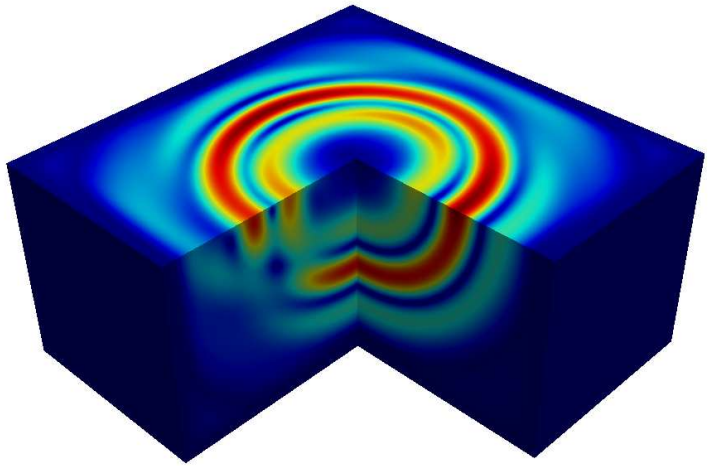
Sinkhole Detection with 3-D Full Elastic Seismic Waveform Tomography

GRIP Meeting 2017

Project Manager:
David Horhota, Ph.D., P.E.



Primary Researchers
Michael McVay, PhD., University of Florida
Scott Wasman, Ph.D., University of Florida
Khiem Tran, PhD., Clarkson University

Need for improved sinkhole detection

- Potential for collapse and fatalities
- Distress of existing structures
- New construction near existing void?

Site investigation

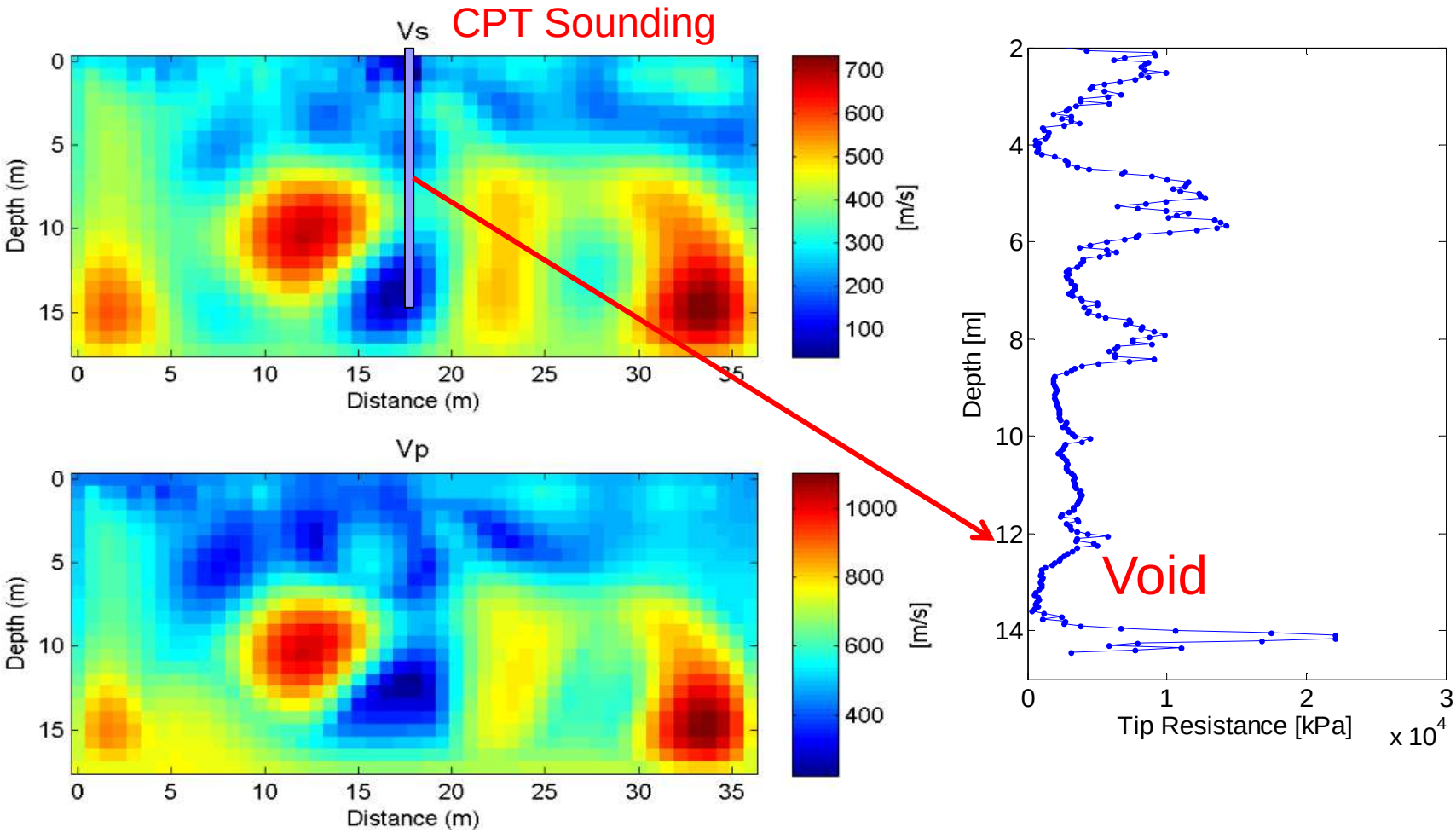
- Identify soil/rock stratigraphy
- Typical invasive testing SPT, CPT – tests < .1% of material
- Need for NDT over large area which can detect anomalies (NDT is faster and cheaper than most invasive tests)

