DEVELOPMENT OF LIMIT STATE BASED STRUCTURAL HEALTH MONITORING THRESHOLDS FOR EFFICIENT BRIDGE MANAGEMENT

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Structural Health Monitoring Challenge 1

- What is it?
- First common challenge seen with SHM
  - Lack of a common definition

Good question!

- A process aimed at providing accurate and in-time information concerning structural health condition and performance (Princeton)
- The process of implementing a damage detection and characterization strategy for engineering structures (LANL)
- The practice of identifying and tracking quantitative performance metrics through measured data and analytical models (IIS)

Structural Health Monitoring Challenge 2

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What you can measure is not what you need; what you need, you cannot measure.

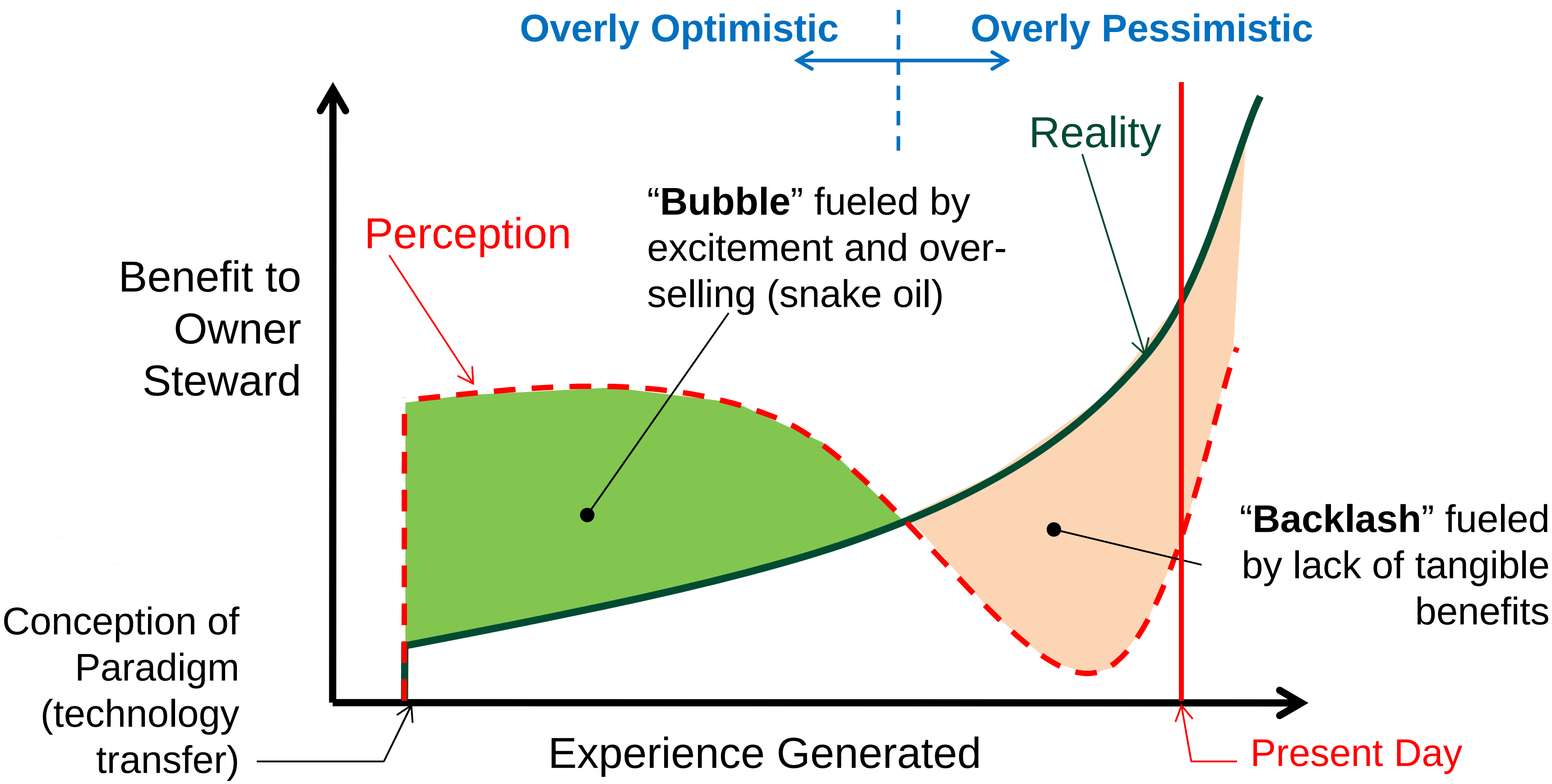
Observable Responses (Measurable) → **Unobservable Attributes ("Health", "Condition", "Damage", "Capacity")**

SHM

Bridge Management Metrics

How can we provide actionable information **from SHM** and integrate **into Bridge Management** frameworks?

Structural Health Monitoring Challenge 3



What to do?

