Opportunities & Responsibilities of Engineers With Respect to Advances in Technology

CPT Thomas B. Messervey
USMA

Sara Casciati
University of Pavia, Italy

Suikai Lu
arsenal research
Vienna, Austria

SMART STRUCTURES Through Technology Leveraged Design & Structural Health Monitoring

*** WARNING ***

This presentation does not:

- Capture all current and emerging technologies
- Provide complete, in-depth coverage of topics

This presentation does:

- Introduce developing ideas
- Provide several examples to stimulate thought

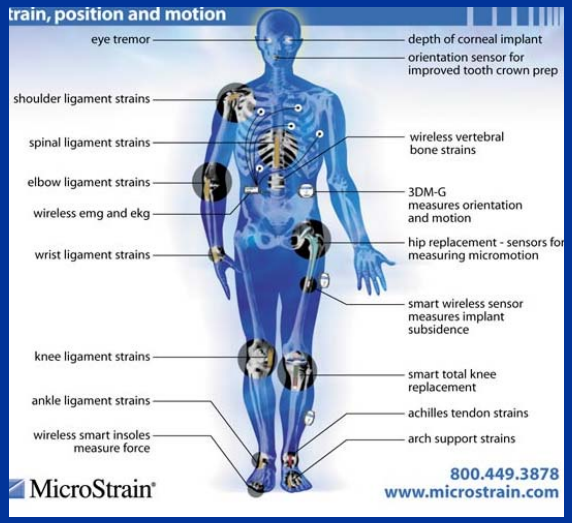
What is a "SMART STRUCTURE?"

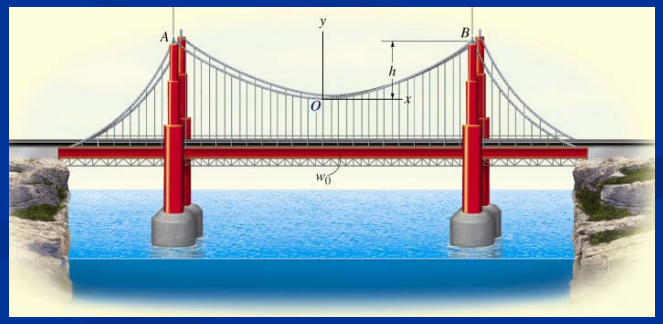
1. Designed with a full life cycle management plan in mind

2. Employs technology leveraged materials where appropriate

3. Has Active and or Passive Controls against damage**

4. Contains ability to monitor it's own health (SMA)

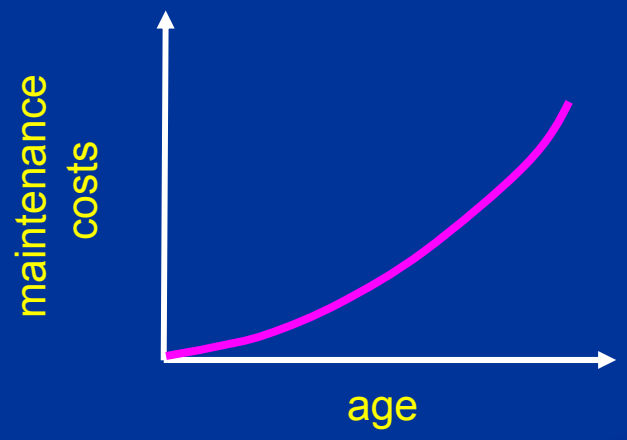




"But who Cares?"

Consider…….

- Explosion of infrastructural growth 1965-1985
- Most bridges, tunnels, buildings are designed with a life span of 30-40 years
- Commercial aircraft are also built for a life span in flight hours of about 25-30 years
- Most aircraft were built in the early 1980s



"Maintenance Generation"
- Yozo Fujino

"Is it a big deal?"

From the FHWA Website (DEC 03)

Deficient Bridges By State				
	Count	# SD	# FO	Tot Def
TEXAS	48,492	2,777	7,543	10,320
PENNSYLVANIA	22,176	5,474	3,878	9,352
OKLAHOMA	23,249	7,568	1,503	9,071
MISSOURI	23,787	5,275	3,108	8,383
IOWA	24,992	5,329	1,836	7,165
OHIO	27,901	3,109	4,041	7,150
CALIFORNIA	23,764	2,907	3,815	6,722
NEW YORK	17,382	2,234	4,409	6,643
MARYLAND	4,994	417	1,015	1,432
TOTALS (50 States)	**592,246**	**79,811**	**81,008**	**160,819**

160,819 Deficient Bridges in the U.S.

Spending **$7 Billion / year** to construct and retrofit bridges

"But we're still falling behind because we are utilizing the same technologies, materials, and methods we were using 20 years ago"

- Steve Chase (SHM 2003 Stanford)

An example of a Smart(er) Structure

Wotton Bridge, Quebec

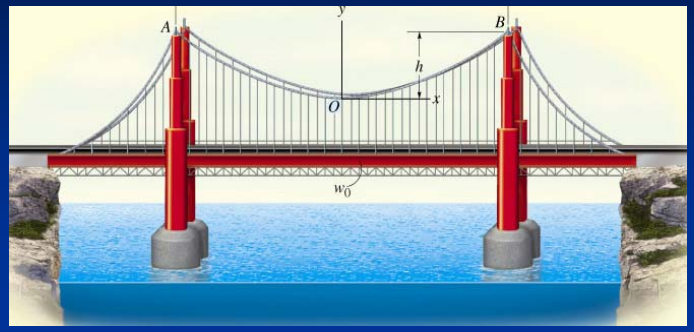
- ✓ Monitoring part of the design
- ✓ Technology leveraged materials
- ✓- Monitor it's own health

What's this?

"What is (health) monitoring?"

EKG
Tachometer
AOAP

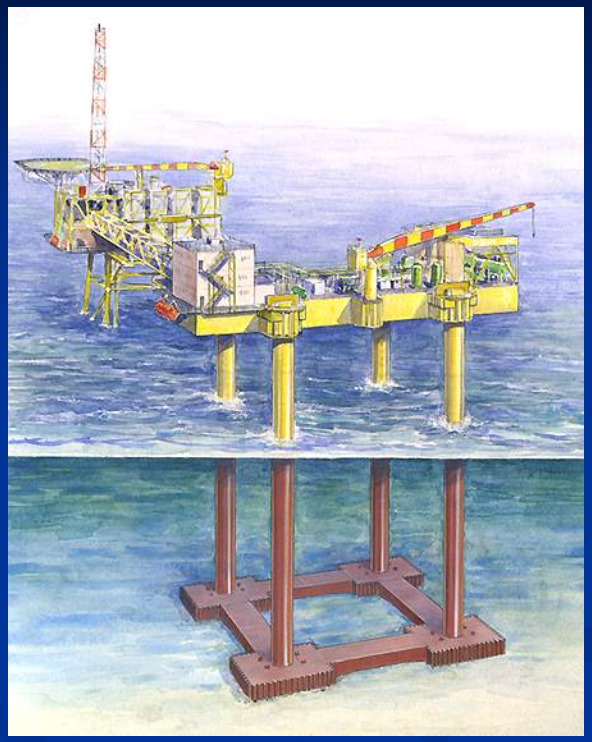
?



4 Levels of damage assessment

1) Is damage present (detection)
2) Where is the damage (localization)
3) How much damage (diagnosis)
4) What is the remaining life of the structure (prognosis)

"How is it done?"

