# SEISMICALLY ISOLATING THE NEW NY BRIDGE

**Presented by:**

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**2015 Western Bridge Engineers Conference**
**September 10th 2015**

NEW YORK STATE OF OPPORTUNITY.
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## BRIDGE APPROACH SPAN GLOBAL ANALYSIS

# INTRODUCTION

# Design-Build Team

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GRANITE™
AB American Bridge
TRAYLOR
TRAYLOR BROS., INC.

HDR
BUCKLAND & TAYLOR
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URS
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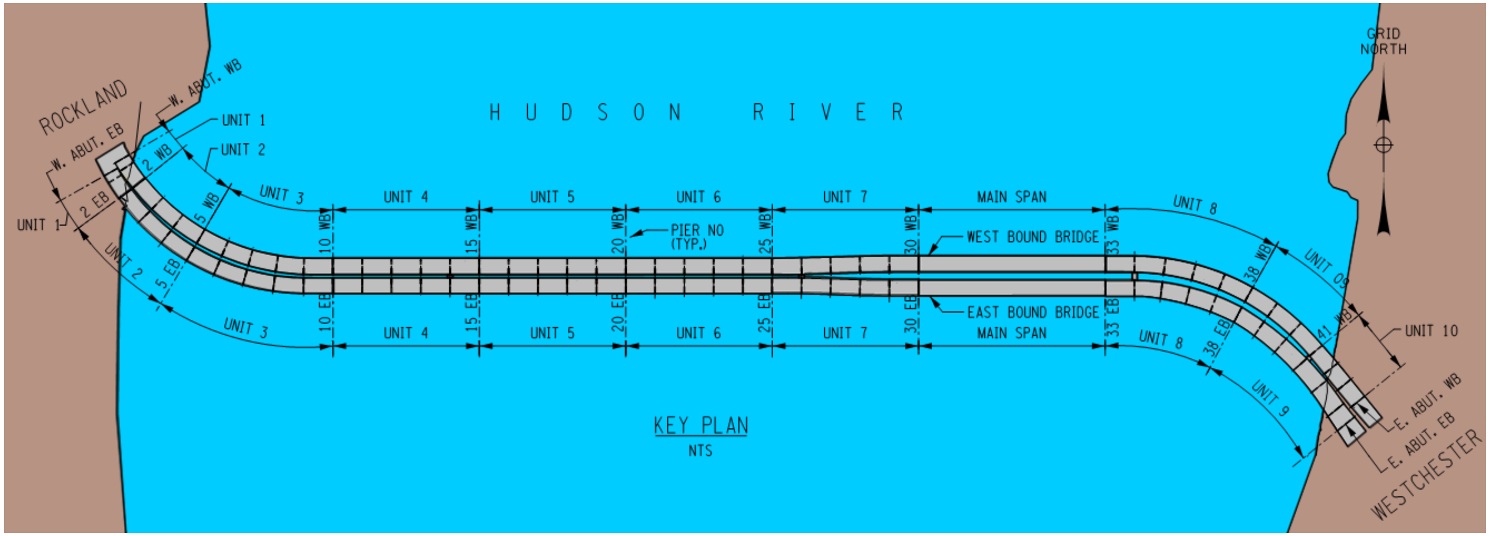
# Bridge Structure Type

## The New NY Bridge (Tappan Zee Hudson River Crossing)

- Three-mile, Twin Hudson River Crossing (Westchester/Rockland)
- 350-foot nominal steel girder approach spans (12 foot deep girder-substringer superstructure.
- Twin-tower cable stayed structures with 1200-foot main spans.



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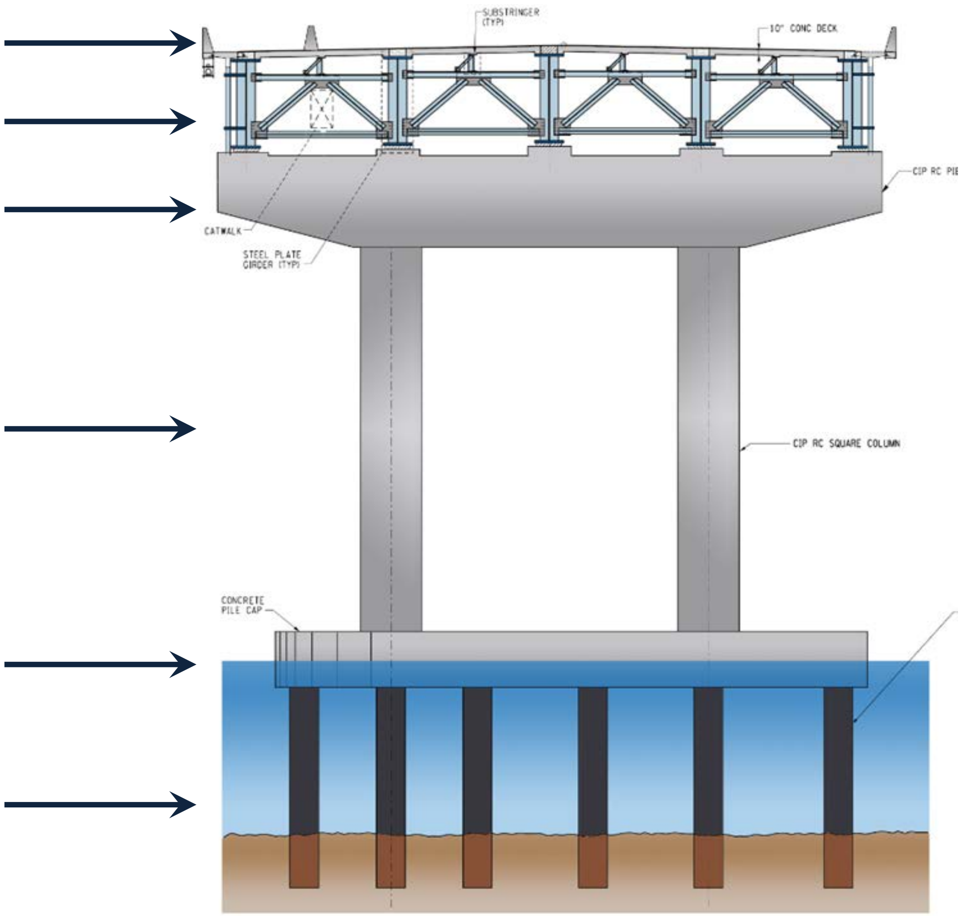
# Approach Configuration



Precast Deck Panels →

Steel Girder/Stringer →

Precast Pier Cap →

CIP Columns →

Precast Pile Cap →

Steel Pipe Piles →

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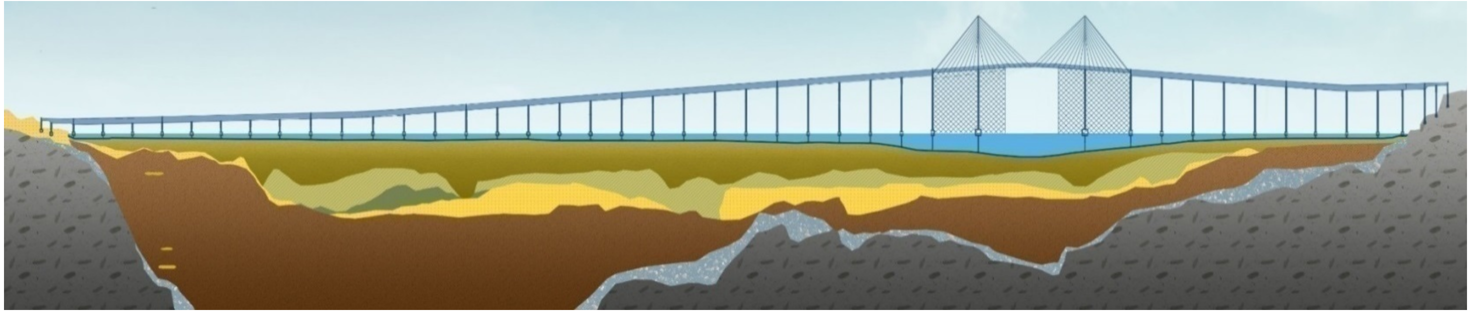
# Global Model

