38th ANNUAL APC/PENNDOT FALL SEMINAR
NOVEMBER 16-18, 2016 / HERSHEY, PA

A Presentation to the APC/PennDOT Fall Seminar
Thursday, November 17, 2016 | *Hershey, PA*

Presented By:
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I-74 Twin Arch Bridges over the Mississippi River

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Outline

- Project overview
- General arrangement
- Stability of the arches
- Lateral force resisting system
- Arch design
- Wind design
- Miscellaneous details

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Project Participants

- The IowaDOT Lead Agency
- Illinois DOT
- Alfred Benesch – Prime Consultant
- Modjeski and Masters – Designer of Arch Superstructure

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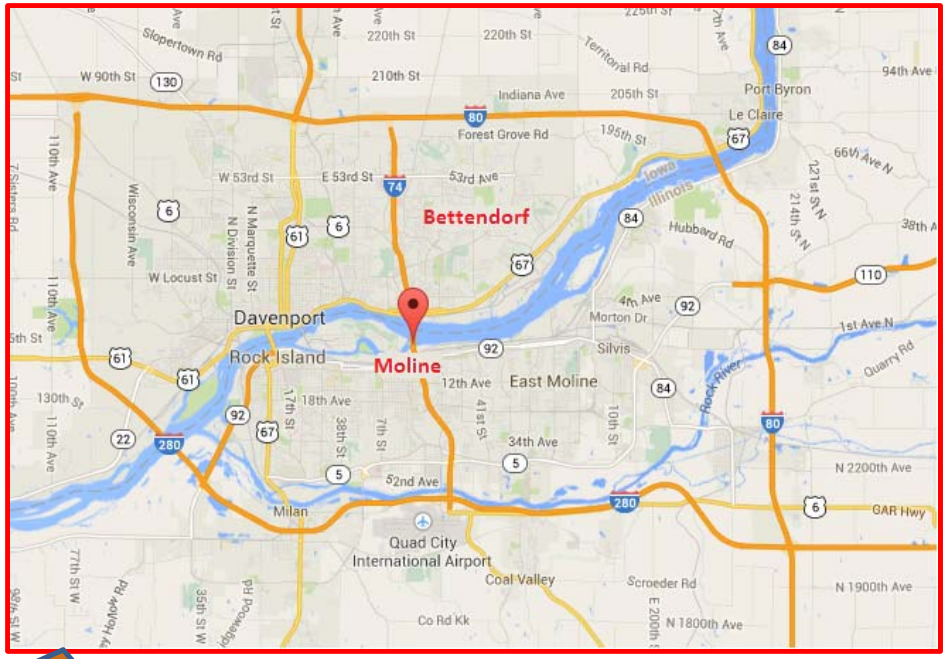
Project Location

- I-74 between Moline, IL and Bettendorf, IA



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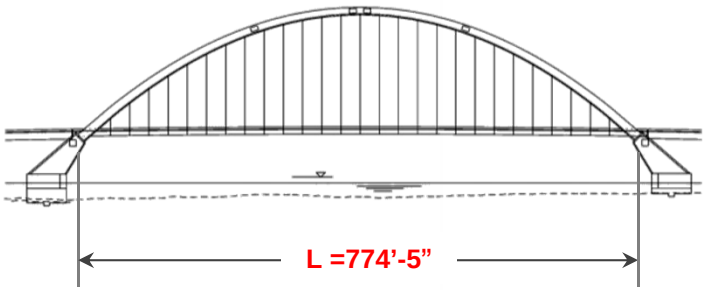
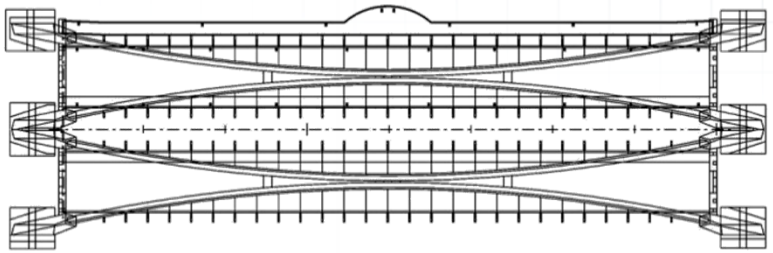
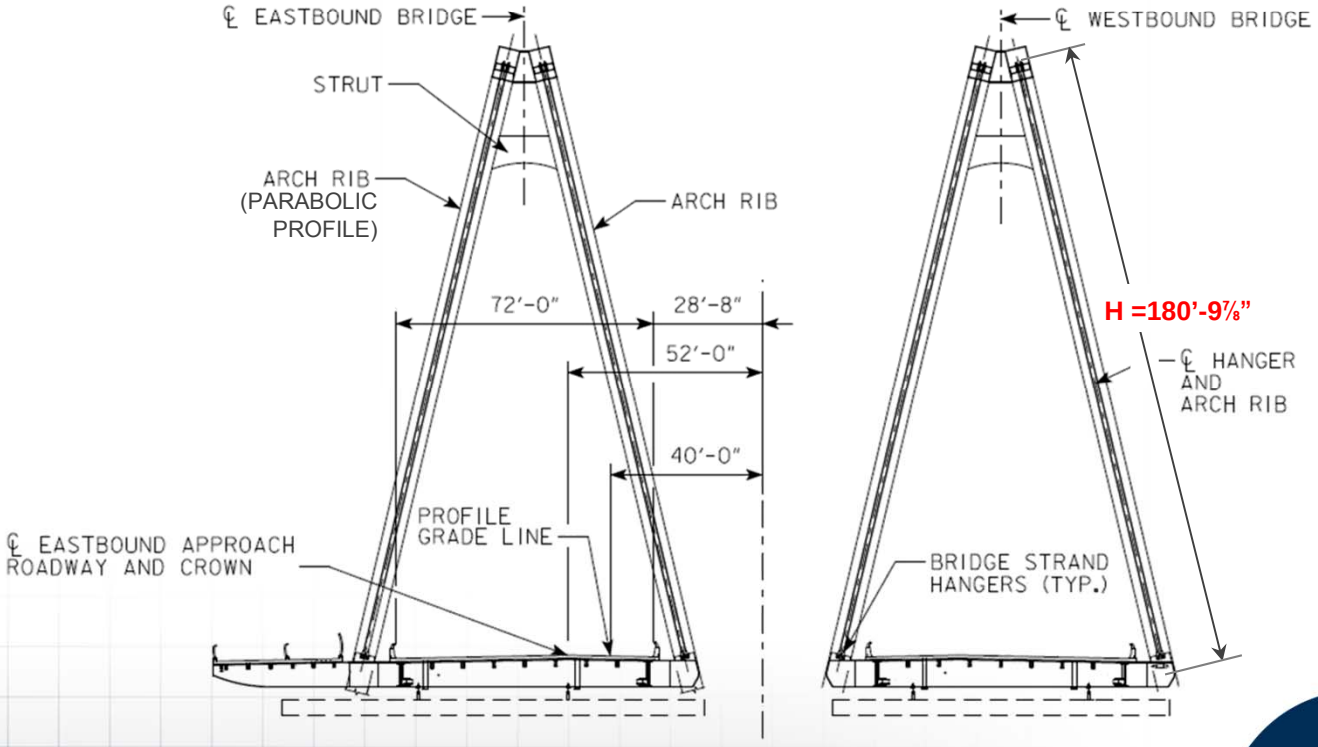
The Bridges







$$\frac{L}{H} = 4.3$$

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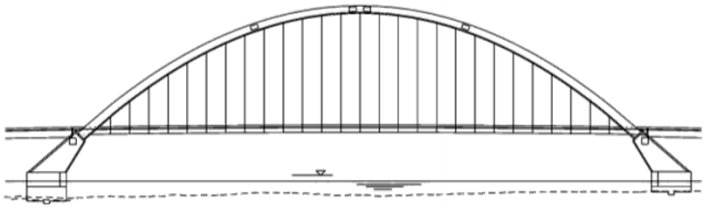
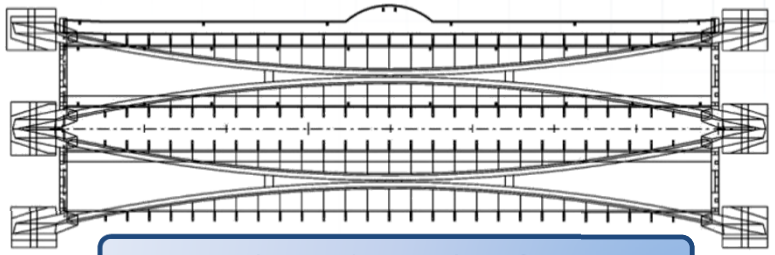
Project Highlights

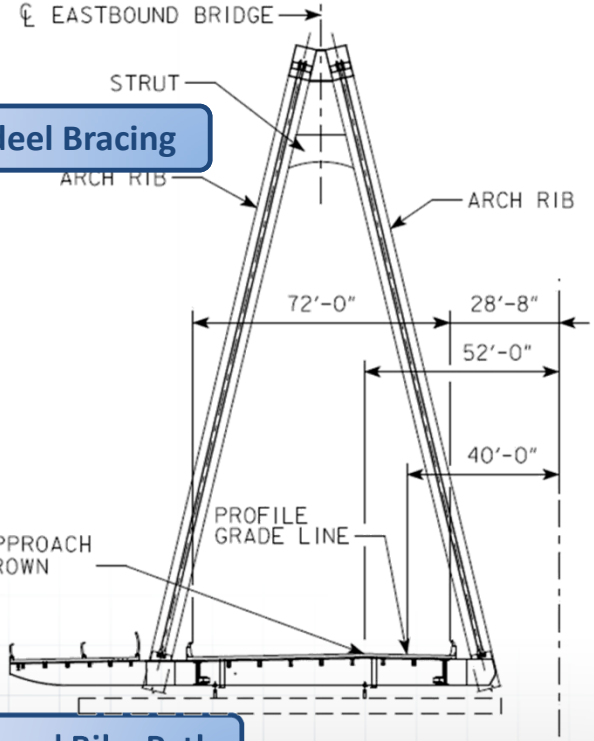


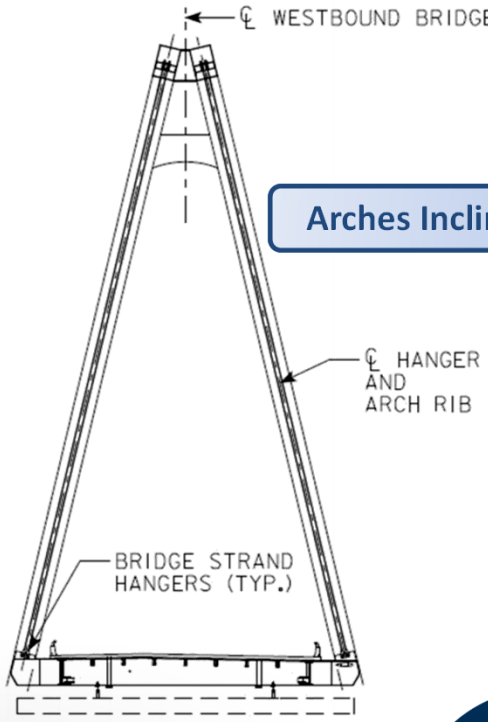
True Arches: Can Buckle In Plane



Long Unbraced Lengths of Arch Rib

Minimal Vierendeel Bracing





Arches Inclined to Each Other

Cantilevered Bike Path

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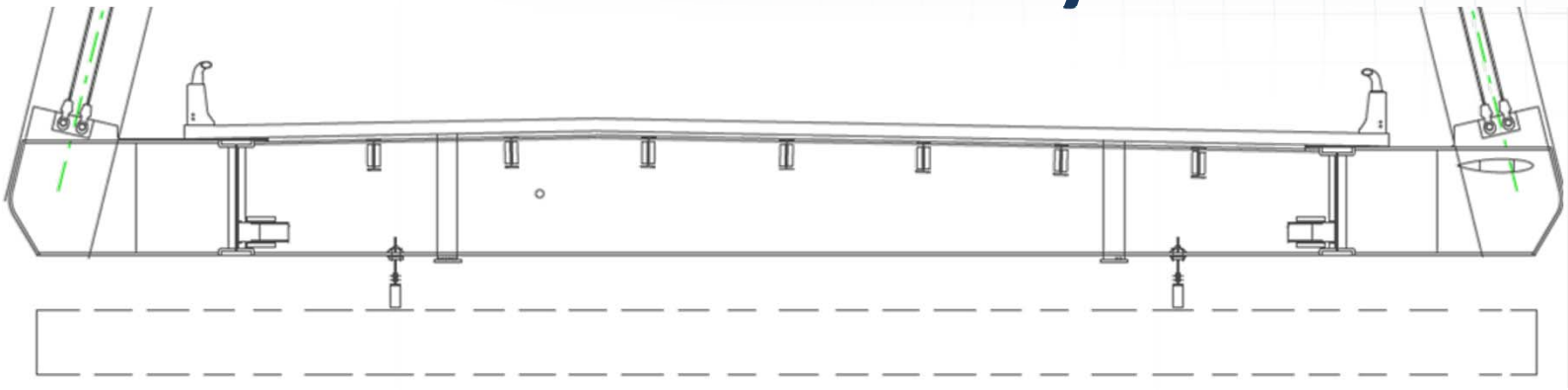
General Structural System



