Down-Hole Geophysical Testing for Rock Sockets

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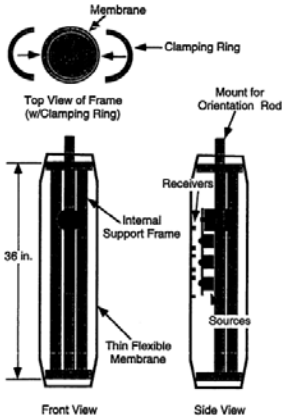
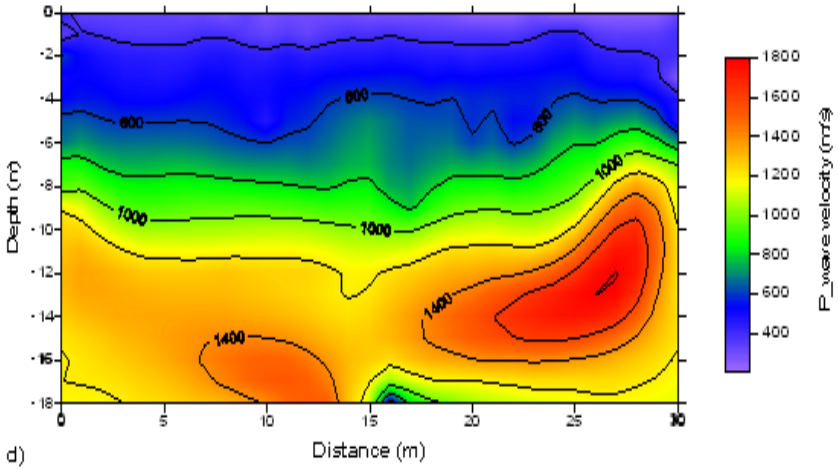
Pengxiang Jiang
University of Florida

FDOT GRIP

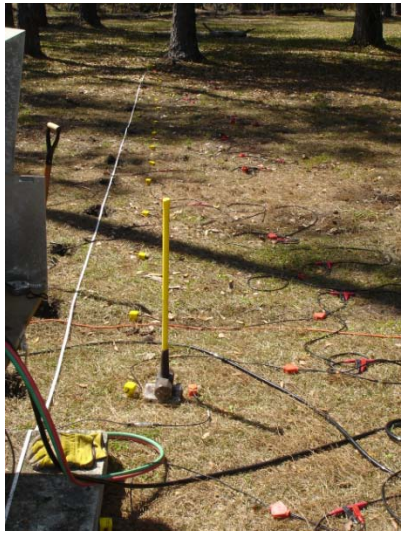
August 17, 2012

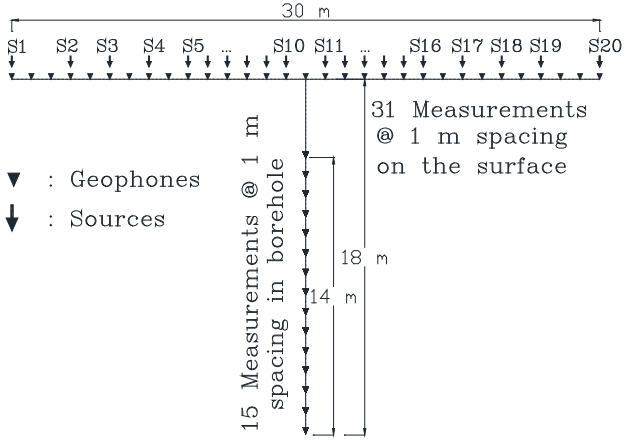




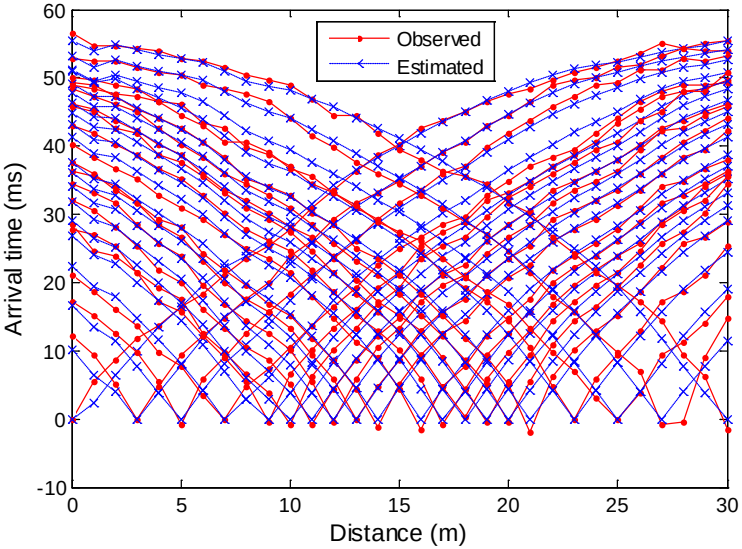
Ft. McCoy

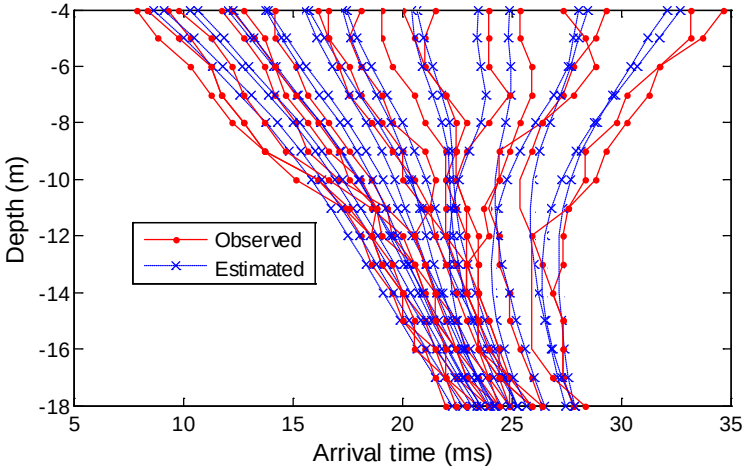
- **Surface array: 31 geophones at 1-m spacing**
- **Borehole array: geophones 4-18 m at 1-m spacing**
- **Sledgehammer source: 1,2,3,4,5,6,8,10,12,15 m each side of well**



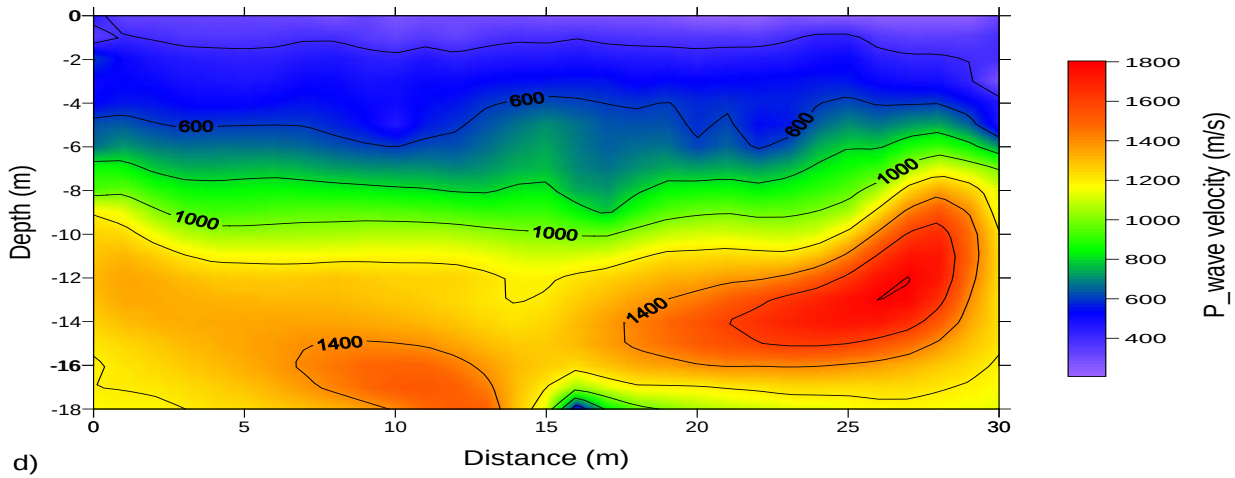


Ft. McCoy

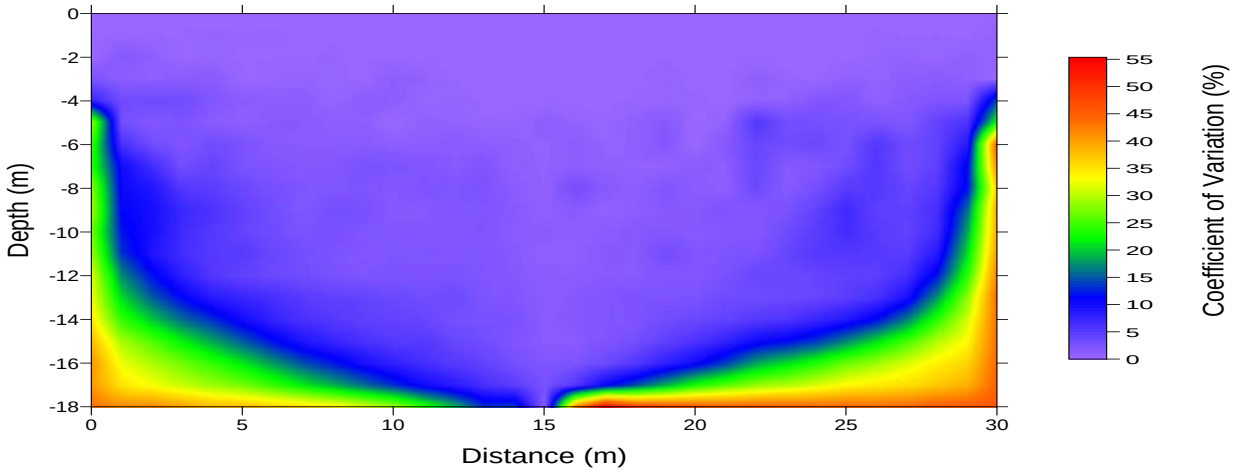

Observed
Estimated
Arrival time (ms)
Distance (m)
60
50
40
30
20
10
0
-10
0
5
10
15
20
25
30


