U.S. Army Corps of Engineers
Engineer Research and Development Center

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Using COMSOL Multiphysics for Geophysical Applications

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Fundamental Geophysical Framework

COMSOL Multiphysics bridges the gap between traditional military and civil geophysical modeling needs; examples presented with the fundamental geophysical framework and modeling for diverse applications such as acoustic coupling of structures in complex atmospheres, energy transmission though the ground during an ultra-shallow geophysics vibroseis study, and water intrusion in levees.

Katrina Levee Breach, New Orleans

Bridge Collapse, Iraq and MS River I-35

Hurricane Agatha sinkhole, Guatemala

Outline

- Case Study 1: Acoustic coupling of structures in complex atmospheres
  - Kyle Koppenhoefer, Sergei Yushanov, Henry Diaz-Alvarez, and Dan Costley
- Case Study 2: Ultra-shallow geophysical vibroseis surveys
  - Jason McKenna, Steve Sloan, Rick Miller, Kyle Koppenhoefer and Sergei Yushanov
- Case Study 3: Water intrusion in levees
  - Dan Costley, Tom Muir and Edgardo Ruiz

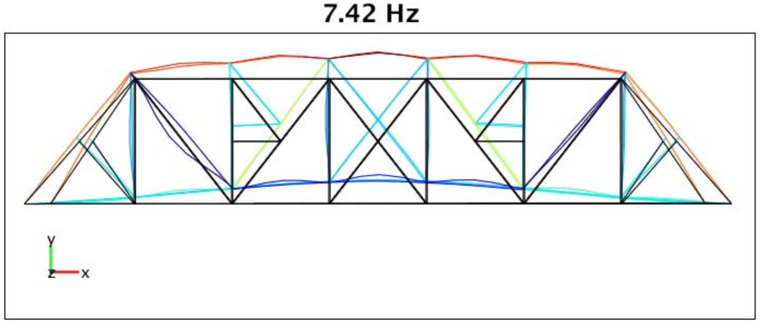
Case Study 1: Acoustic coupling of structures in complex atmospheres

Remote assessment of infrastructure for reconnaissance or battle damage has historically depended upon satellite imagery or information revealed by boots on the ground. Infrasound acoustics can be used to determine fundamental modes of movement for structures without line of site or direct involvement by personnel

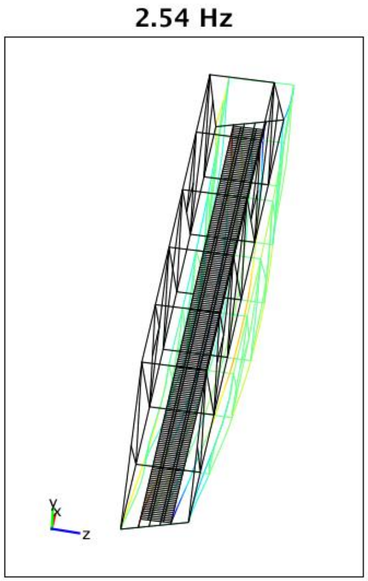
COMSOL modeling can accommodate complicated structures, complicated atmospheric parameters, and complicated propagation pathways.

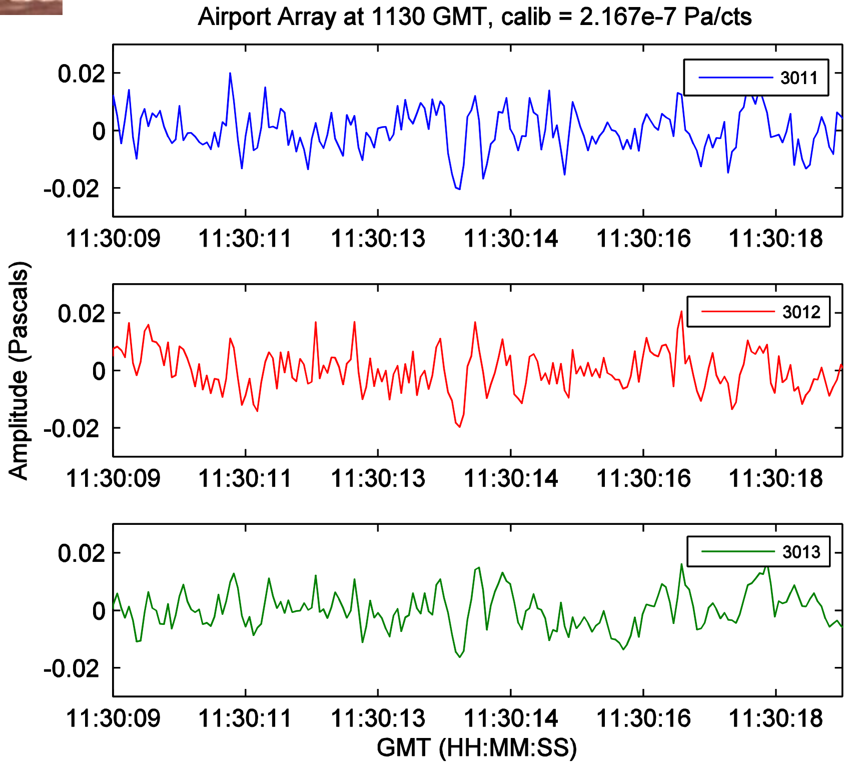
Simple vs. Complicated Sources

Simple sources such as point explosions may have complex propagation paths through the atmosphere.



Complex sources signals such as those from bridges may travel relatively uncomplicated energy pathways, but through very complex atmospheres.

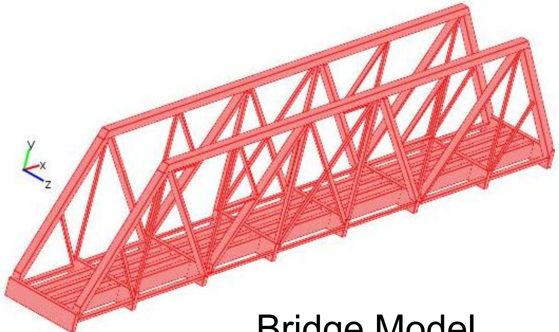




Costley R.D, Diaz-Alvarez, and M.H. McKenna, “Response of Structures to Transient Loading”, Poster, COMSOL Conference 2010