- Deck System:
  - CIP Concrete Deck + Overlay
  - Seven W24 Stringers
  - Two Stiffening Girders
  - Floor Beams spaced at 26’-8”
  - Lateral Bracing between FBs + Wind Tongues
  - Hangers - Two socketed strands

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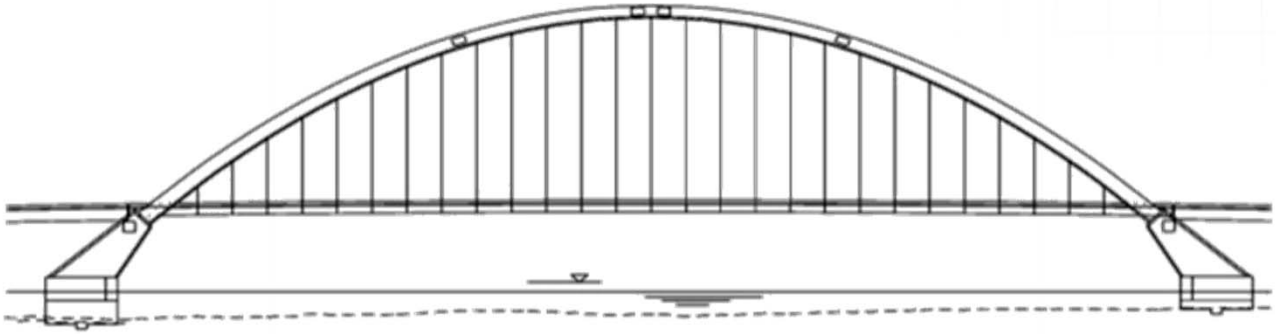
General Structural System



- Arch System:
  - 27 Hangers on each arch
  - Steel Ribs – Box section
  - Three Vierendeel Braces
  - Rib steel/concrete Interface Connection
  - Concrete Ribs + Strut
  - Hybrid drilled shaft foundations

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Stability of the Arches

- For I-74 Arches:
  - Large rise-to-span ratio ∴ snap-through buckling was not an issue
  - Buckling behavior dominated by lateral deformations
  - Max kL/r was calculated to be 96 (100 used in design calculations)
  - Welded box rib has more favorable residual stress distribution, but did not take advantage of.
  - Pcr > 2.0 Times Factored Loads

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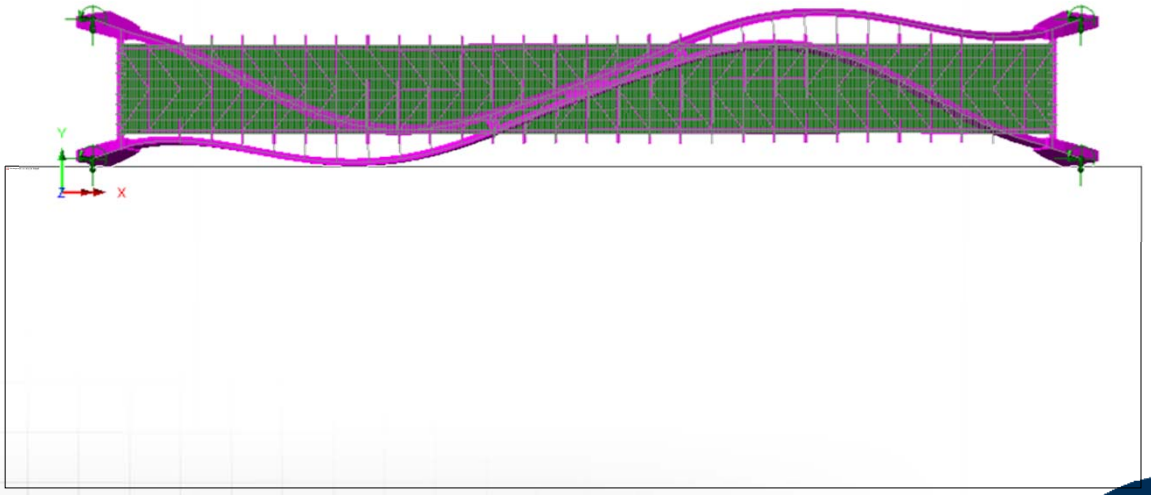
Stability of the Arches

- Finite Element Analysis
  - Various Live Load patterns were investigated to find minimum Pcr
  - Linear Buckling Analysis (Eigenbuckling) used to find modes and preliminary Pcr



Buckling Controlling Mode: Lateral

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Stability of the Arches

- Finite Element Analysis
  - From Pcr, kL/r was back-calculated and used in the AASHTO design equations for capacity

Response	Eigenvalue	P (k)	P_{CR} (k)	Kl/r	P_U (k)
DZ	2.668	4855	12953	95.9	6069
DY	2.659	4968	13210	95.0	6210
M @ Rib	2.730	4739	12937	96.0	5924
M @ Stiff. Girder	2.740	4718	12927	96.0	5897
P @ Rib	2.454	5426	13315	94.6	6783

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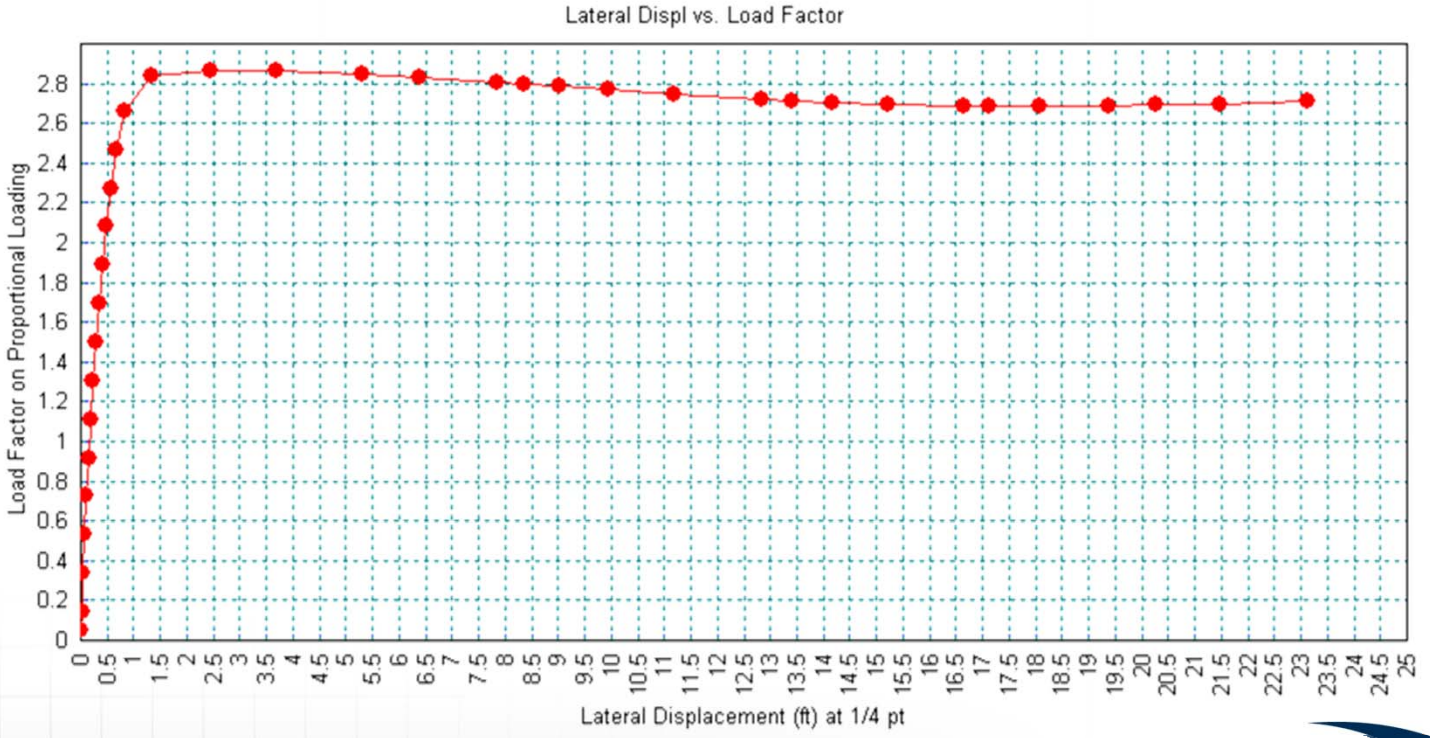
Stability of the Arches

- Finite Element Analysis
  - Full Non-linear Analyses were run to verify Pcr



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Stability of the Arches

- Given slender appearance of Bridge, Could Pcr be Increased?
- Varied location of lower braces
  - Shifting 2 panel points increased buckling load 34% (>3 times factored loads)
  - Reduced loads at the Steel/Concrete connection by 17%
  - Slight change in aesthetics, but large gain in structural behavior

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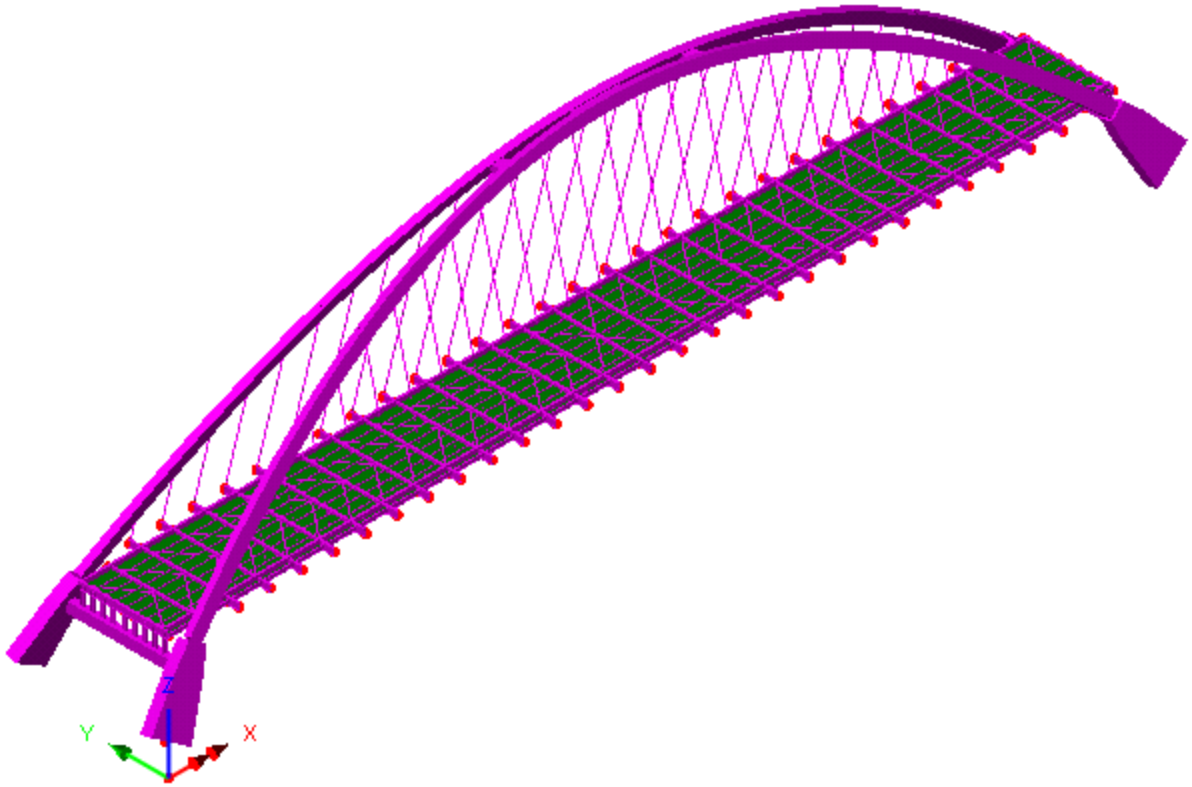
Stability of the Arches



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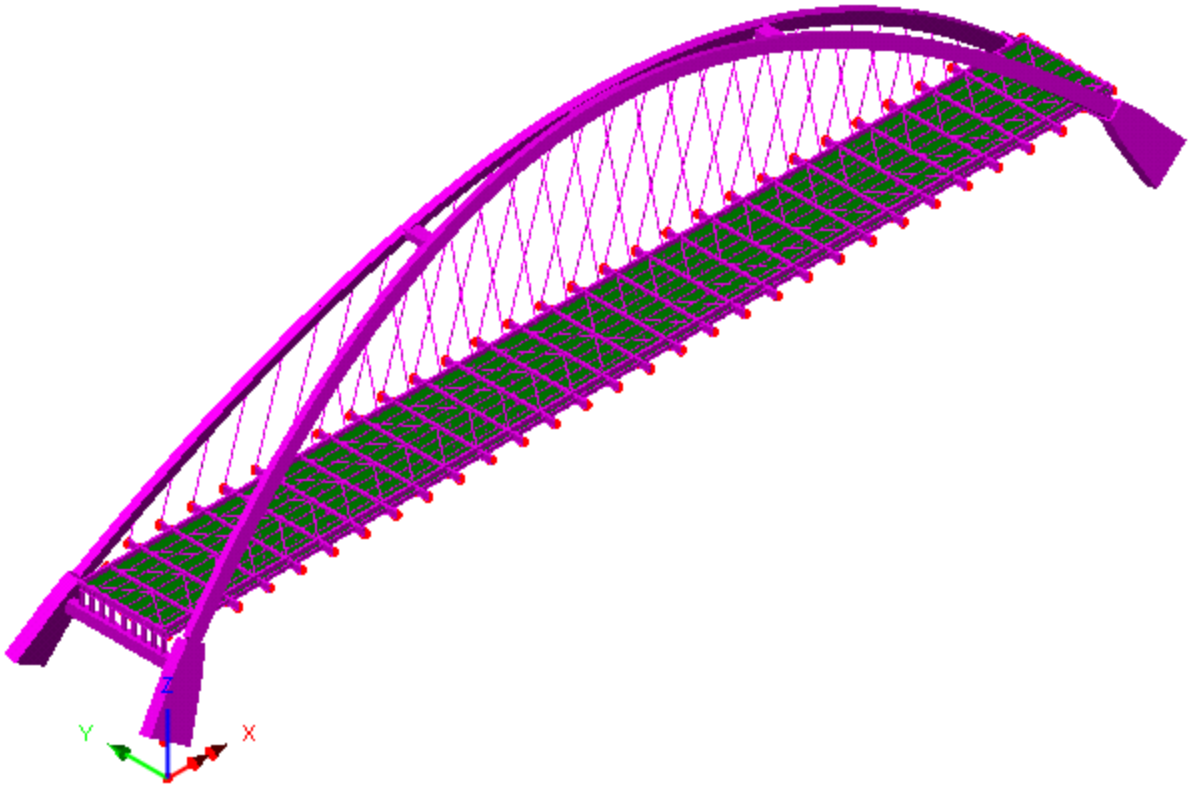
Stability of the Arches



