Improving Multi-Seismic Data integration for Seismic Microzonation Mapping

14th INTERNATIONAL WORKSHOP ON SEISMIC MICROZONING AND RISK REDUCTION

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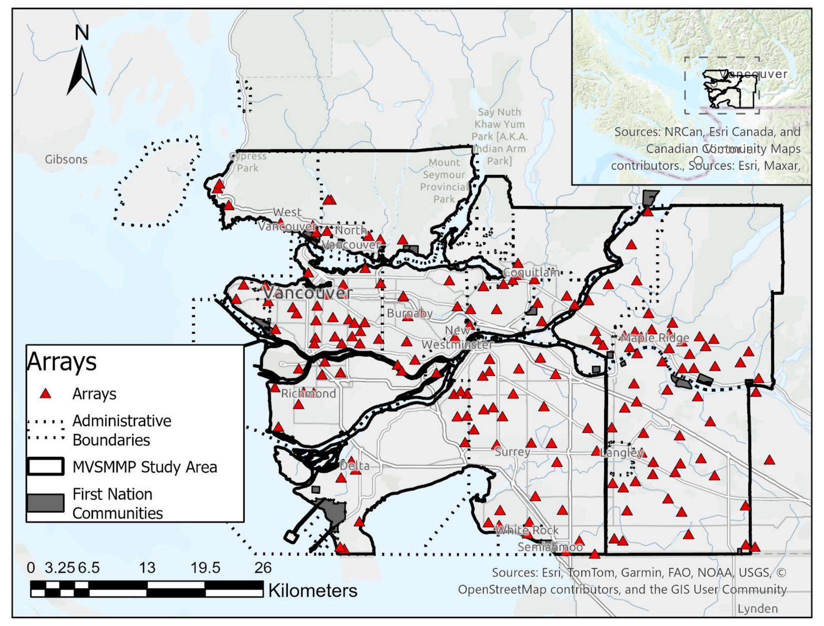
Introduction

To achieve seismic microzonation mapping for Metro Vancouver, British Columbia, Canada, a multi-method seismic field surveying approach was developed to obtain resolved shear-wave velocity (Vs) depth (z) profiling to hundreds of meters depth.

Our multi-method approach involves performing passive-source ambient vibration array (AVA), which provides fundamental-mode dispersion estimates at low frequencies, and time-averaged microtremor horizontal-to-vertical spectral ratio (MHVSR) amplification spectrum at ~25 locations.

Active-source multichannel analysis of surface waves (MASW) surveying is also performed for ~3 different lengths to obtain higher frequency dispersion estimates.

This multi-method surveying approach was performed at 186 sites during six field campaigns (2018 – 2025). AVA-MASW dispersion curve and the site's MHVSR spectral peaks are jointly inverted to resolve Vs(z).



Locations of sites where the multimethod approach was implemented during six field campaigns across Metro Vancouver. At least two of the following methods—AVA, MASW, and MHVSR—were performed at each site.

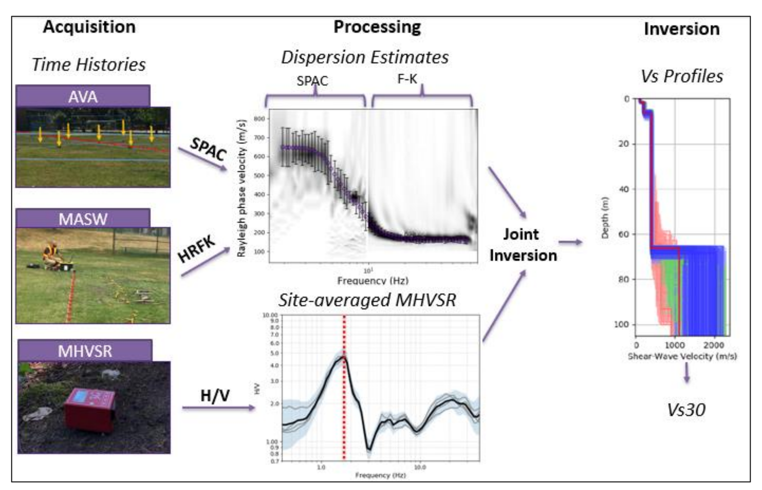
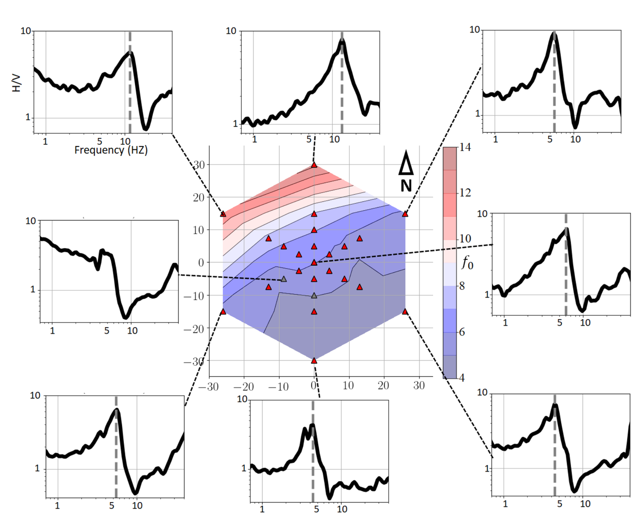


