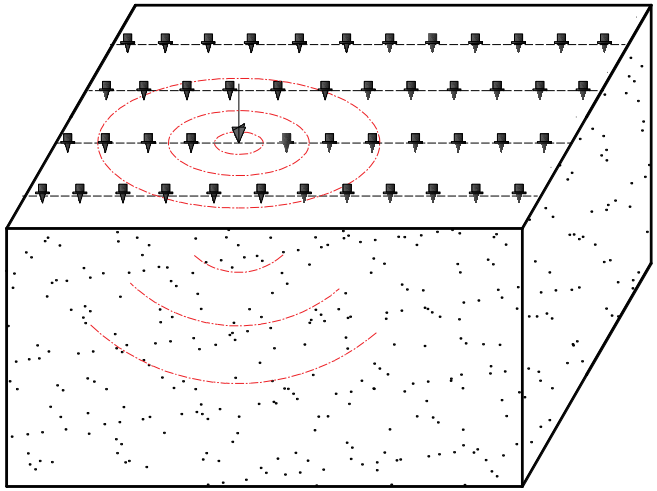
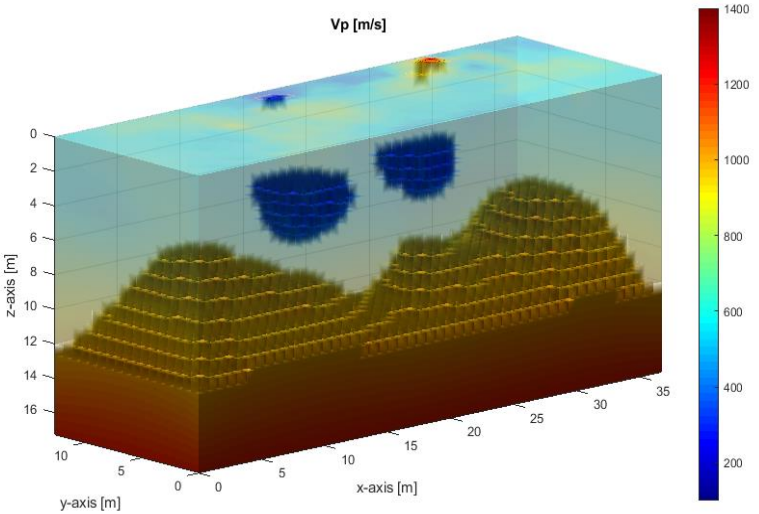
Sinkhole Detection with 3D Full Elastic Seismic Waveform Tomography

GRIP Meeting 2019

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

Primary Researchers
Michael McVay, PhD.
Khiem Tran, PhD.
Scott Wasman, PhD.
Majid Mirzanejad, PhD. student



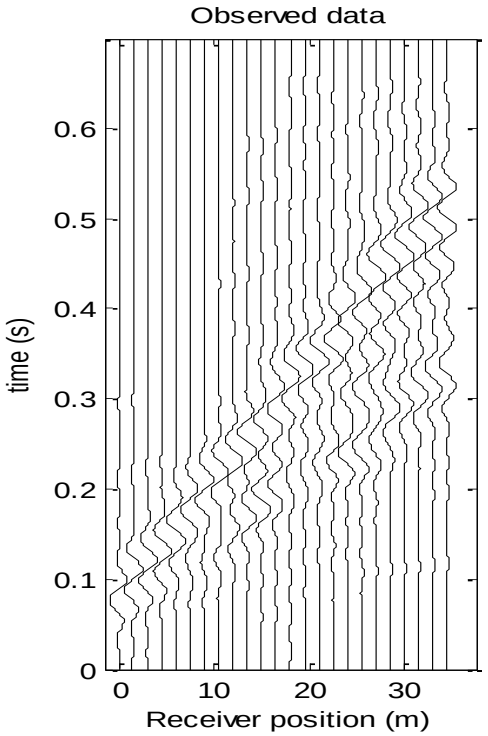


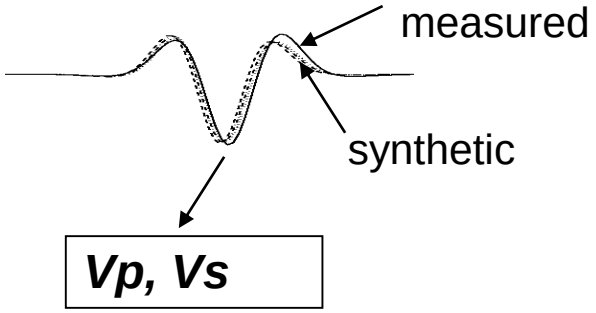
Project objectives

- Develop a 3D FWI method using surface-based seismic waves for detection of subsurface anomalies/voids
- Image vertical and lateral extents of 3D voids

3D FWI Motivation

- 3D FWI is wave-equation based and has the potential to
  - use full information content (waveforms), both phase and magnitude
  - characterize both Vp and Vs of 3D test domain at high resolution (ft pixel)
  - **provide 3D dimensions of a buried void**

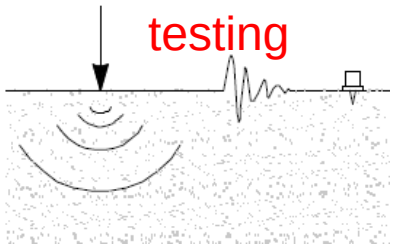




3D FWI method

Material properties
Vs, Vp
?

