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THE STATE UNIVERSITY OF NEW JERSEY

Center for Advanced Infrastructure and Transportation (CAIT)

Overview of Global Structural Assessment Techniques

John DeVitis, David Masceri, Nicolas Romano, John Braley, Adriana Trias, Dominic Wirkijowski, Franklin Moon
Rutgers University

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Instrumentation vs Global Structural Assessment (St-Id)

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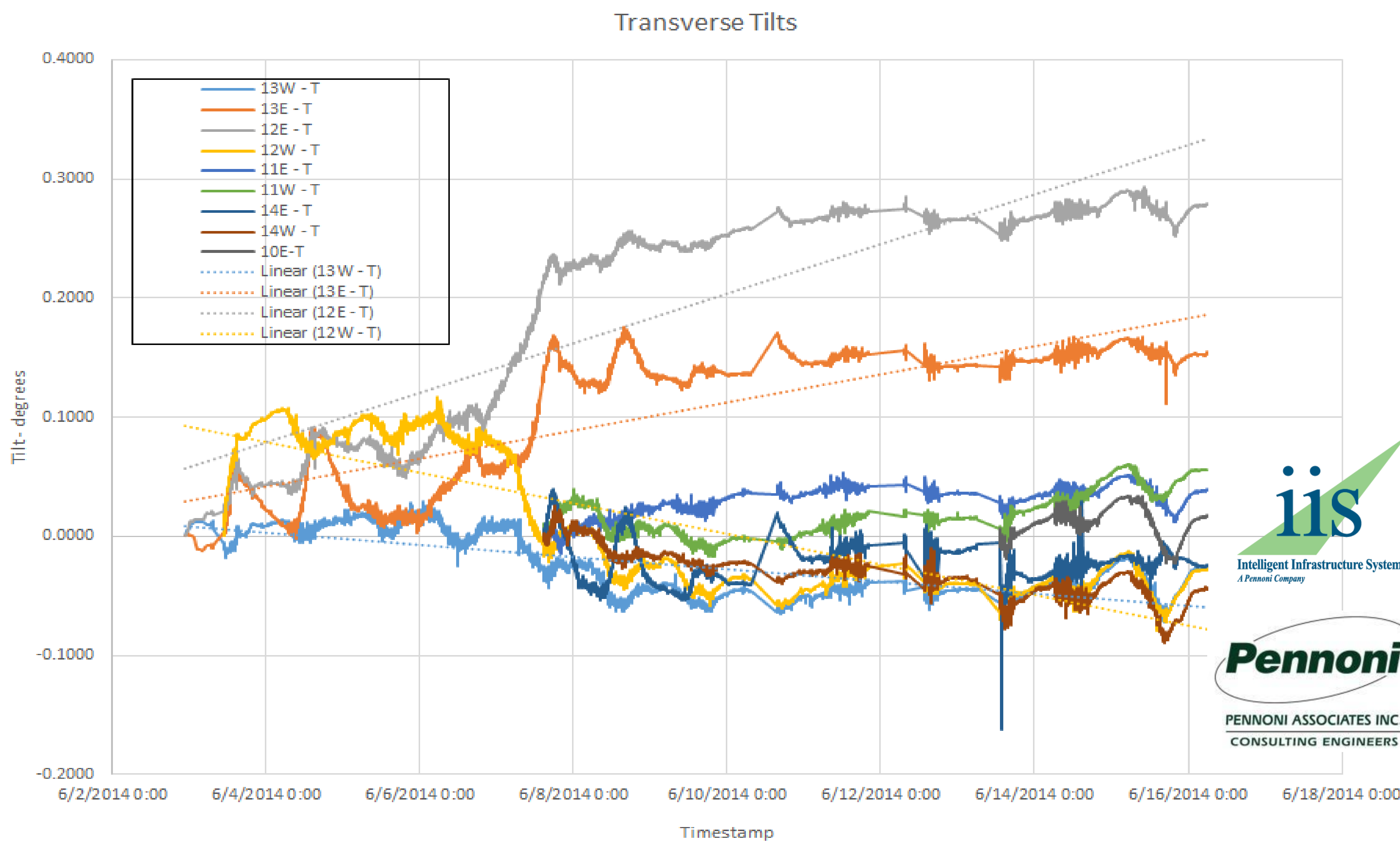
Instrumentation = Direct Measurement



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Fundamental Challenge with St-Id/SHM

Observable Responses (Measureable e.g. strain)

Global Assessment
Structure Dependent

Local NDE
Material Dependent

Unobservable Attributes (Immeasurable, e.g. capacity)

What you can measure is not what you need.

What you need, you can't measure.

All data cannot inform all behaviors

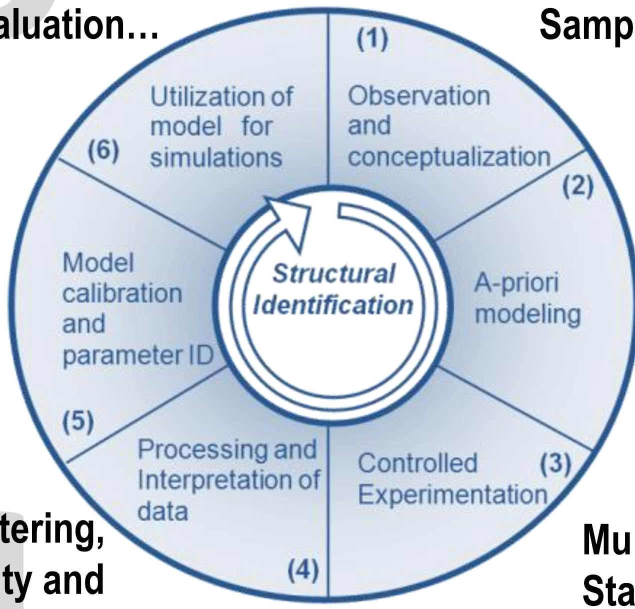
Why is this "Translation" so Difficult?
(Constructed Systems vs. Manufactured System)

Uniqueness	Nearly all constructed systems are custom-designed for specific applications and their mechanical characteristics - applying results from a single structure to a larger population of structures is challenging due to their inherent uniqueness.
Uncertain and Large Intrinsic Forces	Constructed systems maintain complex and non-stationary intrinsic forces due to dead weight, construction loads/staging, temperature effects, deterioration, damage, overloads, etc. These intrinsic forces are nearly impossible to measure in an absolute sense and just their changes often overwhelm the forces due to transient live loads.
Non-Stationarity	Constructed systems are non-stationary due to the non-stationary nature of inputs (temperature, radiation, traffic, wind, etc) as well as their various loading-level and loading-type related nonlinearities.
Complex Continuity Conditions	Most constructed systems, and especially bridge systems are designed with movement systems and/or force releases. These systems are most often unobservable and behave differently under different levels of force and temperature.
Complex Boundary conditions	Constructed systems have unobservable soil-foundation interfaces that are often non-stationary in their contact properties. Soil and even rock properties change with pressure, moisture, temperature and time.
Large Geometric and Temporal Scale	Constructed systems such as major highway bridges or combinations of several bridges and tunnels within regional transportation networks may be longer than several miles, cost several billions of dollars , and be expected to remain in service for well over 100 years.

Structural Identification Framework

Load Ratings, Scenario Analyses, Vulnerability Assessment, Retrofit Evaluation…

Document Review, Site Visits, Inspection, Material Sampling…

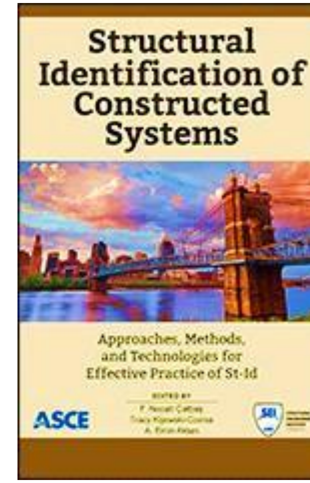


Heuristic Knowledge
Automated Parameter ID
Bayesian Model Updating…

Model Type Selection
Sensitivity Studies
Measurement Predictions
Instrumentation Design…

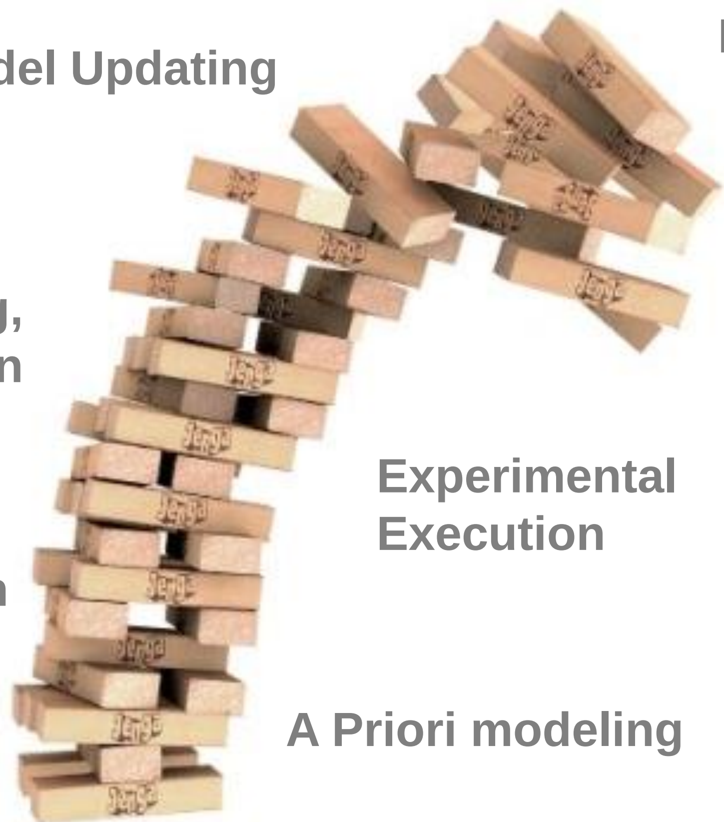
Data Processing (Filtering, Averaging), Linearity and Repeatability, Experimental Data Processing…

