Implementation of Down-Hole Geophysical Testing for Rock Sockets

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FDOT GRIP

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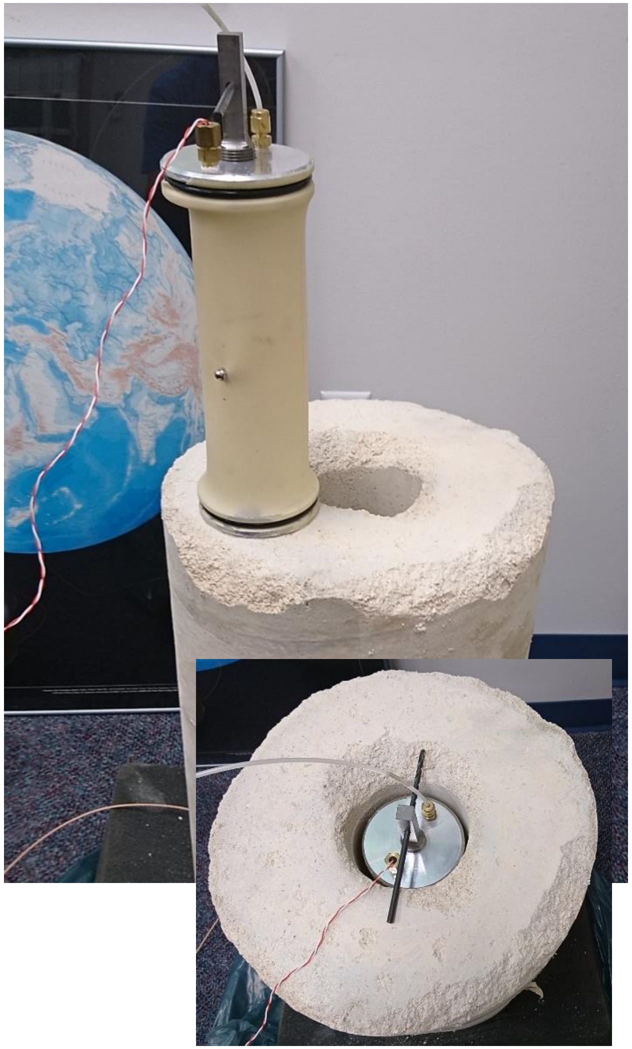
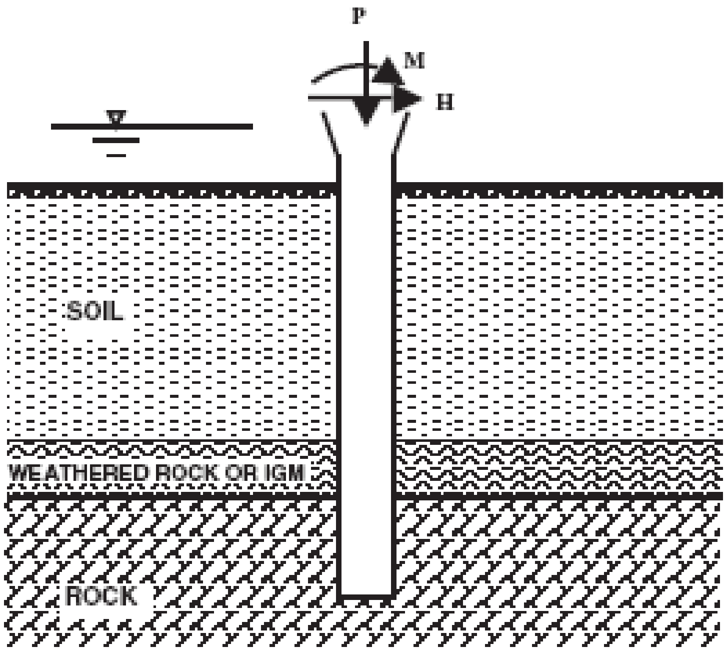
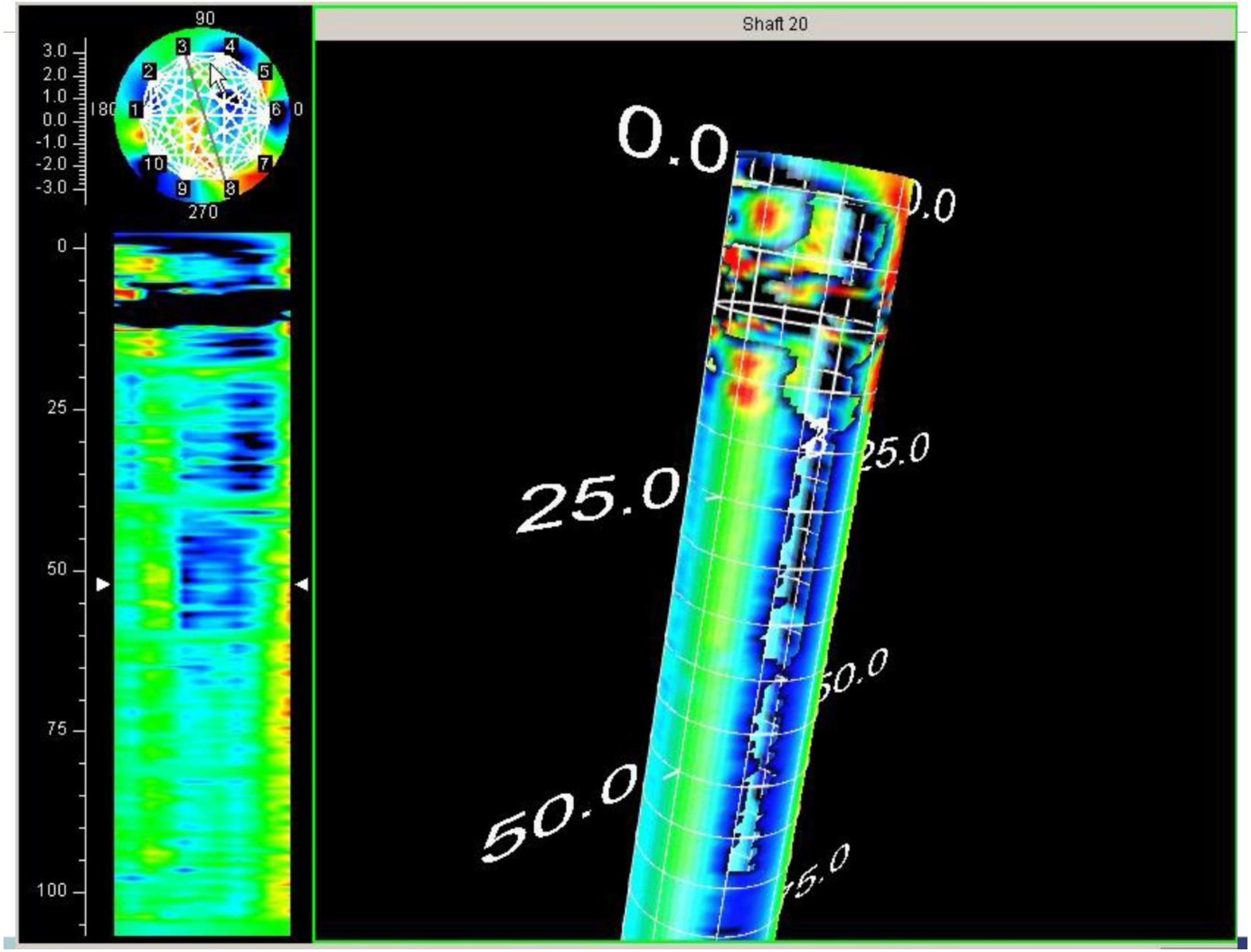


Geophysical Characterization of Rock Sockets

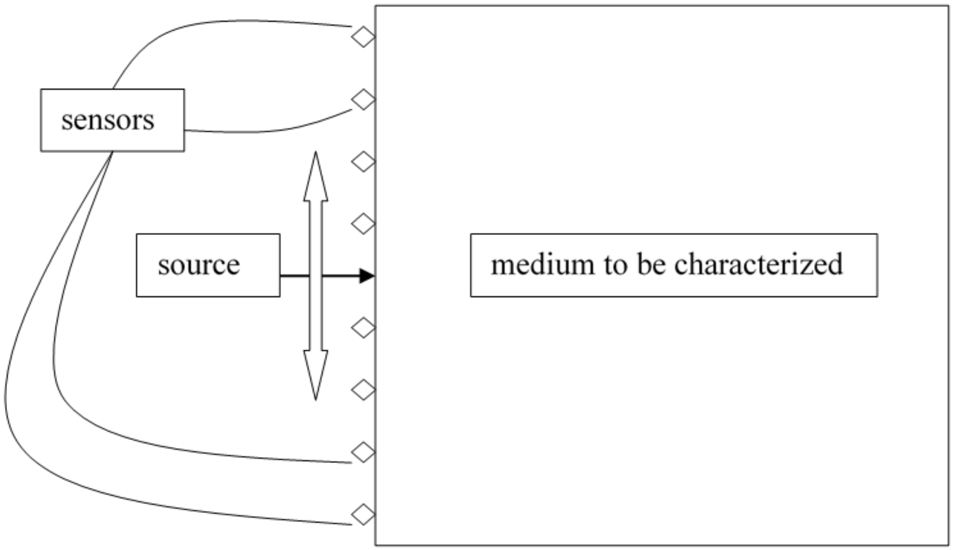
- Rock highly variable: extend characterization to ~5 ft laterally from borehole
- Develop geophysical technique to supplement boring cores and lab results
- Utilize only the one standard borehole
- Integrate with current boring, sampling, and testing tools

