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

GRIP Meeting 2019

Project Manager
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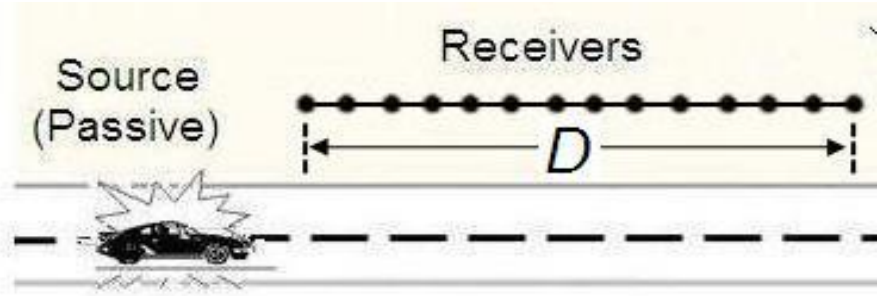

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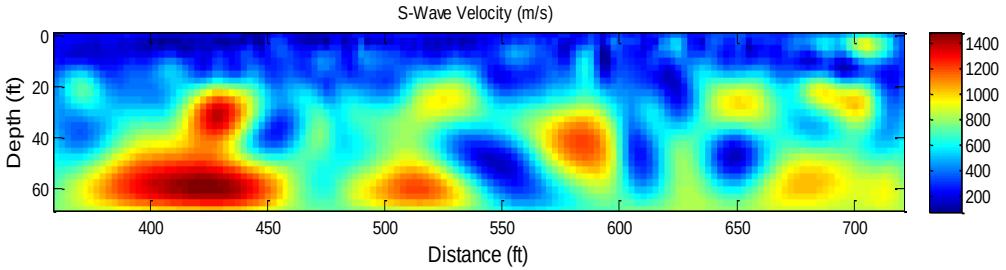


Project objective

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

Problem statement

- Existing 2D/3D full waveform inversion (FWI) methods using active-source wave-fields can be used to identify a buried void to a depth of three void diameters, up to 60 ft depth

- 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 under seismic testing

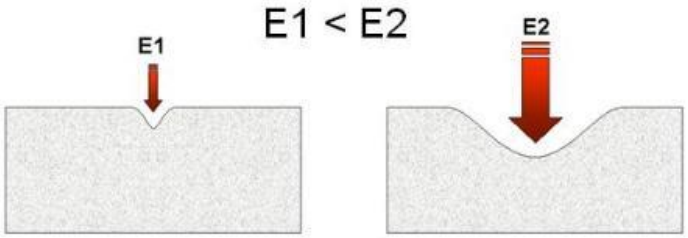
- It is risky to collect active seismic wave-fields on top of large voids, as ground perturbation by an active source may trigger collapses while persons are in the test area.

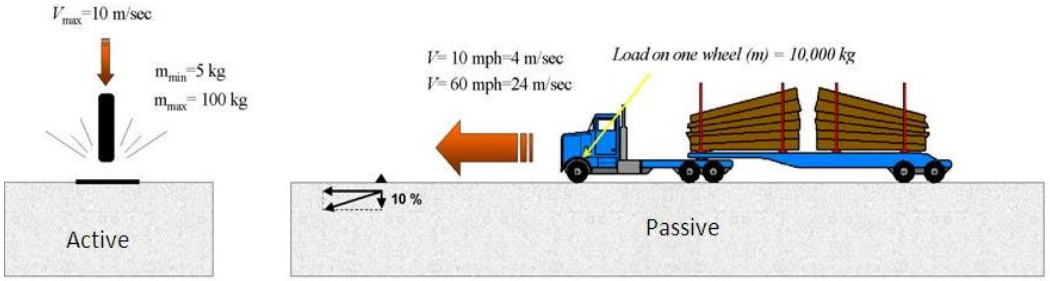
- This project aims to eliminate the requirement of closing traffic during data acquisition, and reduce the field testing risk and effort.

Energy comparison (active vs. passive source)

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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Benefits and challenges of ambient noise

- Traffic noises are rich in low frequency components at 2 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.