Massive sinkhole (250 x 220 x 50 ft) damaged 2 homes in Land O'Lakes, FL (July 14, 2017)

Prior 2-D FWI study: US441

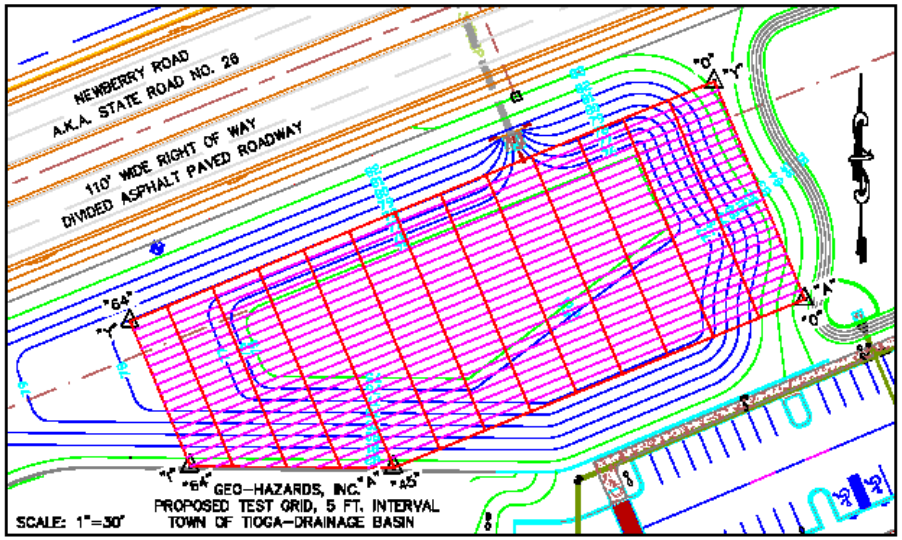
- Repaired sinkhole (known location)
- Land-streamer of 120 ft. length
- 24 geophones at 5 ft. spacing
- Propelled energy generator

