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Resilience and Repair of Major Steel Bridges
December 2, 2021

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Course Description – Submitted for AIA CE Credit

Resilience and Repair of Major Steel Bridges
December 2, 2021

Building on over a decade of collaboration on major steel bridge emergency response projects, our speakers will highlight multiple major steel bridge rehabilitation and emergency-response projects where collaboration between owners, designers, fabricators, contractors and others was essential in returning a critical steel bridge to service. Examples include bridges that were rehabilitated after critical inspection findings and reconstruction due to extensive damage.

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Learning Objectives – Submitted for AIA CE Credit

- Describe several retrofit details that can be considered to repair an existing tension member.
- List the types of structural analysis models that might be considered to better understand the nature of a structure in need of repair.
- List several non-destructive testing methods for the inspection of structural steel.
- Identify leadership and communication strategies that should be implemented for time-sensitive projects.

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Resilience and Repair of Major Steel Bridges

Francesco Russo, PhD, PE
Founder & Principal
Russo Structural Services
Philadelphia, PA

Jason Stith, PhD, PE, SE
Bridge Technical Manager
Michael Baker International
Louisville, KY

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Presentation Outline

- **Introduction**
- **Sherman Minton**
- **Eggner's Ferry**
- **Delaware River**
- **Brent Spence**
- **Hernando de Soto**
- **Lessons Learned**

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Sherman Minton Bridge Emergency Repair 2011

Michael Baker INTERNATIONAL

INDIANA DEPARTMENT OF TRANSPORTATION INDOT

KENTUCKY TRANSPORTATION CABINET

U.S. Department of Transportation Federal Highway Administration

FISH & ASSOCIATES, INC.

PURDUE UNIVERSITY

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Louisville Metro Area

- Location
  - I-64 over Ohio River
  - Link between IN & KY

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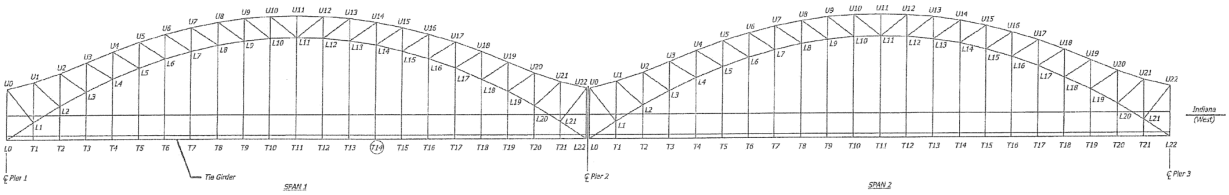
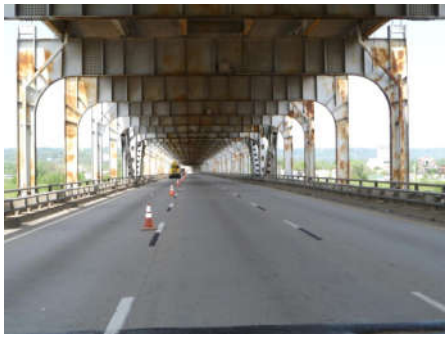
Sherman Minton Bridge Inspection



ELEVATION

- Initial Scope
  - Fracture Critical Bridge Inspection
- Structure Information
  - FC Steel Tied Arch Built 1961
  - 2 – 800’ Spans
  - Double-Deck Structure



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What’s special about this bridge?

- Type of material
  - “T1” steel - antiquated
    - VERY high strength steel
    - Susceptible to fracture at cold temps and with small cracks
- Sensitive details
  - Arch tie welds
  - Diaphragm plates
  - Lateral bracing details

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Leadership Challenge #1

- Tell the owner the bad news before we even get started
  - History of cracking, first noted in 1981
    - Other studies 1992, 93, 94, 95, 99, 2004, 06, 07
  - What we are about to do will find more
  - Be prepared for the news to get worse, not better

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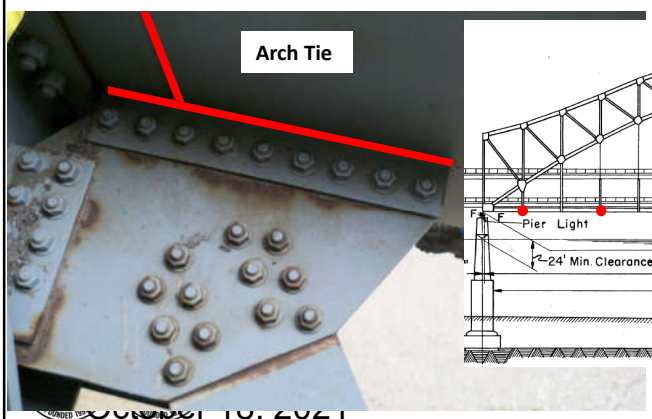
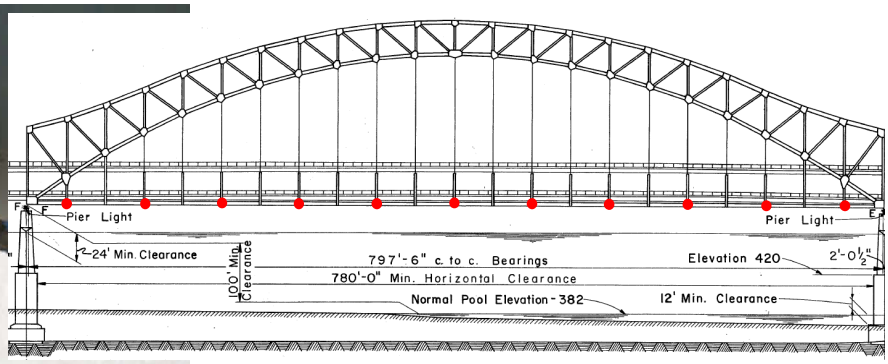
Lateral Bracing Plates

