

Multi-metric Self-Powered Wireless Sensors for Infrastructure Monitoring

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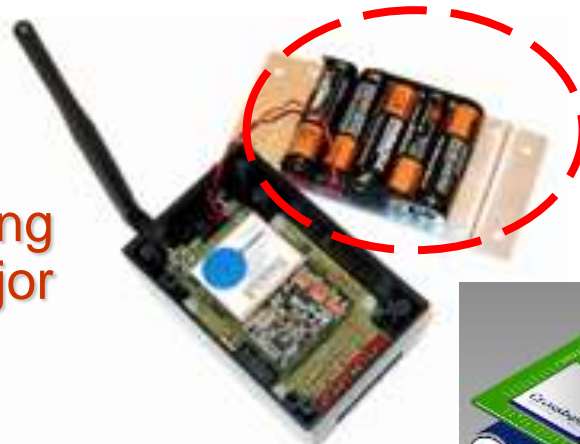
Sensing Issues in Structural Health Monitoring

- **Cost**
- **Size**
- **Power Source**
- **Maintenance – Maintenance free sensors**
- **Data meaning and interpretation**
- **Ease of installation and use**
- **Data type and format – Integration with existing management systems**
- **Extreme events monitoring**

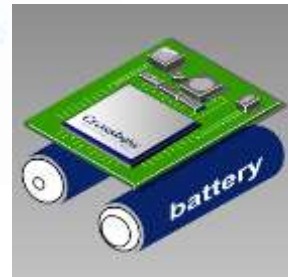
How to monitor events ?

Monitoring systems are expensive, bulky and require a continuous source of power.

Electronic powering is one of the major obstacle !



Yang Wang, Kenneth Loh, Jerome Lynch and Kincho Law, University of Michigan



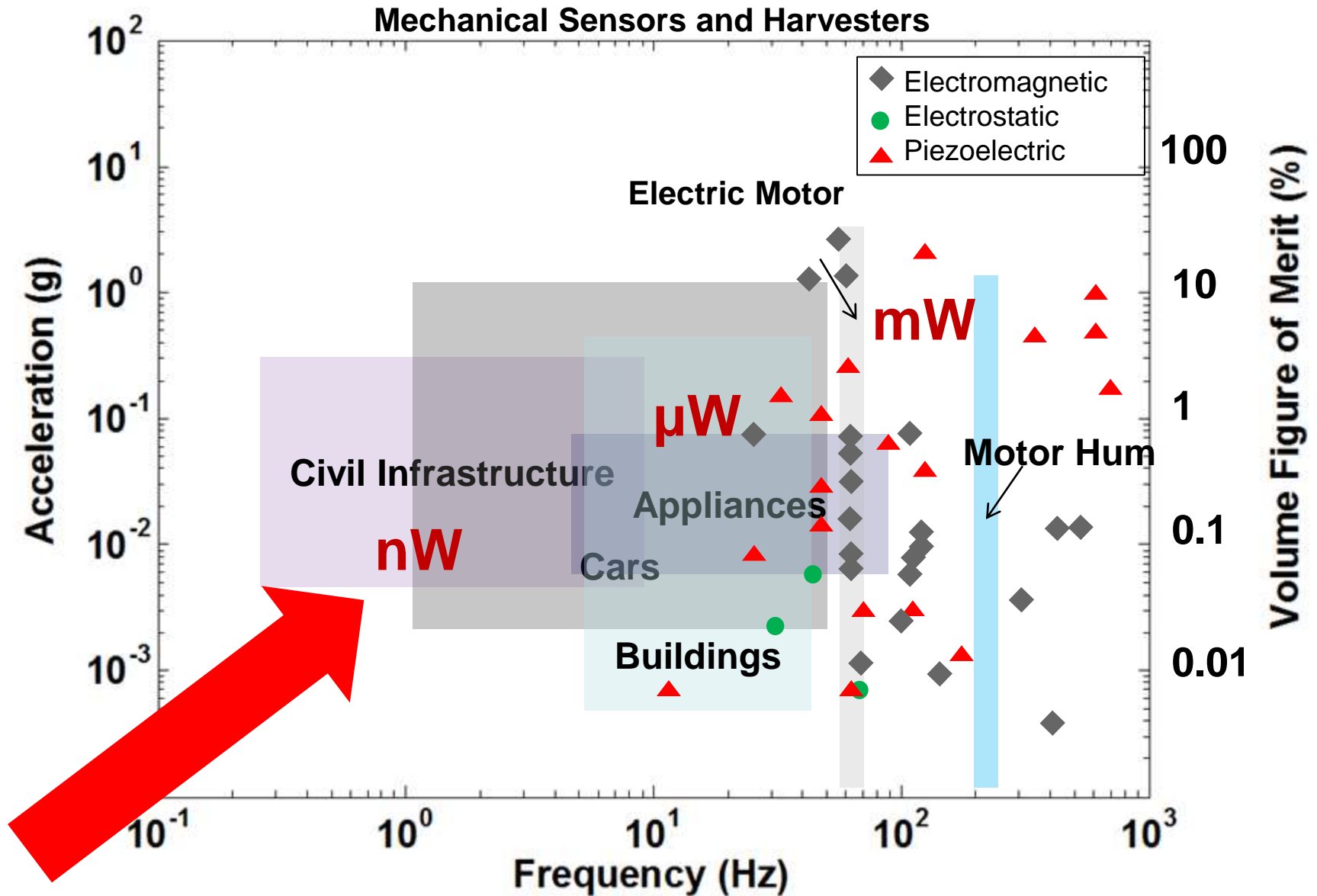
www.hbm.com

Strain-gauges with implanted batteries are impractical solution

Solution: Self-powered sensing

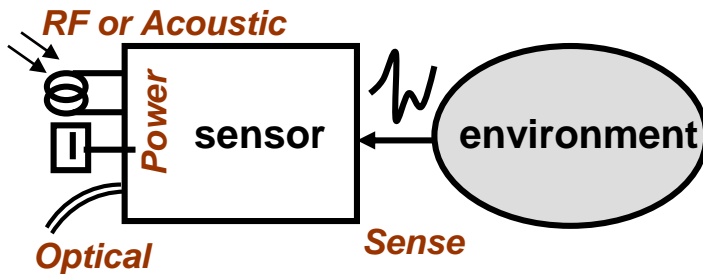
Harvest computing power from the signal being sensed.

Self-powered accelerometers - challenges



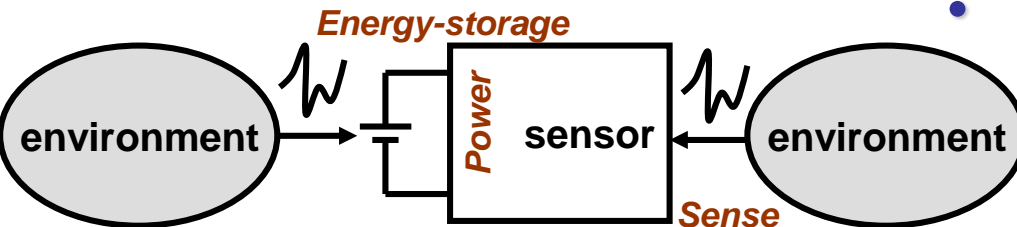
Self-powered Sensors

- Sensors that operate by scavenging energy from the ambient environment.



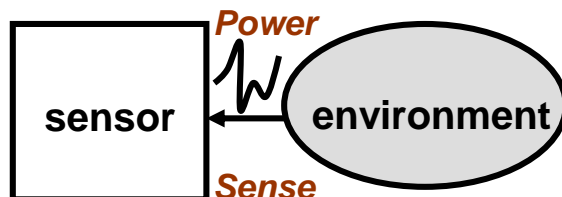
- **Passive Sensors**

- Sensor is active only when the interrogation signal present – radio-frequency, optical or acoustic sensing. **(NOT Zero-downtime – cannot sense rare events)**



- **Trickle-charge Sensors**

- Energy stored by trickle-charging and active only when powering conditions met. **(NOT Zero-downtime – cannot sense rare events)**



- **Direct-powered Sensors**

- Harvest energy for operation from the signal being sensed – e.g. piezoelectric signal used for powering and sensing mechanical strain.

PFG Technology

- Sensors embedded inside “smart structures” that can self-prognosticate damage and mechanical failure.
- **Zero Maintenance Sensors:** Operational life of sensors comparable to the useful life of the structure – **Powering is one of the key challenges.**

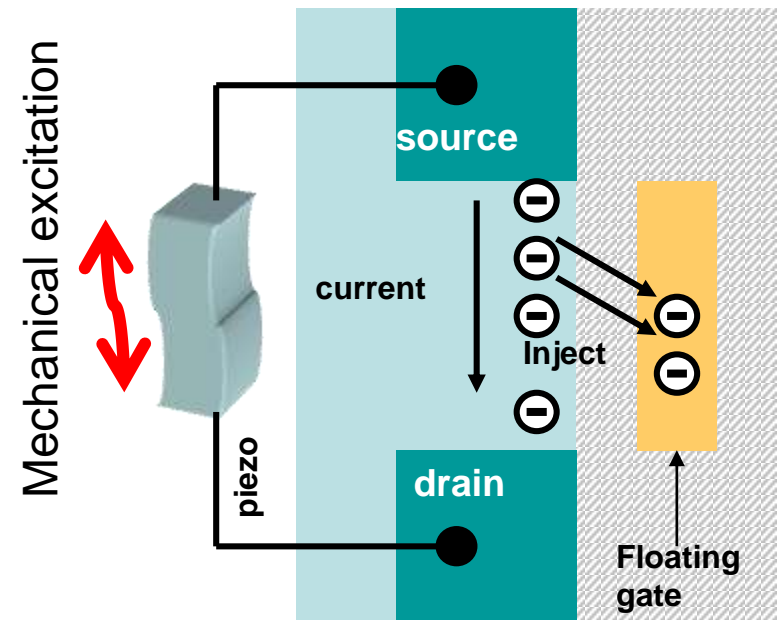
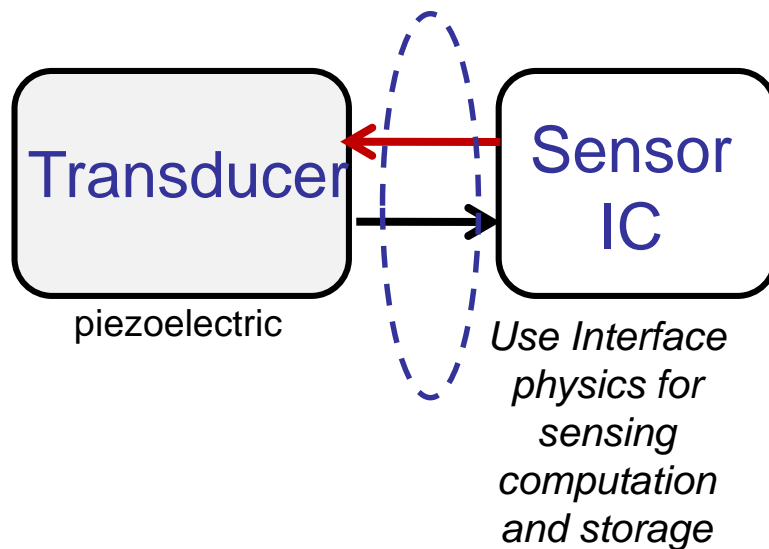


Sensor Size and Powering

Piezo-floating-gate technology

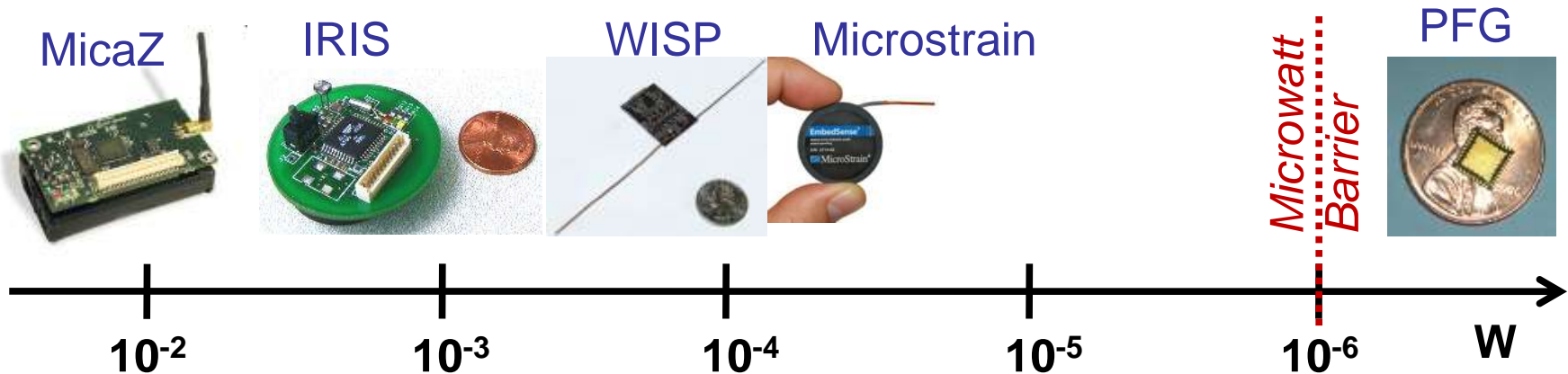
(US Patents: 7,757,565 and 8,056,420)

Eliminate power regulators, energy storage, data converters, RAMs and digital signal processors. Use the physics of the device and the structure to perform computation and storage (Use analog computation instead of digital).



