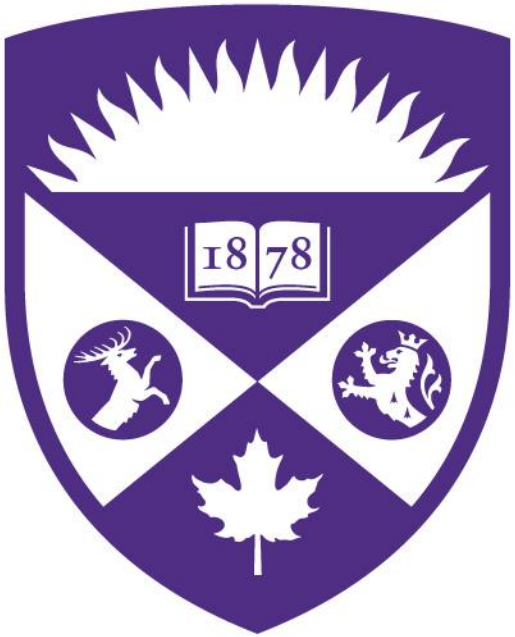

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Comprehensive earthquake site amplification assessment for Greater Vancouver

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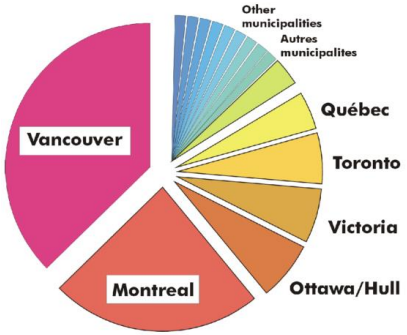
Outline:

1- Earthquake hazard in Southwest BC
2- Geology in Southwest BC
3- Amplification
4- Previous work
5- Database
6- Earthquake spectral amplitudes
7- H/V ratios
8- Port Mann vertical array
9- Conclusions

1- Earthquake Hazard and Risk in SW BC

Southwestern British Columbia (SW BC), including GTA Vancouver, has the highest seismic risk in Canada



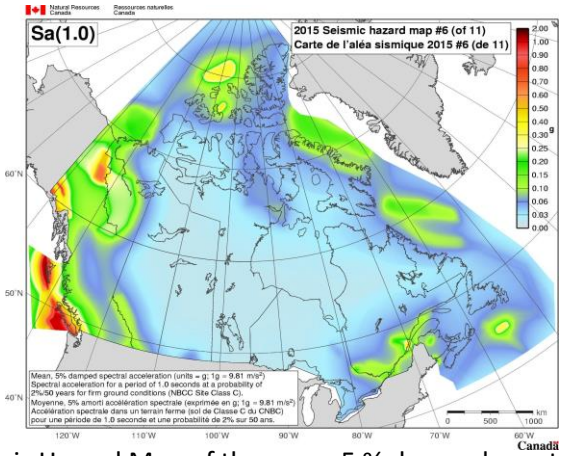
Approximate seismic risk distribution in Canada (Adams et al 2002)

- Hazard is due to
  - 3 types of earthquakes
  - Sedimentary Georgia basin

- Over 2 million people in Metro Vancouver with critical infrastructure.