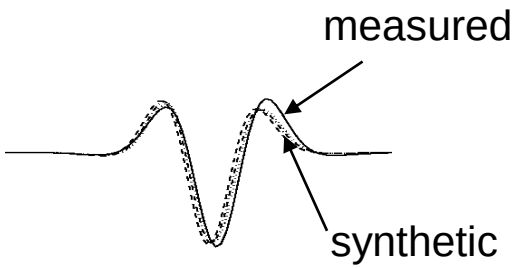
Seismic testing

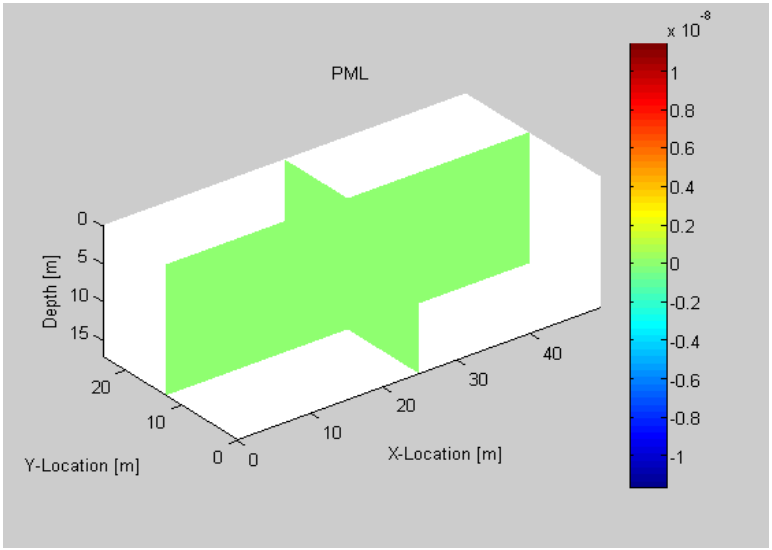


Measured data

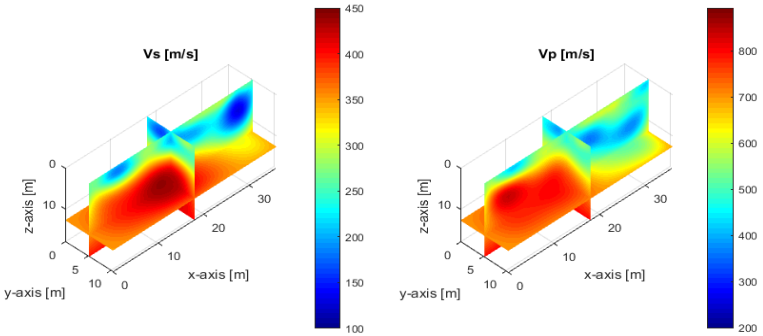
Synthetic data

Signal matching by Gauss-Newton optimization





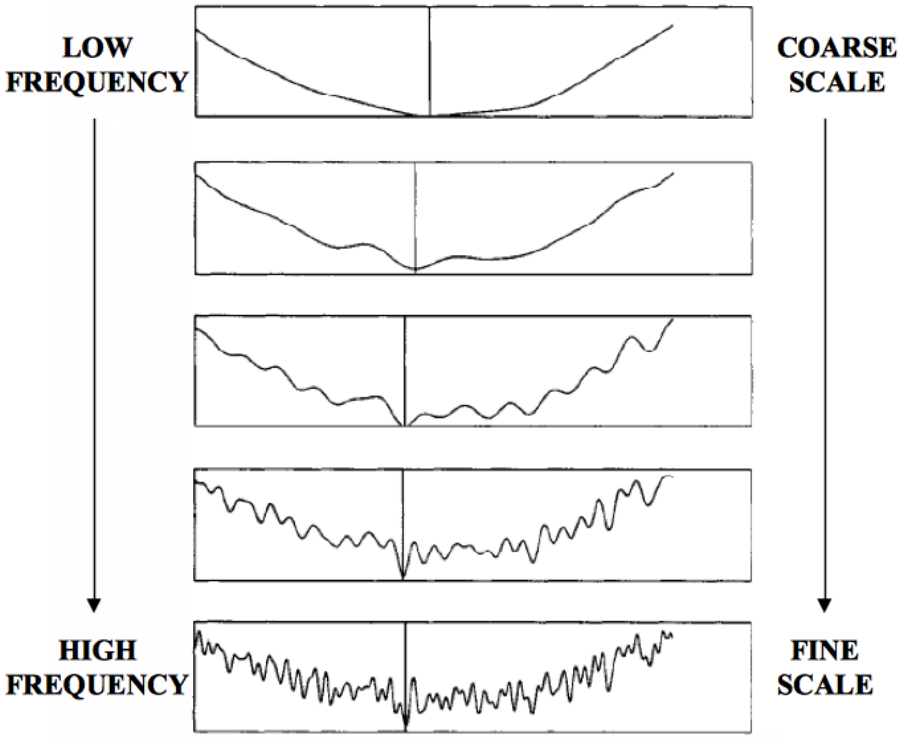
3D wave propagation



Data Analysis

- Start analysis at lowest frequencies and move up
- Low frequencies (large wavelengths) require less detailed information of initial model
- Adding high frequency data gradually helps to resolve variable near surface structures

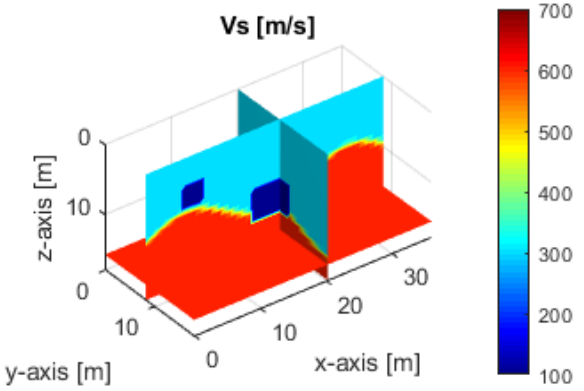
Misfit function

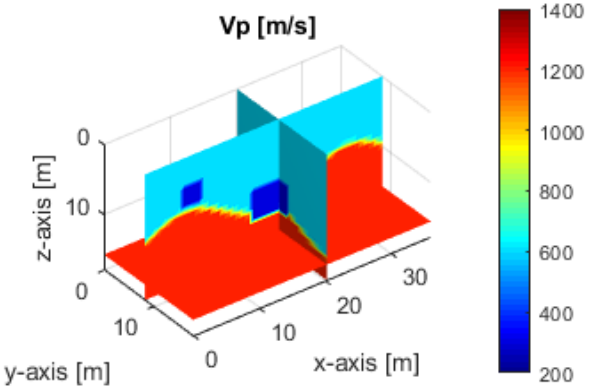


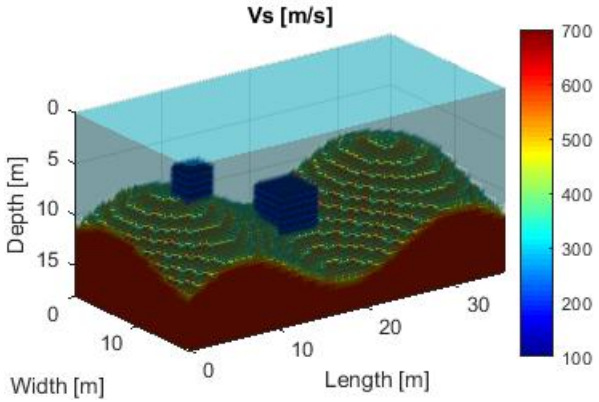
Bunks et al. (1995)

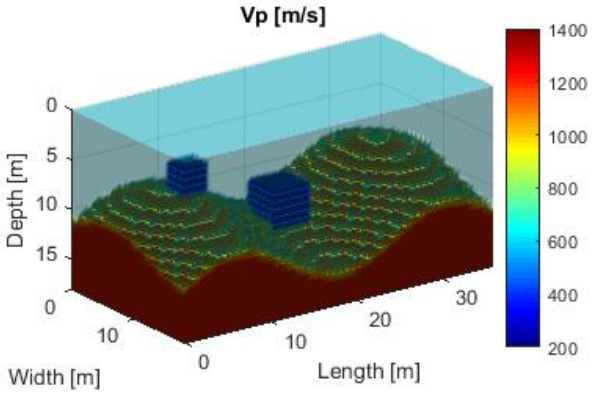
Synthetic test on void

- 24 x 36 x 18 m model of variable soil/rock
- Two voids buried at 6 and 9 m depth