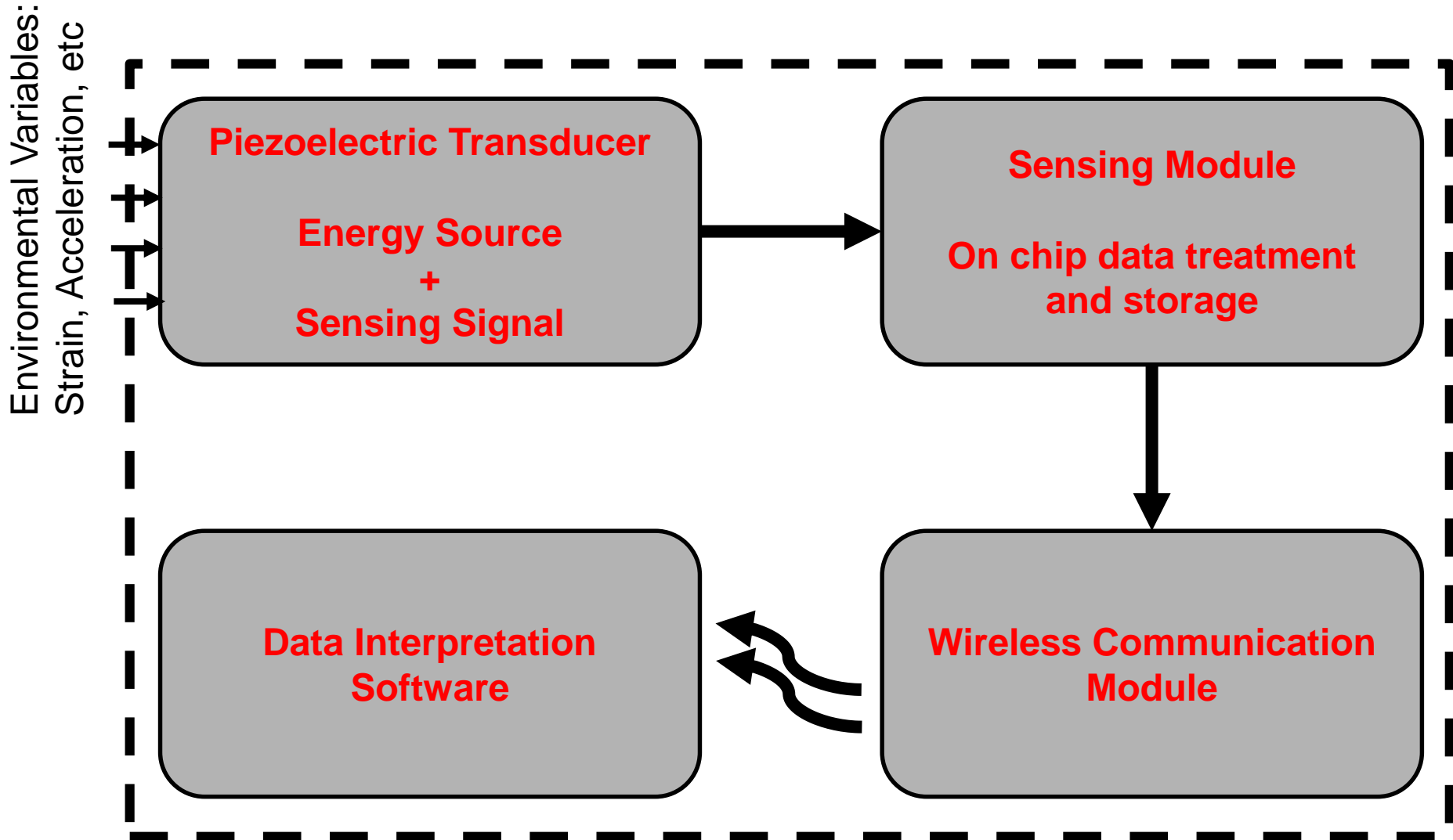
- Piezoelectric ceramics and polymers can generate high-voltages for low strain-levels but at ultra-low-driving currents.

Comparison with other technologies

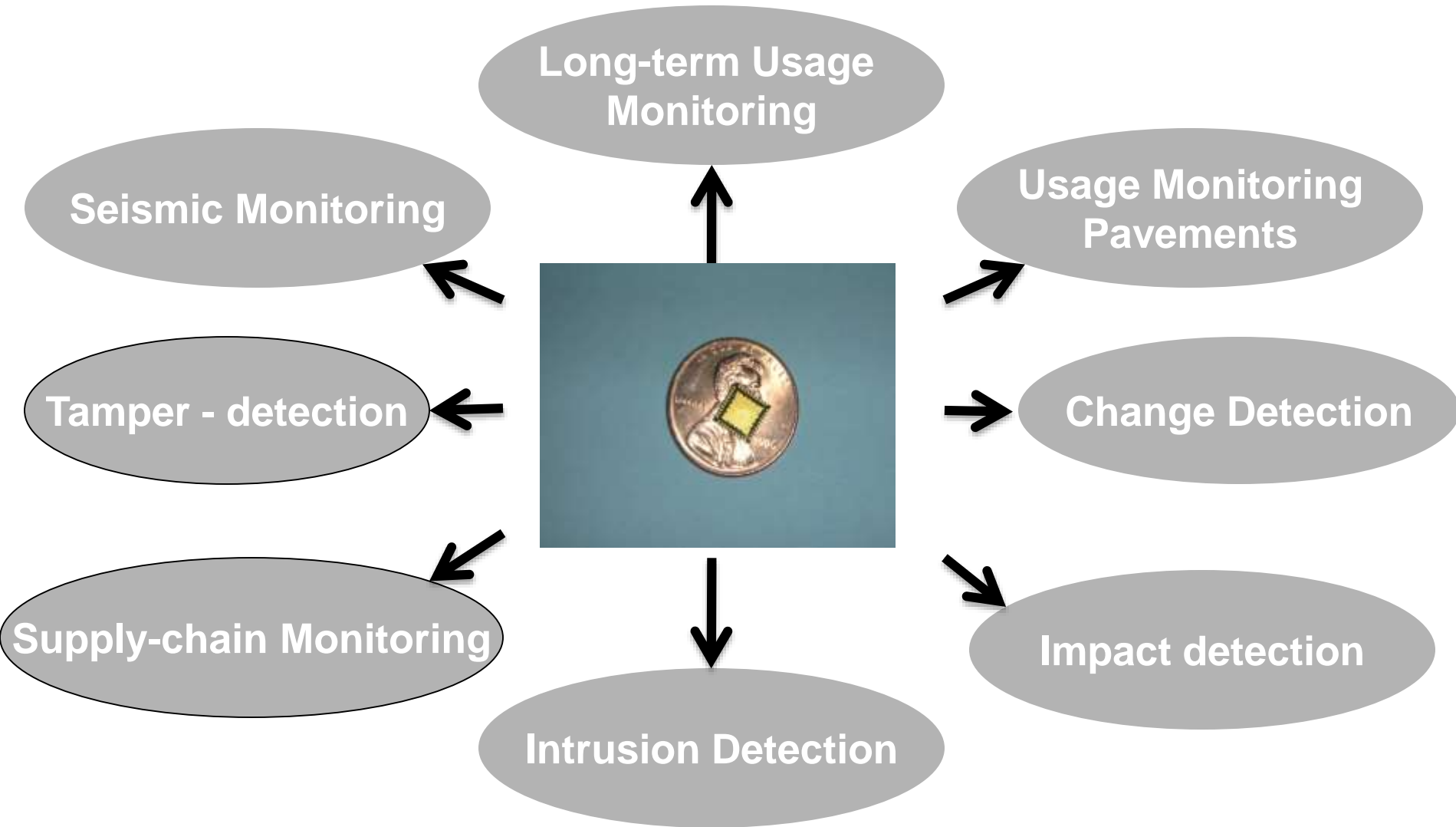


Process	0.5- μm standard CMOS
Size	1900 μm x 1500 μm
Maximum Current consumption	110nA (7-channel level crossing monitoring)
	90nA (3-channel impact monitoring)

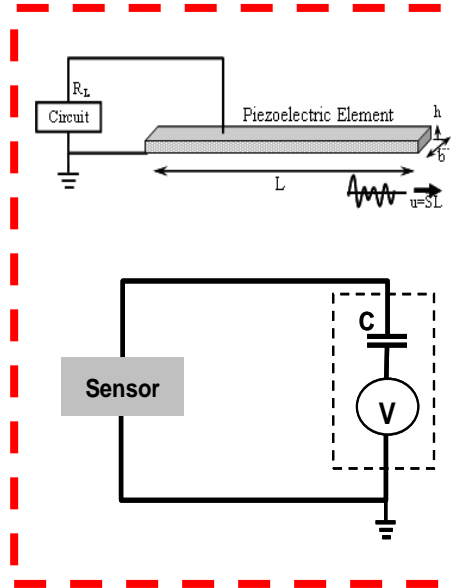
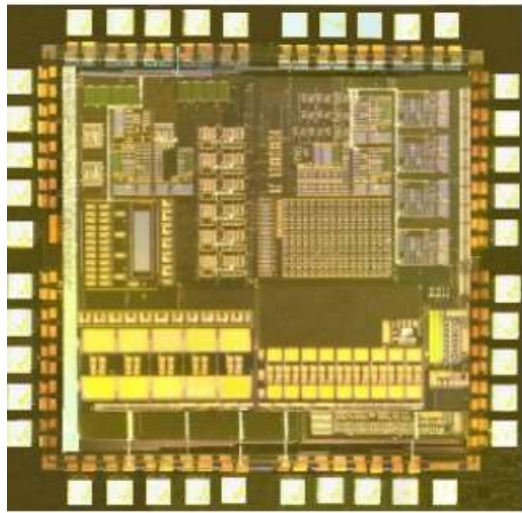
Sensing System Components



Road-map: One sensor multiple Modalities

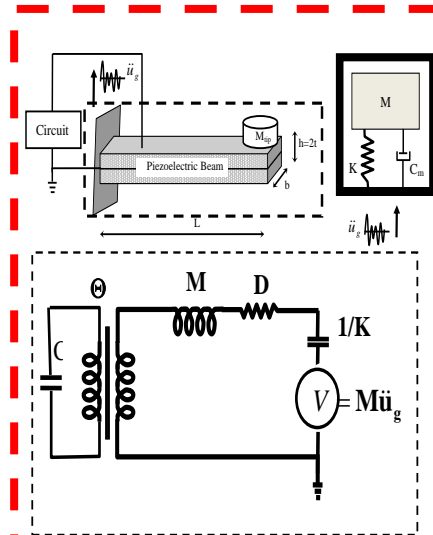
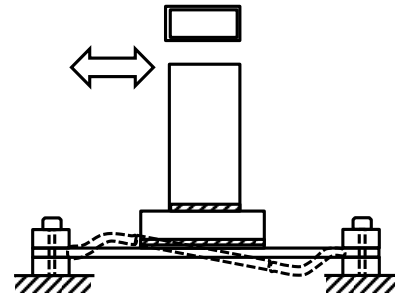