- 11 panels x 2 plates per panel x 2 arch ties x 2 spans = 88 connection plates





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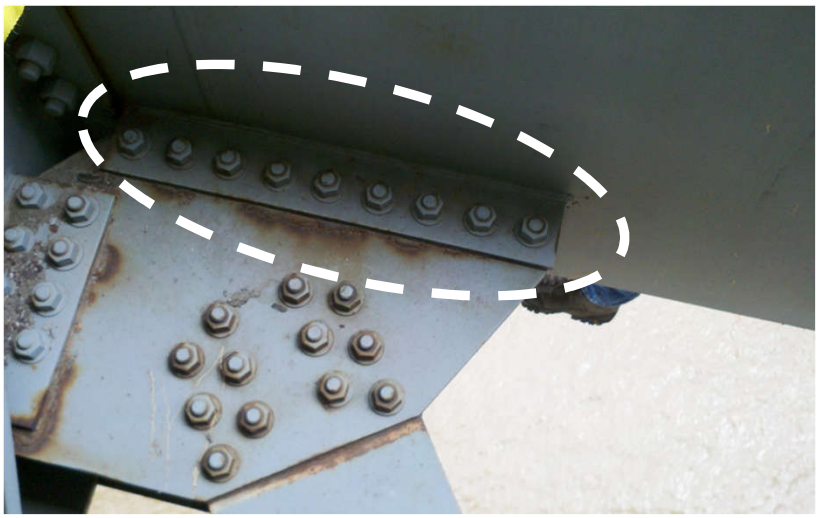
Enhanced Inspection / Preemptive Retrofit

- Remove the lateral bracing plates to inspect what's behind them



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Enhanced Inspection / Preemptive Retrofit

Core the plates and welds and test the materials

Over 300 individual tests were conducted

Conclusion - steel is susceptible to fracture at mild temperatures in the presence of cracks we suspected were out there

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Lateral Bracing Plates

In this connection alone, over 20 cracks were "hiding" behind the connection plate.

Only several days into the preemptive retrofit, the bridge was closed.

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Leadership Challenge #2

- Help the owner manage a crisis
- Activities
  - Complete all remaining testing and plate removal
  - Develop multiple retrofit solutions
  - Agency public information needs
  - Oversight briefings, nearly constant

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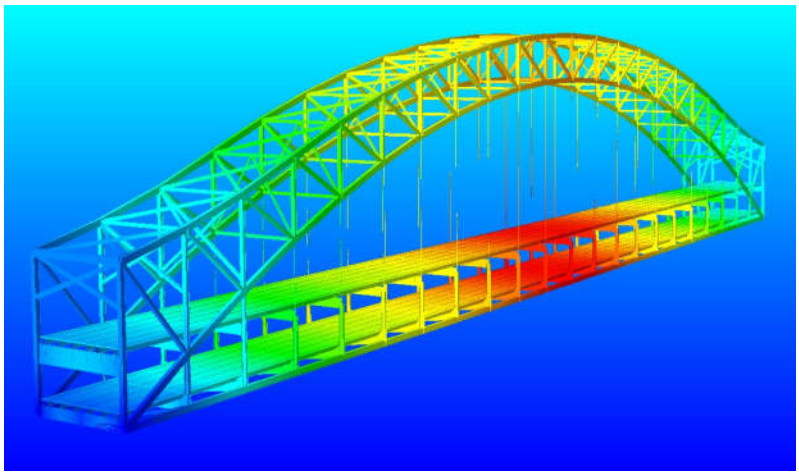
Chosen Retrofit

Global Plating solution chosen 9/27 (Day 16)

Provide a complete "replacement tie" by adding new High Performance Steel retrofit plates for the entire two spans



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Leadership Challenge #3

- Deliver the design in a very compressed schedule
  - NTP on final solution, 9/27
  - Advertisement, 10/4
  - Full design, 20 drawings, specs, 8 days, no sleep

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Discovery and Solution Timeline

- September 9: Bridge Closure, 3 weeks after the start of the Intermediate Repair
- September 27: NDT Completion & Decision to do Global Plating Option
- October 4: Advertisement of Contract Documents
- October 18 : Open Bids & start construction!!

- The Sherman Minton Bridge was returned to service on February 17, 2012.

