Using Two-station Microtremor Array Method to Estimate Shear-wave Velocity Profiles in Seattle and Olympia, Washington

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Outline

- Introduction
- Spatial Auto-correlation
- Data acquisition and processing
- Dispersion curve analysis in terms of Spatial Autocorrelation
- Conclusions

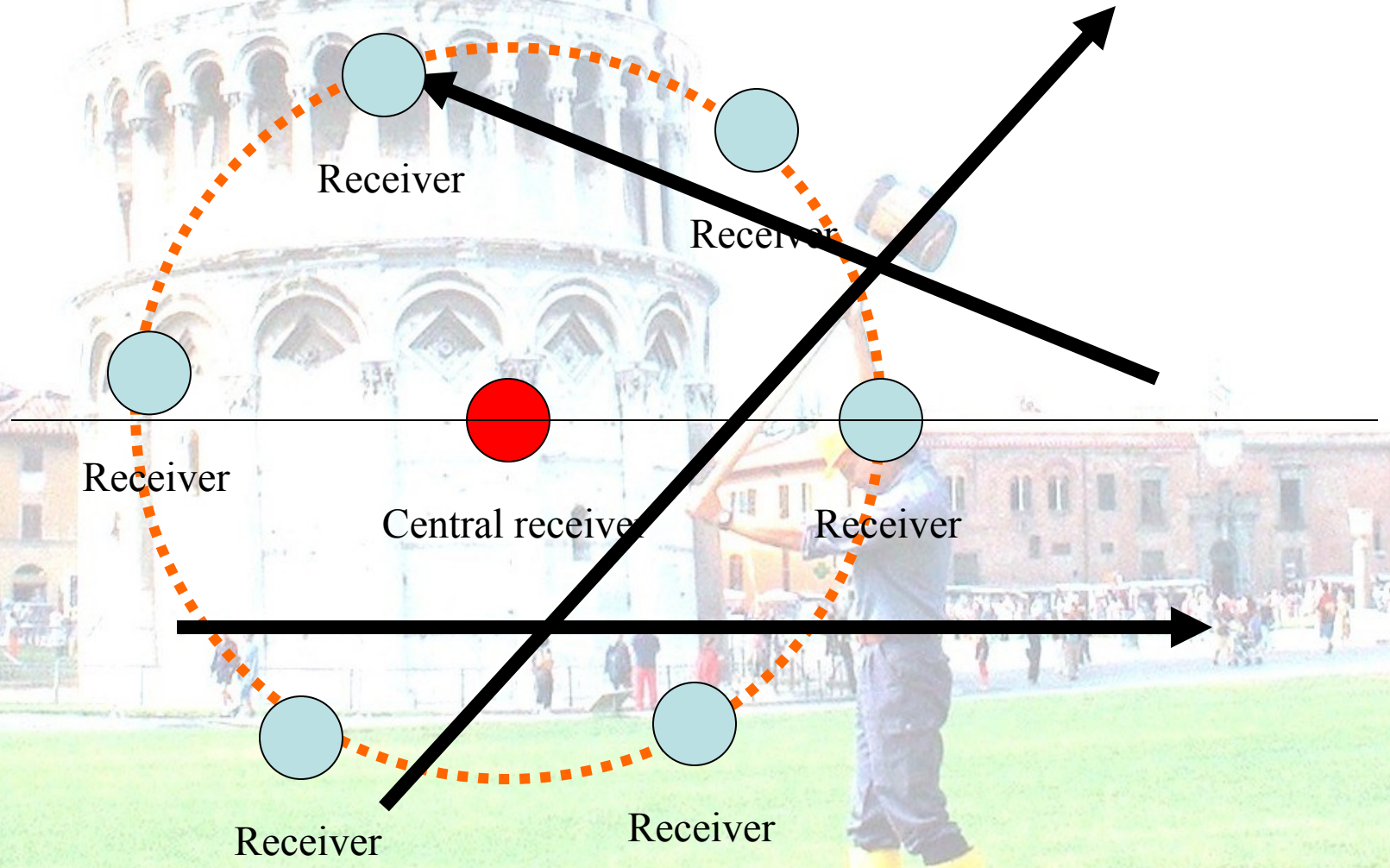
Introduction (1)

- Surface ground motion of earthquakes highly depends on subsurface geological structure.
- For estimating the local site effect, S-wave velocity (Vs) down to a depth of several 10m (e.g. AVS30) is most popular in all over the world.
- Recent several sever earthquakes have revealed that much deeper and two or three dimensional structures also play important role.
- Reflection and refraction methods have been applied to delineate deeper Vs structure.
- These conventional methods are expensive and time consuming so that the development of cheaper and simpler methods has been desired.
- Active and passive surface wave methods have been increasingly getting popular in last 10 years.

Introduction (2)

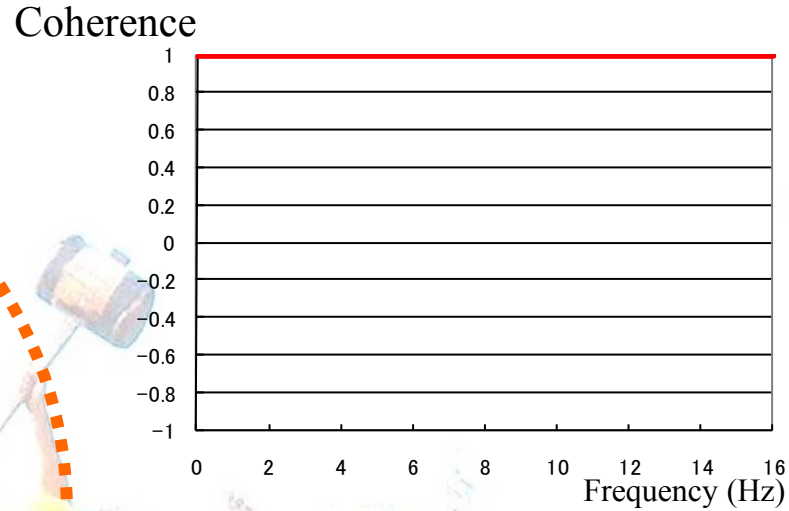
- The passive method or microtremor array measurements (MAM) is particularly attractive because the method does not require any artificial source and the depth of investigation can be increased easily.
- Large scale microtremor measurements have been widely used in last 10 years in Japan for estimating S-wave velocity structure down to a depth of several kilometers.
- In these investigations, triangle arrays with size of several kilometers are used for calculating a phase velocity in frequency range from 0.2 to 1Hz.
- The investigation using the large scale microtremor measurements revealed that abrupt change of deep bedrock depth caused disaster concentration in the 1995 Earthquake in Kobe, Japan.