Multi-Modal Instrumentation
Static/Crawl-speed Truck Testing
Environmental Monitoring
Dynamic Testing…



Design and implementation of Structural Health and Performance Monitoring Systems

Another Perspective on St-Id…



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Distinct Challenges

Signature Bridges

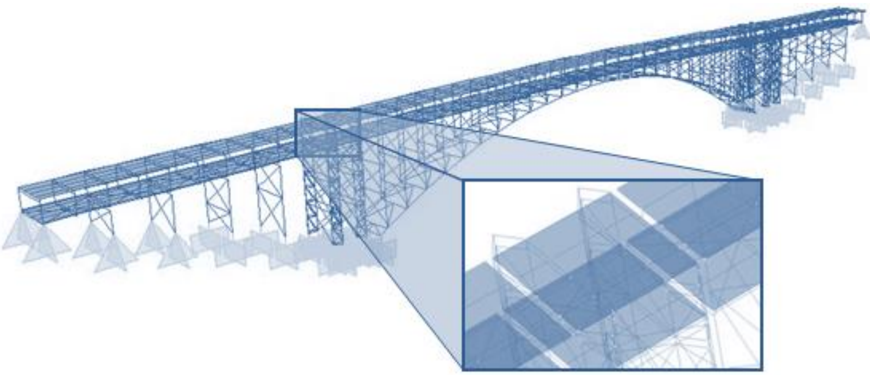
- Logistically difficult to replace
- Unique
- Expensive to maintain
- Owners: Predominantly Toll Agencies

Common Bridges

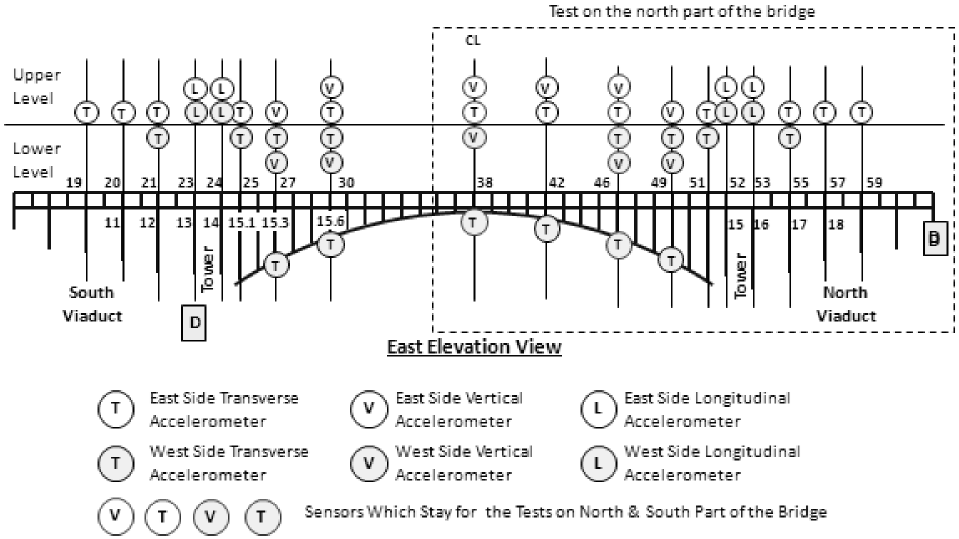
- Large population of similar structures
- Relatively inexpensive to replace
- Difficulty to prioritize investments
- Owners: States, Counties, Turnpikes