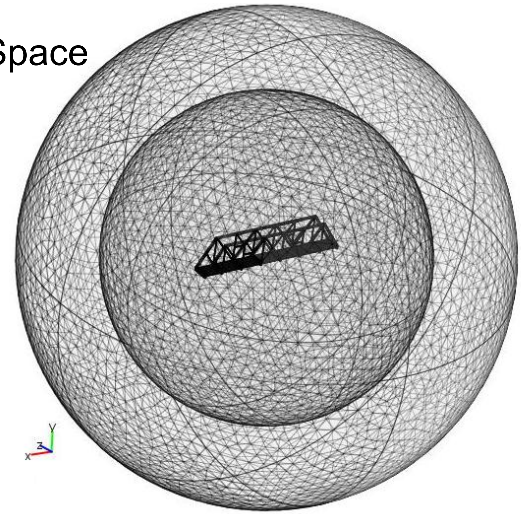
Simplifying a complex source

1. Uniform atmosphere
2. Real topography
3. Real meteorology

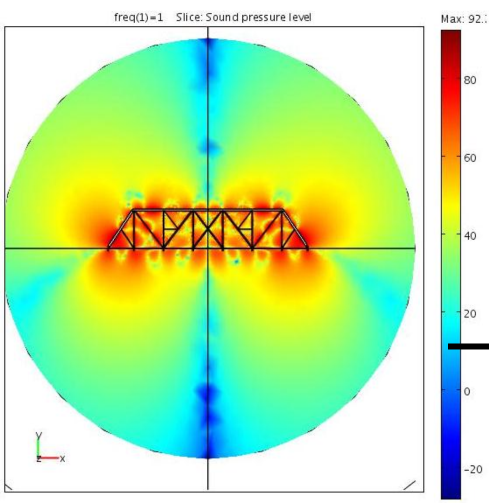


Bridge Model

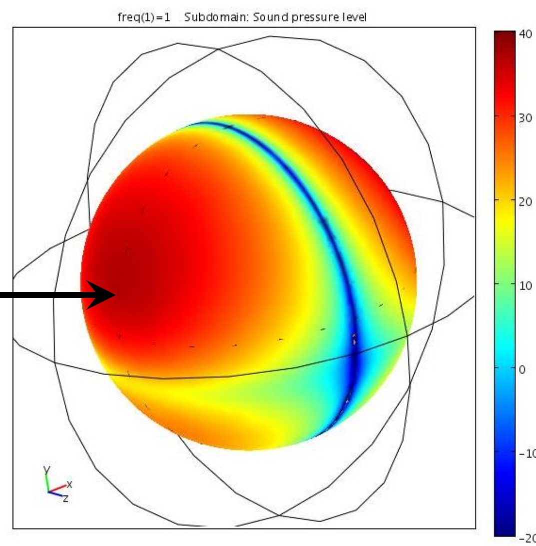
Mesh Space



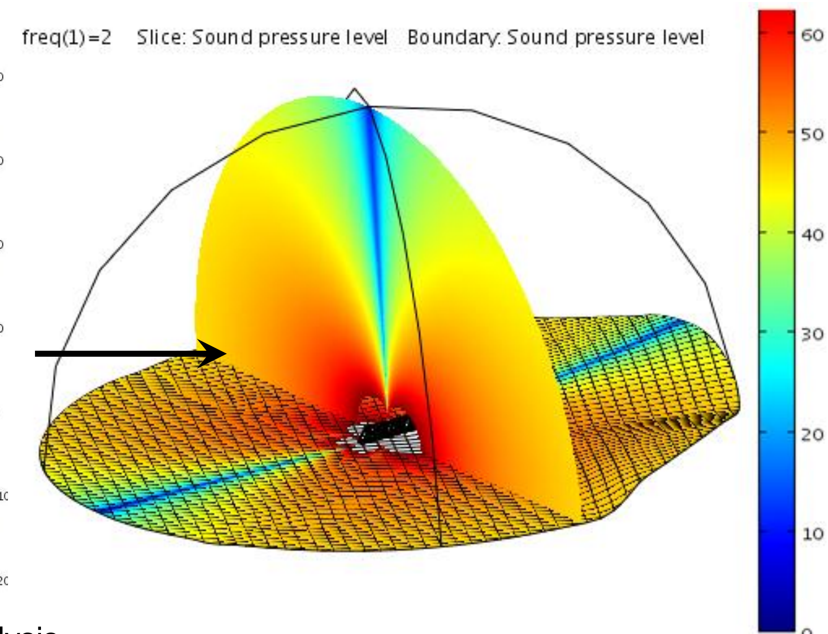
2-D Acoustic Coupling



3-D Acoustic Coupling



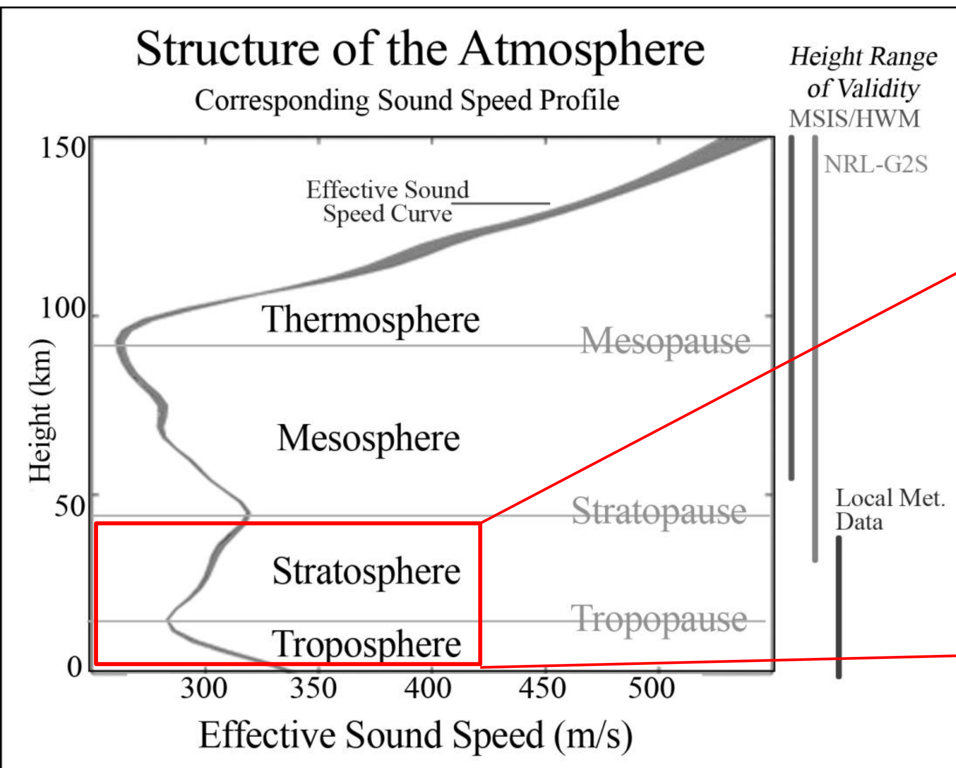
Real Topography Coupling



McKenna, M.H., Yushanov, S., Koppenhoefer, K., and McKenna, J., “Analysis of the Acoustic Response of a Railroad Bridge,” COMSOL Conference 2009.

