In-service Assessment of Road Sinkholes with 2D Ambient Noise Tomography

GRIP Meeting 2020

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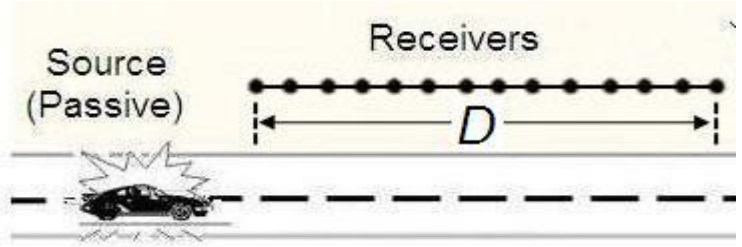
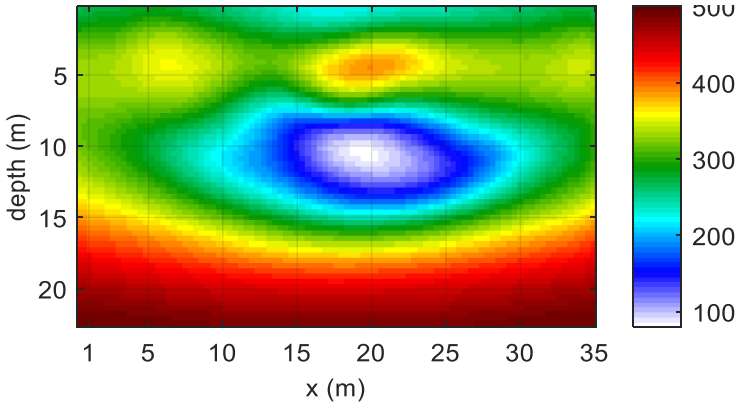




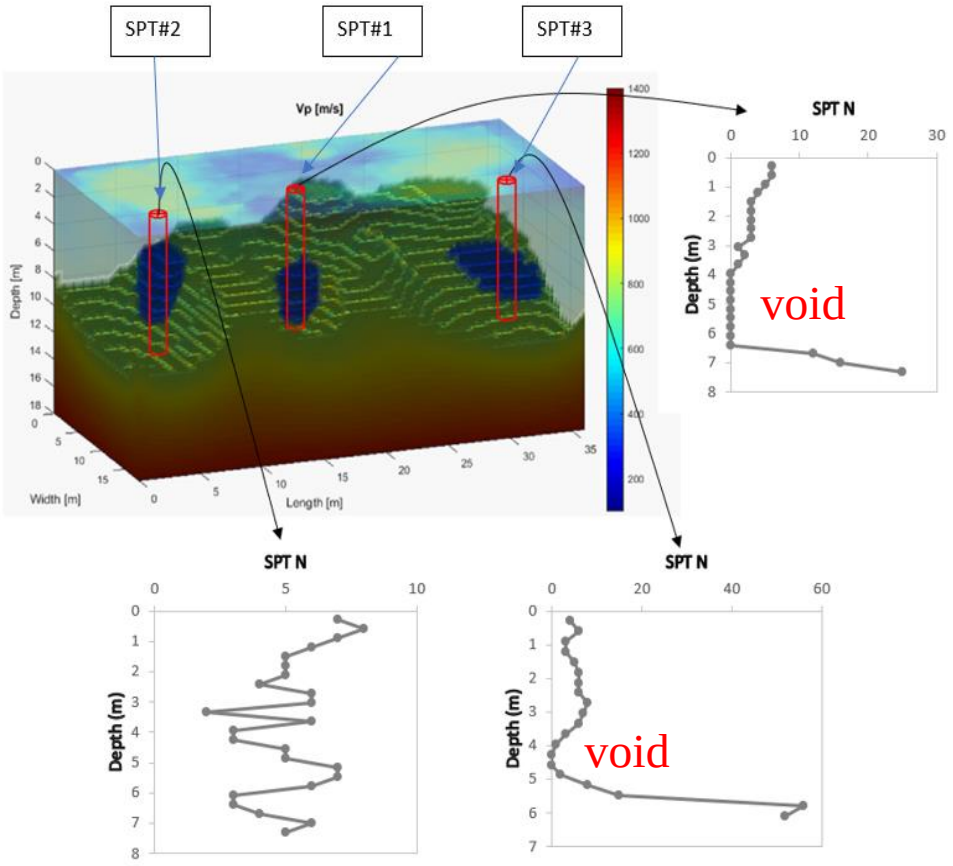
Presentation outline

- Introduction and background
- Project objective
- Research motivation
- Benefits of using traffic noise
- 2D ANT method
- Numerical experiments on void detection
- Field experiment at US 441
- Conclusion

Introduction and background

- Road sinkholes pose significant risk to the health and safety of the traveling public. Successful detection of the pre-collapsed sinkholes (buried voids) is crucial for remediation to minimize the risk.

- Existing 2D/3D full waveform inversion (FWI) methods using active wave-fields can be used to identify a buried void to a depth of three void diameters.



Example of 3D FWI at Newberry

Introduction and background

- However, 2D/3D FWI methods require multiple source impacts to generate the active wave-fields, the data acquisition time is considerable, leading to negative impacts caused by closing the traffic flow during seismic testing.

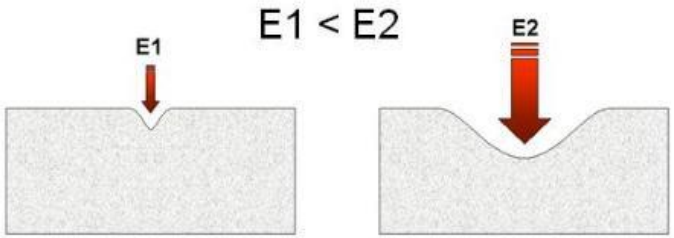
- It is risky to collect active seismic wave-fields on top of large voids, as ground perturbation by an active source may trigger collapses while persons are in the test area.

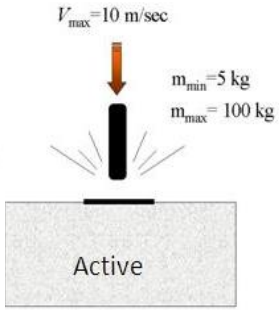
- This project goal is to reduce time of closing traffic during data acquisition, reduce the field testing risk and effort, and increase depths of investigation.