Civil and Mechanical Structures



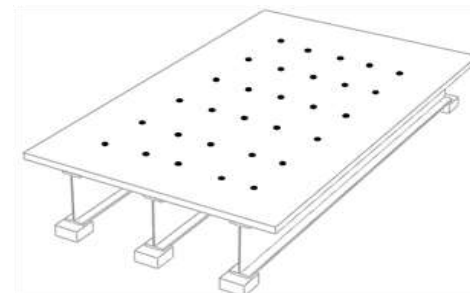
Strain

Strain-rate



Acceleration

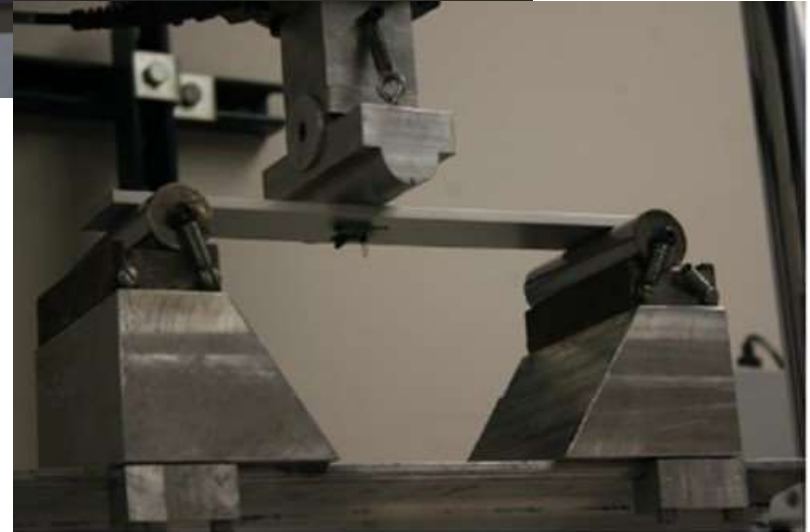
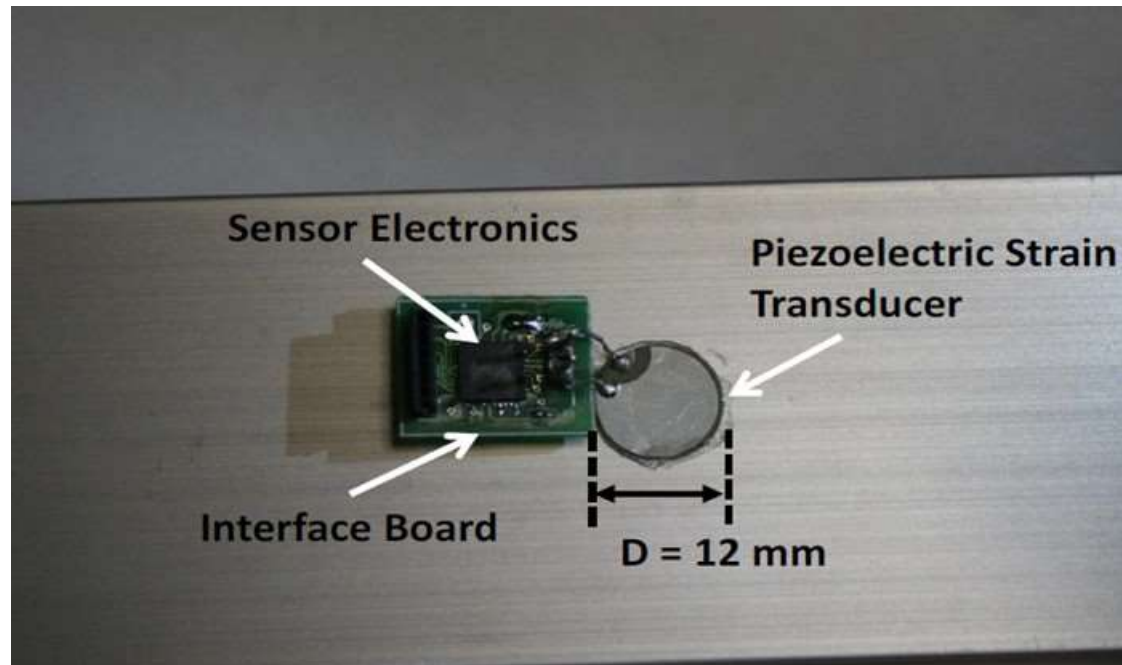
Spectral Features
FFT



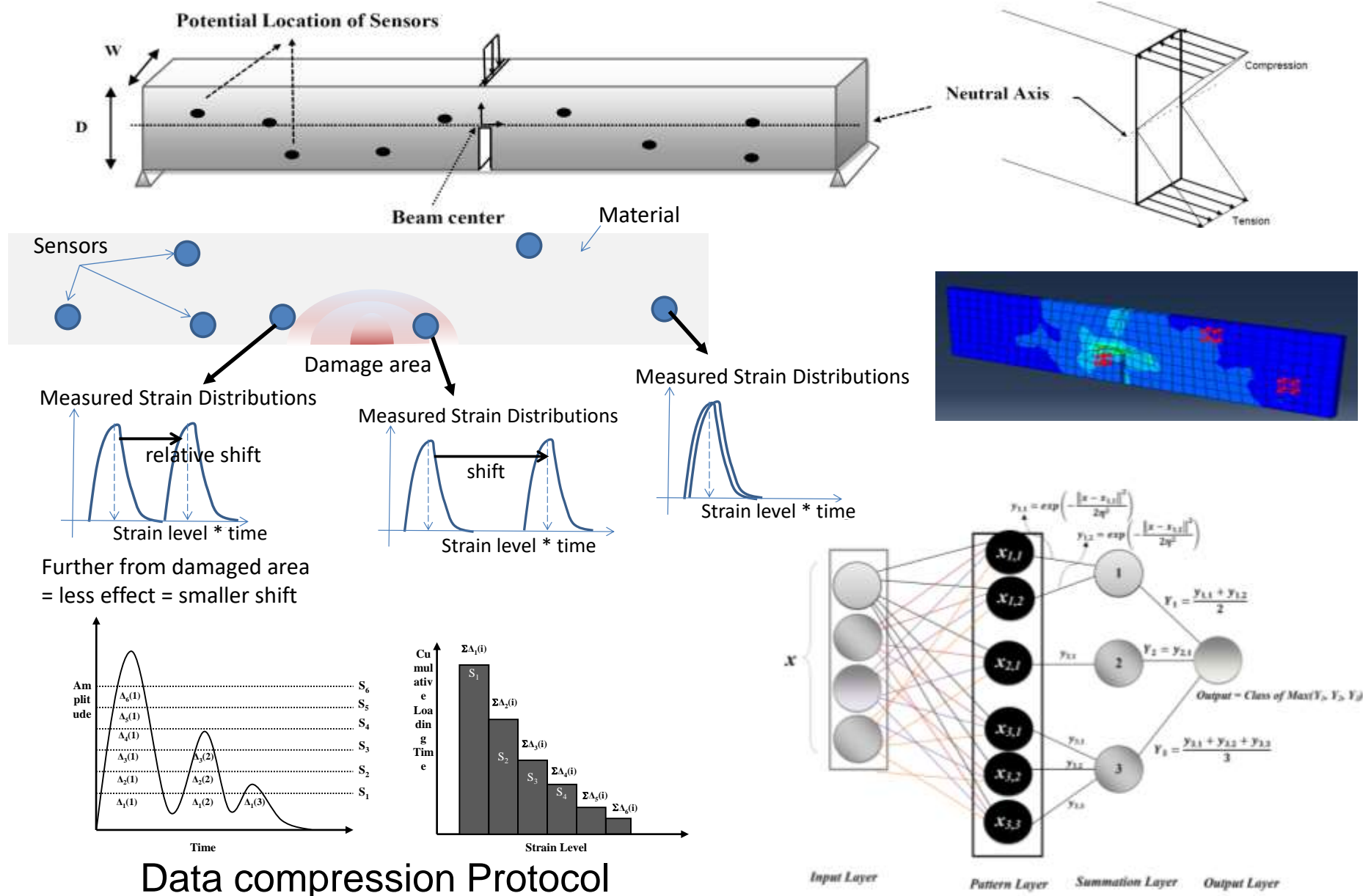
Local

Global

Tested Prototypes – Laboratory Testing

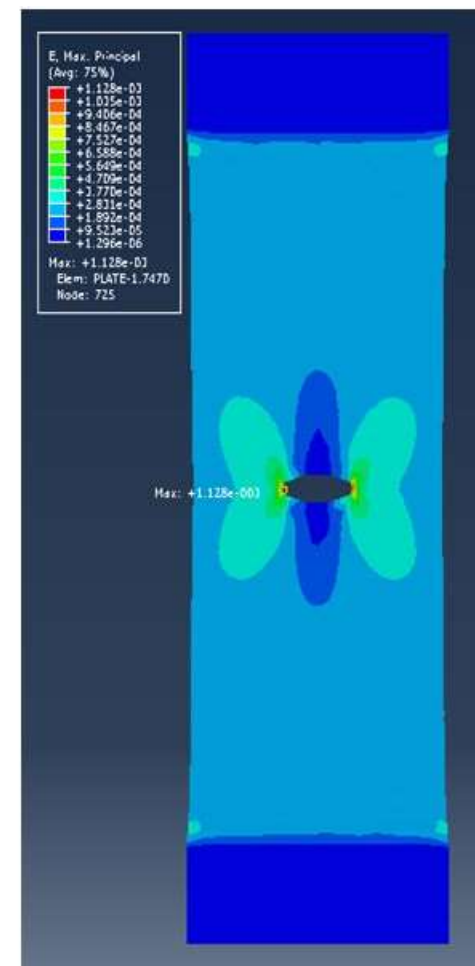
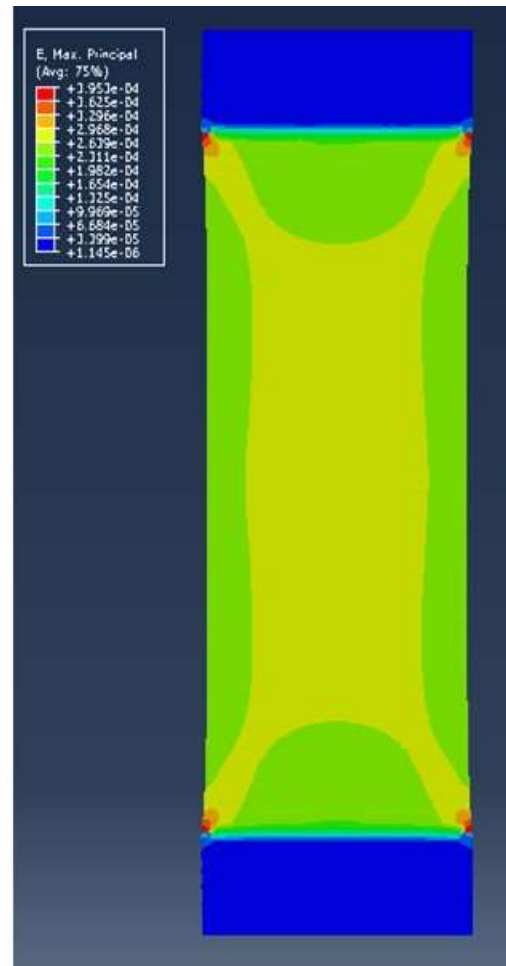
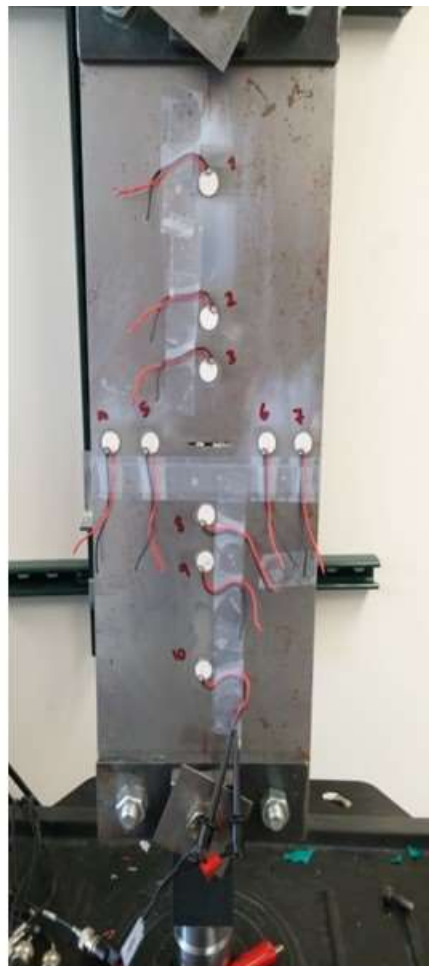
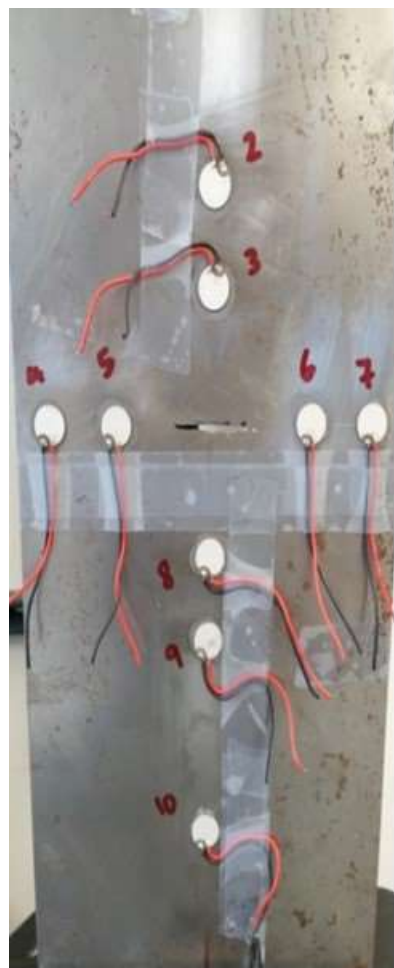


