Analysis of the Acoustic Response of a Rail Road Bridge

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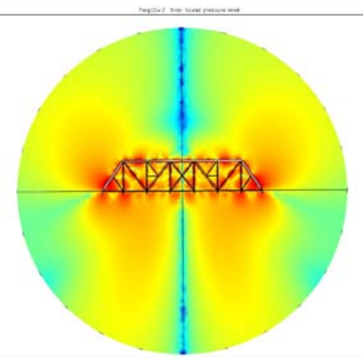
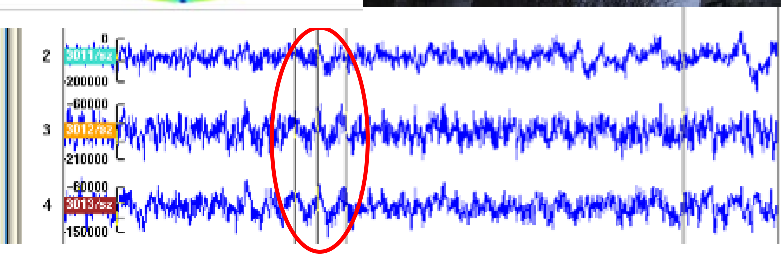




Problem: *Remote assessment of infrastructure for reconnaissance or battle damage has historically depended upon satellite imagery or information revealed by boots on the ground.*

Solution: *Use infrasound acoustics in combination with seismic, meteorological and audible acoustic methods to determine fundamental modes of movement for bridges without line of site or direct involvement by personnel*

Research Objective

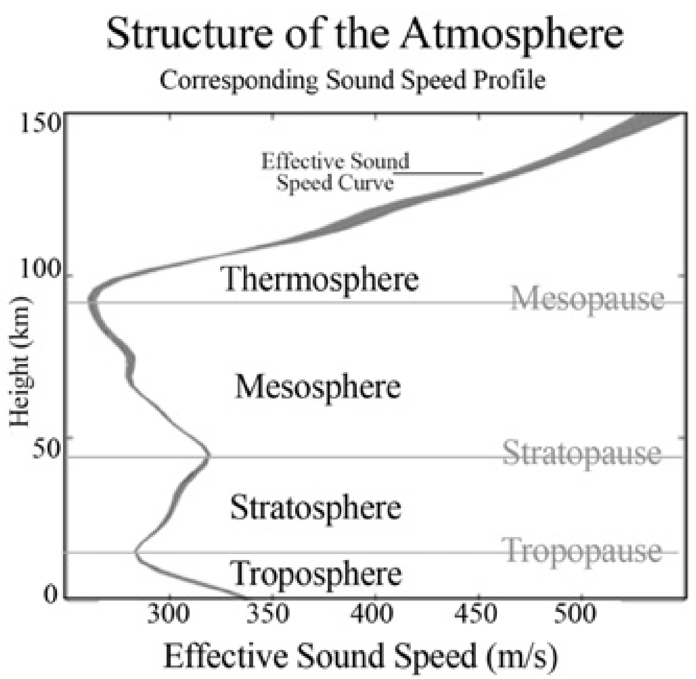
1. To experimentally verify that infrasound can monitor the fundamental modes of motion for a Pratt-Truss bridge at ~30 km standoff.

2. To develop a new finite element representation to numerically predict how structures can couple into the atmosphere and propagate infrasound energy at tactical standoff distance.

Seismic-Infrasound-Acoustic-Meteorological Array

What is infrasound?

- Low frequency acoustics (0.01 – 20 Hz) created by:
  - Volcanoes
  - Earthquakes
  - Bolides (meteors)
  - Explosions in the atmosphere
  - Sub-surface explosions
  - Surf
  - Missiles
  - Rockets
  - Weather systems
  - Animal vocalizations
  - Urban Noise*



PREMISE:

Structures generate coupled low-frequency acoustics as fundamental modes of motion

What is the physics behind these signatures?

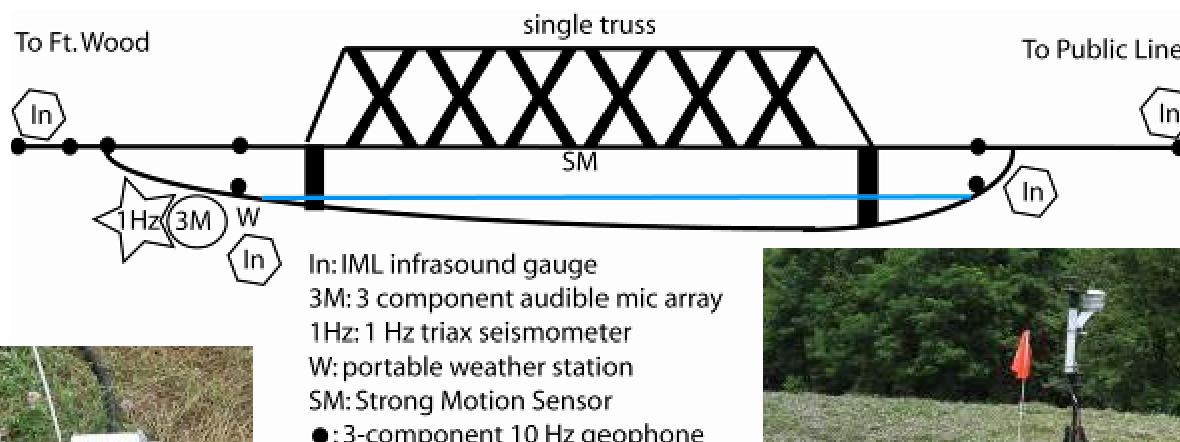
How far do they propagate? Under what conditions?