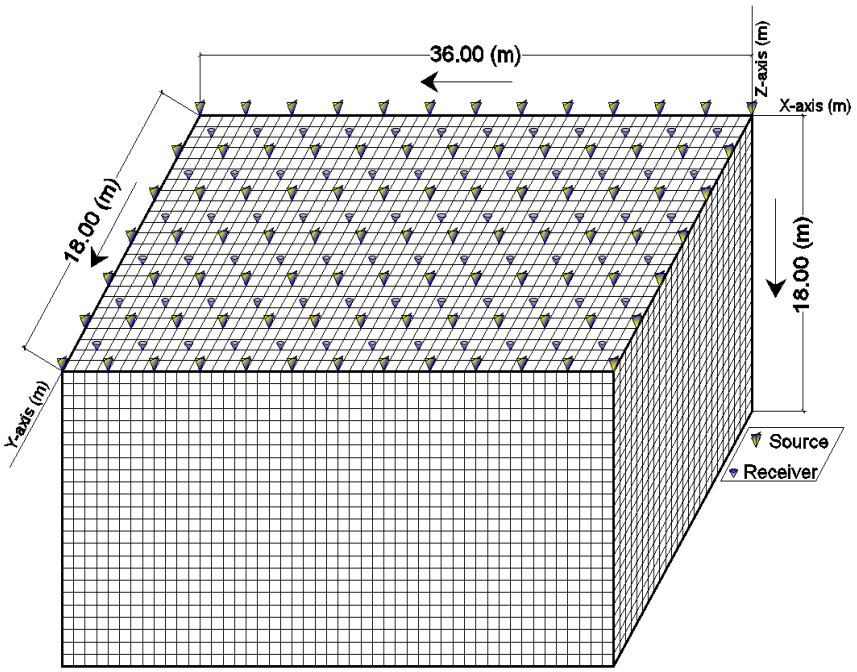




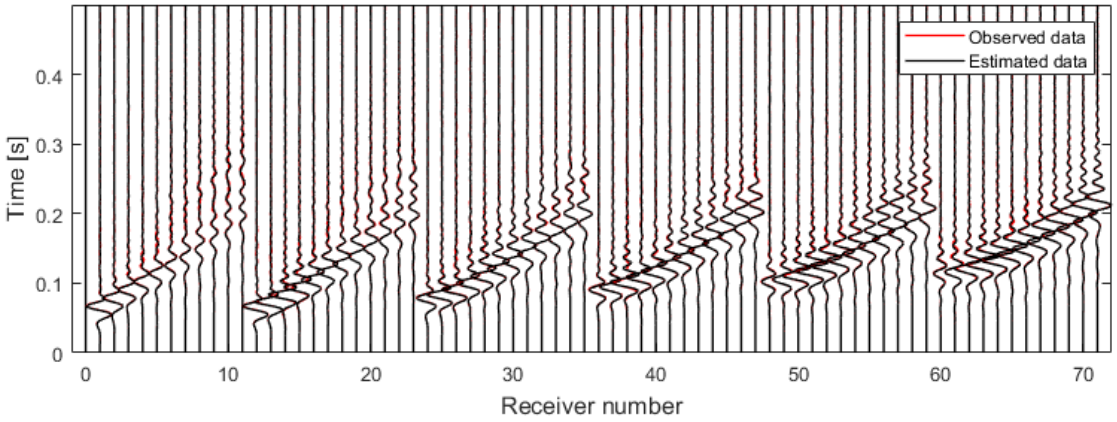
Synthetic test on void

- Test configuration

- 6x12 (72) receivers at 3 m spacing
- 7x13 (91) shots at 3 m spacing

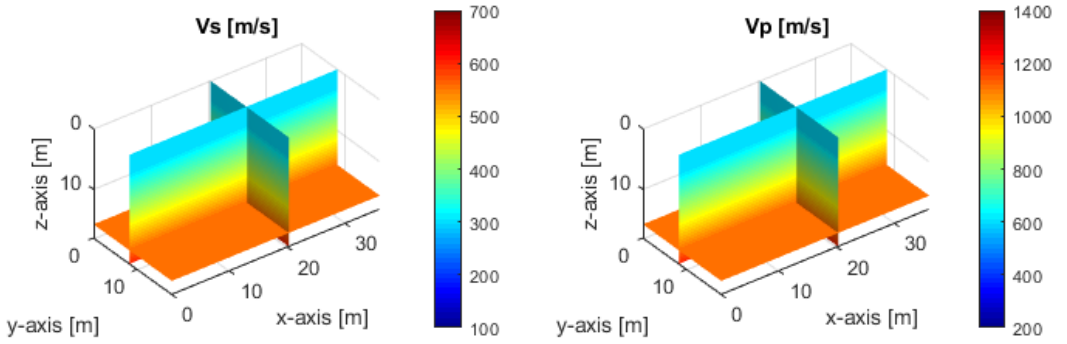


- Sample data for a shot

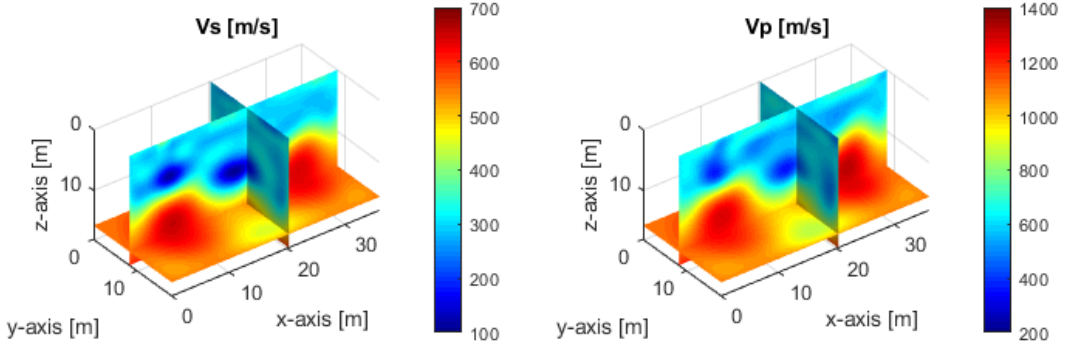


Synthetic result: 3D view

- 2 inversion runs at 15 and 25 Hz central frequencies
- 40 hours on a desktop computer (40 cores of 2.4 GHz each and 1.0 TB RAM)

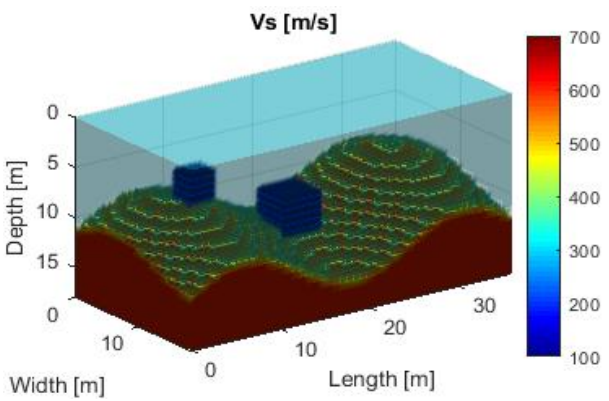


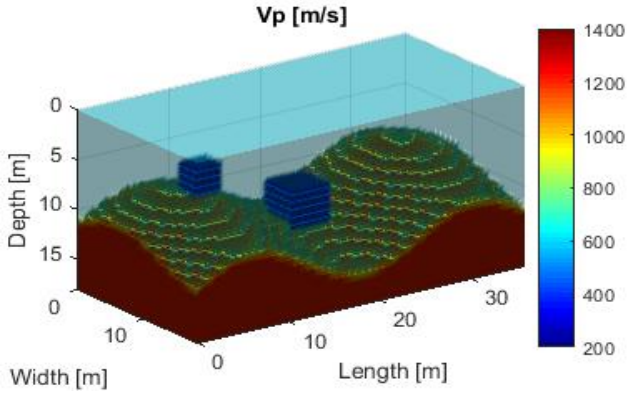
Initial model



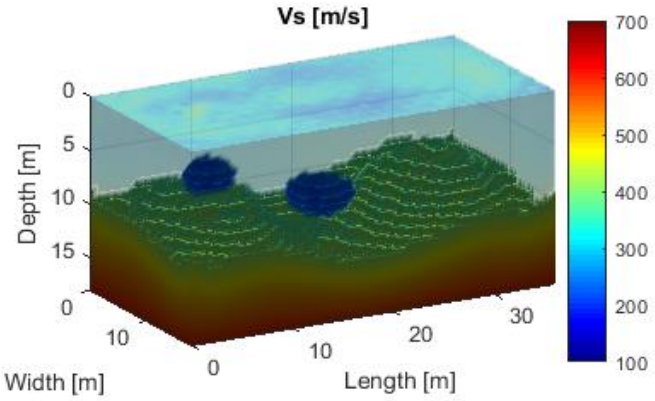
Inverted result

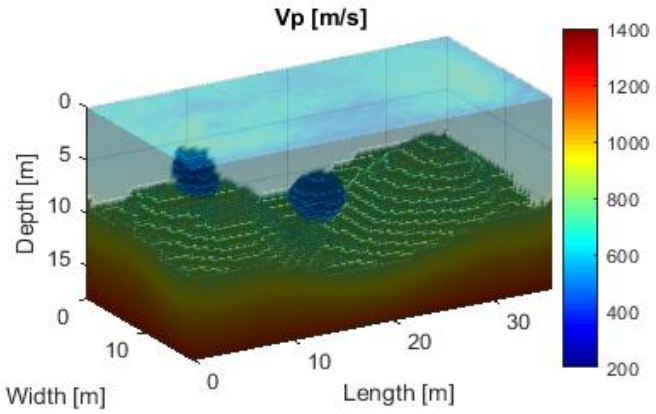
Synthetic result: 3D rendering





True model





Inverted model

How deep a buried void can be detected by 3D FWI?