- **What will the ground shaking be like in future earthquakes?**

- **Undergoing Microzonation project for Metro Vancouver**

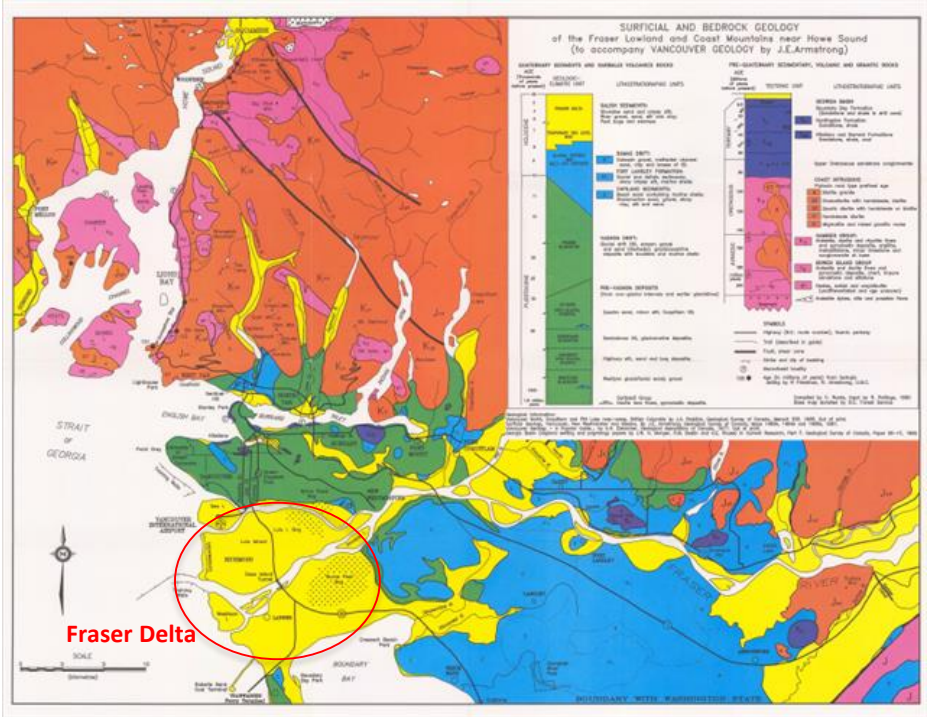


Seismic Hazard Map of the mean 5 % damped spectral acceleration (T =1.0 second) at a probability of 2% in 50 for (site Class C) (Natural Resources Canada 2015)

Greater Vancouver from googlemaps.com

2- Geology in Southwest BC

- The upper layer is young **soft Holocene** sediments mainly silts and sands up to 300 m thickness (Vs ~ 200-300 m/s).
- Middle layer **Pleistocene sediments** composed of ice compacted till and glaciomarine silts and sands (Vs ~ 500 m/s).
- The **Tertiary bedrock** underlying the Pleistocene layer consists of Miocene sandstone and shales with a depth range of 200 m to 1000 m (Vs >~1500 m/s).



Geologic Map of GTA Vancouver (Armstrong 1980)

Silts & Sand

Till & Glaciomarine Silts

Tertiary bedrock

3- Amplification Phenomena

A- **Broad band amplification**: Shortening of shear wave wavelengths and an increase in shear wave amplitudes when crossing into shallower softer layers.

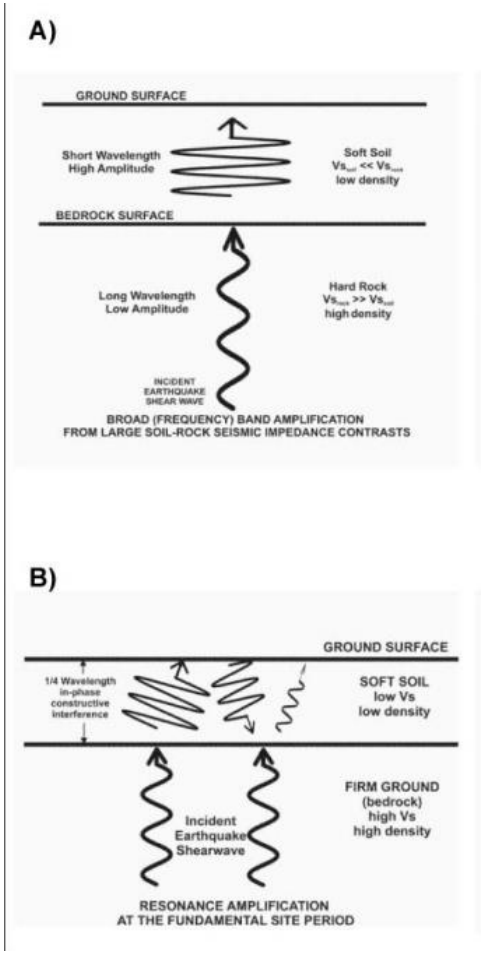
B- **Resonance Amplification**: Waves get trapped and reverberate in the upper layer when the impedance contrast is high (fundamental frequency).

Techniques to measure amplification:

Theoretical.