Spatial Auto-correlation (2D)



Micro-tremors does not propagate with particular direction

Spatial auto correlation (2D)



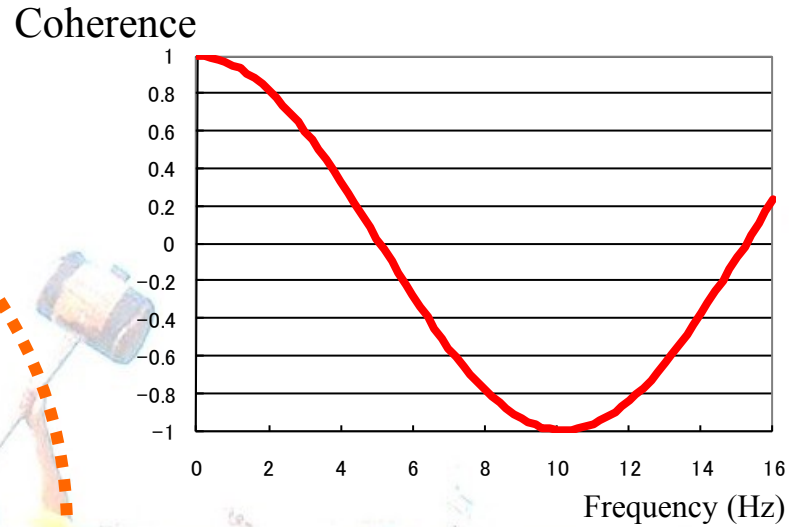
Center receiver

Direction of Propagation

Receiver

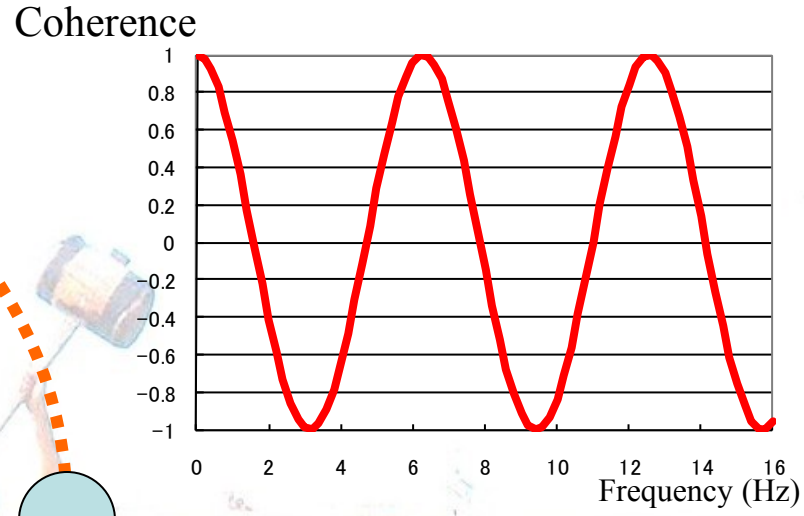
Infinite apparent velocity (wave-number is 0)

Spatial Auto-correlation (2D)



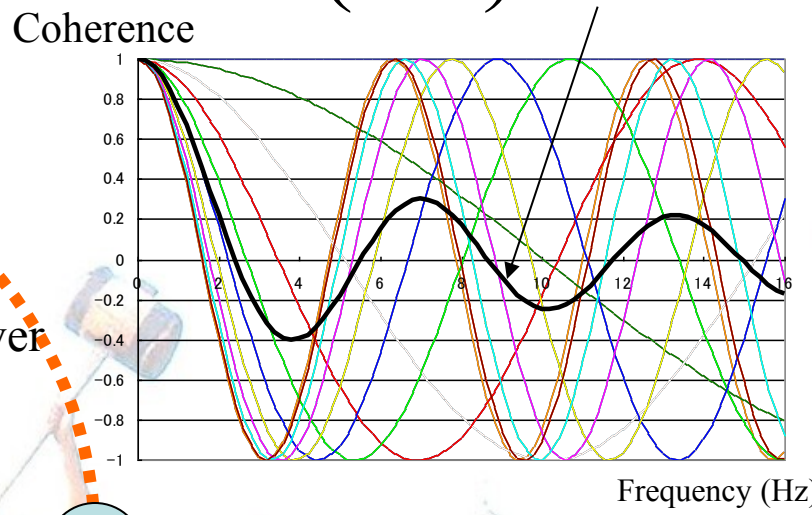
High apparent velocity (small wave-number)

Spatial Auto-correlation (2D)



Low apparent velocity (large wave-number)

Spatial Auto-correlation (2D)

