IMPROVING RESILIENCE, SAFETY, AND SERVICE LIFE OF THE PULASKI SKYWAY

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Presented by Ruben Gajer, PE, Technical Director of Complex Bridges, Arora and Associates, PC

NJDOT- Research Showcase
October 29, 2020

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Pulaski Skyway- Superstructure & Substructure Rehabilitation, Seismic Retrofit Program

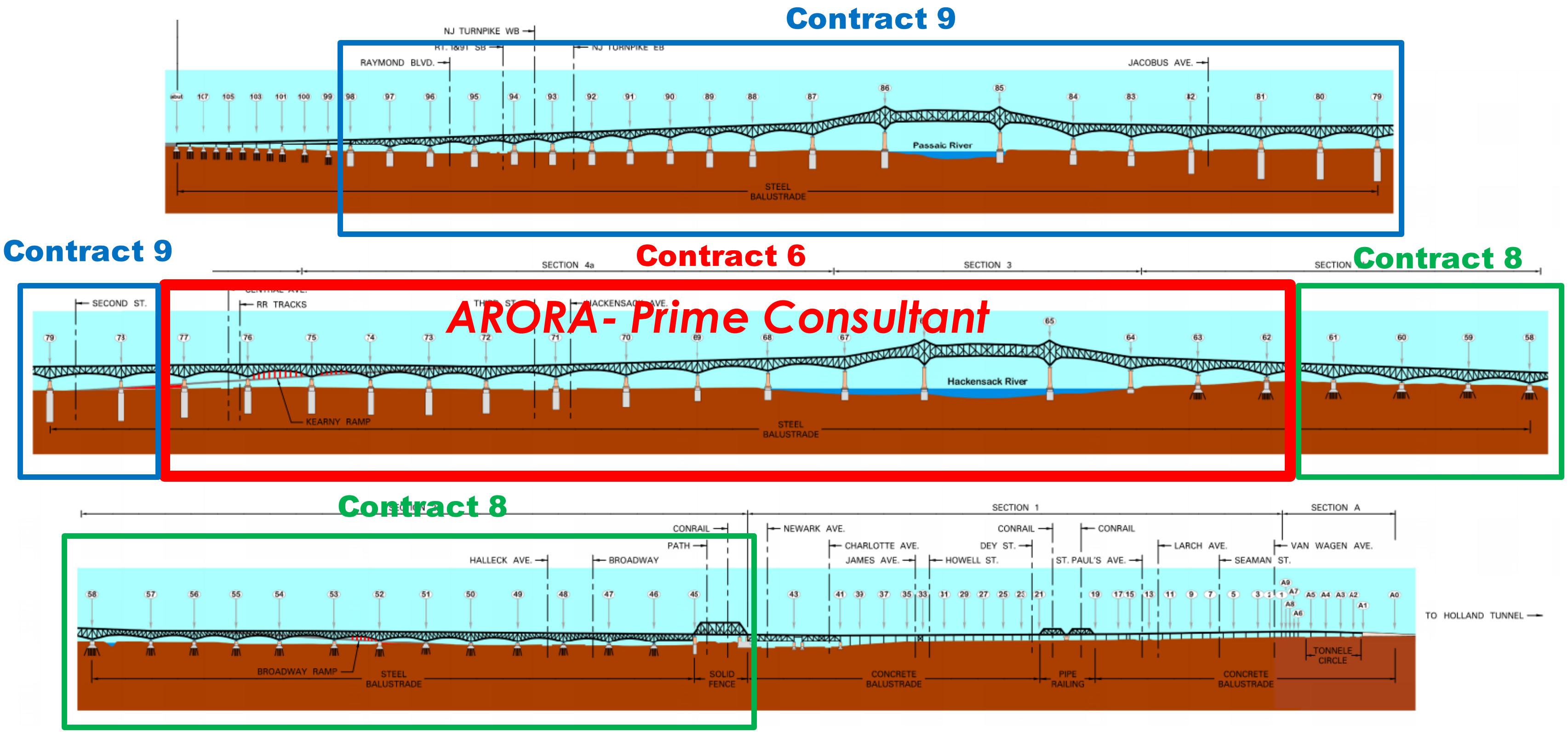
Contract 6 Limits – Pier 62 to Pier 77 (5,041 LF)

Underside of Deck

Hackensack River Crossing

- Vital link in the Northern New Jersey/New York Metropolitan
- 18,498-ft long
- Carries over 70,000 vpd

Pulaski Skyway – Truss Spans Rehabilitation – Contracts By DESIGN



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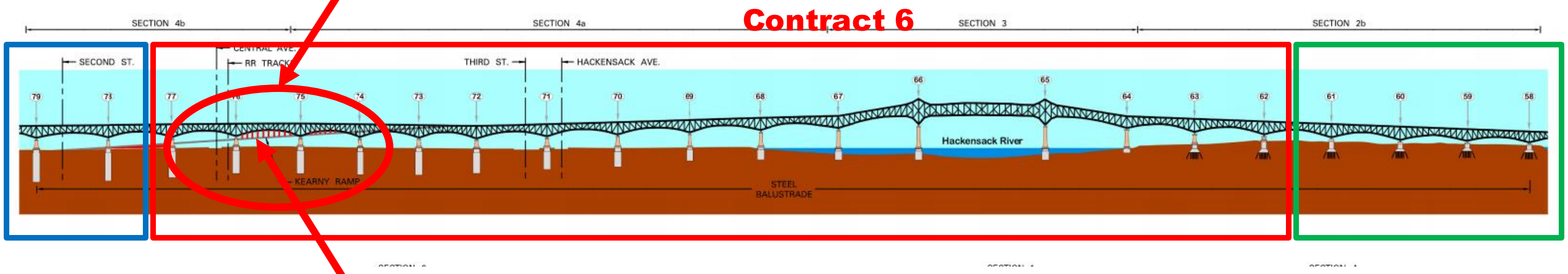
Pulaski Skyway – Truss Spans Rehabilitation – Contracts By DESIGN

Replacement of the Kearny Ramp Ahead of C6: Accelerated Replacement of Two Piers of C6 and Adjacent Truss Rehabilitation



Kearny Ramp

Arora Prime Consultant for Contract 6 (C6)
Superstructure & Substructure Rehabilitation, Seismic Retrofit

Contract 6 Limits – Pier 62 to Pier 77 (5,041 LF)

- ***Inspection and Load Rating***
- ***Design of New Piers and Foundations***
- ***Complex Steel Repairs Design***
- ***Rocker Bent Replacement Design***
- ***Bridge Finite Element Modeling and Analyses***
- ***Seismic Design and Retrofit***
  - ***Soil-Structure-Interaction Analyses***
- ***Ship Impact FE Analyses for Water Piers and Fender Design***
- ***Program-wide Lighting, ITS and Utility Engineering***
- ***Construction Support Services***

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Presentation Agenda

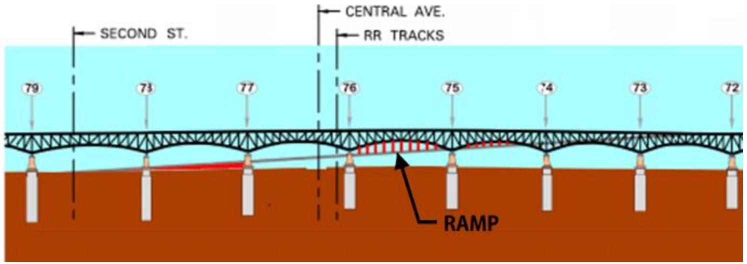
- Pier and Truss Rehabilitation Next to the Ramp
  - Complex Steel Repairs
    - Stagging Analyses
    - Analyses of Repair Details
  - Structural Health Monitoring During Jacking of the Trusses

- Rehabilitation of the Piers and Foundations

- Seismic Analyses and Design
  - Soil-Structure-Interaction Process
    - Derivation of the Design Spectrum

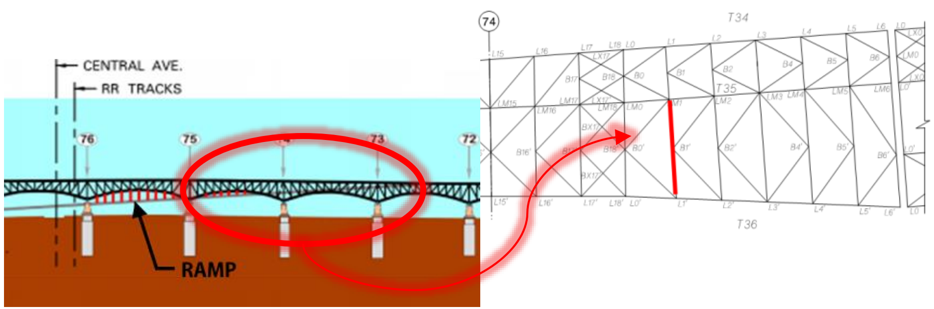
Kearny Ramp Piers Replacement and Truss Rehabilitation

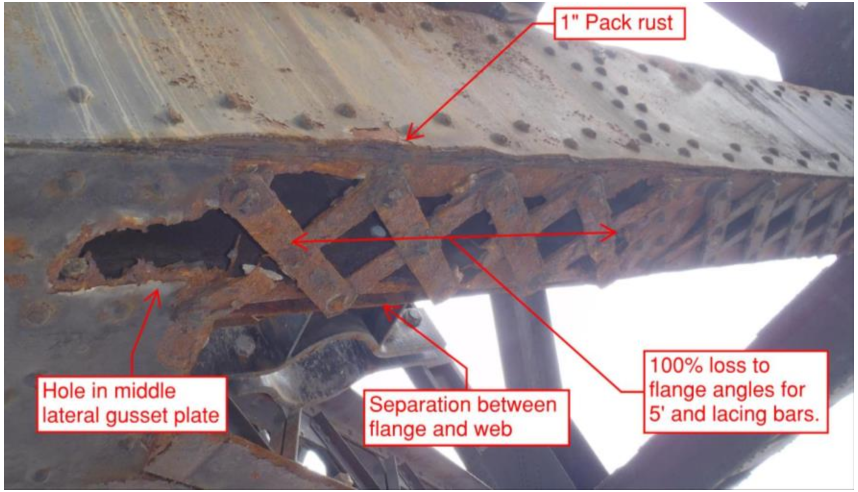
Replacement of the Kearny Ramp within the limits of C6

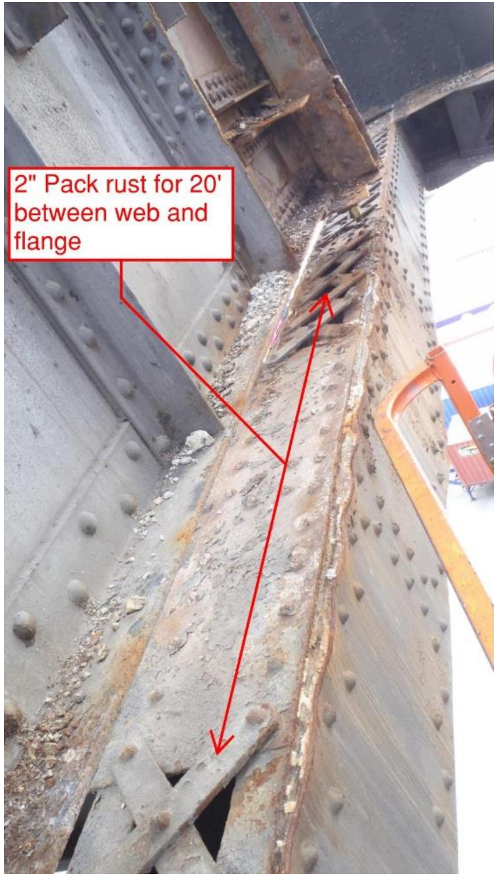


- As part of the global rehabilitation, the Ramp within the limits of C6 is being replaced.
- Structural Inspection of the Trusses after removal of the Ramp revealed additional deterioration not visible w/o removal of Ramp.

Truss Rehabilitation: Inspection Findings– Examples







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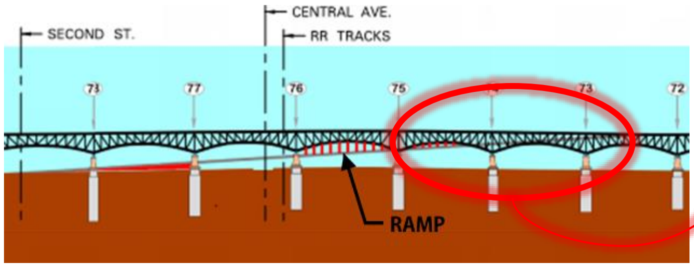
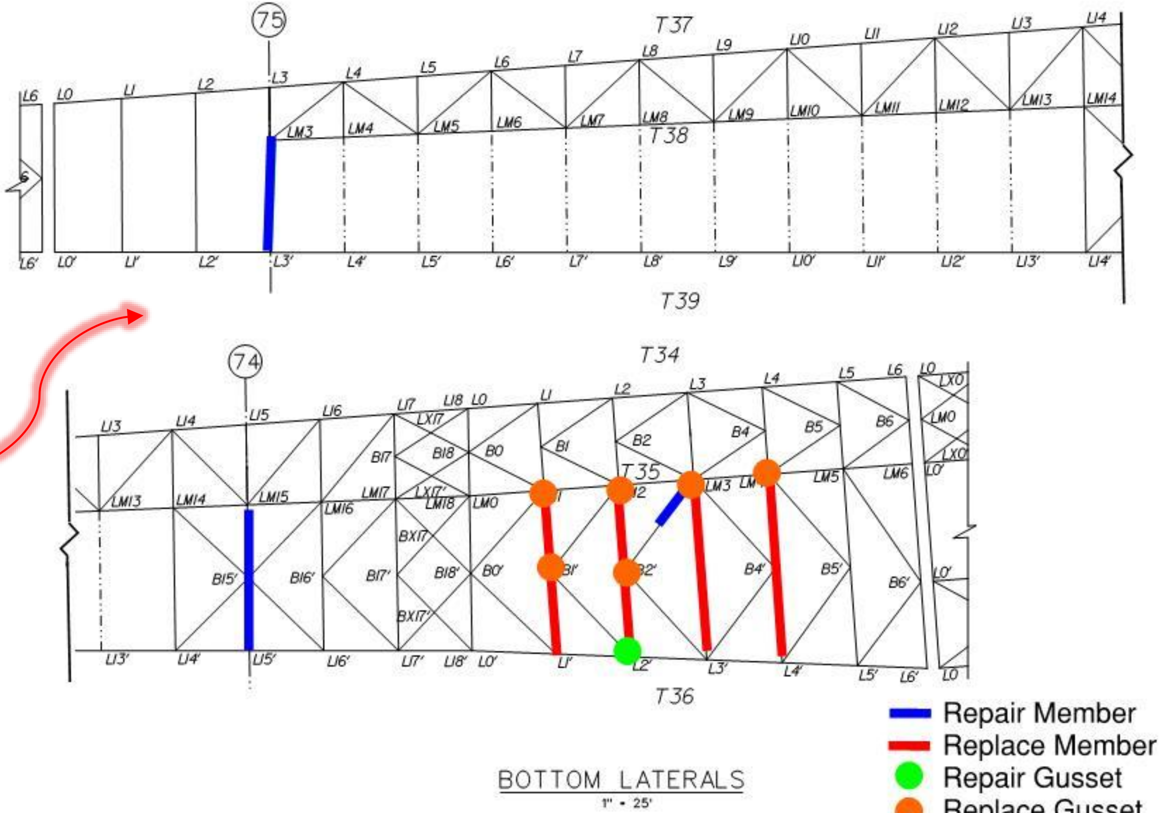
Truss Rehabilitation–Inspection Recommendations