Empirical:

- Standard spectral ratio (SSR) Borcherdt 1970.
- Microtremor horizontal to vertical spectral ratio (MHVSR) Nakamura 1989.
- Earthquake HVSR Lermo & Garcia (1993).



Amplification phenomena sources (Hunter 2010)

4- Previous Work

*Although the **long period (>2 s) energy** in these data sets are poorly defined, we would expect amplifications at longer periods on the thick soils near the centre of the delta. This could pose a hazard to larger structures (extremely tall buildings or large bridges).*

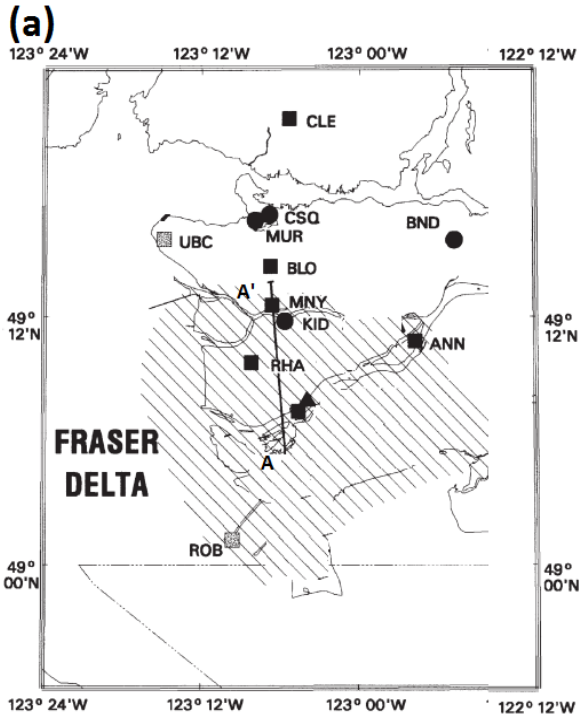
Cassidy & Rogers 2004

5- Database

Earthquakes	Year	Depth (km)	Moment Magnitude (Mw)	Distance* (km)
Offshore Vancouver	2015	60	4.7	~ 71
Vancouver Island	2014	10	6.6	~ 300
Vancouver Island	2011	22	6.3	~ 300
Nisqually, WA	2001	52	6.8	~220
Georgia Strait	1997	3	4.3	~ 40
Duvall, WA	1996	4	5.1	~ 180
Pender Island	1976	62	5.3	~ 50

*Epicentral distance to Vancouver.

- MHVSR performed near RMD09 and VNC14 (Onur et al. 2004)