Prior 2-D FWI study: US441

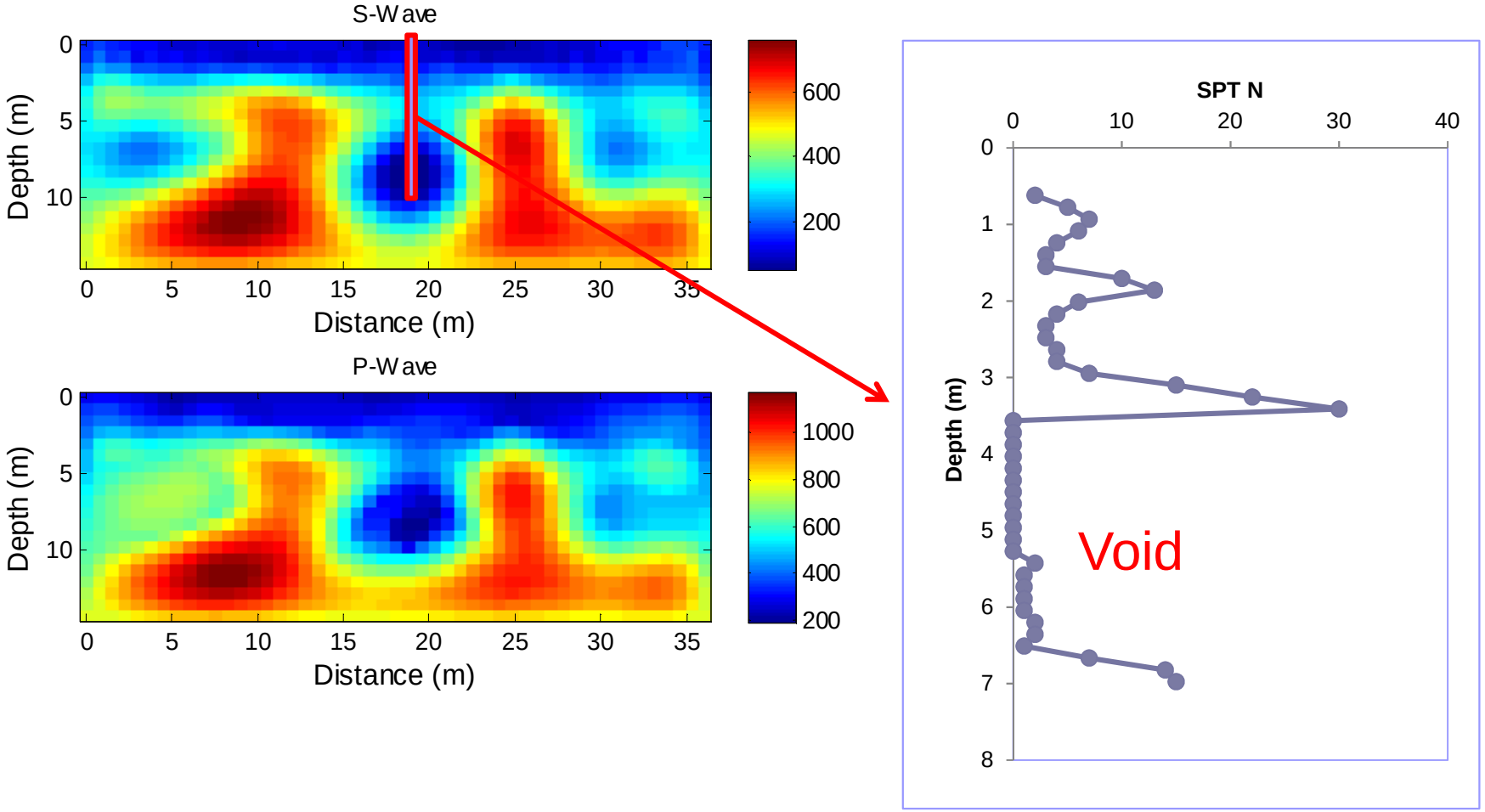


Prior 2-D FWI study: Newberry, FL

- Search for sinkholes (unknown location)
- 10 test lines of 36 m long at 3 m apart



Prior 2-D FWI study: Newberry



Capabilities and limitations of 2-D FWI method

Capabilities :

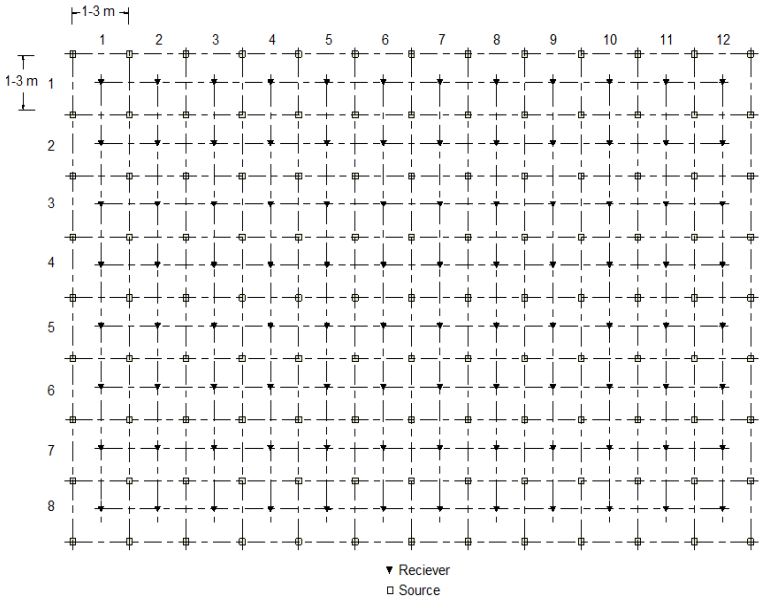
- Both S-wave and P-wave velocities are characterized at high resolution (e.g. 2 ft x 2 ft cell)
- Unknown voids can be identified down 50-60 ft in depth
- Waveform analysis is automated, and developed GUI takes 30 minutes for each test line of 120 ft.

