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Bridge Monitoring for Decision Making of a Vertical Lift Bridge

11th Annual Bridge and Structure Management Conference
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Vertical Lift Bridges

- Frequent Excitation:
  - Normal traffic
  - Wind
  - Span movement
    - Impact when landing
    - Auto/rail traffic halted
- Other Events
  - Heavy vehicles
  - Vessel collisions
  - Emergency lift stop

Jacques Chaban-Delmas Bridge
http://spectrum.ieee.org/slideshow/geek-life/tools-toys/icandy-bridges-beams-and-bots-in-bands

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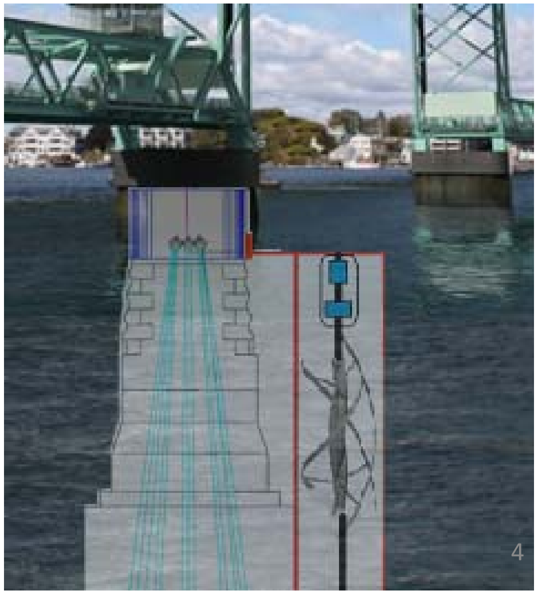
Memorial Bridge

- Carries US Route 1 across the Piscataqua River
- Connecting Portsmouth, NH with Kittery, ME.
- The bridge is the only pedestrian link between the two communities
- The original Memorial Bridge, constructed in 1923 and demolished in Spring 2012 due to structural concerns.

The New Memorial Bridge

- New superstructure built on existing piers
(interior micropiles added)
- Opened to traffic July 2013
- Owned by NHDOT & Maine DOT
- Operation & Maintenance by NHDOT
- Includes an innovative "gussetless" truss connection

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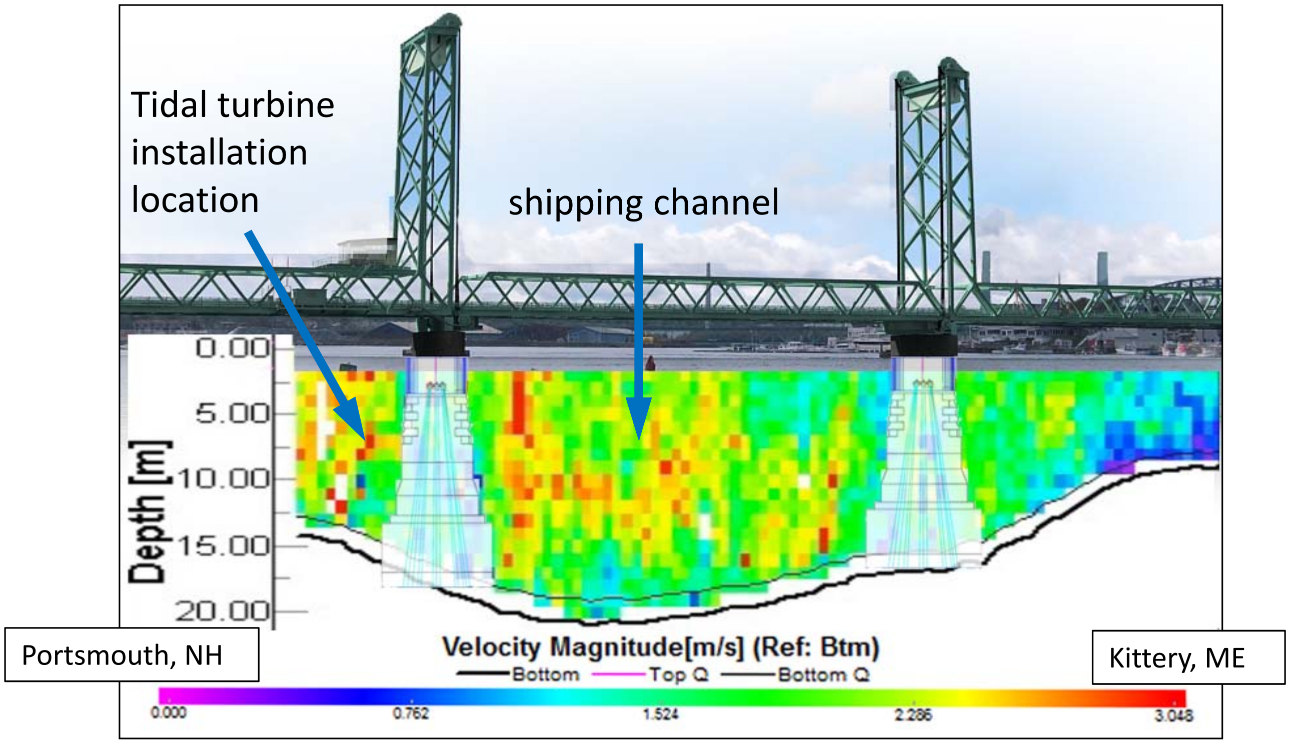
BRIDGE GEOMETRY
50′
300′
163′
300′
139′
25′
TO PORTSMOUTH
TO KITTERY
Bell BSMC 2017

Sustainable Infrastructure



Utilize locally available renewable, sustainable, tidal energy at Memorial Bridge.

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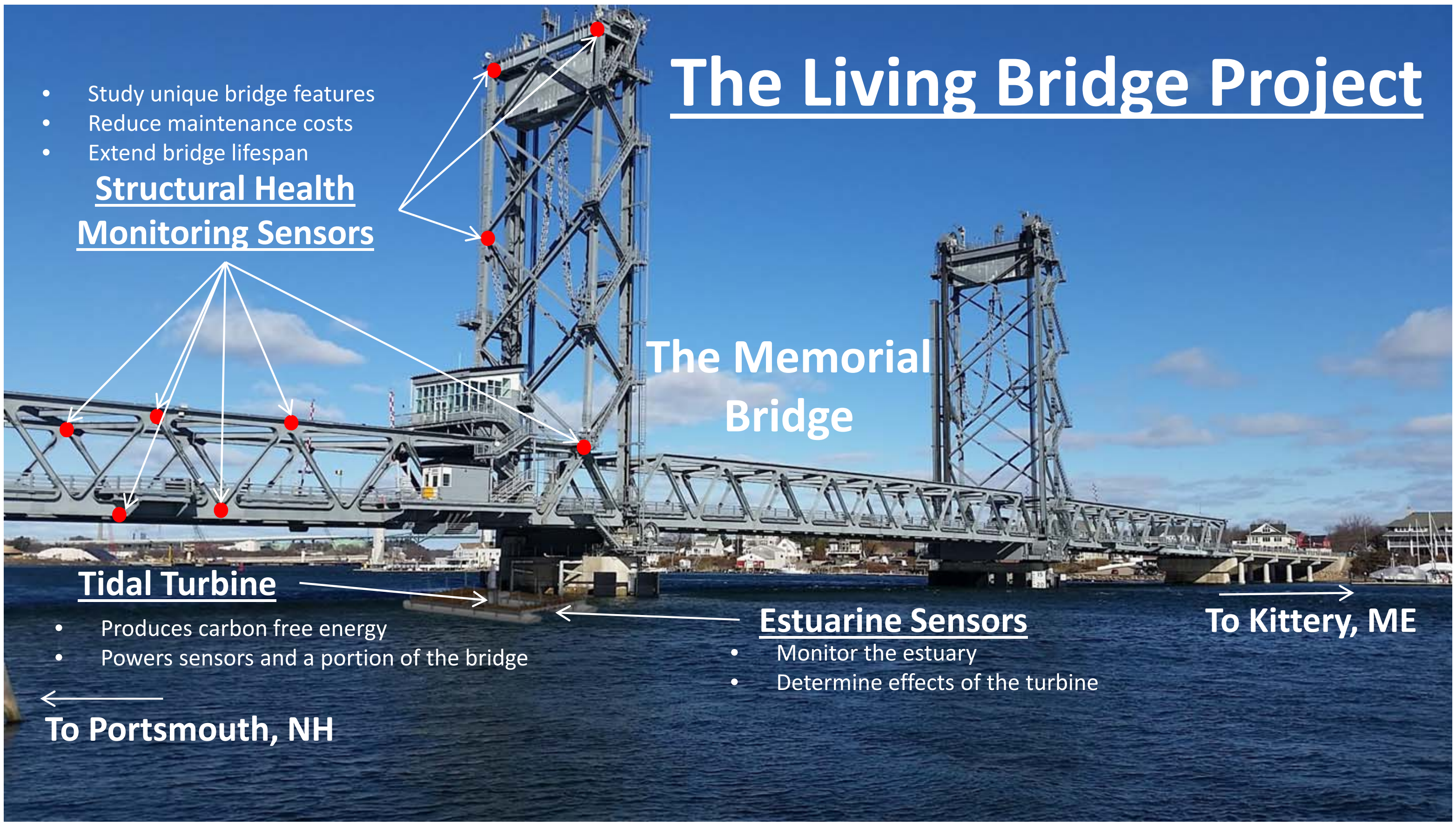

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Four Funded Projects

FHWA AID Demonstration Program: *Living Bridge:* Creating a Benchmark for Bridge Monitoring

U.S. Department of Transportation Federal Highway Administration

Department of Energy: UNH-Center for Ocean Renewable Energy: Infrastructure Improvements

- Tidal turbine deployment platform

NSF Partnerships for Innovation: Building Innovation Capacity: *The Living Bridge:* The Future of Smart, Sustainable, User-Centered Transportation Infrastructure

- Sensors powered by a tidal turbine

New Hampshire DOT Department of Transportation

NHDOT: Research Advisory Council: Tidal Turbine Support Structure

Structural Health Monitoring Process

1. Evaluation

   How will behavior to detected? What to collect and how to collect it?

2. Data Acquisition

   Information Collection Process

3. Feature Extraction

   Turning Measurements into Meaningful Information

4. Feature Discrimination

   What does this information mean?