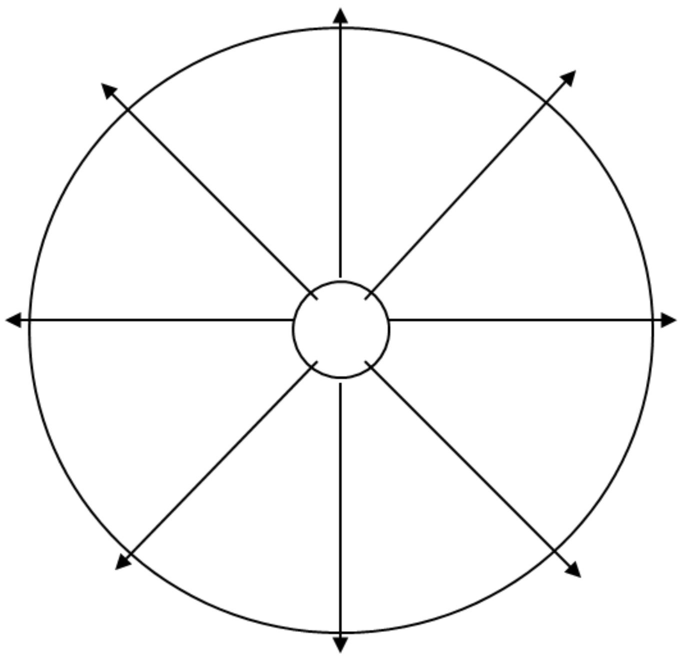


Geophysical Characterization of Rock Sockets



Borehole Tool Schematic

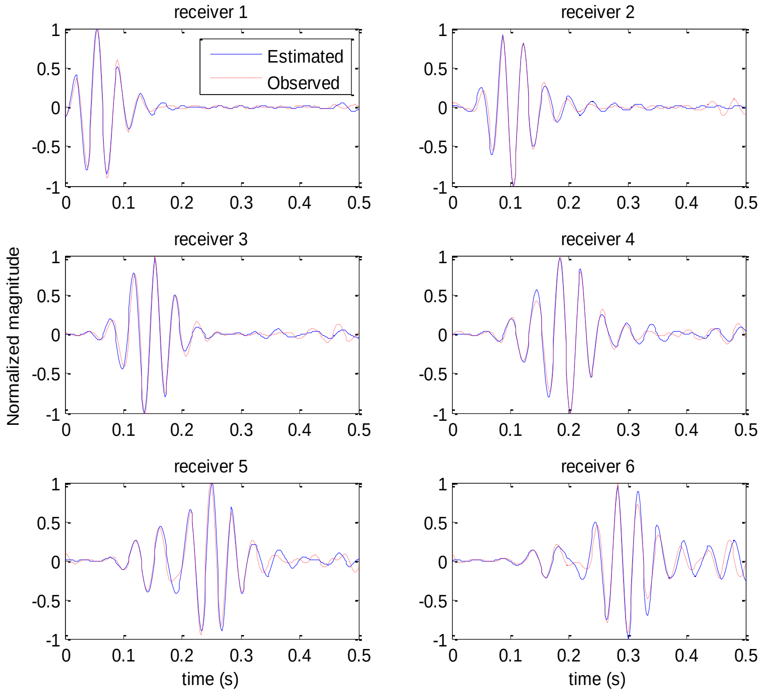




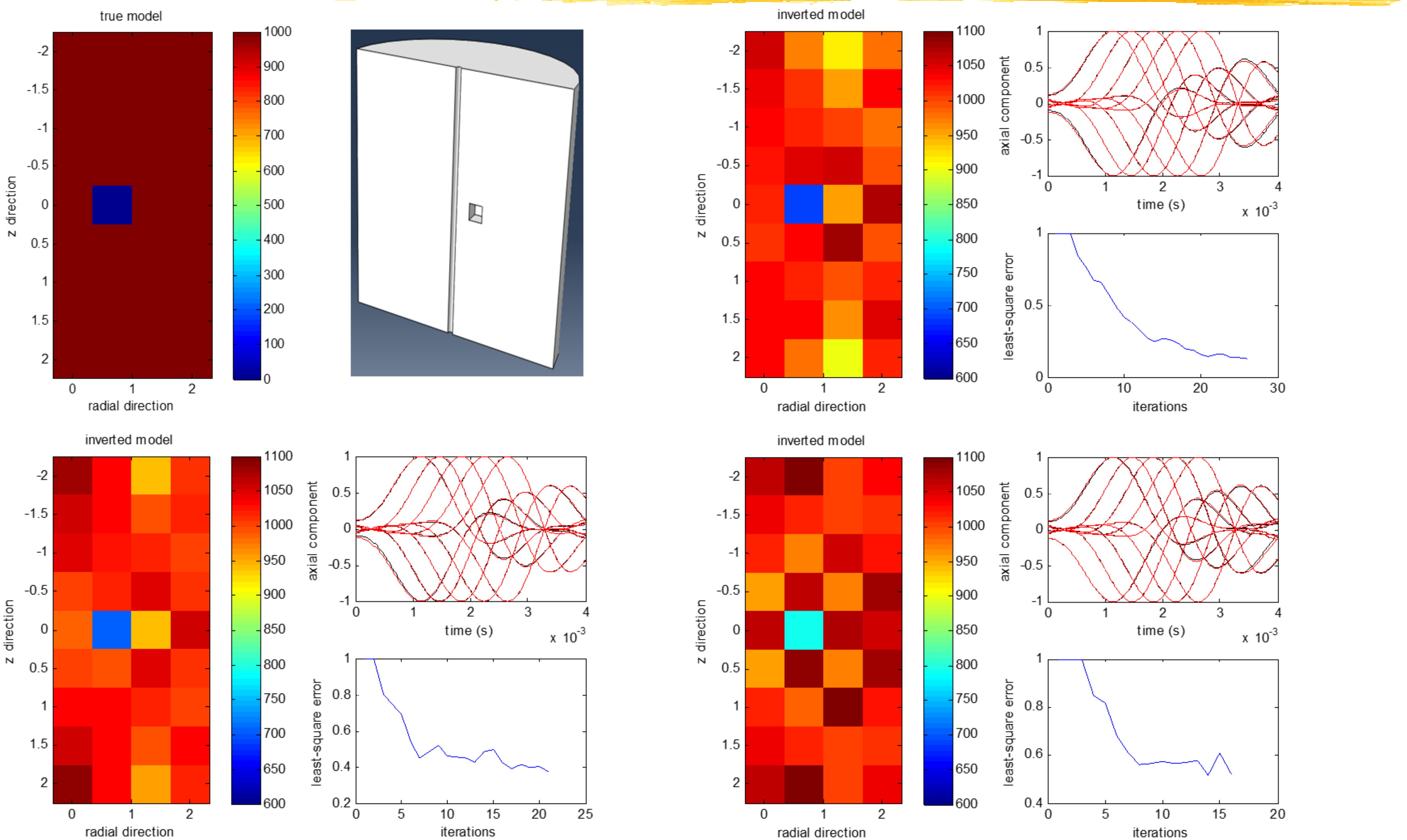
A joining of borehole instrumentation with full waveform inversion

Full Waveform Inversion (FWI)

- Invert for model parameters by matching full waveforms
- Complex profiles create difficulties for traditional techniques (e.g, G, T, O’N, L)
- Studies have demonstrated improved resolution with FWI
- Advancements in wave propagation modeling, inversion algorithms, and computing have made this possible
- Have demonstrated for some challenging synthetic and field data sets



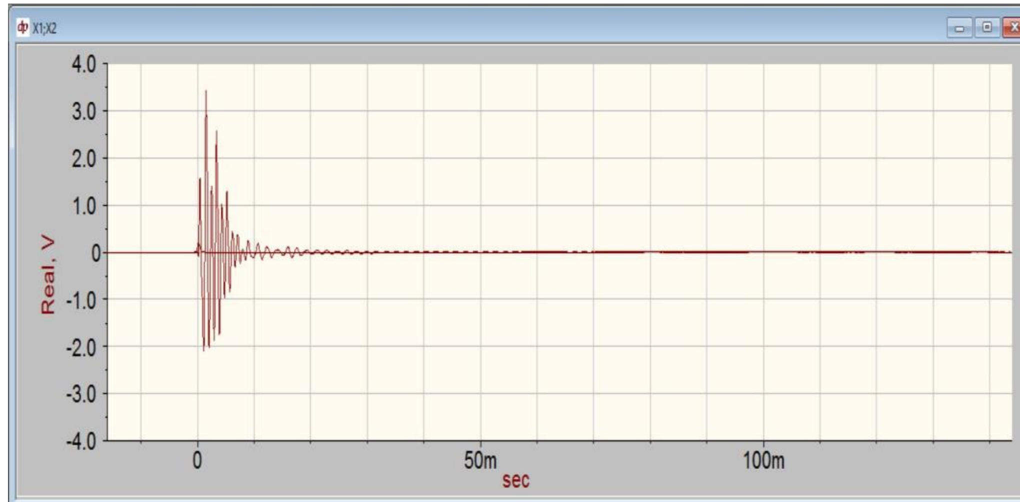
Isolated Anomaly in Homogeneous

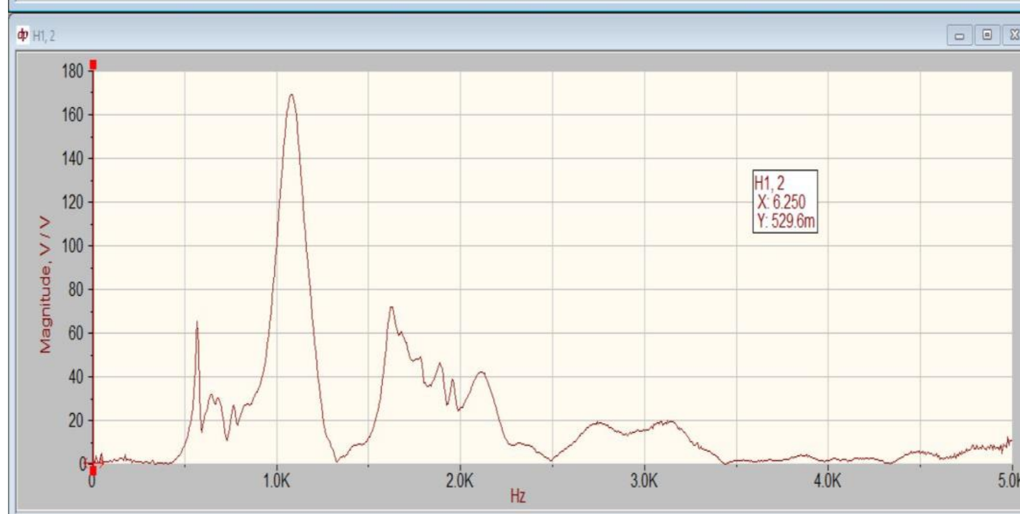


Workplan

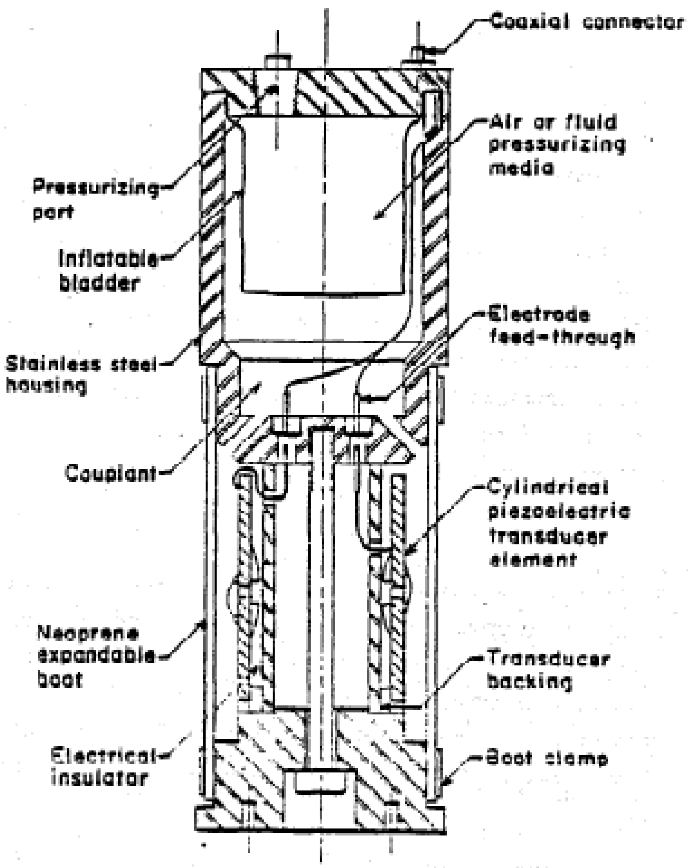
- Task 1: Borehole Instrument
  - Source for generating seismic (mechanical) waves
  - Receiver array for capturing the wavefield
- Task 2: Inversion Software
  - ABAQUS forward model
  - Stand-alone forward model for borehole geometry
  - Artificial neural network (ANN) trained by ABAQUS
- Task 3: Validation Experiments
  - Large laboratory block of synthetic limerock
  - Newberry and Kanapaha test sites
- Task 4: Report