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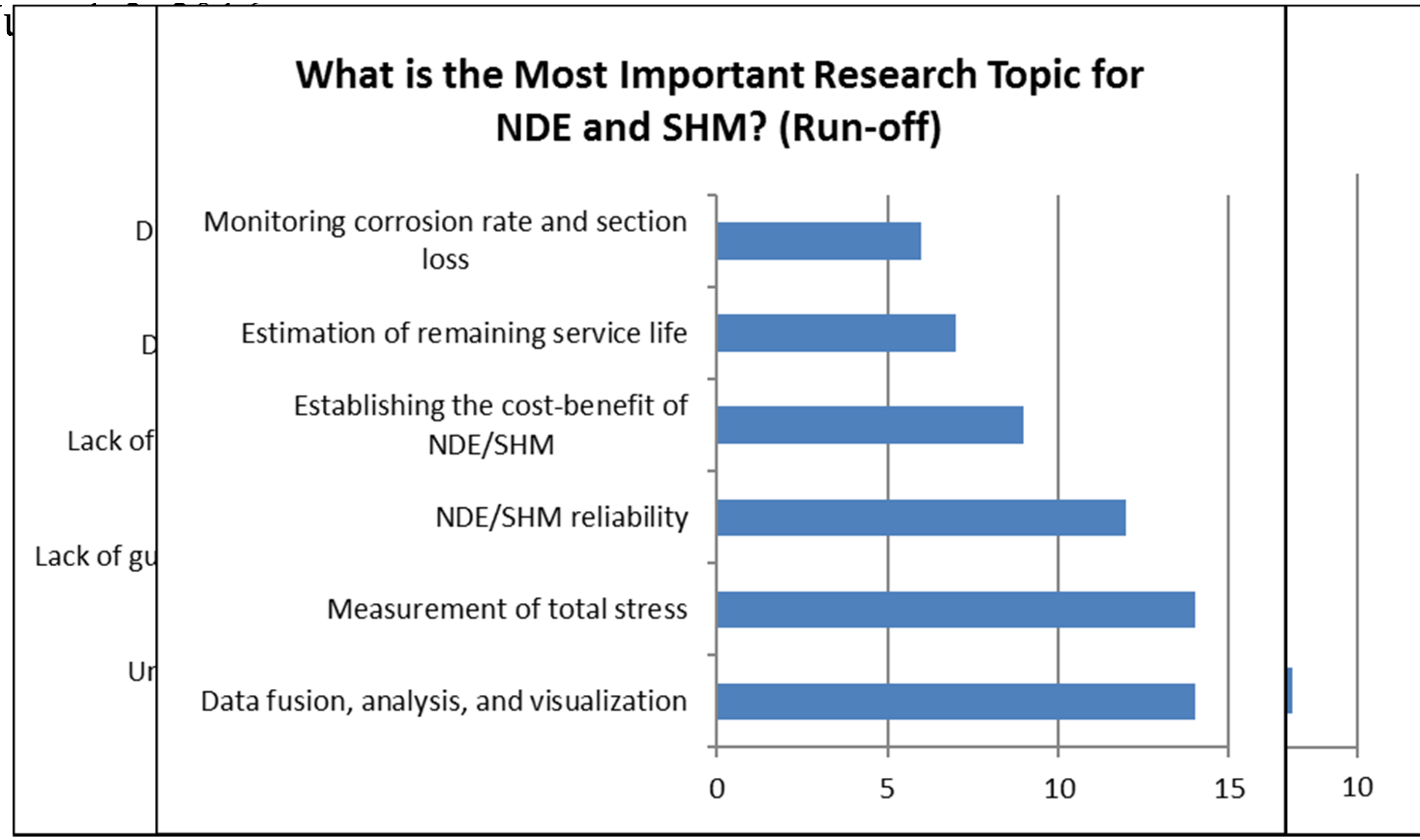
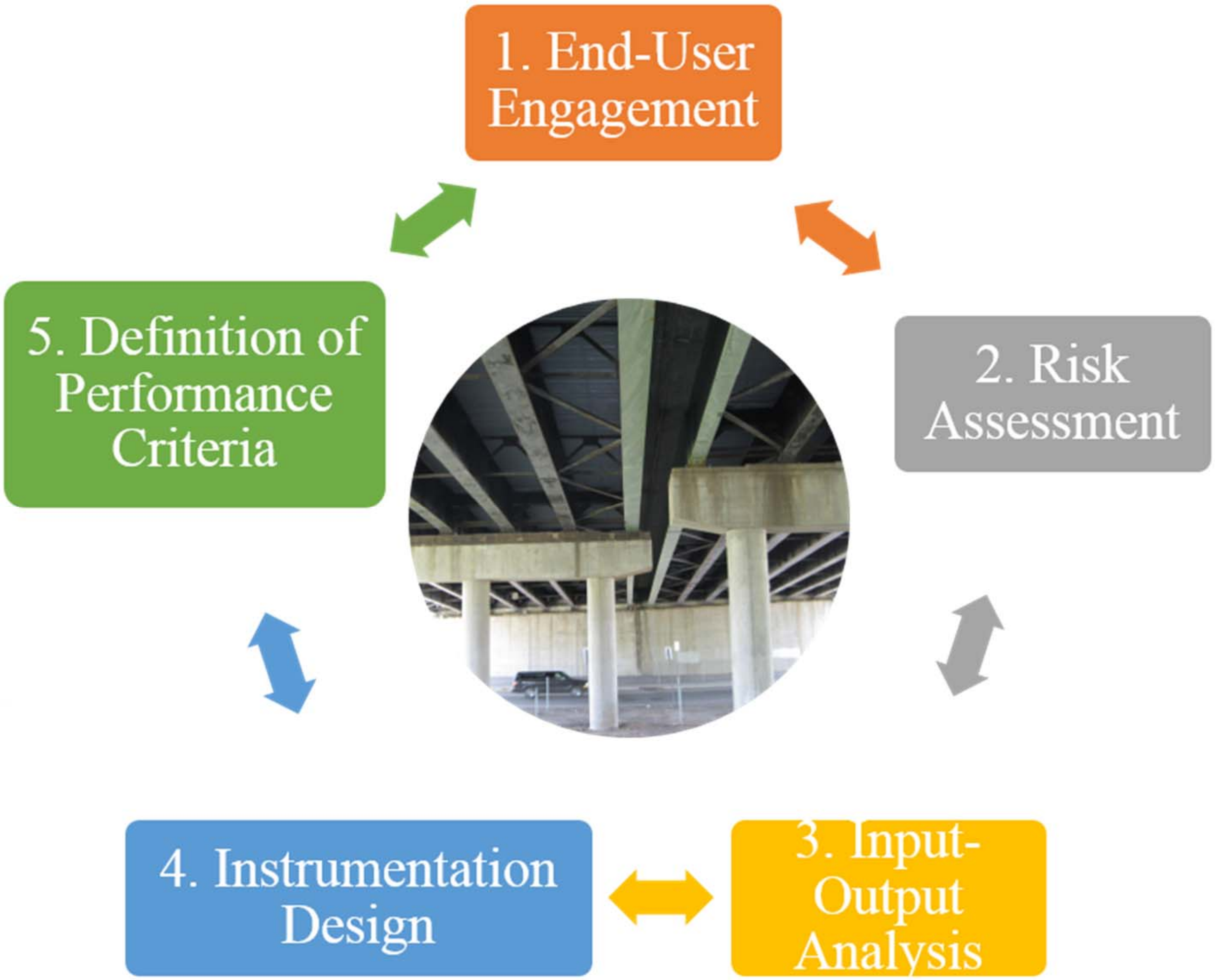
- Ju ... ons