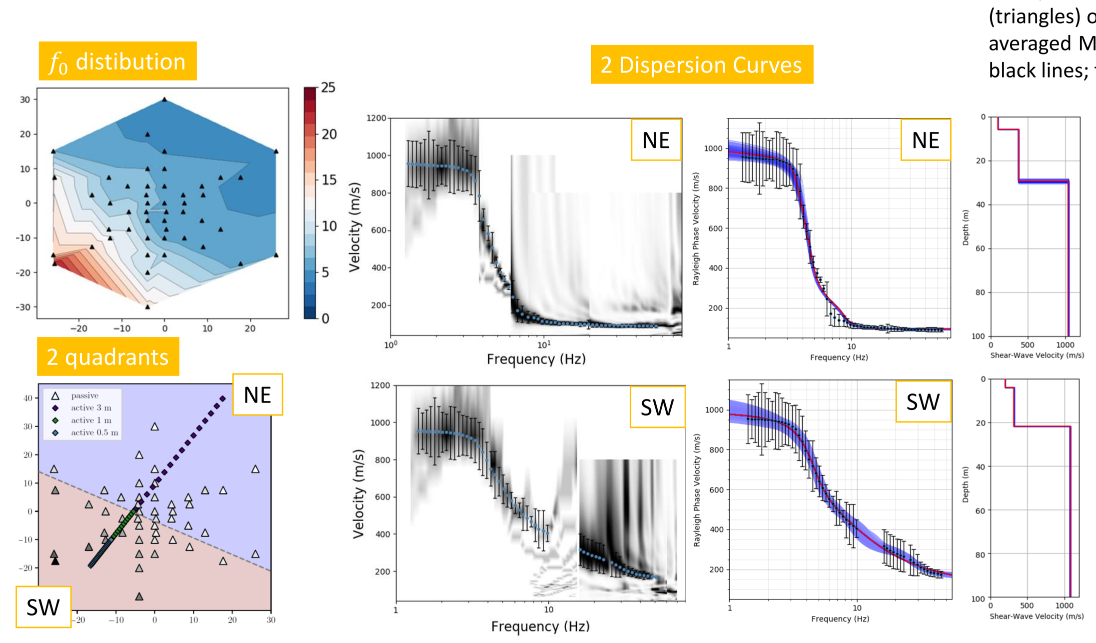
Illustration of the multi-method approach integrating AVA, MASW and MHVSR techniques. The workflow includes data acquisition, processing and joint inversion to derive subsurface profiles.

Vs estimation on complex sites: Lateral variability

- An appropriately sampled f_{0HV} map for the site is readily produced to evaluate the site's lateral variability.
- If high lateral site variability is identified, the site is sub-divided based on the mapped f_{0HV} trend(s).
- Separate dispersion estimates and representative MHVSR spectra are determined using the field survey datasets within each sub-division.
- Two dispersion curves are inverted; each representing an average of one of two quadrants dividing the array site.
- In some cases, the lateral variability captures a significant difference in Vs_{30}.



Example map of contoured f_{0HV} at each seismometer location (triangles) of the AVA testing at the WV0 West Vancouver site. Time-averaged MHVSR spectrum at selected locations are shown by solid black lines; f_{0HV} is shown by a vertical dashed line.