Current St-Id Approaches to Signature Bridges

FE Model



Ambient Vibration Monitoring

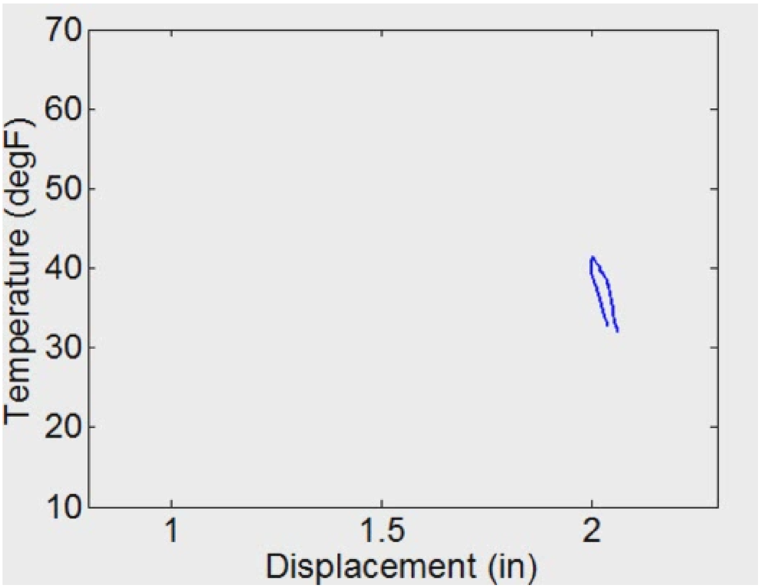


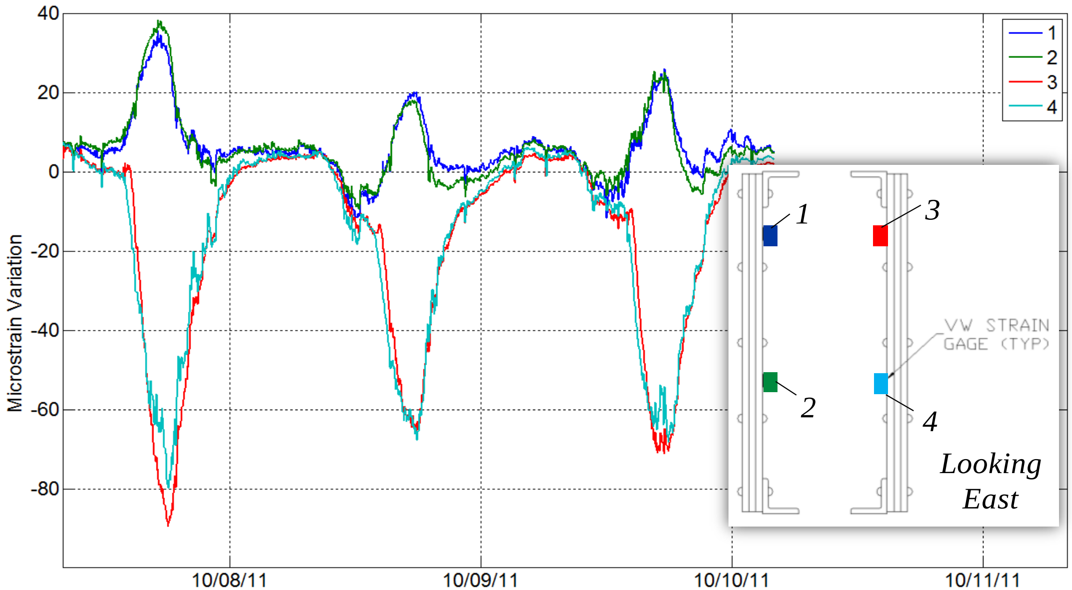
Common model parameters

- element stiffness
- continuity and boundary conditions
- mass

Some selected examples…

Temperature-Driven SHM





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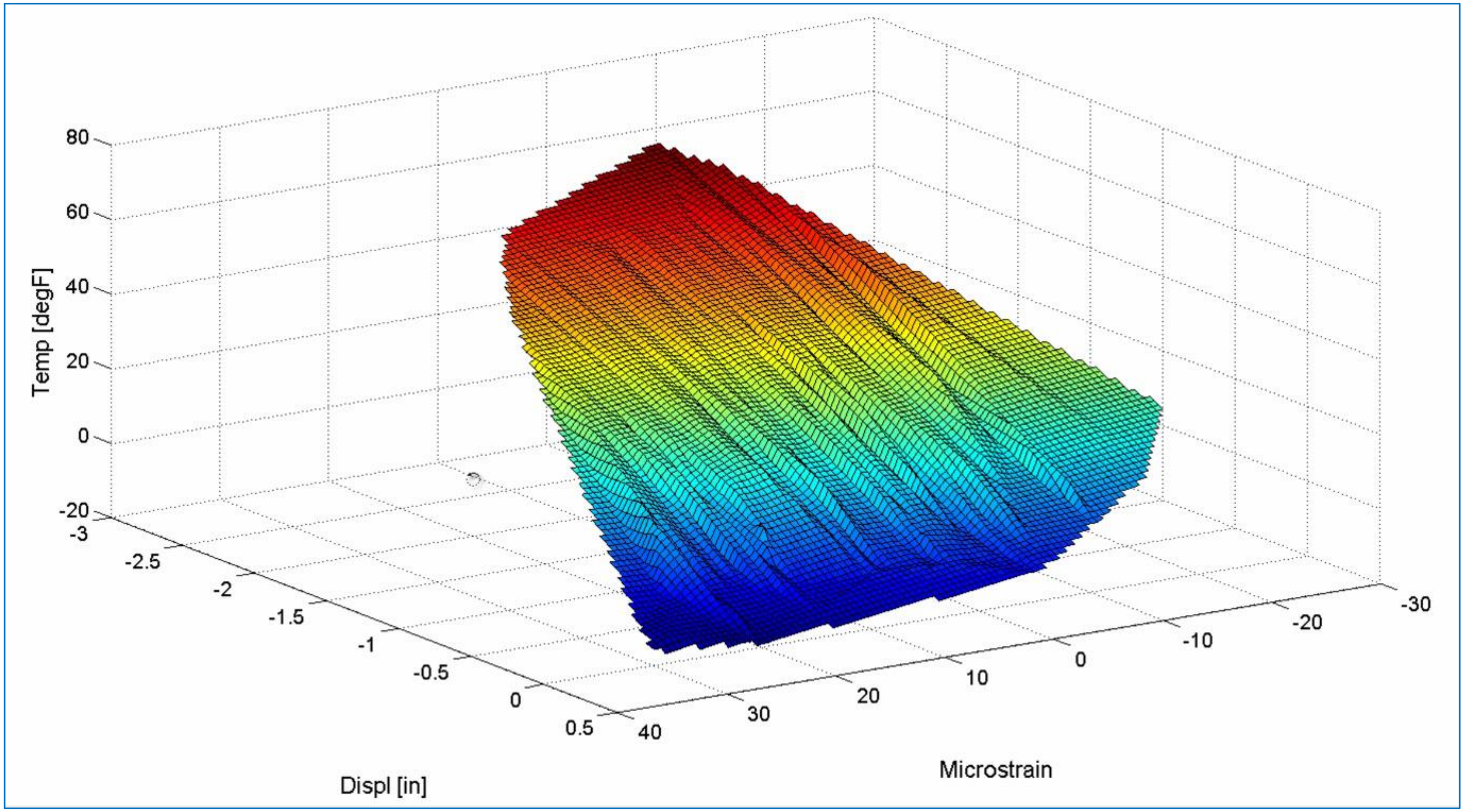
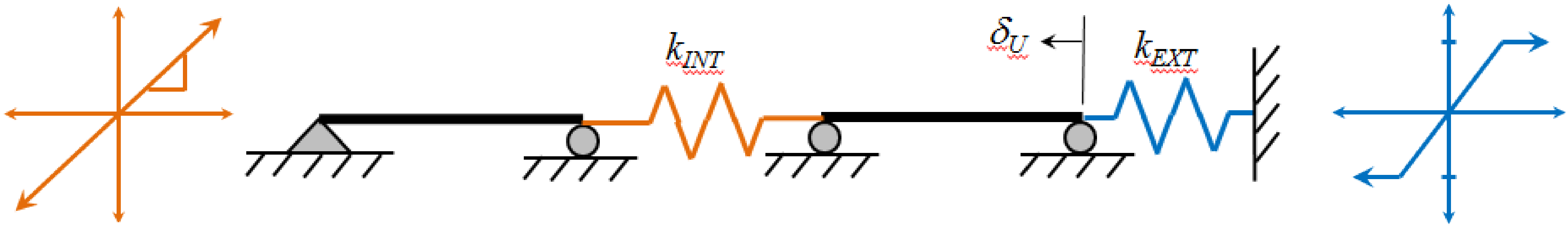
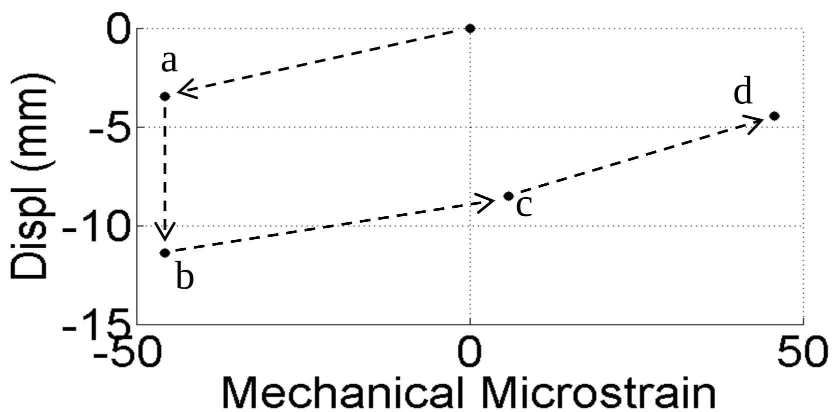
Baseline Plane in Strain-Disp-Temp Space

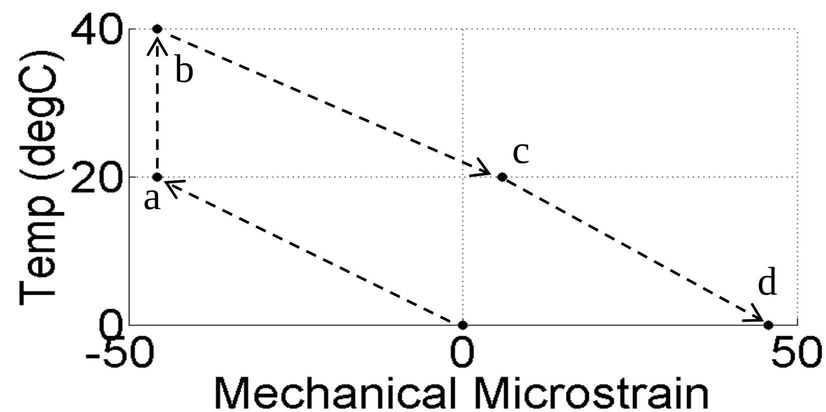


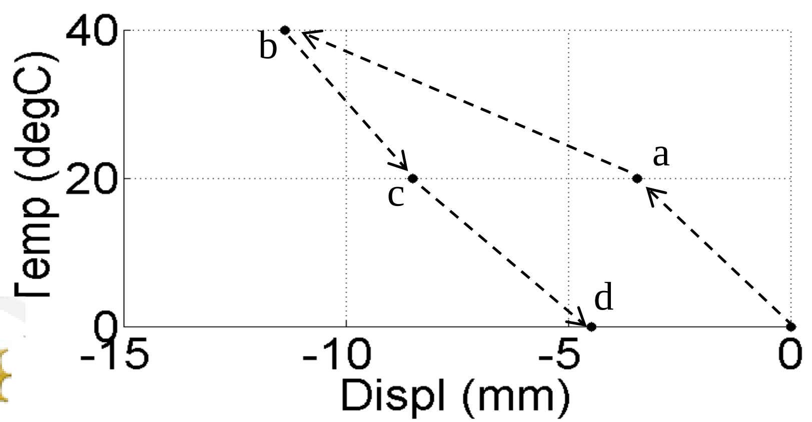
3D Planes offer unique and highly sensitive baseline to degenerative performance problems related to boundary and continuity conditions

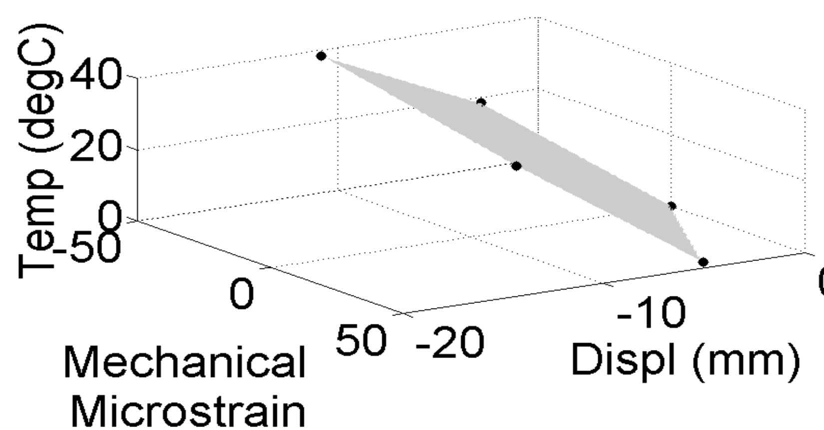
Mechanistic Understanding of the Plane











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Sensitivity to Common Damage Scenarios

Damage Scenario		Temperature-Driven			Vibration-Based	
		Disp.	Strain	Location	Freq.	Mode Shapes
Locking of Expansion Bearing	Avg.	31%	252%	-	2%	1%
	Max	-	375%	U2U3	6%	6%
	Min	-	0%	L0L1	0%	0%
Failure of Slotted Connection	Avg.	3%	114%	-	0%	0%
	Max	-	334%	U1U2	1%	0%
	Min	-	1%	U2U3	0%	0%
Fracture of Tension Chord	Avg.	2%	5%	-	1%	1%
	Max	-	40%	L2L3	1%	2%
	Min	-	0%	L0L1	1%	0%