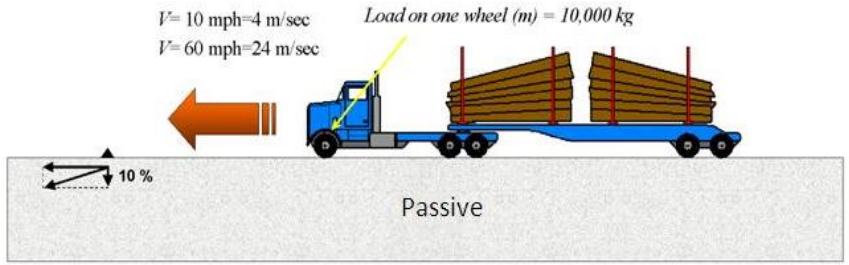
Research motivation

Impact Energy and Deformation

- Surface Deformation ∝ Impact Energy
- Impact Energy (E) ∝ Kinetic Energy = (1/2)*m*v^2







Weight Drop (V_{max}=10 m/sec)	
Mass (kg)	Energy (J)
5	250
10	500
20	1,000
50	2,500
100	50,000

Truck (*mass = 10,000 kg*)		
Speed (mph)	Total Energy (J)	10% Energy (J)
30	720,000	72,000
40	1,280,000	128,000
50	2,000,000	200,000
60	2,880,000	288,000
70	3,920,000	392,000

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Energy comparison (active vs. passive source)

Benefits of using traffic noise

- Traffic noises are rich in low frequency components at 5 to 10 Hz (from heavy trucks), which are important to resolve deep structures to 100-ft depth.

- No wave citation is needed, thus minimizing the risk of collapse due to ground perturbation as well as reducing testing efforts.

- Land-streamer geophones can be deployed quickly in a few minutes on road shoulder or land dividers, and data are acquired without closing traffic.

Challenges:

Uncontrollable wave energy, unknown source locations

Project objective

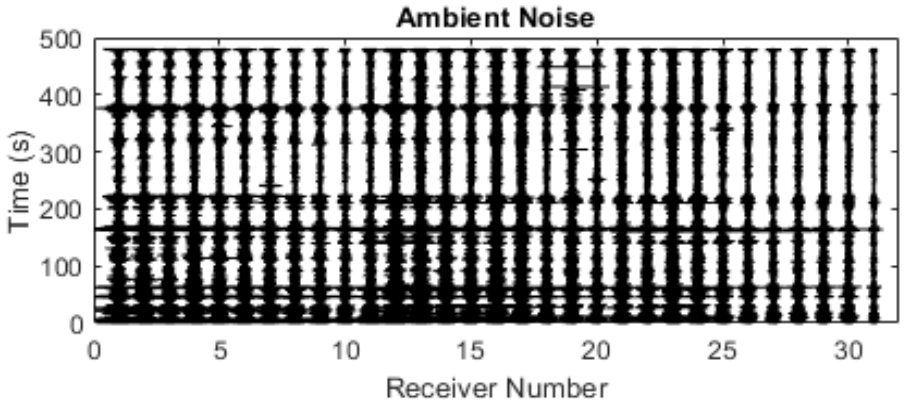
To develop a 2D Ambient Noise Tomography (2D ANT) method using traffic noise for detection of pre-collapsed sinkholes (buried voids) beneath roadways to 100 ft depth

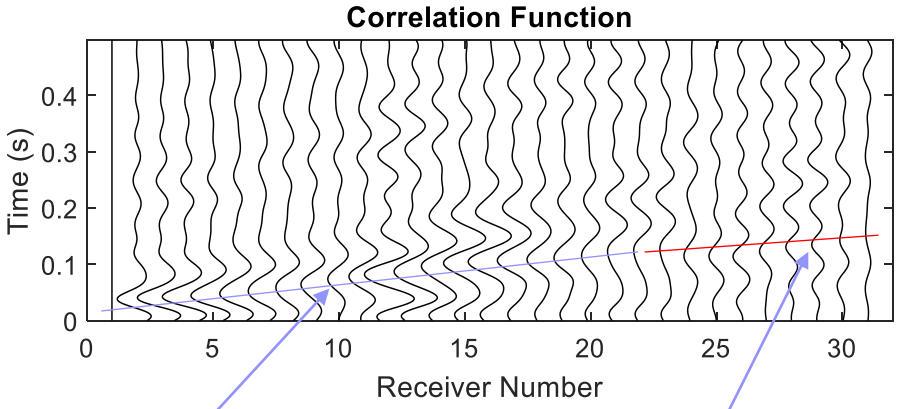
Deliverable 1: 2D ANT algorithm

- Extract measured correlation function (C) from recorded ambient noise

$$\mathbf{C}(t, x_i, x_j) = \mathbf{d}(t, x_i) * \mathbf{d}(t, x_j)$$
$$= \int_0^T \mathbf{d}(\tau, x_i).\, \mathbf{d}(t + \tau, x_j) d\tau$$

Sample traffic noise at Newberry





Direct waves

Refracted waves

2D ANT algorithm

- Simulate synthetic correlation function using 2D wave equations

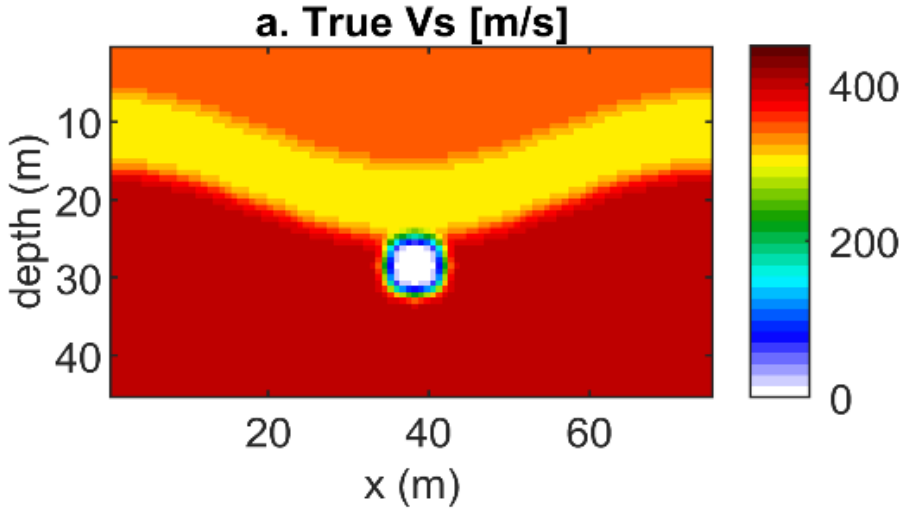
$$\mathbf{G}(t, x_i, x_j) = \mathbf{F}(t, x_i) * \mathbf{F}(t, x_j) = \int_0^T \mathbf{F}(\tau, x_i).\mathbf{F}(t + \tau, x_j) d\tau$$