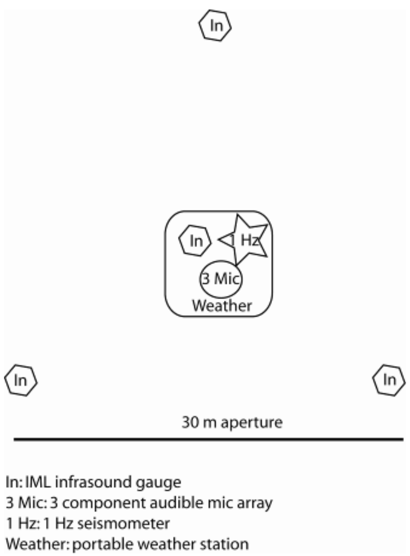
What can you measure/assess about the structure given the acoustic information?

Geophysical Data Collection

- 3 arrays: seismic, infrasound, acoustic and meteorological sensors (SIAM arrays). Infrasound gauges produced for this project by Intermountain Laboratories (IML)
- 5 balloon launches for weather data at receiver array
- Network of on-post met monitoring sites.
- 2 75-ton engines, 8 flat cars

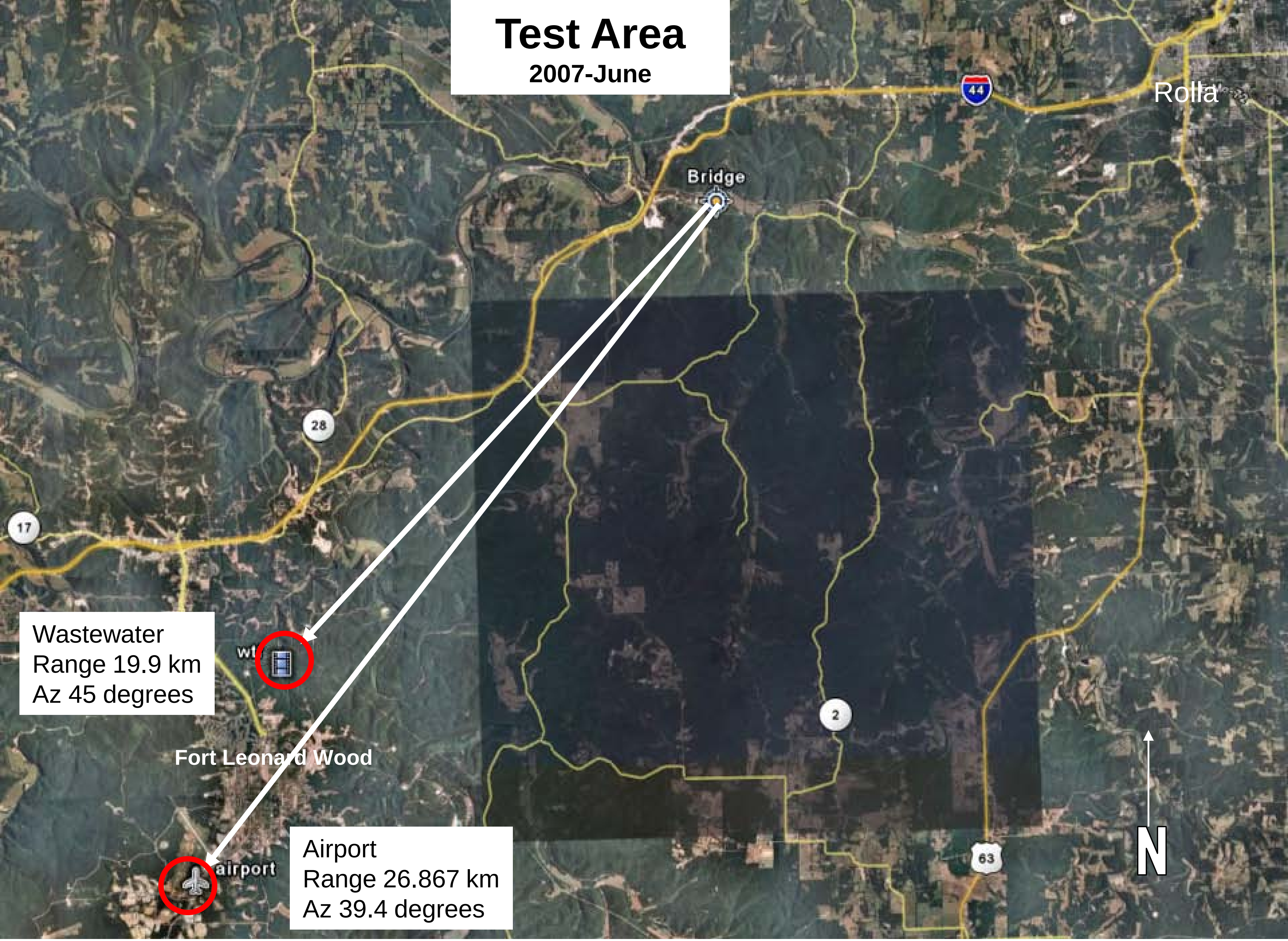
Array deployed at target bridge

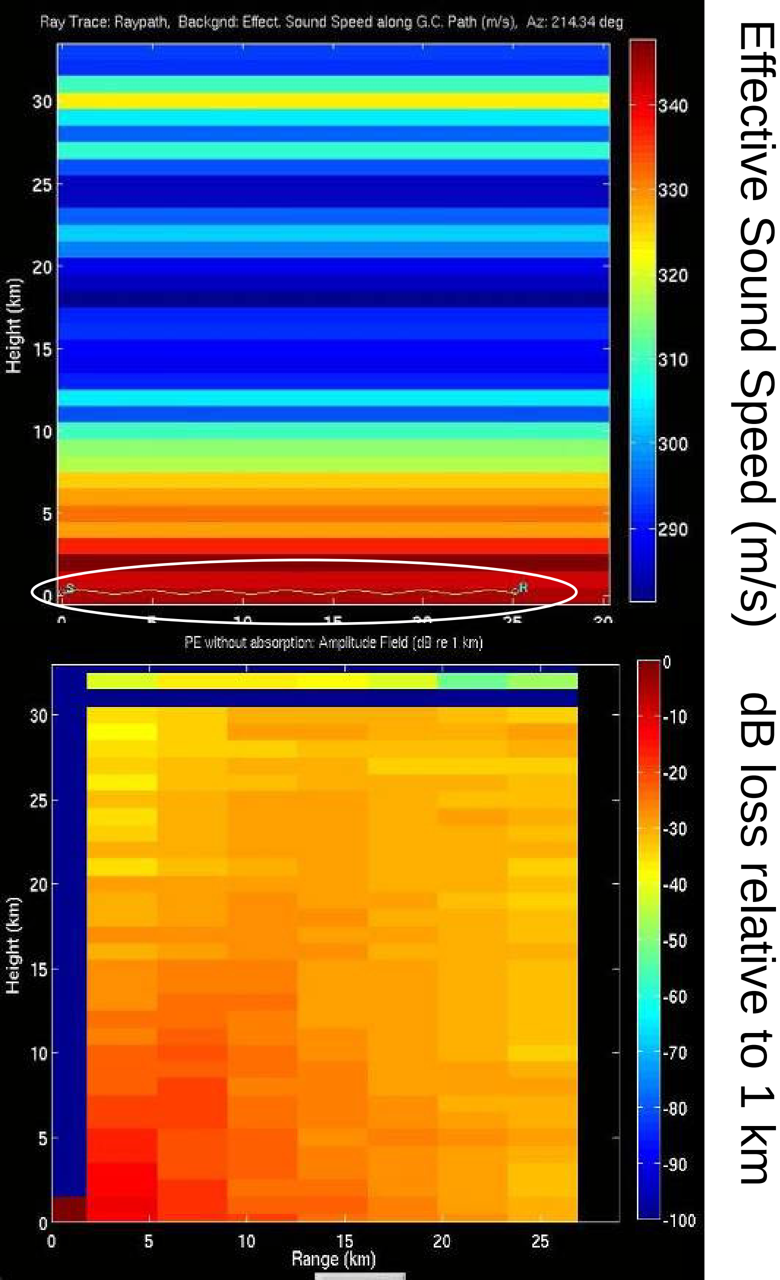




2 standoff arrays

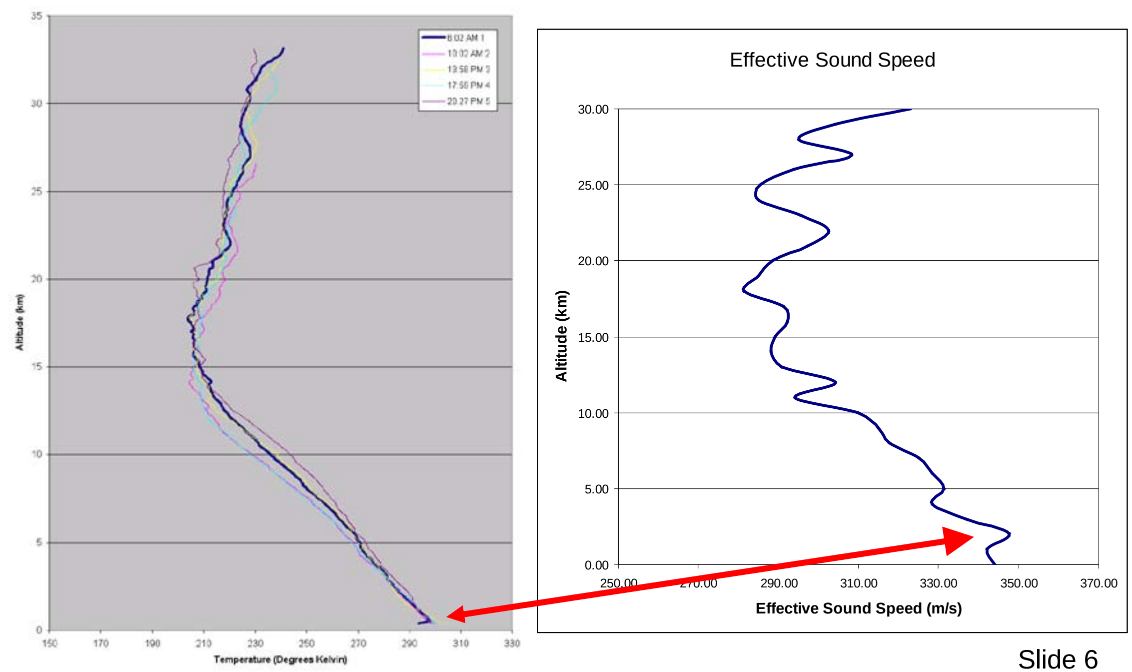
Test Area
2007-June





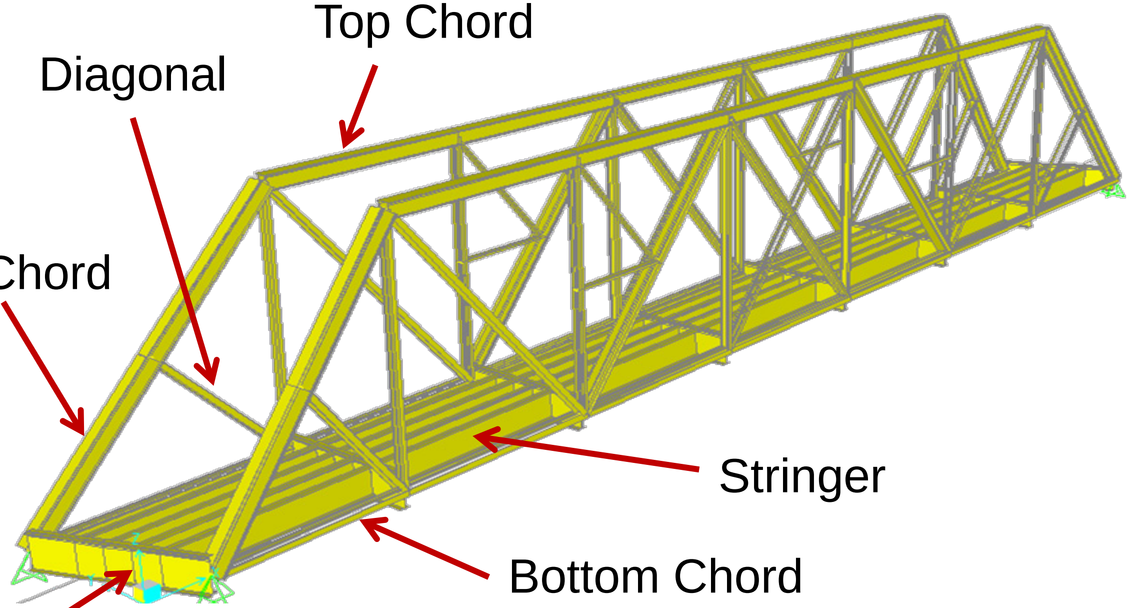
Propagation Modeling

- **Data analysis searching for the bridge signature initially focused on the time window from 4 AM to 8 AM local time.**