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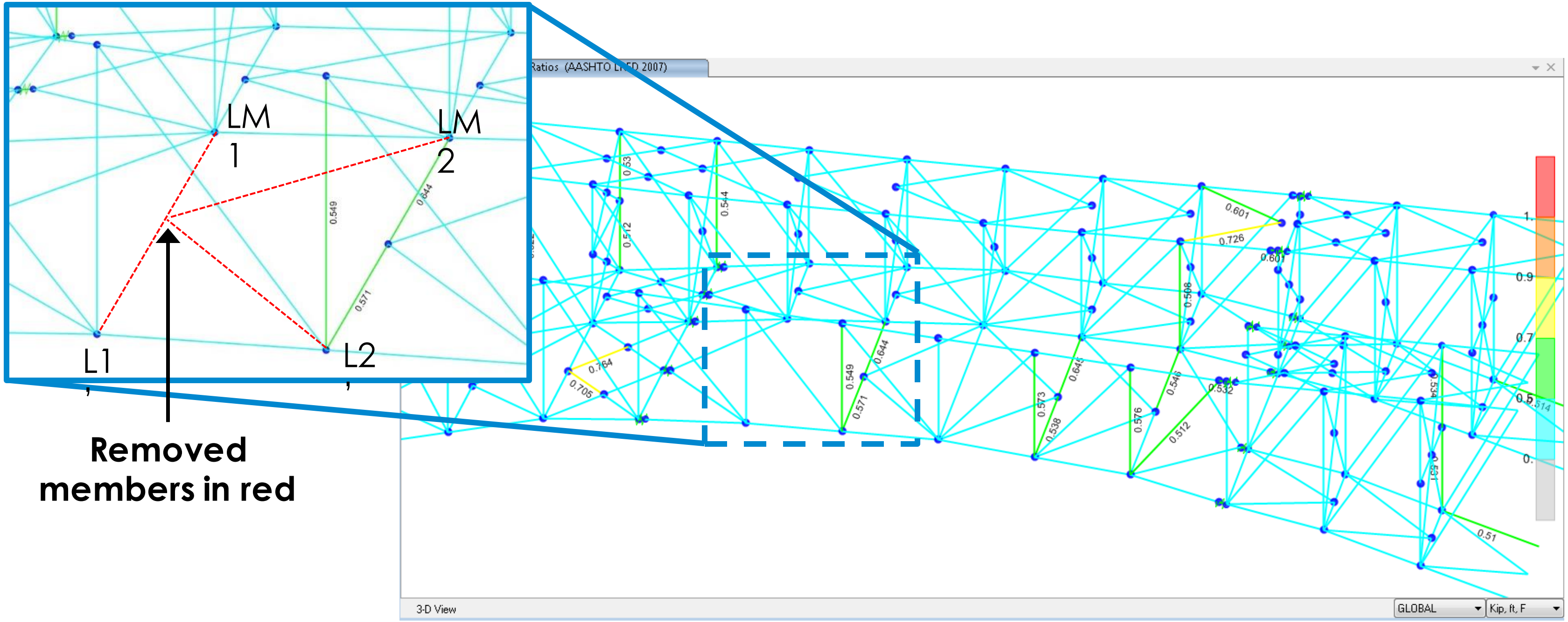
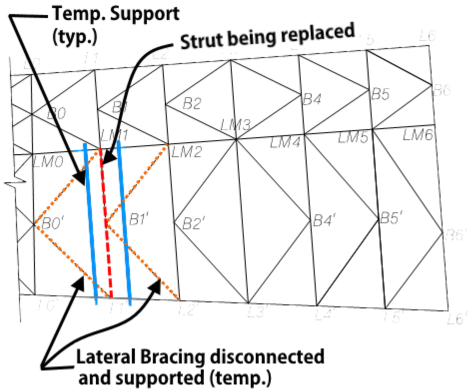
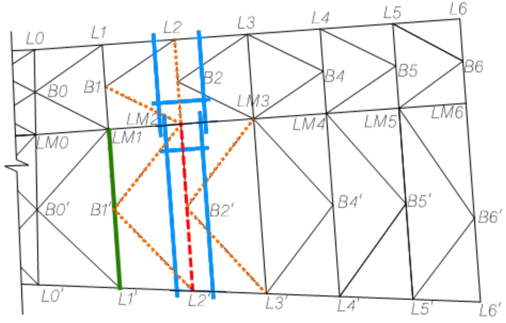
Truss Rehabilitation: CSiBridge Modeling and Analyses to Develop Construction Sequence



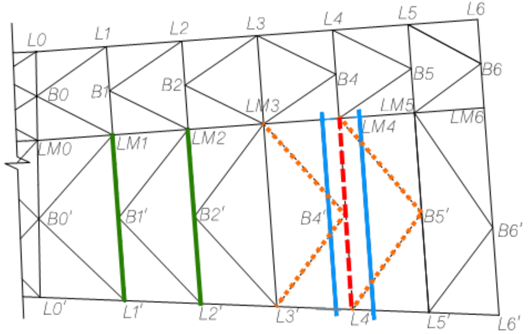
Truss Rehabilitation: Construction Staging



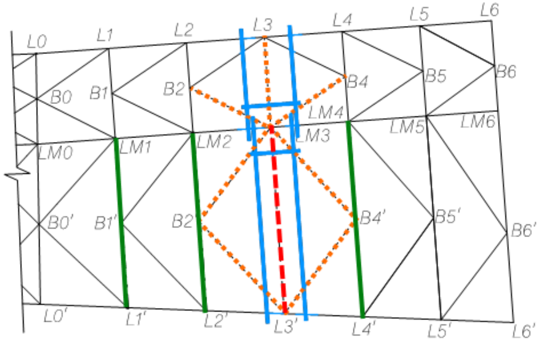
Stage 1



Stage 2

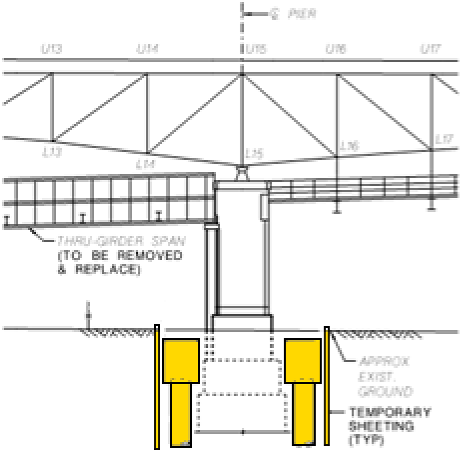


Stage 3

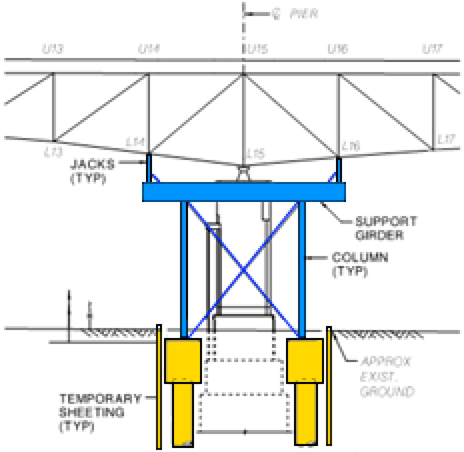


Stage 4

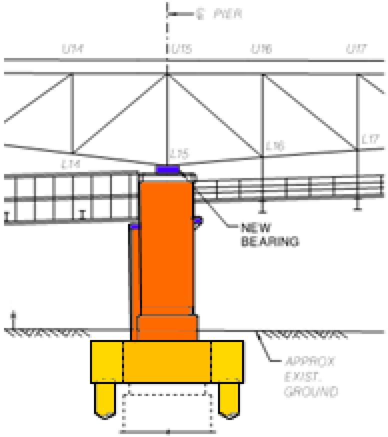
Replacement of the Piers at the Ramp- Construction Staging



STAGE 1



STAGE 2



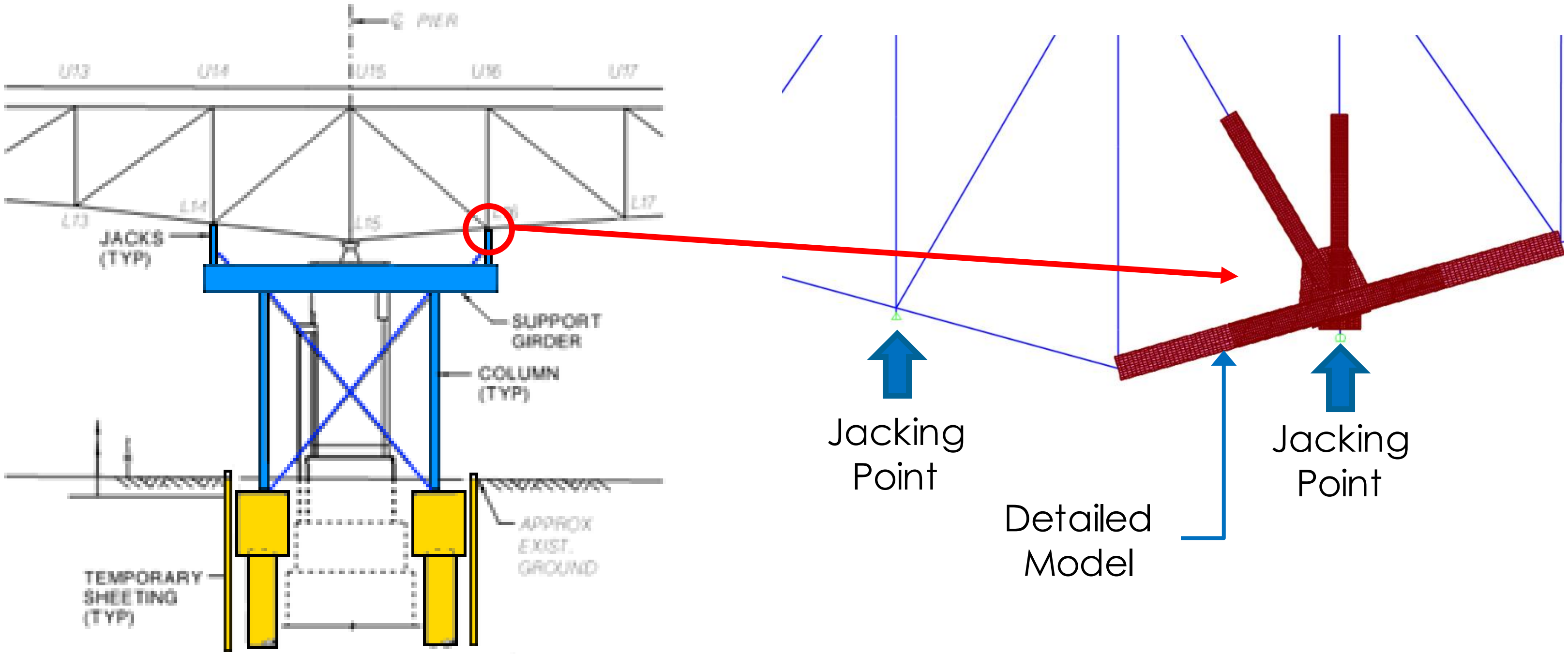
STAGE 3

- Install Temp. Sheeting
- Install drilled shafts and construct Stage 1 footing

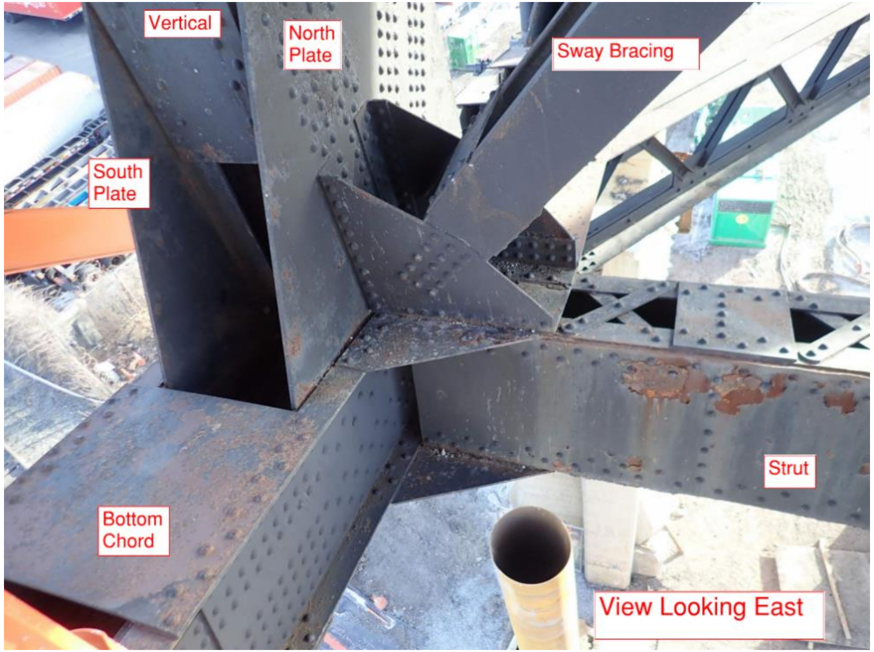
- Install temp. jacking structure
- Jack both trusses and transfer Truss support to temp. support structure.

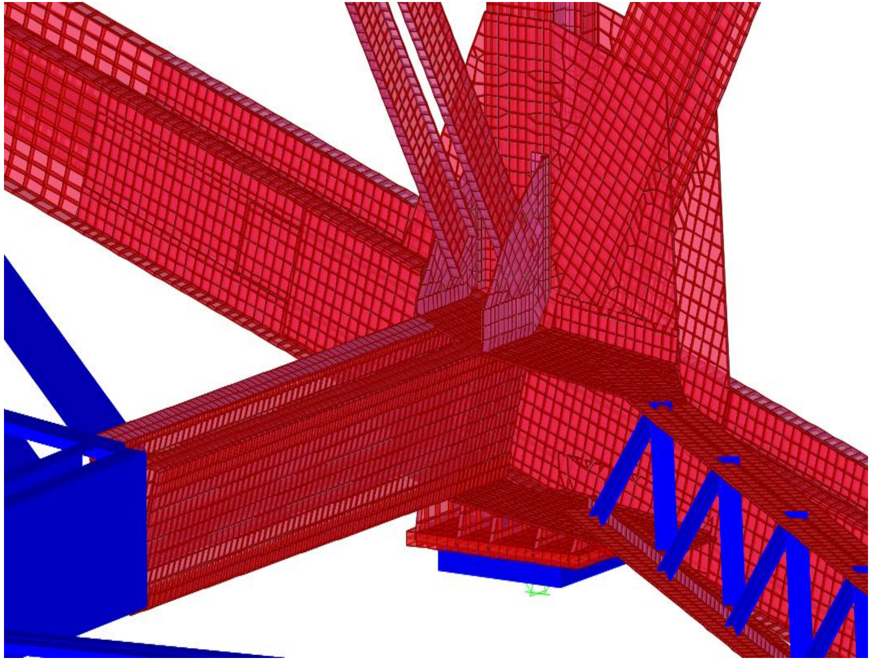
- Construct Stage 3 foundation
- Construct pier and install new bearing
- Remove temp. structure