- Match the synthetic and measured correlations to extract material property (Vs)

$$E = \frac{1}{2}\|G - C\|^2$$

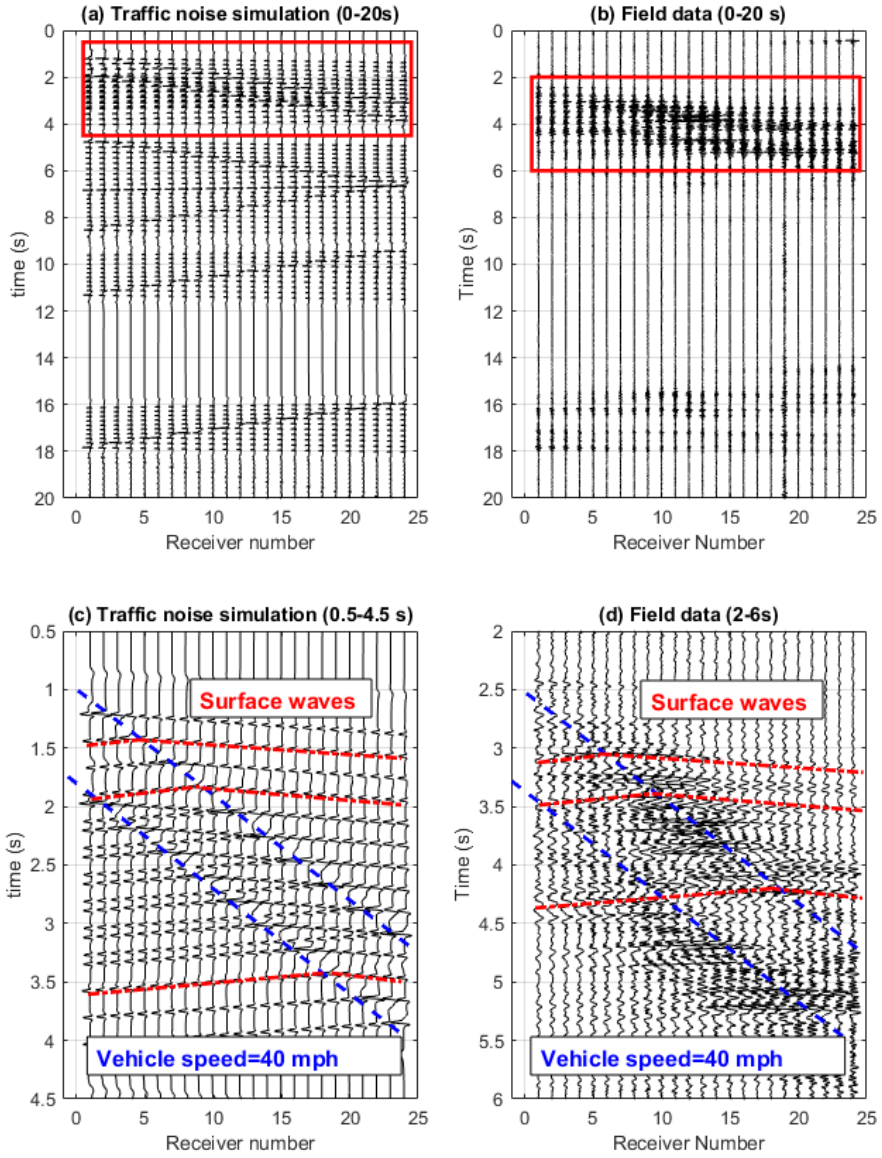
$$\mathrm{V}_s^{\mathrm{n}+1} = \mathrm{V}_s^{\mathrm{n}} + \theta_s^{\mathrm{n}} \delta V_s^n$$

Numerical experiment: one-void model



- 24 receivers on the free surface at 3-m spacing
- Noise data is modeled as moving sources (similar to vehicles)
- Noise data is then assumed as field data, and input in the 2D ANT to extract Vs, Vp.

One-void model



Data comparison

a) Synthetic 20s-length simulated traffic noise data,

b) 20s-length field data recorded on US 441 highway,

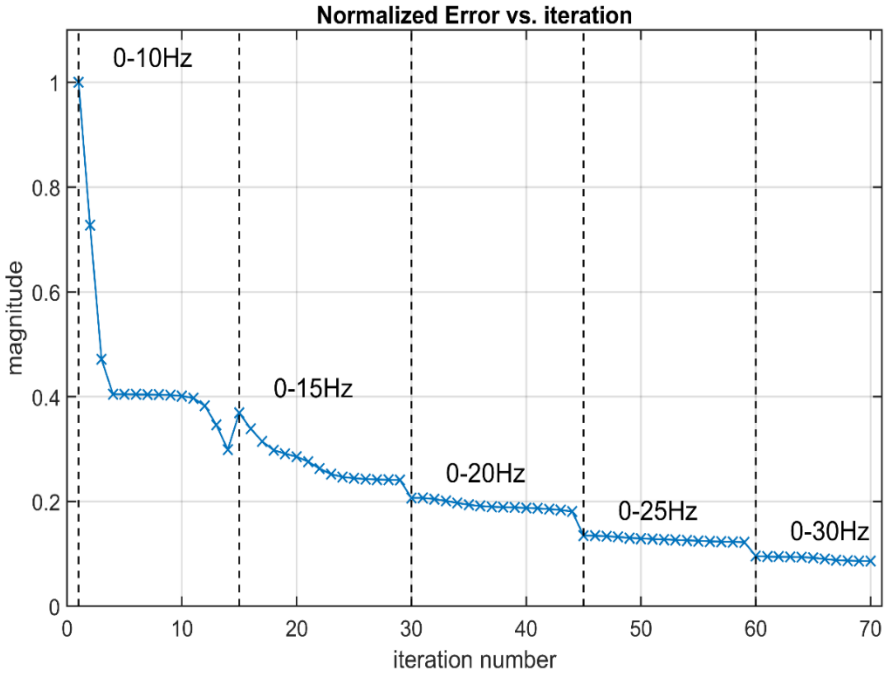
c) Blow-up of data highlighted with red rectangle in a)

