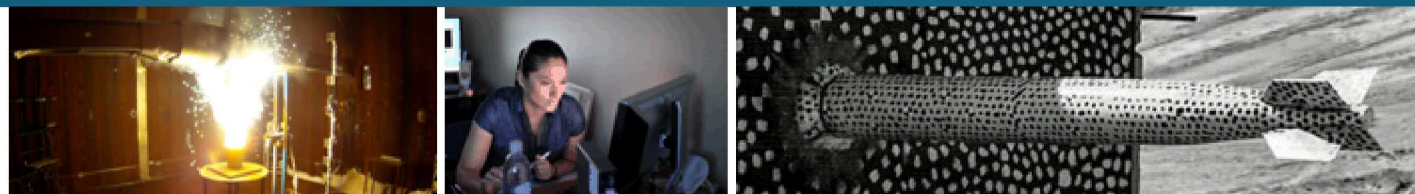


# Practical Vibration Applications in Industry



Dr. Laura Jacobs



Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC, a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-NA0003525.

# Who am I?

Undergrad and Postgrad intern at LANL

- Built and tested a structural health monitoring system

PhD student at Georgia Tech

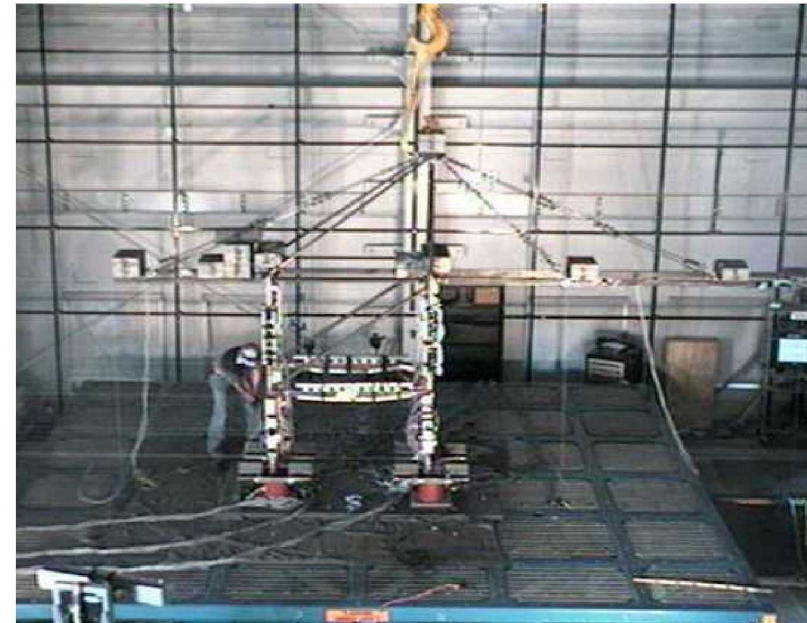
- Analyzed vibration effects on structures

Test engineer in Vibration Lab

- Performed hundreds of tests and analyzed and interpreted data from tests

Product Realization Team/Design Lead

- Interpret requirements and test plans
- Design for vibration environments



# Vibration Topics

Modes and Mode Shapes

Transfer Functions and Frequency Response Functions

Power Spectral Densities

Shock Response Spectra

Mode 3

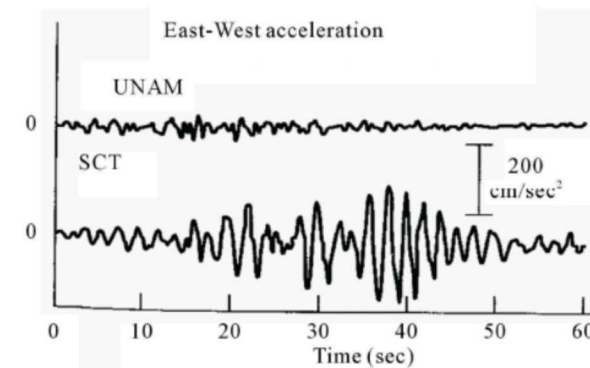
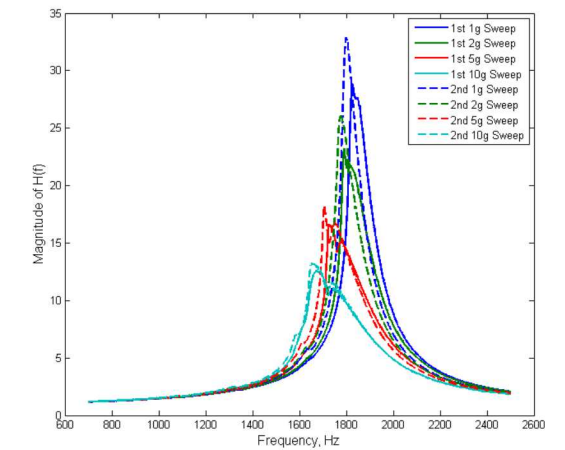
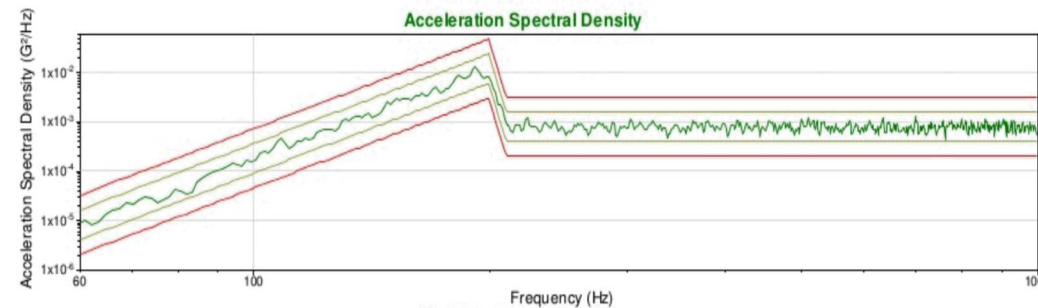
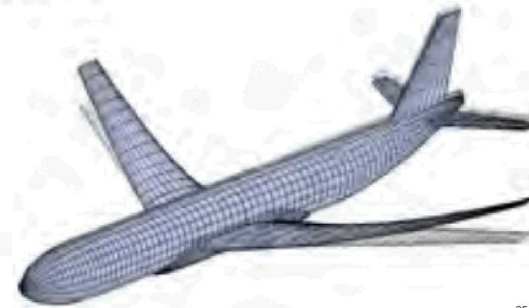
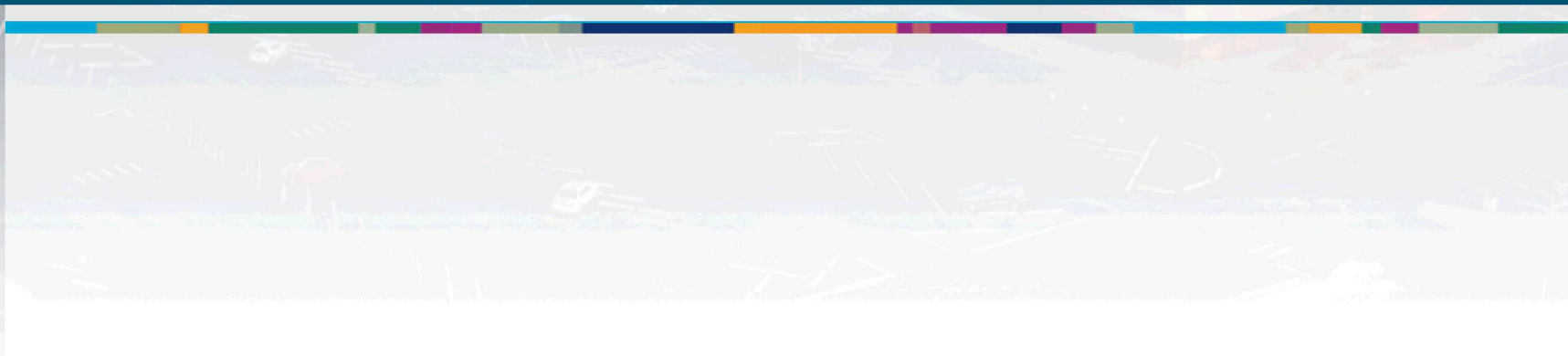
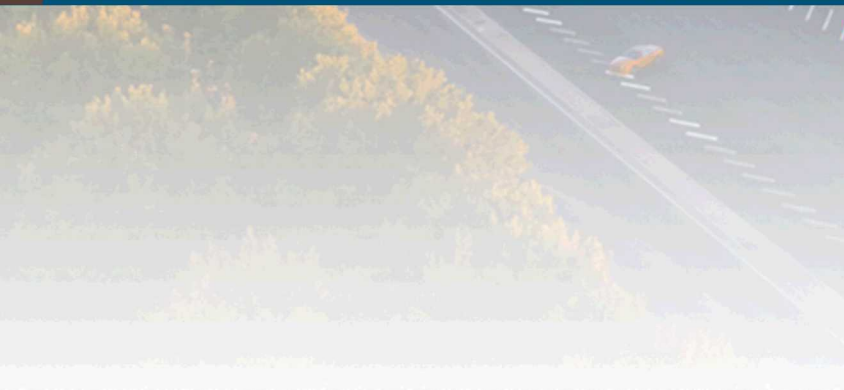