Borehole Receiver

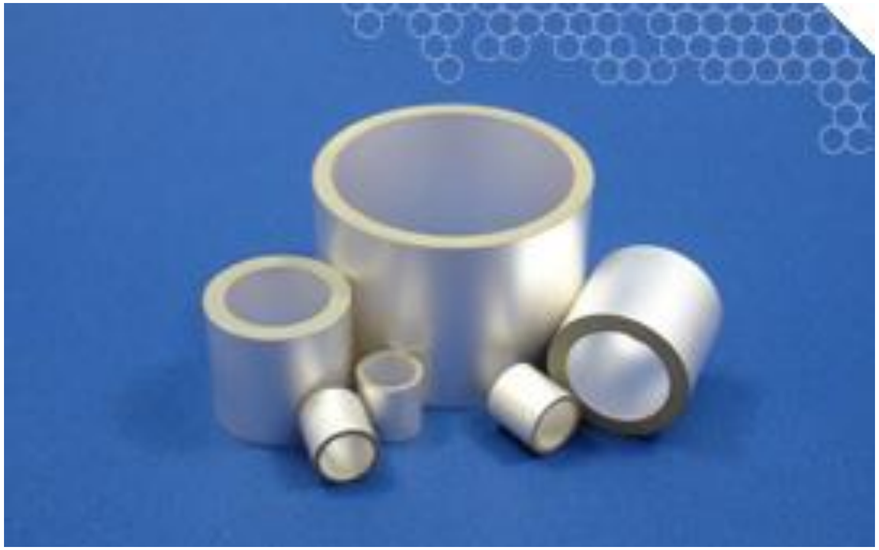




Piezoelectric Borehole Source



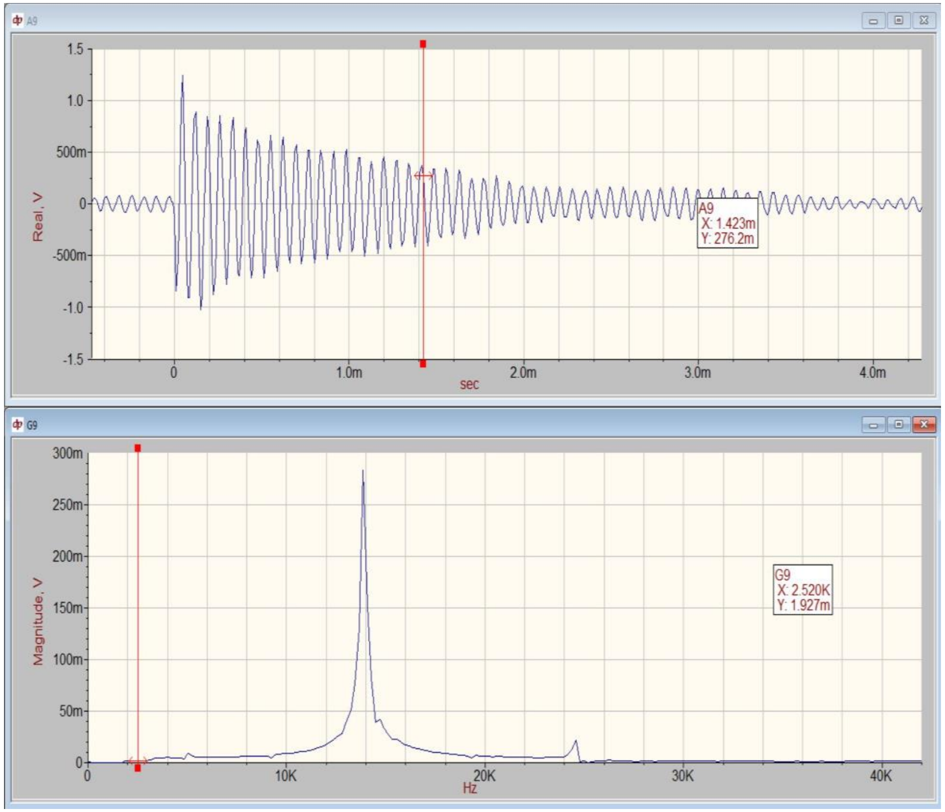
Thill (1978)



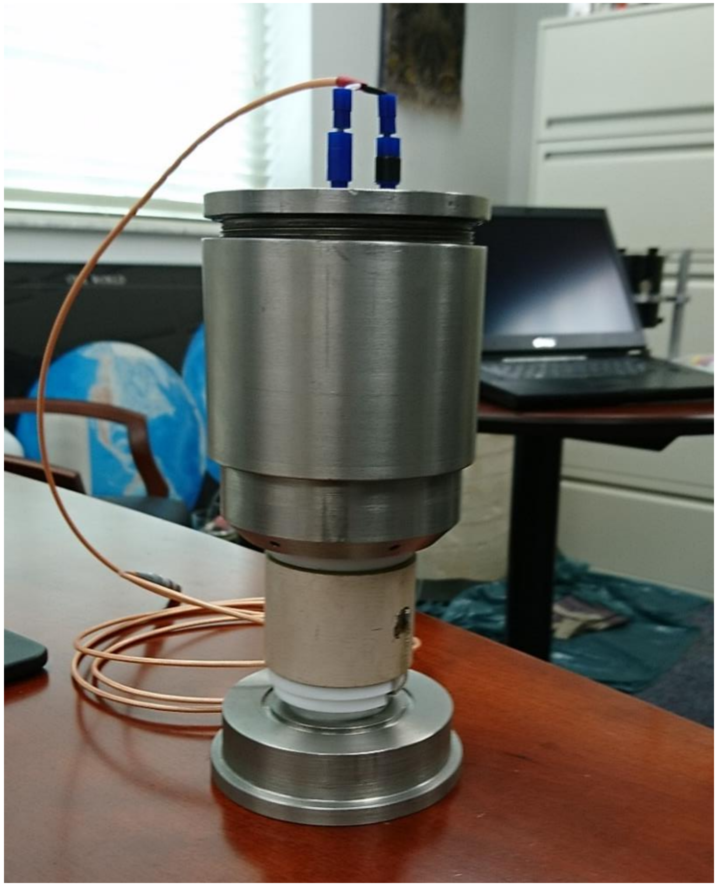
Piezoelectric Cylinders

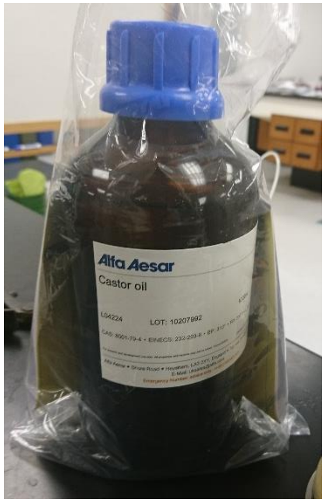
CSL Sensor

Cylinder and Amplifier: 3rd Generation



Inflatable Borehole Source: 17 kHz





Inflatable Source: Stacked 14 kHz

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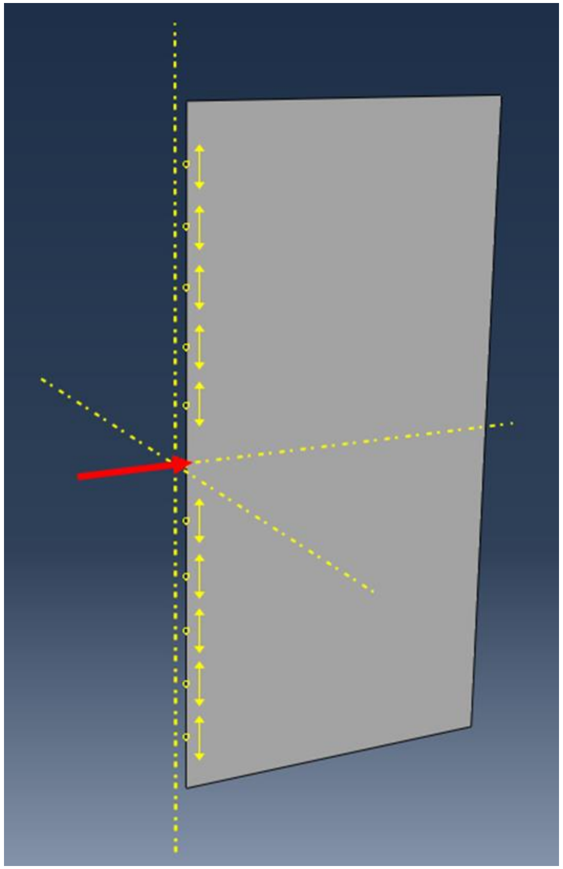
Inversion Schematic

ABAQUS 2.5D FEM



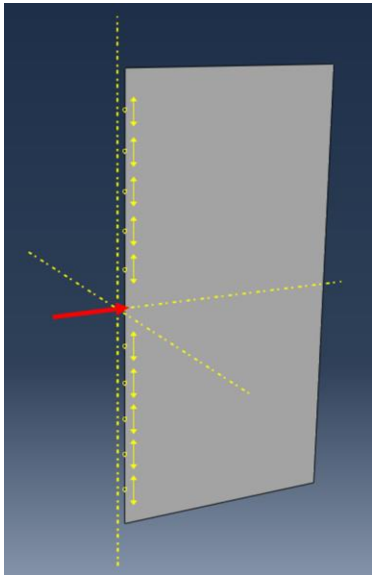
Regularized Gauss-Newton Method

- Residual wave field: $\Delta\mathbf{d} = \mathbf{F}(\mathbf{m}) - \mathbf{d}$
- Least-squares error: $\mathrm{E}(\mathbf{m}) = \frac{1}{2}\Delta\mathbf{d}^t\,\Delta\mathbf{d}$
- Model updating: $\mathbf{m}^{n+1} = \mathbf{m}^n - \alpha^n\,[\mathbf{J}^t\,\mathbf{J} + \lambda_1\mathbf{P}^t\,\mathbf{P} + \lambda_2\mathbf{I}^t\,\mathbf{I}\,]^{-1}\,\mathbf{J}^t\,\Delta\mathbf{d},$
- Gradient matrix J: $\mathbf{J} = \frac{\partial\,\mathbf{F}(\mathbf{m})}{\partial m_p}$
- Step length: $\alpha^n \cong \frac{[\mathbf{J}^t g^n]^t\,[\mathbf{F}(\mathbf{m}^n) - \mathbf{d}]}{[\mathbf{J}^t g^n]^t\,[\mathbf{J}^t g^n]},$

$$g^n = [\mathbf{J}^t\,\mathbf{J} + \lambda_1\mathbf{P}^t\,\mathbf{P} + \lambda_2\mathbf{I}^t\,\mathbf{I}\,]^{-1}\,\mathbf{J}^t\,[\mathbf{F}(\mathbf{m}^n) - \mathbf{d}].$$

Inversion Software

- **ABAQUS 2.5D FEM and regularized Gauss-Newton method**
- **Improved FEM element and mesh and streamlined inversion code**
- **Implemented 2.5D borehole model in Student Version of ABAQUS (free)**
- **Inversion shell in MATLAB**
- **Improved speed to allow longer waveforms**



