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OF NEW JERSEY

Use of Large Mobile Shakers in Bridge Evaluations:
Structural Identification, Dynamic Soil-Structure Interaction Effect Assessment, and Unknown Foundations

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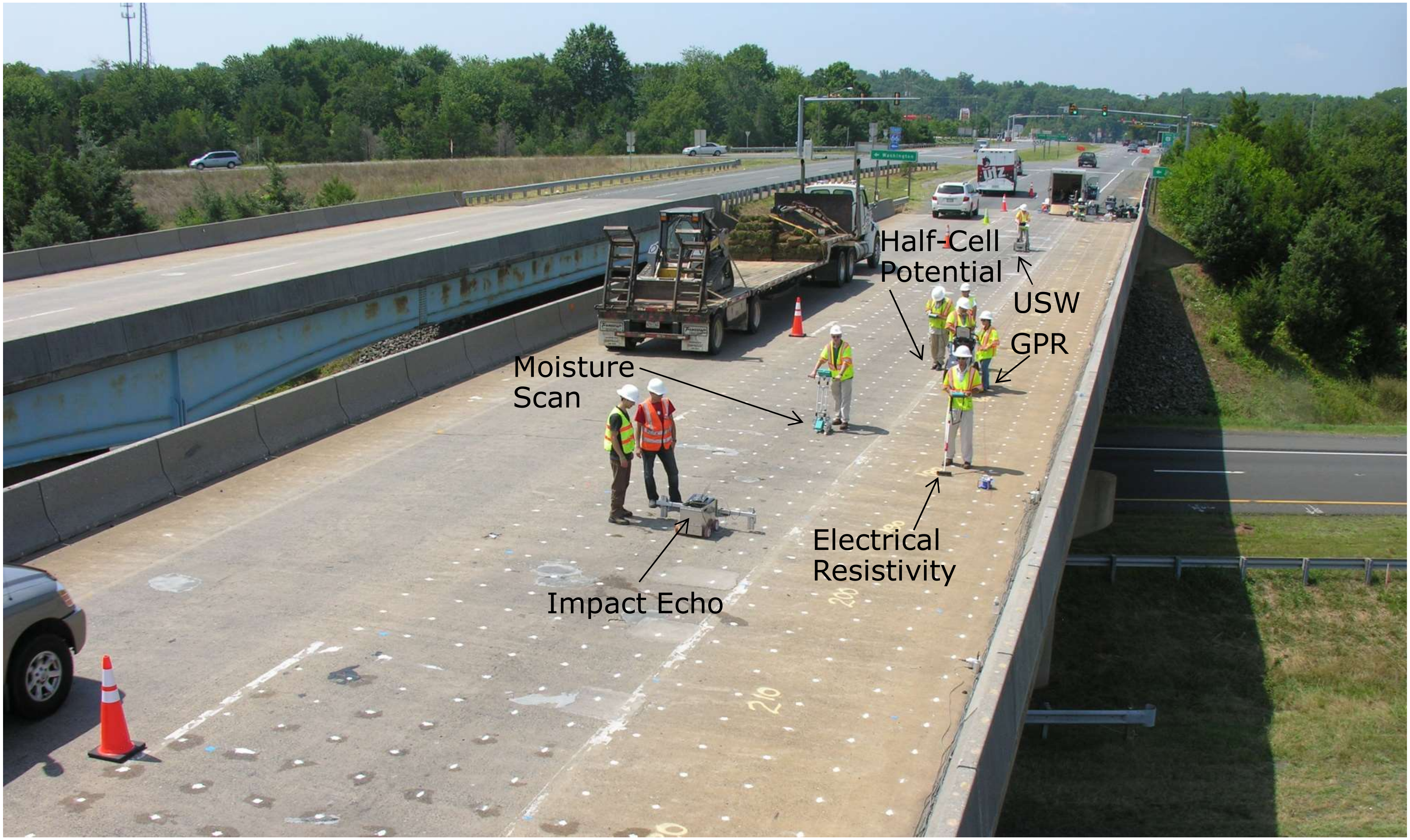
Use of Large Mobile Shakers in Evaluation of Bridges and Other Structures

- Structural identification (St-Id) to:
  - Evaluate and/or monitor the condition/performance of existing infrastructure systems
  - Improve the design of future infrastructure
- Evaluation of the significance of dynamic soil-structure interaction (DSSI) on the dynamic response of bridges to traffic and other loads
- Evaluation of unknown bridge foundations

Manual NDE Data Collection on Bridge Deck



Robotic NDE Data Collection on Bridge Deck

Reinforced Concrete Deterioration Types of Primary Interest

Corrosion

Delamination

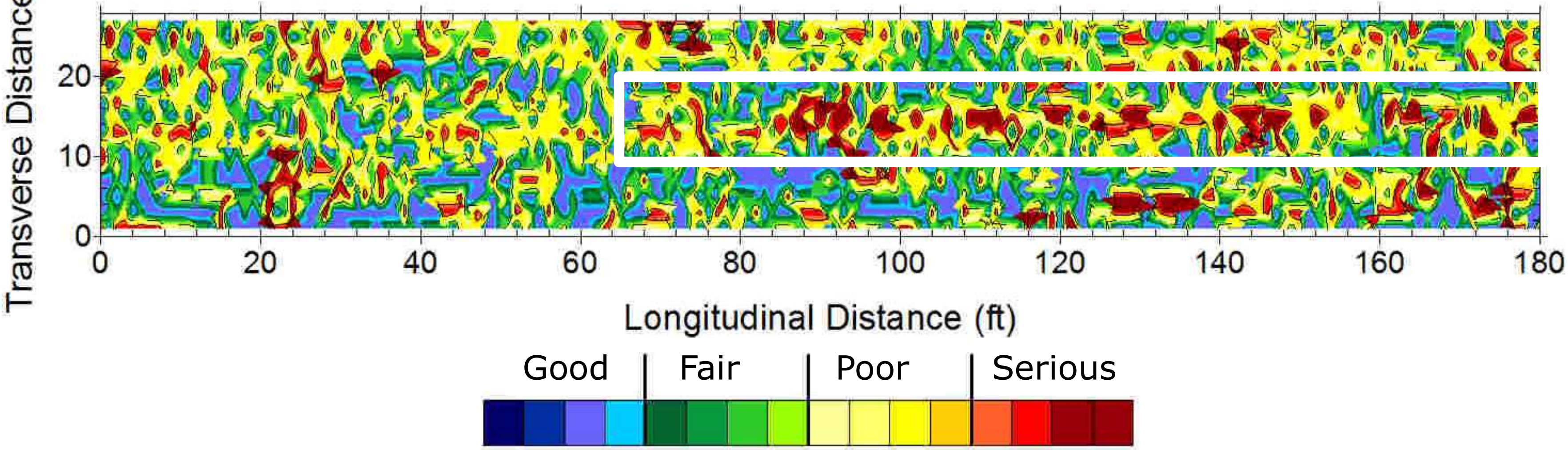
Concrete Degradation

Vertical Cracks

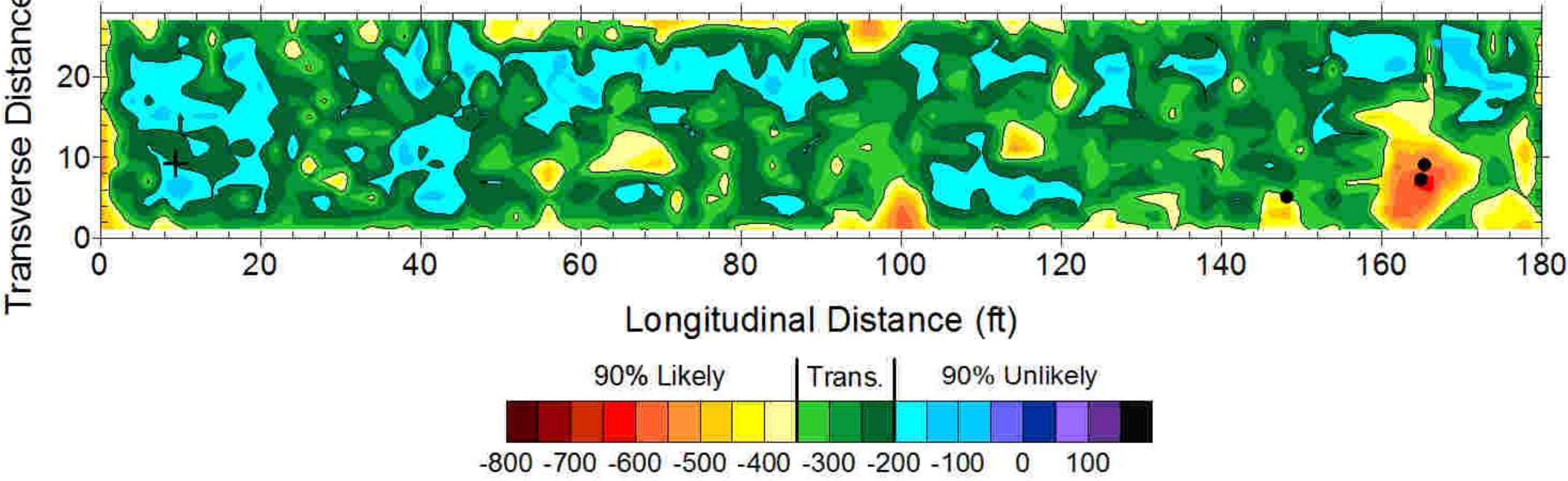
NDE Survey of Deck of Bridge O1, Iowa

Comparison of NDE Technology Results for O1 Bridge, Iowa

Delamination Map from IE Survey



Corrosion Activity Map from HCP Survey



St-Id and Evaluation of Significance of DSSI on the Dynamic Response of Bridges Using Large Mobile Shakers

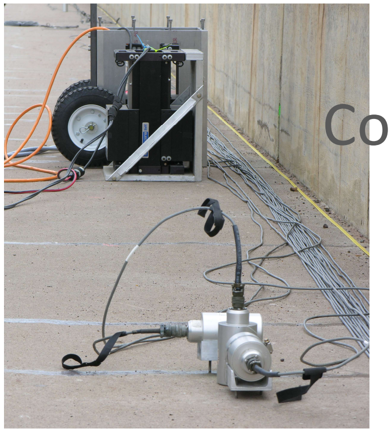
Hobson Avenue Bridge, Hamilton, NJ, Testing

Main objectives:

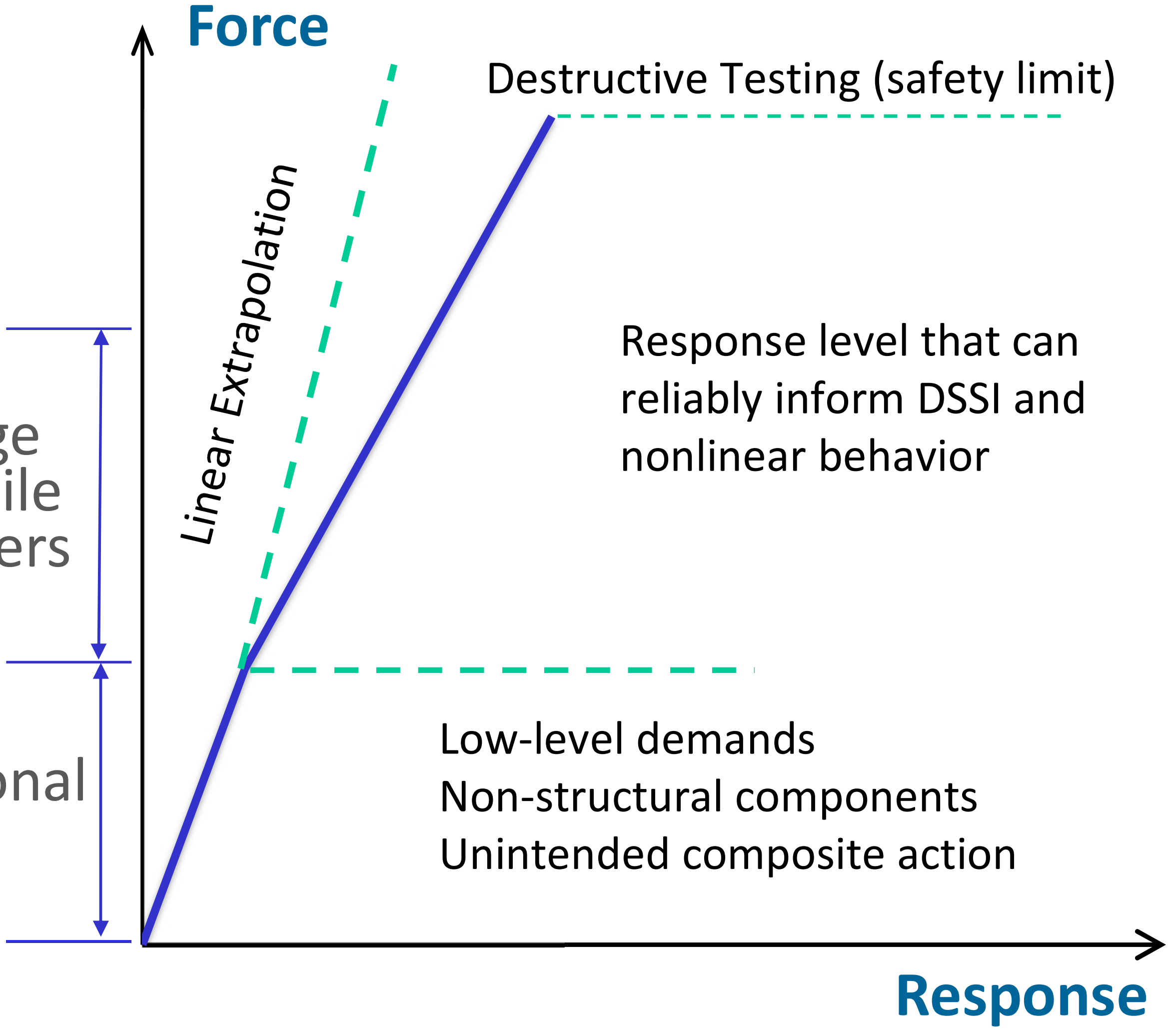
- Carry out low to moderate magnitude shaking of a bridge using a large mobile shaker (T-Rex) and evaluate the response
- Capture and develop better understanding of the significance of DSSI effects on the bridge dynamic response
- Compare the bridge response for a fixed-base assumption and when the DSSI effects are incorporated (through parametric studies and numerical modeling)
- Evaluate the effect of superstructure characteristics on bridge deck performance