- **Numerical modeling of the Radiosonde data predicted only one successful arrival (at 6AM local time).**



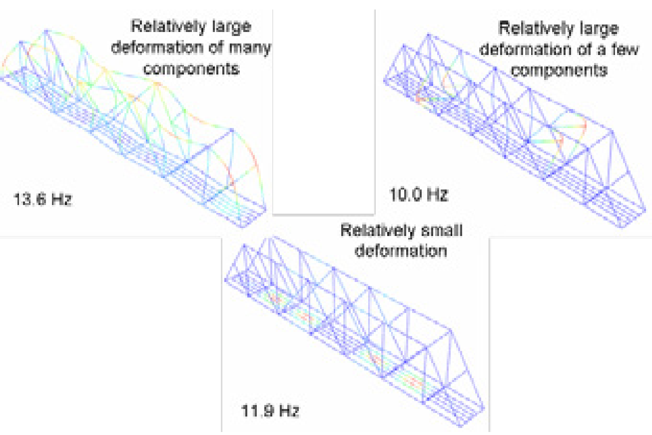
Load Rating

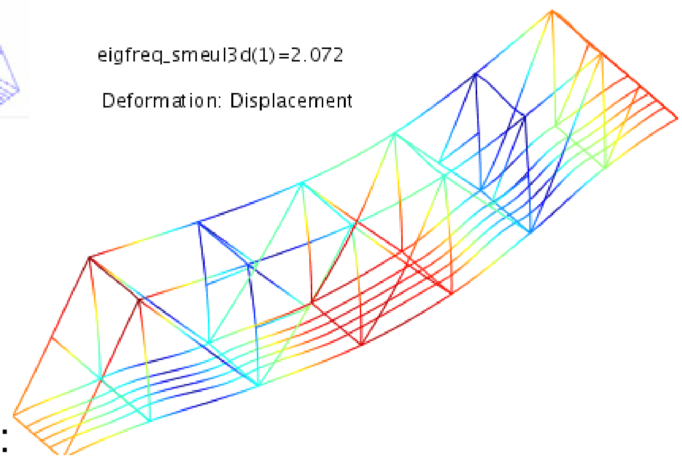
- **Experimental load rating tests:**
  - **Strain Gages (44 Used)**
    - **Main Structural Elements**
  - **One Train Engine**