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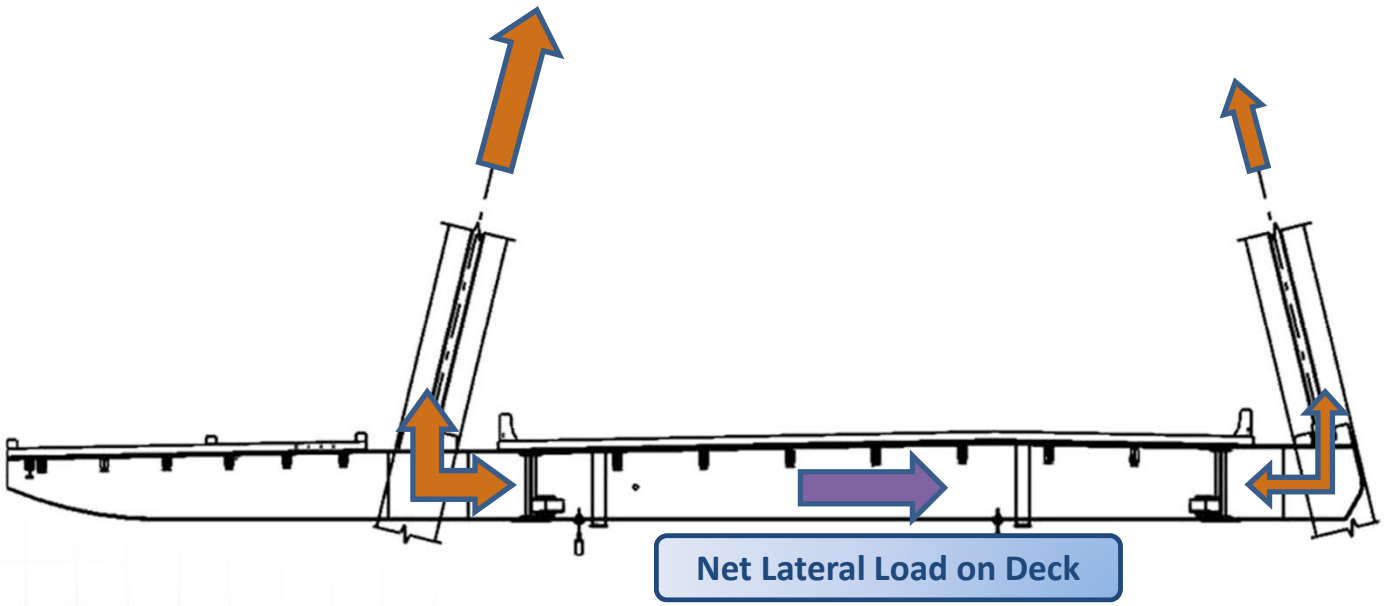
Deck Lateral Force Resisting System

- **Cantilevered Bike Path Effect:**
  - Permanent lateral force due to inclined hangers



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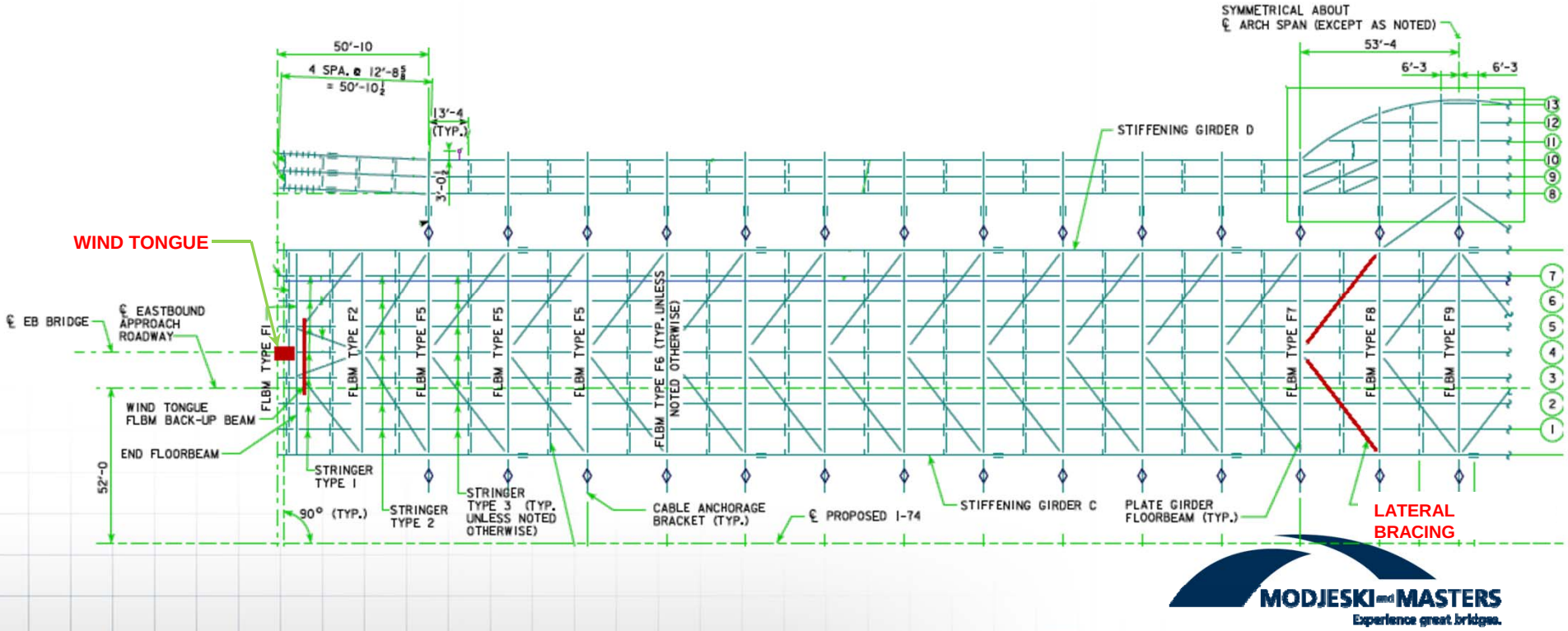
Deck Lateral Force Resisting System

- **Lateral Bracing and Wind Tongues:**
  - Carry lateral loads from roadway to substructure also carries DL due to bike trail

For EB bridge,



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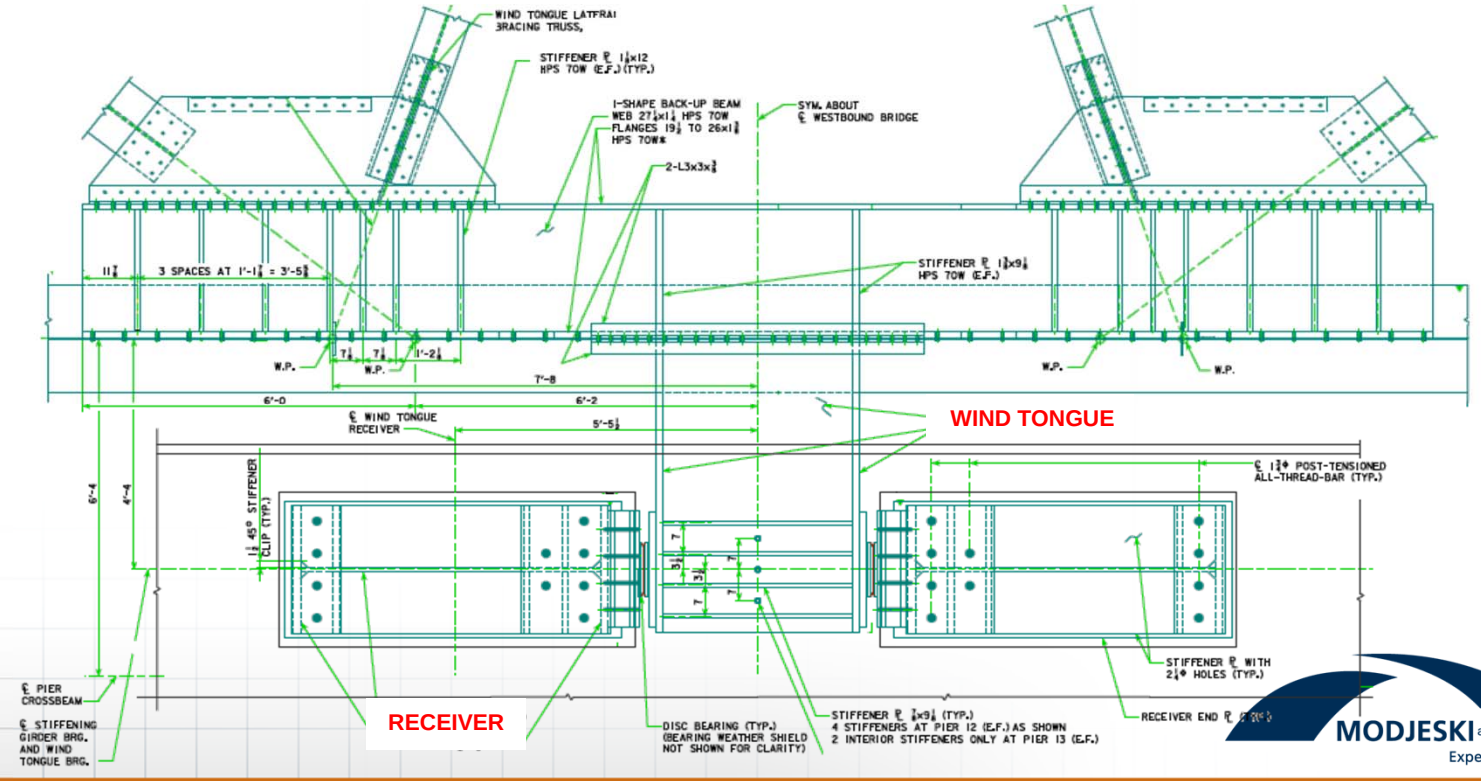
Deck Lateral Force Resisting System

- **Wind Tongue:**
  - I-shape attached to a supporting member which connects into the lower lateral system



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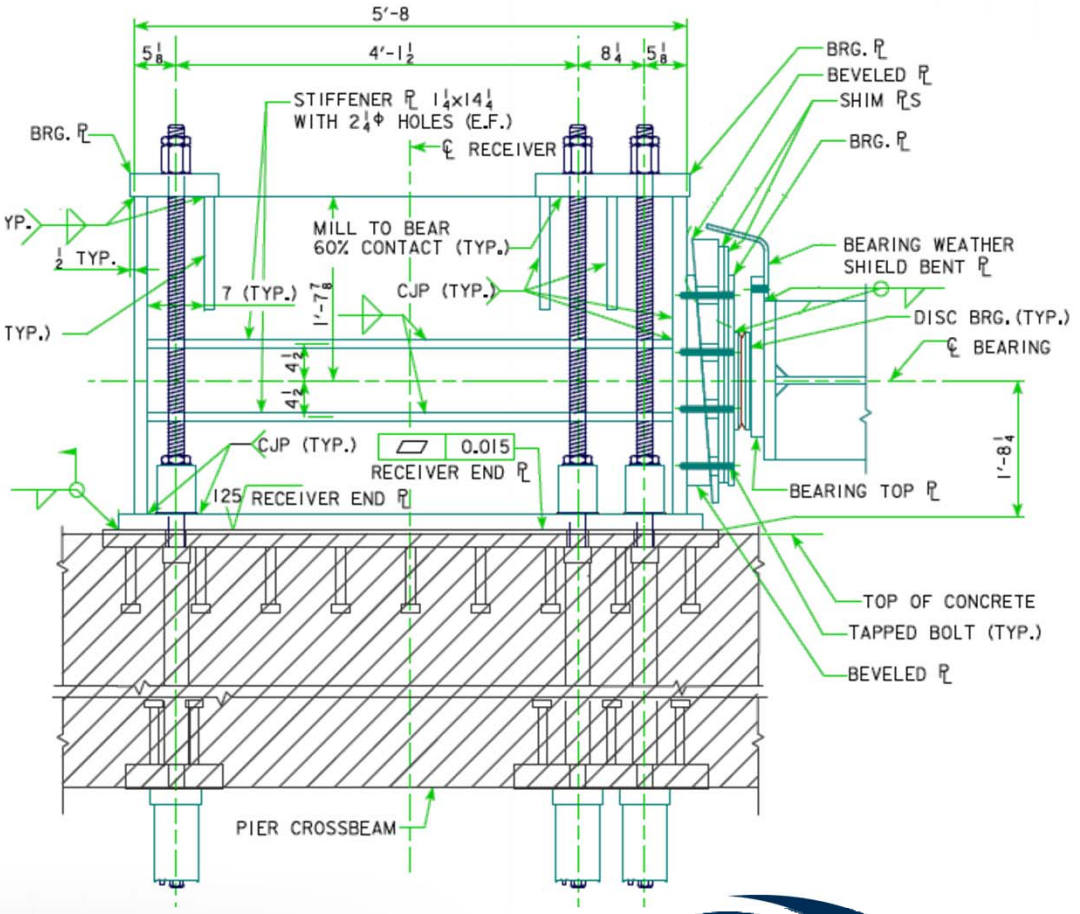
Deck Lateral Force Resisting System