Load Levels during Conventional St-Id vs. NHERI T-Rex Shaking

Large Mobile Shakers



Conventional St-Id



Destructive Testing (safety limit)

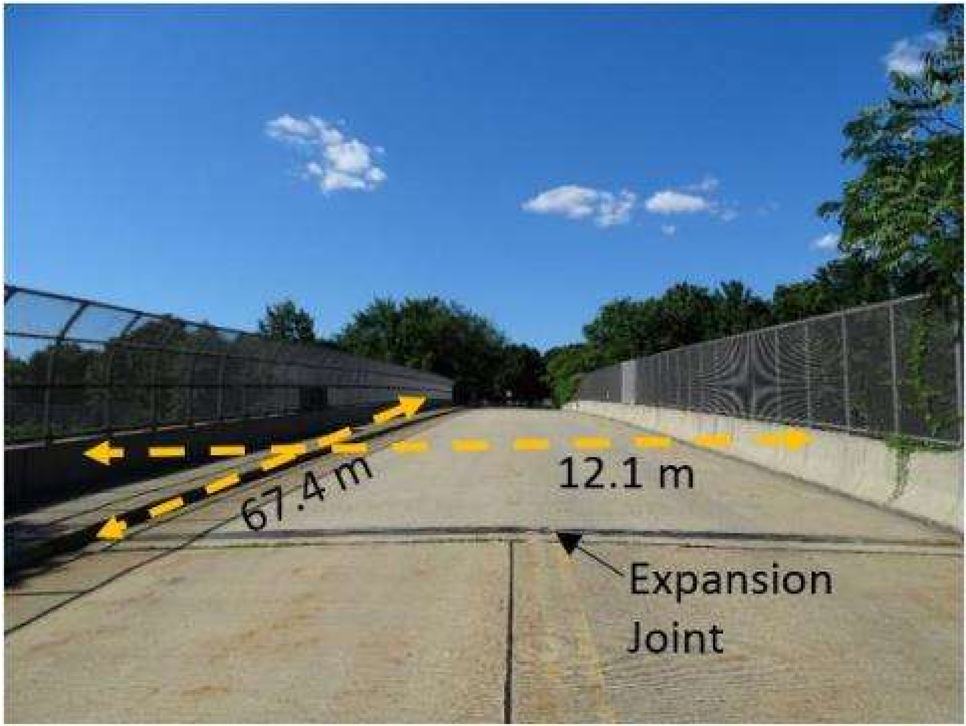
Response level that can reliably inform DSSI and nonlinear behavior

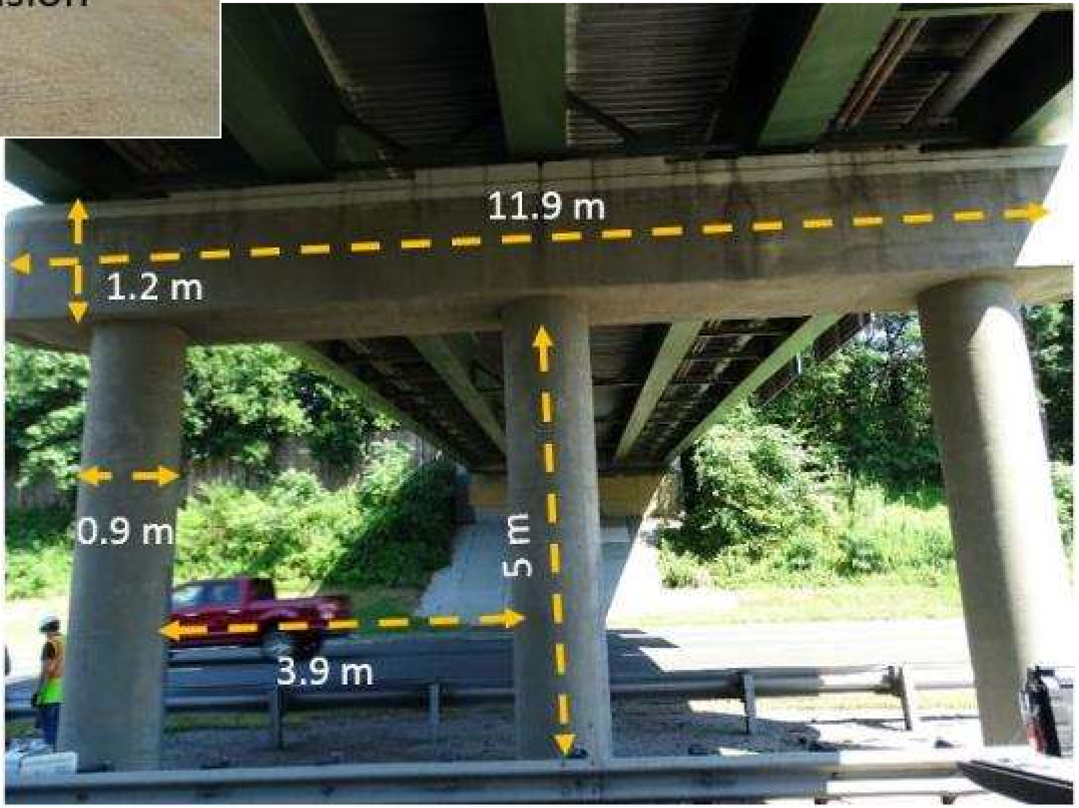
Low-level demands
Non-structural components
Unintended composite action

Hobson Avenue Bridge, Hamilton, NJ

- Bridge over Interstate 195 in Hamilton Township, NJ
- 67.4 m [221 ft] two-span continuous steel girder jointed bridge with a three-hammerhead pier on a shallow continuous reinforced concrete (RC) footing

Hobson Avenue Bridge Deck and Pier





T-Rex on Hamilton Avenue Bridge

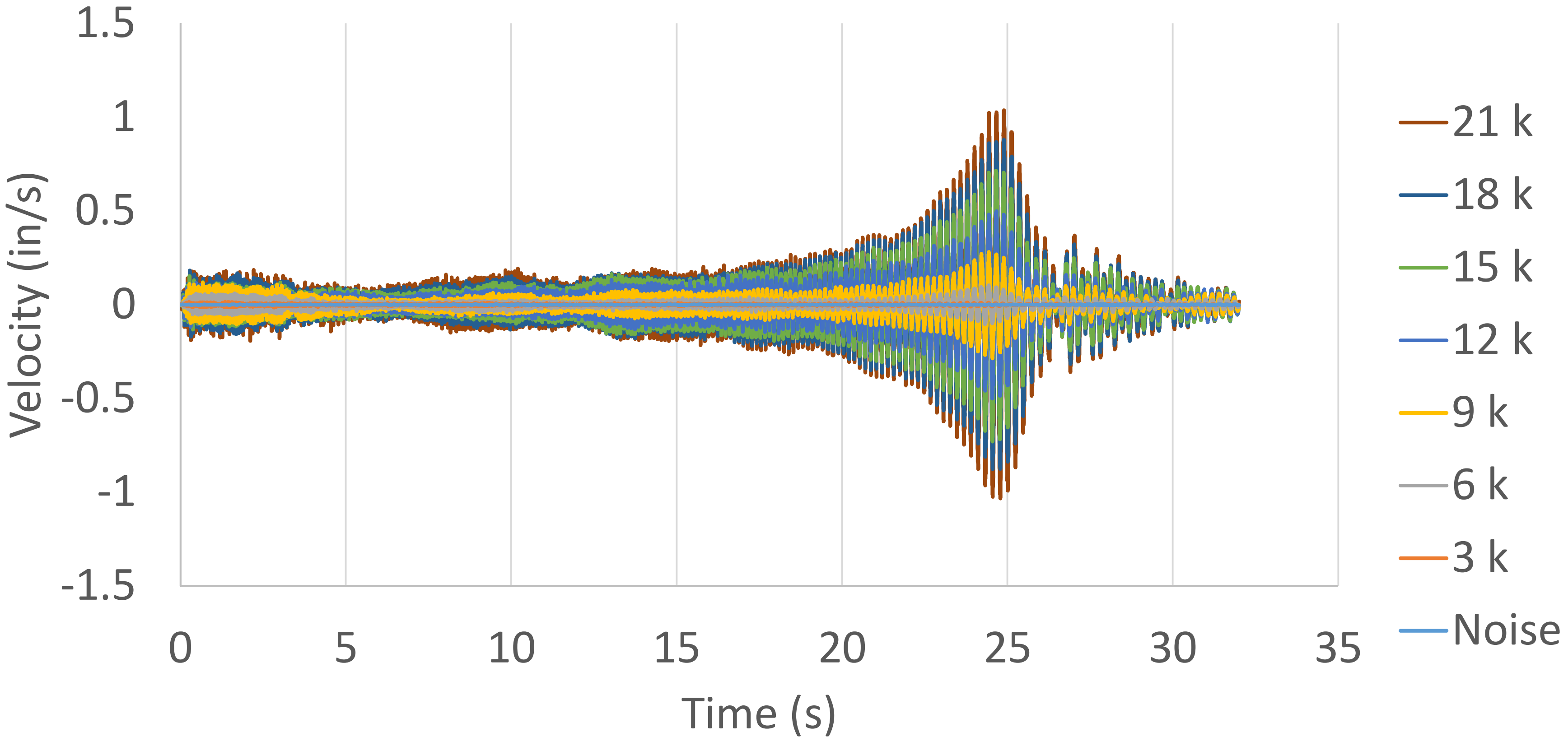
- Transverse, longitudinal, and vertical shaking under varying load magnitudes above pier and above mid span
- Linear chirp applied from 15 Hz to 2 Hz
- Load varied from 3 to 21 kips (14.5 to 94.5 kN)

Hobson Avenue Bridge Sensor Placement

T-Rex on Hobson Avenue Bridge

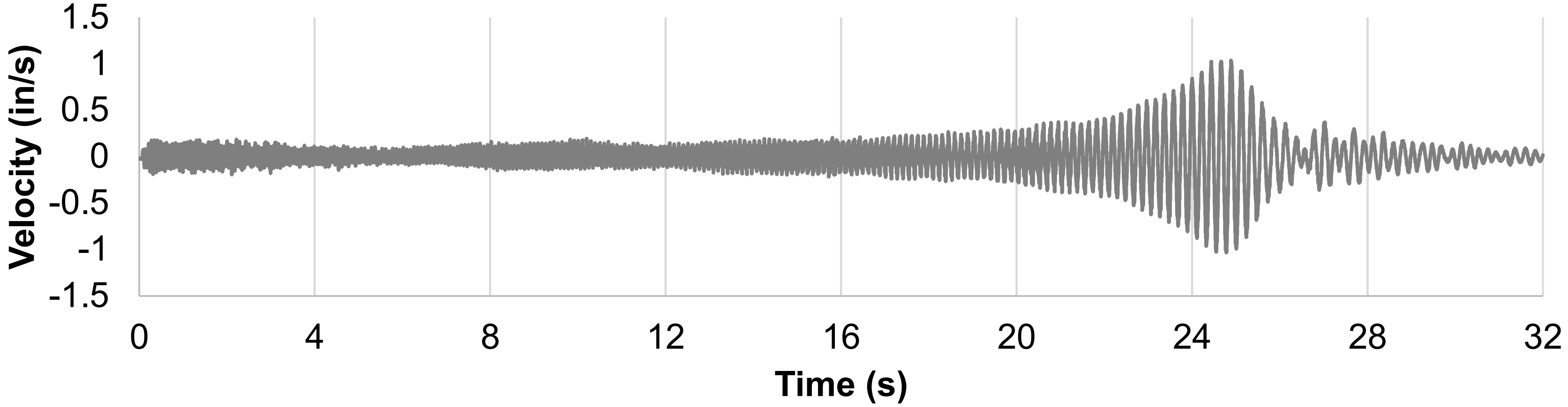
Sample Hobson Avenue Bridge Response to T-Rex Shaking

- Horizontal transverse deck response under different horizontal load magnitudes (linear chirp, 15 to 2 Hz)
- Nonlinear response → double load ≠ double response



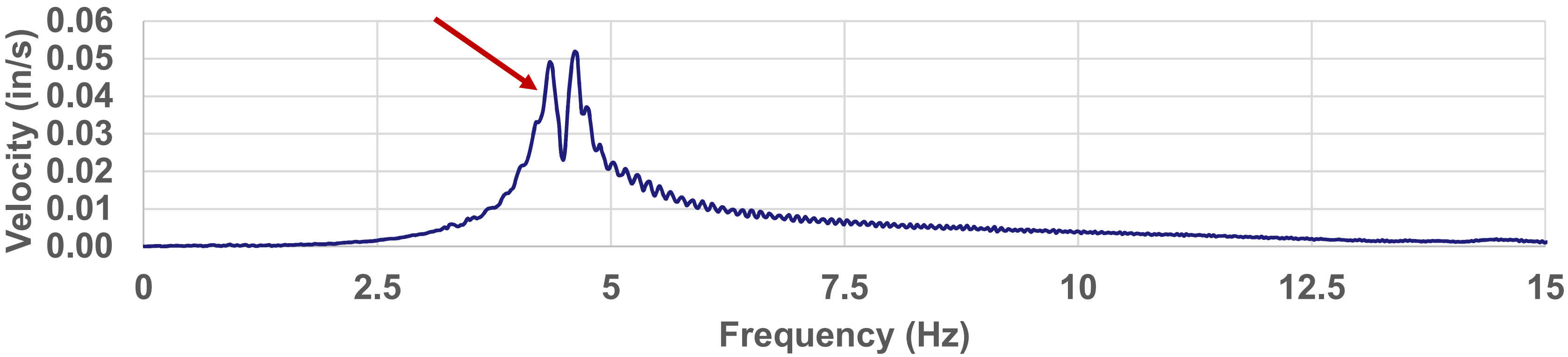
Hobson Avenue Bridge Deck Transverse Response to Horizontal Shaking