Figure 1. Recorded time histories at rock (UNAM) and soil sites (SCT) during Mexico City earthquake (1985) [15].



# Modes and Mode Shapes



# Why do I care about modes and mode shapes?

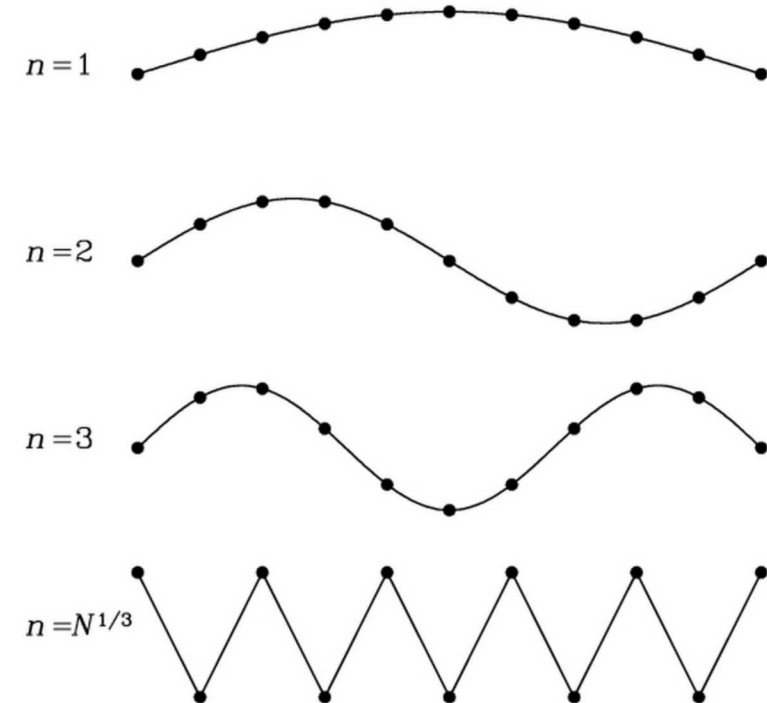
Characterize the dynamic response of your part

Modes will amplify input at a given frequency

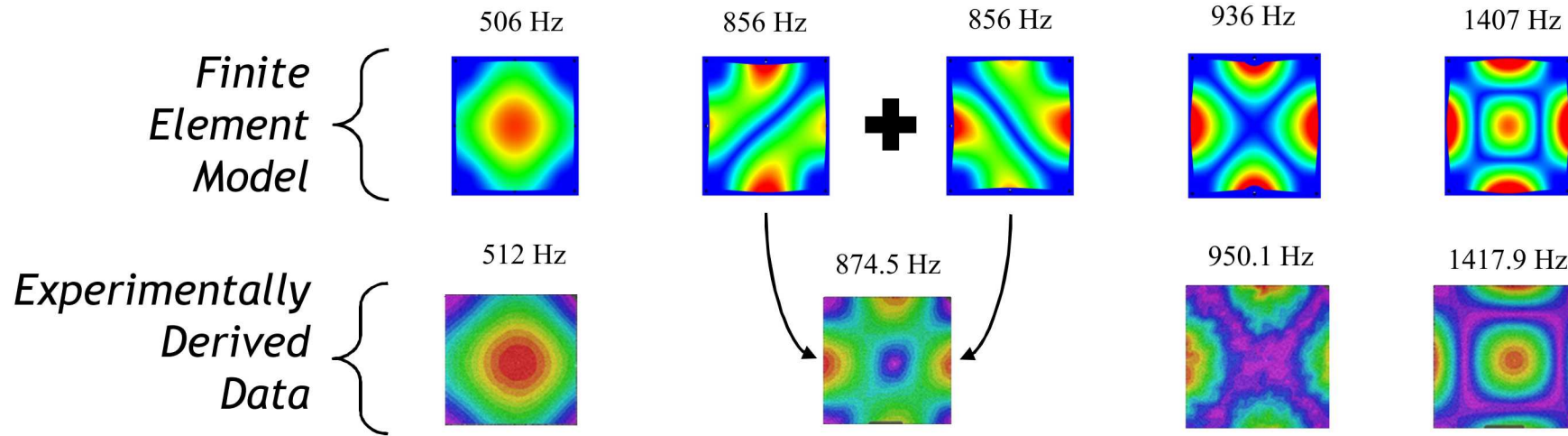
Modes can indicate areas most likely to be damaged

Understanding modes and mode shapes can help guide design decisions to address weaknesses in design

Modes and mode shapes by themselves have limited use, but combined with expected loads can be quite powerful



# Finding Modes and Mode Shapes



Calculated using finite element models

Calculated from test data

Neither one is going to give “right” answer

Both methods provide useful information

# Applications of Modes and Mode Shapes

Do any of you get car sick?