- **Receivers:**
  - Large I-shapes with stiffeners
    - Disc bearings between receivers and wind tongue
    - Compressive force locked into bearings via jacking prior to welding receiver end plate to embedded plate in cross-beam



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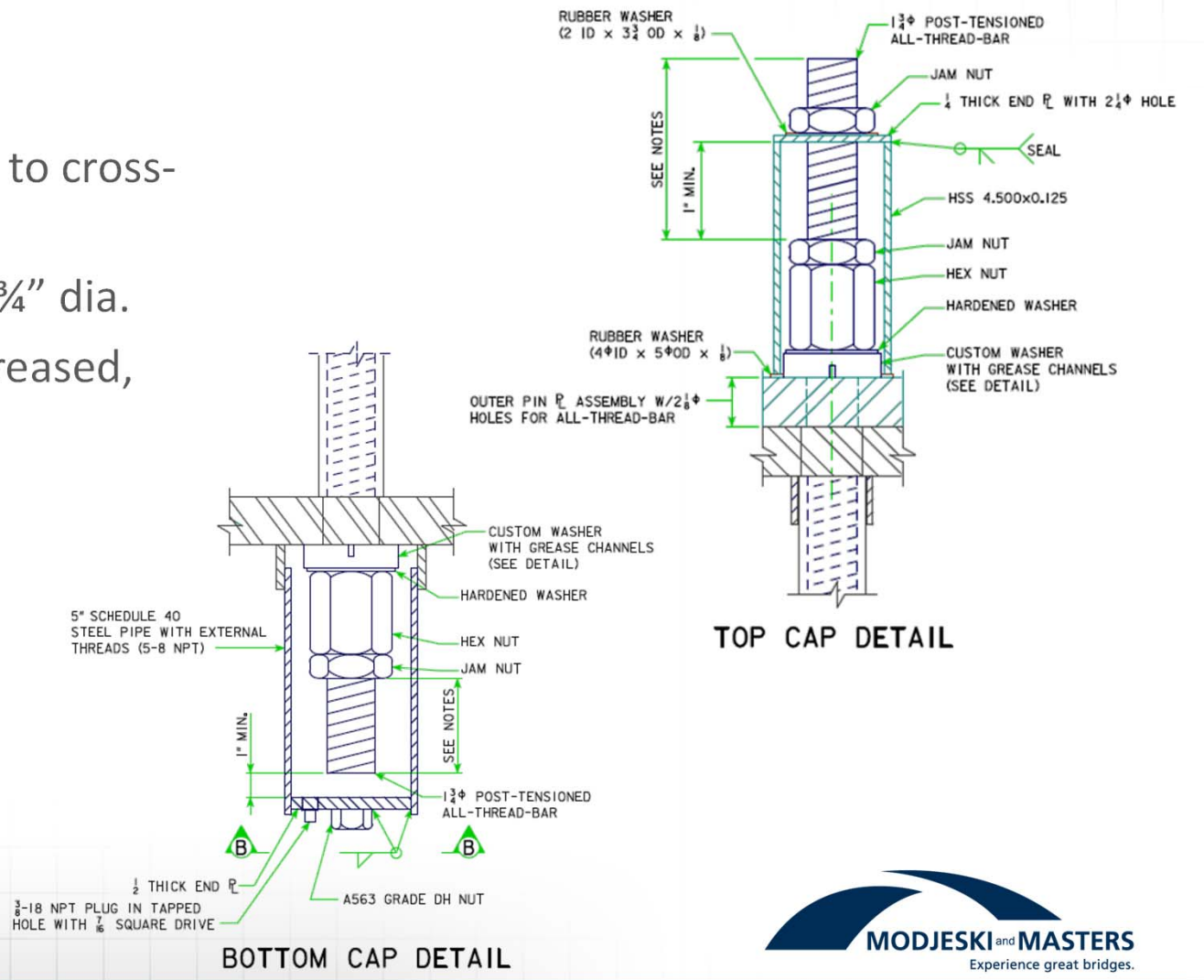
Deck Lateral Force Resisting System

- **Receivers:**
  - Post-tensioned to cross-beam
  - Gr. 150 bars, 1 ¾” dia.
  - Replaceable (greased, not grouted)



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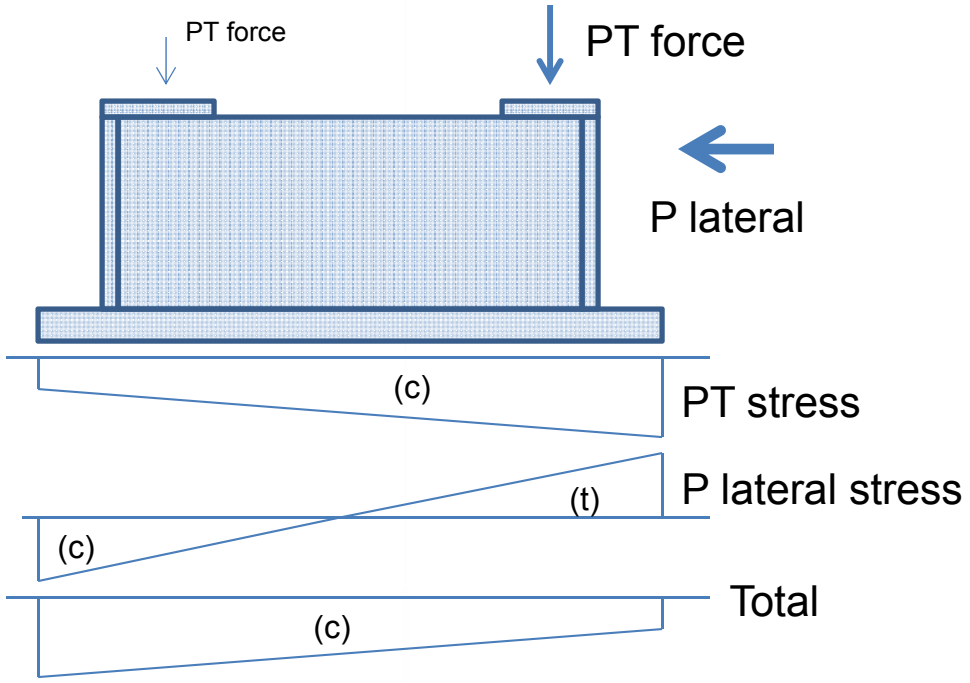
Deck Lateral Force Resisting System

- **Receivers:**
  - Post-tensioned to cross-beam
  - Forces selected to eliminate tension under lateral loading while limiting maximum compressive stress



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Arch Force Resisting System

- **Hangers:**
  - Two bridge strands at each location
    - Improves redundancy and allows for replacement
  - Bridge strand diameters vary along bridge

Arch	Min. Dia. (in.)	Max. Dia. (in.)
Arches without bike trail	1 15/16	2 7/8
Arch with bike trail	2 5/8	3 3/8

  - Controlling load cases
    - Hanger loss or Service (with F.S. = 3.0)

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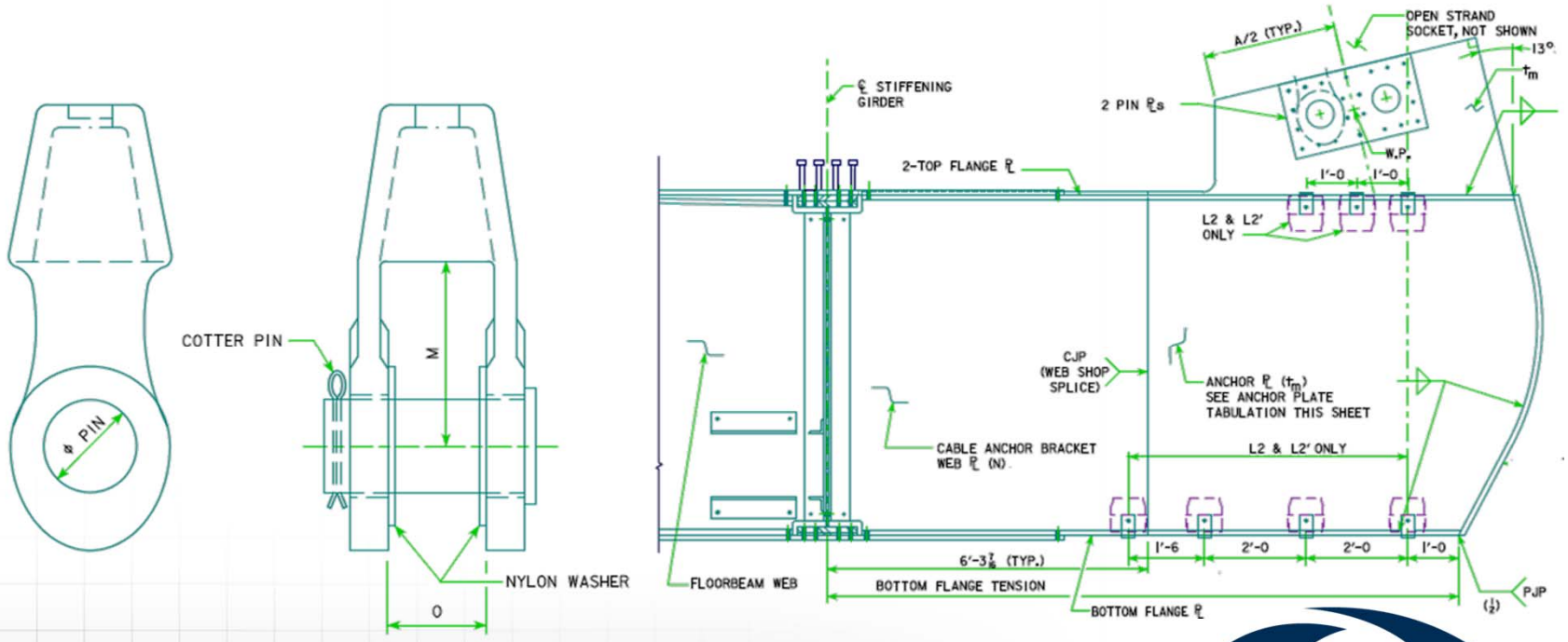
Arch Force Resisting System

- **Hangers: Connections**
  - Open strand sockets at bottom connection to floorbeams
    - Sharkfin with pin plates at ends of floorbeam



OPEN STRAND SOCKET

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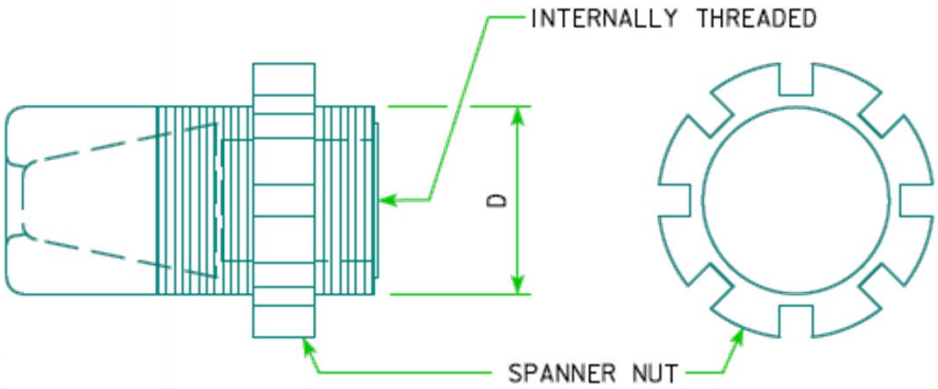
Arch Force Resisting System

- **Hangers: Connections**
  - "Type 7" sockets at top connection to arch rib
    - Internal threads allow for jacking tensioning
    - External threads allow for length adjustment (setting of roadway vertical geometry)