Truss Rehabilitation: Jacking of the Trusses- Complex FEA



Truss Rehabilitation- Complex FEA to Design Difficult Gusset Plates Retrofit

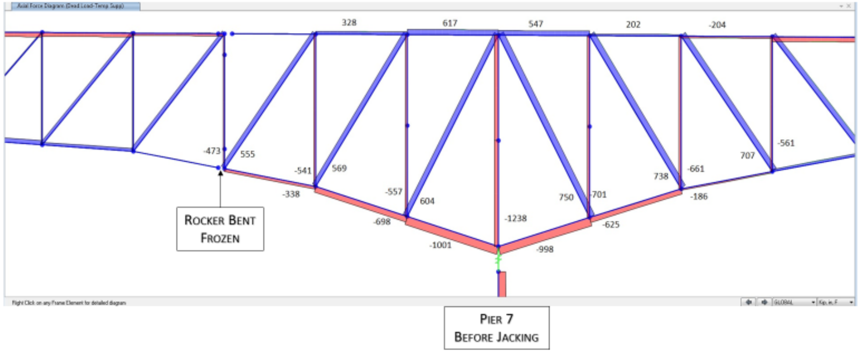




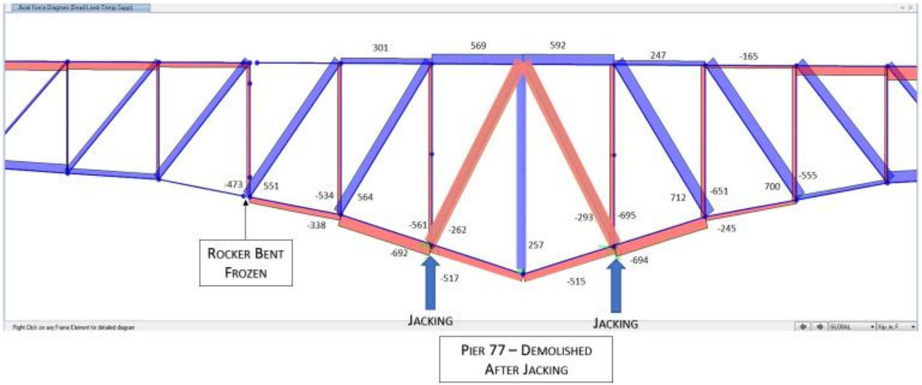
Kearny Ramp Piers Replacement- Structural Health Monitoring of Jacking Operations at Piers 76-77

Pier Replacement: Variation in DL Forces During Jacking of the Trusses

Dead Load Forces Before Jacking – Rocker Bent Frozen



Dead Load Forces After Jacking – Rocker Bent Frozen



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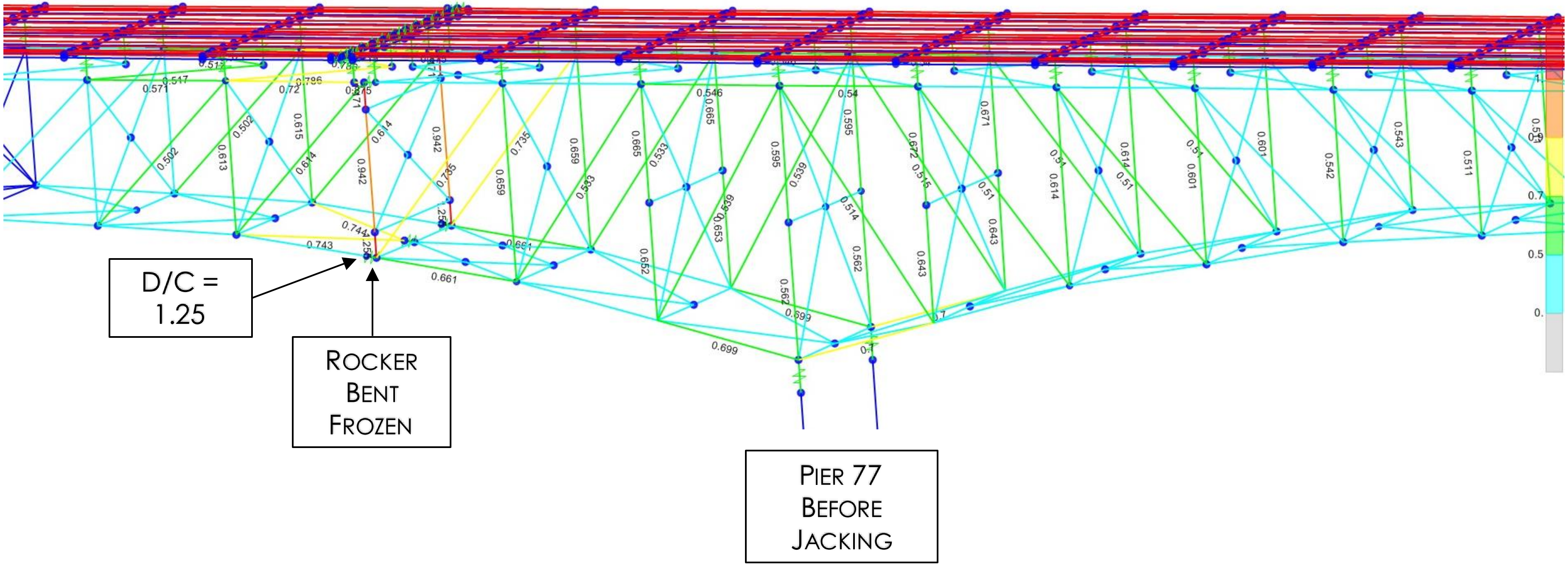
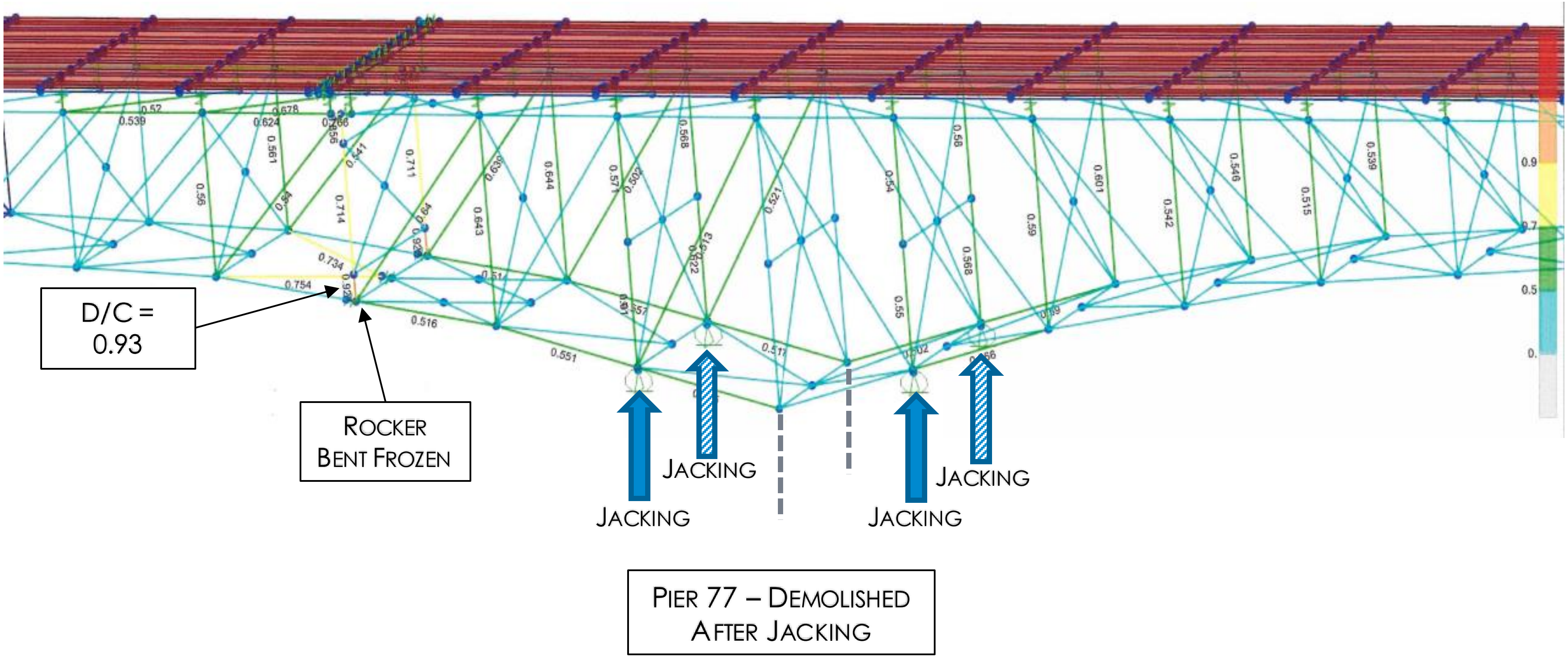
Pier Replacement: D/C – Before Jacking – All Load Cases Considered



Pier Replacement: D/C for After Jacking – All Load Cases Considered



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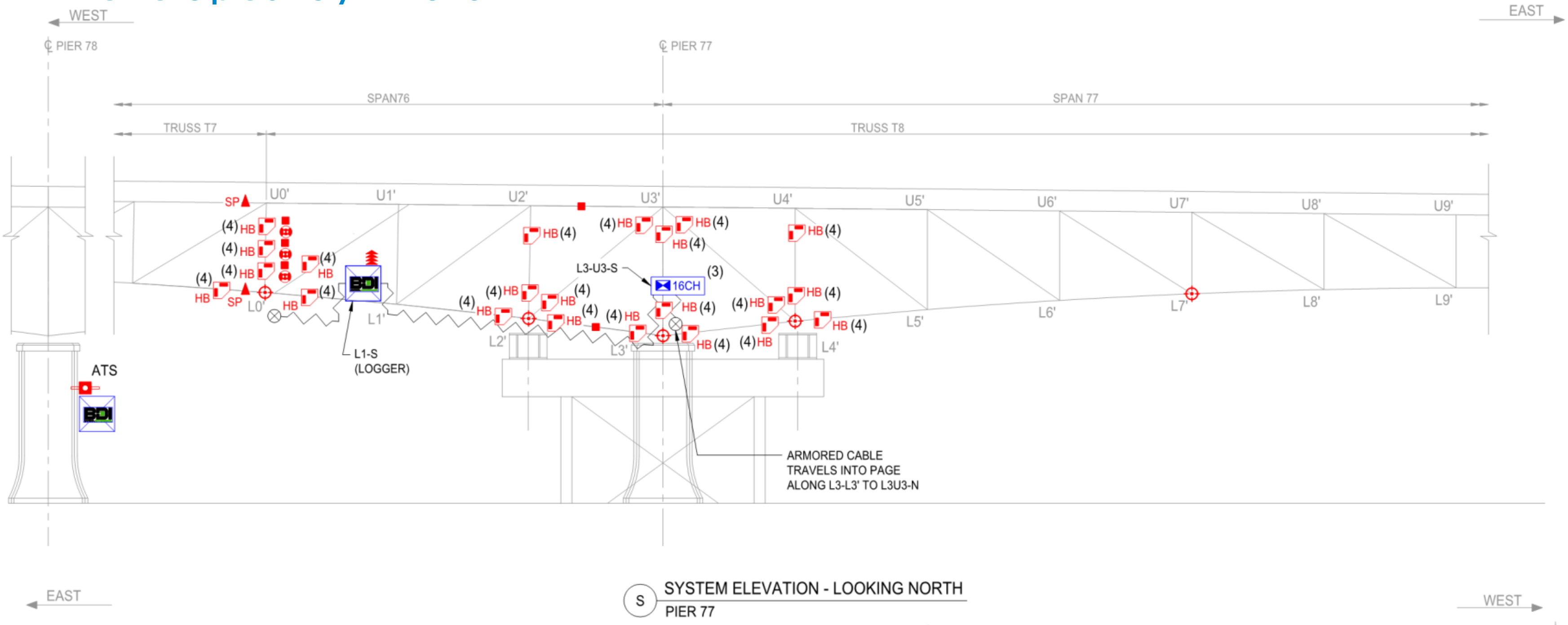
Pier Replacement: Monitoring at Pier 77 Instrumentation Plan Developed by Arora



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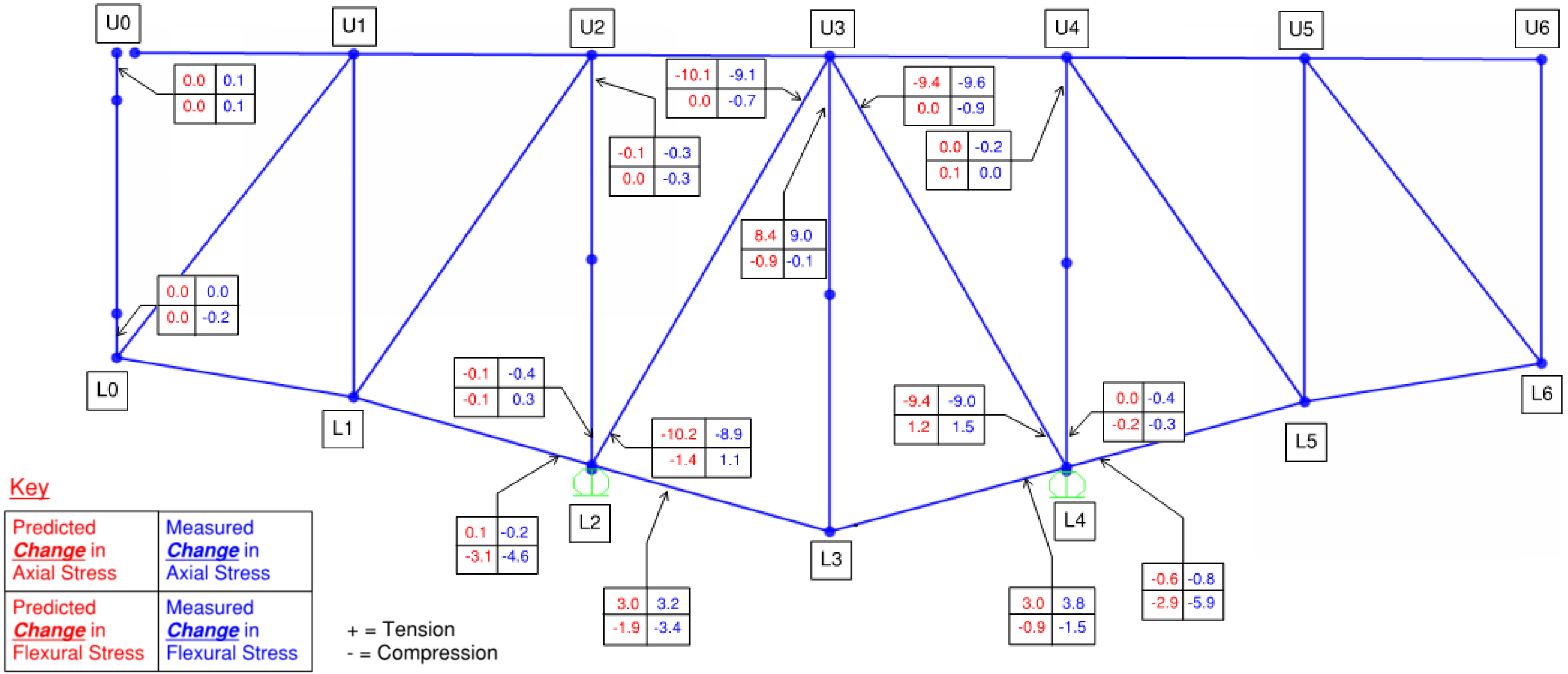
Pier Replacement: Δσ=***Change*** in Stress Due to Jacking Operation ONLY