Velocity history: Deck-West side

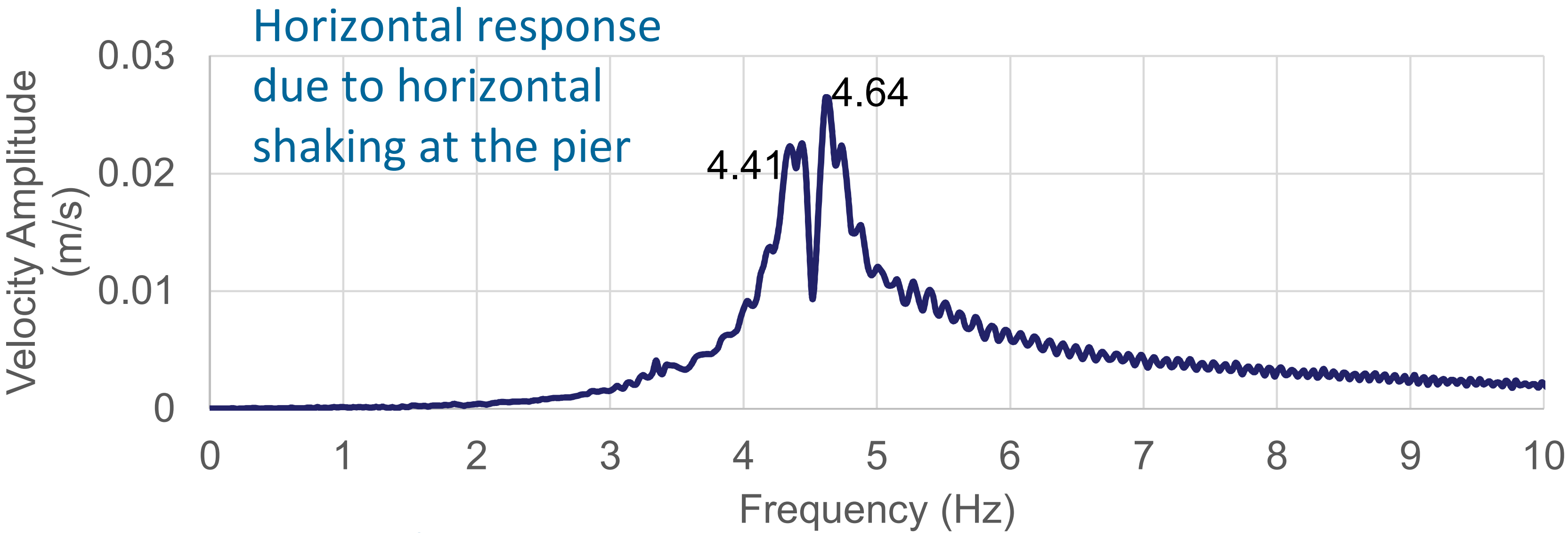


2 resonant peaks @ 4.41 and 4.64 Hz

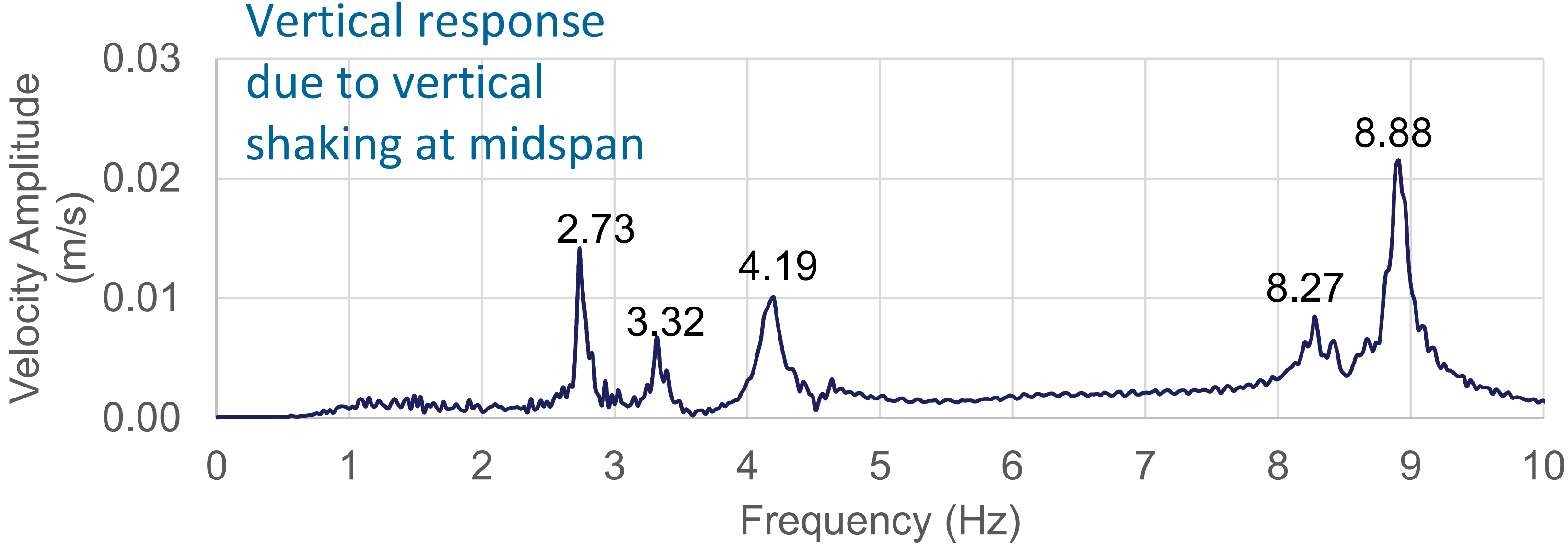
Velocity Spectrum: Deck-West side



Comparison of Horizontal (Transverse) and Vertical Response Spectra of Hobson Avenue Bridge



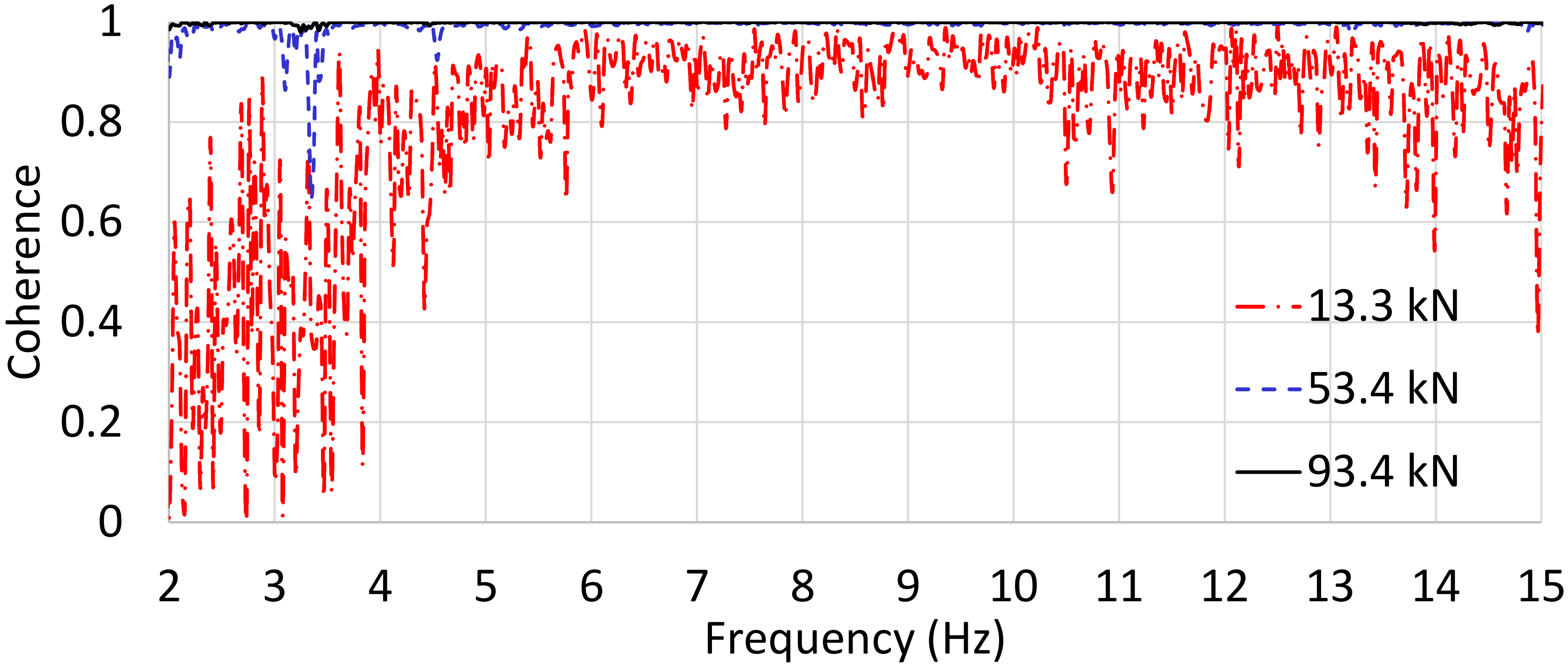
Horizontal response due to horizontal shaking at the pier



Vertical response due to vertical shaking at midspan

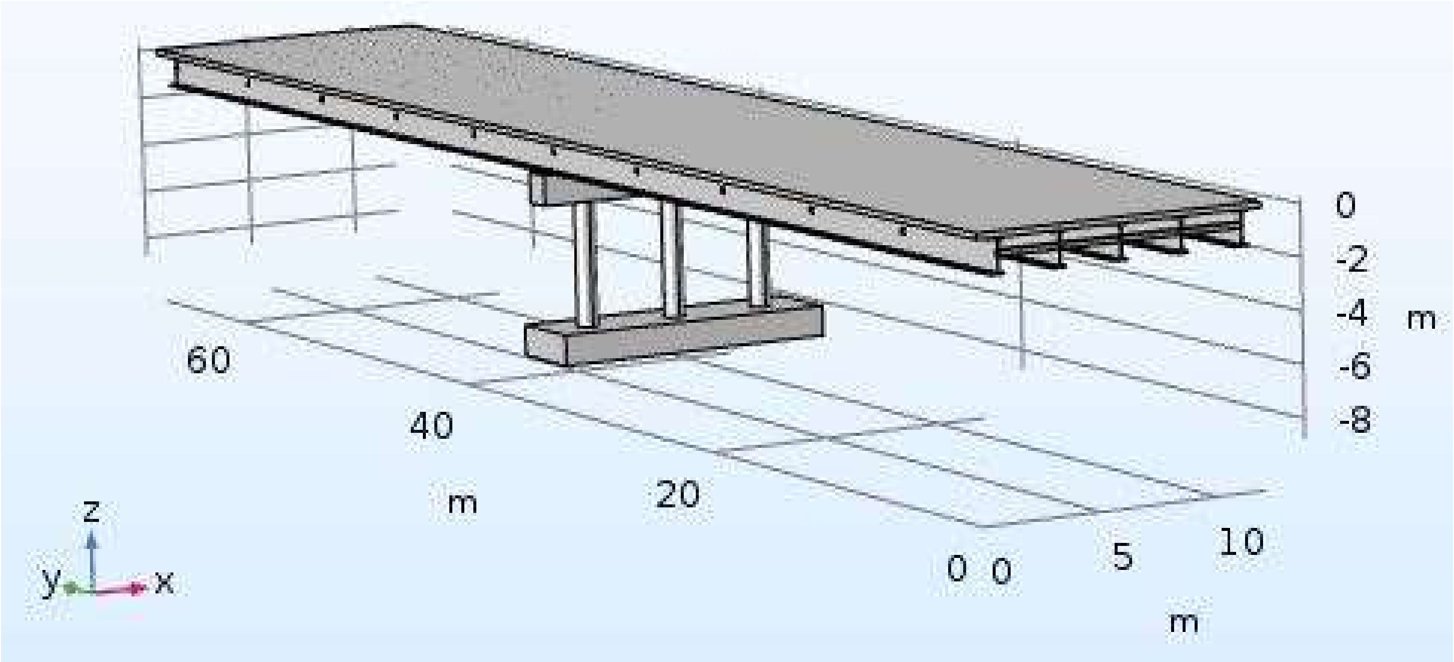
Significance of T-Rex Load Intensity – Coherence Vs. Load

- Coherence - Relationship between the response and excitation
- Substantial loss of coherence across the entire sweep at the lowest load, almost 100% coherence across the entire frequency range for the highest load

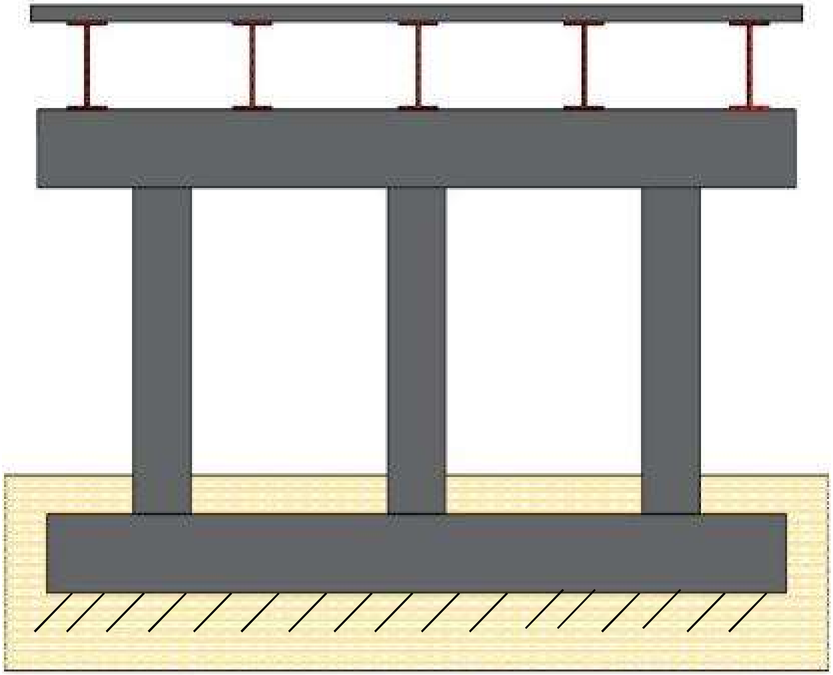


Numerical Model of Hobson Avenue Bridge

- *COMSOL Multiphysics* was used for FE modeling with impedance functions (frequency-dependent rotational and translational complex springs) in the description of the embedded pier footing.
- Numerical studies included frequency and time domain, and eigenvalue analyses.
- Numerical results were compared/validated by the field results.