Source: Los Alamos National Laboratory: “A Review of Structural Health Monitoring Literature: 1996–2001”

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The Goal of Structural Health Monitoring

- Verify design and performance parameters related to the gusset-less connection
  - Design Guide for future connection elements
  - Inspection and Condition Guidelines

- Monitor behavior of the towers during vertical lift operations under a range of environmental conditions
  - Lift/No-Lift Data-Driven Decision Making

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Instrumentation Plan Design

- Consultation with Bridges Designer
  - Assumptions made during design
- Consultation with Bridge Managers
  - Operational Decisions that could be improved with bridge response data
  - Accessibility and infrastructure to sensor locations
- Structural Model
  - Finite Element Detailed Model of the Connection Zone
    - Created in Lusas® to match designer model
  - Structural Beam Model of the Portsmouth Span and Lift Tower
    - Created in SAP2000® to predict global response

Finite-Element Model – ABACUS® and LUSAS®

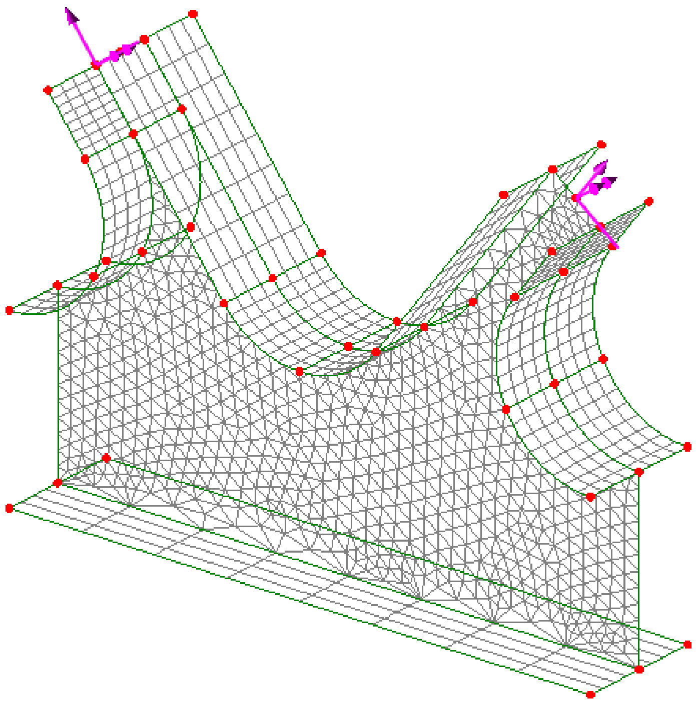
- Based on the geometry of as-built structural plans of the Memorial Bridge
- Created using linear thick shell elements.
- Model will be evaluated with respect to expected loads from the truss members

Goal:

Investigate optimal radius of curve flange

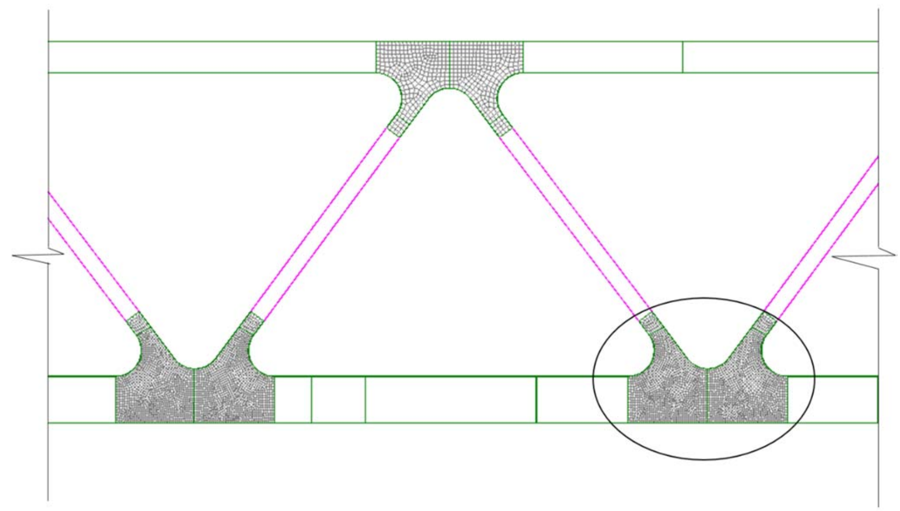
Stress flow through welds

Equivalent Stiffness Properties



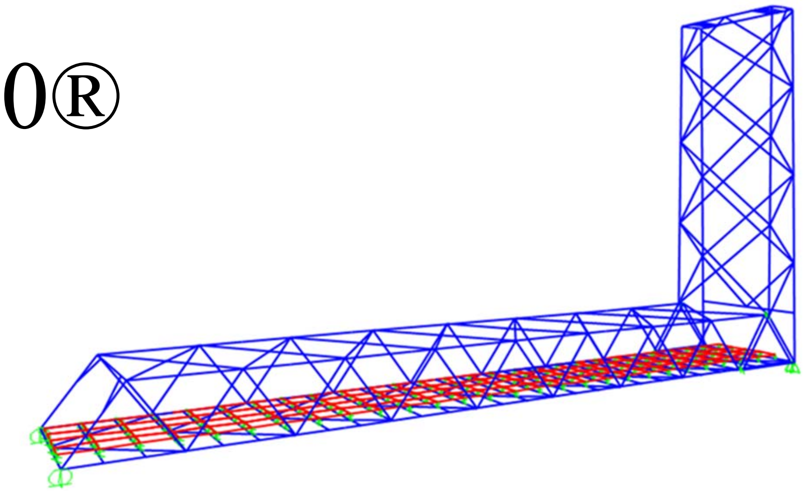
Multi-Scale Structural Model

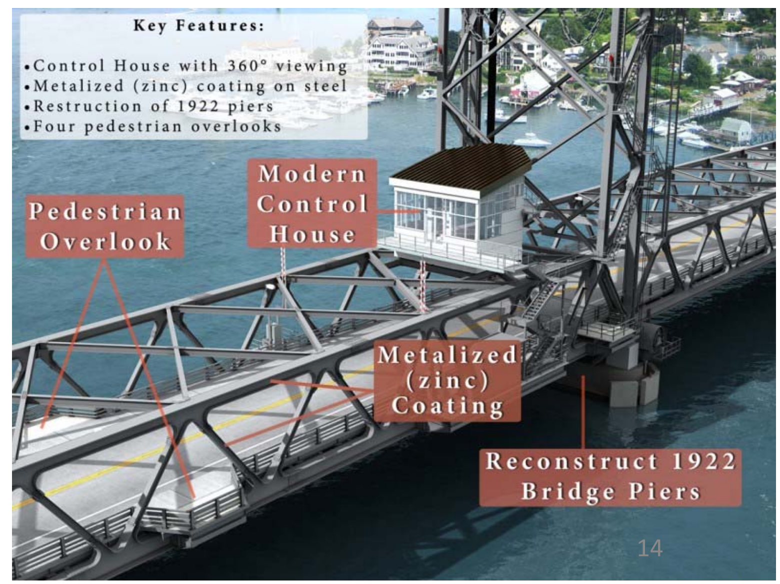
- The global response of the truss is modeled in two way:
  - Mesh a detailed FEM of the gusset-less connection with beam-elements to represent the members created in LUSAS®
  - Employ a stiffness matrix to numerically represent the gusset-less truss connection between the truss members created in SAP2000®



Structural Model in SAP2000®

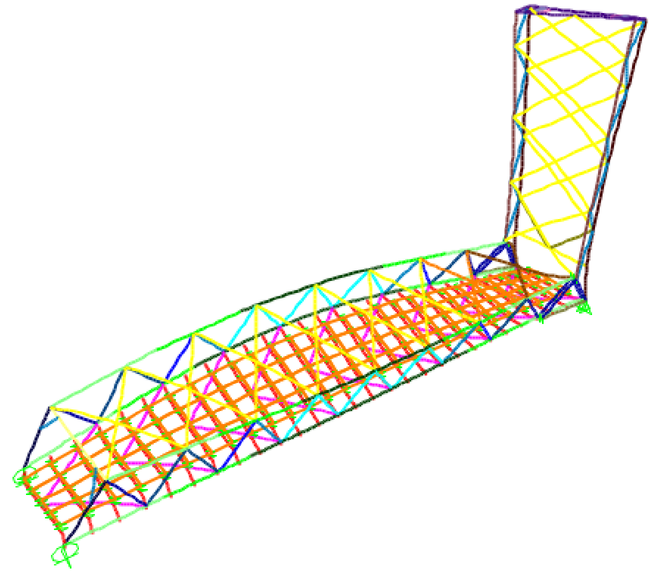
- Three-dimensional model of the Portsmouth Span and the South side Vertical Lift Tower
  - 219 beam elements representing the structural frame
  - 108 shell elements representing the concrete deck
  - links connect the deck to the floor beams at each node
- The knuckle connections represented with a set of linear springs
- The control house, gatehouse, and counterweight are represented by point masses.



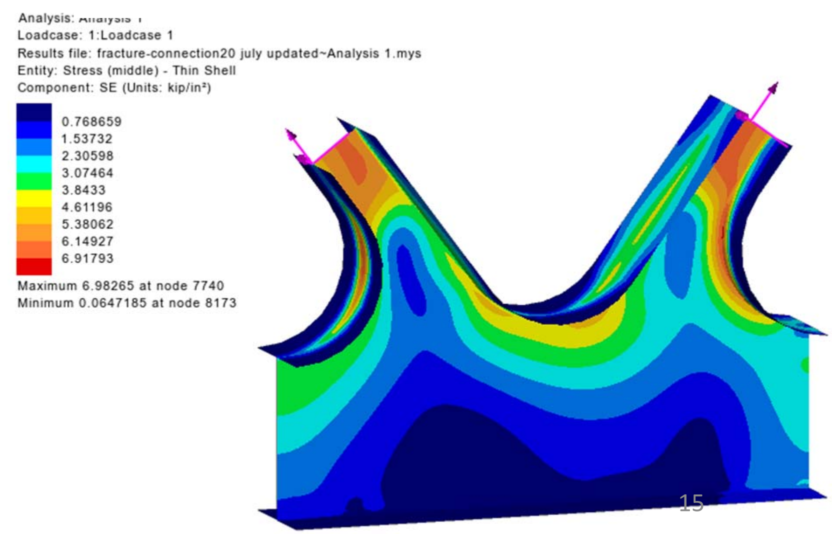


Calibrating the Model

Calibrating a detailed model of the gusset-less connection with structural health monitoring data collected in the in-service bridge increase the value of the model for bridge management



- ➢ Design Verification
- ➢ Design Protocol Development
- ➢ Visual Inspection Planning
- ➢ Structural Behavior Prediction



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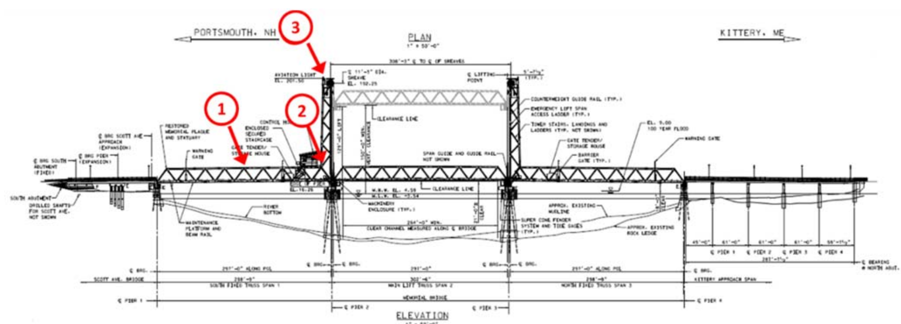
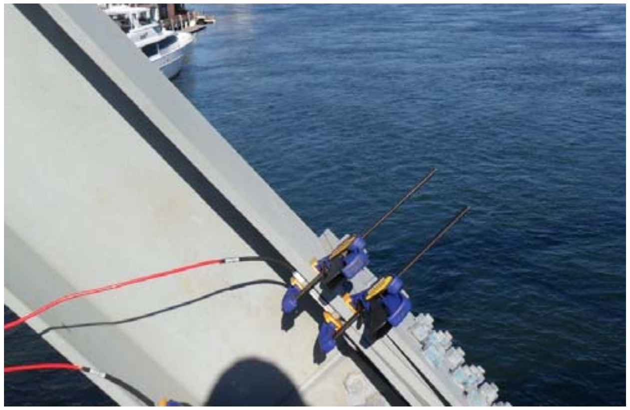
Instrumentation Plan – Preliminary Data