Data Interpretation - Damage

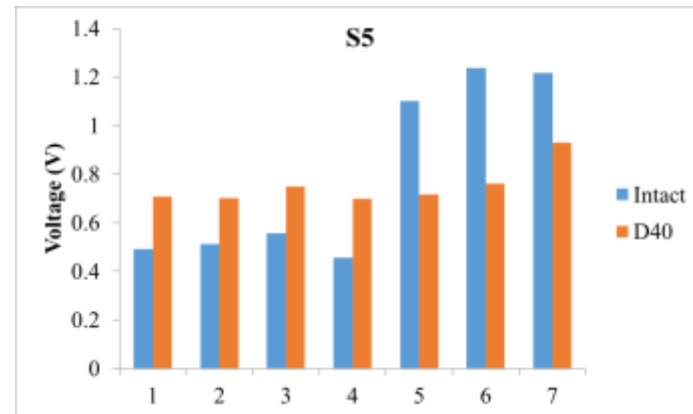
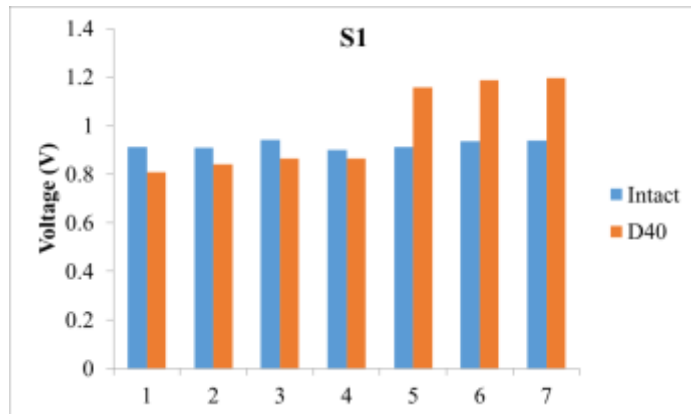
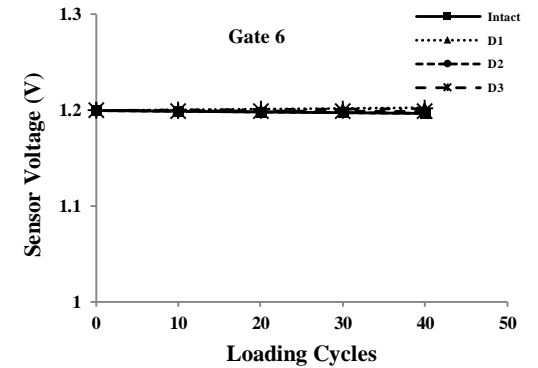
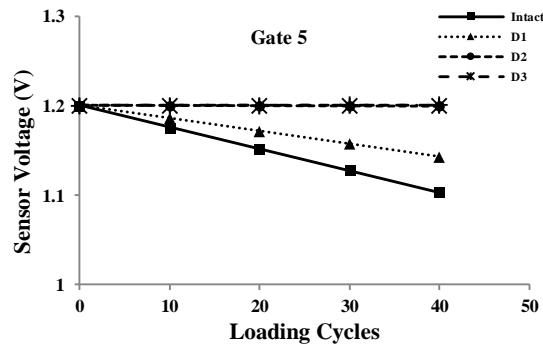
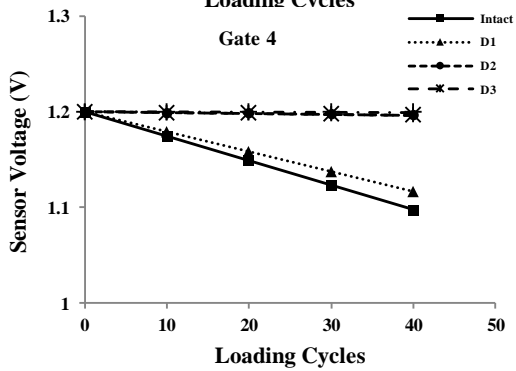
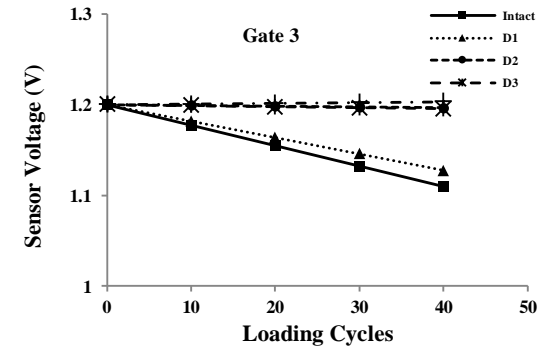
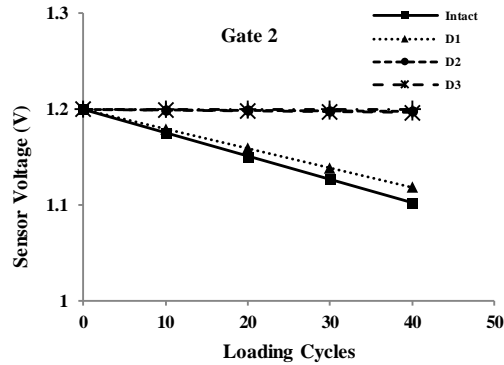
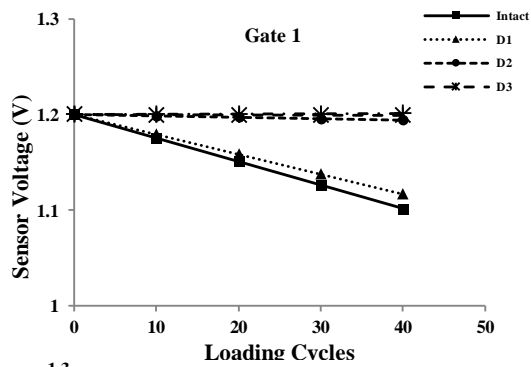


Data Interpretation - Examples

Crack Growth in Steel Plates

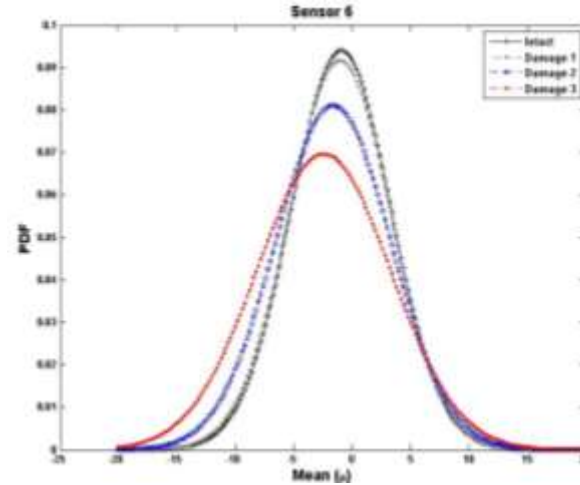
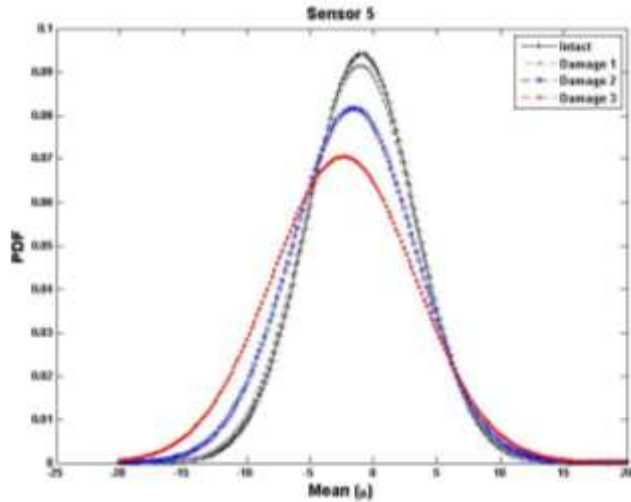


Crack Growth in Steel Plates

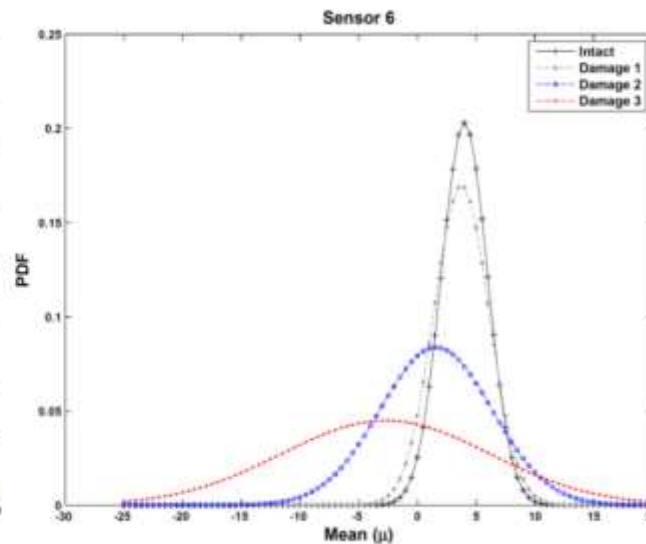
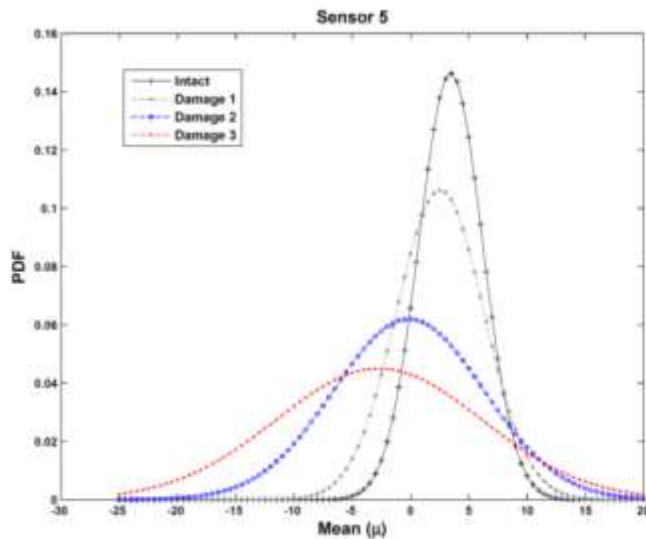