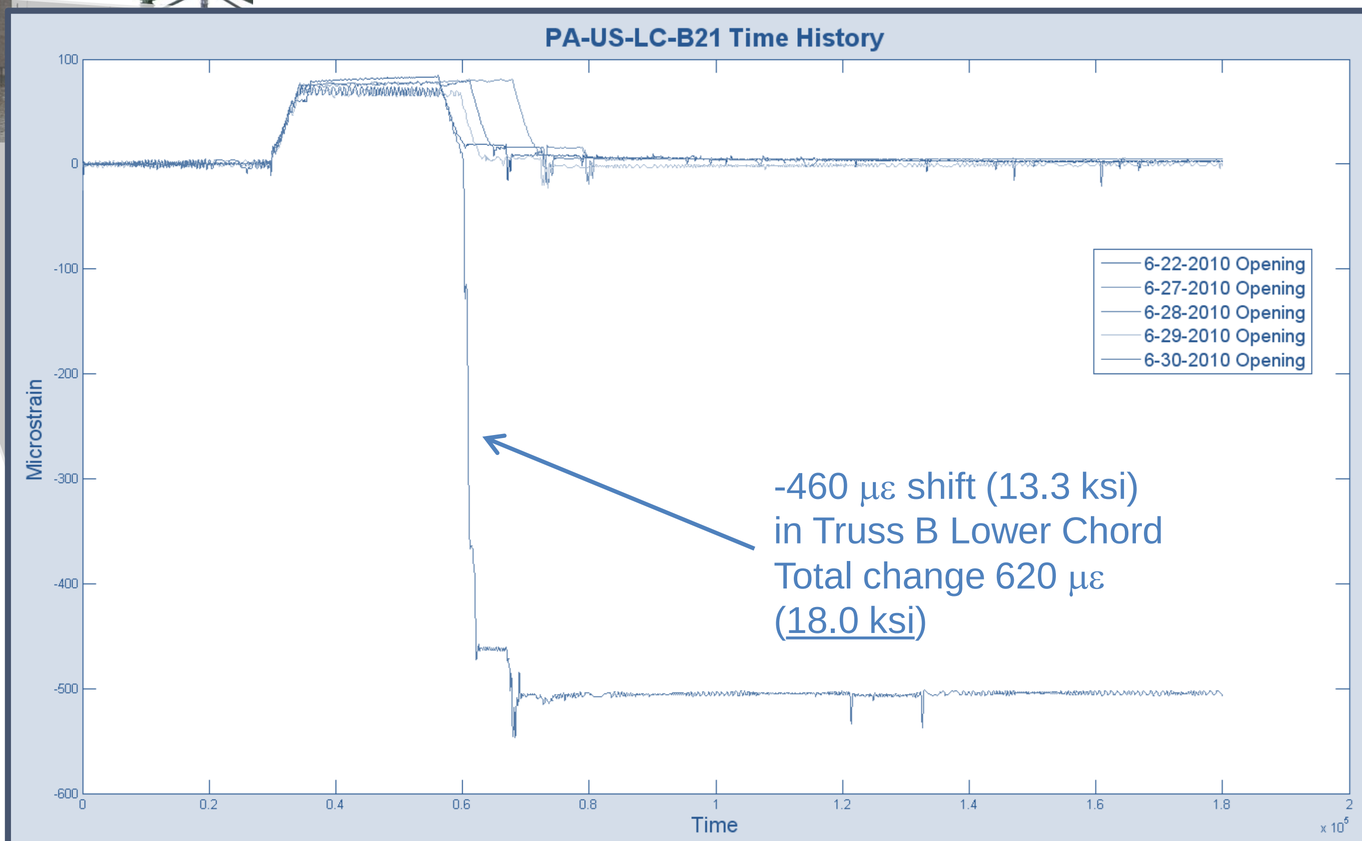
Bayonne Bridge – Raise the Roadway

Raising deck 65' to accommodate larger ship traffic.
Maintaining vehicular traffic passage during construction.
Installing structural health monitoring system.

Example of Construction

Example Triggered Event

Strain Time Histories Captured Along the Lower Chord of Trusses A and B During Construction

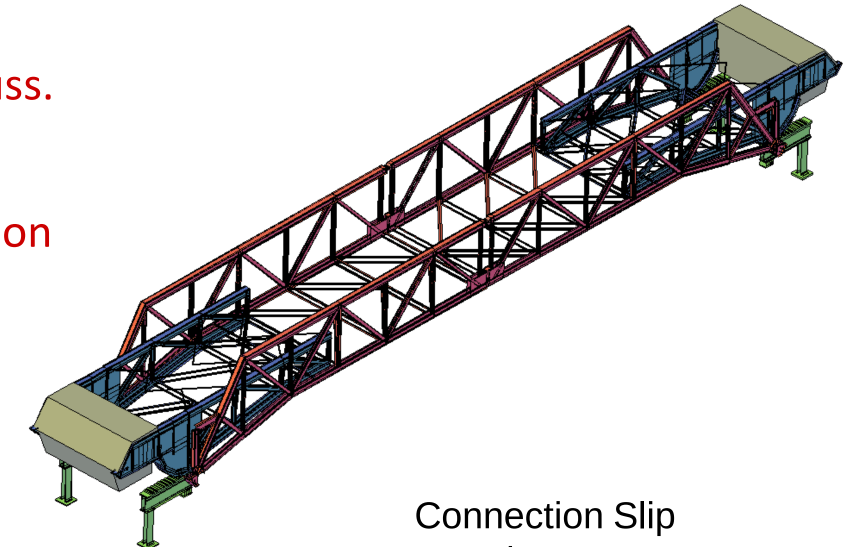


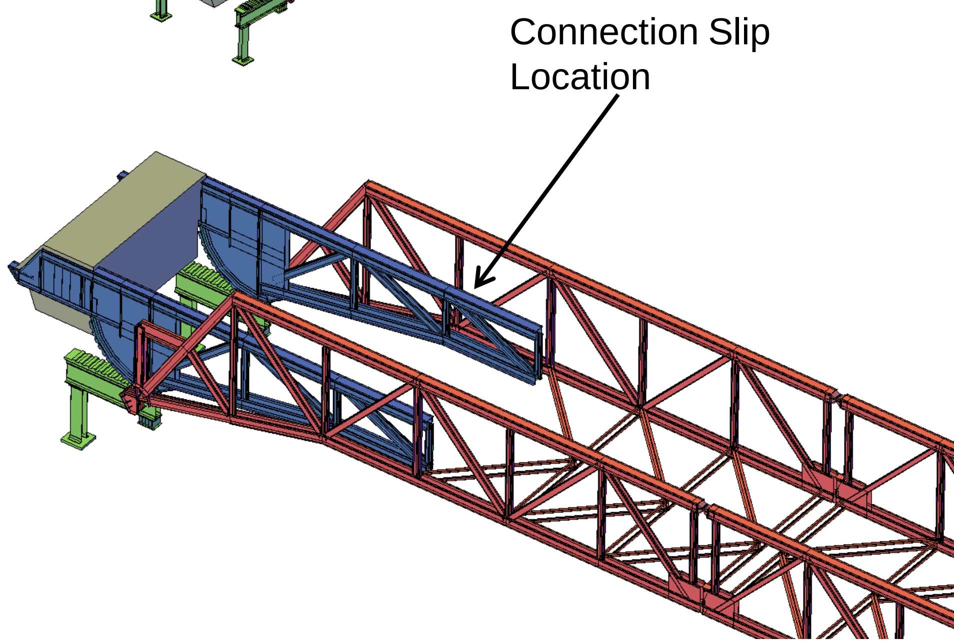
Interpretation, Model Updating, Outcome

The cause was traced (through direct interpretation and FE analysis) to a connection slip in the lifting truss.

The slipped occurred because the contractor insufficiently tightened temporary bolts in anticipation of steel repairs.

The contractor was alerted to the issue and took appropriate corrective actions.