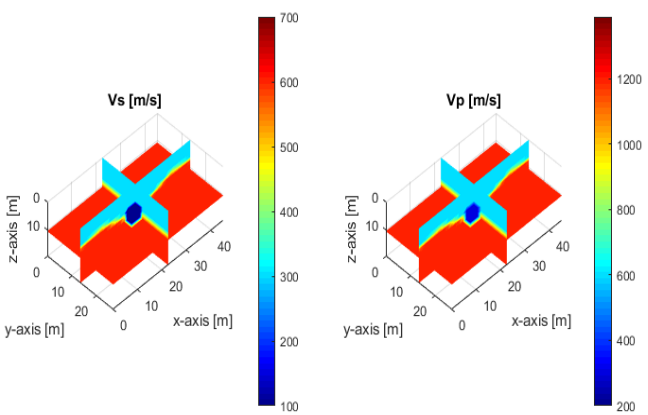
- detectable depth depends on:

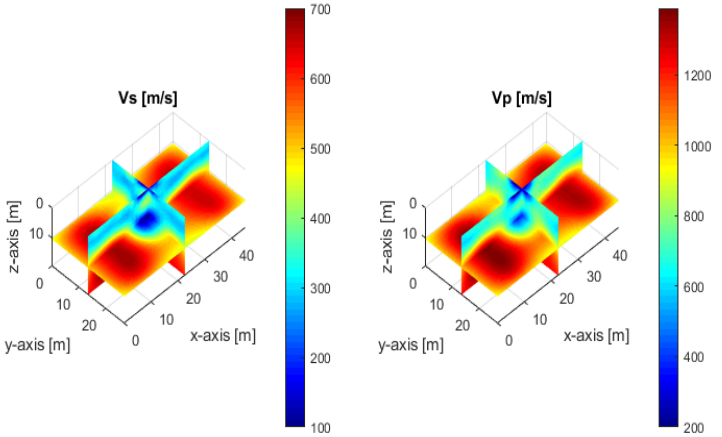
1) Void size

2) Test configuration
(receiver/shot number and spacing)

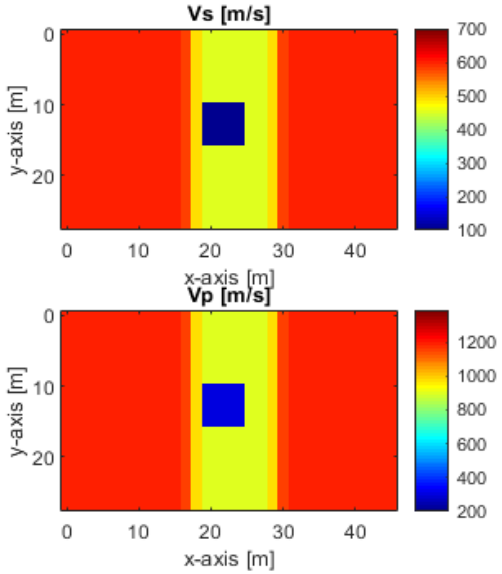
3) Frequency content of measured data
(8 to 60 Hz for PEG or sledgehammer)

Void at depth of 2 diameters (30 ft)

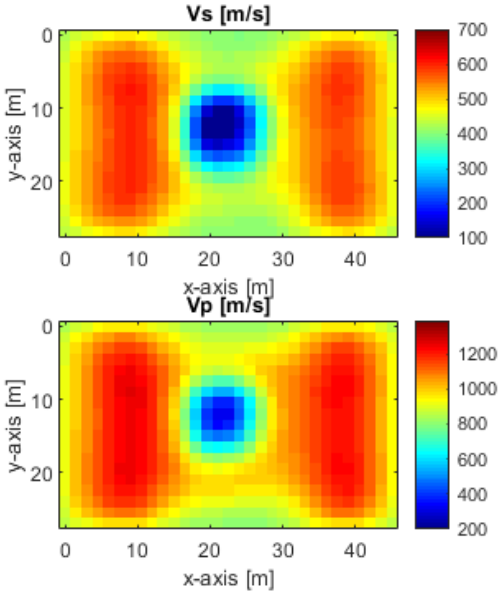




True

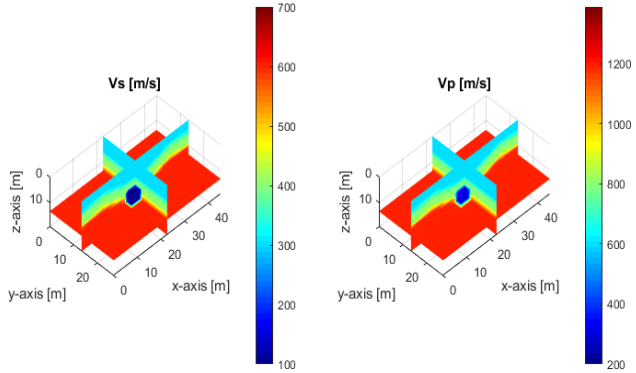


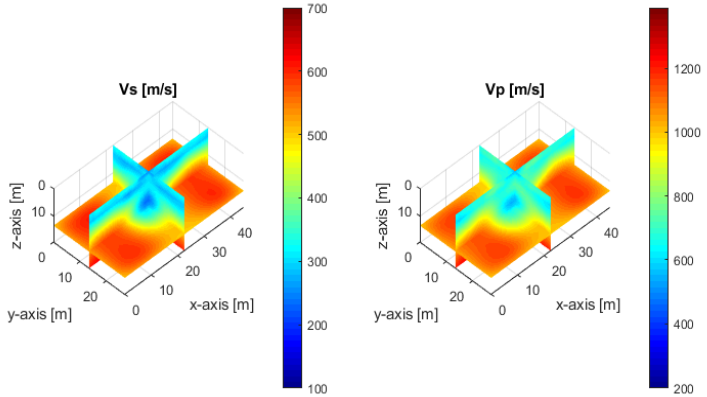
Inverted



Horizontal view
@ void center

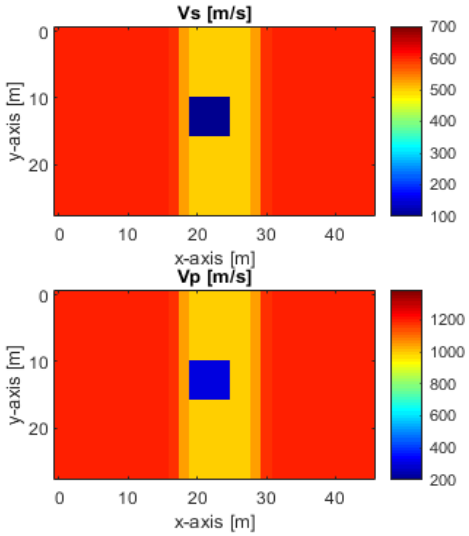
Void at depth of 3 diameters (45 ft)