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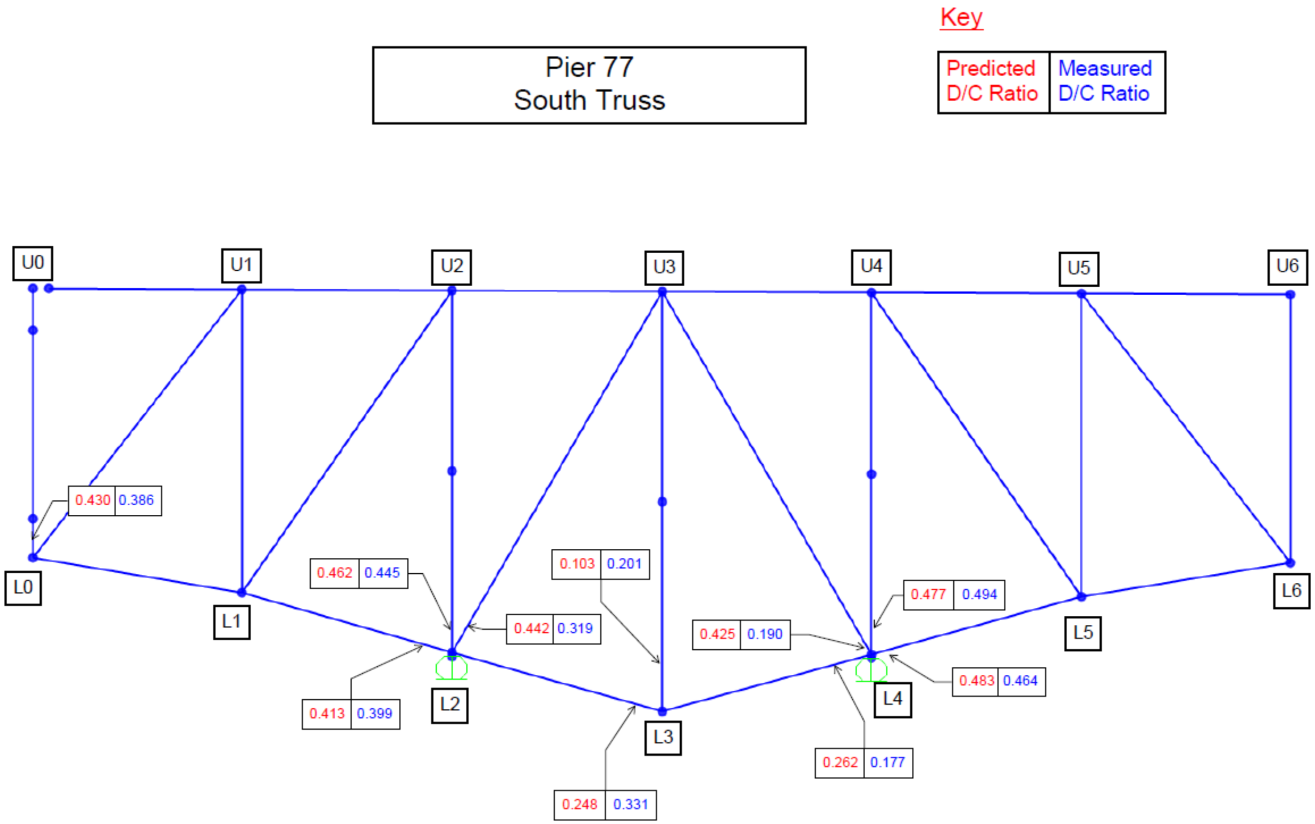
Pier Replacement: Demand/Capacity Ratios-Predicted vs Measured



Pier Replacement: Lessons from Monitoring the Jacking Operations

- ❖ Good agreement with predicted changes in dead load stresses
- ❖ Close agreement with predicted Demand over Capacity (D/C) ratios
- ❖ Confirmed the Operation Procedures were sound and safe
- ❖ Guide to the overall approach to Pier Rehabilitation Program

Rehabilitation of the Piers and Foundations

Rehabilitation of the Piers and Foundations– Typical Existing Piers

<u>Pier 72</u>

<u>Pier 62</u>

<u>Pier 70</u>

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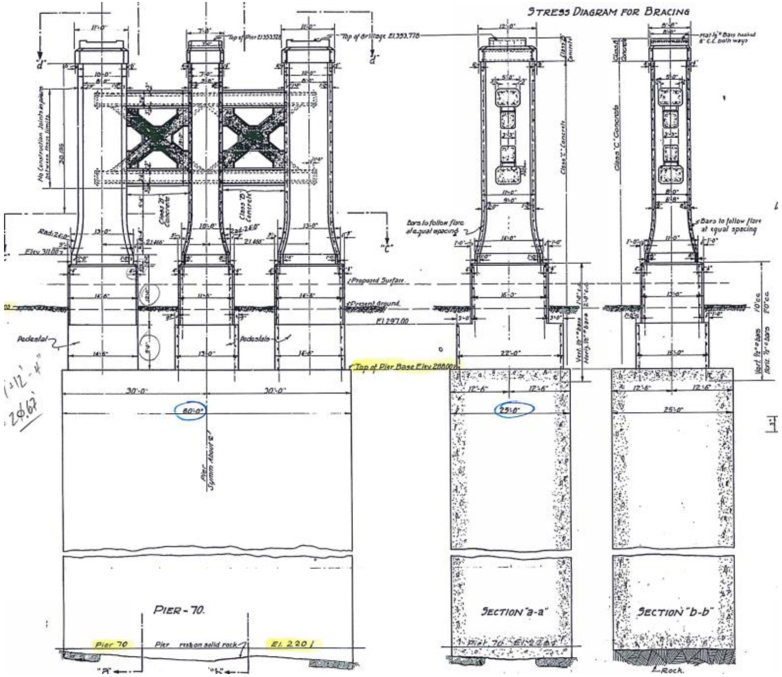
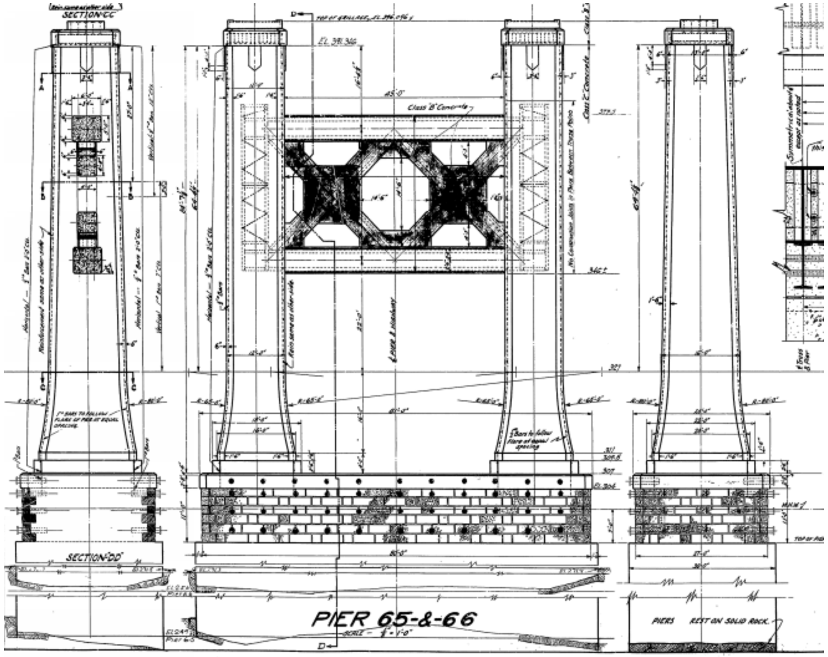
Rehabilitation of the Piers and Foundations– C6 Existing Piers

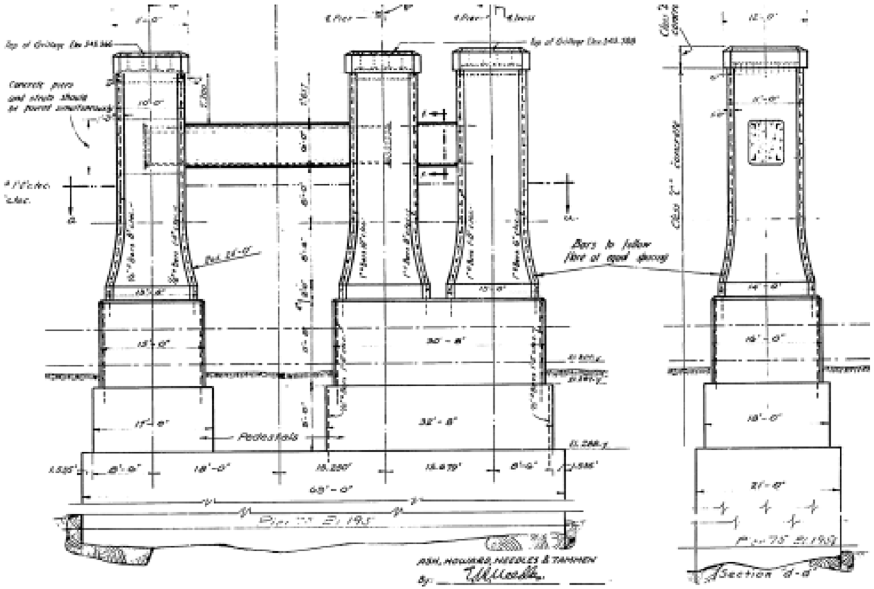


Pier 70

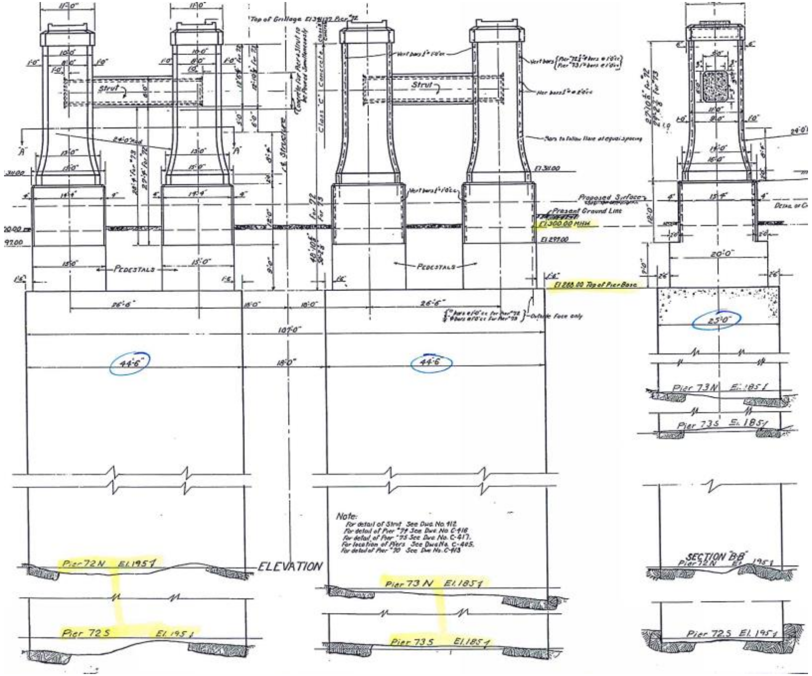


Piers 65 and 66

Rehabilitation of the Piers and Foundations– C6 Existing Piers



Pier 75



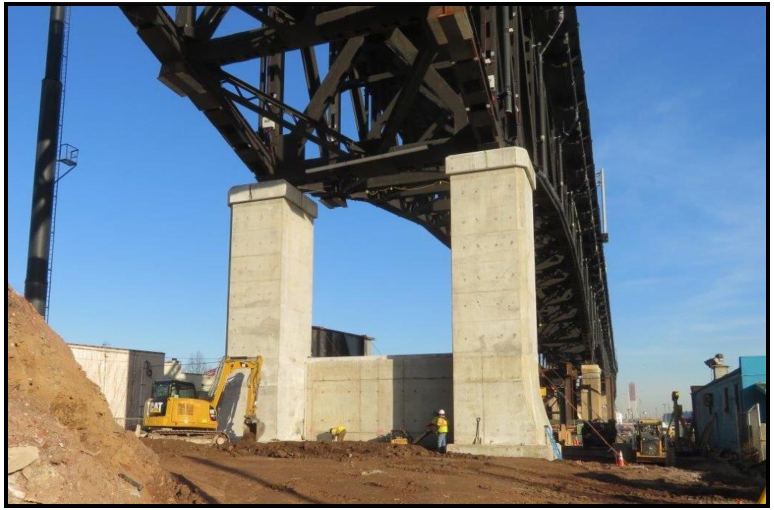
Pier 72

Successful Construction of Piers 76 and 77

PIER 76 CONSTRUCTION

ORIGINAL PIER 76 – ELEVATION
(SHOWN WITH TEMPORARY
SUPPORT SYSTEM)

SUPPORT SYSTEM AT
PIER 77
(EXISITNG PIER
REMOVED)



PIER 77 – SOLID PIER ELEVATION

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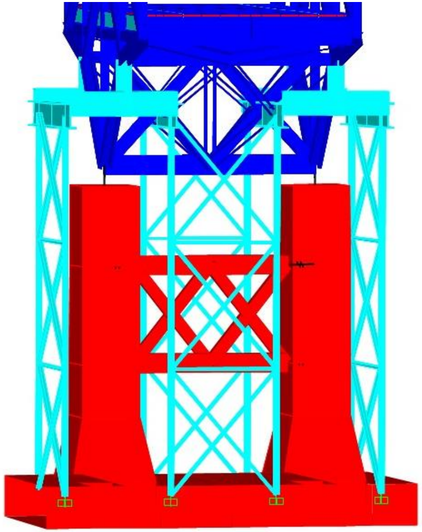
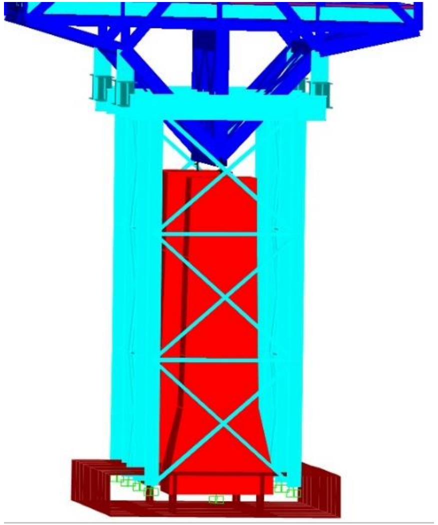
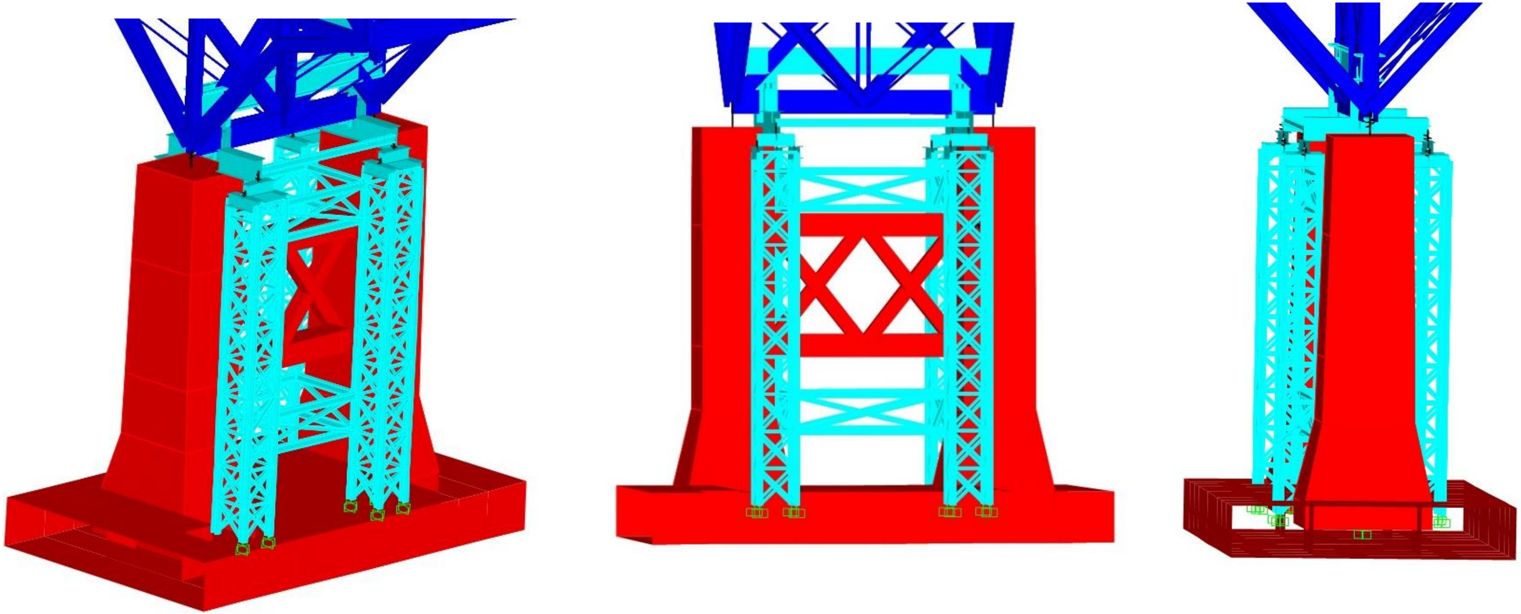
Rehabilitation of the Piers and Foundations- Temporary Supports Evaluation

