SAND2012-5127C

Structural Dynamics Laboratory (ESP500 Structural Mechanics)

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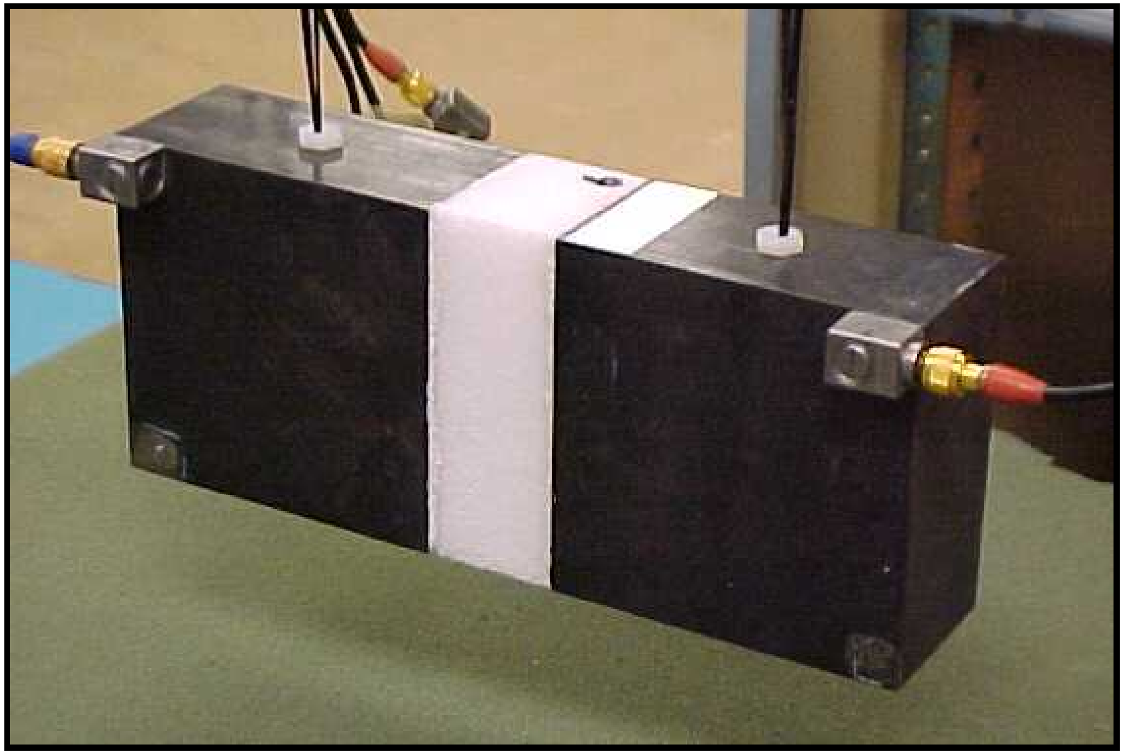
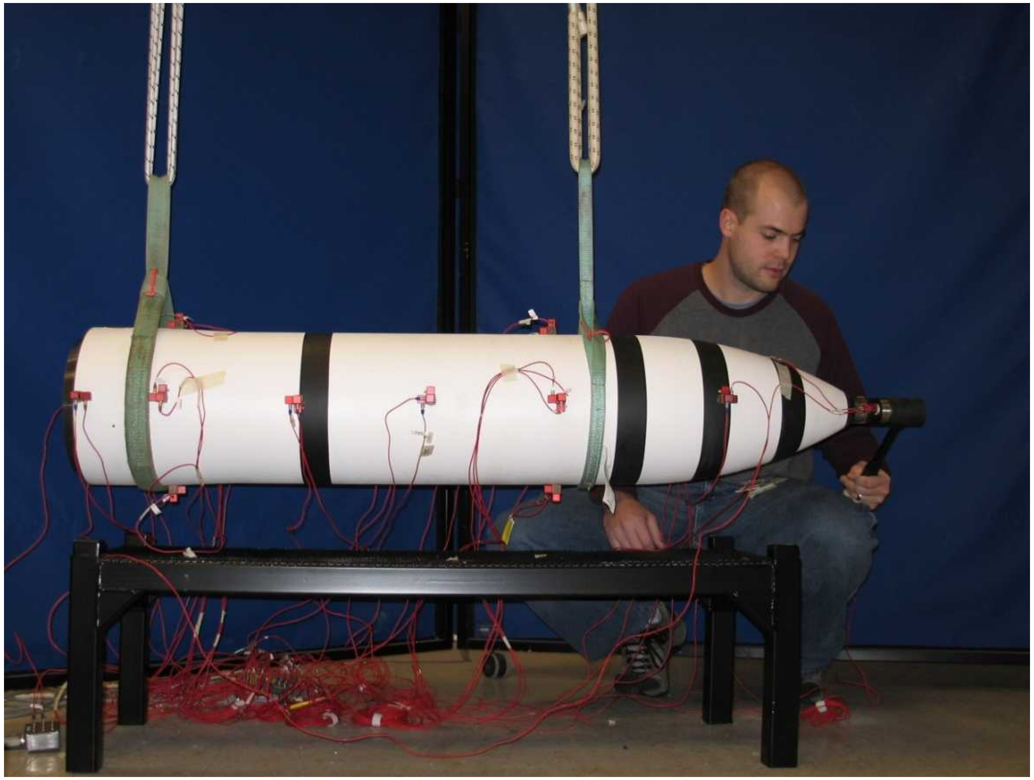
Structural Dynamics Lab