- Goals
  - Magnitude of live load strains excited by traffic and vertical lift operations
  - Natural Frequencies of vibration identification
  - Magnitudes of accelerations & strains during traffic and lift events under multiple environmental loading conditions
- Limitations
  - No adhesives or welding permitted
    - Flanges only
  - Access
    - Topside only



Preliminary Data Collection



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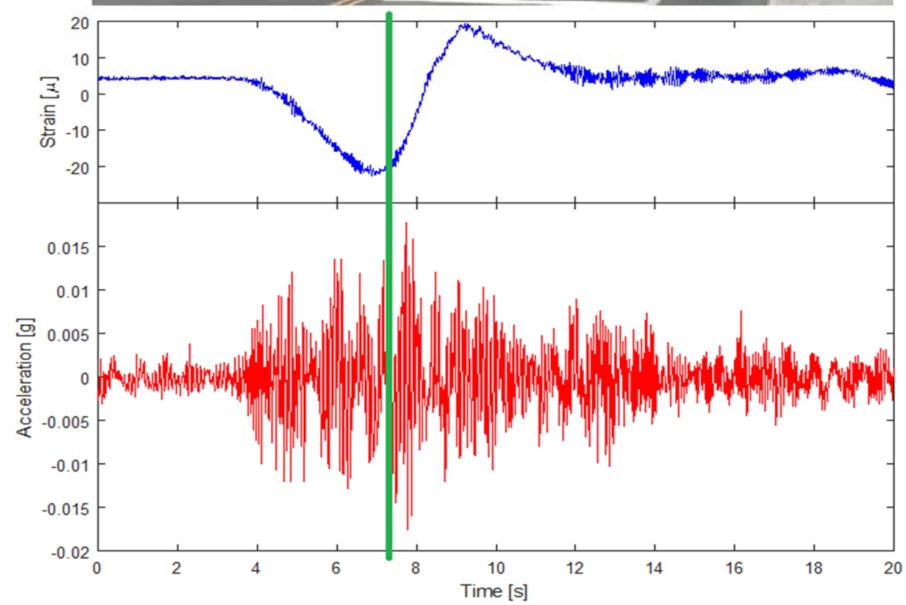
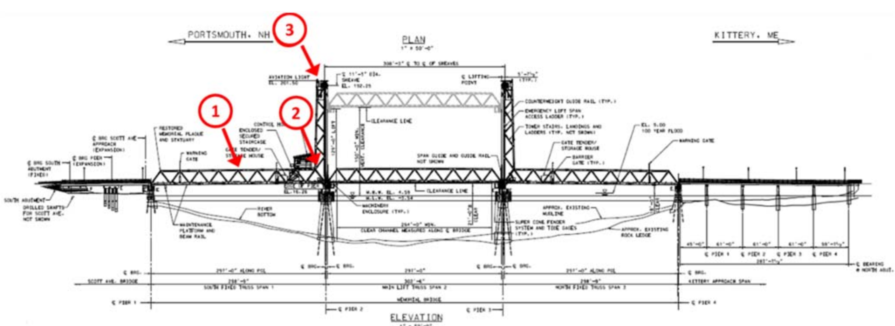
Preliminary Results

- Strain and Acceleration Response to Truck Traffic
- Bridge owners were not aware of the level of truck traffic on the bridge





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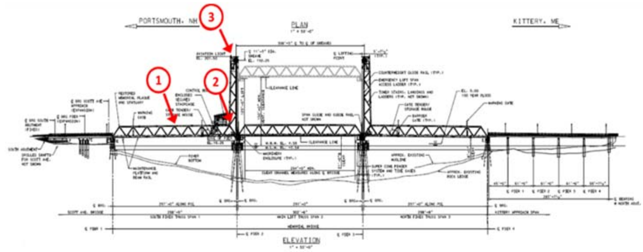
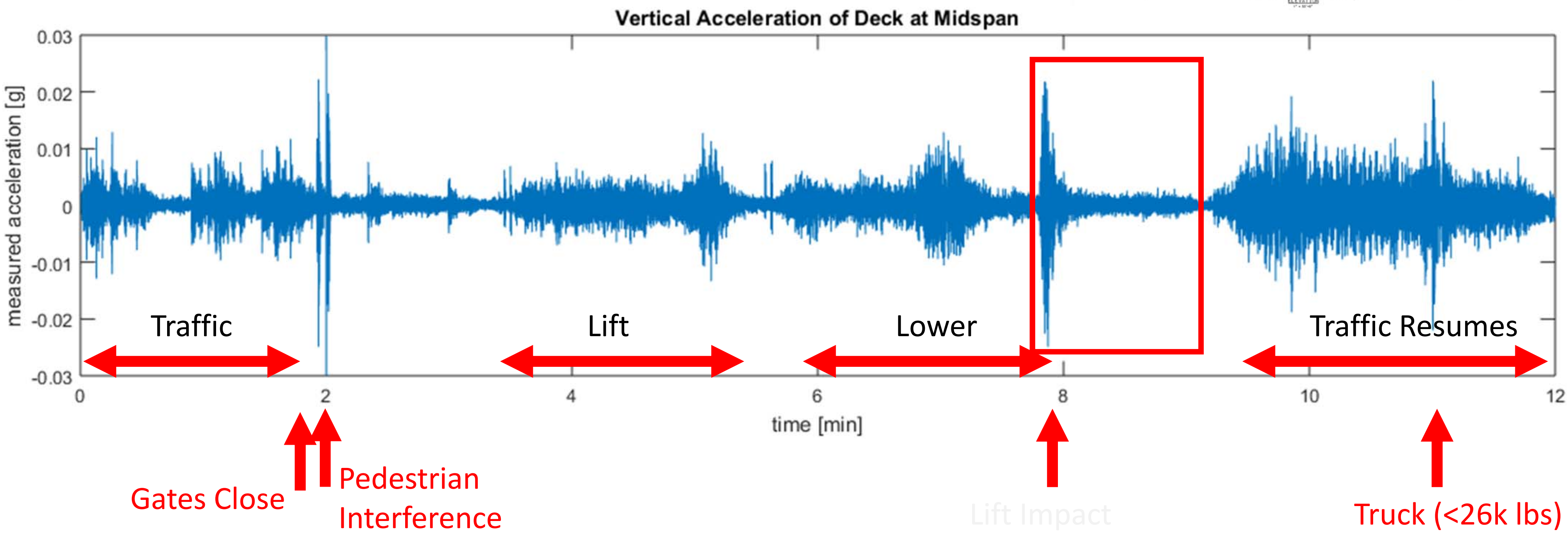
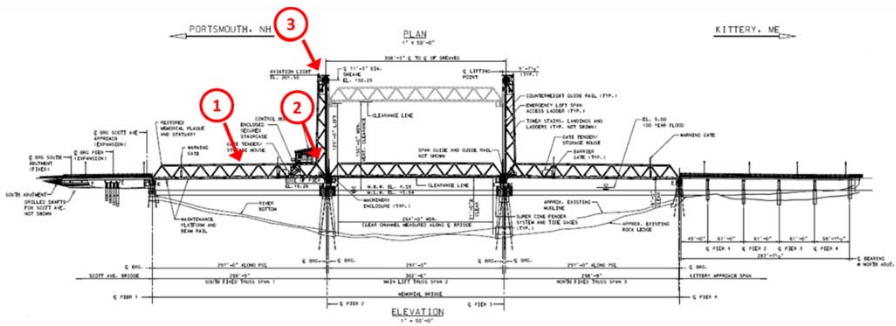
Vertical Lift Impact