Crack Growth in Steel Plates

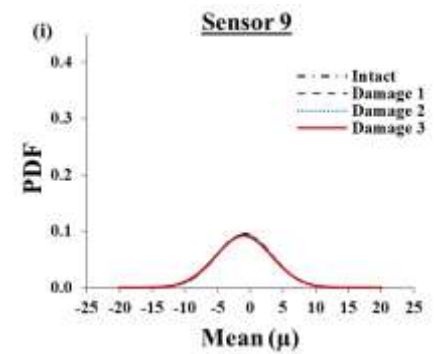
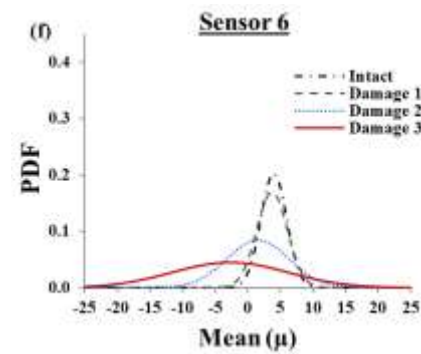
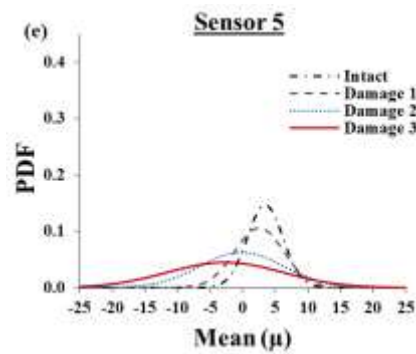
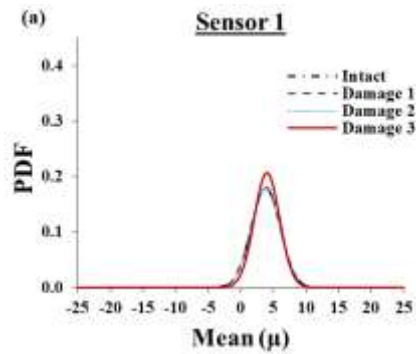
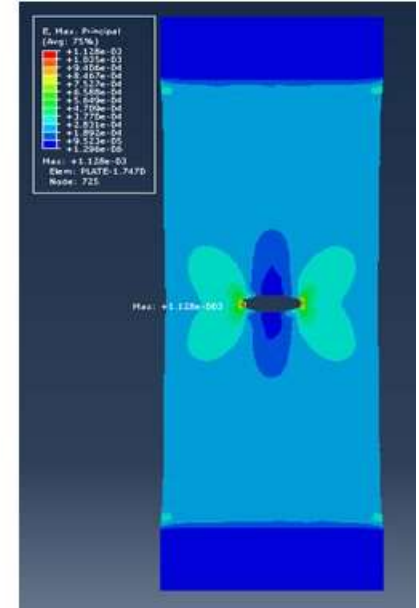
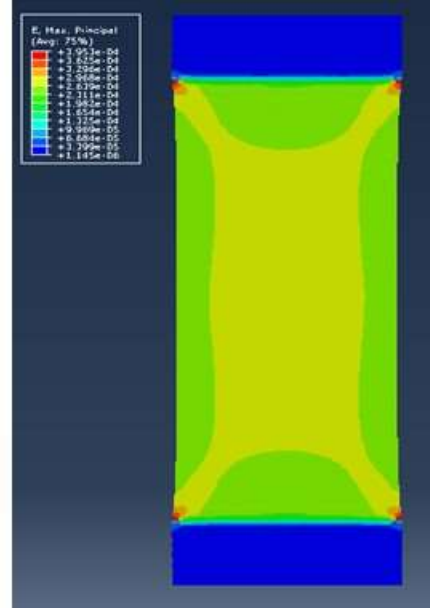
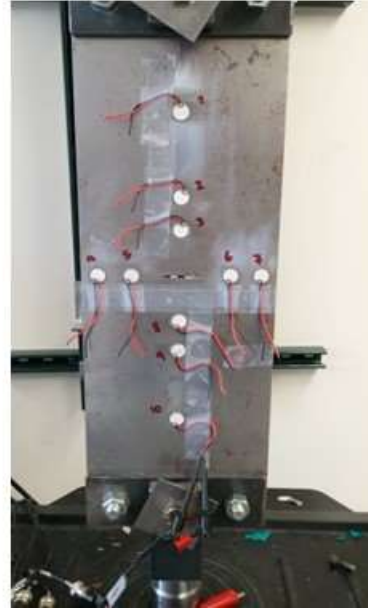
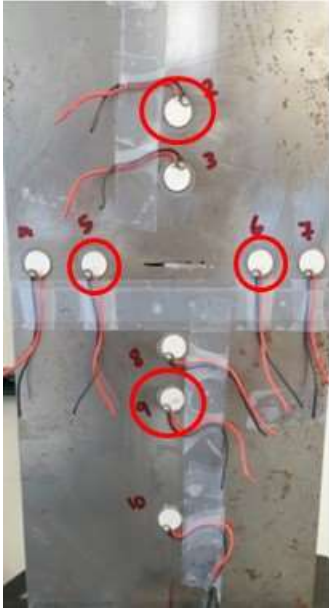
Damage Detection Based on the FE Results (2 Hz, 0.08 mm)



Damage Detection Based on the Experimental Results (2 Hz, 0.08 mm)

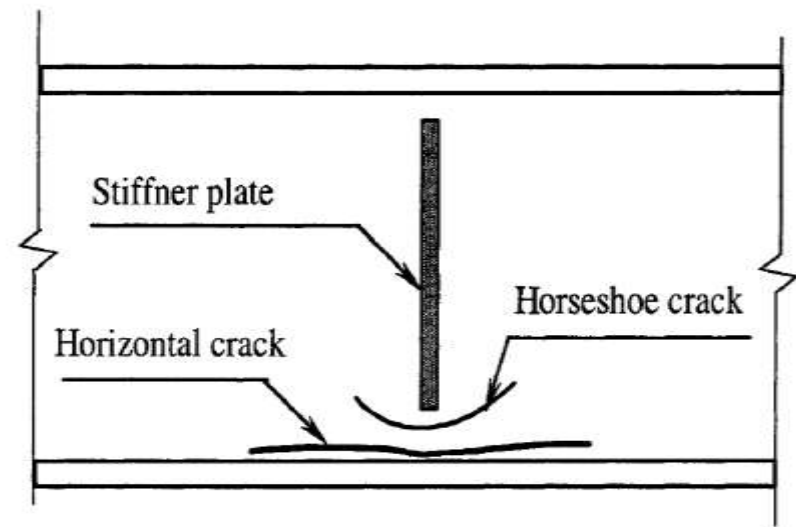
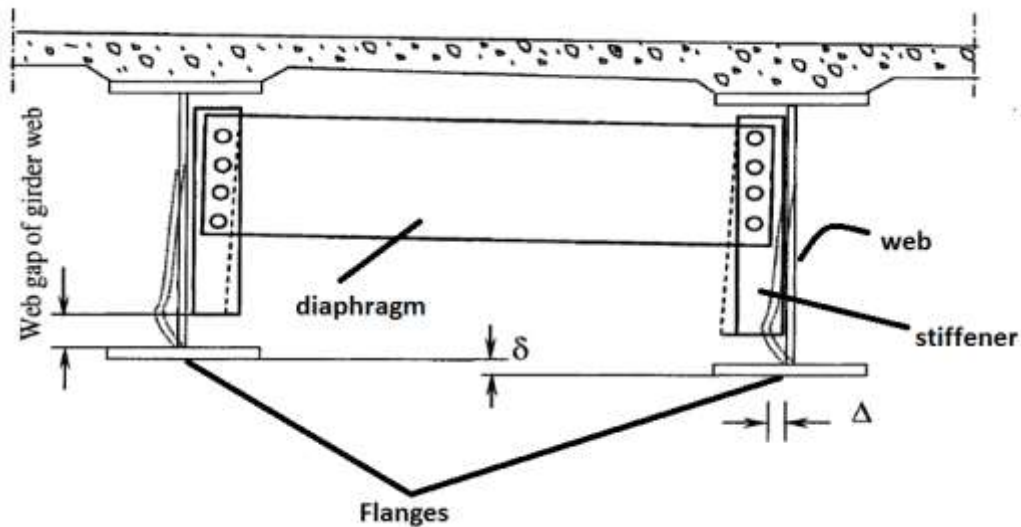
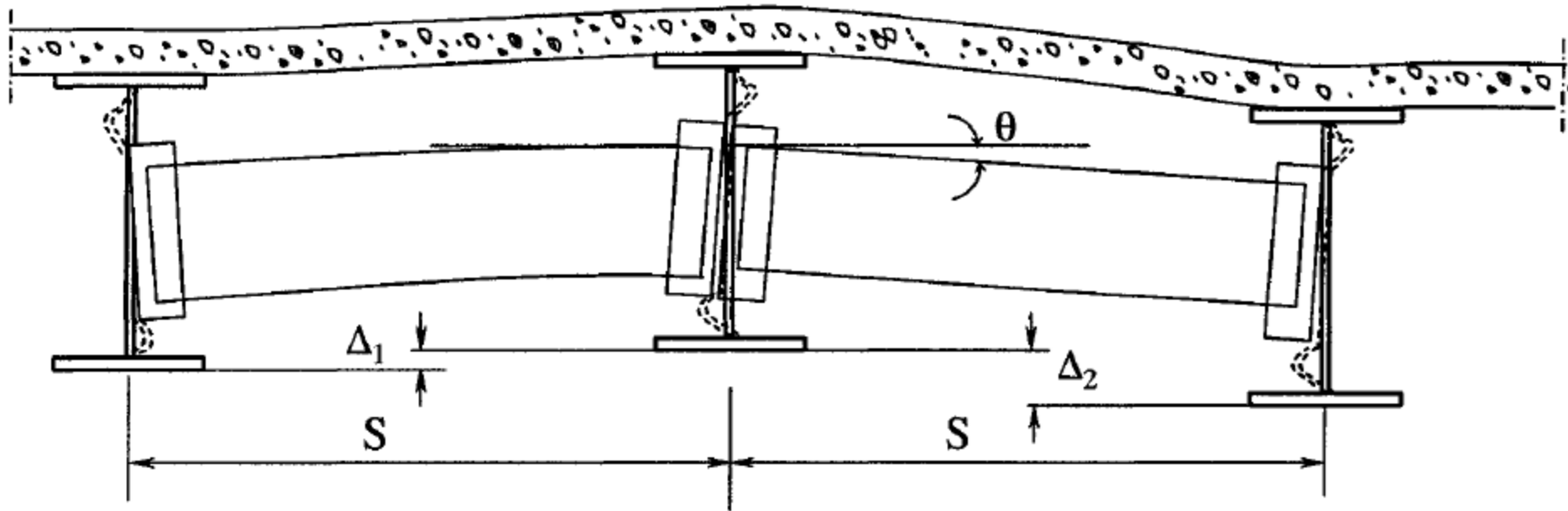


Crack Growth in Steel Plates

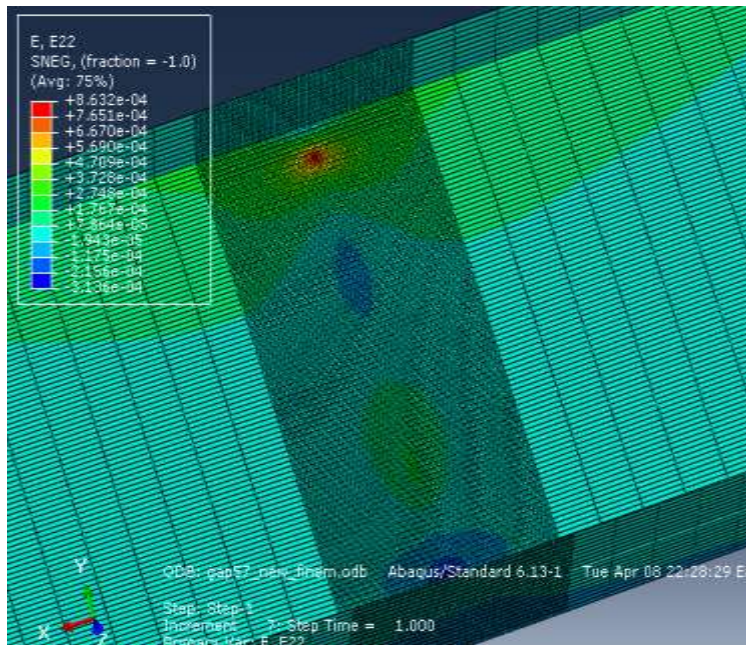


Sample Data

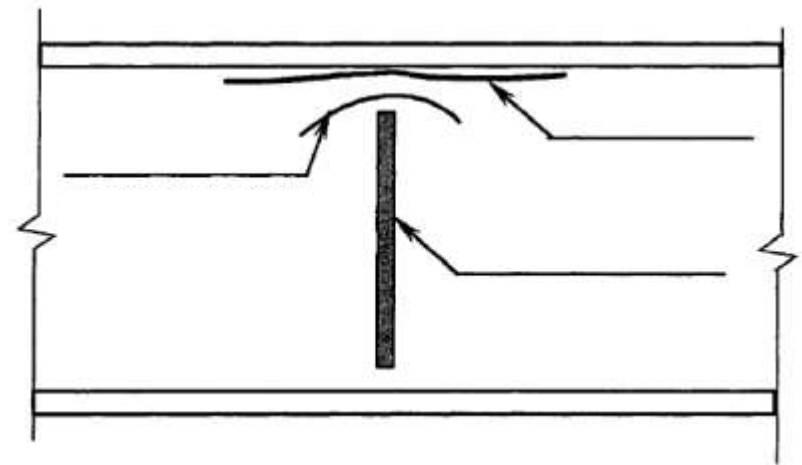
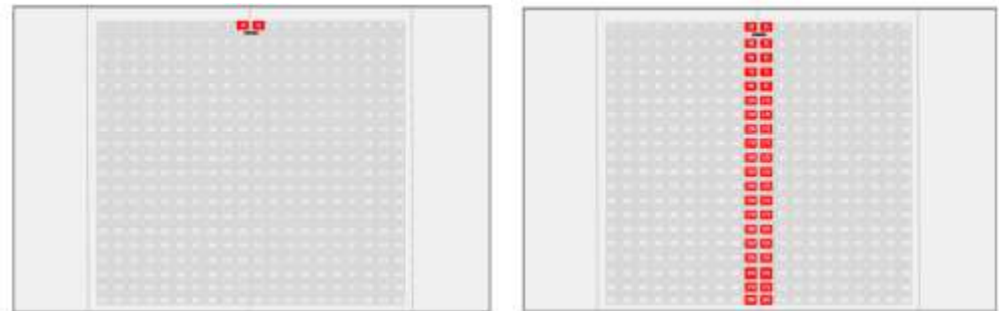
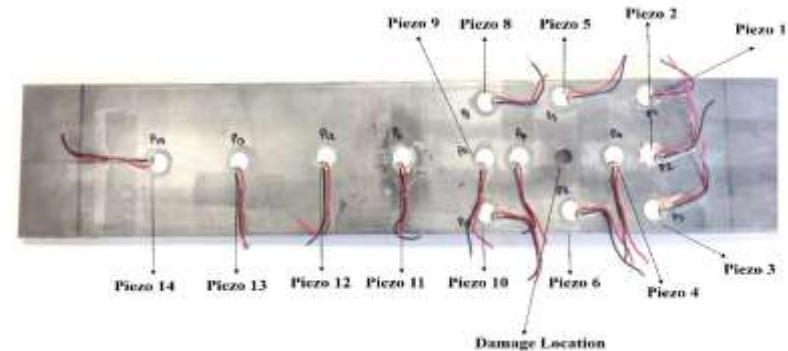
Distortion-Induced Fatigue Cracking in Bridge Girders