TYPE 7 SOCKET

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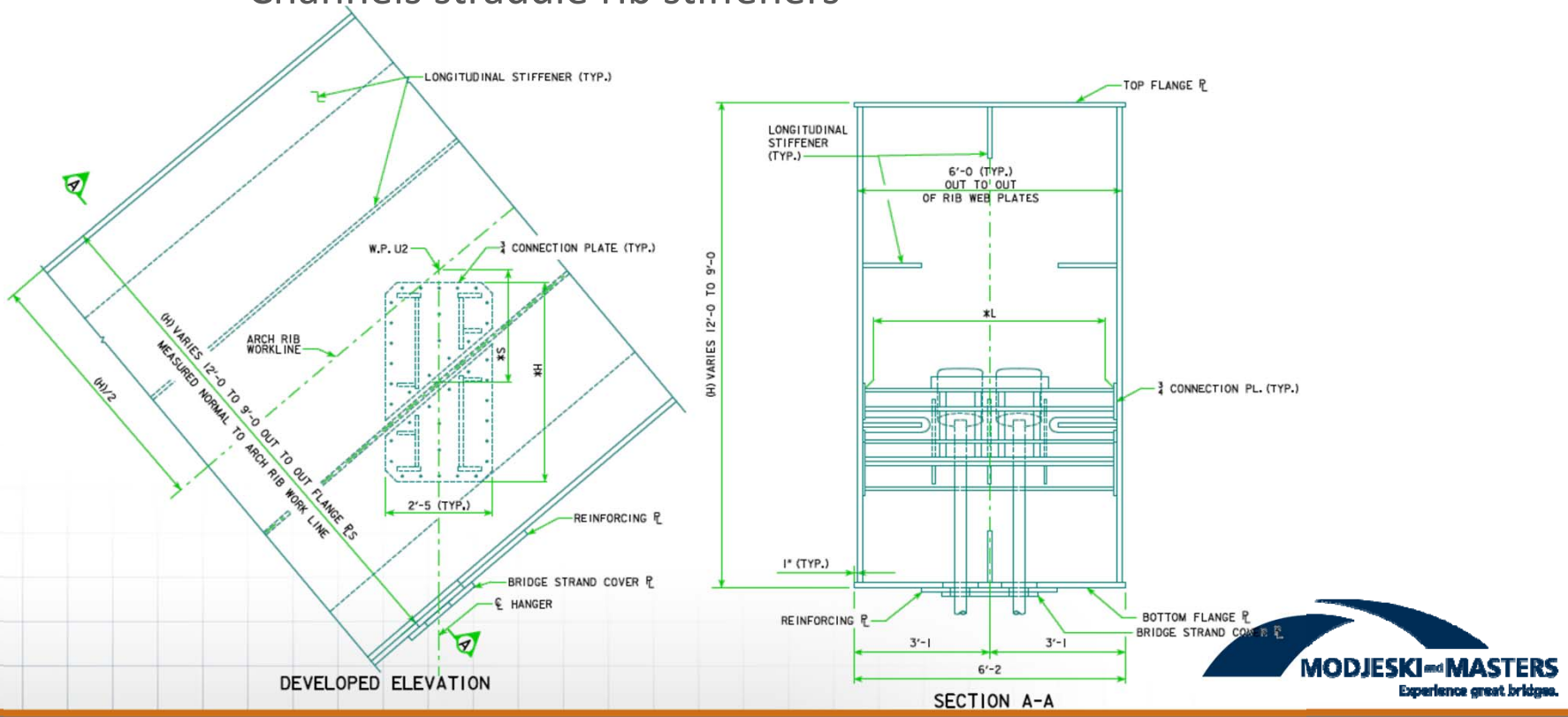
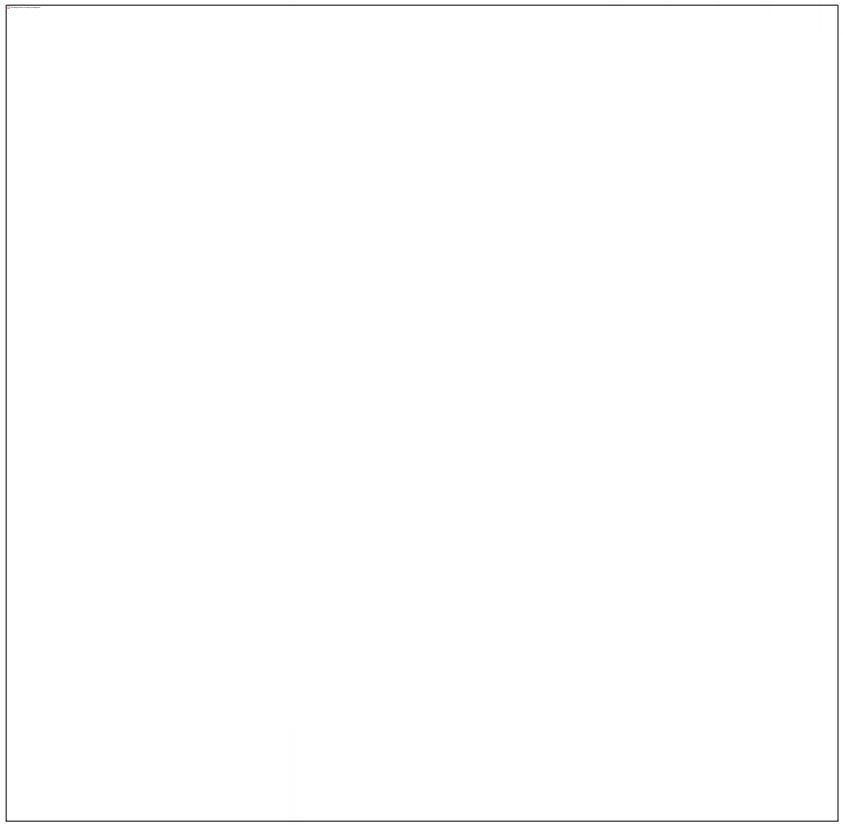
Arch Force Resisting System

- **Hangers: Connections**
  - Stiffened channels span between arch ribs webs
    - Channels straddle rib stiffeners



Arch Force Resisting System

- **Typical Arch Rib Section:**
  - 6’ wide by 9’ to 12’ deep
  - Flange overhangs for fillet welds
  - Stiffeners
    - Explored WT’s, Bulb Flats
    - Simple flat plates used



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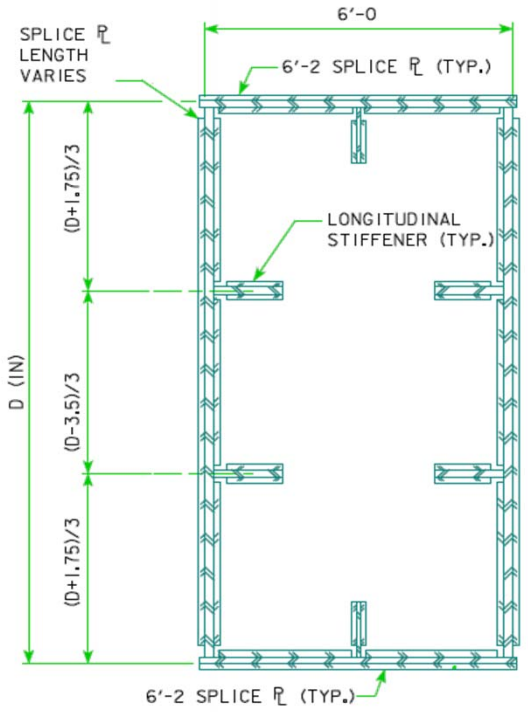
Arch Force Resisting System

- **Arch Rib Splices:**
  - 15 field sections with 14 splices per arch
  - All bolted, 7/8” diameter A325 bolts
  - Connection plates carry all load across splices, no bearing required
  - Stiffeners load carrying, fully connected across splices



Splice of Typical Arch Rib Section

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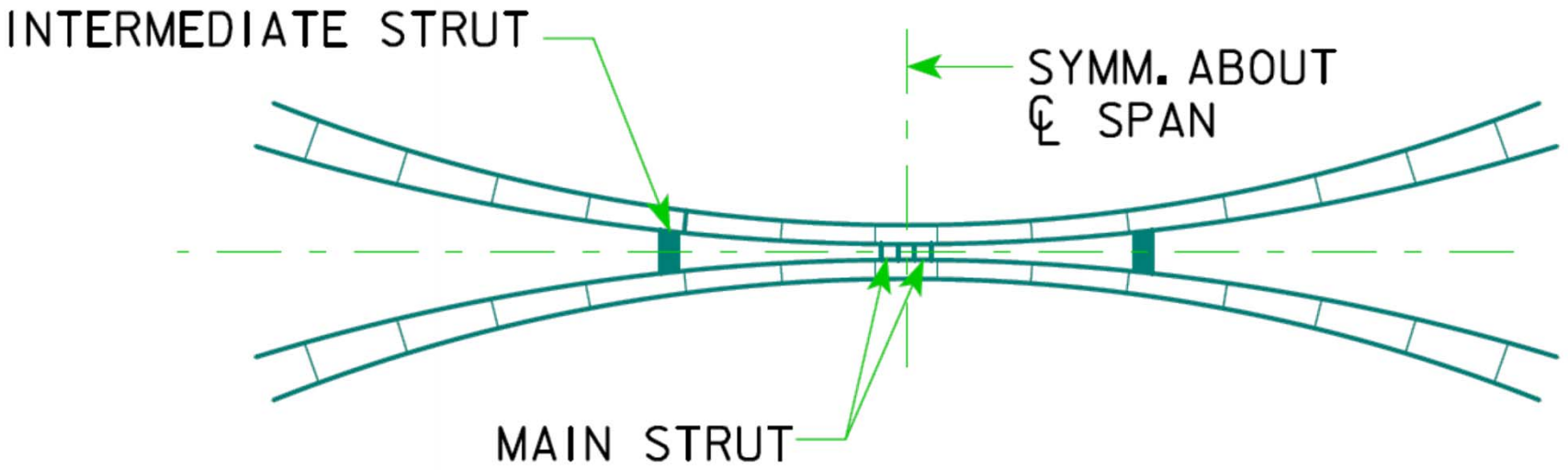
Arch Force Resisting System

- Vierendeel Braces



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Arch Force Resisting System

- **Vierendeel Braces: Intermediate Strut**
  - Part of Portal Frame
  - Curved Bottom Flange

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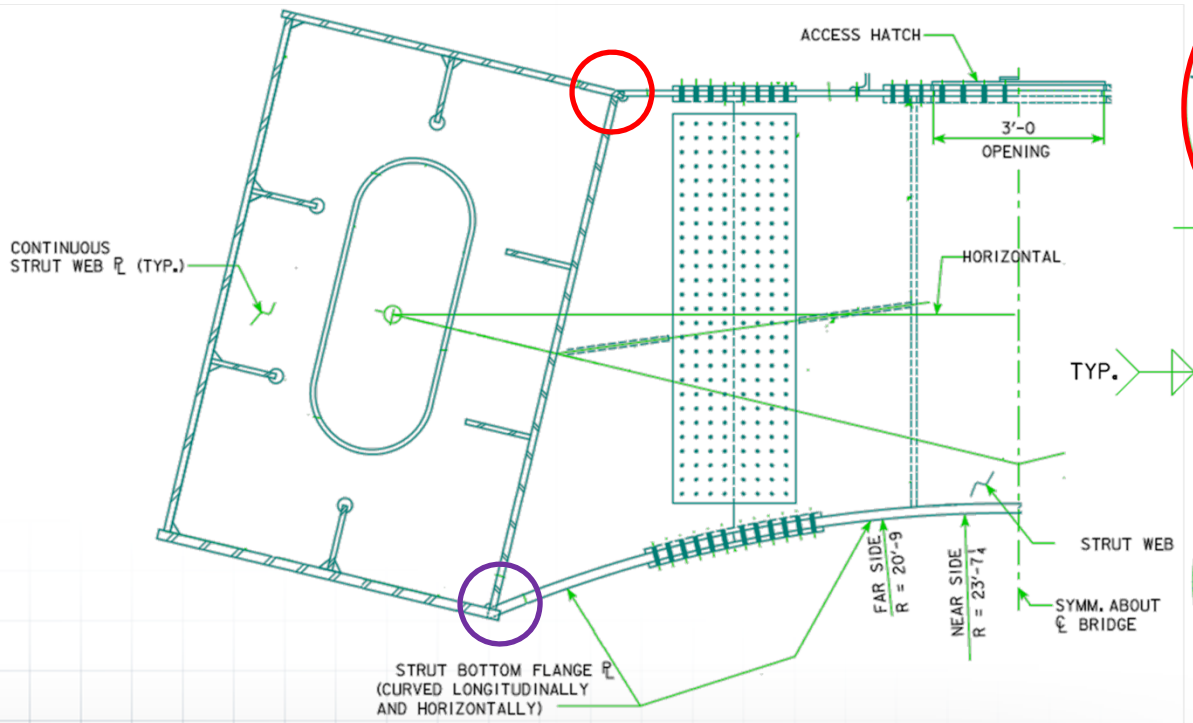
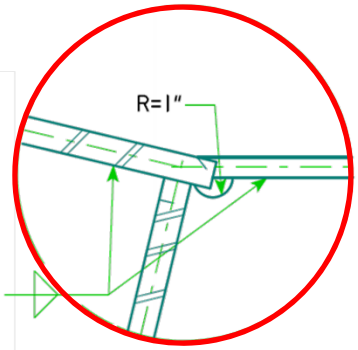
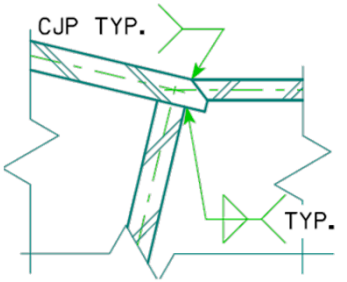
Arch Force Resisting System