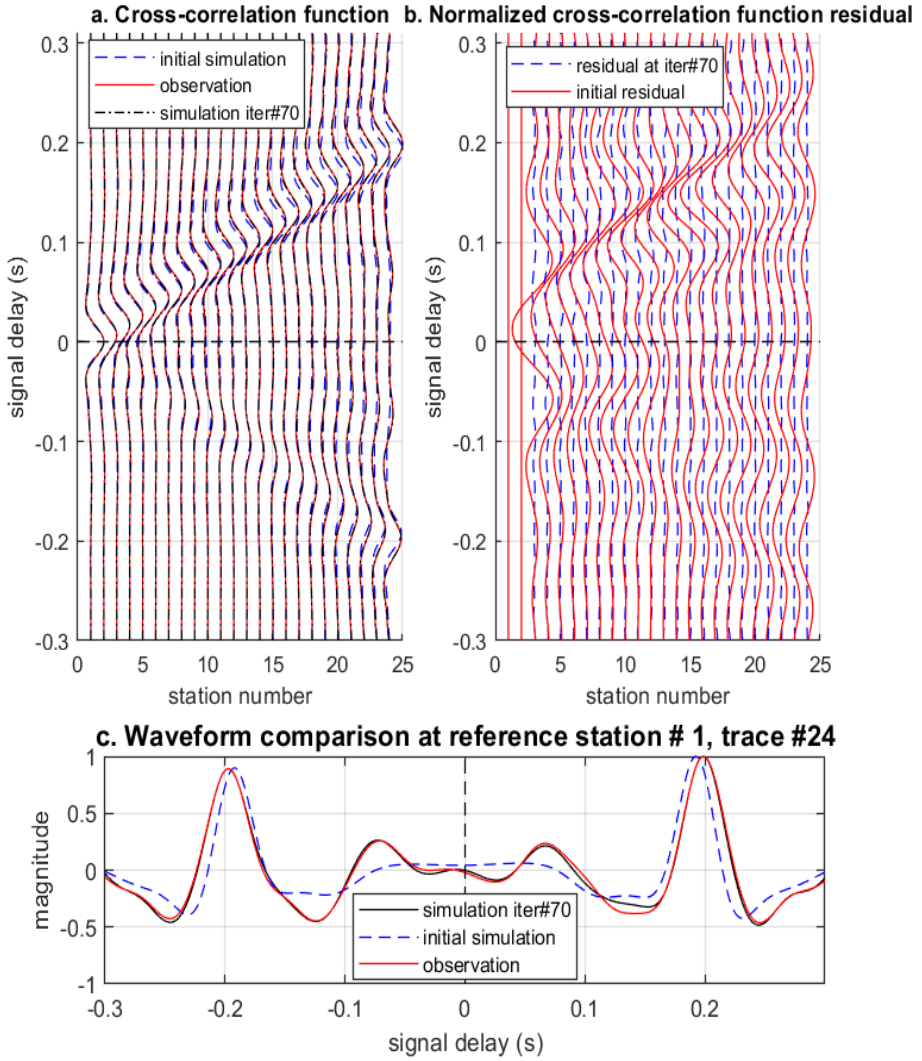
d) Blow-up of data highlighted with red rectangle in b).

One-void model

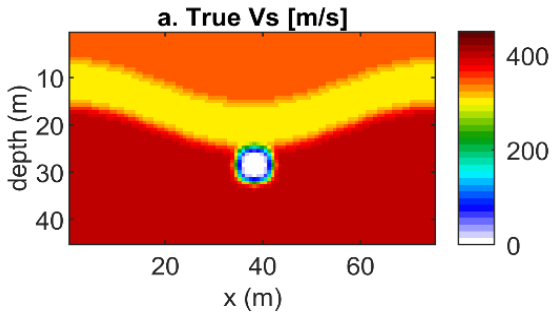
- Data analyses

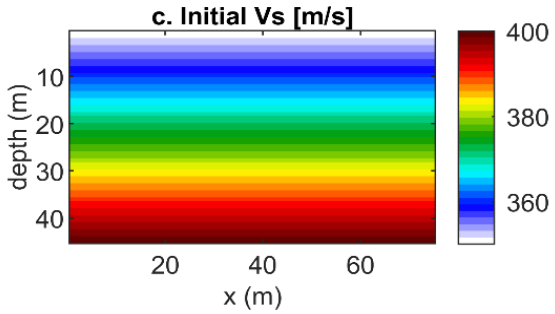
Five inversion runs at
0-10, 0-15, 0-20, 0-25, and 0-30 Hz