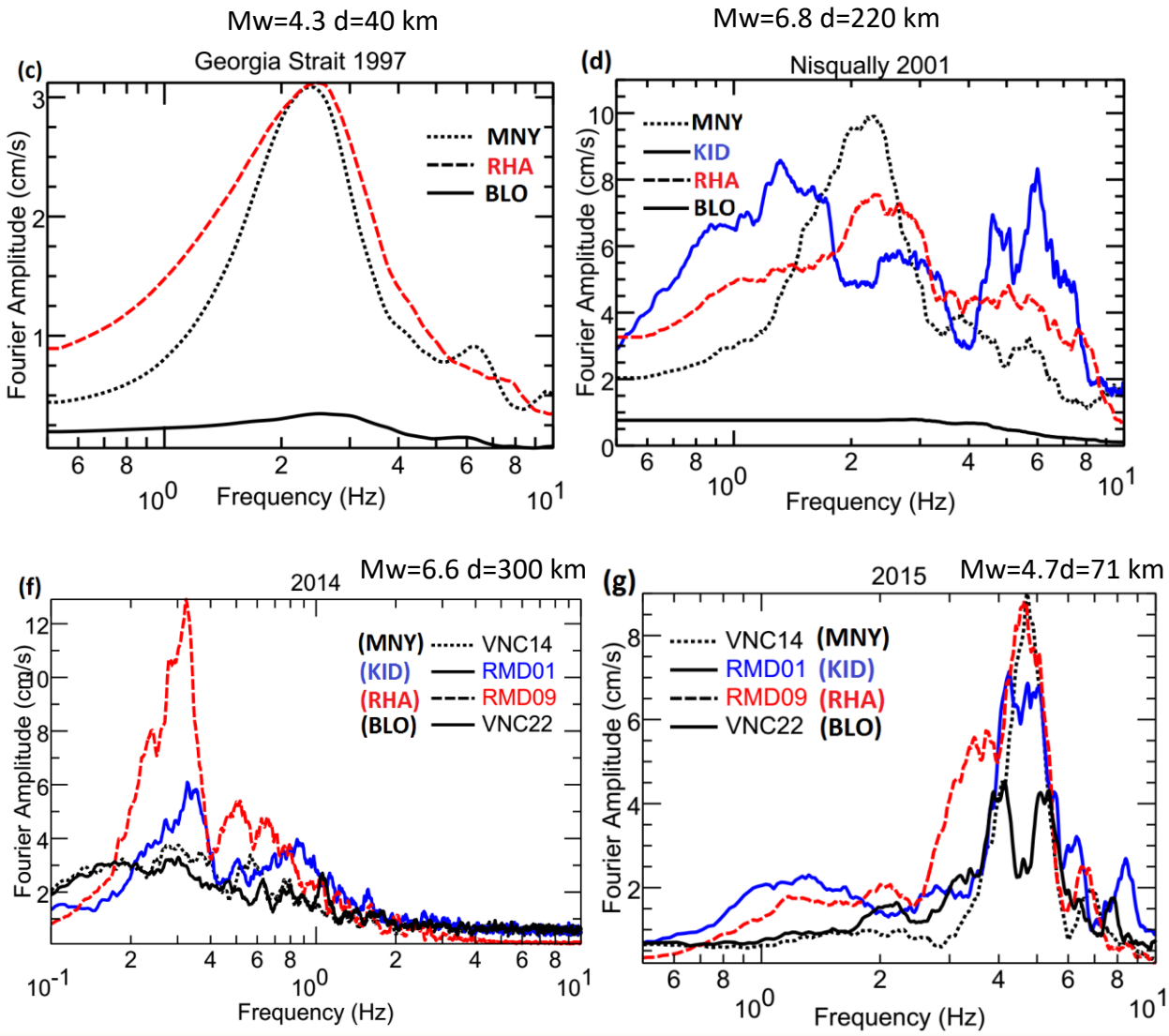
Modified from Cassidy & Rogers 1999

Strong motion Network station

Before 2002	Site description	After 2002
		Internet Accelerometer (IA) continuous recording http://www.bcsims.ca 3 component
Trigger based 2 component.		
MNY	Edge of delta	VNC14
KID	Close to edge	RMD01
RHA	Center of delta: soft deep deposits ~ 300m	RMD09
BLO	Till sediments	VNC22

6- Earthquakes spectral amplitudes

- Most earthquakes energy is between 2-6 Hz.
- The 2011 and 2014 records are rich in low frequency content.
- 2015 earthquake notably has high frequency content.
- Response at delta edge (VNC14~MNY) is comparable or even higher than the response at delta center (RMD09~ RHA) **except** for 2011 and 2014.



7- H/V ratios

RMD09

- 2011 & 2014 show a fundamental frequency around 0.2-0.3 Hz and a peak amplification ~ 8 for RMD09 at delta center, comparable to 1st peak from MHVSR.