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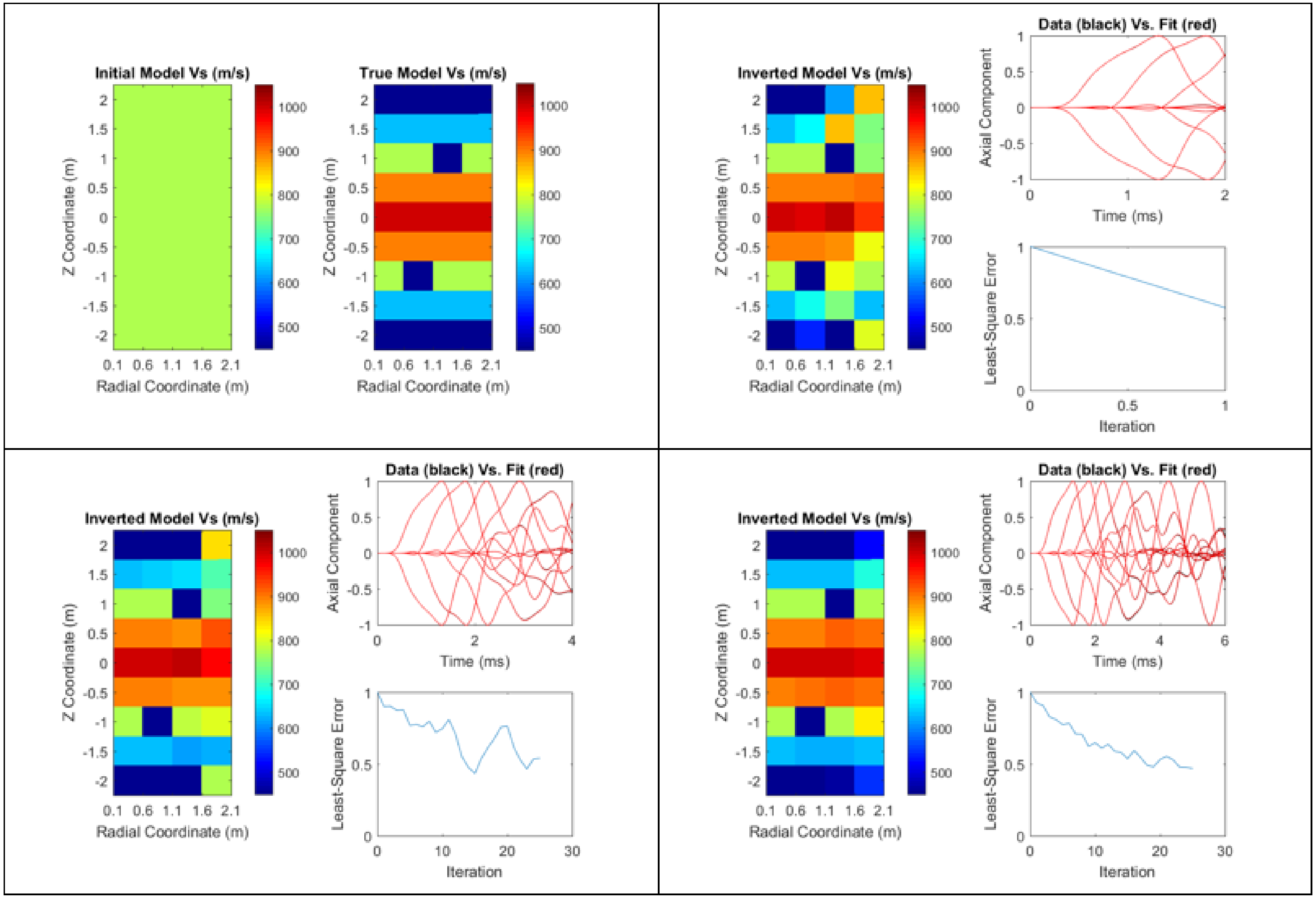
Two Anomalies Same Side

Case 3: Model (13.25m x 5.25m) for 6-ms simulation time



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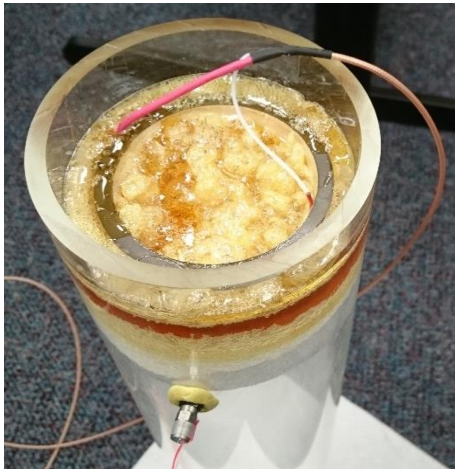
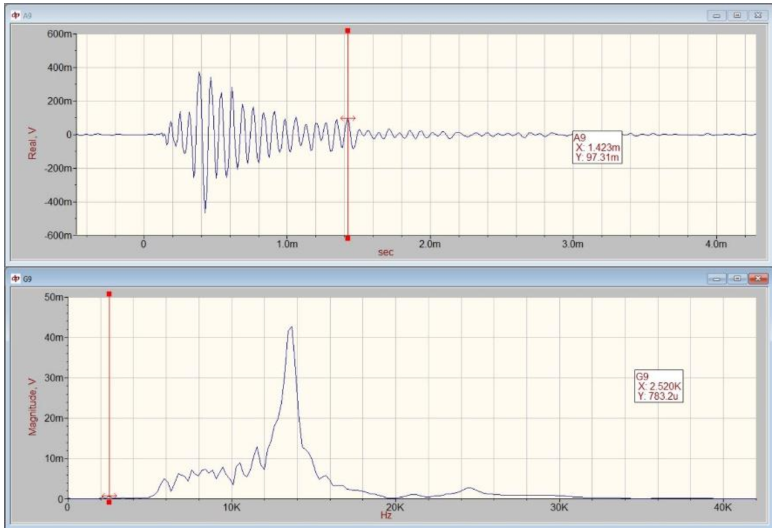
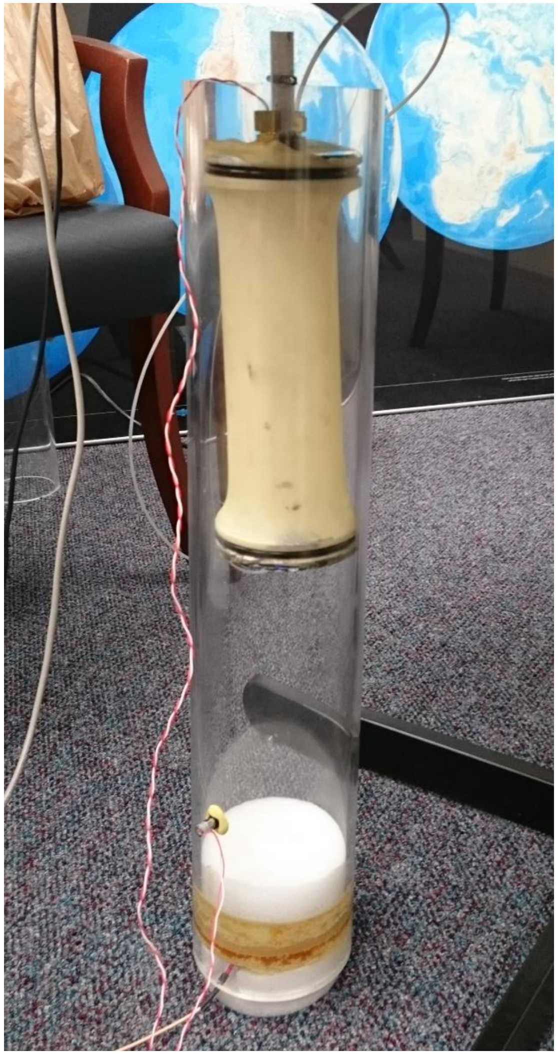
Acrylic Tube

