103rd Annual T.H.E. Conference

February 28 & March 1, 2017

University of Illinois at Urbana-Champaign

Planning and Design

of

IL-104 BRIDGE

OVER

ILLINOIS RIVER

MEREDOSIA, IL

Presenter:

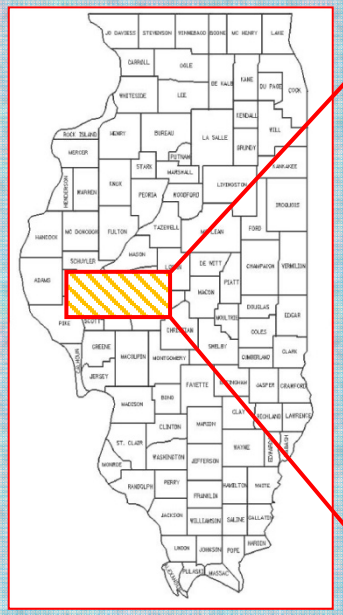
Vinod C. Patel, PE, SE

Exp US Services Inc.

Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. Bridge Design
5. Innovative Details
6. Analysis - Design
7. Construction

Project Location



State of Illinois


ILLINOIS
RIVER
IL 104 / MAIN ST.
MEREDOSIA
NORTH

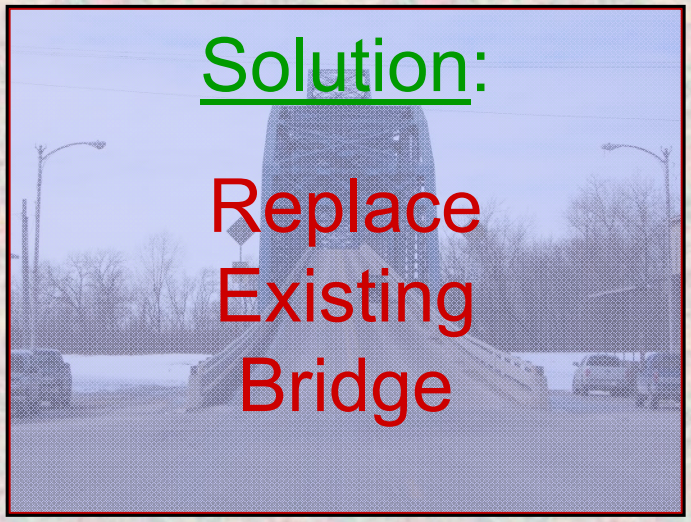
Why the project is needed?

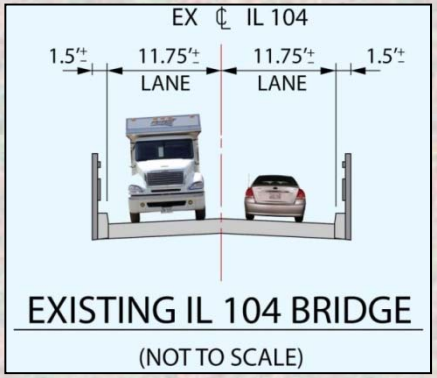
Existing Bridge:

- Structurally Deficient – Built in 1936 / 80 years old
  Has deteriorated with age

  Sufficiency Rating < 15 (out of 100)
  Low Rating => Numerous elements with advanced deterioration;
  Requires close monitoring & frequent maintenance / repairs

- Functionally Obsolete – Narrow Lanes / No Shoulders / Unsafe



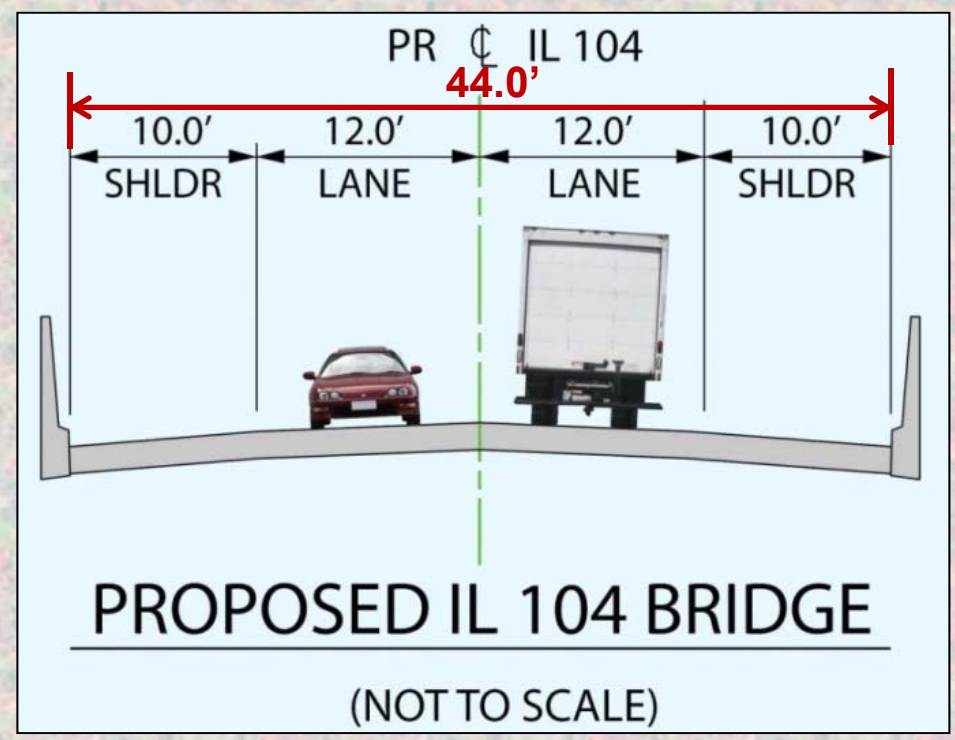


Presentation Outline

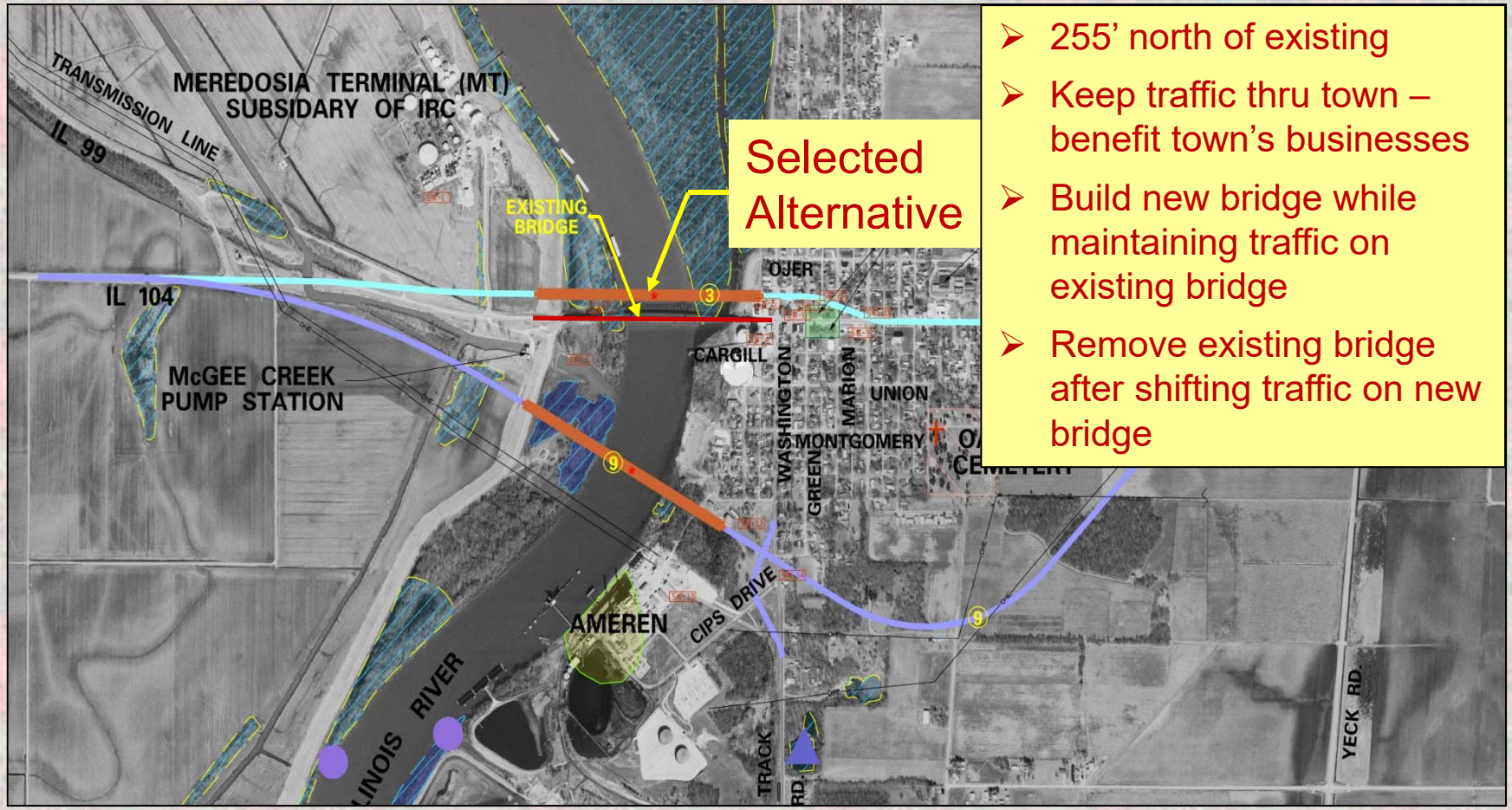
1. Project Overview
2. **Phase I Study (Preliminary Engineering)**
3. Bridge Type Study
4. Bridge Design
5. Innovative Details
6. Analysis - Design
7. Construction

New Bridge - What size to build?

Based on traffic volume, current design standards and the functional requirements -



Where to build?



- 255’ north of existing
- Keep traffic thru town – benefit town’s businesses
- Build new bridge while maintaining traffic on existing bridge
- Remove existing bridge after shifting traffic on new bridge

Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. **Bridge Type Study ➔ Bridge Type & Configuration**
4. Bridge Design
5. Innovative Details
6. Analysis - Design
7. Construction

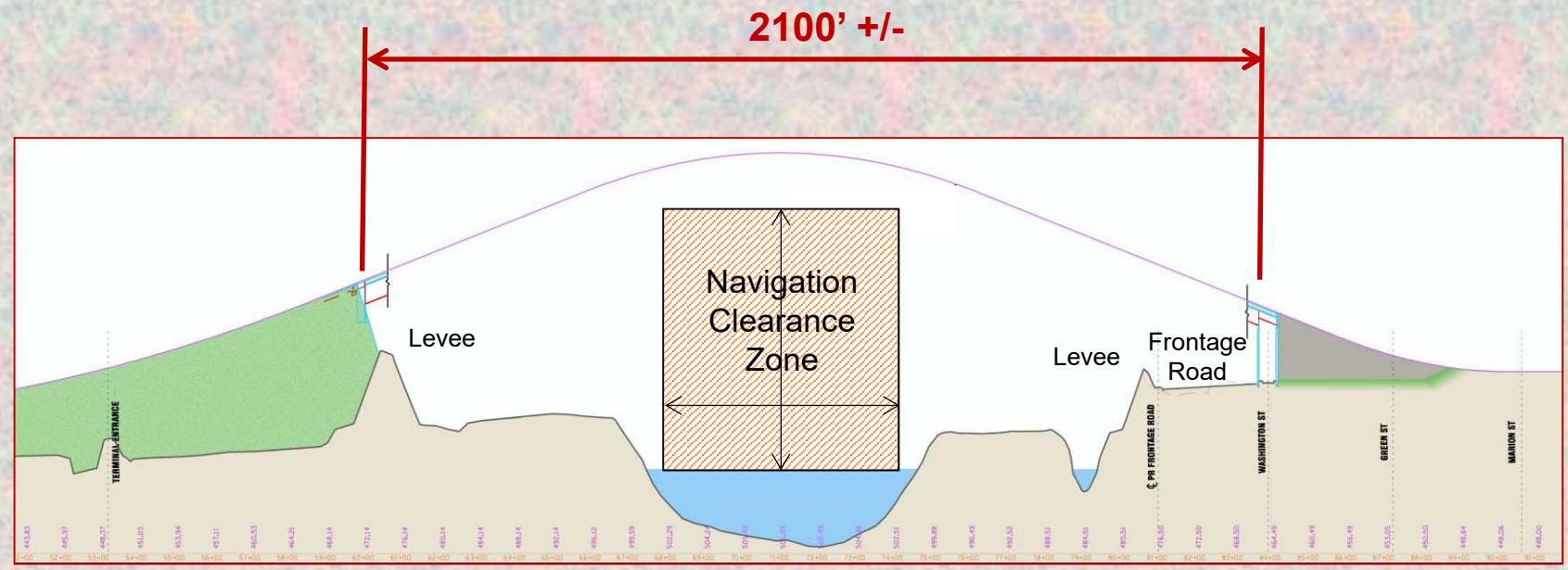
Bridge Type Study – Bridge Profile

Illinois River ➔ A Navigational Waterway

U.S. Coast Guard's Navigational Clearance Requirements:

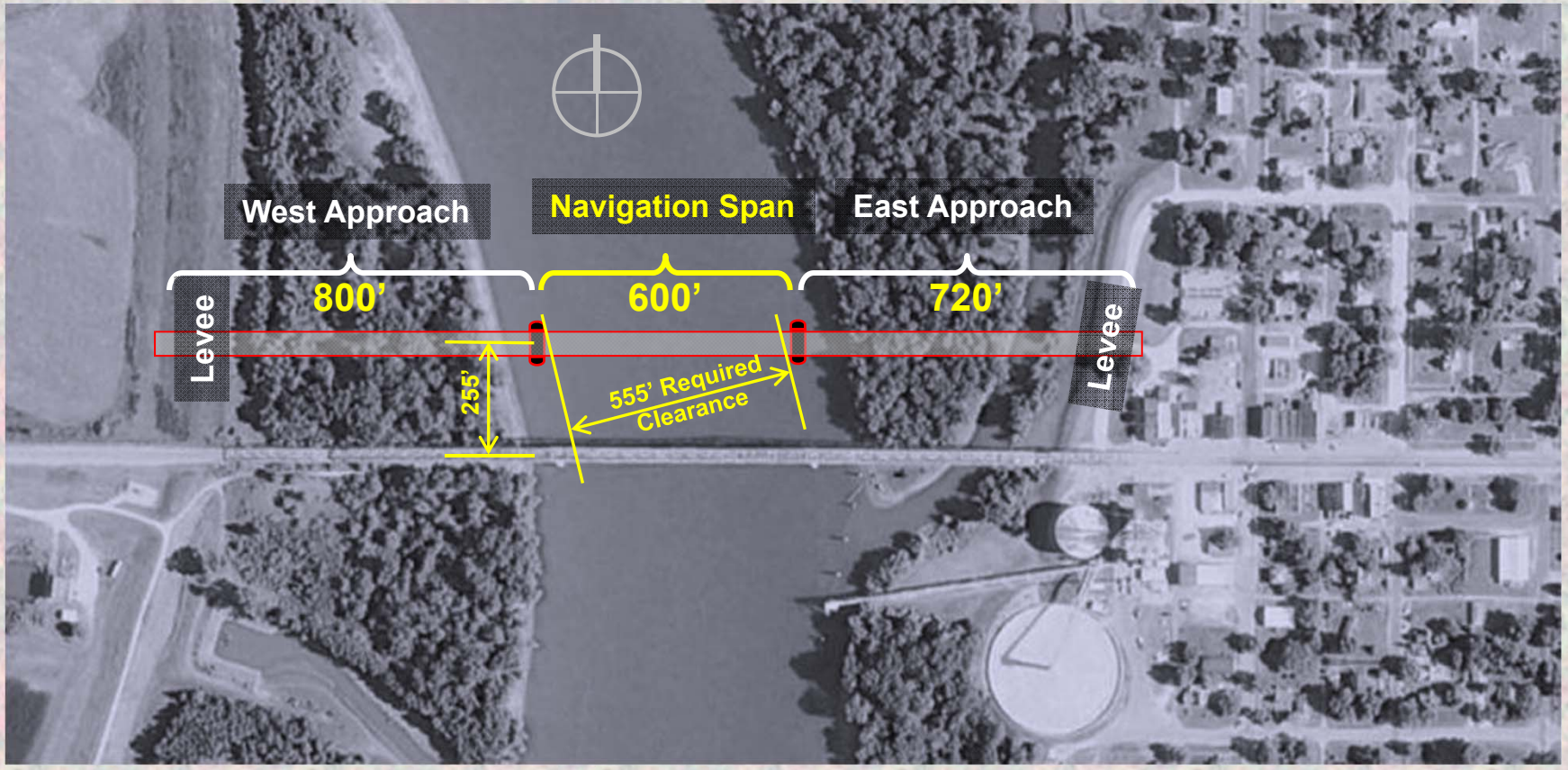
Horizontal Clearance = 555 ft.
Vertical Clearance = 55 ft. above 2% Flowline

Profile Grade = 4% Max.



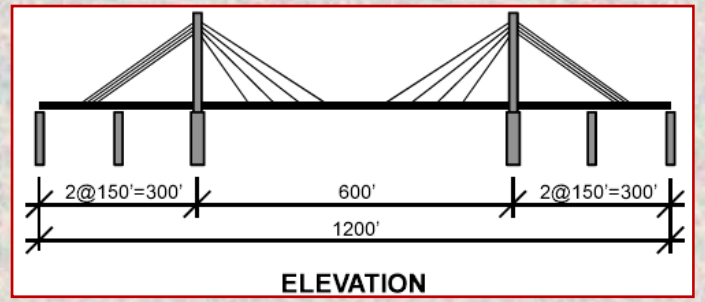
Bridge Type Study: Bridge Limits & Layout

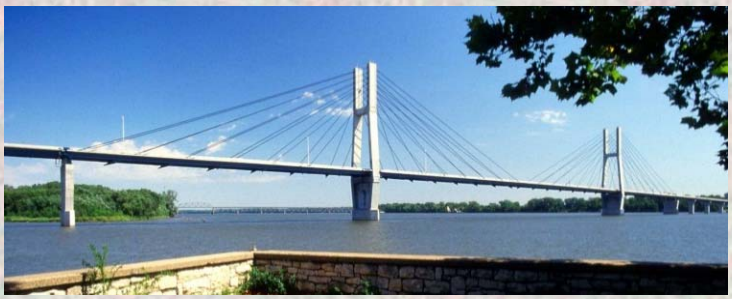
Focus – Main Navigation Span



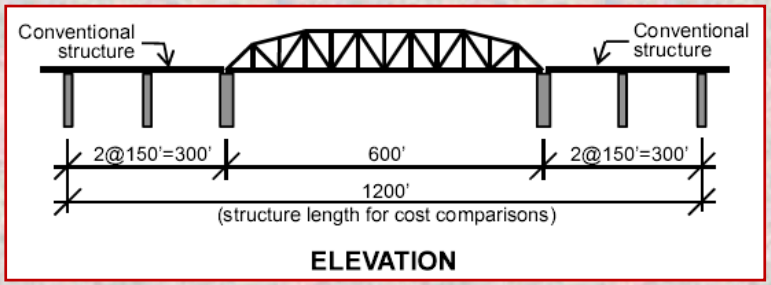
Bridge Type Study: Focus – 600’ Main Navigation Span

Cable-stayed

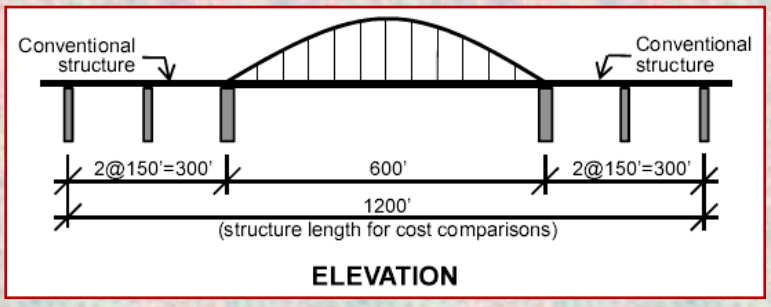




Truss



Tied-arch



Bridge Type Study

Evaluation Criteria ➔ Evaluation:

- Costs – Initial & Life Cycle ➔ virtually same for all
- Constructability ➔ advantage Cable-stayed
- Inspection and Maintenance ➔ advantage Arch
- IDOT Experience / Familiarity ➔ advantage Arch