Where in the car are you least likely to feel sick?

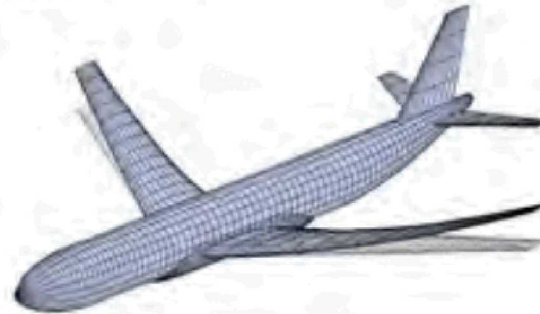
How do car manufacturers use modes and mode shapes?

- Work to shift the mode of cars away from the input frequencies
- Create a node of a mode where the driver sits

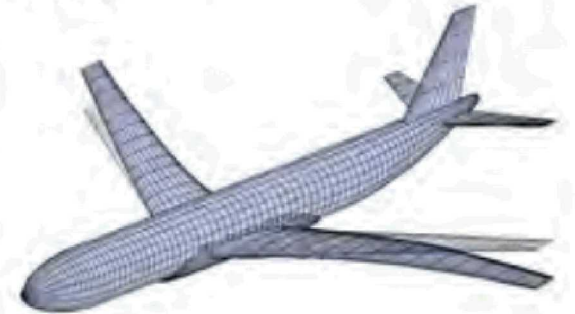
What about airplanes?



Mode 1

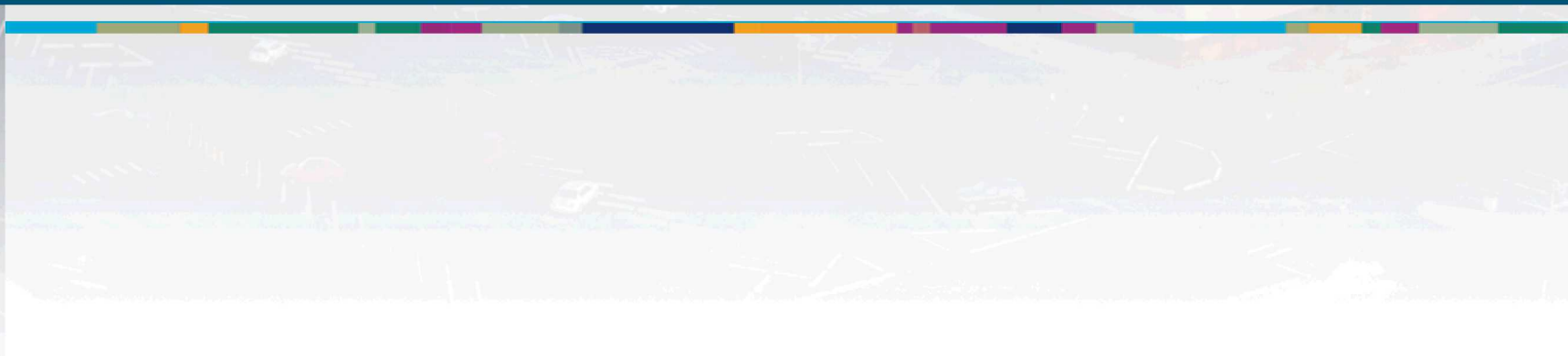
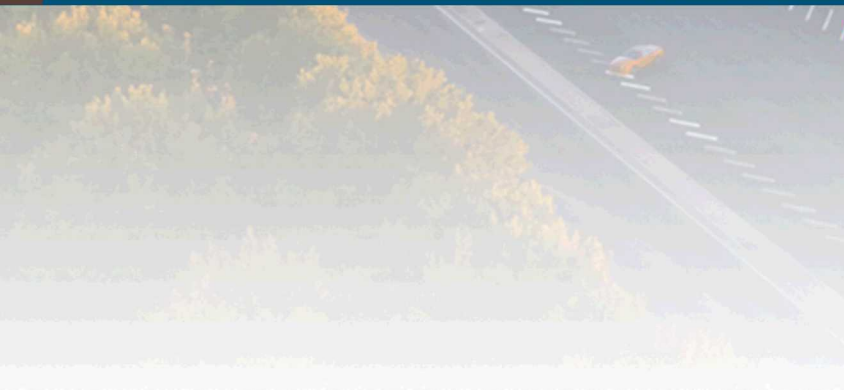


Mode 2

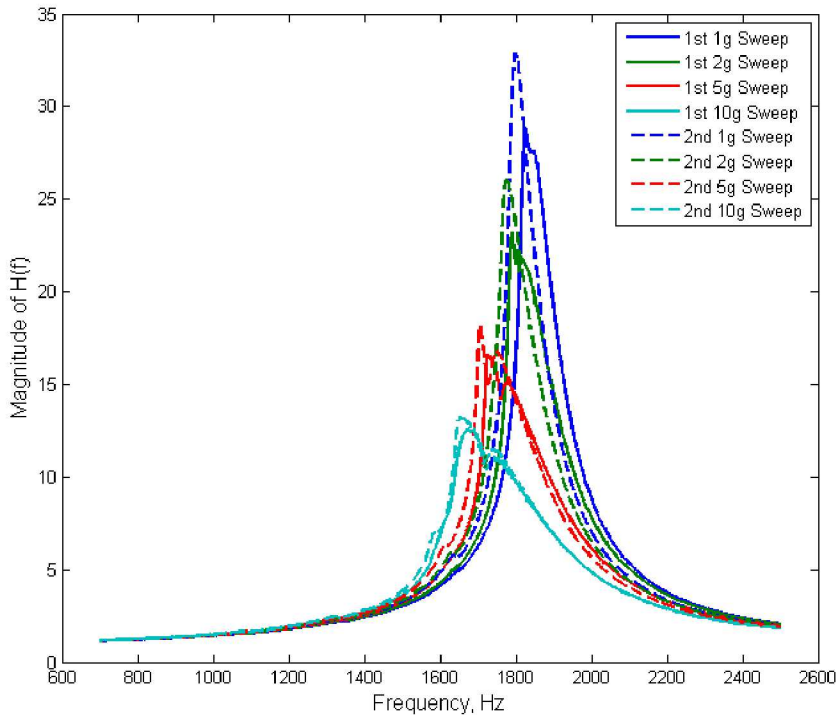




# Transfer Functions/Frequency Response Functions



# Why do I care about Frequency Response Functions?



Frequency Response Function (FRF) – ratio of input to output

Driven by modes, mode shapes, and damping in system

If you apply the FRF to the known input, can determine loads on system

Once you know loads, can calculate stresses in the system and determine if and where damage will occur