- **Vierendeel Braces: Intermediate Strut**
  - Complex connection details

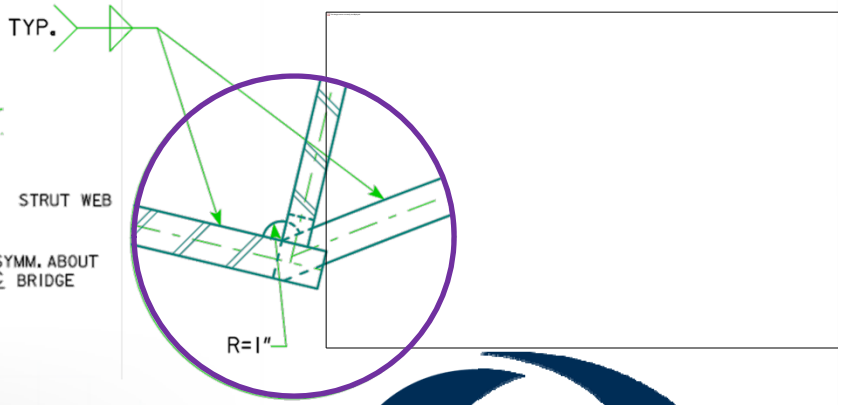




Outside the Strut



Inside the Strut



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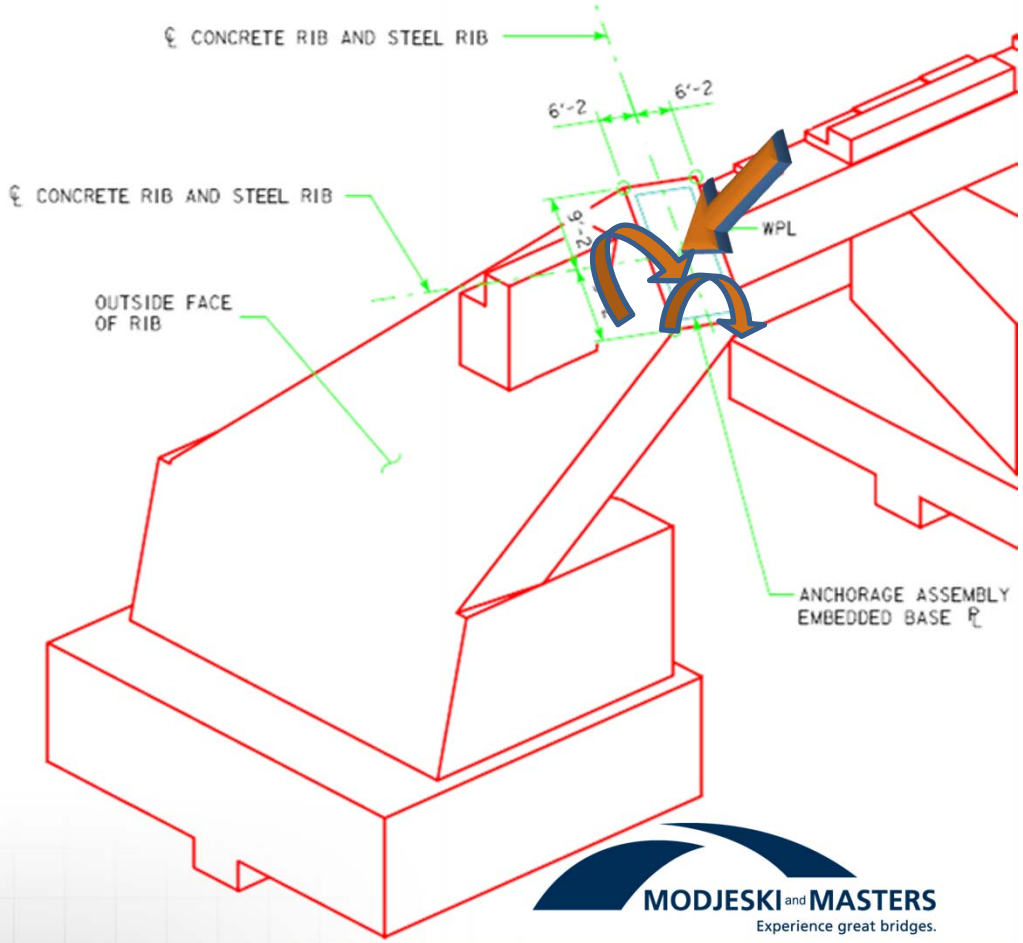
Arch Force Resisting System

- **Arch Steel/concrete Interface Connection**
  - Combined Forces
    P + Mx + My
  - Significant lateral bending
  - High concrete bearing pressures
  - Corrosion protection measures (grouting)



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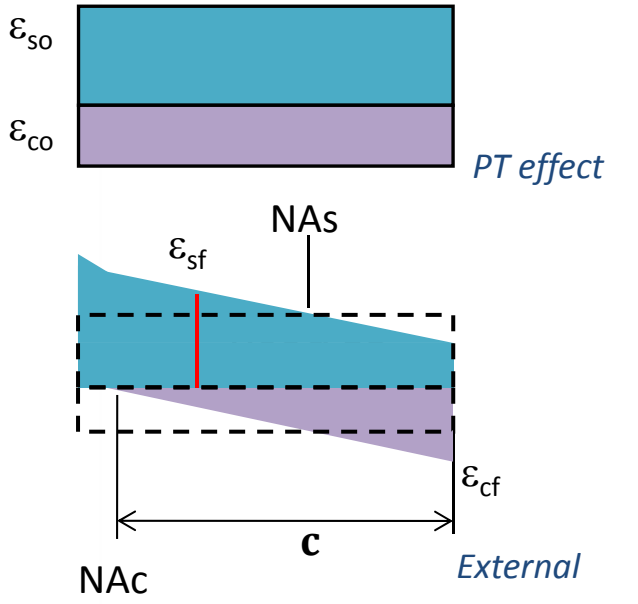
Arch Force Resisting System

- **Arch Steel/concrete Interface Connection**
  - Analysis/Design:
    - Critical load combinations:
      - STRIII, STRV
    - Conservative design comb.:
      - $Pu_{Max/Min}$ + Mu Envelope
  - Strain compatibility approach determine stresses in concrete and PT bars
  - No uplift under service loads



Strain Compatibility Stages

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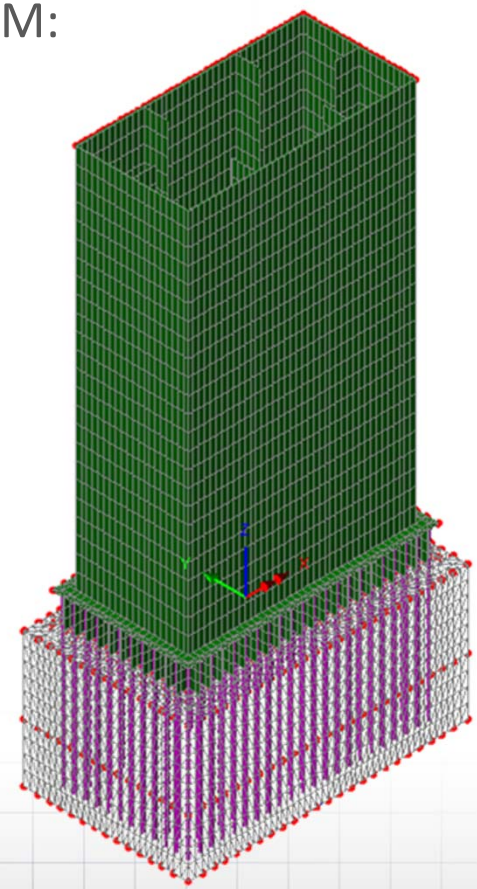
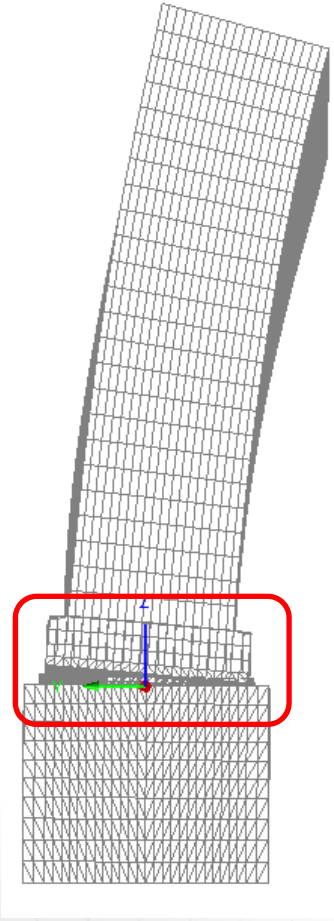
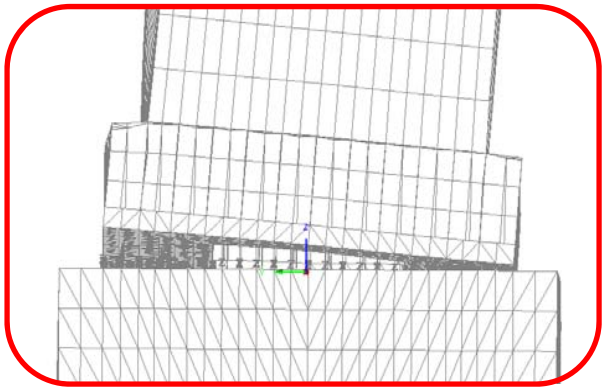
Arch Force Resisting System

- **Arch Steel/concrete Interface Connection**
  - FEM:







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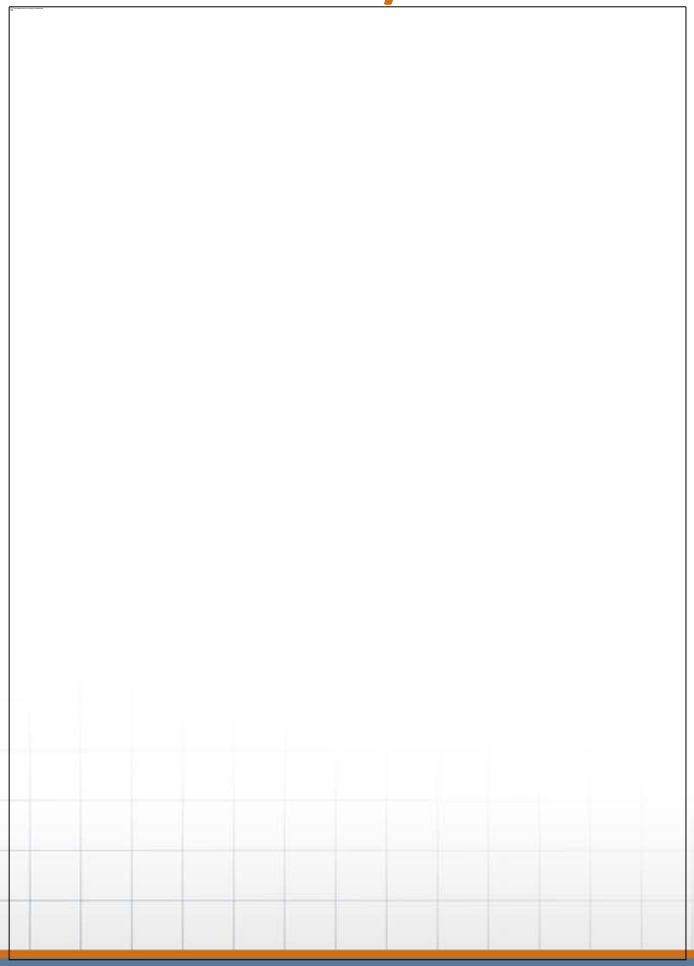
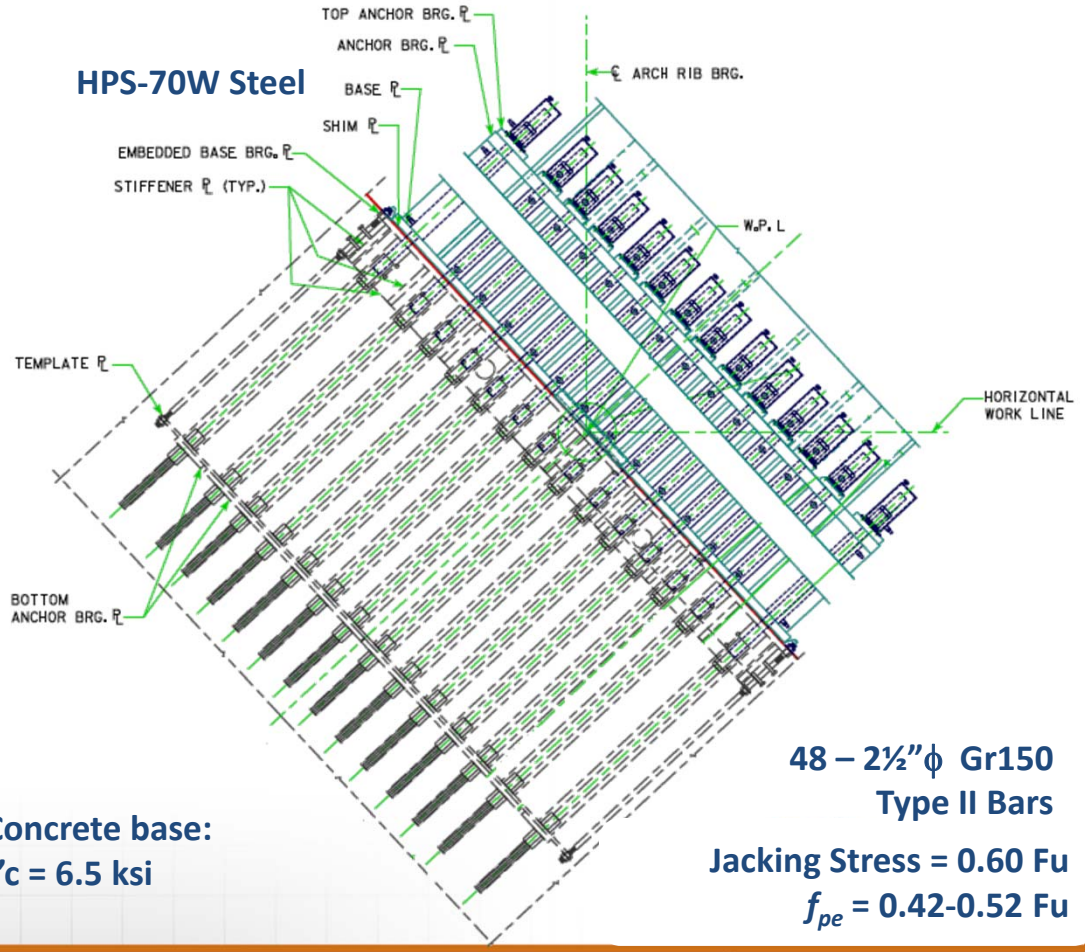
Arch Force Resisting System