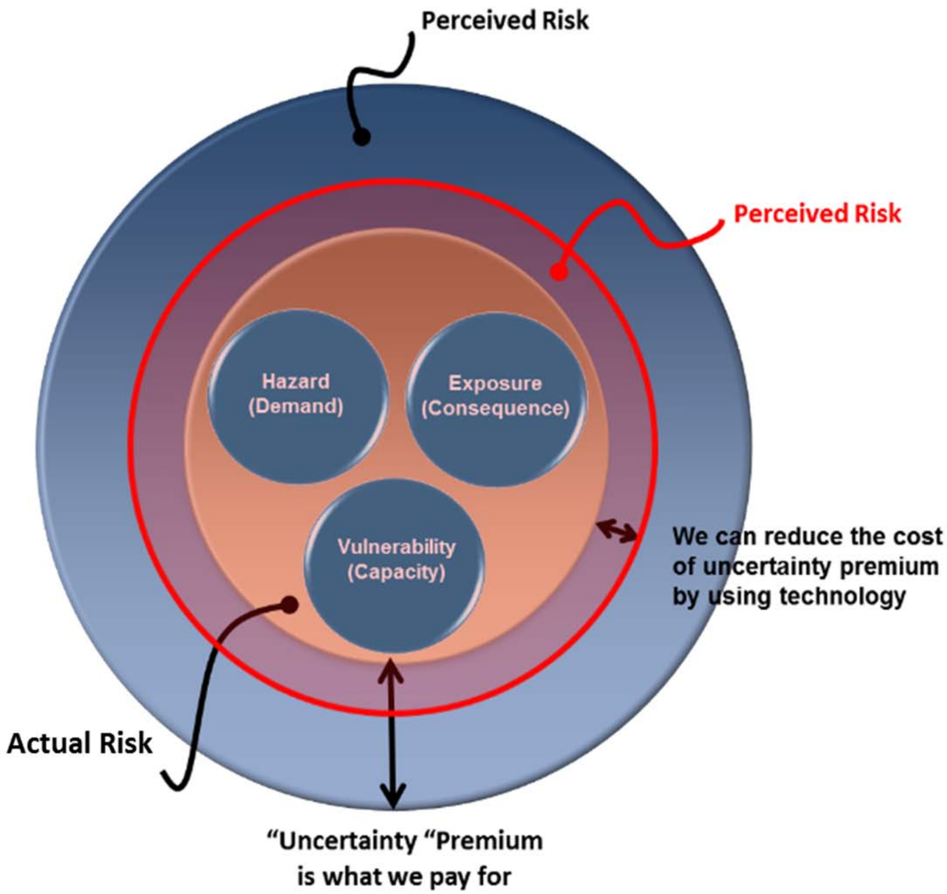
Meanwhile…

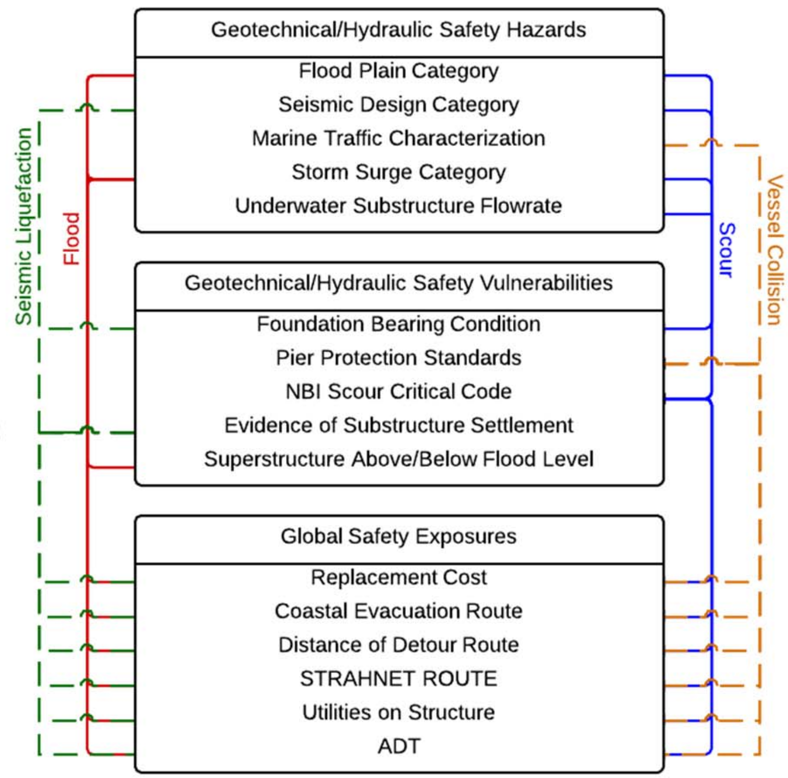
- Continue to engage with peers and colleagues on best practices and share experiences
- Our opinion on best practices to SHM
  - Constant engagement with the end-user
  - Design, not procurement.
  - Definition of clear ***performance requirements*** at the RFP stage
    - Allows for creative design by bidders on providing the translation of measurements to actionable information

Performance Requirement Framework



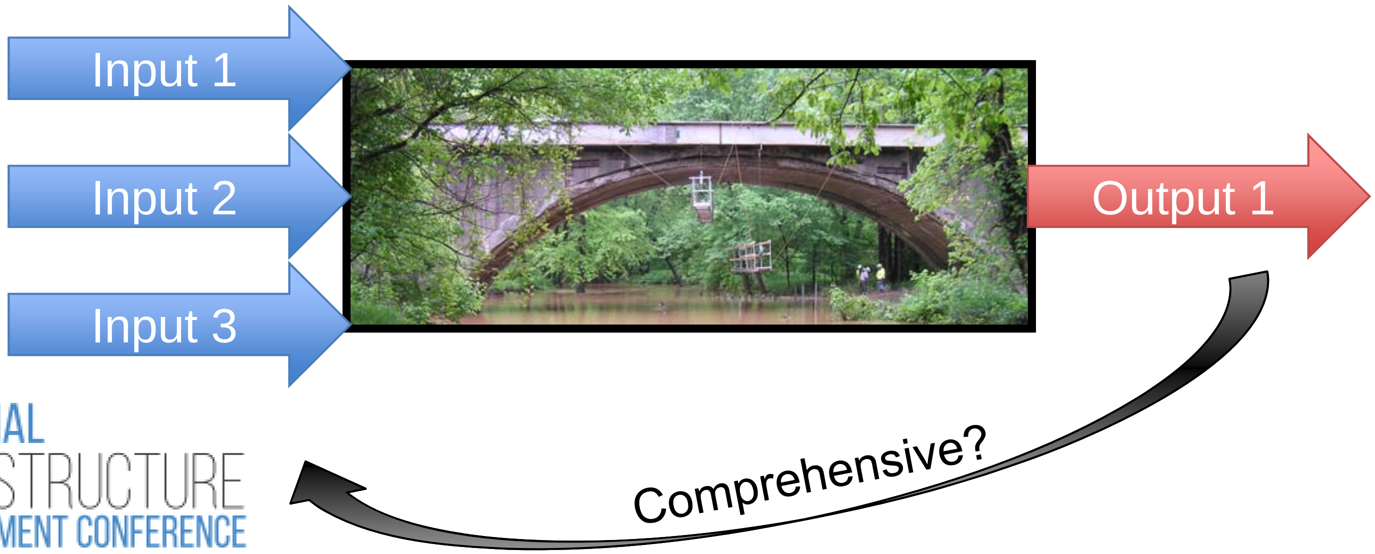
Risk Assessment





Input-Output Analysis

- **Inputs**: Parameters independent of the bridge structure which tend to act upon the bridge
  - Wind, vessel impact, overloads, temperature gradients, etc.
- **Outputs**: Response of the bridge as a function of material or structural properties
  - Displacement, strain, surface temperature, rotation, etc.



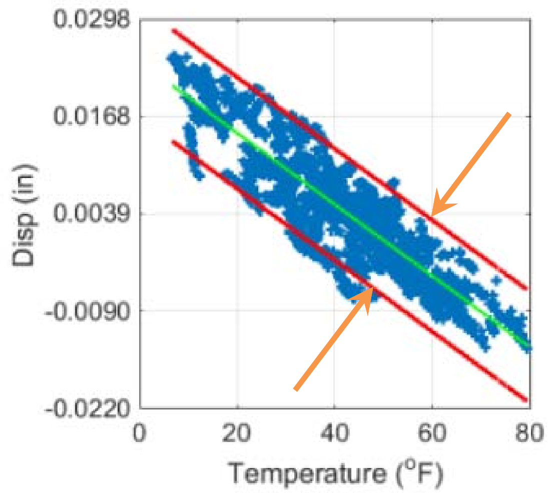
Instrumentation Design

- Armed with required input and output m… the SHM system can be designed:
  - Type / size / location of sen…
  - Data acquisition str…
  - Protection s… …ssary)
  - Lev… …s determined on a case
  - …azard simulation

How does this relate to bridge management?

Performance Criteria

- Metrics used to establish acceptable levels of hazards or vulnerabilities
- Serve as the foundation for alerting and integration into ITS / TMC / AM systems
- Directly informed
  - Tend to be institutional or code-based and related to Inputs
    - Maximum legal loads
    - Maximum allowable wind speeds
- Indirectly informed
  - Tend to relate to structural safety (ie, Outputs)
    - Usually require structural engineering analysis
    - Remaining capacity
    - Allowable movements