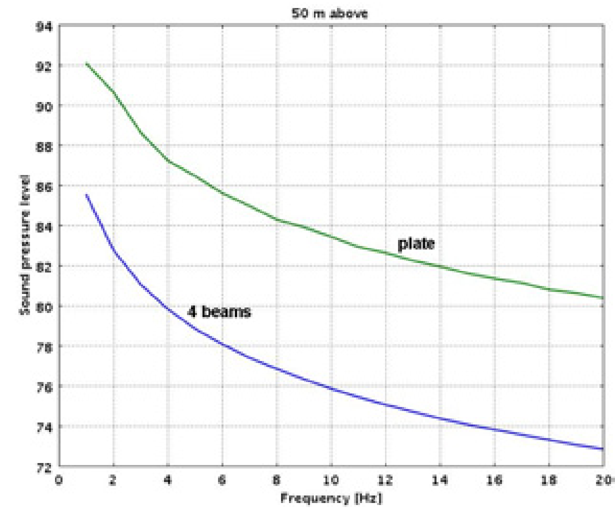


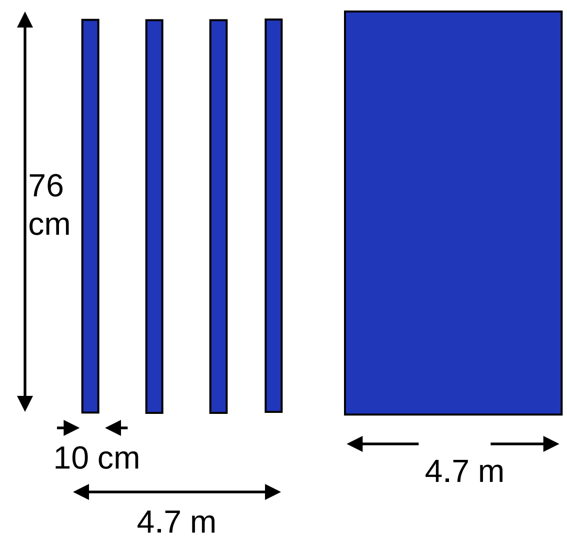
Modal Analysis: COMSOL

- Key components :
  - Required a simplified source to limit computational costs
  - Accurate representation of the acoustic energy emitted









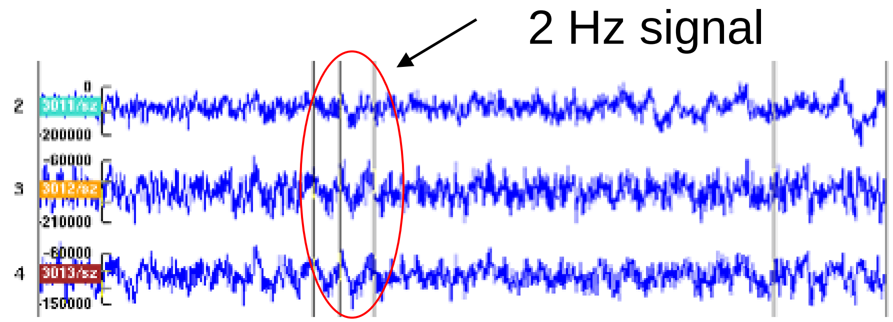
- Technical Hurdles overcome:
  - Beam/truss elements can be represented as point sources
  - Geometry of beams important for acoustic response
  - no single area dominates acoustics