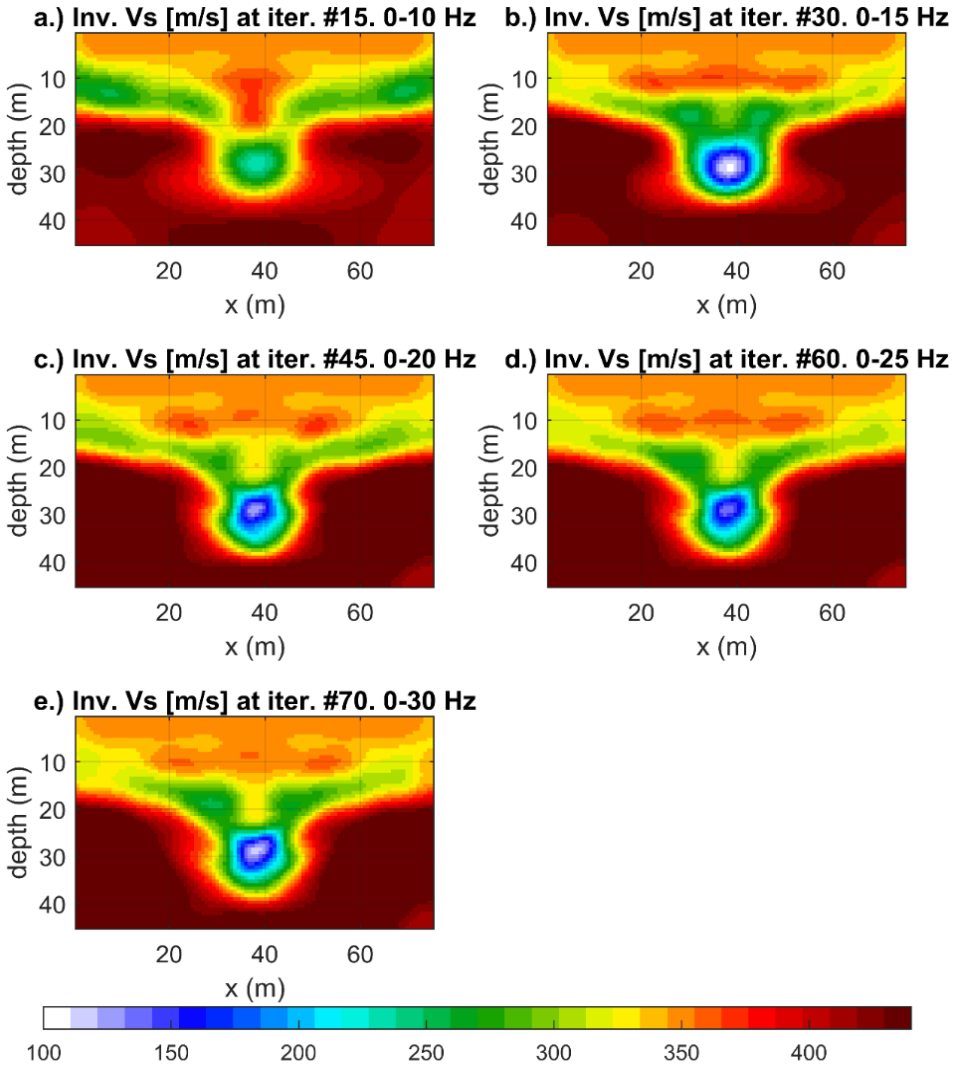


One-void model results



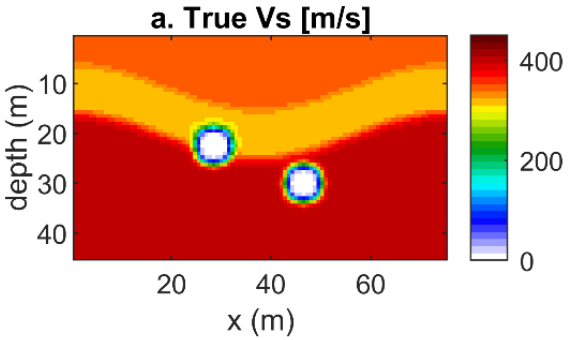


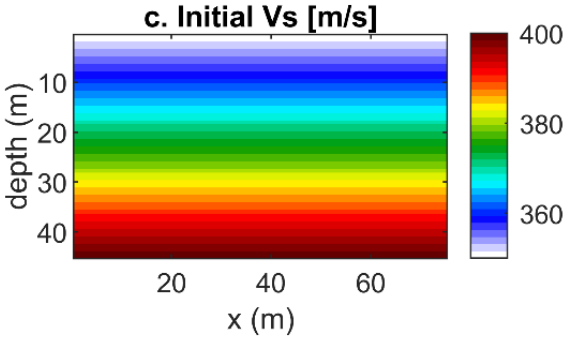
True and initial models



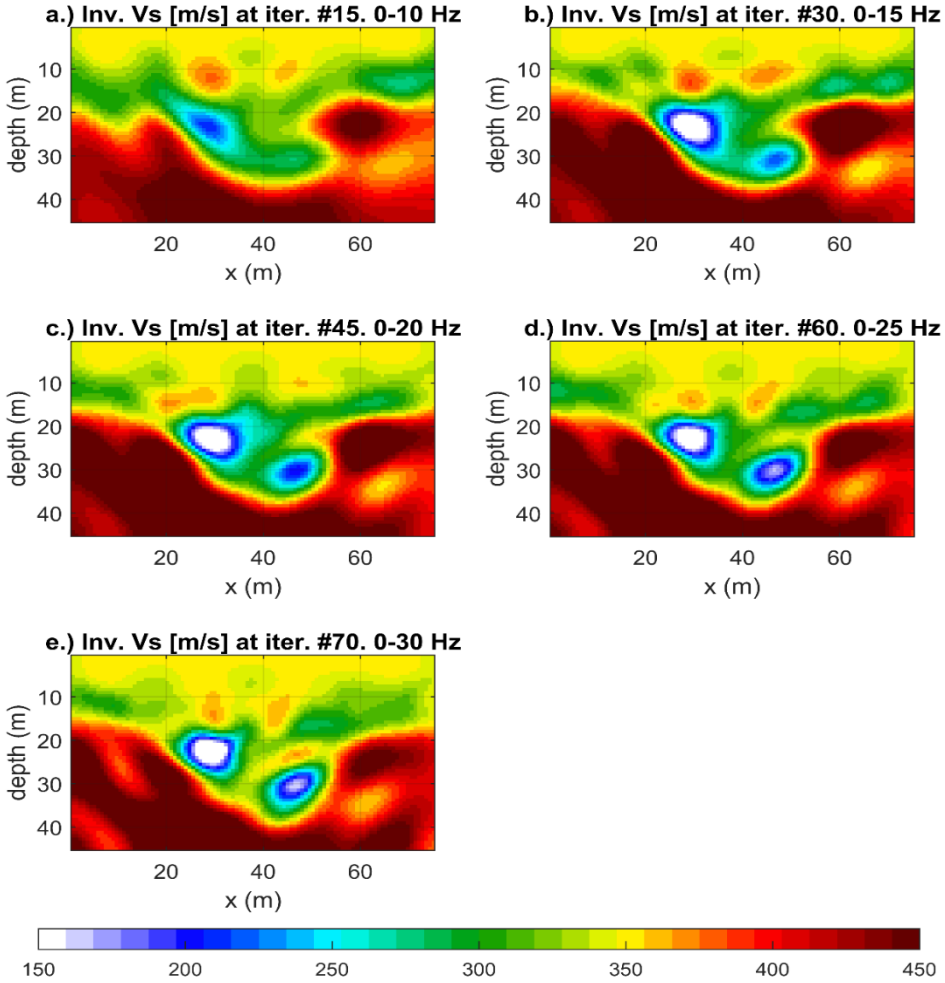
Inverted profiles of 5 inversion runs with increasing frequencies