Observed
Estimated
Depth (m)
Arrival time (ms)
-4
-6
-8
-10
-12
-14
-16
-18
5
10
15
20
25
30
35

Ft. McCoy


Depth (m)
Distance (m)
600
1000
1400
P_wave velocity (m/s)
1800
1600
1400
1200
1000
800
600
400

d)

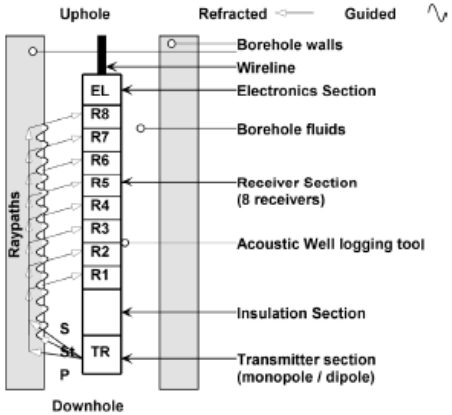

Depth (m)
Distance (m)
Coefficient of Variation (%)
55
50
45
40
35
30
25
20
15
10
5
0

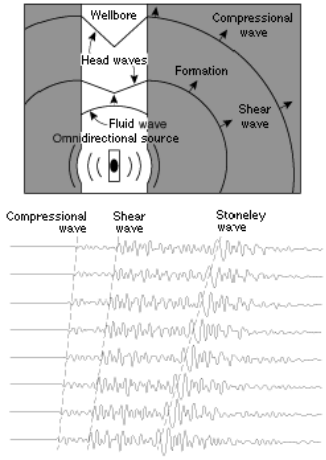
Workplan

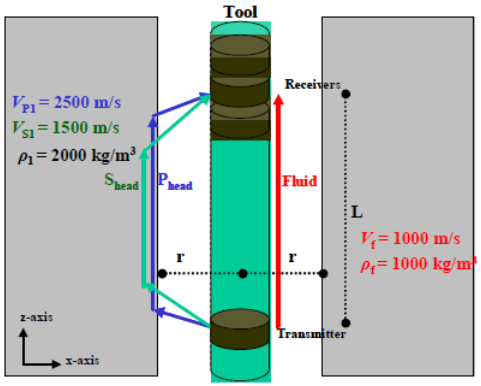
- **Task 1: Review Literature and State of Practice**
  - **Single-well borehole logging devices**
- **Task 2: Computer and Synthetic Model Studies**
  - **Borehole instrumentation, full waveform analysis**
  - **Preliminary array design: geometry, instrumentation**
- **Task 3: Array Experiments**
  - **Test/modify preliminary array design**
  - **In-house instrumentation**
- **Task 4: Design Borehole Tool**
  - **Mechanical design of array, analysis software**
- **Task 5: Report**

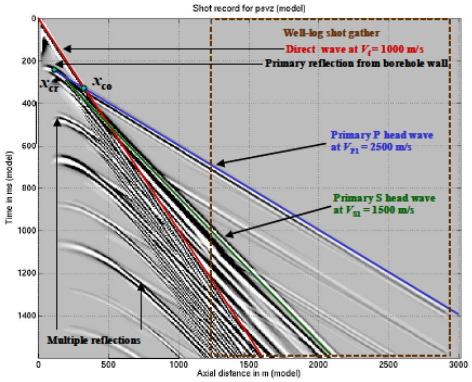
Chabot (2003)

- University of Calgary
- Sonic logging tool in fluid-filled borehole
- Seismic reflection-style processing
- Full waveform analysis of body waves (P and S)
- No surface waves



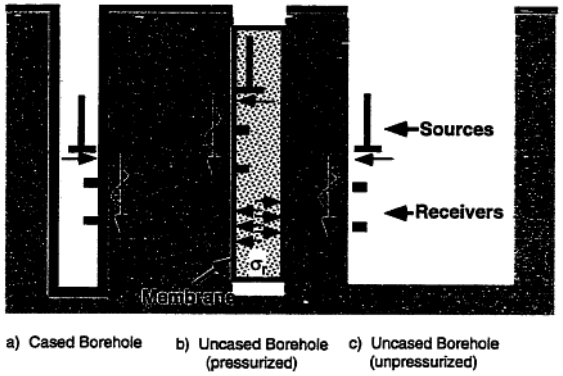


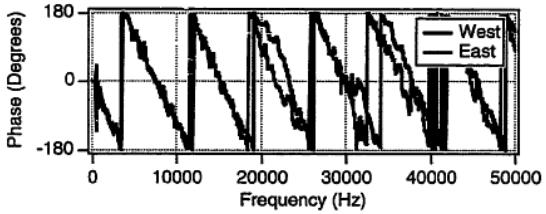


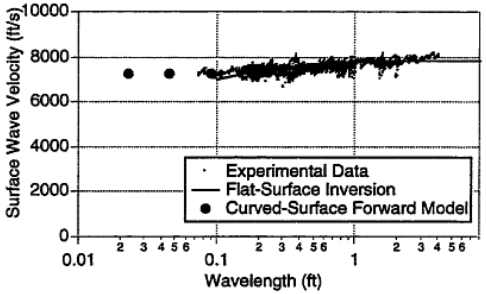


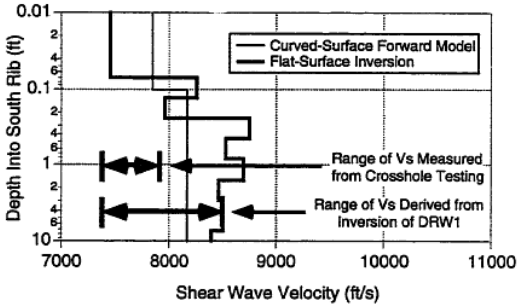
Kalinski (1998)

- University of Texas (Stokoe)
- SASW along axis of borehole (1-D)
- Concrete, rock, and soil
- Geometry-induced dispersion