- Experimental Modal Analysis
- Frequency Response Functions
- Modal Test Setup
- Modal Examples
  - Beam Modal
  - Foam Modal
  - Health Monitoring
- Other Test Techniques



Experimental Modal Analysis

- Characterize dynamic response of structures
- Uses input/output relationship (FRF)
- Useful for analytical model validation
- Extract material/ structural parameters
- Non-destructive test
- ASSUMES LINEARITY



Modal Analysis Parameters

- Natural Frequencies (ω_n)
  - Frequencies at which structure resonates
- Damping ratio (ζ_n)
  - Rate at which vibration at ω_n decays to zero
- Mode Shapes (Φ_n)
  - Shape structure forms at natural frequency

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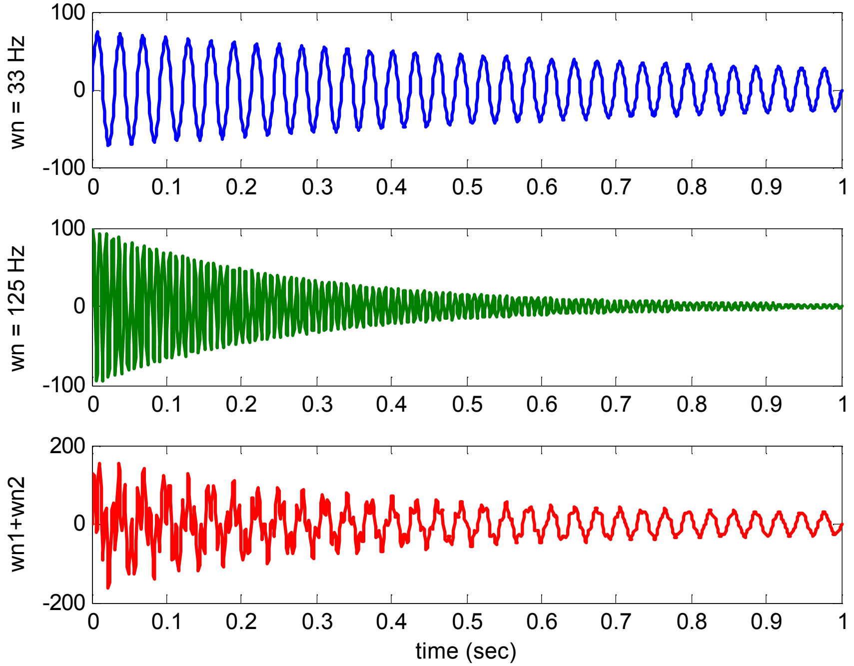
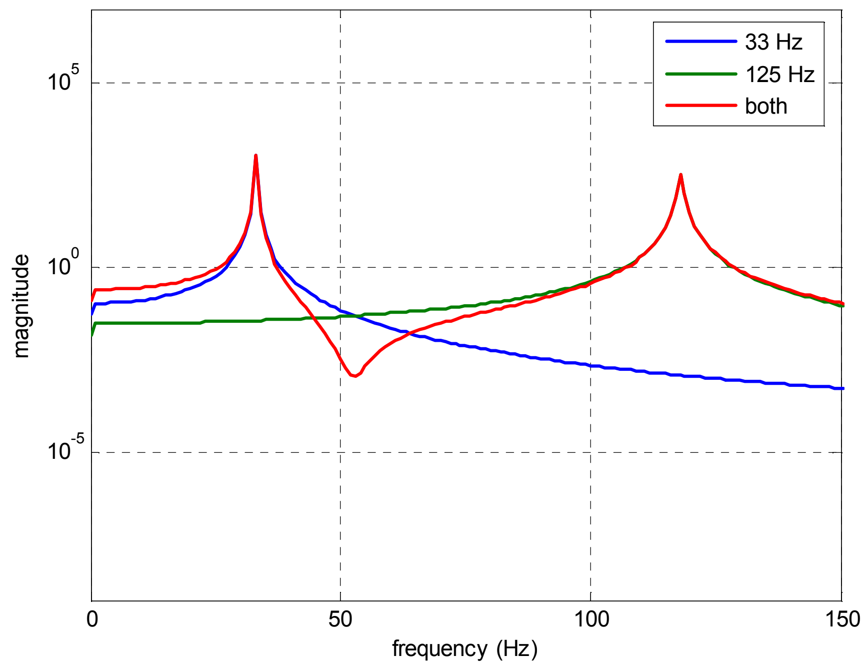
Welcome to the Frequency Domain! (Yes, I was scared too)