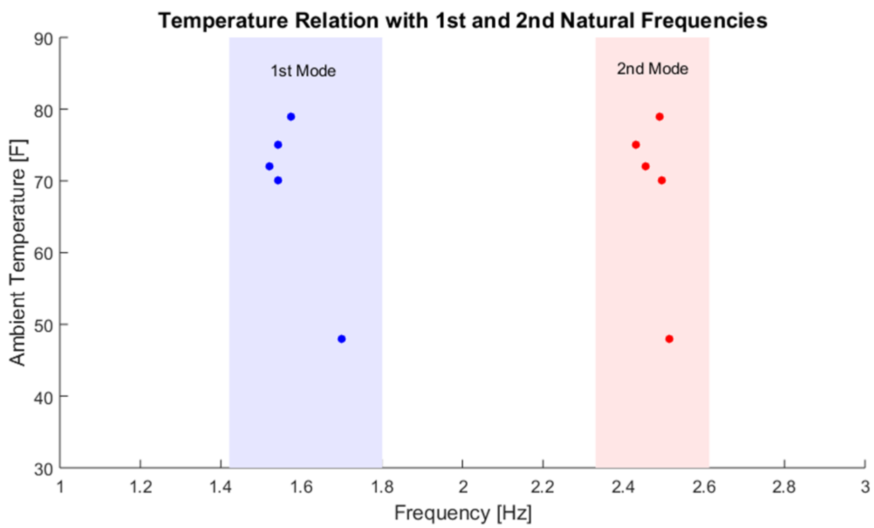




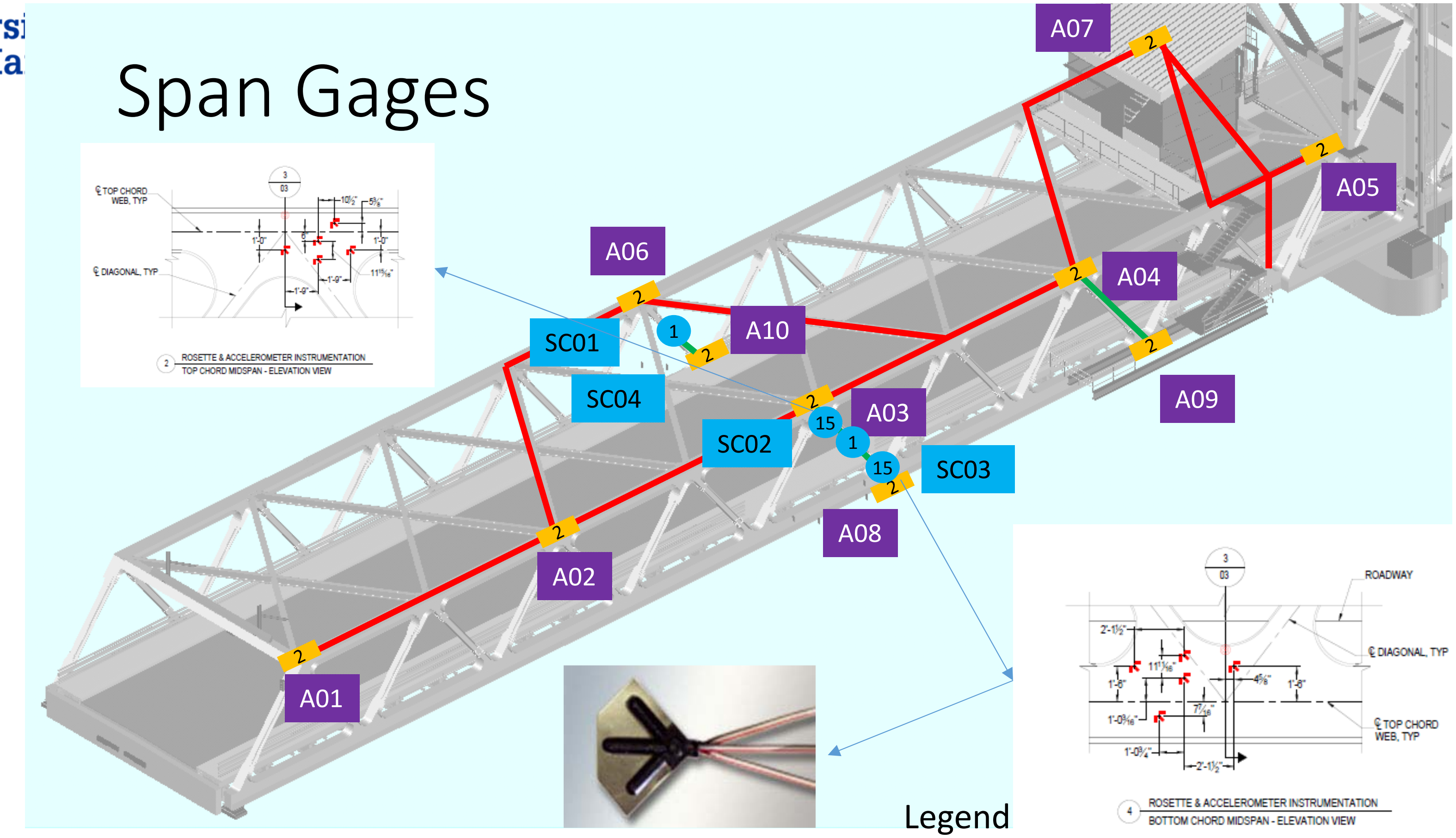
Temperature Impact

- We can begin to look at the catalog of responses to draw correlations with environmental effects
- Example: ambient temperature
  - Most preliminary data are from 70-80F range
  - Expanded catalog will allow better characterization of relationship





Span Gages



Total Gauges on Portsmouth Span
2 Uniaxial strain gauge
10 strain rosettes
clustered at 2 locations with three readings from each rosette
10 biaxial accelerometers

Legend

- Existing conduits
- Proposed conduits
- 2 Proposed accelerometers w/ channel qty.
- 15 Proposed strain gage clusters w/ channel qty.
- 2 Proposed tilt meters w/ channel qty.
- D Proposed weather stations (Digital)

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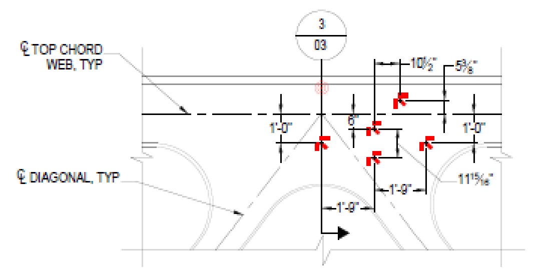
Installation of strain gages at the connections

Clusters of five strain rosettes at two connection nodes on the span which allow for investigation of force path through the webs of the gusset-less connections



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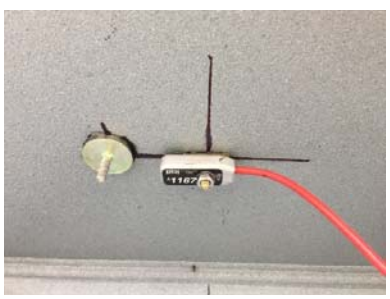
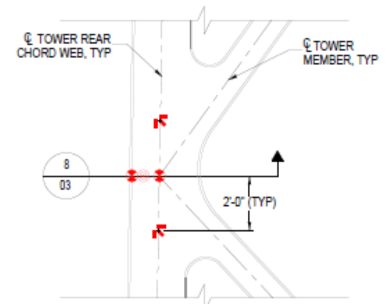
Vertical Lift Tower Gages

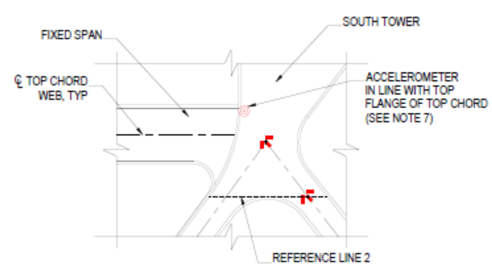
Total Gauges on Portsmouth Tower:

- 6 strain rosettes clustered at 3 locations with three readings from each rosette
- 4 biaxial accelerometers
- 4 biaxial tiltmeters
- 3 weather stations

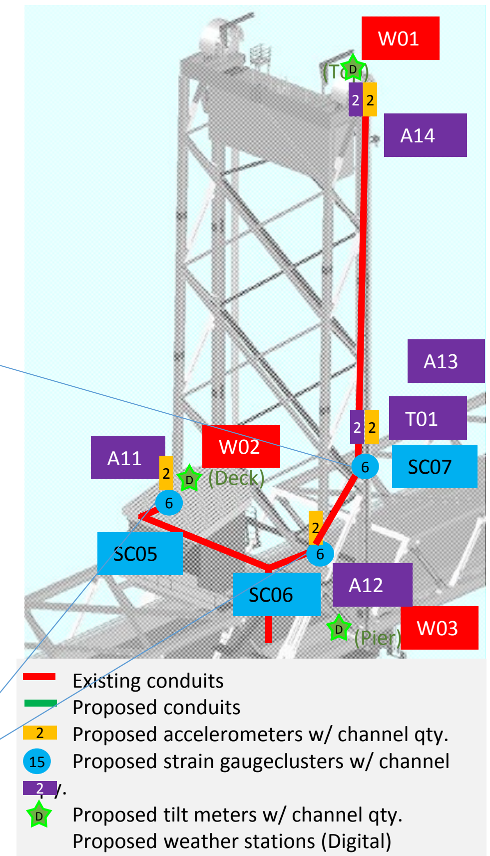




7 ROSETTE, TILTMETER & ACCELEROMETER INSTRUMENTATION
TOWER MIDSPAN - ELEVATION VIEW



6 ROSETTE & ACCELEROMETER INSTRUMENTATION
TOWER BOTTOM - ELEVATION VIEW



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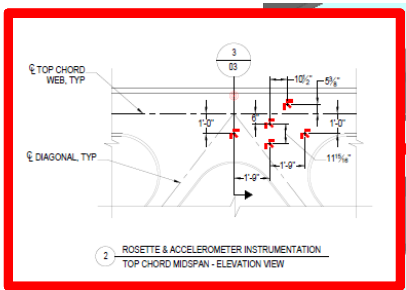
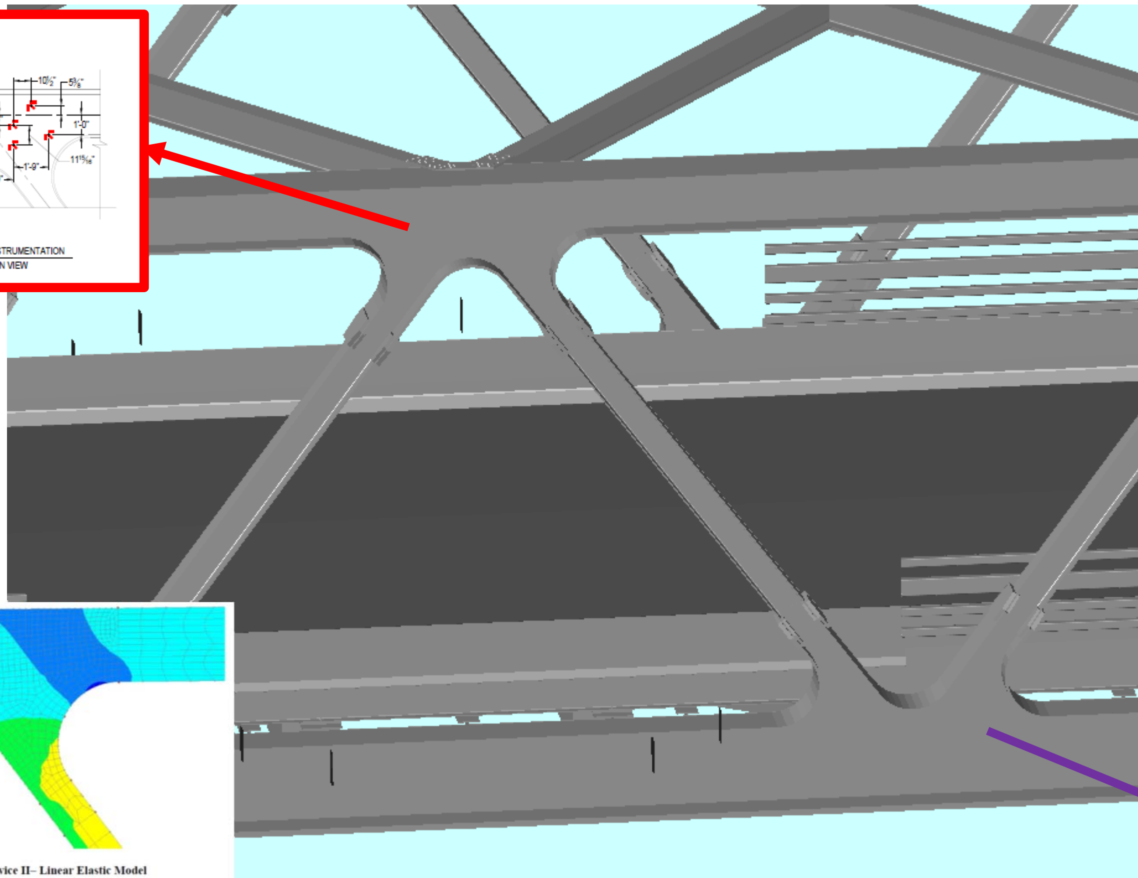
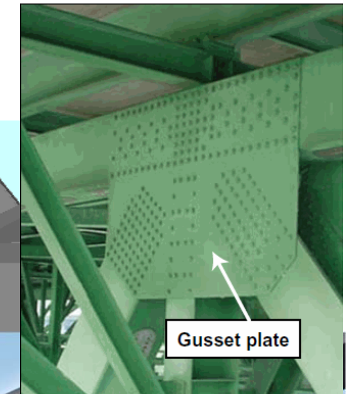
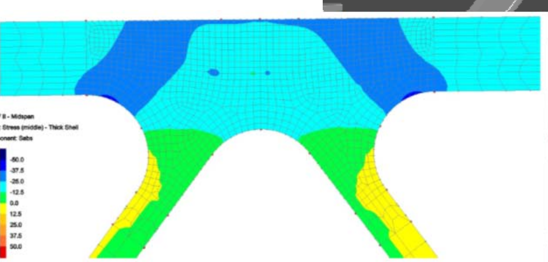
Connection Behavior for Design Verification and Condition Assessment