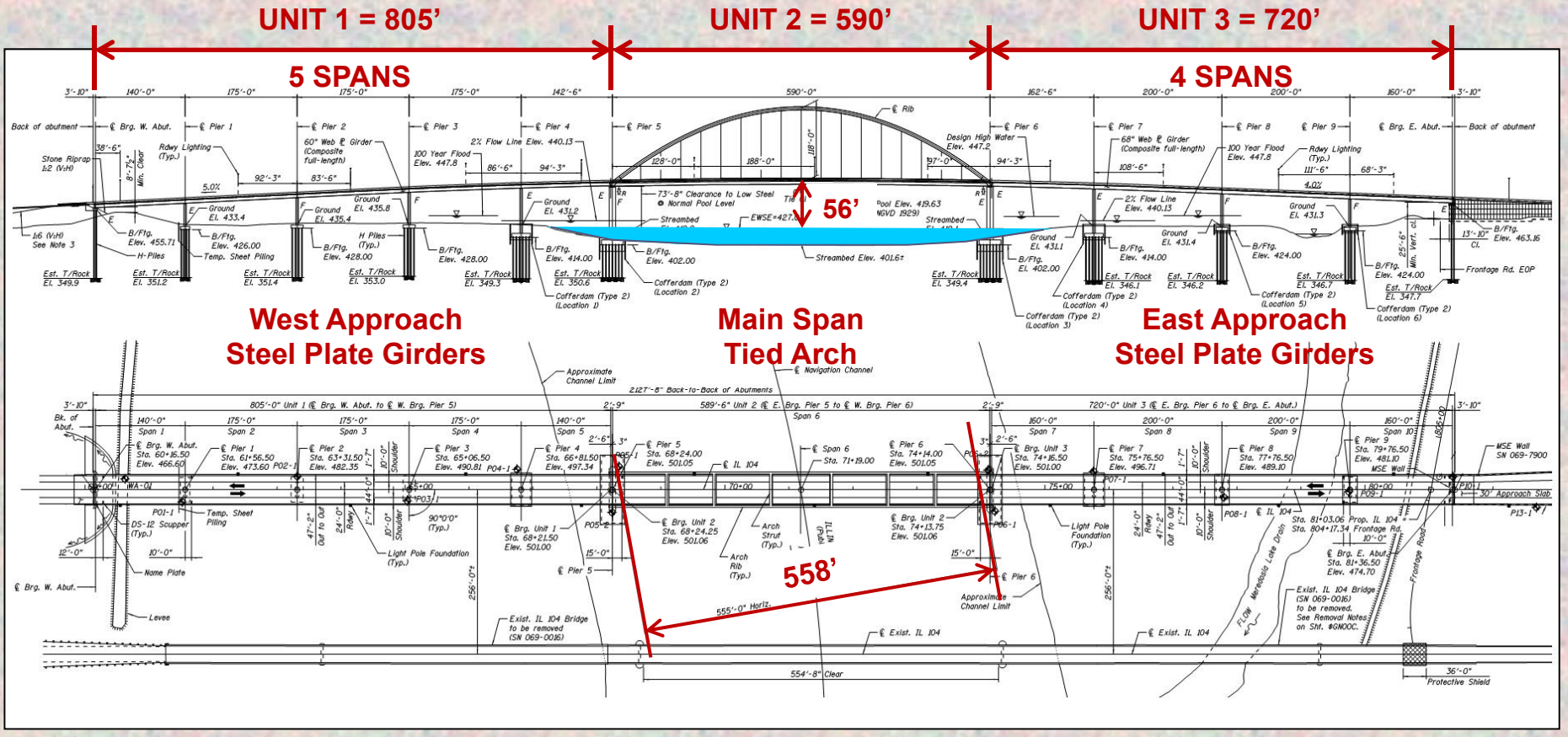
Selected Bridge Type ➔ Tied-Arch

Selected Bridge Type ➔ Tied-arch

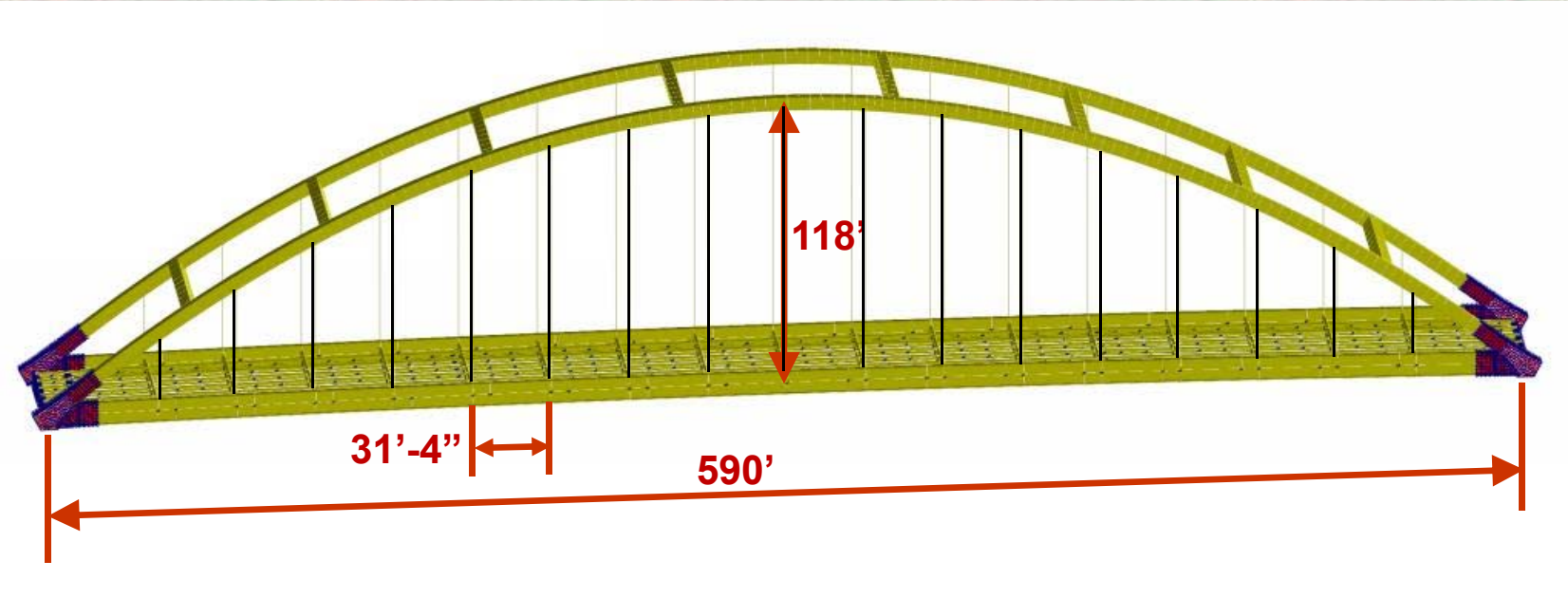
Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. **Bridge Design**
5. Innovative Details
6. Analysis - Design
7. Construction

Proposed River Bridge – General Plan & Elevation

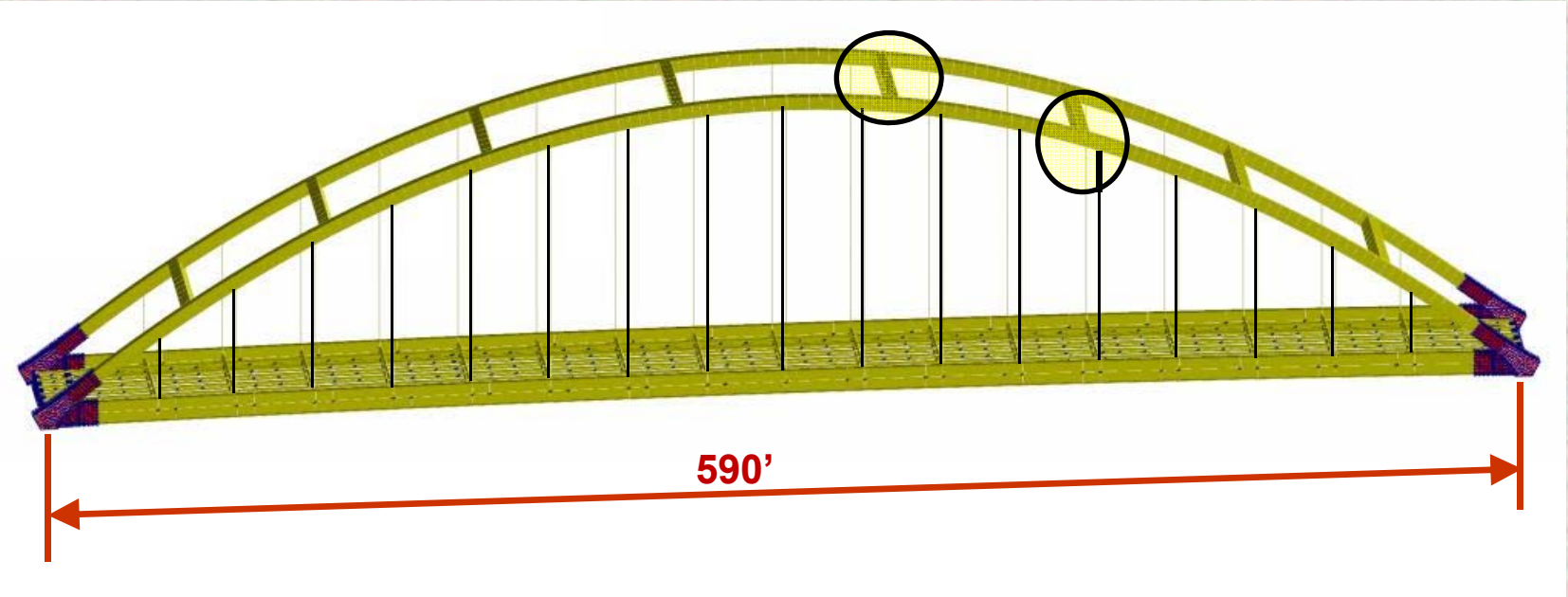


Arch Span Features



- 590-foot span; 118-foot rise (= 1/5th of Span)
- Floor beams & hangers spaced at 31’- 4”

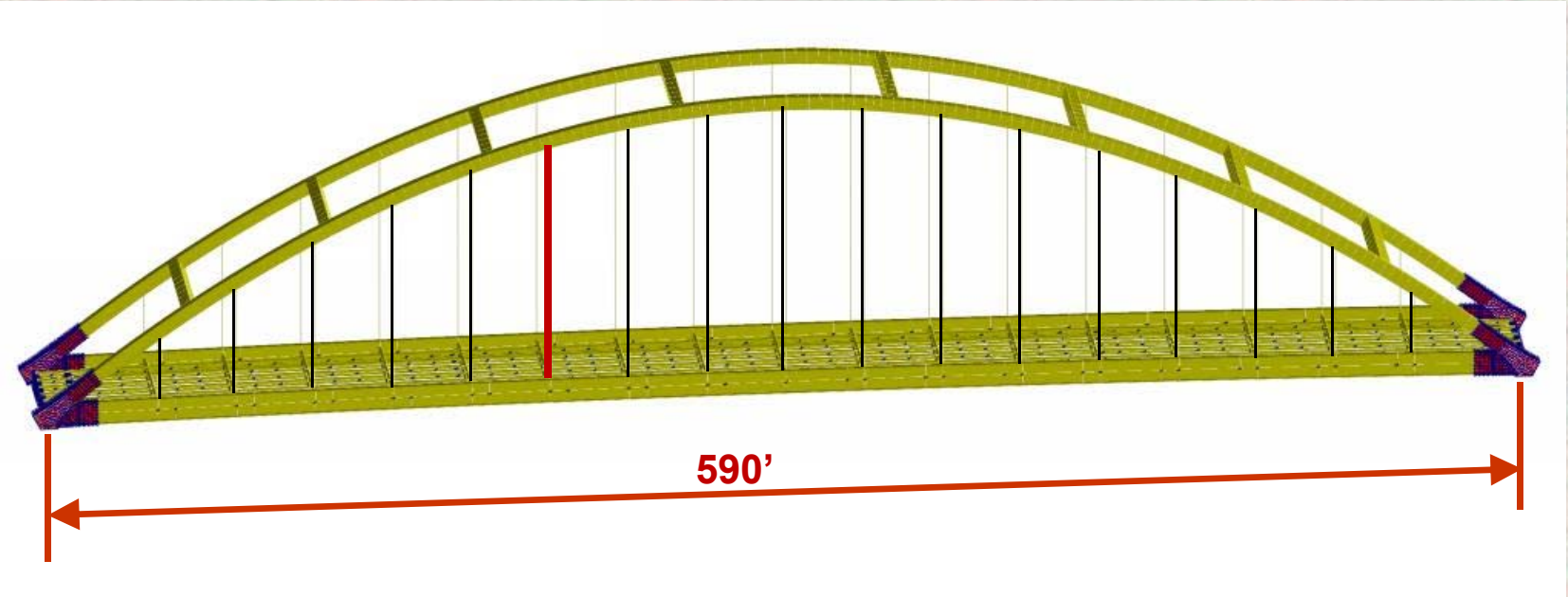
Arch Span Features



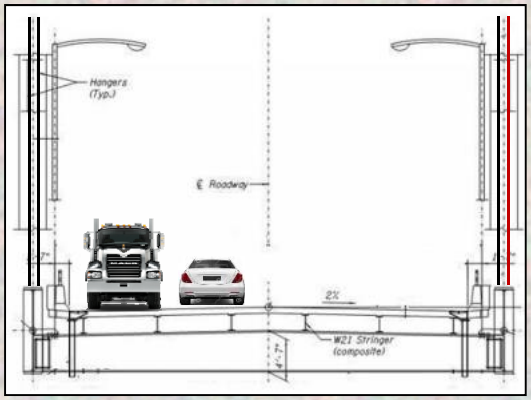
- Rib Bracing – Vierendeel Struts @ approx. 2 times the hanger spacing; No diagonal or “K” bracing; Clean/Open Structure

- Struts are offset from hangers – Simplifies connections of struts and hangers to rib

