# Analysis of the Acoustic Response of a Railroad Bridge

Mihan H. McKenna[2], Sergei Yushanov[1], Kyle Koppenhoefer*[1], and Jason McKenna[2]
[1]AltaSim Technologies, LLC, [2]U.S. Army Engineering Research and Development Center
*Corresponding author: 130 East Wilson Bridge Road, Columbus, OH 43085,
kyle@altasimtechnologies.com

**Abstract:** Aging infrastructure (e.g., railroad bridges) requires frequent inspections to assess their structural integrity. However, the large amount of existing infrastructure, and the distance between these structures present significant challenges to inspectors. A simple, method to monitor the structural integrity of infrastructure is needed. Acoustics-based technologies represent a simple, and relatively inexpensive, technique to monitor the integrity of a structure. To develop these techniques, designers must understand the frequencies and sound pressure levels that develop from a typical bridge structure. Infrasound is acoustic energy whose frequency is below that of human perception. Large infrastructure, such as bridges, emits such signals at their natural or driven frequencies of vibration, providing an indication of the structural condition. The feasibility of this type of monitoring was recently evaluated during an in-service load test of a single through-truss railroad bridge at Ft. Leonard Wood, MO, in conjunction with local infrasound monitoring.

**Keywords:** Acoustic, structural integrity, infrasound.

## 1. Introduction

Infrasound is low frequency sound waves between 0.1 to 20 Hz. Since typical human hearing ranges from 20 Hz to 20,000 Hz, humans do not hear infrasound. There are many sources of infrasound including volcanoes, earthquakes, bolides (meteors), man-made explosions, mining explosions, atmospheric explosions, surf, missiles, rockets, weather systems and even animal vocalizations [1].

In order for up-going infrasonic energy to be observed at Earths surface, it must reach an area of higher sound velocity than at the point of origin. If this occurs the energy turns and then returns to the surface of the earth. Temperature strongly affects the effective sound speed. Thus, the temperature variation through the atmosphere determines if infrasound energy returns to Earths surface. Figure 1 shows the sample effective sound speed profile with the regions of the atmosphere labeled.

Large man-made structures, such as bridges, have been reported to generate infrasound [3,4]. However, little research has been done into the diagnostic possibilities in the data recorded near these structures; Donn [3] was unable to discern the source driver for the infrasound generated by the bridge. It is likely that these infrasound signals contain information about the natural modes of vibration of the infrastructure. Thus, infrasound monitoring of structures may provide a future methodology for assessing the condition of significant infrastructure. Given the complexity of developing this assessment methodology, computational modeling can provide valuable insight into how infrasound develops and propagates. The development of an acoustic source model of a structure provides an important first step for developing this modeling methodology.

The development effort described in this paper seeks to produce a model of the Ft. Leonard Wood railroad bridge that will be an infrasound source for a larger atmospheric model.

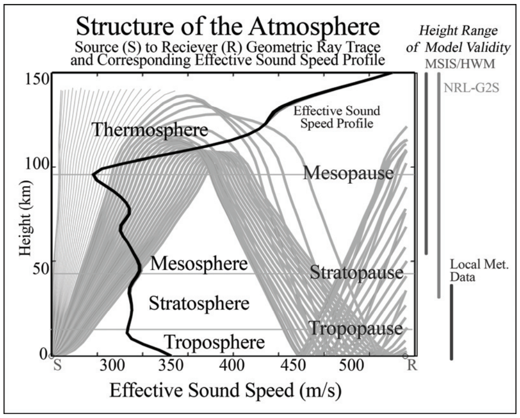

Figure 1. Idealized atmospheric structure [2].

Figure 2. Bridge 0.3 on Ft. Leonard Wood

## 2. Modeling Methodologies – COMSOL Multiphysics

Developing the acoustic source model for a bridge requires two physics; structural vibration and acoustic wave propagation. Given the two physics in this source model, COMSOL Multiphysics provides an ideal platform for developing this source model.

For structural vibration, the railroad bridge at Ft. Leonard Wood, as shown in Figure 2, can be represented using beam elements. Thus, the use of three-dimensional beams requires that the Solid Mechanics Module provided the computational capabilities to calculate the structural vibration of the bridge. The calculations were conducted using an eigenfrequency analysis application mode.

First, a model was constructed to calculate the natural frequencies and mode shapes of the bridge. The modal analysis is based on the data collected during the load rating portion of the field experimentation. Beam elements provided the basis for modeling the structure in this model. Section properties were assisted to each beam element as specified in Table 1

Figure 3 shows the location of each section specified in Table 1. Figure 4 shows the finite element model constructed in COMSOL. The model is constrained by pins at both ends of the bridge.