- Wireless/land-streamer geophones can be deployed quickly in a few minutes, and data are acquired without closing traffic.

Challenges:

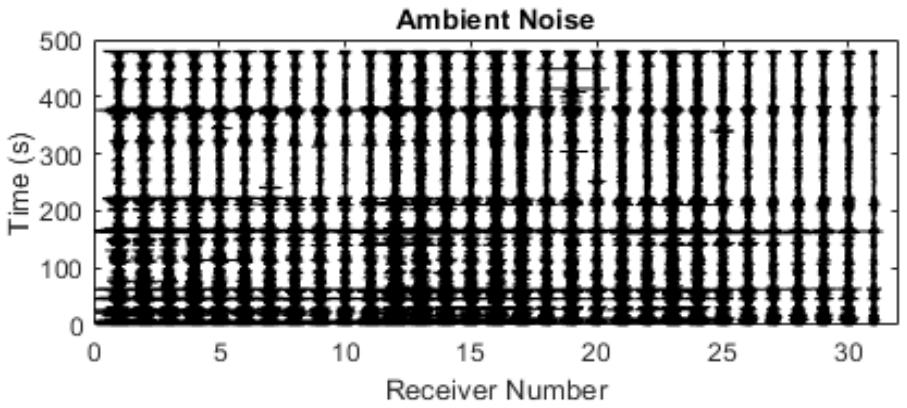
Uncontrollable wave energy, unknown source locations

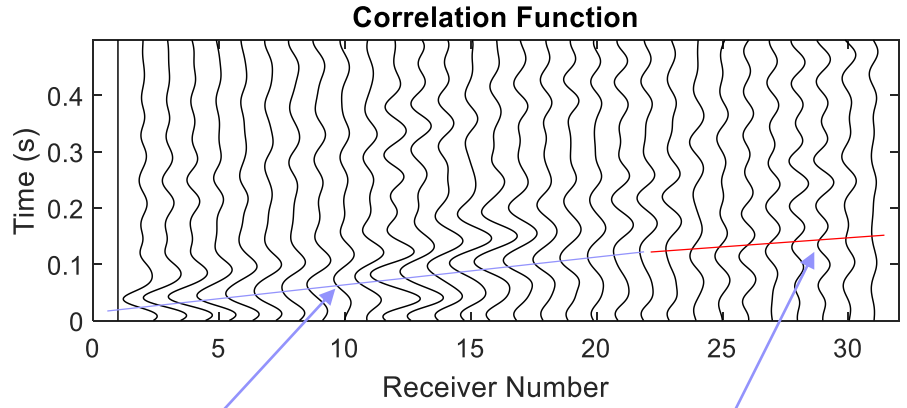
Task 1: Develop 2D ANT computational algorithm

- 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

Task 1: Develop 2D ANT computational algorithm

- Simulate synthetic correlation function (G) wave equations and match with the measured one (C)

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

- The partial derivative of the correlation function between receivers at x_i and x_j with respect to a model parameter m_p is computed as:

$$\mathbf{J}_{i,j}^{p} = \frac{\partial \mathbf{G}(t, x_i, x_j, \mathbf{m})}{\partial m_p} = \frac{\partial \left(\mathbf{F}(t, x_i, \mathbf{m}) * \mathbf{F}(t, x_j, \mathbf{m}) \right)}{\partial m_p}$$

$$= \frac{\partial \left(\int_0^T \mathbf{F}(\tau, x_i, \mathbf{m}).\, \mathbf{F}(t+\tau, x_j, \mathbf{m}) d\tau \right)}{\partial m_p}$$

$$= \int_0^T \frac{\partial \mathbf{F}(\tau, x_i, \mathbf{m})}{\partial m_p} . \mathbf{F}(t+\tau, x_j, \mathbf{m}) d\tau + \int_0^T \mathbf{F}(\tau, x_i, \mathbf{m}). \frac{\partial \mathbf{F}(t+\tau, x_j, \mathbf{m})}{\partial m_p} d\tau$$

$$= \frac{\partial \mathbf{F}(t, x_i, \mathbf{m})}{\partial m_p} * \mathbf{F}(t, x_j, \mathbf{m}) + \mathbf{F}(t, x_i, \mathbf{m}) * \frac{\partial \mathbf{F}(t, x_j, \mathbf{m})}{\partial m_p}$$