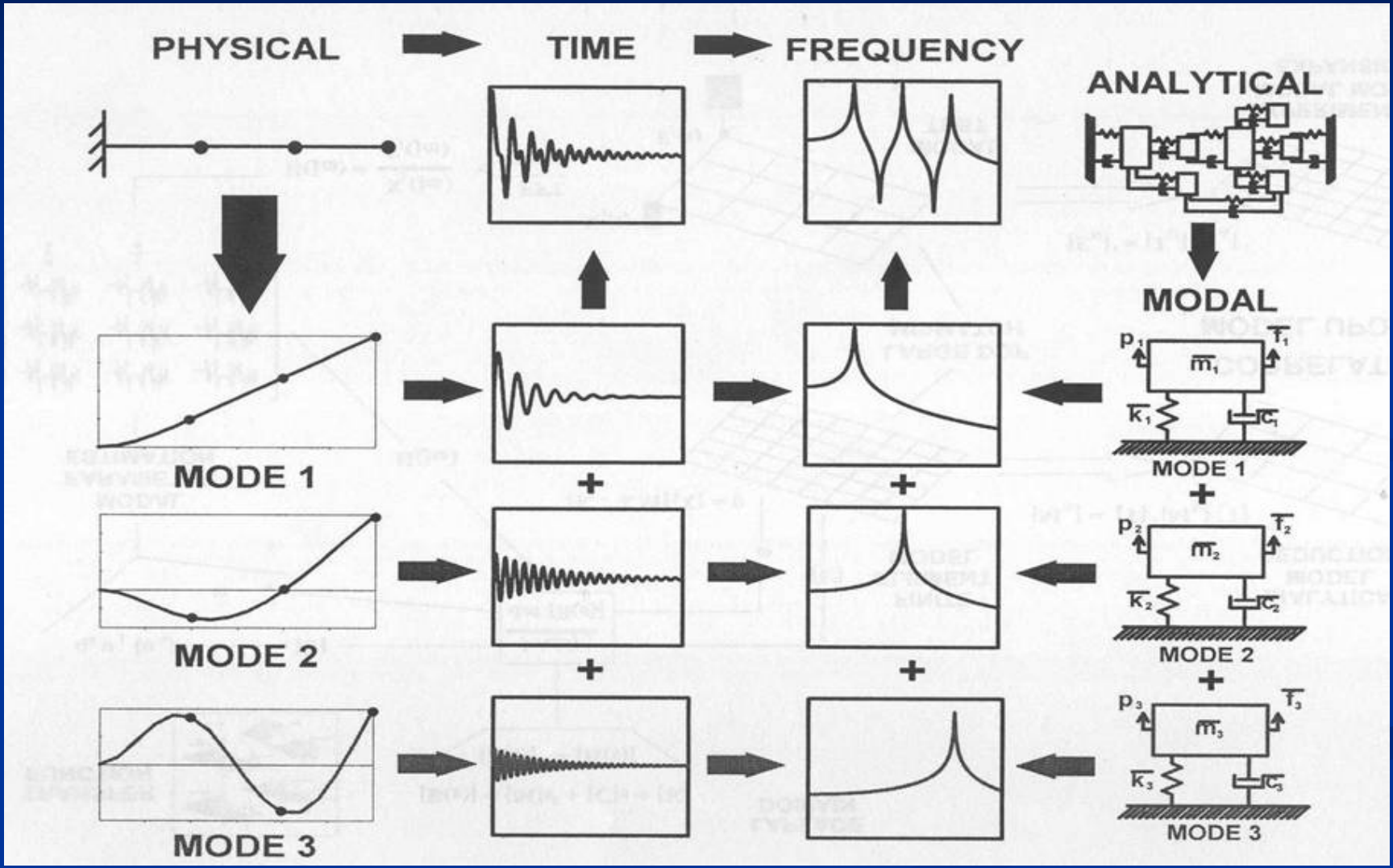


Modal Analysis: → Detect changes in the vibrational response of a structure to loading

(Change in stiffness = damage)

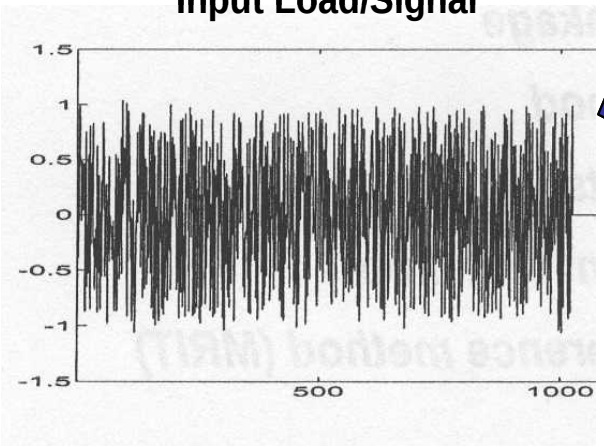
*** Cool Video

"How is it done? (II)"

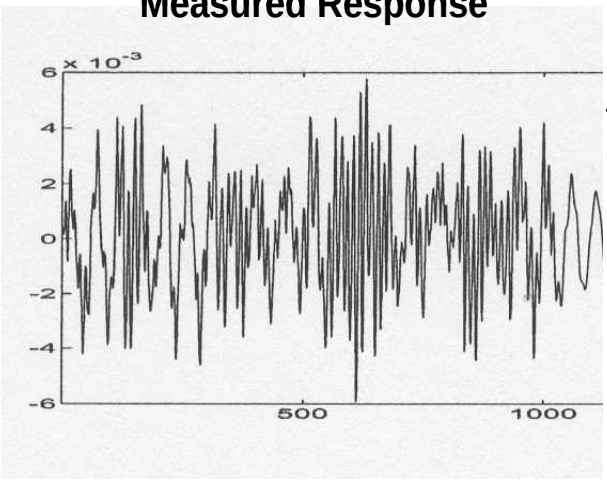


"What it looks like"

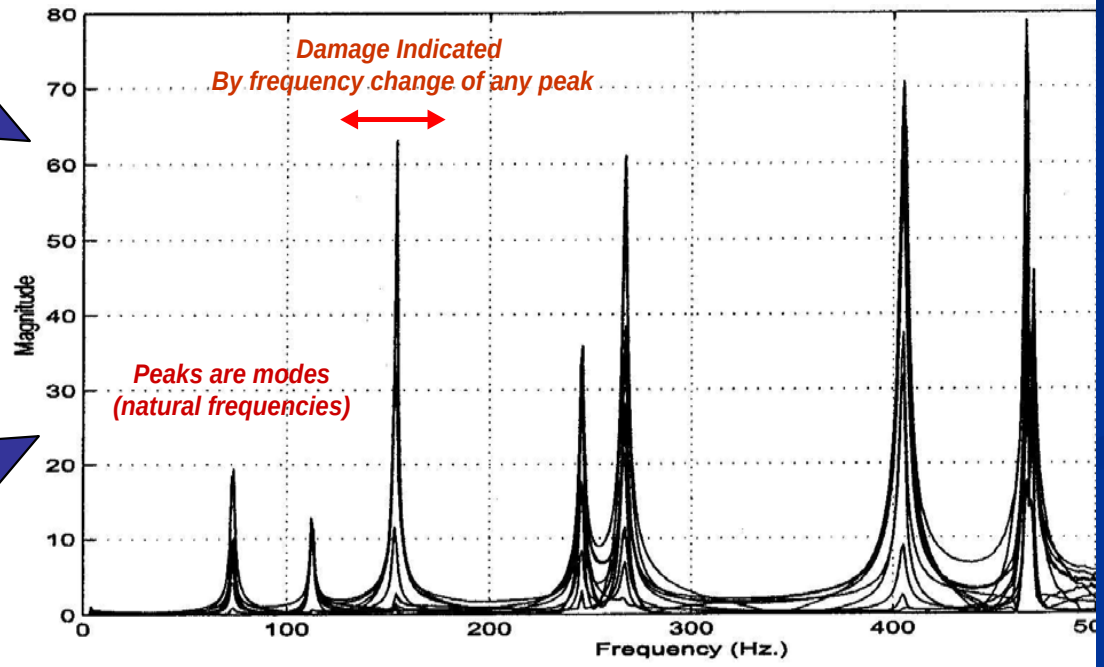
Input Load/Signal



Measured Response



Frequency Response Function



FINITE ELEMENT MODEL
(to "see" response)

"Does it Work"

Sometimes and Maybe

Great for:

- Identifying resonant frequencies (flutter / Tacoma Narrows)
- Improving / validating FE models

Challenges:

- High processing demands
- Careful and robust sensor placement
- Lack of sensitivity to damage (2-4% modal peak shift)
- Sensitivity to environmental effects (>>4%)