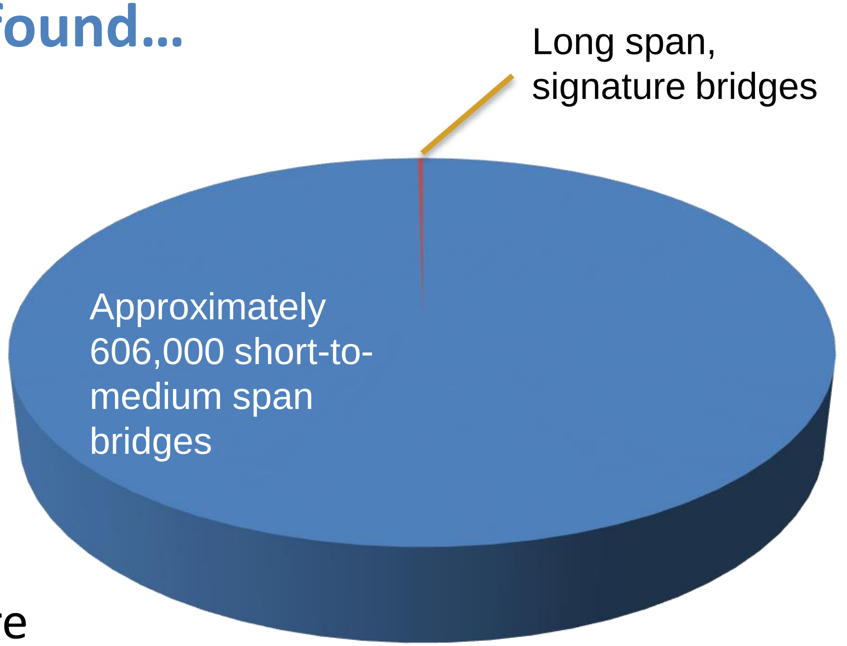




Implementation of Current Practice

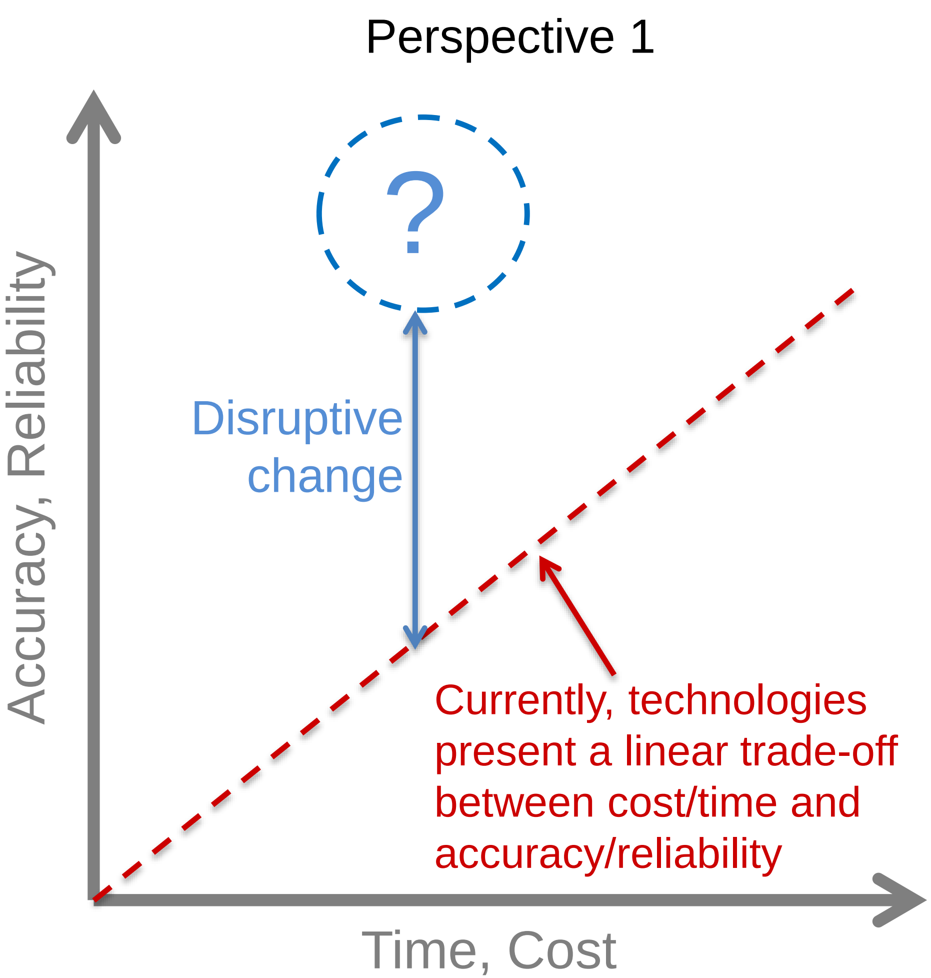
A recent NCHRP study (Hearn 2014) found…

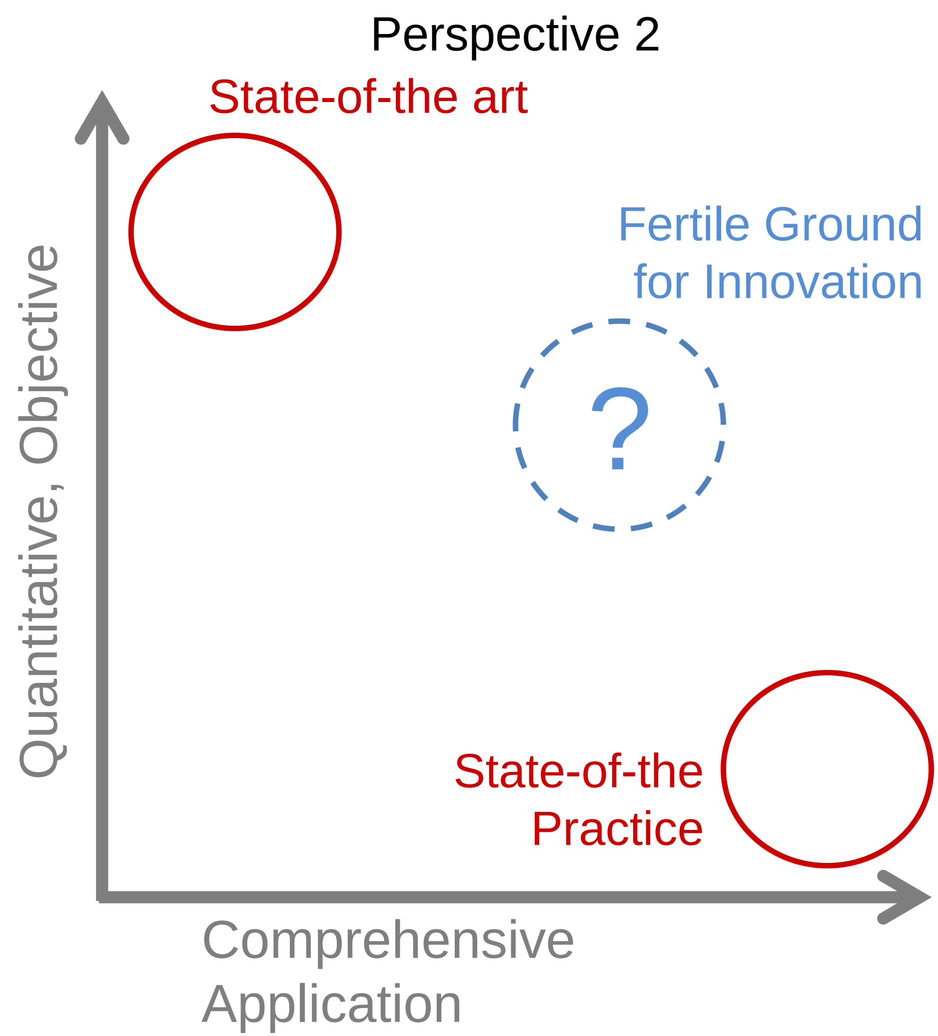
- 80% of bridges are rated using simplified structural analysis procedures.
- 16% of bridges received no load rating
- Approximately 0.1% of bridges (~600) are rated based on load testing procedures
- Approximately 10% of bridges (~ 60,000) are posted for less than legal loads.



Hearn, G. (2014). State bridge load posting processes and practices. Washington, DC: Transportation Research Board of the National Academies.

Innovation Space





THMPER™ System for Rapid Capacity Evaluation

Targeted Hit for Modal Parameter Estimation and Rating

Step 1

Rapid modal impact testing using a self-contained mobile device

Step 2

Semi-Automated pre- and post-processing to obtain global frequencies and mode shapes