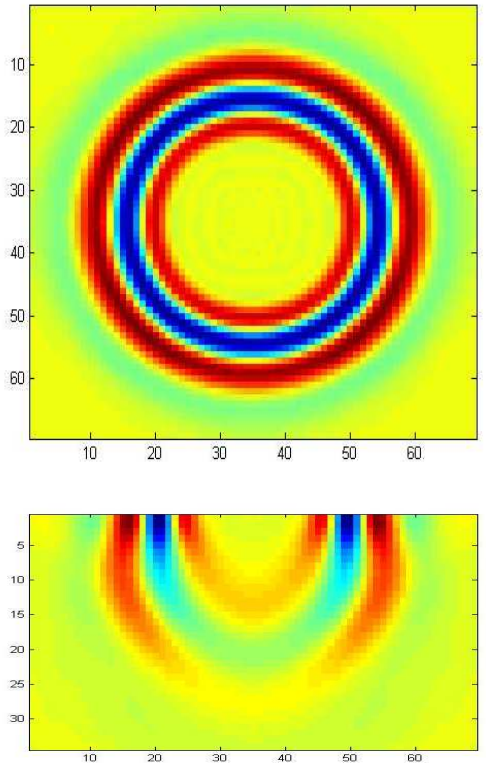
Limitations:

- 2-D FWI still requires significant field testing effort to identify an unknown void
- Due to 3-D effects, offline voids may appear (false alarm) as distort anomalies
- Due to 3-D effects, material properties are averaged out of testing plane, less accurate if compared to invasive tests (point by point)

Proposed 3-D full waveform tomography

- Use 2-D uniform grids of geophones and shots on the ground surface
- Invert measured data to extract 3-D velocity structures directly below the test area
- Completely address 3-D effects, potentially produce more accurate and higher resolution results than 2-D FWI





Propagation of 3-D waves: plan view on surface (top) and side view (bottom).

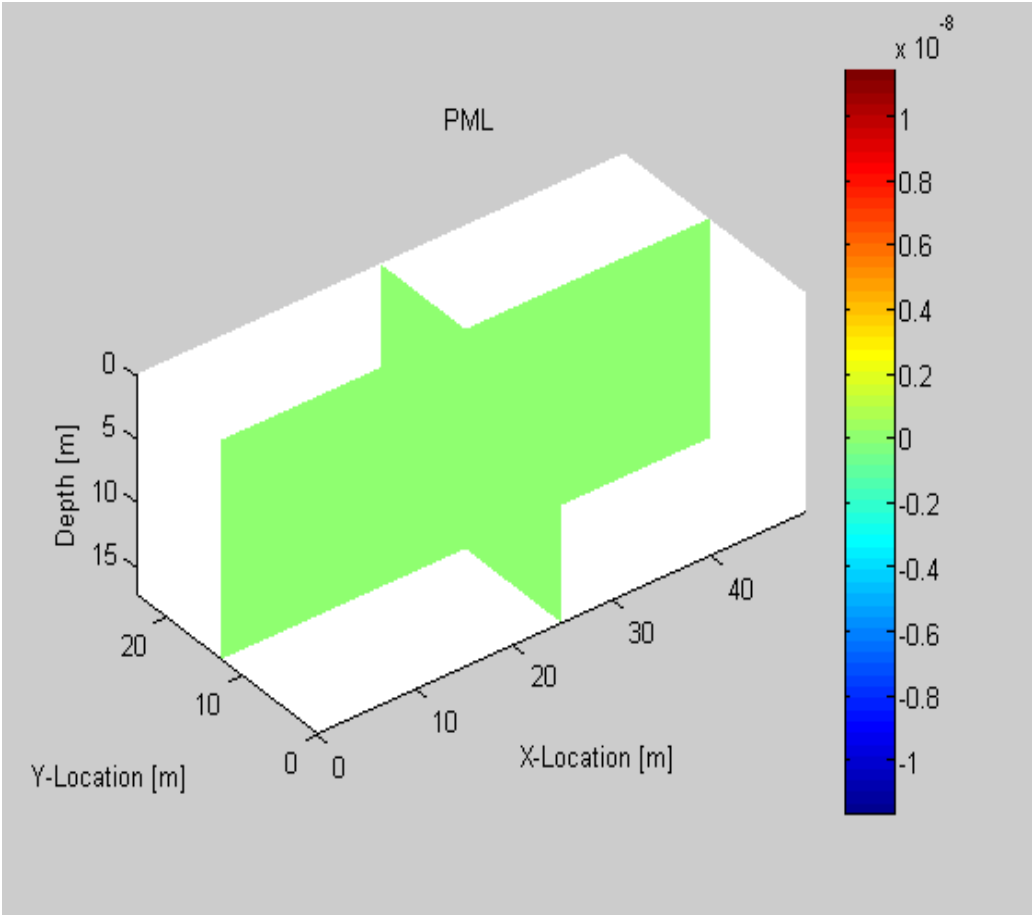
Task 1: *Development of 3-D FWI Algorithm for Void Detection*