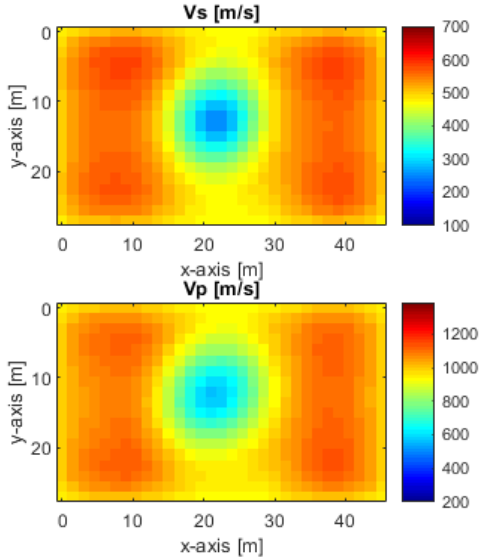


True

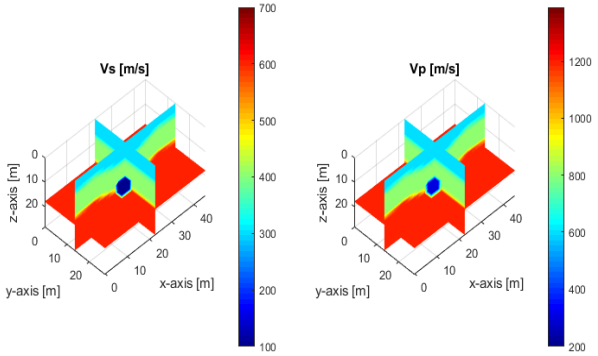
Inverted

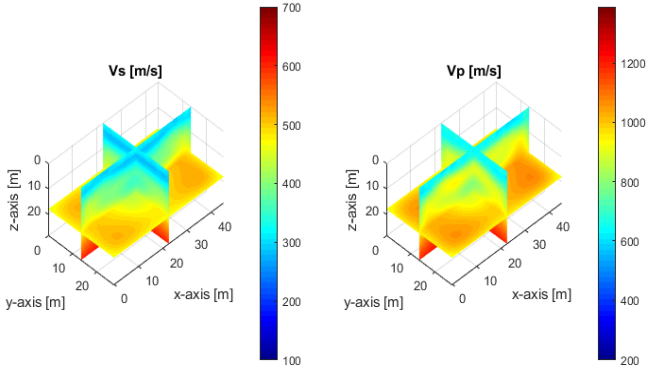


Horizontal view
@ void center

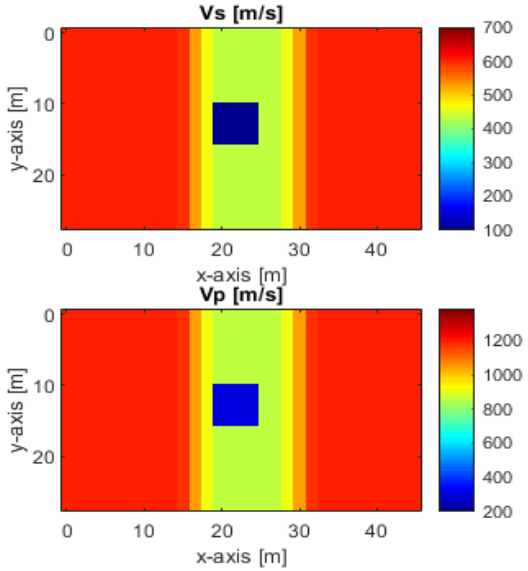


Void at depth of 4 diameters (60 ft)



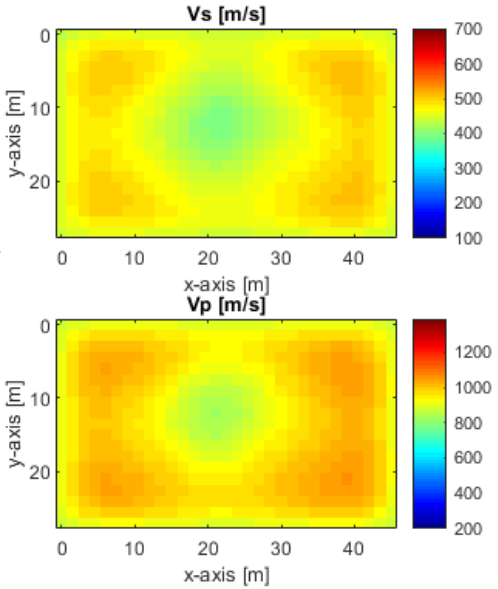


True



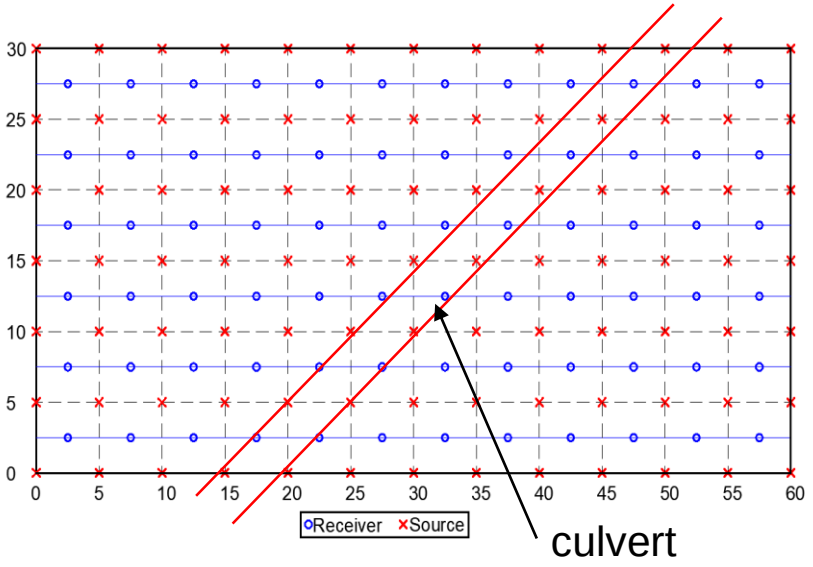
Horizontal view @ void center

Inverted



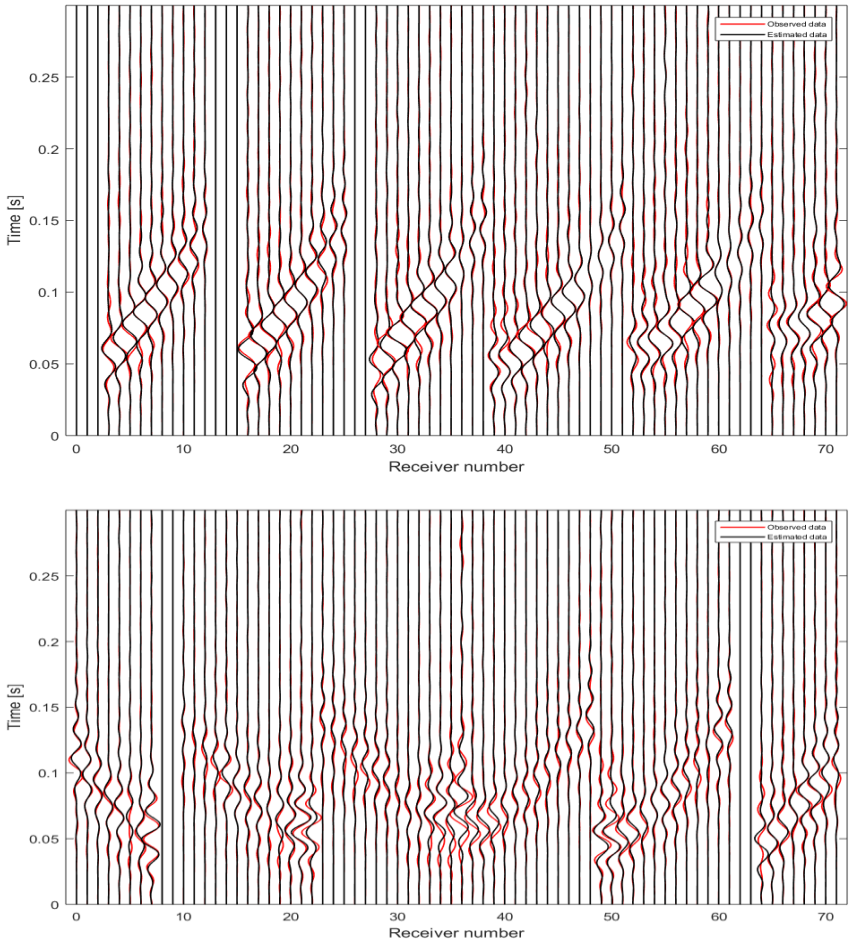
UF campus: buried culvert

- Plastic culvert pipe: 40” diameter, buried at 10 ft depth.
- Test area of 30 x 60 ft
- 72 geophones located in 12 x 6 grid at 5 ft spacing
- 91 shots located in 13 x 7 grid at 5 ft spacing
- 10 lb. sledgehammer

