Dynamic Analysis of a Roller Compacted Concrete Dam

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Introduction: The U.S. Army Engineer Research and Development Center (ERDC) is currently exploring the use of infrasound sensors to monitor the health of structures of interest. Infrasound is acoustic energy below 20 Hz and is capable of propagating many kilometers from the source with little attenuation. One type of infrasound source is large infrastructure, such as dams and bridges which emit such signals at their natural or driven frequencies of vibration, providing an indication of their global structural condition. Field investigations have been completed at the Portugues Dam, in Ponce, Puerto Rico to explore this research area. This dam is the first single-centered roller compacted concrete (RCC) thick arch dam constructed by the U.S. Army Corps of Engineers. The dam is 220 ft tall and 1230 ft long and has an ogee spillway 140 ft long with base and crest thicknesses of 111 ft and 30 ft, respectively.

Figure 1. Arial view of the Portugues Dam

Problem: Currently, determination of structural health requires intensive hands-on measurements of individual elements at repeated intervals. Fundamental, vibrational modes of motion for large structures, such as bridges and dams, are usually in the sub-audible, infrasound frequency range.

Solution: Persistent, remote infrasound assessment provides a method for standoff assessment of the modal behavior of structures under variable conditions for structural health monitoring and damage assessment.

Field Evaluation: Seismic-Infrasound-Acoustic-Meteorological (SIAM) arrays were installed at distances 0.2Km, 1.0Km, 6.0 km to remotely monitor the dam's response to passive (ambient) and active excitation (impulse loads). The tests completed at Portugues Dam were the first ever performed on a RCC dam, and present a unique opportunity for evaluating an infrasound array's ability to capture the fundamental vibrational modes of the dam from remote locations that infer (pre and post event) structural response characteristics.

Figure 2. Seismic-Infrasound-Acoustic-Meteorological (SIAM) array

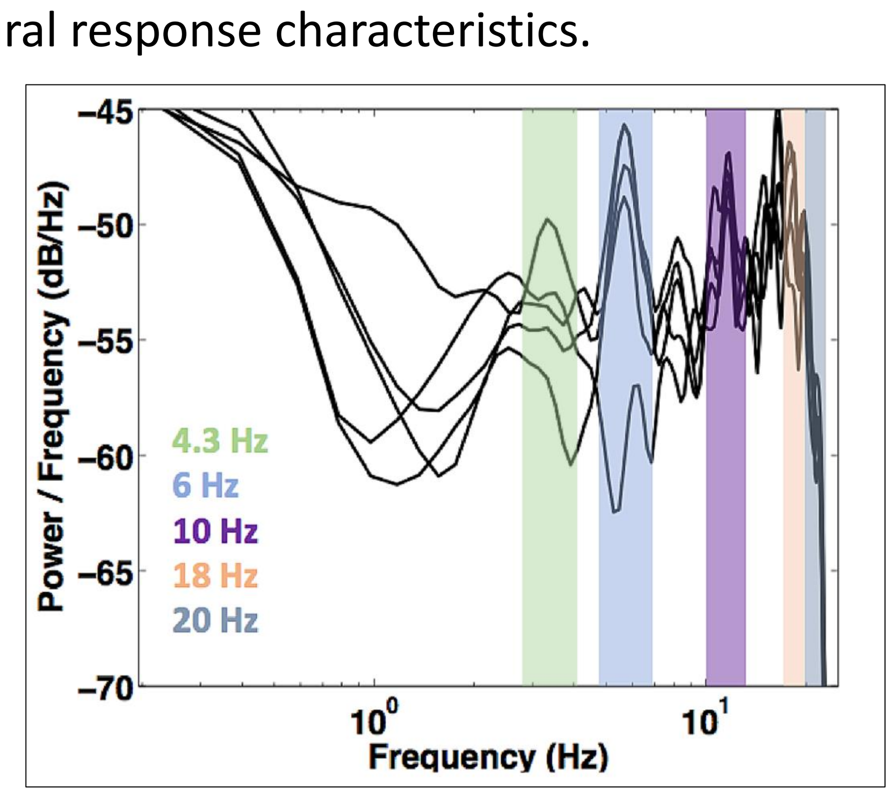

Figure 3. PSD analysis of the force excitation signal from SIAM

Analytical Results: A finite element model (FEM) of the dam and surrounding bedrock was developed in COMSOL to determine the fundamental modes of vibration. The goal was to confirm that the fundamental modes were in the infrasound pass-band, between 0.1 to 20 Hz. The FEM produced frequencies of 4.8 Hz, 6.7 Hz, and 10.2 Hz

Figure 4 . Finite Element Analysis - Structural Model

Dynamic Test: To validate the results from the FEM dynamic analysis, Performance Based Testing (PBT) was conducted at the dam. The PBT consisted of measuring the crest input and output response to a force excitation using Cold Gas Thruster (CGT). The CGT is able to produce transient forces with amplitudes up to 20,000 lb, on a time-scale of approximately 5 ms. Through the use of the CGT and accelerometers mounted on each monolith of the dam, it was possible to measure the dynamic response.