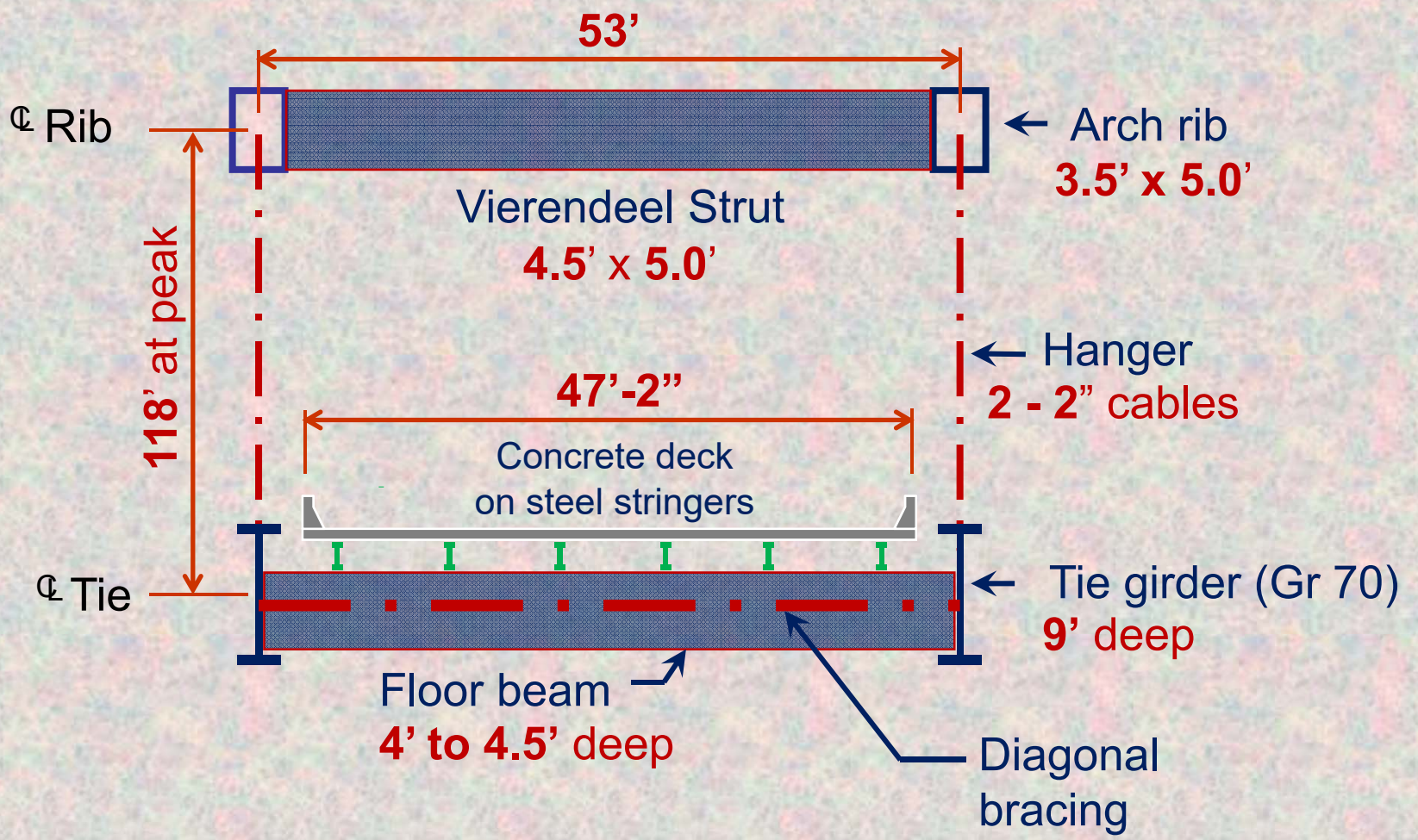
Arch Span Features



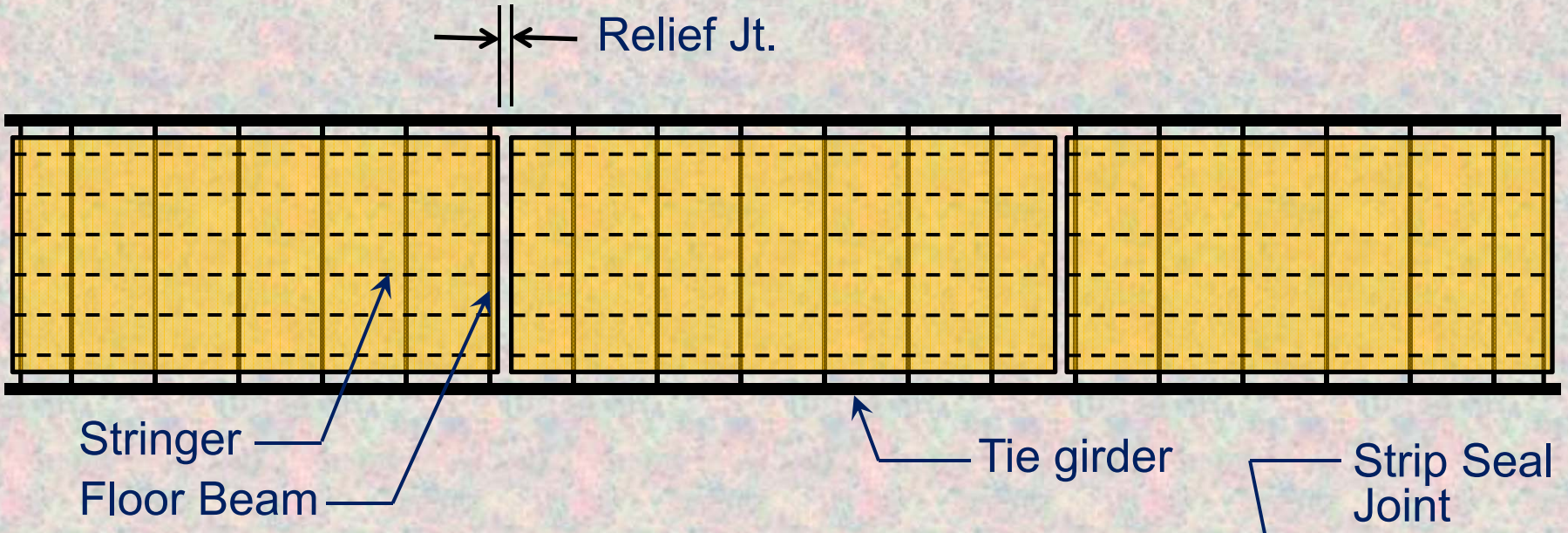
- Redundant hangers (2 – 2” cables)
- With loss of 1 cable or when cable needs to be replaced, a single cable can support two traffic lanes on far side of the deck
- Loss of Complete Hanger – would not collapse nor incur permanent damage



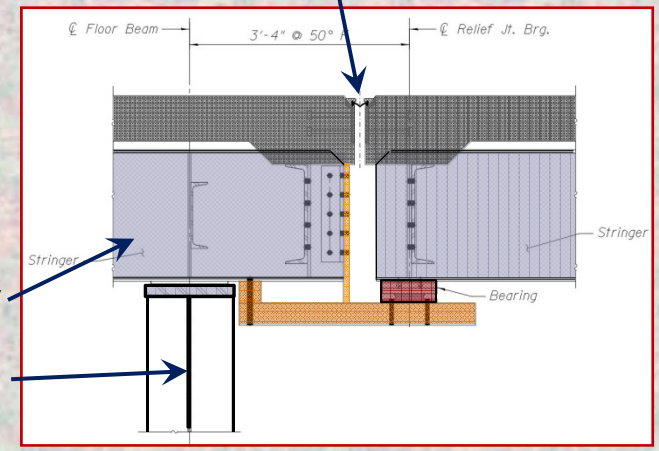
Arch Span Features



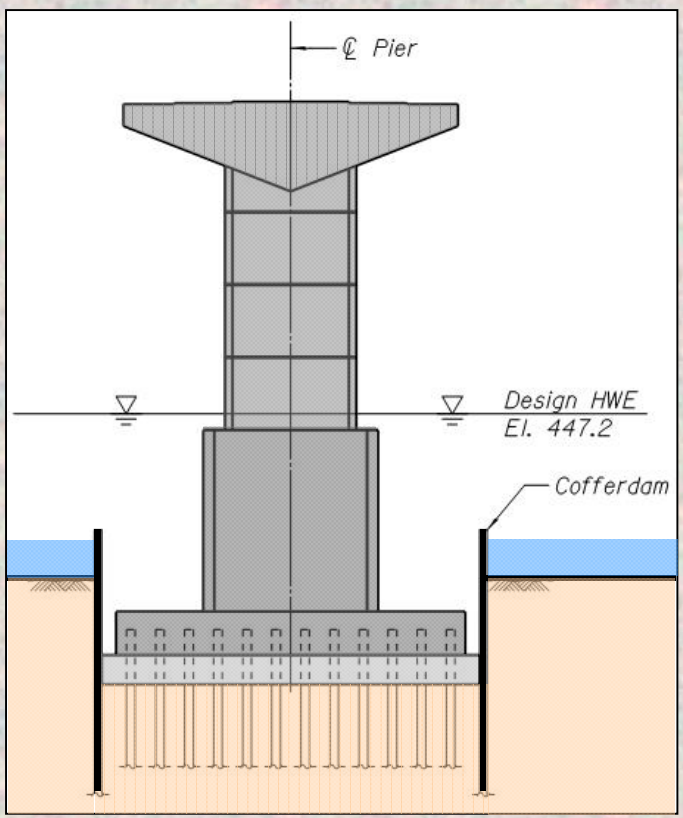
Arch Span Features



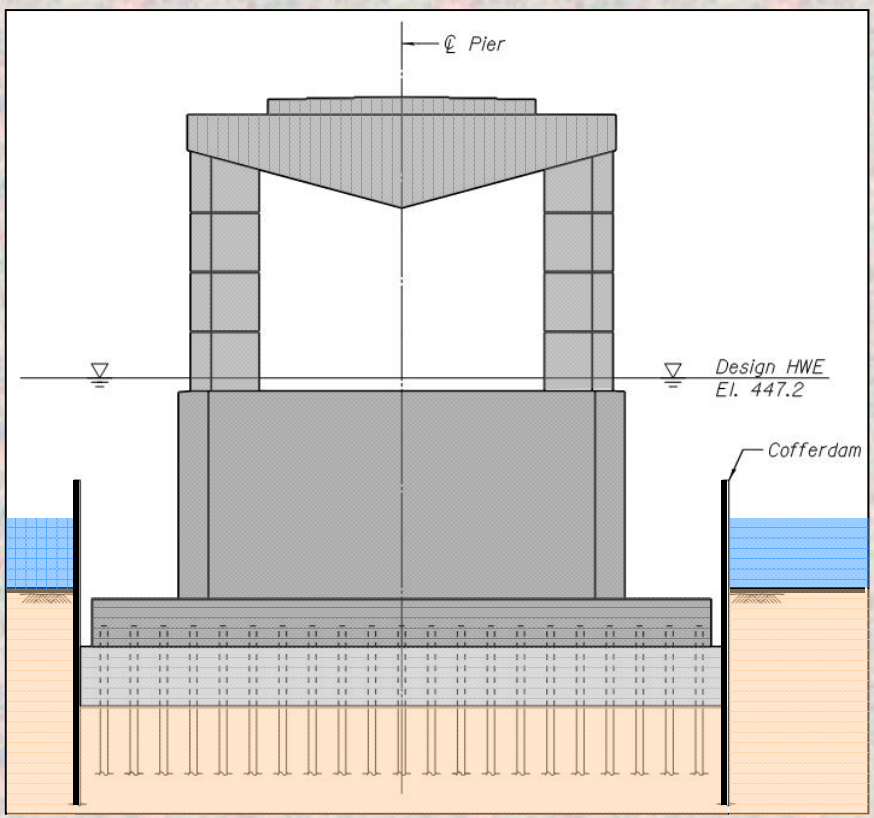
- Relief joints in the deck and stringers uncouple them from the arch structure.
- Allows conventional replacement of the deck and stringers.



Proposed River Bridge – Piers



Approach Piers

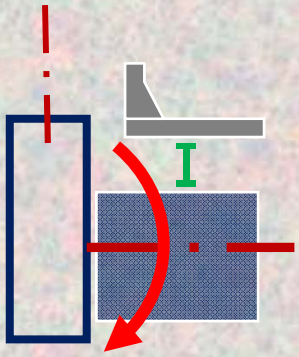


Main Piers

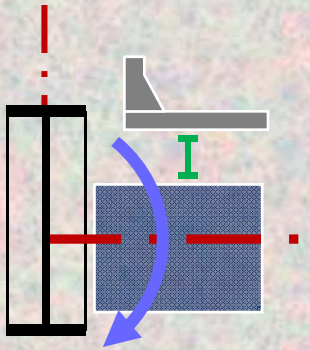
Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. Bridge Design
5. **Innovative Details**
6. Analysis - Design
7. Construction