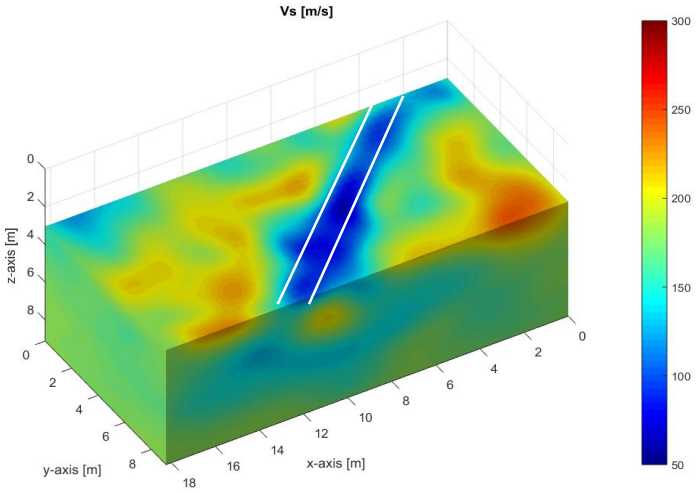


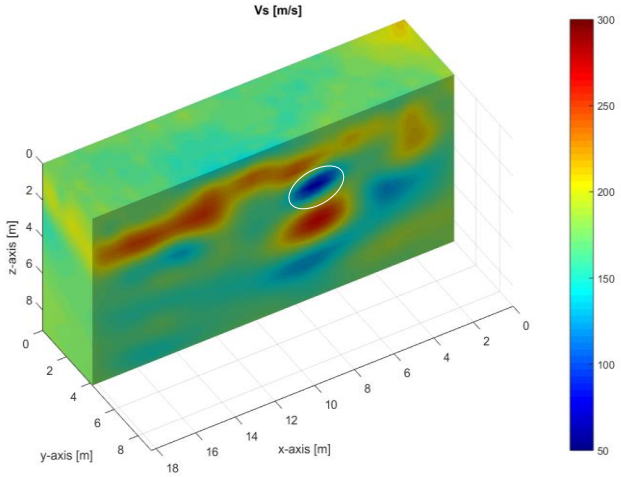
UF campus: buried culvert

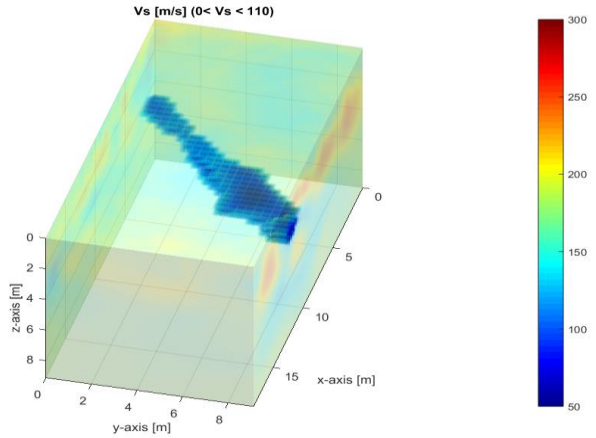
- Test domain is divided into 27,000 cube cells of 1.25 ft size
- One inversion run from 10 to 60 Hz
- 15 hours of computer time on a desktop computer

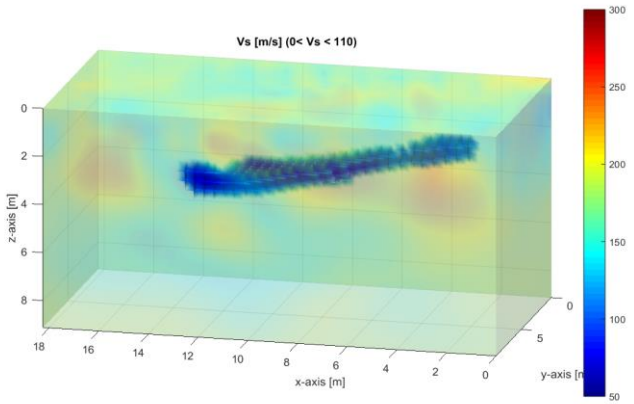


UF campus: buried culvert



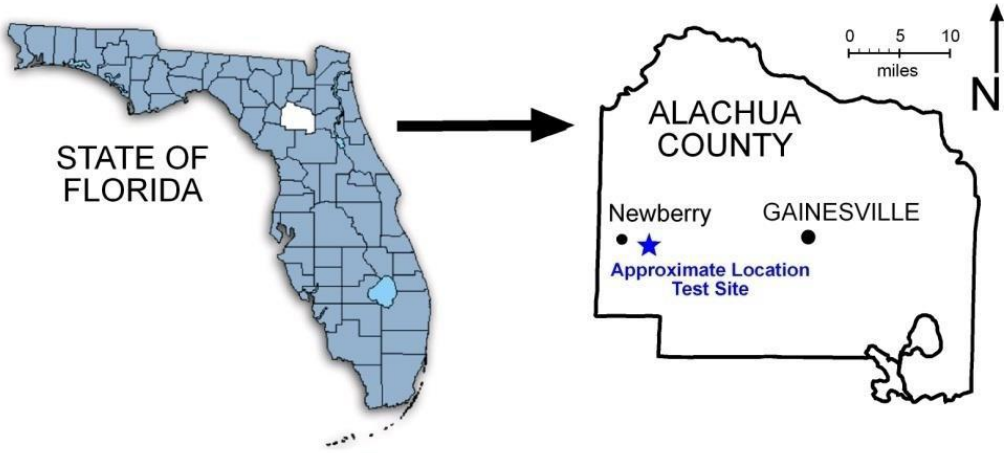


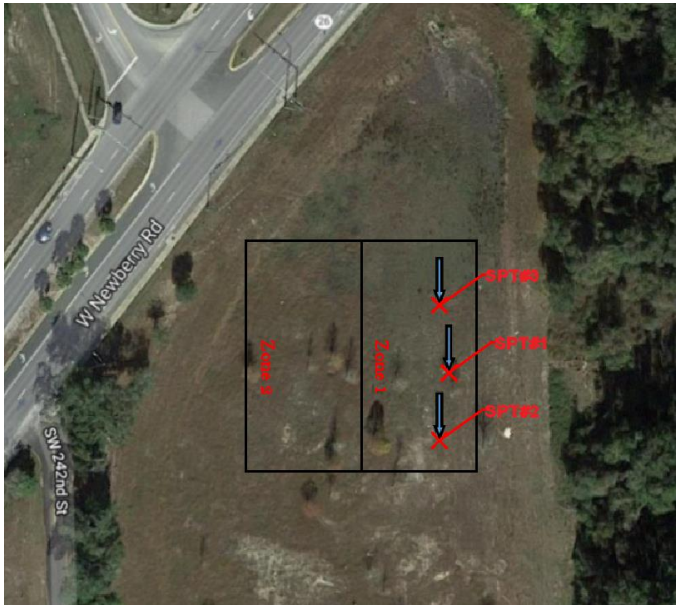




Newberry site

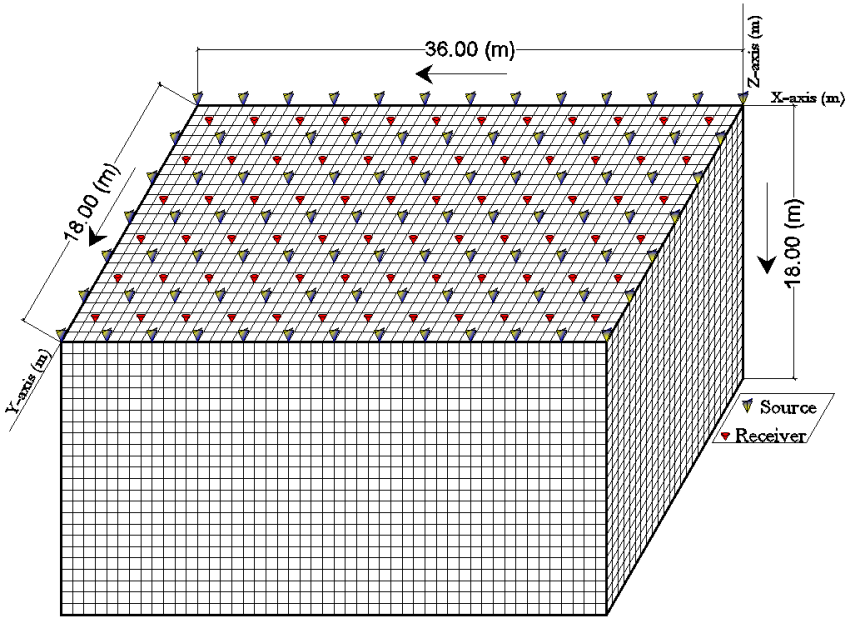
- Dry retention pond in Newbery, FL
- Top of bedrock from 2-10 m depth
- Site was marked by 25 lines (A to Y) at 3 m spacing
- Conducted blind tests on 2 new areas, each of 60 x 120 ft