Two-void model





True and initial models

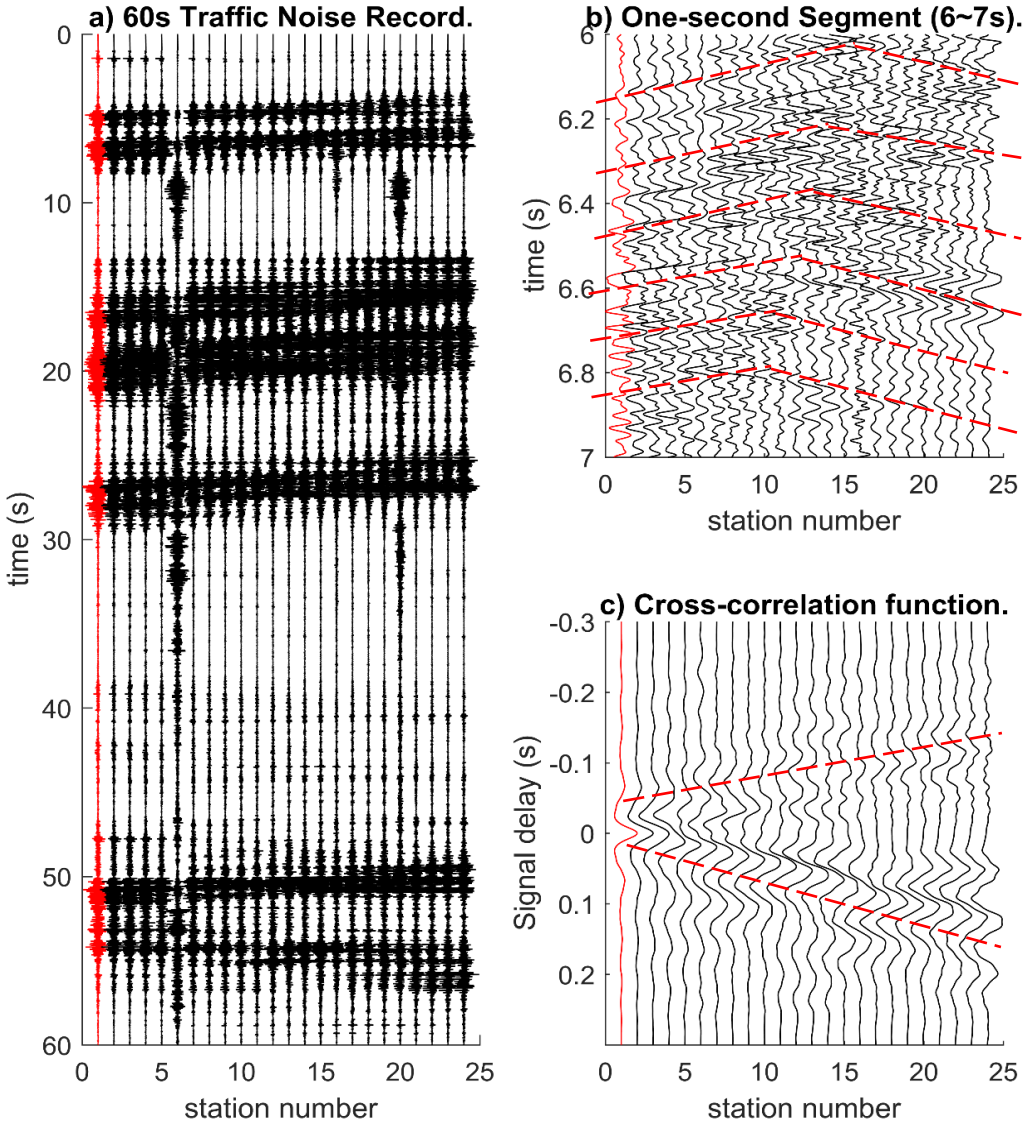


Inverted results of 5 inversion runs with increasing frequencies

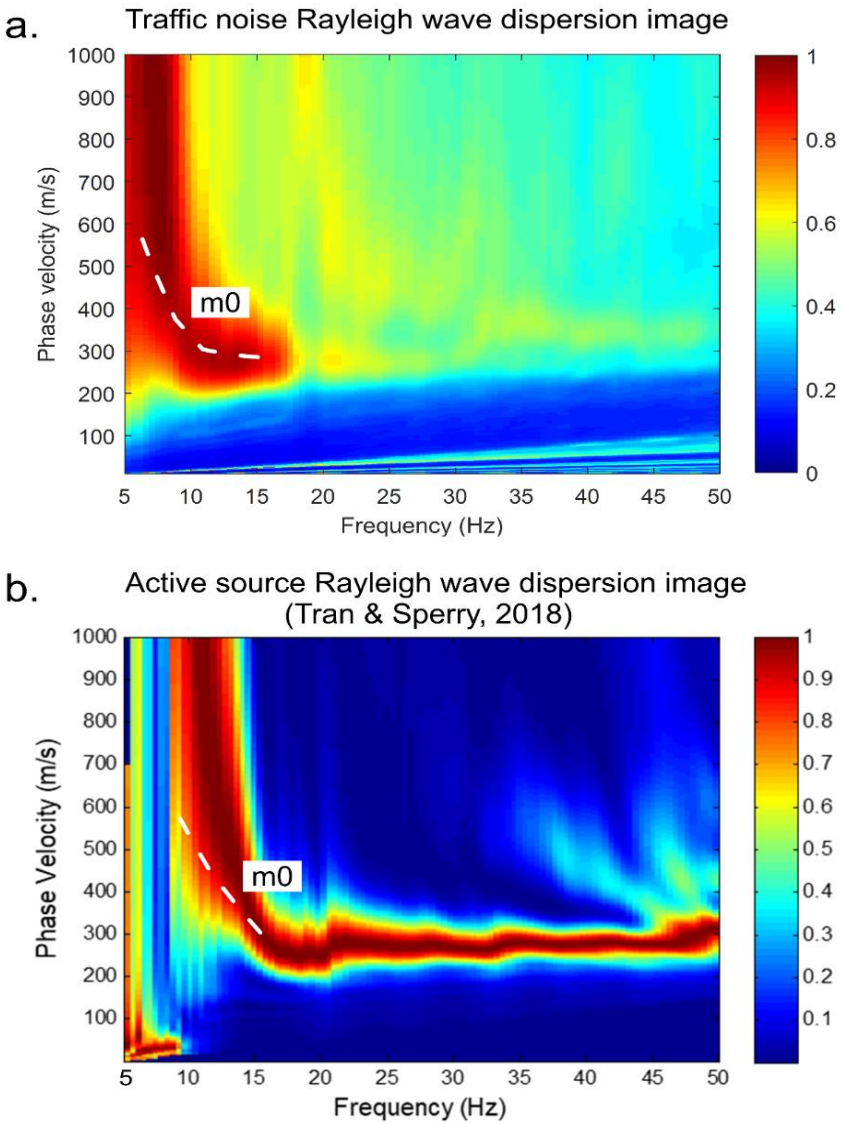
Field experiment at US 441

- 24 land-streamer geophones on the surface at 1.5-m spacing