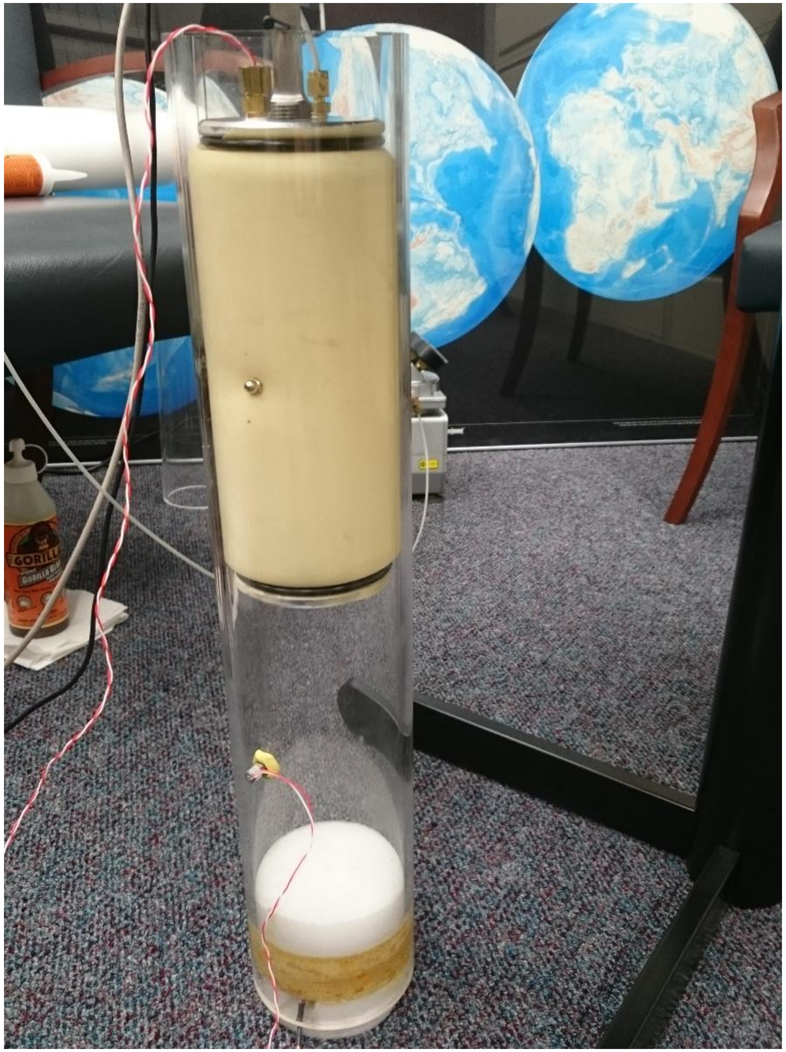


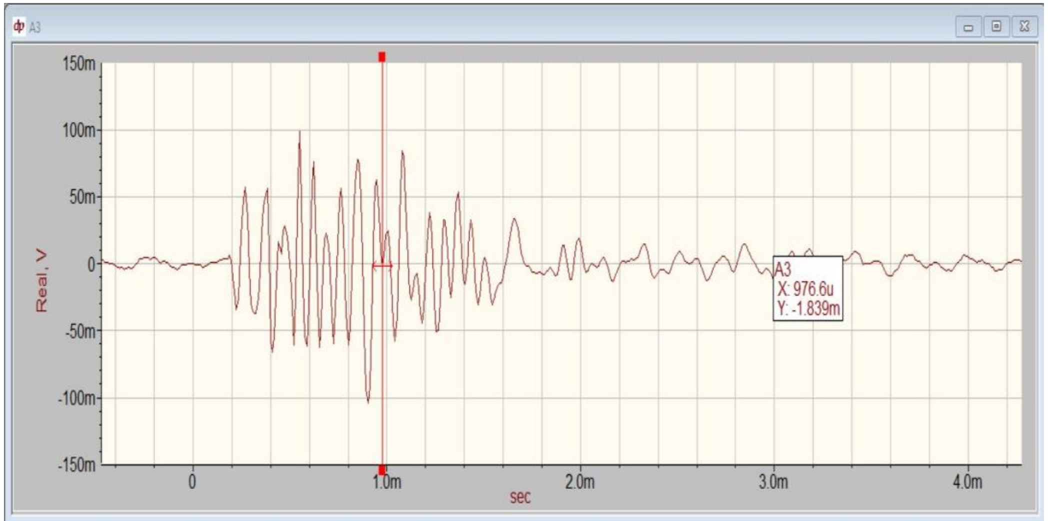


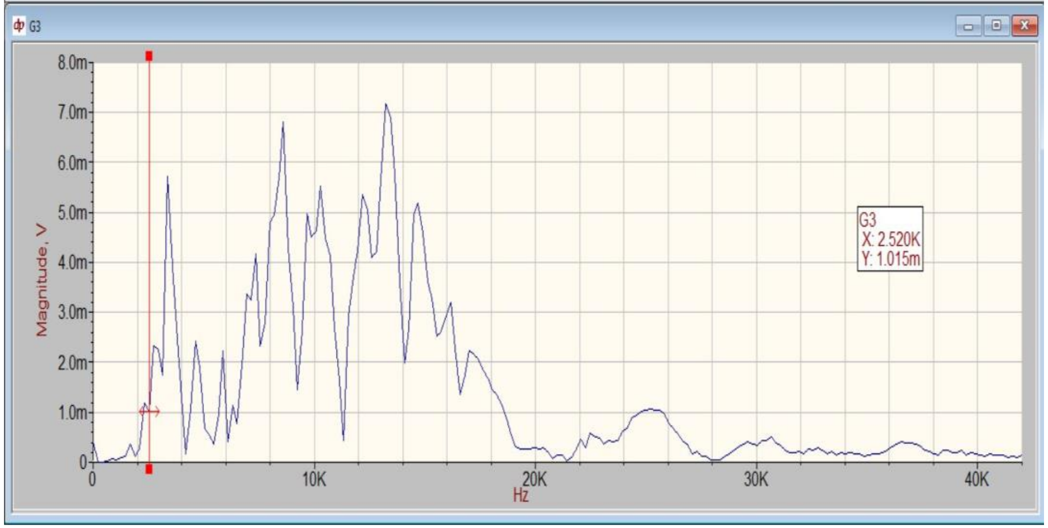
Combined Source/Receiver Concept



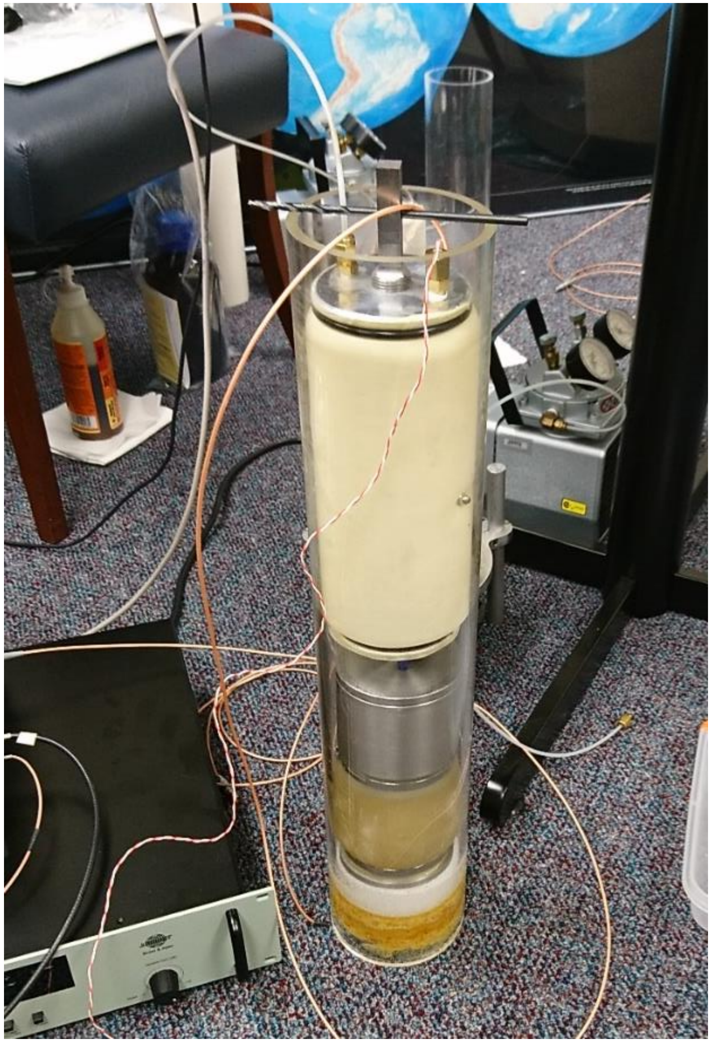
Receiver Improvements

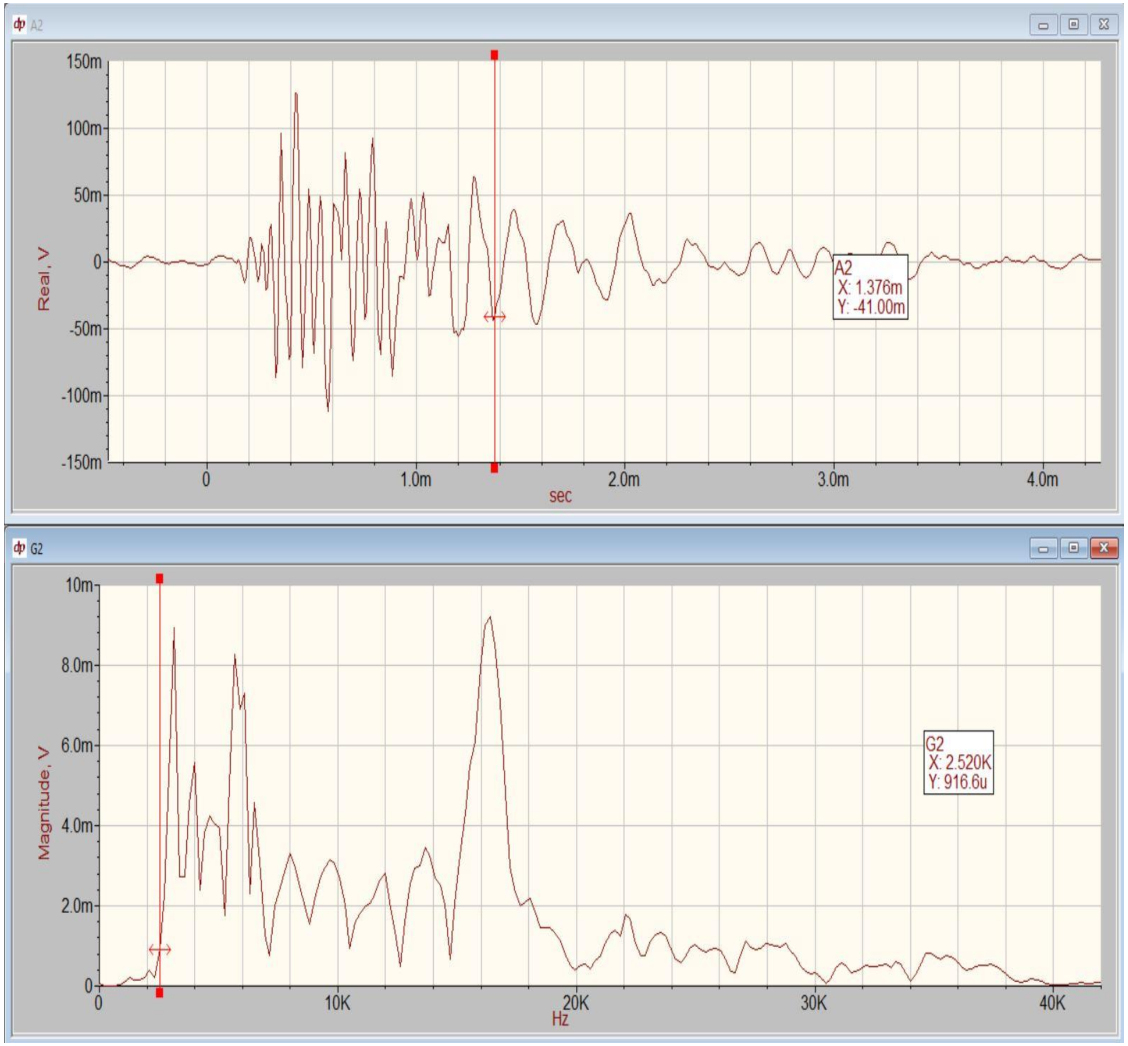




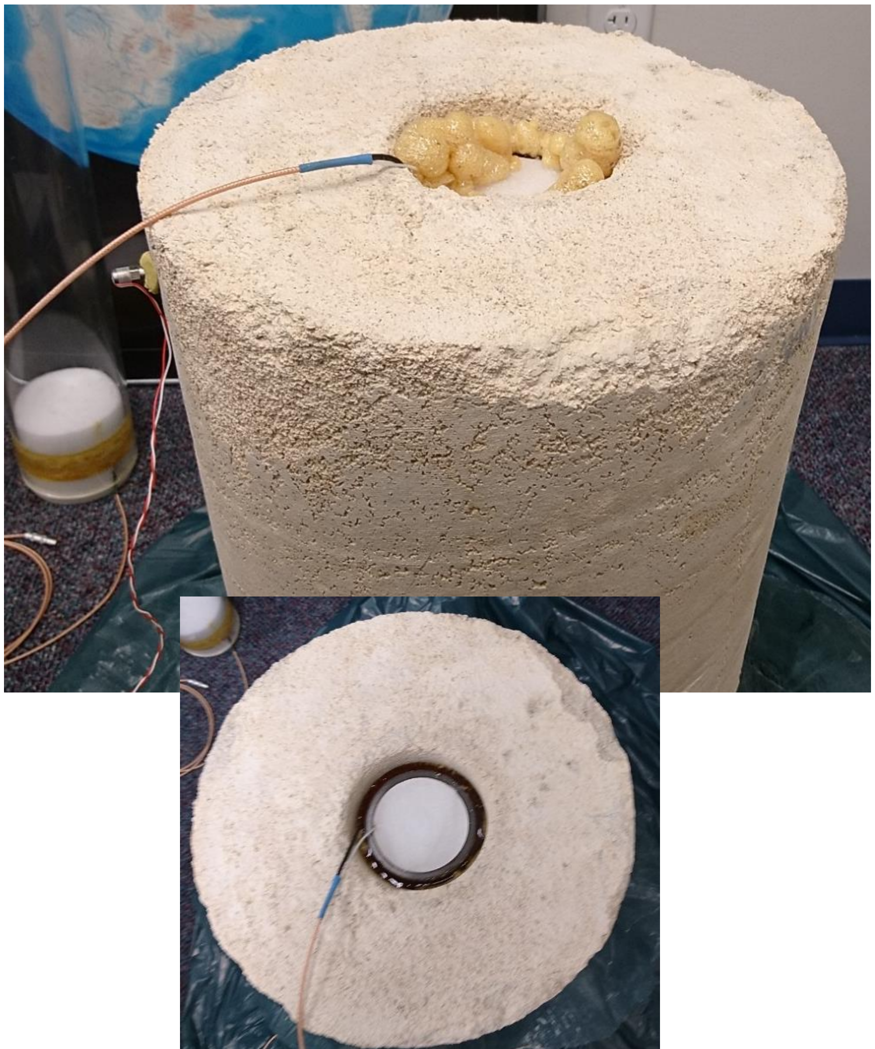