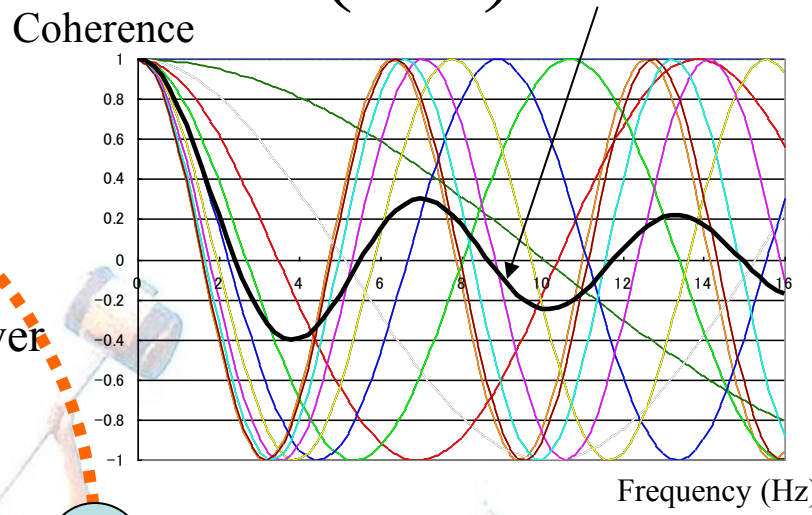


Averaging all direction coherence (cos function) results in Bessel function

SPAC with Small Number of Sensors

- Most people use a spatial autocorrelation (SPAC) method for calculating phase velocities from ambient noise and the method requires at least 4 or 7 sensors placed on center and corners of triangles.
- Margaryan et al. (2009) showed that the SPAC using only two sensors yields almost identical phase velocities as one of 4 or 7 sensors on triangles.
- The SPAC using small number of sensors enables us to perform the MAM much easily.
- Hayashi and Underwood (2012a) have shown that S-wave velocity profiles to a depth of 2 to 3 km can be determined by the SPAC using two sensors in the San Francisco Bay area
- We have performed the SPAC using two sensors at several sites in Seattle and Olympia, Washington.

Spatial Auto-correlation (2D)



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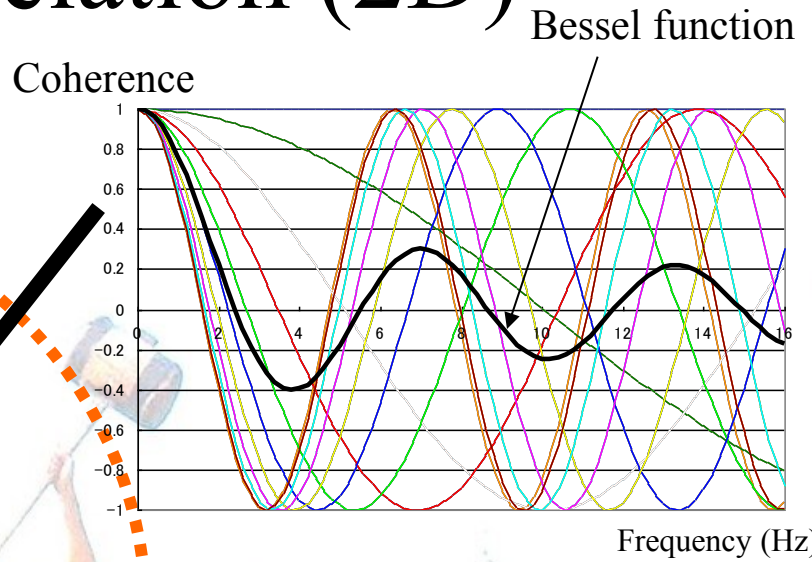
Spatial Auto-correlation (2D)