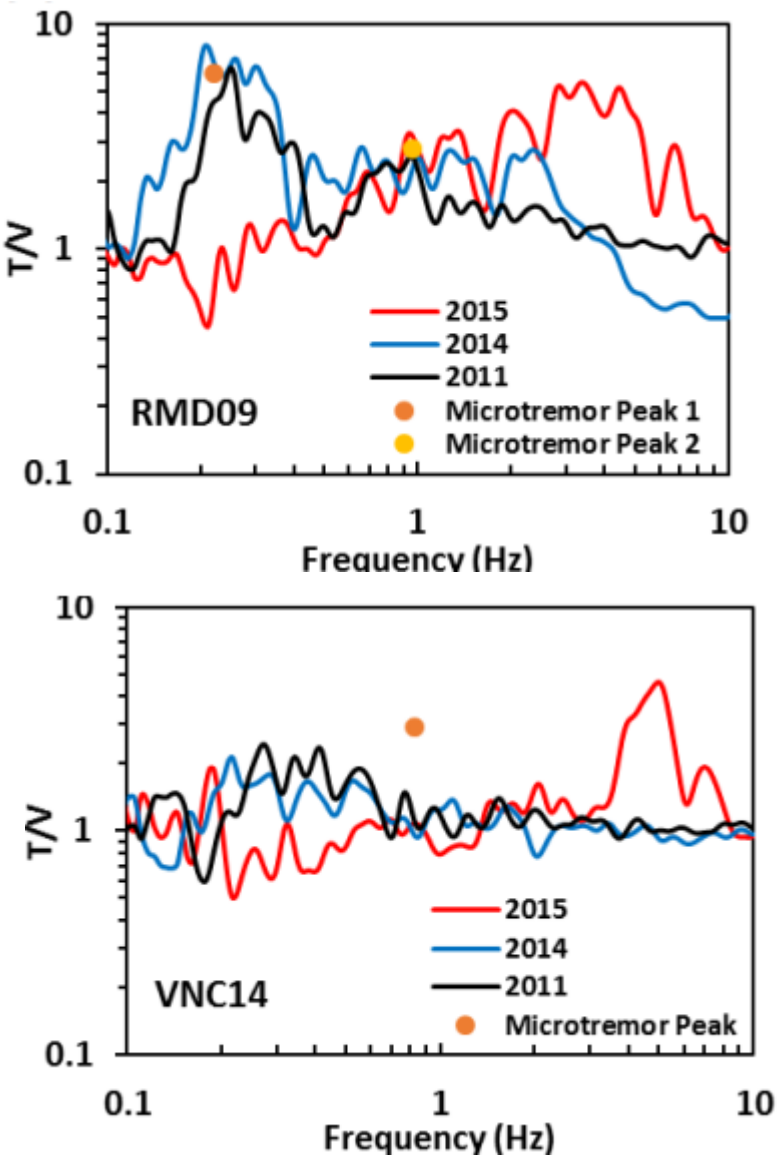
- 2015 show a peak of 6 at a broad frequency 3-6 at RMD09.

VNC14

- 2011 & 2014 show a relatively small peak ~2 around 0.2-0.4 Hz at VNC14.

- 2015 shows a peak ~5 at 5 Hz.

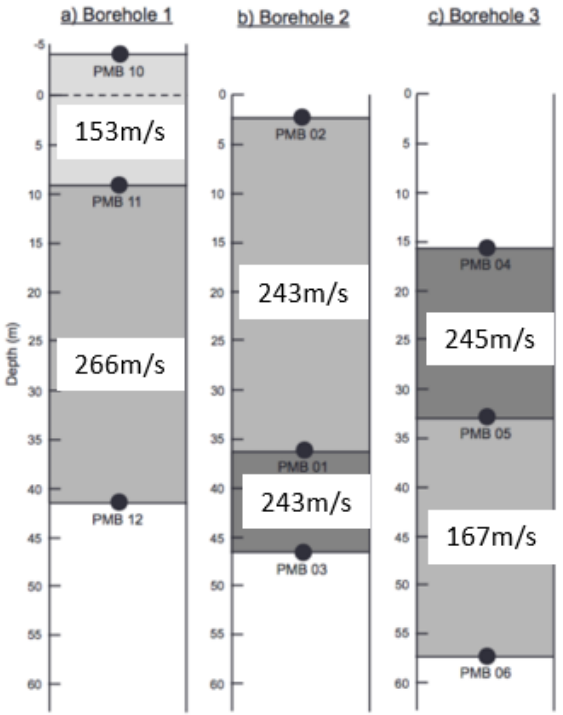
- MHVSR show a peak ~3 at 1 Hz.