## Purpose of the Global Analysis Model

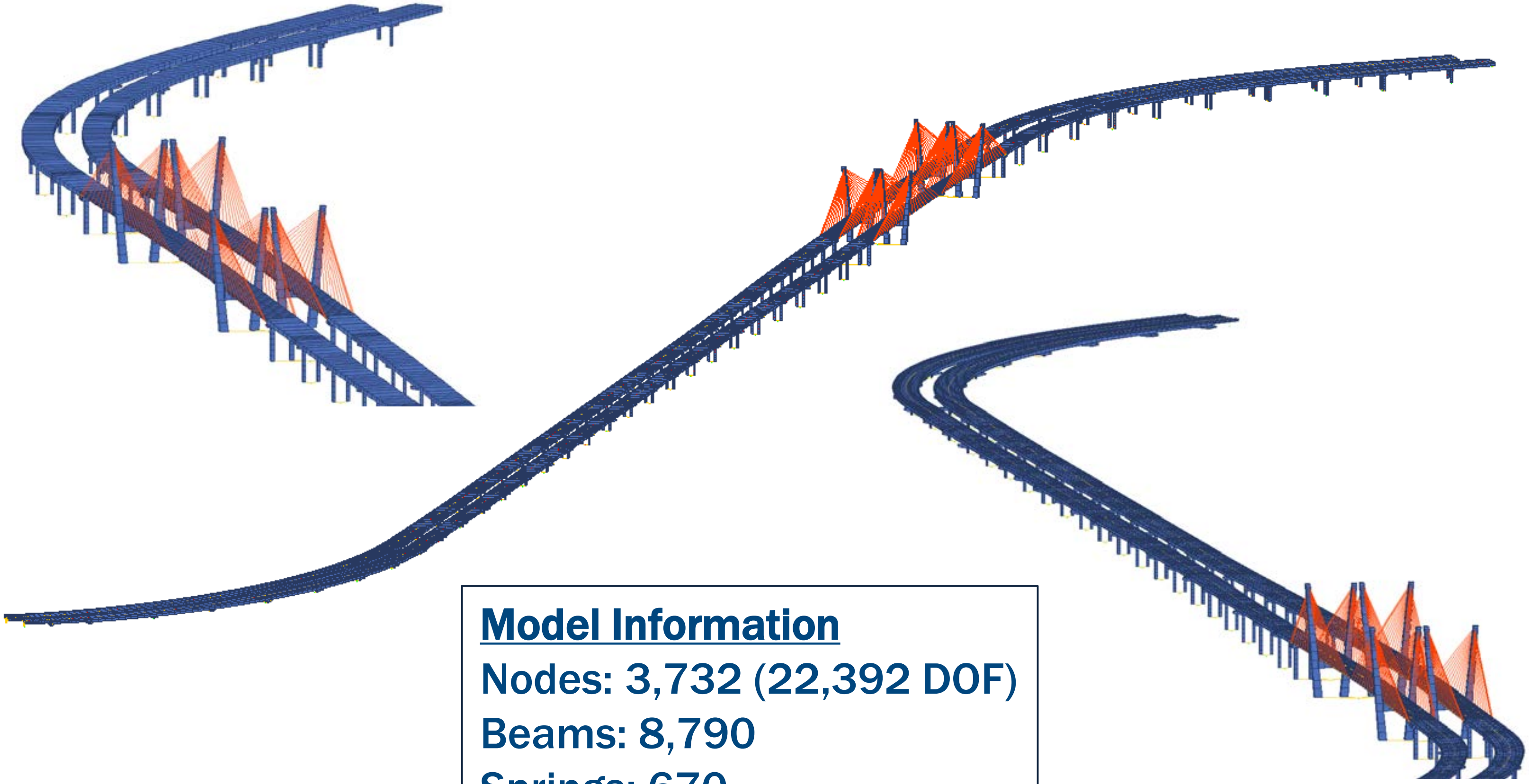
- Analytical model of the Crossing (Abutment to Abutment)
- Provide design teams with global load inputs for local element design
- Develop EQ demands for bearing and expansion joint design
- Becomes “foundation” for a 3D spatial design model (BIM)
- Software Used: RM Bridge and ADINA



BRIDGE APPROACH SPAN GLOBAL ANALYSIS

# MODEL CREATION

# Global RM Bridge Model



**Model Information**

Nodes: 3,732 (22,392 DOF)
Beams: 8,790
Springs: 670
Cables: 192
(ADINA model similar)

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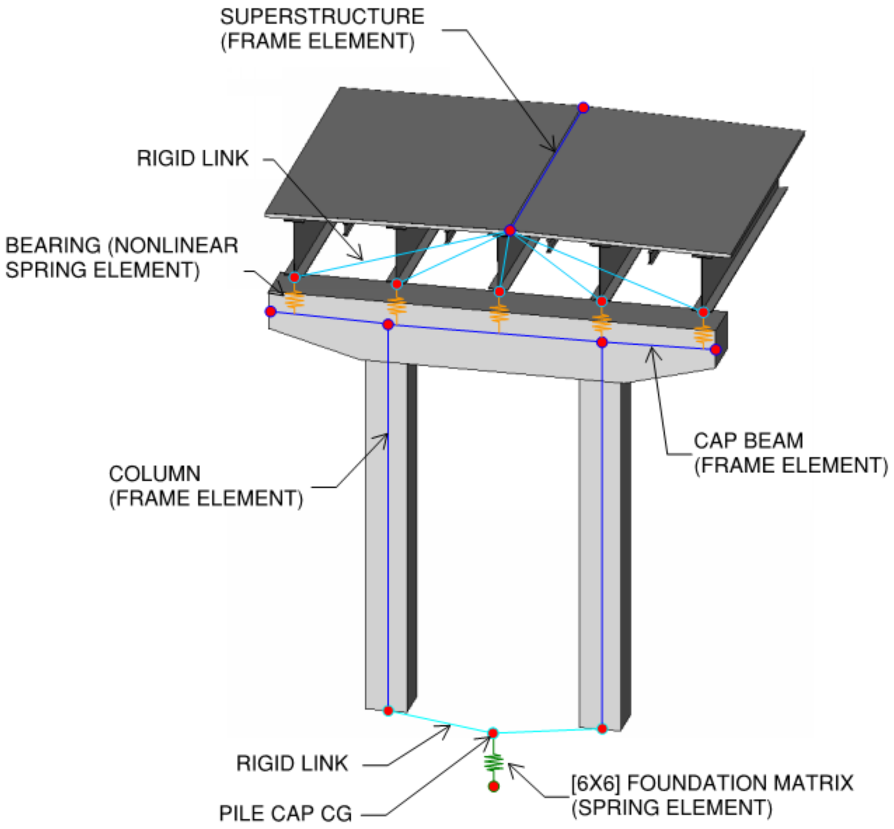
# Modeling Approach

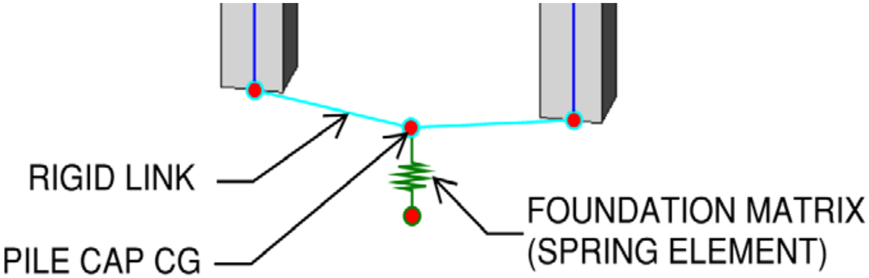
- Beam Elements
  - Superstructure
  - Pier Cap
  - Columns
- Rigid Links
  - Superstructure to Bearings
  - Pier Cap to Bearings
  - Columns to Foundations
- Springs
  - Bearings – Nonlinear/Linear
  - Foundations – Stiffness Matrix

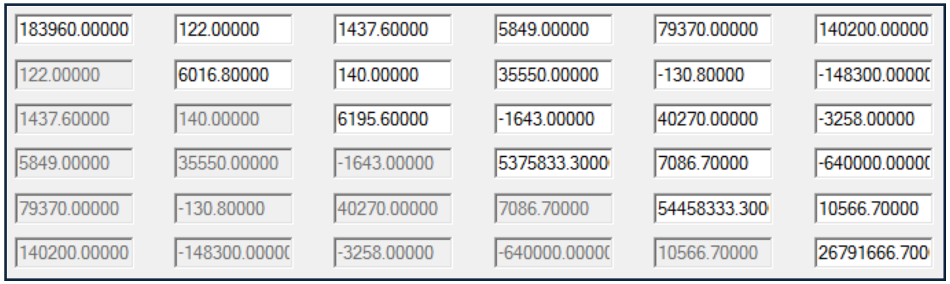


Global Analysis Model Schematic
(not all nodes shown for clarity)

# Foundation Springs

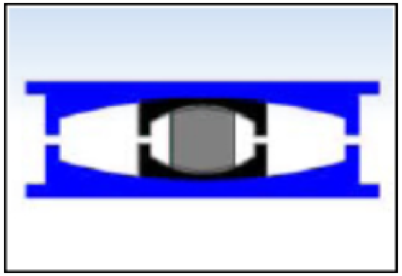
- Equivalent stiffness derived from FB-MultiPier
- Equivalent stiffness modeled in global analysis at CG of pile cap by equivalent sub-structured 6x6 secant stiffness matrix