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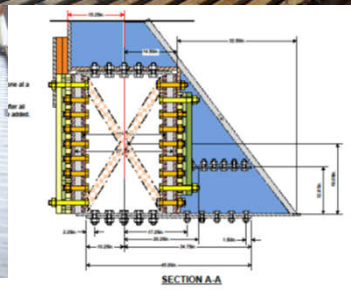
Global Plating Option



A+B Contract

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Eggner's Ferry Span Replacement

"This is the future of bridge design and construction"
- Walter Gatti

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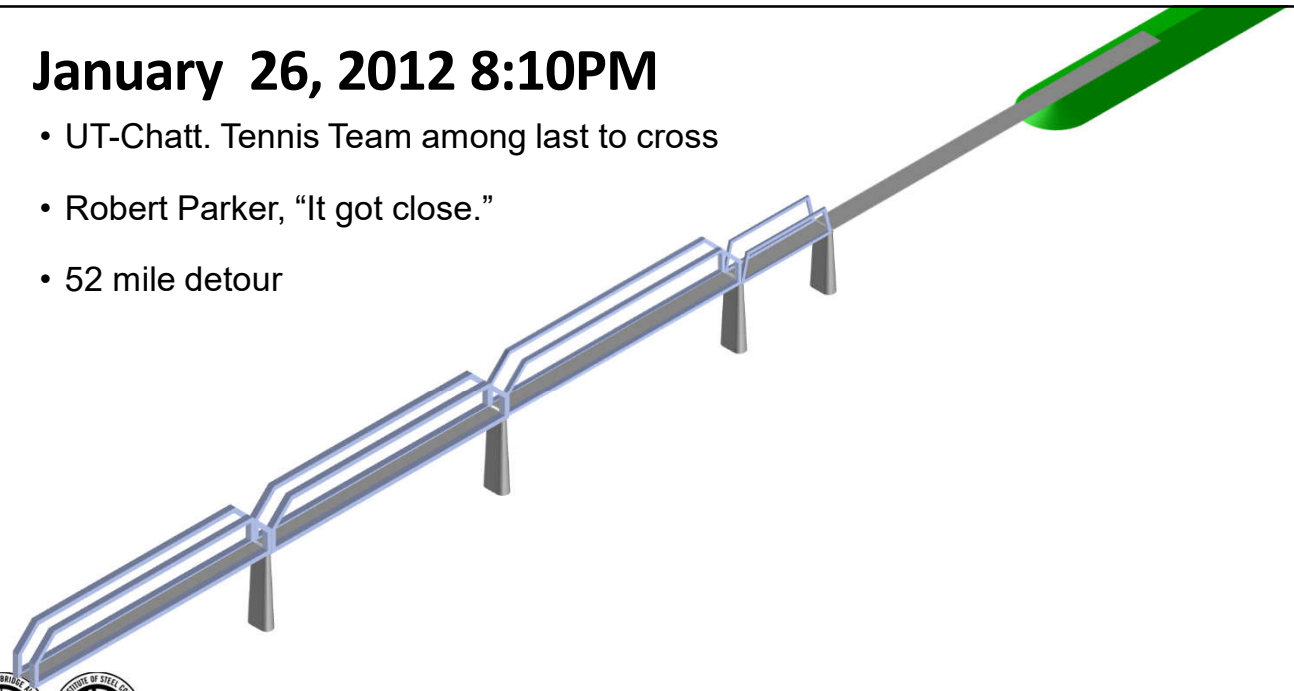
January 26, 2012 8:10PM

- UT-Chatt. Tennis Team among last to cross
- Robert Parker, “It got close.”
- 52 mile detour



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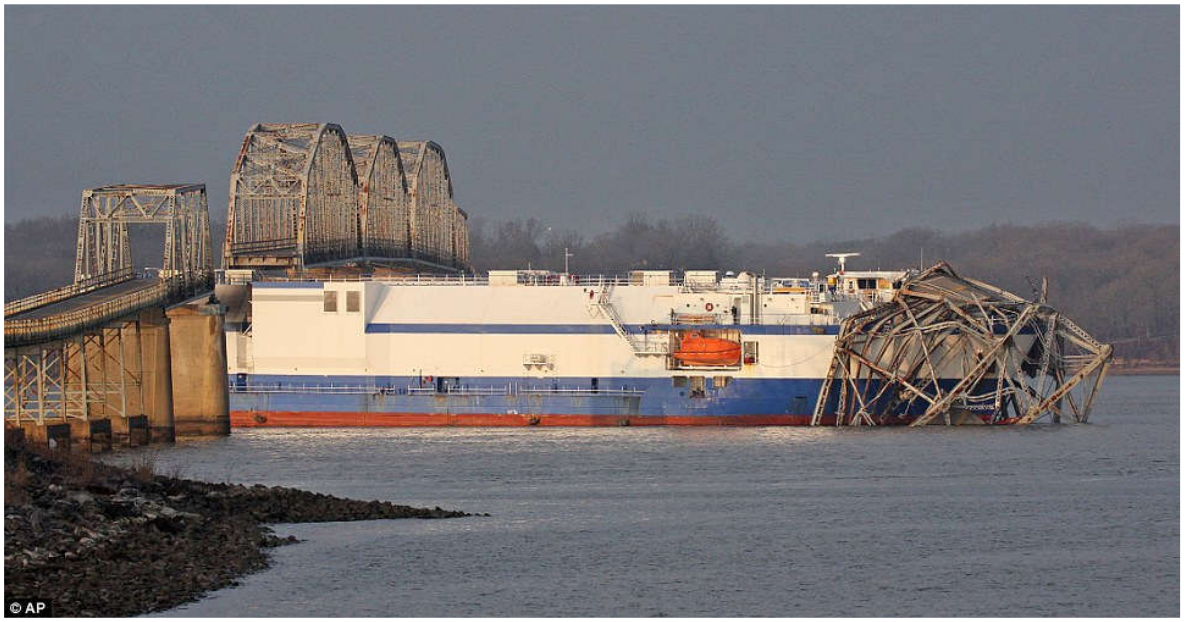
The next morning…