Tie Girders : I-sections……not Box-sections



Conventional



This Bridge

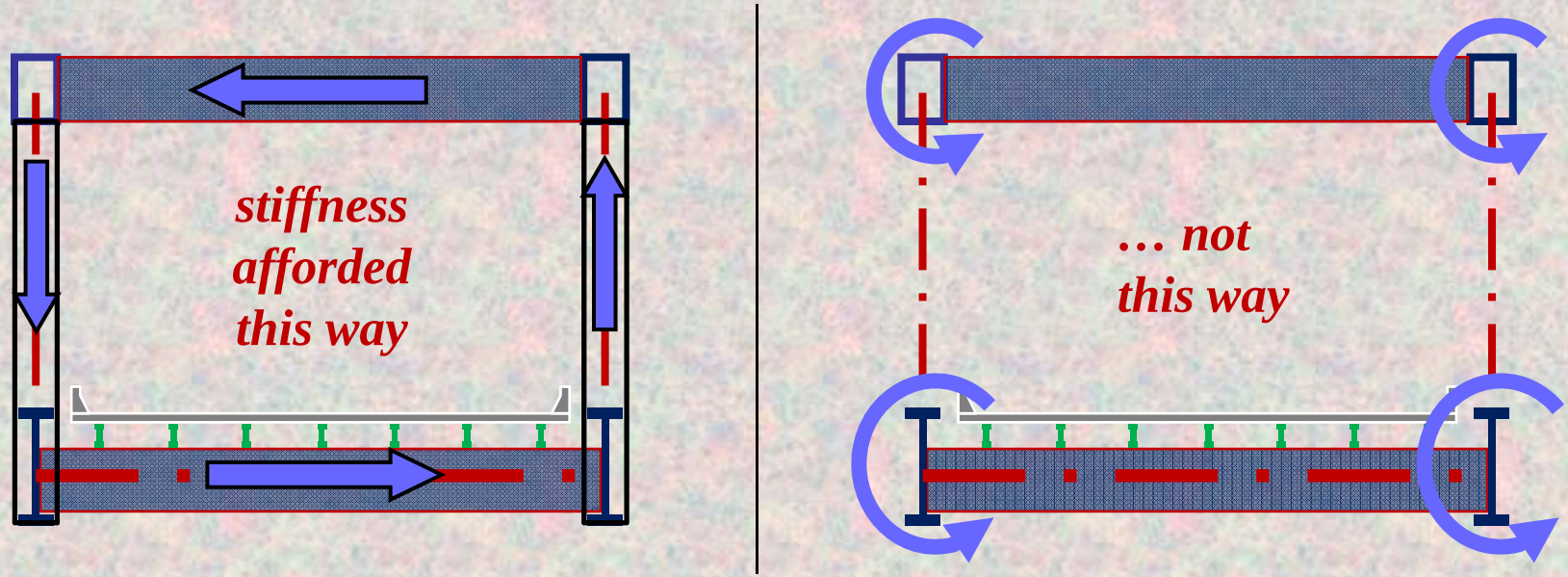
Advantages:

- Very economical
- Greatly simplifies the floor beam connections
- Torsionally flexible; reduces secondary stresses and potential fatigue cracking in FB connections
- Easier to inspect & maintain

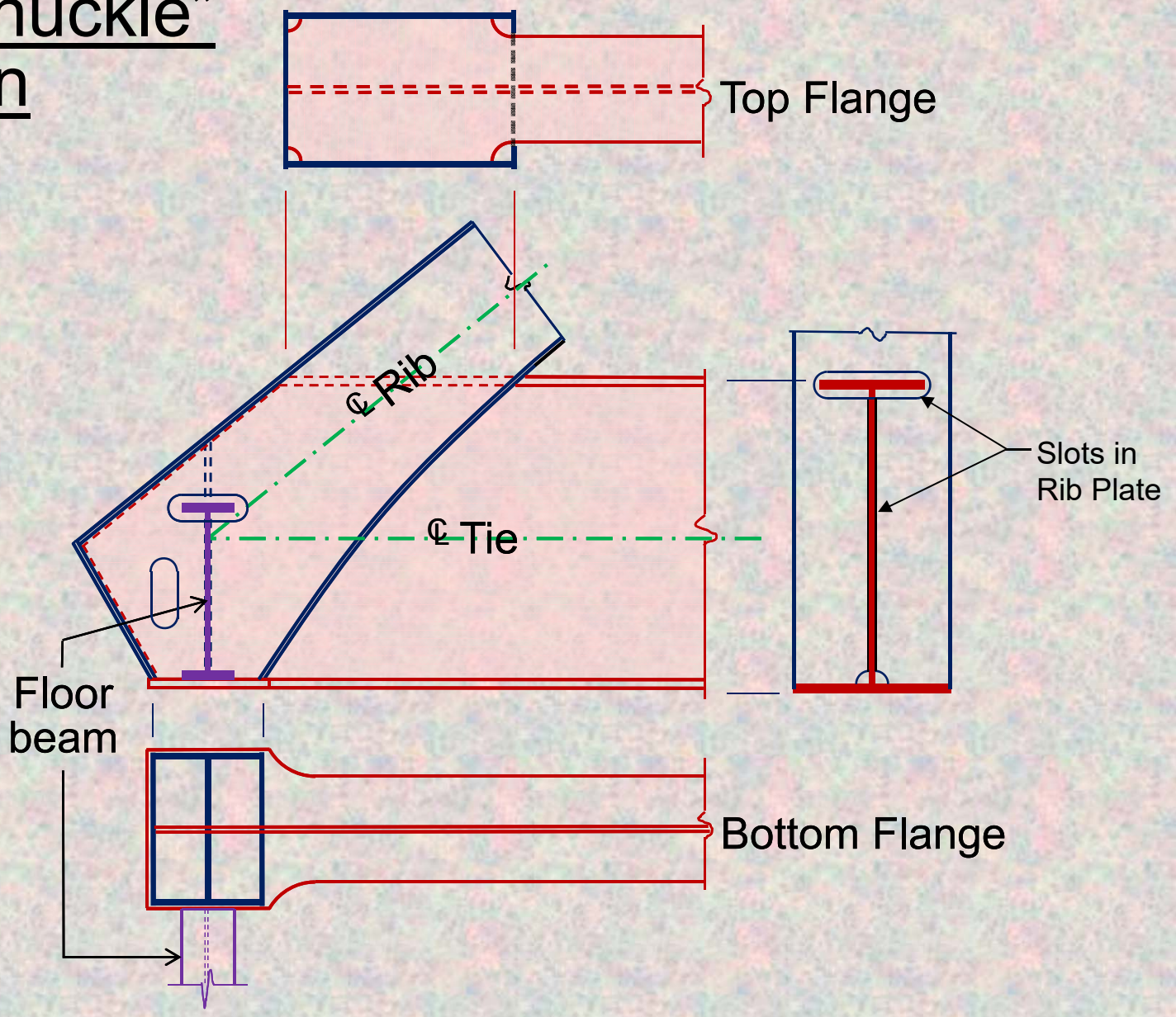
Tie Girders : I-sections……not Box-sections

Overall Torsional Stiffness:

- No loss of overall torsional stiffness of the arch system



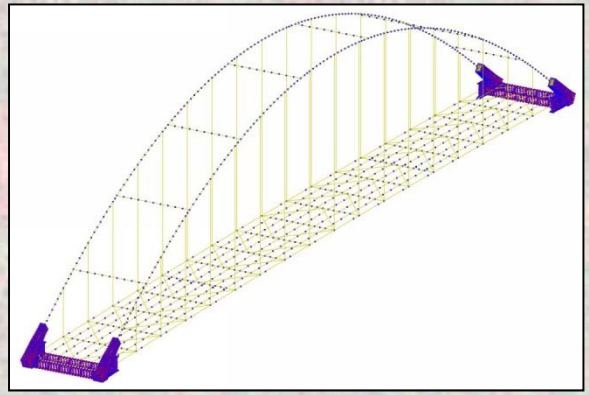
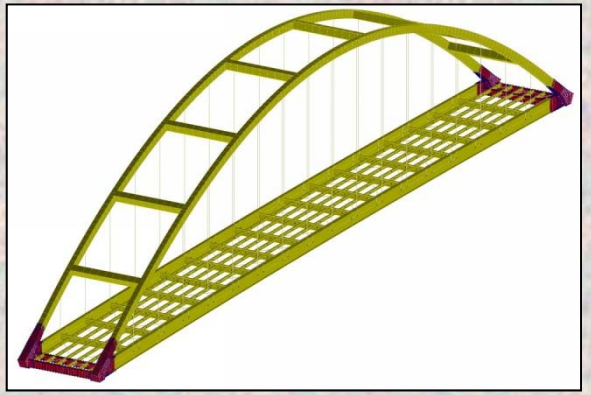
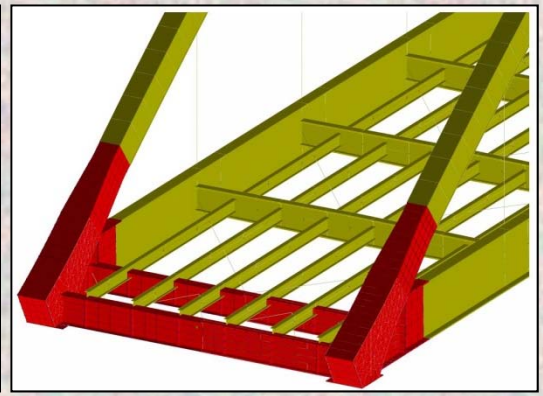
Tie-Rib "Knuckle" Connection



Presentation Outline

1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. Bridge Design
5. Innovative Details
6. **Analysis - Design**
   - ➔ Complex Analysis
   - ➔ Unique Design Loads
   - ➔ Unique Design Checks
7. Construction

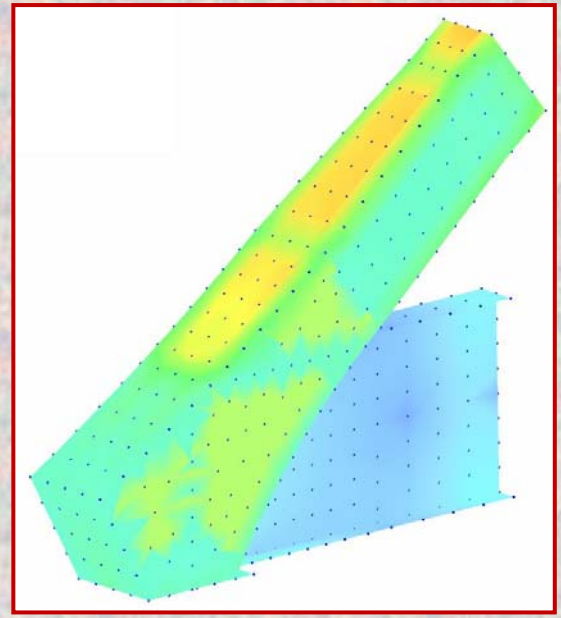
Analysis & Design

- Used LARSA 4D for modeling and analysis
- Modeled as line elements, except plate elements for knuckles and the Floor Beams framing in to the knuckles
- 4,695 nodes

Analysis & Design

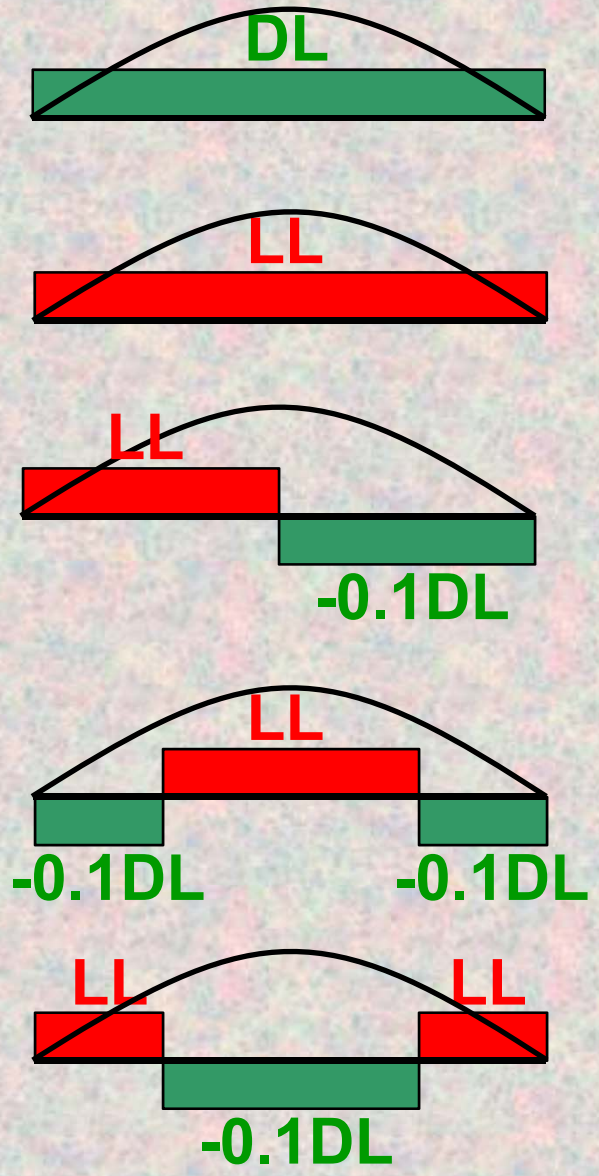
- Live Load – AASHTO HL-93 applied as incrementally moving load
- Variable transverse placements to maximize force effects in various members
- Analysis Data ➔ Force envelopes by member groups
- Strength checks by AASHTO LRFD
- Knuckle behavior not definitive; Stresses checked by stress contours