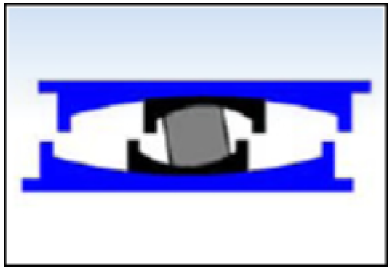


| | | | | | |
|---|---|---|---|---|---|
| 183960.00000 | 122.00000 | 1437.60000 | 5849.00000 | 79370.00000 | 140200.00000 |
| 122.00000 | 6016.80000 | 140.00000 | 35550.00000 | -130.80000 | -148300.0000 |
| 1437.60000 | 140.00000 | 6195.60000 | -1643.00000 | 40270.00000 | -3258.00000 |
| 5849.00000 | 35550.00000 | -1643.00000 | 5375833.3000 | 7086.70000 | -640000.0000 |
| 79370.00000 | -130.80000 | 40270.00000 | 7086.70000 | 54458333.300 | 10566.70000 |
| 140200.00000 | -148300.0000 | -3258.00000 | -640000.0000 | 10566.70000 | 26791666.700 |

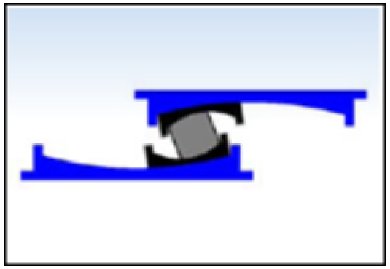
# Triple Friction Pendulum Bearings



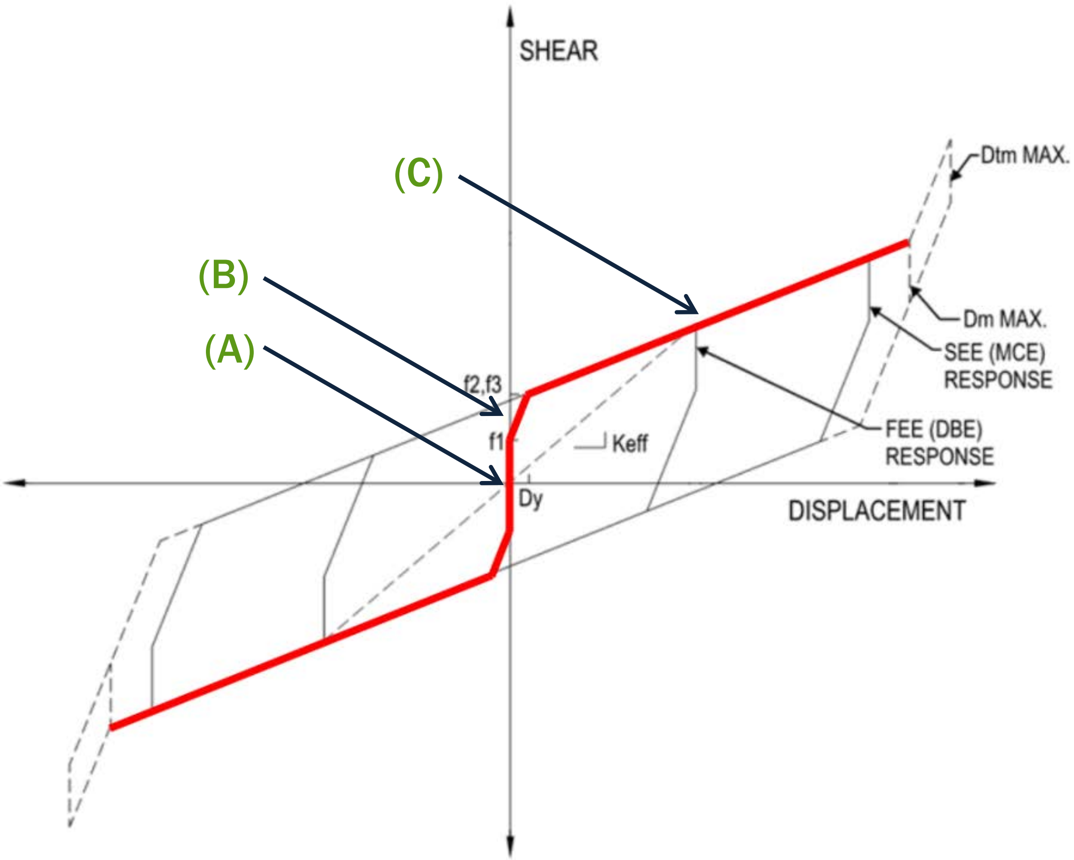
(A) Centered Position



(B) Inner Pendulum Motion



(C) Outer Pendulum Motion



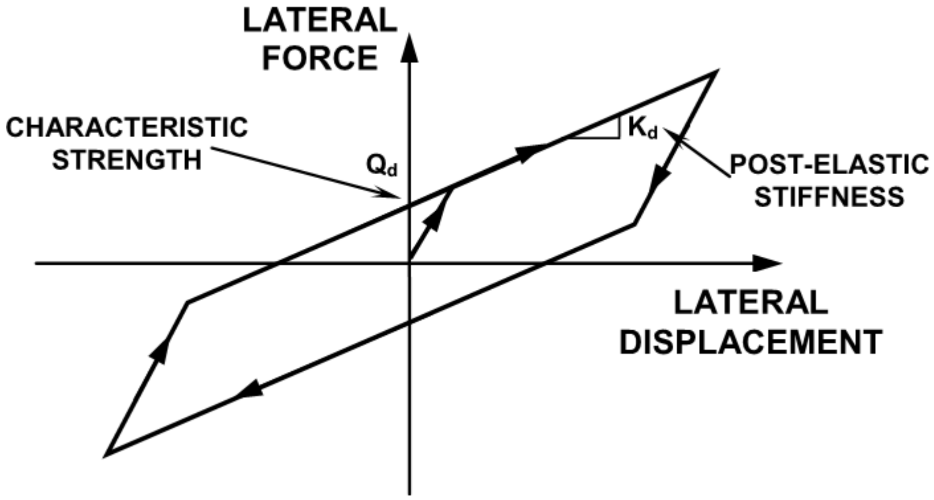
# Triple Friction Pendulum Bearings

# Isolation Bearing Behavior

- Non-Linear Spring Properties (Service Loading)
  - Friction Pendulum Bearings modeled as non-linear springs to accurately represent bearing behavior

- Friction Force
  - μ x Normal Force
  - Characteristic Strength (Qd)

- Restoring Force
  - Normal Force / Re
  - Re = Effective Radius
  - Re-centering Capabilities
  - Post-Elastic Stiffness (Kd)