Complex propagation

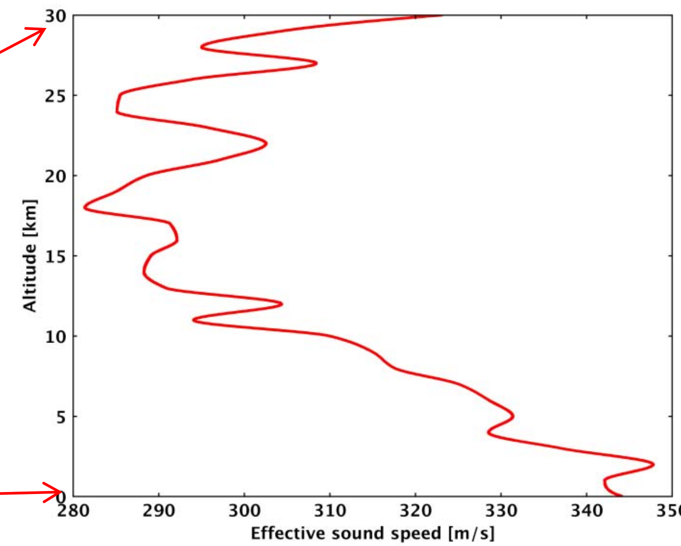
- **The statistical profiles (MSIS/HWM) are generated from 15 year averages and do not take into account immediate, or real time, temperature information.**
- **For rays turning at thermospheric heights sound velocities have little seasonal variation.**



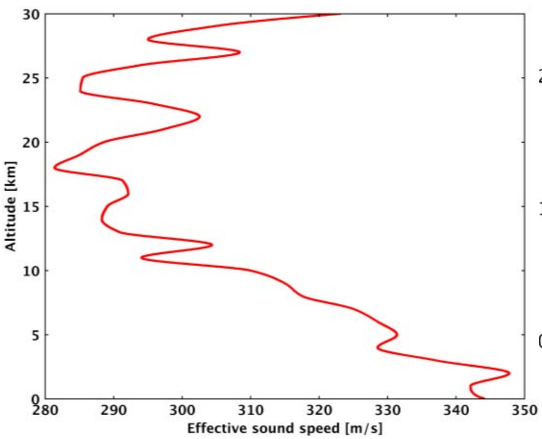
Local meteorological profiles

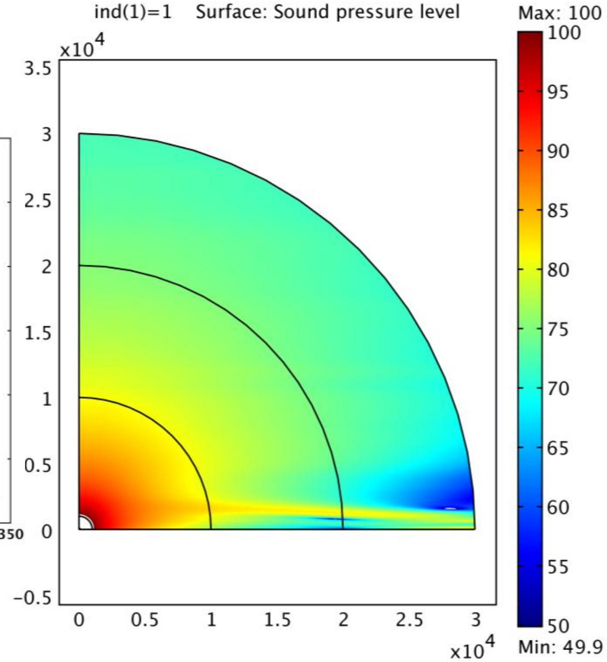
- **Radiosonde, balloon, soundings**
- **Taken at set intervals, depending on interest of monitoring entity.**
- **Valid measurements only to the maximum height of sampling for each individual profile.**
- **Profiles only at location of study.**
- **Limited spatial sampling.**

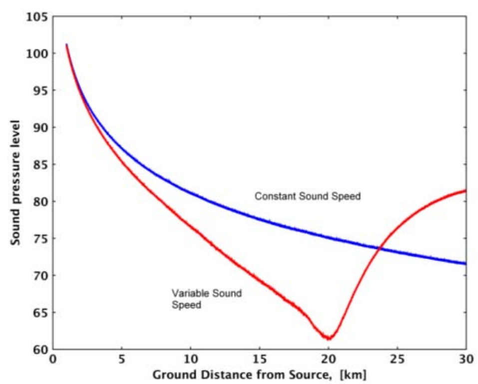
Sound Speed Profile Ft. Wood June 2007



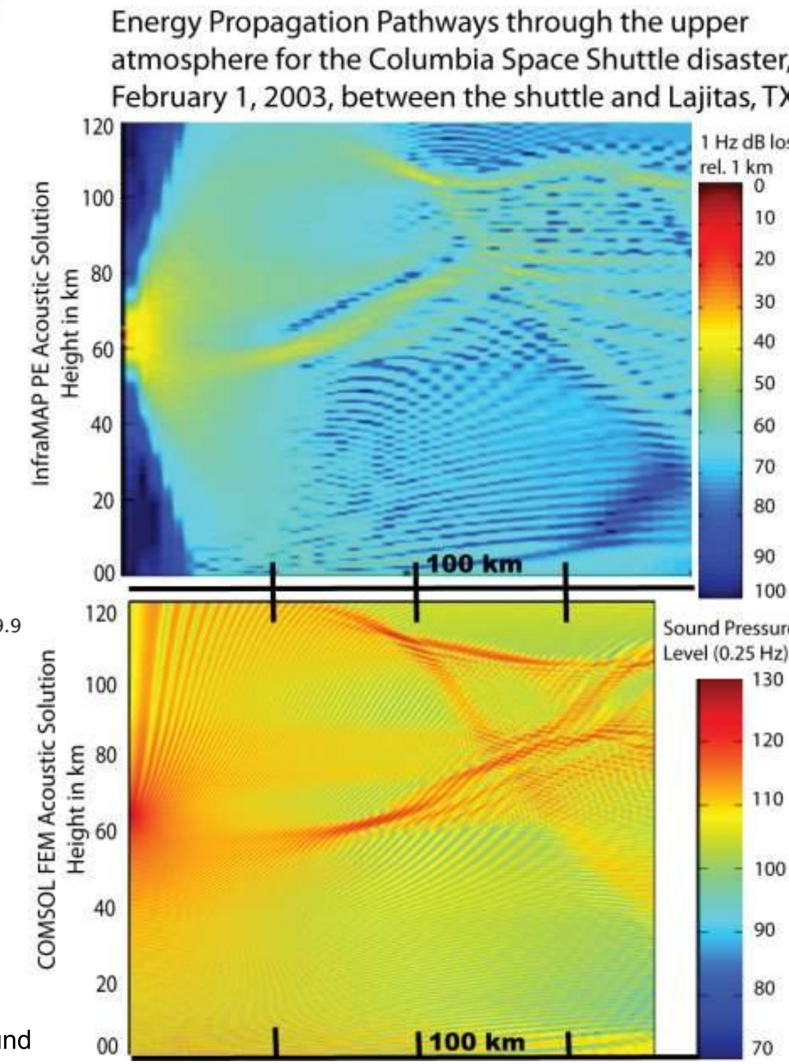
Propagation pathways for the June 2007 Ft. Leonard Wood Structural Experiment







Validation for simple source, complex path: Columbia Shuttle



McKenna, Mihan. (2010) COMSOL Acoustics Module for Finite Element Modeling for Infrasound Propagation. COMSOL NEWS 2010. pp. 44-47.