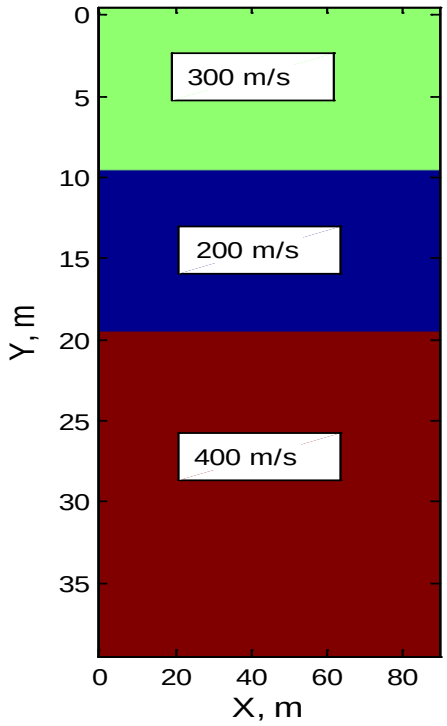


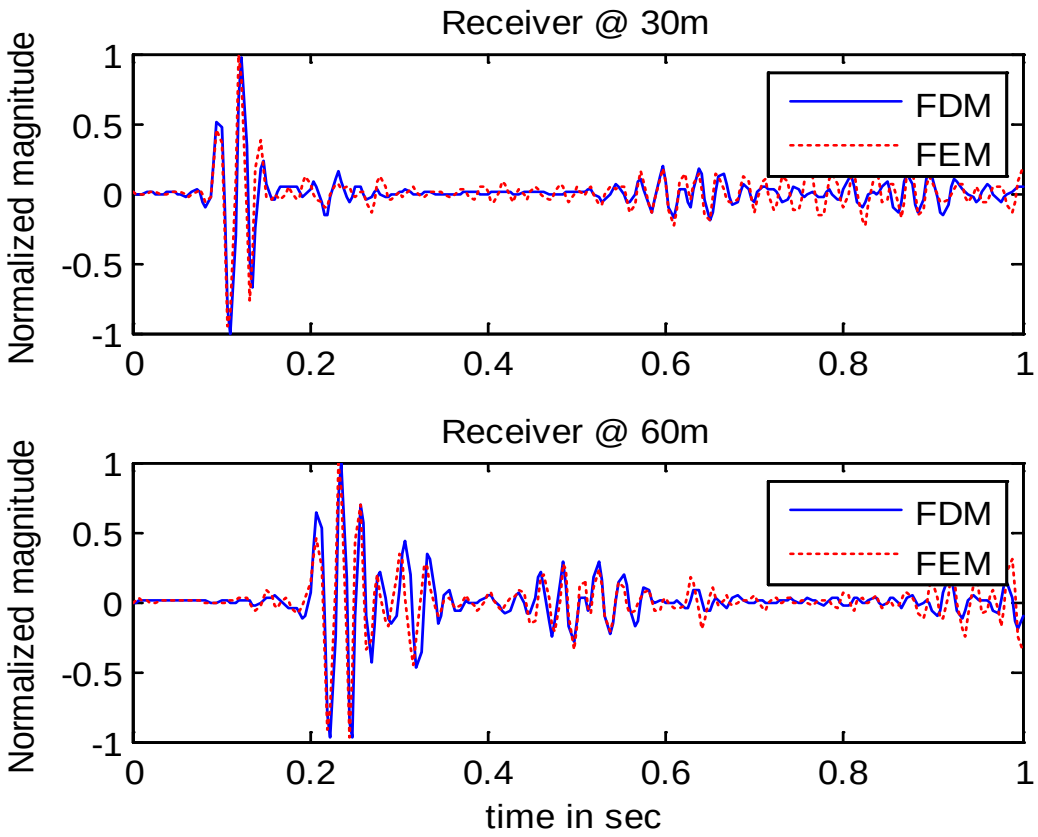




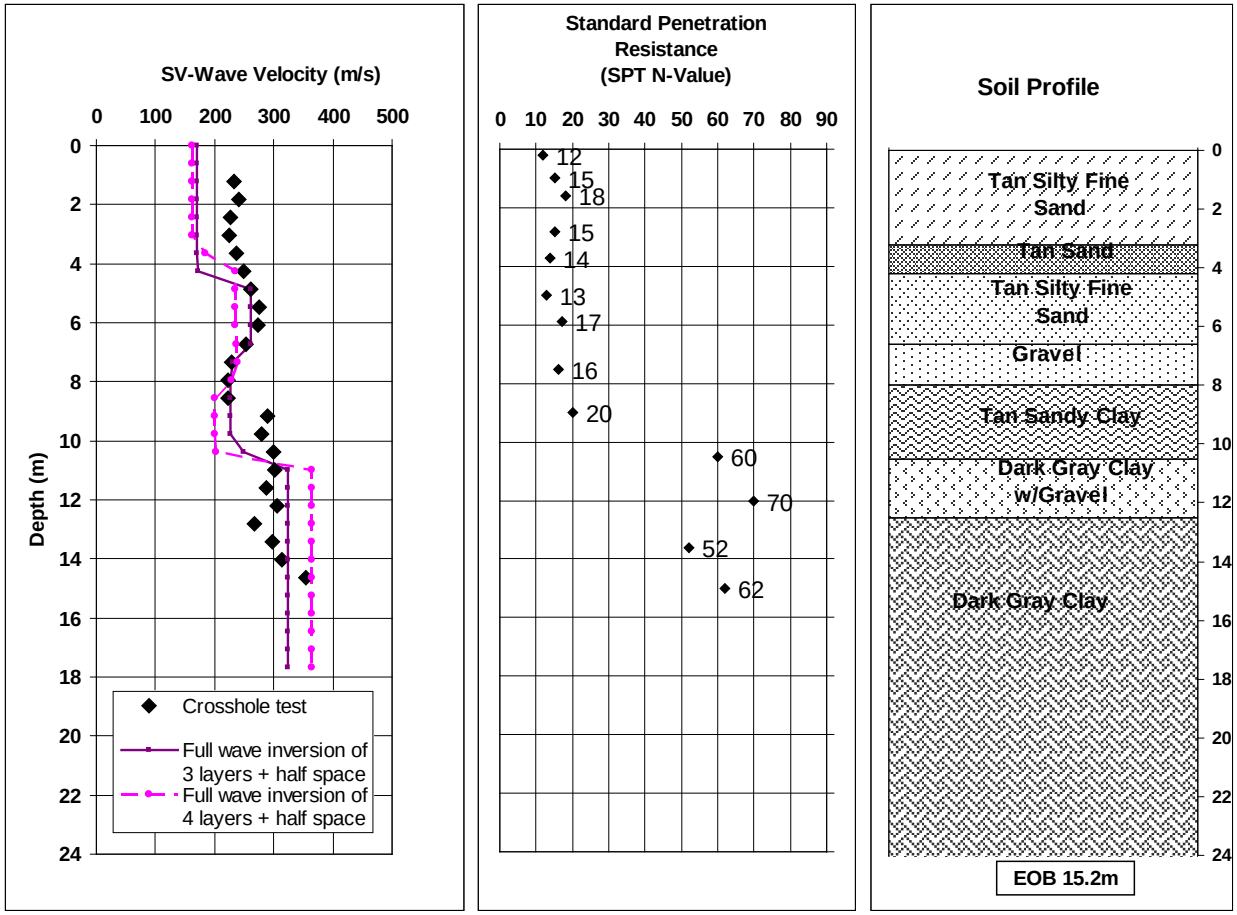


Full Waveform: FD vs. FEM

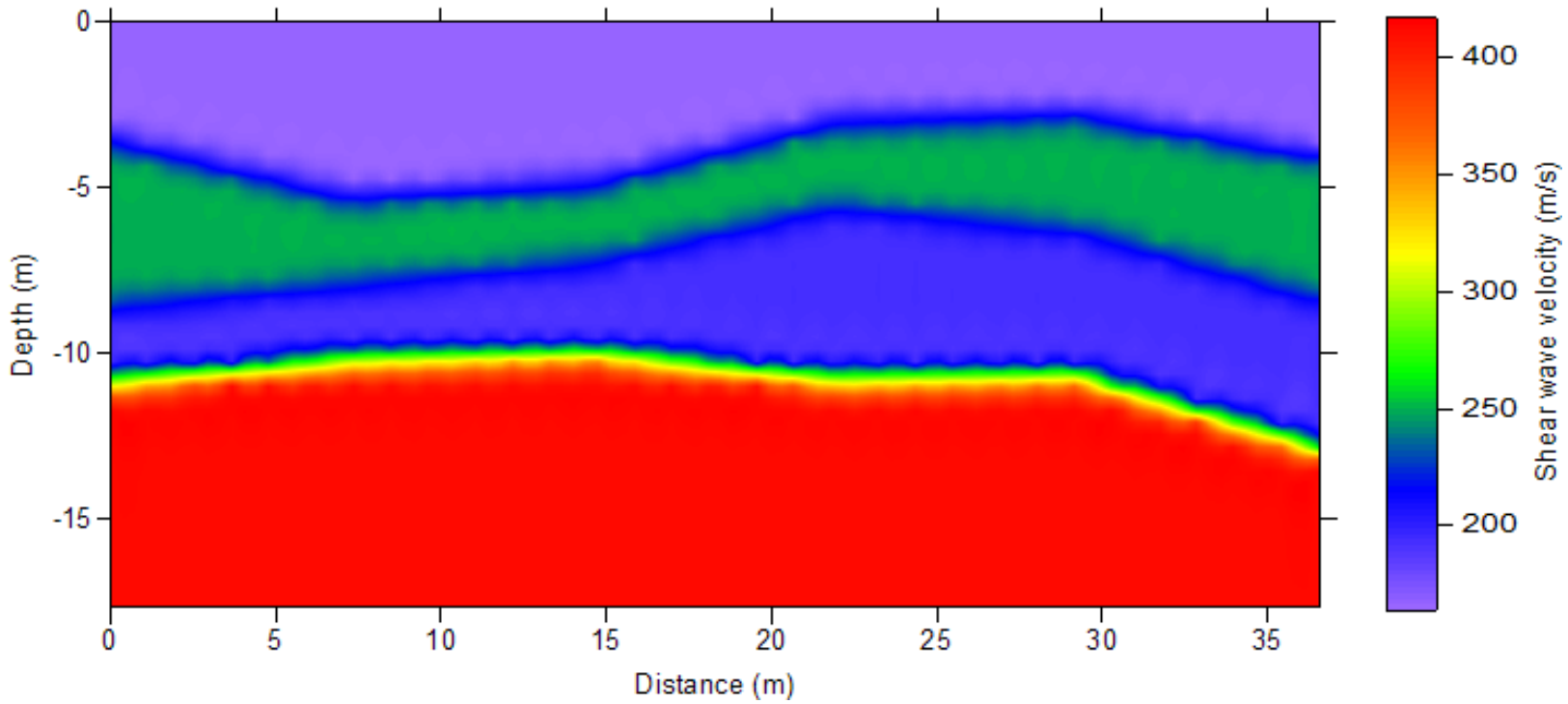




Full Waveform: LVL at TAMU

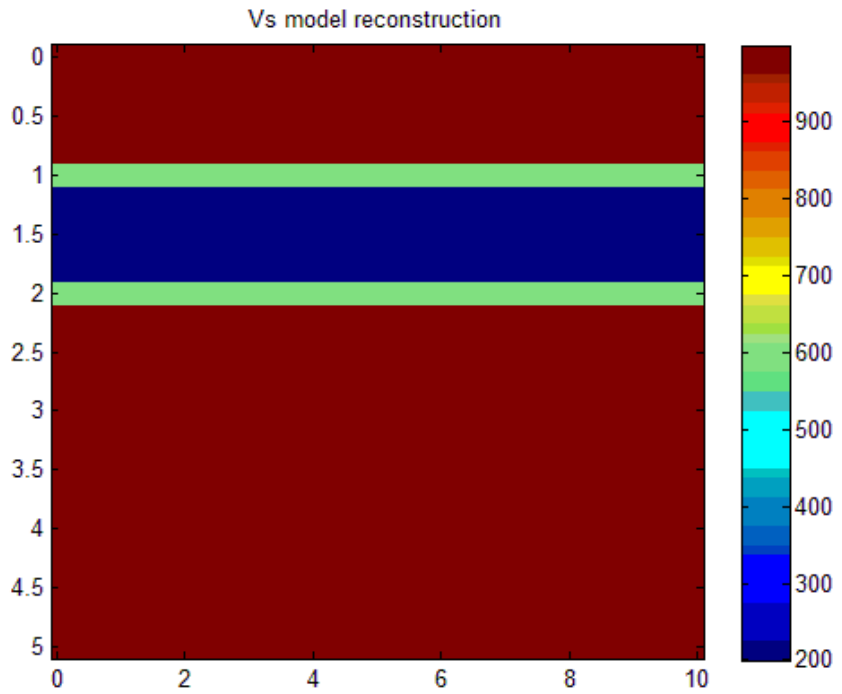


Full Waveform: Seg 2D at TAMU

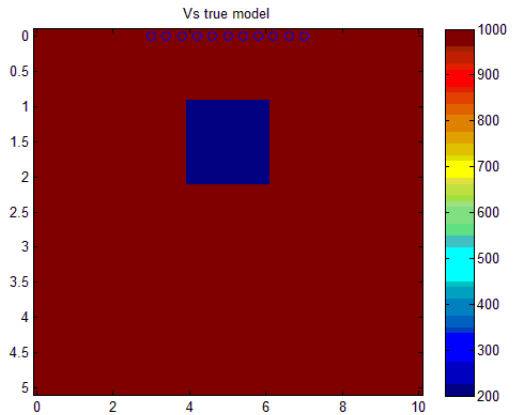


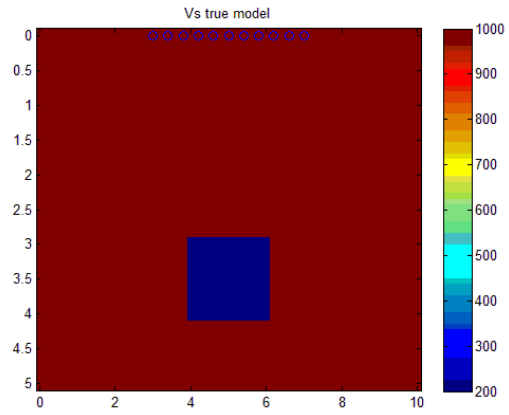
FWI: Layer

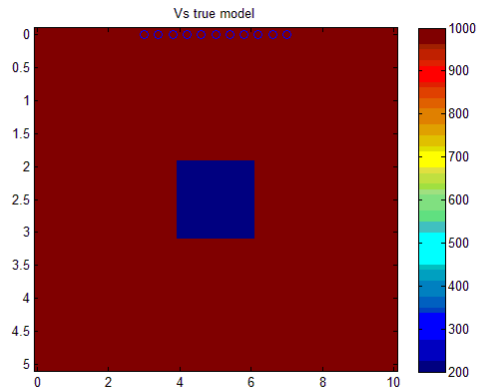
- **2D finite difference model**
- **Simulated annealing and genetic algorithm**
- **Surface array**
- **Array and source design**