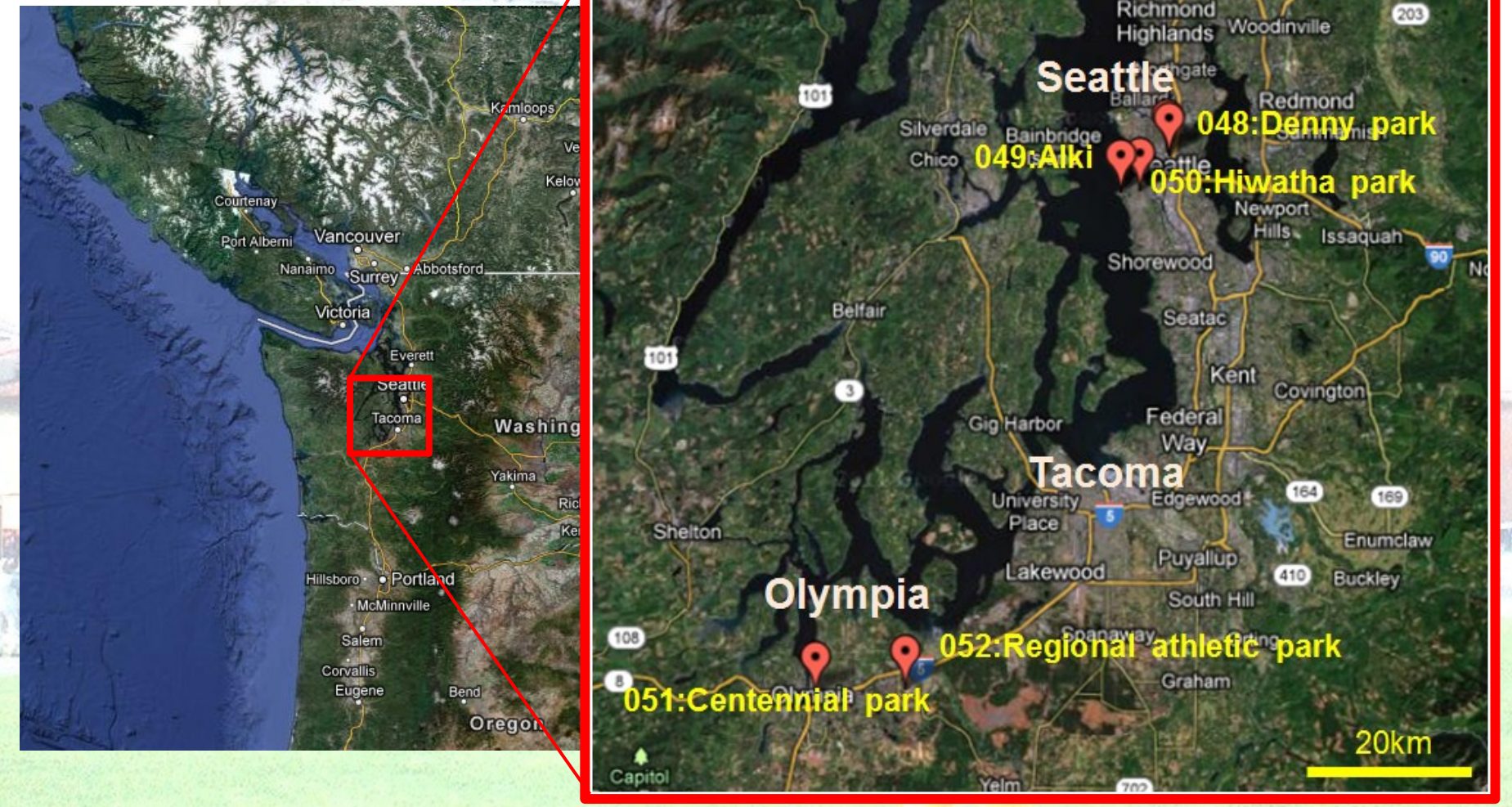


Averaging all direction coherence (cos function) results in Bessel function

Data Acquisition and Processing

- Microtremor array measurements have been performed at three sites in Seattle and two sites in Olympia.
- Separation of two seismographs varies from 10 to 3102m.
- In each measurement, 10 to 60 minutes ambient noise was recorded.
- Sampling time is 10msec.
- Two seismographs including three-component accelerometer (McSEIS-MT Neo) made by OYO Corporation were used for data acquisition.
- The seismographs include GPS clock and two seismographs can be synchronized in any distance.

Site of Investigation



Example of array configuration

Seismograph (McSEIS-MT Neo)

Sensor : Servo-Accelerometer
Resolution : 1μG
Sensitivity : 2.0V/G
Range : +/-4G
Frequency Response : 0.1 – 200Hz
Dynamic range : 120dB(Measured)
A/D Converter : 32bits
Sample Time : 2, 4, 10, 20, 50msec
Dimension :
220mm(W) ×245mm(D) ×250mm (H)
Weight : Approx. 7.5kg
(Main unit 5kg, internal battery 2.5kg)

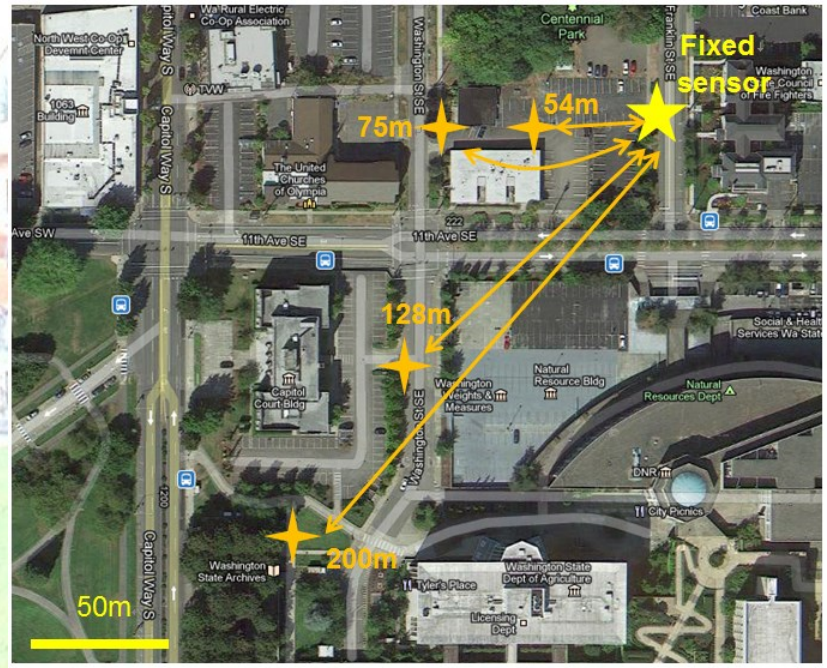
Example of Data

Large array in Downtown Seattle

Denny park (048)

Small array in Downtown Olympia

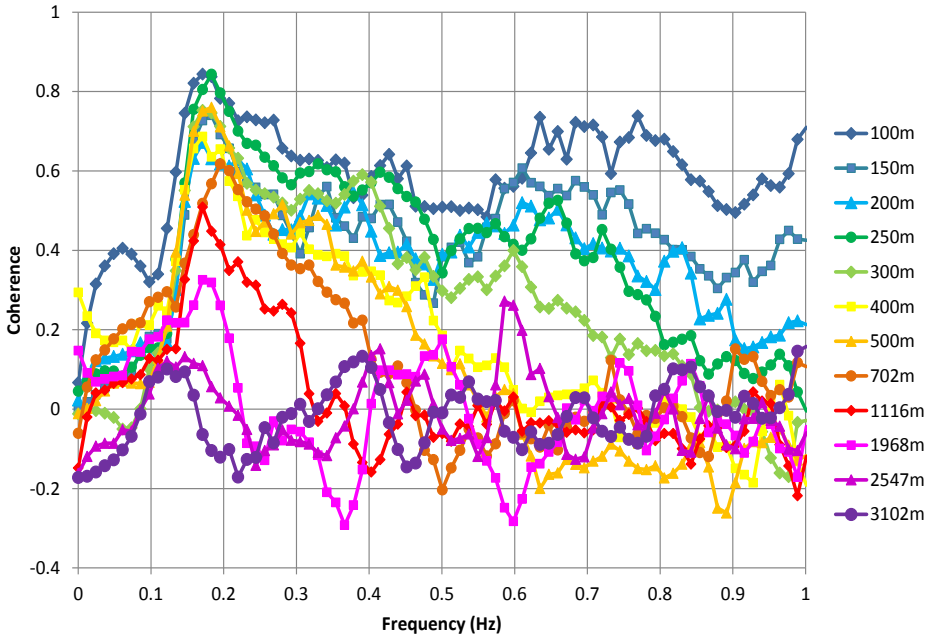
Centennial Park (051)