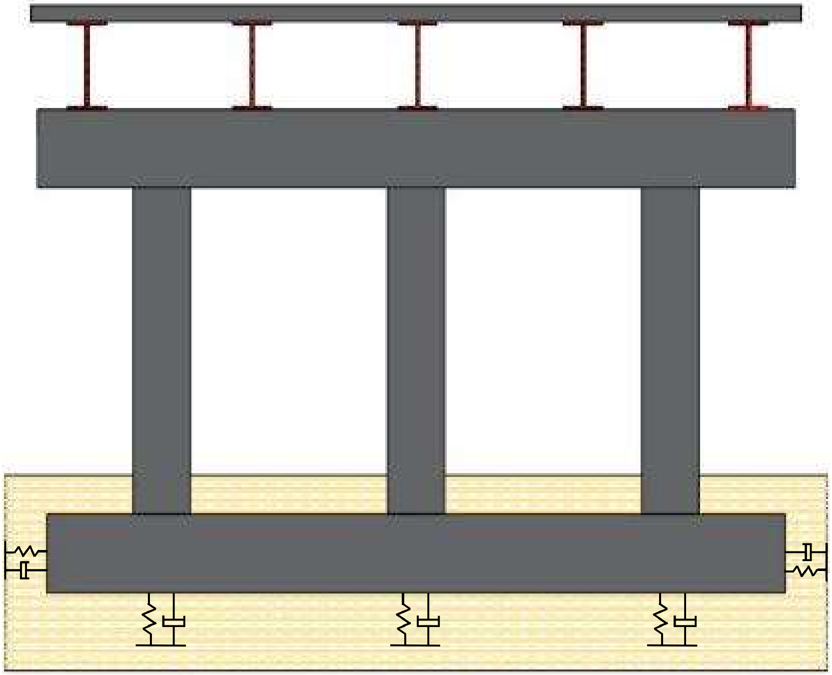


Fixed Base and DSSI Effects Incorporating Simulation Models



Fixed Base Model

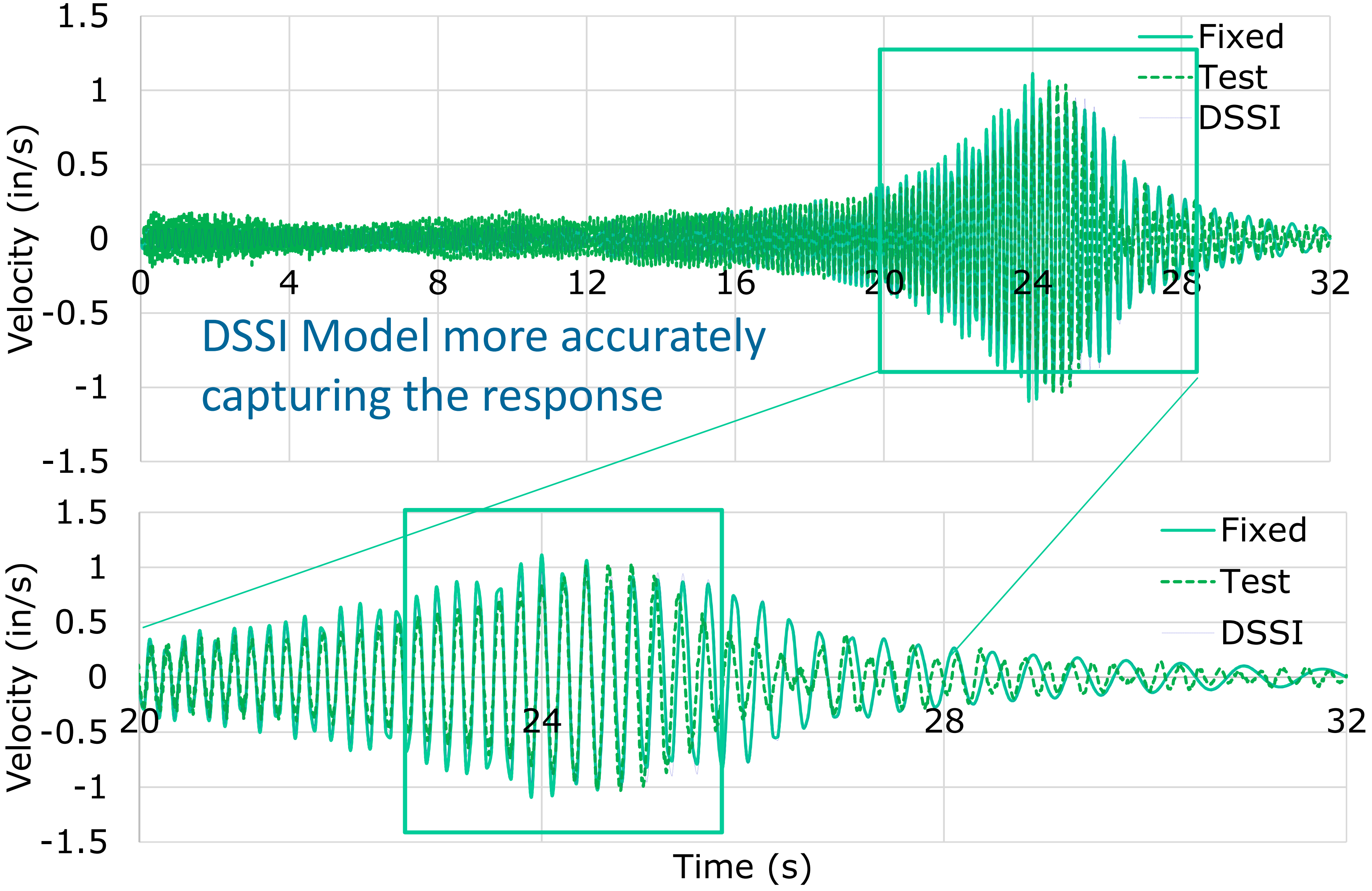
Rigid base



DSSI Incorporating Model

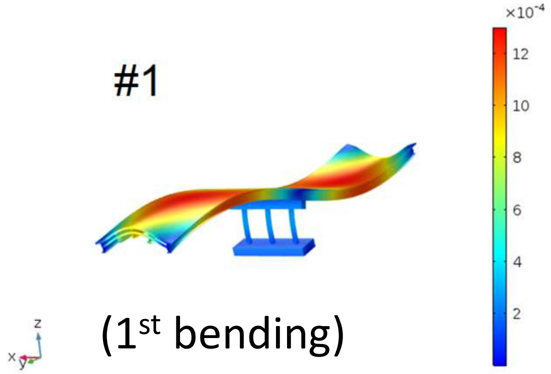
Spring-dashpot impedance functions

Comparison of Experimental and Numerical Results
Horizontal Deck Response to Horizontal Loading

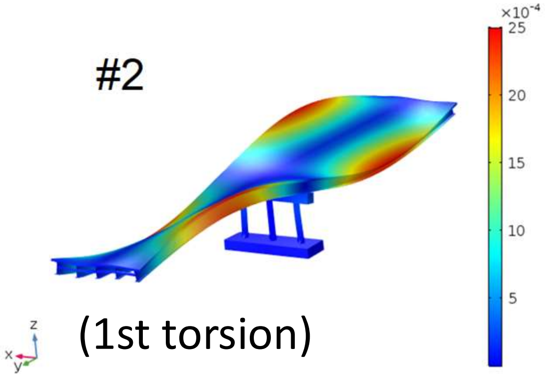


DSSI Model more accurately capturing the response

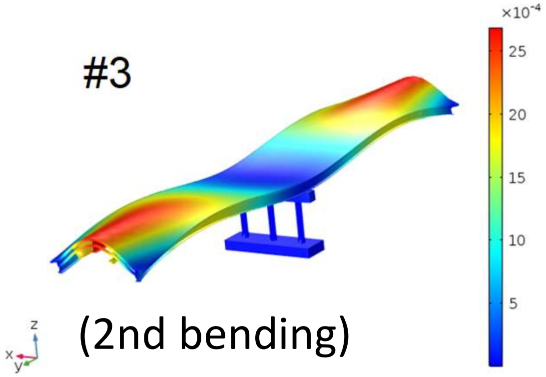
Hobson Ave Bridge – Eigenmodes from Numerical Model


#1

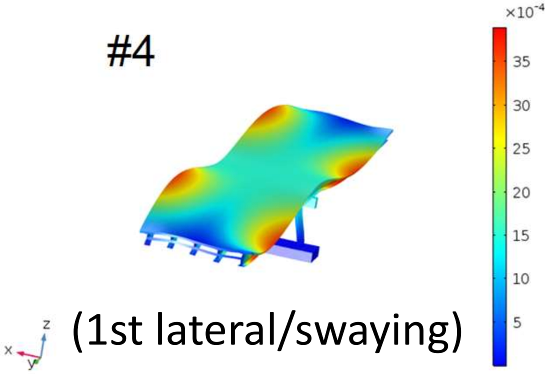
(1st bending)


#2

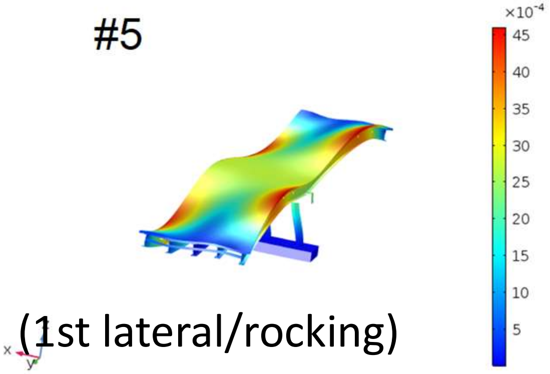
(1st torsion)


#3

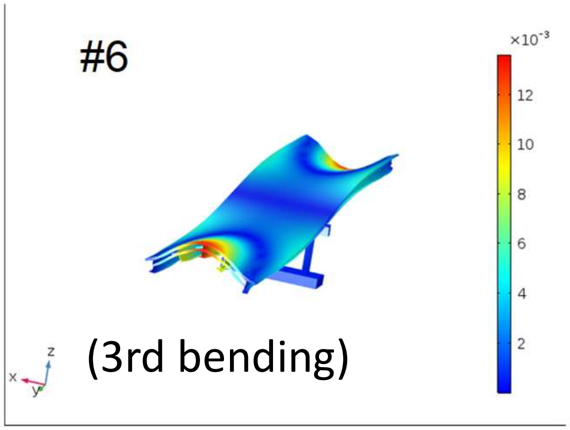
(2nd bending)


#4

(1st lateral/swaying)


#5

(1st lateral/rocking)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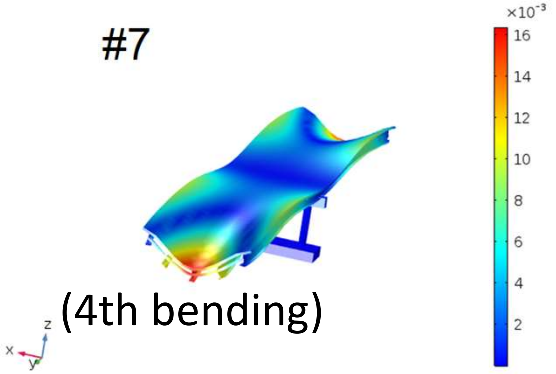
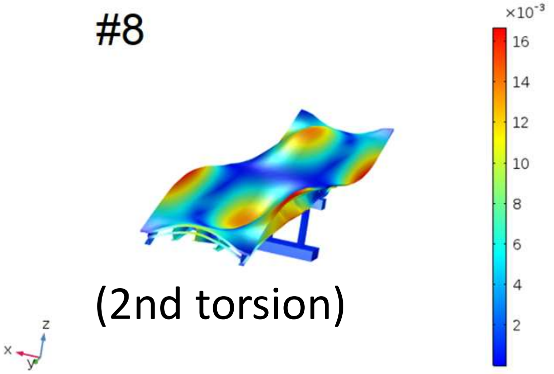
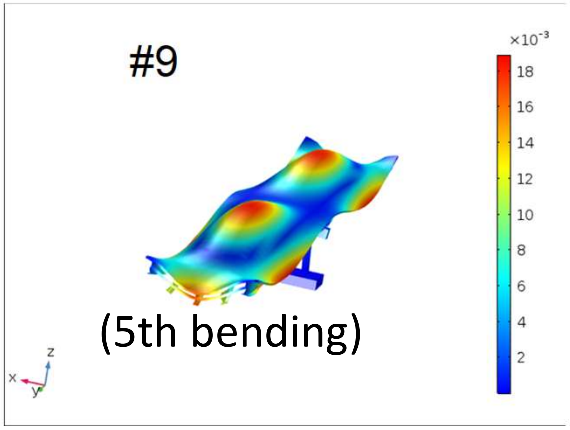
(3rd bending)


#7

(4th bending)


#8

(2nd torsion)


#9

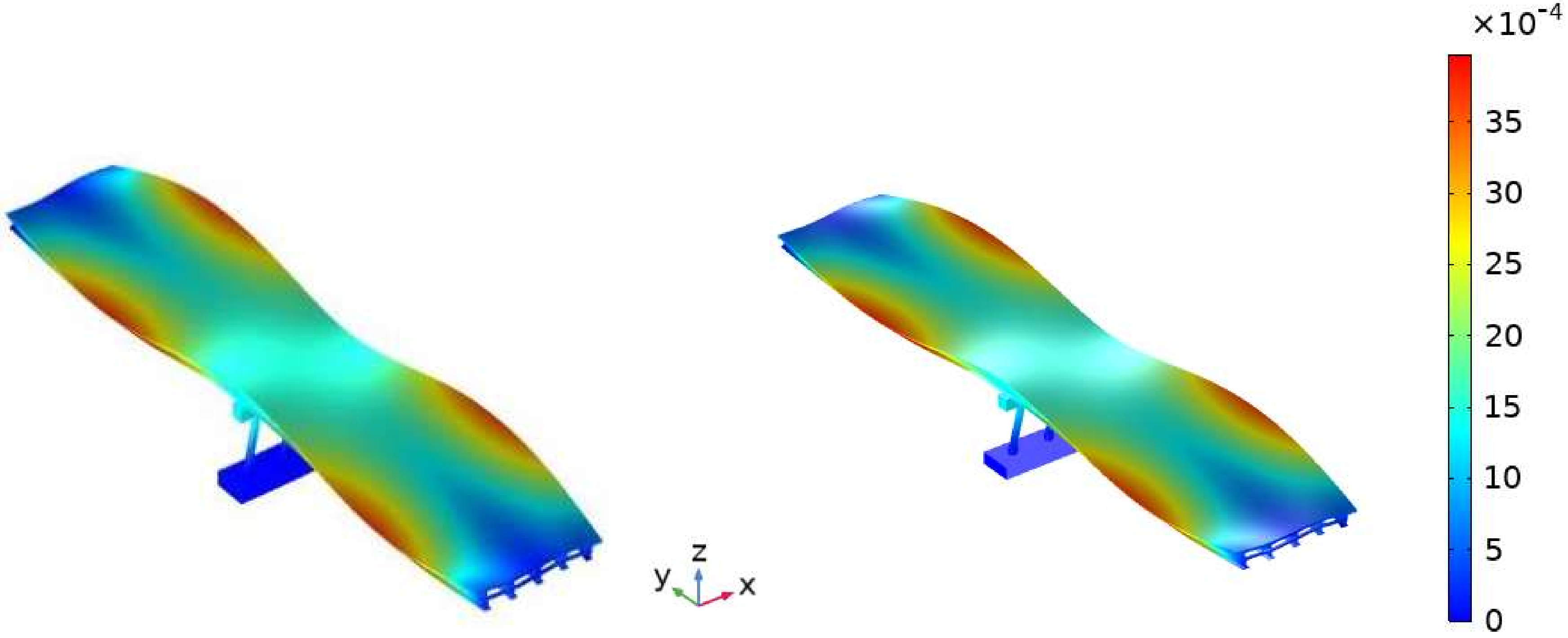
(5th bending)