8- PortMann Bridge Borehole recordings during 2015 earthquakes

- 1st vertical array borehole recordings in BC.
- Bottom sensors are in till.
- Average Vs between sensors was calculated by cross correlation
- 1D theoretical response :

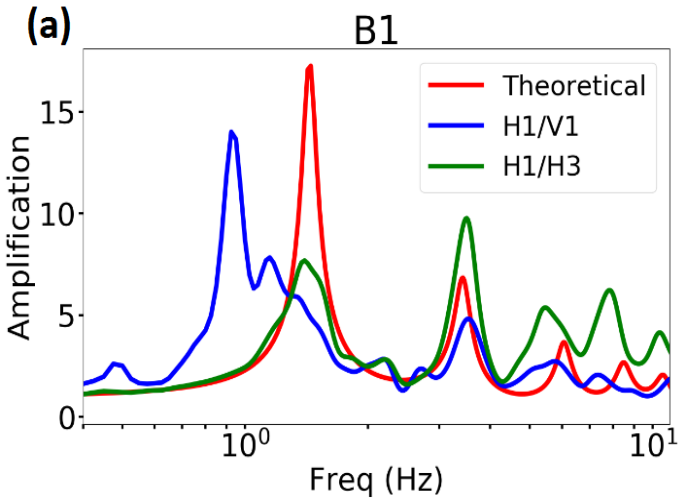
Holocene unit weight: 19.5 kN/m3, damping ratio= 4% (Onur et al. 2004)
Rigid half space (Kwok et 2007)

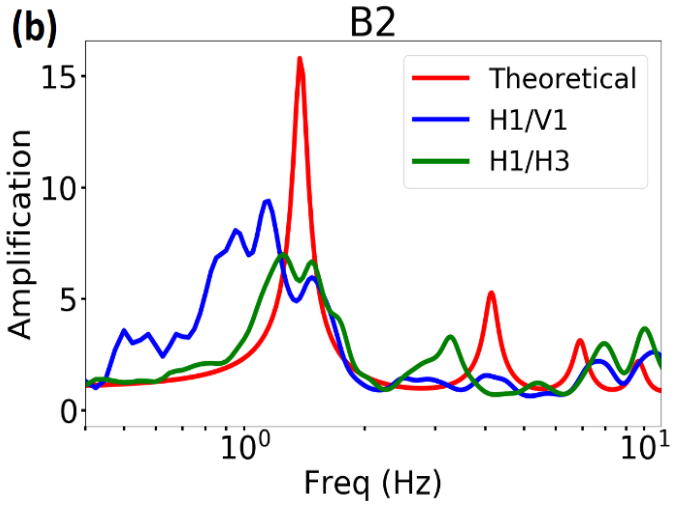


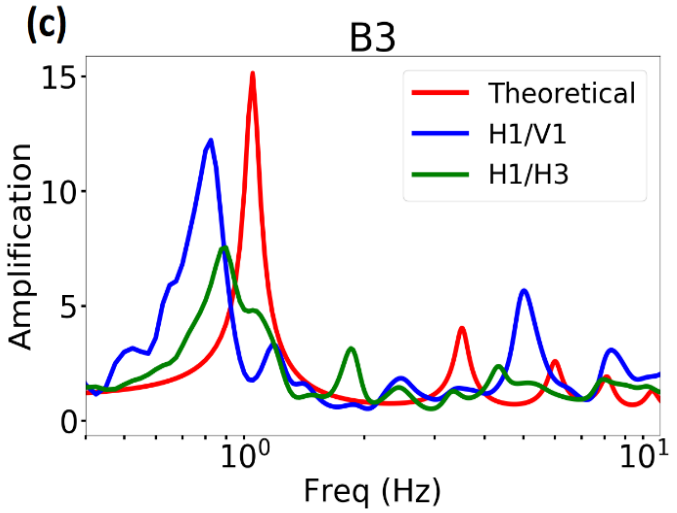
Modified from Jackson et 2017

8- PortMann Bridge Borehole recordings during 2015 earthquakes

- Comparison between 1D model and empirical amplification (top to bottom / top horizontal to vertical)







- H1/V1 amplitude is higher and shifted to lower frequencies compared to H1/H3.
- 1D model amplitude is higher than H1/H3, however fundamental frequency are matching except borehole 3.

9- Conclusions

- The 2011 and 2014 earthquakes, rich in long period energy, allow us to quantify the amplification at long periods.
- Long period linear amplification ~8 is observed in the center of Fraser delta.
- With more validation, microtremor H/V may offer a robust measure of site amplification in Vancouver.
- 1D theoretical amplification model is capable of predicting the fundamental frequencies at boreholes, amplitudes are not matching observations.
- Future Records from the borehole array are very important to add more insights into the site response in Vancouver.

Thank you

Questions ??

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