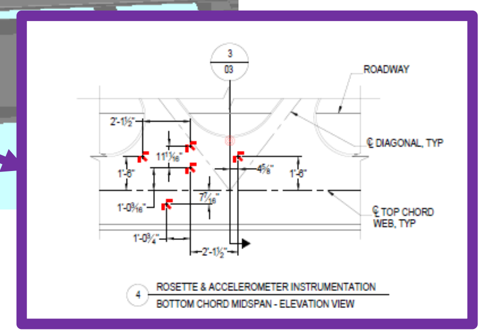








ure 15: Panel Point U5 Maximum Web Stress - AASHTO Service II– Linear Elastic Model



Covington, Engel, Kelly-Sneed, Noh and Zoli, “Portsmouth Memorial Bridge Replacement” 2013 SEI Illinois Chapter Lecture

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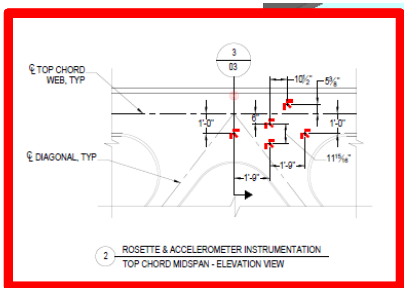
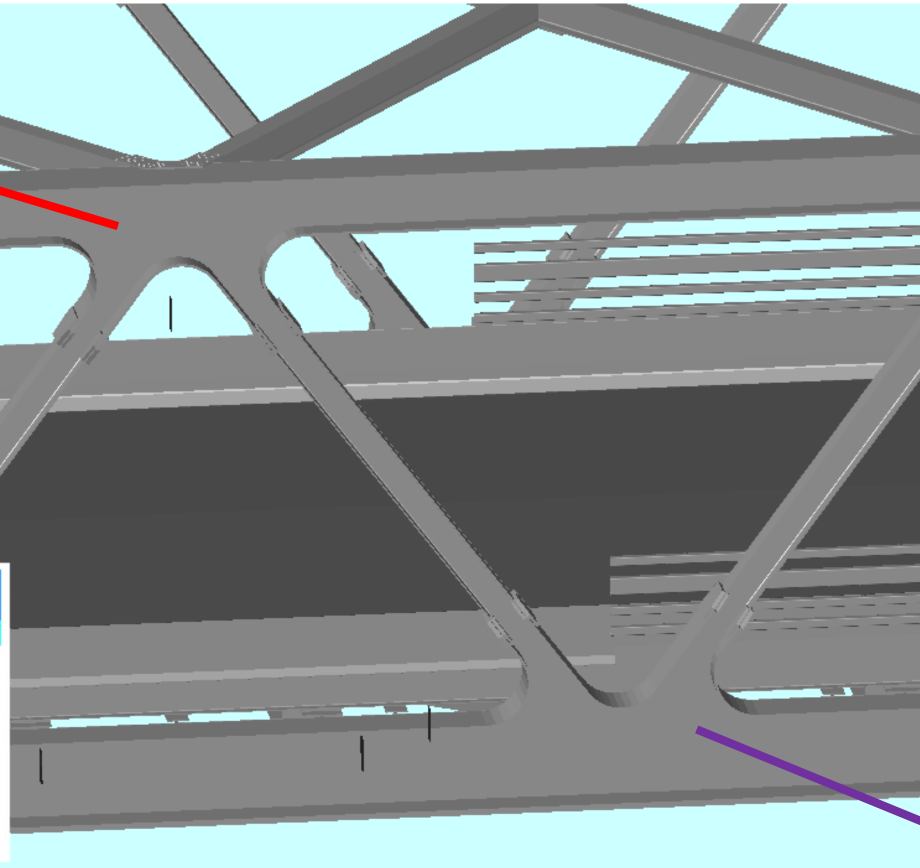
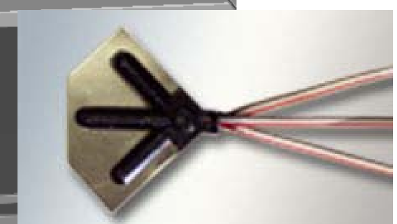
Connection Behavior for Design Verification and Condition Assessment







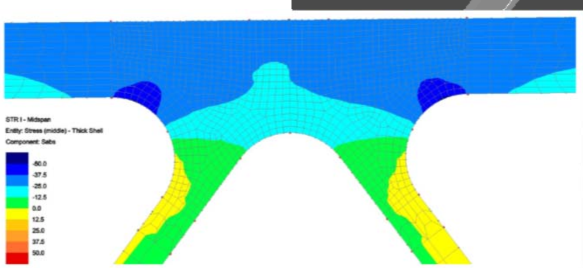
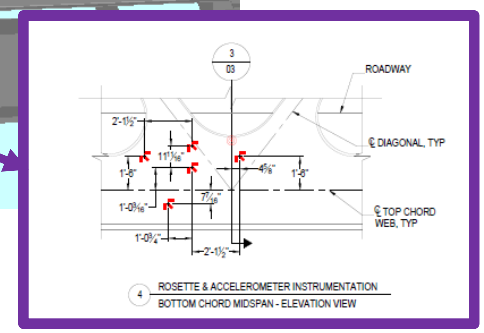


Figure 12: Panel Point U5 Maximum Web Stress - AASHTO Strength I – Linear Elastic Model



Covington, Engel, Kelly-Sneed, Noh and Zoli, "Portsmouth Memorial Bridge Replacement" 2013 SEI Illinois Chapter Lecture

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Structural Response Data

- Currently, data is collected at 5 minutes intervals (min, max and average)
- Triggers for high speed data collection – such as heavy trucks or lifts – are under development
- Database storage/on site storage will begin in the coming weeks
- Web-based data interface is underdevelopment with CS/IT Group at UNH

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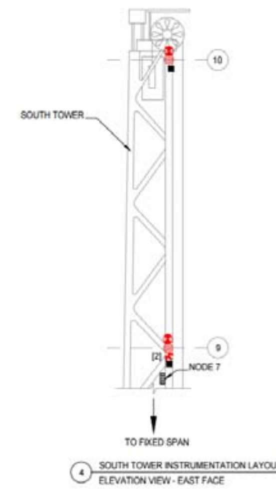
Data Collection During a Lift



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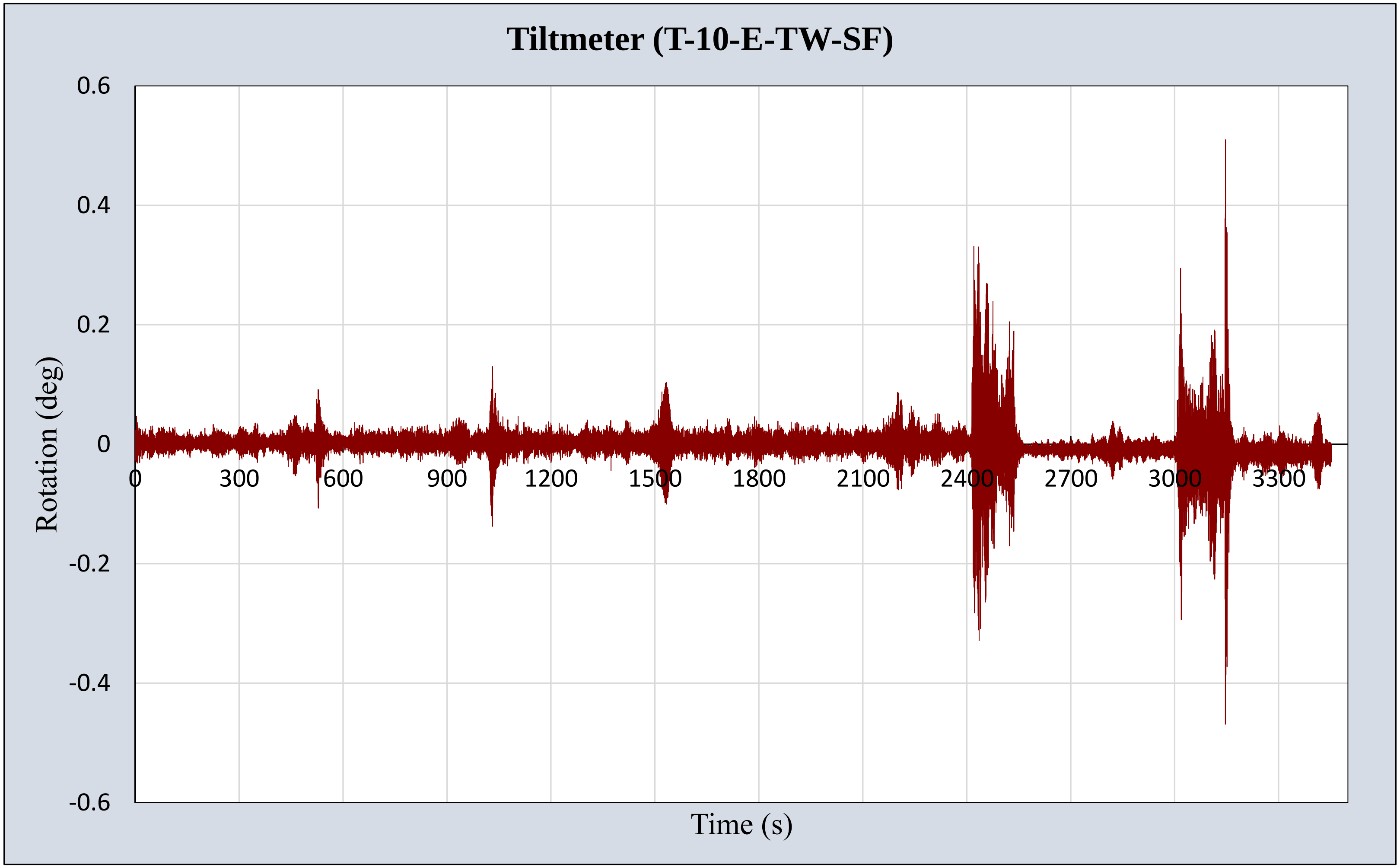