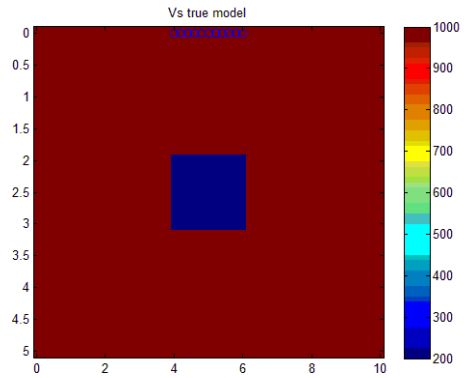


FWI: Block

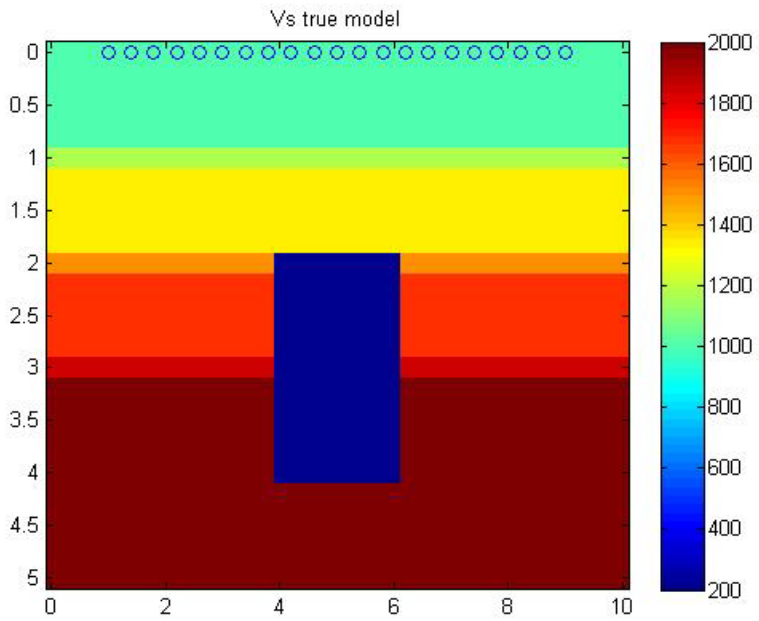

Vs true model
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
1000
900
800
700
600
500
400
300
200

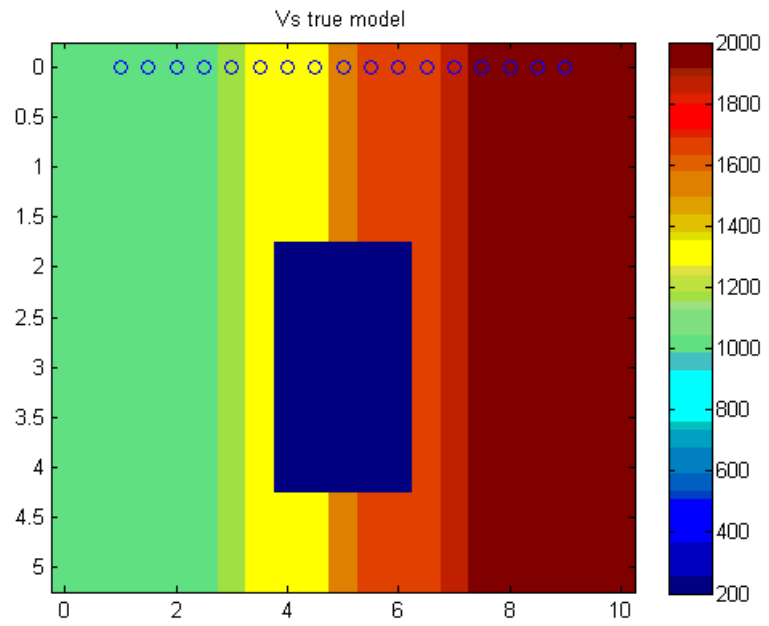

Vs true model
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
1000
900
800
700
600
500
400
300
200


Vs true model
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
1000
900
800
700
600
500
400
300
200

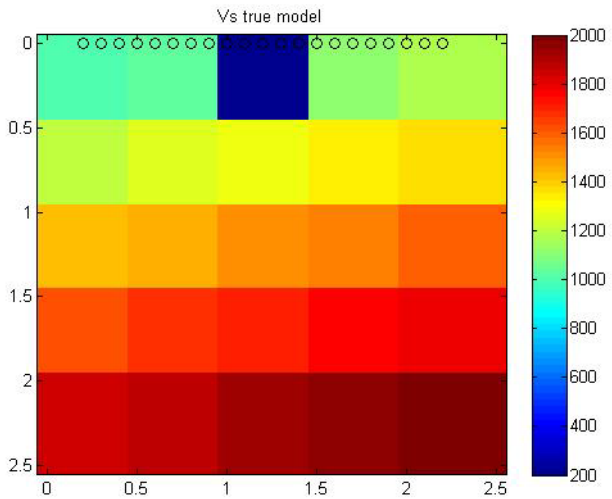

Vs true model
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
2
4
6
8
10
1000
900
800
700
600
500
400
300
200

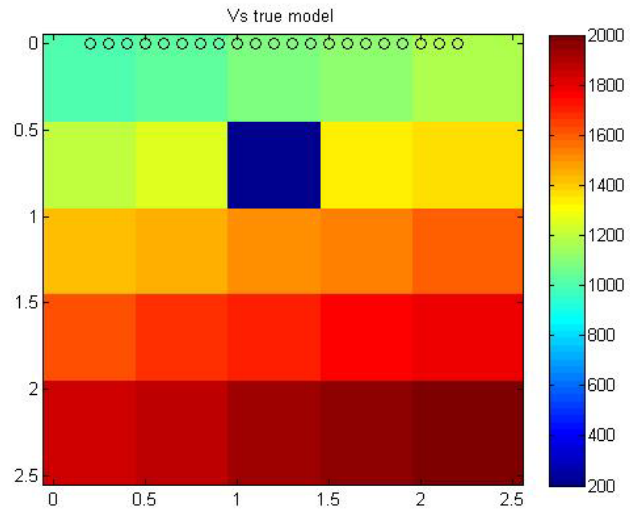
FWI: Block in Gradient

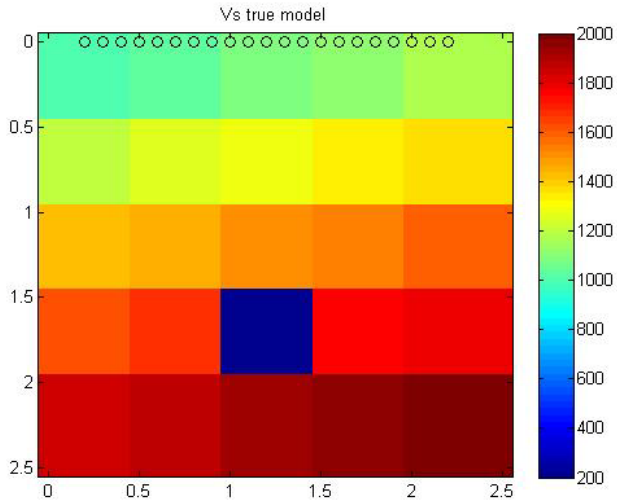


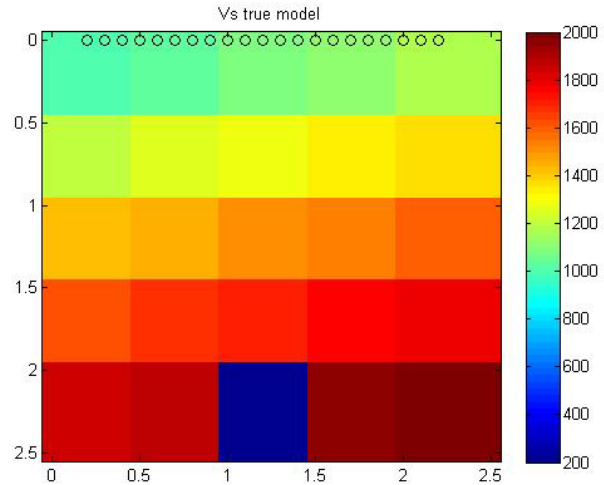


FWI: 5x5 Grid, 0.5 m









Forward Model Questions

- **<u>Original premise</u>: Can we slice a radial plane from the borehole, put a source and array of receivers along the vertical borehole axis edge, and then model with a 2D, plane-strain, flat-ground model?**
- **<u>Under investigation</u>: Or, do the actual surroundings of the borehole geometry significantly influence the wavefield and the waveforms collected along the borehole axis?**

Geometry-Induced Dispersion

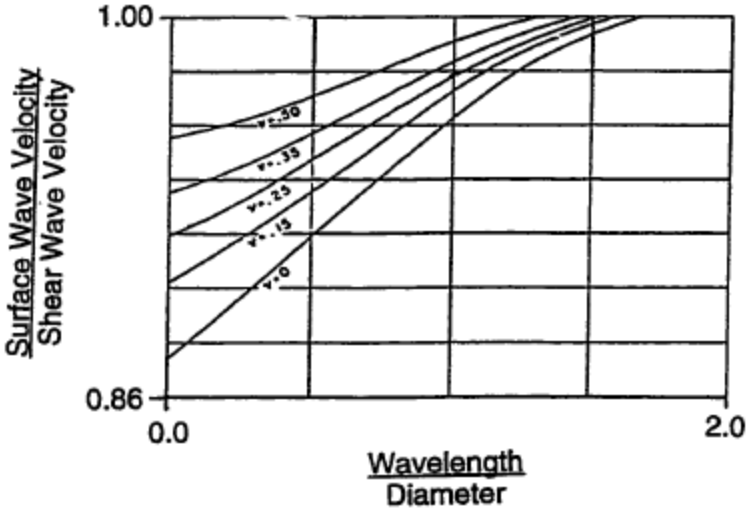


Figure 2.11. Geometry-Induced Dispersion of a Surface Wave Propagating Axially in an Uncased, Empty Cylindrical Cavity (Biot, 1952).