RESEARCH CONDUCTED I

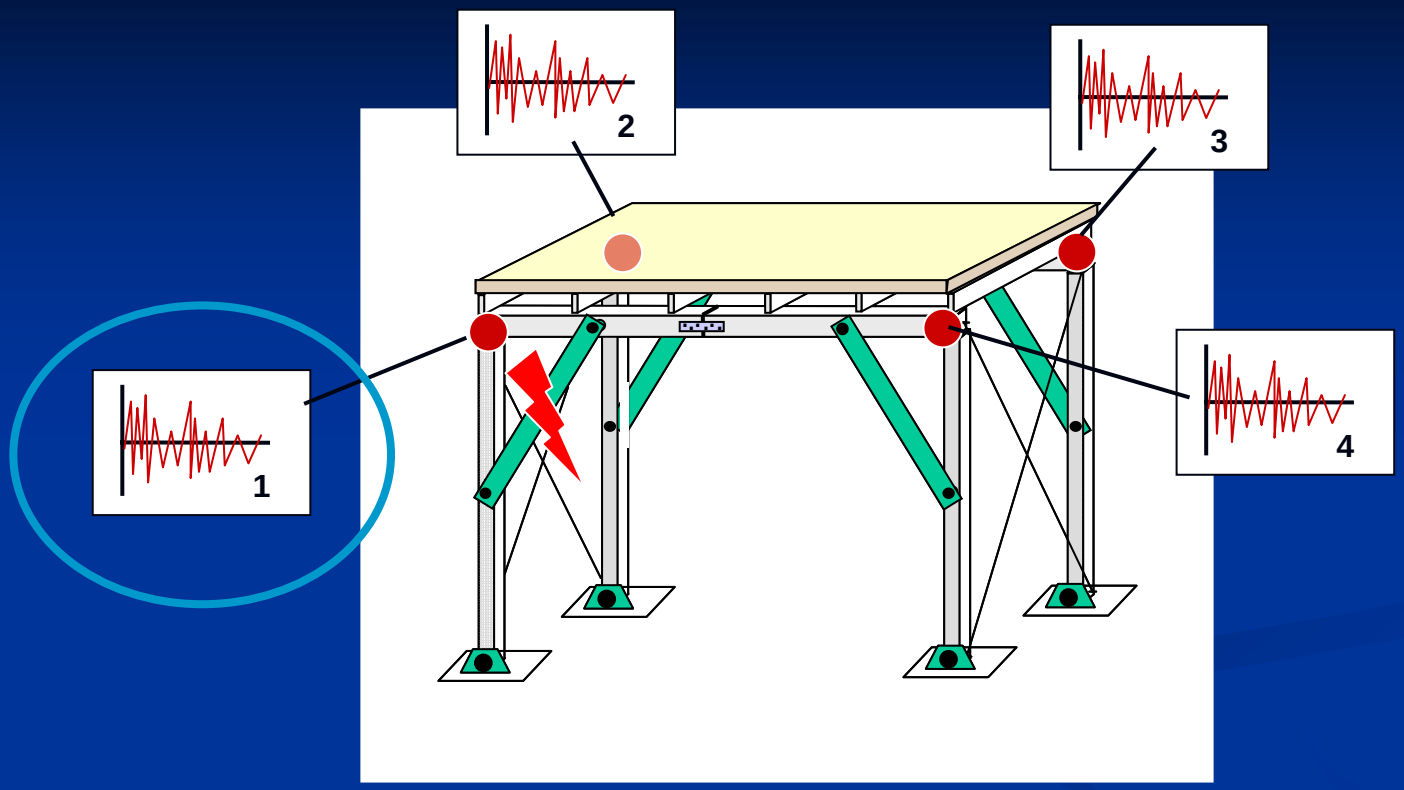
Statistical Response Surface Approximation

Goal: Determine the health of a structure based only from response surface data

- Independent of structural characteristics
- Not dependent on an FE model
- Decreased calculations / processing demand

→ **Wireless Monitoring Solution**

"How is it done?"



Time 1 (Undamaged) $\quad \text{[1]} = \beta_1 + \beta_2 \text{[2]} + \beta_3 \text{[3]} + \beta_4 \text{[4]} + \varepsilon$

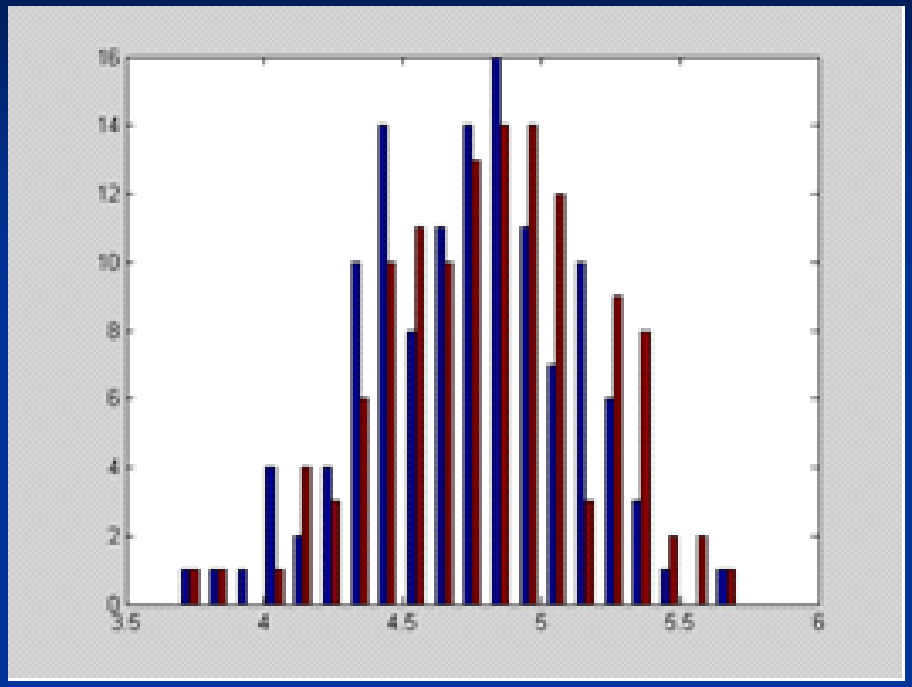
Time 2 (Damaged) $\quad \text{[1]} = \beta_1 + \beta_2 \text{[2]} + \beta_3 \text{[3]} + \beta_4 \text{[4]} + \varepsilon$

VARIANCE

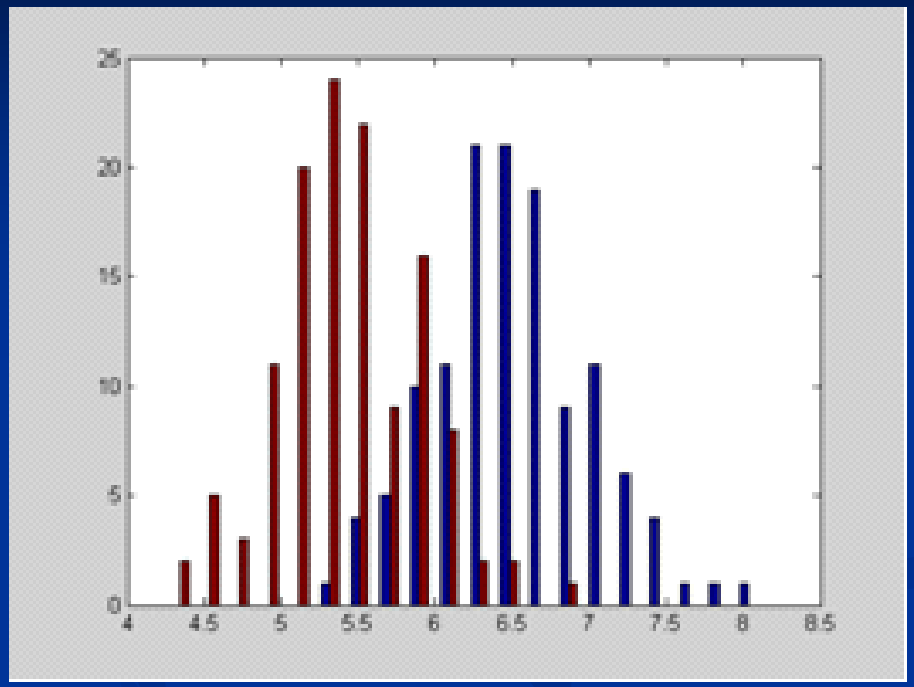
VARIANCE

PDF

"How is damage indicated"