You can modify your design using this information

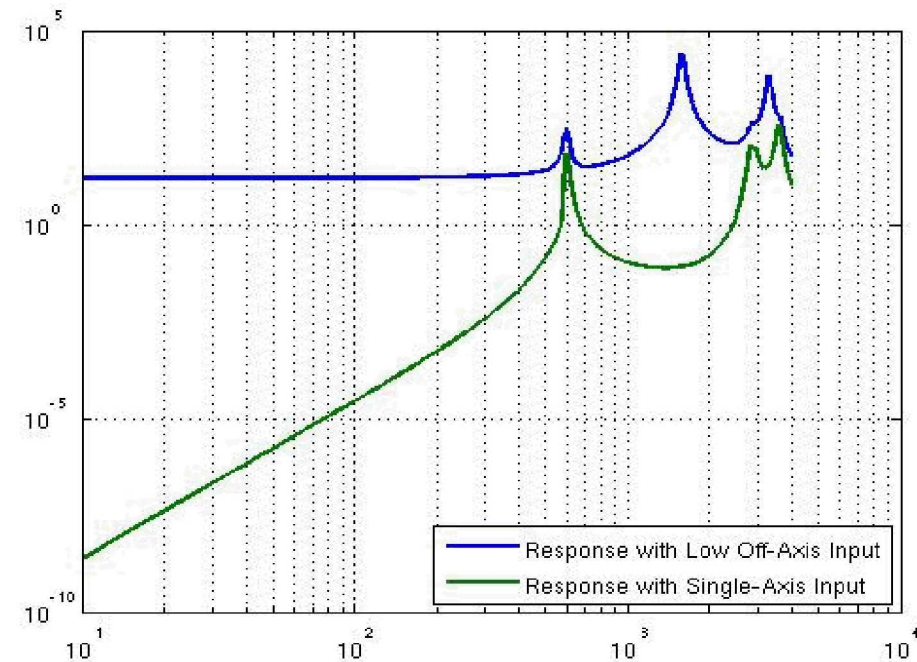
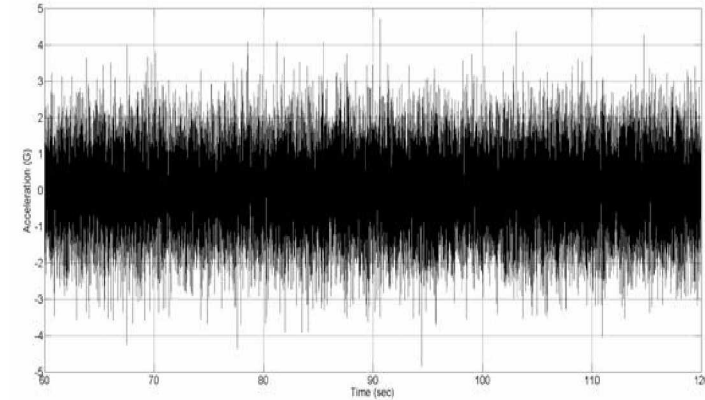
# Calculating FRFs

FRFs can be determined two ways

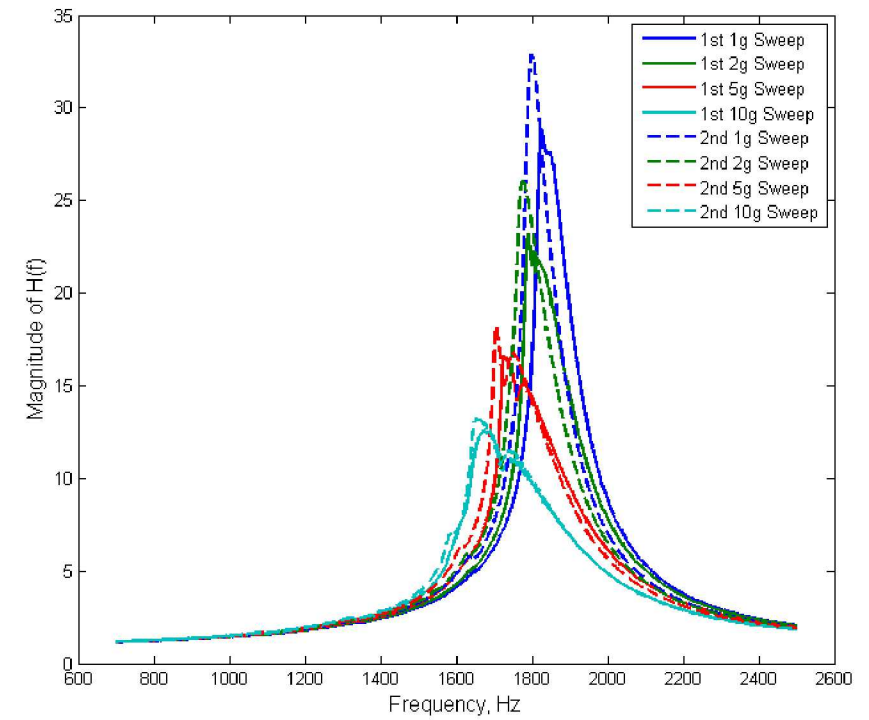
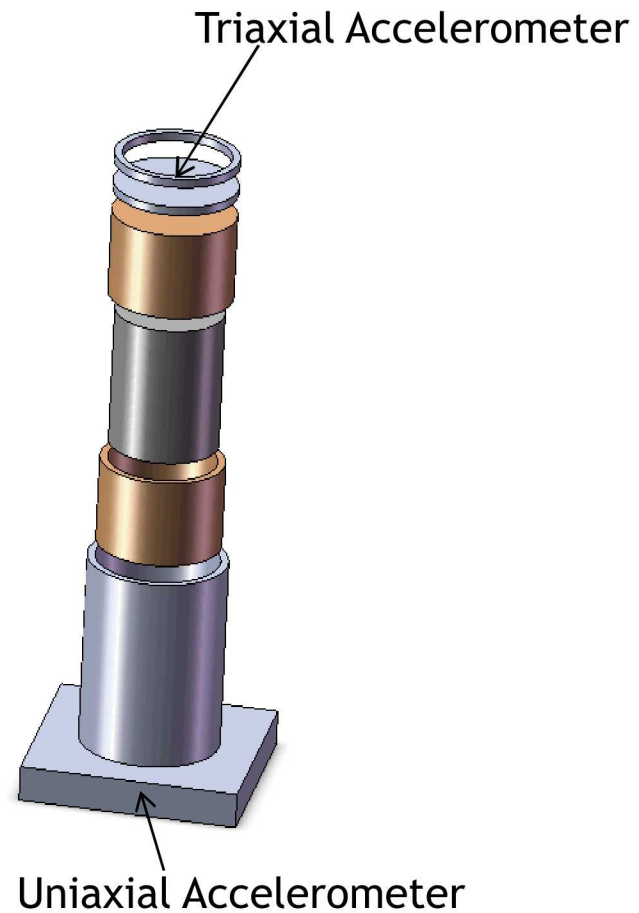
- Finite Element Analysis (FEA)
- Experimentally