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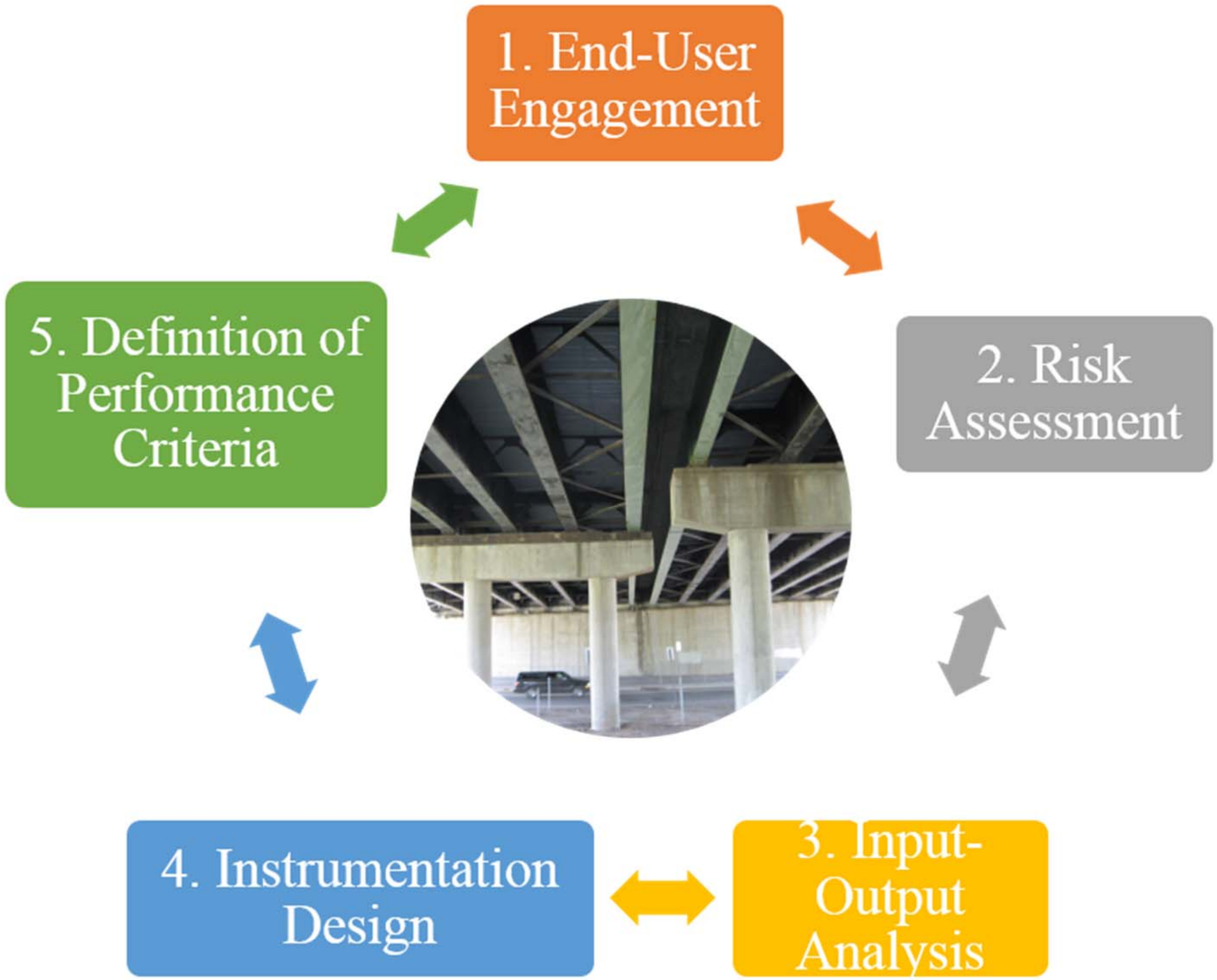
End-User Engagement



CASE STUDY: MULTI-GIRDER STEEL BRIDGE

ENGINEERING-BASED PERFORMANCE METRICS TO SUPPORT BRIDGE MANAGEMENT

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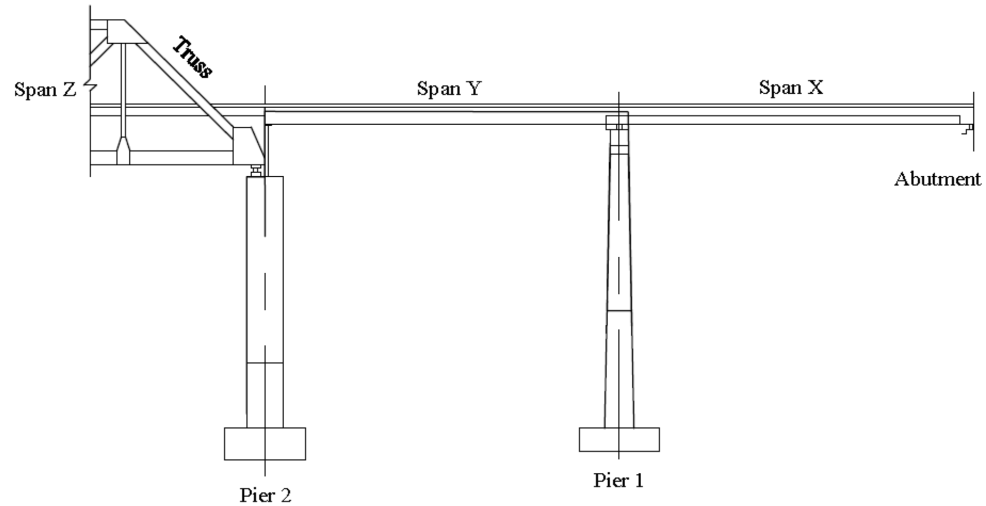
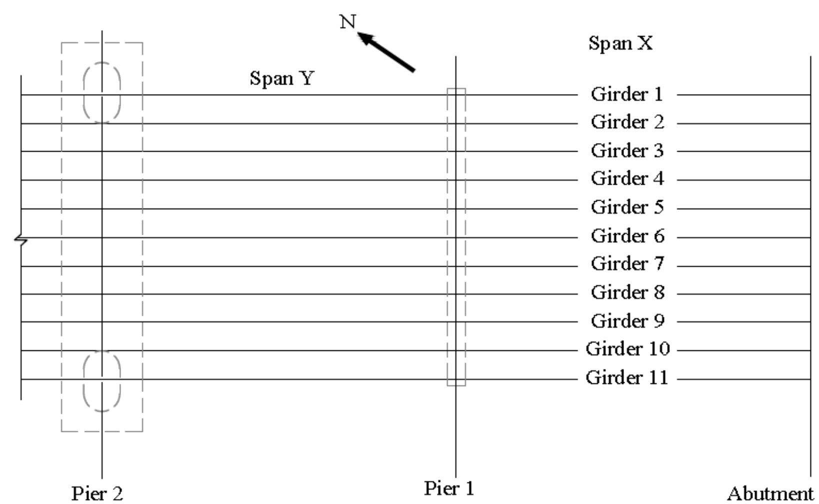
Background / Motivation

- A 46 year old bridge will be subject to nearby site construction with significant loading (1,000T +).
- Characteristics:
  - 1,767' total length
    - Two-span continuous steel multi-girder approach
    - Continuous steel truss
  - Four lanes
  - Varied substructures
    - Pile-supported abutments
    - Pile-supported piers
    - Piers on bedrock
- Note: Confidential project





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Pre-contract stakeholder meeting

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- Goals:
  - Determine feasibility of SHM
  - Establish performance requirements of interest
    - Monitor for permanent rigid body translations of the two piers in all three directions
    - Monitor for permanent rigid body rotations of the two piers in all three dimensions
    - Ensure that any measured rigid body movements do not impact the load rating of the steel multi-girder span with respect to Strength and Serviceability limit states.
    - Ensure that any measured rigid body movements do not generate cracking in the reinforced concrete piers.
    - Ensure that any measured rigid body movements do not bottom out any of the movement systems.