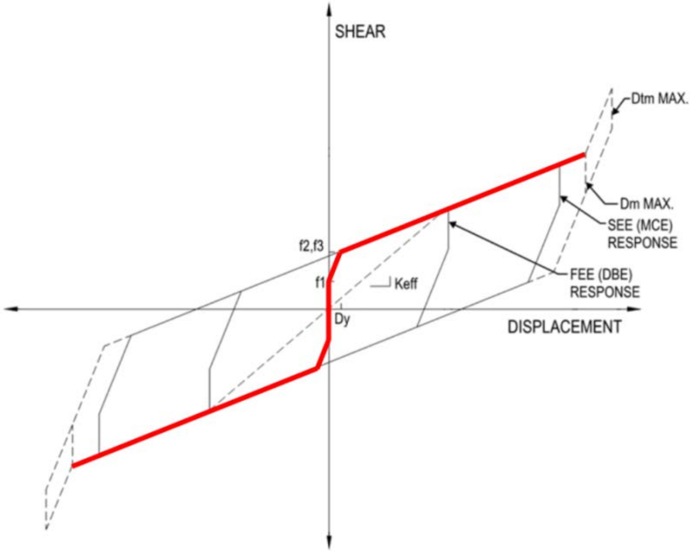


Idealized Force-Displacement Relation

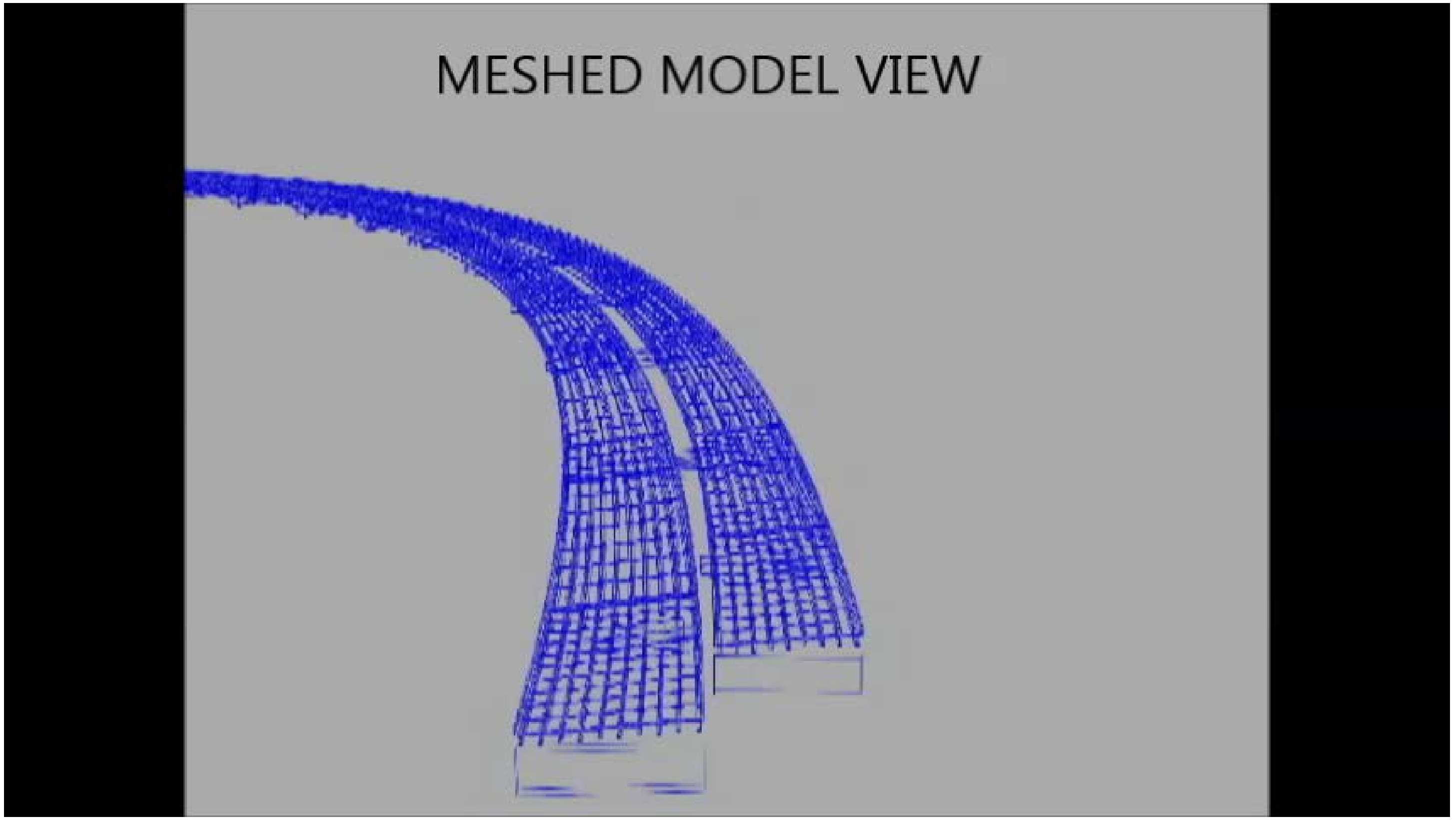
# Bearing Springs

- Bearing Springs represented by:
  - Non-Linear Springs for WS/WL/BR/TU (RM Global Model)
  - Equivalent Linear Springs for EQ (RM Global Model - Multi-Mode Response Spectrum)
  - Solid Elements with Contact Surfaces (ADINA - Time History Model)

- Spring properties developed using bearing reactions for various loading conditions



# Global Model Walk-Thru



MESHED MODEL VIEW

BRIDGE APPROACH SPAN GLOBAL ANALYSIS

# ANALYSES

# Service Level Analysis

| Load Case | Envelope | Friction Type | Value ($\mu$) |
|---|---|---|---|
| **Thermal** | Force & Displacement | "Slow Friction" | 1/2 (Upperbound $\mu_{dynamic}$) |
| **WS/WL/BR** | Force | "Fast Friction" | Upperbound $\mu_{dynamic}$ |
| | Displacement | "Fast Friction" | Lowerbound $\mu_{dynamic}$ |

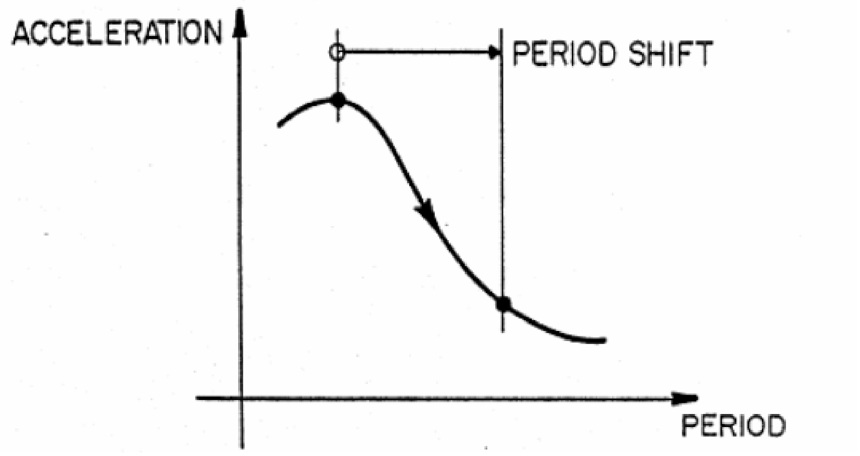
- Upper/lower bound dynamic coefficients are the product of the nominal dynamic friction coefficient multiplied by applicable system modification properties per AASHTO
- Bearings designed for "no slip" during service level dynamic lateral forces (Lateral Force < $\mu_{DYNAMIC}$)

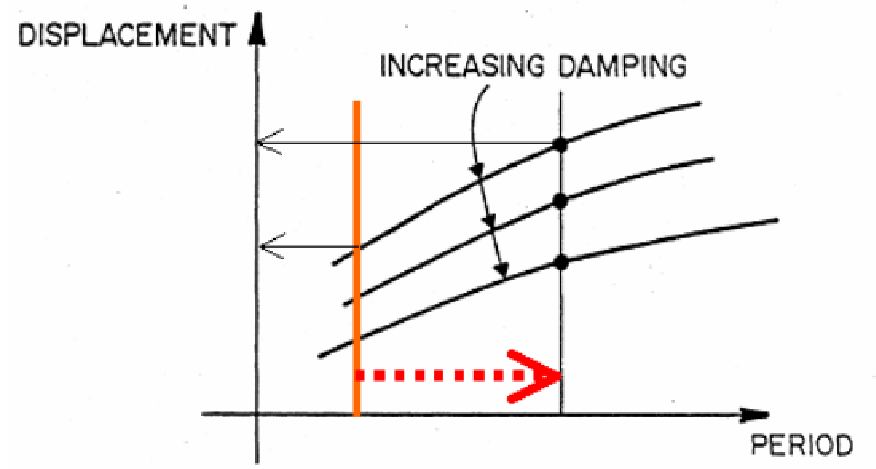
# Benefits of Seismic Isolation

- Elastic Dynamic Analysis (Multi-Modal Response Spectrum)
- Type 3 Seismic Design Strategy (Essentially Elastic Design)
- Increase fundamental period of vibration and energy dissipation capacity
  → Reduce seismic forces transferred to substructure
- Design substructure as essentially elastic
- Minimal damage to main structural components (i.e. no plastic hinging)
- Avoid designing capacity protected elements