Experimentally derived FRFs can tell you a number of things

- What your modes are
- What your damping is
- What your mode shapes are
- How good your assumptions in your FEA are
- If there are nonlinearities present in the system

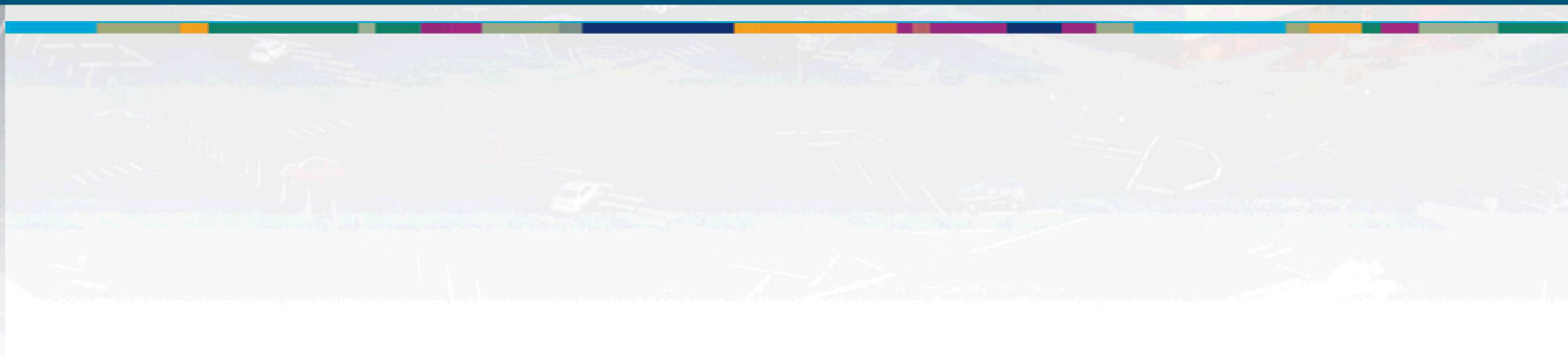
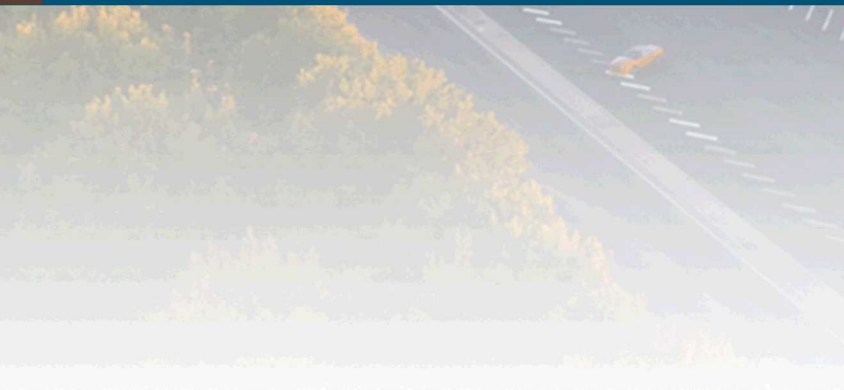


# FRFs in a SDOF System

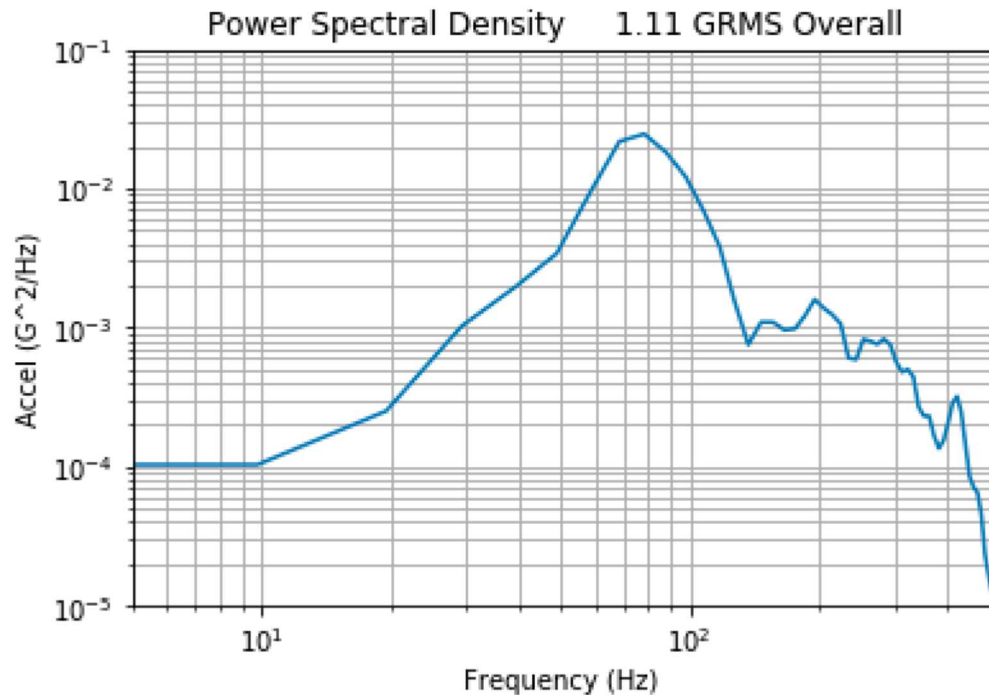




# Power Spectral Densities



# Why do I care about power spectral densities?



Power Spectral Densities (PSDs) - determining frequency content of a steady state input