Results obtained at site V003 in Vancouver. The f_{0HV} map shows sufficient variability to subdivide the site into two quadrants. Separate dispersion curves were estimated and inverted to obtain two representative Vs(z) profiles

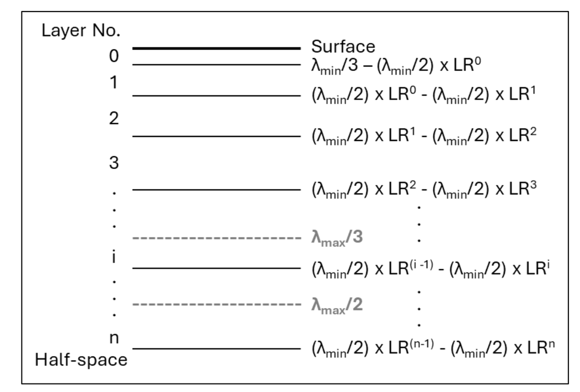
- The south-west quadrant Vs_{30} falls near the class C-D boundary, while the north-east model falls well within class D.
- Using a multi-site solution may be necessary to accurately characterize such sites in terms of their Vs_{30}.

Conclusions:

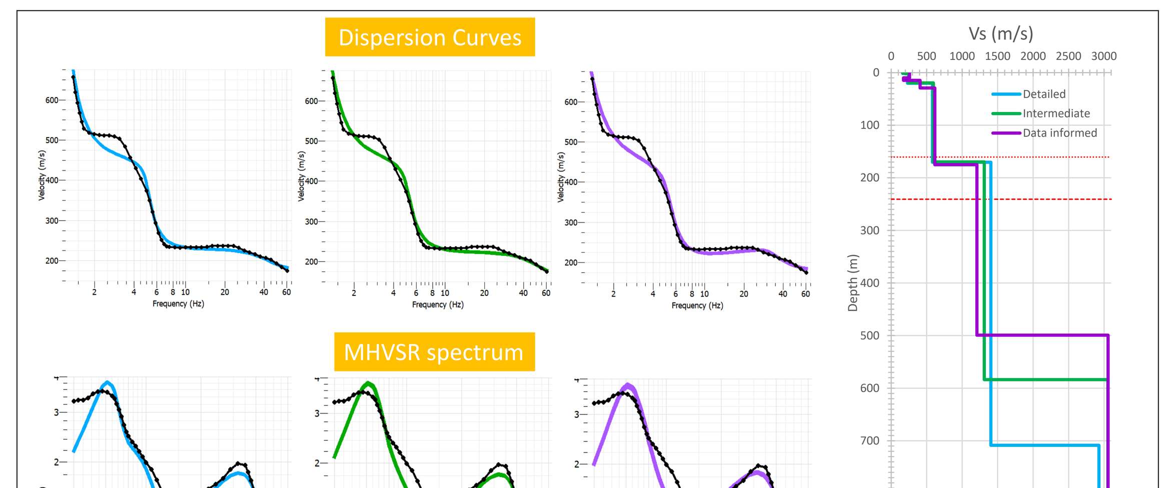
- MHVSR has proven useful for identification of lateral heterogeneity and identification of frequency bandwidths with higher mode contamination.
- Lateral heterogeneity can have a significant effect on the Vs_{30} at a site. Sectioning sites allows for more accurate Vs_{30} range where a single value may not suffice.
- Vs and Vp refraction provide additional velocity information and can often be performed simultaneously with MASW surveys when lateral heterogeneity is suspected.

Innovative Model Parametrization

- Rayleigh-wave dispersion estimates from **MASW** and **AVA** were combined to obtain a full dispersion curve.
- The **MHVSR** shape was also used in the inversion as an elliptical curve, including both the fundamental frequency and secondary peaks..
- The layered Earth model was parametrized using the **layering ratio** approach (Cox & Teague, 2016), evaluating three different layering ratios (LR).
- Maximum and minimum wavelengths were extracted from the dispersion curve and MHVSR for model fitting.
- The layering ratio acts as a multiplier to systematically increase the potential thickness of each layer.