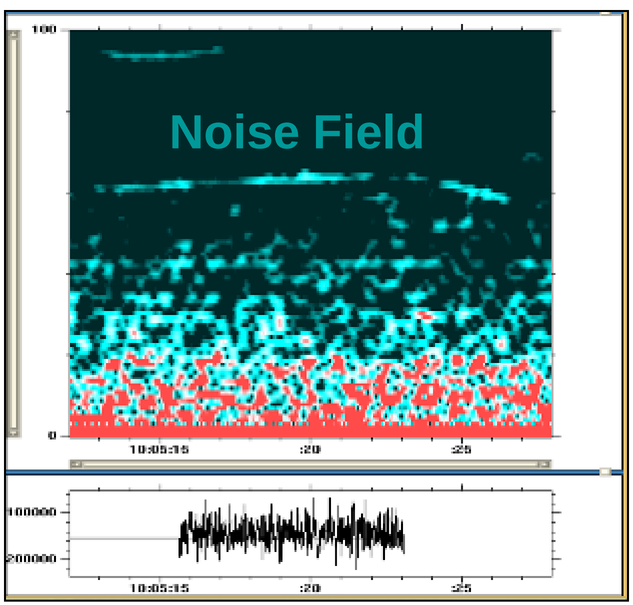
Infrasound Bridge Signal

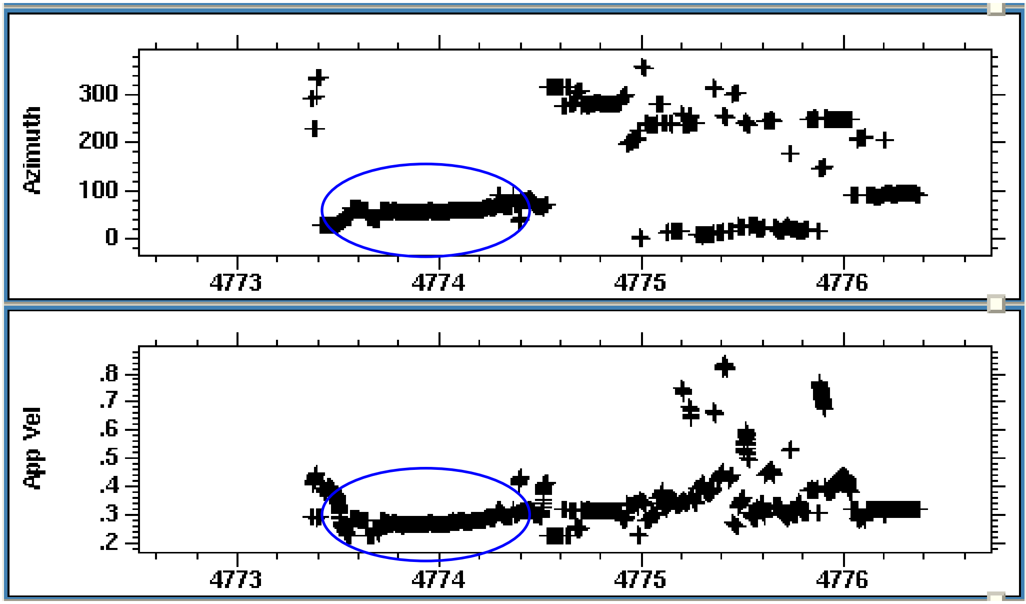
•Bridge signal was seen at both remote arrays.

•fK (frequency-wave number) analysis results correspond with bridge azimuth and infrasound passband/phase velocity.

•Includes fundamental mode frequencies of interest (2, 6 and 13hz) - extremely low amplitude signal and difficult to tease from the background noise.







sample record number

Model Development

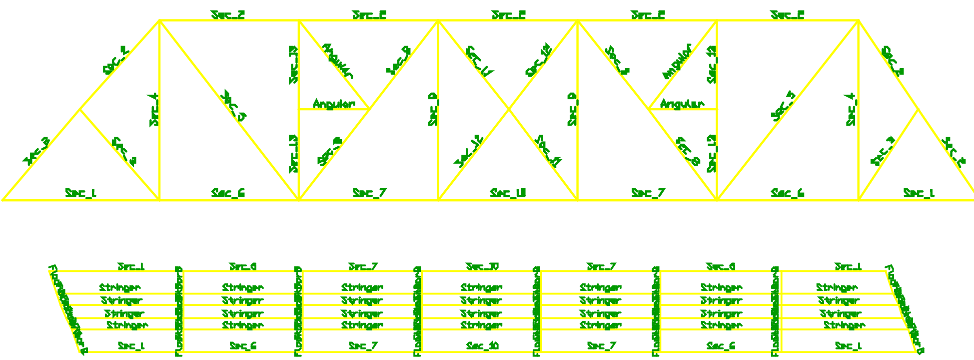


Figure 1. Elevation and plan view of bridge at Ft. Leonard Wood showing section names corresponding to the model produced in the load rating.

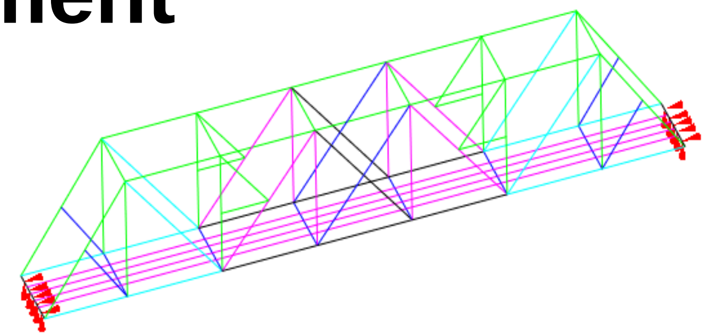


Figure 2. Finite element model constructed using COMSOL Multiphysics.

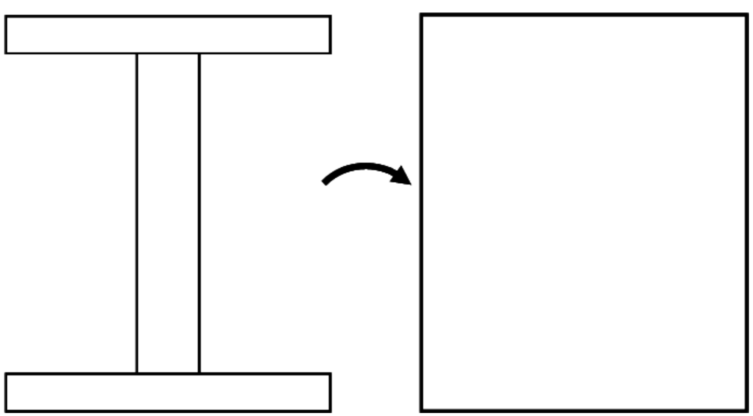


Figure 3. Equivalent section used for acoustic analysis.