Risk Assessment

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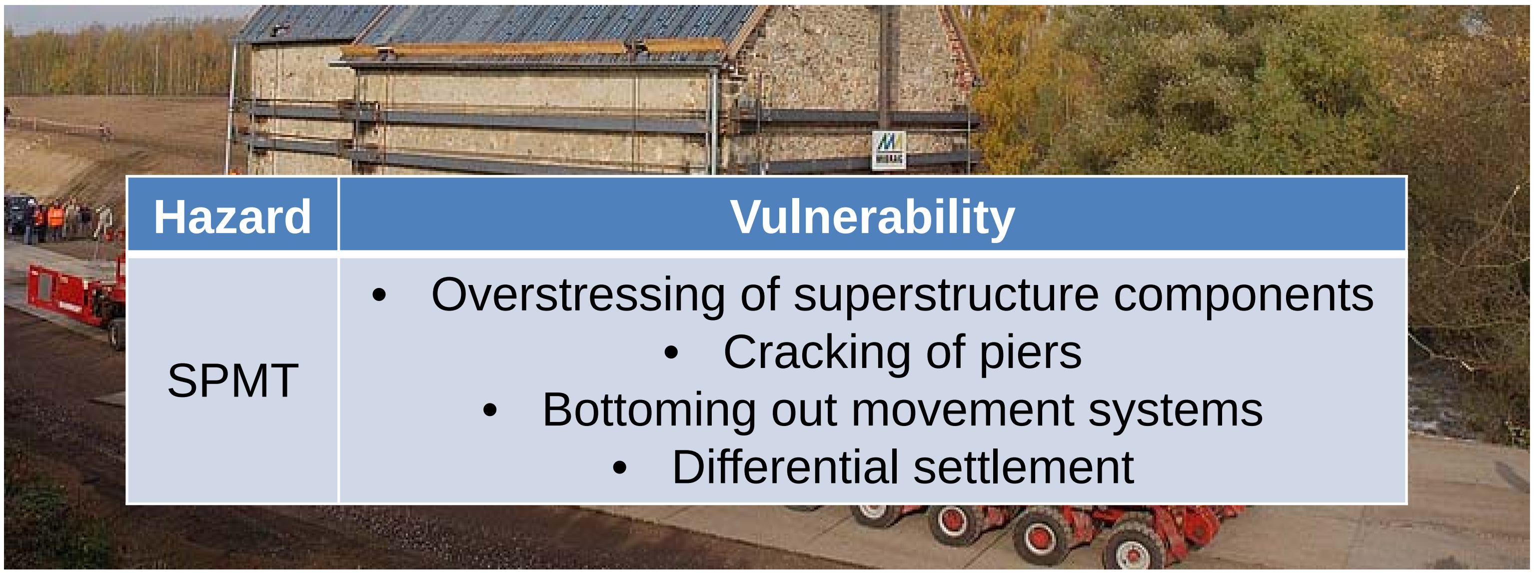
- One fundamental risk that motivated this project..



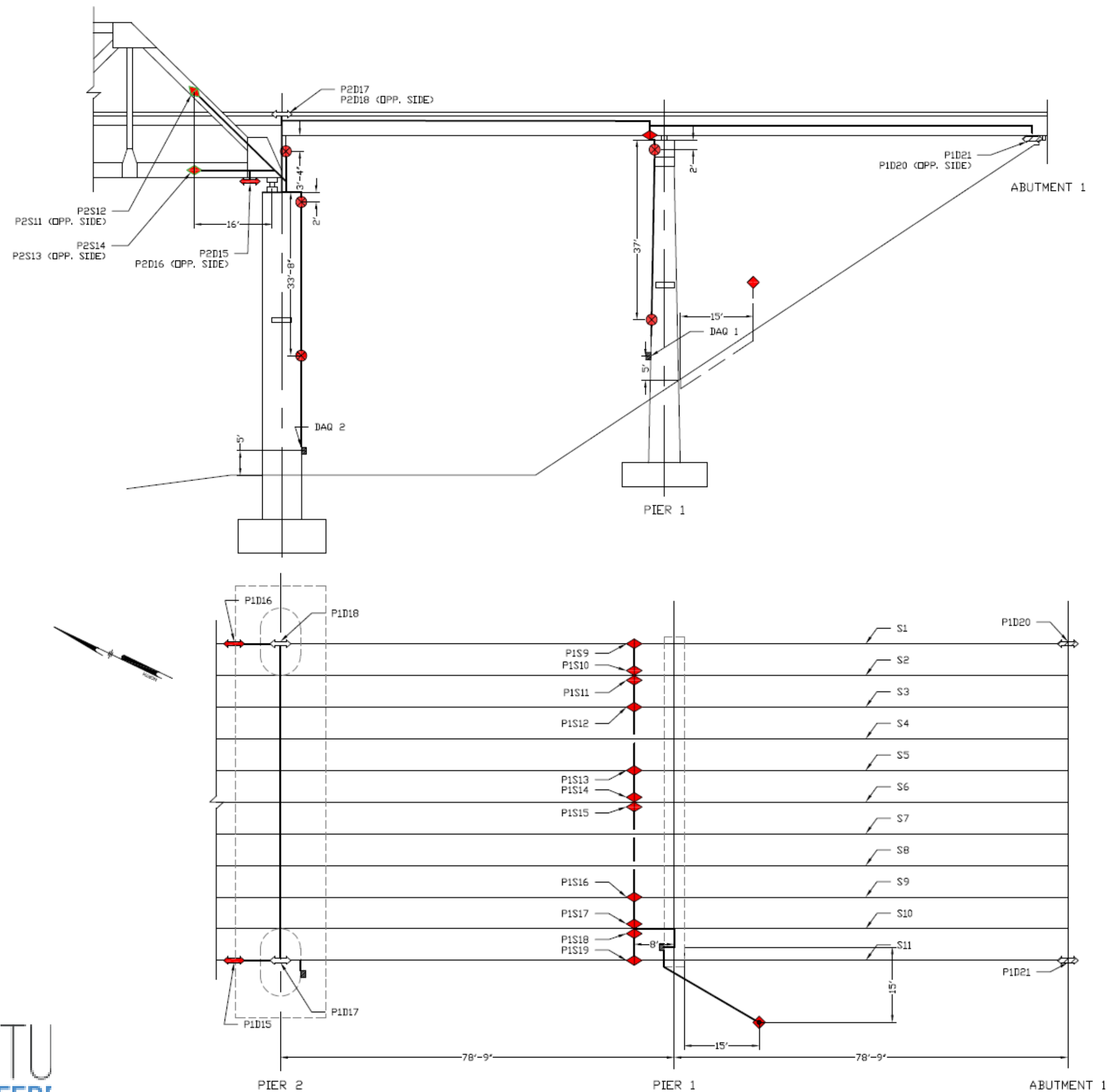
Hazard	Vulnerability
SPMT	• Overstressing of superstructure components • Cracking of piers • Bottoming out movement systems • Differential settlement

Image source: http://bright-cars.com/photo/scheuerle-spmt/08/default.html

Input – Output Analysis

Performance Metric	Input	Output	Sensing Approach
Rigid body translations	• Thermal • Heavy load	• Expansion / contraction • Translation • Axial force • Support movement	• VW Displacement • Laser Distance • Weather • Local Temperature • VW Strain
Rigid body rotations	• Thermal • Heavy load • Live load	• Expansion / contraction • Rotation	• VW Tilt • Weather • Local temperature
* VW = Vibrating Wire type sensors			

Instrumentation Design



Definition of Performance Criteria – Superstructure Capacity

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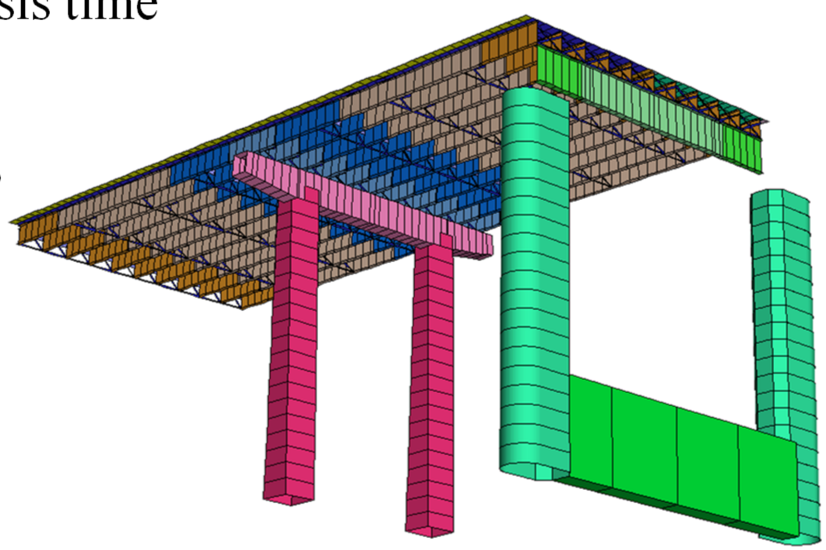
- 3D FE refined load rating computation
  - Agency and AASHTO defined rating vehicles
  - Required to simulate the occurrence of live load together with movements defined under the performance requirements
  - Added benefit to owner was improved live load ratings (>1) due to refined analysis
  - Automation used to cut down analysis time
- Allowable superstructure ratings given support movements were computed.
  - In line with NCHRP 12-103