Rehabilitation of the Piers and Foundations Temporary Supports Evaluation



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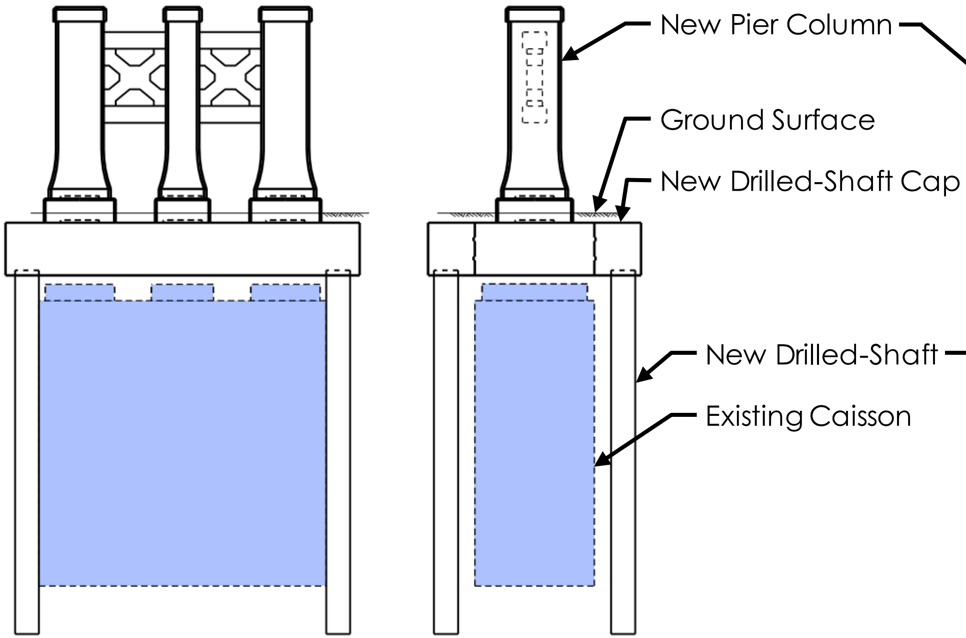
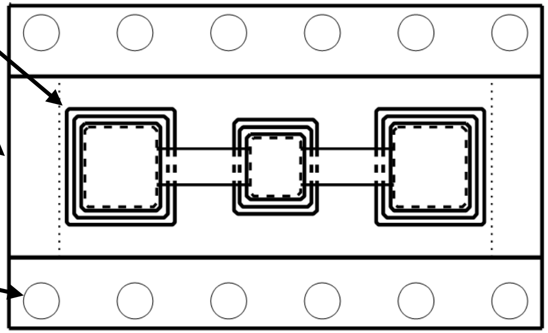
Rehabilitation of the Piers and Foundations- Typical Recommended Pier-Foundation Rehabilitation



Elevation View



Plan View

Seismic Analyses and Design:

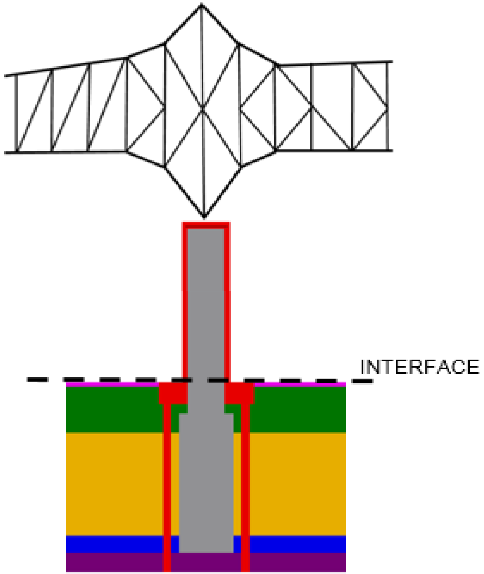
- Soil-Structure-Interaction Process
  - Derivation of the Design Spectrum

Seismic Analyses and Design: Soil Structure Interaction Process

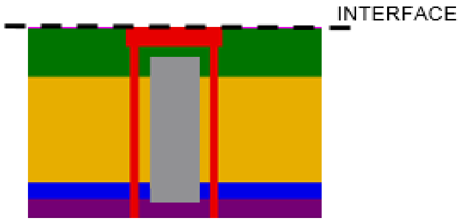
The SSI analytical/design process is multidisciplinary and includes:

- Geotechnical and soil dynamics aspects
- Structural and structural dynamics facets
- Numerical issues
- Earthquake engineering matters
- Finite element analysis (FEA) challenges
- Software considerations.

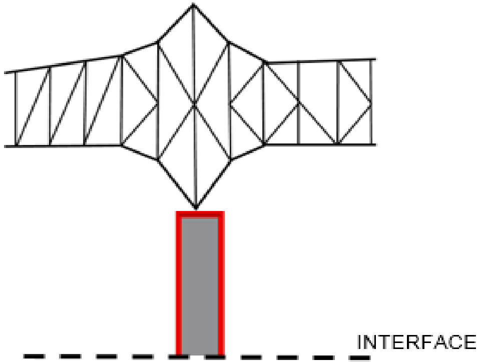
Seismic Analyses and Design: Uncoupled Model Analysis



Soil/Foundation System

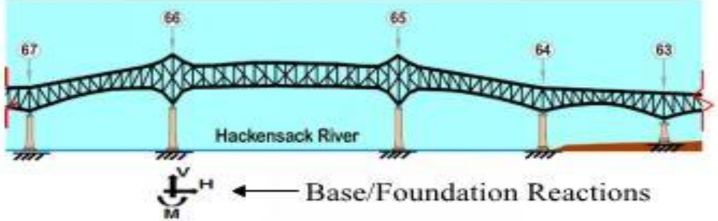


Truss/Pier System

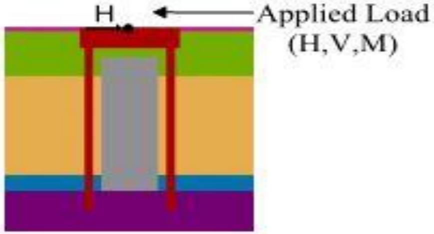


- Total System Broken Into Two Uncoupled Systems
- Computationally More Efficient
- Suited for Multimode Response Spectrum Analysis

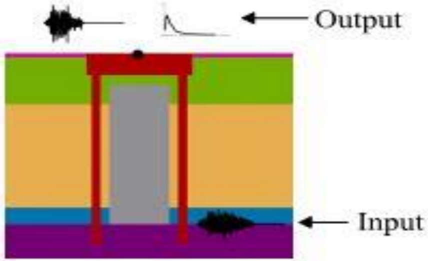
Seismic Analyses and Design: SSI Analyses Process - Main Steps



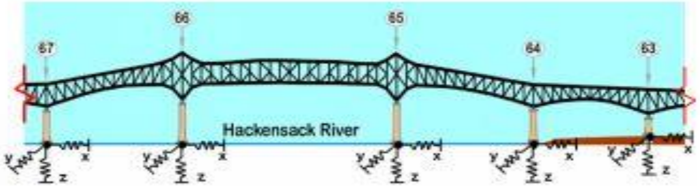
Step 1a - Analyze Bridge Supported on Fixed Base Foundations



Step 1b - Inertial Analysis of Foundation/Soil System

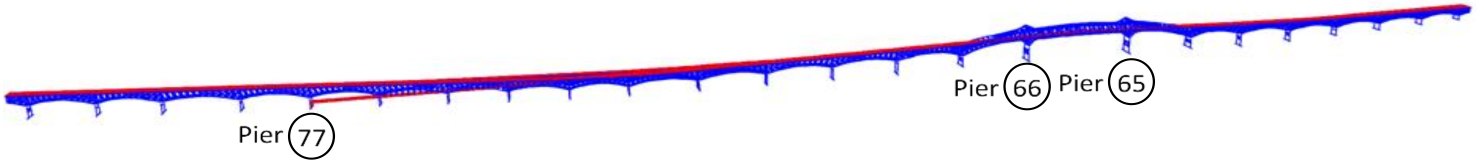


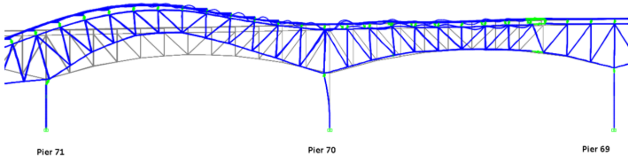
Step 2 - Kinematic Analysis of Foundation/Soil System

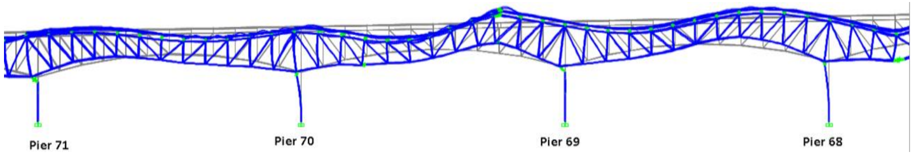


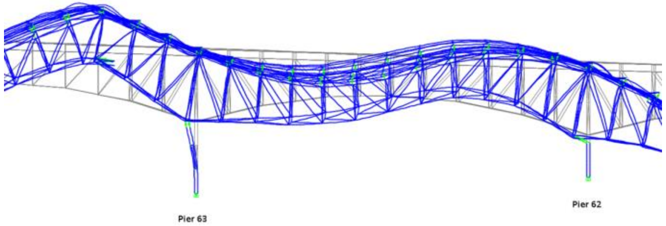
Step 3 - Analyze Bridge Supported on Foundation/Soil Springs

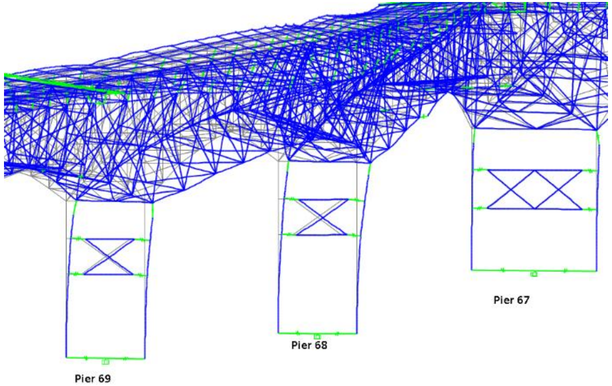
Seismic Analyses and Design: CSiBridge FE Model of the Bridge Section under Contract 6











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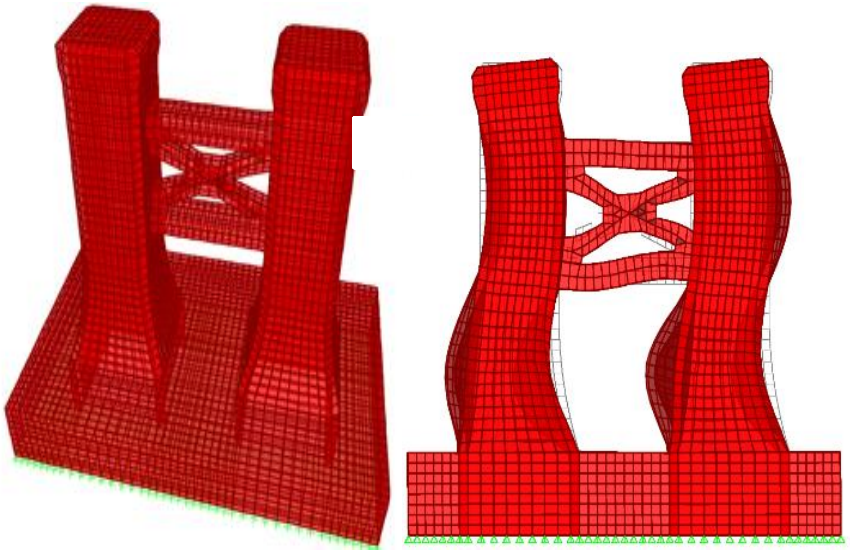
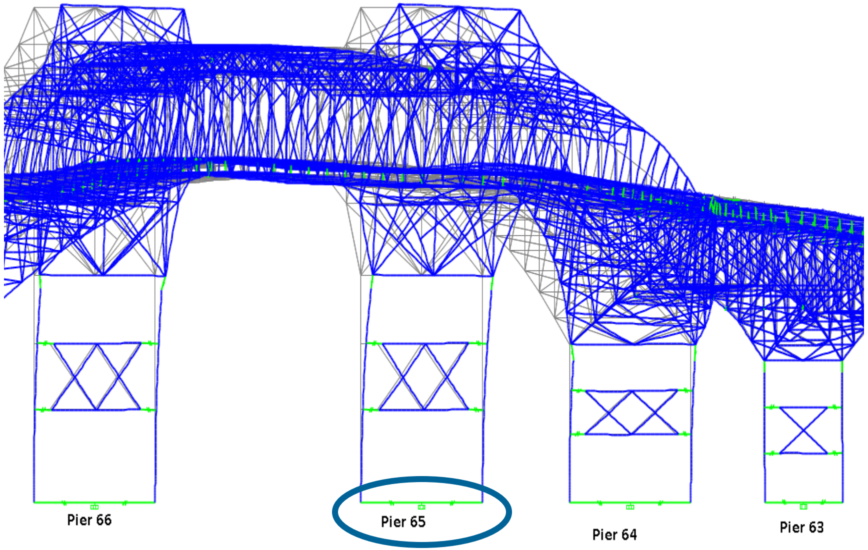
Seismic Analyses and Design: Standalone Model Pier 65 – Vibration Modes Verification