- Arch Steel/concrete Interface Connection





Concrete base:
f'c = 6.5 ksi

48 – 2½"ϕ Gr150
Type II Bars

Jacking Stress = 0.60 Fu
f_{pe} = 0.42-0.52 Fu

Wind Design

- Design wind speeds:
  - Strength – 100 year RP – 91.7 mph
  - Const. stability – 1000 year RP – 116.3 mph
  - Final stability – 10,000 year RP – 138.7 mph
- Strength design enveloped static wind and buffeting analysis results
- Vortex shedding vibration issues

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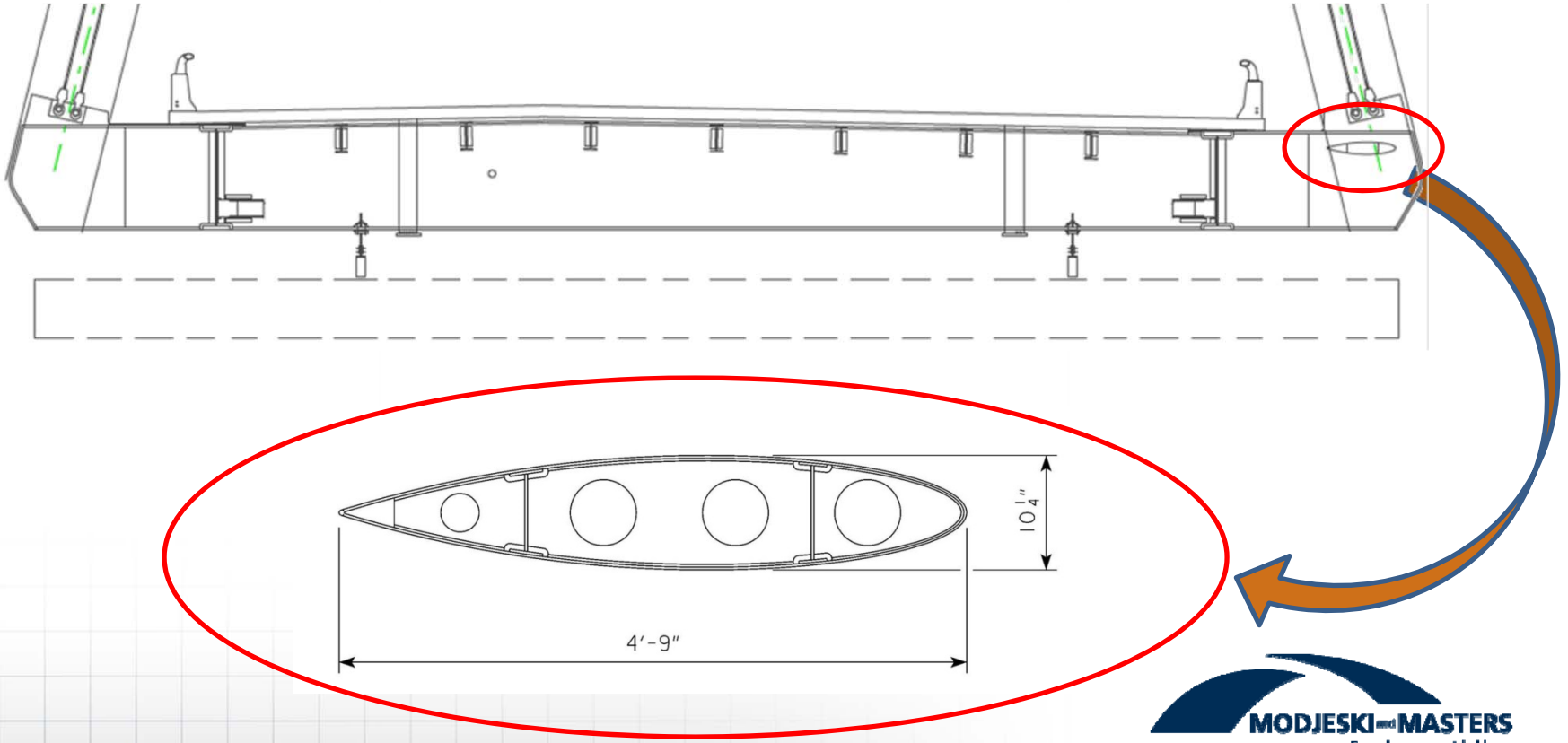
Wind Design

- **Winglet (airfoil shape):**
  - Reduce susceptibility of WB bridge to vortex-induced motions



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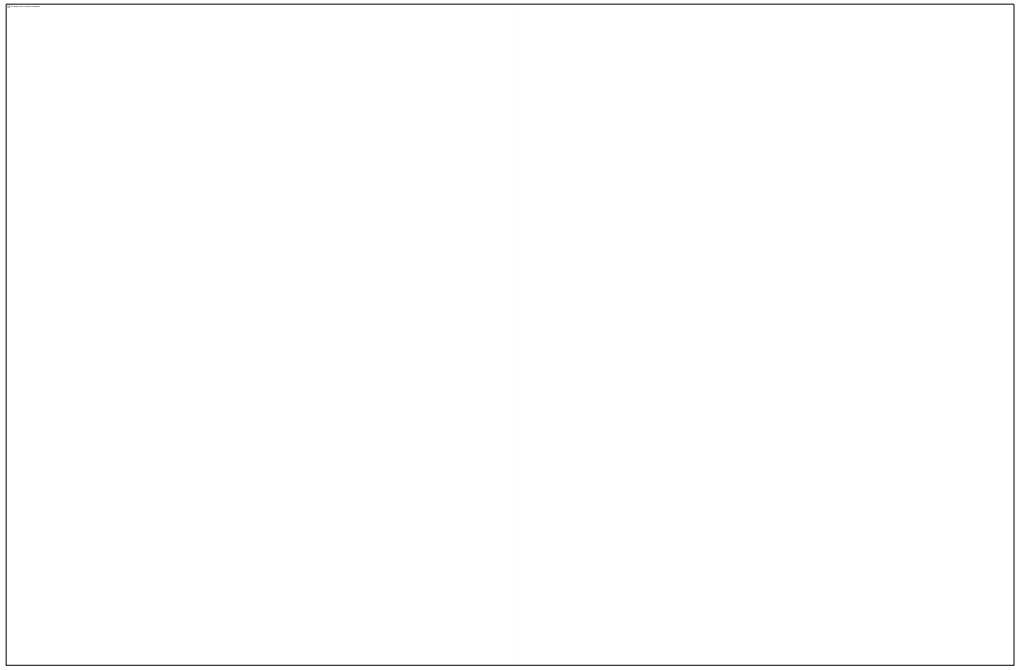
Wind Design

- Wind from one direction only
- Airfoil shape
  - NACA 0018
  - B-17 wing



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Pedestrian Dynamics Check

- Vibrations due to pedestrians
- Vibrations due to traffic
- All checks were within allowable accelerations

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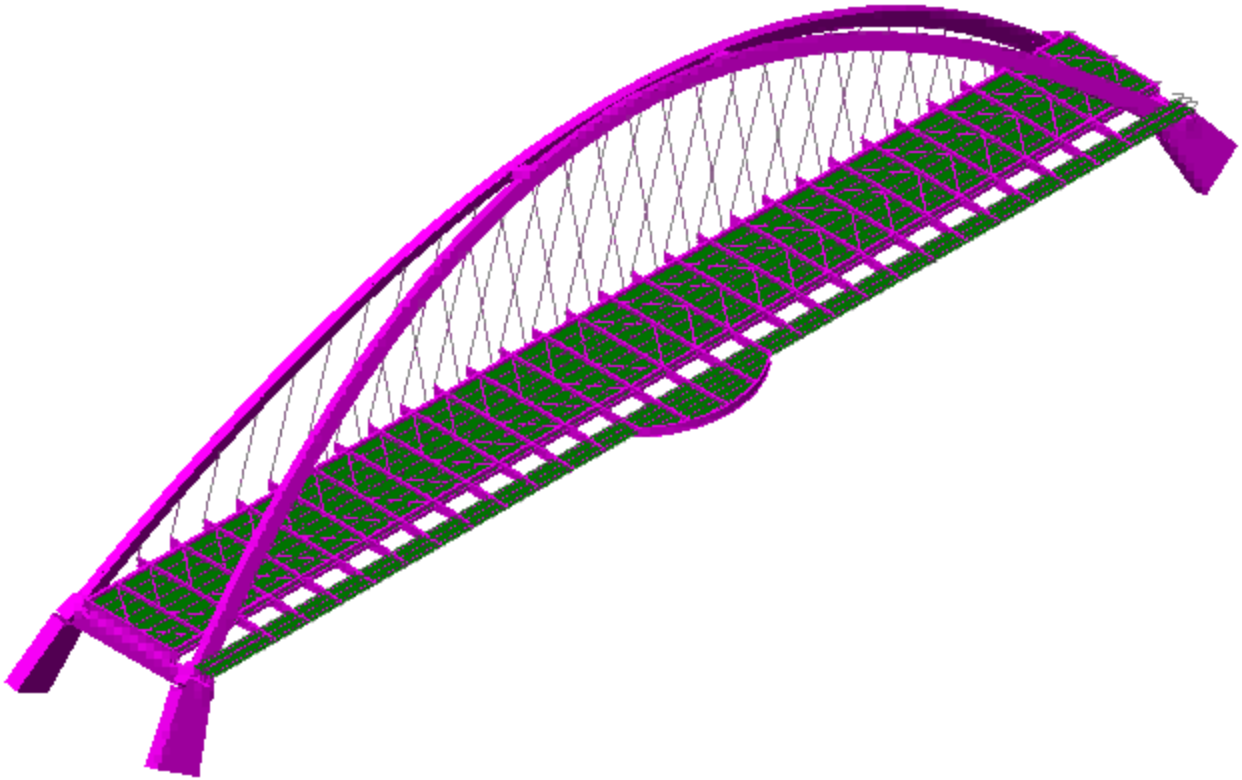
Pedestrian Induced Vibrations



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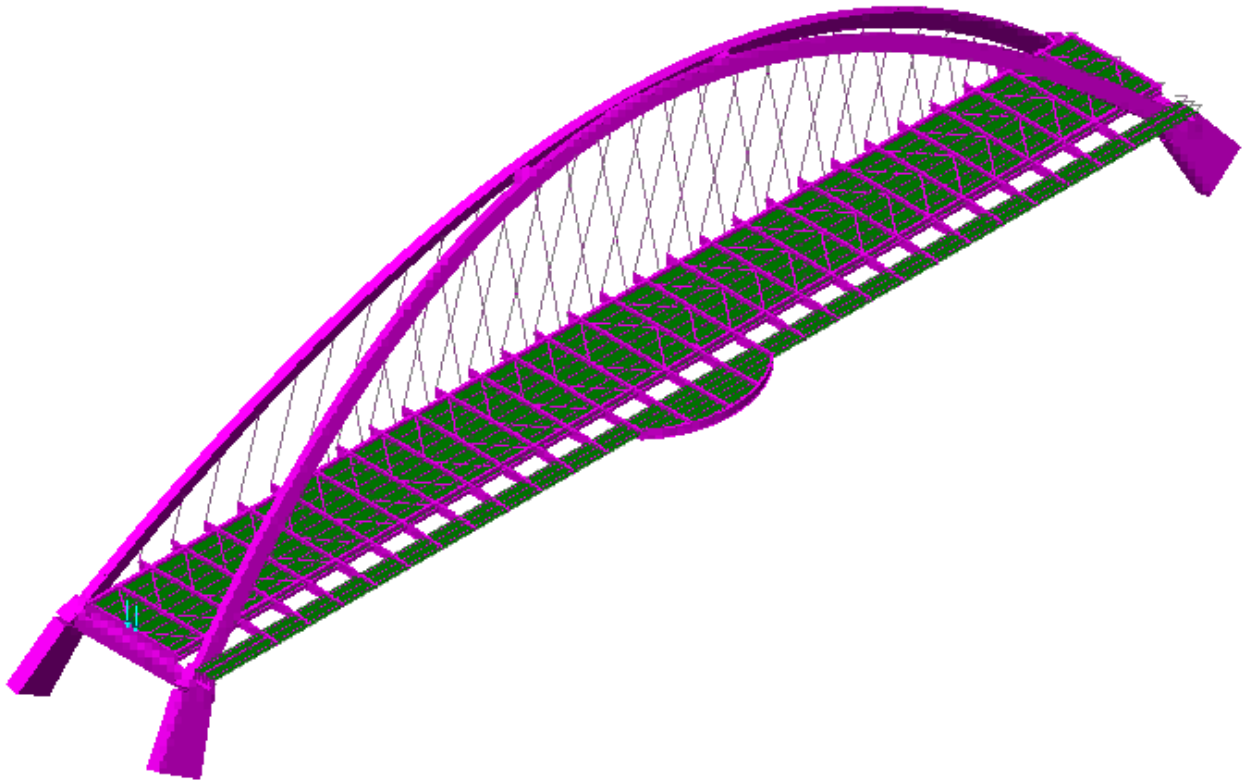
Truck Induced Vibrations