Detailed model	Intermediate model	Data-informed model
• LR=3.5 • Maximum depth ≤ λmax/2 • Layers are more discretize at shallow depths.	• LR=6 • Maximum depth ≤ λmax/3 • Fewer layers at shallow depths.	• Number of layers determined by fitness of the dc and MHVSR data. • Maximum depth ≤ λmax/2 • More layers towards surface.



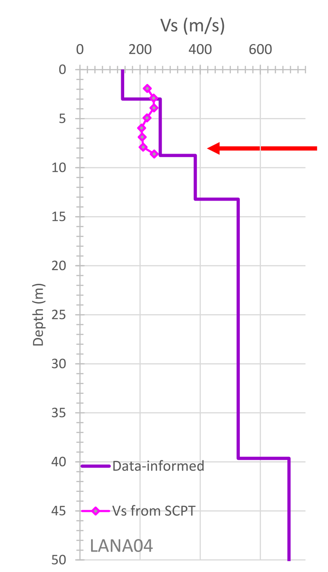
X (m/s)	Zx_min (m)	Zx_max (m)	Zx_ave (m)
250	0	1.8	0.9
600	20	29	24.5
1300	170	175	172.5
3000	499	709	604

Tree Models using the different layering approach for array site LANA13 in Langley

- Including the MHVSR shape, fundamental frequency, and secondary peaks improves model fit and highlights Vs jumps or impedance contrasts in Vs(z) profiles.
- The tri-model parametrization constrains the depth of major impedance contrast (Z_x), the average thickness and Vs of key layers.

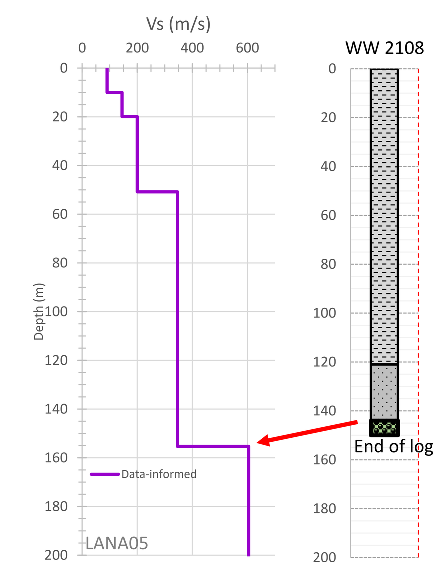
Validation of Vs(z) profiles with other datasets

Vs(z) profiles are validated against geotechnical data, seismic reflection profiles, and well logs. Model with lowest misfit is selected.



Comparison of Vs from SCPT

- SCPT refusal aligns with major impedance contrast on Vs inverted profile.
- Vs from SCPT similar to Vs from inverted model.



Comparison of Vs based on lithology

- Major changes in Vs align with geology changes from nearby well logs.

Conclusions:

- The inclusion of ambient vibration field surveying is crucial to deriving reliable deep Vs(z) profiles and necessary to combine with other geodatasets (e.g., well log lithology, seismic reflectors) to develop a regional 3D Vs model to 1000 m depth for conducting seismic microzonation mapping in Metro Vancouver with diverse Quaternary geology.
- Recent innovation of a tri-model-parameterization approach improves uncertainty characterization of the Vs(z) models while also improving identification of Vs 'jumps' or seismic impedance contrasts in the resolved Vs(z) models and is more harmonious for development of regional 3D Vs models and regional seismic microzonation mapping.

About the project:

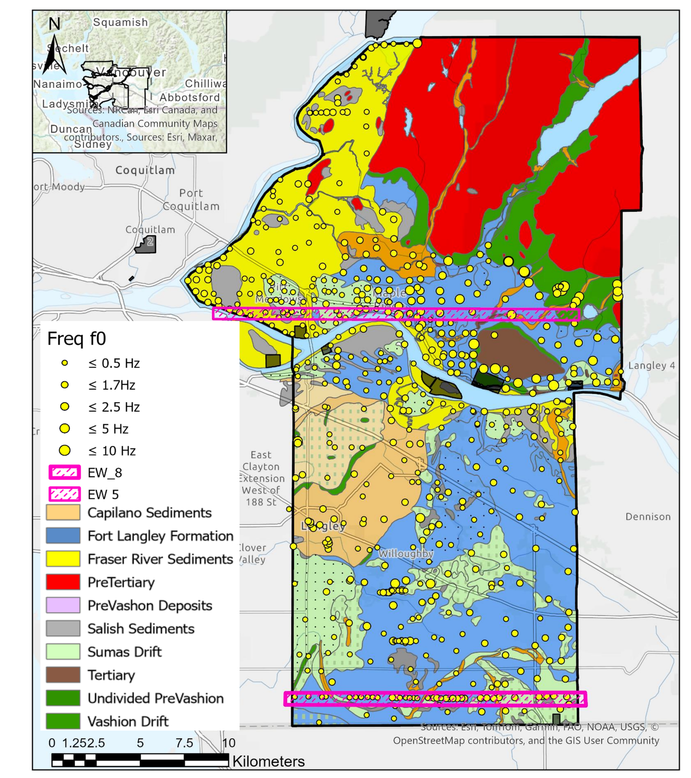
The Metro Vancouver seismic microzonation project is a multi-year (2017-2026) research project that involves the assessment and mapping of:

- Earthquake Shaking Hazard (Amplification, Basin Effects, Site Class, Site Period)
- Liquefaction Susceptibility and Potential Hazard
- Landslide Susceptibility and Potential Hazard

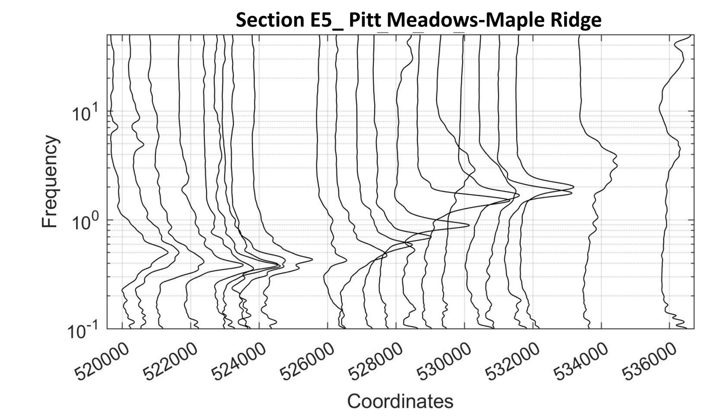
MHVSR and co-located data

MHVSR surveying and processing

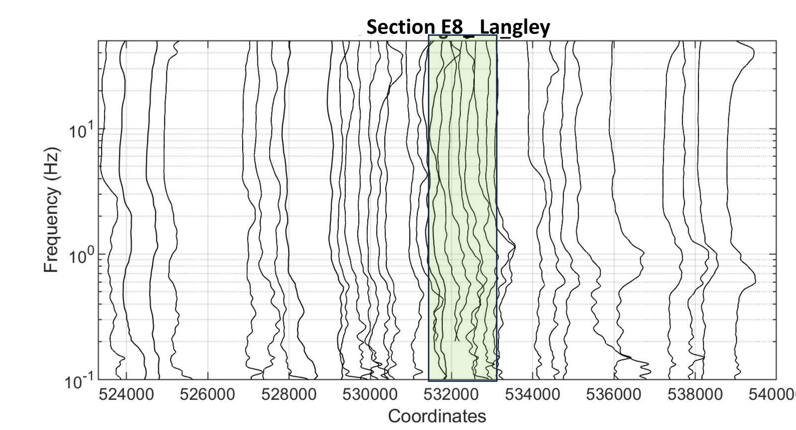
- Over 2,640 single-seismometer MHVSR measurements were collected across Metro Vancouver, including approximately 590 in eastern Metro Vancouver.
- Identification of MHVSR spectral peaks becomes more difficult toward the east, reflecting increasing multi-glacial geologic complexity.
- An innovative distance-profile visualization of MHVSR spectra (Pratt, 2018; Ramirez et al., 2025) was used to track major and minor peaks related to high and low impedance contrasts.



Geologic map showing fundamental frequency (f_0) from MHVSR. Magenta rectangles indicate the E–W cross sections plotted on the right panels.