With the vibrational characteristics of the bridge defined, a second model to calculate the acoustic response of the bridge was developed. For the acoustic analysis, the pressure acoustics application mode from the acoustics module was used. Although COMSOL does support meshing of lines, these "beam" elements represent a poor choice for the acoustic model due to their lack of free surfaces that produce acoustic waves as the structure interacts with the air. To include the effects of the surface area of the beams, the acoustic model represents the beams as hollow rectangles that encompass the outer parameter of the beam. These equivalent sections produce the acoustic response of the bridge during vibration.

With the acoustic-structure interaction developed for the bridge, the next step was to include the surrounding terrain for the bridge. Ten meter National Elevation Dataset data was used for the topography profile, provided by the USGS. Figure 5 shows the local topology for a 500 m square that centers on the bridge. The white region that runs across the square is the river bed over which the bridge is built.

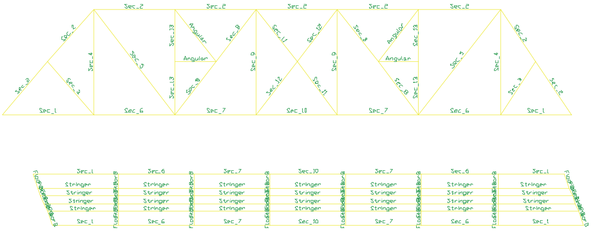

Figure 3. Elevation and plan view of bridge at Ft. Leonard Wood showing section names provided in Table 1.

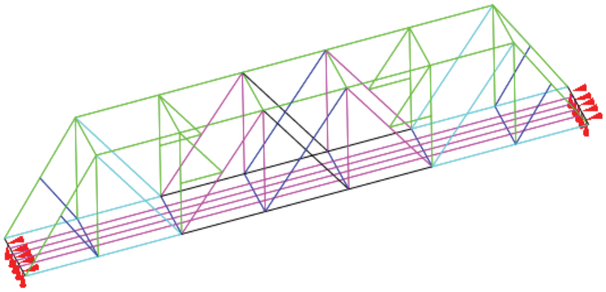

Figure 4. Finite element model constructed using COMSOL Multiphysics.

Table 1. Section properties for Bridge

| Section | Area (in^2) | Torsional Constant (in^4) | Moment of Inertia 3-3 (in^4) | Moment of Inertia 2-2 (in^4) |
|---|---|---|---|---|
| 1 | 24.125 | 16.806 | 88.599 | 1655.393 |
| 2 | 48.832 | 13.058 | 2593.331 | 2024.503 |
| 3 | 6.125 | 0.131 | 53.253 | 255.188 |
| 4 | 21.938 | 6.769 | 177.817 | 122.856 |
| 5 | 21.000 | 13.852 | 85.750 | 891.188 |
| 6 | 24.125 | 16.806 | 88.599 | 1655.393 |
| 7 | 42.000 | 27.705 | 171.500 | 2124.938 |
| 8 | 16.422 | 0.924 | 338.938 | 617.545 |
| 9 | 12.250 | 1.725 | 224.724 | 36.162 |
| 10 | 42.000 | 27.705 | 171.500 | 2124.938 |
| 11 | 7.250 | 0.331 | 30.432 | 355.182 |
| 12 | 7.250 | 0.149 | 36.120 | 181.882 |
| 13 | 6.750 | 0.143 | 149.038 | 36.047 |
| Stringer | 35.500 | 8.763 | 8019.458 | 98.490 |
| Angular | 3.875 | 0.081 | 2.876 | 58.416 |
| Floor Beam | 46.500 | 14.785 | 15351.375 | 166.219 |

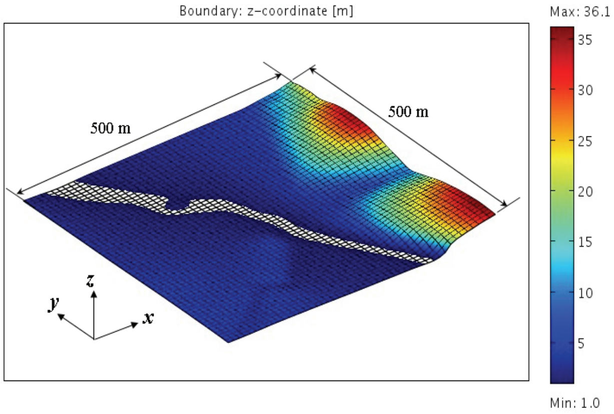

Figure 5. Local topology for a 500 m square centered on the bridge.