Comparison of Experimental and Numerical Results

Eigen-frequency comparison in Hz

Mode	Experimental	DSSI Model	%Error
#1 (1st bending)	2.73	2.68	-1.83
#2 (1st torsion)	3.32	3.28	-1.20
#3 (2nd bending)	Not seen	3.68	N/A
#4 (1st lateral/swaying)	4.41	4.2	-4.76
#5 (1st lateral/rocking)	4.64	4.77	2.80
#6 (3rd bending)	Not seen	6.12	N/A
#7 (4th bending)	Not seen	6.84	N/A
#8 (2nd torsion)	8.27	8.36	1.09
#9 (5th bending)	8.88	9.14	2.93

Comparison of Mode Shapes for DSSI and Fixed Base Models
1st Lateral-Swaying Mode

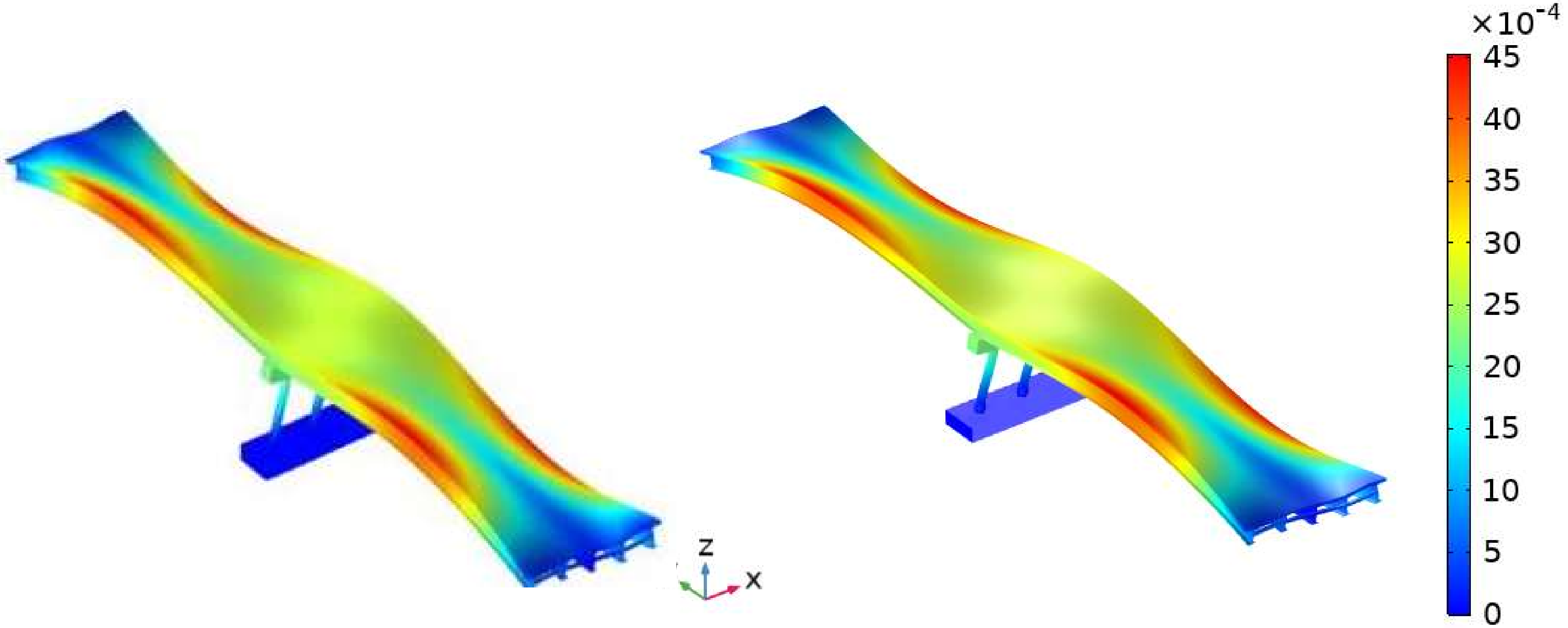


DSSI - 4.20 Hz

Fixed Base - 4.21 Hz

Comparison of Mode Shapes for DSSI and Fixed Base Models

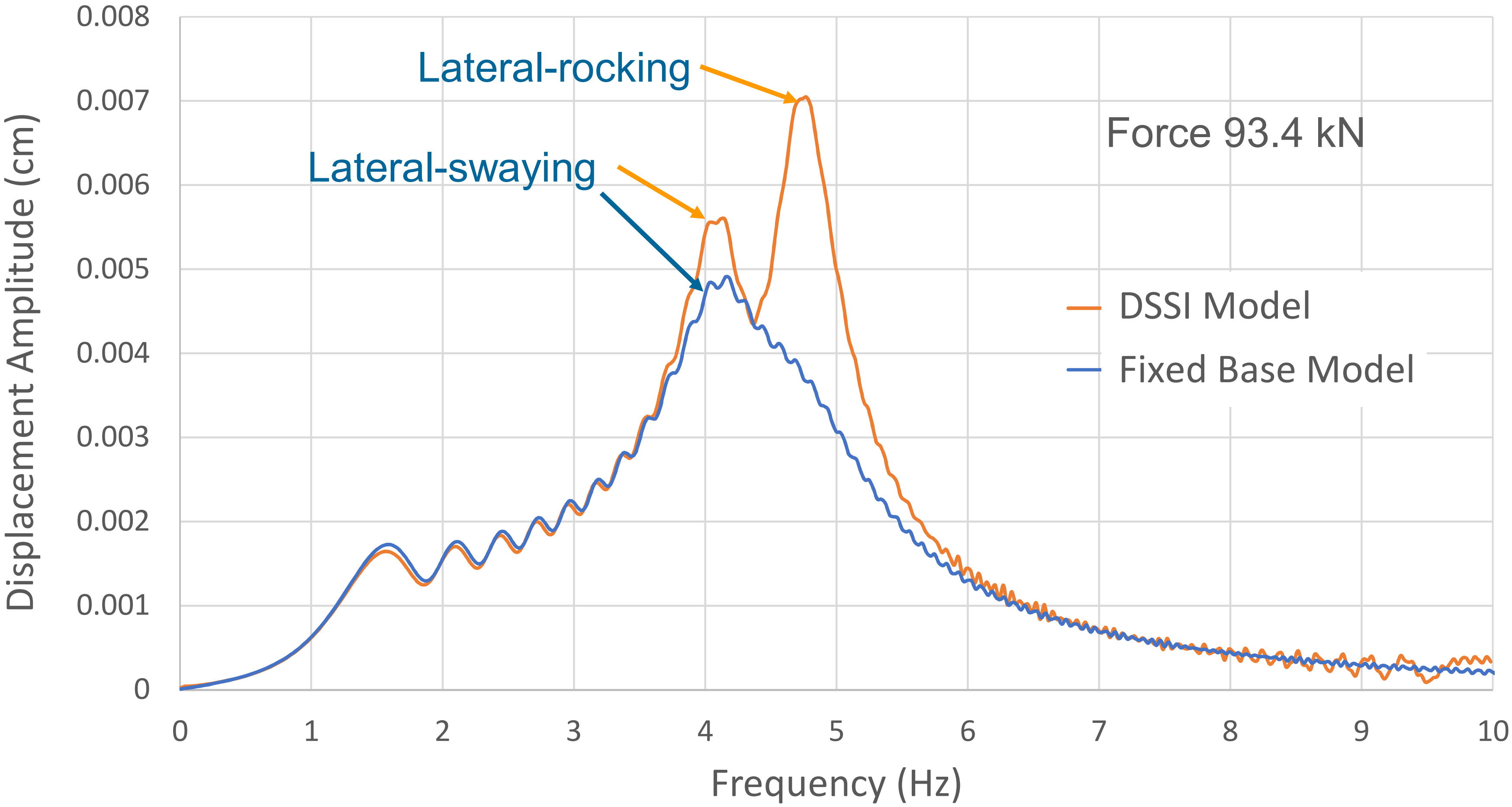
1st Lateral-Rocking Mode



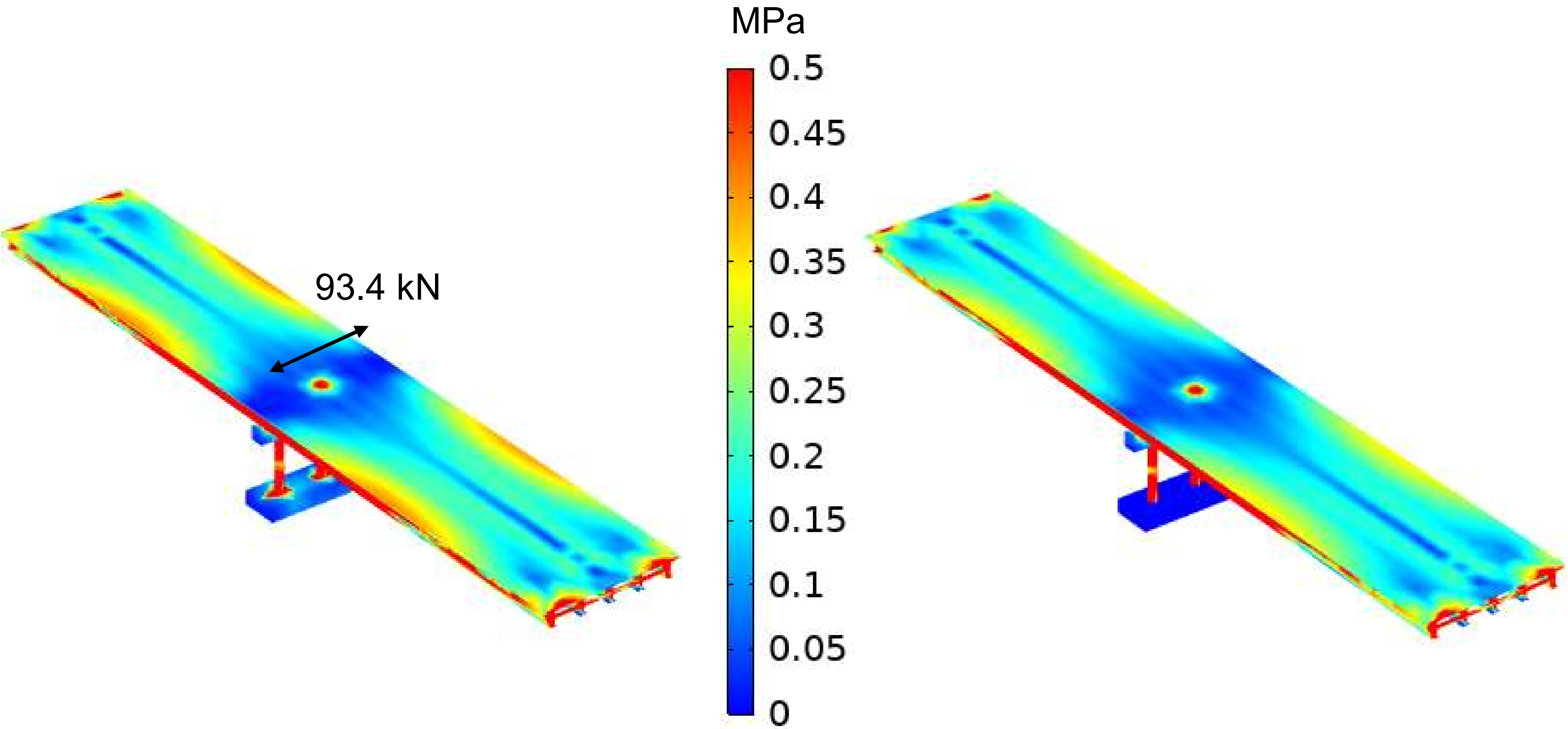
DSSI - 4.77 Hz

Fixed Base - 4.81 Hz

Comparison of Transverse Displacement Response Spectra of Fixed-Base and DSSI-Incorporating Models Due to Transverse Shaking



Comparison of von Mises Stress Distributions on Top Rebar Level for DSSI and Fixed Base Models
1st Lateral-Swaying Mode – Horizontal Load