- 3-D wave equations

$$\rho \frac{\partial v_i}{\partial t} = \frac{\partial \sigma_{ij}}{\partial x_j} + f_i \quad where\ i, j = 1,2,3$$

$$\frac{\partial \sigma_{ij}}{\partial t} = \lambda \frac{\partial v_k}{\partial x_k} + 2\mu \frac{\partial v_i}{\partial x_j} \quad \text{if} \quad i \equiv j$$

$$\frac{\partial \sigma_{ij}}{\partial t} = \mu \left(\frac{\partial v_i}{\partial x_j} + \frac{\partial v_j}{\partial x_i} \right) \quad \text{if} \quad i \neq j$$

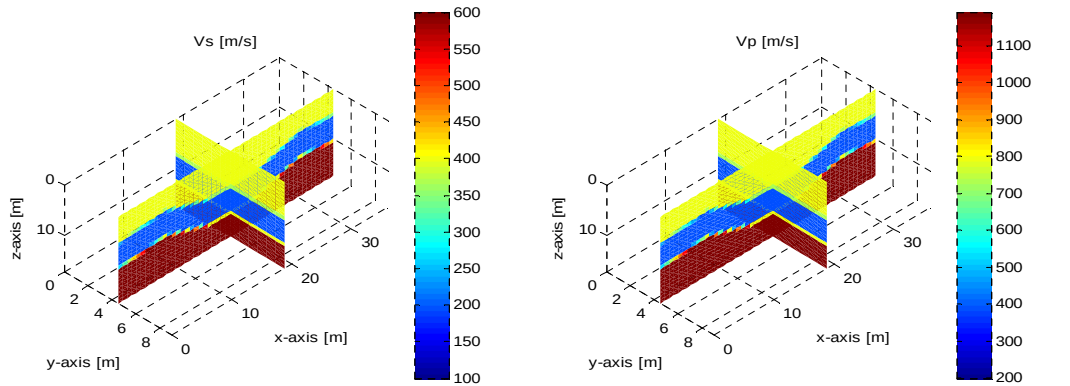


- Inversion by cross-adjoin gradient method

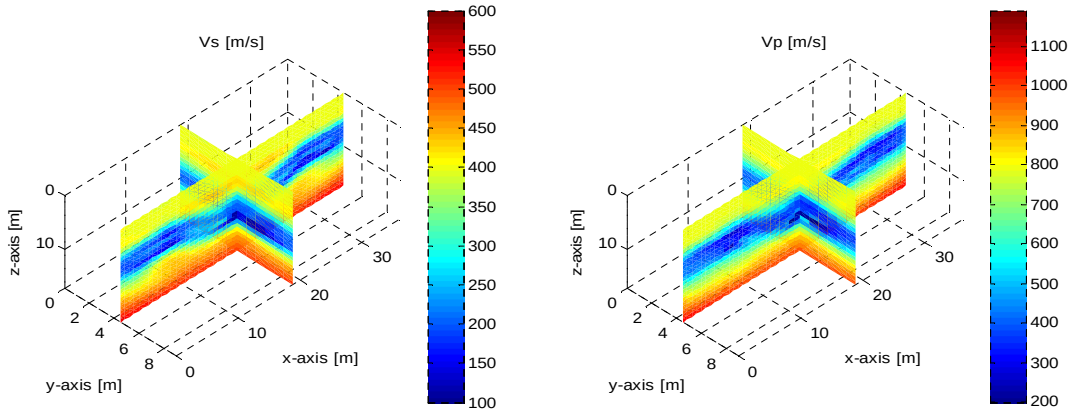
  - Match modeled (estimated) to measured seismic data to extract material properties (Vs, Vp) of subsurface structures

Task 2: *Optimization of Test Configurations and Active Sources for Void Detection*

- Develop efficient test configurations (source and sensor locations)
- Investigate the optimal frequency range for selection of active sources (drop height, sizes of impact plates)
- Preliminary study on synthetic data, it takes about 40 hours for layer profile (no void). Need to cut computer time.