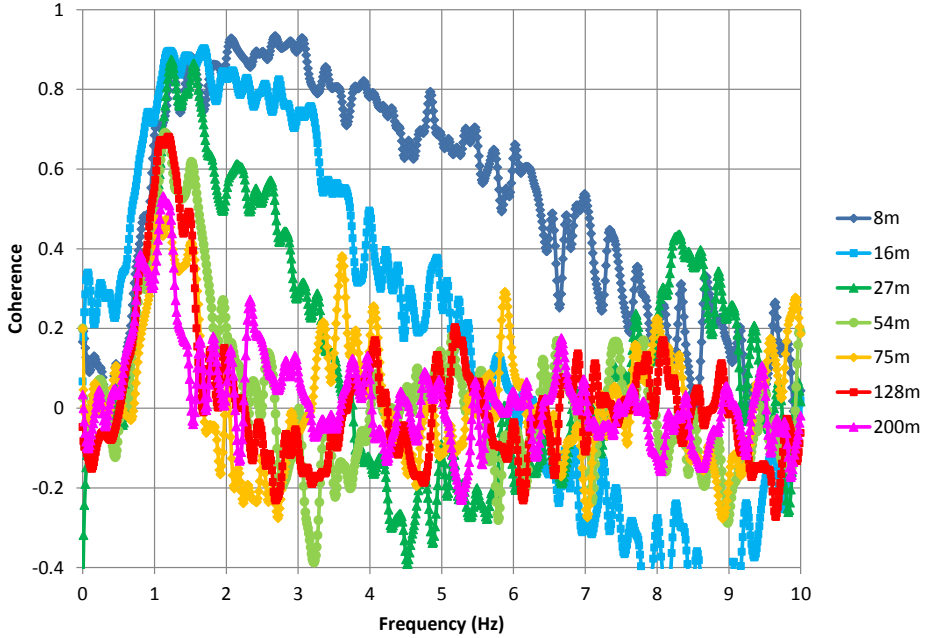
Example of Spatial Auto-correlation

Coherences as a function of frequency

Denny park (048)



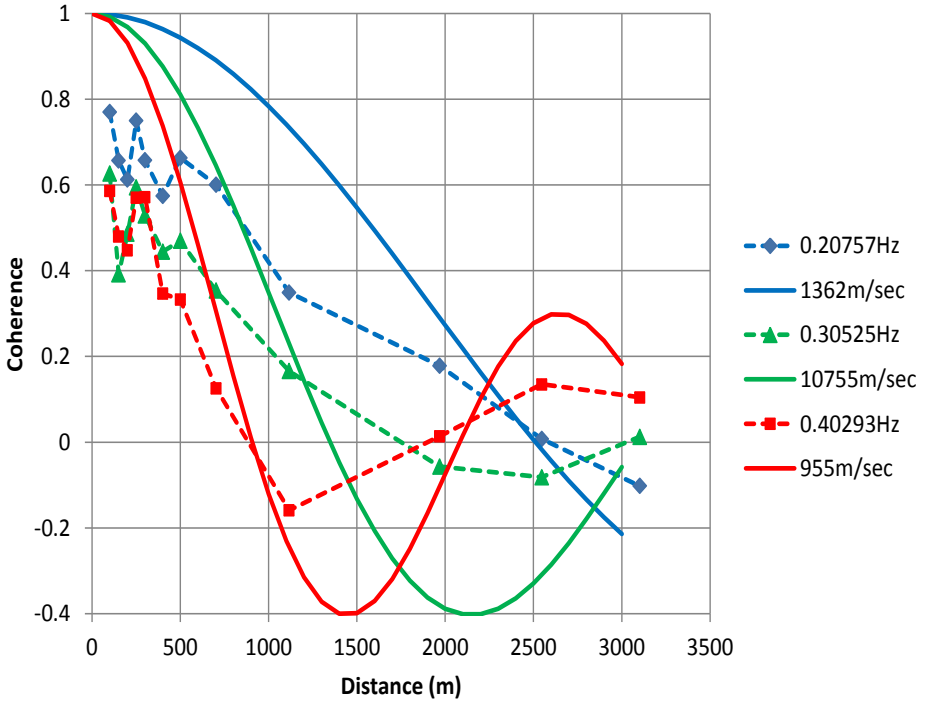
Centennial Park (051)



Example of Spatial Auto-correlation

Coherences as a function of distance

Denny park (048)