Standalone Model



Global Model

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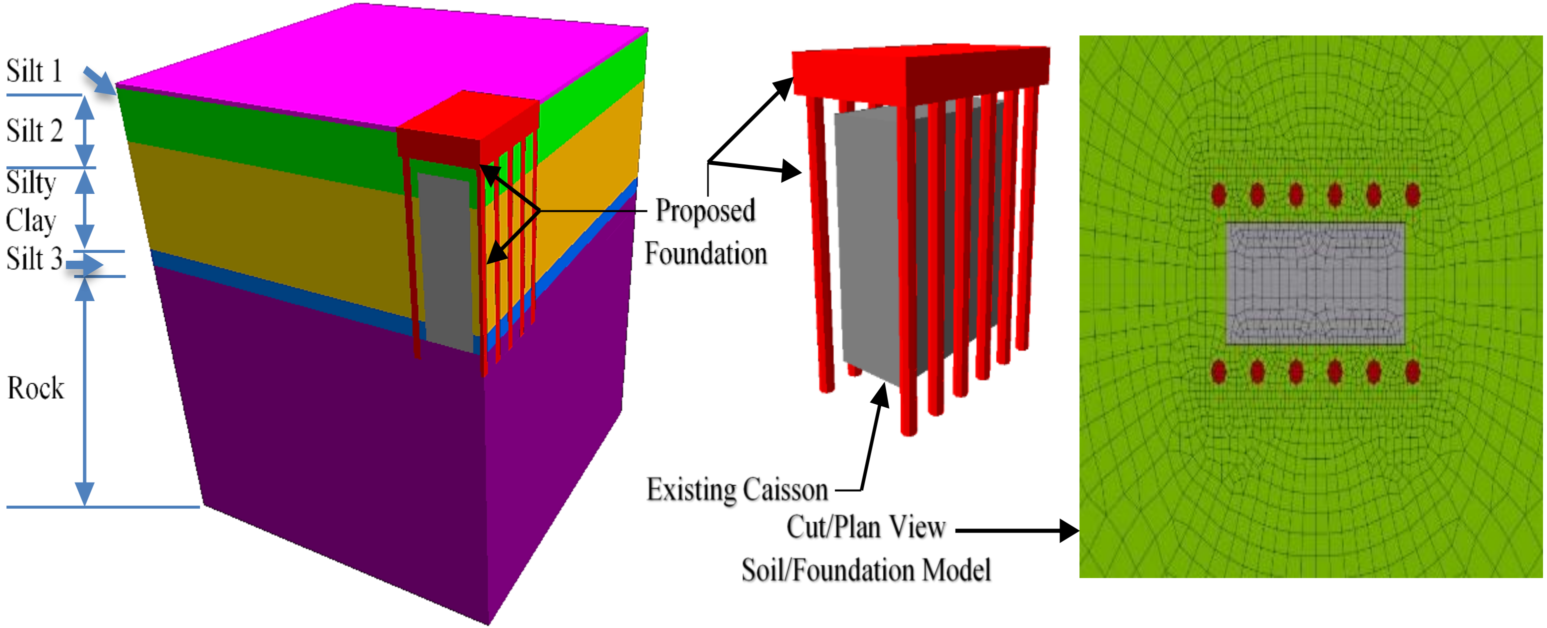
Seismic Analyses and Design: Example of MIDAS FE Model of one Soil/Foundation System Analyzed

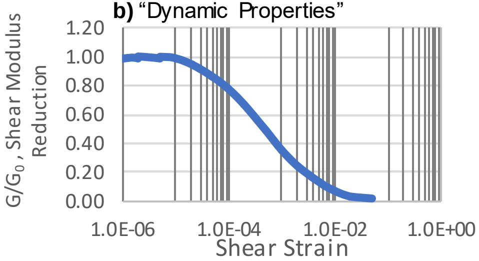


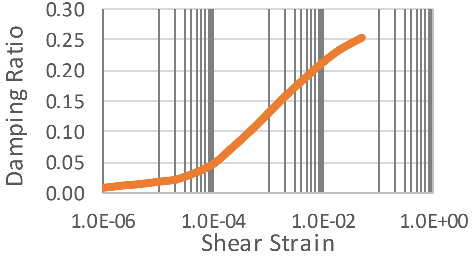
Seismic Analyses and Design: Soil Free Field Analysis – 1D Analysis

Input

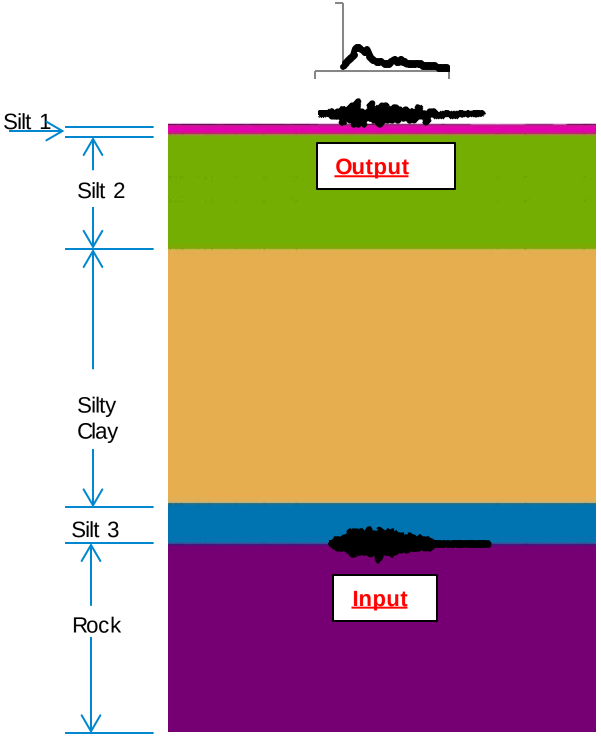
a) Rock Time History Record

b) "Dynamic Properties"





V_s – Profile
G_o – Initial Shear Modulus
Saturated Unit Weight



Output

a) Soil Free Field Response Time History and Spectrum

b) Each Layer:

- $G_{\text{Strain Compatibility}} = G_{\text{Converge}}$
- Material Damping Ratios (Strain Compatibility)

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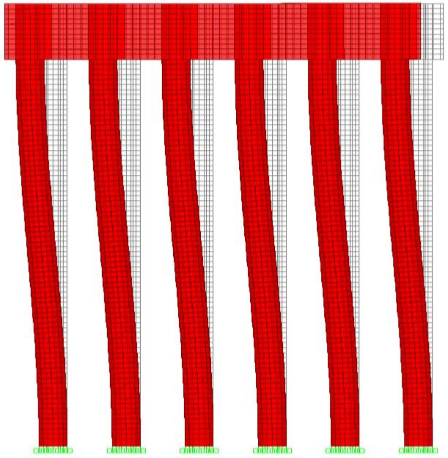
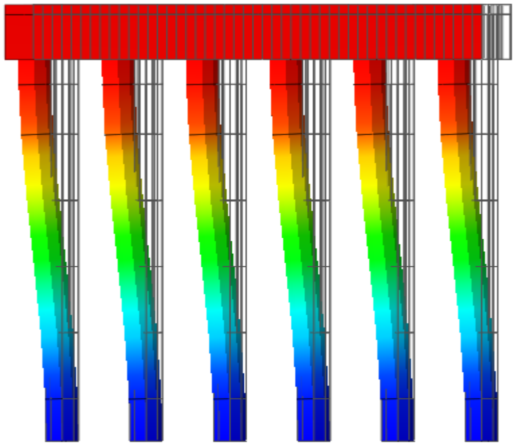
Seismic Analyses and Design: Standalone Foundation Models
MIDAS Modeling vs. CSiBridge Modeling - Mode 2, Period = 1.395 sec



CSiBridge



Midas GTS NX

No Soil – Foundation Standalone

Solve: $[k]\{x\} + [M]\{a\} = 0$

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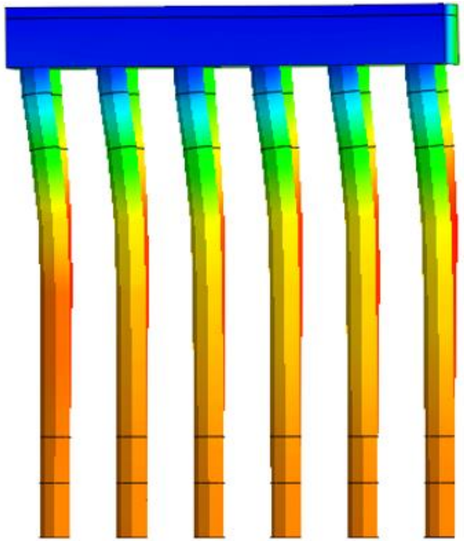
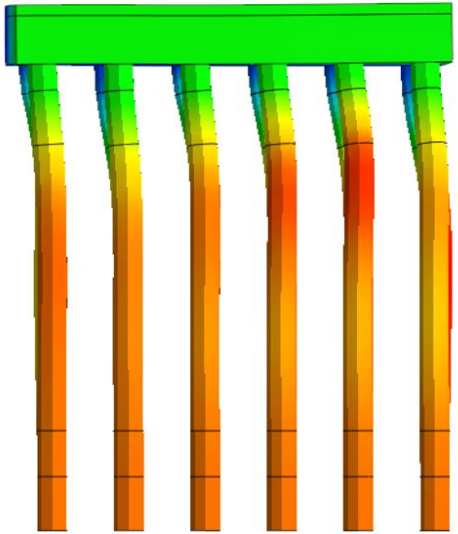
Seismic Analyses and Design: Standalone Foundation: MIDAS Foundation Modeling- Refined vs. Coarse Foundation Models



<u>Coarse (Midas GTS NX)</u>
Period = 0.266 sec

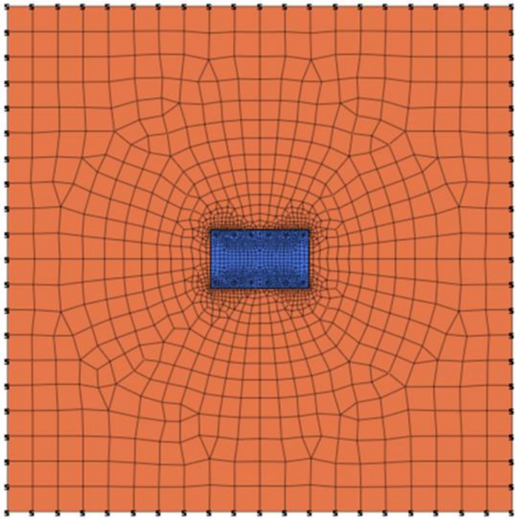


<u>Refined (Midas GTS NX)</u>
Period = 0.274 sec

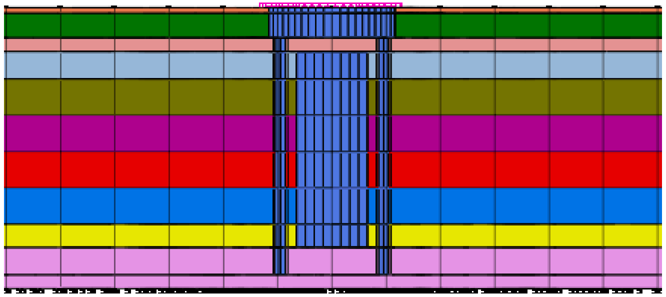
No Soil – Foundation Standalone

Solve: $[k]\{x\} + [M]\{a\} = 0$

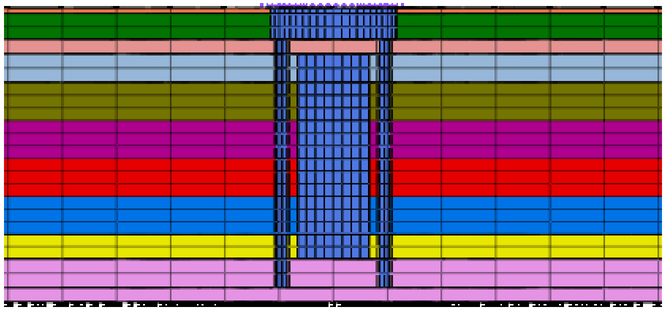
Seismic Analyses and Design: Foundation/Soil Block Mesh Layout



Plan View



Coarse Mesh



Refined Mesh

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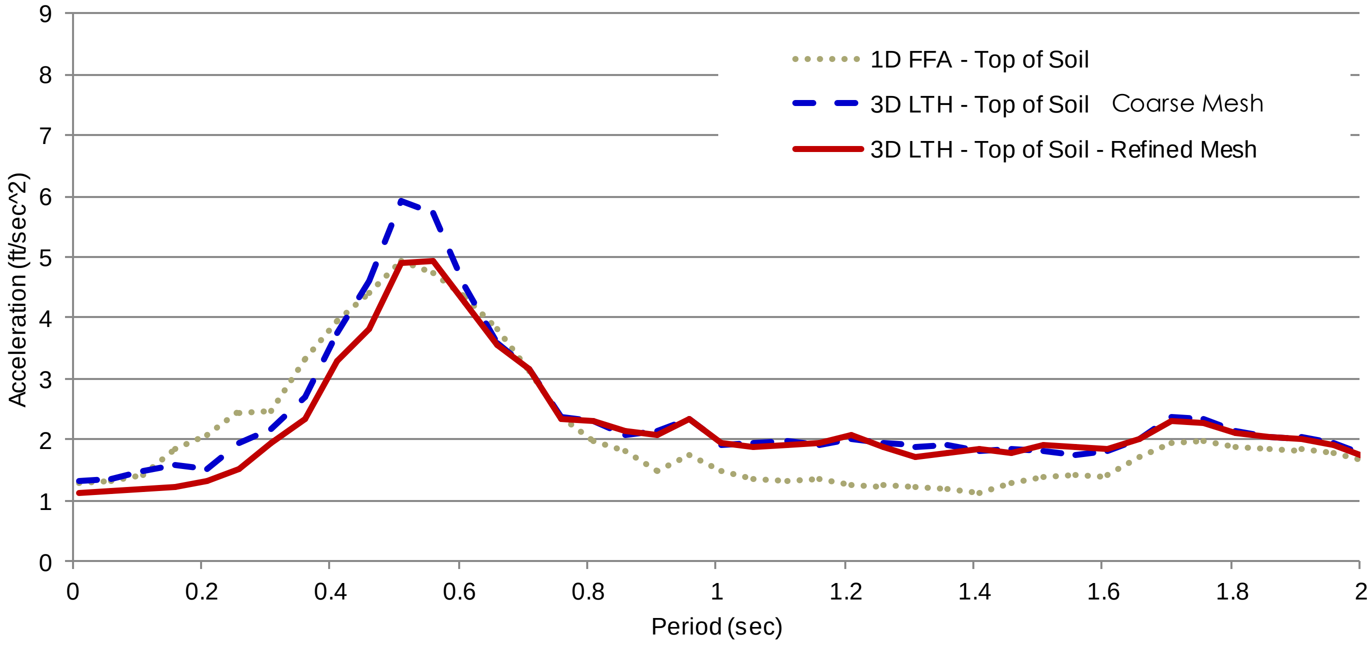
Seismic Analyses and Design: Response Spectra: Refined vs. Coarse Model of Foundation - Free Field



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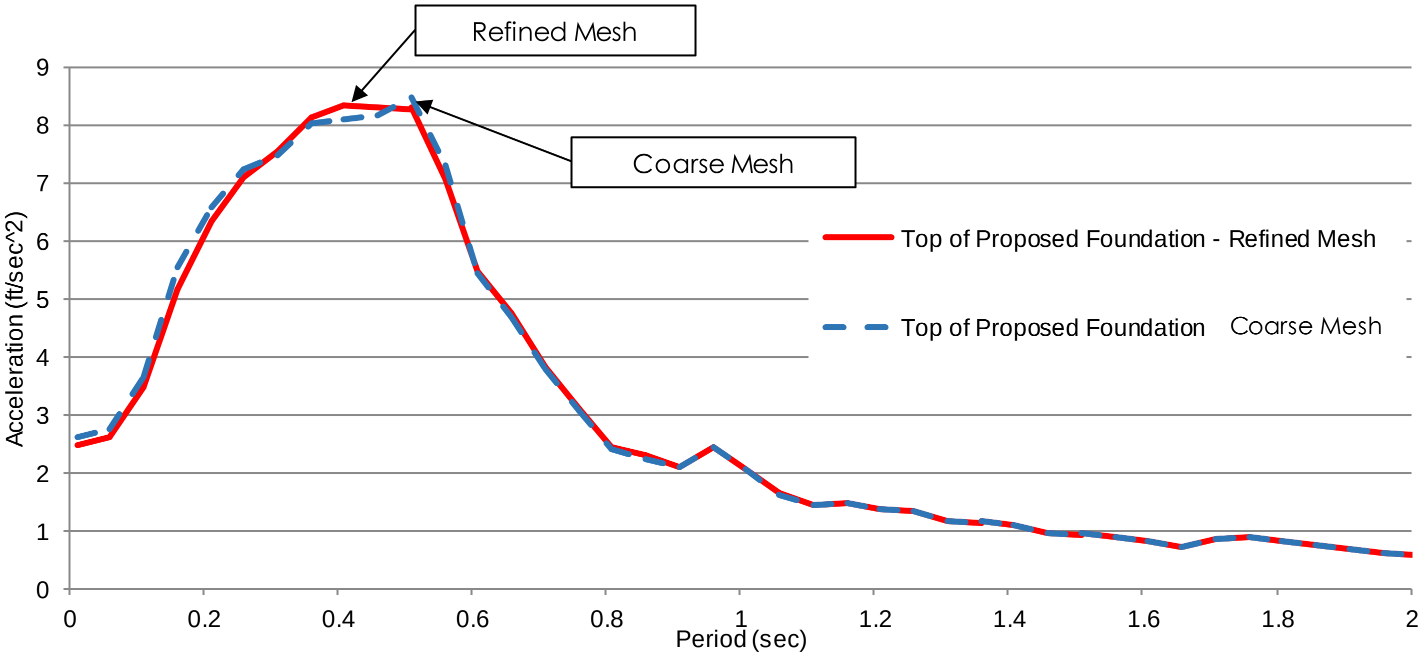
Seismic Analyses and Design: Response Spectra: Refined v. Coarse Model of Foundation - Top of Proposed Foundation