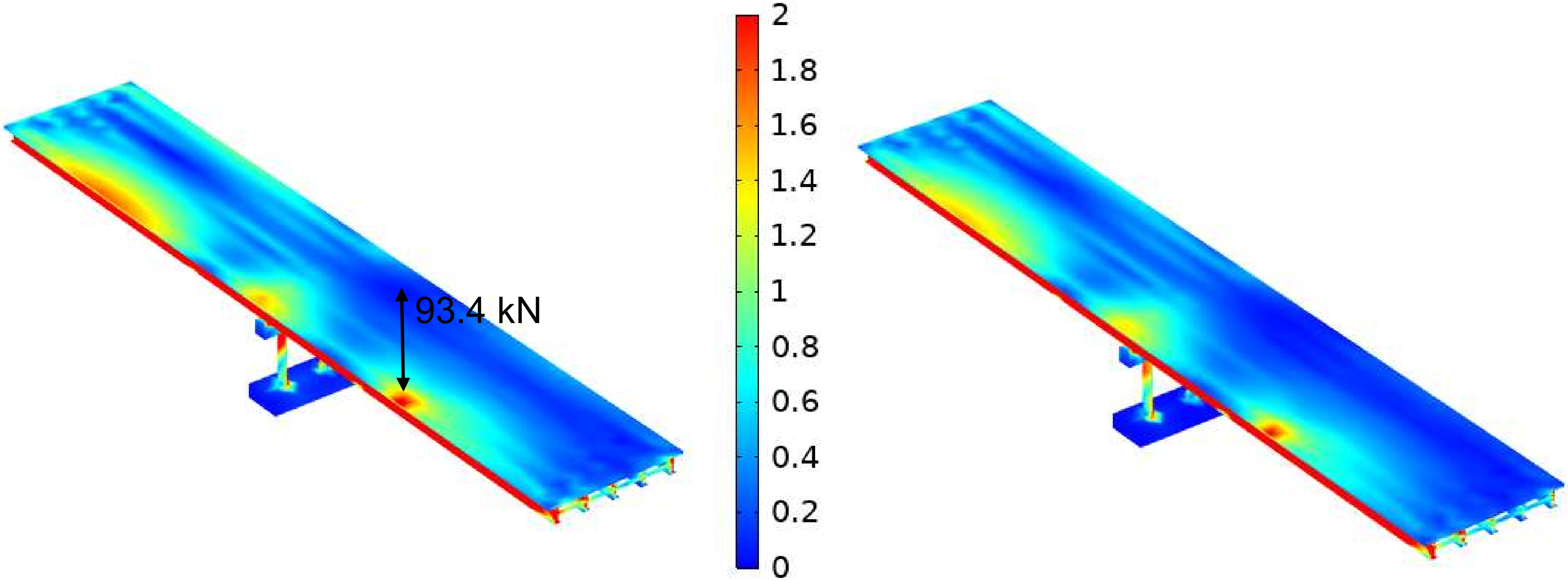
DSSI - 4.20 Hz

Fixed Base - 4.21 Hz

Comparison of von Mises Stress Distributions on Top Rebar Level for DSSI and Fixed Base Models
1^{st} Lateral-Swaying Mode – Vertical Load

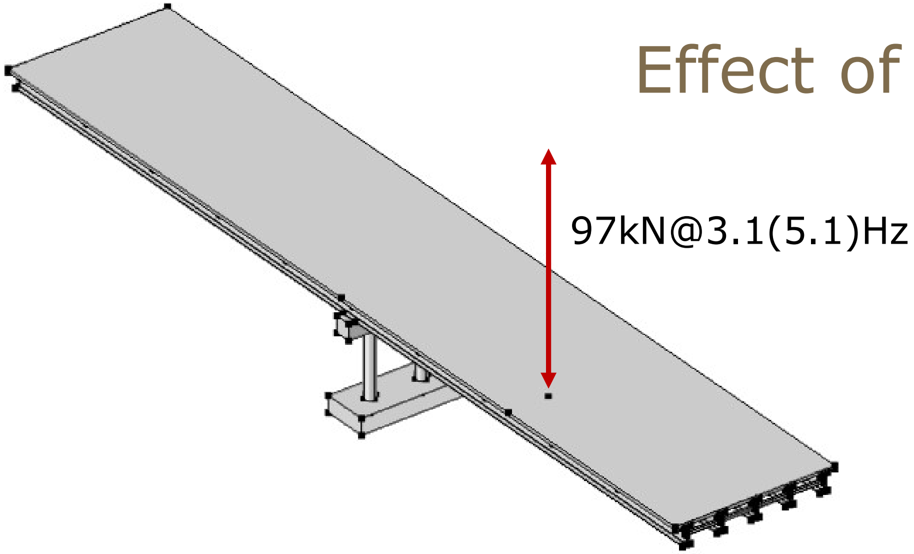
DSSI - 4.16 Hz

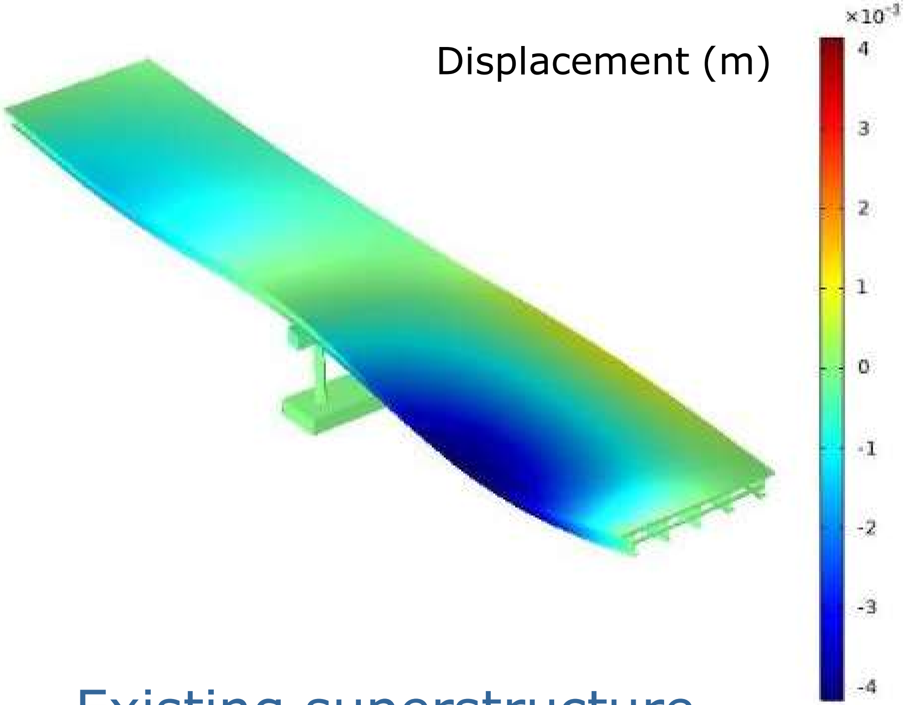
Fixed Base - 4.21 Hz



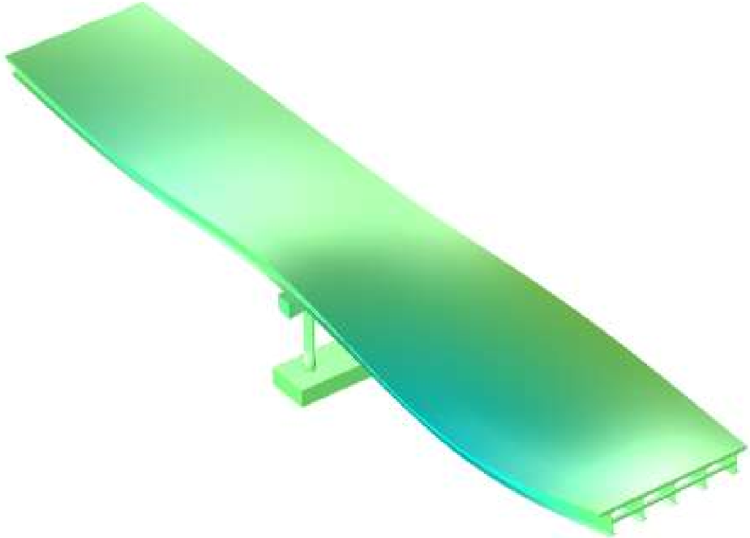
Effect of Superstructure Stiffness on Maximum Vertical Displacements

Fixed-base model



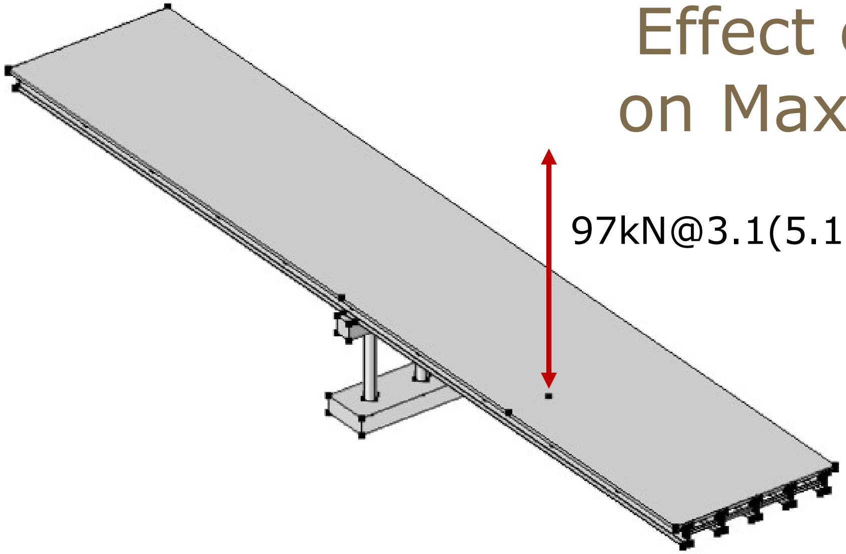


Existing superstructure

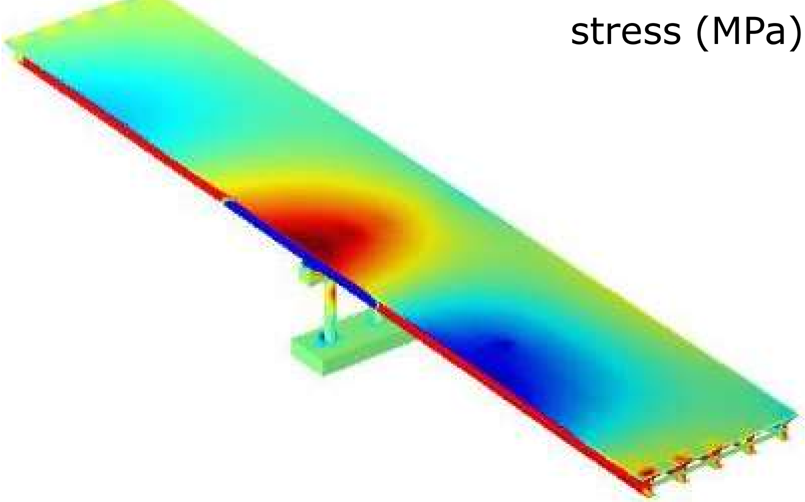


Four times stiffer girders

Effect of Superstructure Stiffness on Maximum Longitudinal Normal Stresses at the Top of the Deck

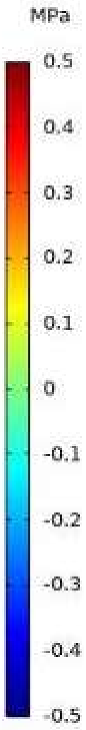


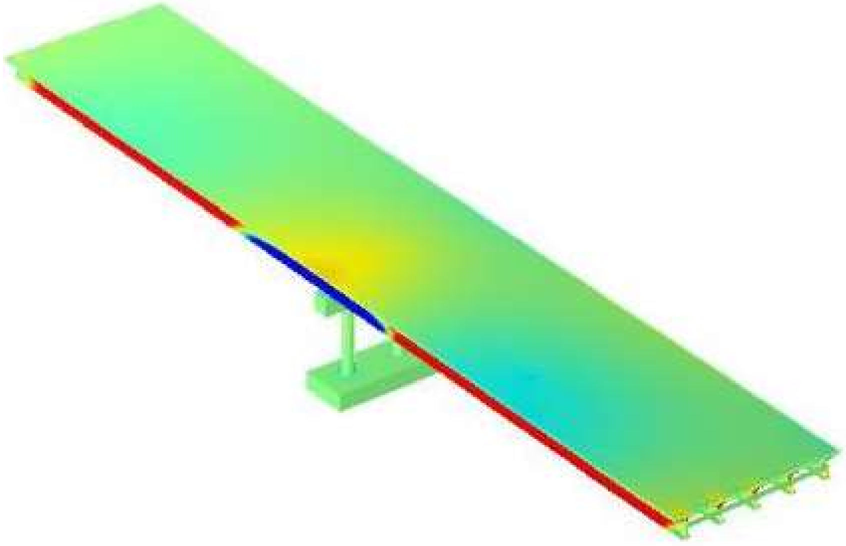
Fixed-base model



Existing superstructure

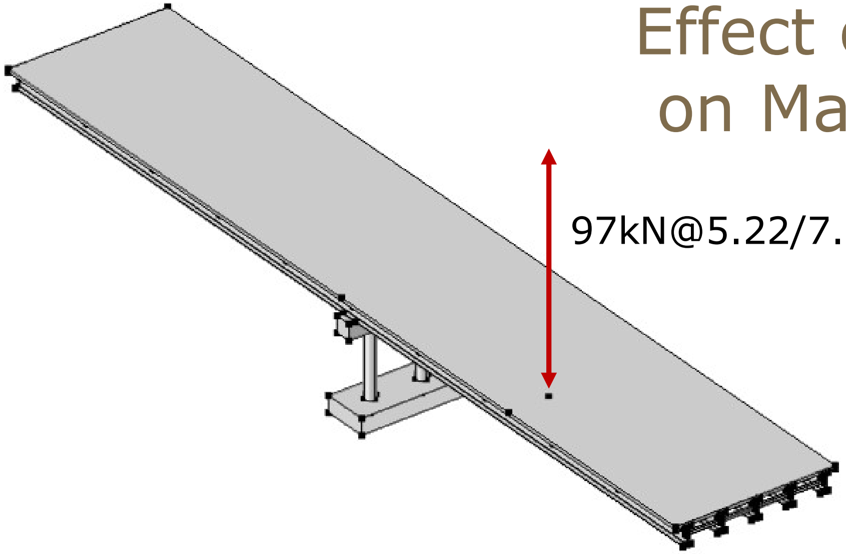
Maximum normal stress (MPa)





Four times stiffer girders

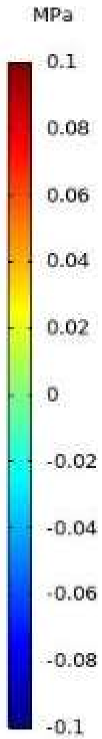
Effect of Superstructure Stiffness on Maximum Transverse Normal Stresses at the Top of the Deck