Undamaged



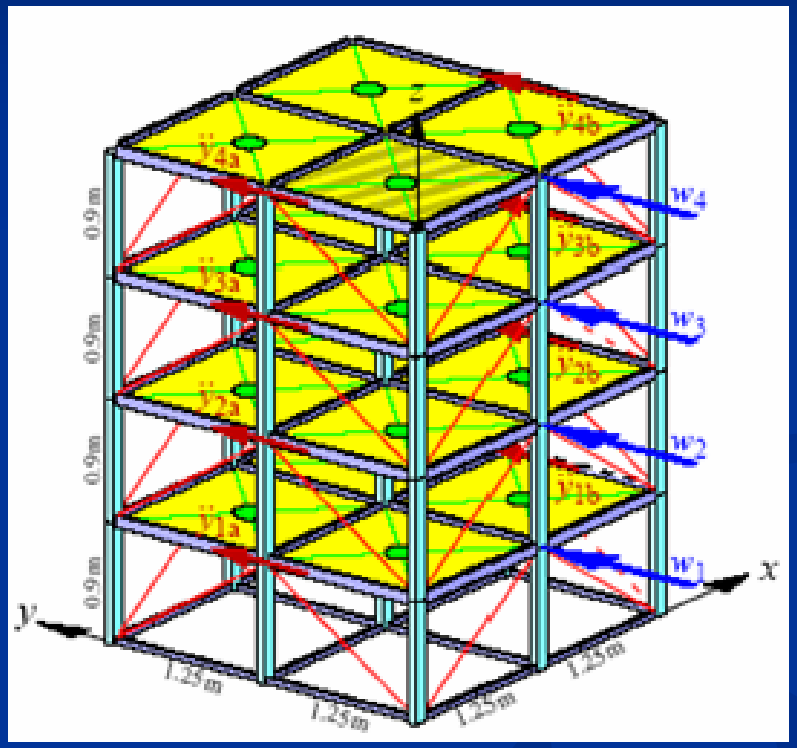
Damaged

Shift in the Probability Density Function of the Variance of the Error between a sensor at two periods of time

Didn't Look "Into" the Structure
Didn't transform Data between domains
Didn't need an FE Model
Not sensitive to changes in temperature***

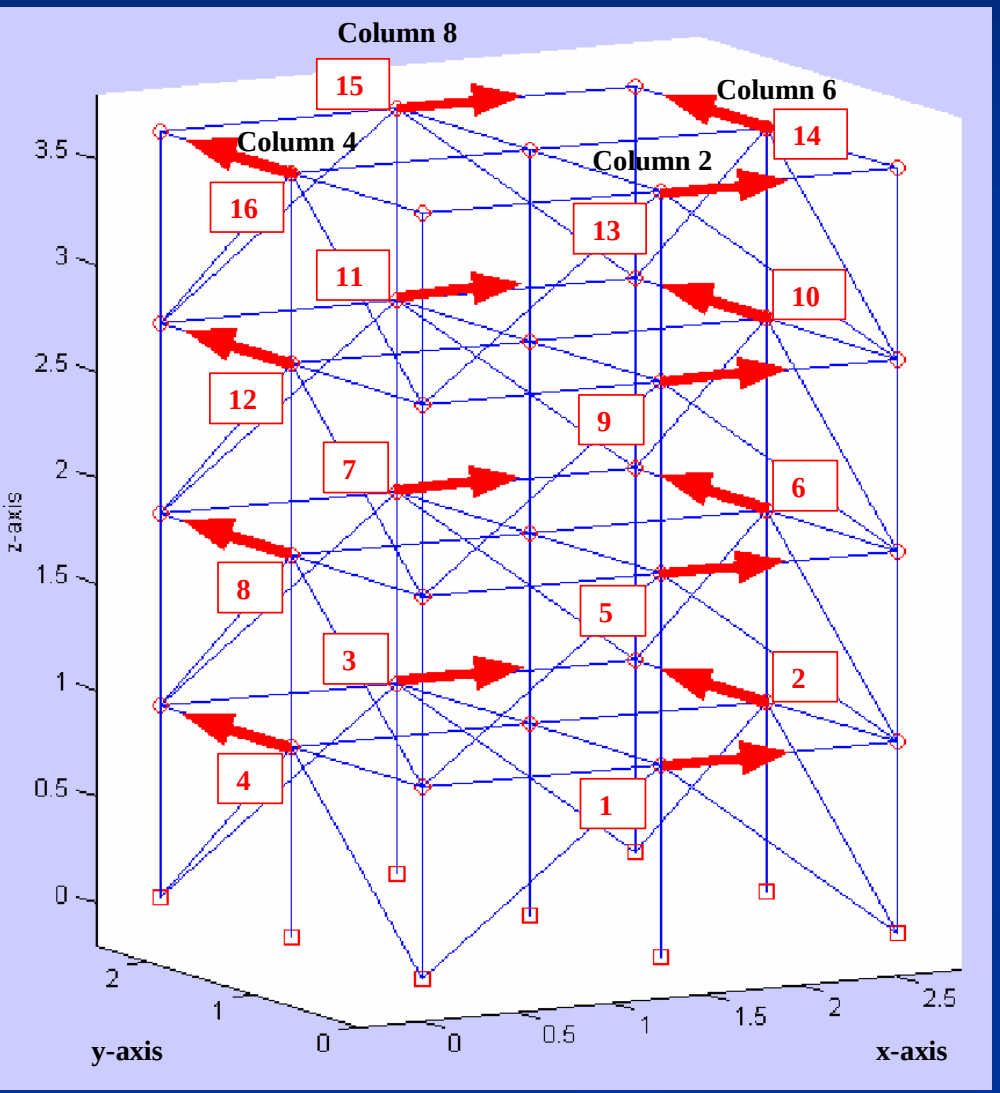
Application to the ASCE SHM Task Group Benchmark Problem

Real Structure
at the
University of British Columbia



Analytical Model (12 or 120 d.o.f.)
whose response to different loads
is computed by datagen.m
(wuscel.cive.wustl.edu/asce.shm/)

Application to the ASCE SHM Task Group Benchmark Problem



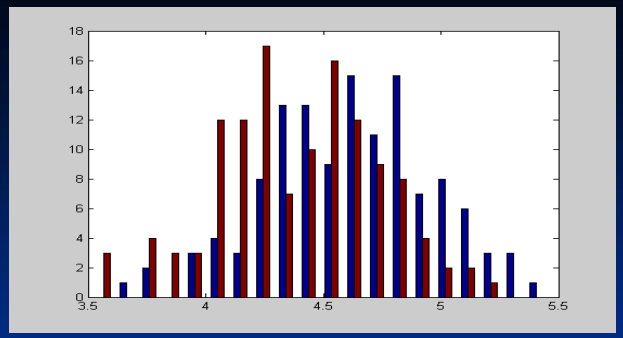
<u>Sensors locations and id numbers</u>

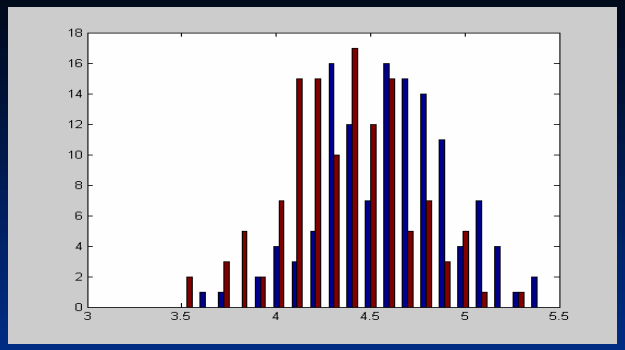
- Total: 16 accelerometers
- 4 sensors per floor
- 2 sensors per d.o.f. per floor
- N_S = 8 total sensors per d.o.f.