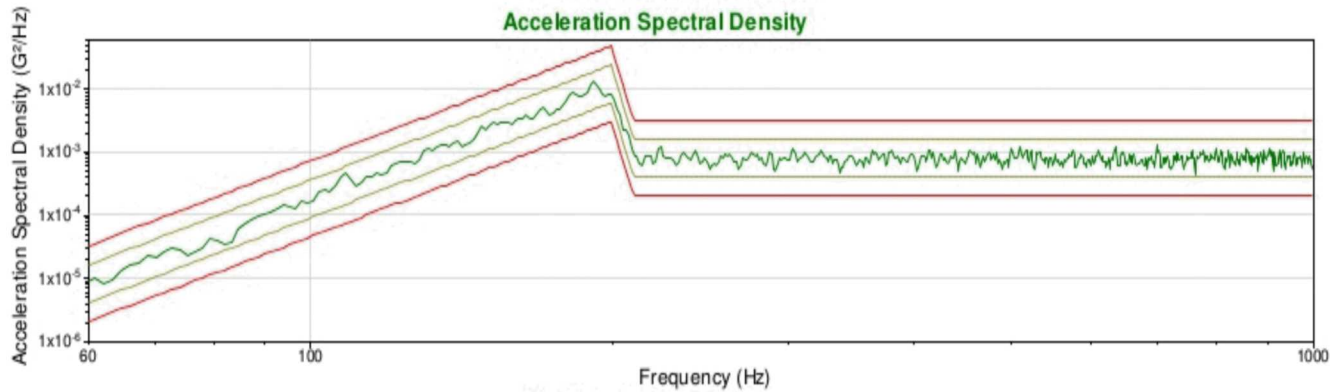
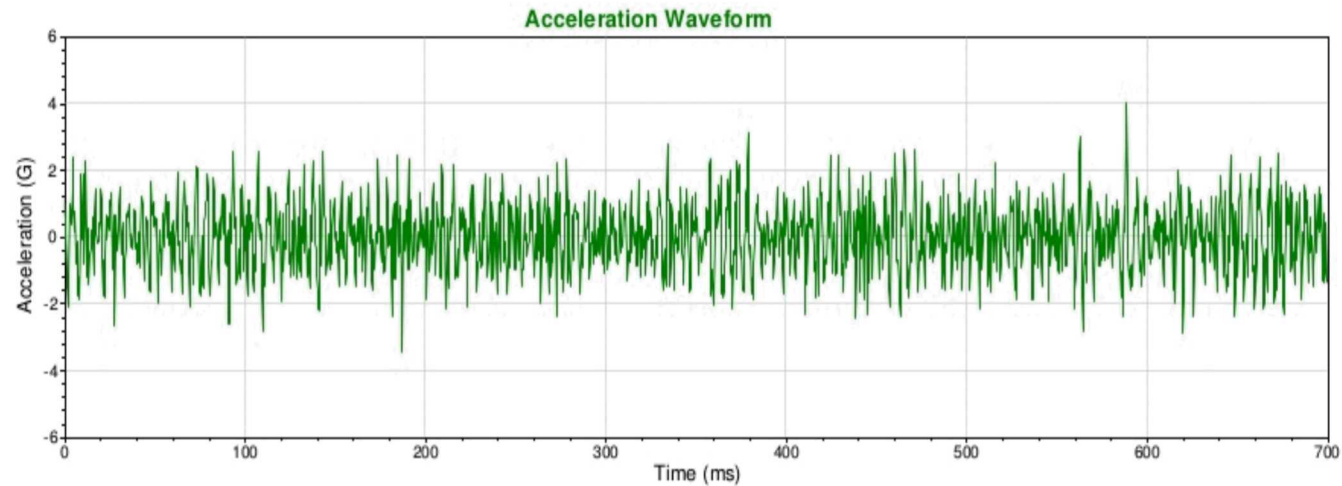
Random environments are common:

- Airplane turbulence
- Road noise
- Steady wind loads
- Rocket launches

Can be difficult to get much information from a time history, but a PSD can be powerful

Allows us to see potential areas of concern with designs

# Comparison of Time History to PSD



You have a circuit board in a part that keeps breaking in the field.

You measured the vibration in the field and got this result.

You did a modal test on your part and found it has a mode at 200Hz.

Why does it keep failing?

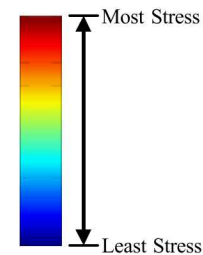
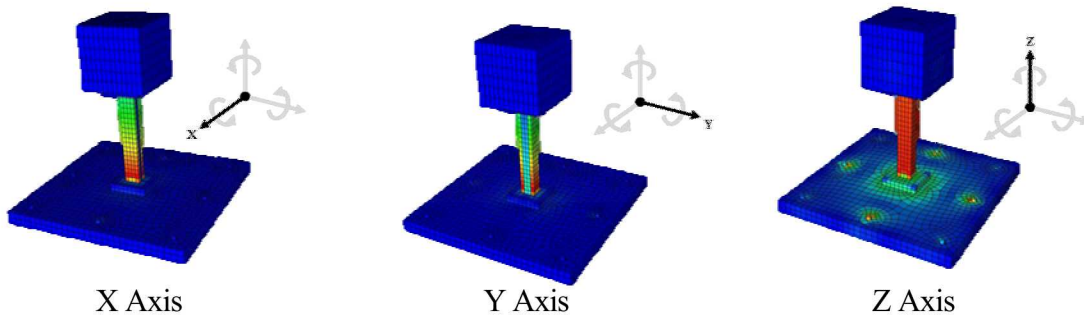
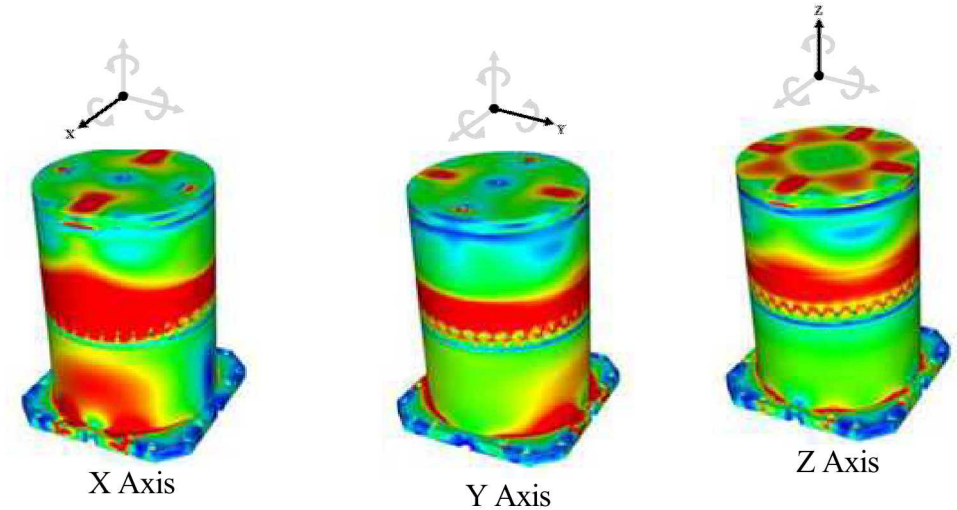
What can you say now?