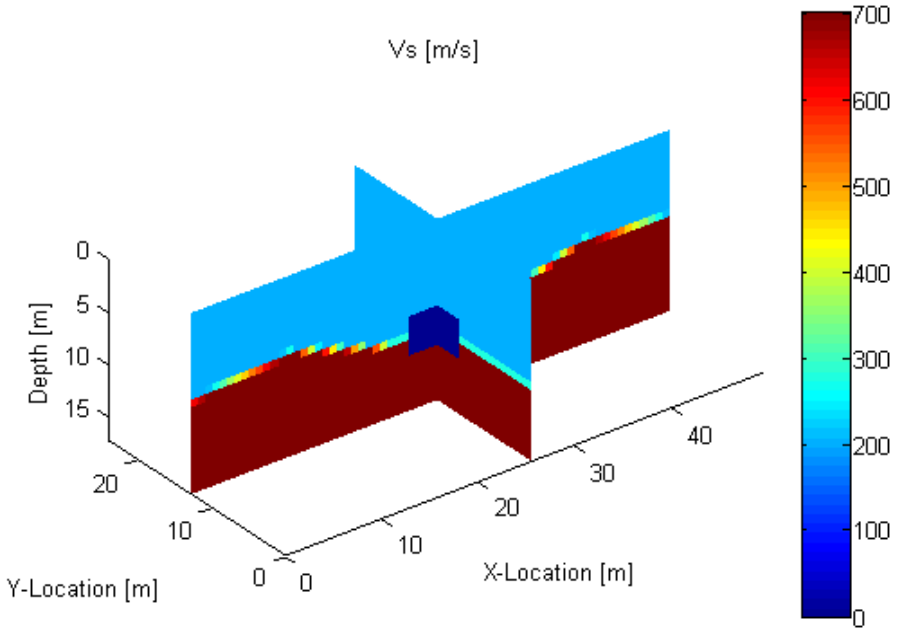
True model



Inverted model

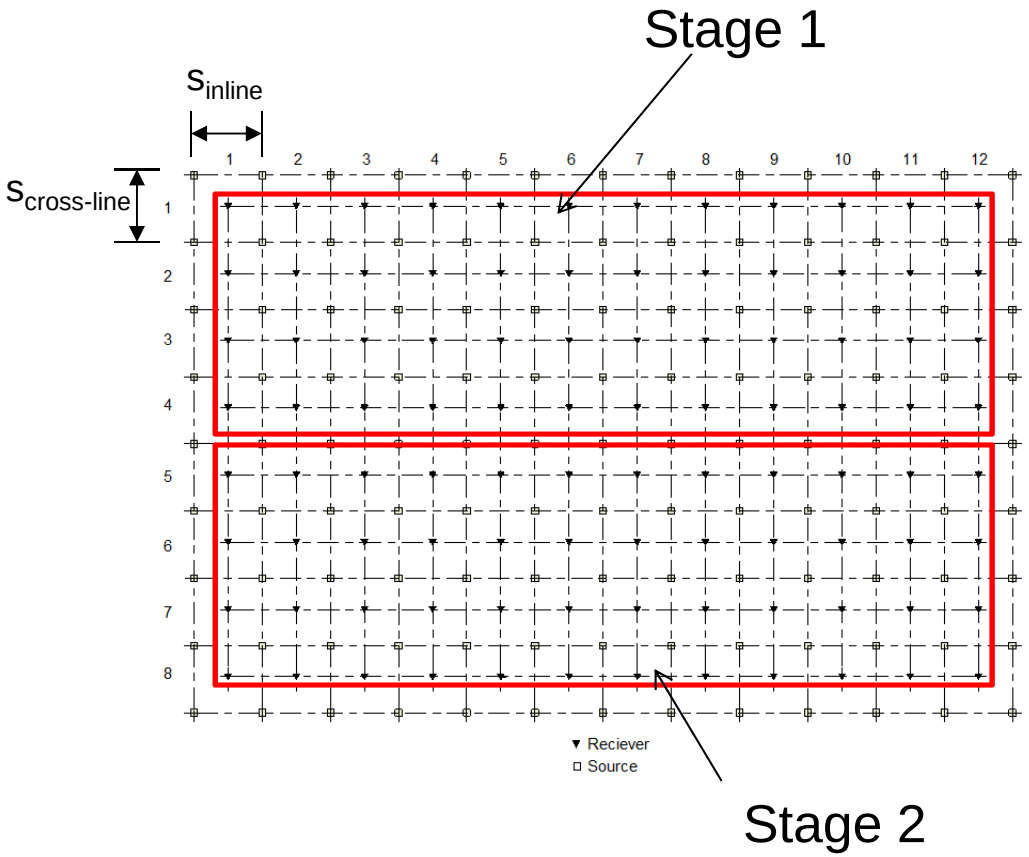
Task 3: *Investigation of 3-D Embedded Void Sensitivity*