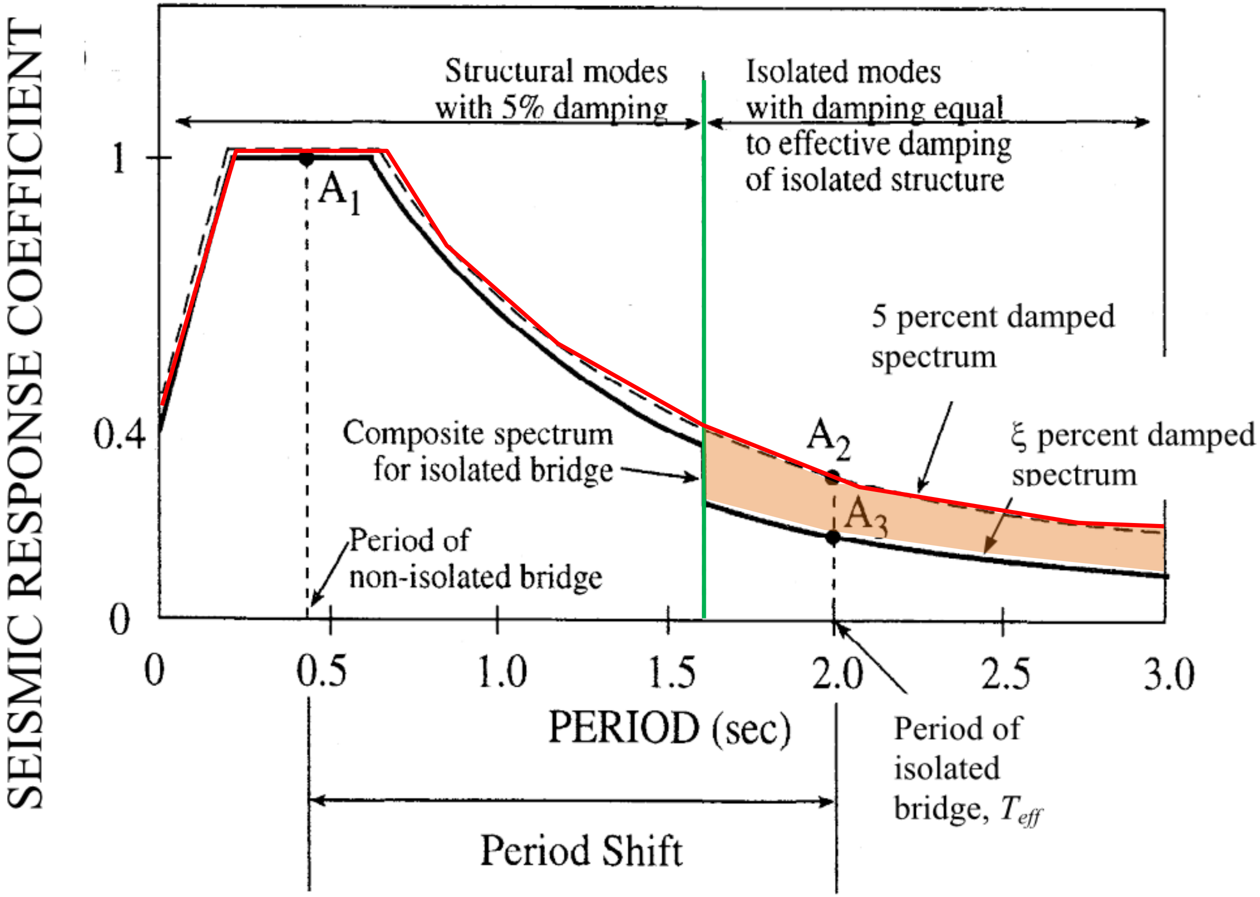
# Seismic Isolation Advantages

- Acceleration: Period shift decreases accelerations
- Energy Dissipation: Increased damping



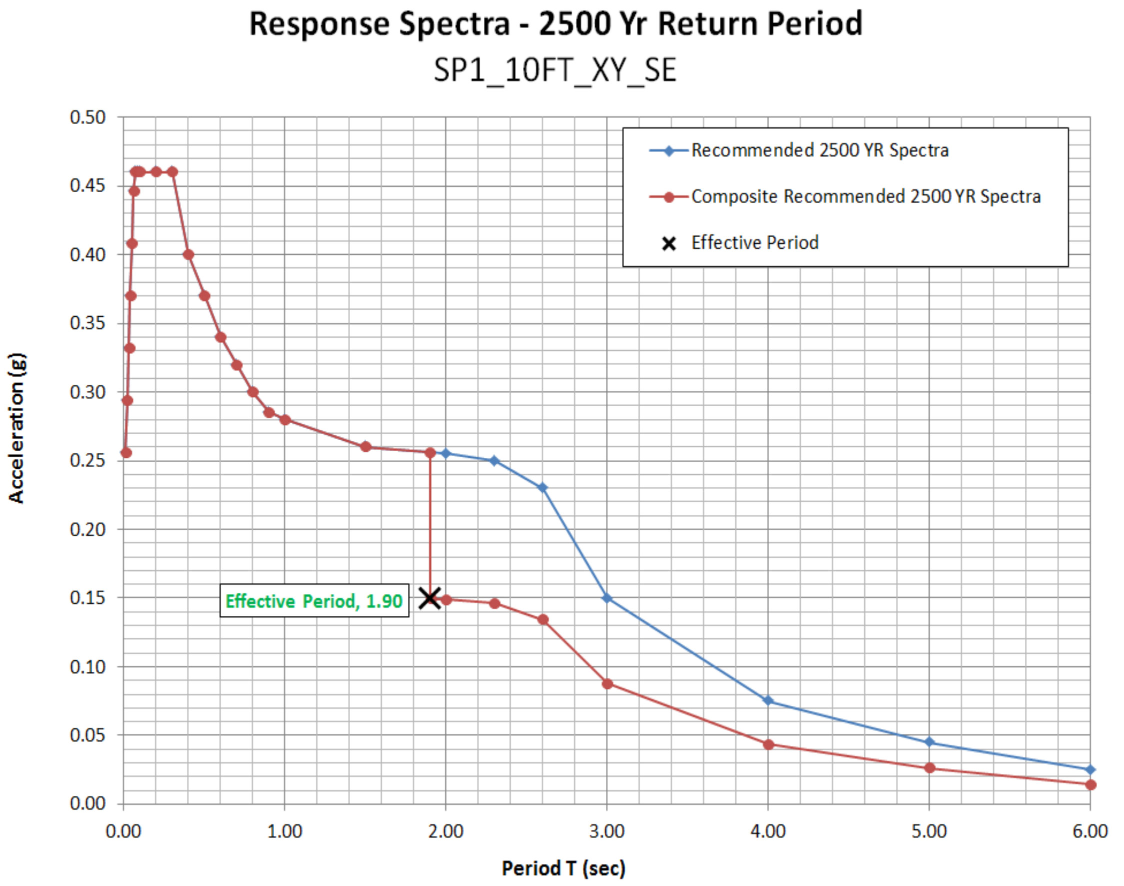


# Modified RSA Curve



# Site Specific RSA Curve

| Recommended 2500 YR Spectra | | Composite Recommended 2500 YR Spectra | |
|---|---|---|---|
| Period (sec) | Acceleration (g) | Period (sec) | Acceleration (g) |
| 0.01 | 0.26 | 0.01 | 0.256 |
| 0.02 | 0.29 | 0.02 | 0.294 |
| 0.03 | 0.33 | 0.03 | 0.332 |
| 0.04 | 0.37 | 0.04 | 0.370 |
| 0.05 | 0.41 | 0.05 | 0.408 |
| 0.06 | 0.45 | 0.06 | 0.446 |
| 0.07 | 0.46 | 0.07 | 0.460 |
| 0.08 | 0.46 | 0.08 | 0.460 |
| 0.1 | 0.46 | 0.10 | 0.460 |
| 0.2 | 0.46 | 0.20 | 0.460 |
| 0.3 | 0.46 | 0.30 | 0.460 |
| 0.4 | 0.40 | 0.40 | 0.400 |
| 0.5 | 0.37 | 0.50 | 0.370 |
| 0.6 | 0.34 | 0.60 | 0.340 |
| 0.7 | 0.32 | 0.70 | 0.320 |
| 0.8 | 0.30 | 0.80 | 0.300 |
| 0.9 | 0.29 | 0.90 | 0.285 |
| 1 | 0.28 | 1.00 | 0.280 |
| 1.5 | 0.26 | 1.50 | 0.260 |
| 2 | 0.26 | 1.90 | 0.256 |
| 2.3 | 0.25 | 1.90 | 0.150 |
| 2.6 | 0.23 | 2.00 | 0.149 |
| 3 | 0.15 | 2.30 | 0.146 |
| 4 | 0.08 | 2.60 | 0.134 |
| 5 | 0.05 | 3.00 | 0.088 |
| 6 | 0.03 | 4.00 | 0.044 |
| 1.90 | 0.26 | 5.00 | 0.026 |
| 1.90 | 0.26 | 6.00 | 0.015 |



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# PARALLEL MODEL CHECK

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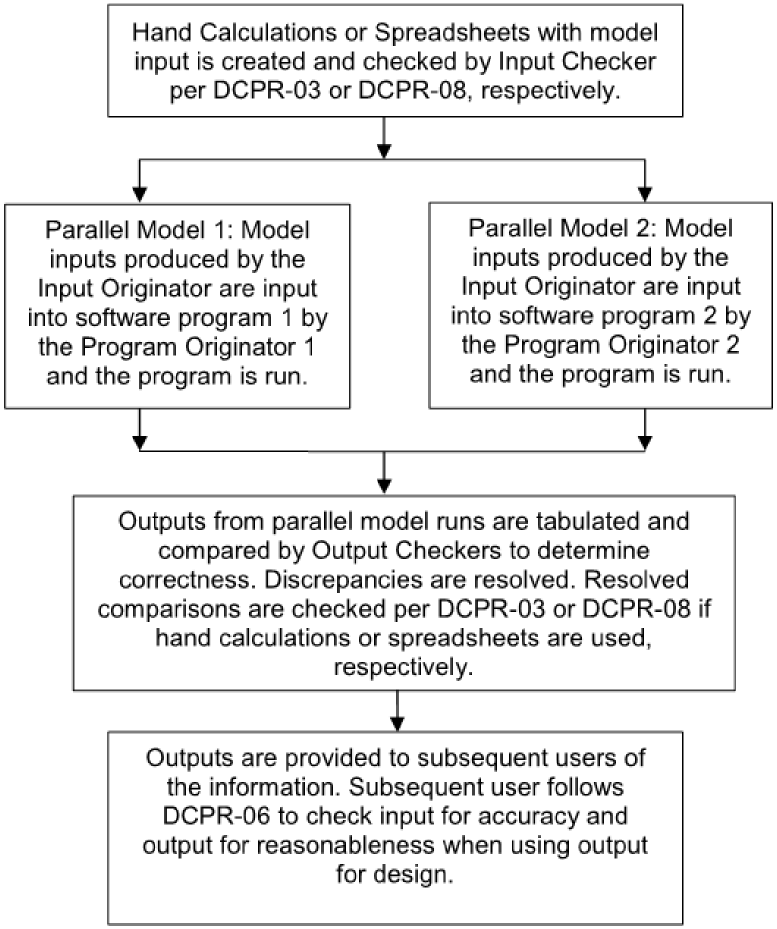
# Parallel Model Check

- Multi-Modal RSA (RM Bridge) checked against a THA (ADINA)
- ADINA bearing model – replicated TFP hysteresis curve
- In ADINA, bearings are modeled using:
  - Contact Surfaces
  - Solid Elements
  - Large Displacement Element Formulation
- ADINA model – check static, service load results from RM Bridge model

**Figure DCPR-16**
Flow Chart of Parallel Model Checking



Hand Calculations or Spreadsheets with model input is created and checked by Input Checker per DCPR-03 or DCPR-08, respectively.