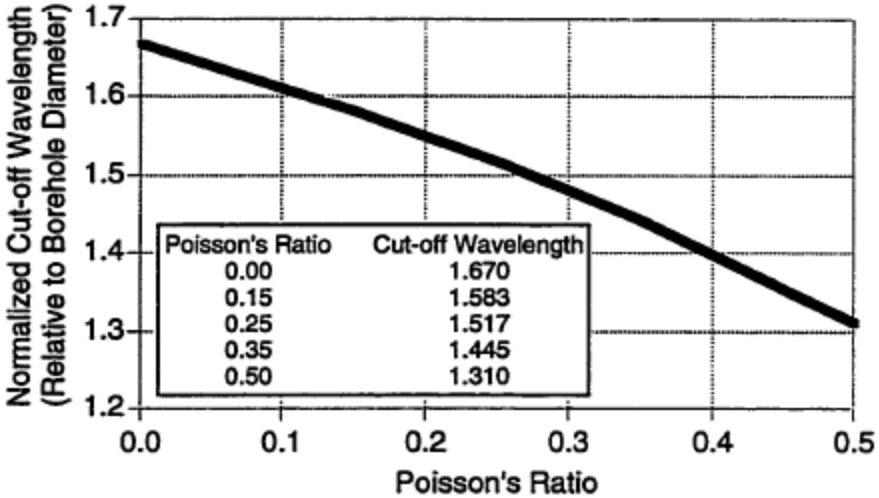
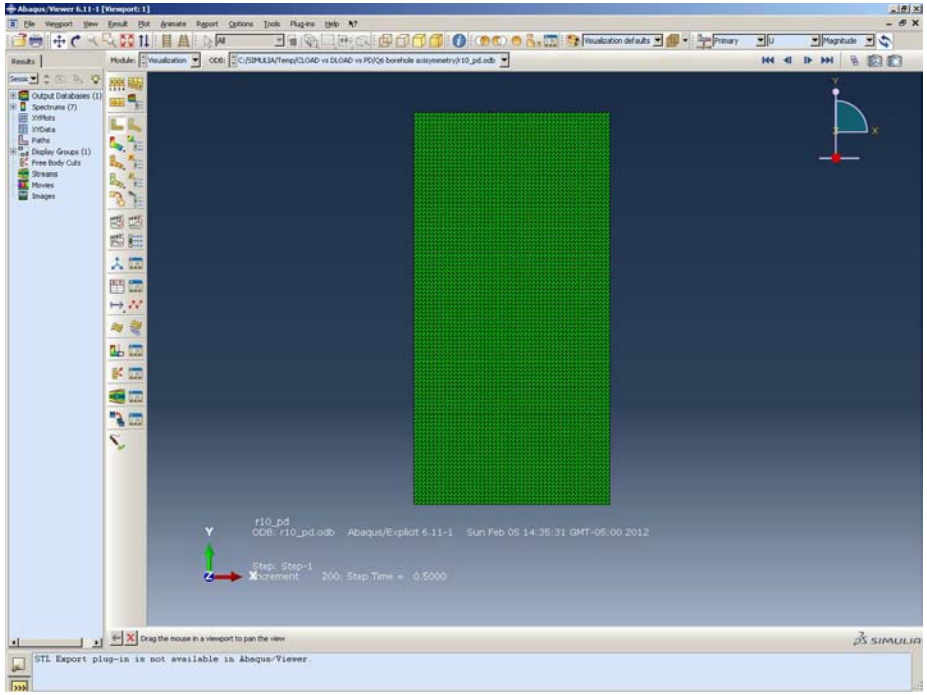


Figure 2.12. Cut-off Wavelengths Observed in an Open, Empty Cylindrical Cavity (Biot, 1952).

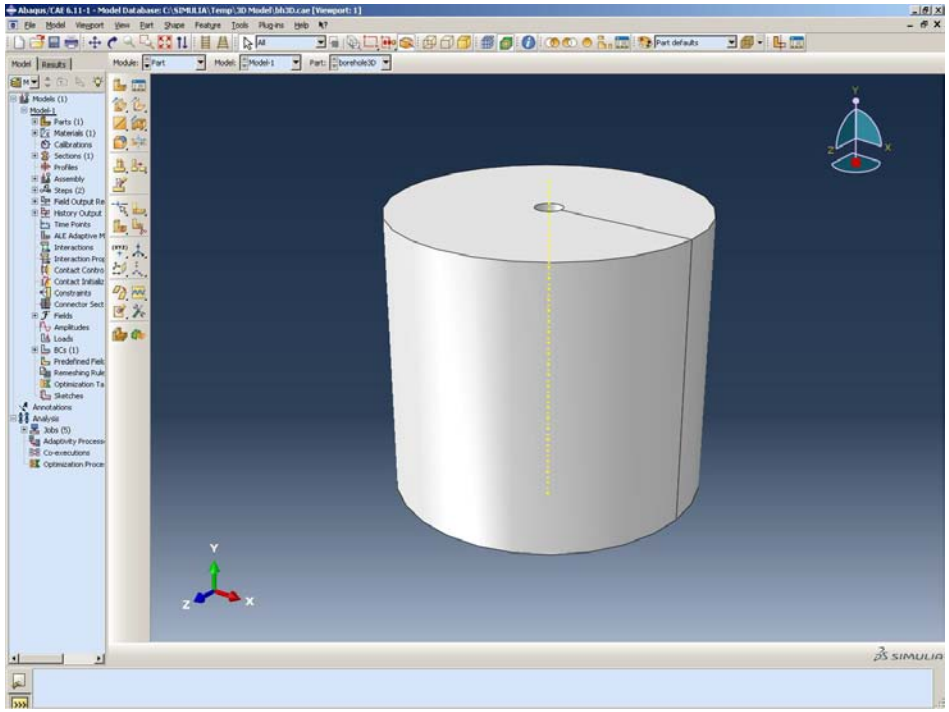
2D, Flat-Ground Models

- **<u>Plane-strain</u>: FD, Plaxis, Abaqus**
- **<u>Axisymmetric</u>: Plaxis, Abaqus**
- **Waveforms similar for all three codes**
- **Movies**



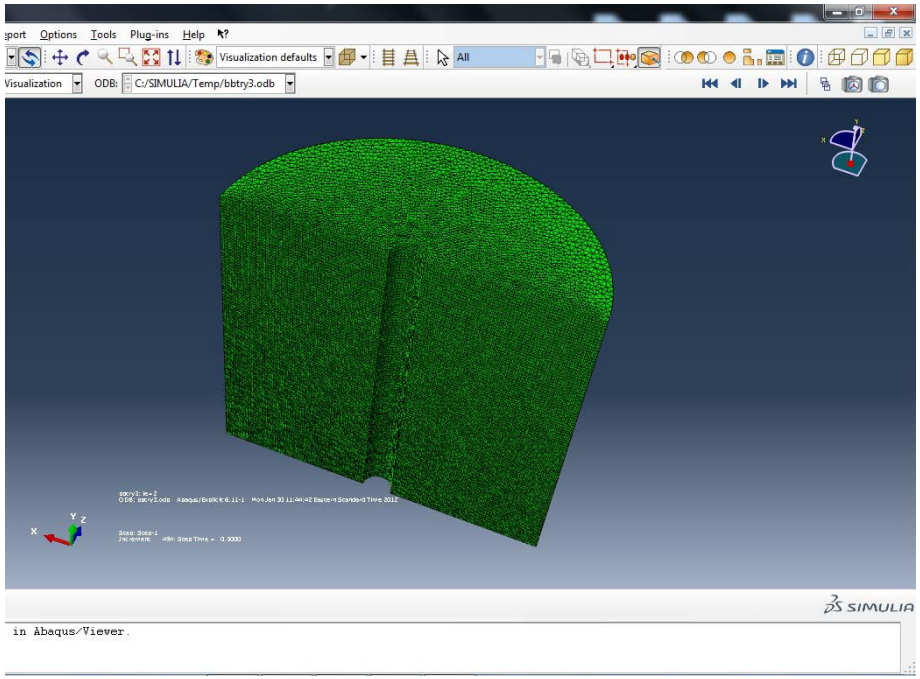
2.5D, Axisymmetric, Borehole Model

- **Two models: Plaxis, Abaqus**
- **Ring load**
- **Waveforms similar for both codes**