- Identify the maximum depth at which any void can be characterized with confidence
- Voids will be embedded at different depths from one to five diameters.
- For each case, wave fields at multiple frequency ranges from 5 to 100 Hz will be computed for alternative test configurations (receiver and shot grids) and used for the 3-D FWI analysis



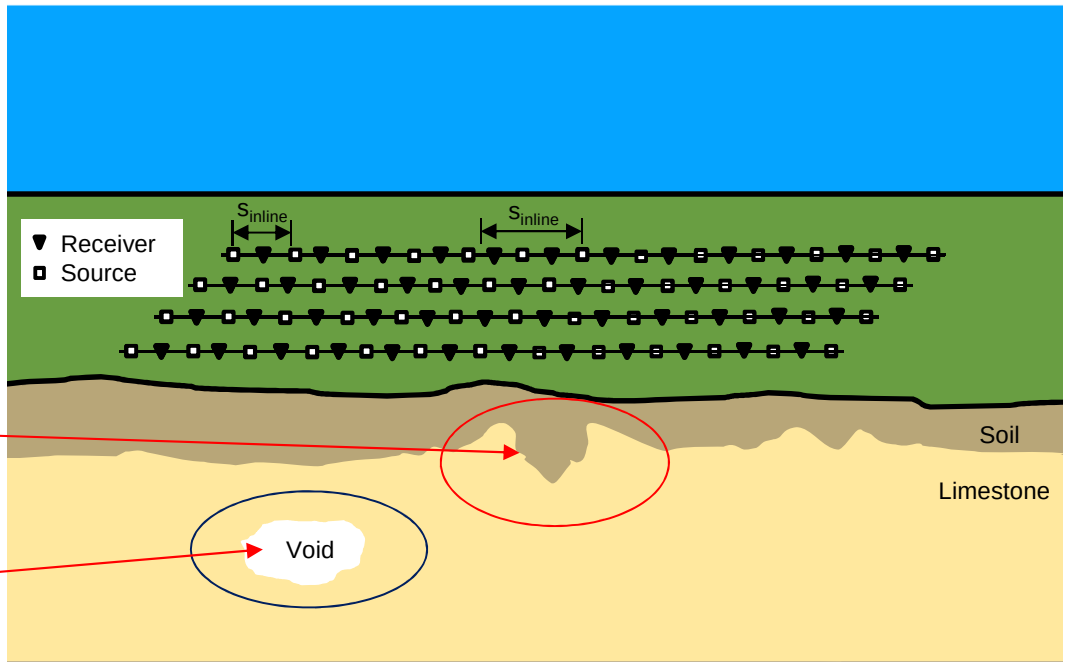
Task 4: *Verification of Proposed 3-D FWI on Full Scale Test Sites*

- Apply to 3 test sites (Newberry, Gainesville, and one selected by FDOT)
- Use 48 geophones and PEG source
- Follow test configurations identified in Tasks 1 to 3, combine data from stages if needed
- Vary s_{inline} & $s_{cross\text{-}line}$ 3 -10 ft
- Vary PEG properties (mass, drop height, impact plate)
- Compare seismic results to invasive tests CPT/SPT for verification