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Seismic Analyses and Design: Obtaining the Interface Motions–3D Time History Analysis

Output:
Interface Motions (at Soil/Foundation and Pier/Superstructure Interface): TH and Spectrum

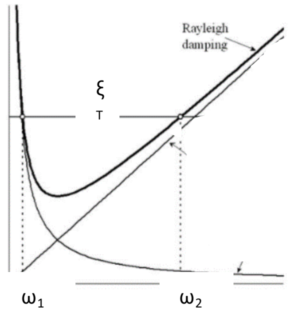
Input:

a) Rock Time History Record

b) From 1D FFA, Each Layer

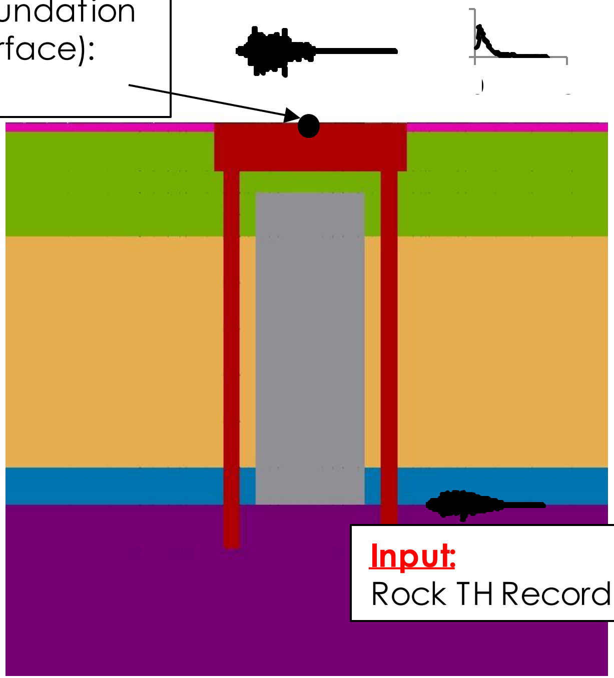
- $G_{converge}$
- Material $Damping_{Converge}$
- Saturated Unit Weight

c) System Damping



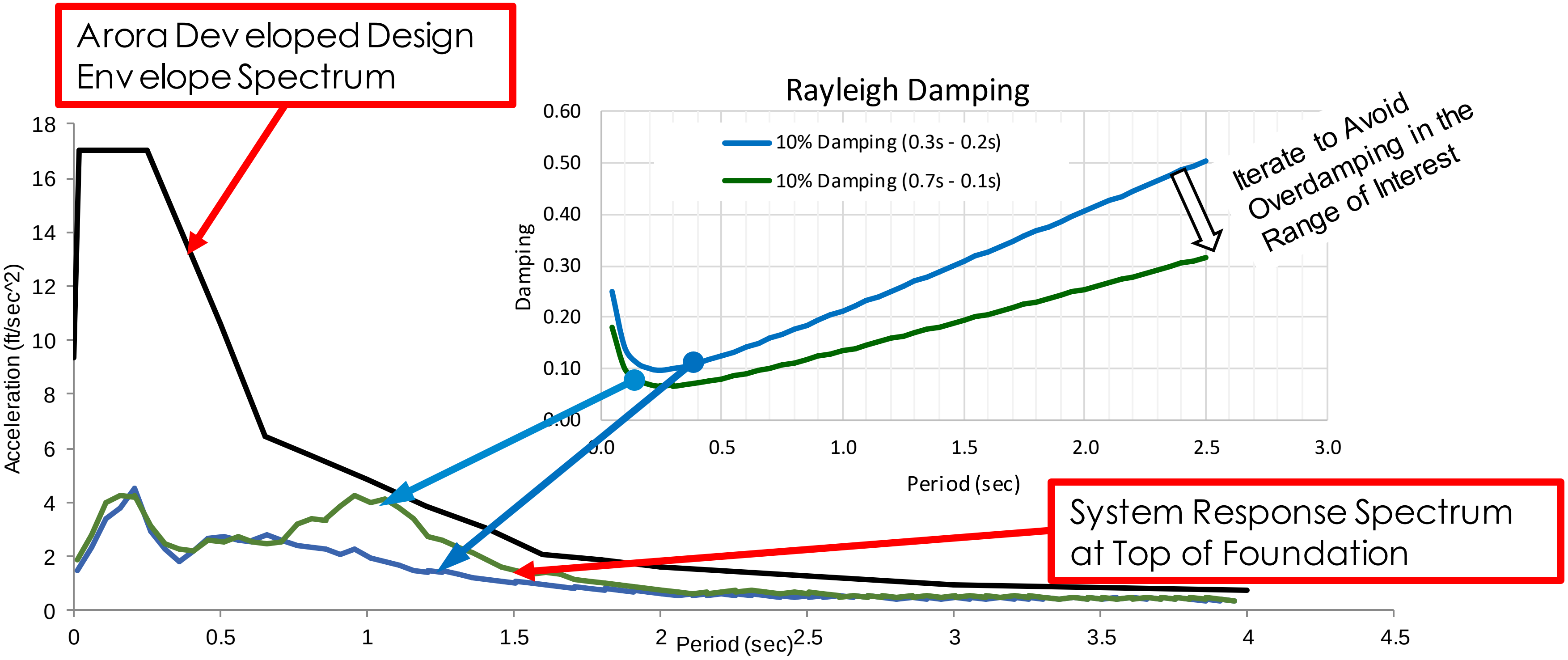
Solve: $[k]\{x\} + [M]\{a\} + [c]\{v\} = \{F_t\}$

$[C] = \alpha \cdot [M] + \beta \cdot [K]$ = **Rayleigh Damping**

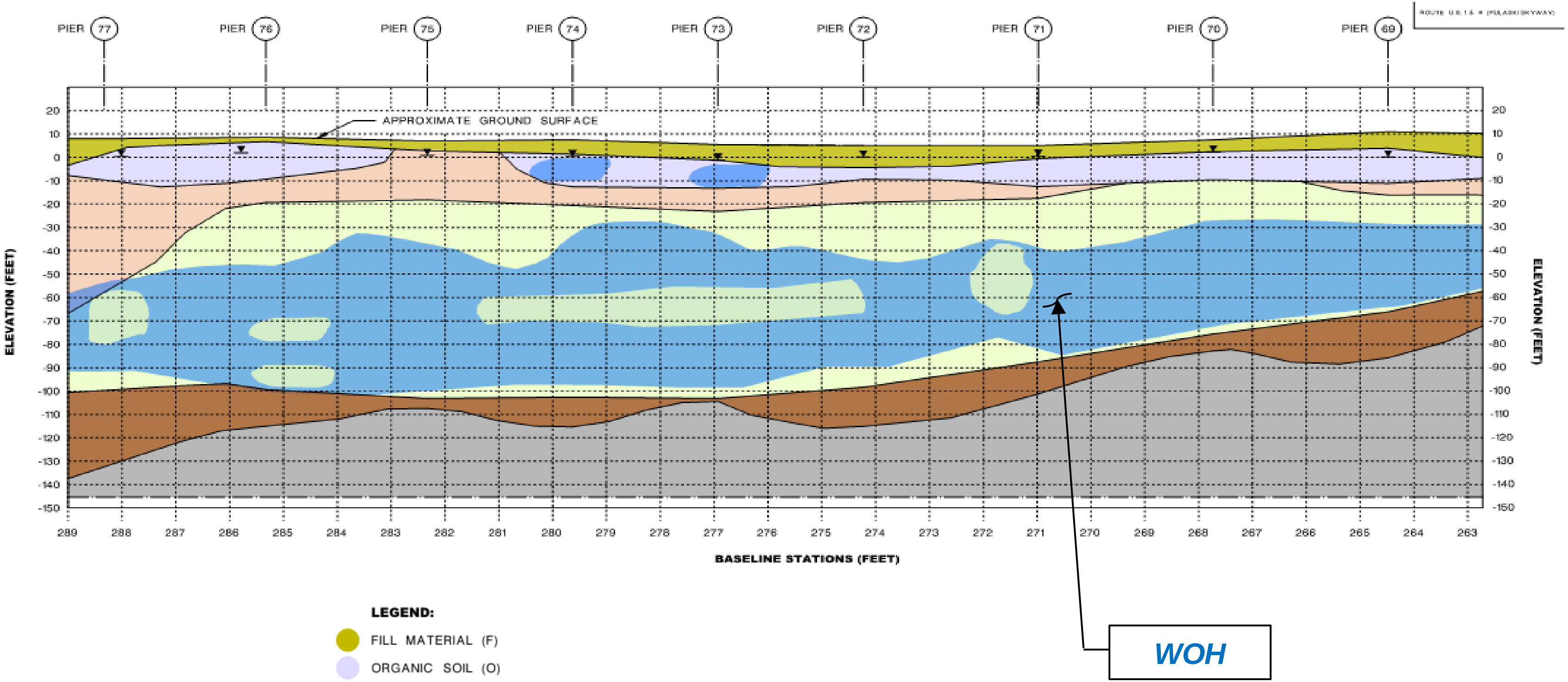


Input:
Rock TH Record

Seismic Analyses and Design: Soil-Foundation System Damping Effects



Seismic Analyses and Design: C6 Section Subsurface Profile



LEGEND:

- FILL MATERIAL (F)
- ORGANIC SOIL (O)
- LOOSE TO MEDIUM SANDS (S)
- SOFT COHESIVE SOIL INTERBEDDED WITH MEDIUM STIFF COHESIVE LAYER (C1)
- GLACIAL TILL (GT)
- BEDROCK (R)
- GROUND WATER ELEVATION

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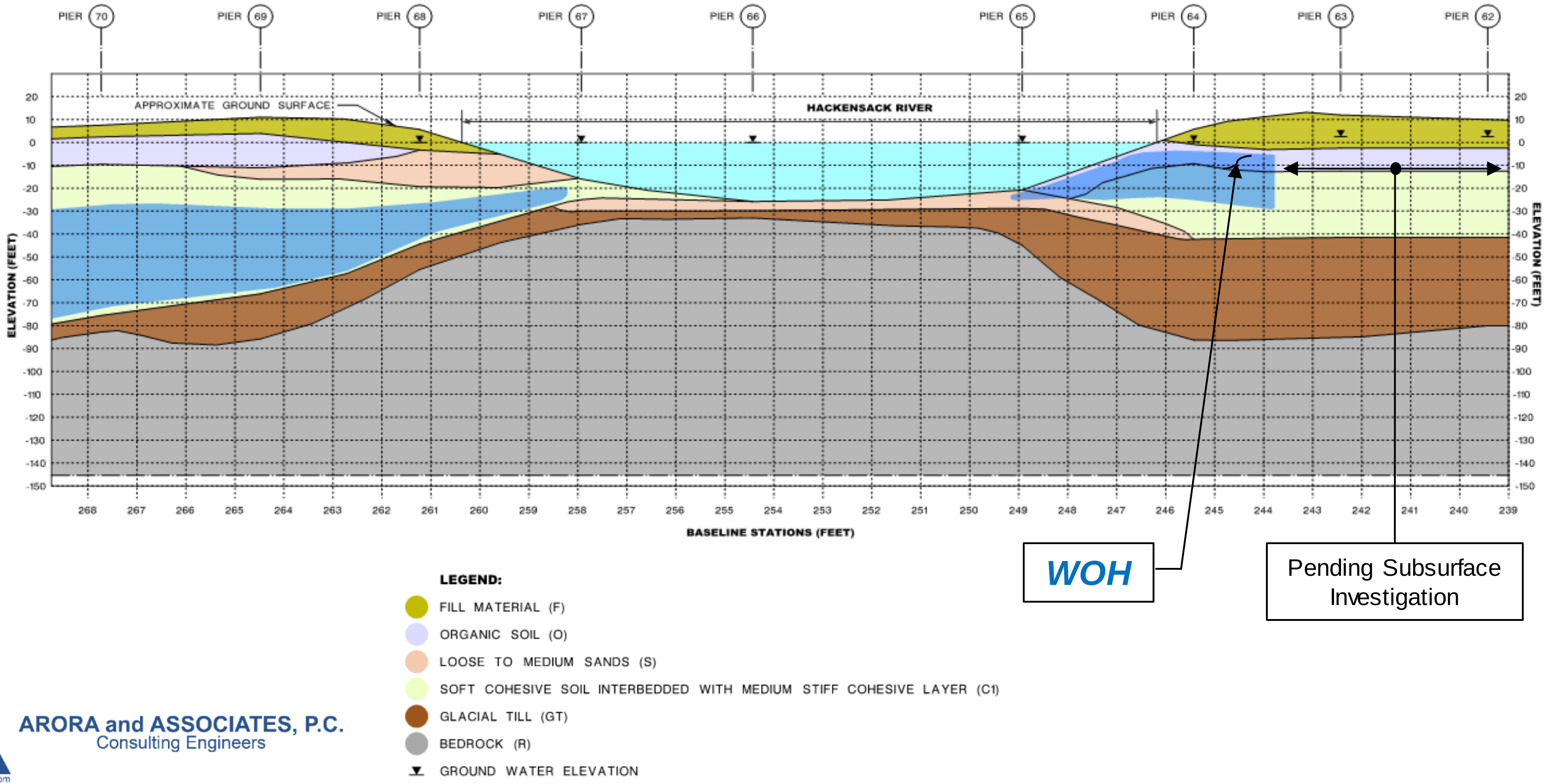
Seismic Analyses and Design: C6 Section Subsurface Profile