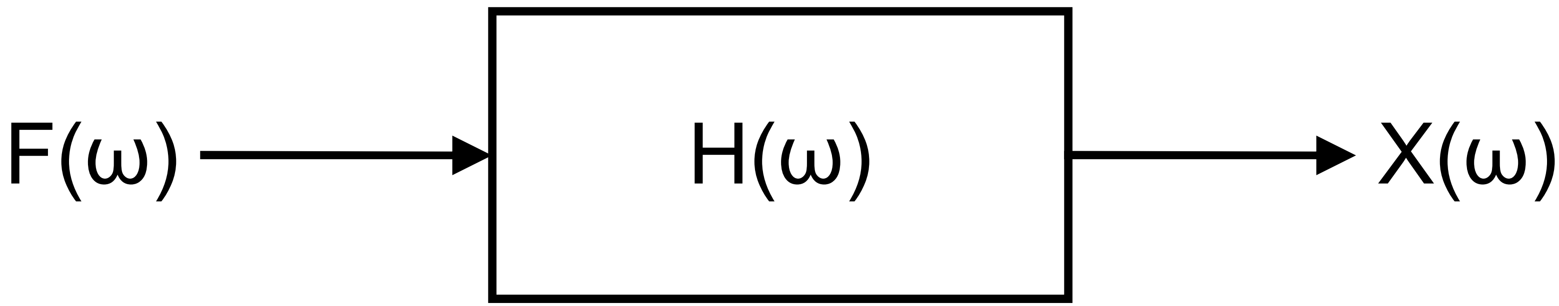




- Fast Fourier Transform
  - Examine frequency content in time history signals
  - Really fast!

Frequency Response Function

- Linear System with Force Input and Displacement Response



$$H(\omega) = \frac{X(\omega)}{F(\omega)} = \frac{\phi\phi}{\left(\omega_n^2 - \omega^2\right) + i2\varsigma_n \omega\omega_n}$$

experimental analytical (fit)

Frequency Response Functions

- Experimental modal testing typically measures accelerance due to easy-to-implement force transducers (most of the time) and the underlying physics of accelerometers.
- Can use any FRF for natural frequency and damping estimation, but mode shapes only scale properly for force input.