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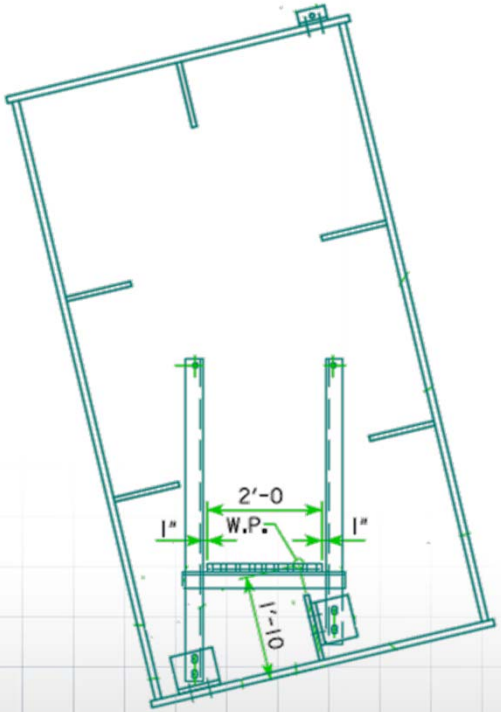
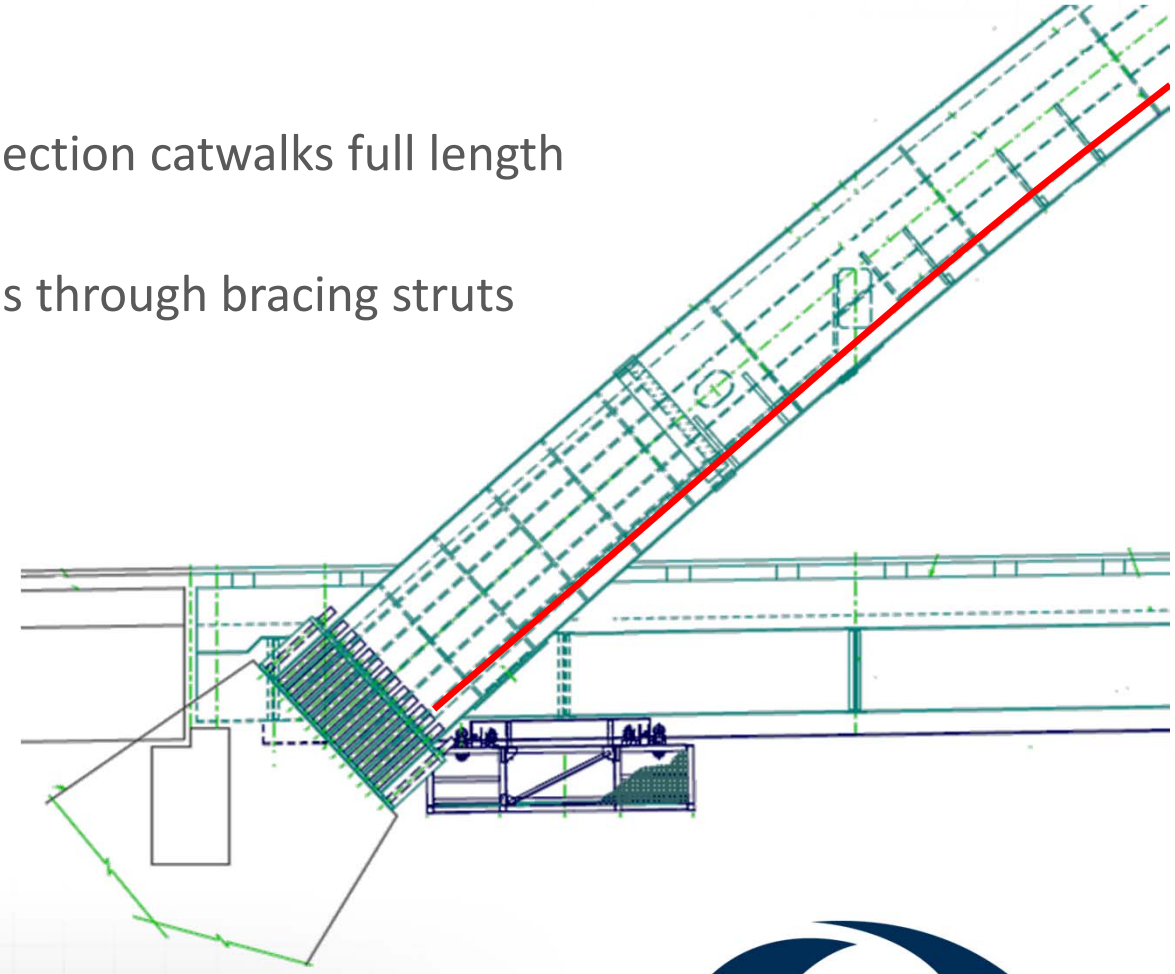
Miscellaneous Details

- **Arch Rib Walkway:**
  - Transversely level inspection catwalks full length interior of arch
  - Access between arches through bracing struts





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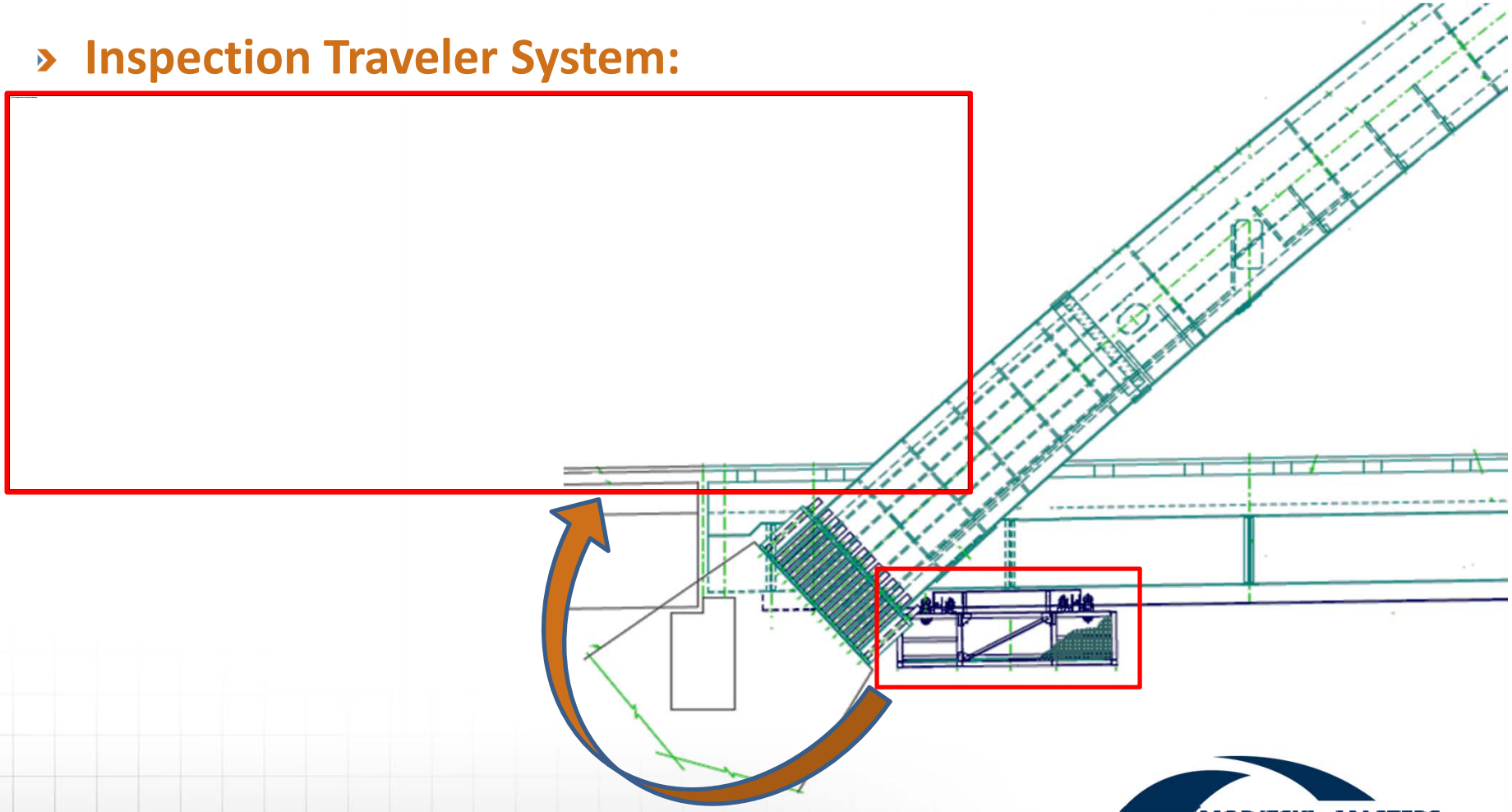
Miscellaneous Details

- **Inspection Traveler System:**



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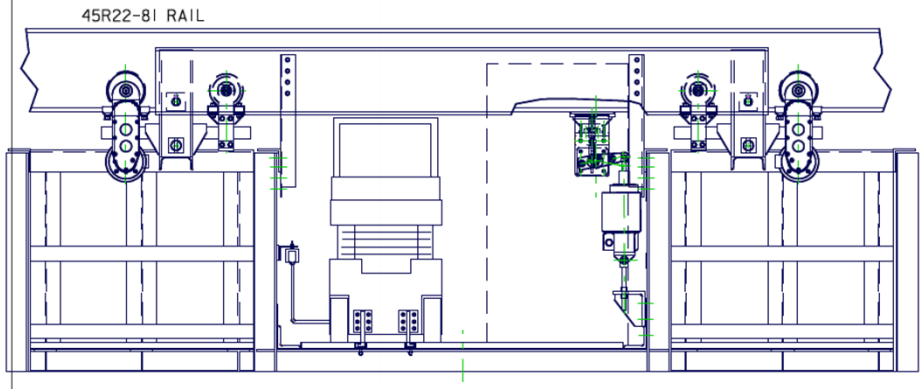
Miscellaneous Details

- **Inspection Traveler System:**



TYPICAL SECTION A-A

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Arch Construction Sequence

- Designer's construction sequence req'd
  - Fixed arch
  - Torsionally stiff
  - One arch more heavily loaded
- Geometry control critical to achieving correct stress state

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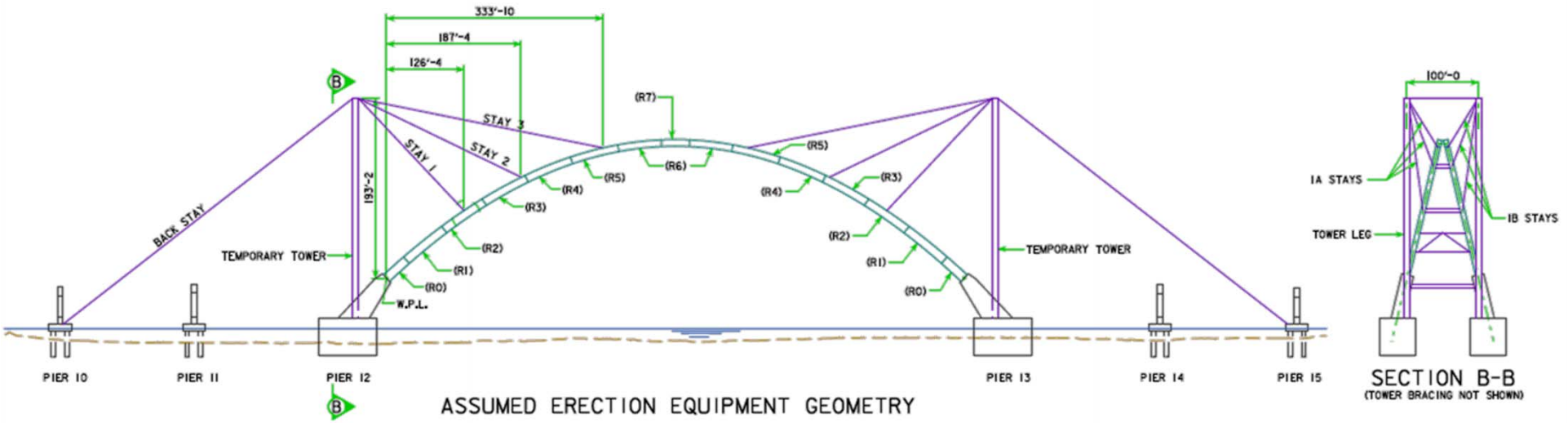
Arch Construction Sequence



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- John Kulicki – Modjeski and Masters
- David Morrill – Alfred Benesch

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Questions?

Thank You!

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