FLOOR	SENSORS	
	x-d.o.f.	*y*-d.o.f.
Floor 4	15 13	16 14
Floor 3	11 9	12 10
Floor 2	7 5	8 6
Floor 1	3 1	4 2

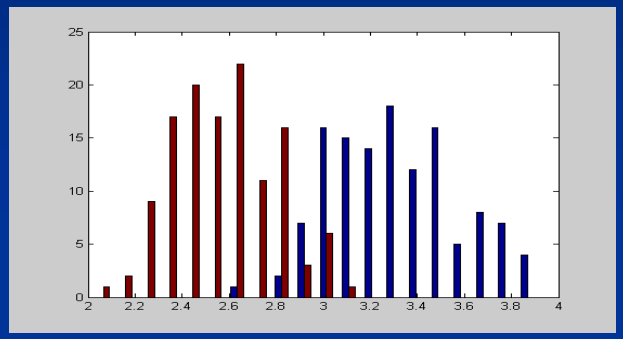
CASE2: Damage Pattern 2

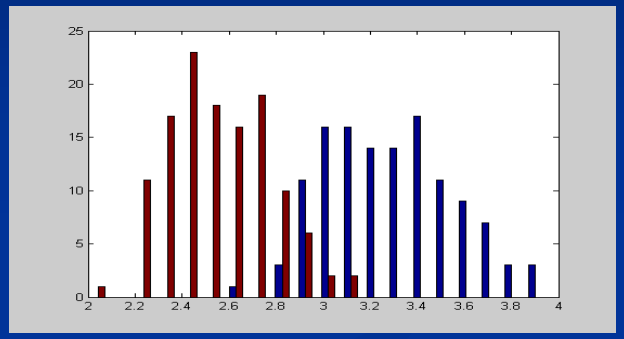
4th Floor



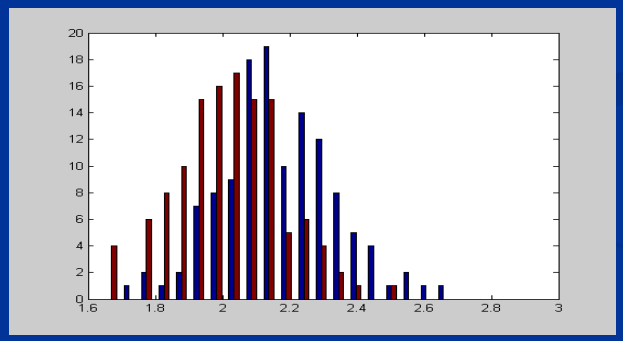


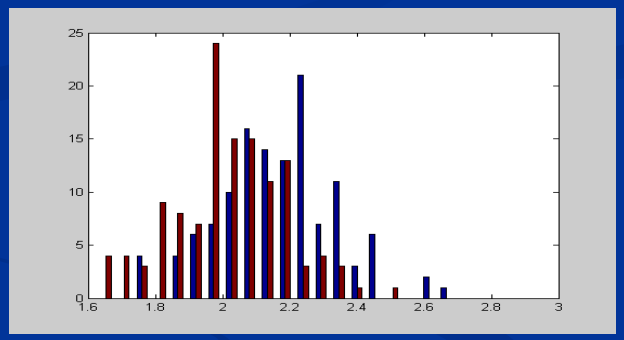
3rd Floor



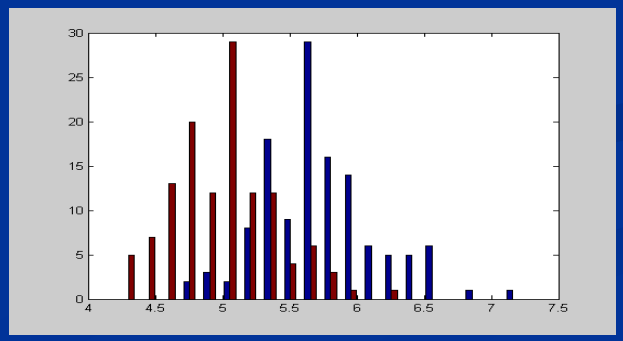


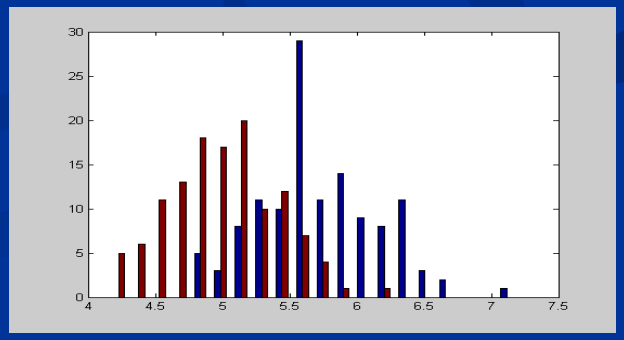
2nd Floor





1st Floor

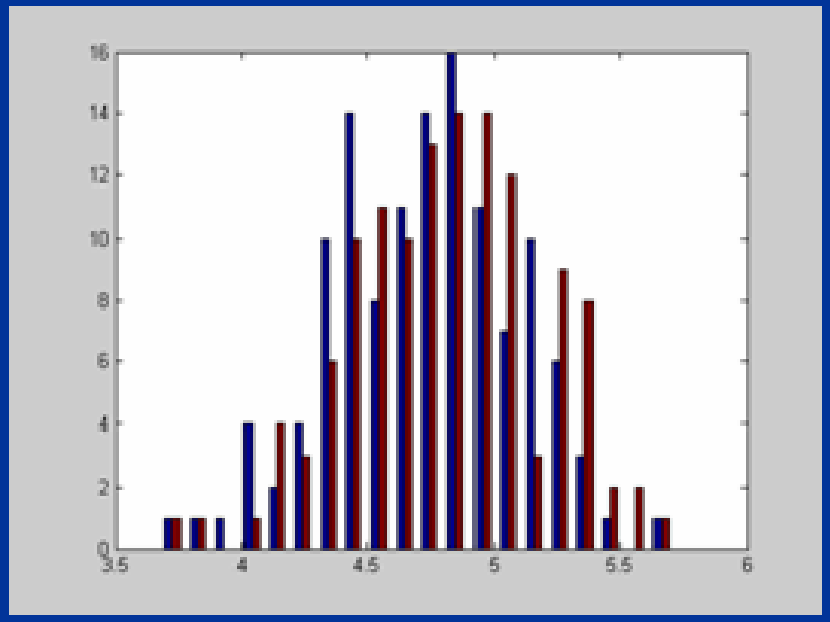




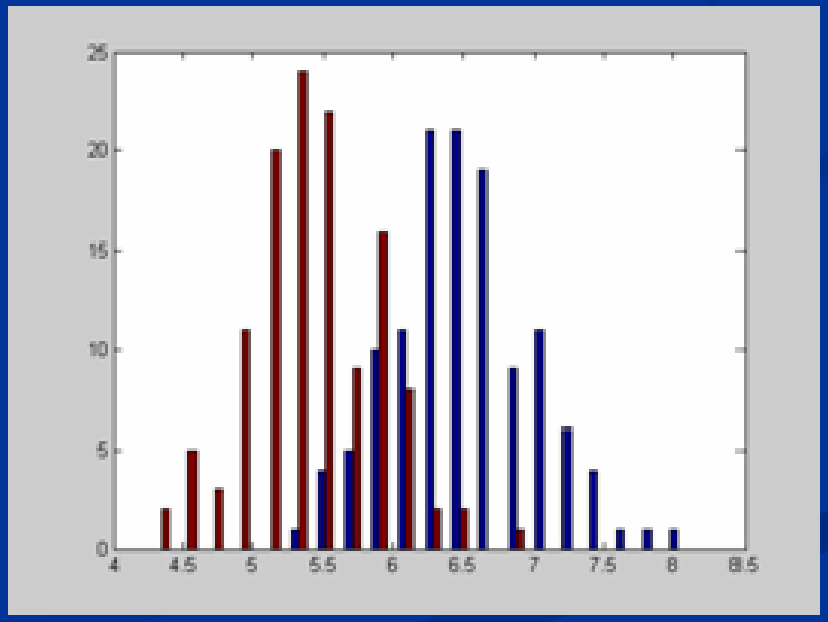
Results

- Can Further localize the damage by looking at which sensor on a particular floor has the largest shift. For example:

Sensor 4



Sensor 2



Damage Likely Here

Results

- ✓ Can Detect
- ✓ Can Localize
- 😐 Intensity?
- 😐 Remaining Life?