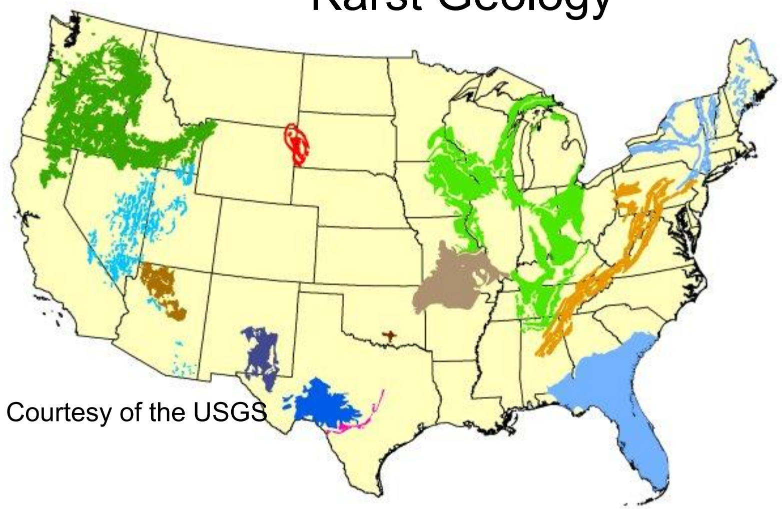
Further Investigation

- Expanding structural models to include dams, levees, other structures of interest
- Investigation of damage on modal responses
  - Corrosion effects, scour
  - Battle damage and natural disasters

- Four-dimensional atmospheric modeling using real data
- Validation of statistical atmospheric models with experimental waveforms at variable distances

Case Study 2: Ultra-shallow geophysical seismic surveys using vibroseis

Karst Geology



Courtesy of the USGS

Reflection profiles can be used to find sink holes, or other subterranean voids, to delineate edges of potential problems. Vibroseis surveys can produce a vertical velocity profile given an estimated transfer function of propagation path and sensor.

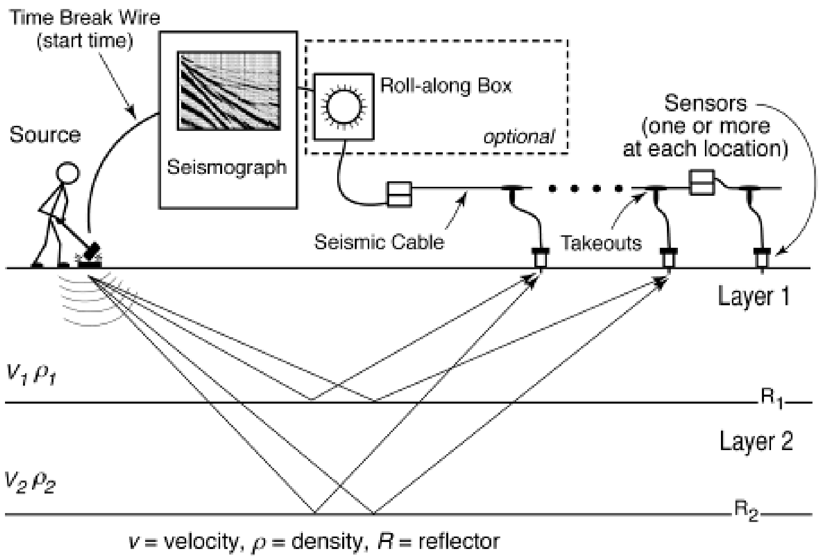
Guatemala Sink Hole, 2010

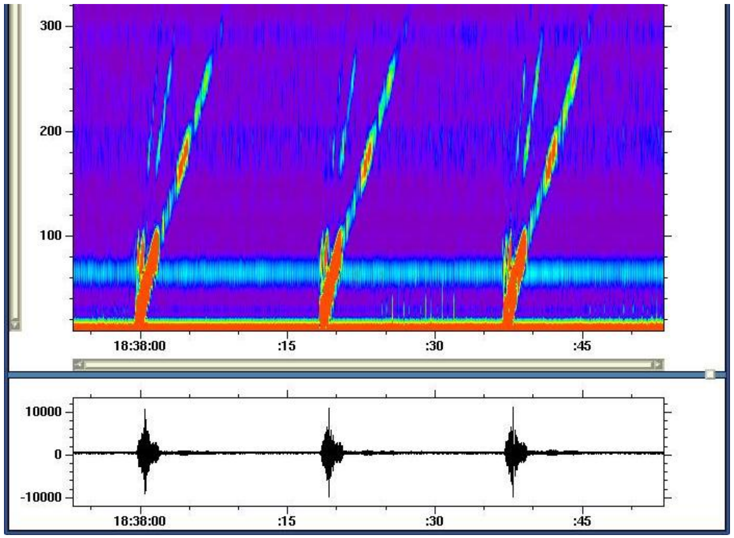
Use COMSOL to validate seismic velocity profile and calibrate models of the subsurface: how accurate are velocity models?

Model Scenario

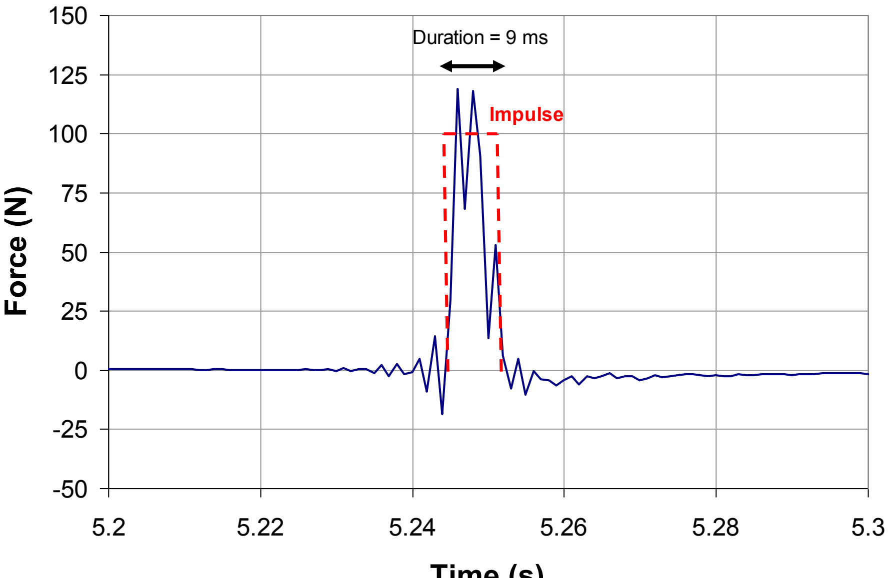
Utilizing an experimental layered velocity profile from a vibroseis survey in Yuma Proving Ground use COMSOL to validate seismic velocity profile.