Unique Design Loads

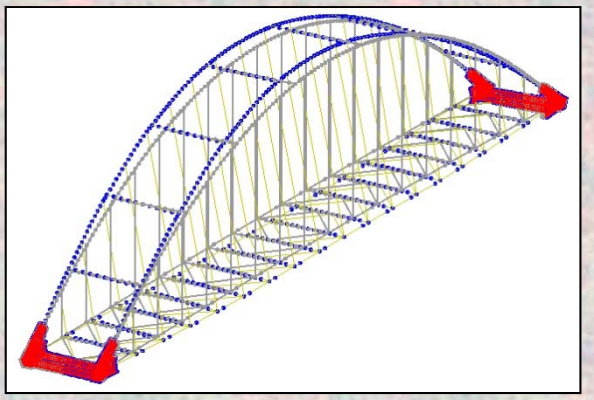
- Nothing in AASHTO on loads specific to arch bridges, which are very sensitive to unbalanced load
- Used these load cases for design:
  - Dead Load
  - Live Load *
  - 10% Dead Load reduction where there is no LL

* Applied as moving loads

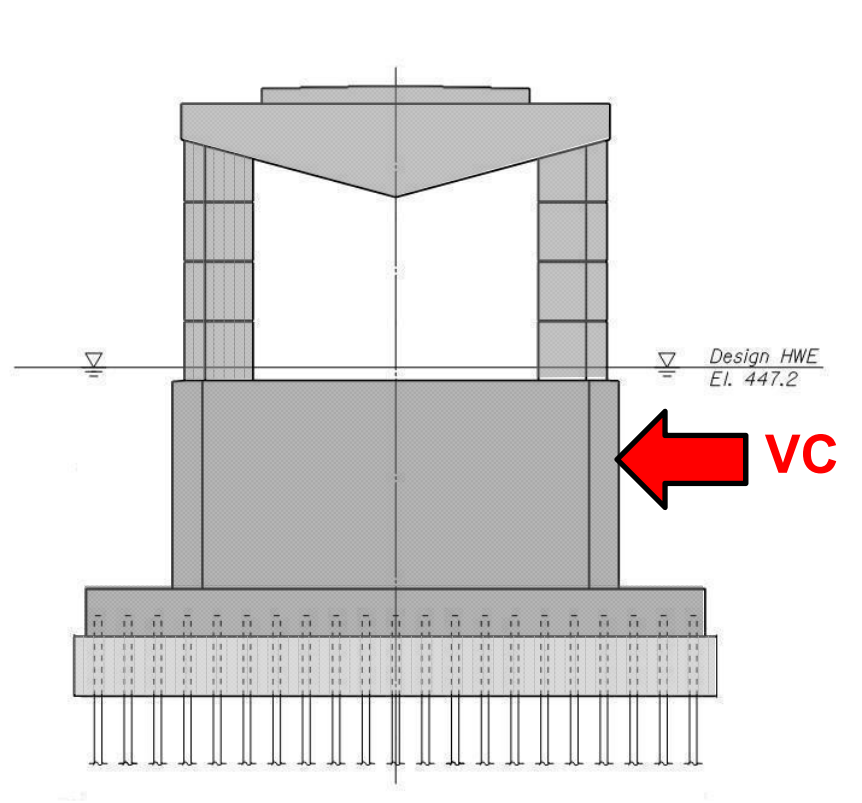


Stability Design of Arch Span

- No guidelines in AASHTO Design Specifications
- Used AISC's **Direct Analysis Method** - commonly used for complex building structures – Most rational & transparent stability design method
- Considered geometric imperfections (L/1000 lateral offset of ribs)
- Considered 20% stiffness reduction to account for unanticipated residual stresses and local yielding
- Performed second-order analysis using LARSA 4D in both vertical and lateral directions
- Strength checks by AASHTO LRFD

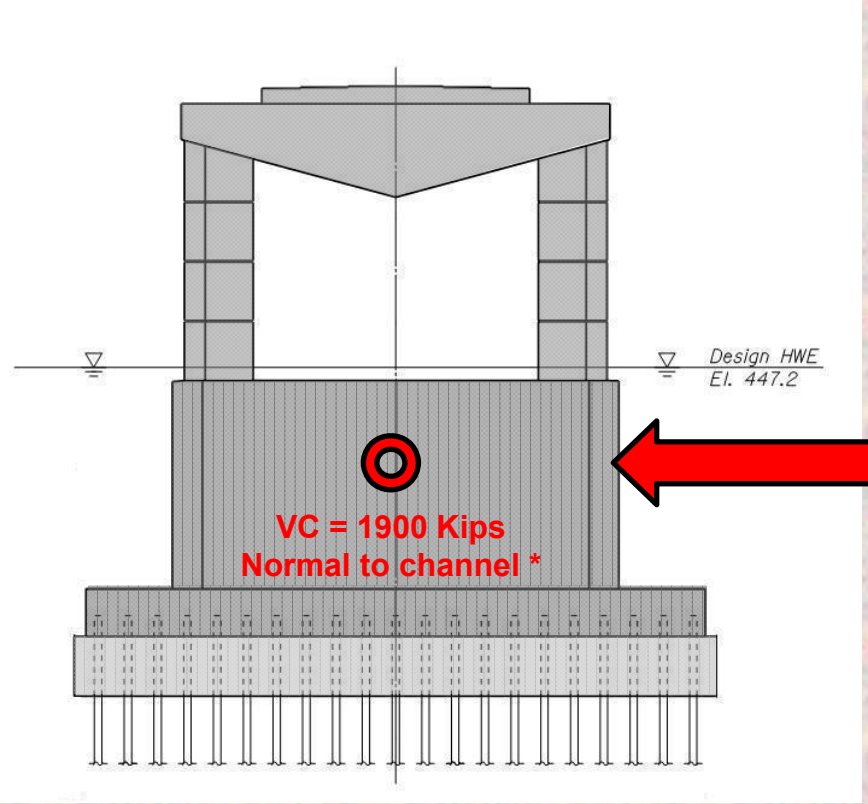


Vessel Collision Design



- River traversed by Large / Heavy Barges
- Operational Classification: **Critical Bridge**
- **VC** Force computed using probability based analysis that considered:
  - Waterway depth & geometry – straight or curved
  - Type, size & frequency of Vessels
  - Vessel direction & speed

Vessel Collision Design



Main Pier

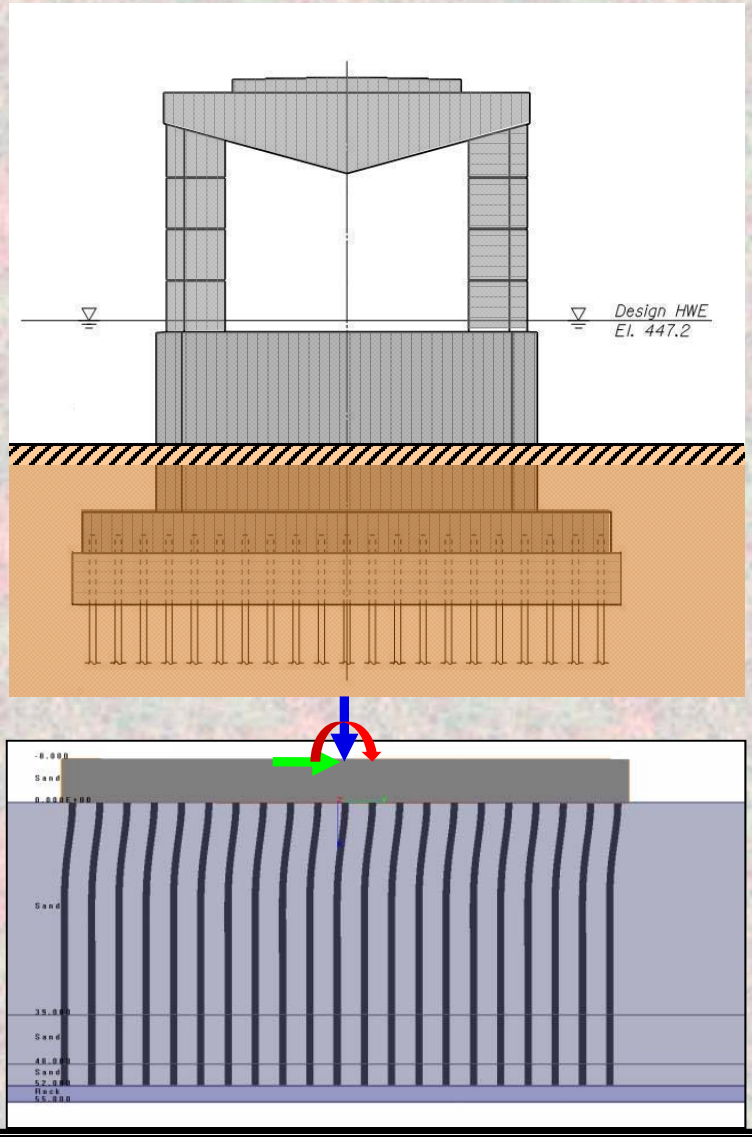
Design Vessel

3x5 (15) Barge Tow

VC = 3800 Kips
Parallel to channel *

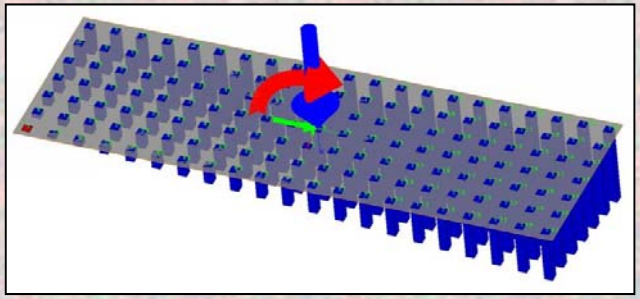
*** Not to be applied simultaneously**

Foundation Design



- All Vertical Piles vs. Battered Piles
- Lateral Load Resistance:
  - Battered piles - Only axial capacity
  - Vertical piles - Axial & bending capacity of piles in conjunction with soil resistance
- Soil Structure Interaction –

  Used "GROUP" by Ensoft for analysis



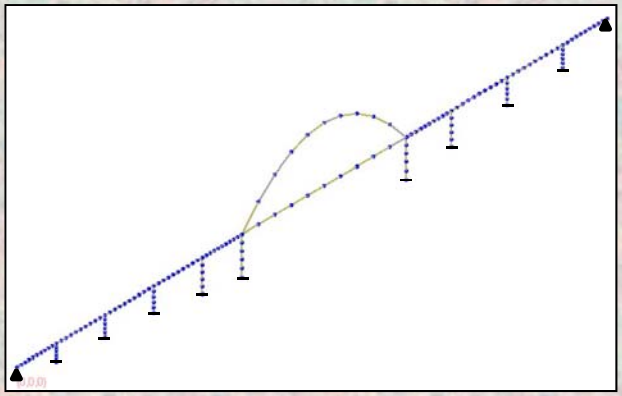
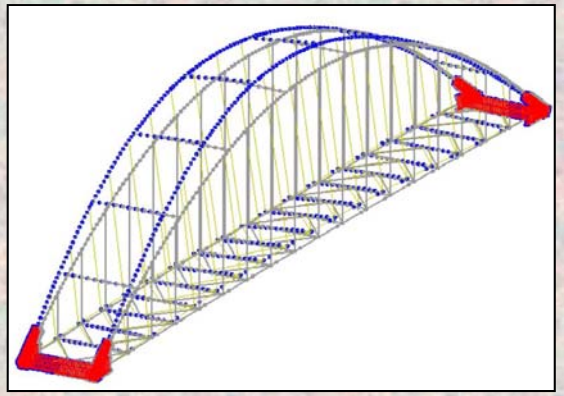
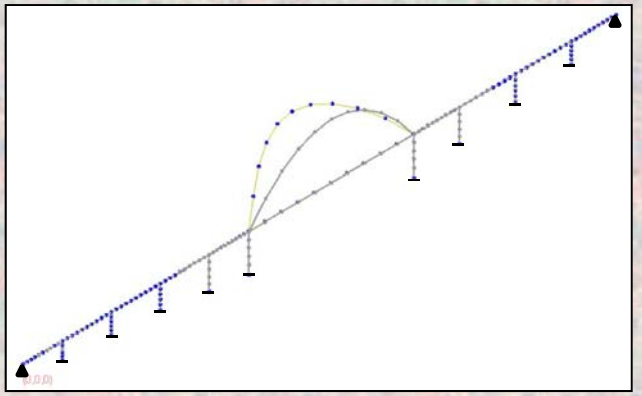
- Economical Design – 40% less piles, smaller foot-print of footing & cofferdam, easier pile installation; $2M saving