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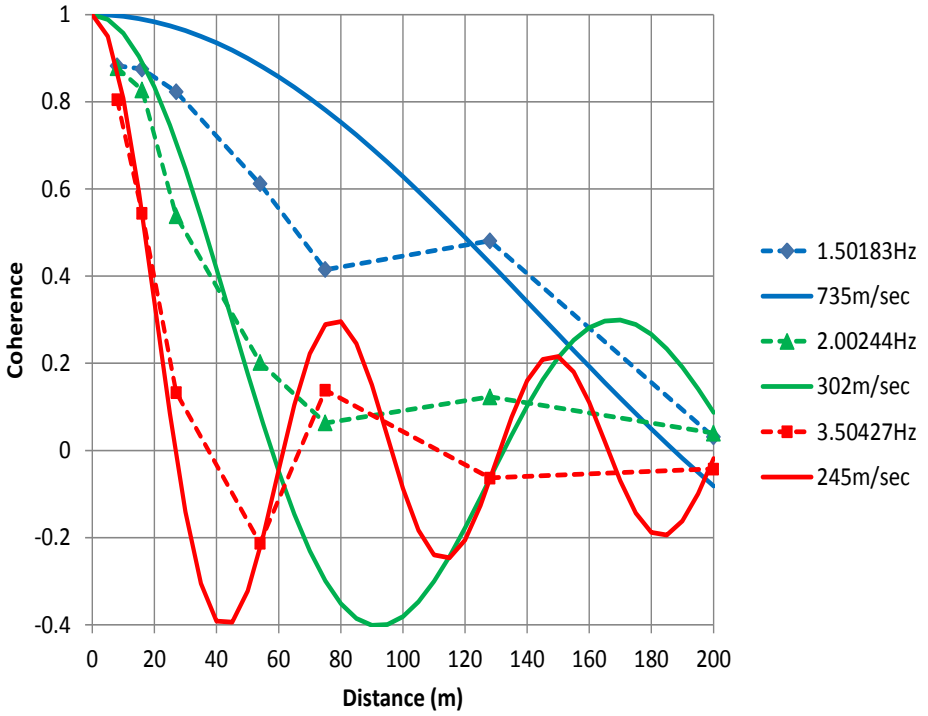
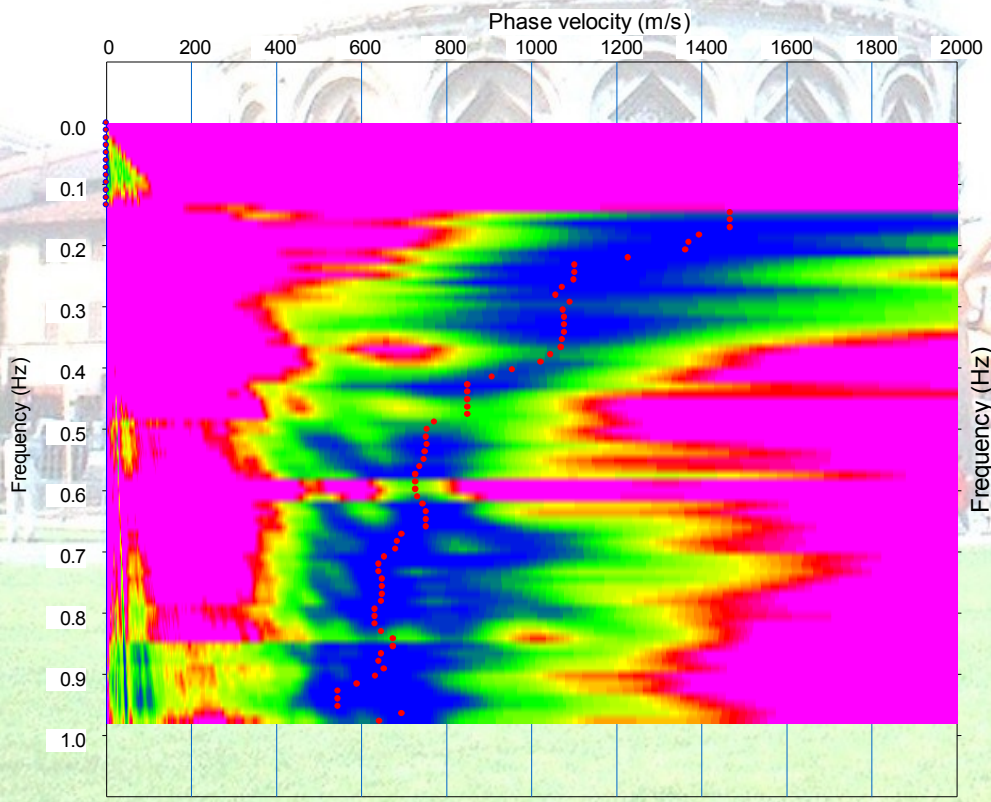


Example of Spatial Auto-correlation

Error between observed coherences and theoretical Bessel functions

Denny park (048)