- Point impulsive hammer for simple source
- Complicated vibroseis source:
  - Model waveform should match experimental results from nearby geophone
  - If they don't, what's missing? How well understood is the energy transmitted into the ground from the vibroseis?



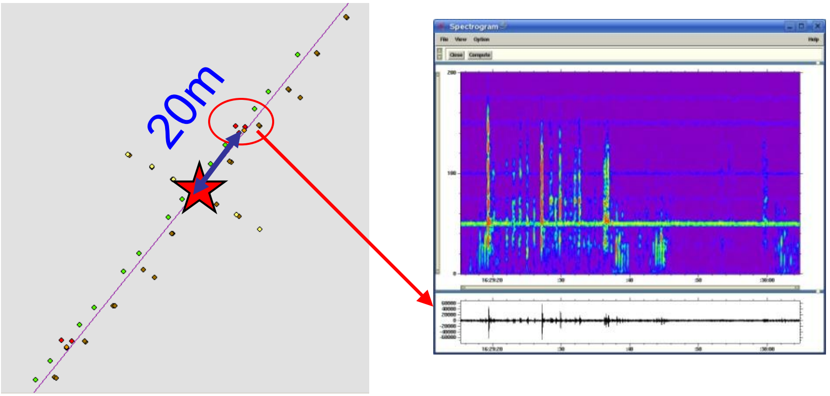


Short Duration Loading: Simple Hammer Source



Hammer Pulse

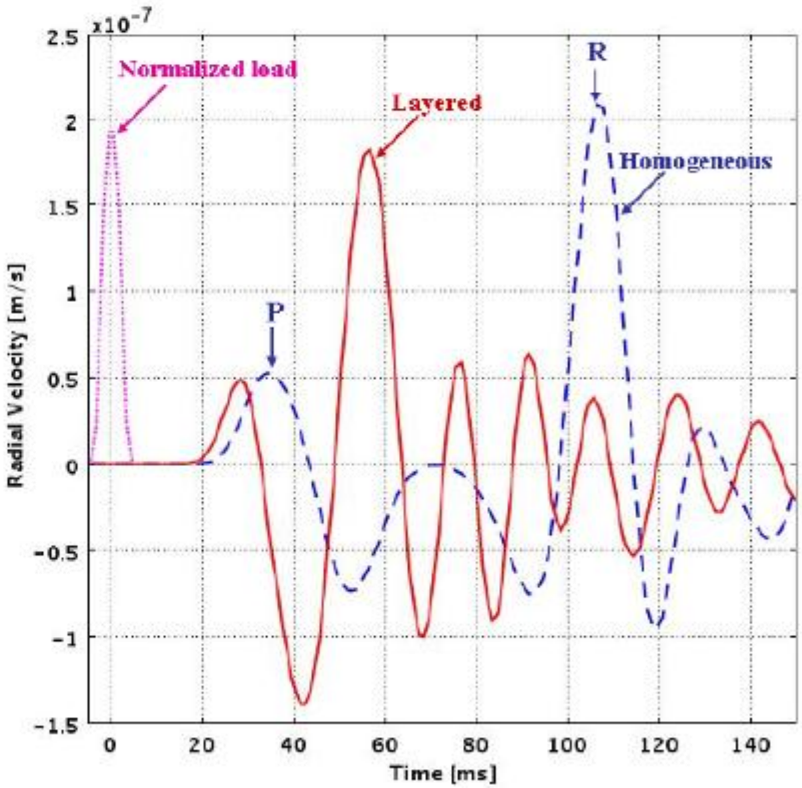
Development of a parameter space that replicates in-field conditions and analyze the effects on the modeled waveform. Point Source Loading: square wave and smoothed functions?

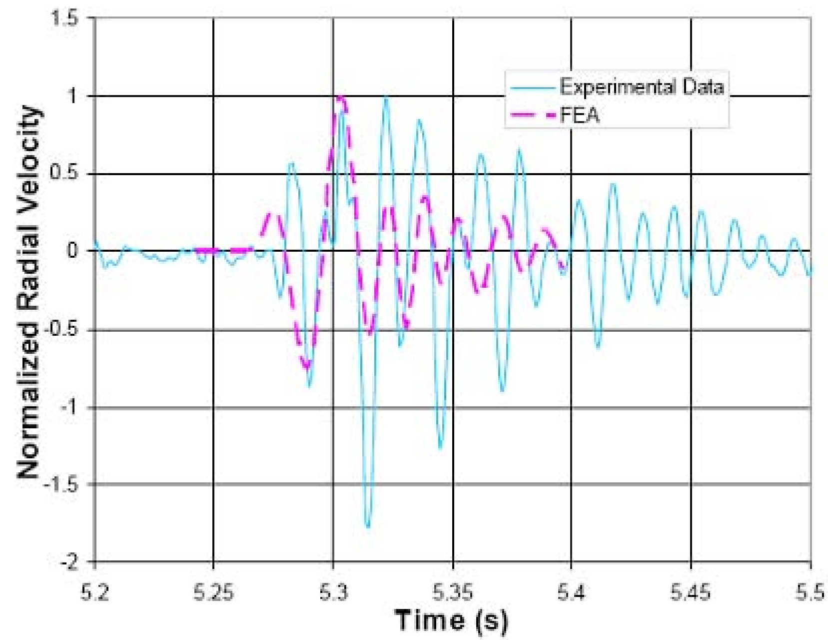


Layered model has 10 velocity zones determined from the vibroseis profile. Experimental data was collected for both a point source and the vibroseis source, off-axis on a reference geophone.

The point source model used the velocity profile to validate against a simple source input. Vibroseis modeling should reproduce experimental results if the energy going into the ground is well-understood and the velocity profile is accurate.