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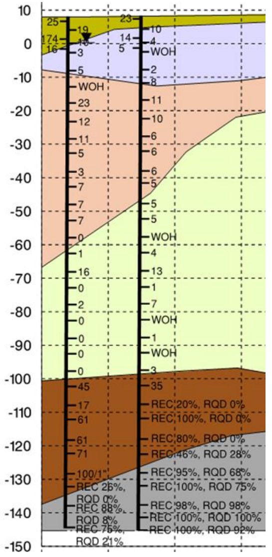
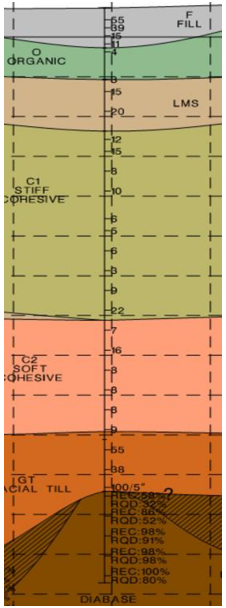
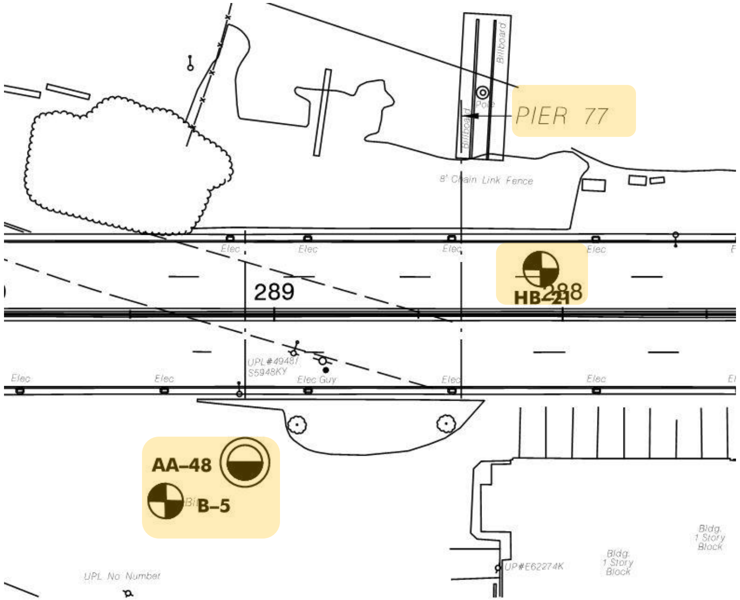
Seismic Analyses and Design: C6 Section Subsurface Profile

- B-5 – Boring By Parsons Brinckerhoff
- AA-48 – Boring By Arora and Associates

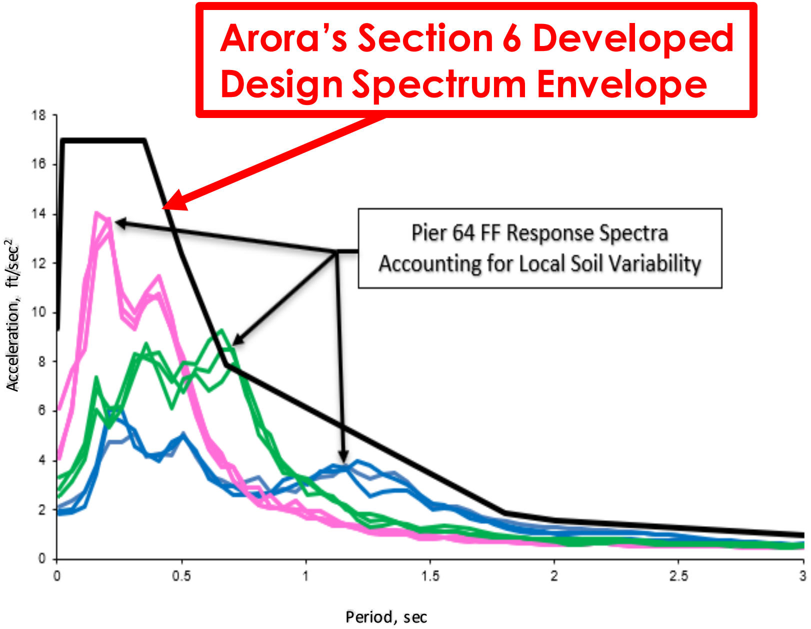


- HB-21 – Boring By HNTB

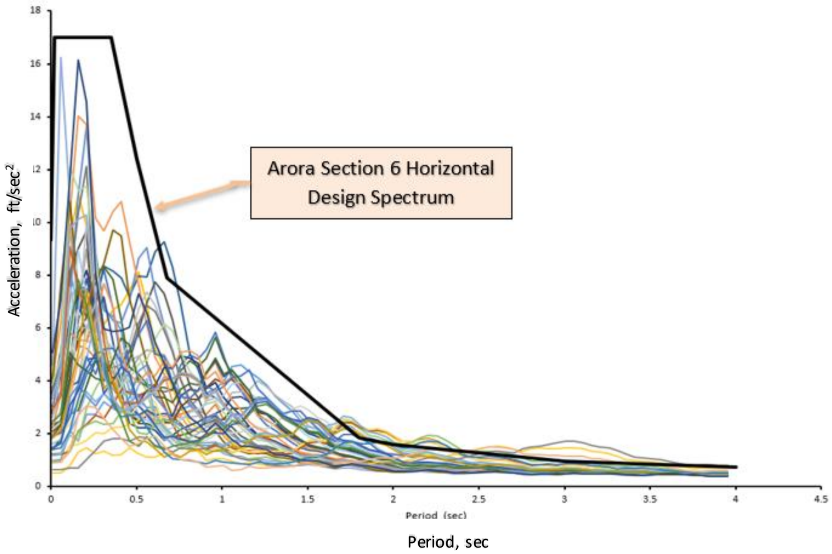




Seismic Analyses and Design: Developing The Design Spectrum

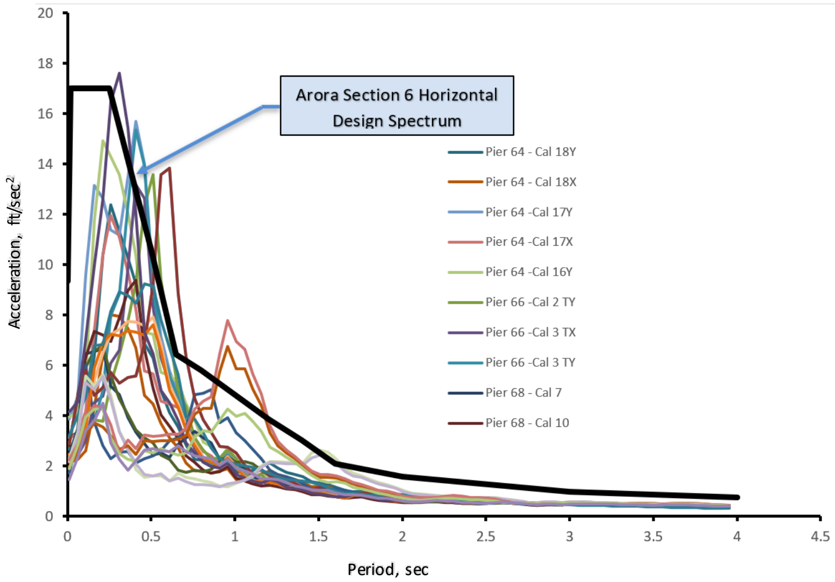


A: Free Field Response Pier 64 – Soil Properties Variation

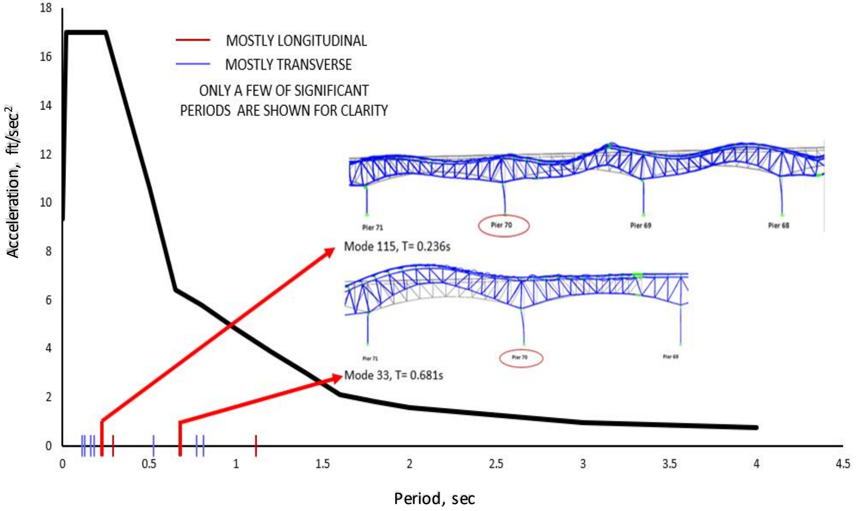


B: Free Field Response, Piers: 62, 64, 67, 68, 69, 70, 72, 75, 76, 77

Seismic Analyses and Design: Developing The Design Spectrum



A: Response Spectra at Top of Proposed Foundation – Accounting for SSI Kinematic Effects at Piers 64. 68, 70 and 75



B: Significant Periods of Vibration for Pier 70

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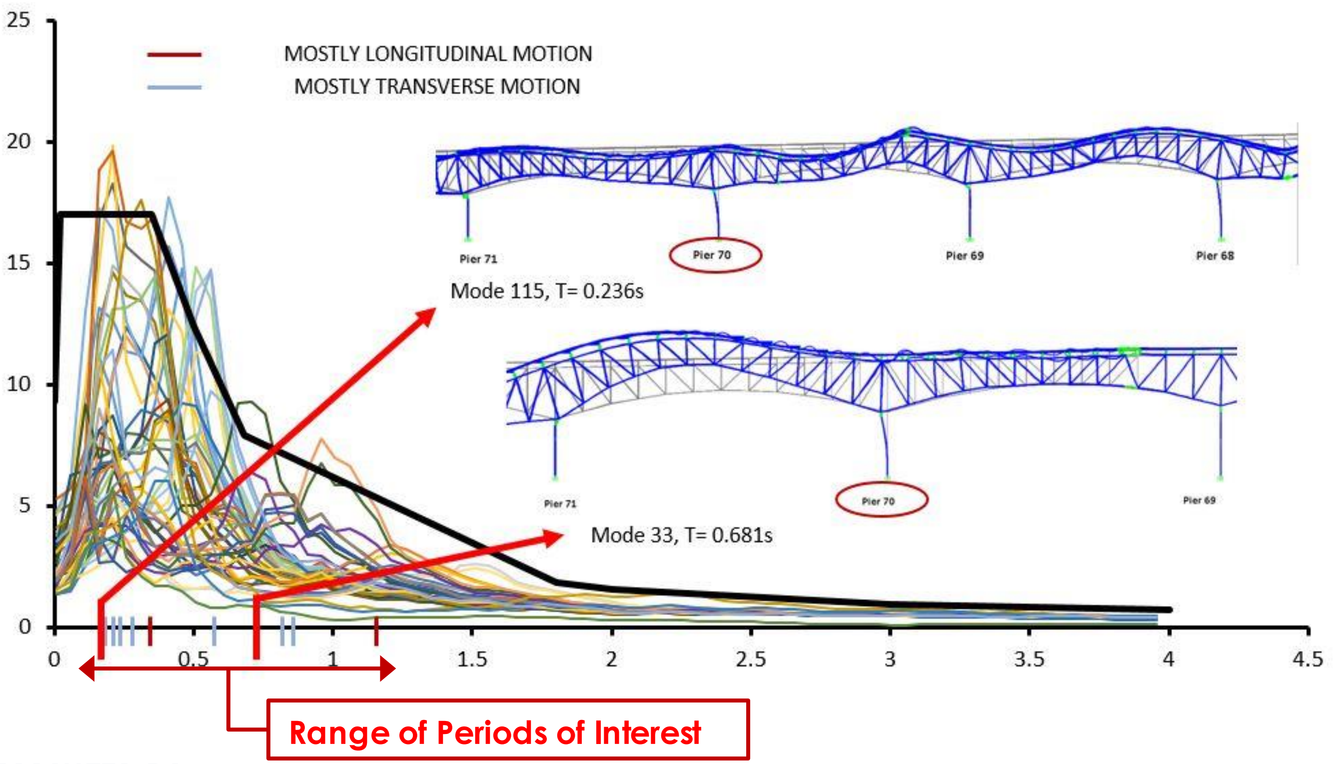
Seismic Analyses and Design: Superstructure/Pier Periods of Significant Modes



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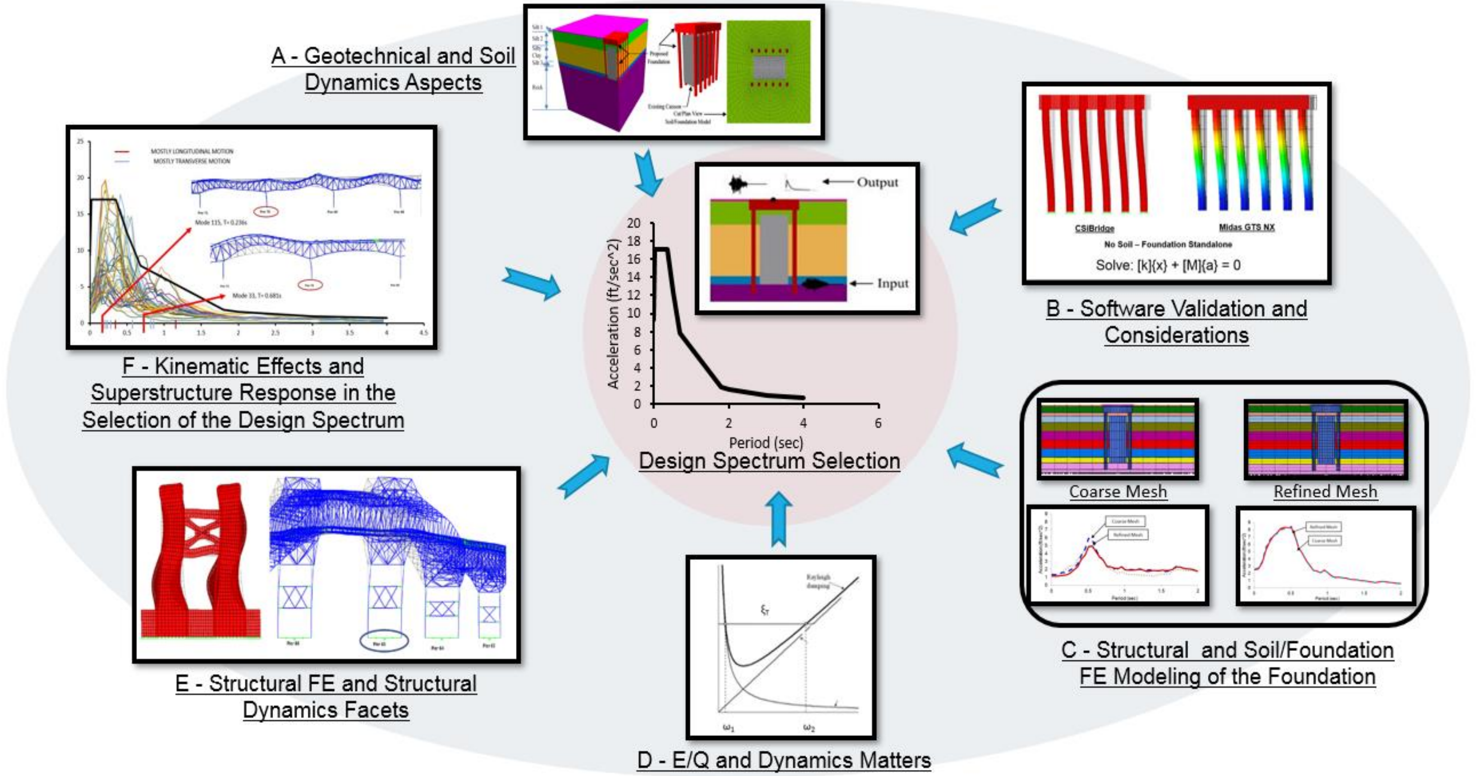
Seismic Analyses and Design: Recommended Design Spectrum Development



IMPROVING RESILIENCE, SAFETY, AND SERVICE LIFE OF THE PULASKI SKYWAY

Ruben Gajer, Khairul Alam, Jaimin Amin, Glenn P. Deppert, Reilly Thompson, Matt Tchorz, Mathew Williams, and Adrian Dumitru

Presented by Ruben Gajer, PE, Technical Director of Complex Bridges, Arora and Associates, PC

NJDOT- Research Showcase
October 29, 2020

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