Definition of Performance Criteria – Serviceability

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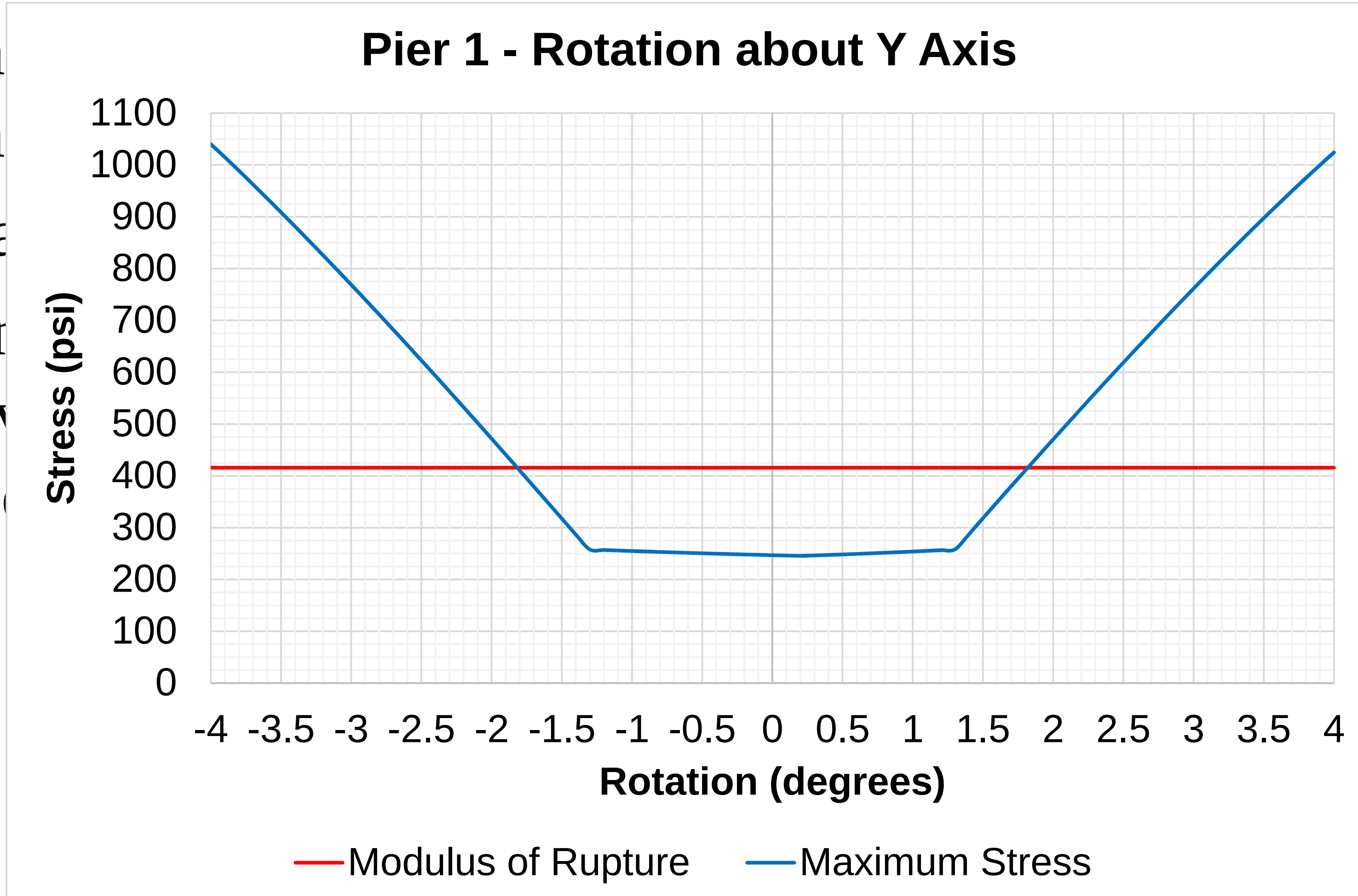
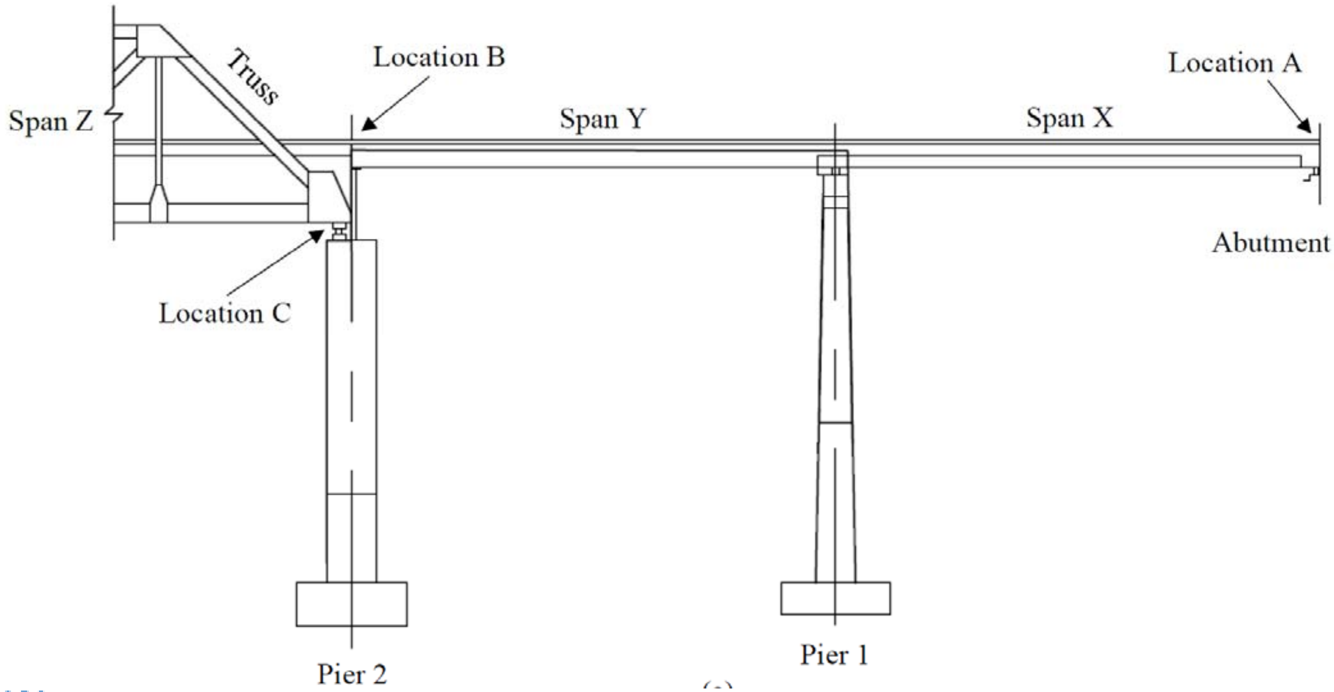


Definition of Performance Criteria – Kinematic Systems (Movement Mechanisms)

- Given the height of the piers, it was most likely to bottom out movement mechanism before reaching other limit states



