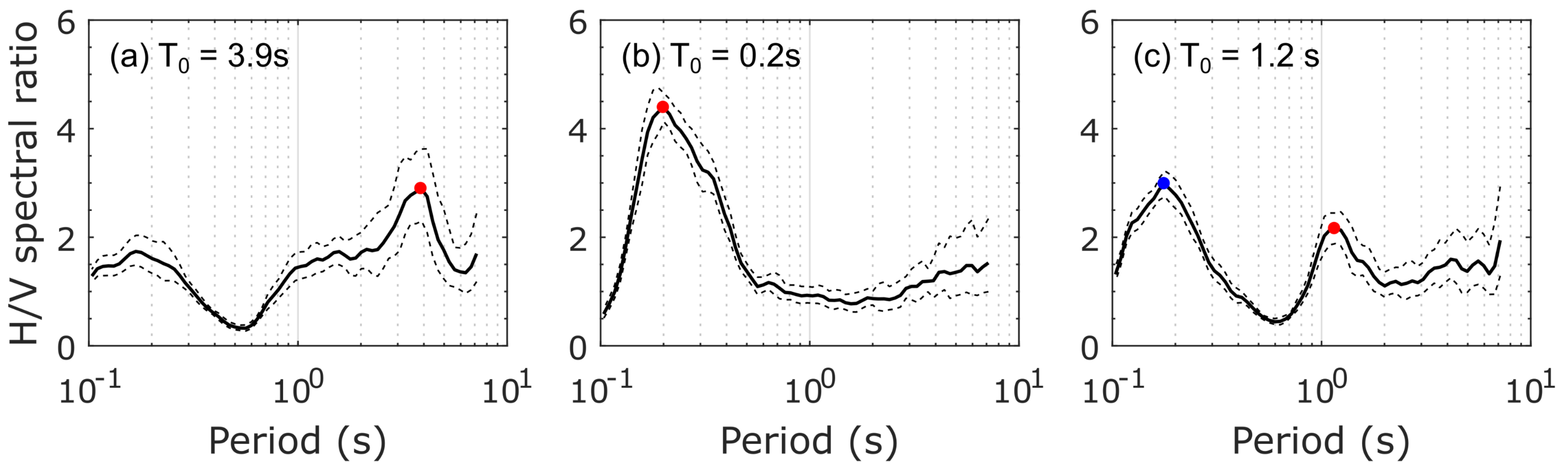

Figure 3: H/V spectral ratios from example sites representative of (a) deep, (b) shallow and (c) multiple impedance contrasts. T_0 is indicated by the red circle.

The H/V peaks at sites near Napier (Fig. 4a) were likely representative of the T_0 of the soil profile to bedrock and are the focus of this discussion. The variation in T_0 estimates aligned well with the topography. Locations more than a few hundred metres away from the base of Bluff Hill and/or the surrounding hills have T_0 greater than 0.6 sec and, at a minimum, would be classified as site class D in accordance with NZS1170.5:2004, as indicated in Fig. 4b by red circles.