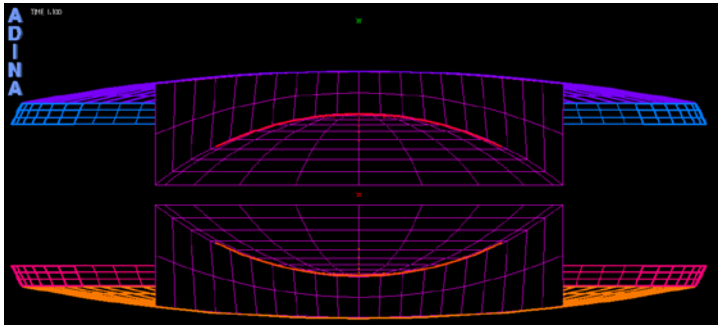
Parallel Model 1: Model inputs produced by the Input Originator are input into software program 1 by the Program Originator 1 and the program is run.

Parallel Model 2: Model inputs produced by the Input Originator are input into software program 2 by the Program Originator 2 and the program is run.

Outputs from parallel model runs are tabulated and compared by Output Checkers to determine correctness. Discrepancies are resolved. Resolved comparisons are checked per DCPR-03 or DCPR-08 if hand calculations or spreadsheets are used, respectively.

Outputs are provided to subsequent users of the information. Subsequent user follows DCPR-06 to check input for accuracy and output for reasonableness when using output for design.

# ADINA Bearing Modeling



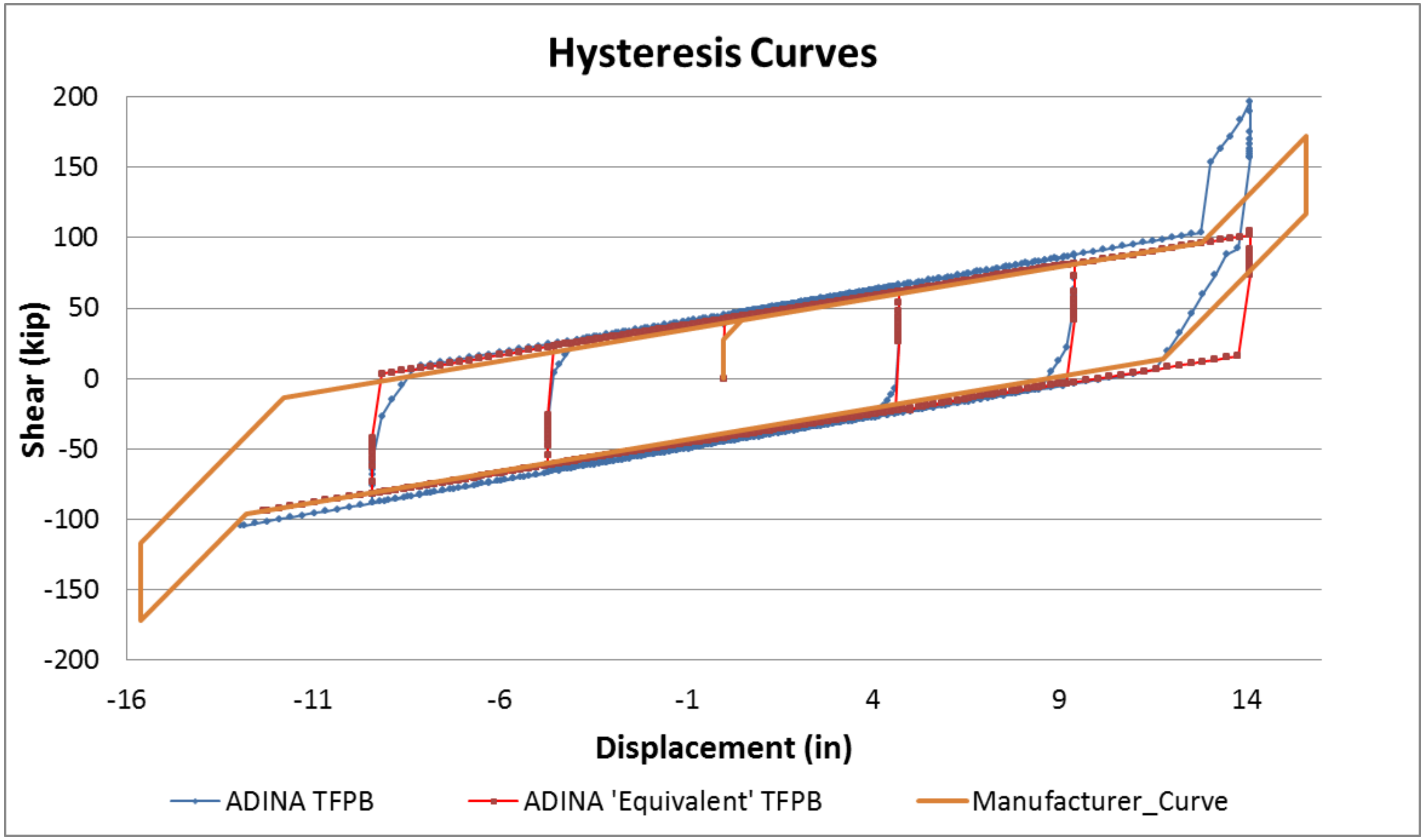
- Explicitly modeled Friction Pendulum Bearings
  - Solid elements: Represent articulated sliding components
  - Contact surfaces: Represent upper and lower sliding planes

- Large displacement geometric nonlinearity is activated

- Coefficients of friction are assigned to pairs of contact surfaces
  - Shear force = (coefficient of friction) x (normal force)

- Influence of boundary rotations at the pier cap and superstructure level are implicit in the THA