$$H(\omega) = \frac{X(\omega)}{F(\omega)}$$

receptance

$$H(\omega) = \frac{\dot{X}(\omega)}{F(\omega)}$$

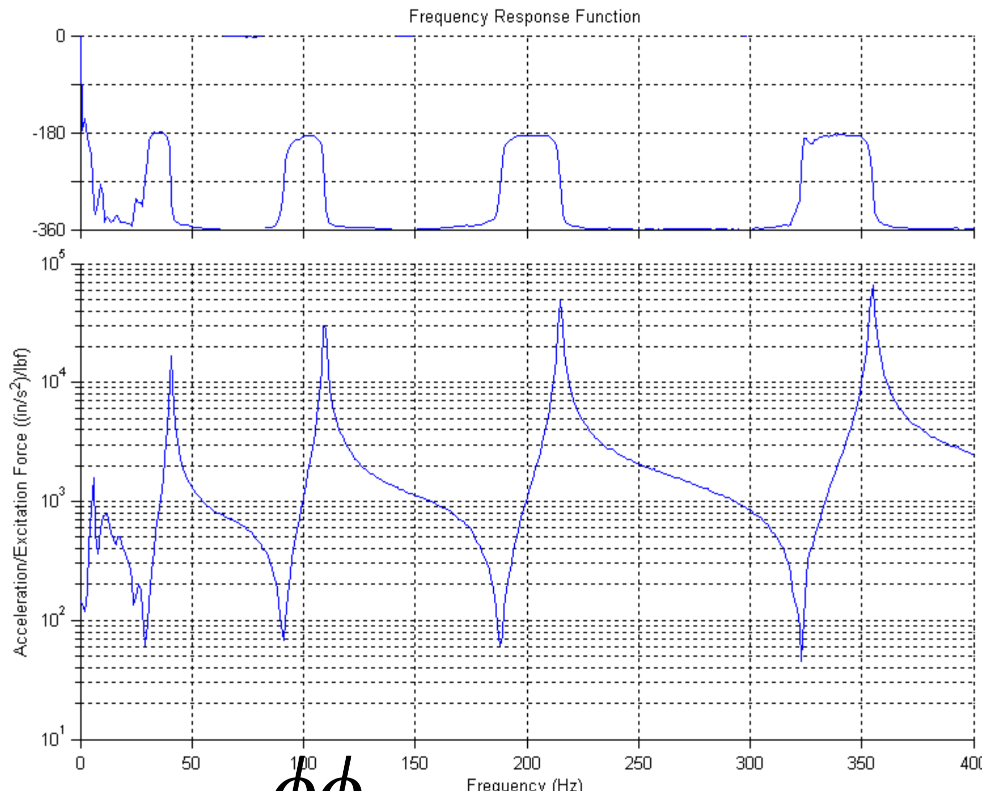
mobility

$$H(\omega) = \frac{\ddot{X}(\omega)}{F(\omega)}$$

accelerance

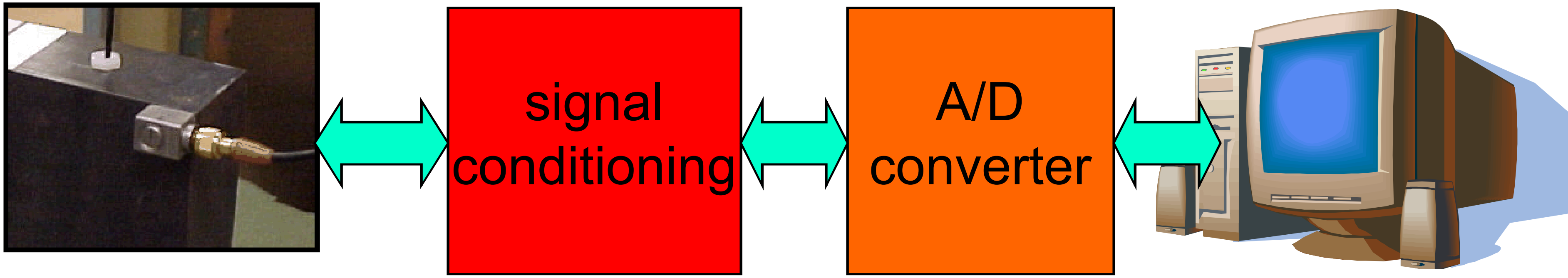
Frequency Response Function

- FRFs are complex numbers, typically magnitude is plotted
- Frequencies at the peaks indicate natural frequencies
- Sharpness of peaks indicate damping
- Amplitudes at peaks used to calculate mode shapes



$$H(\omega) = \frac{\phi\phi}{\left(\omega_n^2 - \omega^2\right) + i2\varsigma_n \omega \omega_n}$$