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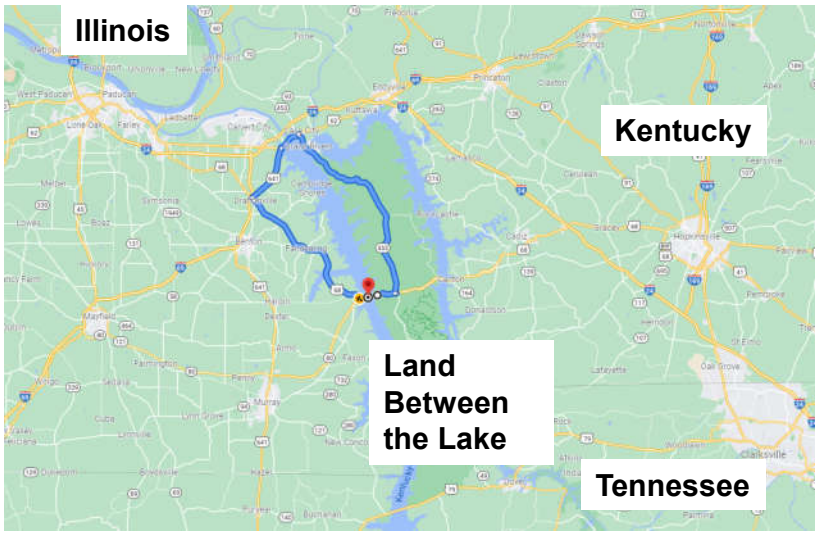
- Located in W. Kentucky



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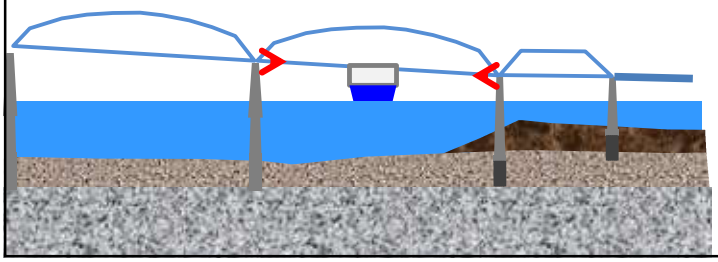
Replacement Considerations

- Prefab 2 Span (Acrow) Bridge
- 3 span Steel Plate Girder
- Nickajack Bridge Reuse
- New Single Span Truss



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Expediting Procurement

January 26th Accident

- Simple Span Truss

Adv. Date: February 27, 2012

- Procurement thru Div. of Purchases
- Addendum 1 – March 2, 2012 (30% Plans)
- Addendum 2 – March 5, 2012 (WSPG and Rolled Sections)

Bid Date: March, 7, 2012

Open to Traffic: May 27, 2012 (Memorial Day Weekend)

- $50,000/Day Penalty

Award and Execution

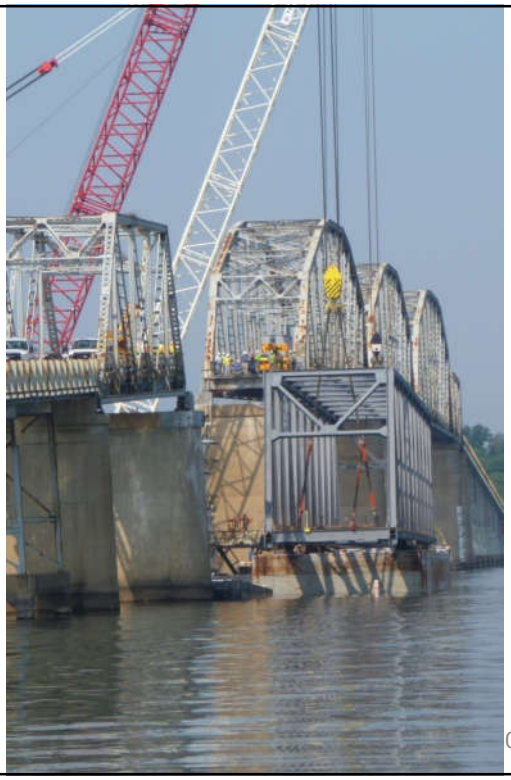
Awarded: 03/07/2012

3 Bids Received

- $7M
- $11.2M
- $11.4M

Contractor: Hall Contracting - $7M

- Designer: Michael Baker
- Fabricators:
  - Beam/Angles – Padgett, New Albany, IN
  - Gussets – United Steel, Louisville, KY