Model Variation

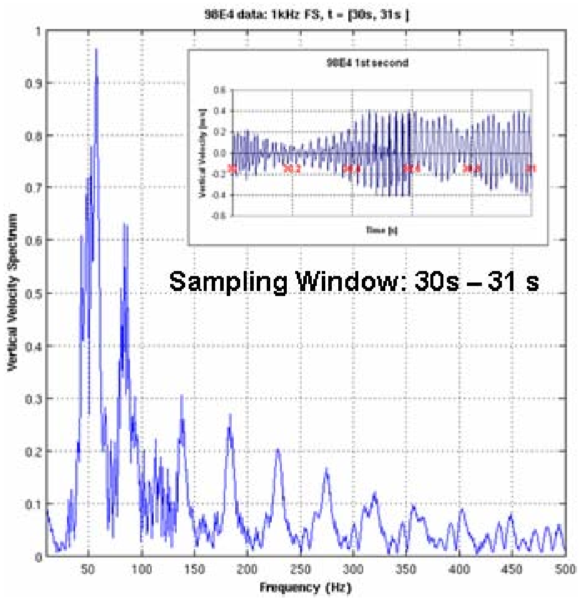




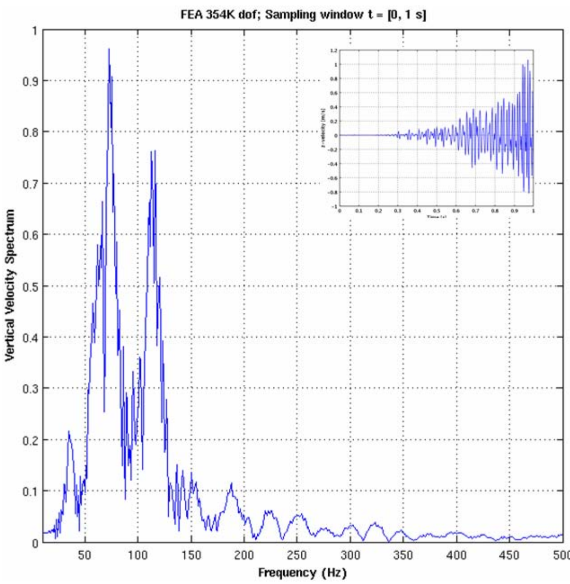
- Left: Effect of varying wave speed through layers in the computational model (R=20 m).
- Right: Comparison of finite element results with experimental data (R=20 m). The time specified on the ordinate is relative to the start of the experiment.

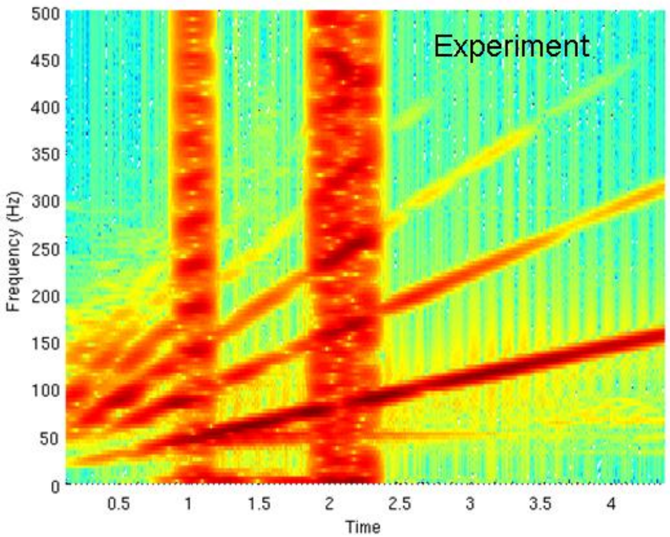
Vertical Velocity

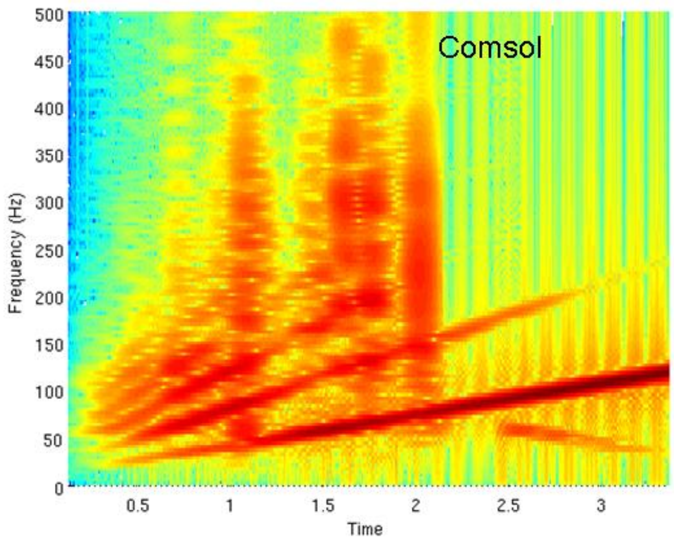
Experimental Data



FEA Data



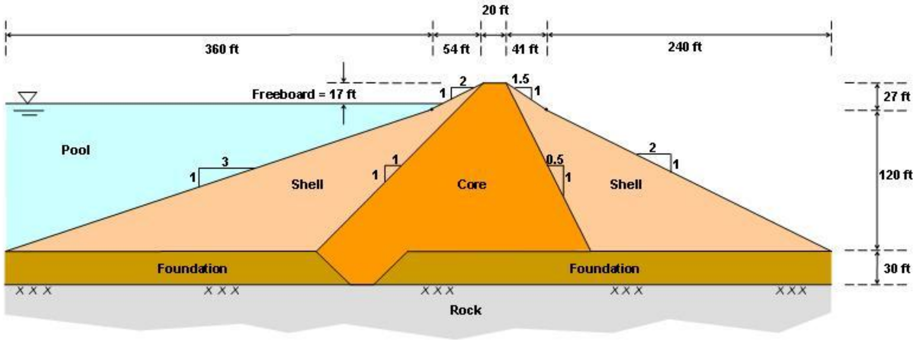


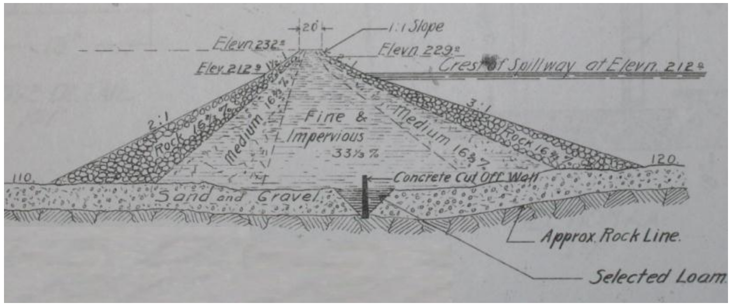


Further Investigation

- Defining input forcing function for the vibroseis has broad applications:
  - Oil and Gas exploration
  - Subsurface imaging for voids and structures
- Input forcing functions developed from vibroseis accelerometers on the plate
  - Forces measured on vibroseis may not be transmitted to soil
  - Acceleration of local structure in vibroseis
- Refinement of velocity structure modeling techniques