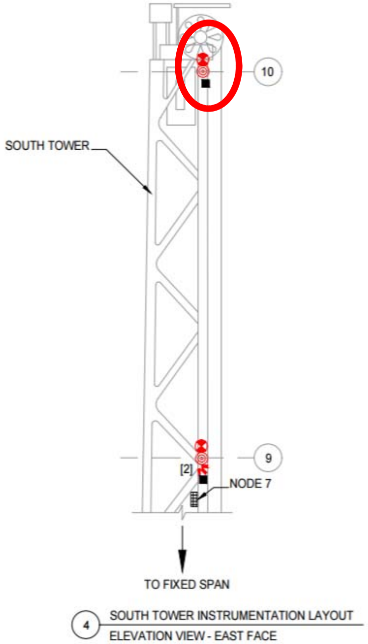

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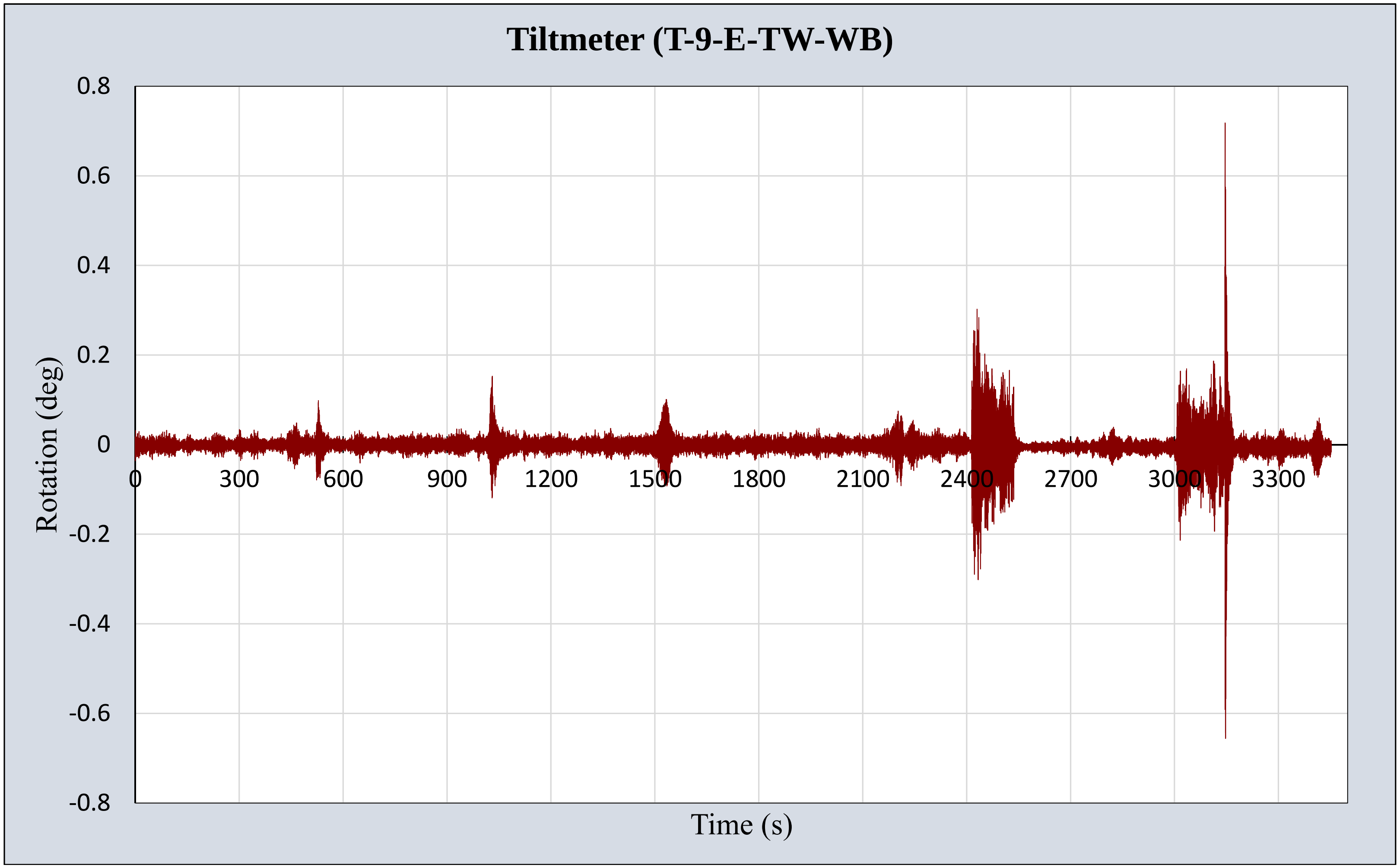

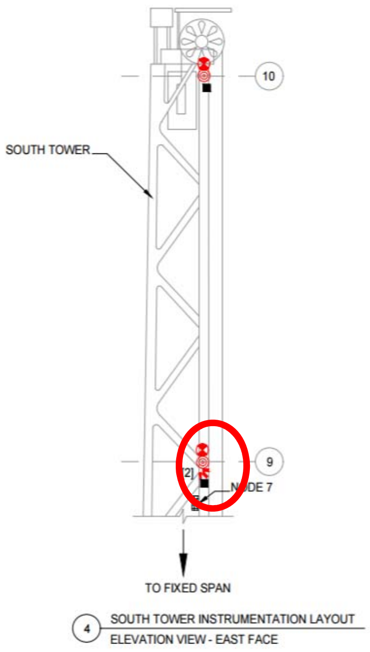

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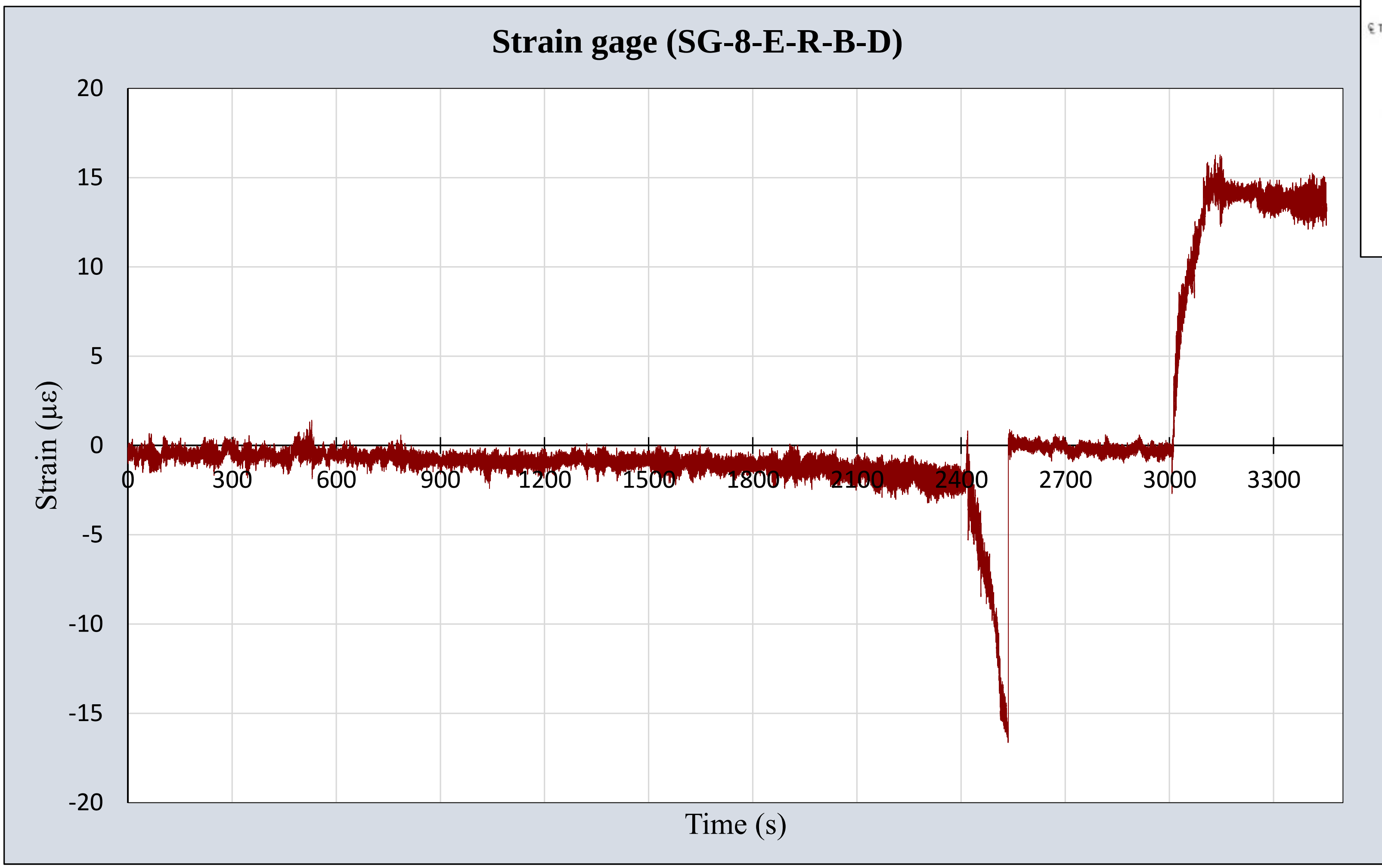

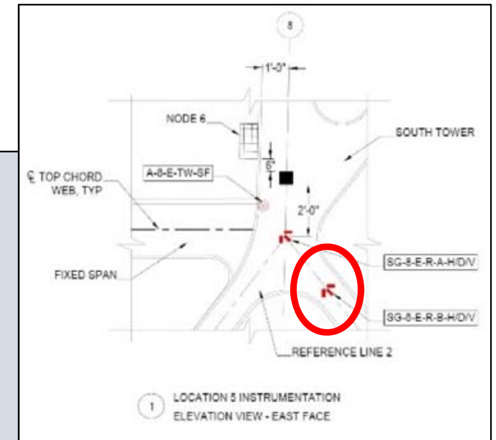

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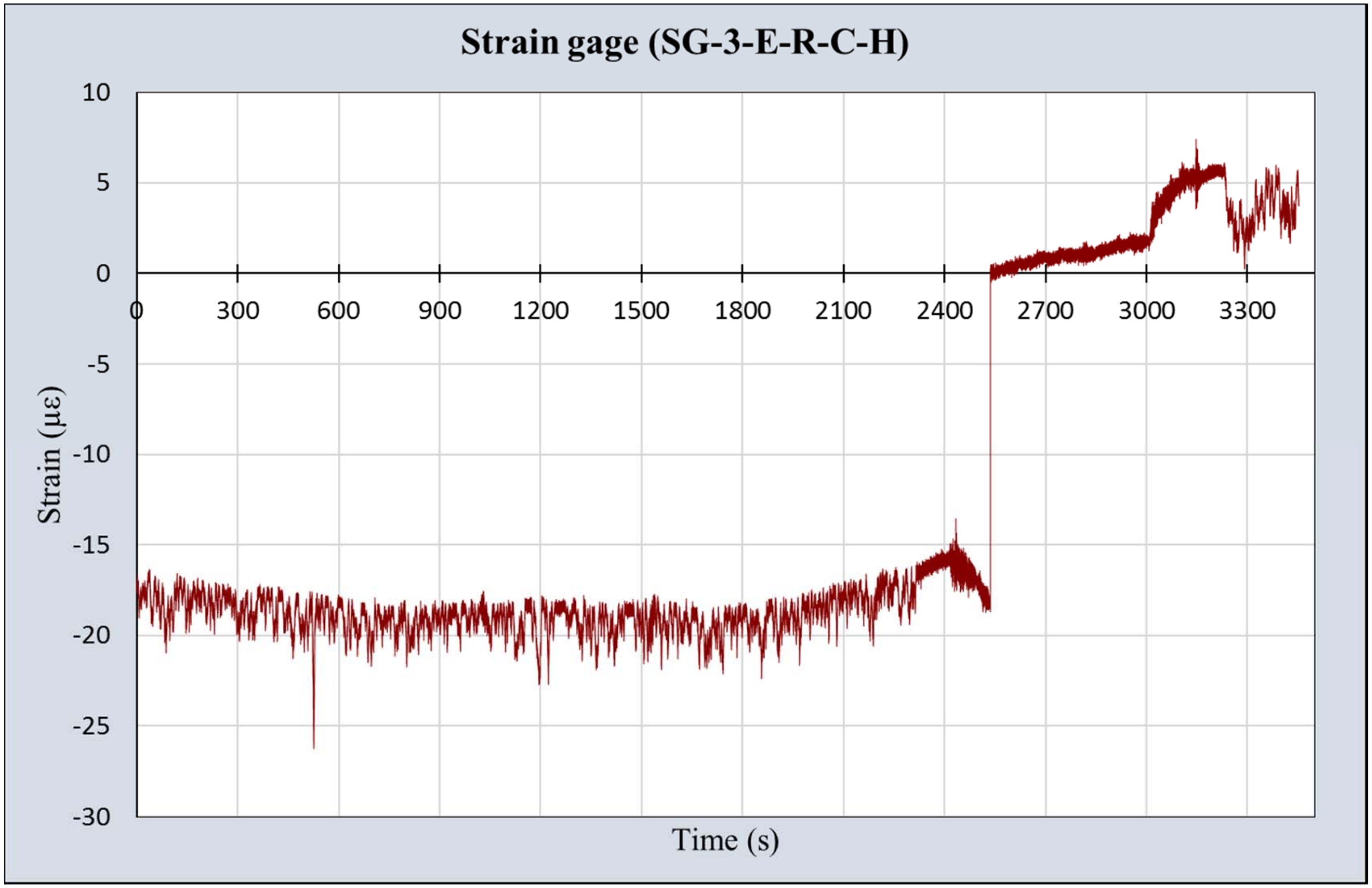