# Hysteretic Response

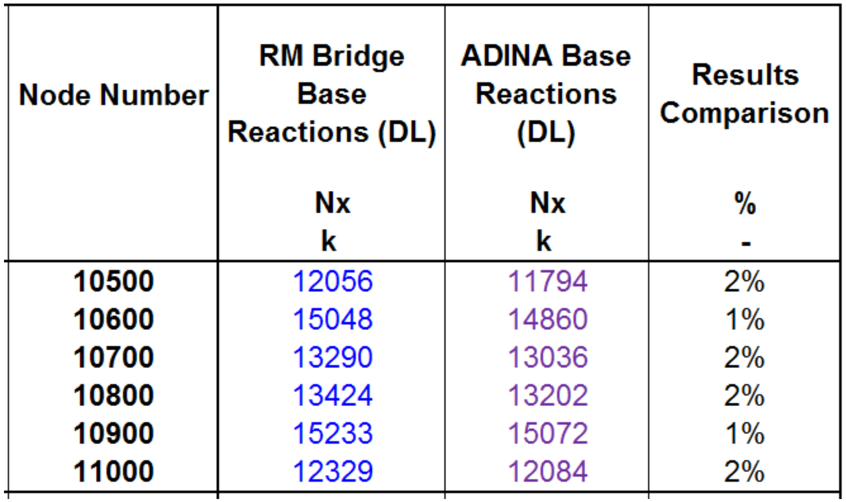


# Hysteretic Response

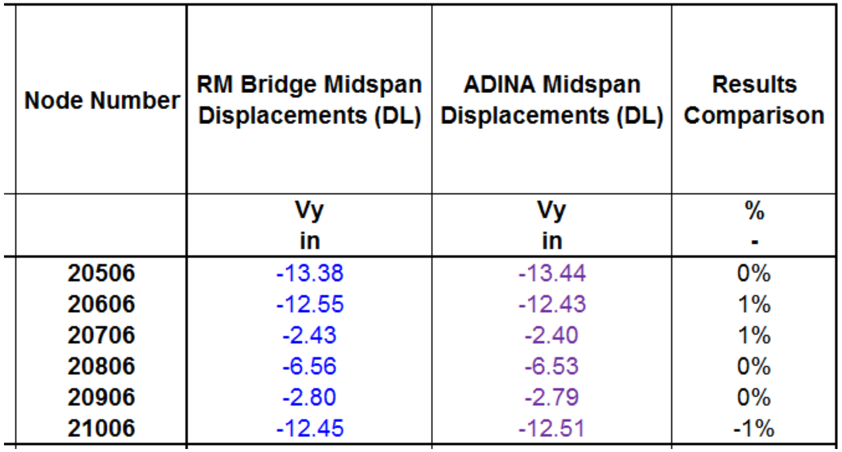
# Dead Load Comparison

- DL base reactions are compared to verify system mass and DL distribution

- DL displacements are compared to check stiffness between models



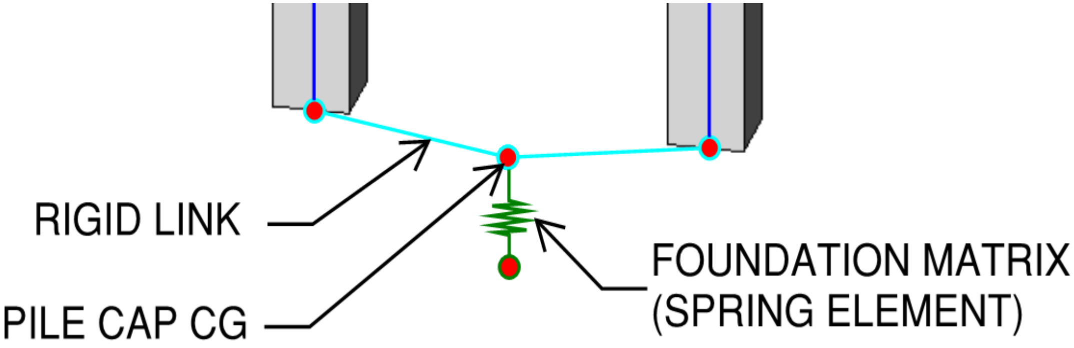
| Node Number | RM Bridge Base Reactions (DL)<br>Nx<br>k | ADINA Base Reactions (DL)<br>Nx<br>k | Results Comparison<br>%<br>- |
|---|---|---|---|
| 10500 | 12056 | 11794 | 2% |
| 10600 | 15048 | 14860 | 1% |
| 10700 | 13290 | 13036 | 2% |
| 10800 | 13424 | 13202 | 2% |
| 10900 | 15233 | 15072 | 1% |
| 11000 | 12329 | 12084 | 2% |



| Node Number | RM Bridge Midspan Displacements (DL) | ADINA Midspan Displacements (DL) | Results Comparison |
|---|---|---|---|
| | Vy<br>in | Vy<br>in | %<br>- |
| 20506 | -13.38 | -13.44 | 0% |
| 20606 | -12.55 | -12.43 | 1% |
| 20706 | -2.43 | -2.40 | 1% |
| 20806 | -6.56 | -6.53 | 0% |
| 20906 | -2.80 | -2.79 | 0% |
| 21006 | -12.45 | -12.51 | -1% |

# THA – Foundation Modeling

- Foundation stiffness modeled in ADINA using 2-node general element (12x12 stiffness matrix defined from 6x6 secant stiffness matrix from FBMulti Pier)
- TH displacement load functions applied at one node; other node represents CG of pile cap
- Lumped mass assigned at CG pile cap to account for foundation mass



# THA – Rayleigh Damping

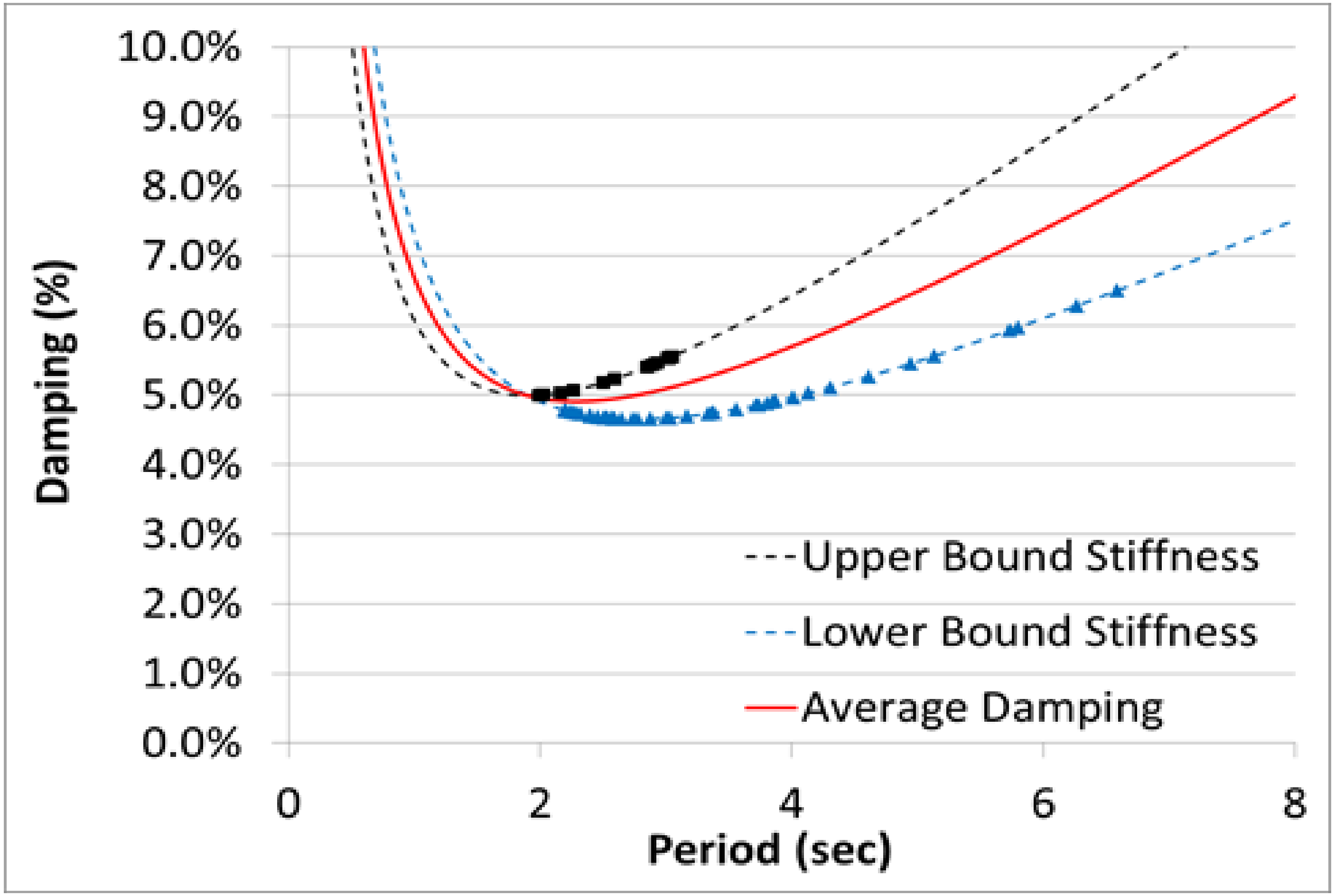
- Rayleigh damping coefficients (α and β) for superstructure elements are derived targeting an average 2% viscous damping over superstructure modal frequencies.

- Rayleigh damping coefficients for substructure and foundations are derived targeting an average 5% damping over substructure modal frequencies.

- Rayleigh Damping Constant: C = α*(Mass) + β*(Stiffness)

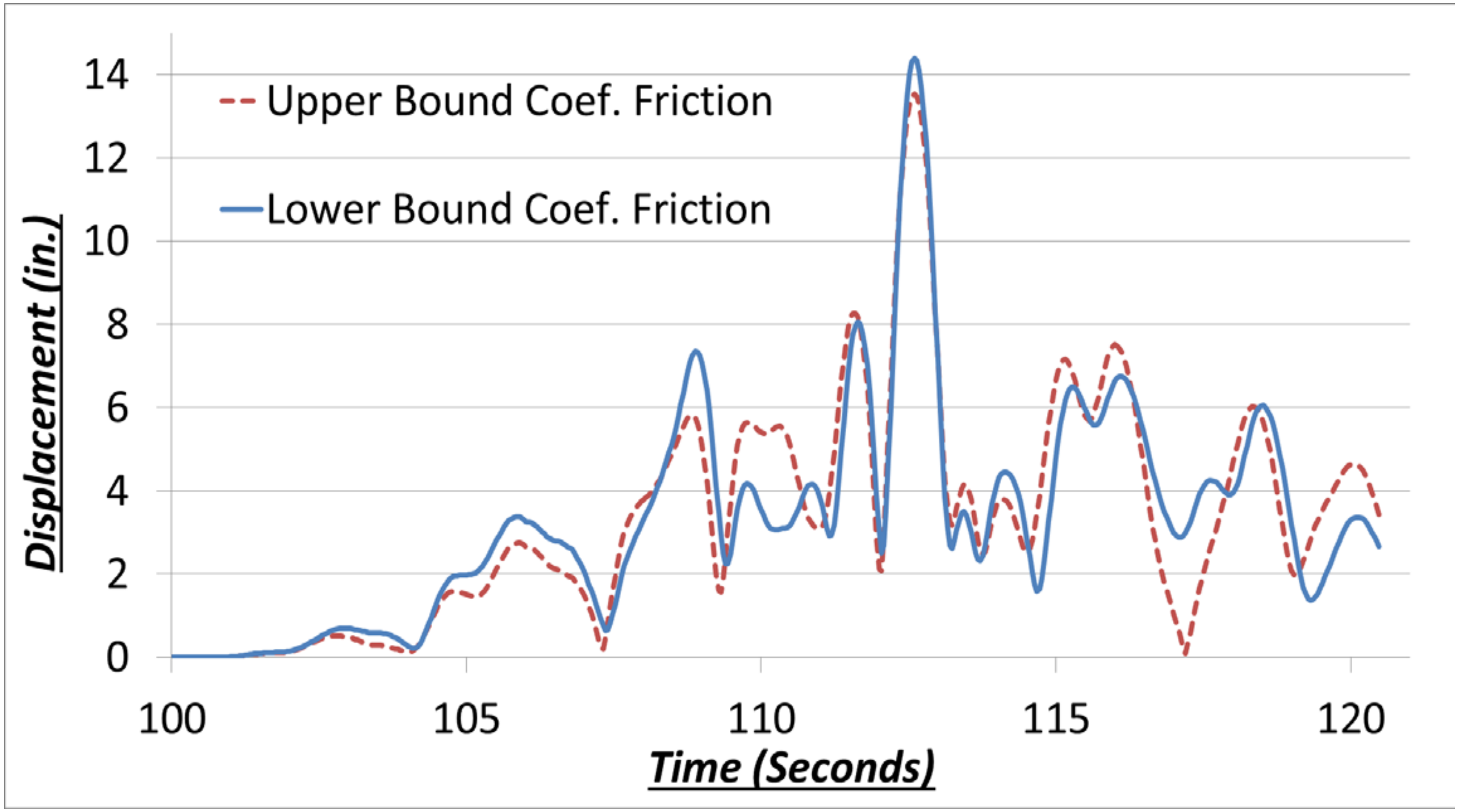
- Foundation damping is achieved by applying dashpots for all 6 DOF. Dashpots are assigned between adjacent foundation nodes (driving and CG of pile cap nodes).