Study 3
Water Intrusion in Levees

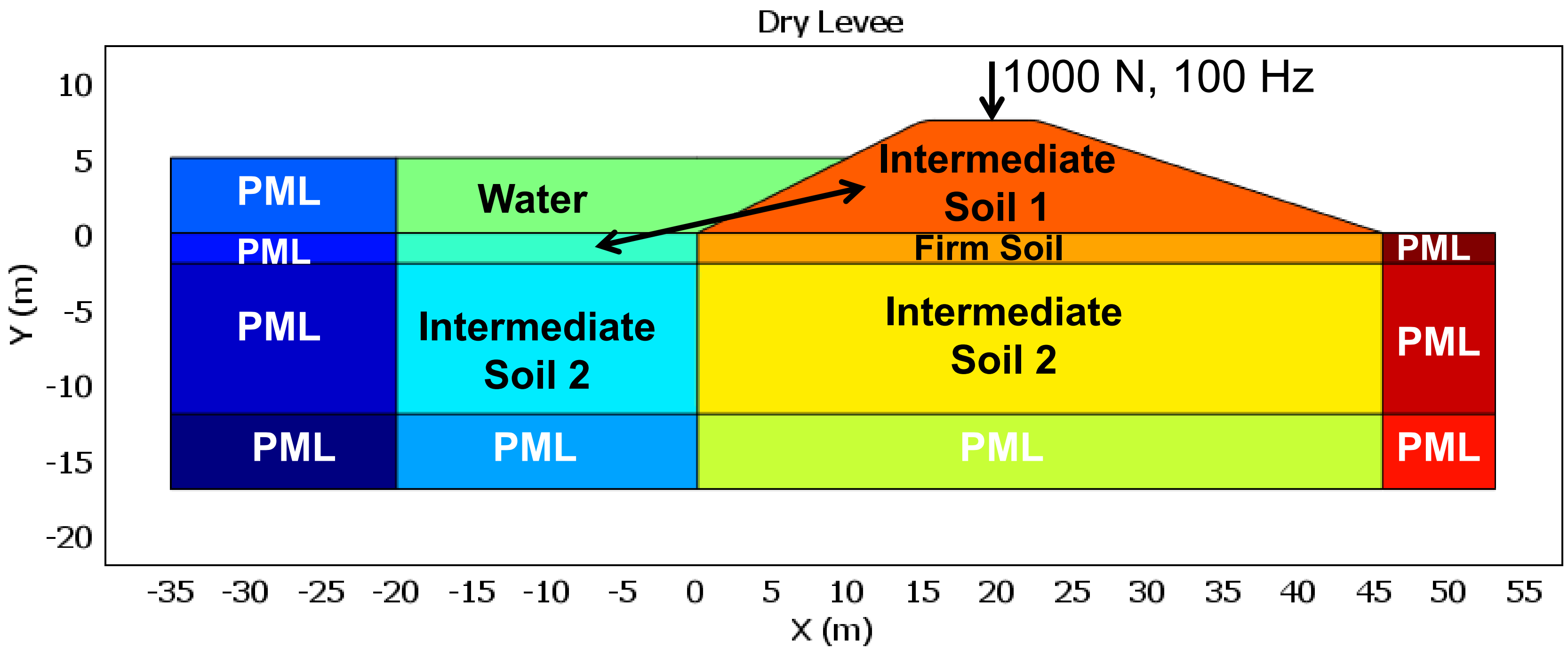




The Patillas earth dam was constructed by hydraulic fill methods in 1914 in seismically hazardous southeast Puerto Rico for rural irrigation and flood control purposes. A reassessment was performed to evaluate the risk to subsequent urban development taking into account new seismic design considerations. There was little information regarding the properties of the materials used for the construction of the dam and its foundation.

Given experimental data, can water intrusion into the foundation be verified using COMSOL modeling?

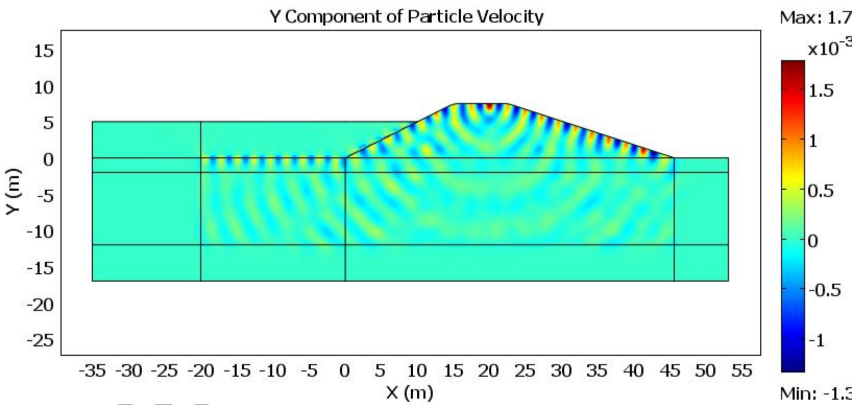
Levee Model

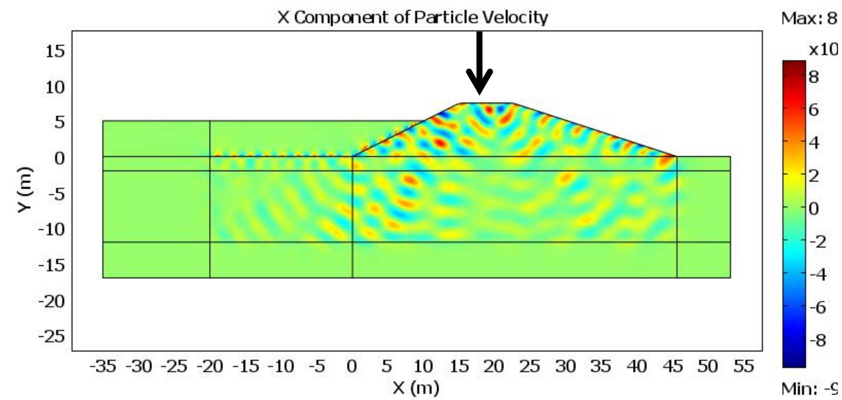


- Soil values from document by T.E. Owen
  - Poisson's ratio: v = 0.315 for all dry soils
- Intermediate Soil 1
  - ρ = 1600 kg/m^3; c_S = 262 m/s; c_P = 415 m/s; G = 1.10e8 Pa; E = 2.89e8 Pa
- Intermediate Soil 2
  - ρ = 1600 kg/m^3; c_S = 311 m/s; c_P = 488 m/s; G = 1.10e8 Pa; E = 2.89e8 Pa
- Firm Soil
  - ρ = 2000 kg/m^3; c_S = 390 m/s; c_P = 747 m/s; G = 3.04e8 Pa; E = 8.00e8 Pa