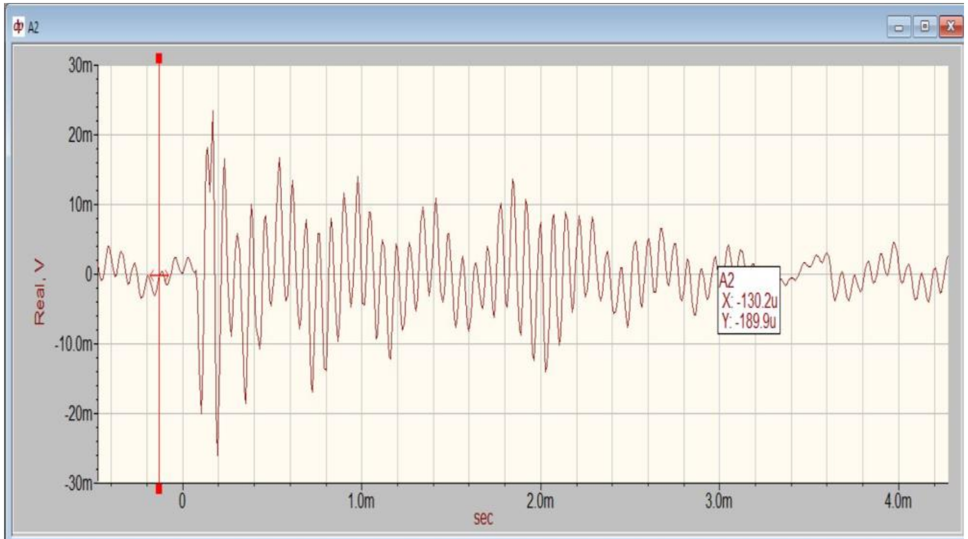
Inflatable Source and Receiver

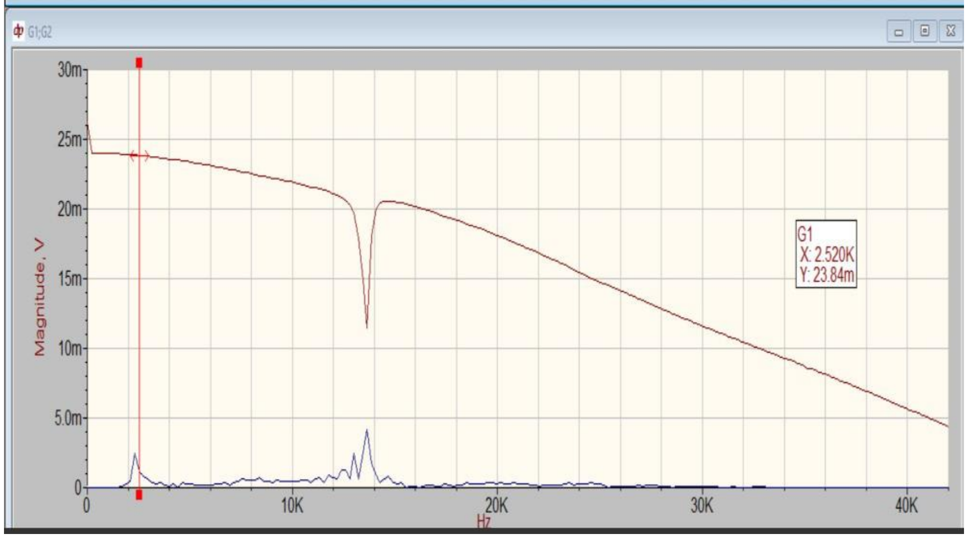




Synthetic Limerock Borehole Model







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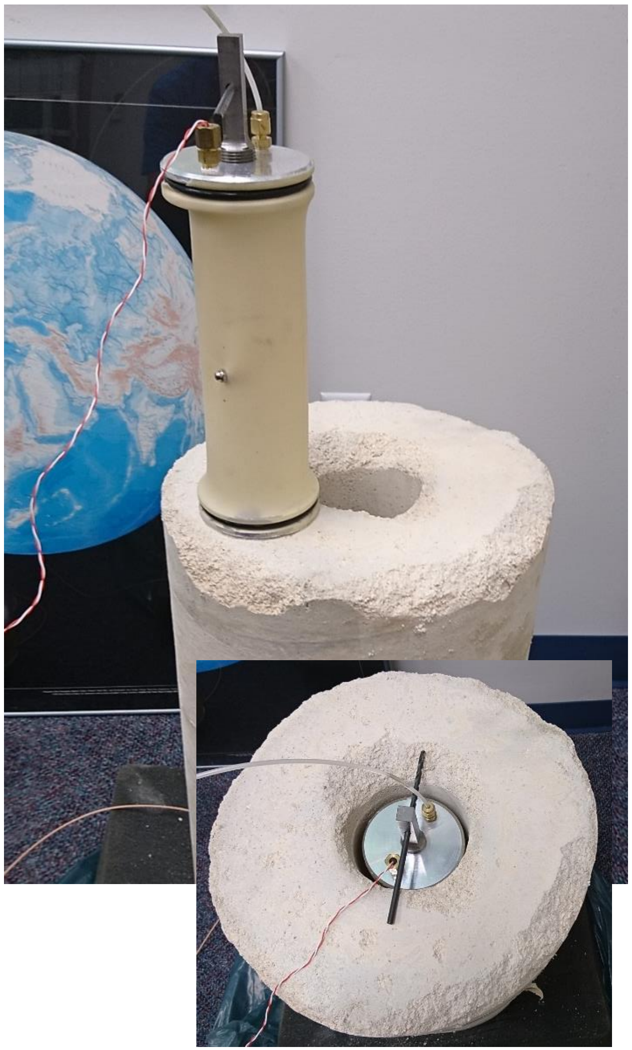
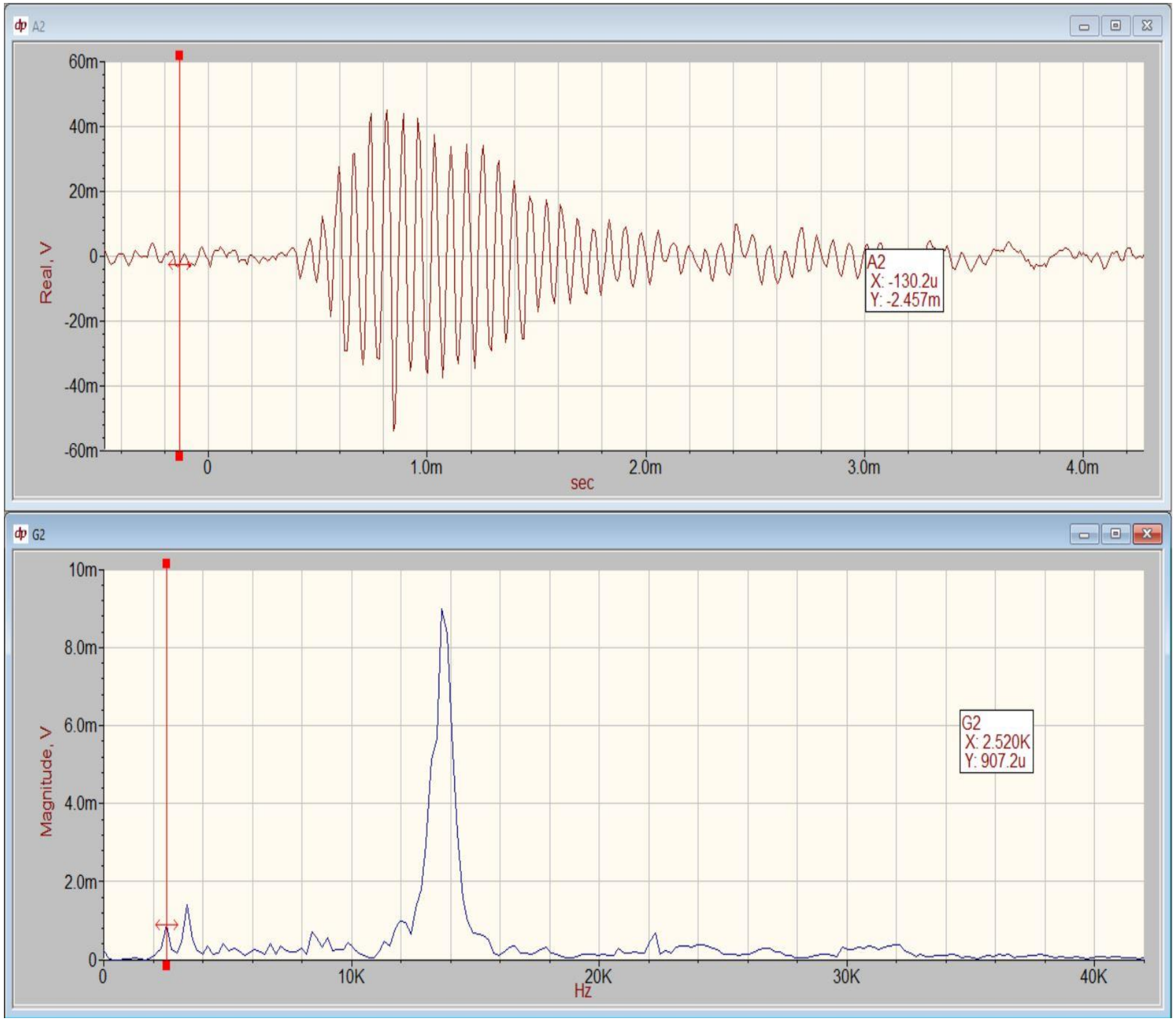
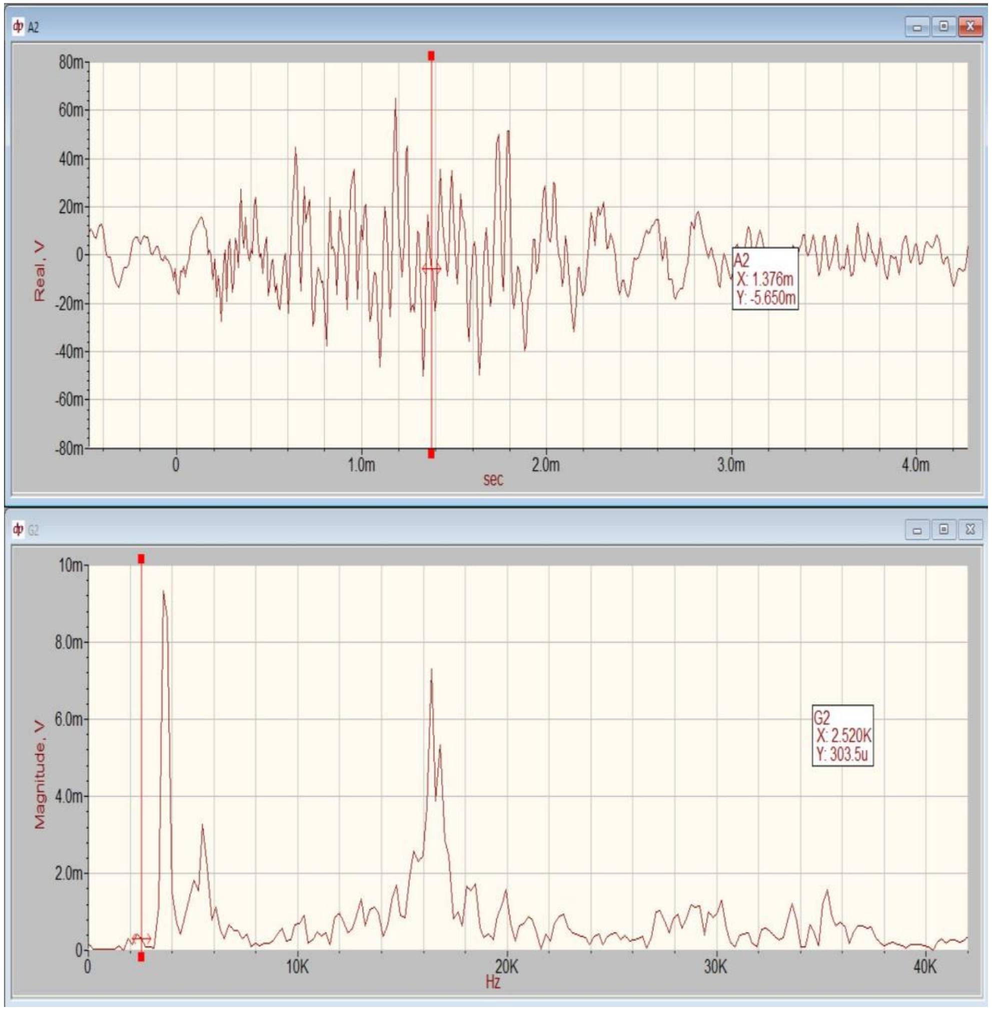