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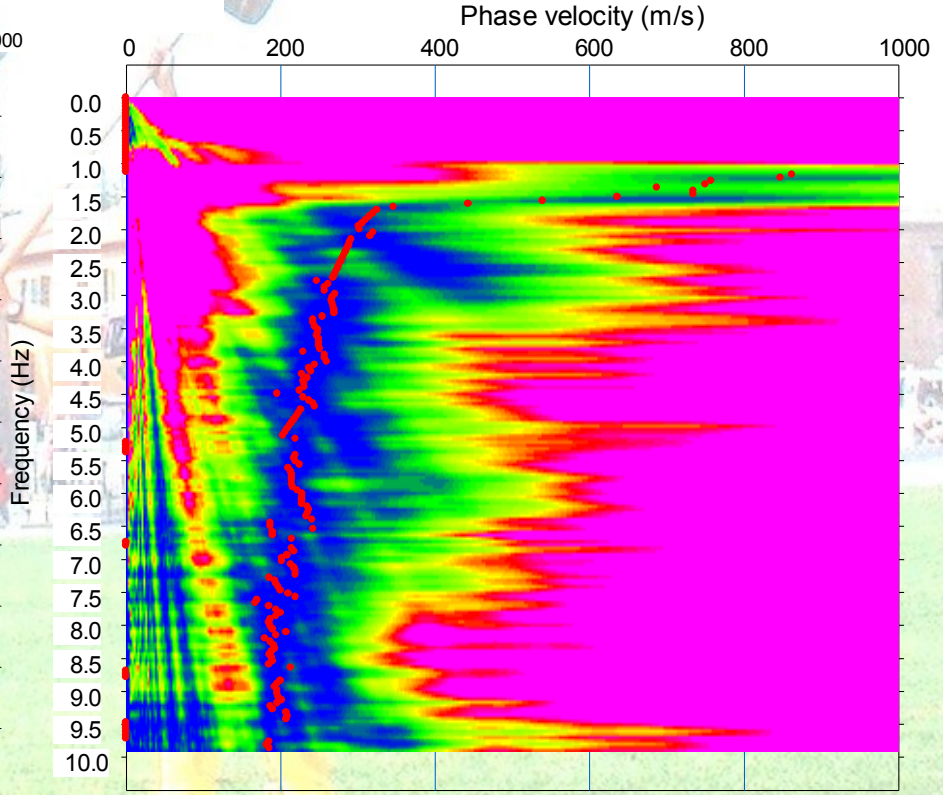
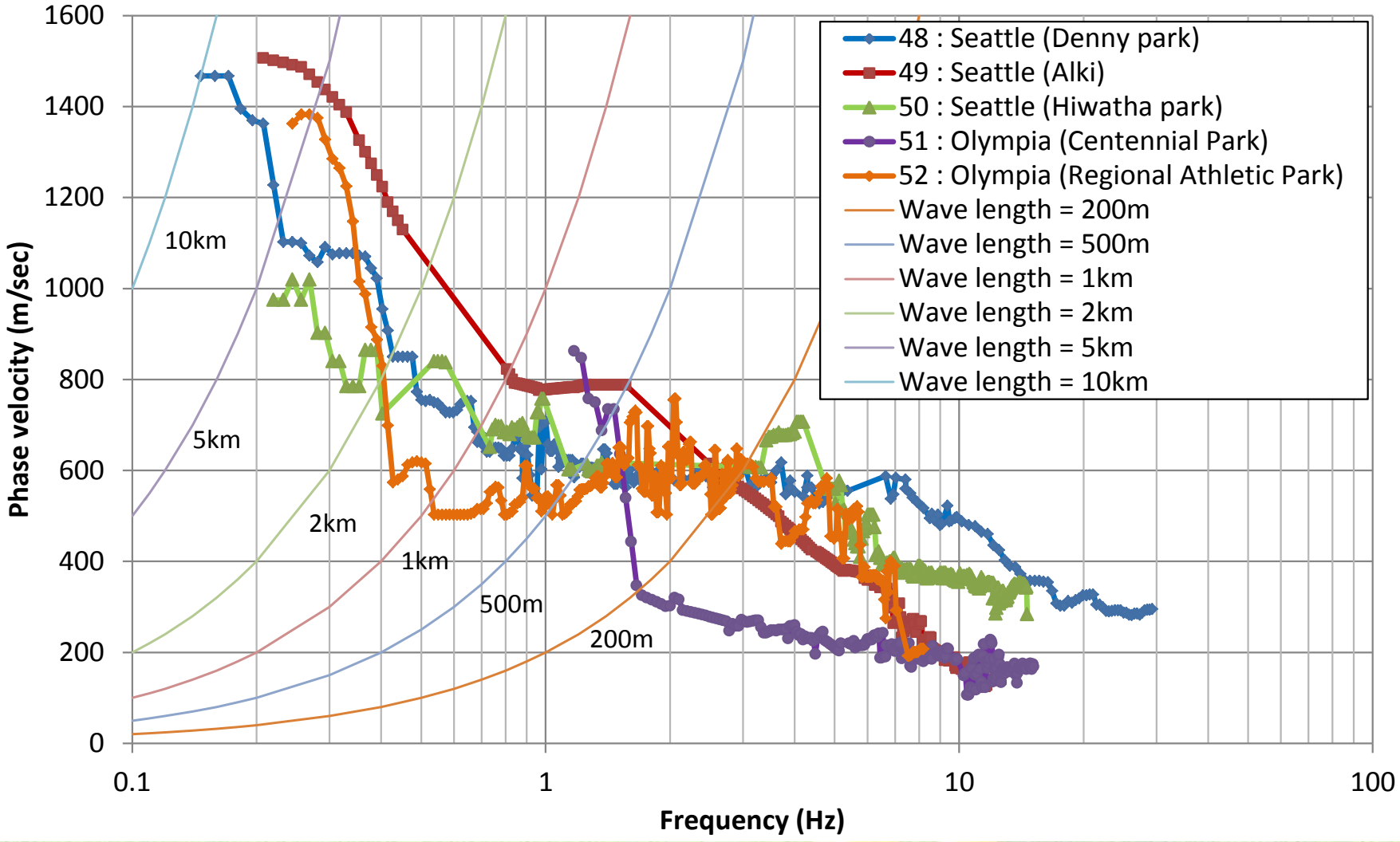
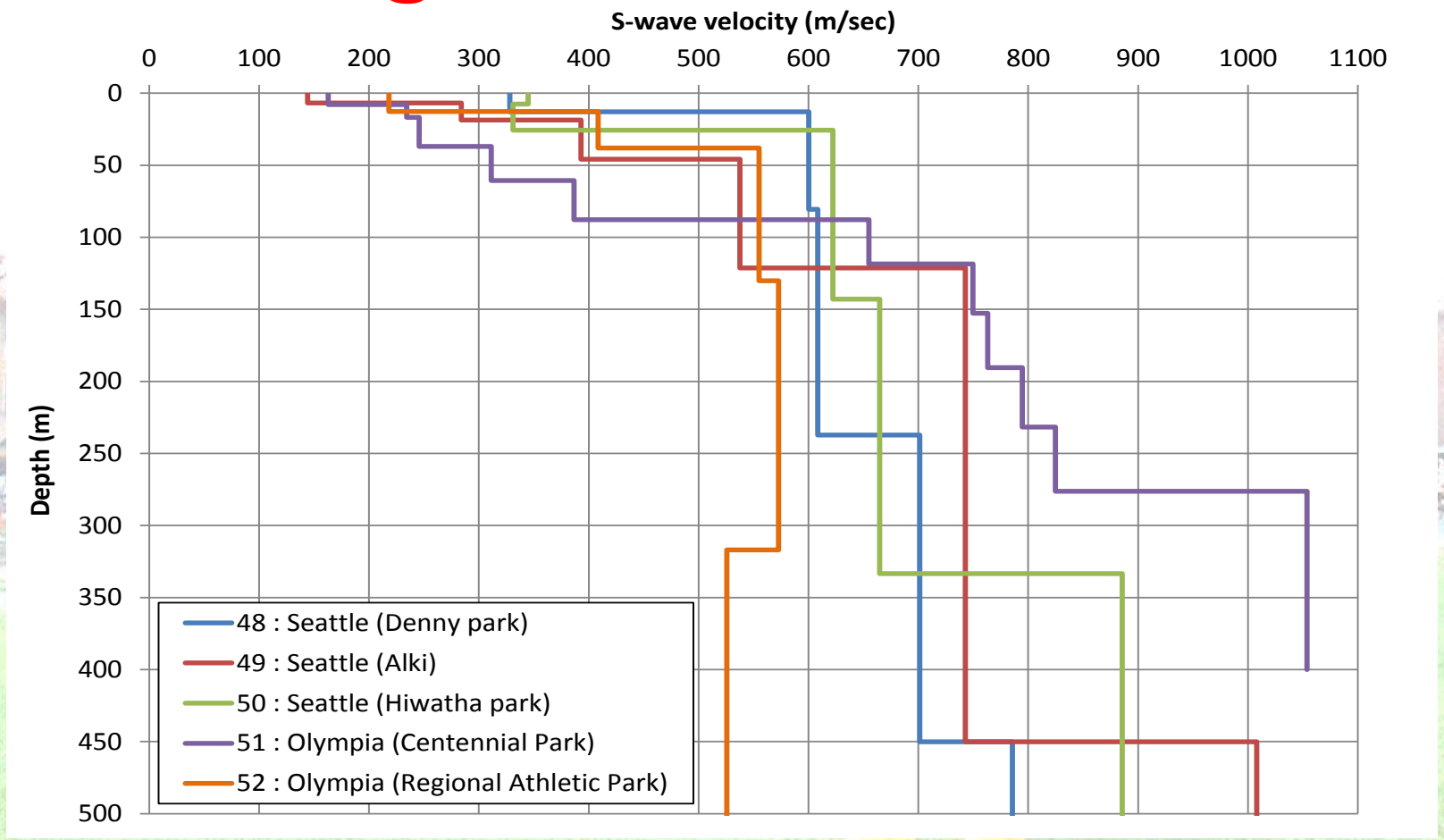