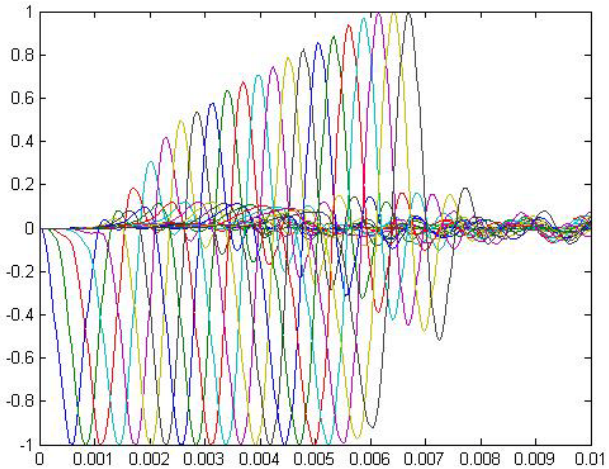
3D Borehole Model

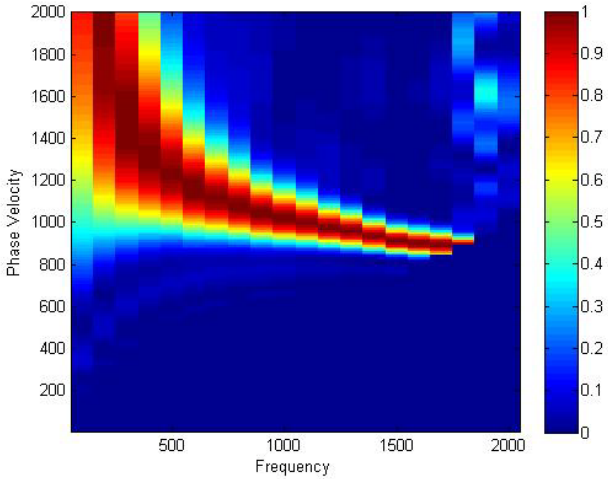
- **Abaqus**
- **Ring load**
- **Point load**
- **Movies**



3D Borehole Model, 50 cm Radius

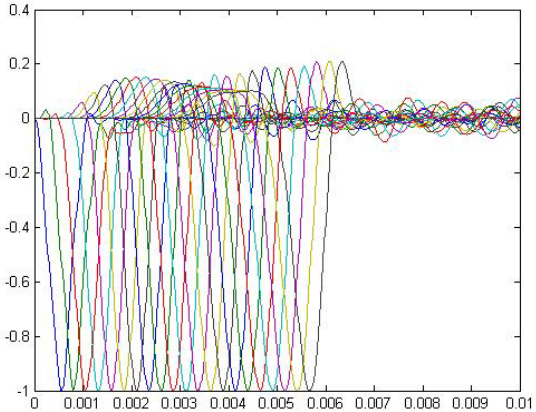
- **Code: Abaqus**
- **Configuration: R=10 m, r=50 cm, L=20 m**
- **Properties: Vs=1000 m/s**
- **Array: 20 @ 0.25 m along borehole wall**
- **Source: point, triangular, center of cylinder, S=0.25 m**

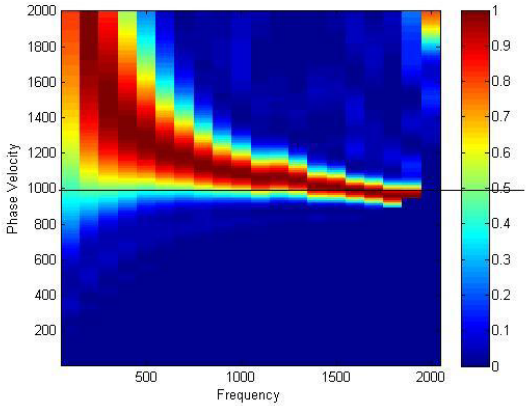




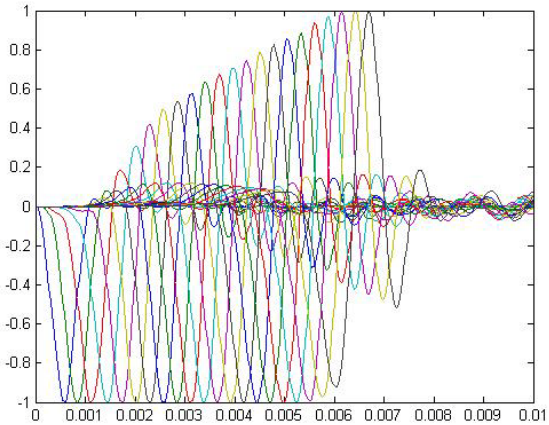
3D Borehole Model, 5 cm Radius

- **Code: Abaqus**
- **Configuration: R=10 m, r=5 cm, L=20 m**
- **Properties: Vs=1000 m/s**
- **Array: 20 @ 0.25 m along borehole wall**
- **Source: point, triangular, center of cylinder, S=0.25 m**