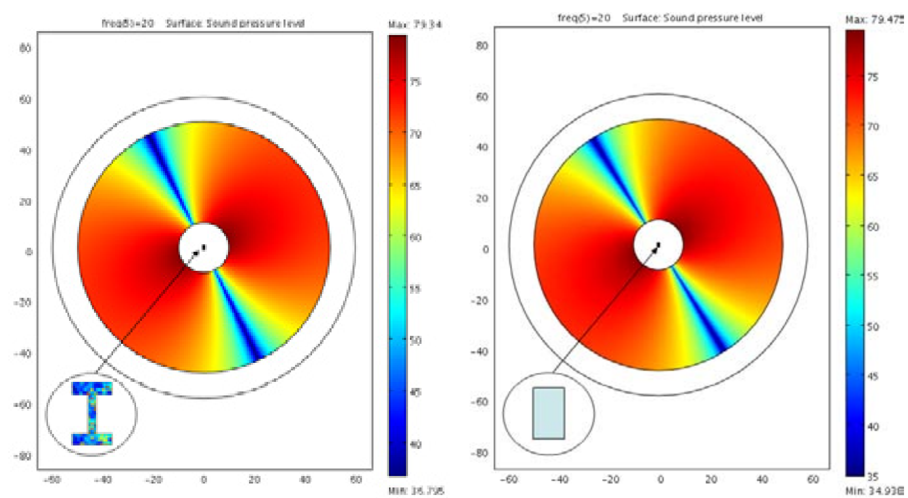
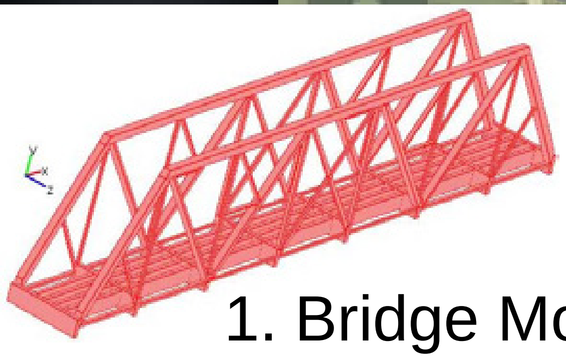
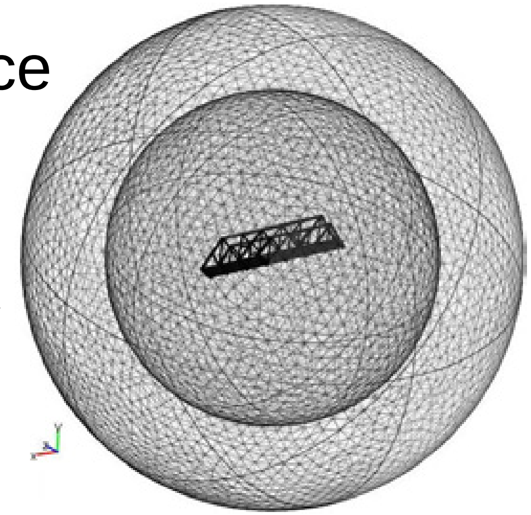


Figure 4. Acoustic Assumtion. Comparison of sound pressure levels from detailed model of I-beam and rectangle that encompasses outer dimensions of I-beam. Inner area around section has been removed to show details of far-field solution.