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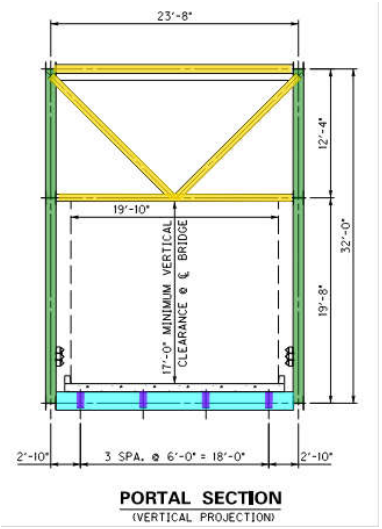
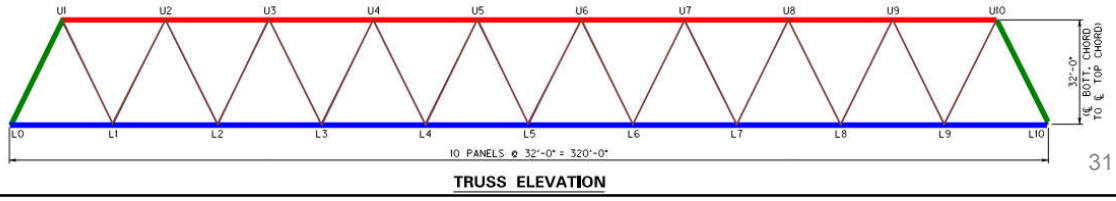
Simple and Repetitive

Structural Steel Material List

- *18 - HP 16x183 Top Chord*
- *36 - HP 16x88 Diagonals*
- *20 - HP 16x121 Bot Chord*
- *4 - HP 16x183 Portals*
- *84 – ¾" Gusset/Connection Plates*
- *24 – W12x40 Struts*
- *11 – W24x103 Floorbeams*
- *40 – W18x86 Stringers*
- *13,000 – 1" Dia Bolts*





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Lifting Truss

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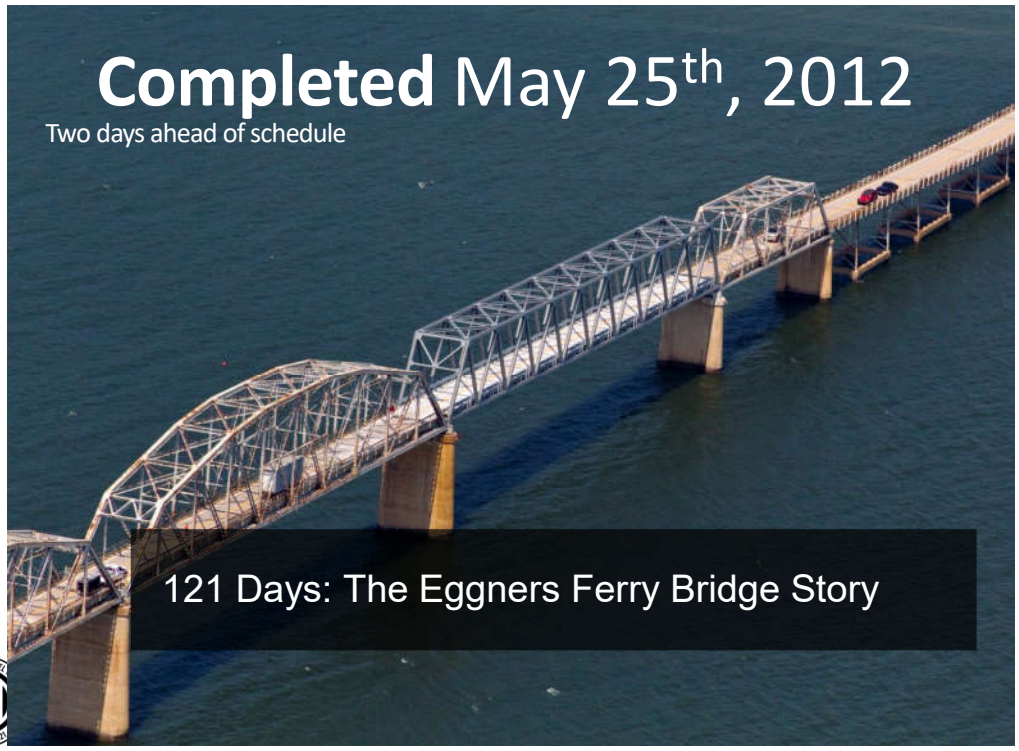

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Lessons Learned

Trusted Partnerships

Quick Decisions

Keep it Simple

- **Simple but Efficient**
- **All Rolled Sections**
  - **No Shop Welding**
  - **Minimal Fabrication**
- **Use Technology**
  - **Digital File Sharing**
  - **Hi-Tech Fabrication**
  - **13,000 Bolts, No Misfits**

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Delaware River Bridge

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Delaware River Bridge

- 1.2-mile-long, 4-lane bridge
- Jointly owned by the PA Turnpike Commission and New Jersey Turnpike Authority
- Carries I-276 (now designated I-95) over the Delaware River
- Opened to traffic on May 23, 1956
- Carries more than 42,000 vehicles per day