# PSDs Can Help Find Failures

Combining PSDs with transfer functions, modes, and mode shapes can be powerful

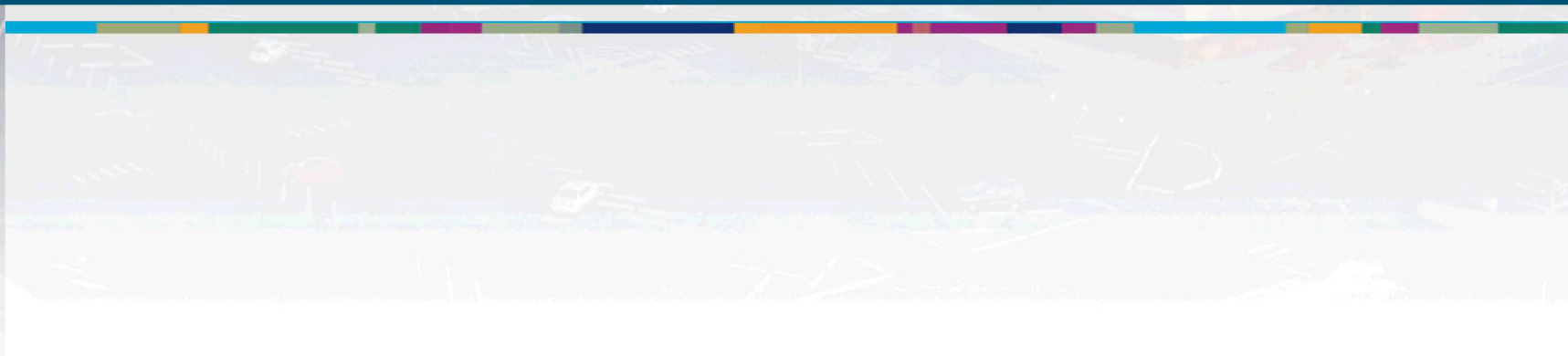
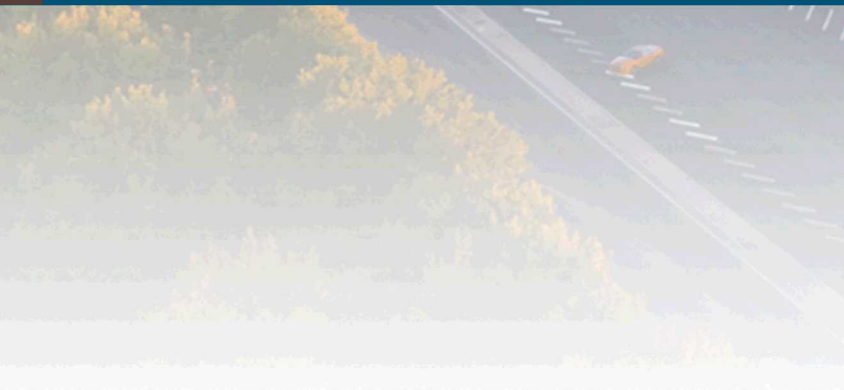
- Can see how much a part amplifies the input
- Can see the deformations that would occur

Inputting the PSD into FEA, can find stress and where you would have material failures

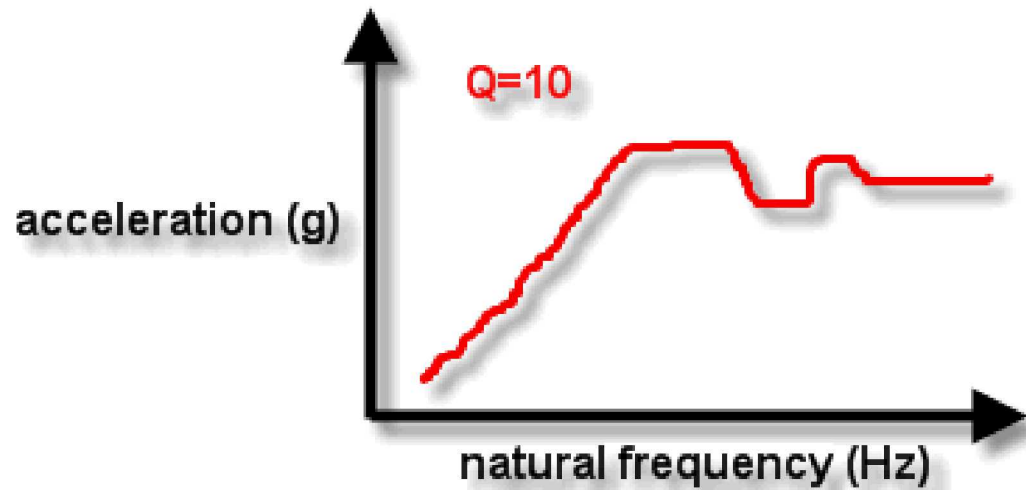




# Shock Response Spectra



# Why do I care about shock response spectra?



Shock Response Spectra - determining frequency content of a transient input

Shocks are common:

- Stage separation of rockets
- Airplanes landing
- Speed bumps and pot holes
- Impacts
- Wind gusts