Step 3

Automated FE modeling using NBI data and on-site assessment

Step 4

Automated FE model calibration and load rating

Step 5

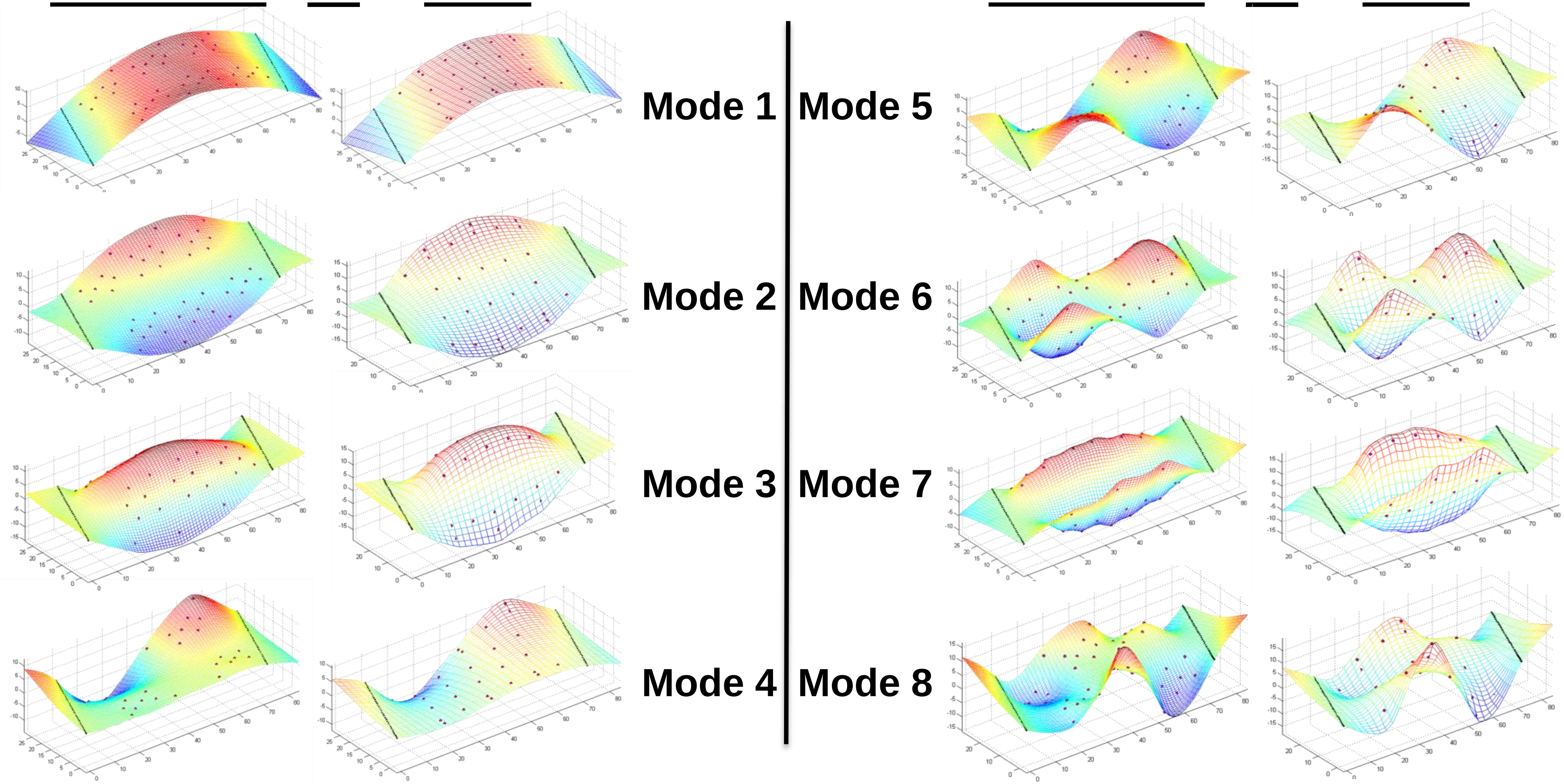
Reporting

* Patent pending

THMPER System – Rapid Data Collection

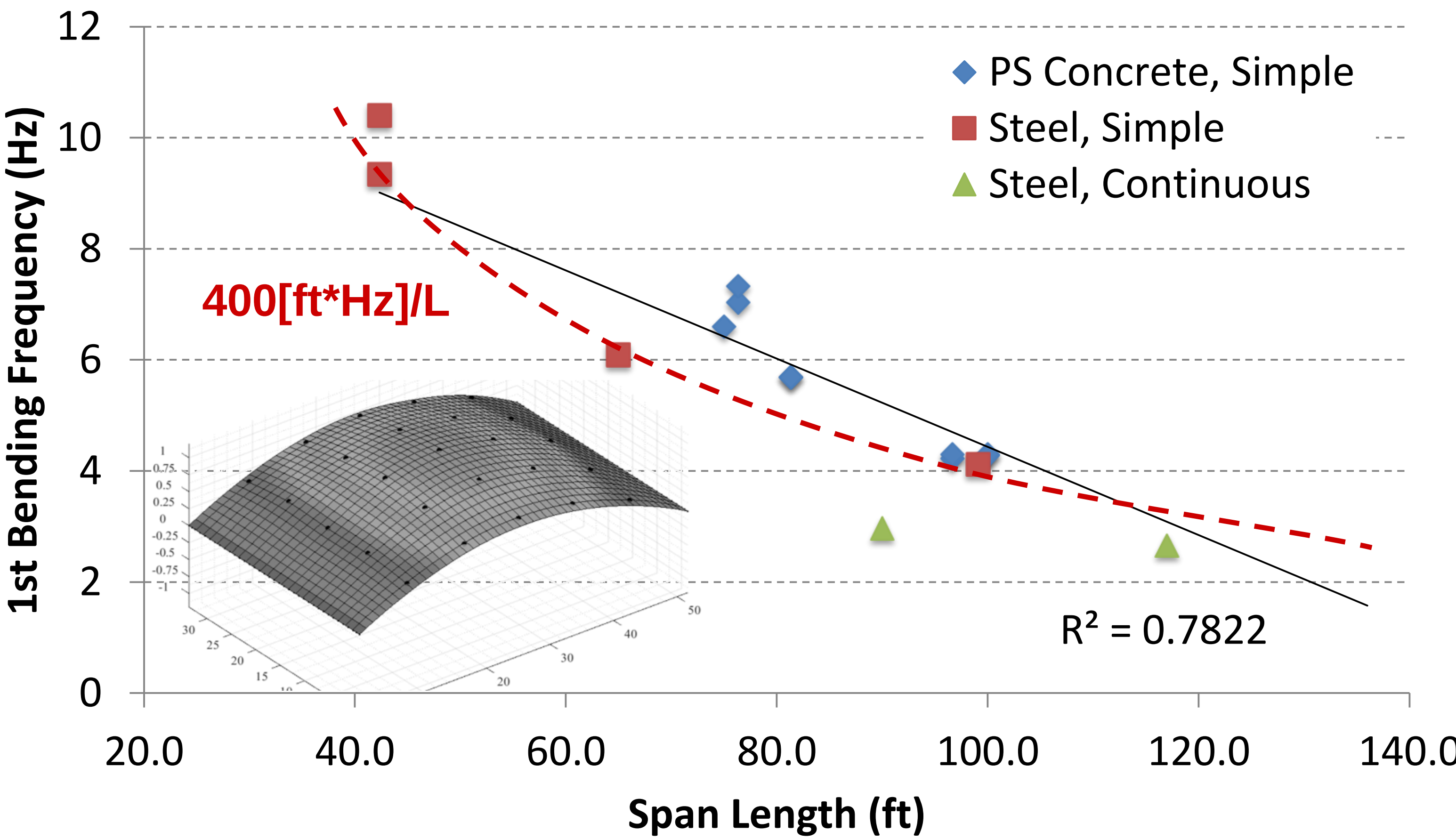
THMPER™ Comparison with MIMO*

THMPER™ VS MIMO **THMPER™ VS MIMO**



* Best practices approach to modal impact testing

Primary Trend of 1st Bending Frequency

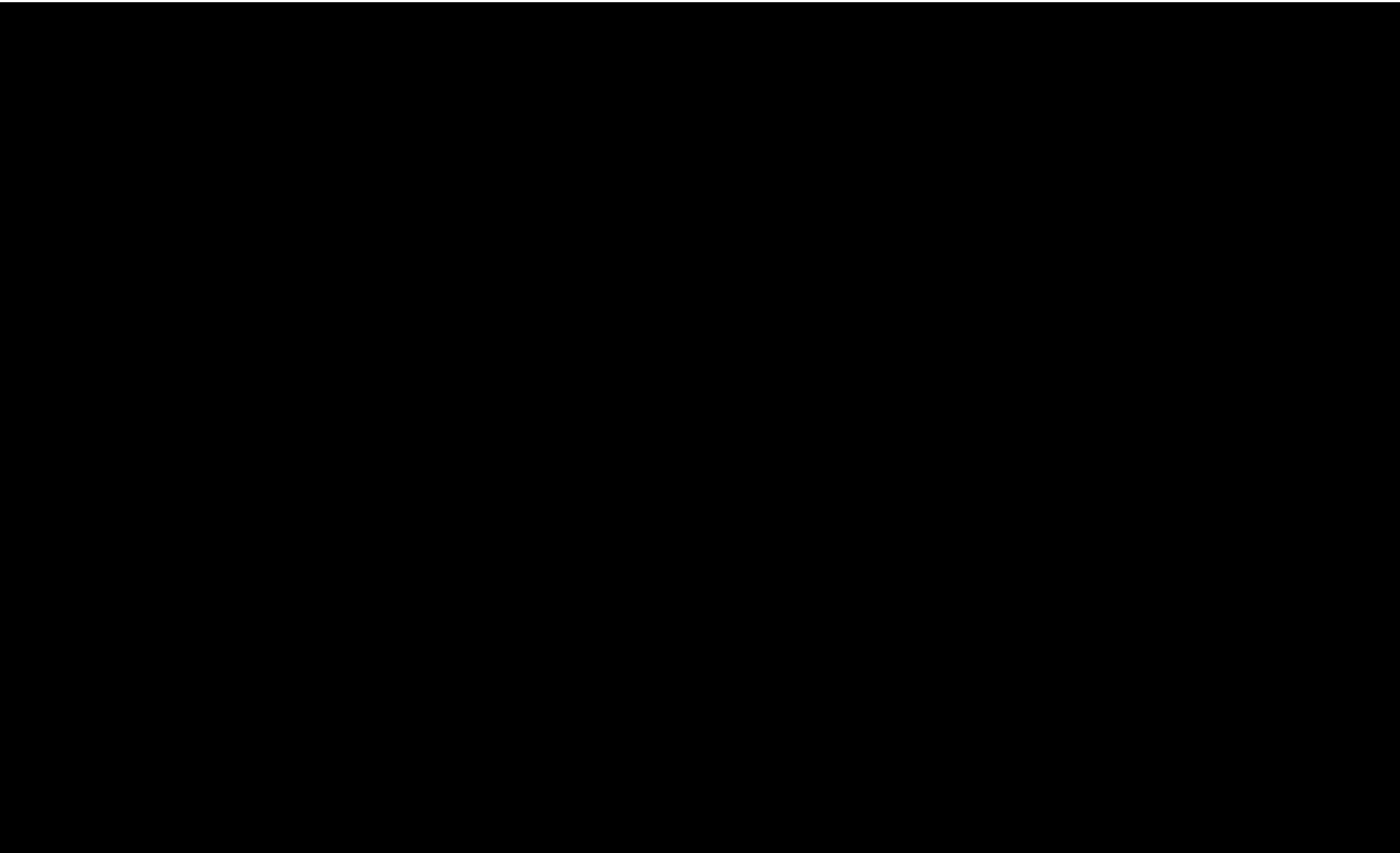


$$w = \sqrt{\frac{k \sim 1/L}{m \sim L}}$$

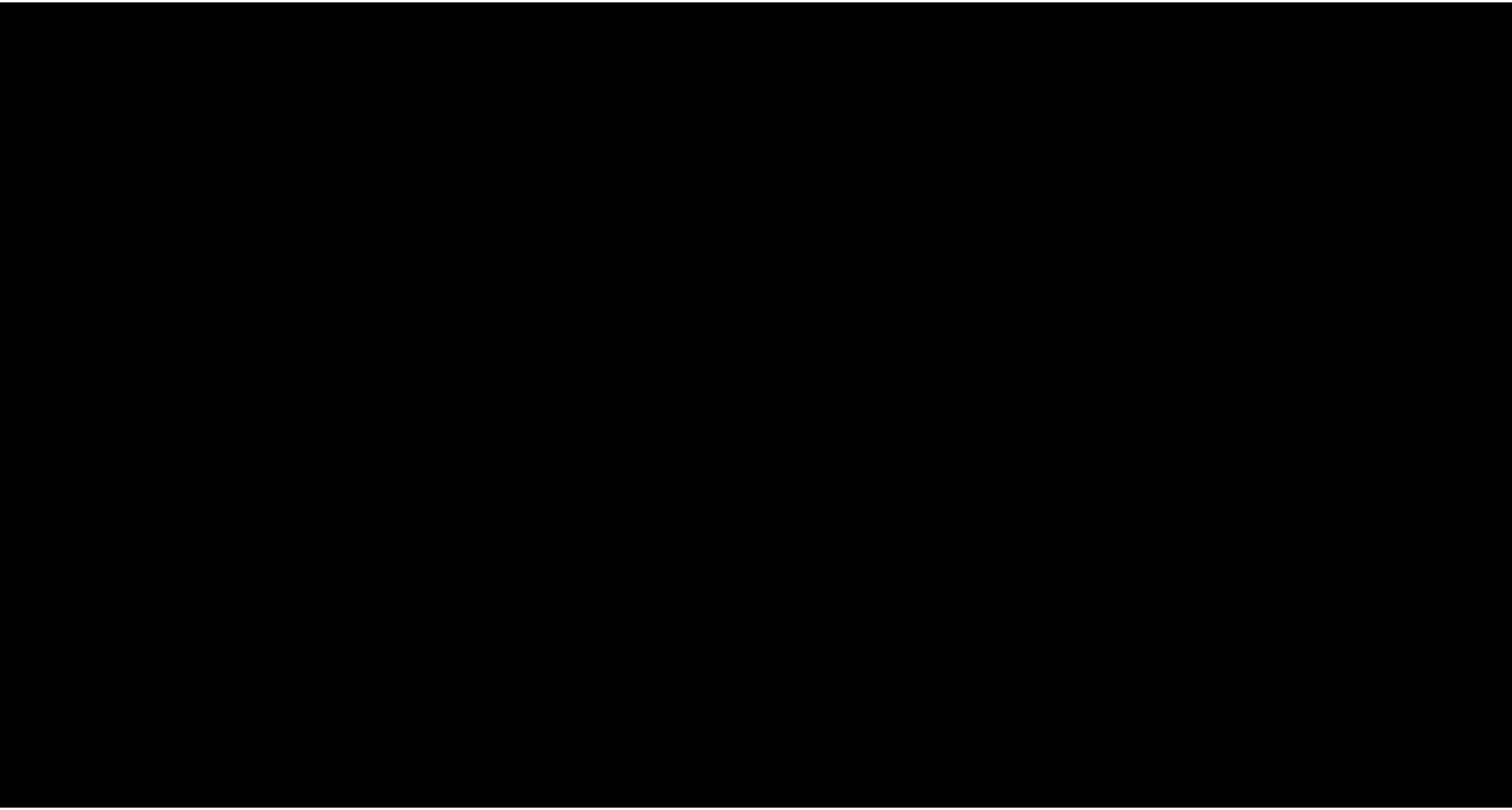
$$w \sim \sqrt{\frac{1}{L^2}}$$

$$w \sim \frac{1}{L}$$

Automated FE Model Creation and Simulation



Automated Model Updating and Rating



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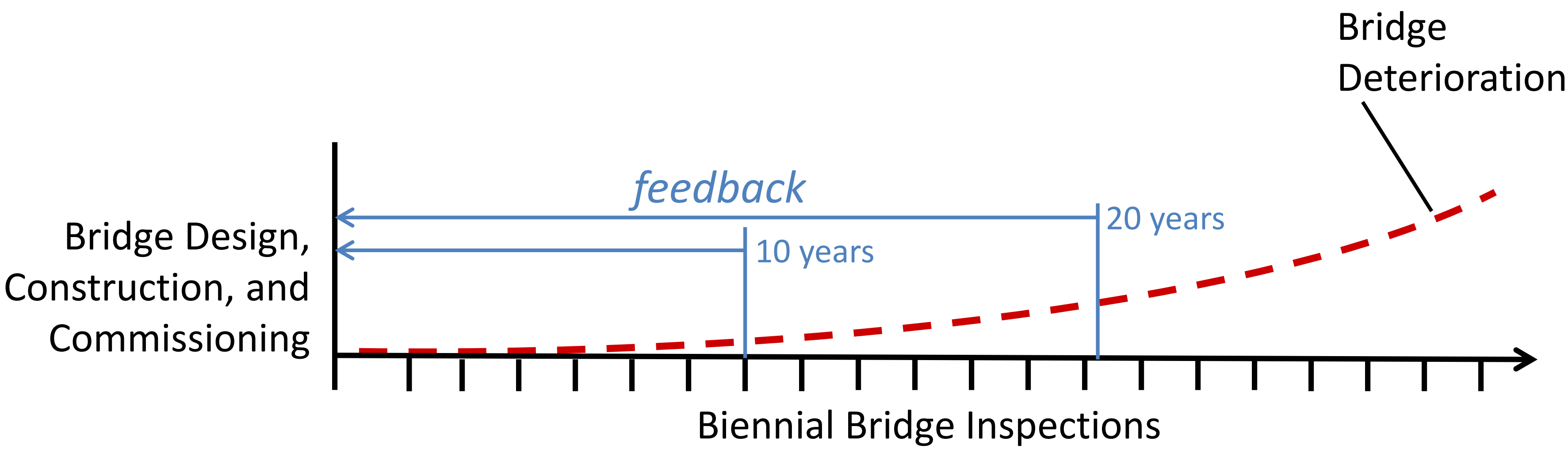
Thoughts on Global Assessment Applications