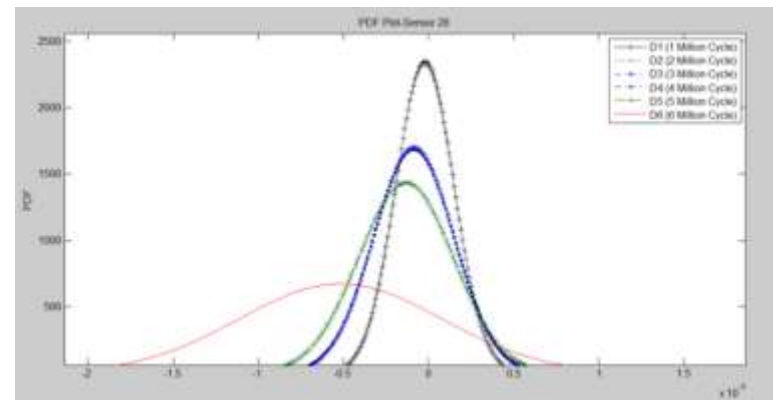
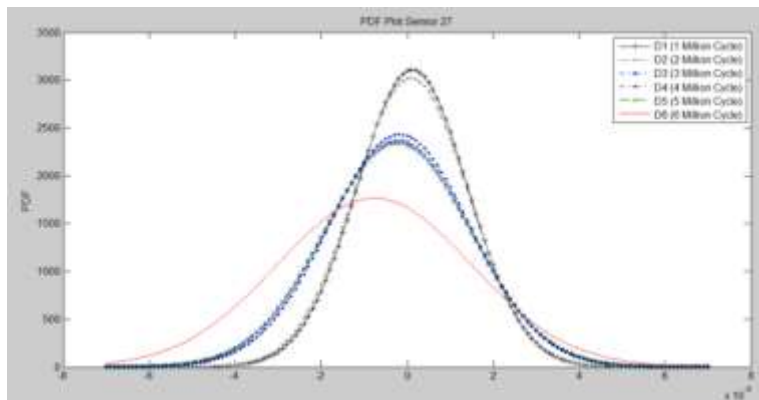
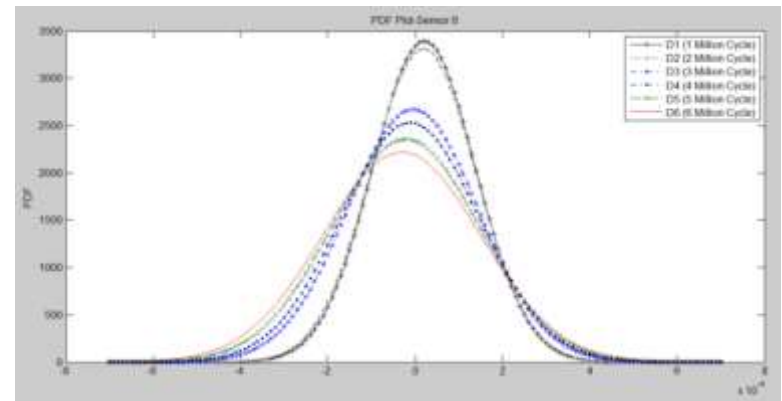
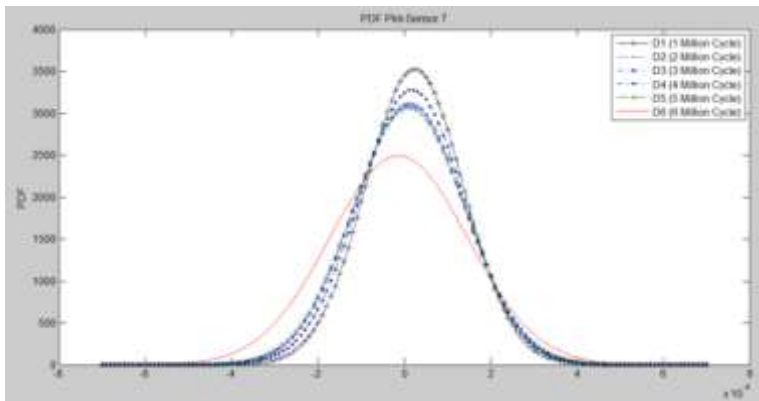
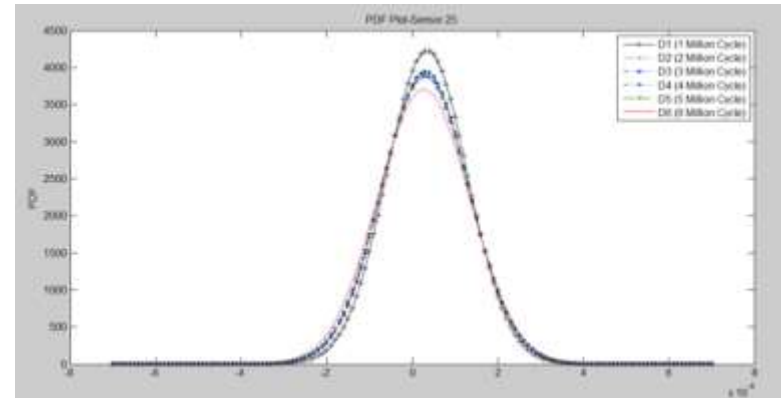
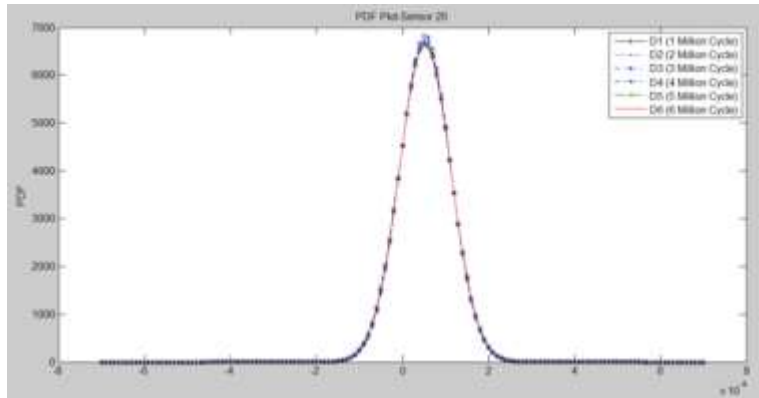
Distortion-Induced Fatigue Cracking in Bridge Girders