Result

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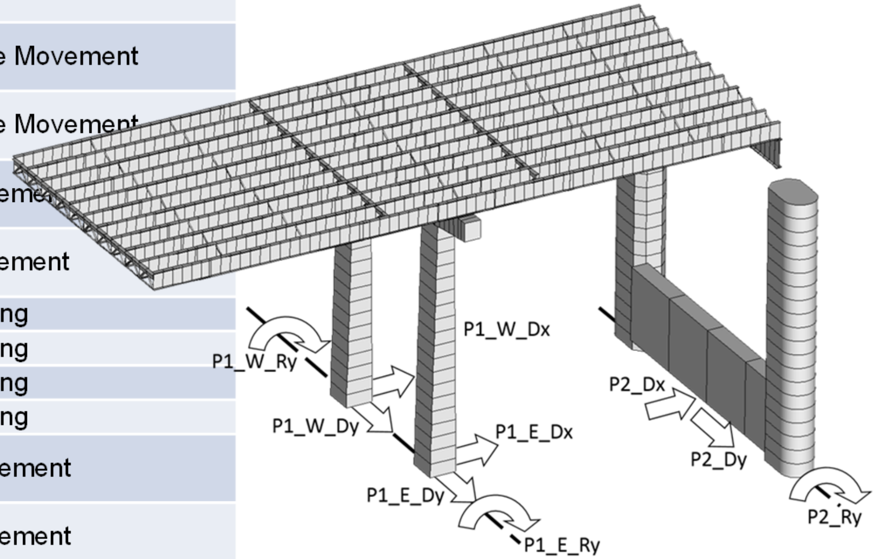
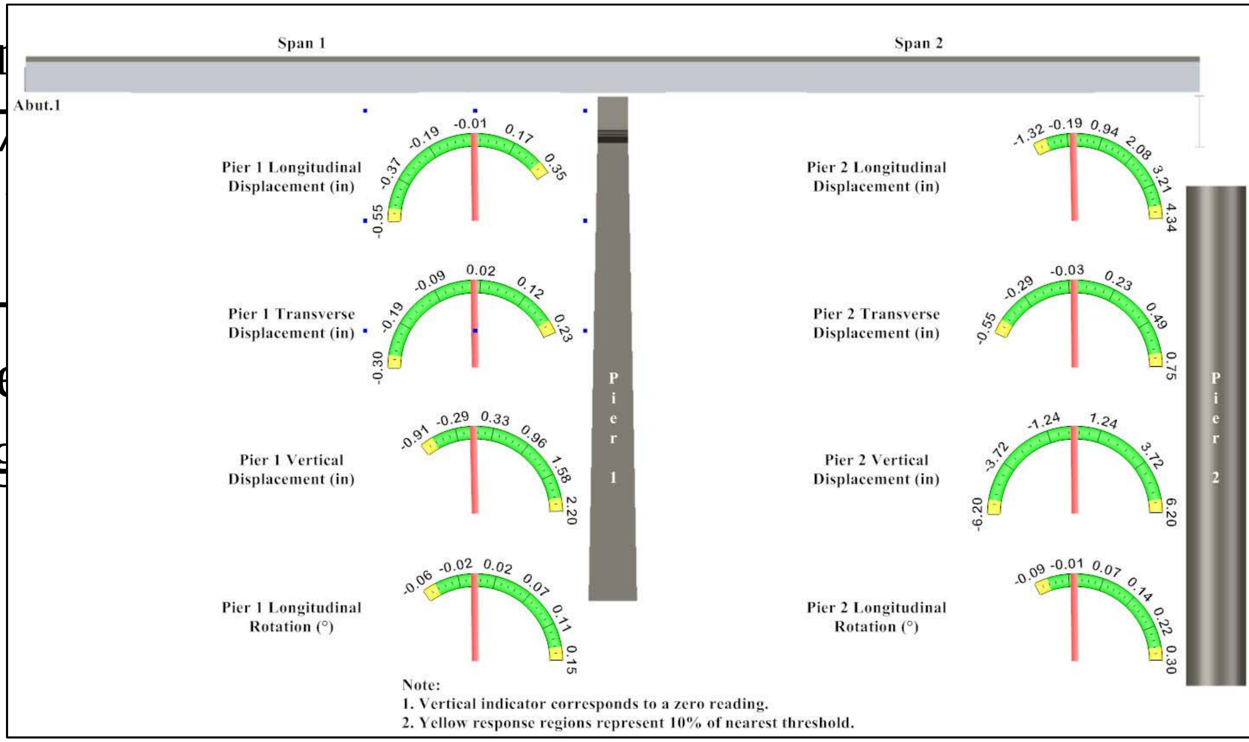
	Movement	Allowable	Governing Case
Pier 1	+ Ry (°)	0.15	Pier Serviceability - Differential Rotation
	- Ry (°)	0.06	Kinematic - Abutment 1 Expansion Joint
	+ Dx (in)	2.2	Pier Serviceability - Differential Longitudinal Movement
	- Dx (in)	0.91	Kinematic - Abutment 1 Expansion Joint
	+ Dy (in)	0.35	Pier Serviceability - Differential Transverse Movement
	- Dy (in)	0.55	Pier Serviceability - Differential Transverse Movement
	+ Dz (in)	0.2	Pier Serviceability - Differential Settleme
	- Dz (in)	0.3	Pier Serviceability - Differential Settlement
Pier 2	+ Ry (°)	0.3	Kinematic - Span 3 Rocker Bearing
	- Ry (°)	0.09	Kinematic - Span 3 Rocker Bearing
	+ Dx (in)	4.34	Kinematic - Span 3 Rocker Bearing
	- Dx (in)	1.32	Kinematic - Span 3 Rocker Bearing
	+ Dy (in)	0.75	Pier Serviceability - Transverse Movement
	- Dy (in)	0.55	Pier Serviceability - Transverse Movement
	+ Dz (in)	6.2	Superstructure Rating - Negative Bending Interior Girder
	- Dz (in)	6.2	Superstructure Rating - Negative Bending Interior Girder



Implementation

- Geotechnical consultant computed expected movements
  - Well within SHM thresholds
- Real-time display created for on-site situational awareness
- Syster … using a CAT-7 …
  - 20 …
- Long- … f bridge and be … mparison during …
  - 15 …



Integration of SHM Data into Bridge Management Frameworks - Thoughts

- This specific case study is hoped to demonstrate how SHM systems can be used to translate raw measurements into actionable information that can be integrated into management structures
  - Simple as visual alert
  - Complex as integration with TMC or other controls
- End-user buy-in and understanding of how thresholds were established and computed are essential
- Sensors should only be used if they can (directly or indirectly) inform a specific performance metric
  - "I have a solution – what's your problem?" versus "Where do your concerns lie?"

Structures Congress 2018

- SHM / Asset Management Session
  - Please contact ndubbs@iisengineering.com if interested

CALL FOR ABSTRACTS - STRUCTURES CONGRESS 2018

The SEI National Technical Program Committee has opened the call for abstract and session proposals. Several new types of sessions will be available.

- Innovative Executive Sessions (IES) with opportunities for interaction
- Comprehensive Sessions that can extend beyond the traditional 90 minute time-frame
- Panel Sessions including multi-discipline project teams, debates or other formats.
- Case Studies on timely topics
- Other creative sessions that encourage audience participation and even breakout groups

All session proposals and abstract submissions are due June 5, 2017. Learn more on the Congress website.

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What frameworks to testing of bridges even exist?