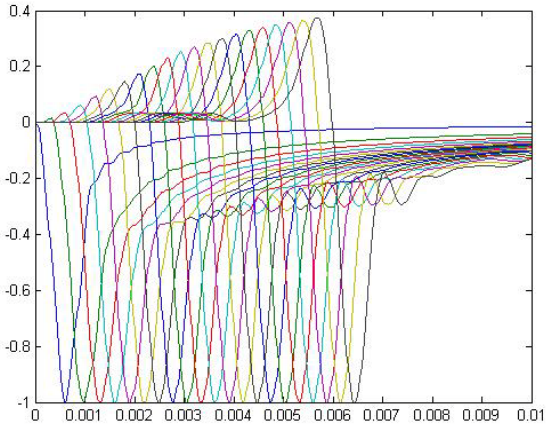




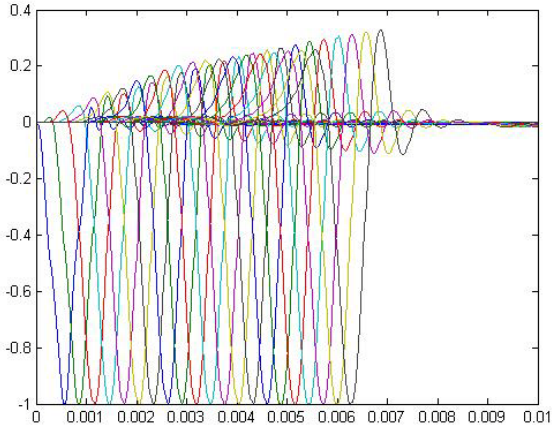
Compare: Waveforms



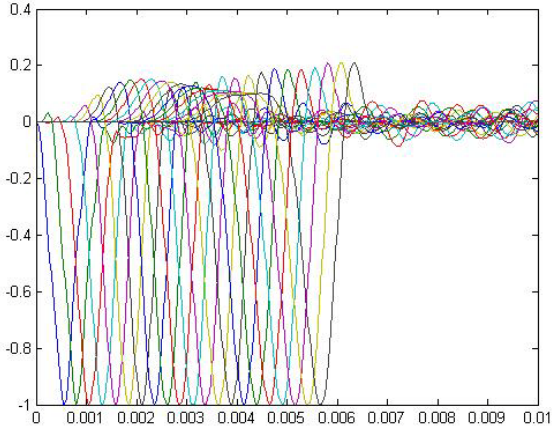
2D



50 cm

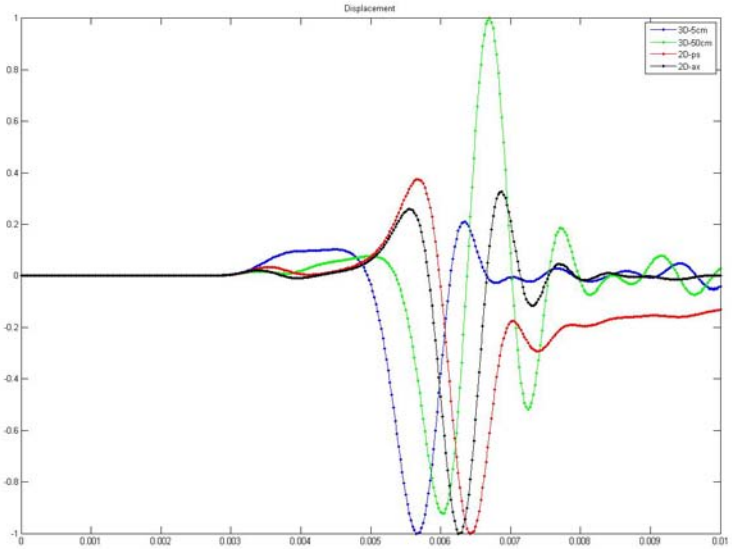


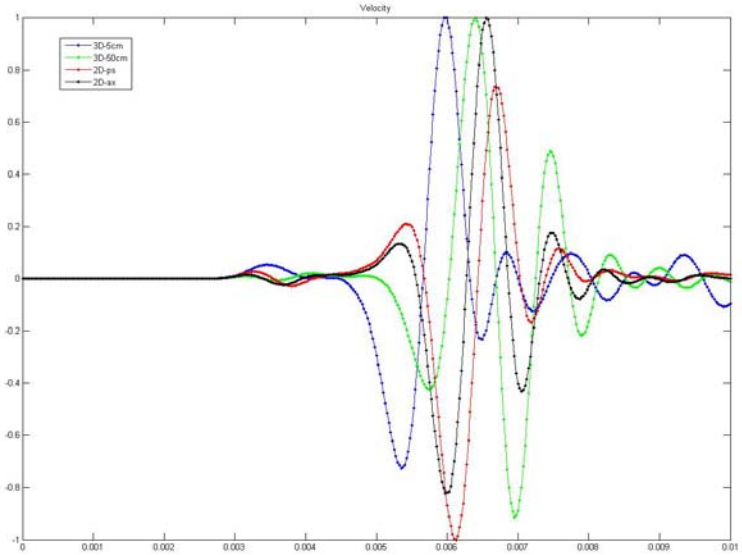
2.5D



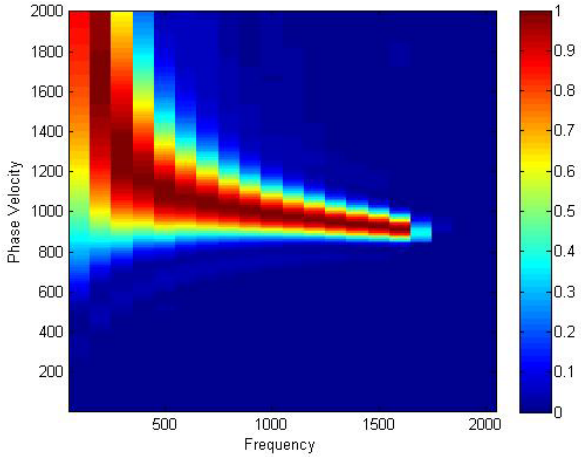
5 cm

Compare: Waveforms at x=middle

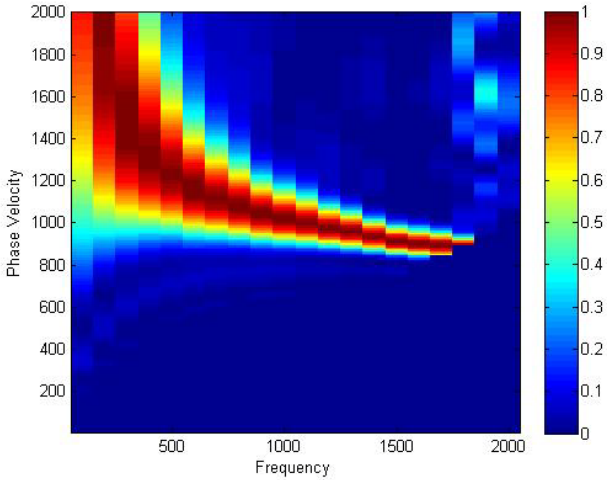




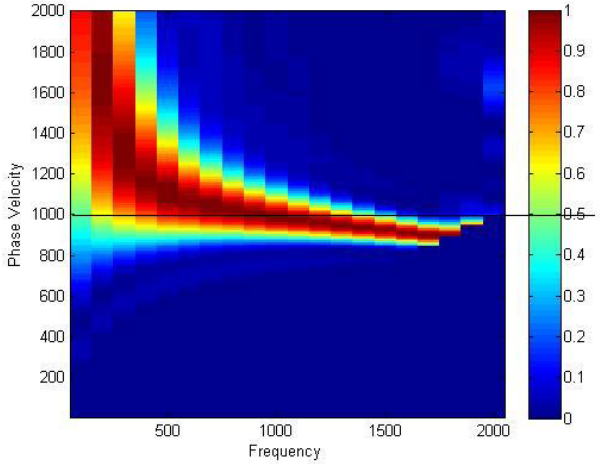
Compare: Dispersion Images



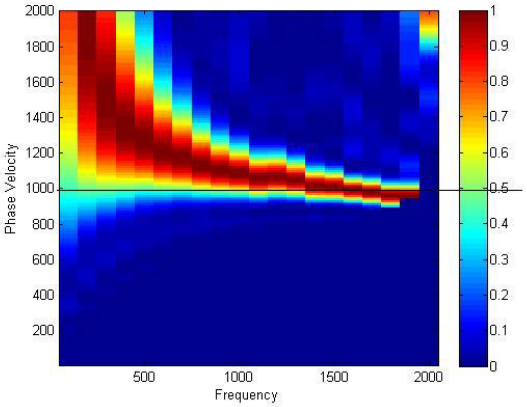
2D



50 cm



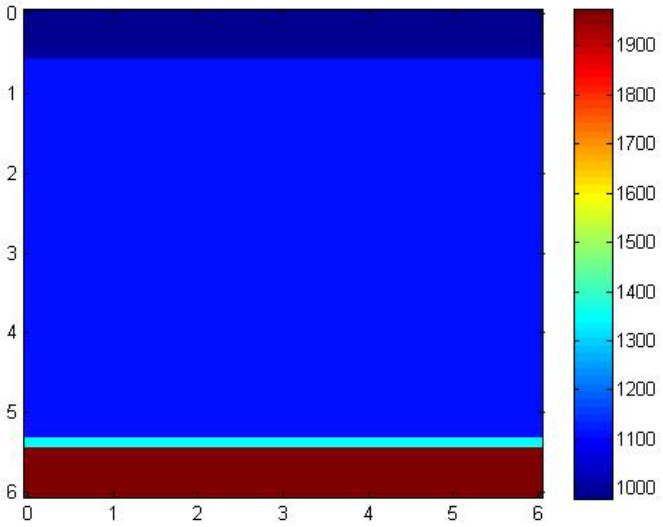
2.5D



5 cm

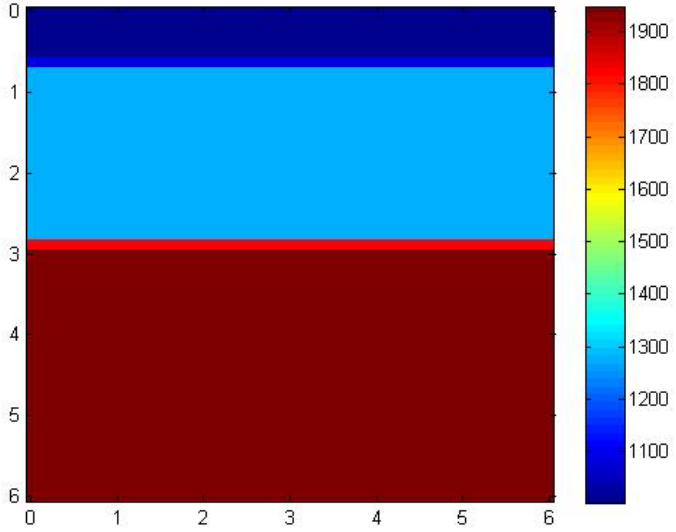
Inversion with 2D, Plane-Strain, Flat-Ground Model: 3D Flat Ground

- **Code: Abaqus synthetic**
- **Configuration: 20 m cube**
- **Properties: Vs=1000 m/s**
- **Array: 10 @ 0.5 m**
- **Source: point, triangular, S=0.5 m**
- **Inversion: 6 m x 6 m, 2 layers +half-space**
- **Waveforms not well matched, but return about 1000 m/s**



Inversion with 2D, Plane-Strain, Flat-Ground Model: 50 cm Radius

- **Code: Abaqus synthetic**
- **Configuration: R=10 m, r=50 cm, L=20 m**
- **Properties Vs=1000 m/s**
- **Array: 10 @ 0.5 m along borehole wall**
- **Source: point, triangular, center of cylinder, S=0.5 m**
- **Inversion: 6 m x 6 m, 2 layers +half-space**
- **Waveforms not well matched, return stiffer than 1000 m/s**



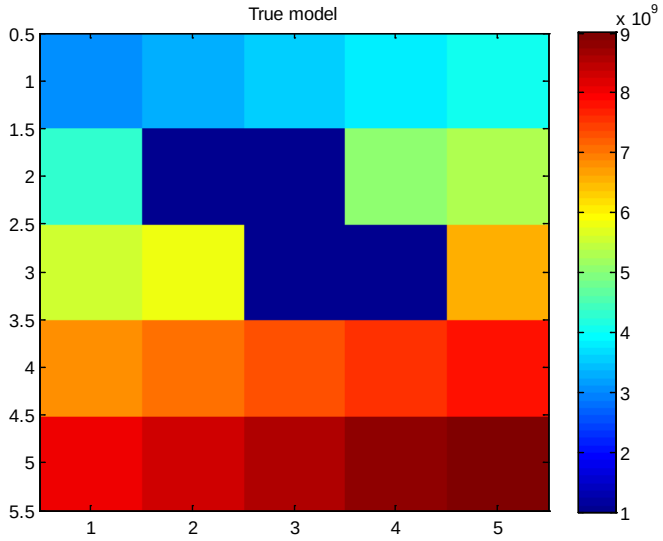
Forward Model Questions

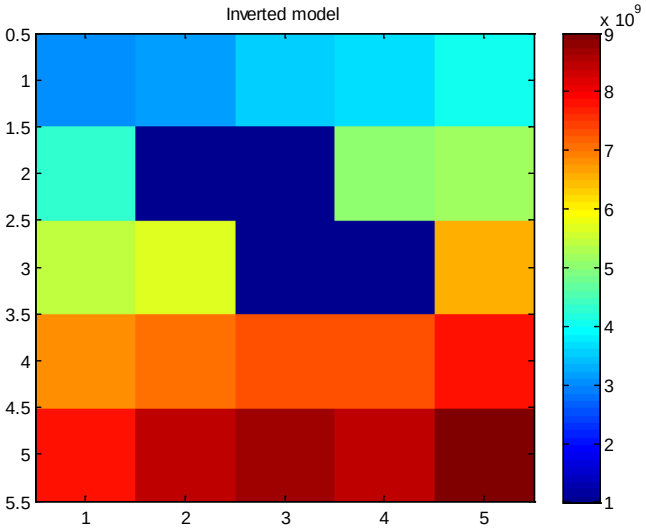
- **<u>Summary</u>: appears that borehole influence is significant, based on wavefield movies, dispersion curves, waveform comparisons, and inversions assuming 2D plane-strain, flat-ground model**
- **<u>Future</u>: original premise does not appear feasible, require a forward model that includes borehole geometry, e.g., build a FD model, use existing FEM code**

Two Solutions

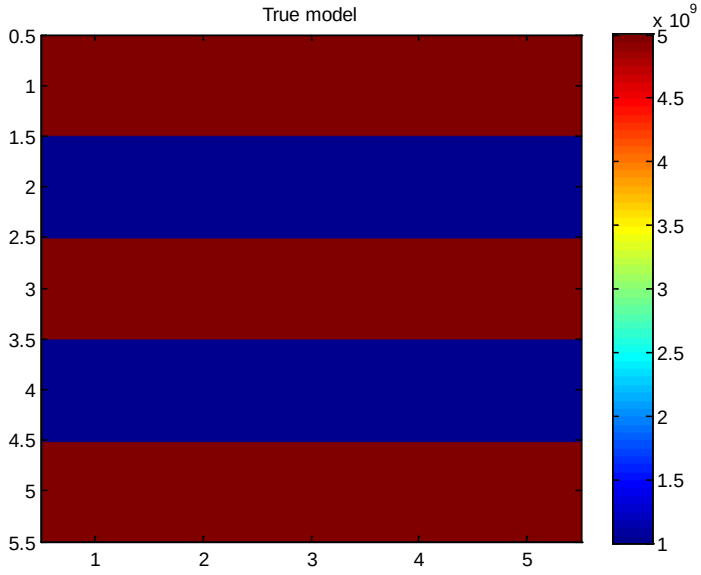
- Have built two inversion models that use borehole model in Abaqus to invert waveforms collected along vertical wall of borehole
- First inversion model uses simulated annealing
- Second inversion model uses linearized, local inversion following recent work of Tran
- 2.5D a few seconds, 3D an hour for each forward
- Good for a ring experiment, 2.5D and 3D similar