Figure 5. Cold Gas Thruster (CGT)

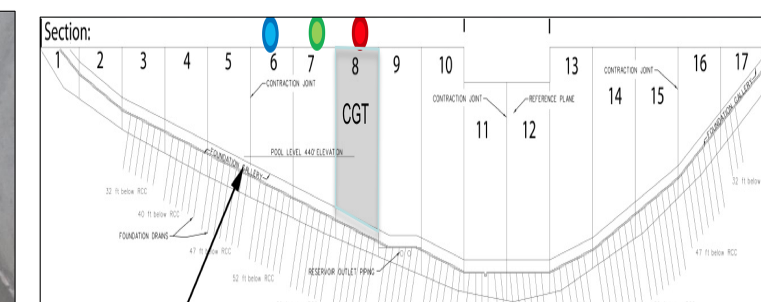

Figure 6. CGT and accelerometers

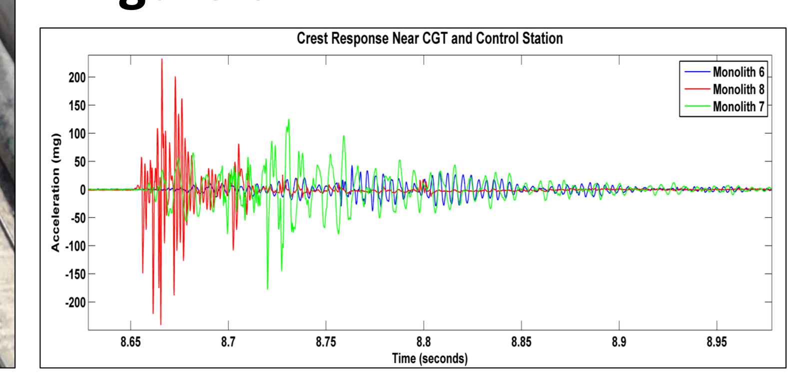

Figure 7. CGT induced transient responses at the crest of the dam.

Seismic Wave Propagation: A seismic wave propagation analysis was developed as an input parameter for the pressure acoustic model. Figure 8 show the propagation of the seismic wave caused by the CGT. The Computational Fluid Dynamics (CFL) condition used for this model was CFL=0.1. From this the maximum element size and the maximum time step, 7.1059 m and 3.33e-4 s where calculated. These values were calculated by using the P-wave velocity of 2131.8 m/s for concrete, 50Hz as the maximum frequency of the load, and N=6 (number of elements per local wavelength).