- Traffic noises were recorded for 10 minutes with multiple passing vehicles.
- Active data by PEG (40 kg drop weight) were collected.

Field experiment at US 441



Field experiment at US 441

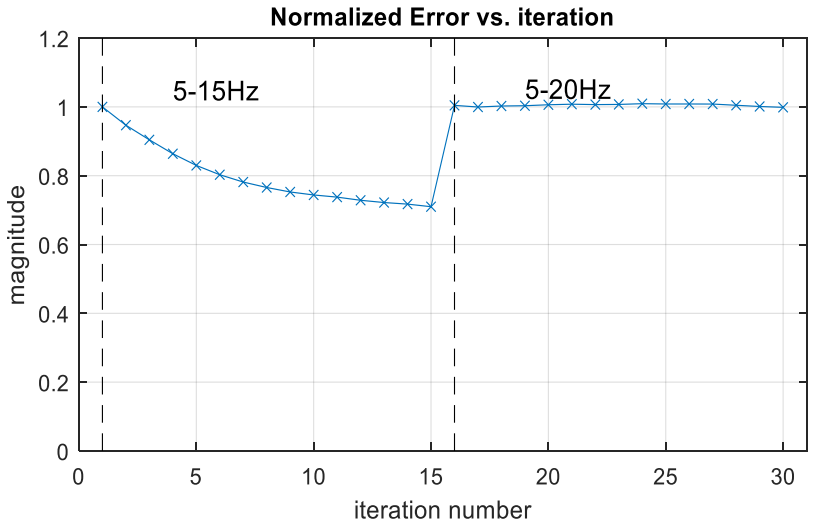


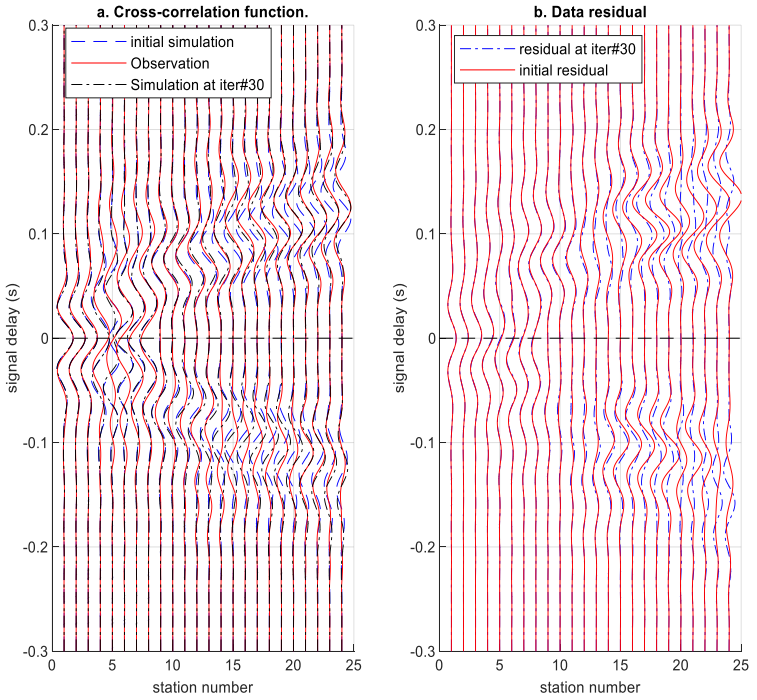
Passive vs. active wave energy comparison