# THA – Rayleigh Damping



# THA – Pier Response

# THA – Bearing Disp. Demands



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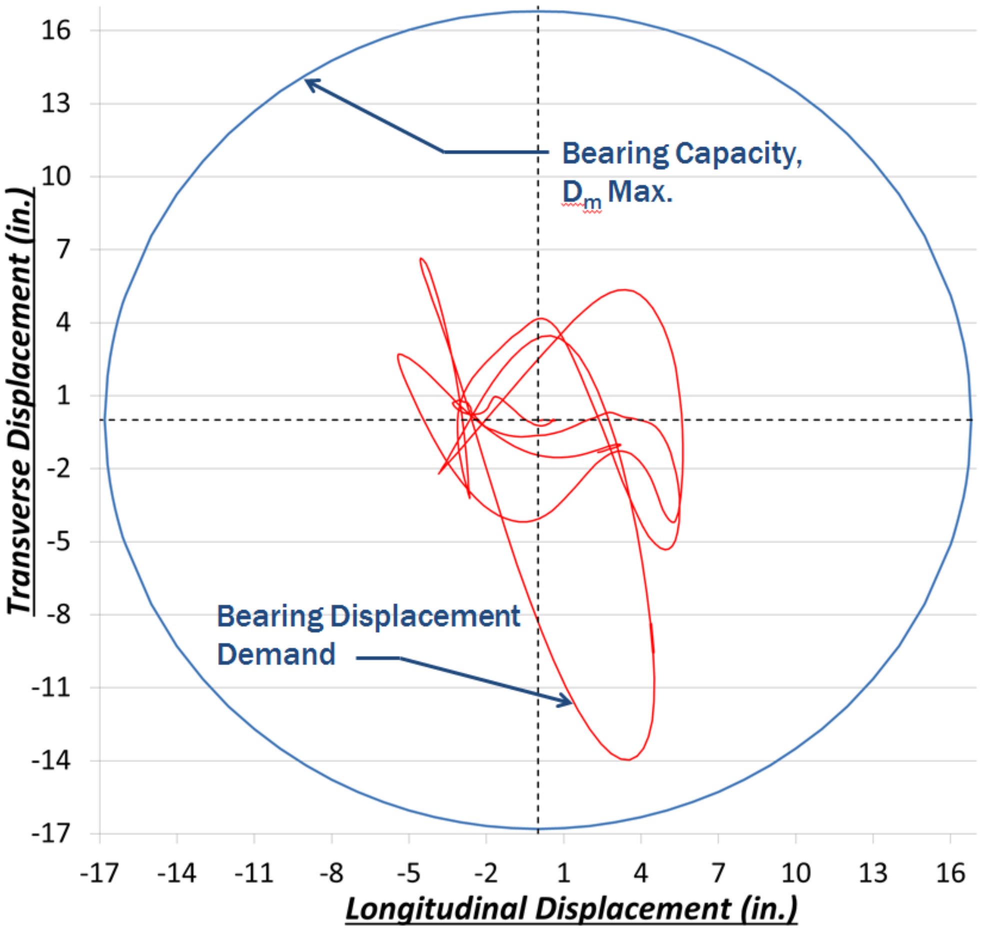
# THA - Bearing Disp. Demands



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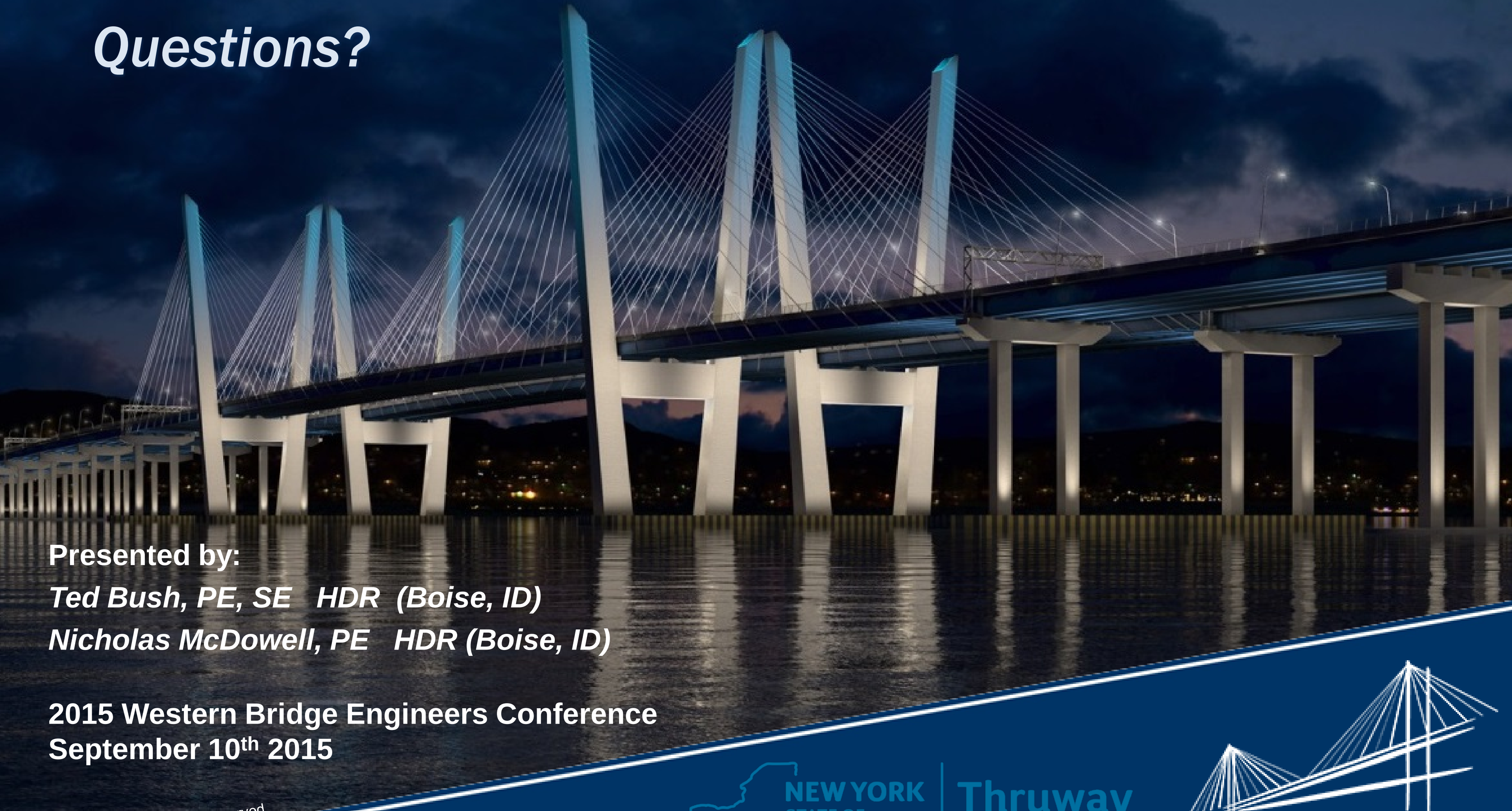
## Questions?



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