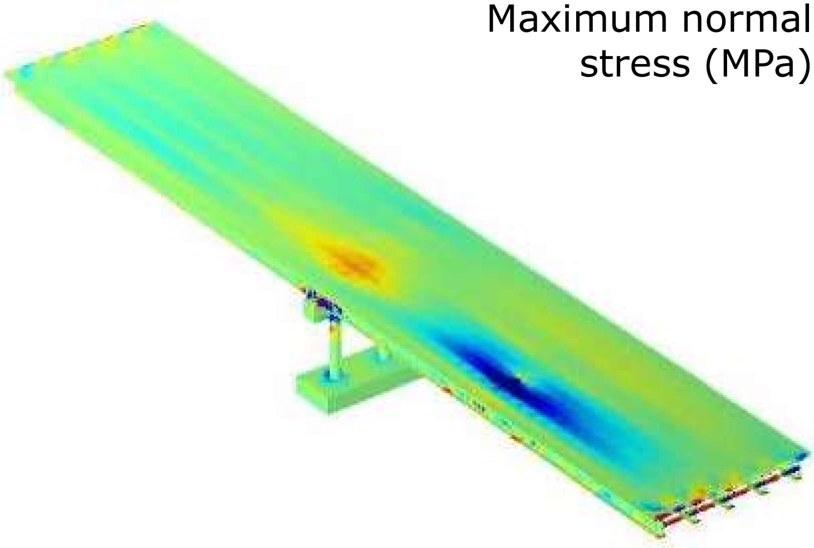


97kN@5.22/7.22Hz

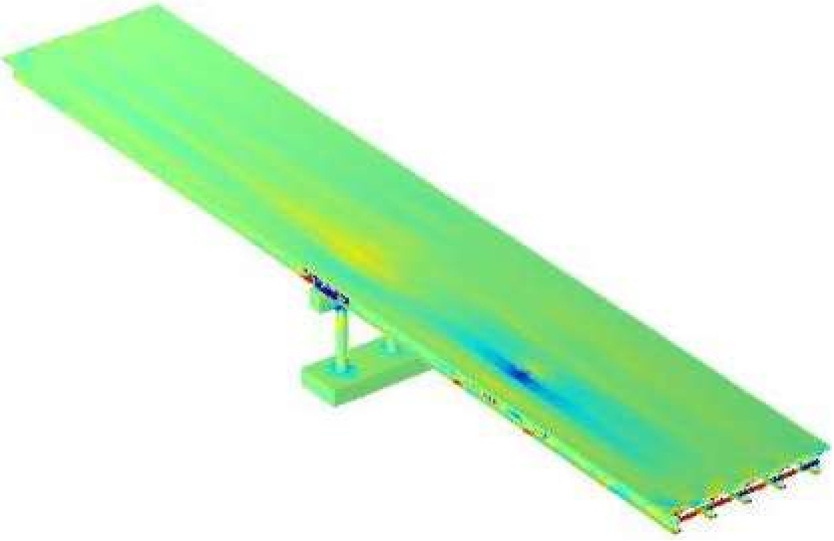
Fixed-base model

Maximum normal stress (MPa)



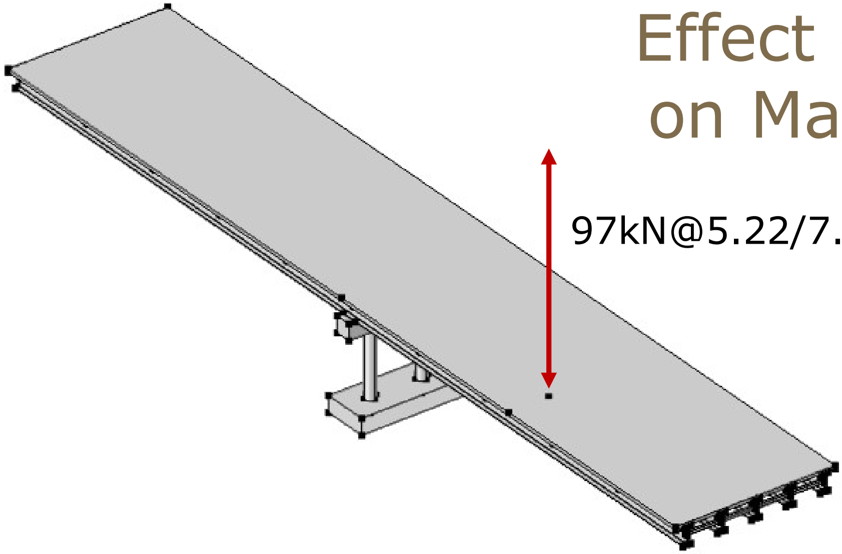


Existing superstructure

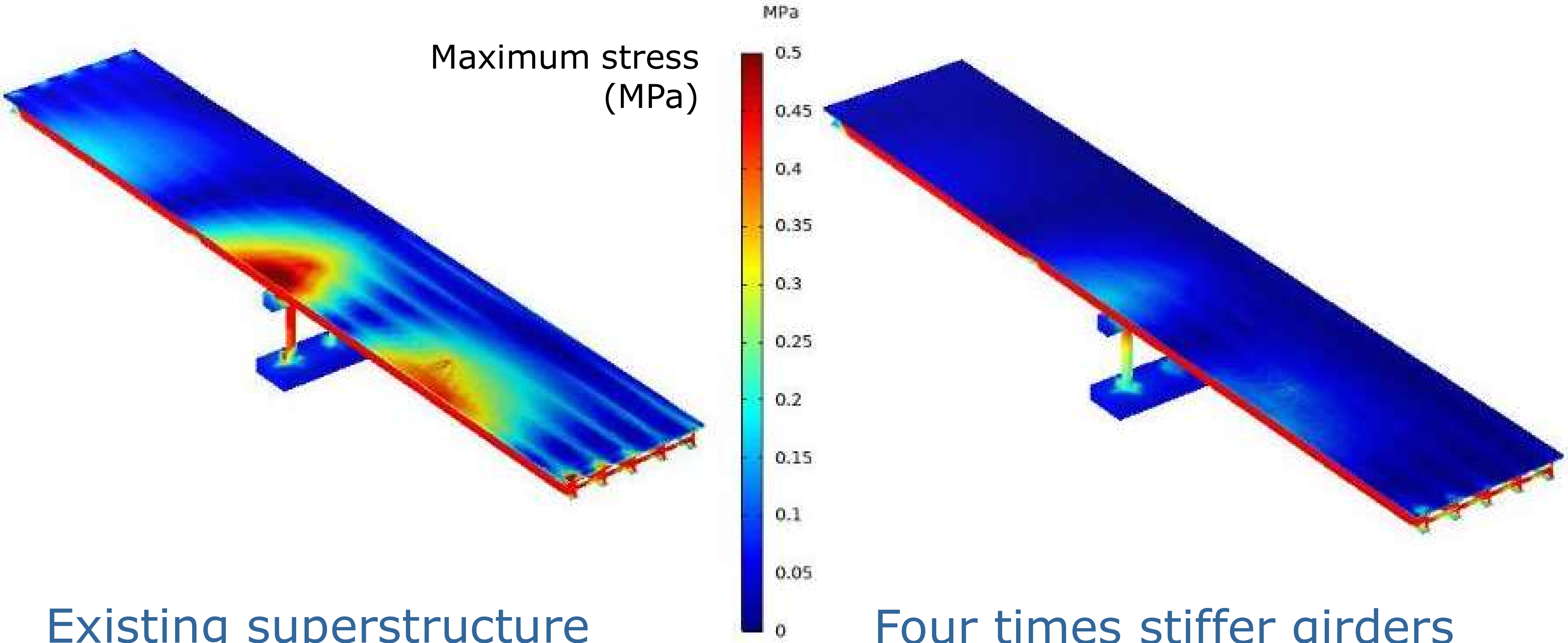


Four times stiffer girders

Effect of Superstructure Stiffness on Maximum Von Mises Stresses at the Top Rebar Level



Fixed-base model



Maximum stress (MPa)

Existing superstructure

Four times stiffer girders

Evaluation of Dynamic Stiffness (Impedance) Functions and Bearing Capacity of Unknown Foundations

Information Needed for Estimation of Dimensions or Bearing Capacity of Unknown Shallow Foundations

Different scenarios used depending on the missing information, but all rely on matching the experimental response data with those of the simulation model and use of available correlations.

For example:

- Foundation dimensions – From the shear wave velocity (modulus) profile and pier column dimensions (to make initial estimates).
- Bearing capacity- From the estimated foundation dimensions and correlations between the shear wave velocity and soil strength parameters.

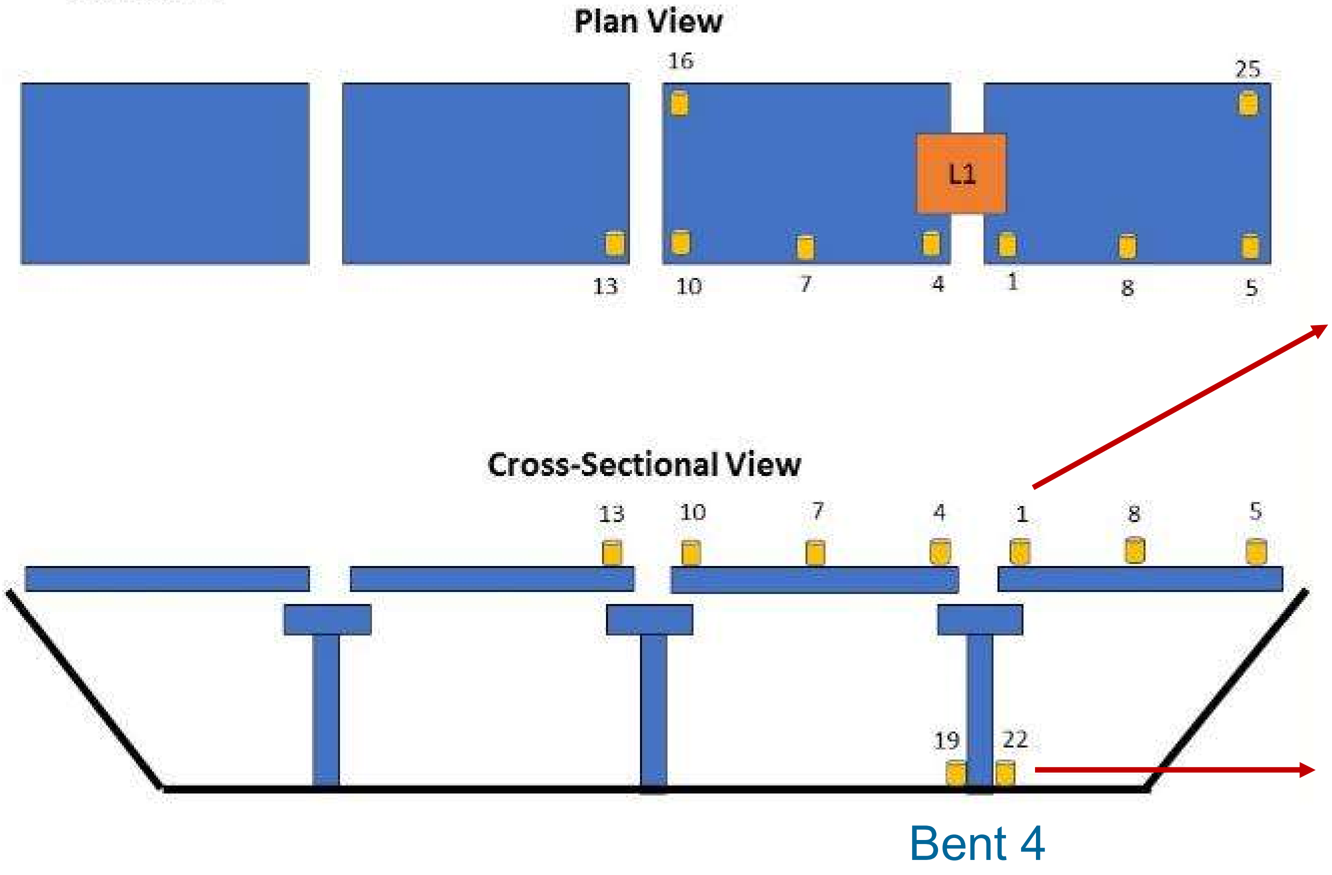
Evaluation of Gate Creek Bridge Foundation, Vida, OR

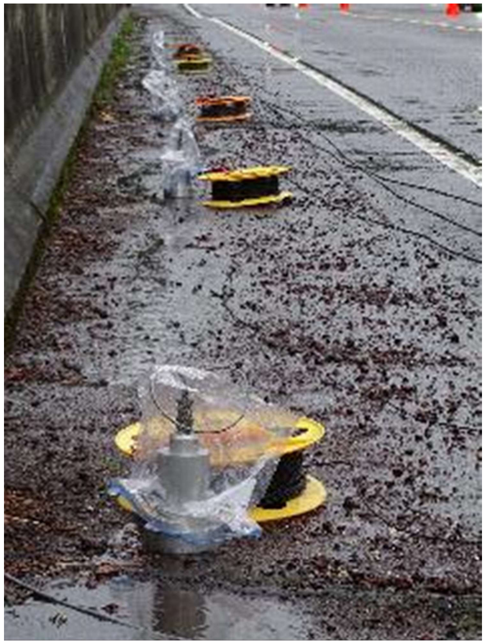
- Single hammerhead cast-in-place pier on a shallow continuous reinforced concrete footing
- Pier excited vertically right above the pier
- Geophones placed on both the deck and pier near the ground surface