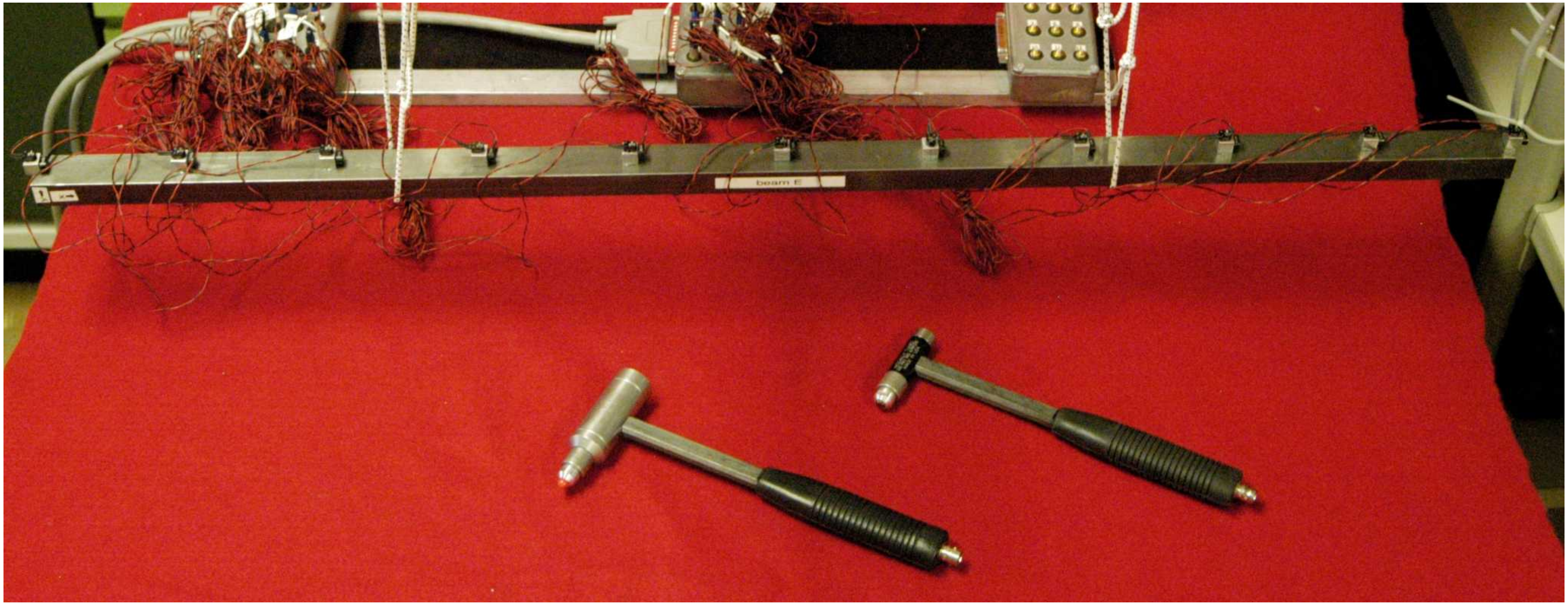
Modal Test Setup



Input/output transducers | filters, power supplies | digitizes data | data aquisition computer

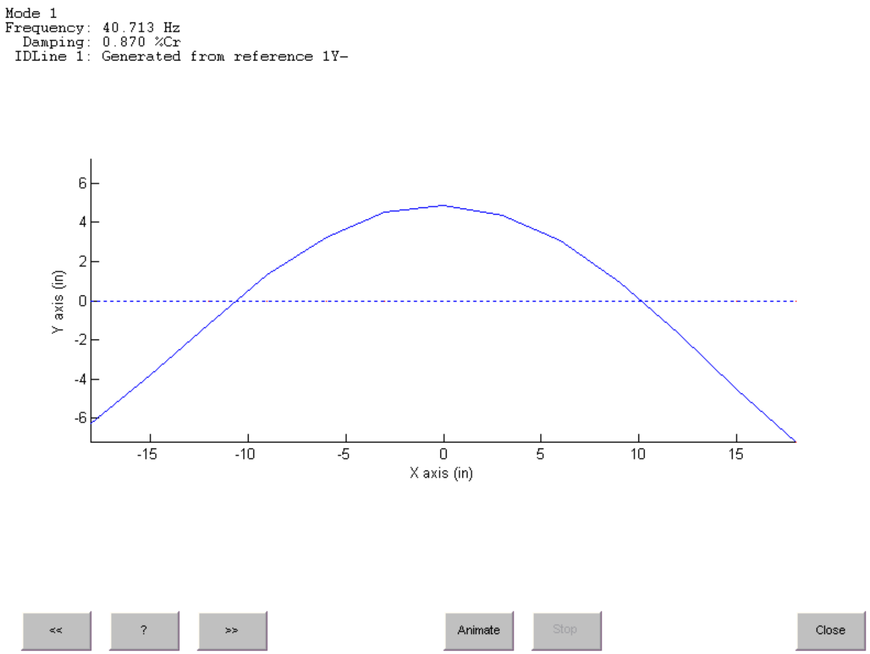
- Typically use force hammers and accelerometers.
- Data acquisition parameters must be selected: spectral lines, maximum frequency, frame size.
- Parameter selection determines: sampling frequency (2.56×max freq.), Δt (1/samp.freq.), Δfreq (1/frame size).

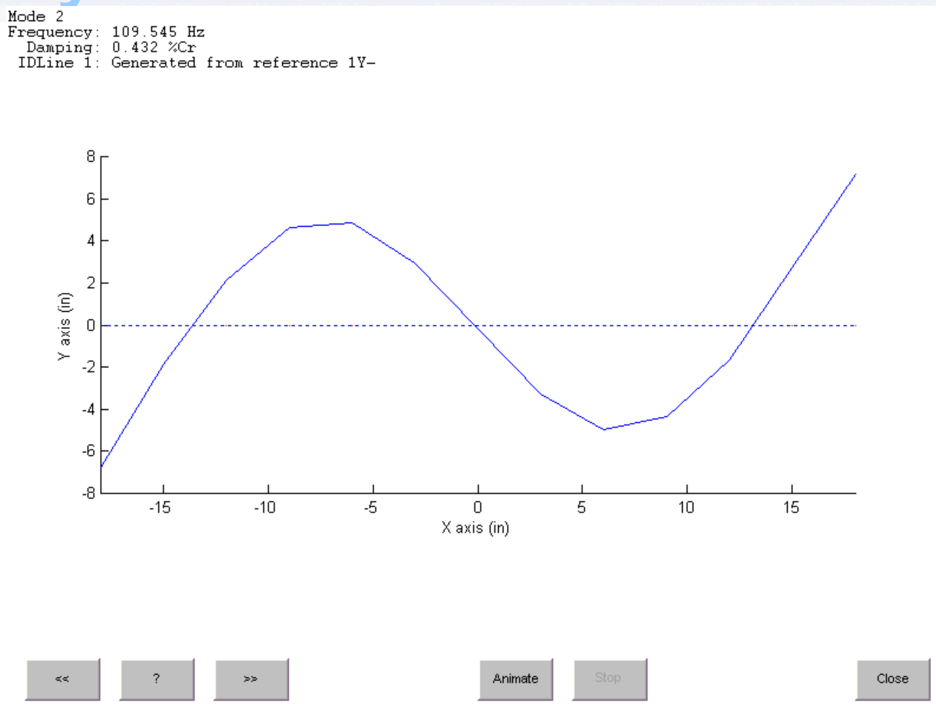
Modal Analysis of Beam



- Find natural frequencies, mode shape of beam
- Look at time histories, FRF, coherence
- Use FRF real/imag plot and smac (MATLAB program) to find results