RESEARCH CONDUCTED II

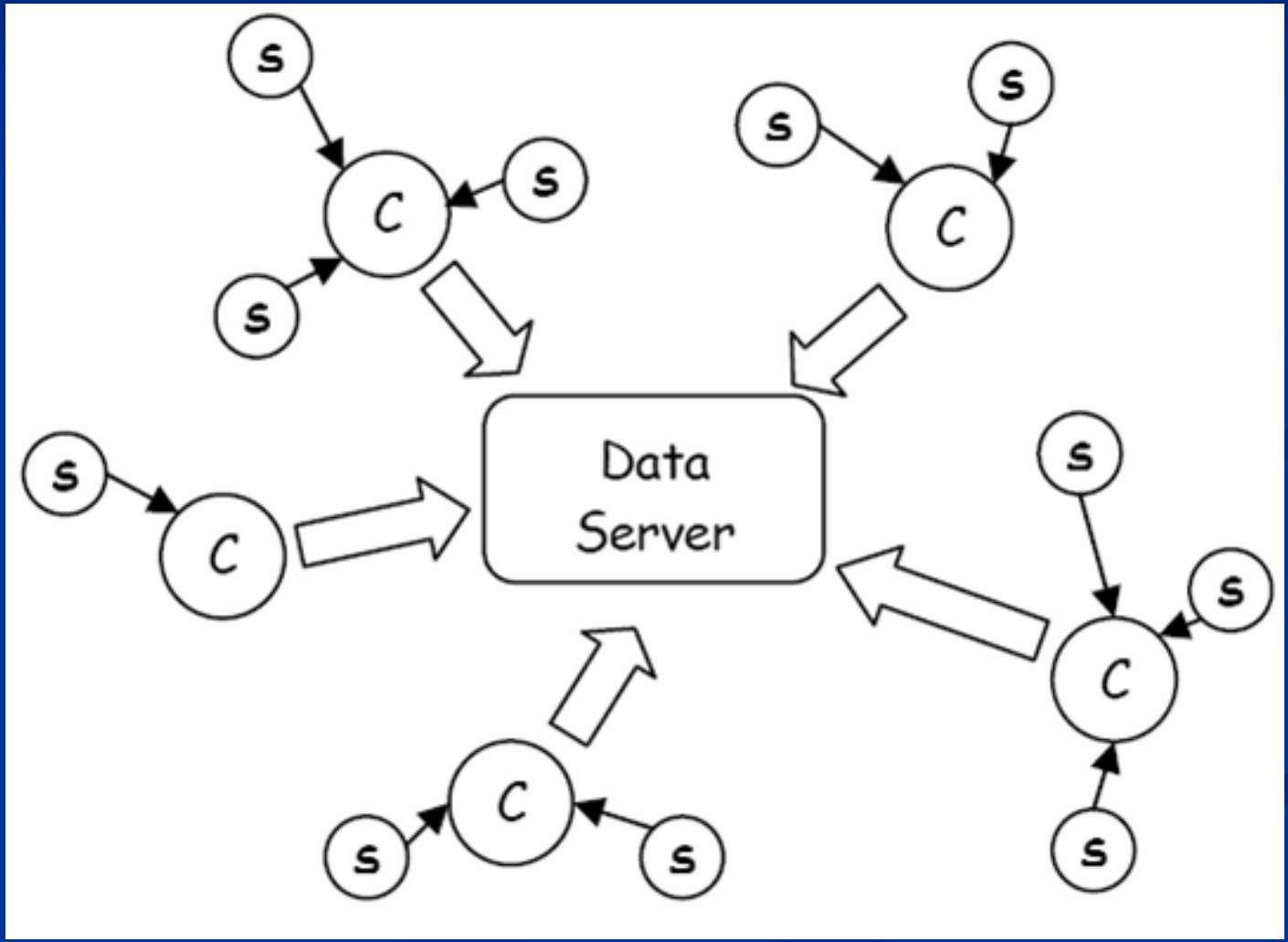
Vibrational Power Harvesting

Goal: Realize a self-powered wireless sensor network for structural health monitoring

- Cost savings (no cables)
- Ease of installation
- Ease of modification

→ **Power?**

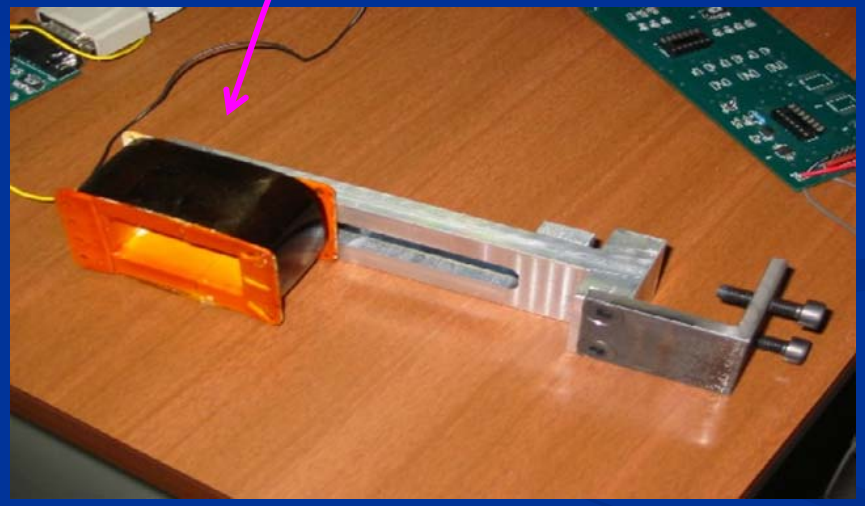
Wireless Architecture Under Development



What we did

Magnet

10000 Wraps
copper wire

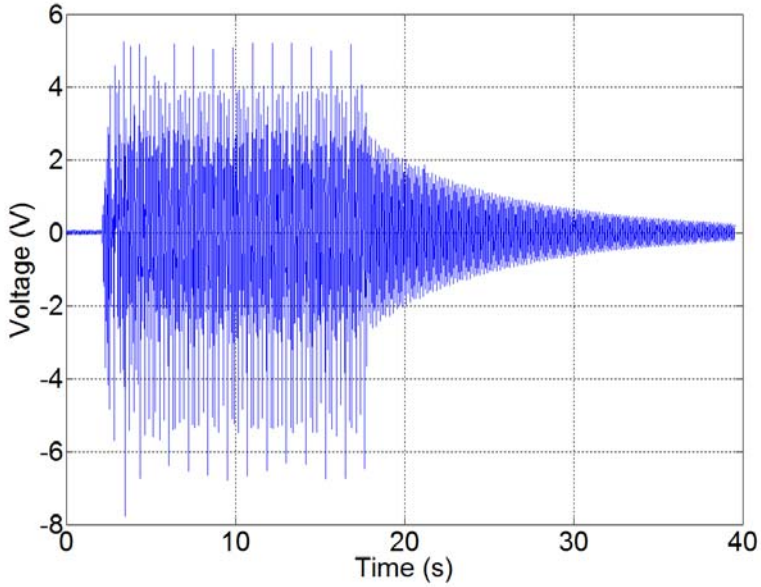


$$P = \frac{\pi k^2 d^2 f^2 N}{16 l_T \rho}$$

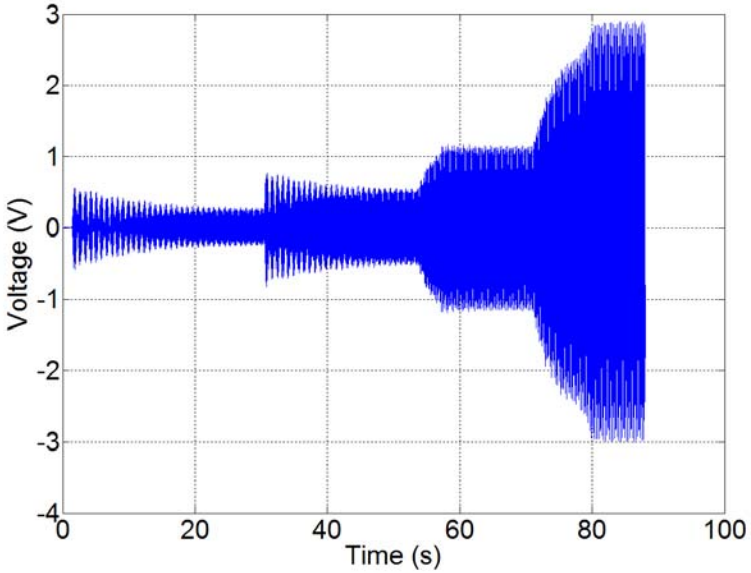
P = available power
k = constant
d = wire diameter
f = vibration frequency
N = number of turns of the coil
IT = length of one turn
ρ = copper resistivity ≈ 17 nΩm