Strains in the central girder - Gap = 57mm

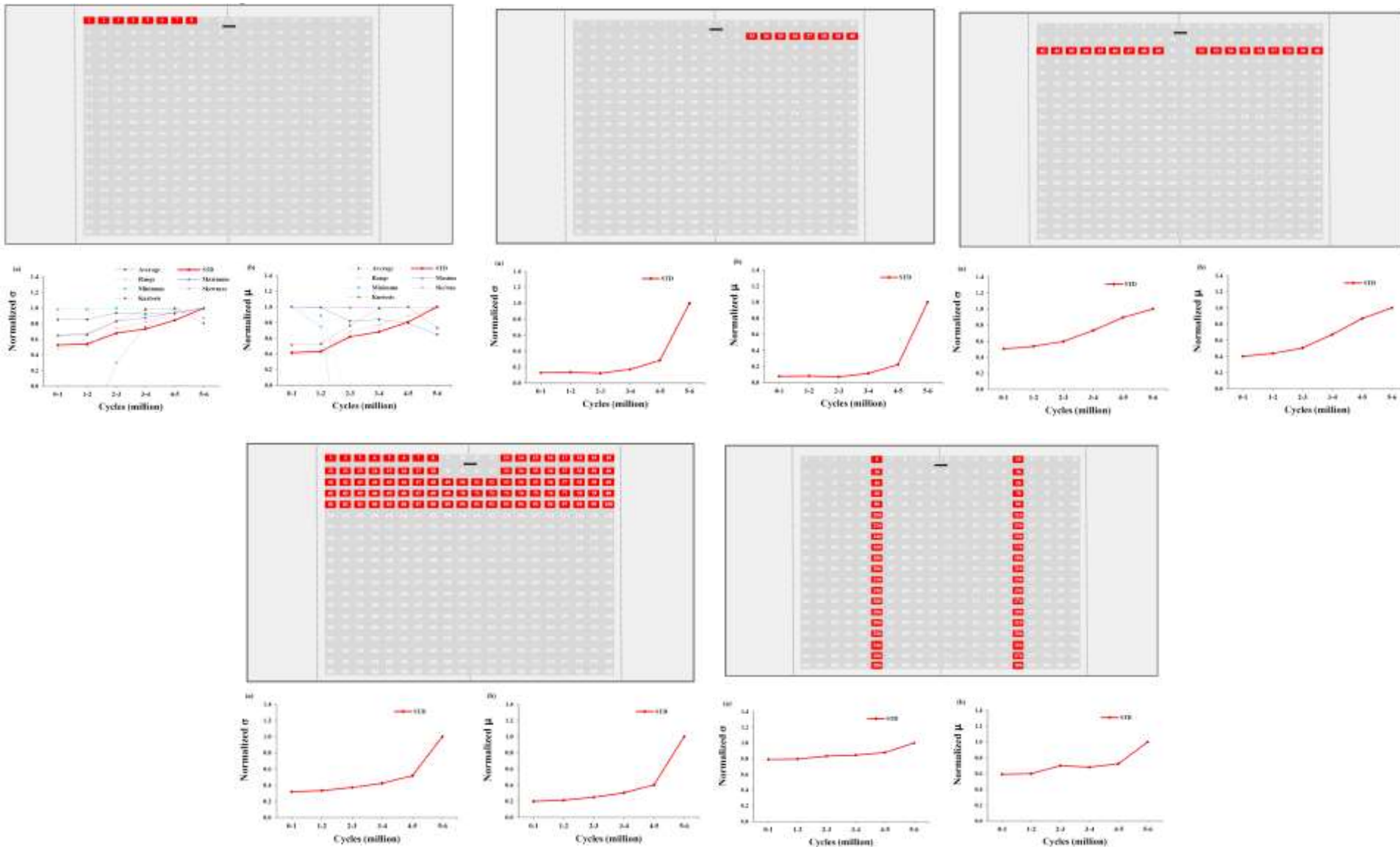


Distortion-Induced Fatigue Cracking in Bridge Girders

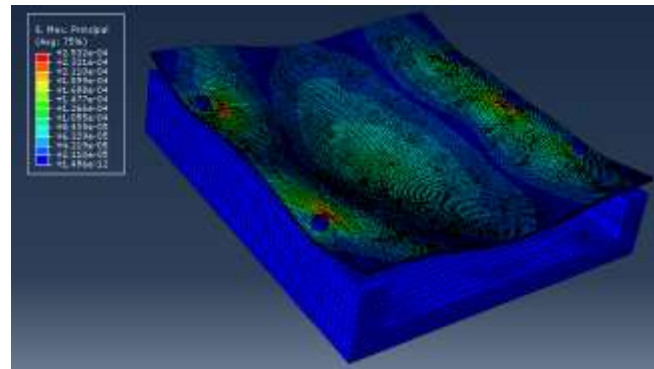
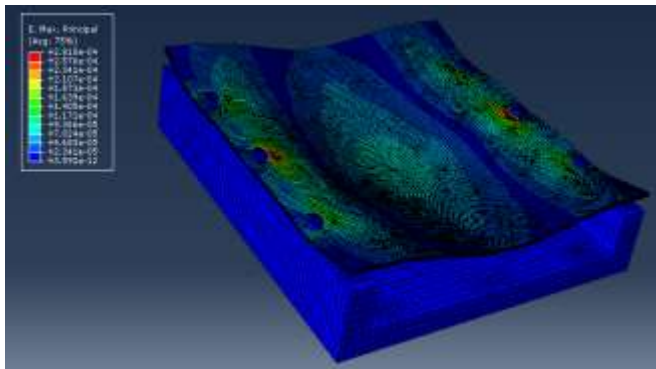
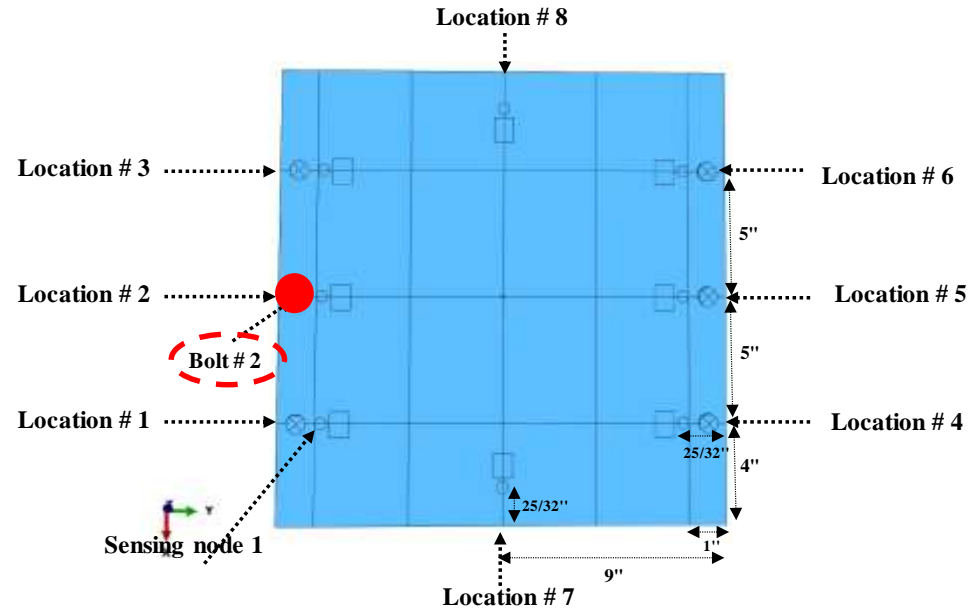
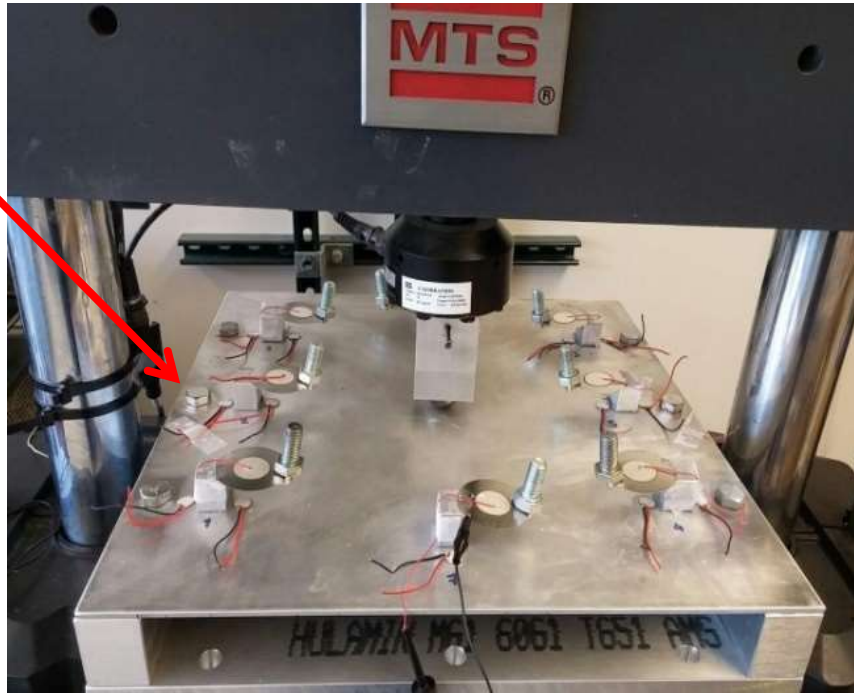


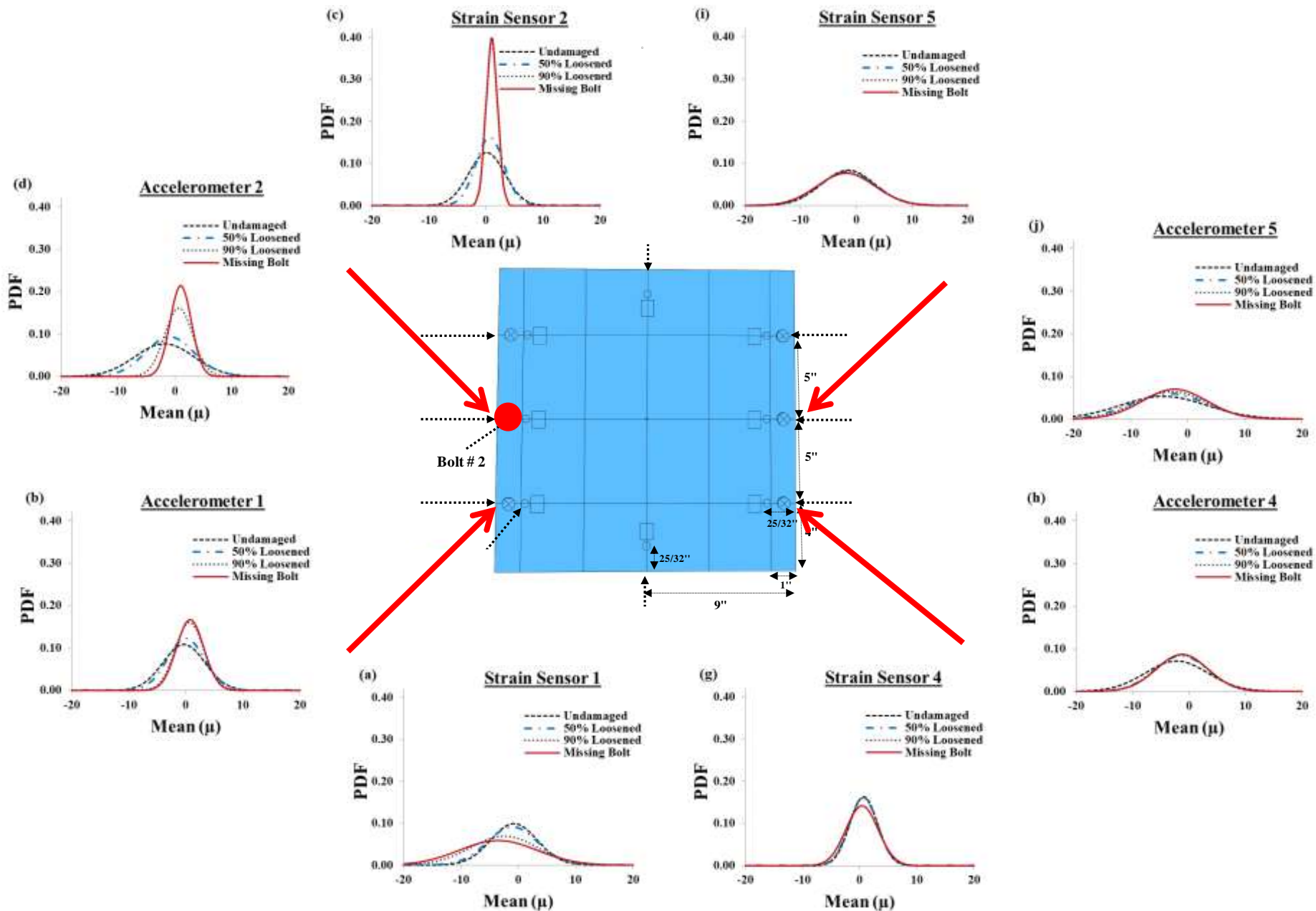
Distortion-Induced Fatigue Cracking in Bridge Girders

Sensor Group Effect



HYBRID NETWORK OF SELF-POWERED ACCELEROMETER AND STRAIN SENSORS

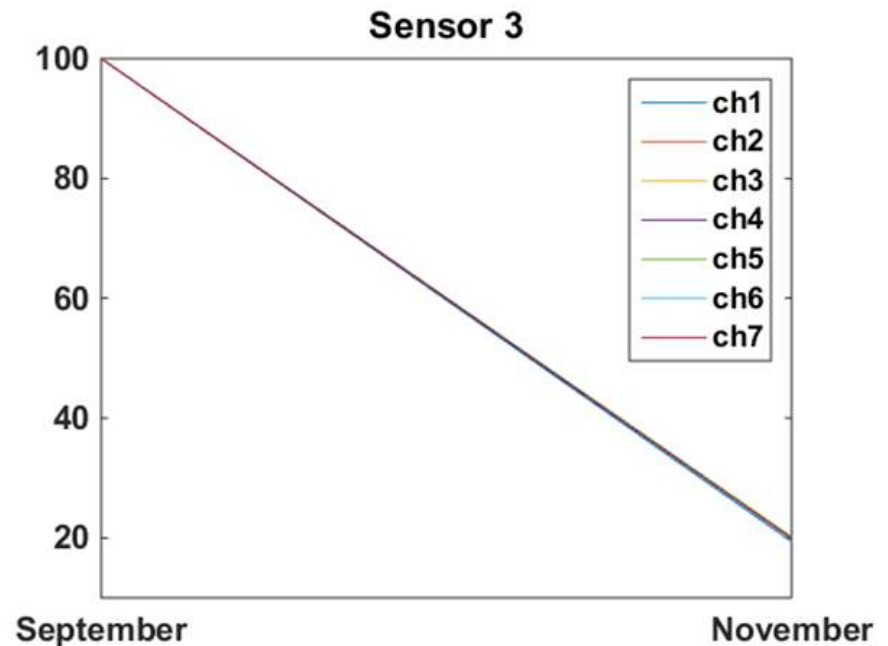
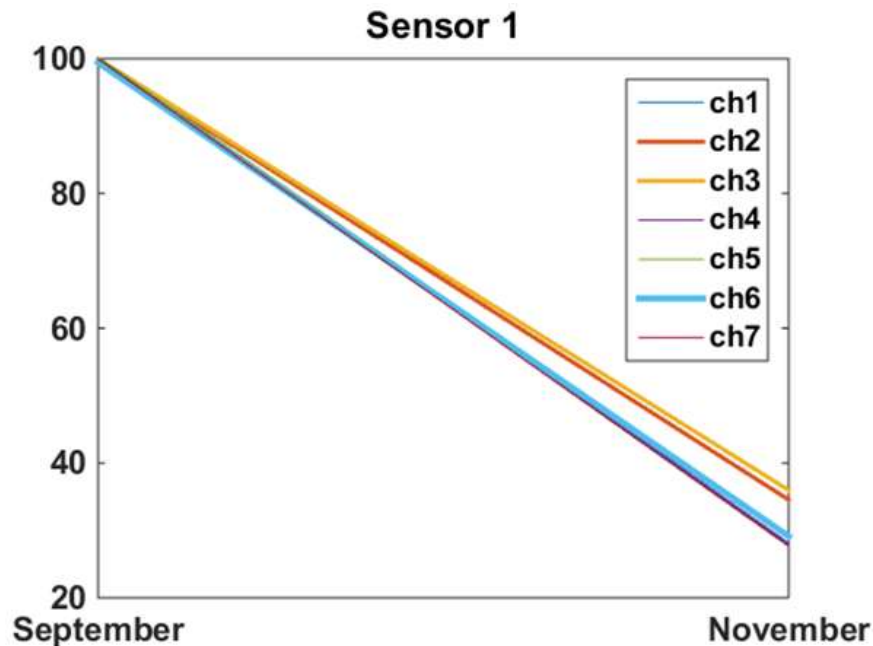
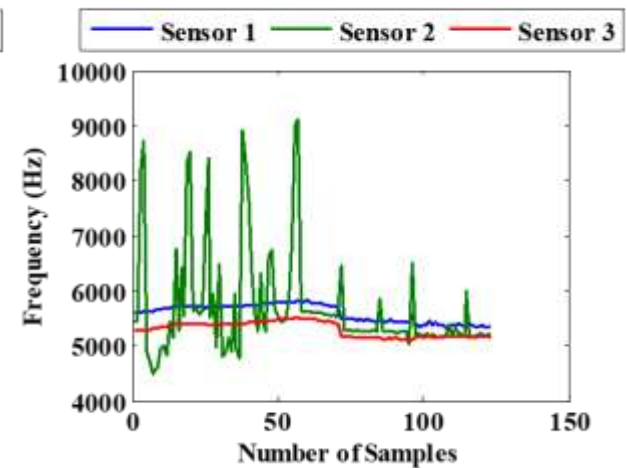
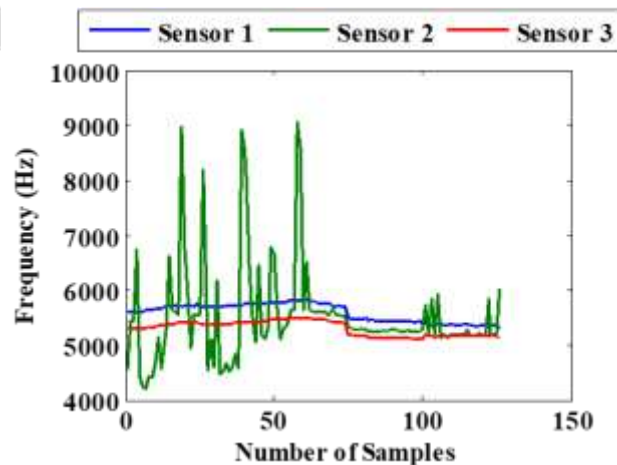
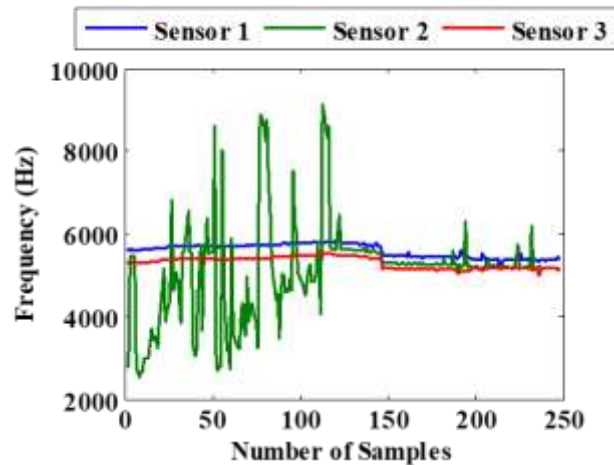