Modal Analysis of Beam

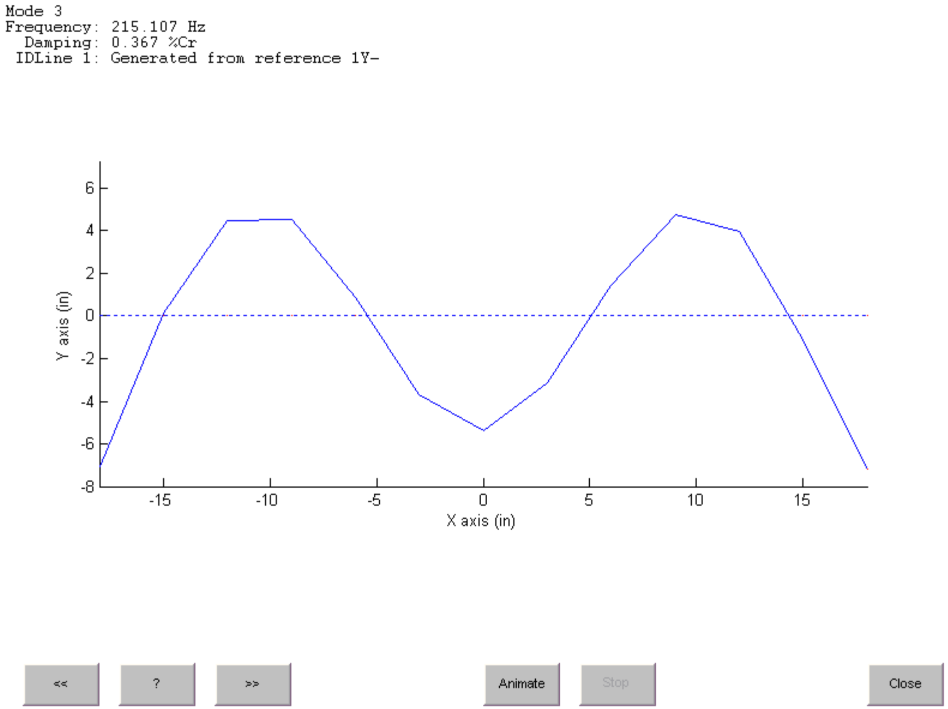


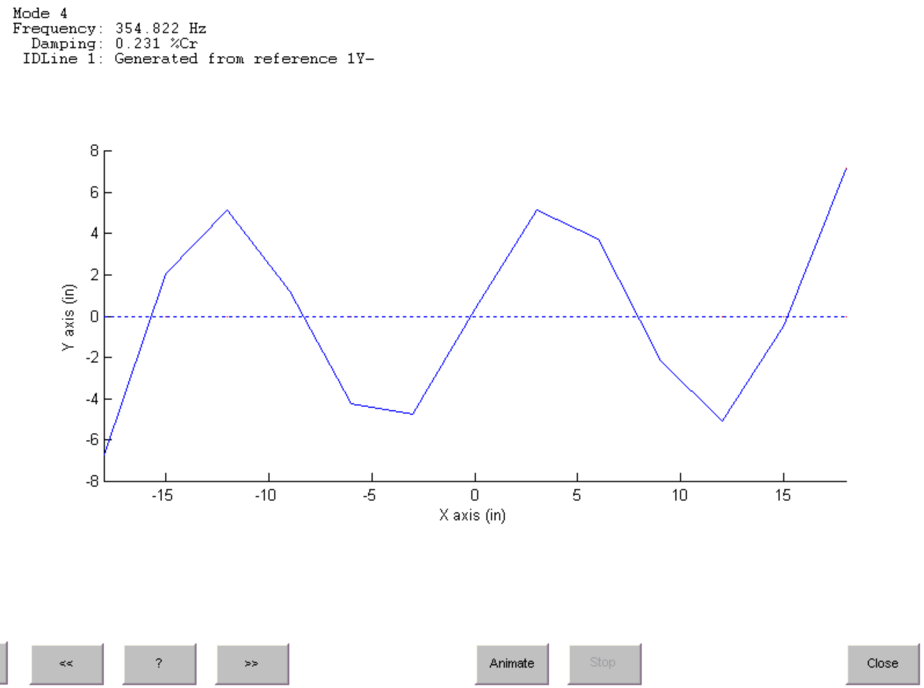


ωn = 40 Hz, ζ = 0.87%

ωn = 109 Hz, ζ = 0.43%

Modal Analysis of Beam



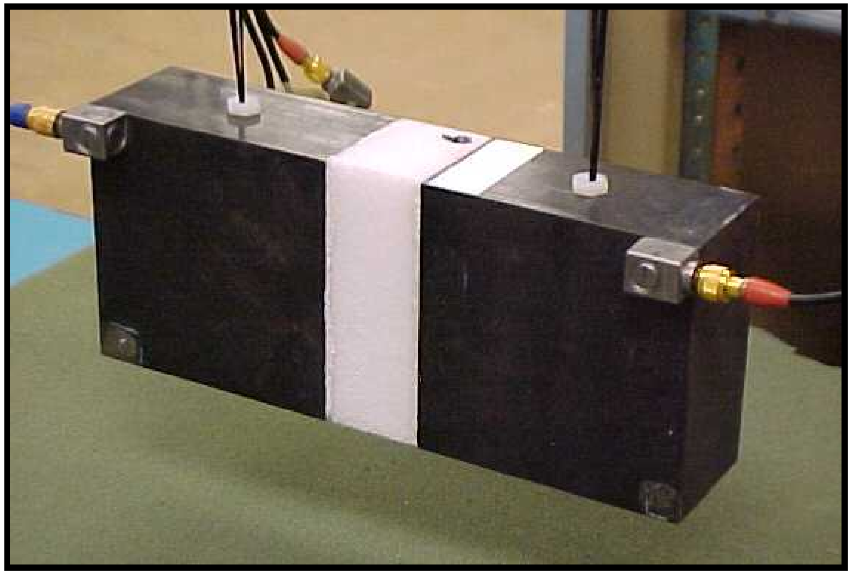


$\omega n = 215$ Hz, $\zeta = 0.36\%$

$\omega n = 354$ Hz, $\zeta = 0.231\%$

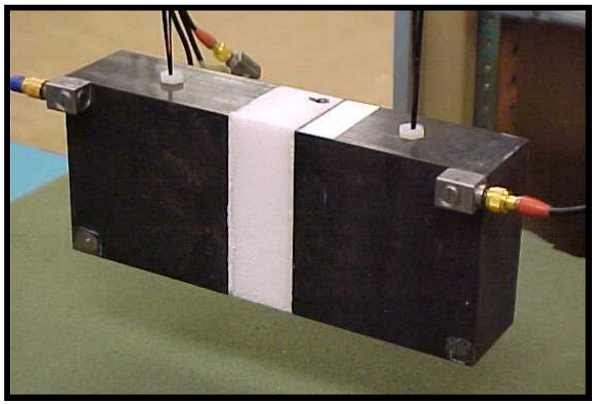
(requires more measurement points)

Foam Example

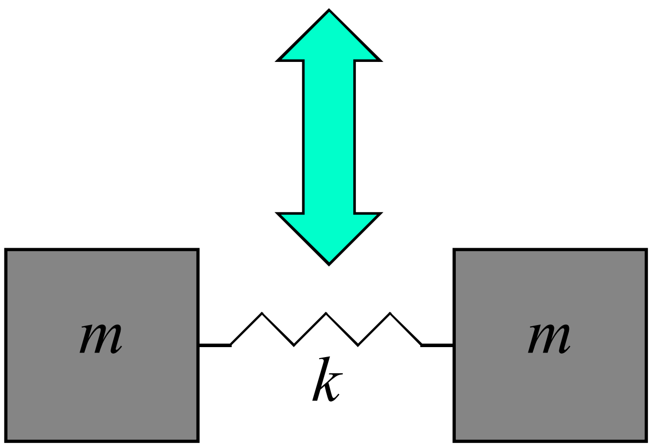


- Two large masses connected with foam
- Model validation experiment for the foam
- Calibrate modulus used in material model

Simple Calibration method



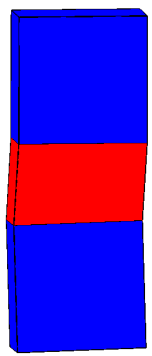
- View foam experiment as simple model
- Derive natural frequencies from simple model
- Find axial, bending, torsion frequencies experimentally (from mode shapes)
- Solve for stiffness, *k*



$$\omega_{axial} = \sqrt{\frac{2k}{m}}$$

← unknown

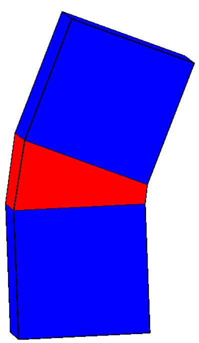
Simple Calibration method



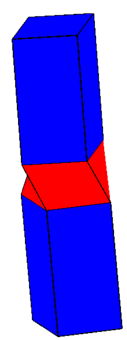
unknown

$$k_{axial} = \frac{EI}{l}$$

- Use various stiffness models to calculate modulus
- Show modal movies
- Congrats, you are a Calibration Expert!!!!!