Evaluation of Gate Creek Bridge Foundation, Vida, OR

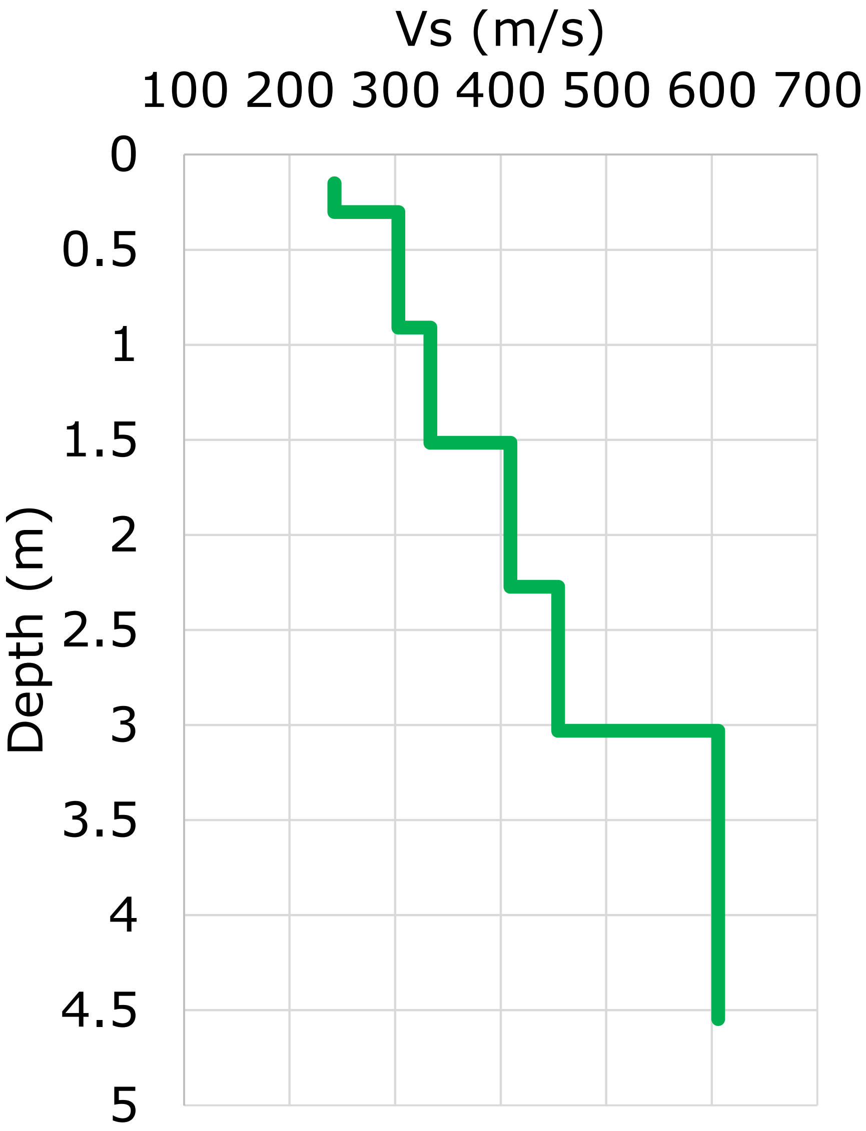
Evaluation of Gate Creek Bridge Foundation, Vida, OR Placement of Geophones

Location 1

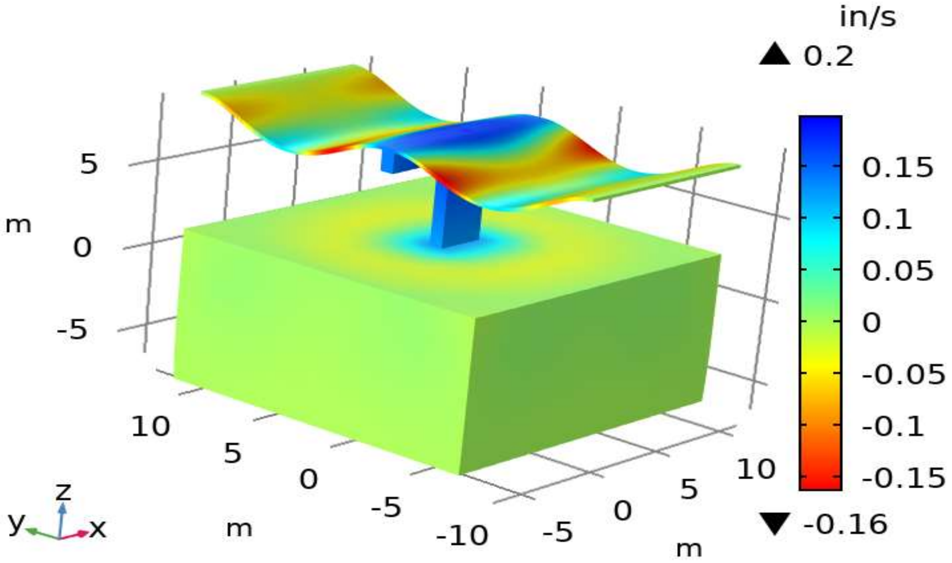


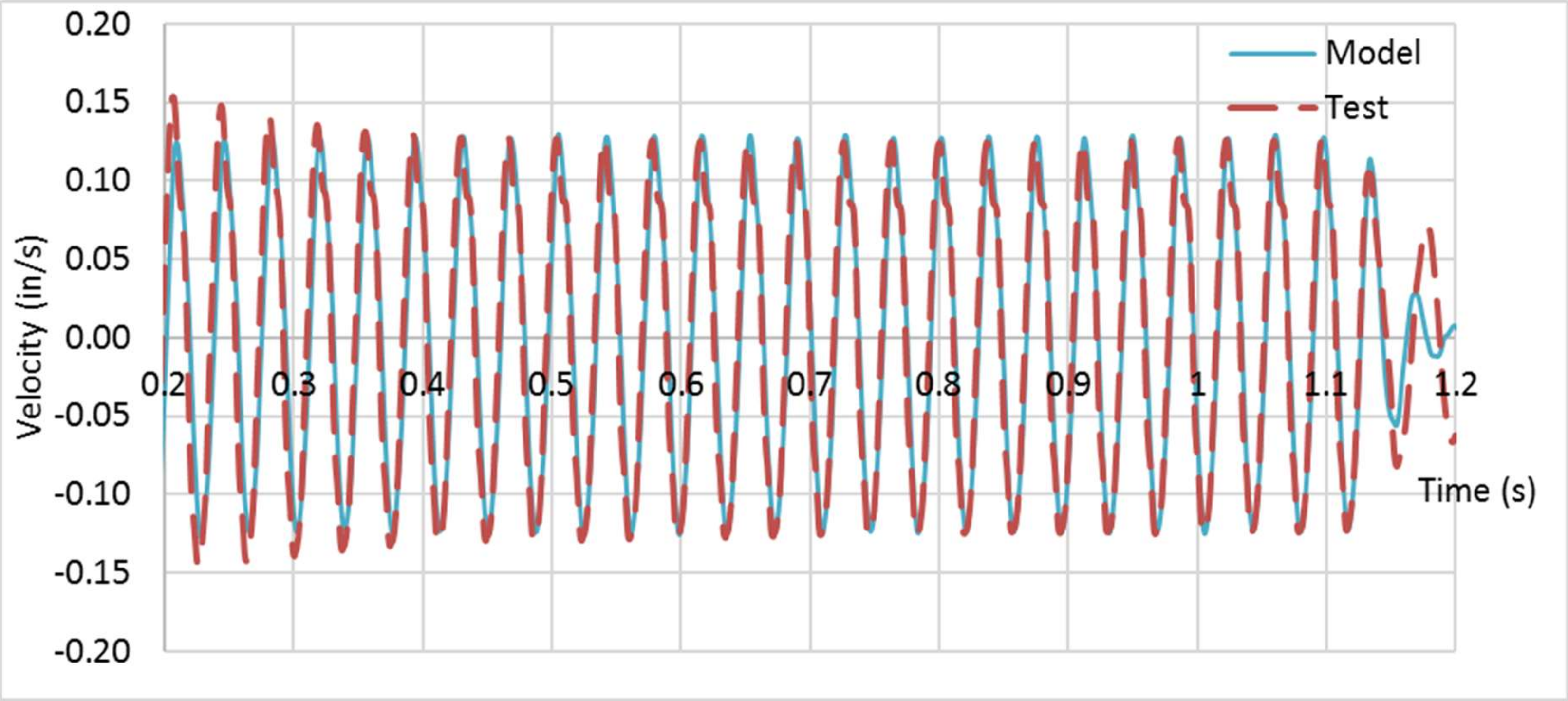


Evaluation of Gate Creek Bridge Foundation, Vida, OR
Shear Wave Velocity Profiling by SASW

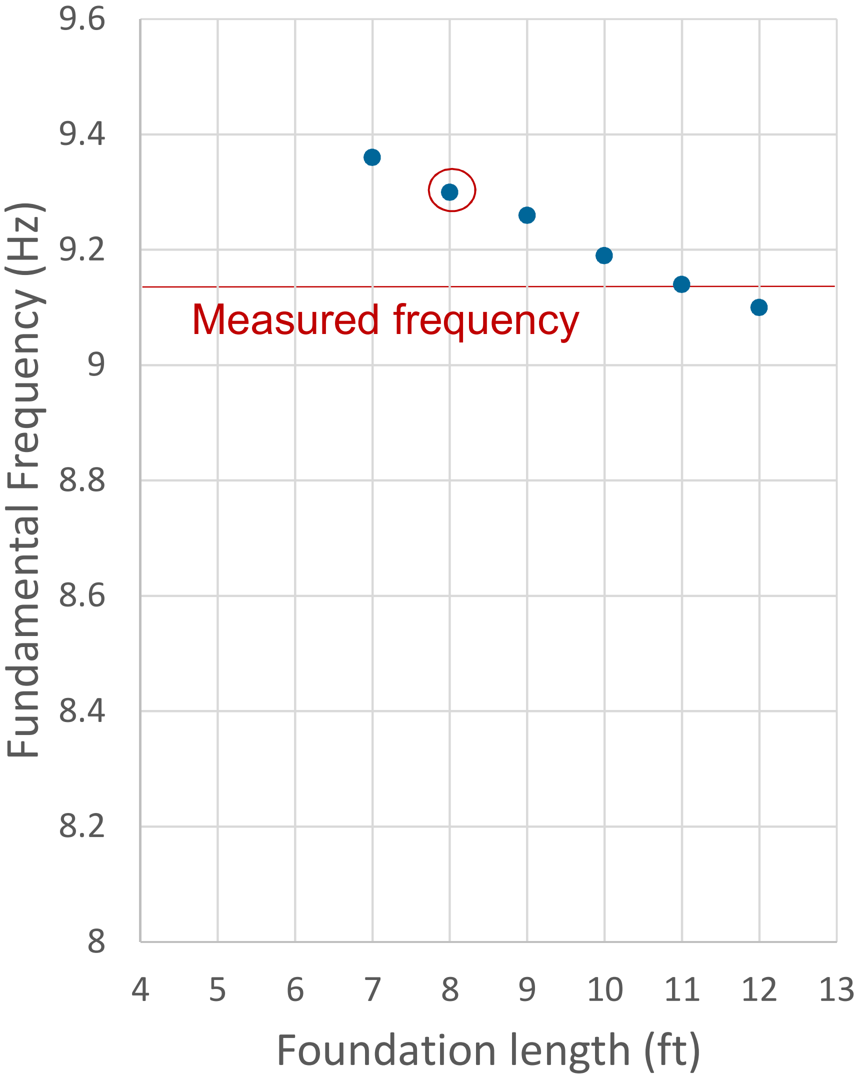


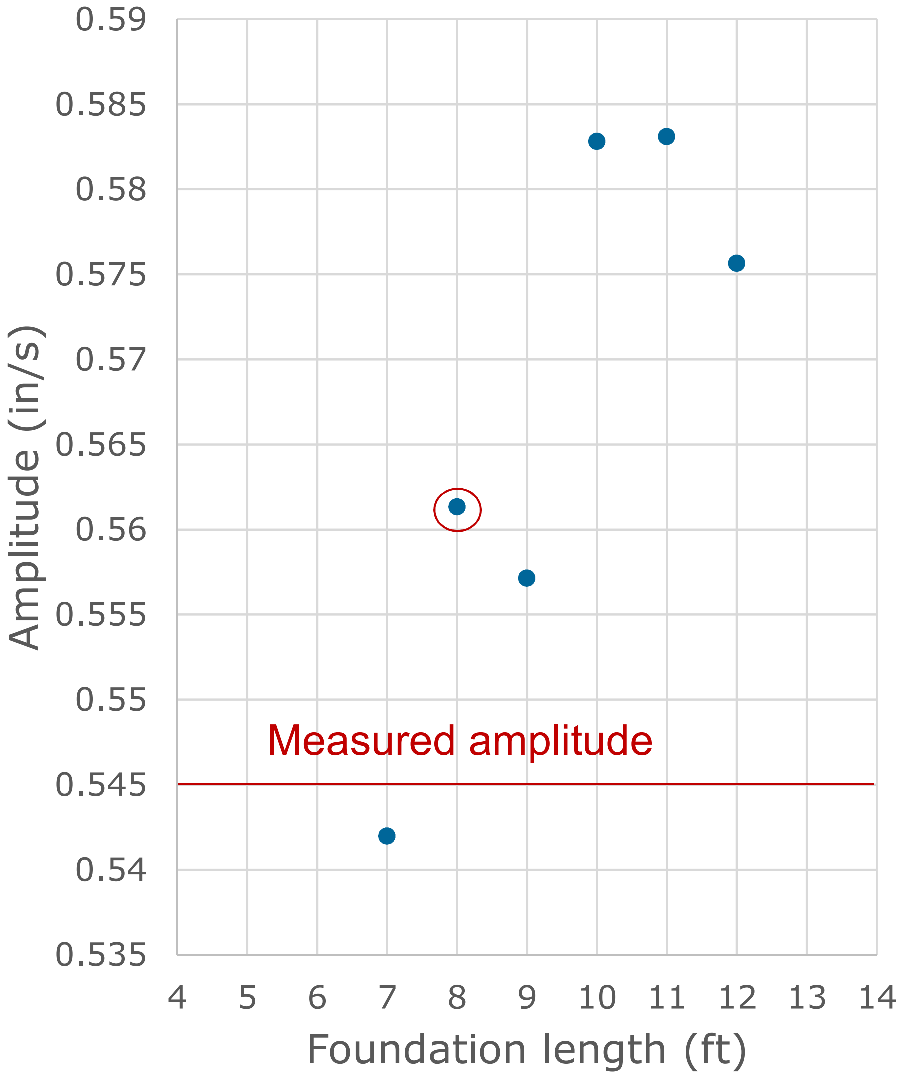
Evaluation of Gate Creek Bridge Foundation – Matching of Experimental and Numerical Model Results





Evaluation of the Gate Creek Bent 4 Foundation Width





Model assumed foundation length of 15 ft, Vs of 350 m/s, depth of embedment 8 ft.
Pier column was 9 ft by 2.5 ft.

Conclusions

- Large mobile shakers are an effective tool to assess the dynamic characteristics of bridges, including the DSSI effects.
- Increasing the load magnitude improves coherence, provides more clear transfer functions, and leads to better identification of dynamic characteristics.
- The DSSI-incorporated simulation models show an overall better accuracy in terms of capturing the dynamic response of bridges than the fixed base models.
- Evaluation of dynamic stiffness and bearing capacity of unknown foundations using large mobile shakers is promising.

Thank you!

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