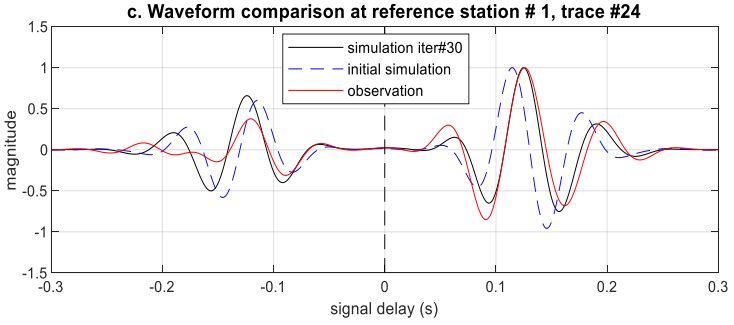
Field experiment at US 441

- Data analyses

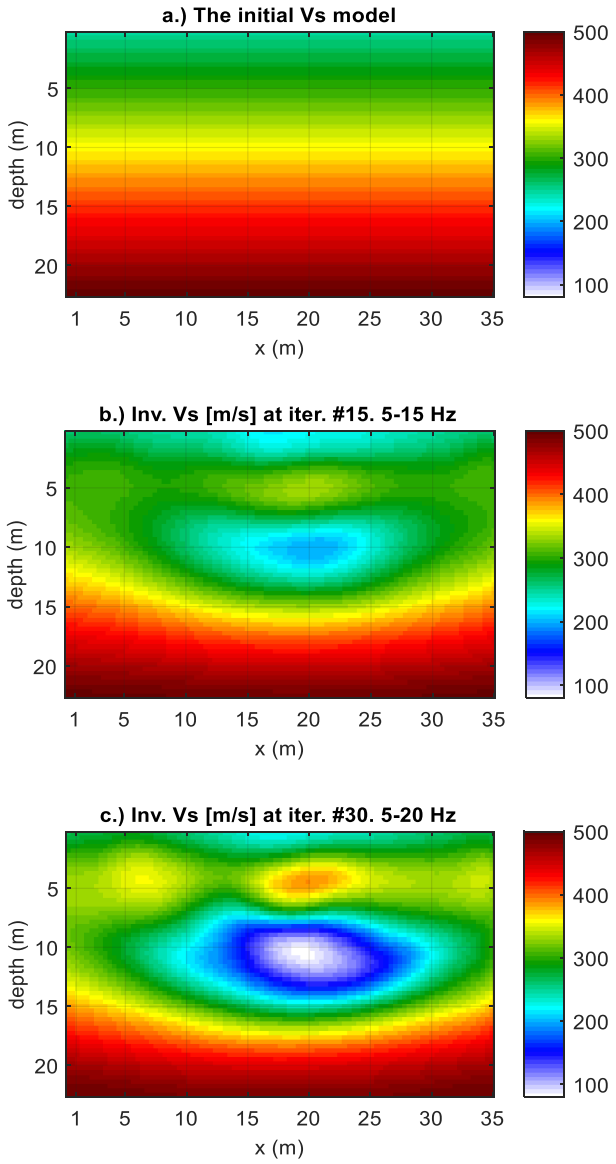
Two inversion runs at
5-15, 5-20 Hz

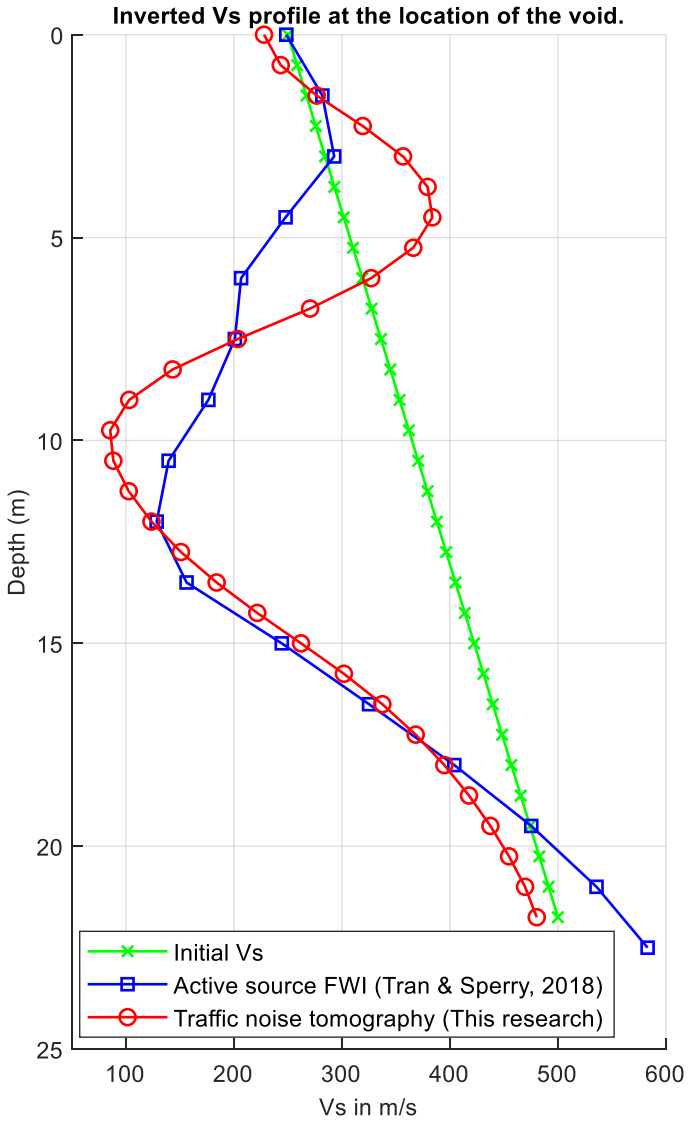






Field experiment at US 441



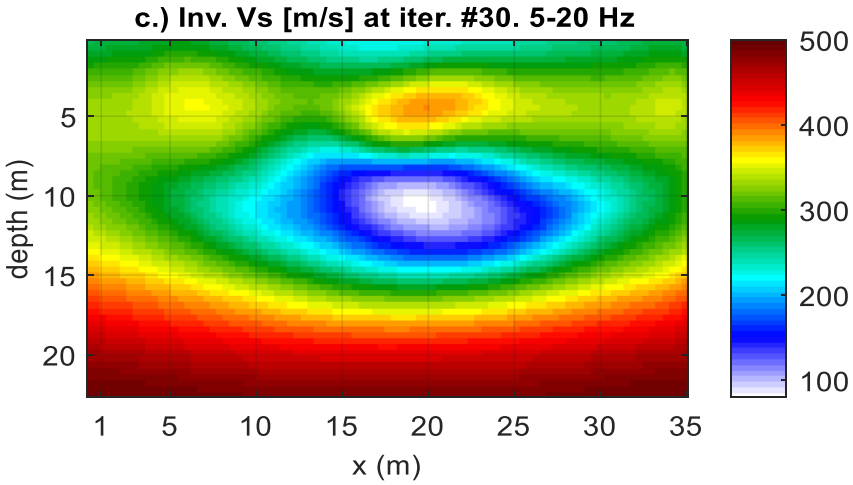


Inverted results

Conclusion

- We have developed a new 2D ANT method for void detection using ambient traffic noise
- The 2D ANT method is demonstrated on a realistic synthetic model with the accurate recovery of the model variable layers and buried voids.
- The field result shows that the 2D ANT method is capable of resolving the subsurface velocity structures and detecting a roadway anomaly/void.
- The inverted Vs profile of the 2D ANT agrees with that of 2D active-source FWI, including Vs value and depth of the anomaly.

Thank You!


c.) Inv. Vs [m/s] at iter. #30. 5-20 Hz
depth (m)
5
10
15
20
1
5
10
15
20
25
30
35
x (m)
500
400
300
200
100