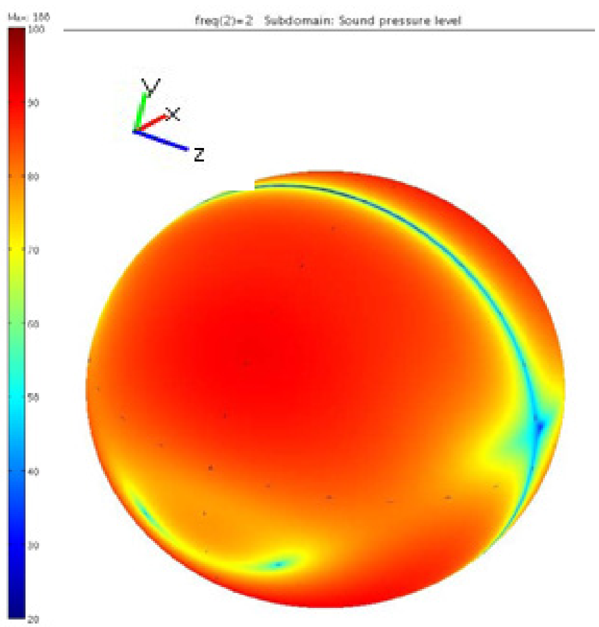
1. Bridge Model

2. Mesh Space

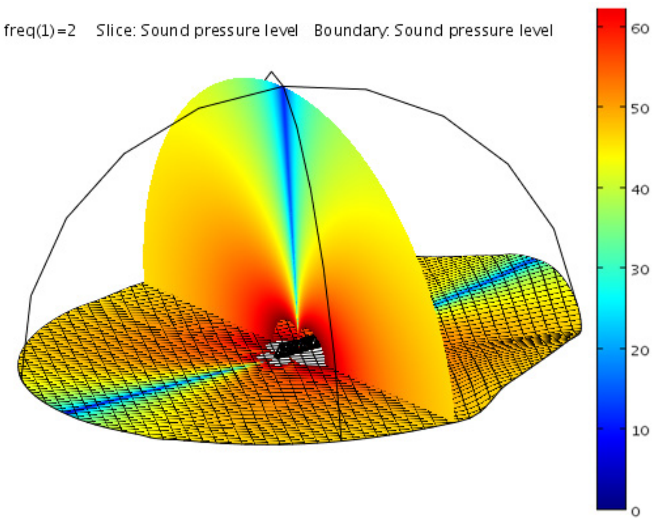


2 Hz dominant frequency shown

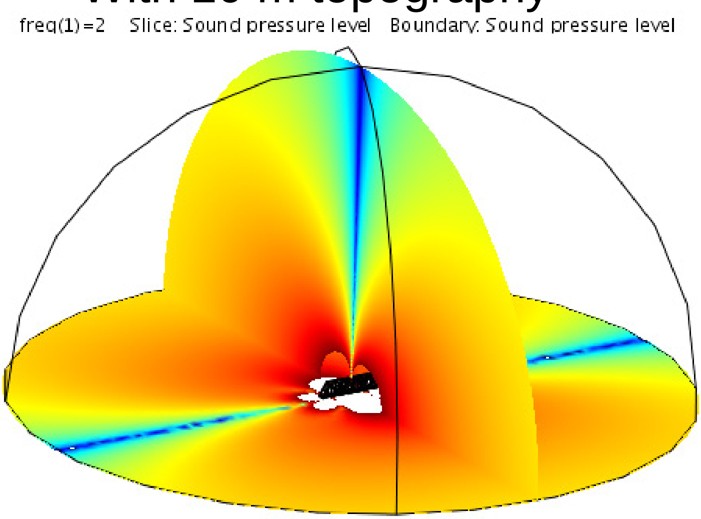
3. 3-D Acoustic Coupling



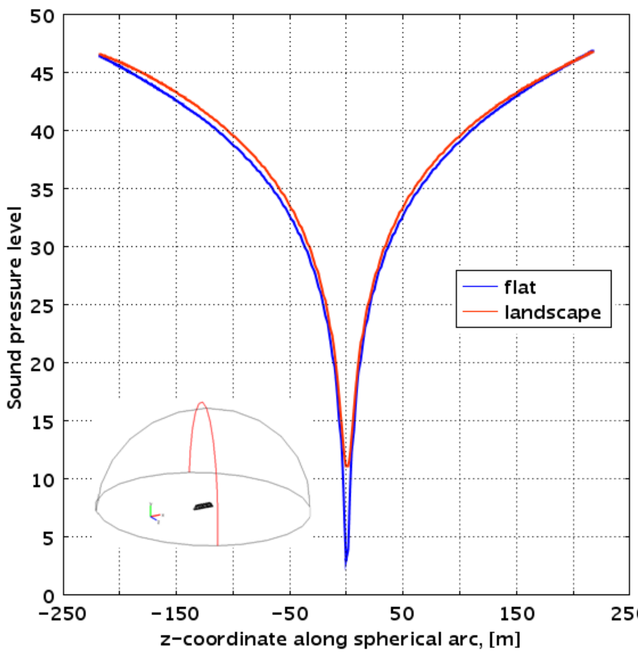
Far-Field Radiation Pattern: Infrasound Source



With 10 m topography



Flat Earth



The acoustical radiation pattern at 50 m can be a representative infrasound source to insert into propagation modeling packages. At 500 m, the source is affected by topography (top left), though in this case, the residual topography effect is small but asymmetric (above).

Conclusions

- The bridge was observed using infrasound arrays from approximately 20 km, verifying the COMSOL modal modeling.
- Initial source modeling indicates that the bridge functions as a directional source, with energy propagating along the river bed, perpendicular to the direction of traffic, affecting visibility under varying meteorological conditions, though with minimal effect of topography.
  - Though the topographic contribution to propagation was minimal for *this scenario*, more extreme topography in more geophysically complex areas would likely have more impact on the representative source.
- The use of infrasound to monitor structures deserves further study. While a rail bridge was selected for this test case, large dams, cables that suspend cable-cars, and vehicle bridges should be considered for future work.
- If SIAM arrays could be emplaced in areas of interest, continuous monitoring could give indication into the change in structural health of a target, though *the changes due to wear or active damage would need to be great enough to affect the fundamental modes of the structure.*
- This persistent surveillance technology could be applied to civil cases as well, however, the authors emphasize <u>this is not a 'silver-bullet' approach to domestic structural health monitoring or homeland security applications</u>.