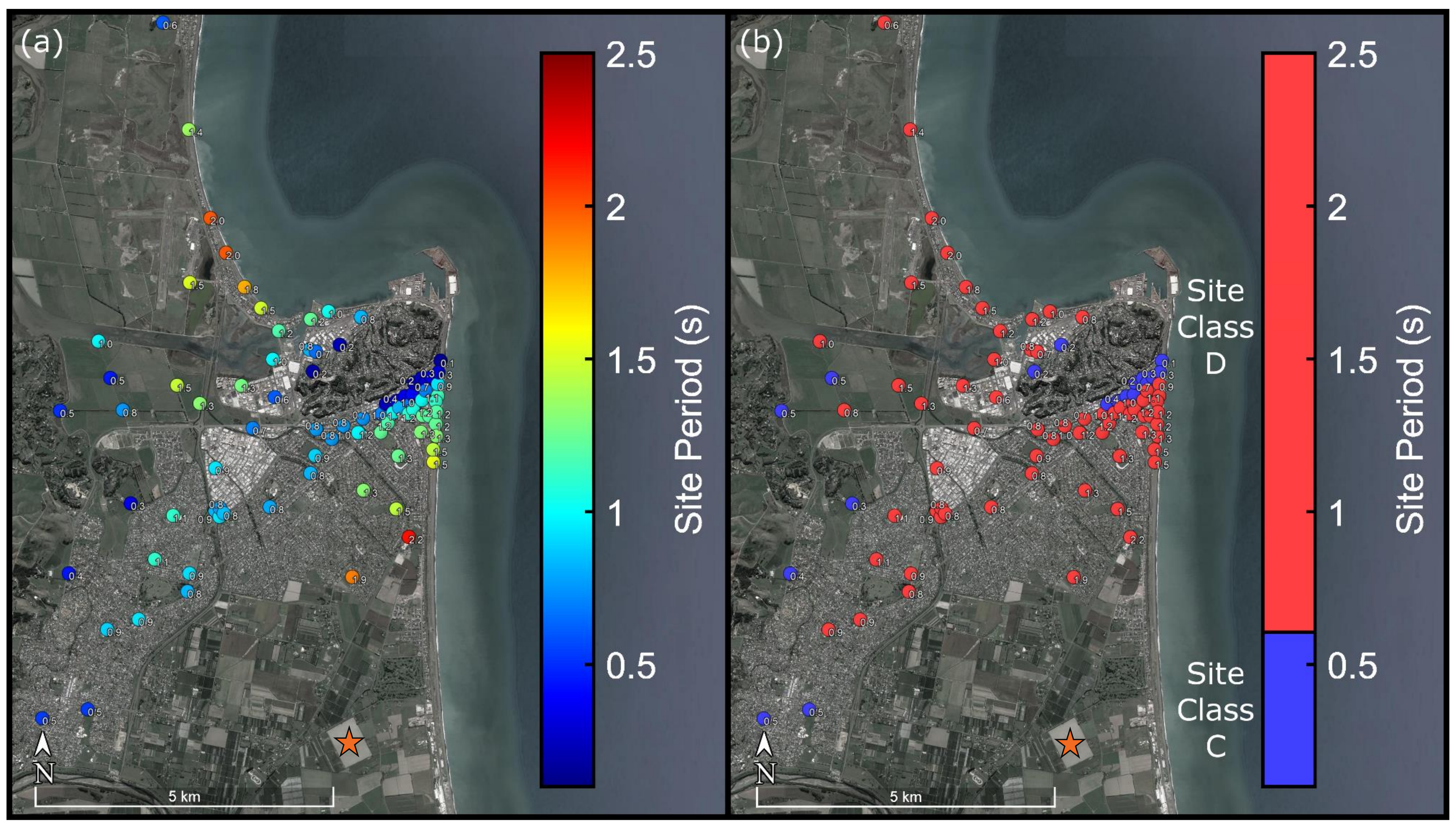

Figure 4: Map of T_0 in Napier area with point colour indicating (a) site period and (b) NZS 1170-5 Site Class C or D. The location of the Meeanee surface wave testing site is indicated by the star-shaped marker

Surface wave testing: 310,000 ground models were considered in the SW inversion. For each ground model, a DC was forward modeled and compared to the experimental DC. The 100 ground models with the lowest misfit to the experimental data are summarized in Fig. 5. In Fig. 5a, each of 100 theoretical DCs fall with in the uncertainty bounds of the experimental DC.

The V_S profiles (Fig. 5b) indicate that the near-surface soils are soft, consistent with a regularly tilled farm field. The soft soils are underlain by approx. 50 metres of stiffer soils and hundreds of metres of stiff-soil/soft-rock. Bedrock is approx. 500 m below the ground surface, as indicated by the increased V_S.