1. A successful application of SHM/St-Id depends on the presence of a "problem" that sensor data may inform
2. If a sensor is applied without understanding how the data will be used, then the data will likely be useless
3. All types of data cannot inform all types of behaviors
4. Translating measured data into something useful requires sound heuristics, simulation models, and/or data from populations of similar structures
5. You don't get something for nothing
6. The simplest solution, is the best solution

Accelerating the Feedback Loop



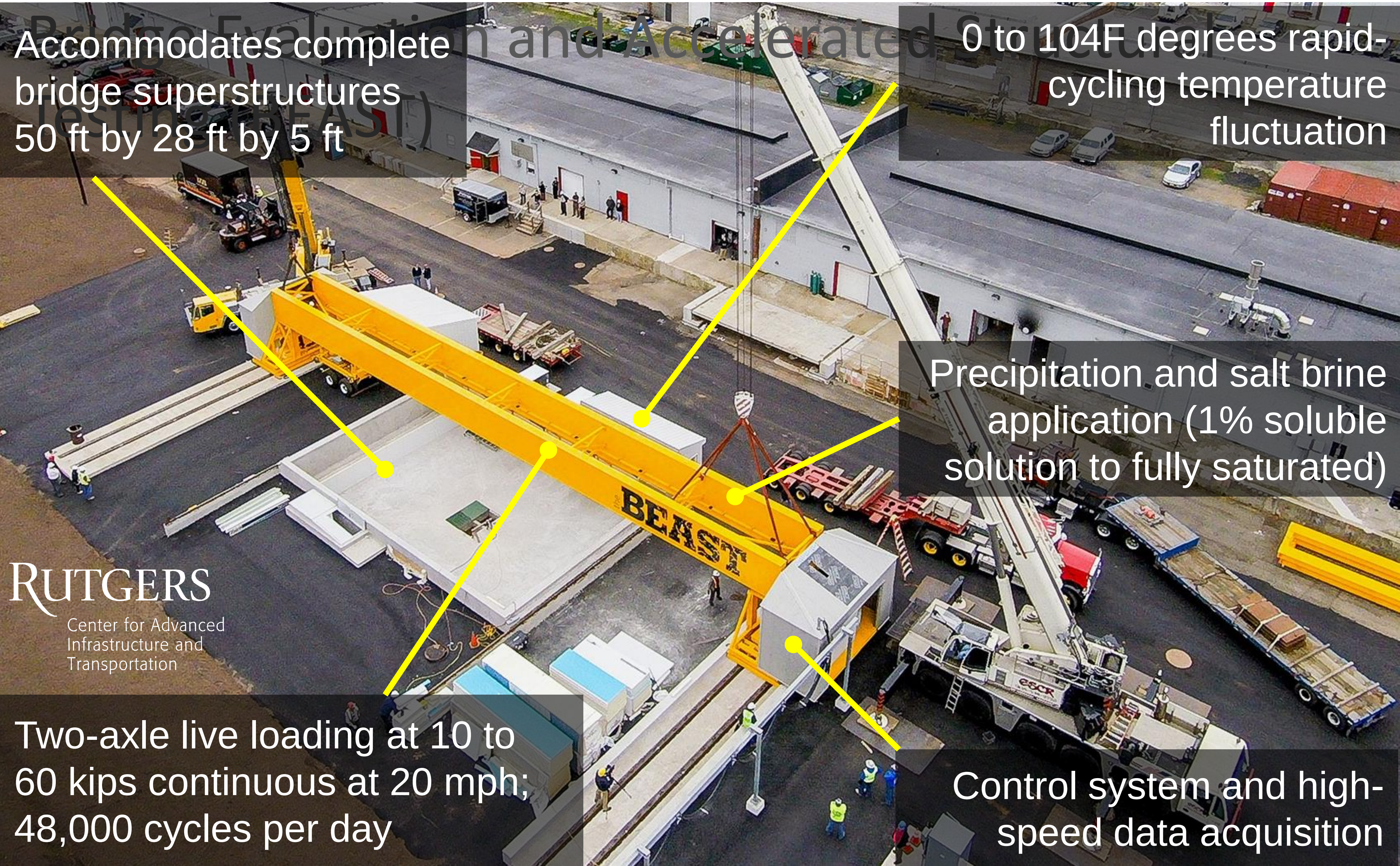
The long-durations of the current feedback loop are stifling innovation

Best Cell Phone (2007)
“Offers everything you could want in a cell phone”
-PC World

AT&T Phone (1997)
Big Breakthrough…
- Internal antenna

The BEAST – Accelerated Aging of Bridges

Bridge Evaluation and Accelerated Structural Testing (BEAST)