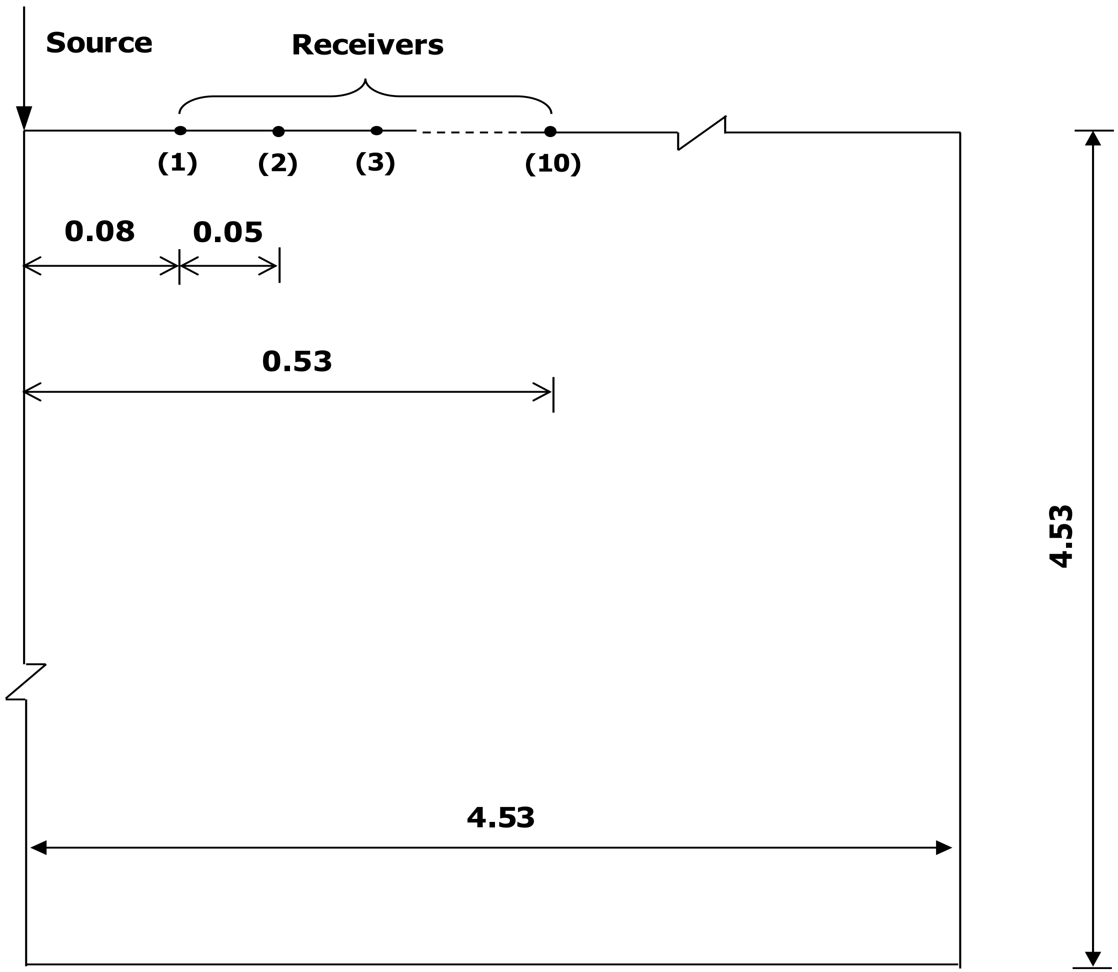
Synthetic Limerock Borehole Model



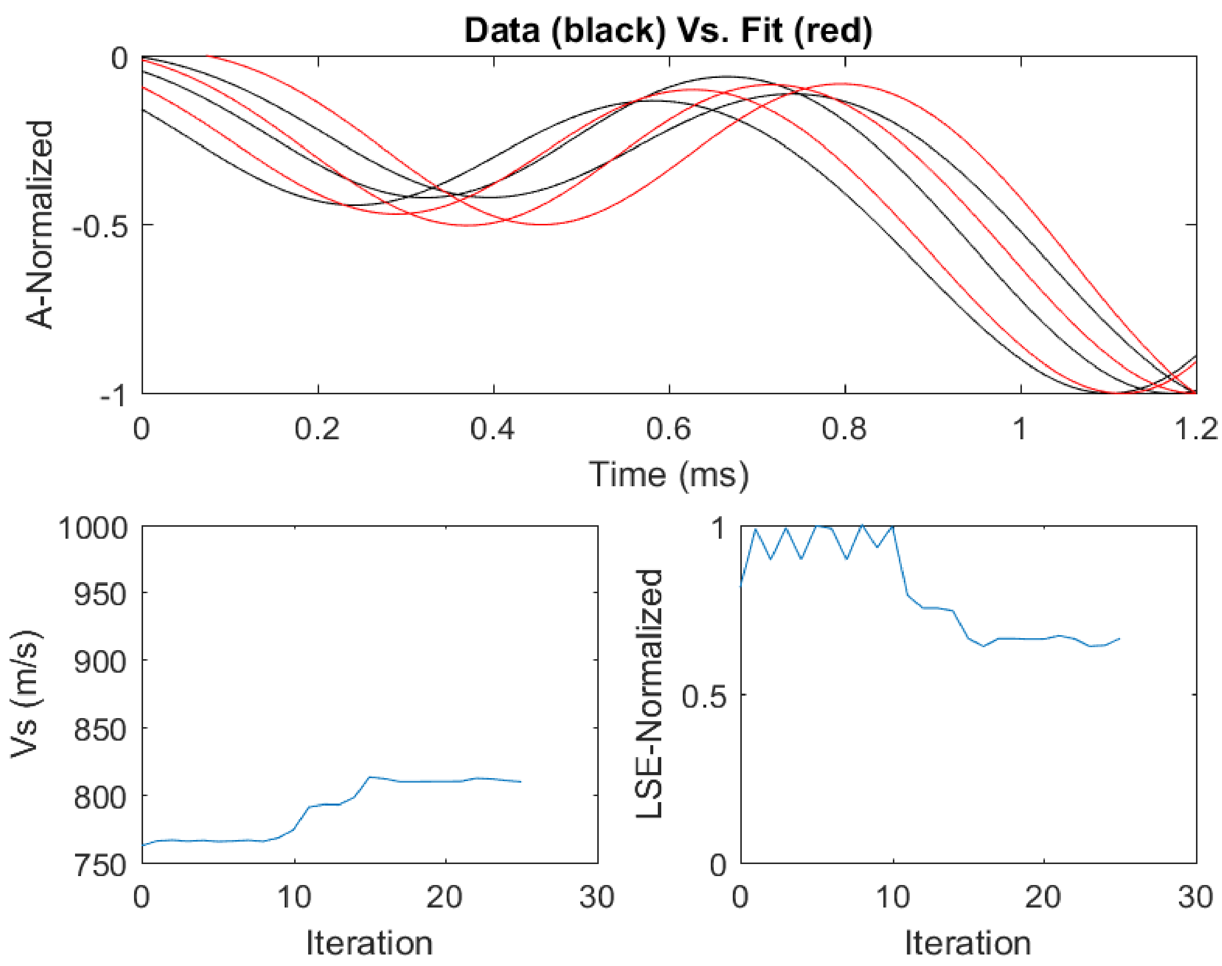
Synthetic Limerock Block: Experiments

- Full waveform tests on top surface
- Free-free resonant column tests on companion cylinder
  - Vp = 1500 m/s
  - Poisson's ratio = 0.2
  - Thus Vs = 920 m/s