Comparison of Observed Dispersion Curves



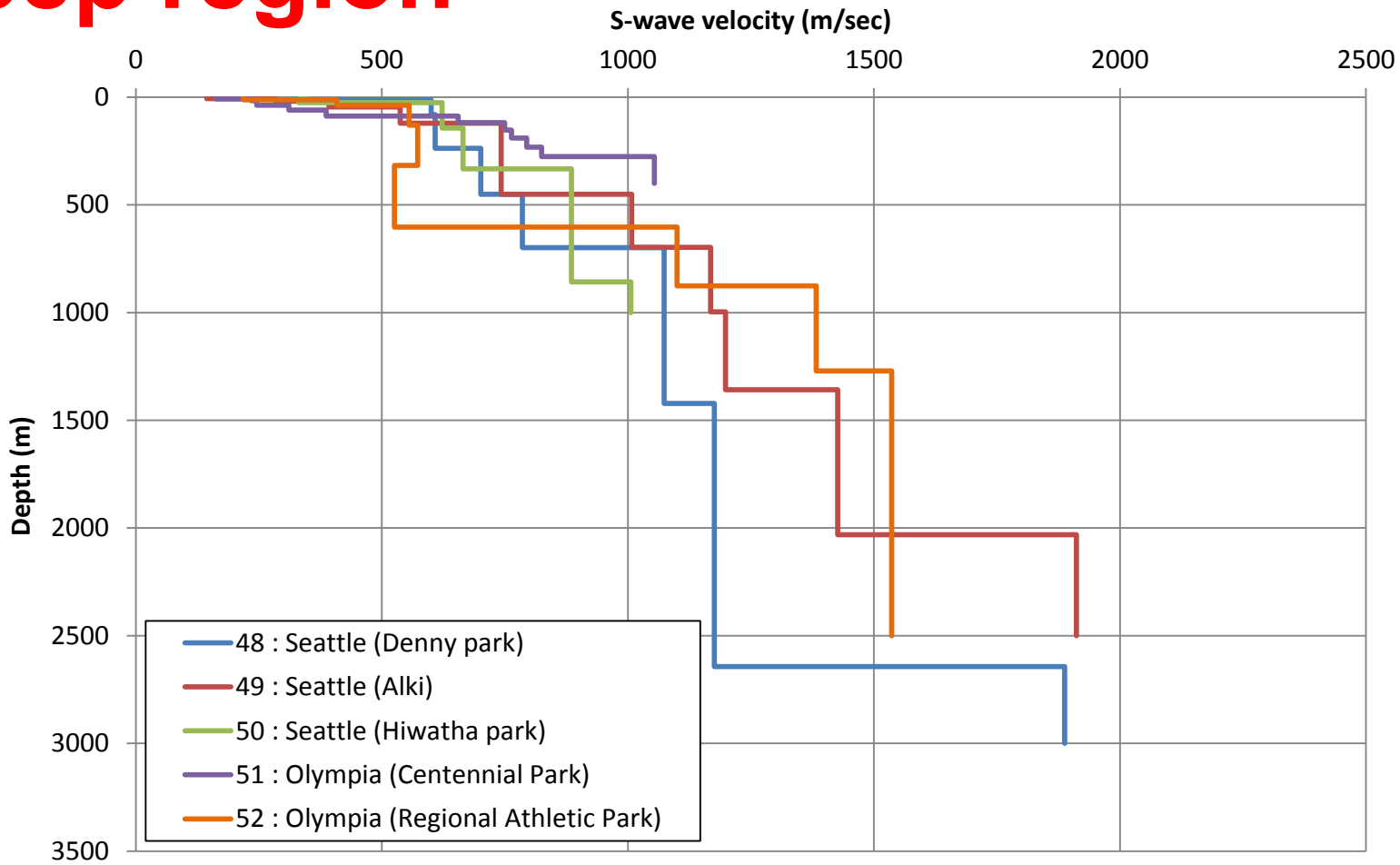
Comparison of S-wave Velocity Models Obtained by Inversion

Shallow region



Comparison of S-wave Velocity Models Obtained by Inversion

Deep region



Conclusions

- 2ST-MAM were performed at several sites in Seattle and Olympia, Washington in order to estimate deep Vs structures of the area and evaluate the applicability of the method to such investigations.
- Our investigation results imply that the 2ST-MAM can detect accurate phase velocities down to a frequency of 0.2Hz and a maximum penetration depth as deep as 2 to 3km.
- At the downtown Seattle, the bedrock with an Vs higher than 1500m/s was determined at a depth of greater than 2500m.
- At the central Olympia, a low velocity layer with Vs less than 400m/s was determined to a depth of 90m.
- These preliminary results have shown that using the 2ST-MAM method is applicable to deep and shallow depth-to-bedrock investigations, and provides fast, cost-effective and accurate Vs estimates.