Results

Resonant Frequency 9.27 Hz
Peak Voltage: 5V



Frequency 8 Hz
Peak Voltage: 3V



Not a lot of power

Using MEMS (would have to)

25 Samples / Second

1 Sample every four seconds

Results

- ✓ Can Generate Power
- 😐 Requires optimal amplitude/frequency
- 😐 Not a lot of power
- 😐 Could be a supplementary power source

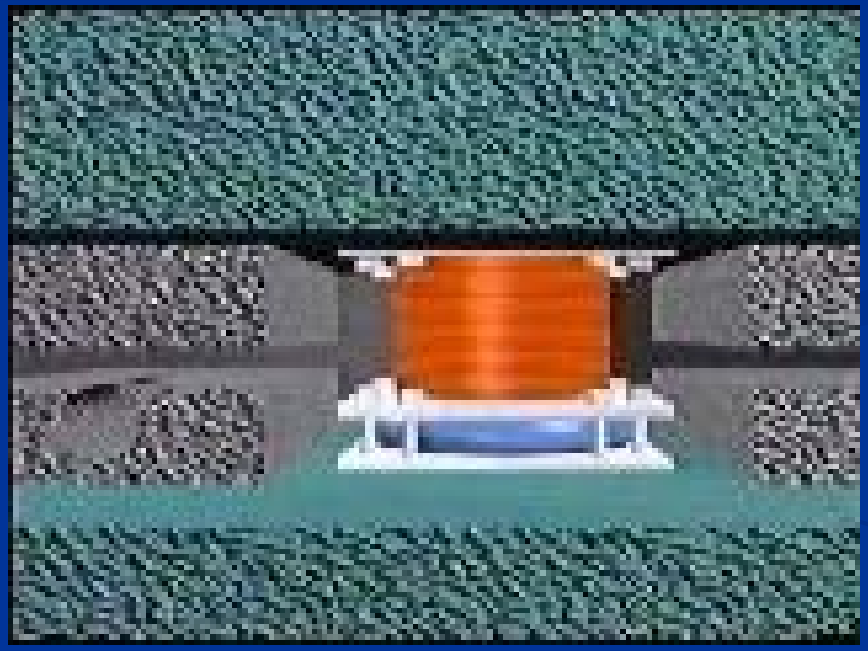
RESEARCH CONDUCTED III

Using Copper Based Shape Memory Alloys (SMAs) as a Passive Control Device

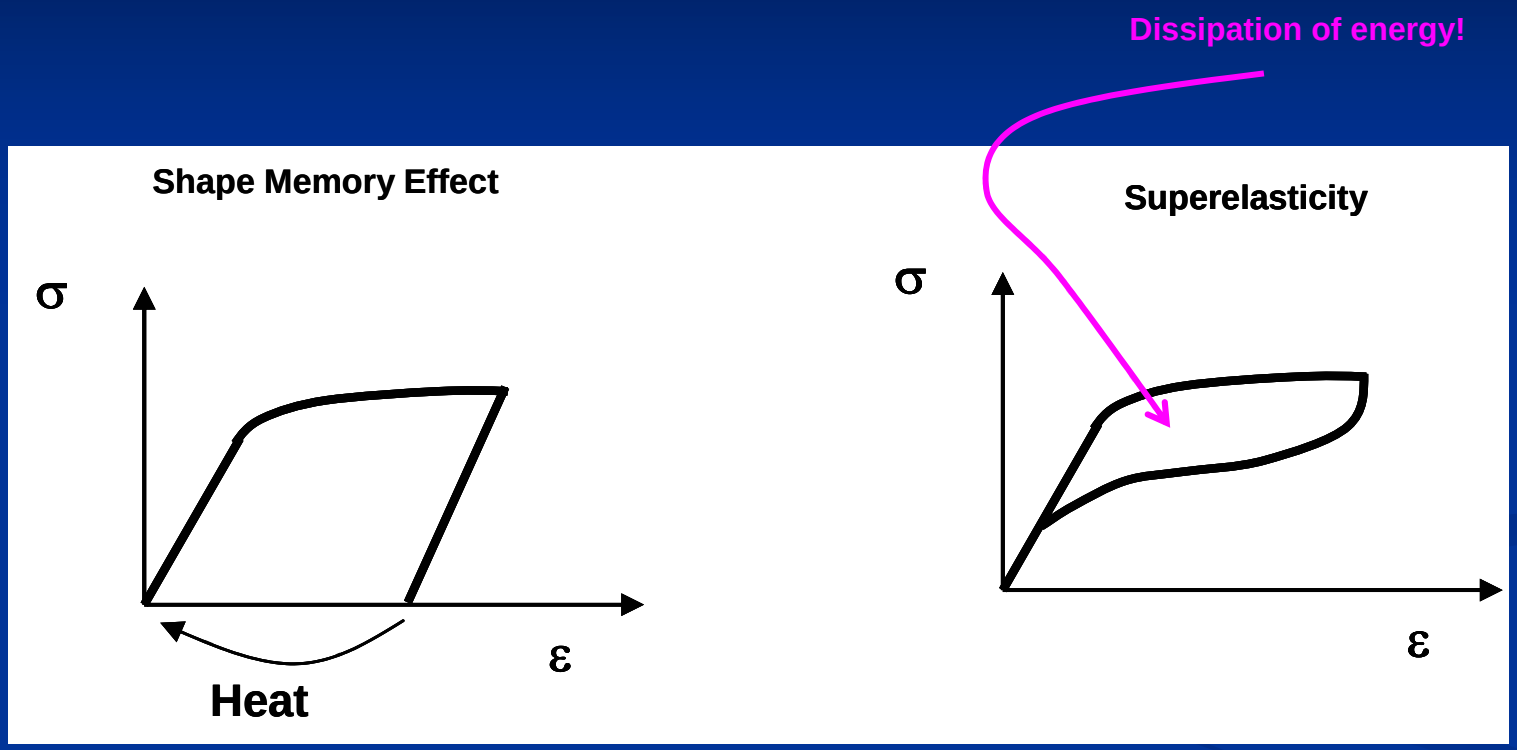
Goal:
1) Leverage new materials to provide structural damping and to increase structural stiffness
2) Better understand / classify Cu-based SMAs

"What is a Passive Control Device?"

Base Isolation System
Shock Absorbers



"What is a Shape Memory Alloy?"

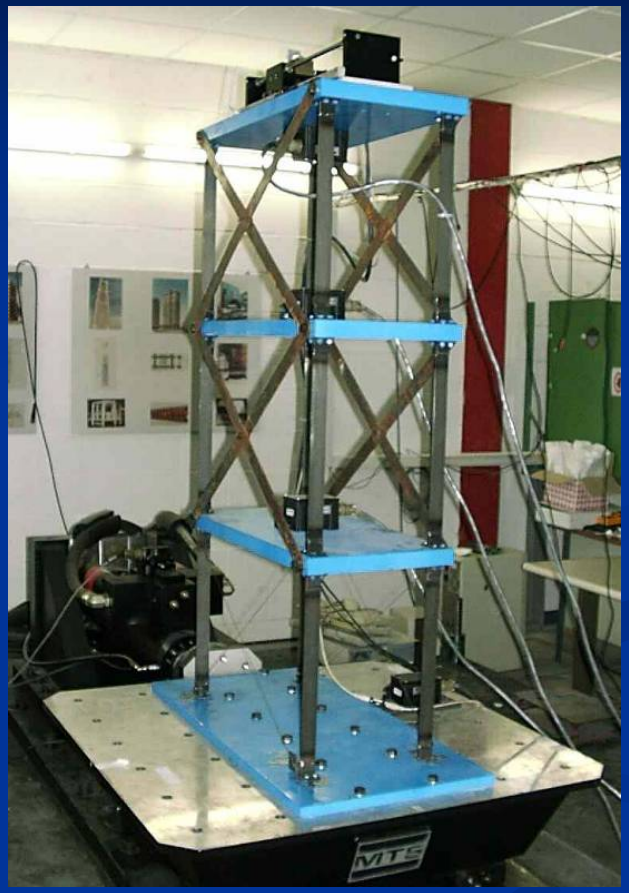


Martensite (T1)
"Shape Memory Effect"