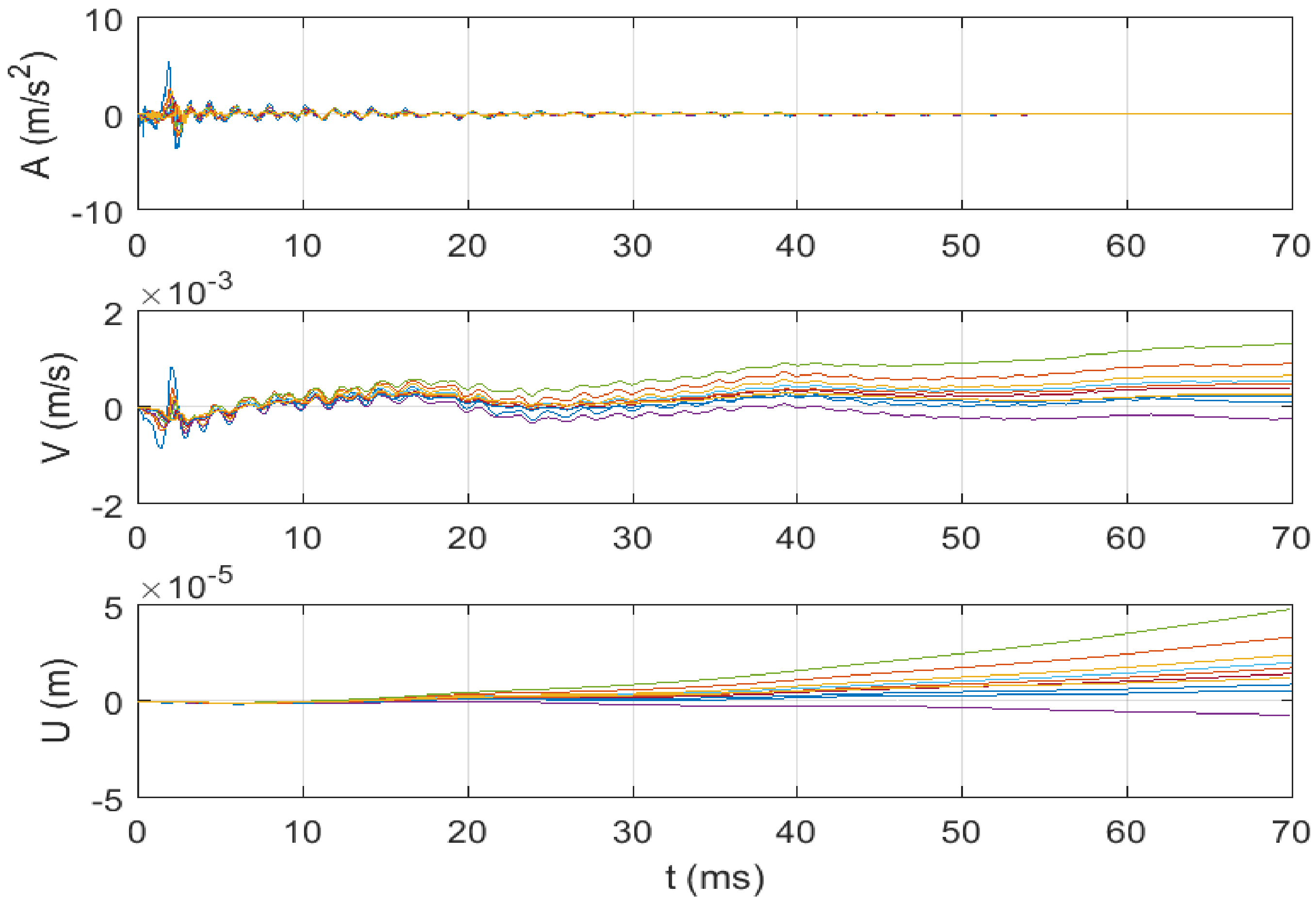
Synthetic Limerock Block: FEM Model



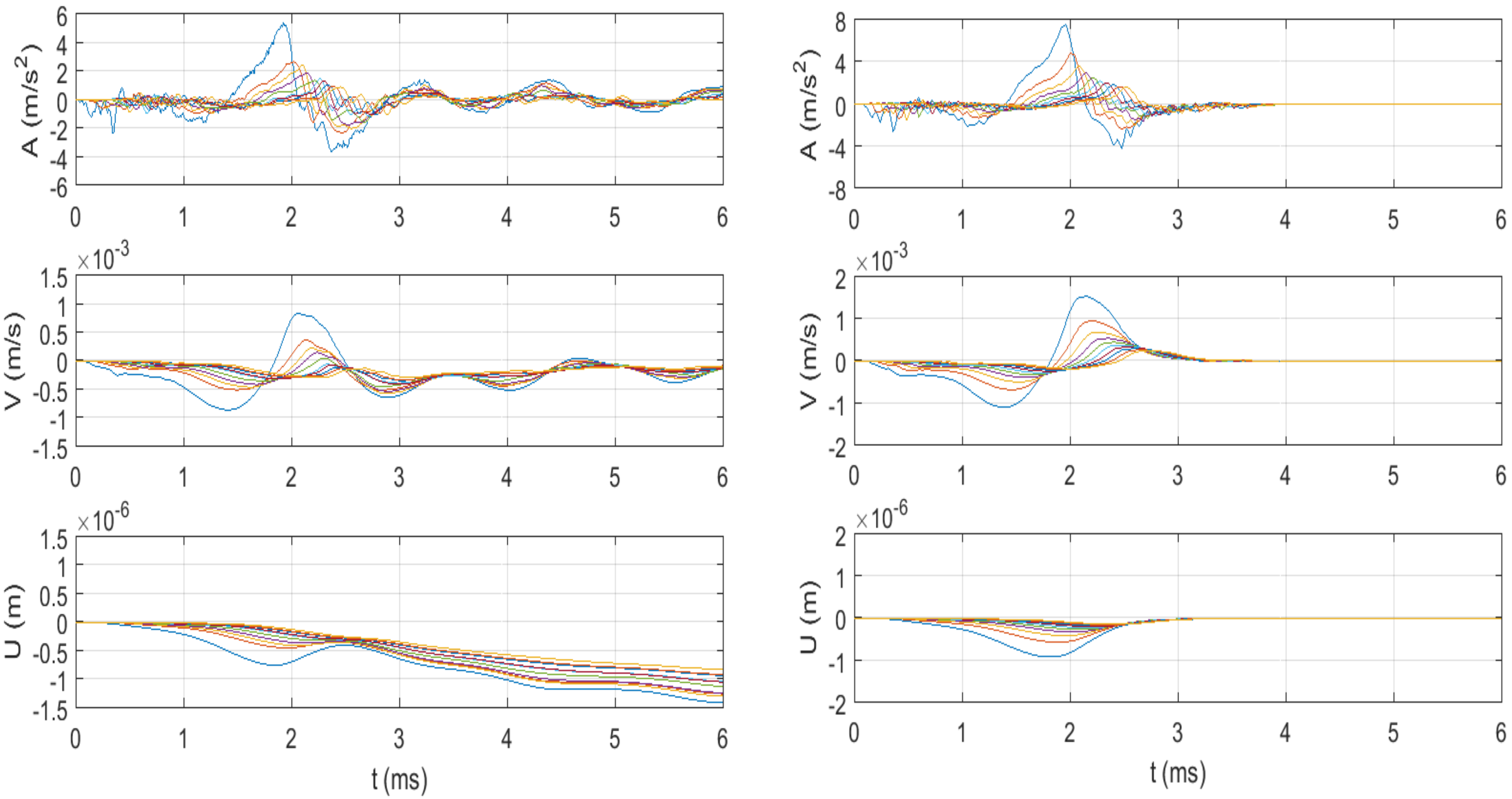
Synthetic Limerock Block: Acceleration



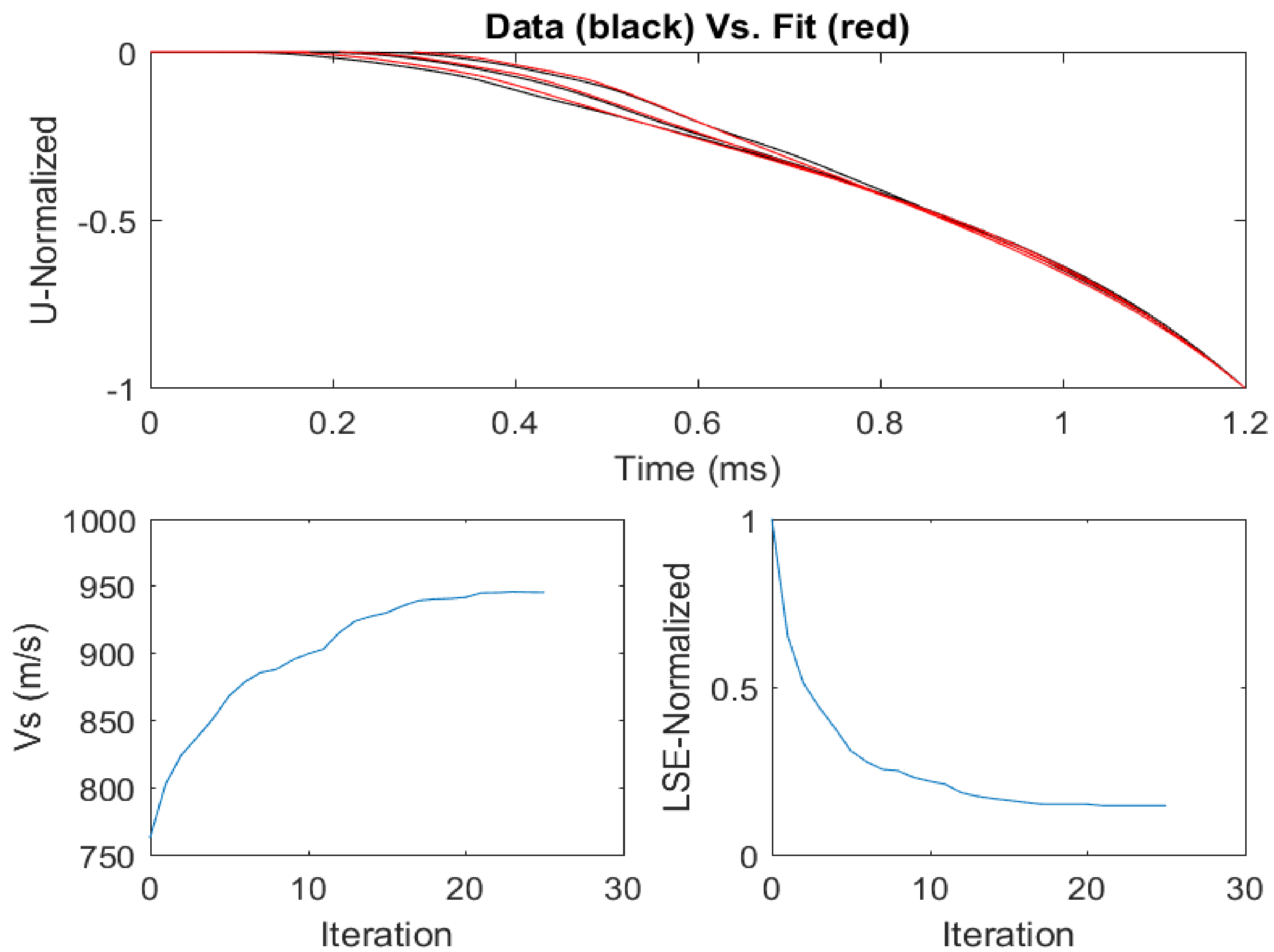
Synthetic Limerock Block: No Filter



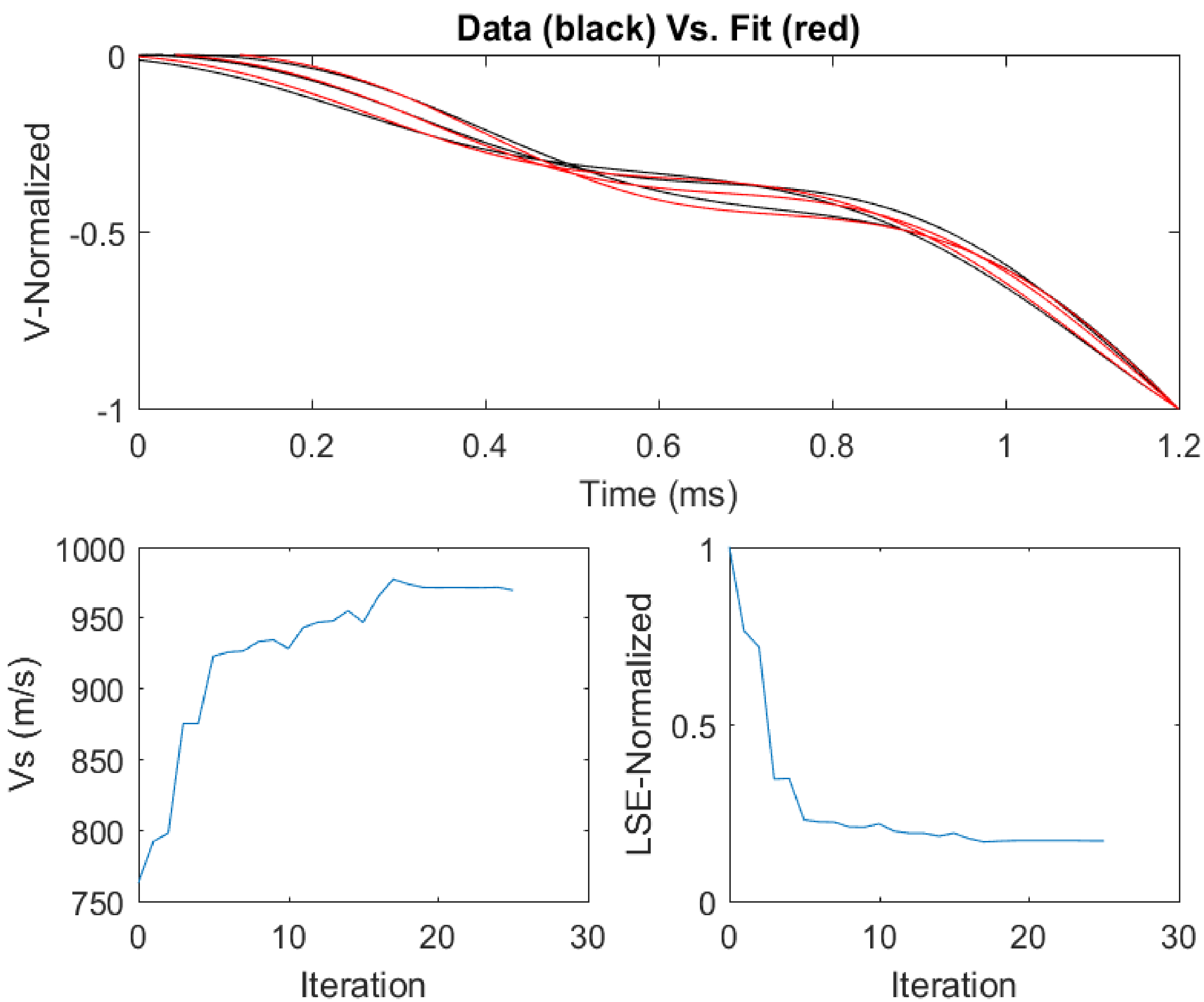
Synthetic Limerock Block: High-Pass



Synthetic Limerock Block: Displacement

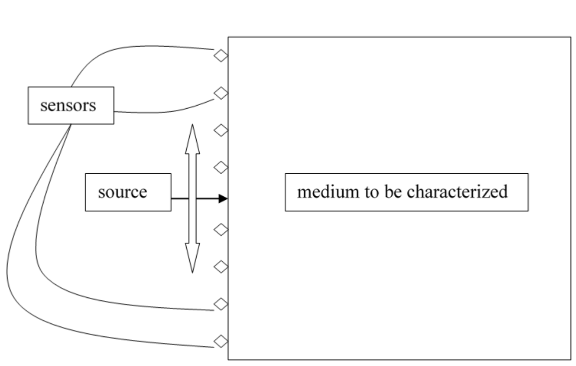


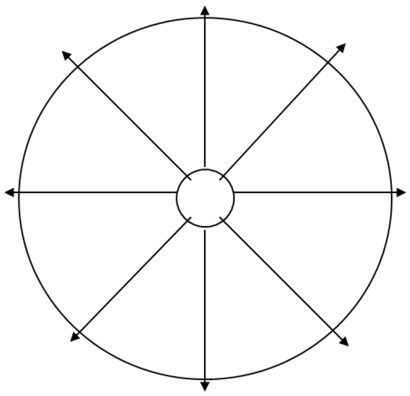
Synthetic Limerock Block: Velocity



Next Activities

- Tune the source/receiver array to achieve 5-ft penetration: size, spacing, frequency, energy
- Continue development of processing and inversion techniques on data from field experiments





Thank You!