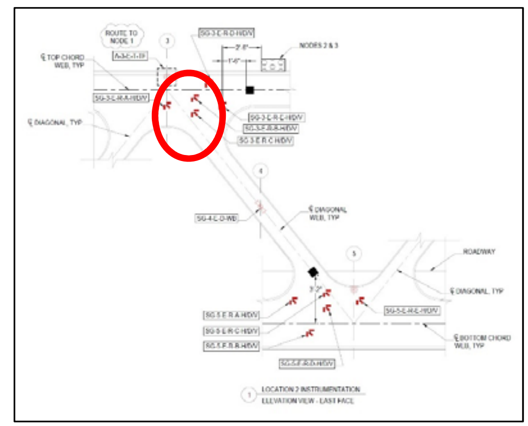

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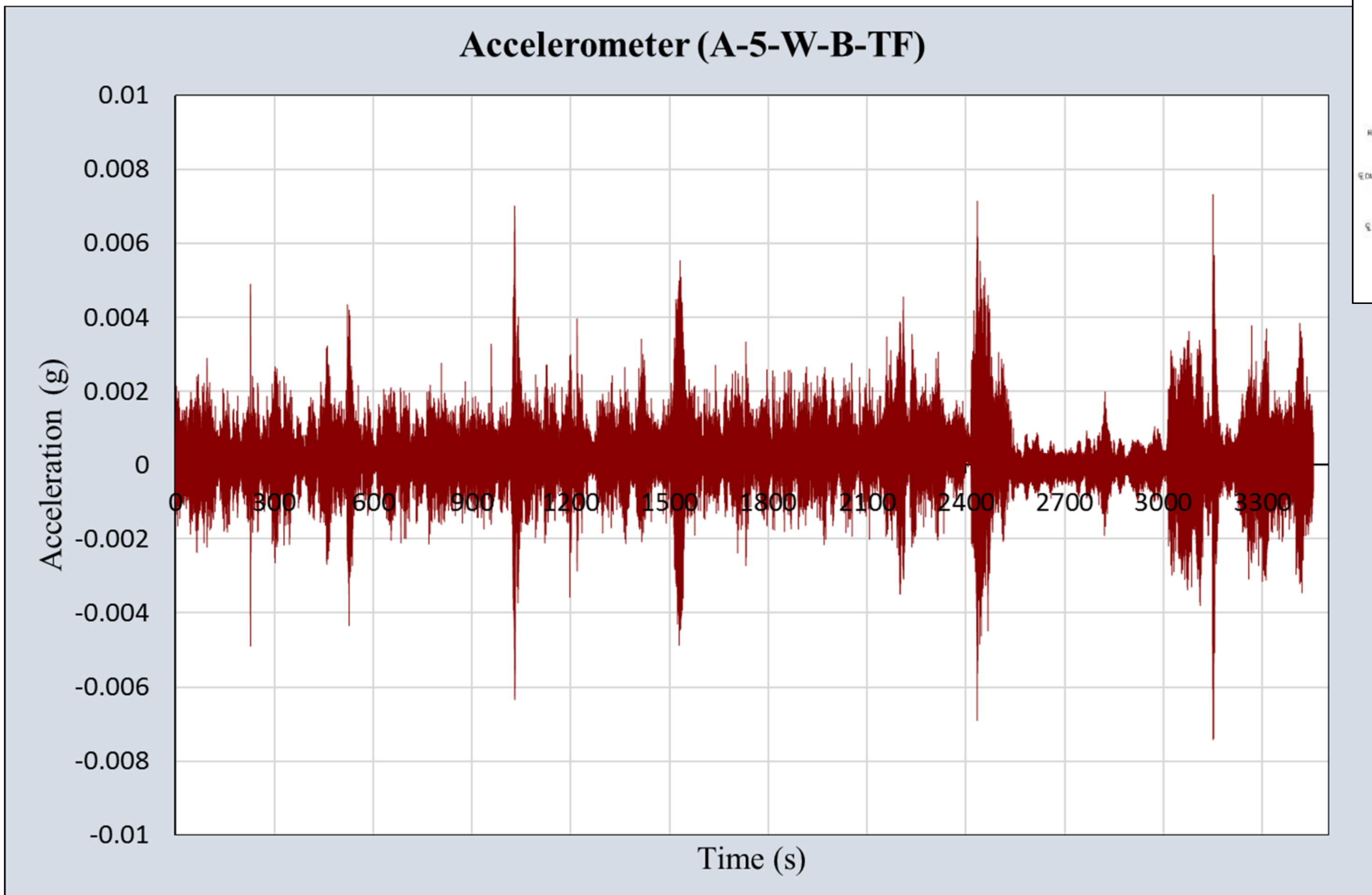

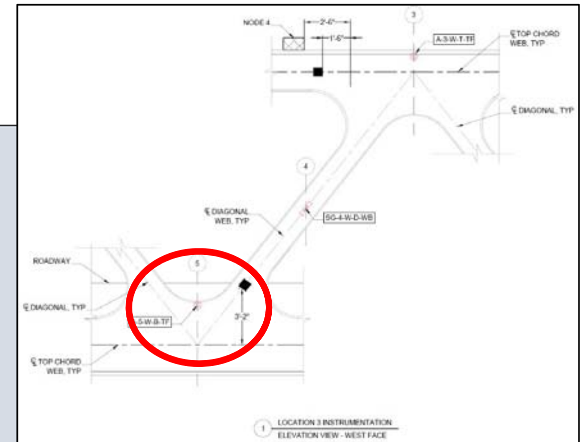

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Wind Load Development

- ➢The slender nature of the vertical lift towers and the coastal locations of the bridge prompted a study of the wind speeds, temperature variations and resulting wind design pressure
- ➢This study is in anticipation of the structural response of the bridge

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Development of Wind Loads

$$q = 0.5\rho V^2$$

- Wind loads developed after thorough examination of codes including ASCE, Eurocode, and AASTHO
  - Conservative “hybrid” cases developed capturing
    - Effect of temperature variability (change in air density)
    - Change in wind speed with altitude
    - Effect of wind on the tower system for lifted and un-lifted states of the bridge
    - Potential aerodynamic interaction
- Wind effects analyzed in SAP2000® in conjunction with thermal and dead loads

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Comparison of Code

Eurocode

$q = 0.5\rho V_b^2$

$F_w = 0.5\rho V_b^2 C A_{ref}$

ASCE 7-10

$q_z = 0.00256 K_z K_{zt} K_d V^2$

$F = q_z G C_p$

Based on 60 degree F

AASHTO

$V_{DZ} = 2.5\ V_0 (V_{30}/V_B)\ ln(z/z_0)$

$P_b = (\rho b^2/m)(16 V_r^2/bLf_b^2)$

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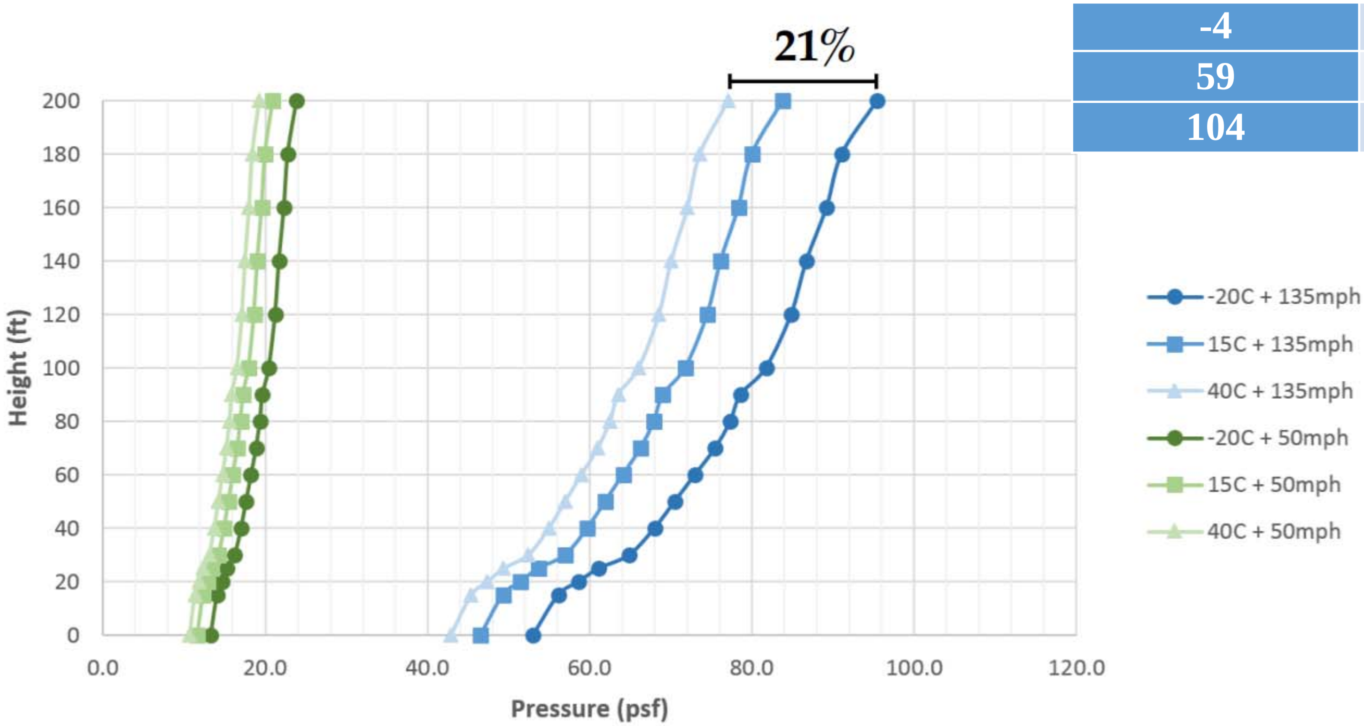
Development of Wind Loads