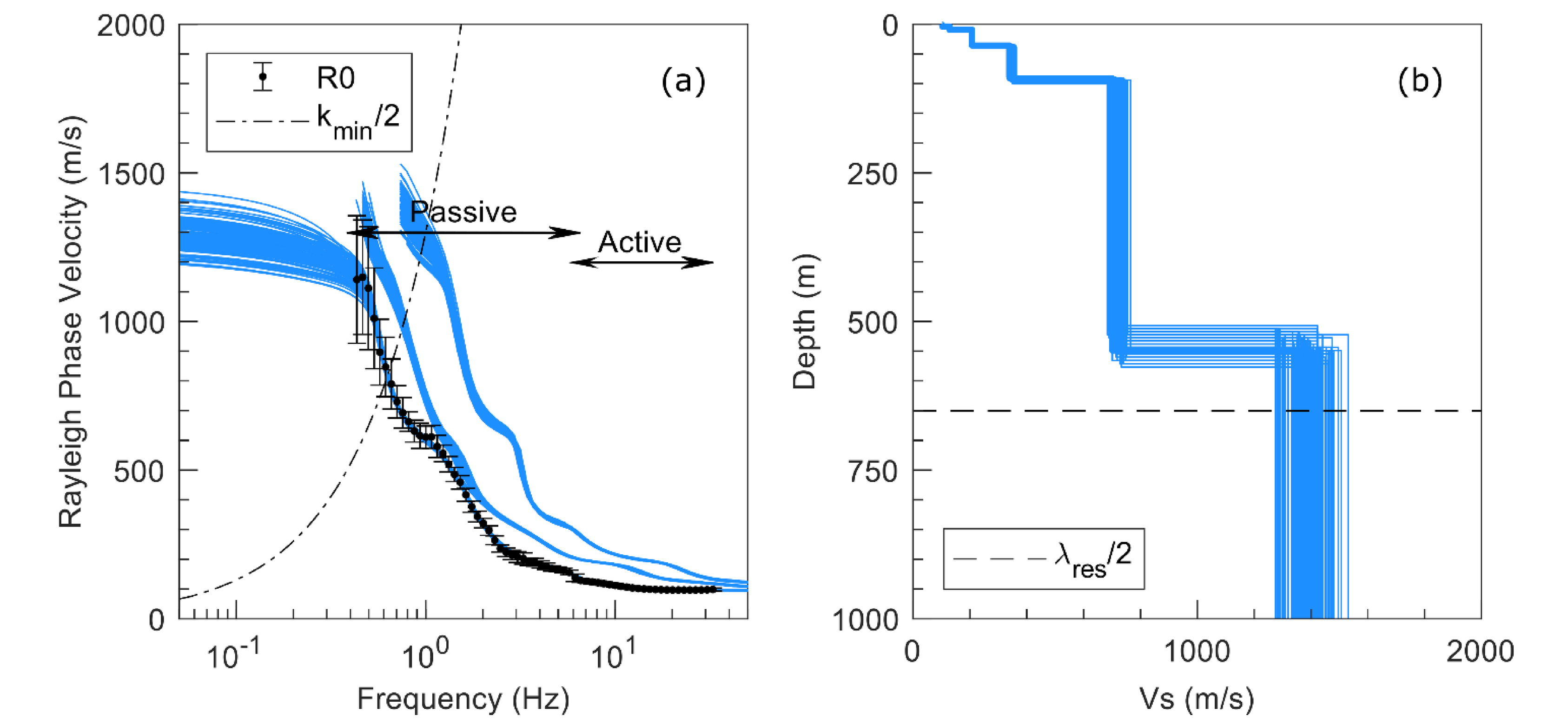

Figure 5: SW inversion results for the Meeanee site: (a) Rayleigh wave dispersion curves and (b) shear wave velocity profiles

Conclusions

The T_0 map and the Meeanne V_S profiles provide insight in the dynamic characteristics of the Heretaunga Plains sedimentary basin, enabling the development of a basin velocity model and a more robust characterisation of the seismic hazard in the Hawke's Bay region.

Additional H/V and SW testing, coupled with other deep geotechnical site investigations, is needed near Hastings to identify impedance contrasts and constrain the multiple observed H/V peaks in the area.