- Accommodates complete bridge superstructures 50 ft by 28 ft by 5 ft
- 0 to 104F degrees rapid-cycling temperature fluctuation
- Precipitation and salt brine application (1% soluble solution to fully saturated)
- Two-axle live loading at 10 to 60 kips continuous at 20 mph; 48,000 cycles per day
- Control system and high-speed data acquisition

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BEAST


round
3
distance
0.06mi
t Conditions
re 73 °F
me 0d 00h 00m 13s

round distance
6 lbs 712374 13491.92mi
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perature 104 °F
sed Time 180d 04h 20m 30s

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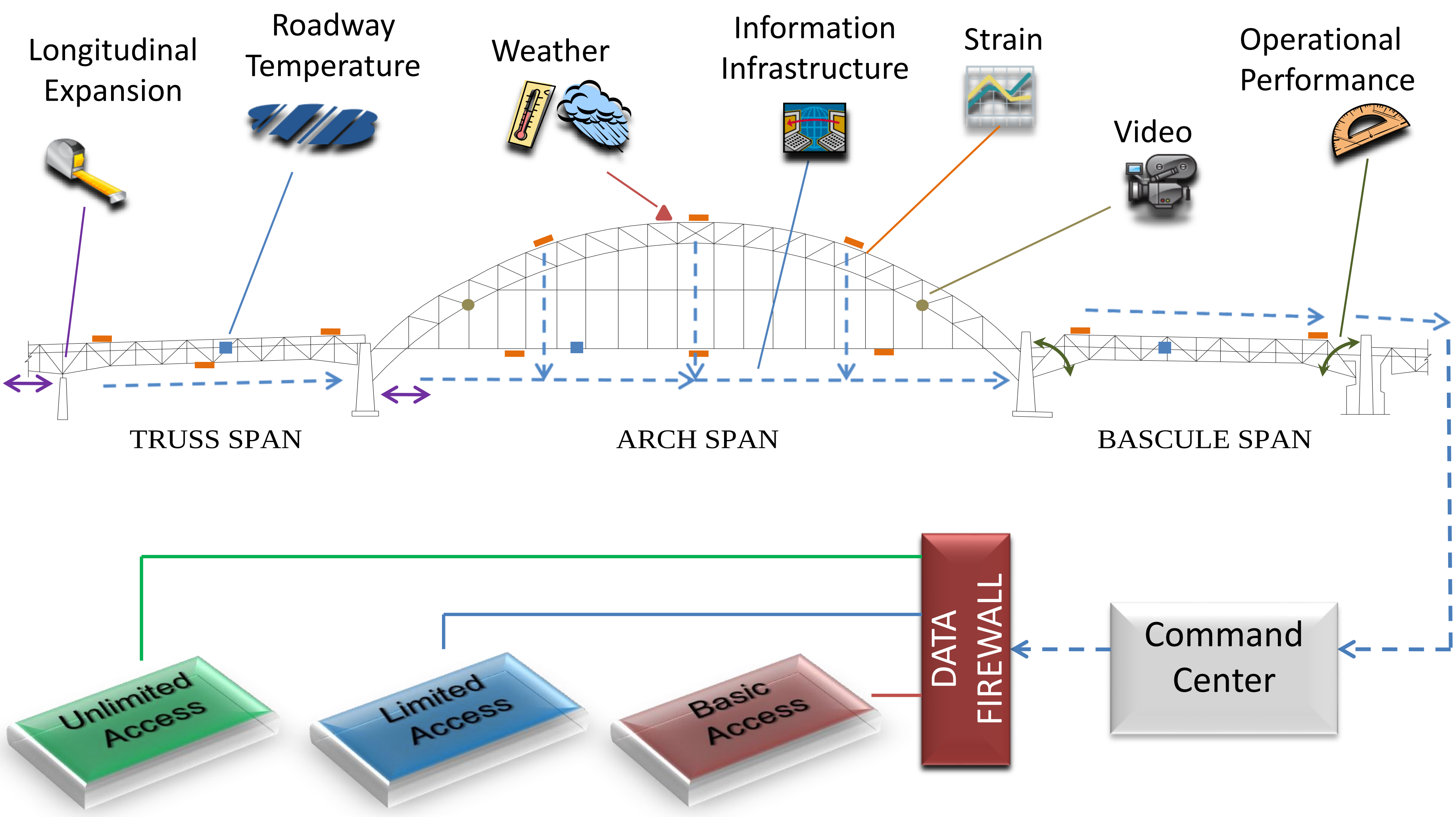
Structural Health Monitoring Systems



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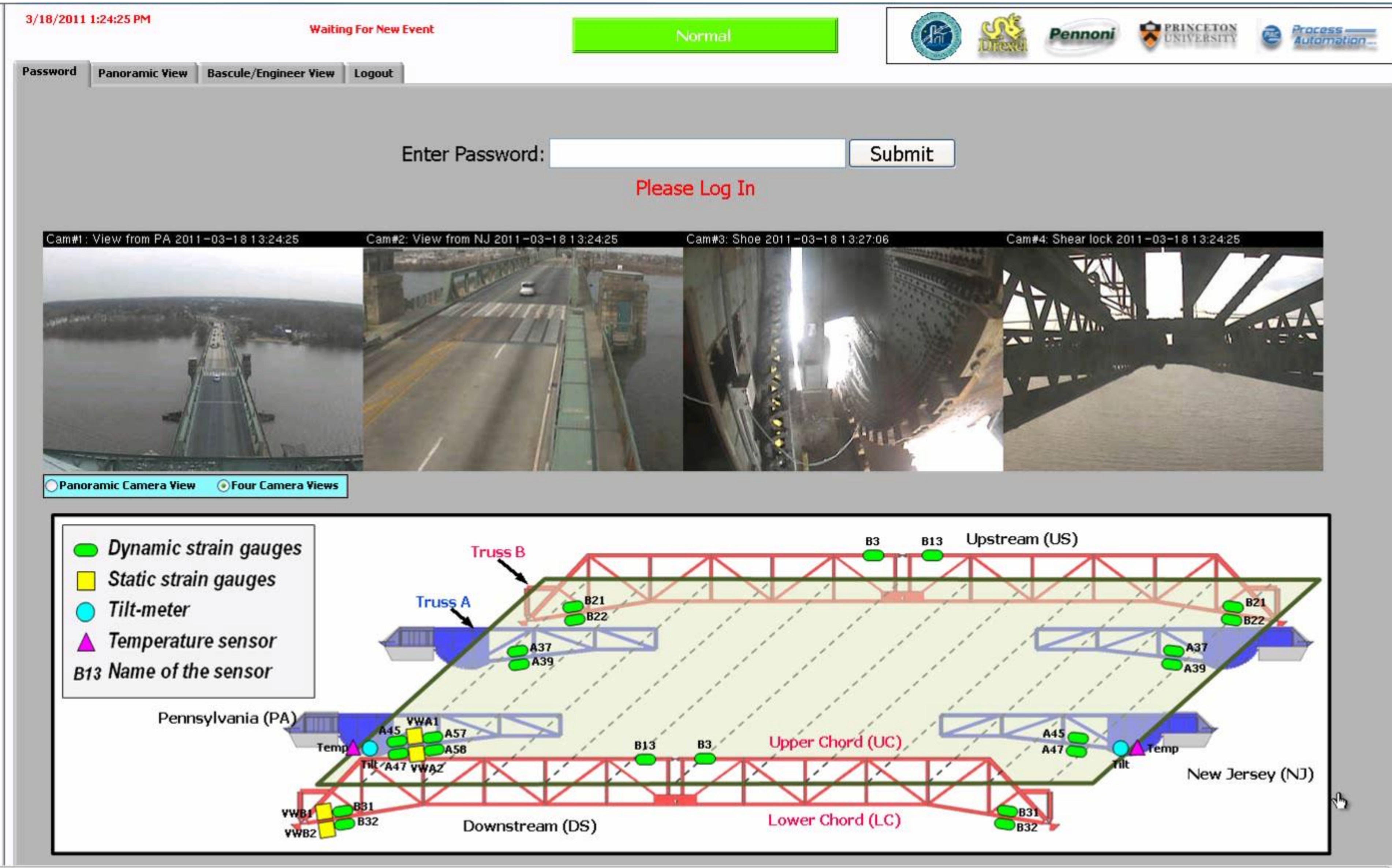

3/18/2011 1:24:25 PM
Waiting For New Event
Normal
Pennoni
PRINCETON UNIVERSITY
Process Automation
Password
Panoramic View
Bascule/Engineer View
Logout
Enter Password:
Submit
Please Log In
Cam#1: View from PA 2011-03-18 13:24:25
Cam#2: View from NJ 2011-03-18 13:24:25
Cam#3: Shoe 2011-03-18 13:27:06
Cam#4: Shear lock 2011-03-18 13:24:25
Panoramic Camera View
Four Camera Views
Dynamic strain gauges
Static strain gauges
Tilt-meter
Temperature sensor
B13 Name of the sensor
Truss B
Truss A
Upstream (US)
Downstream (DS)
Pennsylvania (PA)
New Jersey (NJ)
Upper Chord (UC)
Lower Chord (LC)
B3
B13
B21
B22
B31
B32
A37
A39
A45
A47
A57
A58
VWA1
VWA2
VWB1
VWB2
Temp
Tilt

So what?

- Tracking/identifying overloaded vehicles
- Tracking/documenting ship passage
- Deploying di-icing agents
- Tracking future construction
- Informing inspections – especially related to movement systems
- Rapid assessment following extreme events
- Tracking of fatigue and fracture