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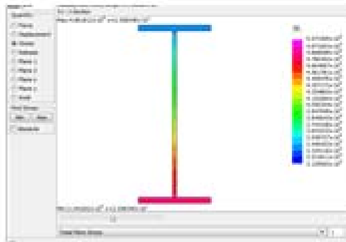
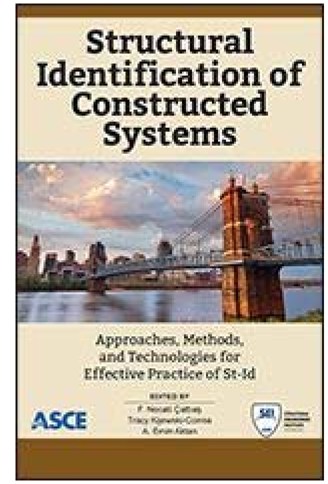
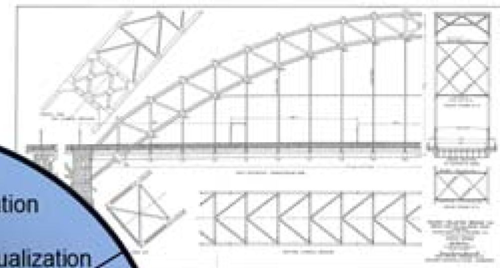
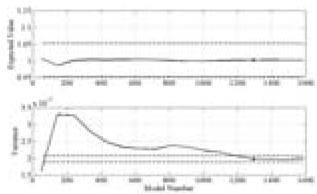
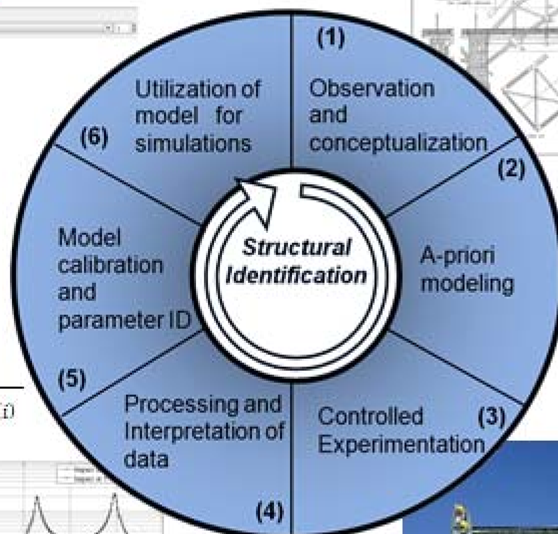
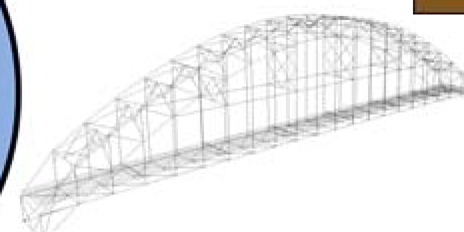




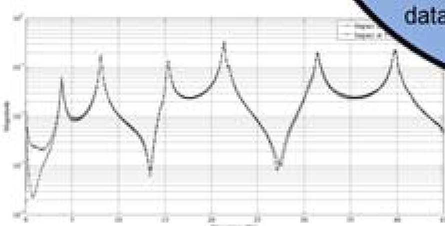


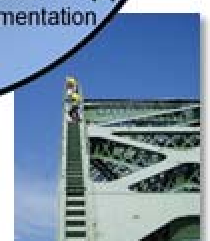


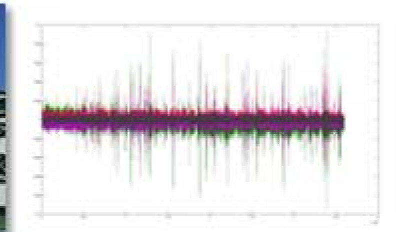




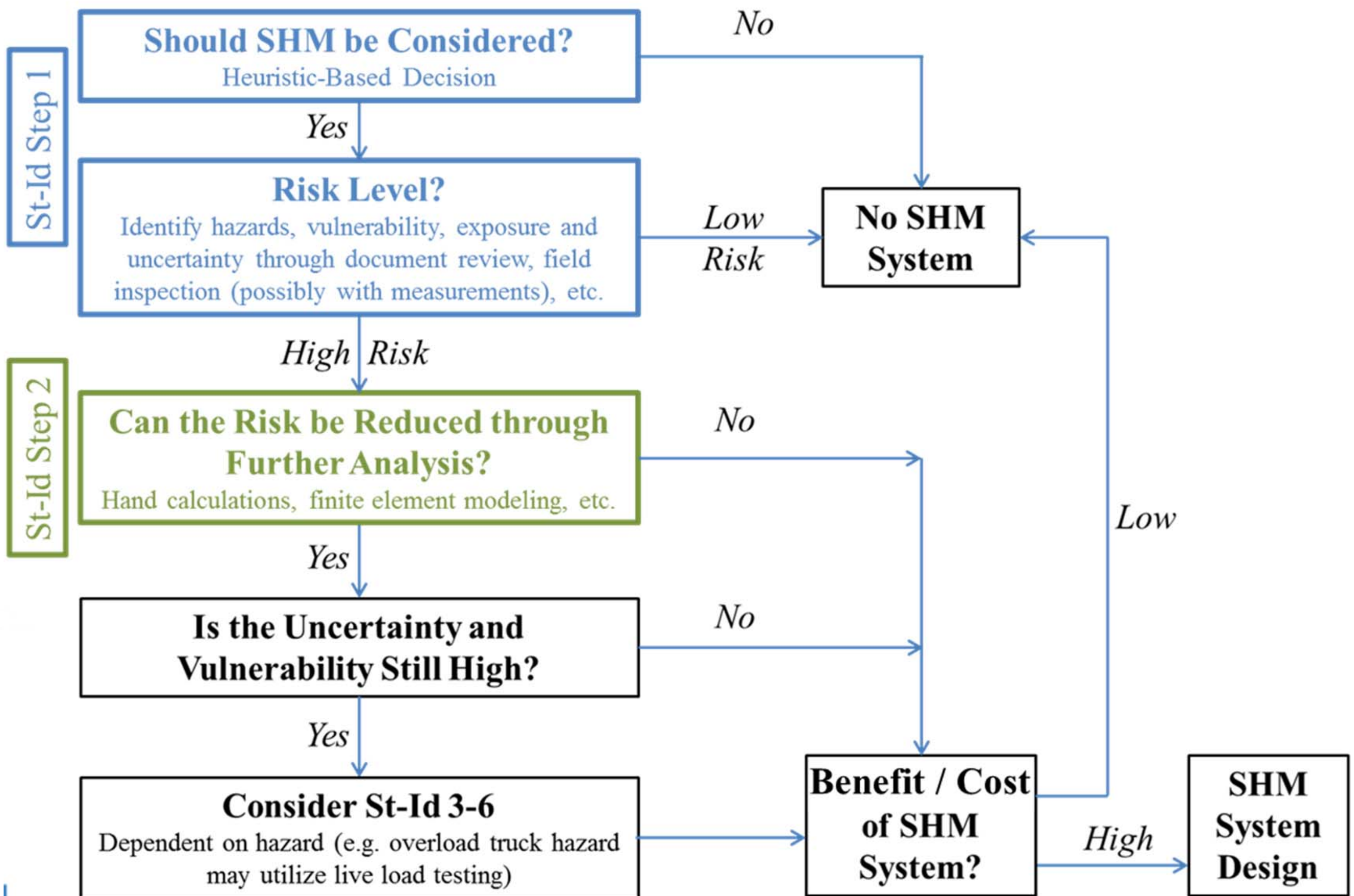
$$MAC = \frac{\left|\varphi_{ana(i)}{}^{T} \cdot \varphi_{\exp(i)}\right|^{2}}{\varphi_{ana(i)}{}^{T} \cdot \varphi_{\exp(i)} \cdot \varphi_{\exp(i)}{}^{T} \cdot \varphi_{ana(i)}}$$







SHM Design Approach – Crawl, walk, then run…



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