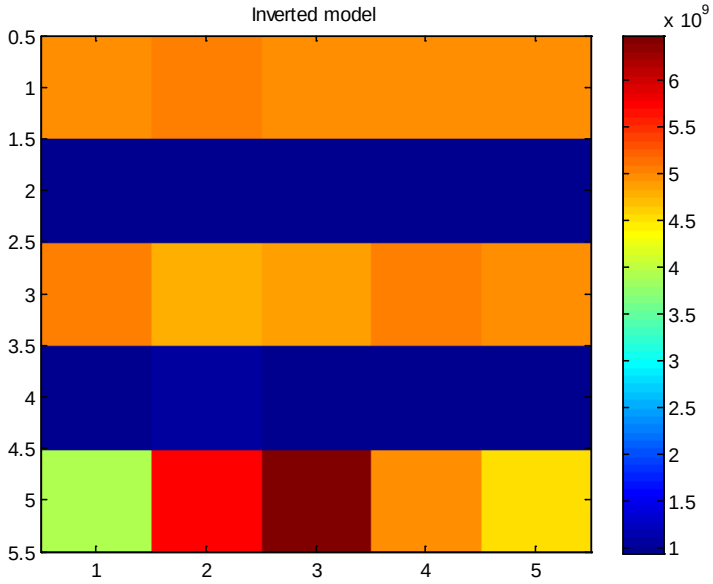
Abaqus FWI: Flat-Ground, 5x5 Grid





Abaqus FWI: 2.5D Borehole, 5x5 Grid

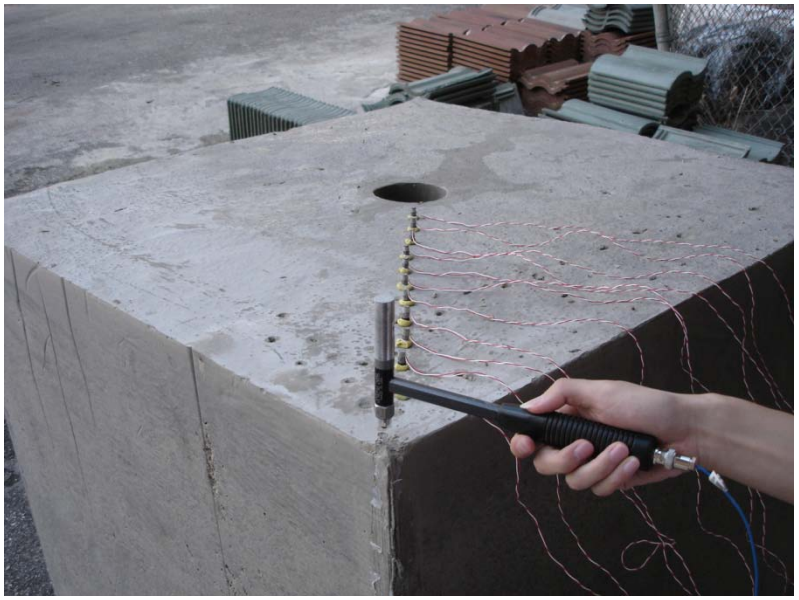


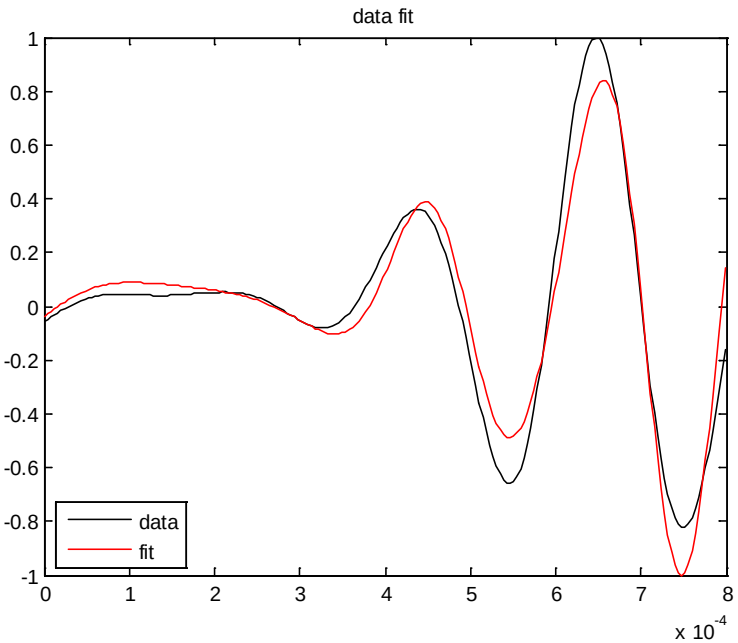


Array Experiments

- **Test multi-sensor array concept and full waveform inversion on experimental data**
- **Use existing instrumentation**
- **Flat surface and borehole**
- **Do we use fluid-filled or dry hole?**
- **How to do tests on a model with correct-scale array and instruments? Effects of boundaries?**
- **How to design/construct a model with properties of Florida limerock?**

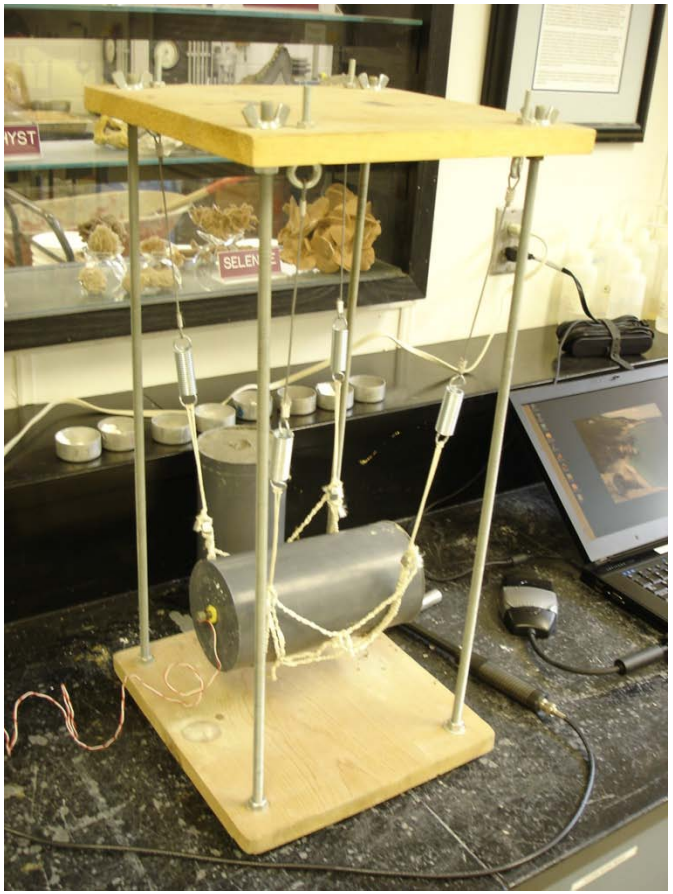
Synthetic Limerock Specimen



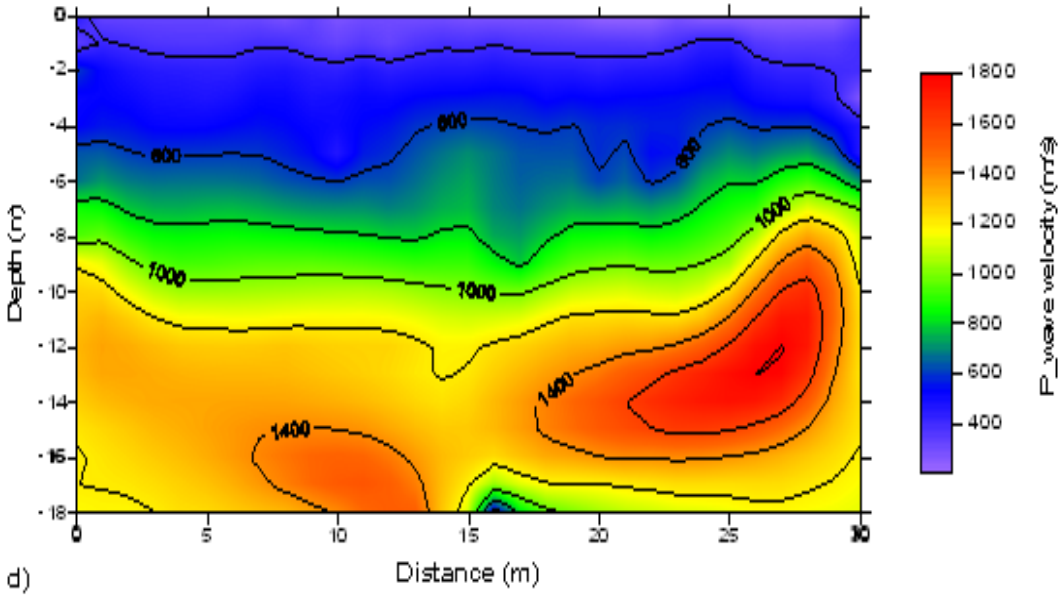


Synthetic Limerock Specimen

- **Preliminary results**
- **Vs = 935 m/s from FWI**
- **Free-free resonant column tests**
- **Vp = 1500 m/s**
- **Poisson's ratio = 0.2**



Thank You!


Depth (m)
Distance (m)
P_wave velocity (m/s)
600
1000
1400
1800
1600
1400
1200
1000
800
600
400
d)