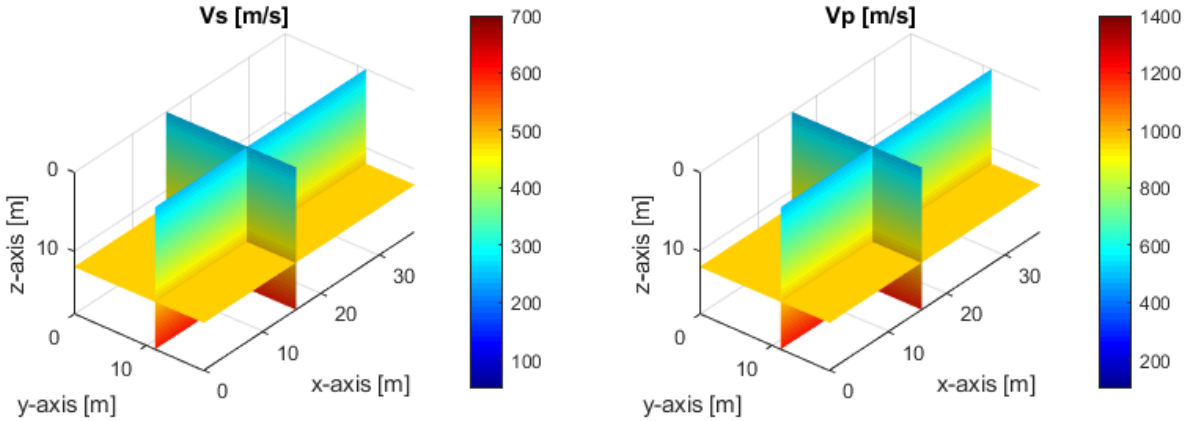
Newbery site

- Test area of 36 x 18 m (120 x 60 ft)
- 72 geophones located in 12 x 6 grid at 3 m spacing
- 91 shots located in 13 x 7 grid at 3 m spacing
- Propelled energy generator (PEG-40 kg) source

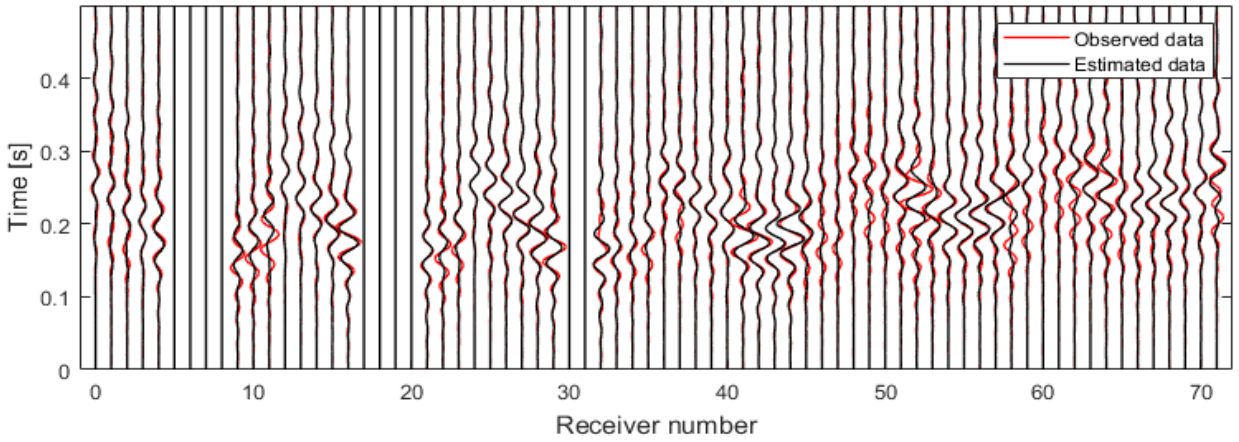


Newberry analysis

- 2 inversion runs at 15 and 25 Hz central frequencies
- 40 hours on a desktop computer