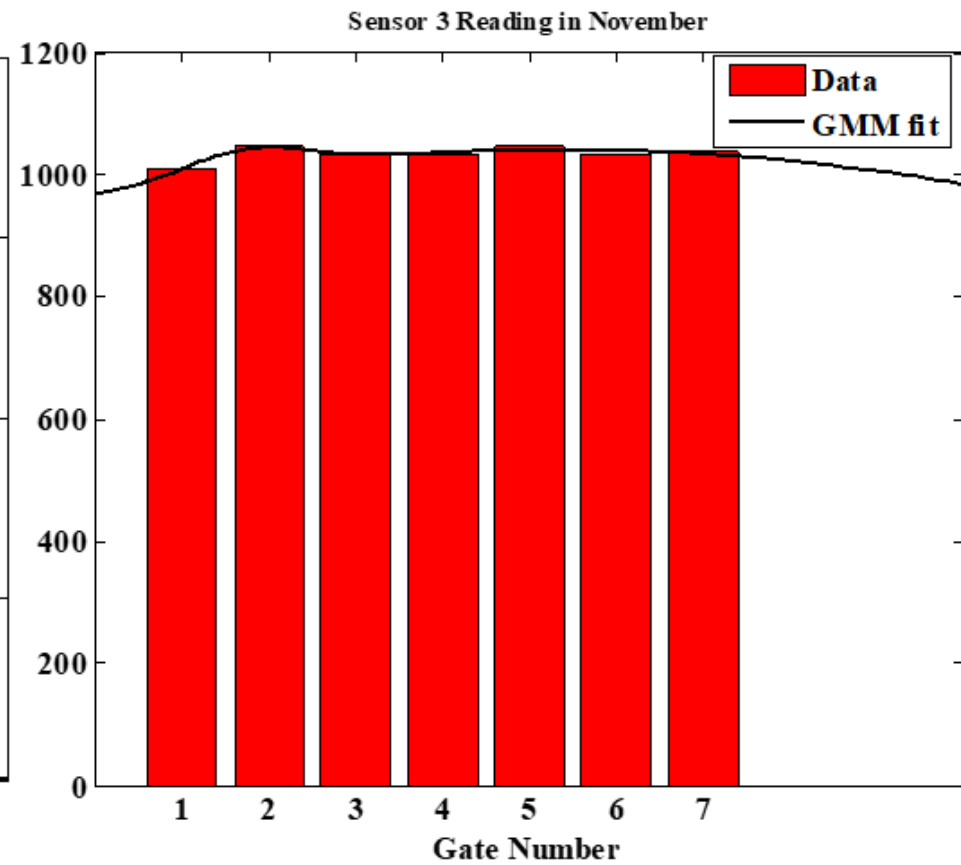
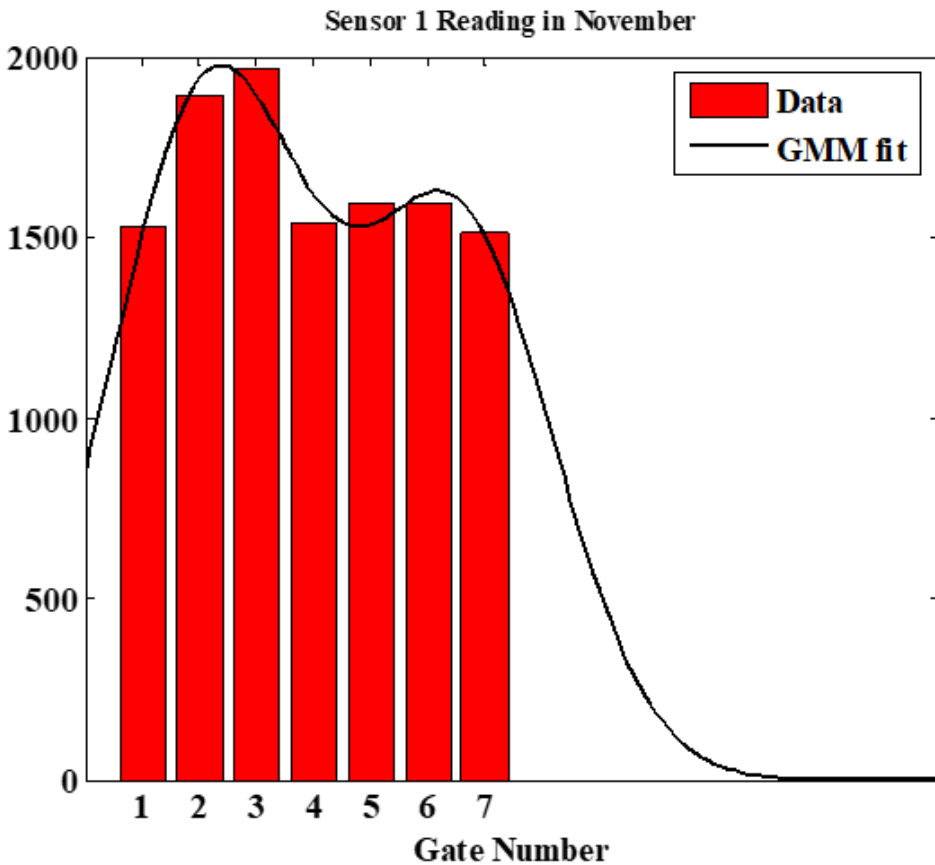
Large Scale Testing – Mackinac Bridge Michigan



Large Scale Testing – Mackinac Bridge Michigan



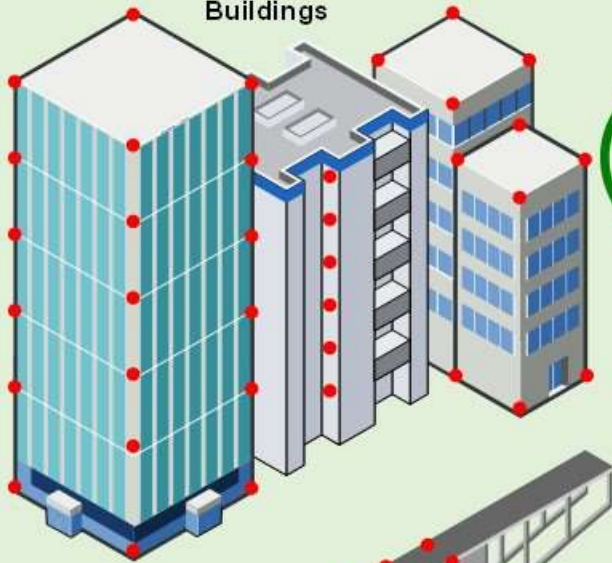
Large Scale Testing – Mackinac Bridge Michigan



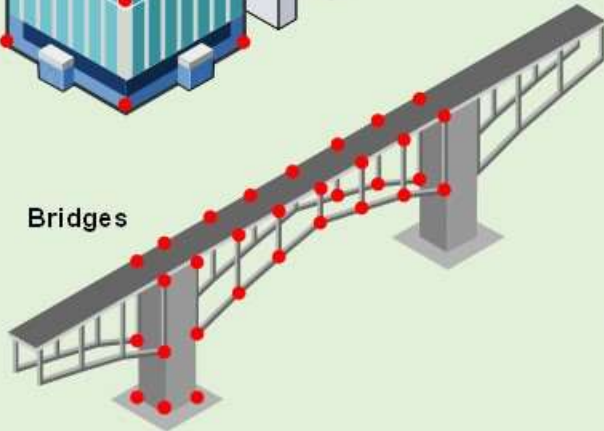
Towards infrastructural Internet-of-things

Test-beds

Buildings

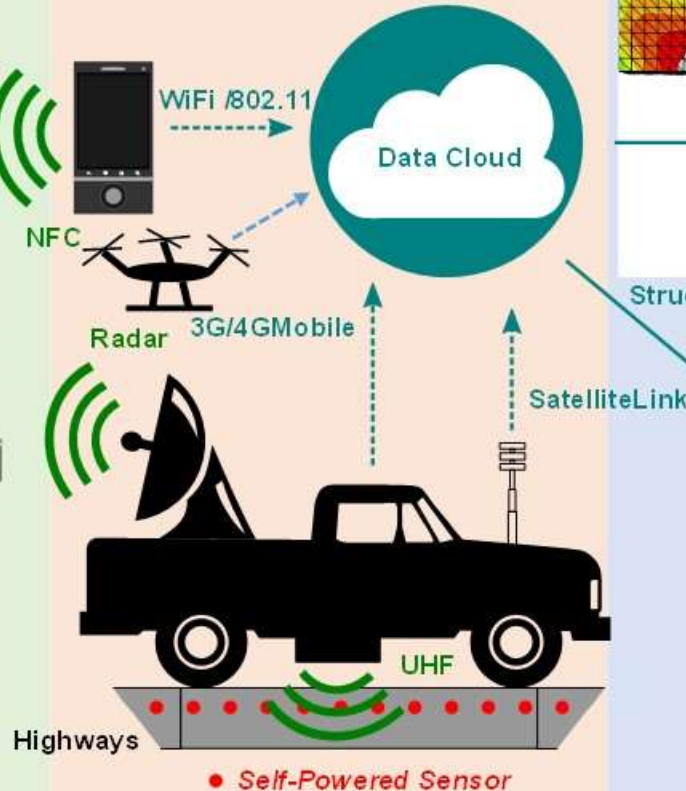


Bridges



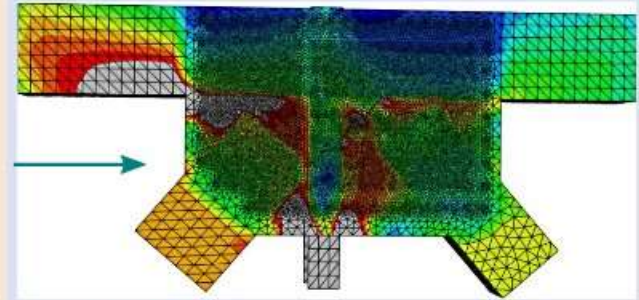
- Buildings (**UNR**)
- Highways (**State & International Department of Transportation**)
- Bridges (**Mackinac Bridge Auth.**)

Sensors

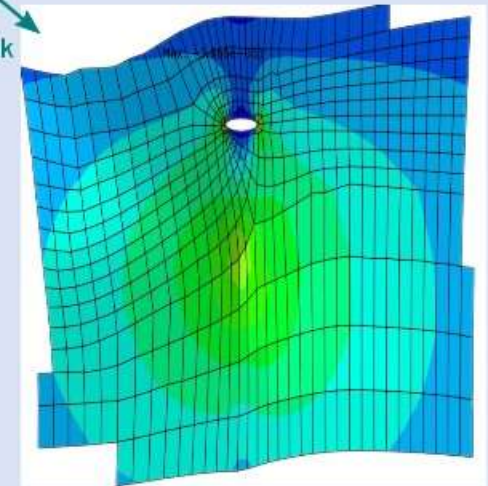


- Self-powered Health Monitoring Sensors
- Hybrid Energy Scavenging RFID Processors.

Data Interpretation



Structural Forensics



- Data aggregation, analytics and damage prediction.
- Structural forensics.

Multi-metric Self-Powered Wireless Sensors for Infrastructure Monitoring

**Nizar Lajnef¹, Shantanu Chakrabartty²,
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