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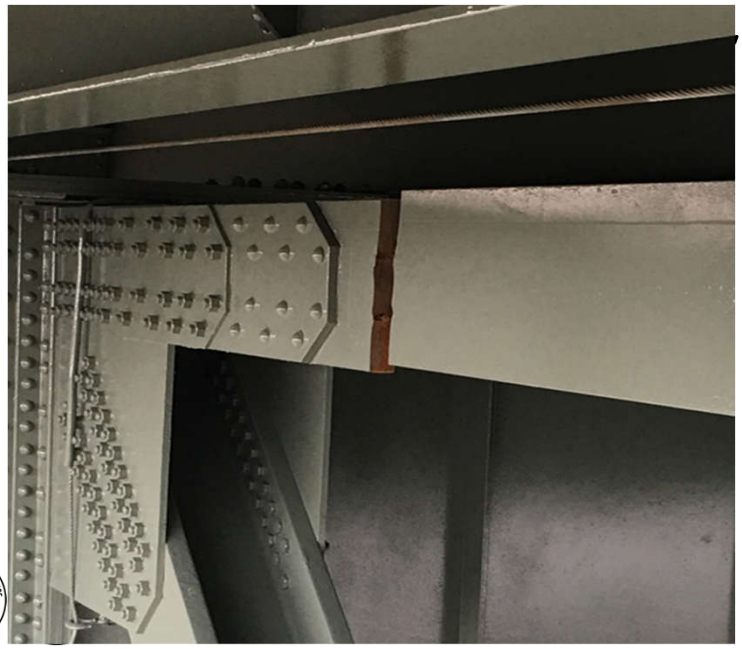
Expect the Unexpected – Usually



The Leadership Challenges

- Management – of many things and many people
- Moving goalposts and evolving demands
- The need for sound technical judgements
- Communicating highly technical information to various non-technical personnel at many levels
- Keeping on top of all the immediate needs, finding time to plan for long lead items

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Management Challenges … a Partial List

- Traffic management and agency coordination
- Public communication
- Organize resources
  - Two clients, PA and NJ turnpike
- Establish on-site and home office dedicated “war rooms”
- Communications – hourly, daily, weekly, etc.
- Utilize agency General Consultant Engineers
  - Michael Baker (PA), HNTB (NJ)
- Utilize resources already on-site or in area
  - Allied Painting, Cornell, STV
  - Urban, PKF
- Secure additional services from many small businesses

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Immediate Action Plan

- Close the bridge
  - Traffic impacts
  - Public relations
  - Mobilize agencies and on-call consultants
  - Clear the bridge of all non-essential items and personnel
- Will the bridge collapse?
  - Install temporary stabilizing splices
- Is that good enough?
  - Install shoring towers
- Can the bridge be saved?
  - Investigation, testing, forensic engineering

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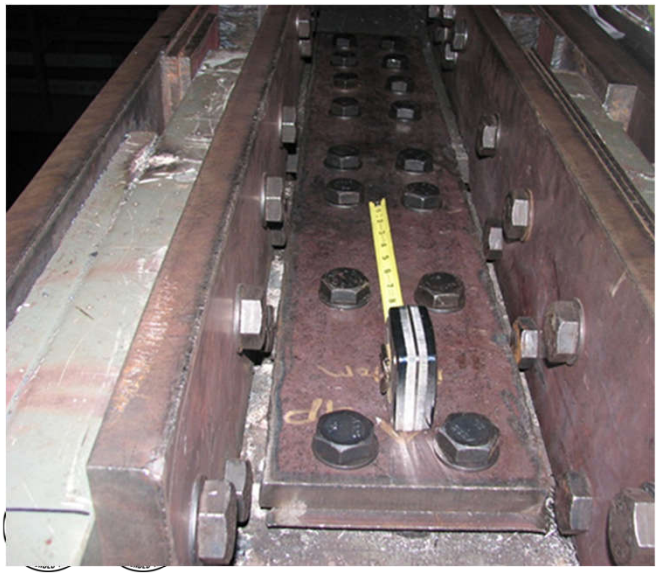
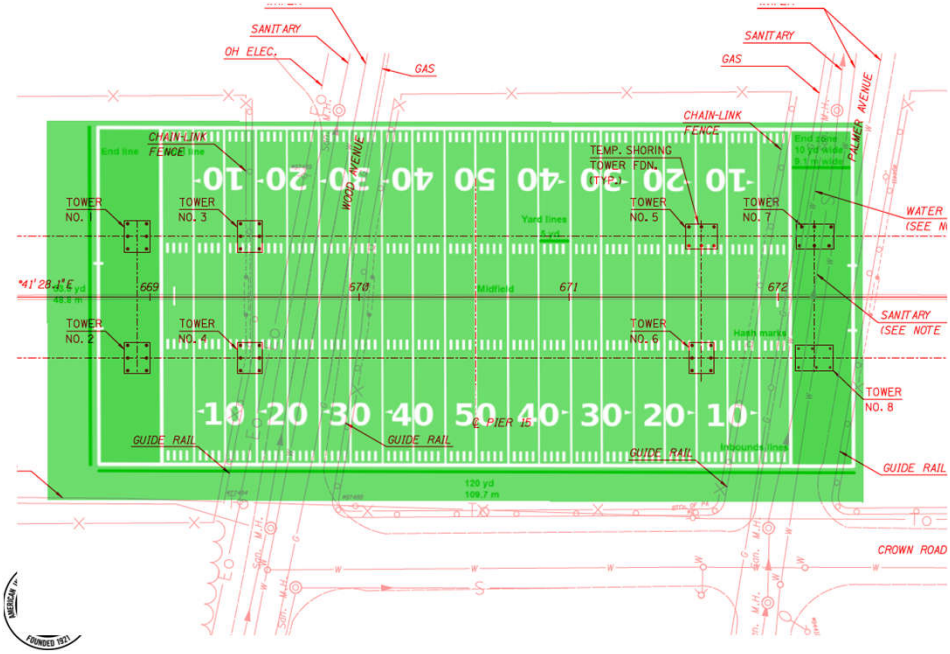
Days 1 – 3: Design, Fabricate, Install a Splice