Austenite (T2)
"Superelasticity"

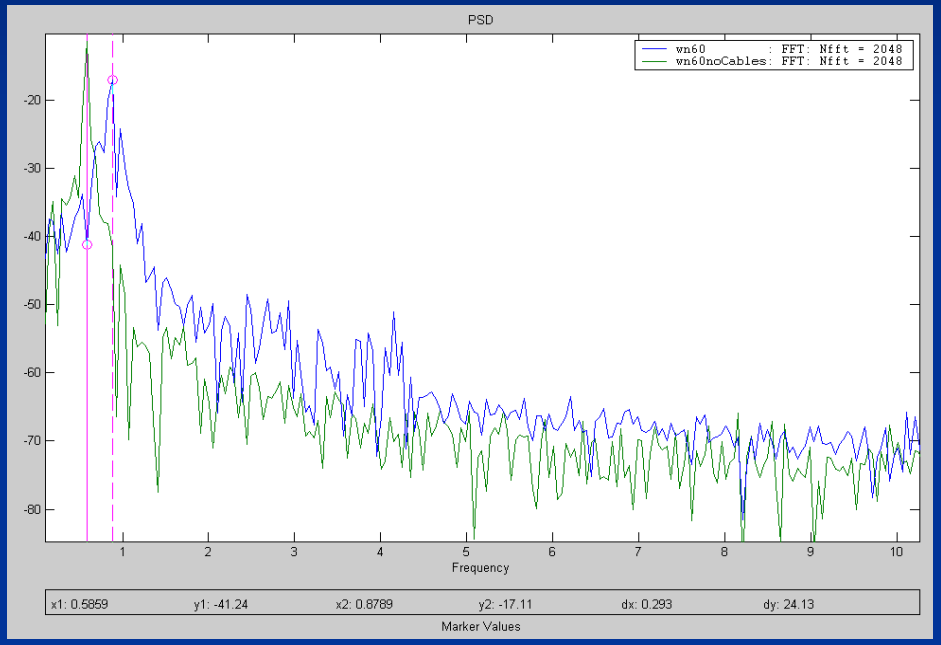
Possible (although challenging) to design a material of desired properties

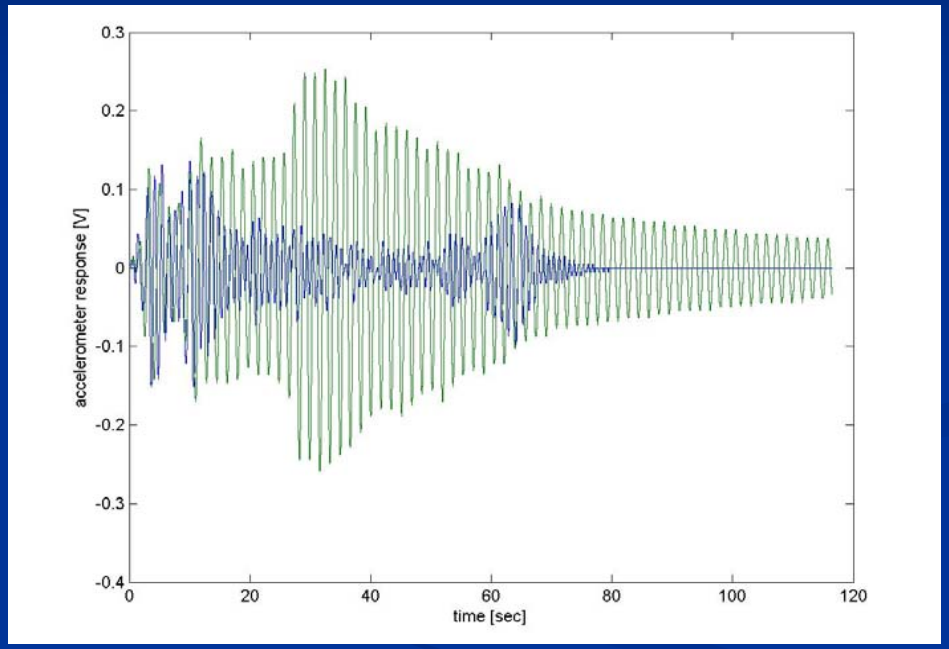
What we did



Results

Shift of First Mode





Increased Stiffness

Damping

Military Applications & Future Research

- **Sensor Technology / Army AOAP**
- **Critical Component Management**

Real Time on board alert data if critical elements exceed a critical strain value

http://www.wnbc.com/news/3269249/detail.html

Military Applications & Future Research II

- **Structural Assessment in a deployment scenario**

Collecting Structural Data

Collecting Soils Data

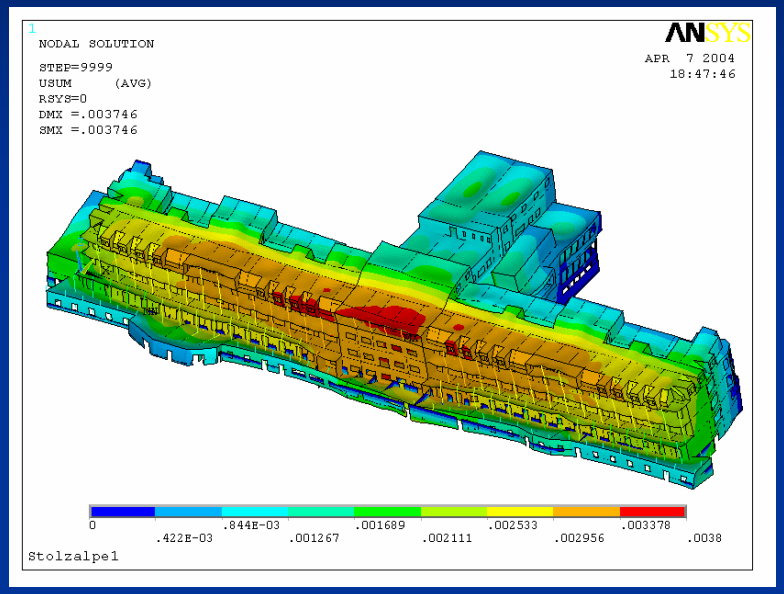
Mobile Trailer with a
7000 lb oscillating mass
and data acquisition equipment

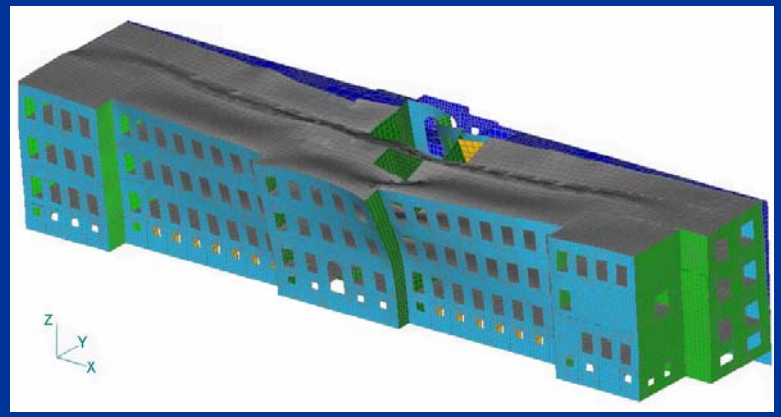
FE MODEL @ Higher HQ

VICTORIA

Structural Assessment and Retrofit Prioritization

FE Model





Risk Mapping

cell	Room no.	GPR	GSR	GI
I	28	6	3	7.66
II	26	3	4	4.52
IV	3	4	5	6.27
V	8	7	5	10.40

Conclusions

There is a need for Smart Structures & Structural Health Monitoring

As Engineers and Leaders, we need to leverage new methods and technology to safeguard resources and lives

As educators, we need to consider how we educate the engineers of tomorrow

Acknowledgments

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Department of Mathematics, West Point

University of Pavia, Italy

Arsenal research, Vienna Austria

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