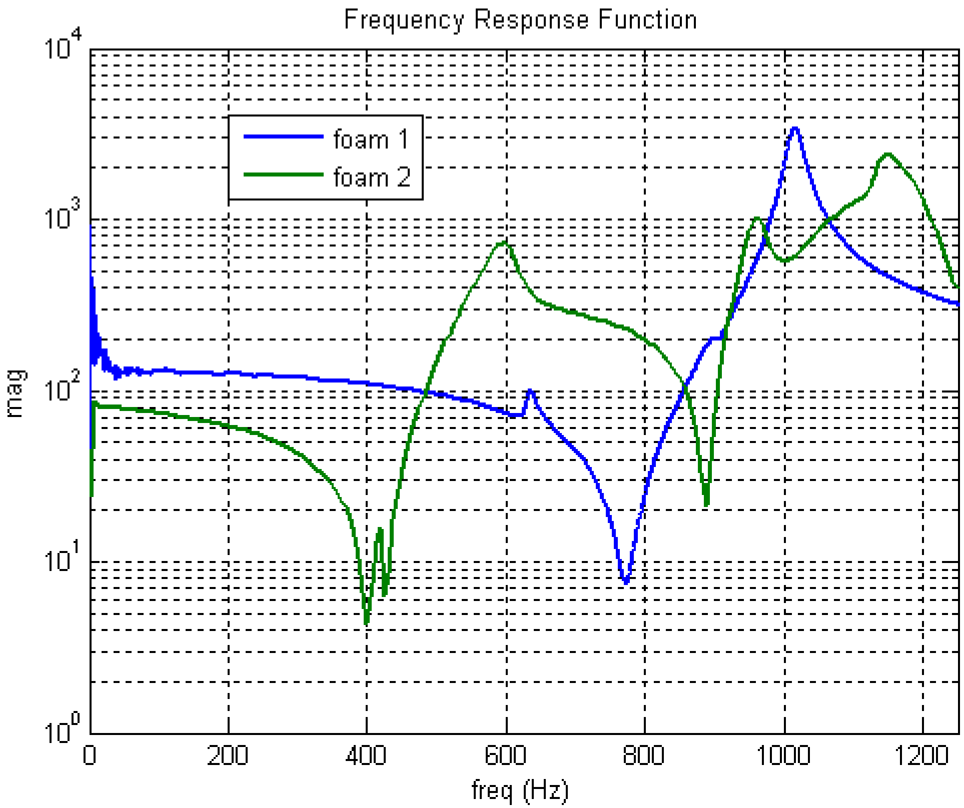


$$k_{bend} = \frac{3EI}{l^3}$$

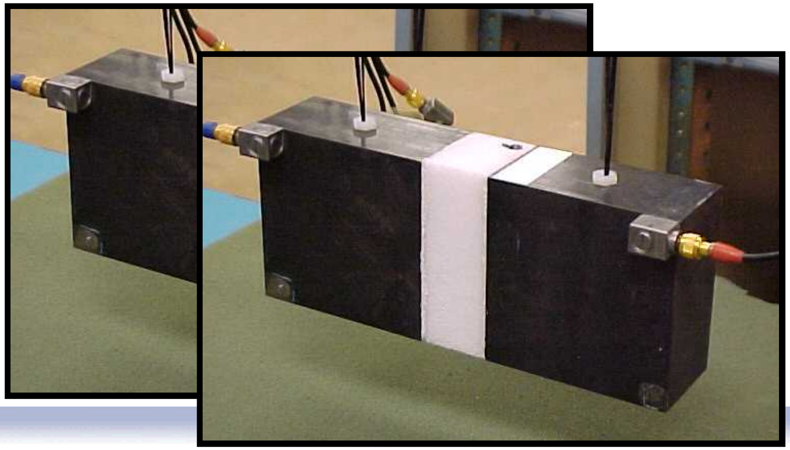


$$k_{torsion} = \frac{GJ_P}{l}$$

Health Monitoring Example



- Similar structures, same foam
- Which one has been tested in thermal cycles?
- Look for non-symmetric peaks (non-linearity), increased damp.
- Answer: *foam 2*



Other: Vibration Shaker Testing

- Electro-dynamic shakers used with closed-loop control system and control/limit accels to provide vibration input environment.
- PSDs used for control, but acceleration admittance $(\ddot{X}/\ddot{X})$ can be

Other: Acoustic Testing

- Loud-speakers used to provide acoustic/vibration environment
- Closed-loop control system used with control and limit mics for input.
- Several variations of setup exists: DFAT, reverberant /anechoic chamber.
- Not typically used for modal analysis, mainly for model validation.

MSI loudspeakers in Building 6560 reverberant chamber

The End

Any Questions?