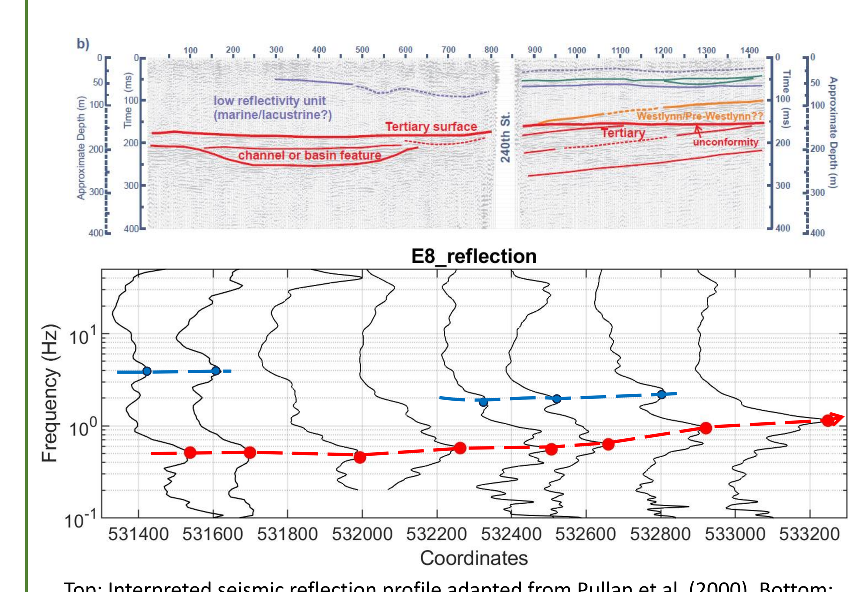
In the western part of the profile, a shift toward lower frequencies indicates a local deepening of the main impedance contrast, which becomes shallower again toward the east. Peak amplitudes decrease as the profile approaches the pre-Tertiary bedrock.



MHVSR spectra exhibit low amplitudes toward southern Langley, suggesting a low impedance contrast in the subsurface layers. The major distinguishable peaks are associated with the presence of Sumas Drift.

Integration of MHVSR cross sections with reflection profiles

- Reflection profile along 8th Avenue (Langley, BC) conducted by Pullan et al., (2000); MHVSR data collected along the same line for comparison.
- Profile shows a steady Tertiary surface overlain by probable Westlynn Drift to the east end.
- MHVSR f_0 peaks align with the interpreted Westlynn–Tertiary interface, with lowest f_0 where the surface deepens.
- MHVSR f_1 (blue circles):
  - Left: marks impedance contrasts in the low-within the low reflectivity unit.
  - Right: coincides with stronger reflectors in the upper unit over Westlynn Drift.



Top: Interpreted seismic reflection profile adapted from Pullan et al. (2000). Bottom: MHVSR spectra collected along the same profile.

Conclusions:

- Distance MHVSR profiles enhance stratigraphic interpretation when combined with other geodata.
- Low MHVSR amplitudes suggest a gradual Vs increase in the Fort Langley formation, likely due to repeated glaciations.
- Integration of MHVSR cross sections with other geotechnical datasets is planned as future work to develop relationships that could enable estimating the depth to units of major impedance contrast.

Selected references:

- **Cox, B. R., & Teague, D. P.** (2016). *Layering ratios: a systematic approach to the inversion of surface wave data in the absence of a priori information. Geophysical Journal International, 207*(1), 422-438.
- **Pullan, S. E., Good, R. L., Jarvis, K., Roberts, M. C., and Vanderburgh, S.** (2000). *Application of shallow seismic-reflection techniques to subsurface structural mapping, Fraser Lowland, British Columbia.* In *Mapping, Geophysics, and Groundwater Modelling in Aquifer Delineation, Fraser Lowland and Delta, British Columbia,* Geological Survey of Canada Bulletin 552, pp. 49–74.
- **Pratt, T. L.** (2018). *Characterizing and imaging sedimentary strata using depth-converted spectral ratios: An example from the Atlantic Coastal Plain of the eastern United States.* Bulletin of the Seismological Society of America, 108(5A), 2801–2815, https://doi.org/10.1785/0120180046.
- **Ramirez, F., Selway, K., Maupin, V., *et al*.** (2025). *Mapping 3D sedimentary structures with joint inversion of H/V spectral ratios and multimode dispersion curves.* Bulletin of the Seismological Society of America, **115**(2), 619–645. https://doi.org/10.1785/0120240174