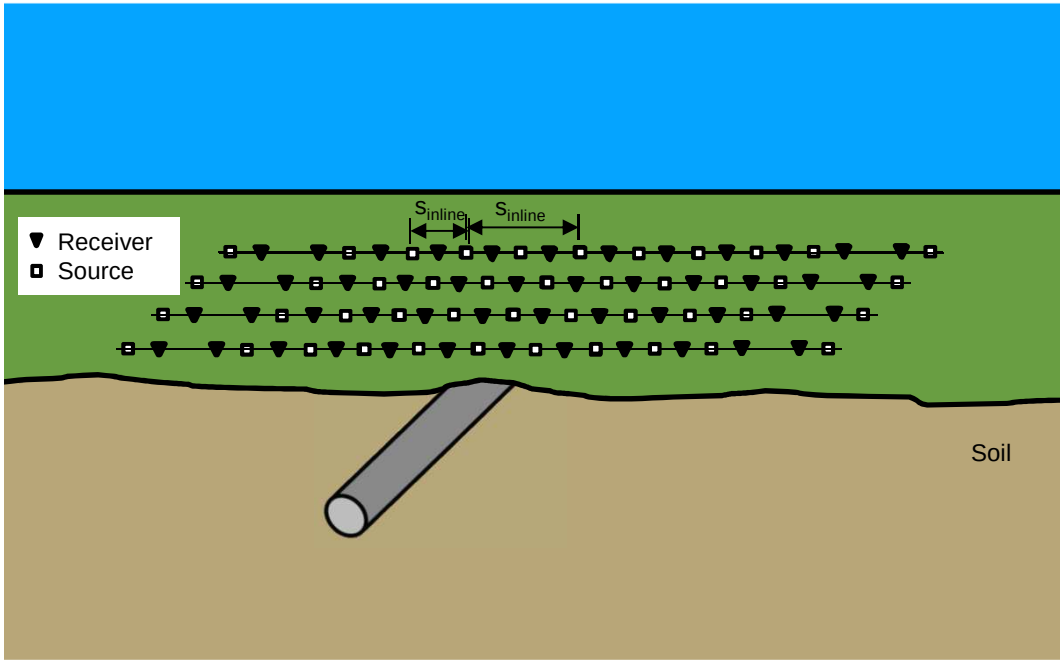
Task 4: *Verification of Proposed 3-D FWI on Full Scale Test Sites*

- Initial investigation using coarse 2D shot grid for general feature identification
- Use fine 2D shot grids to identify soil/rock interface for local variability (limestone pinnacles)
- Use local fine 2D shot grid to identify voids (cavities) in limestone

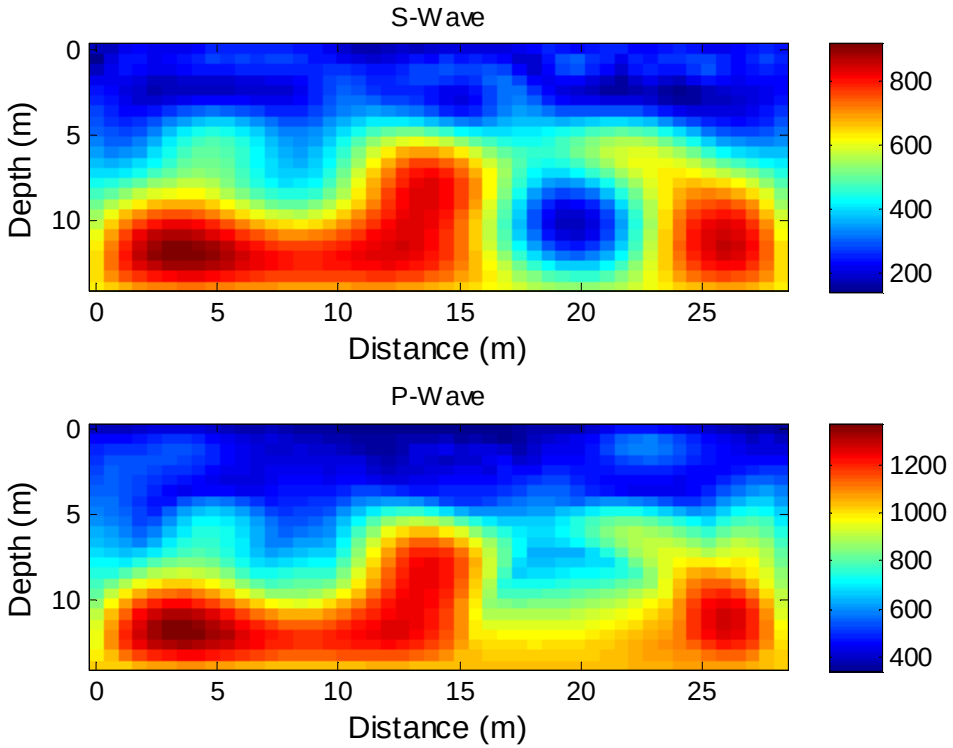


Task 4: *Verification of Proposed 3-D FWI on Full Scale Test Sites*

- Perform blind study on site with know buried objects (concrete pipes, culverts, etc.)
- Initial investigation using coarse 2D shot grid for general identification
- Use local fine 2D shot grid to identify location and size of buried object
- Must account for influence pipe or culvert boundary on measured signals



Thank You!


S-Wave
Depth (m)
0
5
10
0
5
10
15
20
25
Distance (m)
800
600
400
200
P-Wave
Depth (m)
0
5
10
0
5
10
15
20
25
Distance (m)
1200
1000
800
600
400