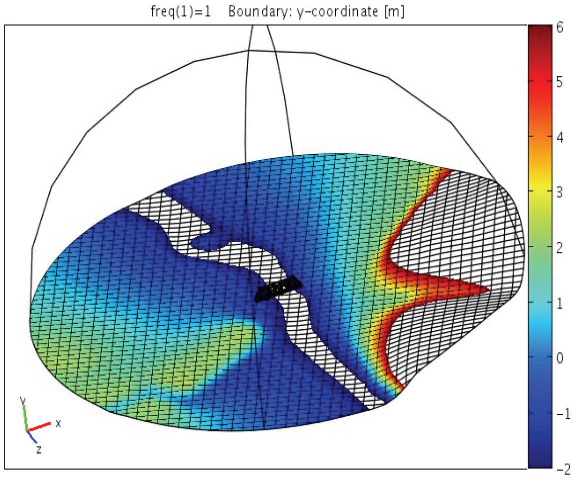

Figure 6. Local topology for a hemispherical region with radius of 500 m around the bridge.

To incorporate the terrain into the acoustic model shown in Figure 5, a hemisphere with a radius of 500 m was mapped onto the available topological data, as shown in Figure 6. This model provides the acoustic response of the bridge as it interacts with the local topology. These models assume the sound reflects perfectly off the topography without any impedance.

## 3. Results and Discussion

The eigenfrequency analysis conducted in COMSOL shows a resonant frequency of the bridge at 2 Hz that should produce significant acoustic energy. Thus, the acoustic analyses focus on the 2 Hz vibration.

By using the simplified geometric model of the bridge, the distribution of acoustic energy from a 2 Hz vibration of the bridge can be calculated. Figure 7 shows the distribution of sound pressure level developed from the vibrating bridge model as it interacts with the local topography. Figure 8 shows the sound pressure distribution for the same 2 Hz bridge vibration as it reflects off a planar surface. The effect of local topographic details is clearly shown by comparing the sound pressure levels along a circumferential arc in Figure 9. These results clearly show a small perturbation of the sound pressure levels due to the local topography.

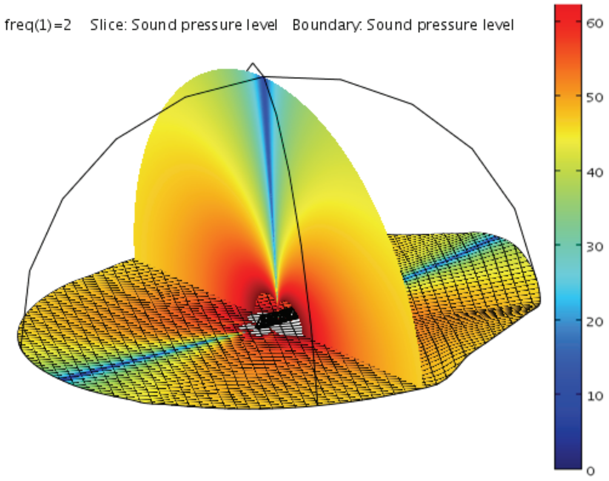

Figure 7. Sound pressure distribution developed from bridge as it interacts with topography.

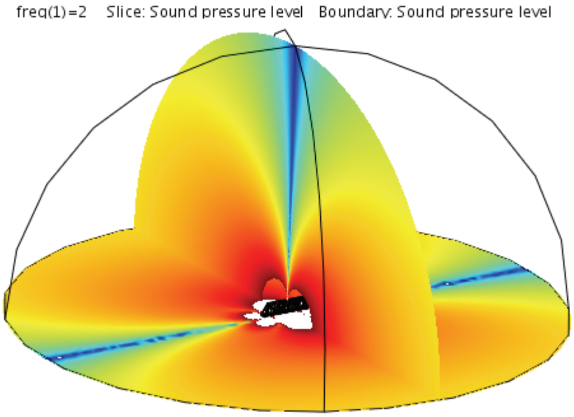

Figure 8. Sound pressure distribution developed from bridge as it interacts with a planar topography.

## 7. Conclusions

This work shows the use of COMSOL Multiphysics to predict the vibrational modes of a complex structure and the use of these vibrational modes as an acoustic source.

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 with minimal effect of topography. Further study will include synthesis of the meteorological data from the multiple on-site stations to create a four-dimensional, time-dependent atmospheric space.

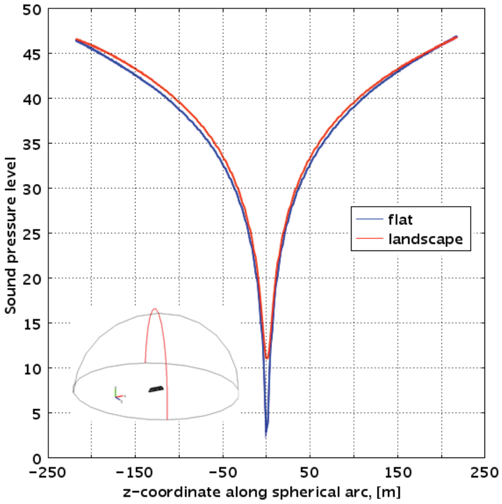

Figure 9. Comparison of sound pressure levels for actual and planar topography for the arc indicated in the figure.

## 8. References

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