ASCE basic wind pressure numerical coefficients as a function of temperature

Temperature (˚F)	Numerical Coefficient
-4	0.00291
59	0.00255
104	0.00235

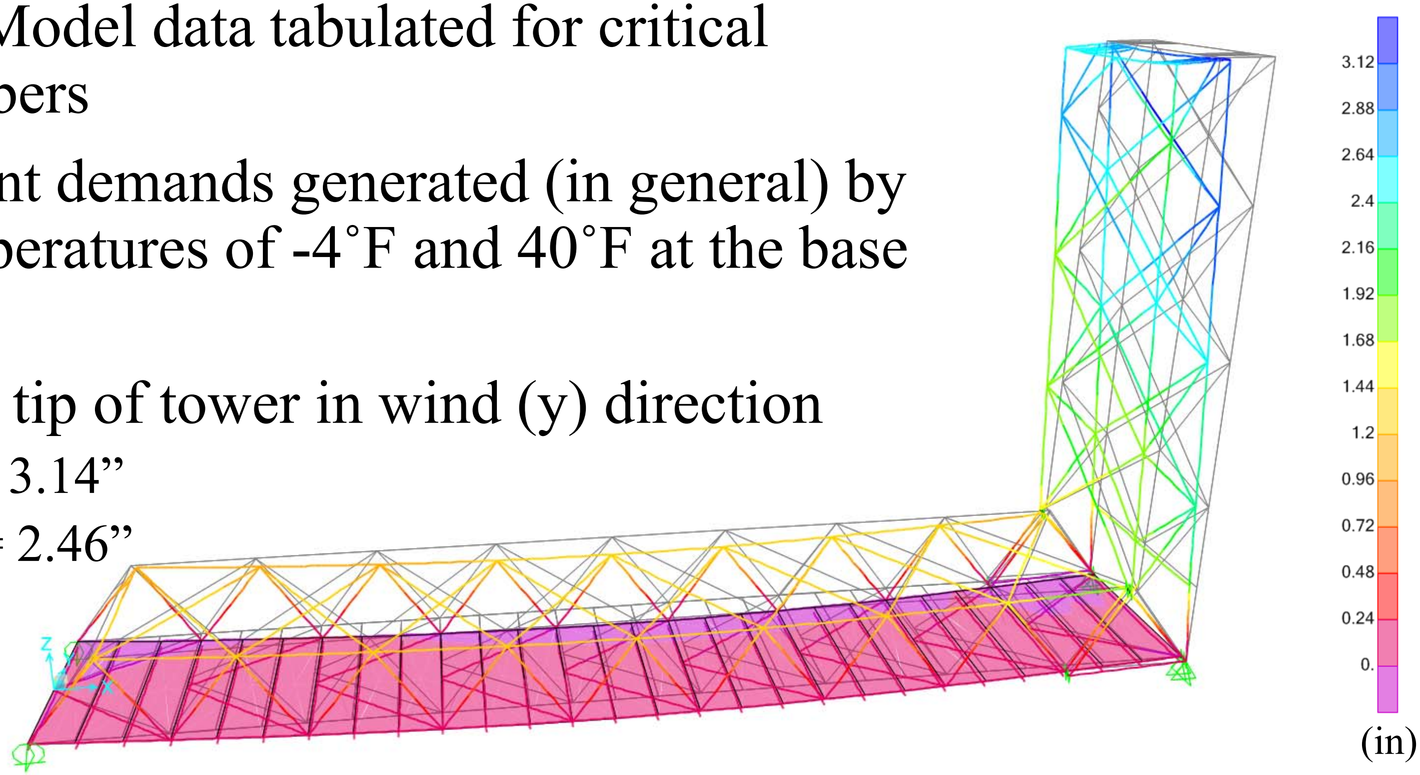


Development of Wind Loads

- Max base wind speed =100mph
  - ASCE 7-05
  - NOAA data
- Base temperatures
  - -4˚F (-20˚C)
  - 59˚F (15˚C)
  - 40˚F (40˚C)
- Wind acting perpendicular to the span length
- Analyzed with lift span in both up and down position

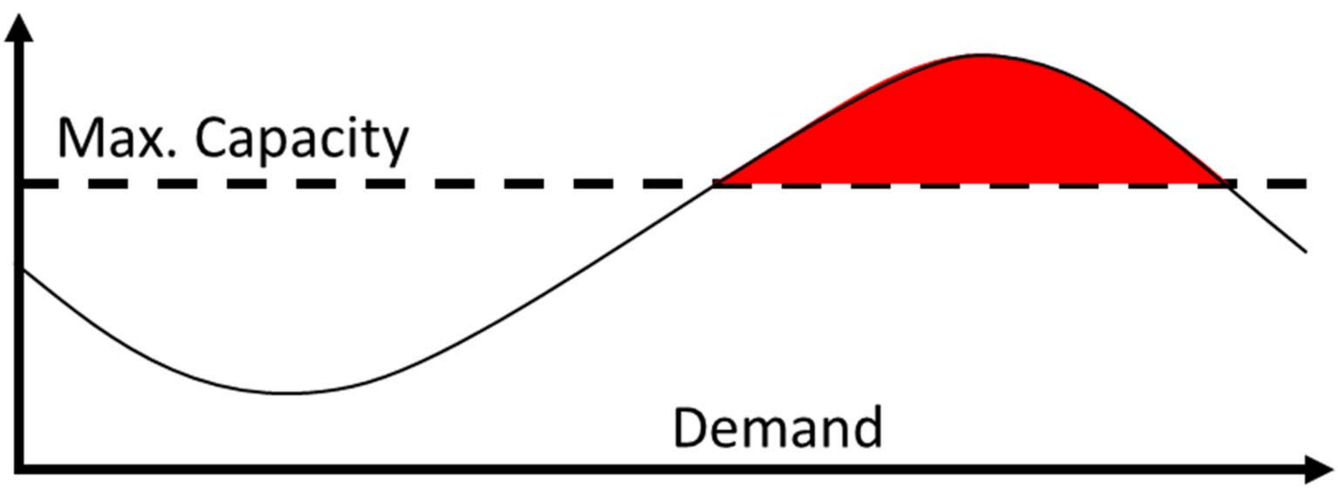
Wind Load Results

- SAP2000® Model data tabulated for critical system members
- Worst moment demands generated (in general) by extreme temperatures of -4˚F and 40˚F at the base of tower
- Deflection at tip of tower in wind (y) direction
  - -4˚F case = 3.14”
  - 40˚F case = 2.46”



Data Driven Demand Prediction

- By collecting data, a hybrid demand prediction can be developed
  - Combined Analytical tools and collected data
- For both strength and fatigue limit states



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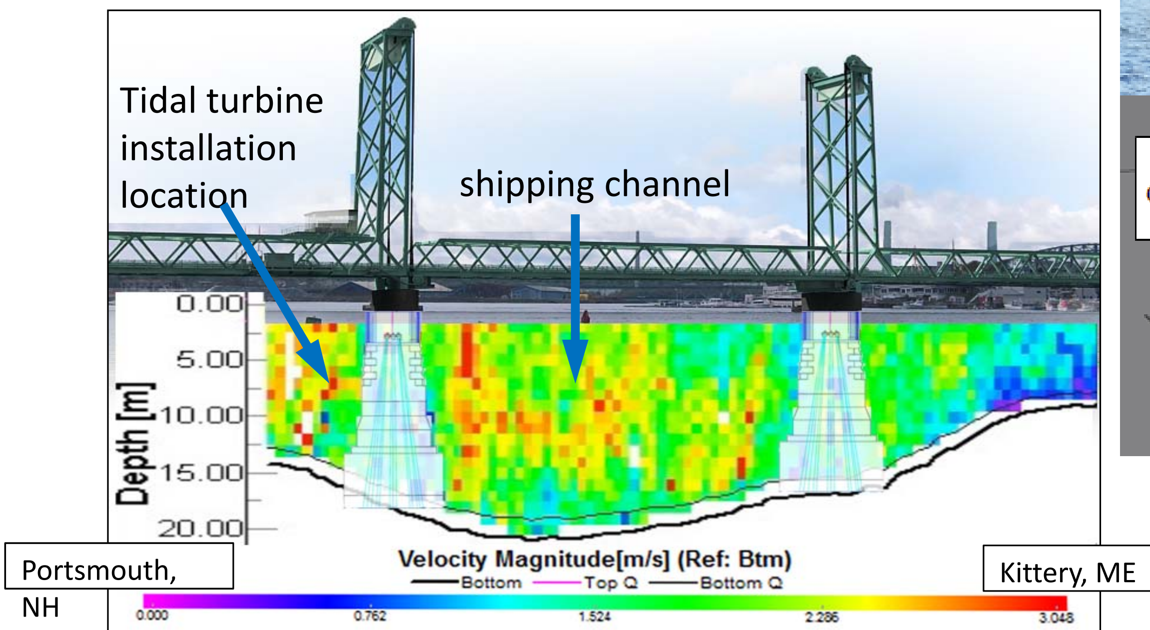
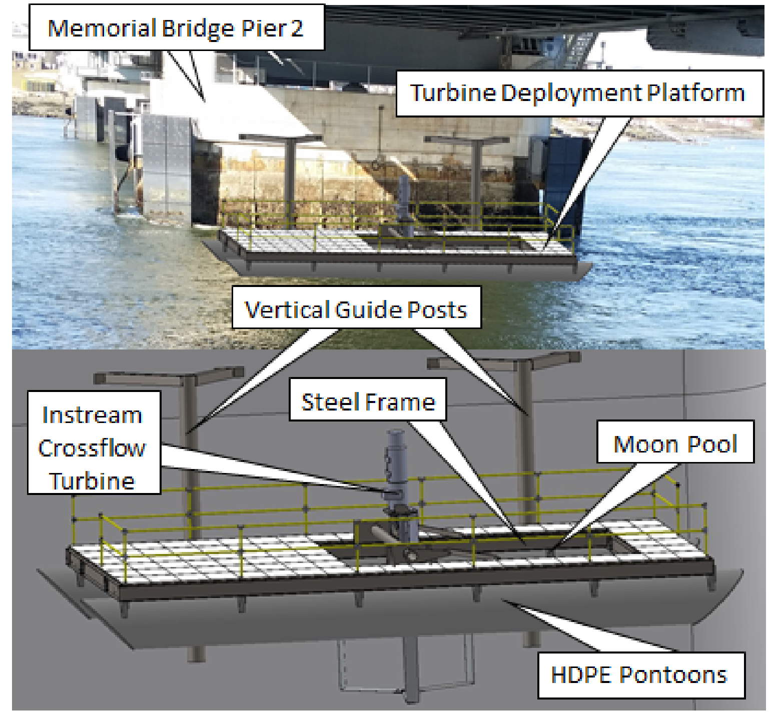
Conclusion

- Identification of the modal frequencies and mode shapes will allow to facilitate the structural parameter estimation of the identified structural parameter for model calibration.
- Environmental data collected via the three weather stations will create a data-informed basis for bridge operations, specifically related to the lift/no-lift decisions and basis for wind design load assessment.
- The combination of a local model of the connections within a global model of the truss, deck and floor beam elements to allow more efficient predict the performance of the bridge as a system.
- The innovative gusset-less connections combined with the repetitive vertical lift operations create an opportunity to advance the state of structural engineering design.

University of New Hampshire Future Work

- Structural Health Monitoring System Installed and Operational
- Model Calibration and Integration
- Demand Prediction and Design Verification
- Sensors Powered by Tidal Energy





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Tidal Turbine Deployment System

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