Coordination and Site Constraints



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Shoring / Jacking Towers

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Assign a Point Person for Everything

- Utility coordination and relocation
- PennDOT / NJDOT and local agency coordination
- Document retrieval
- Project communications
- Field work / repair playbook
- Bridge inspection
- Splice design
- Shoring towers
  - Structures, Geotech, construction
- Material sampling and testing
- Nondestructive evaluation
- Structural analysis / rehab design

- All disciplines had a single point of contact
- Mandatory AM and PM meetings for double-shift work the first few weeks
- Probably 15 – 20 key people needed just to run this job

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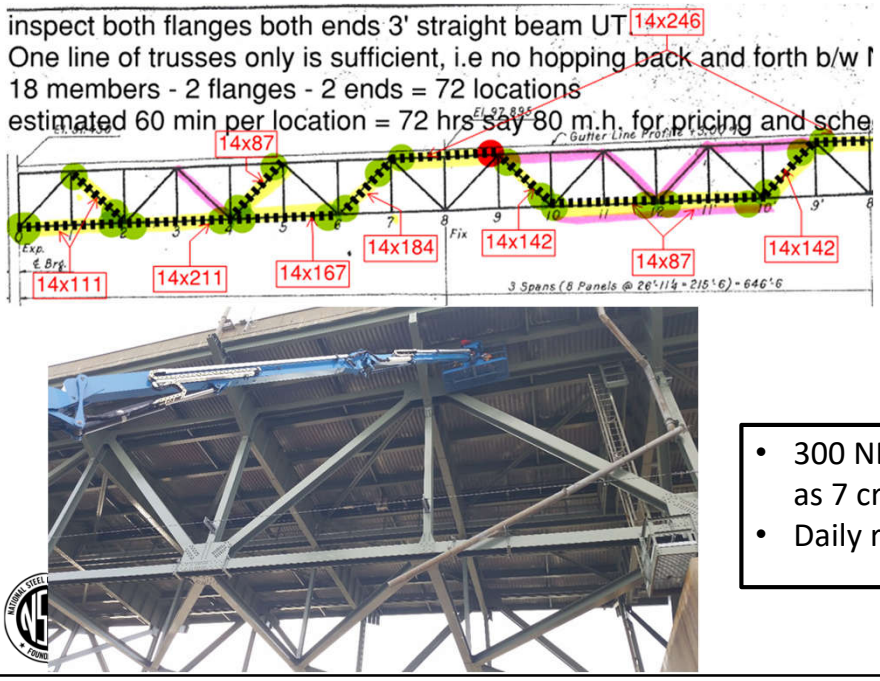
Was This Problem Unique?



- 300 NDT tests performed by as many as 7 crews working simultaneously
- Daily reporting of results

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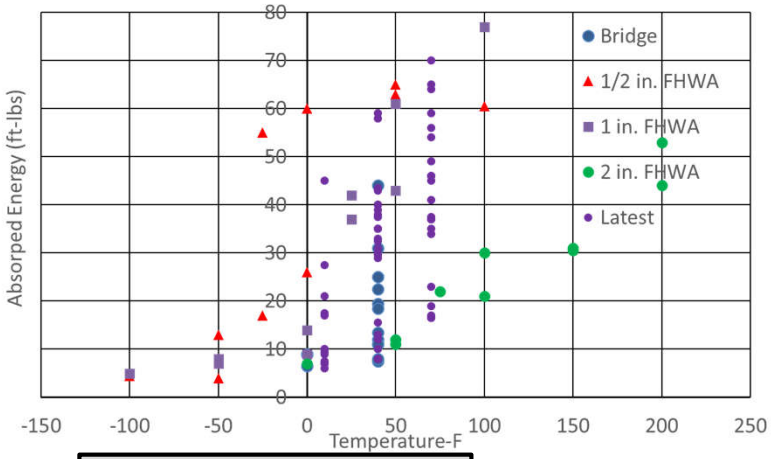
Is the Material Suitable?