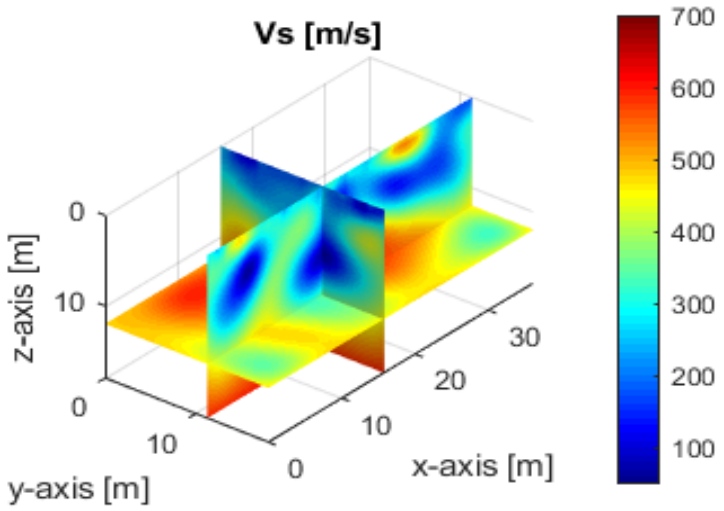


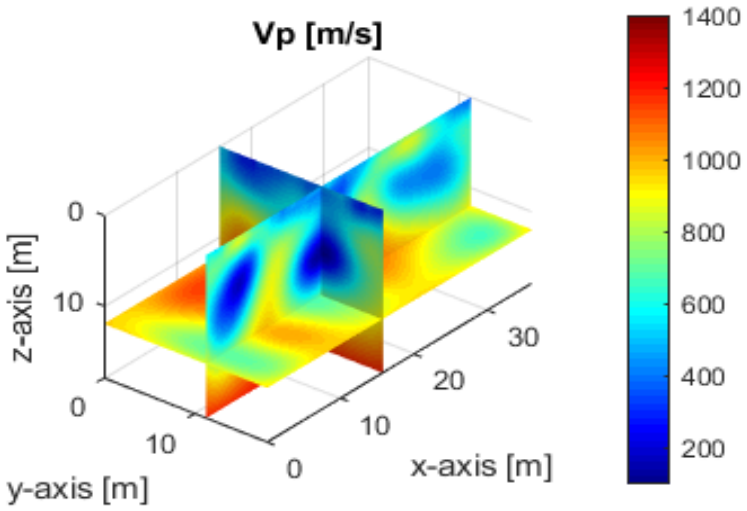
Initial model



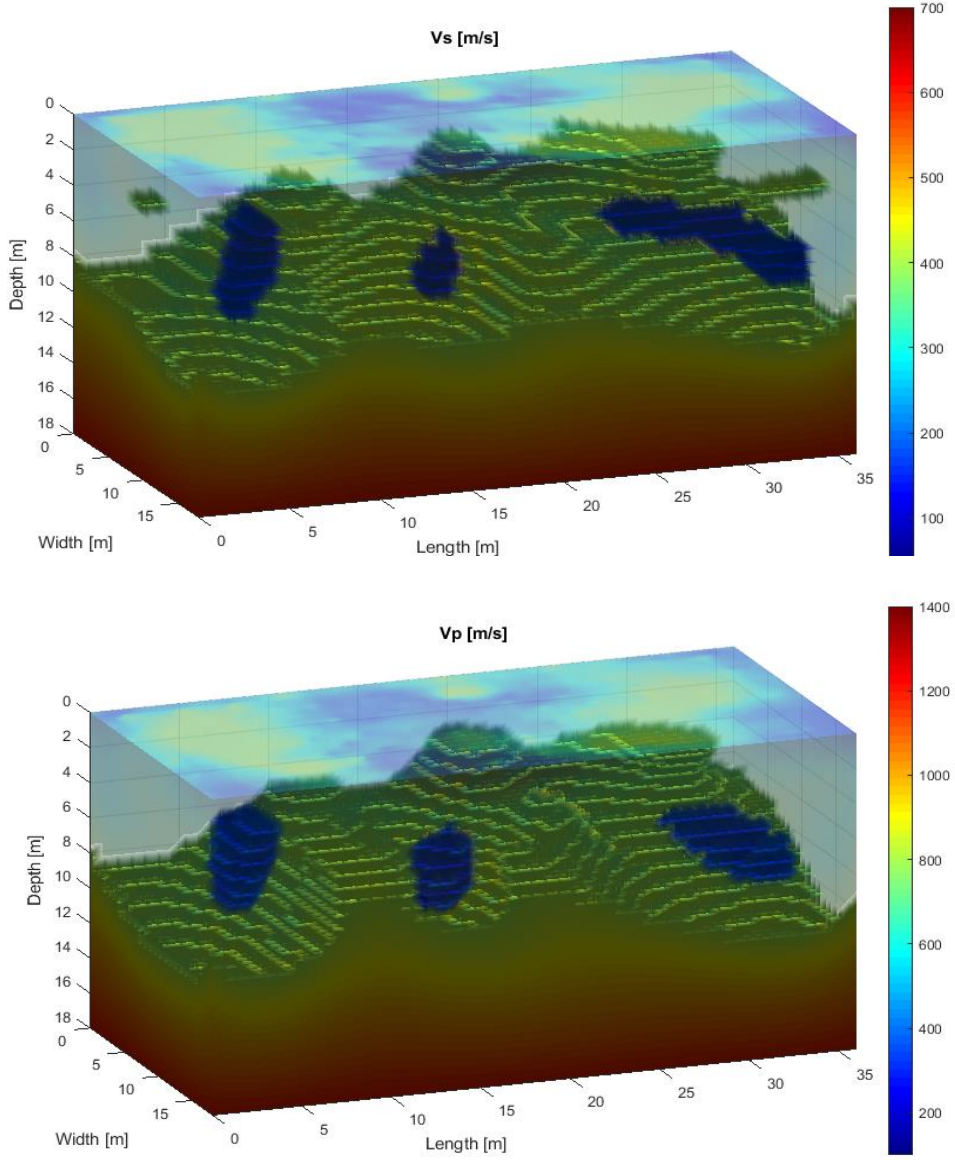
Wave comparison

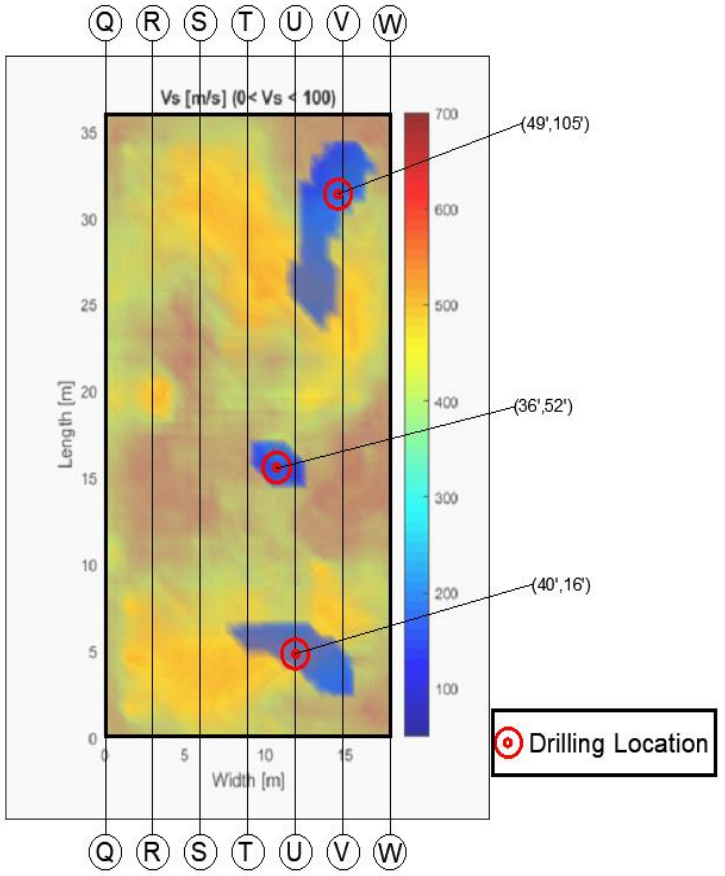
Newberry result: 3D view



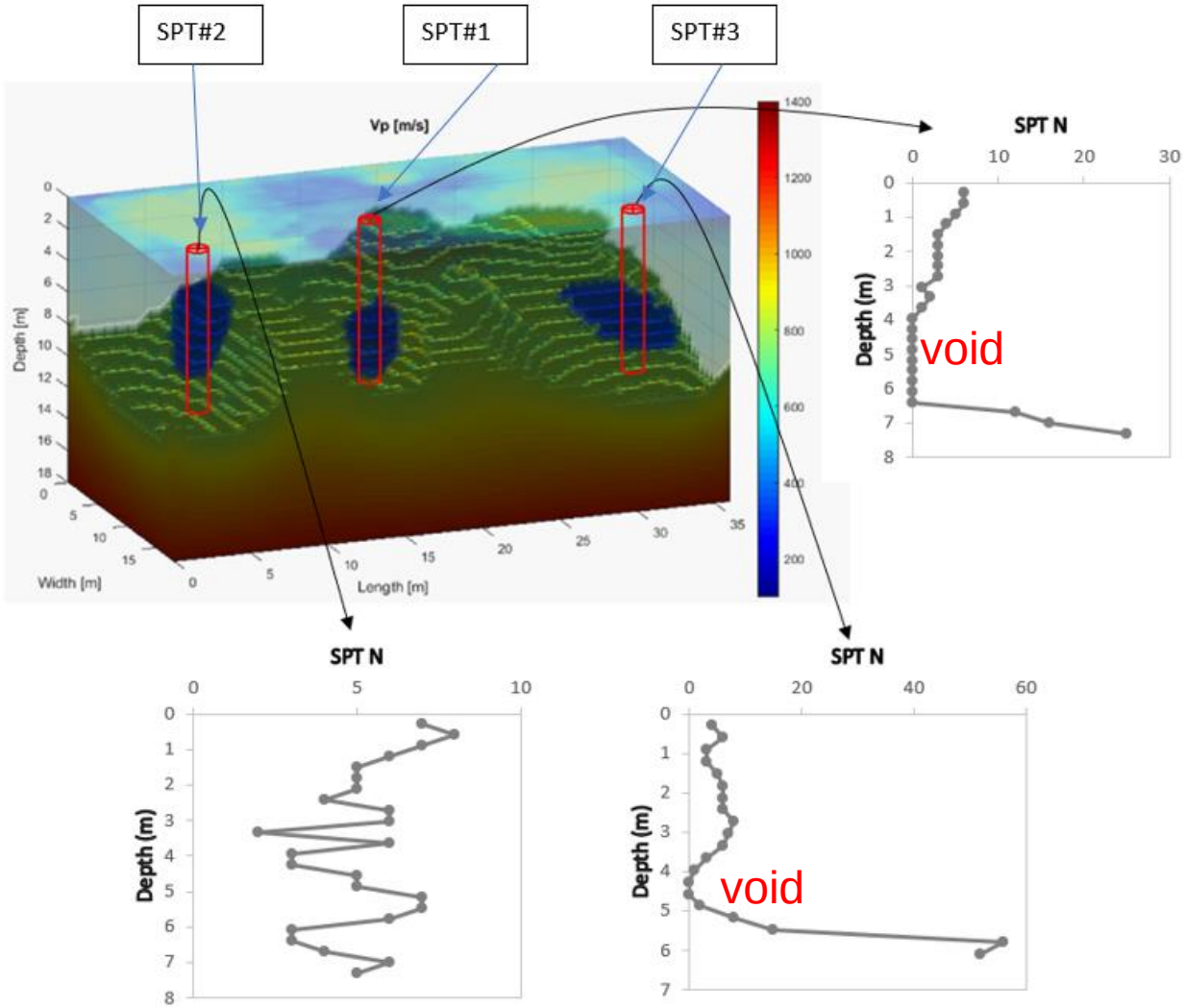


Newberry result: 3D rendering





SPT confirmation



Conclusion

- Both Vs and Vp can be characterized at high resolution (ft pixel) to 60 ft in depth by the developed 3D FWI method.
- Buried voids could be identified to 3-diameter depth (up to 60 ft depth) with only surface measurement.
- 30 - 40 hours of computer time for each test area of 120 x 60 ft