Seismic Analysis & Design

- Bridge location: SPZ “2” and Site Soil Classification “E”
- Seismic Design for 2500-year Return Period
- AASHTO provides Seismic Response Spectrum only for 1000-year return period
- Used 2500-year Response Spectrum provided by NEHRP(*) with a “2/3rd” Design Factor – AASHTO equivalent design for 1500-year return period

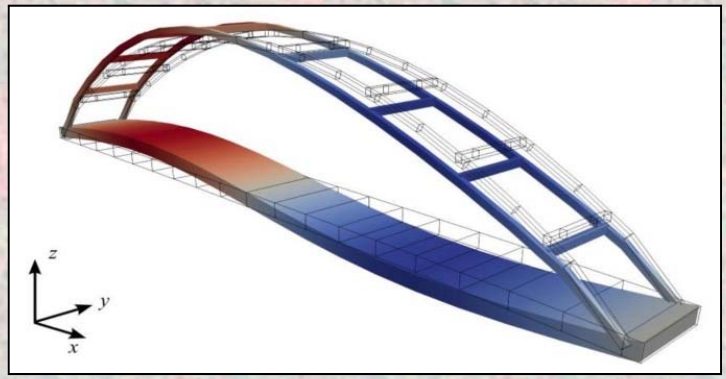
(*) NEHRP = National Earthquake Hazards Reduction Program

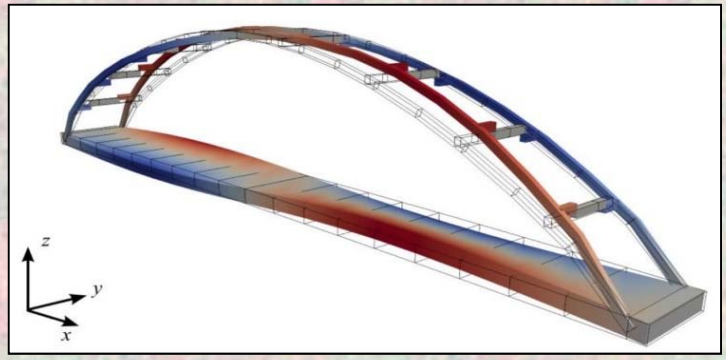
Seismic Analysis & Design

- A simplistic 3D linear elastic model of entire bridge –
  - Approach spans as continuous beams
  - Arch as two beams (parabolic – ribs + struts, straight - tie girders + deck); Equivalent mass and stiffness derived by vibration analysis of the full 3D arch model
  - Piers as vertical cantilevers – mass & stiffness of Piers & Foundations
- Elastic model analyzed for various modes & frequencies; Seismic forces were computed by modal superposition using Complete Quadratic Combination (CQC) method.

Aerodynamic Stability – Study by RWDI





1st Stage:

- Analytical Desktop Study – using Computational Fluid Dynamics analysis
- Vibration modes provided by **exp**
- Findings:
  - Provided Wind Loads for Design (*)
  - Aerodynamic Stability Not Clear
  - Testing Required to Confirm Stability

  (*) Less than AASHTO loads

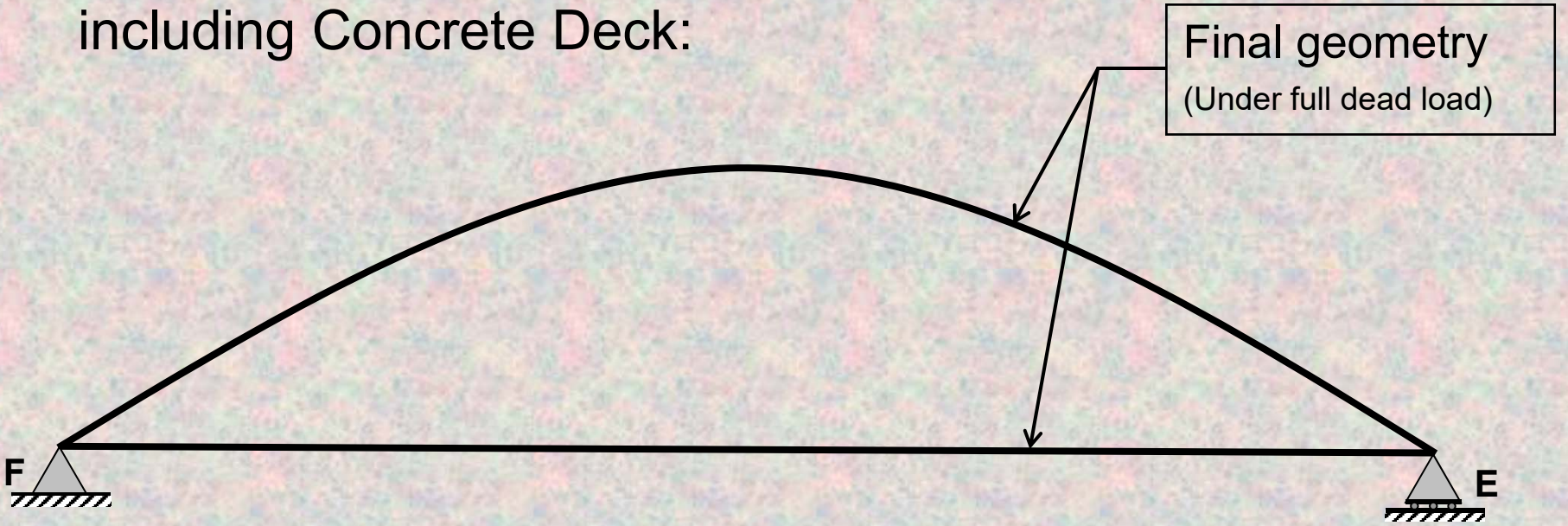
Aerodynamic Stability

2nd Stage:

- Tested Sectional Model in Wind Tunnel
- Investigated stability against flutter, vortex shedding & galloping
- Findings:
  - Confirmed Aerodynamic Stability
  - Flutter - OK
  - Vortex-Shedding Excitation - OK
  - Galloping - OK

Fabrication Geometry & Pre-stressed Assembly

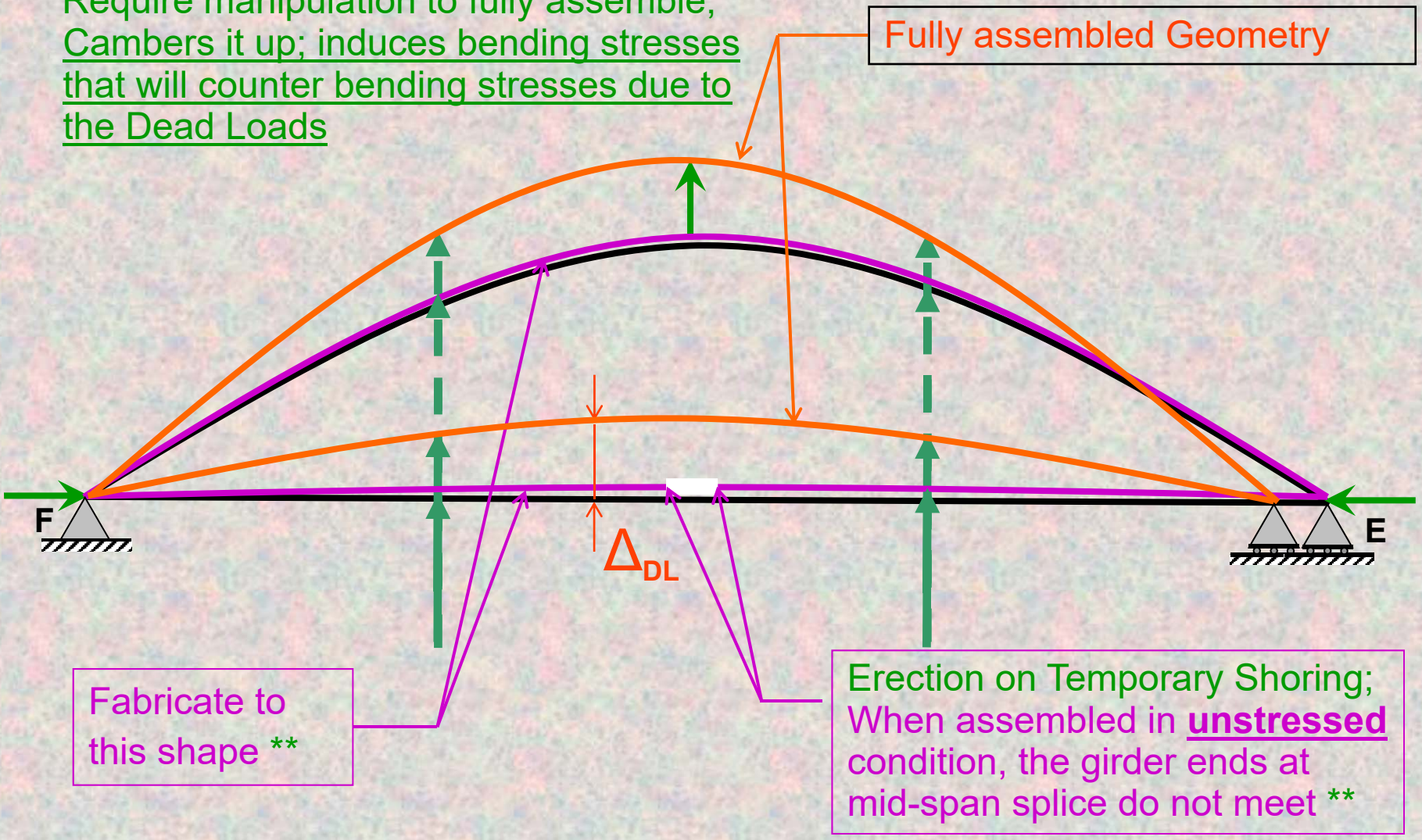
Fully Constructed Arch Span
including Concrete Deck:



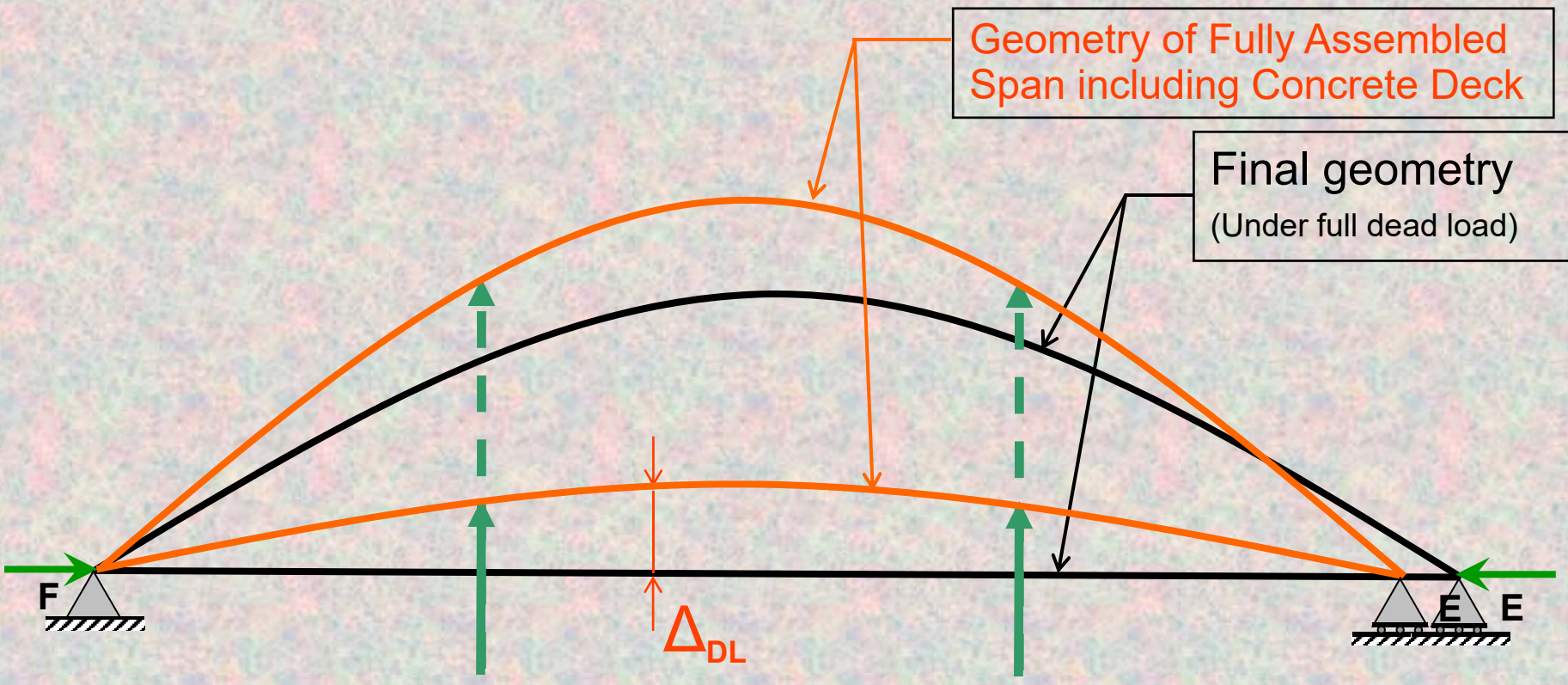
- Conforms to theoretical Roadway Profile after DL displacements
- Has Minimal Flexural Stresses due to Dead Load