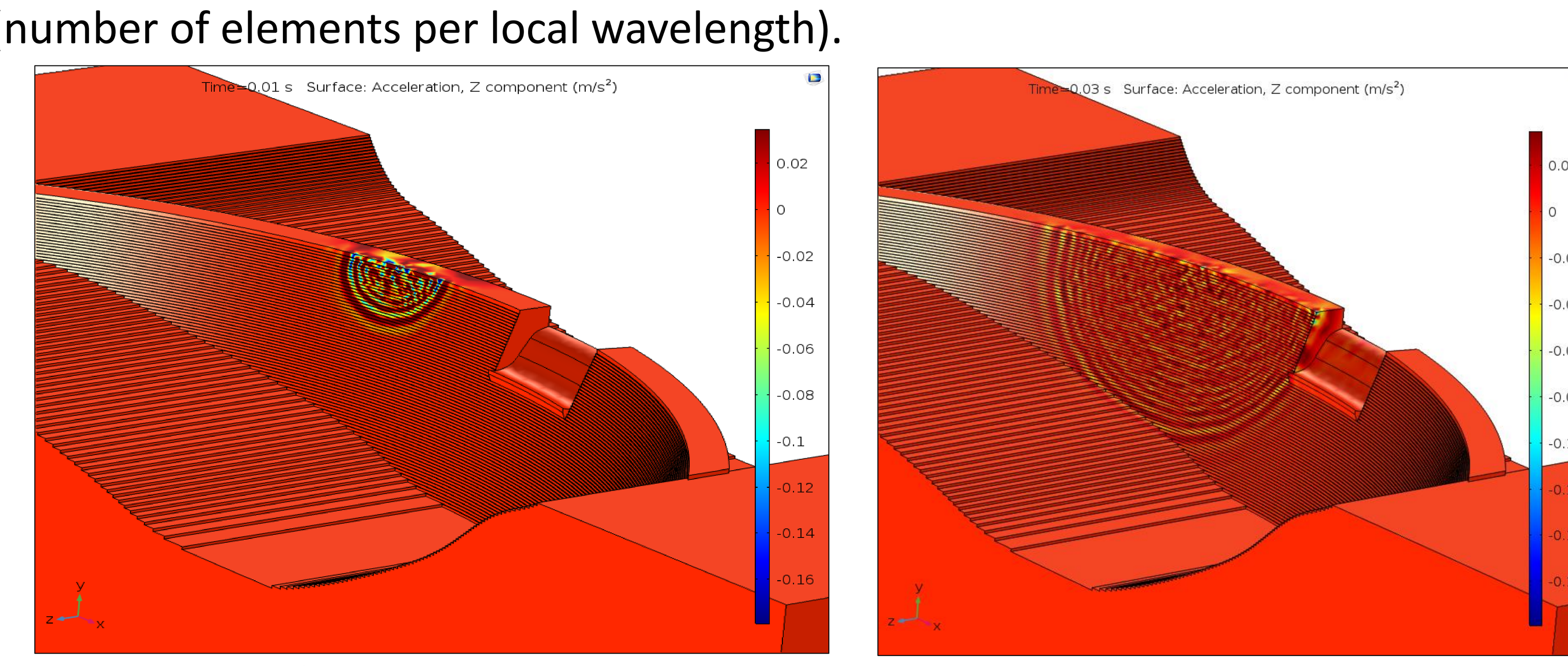

Figure 8. Surface acceleration, Z component due to the CGT blast.

Acoustic Model: The acceleration data from the surface of the dam was transformed to the frequency domain to generate the acoustic model. From this analysis the magnitudes of the energy emitted for the different frequencies of interest were analyzed. The mesh consists of free tetrahedral.

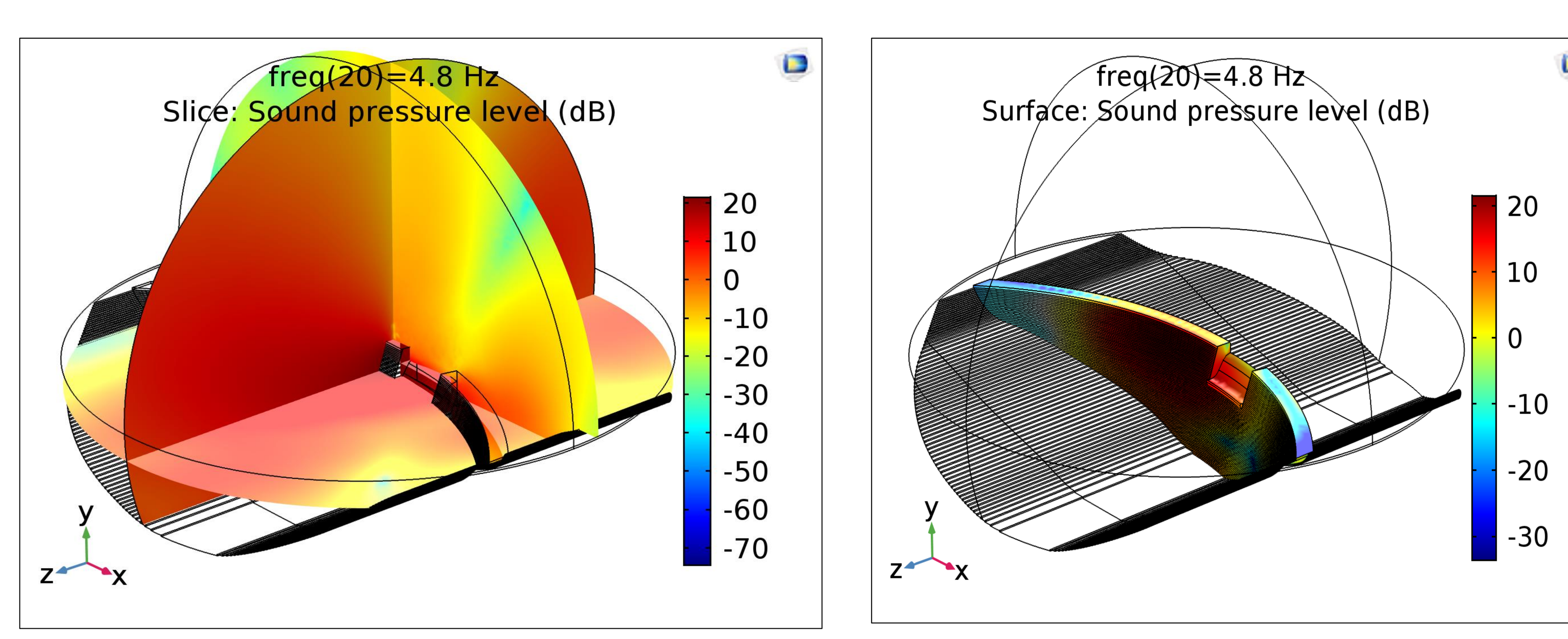

Figure 9. Sound Pressure Level for 4.8 Hz, results from the Acoustic Model analysis.

Conclusions: Results from COMSOL Multiphysics analysis agree with the SIAM field experimental data and were used to validate the frequencies of the dam under different loading conditions. Vibrational response and the acoustic radiational patterns from the dam show that the frequency response changes as the shear waves produced by the CGT excitation move across the dam. COMSOL is a great tool to rapidly characterize the structural condition across a broad spectrum.

References:

•V. Chiarito, Z. Duron, et.al, "Dynamic Testing of the Cable Suspension System at the Waldo-Hancock Bridge," US Army Corps of Engineers, ERDC/GSL report, September 2009.
•M. McKenna, et al., "Analysis of the Acoustic Response of a Rail Road Bridge," COMSOL Conference, October 2009.