Allows us to see potential areas of concern with designs

# Shock Response Spectra – Mexico City 1985

Earthquake of magnitude 8.0 struck Mexico City in 1985

400 Buildings collapsed

Nearly all of the buildings that collapsed were between 5-15 stories

Other buildings from 5-15 stories

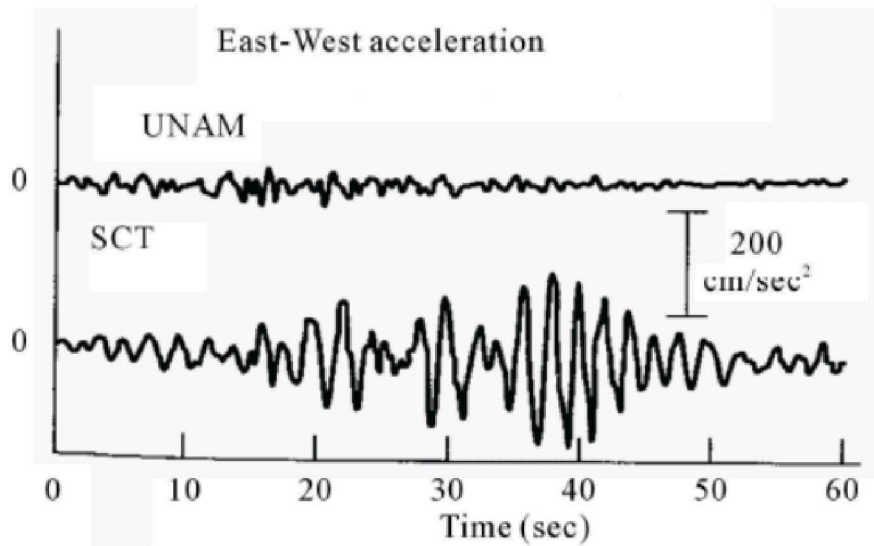
Buildings shorter than 5 stories survived

Buildings taller than 15 stories survived

Why?



By United States Geological Survey - [http://libraryphoto.cr.usgs.gov/cgi-bin/show\\_picture.cgi?ID=ID.%20Celebi,%20M.%20%203ct&SIZE=large](http://libraryphoto.cr.usgs.gov/cgi-bin/show_picture.cgi?ID=ID.%20Celebi,%20M.%20%203ct&SIZE=large), Public Domain

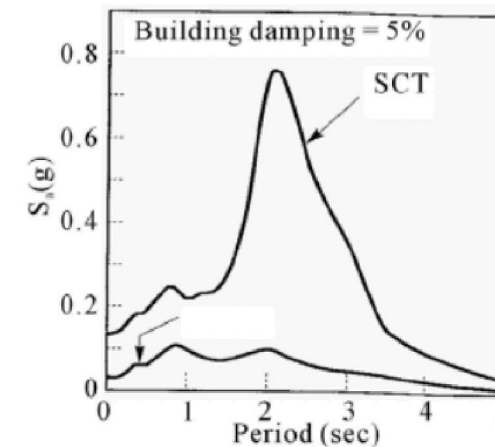


**Figure 1. Recorded time histories at rock (UNAM) and soil sites (SCT) during Mexico City earthquake (1985) [15].**

Fact: 5-15 story buildings have natural periods of about 2.5 seconds

Can you make a hypothesis about why 5-15 story buildings were most affected based on the time history of the recorded ground motion?

What if we looked at the shock response spectra?



**Figure 2. Response spectra of ground motions recorded at rock (UNAM) and soil sites (SCT) during Mexico city earthquake (1985) [15].**

# Ask Me About

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Shock Response Spectra

Mode 3

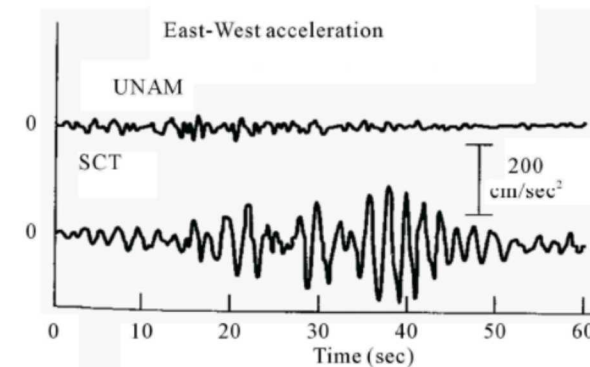
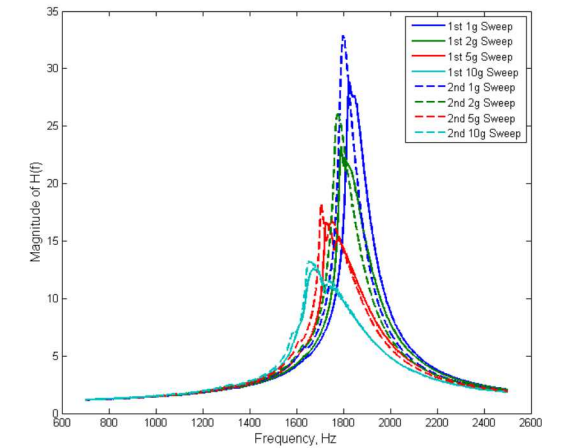
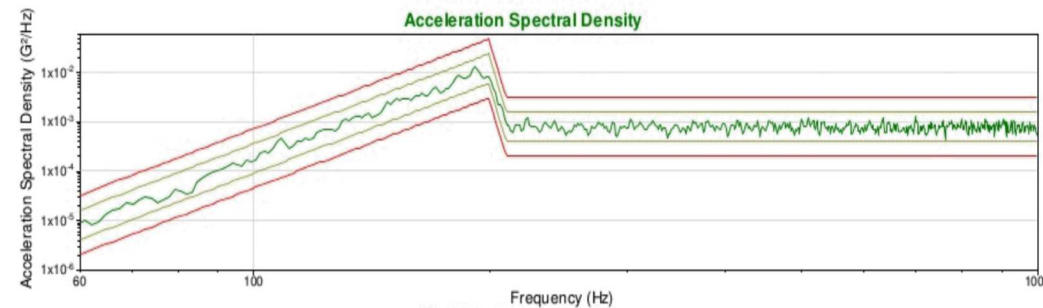
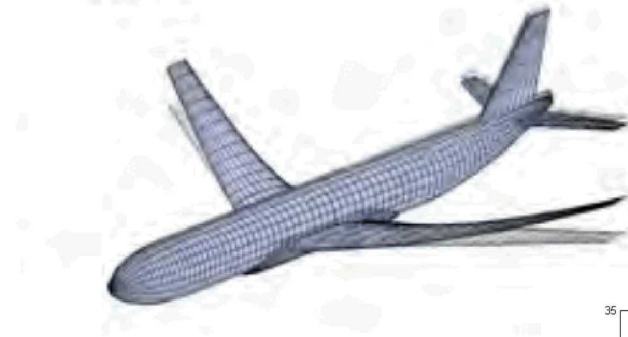


Figure 1. Recorded time histories at rock (UNAM) and soil sites (SCT) during Mexico City earthquake (1985) [15].