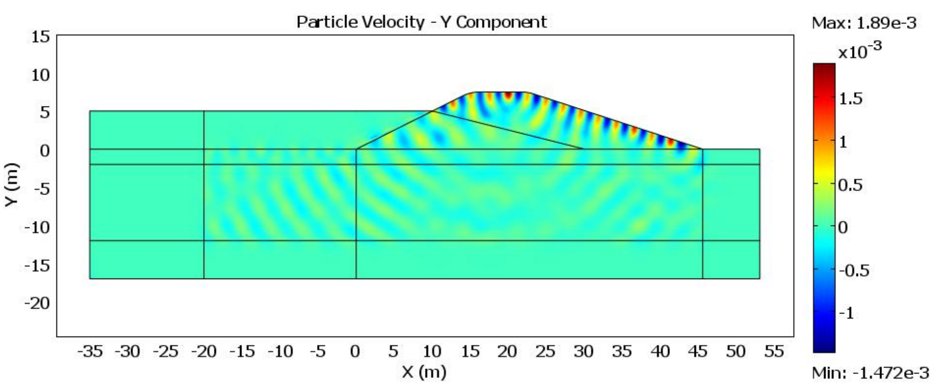
Dry Levee

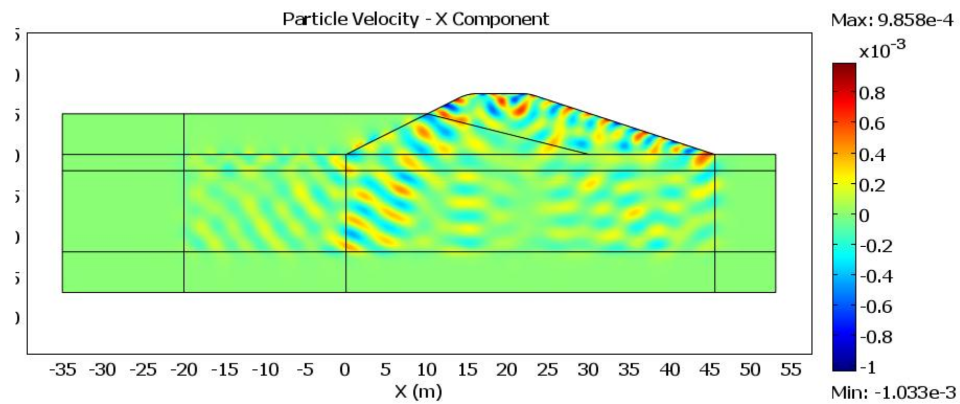
1000 N, 100 Hz





Wet Levee



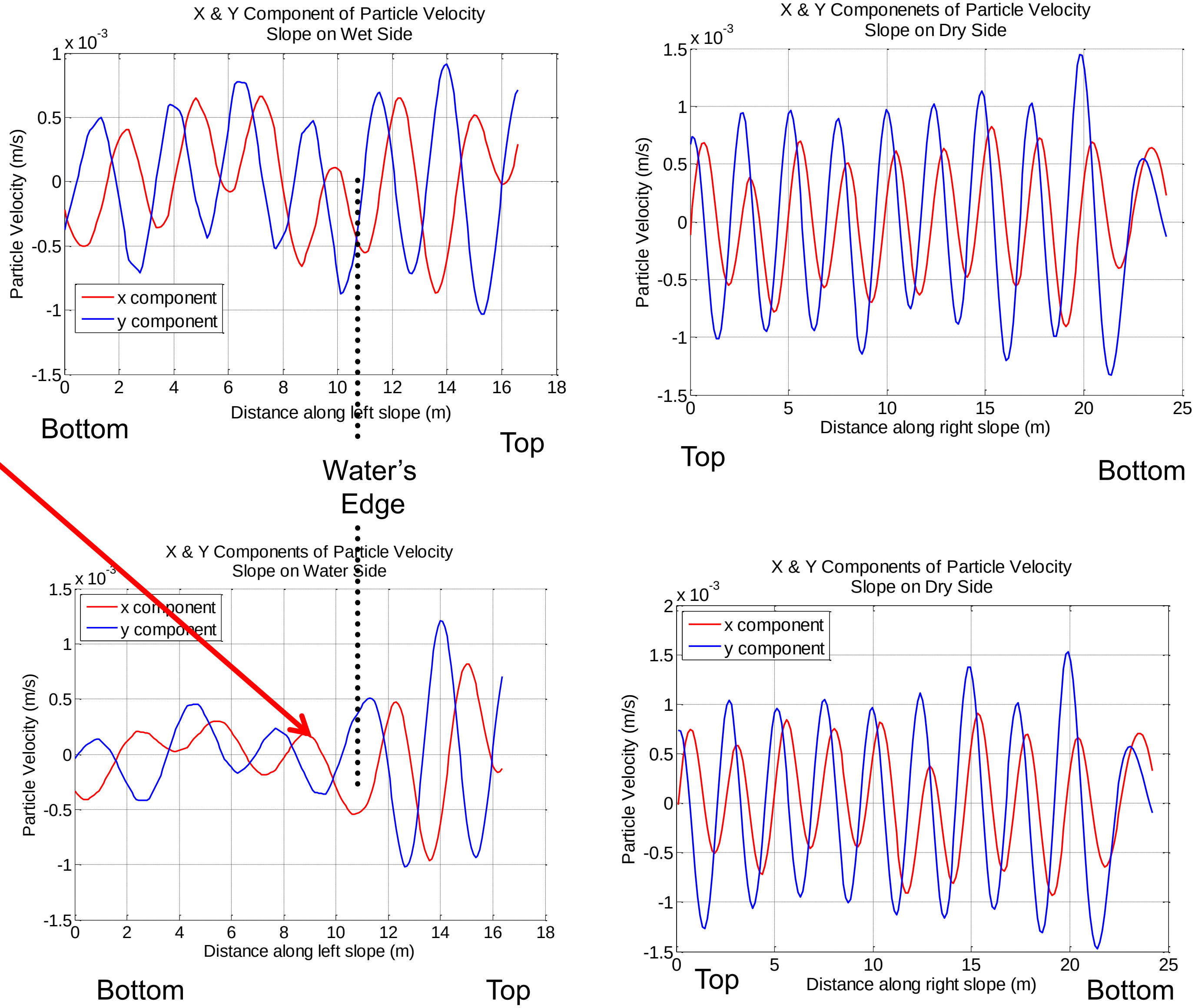


- Saturated sediment inserted into levee:
  - ν = 0.472; ρ = 1493 kg/m^3; c_S = 366 m/s; c_P = 1596 m/s; E = 5.9e8 Pa
- Note that Poisson's ratio, density, and compressional wave speed are closer to values in water

Dry Levee

Significant difference in particle velocity on left slope (bottom) when compared to healthy, dry levee (top)

Wet Levee



Further Investigation

- FE Modeling of levees potentially useful for:
  - designing experiments and interpreting experimental results
  - evaluating diagnostic techniques for levee health monitoring (seismic, GPR, EMI)
  - Predicting failure planes for seismic hazards
  - Dynamic behavior of the levee during seismic events
  - Liquefaction studies
- Capable of accommodating real-world geometry and material properties and realistic defects

Questions?