Task 2: Optimize field testing configurations and investigate impacts of ambient noises characteristics

- Develop the optimal test configurations (number and spatial density of receivers) that will be used for field test

- Investigate the required ambient noise frequency range for characterization of subsurface profiles to 100-ft depth; the required frequency range will be used to determine the recording time of traffic noises in the field

- This task will be done via numerical investigation (e.g. simulate synthetic ambient noise & analyze by 2D ANT algorithm from Task 1)

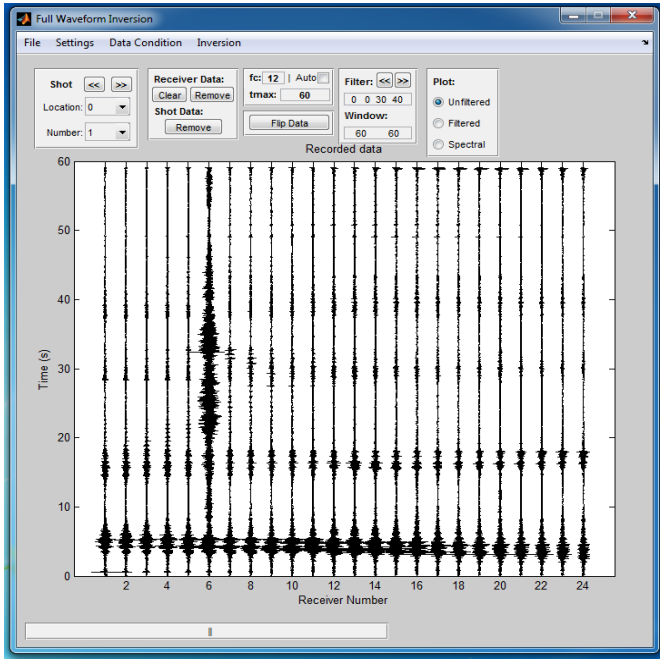
Task 3: Verify 2D ANT method at field sites with ground truth

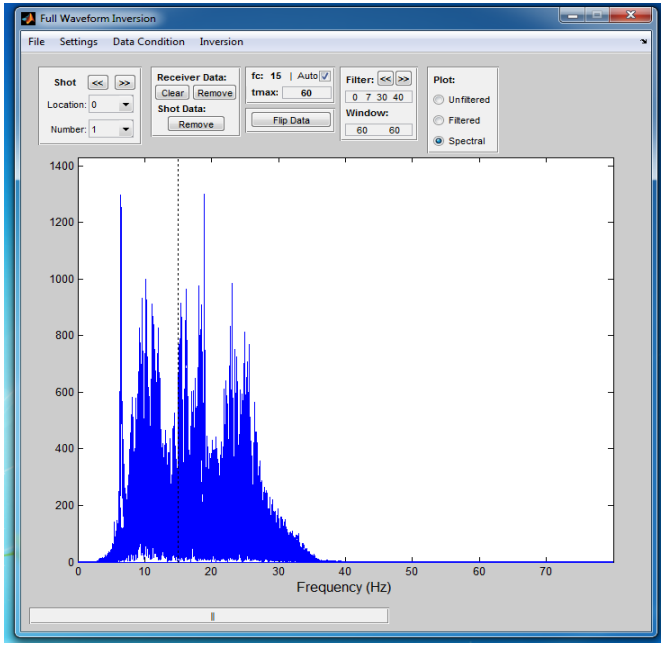
- 2D ANT will be verified at 2 test sites (US 441 and another)
- 24-channel wireless geophone system and 24-channel land-streamer (wire) system
- Geophone array is expected to be at least 200-ft in length
- Recorded traffic noise will be analyzed in the field

Land-streamer

Task 4: Implement the 2D ANT algorithm into existing 2D FWI software

- GUI for 2D ANT will be done in Matlab and converted to executable file
- Users can graphically input receiver locations, raw ambient noise data, condition and analyze data





Task 5: Draft Final and Closeout Teleconference

Task 6: Final Report

Thank you!