Fabrication Geometry & Pre-stressed Assembly

** Require manipulation to fully assemble; Cambers it up; induces bending stresses that will counter bending stresses due to the Dead Loads



Fabrication Geometry & Pre-stressed Assembly

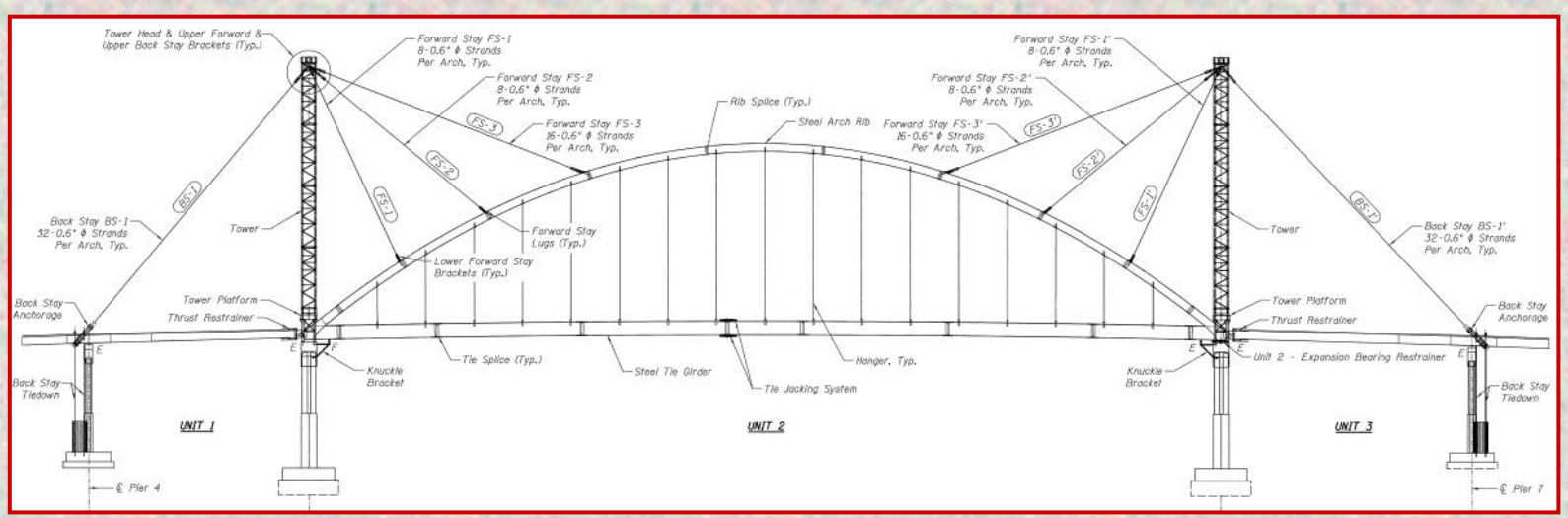


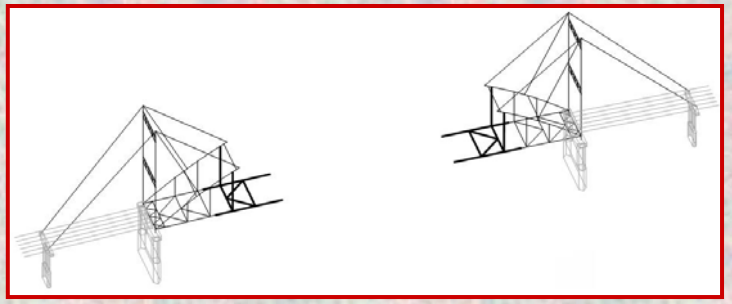
The fabrication geometry was computed working backwards to account for the deflections and bending stresses due to the dead loads

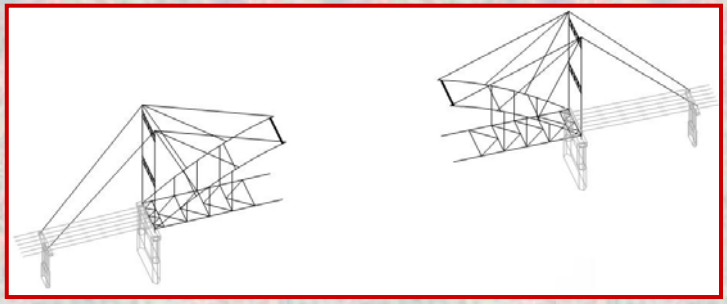
Presentation Outline

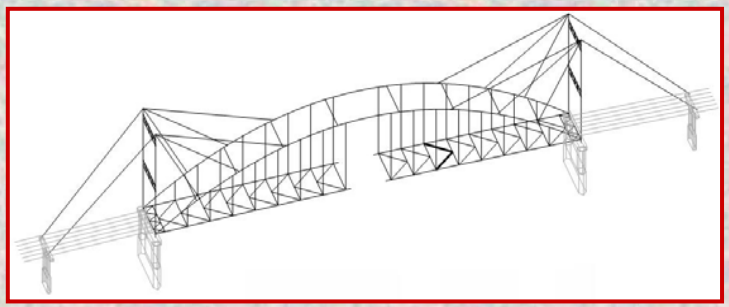
1. Project Overview
2. Phase I Study (Preliminary Engineering)
3. Bridge Type Study
4. Bridge Design
5. Innovative Details
6. Analysis - Design
7. **Construction**

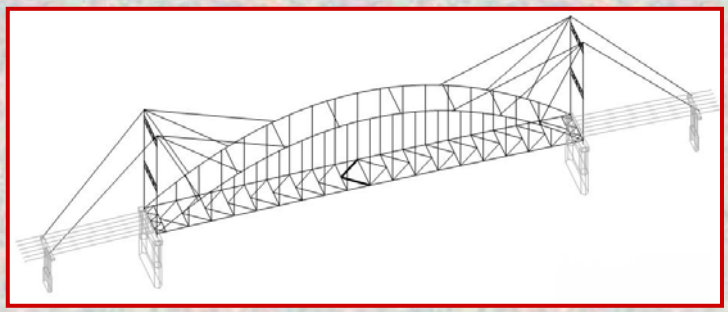
Arch Erection (engineered by Hanson Engineers)



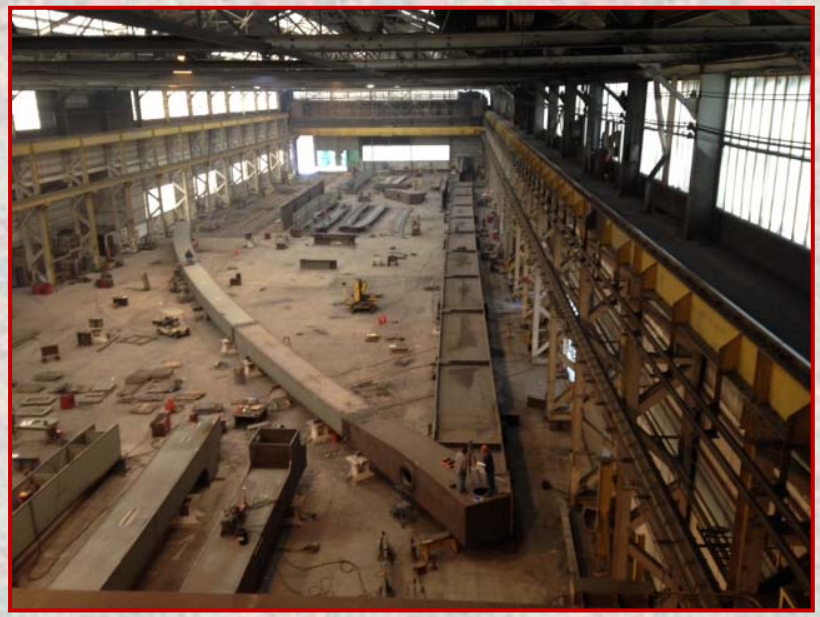




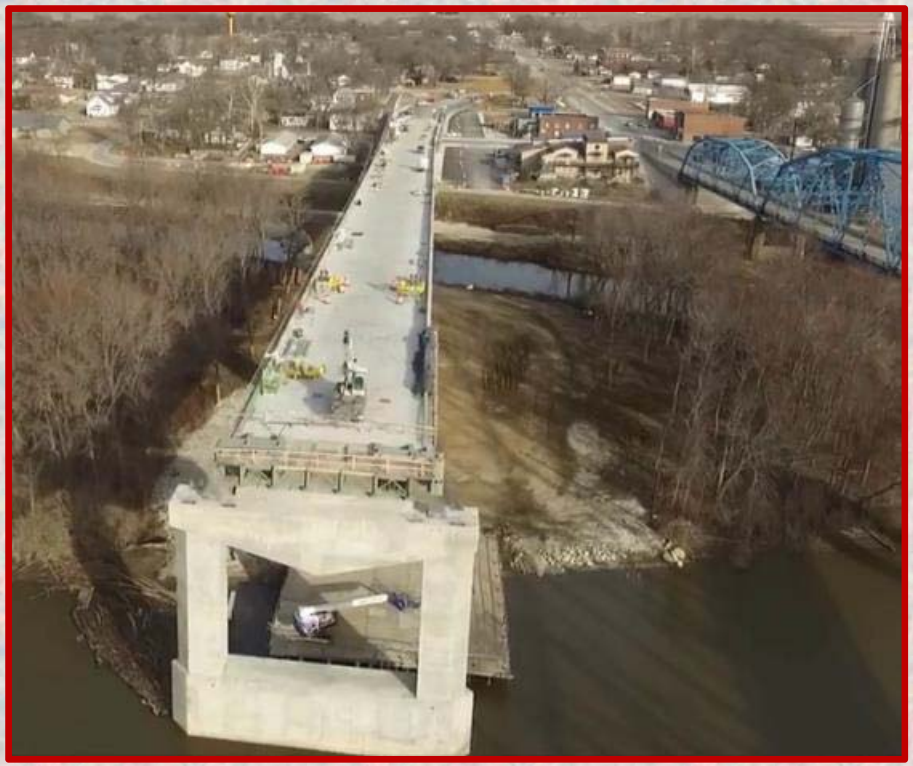




Steel Fabrication / Shop Assembly



Construction – February 2017



East Approach Unit
(looking east)

West Approach Unit
(looking west)

Acknowledgements

Client:	Illinois Department of Transportation, District 6 IDOT Bureau of Bridges & Structures Springfield, IL
Geotechnical:	Wang Engineering, Lombard, IL
Peer Review:	Alfred Benesch Co., Chicago, IL
Wind Engr'g.:	RWDI, Ontario, CN
Contractor:	Halverson Construction Co., Springfield, IL
Fabricator:	Industrial Steel Construction, Gary, IN

Questions?