- 240 CVN samples
- 10 Tension
- 4 CT specimens
- Chemistry
- Examination of fracture surfaces

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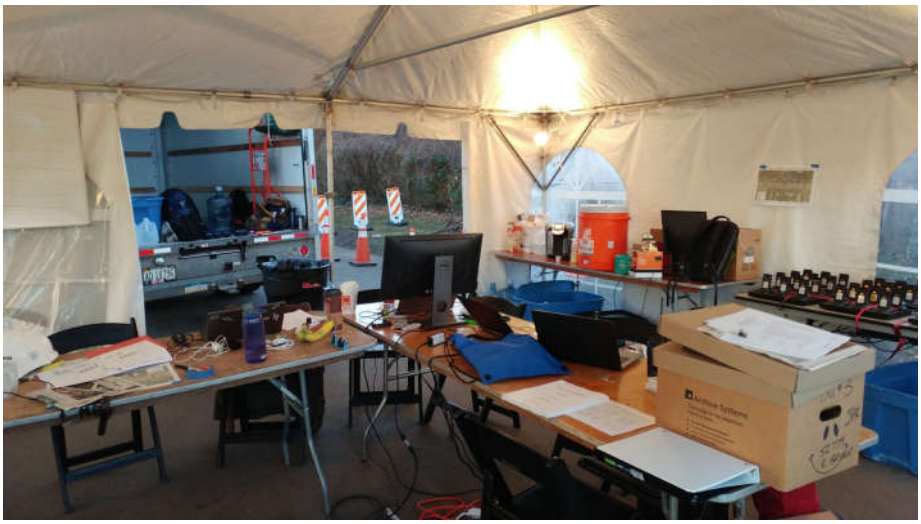
Let's Fix the Bridge

- Field office for repair day
- This took weeks of planning while other activities were ongoing



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Let's Fix the Bridge

- Ensure all equipment is ready, including backups (something will break)
- People need backups too
- Contractor, engineering, equipment vendor coordination was essential

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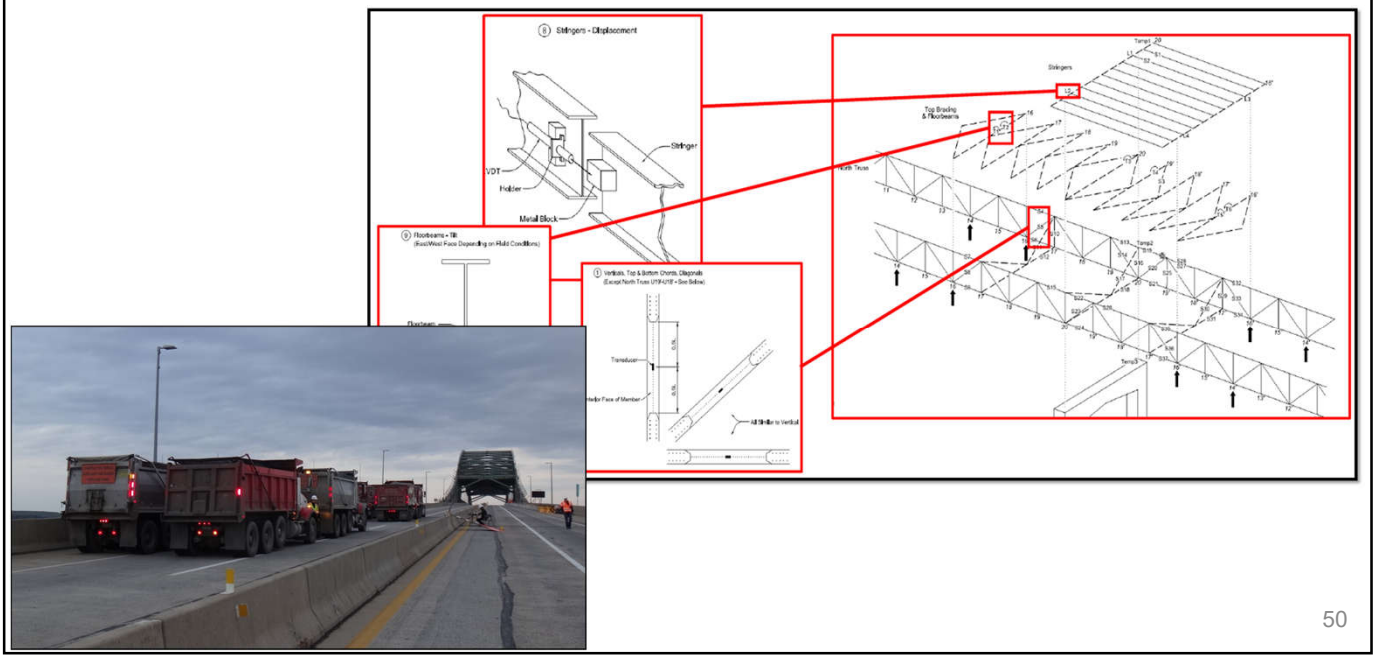
Let's Fix the Bridge

- Repair / replacement chord installation

Instrumentation and Live Load Testing



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Closing Thoughts

- This is not a time for one person to be in charge
- Dozens of highly qualified people are essential to success from small and large firms alike
- Reporting should be clear and to specific people
- There isn't time for everyone to come to a bunch of meetings, too much work to do. Let the workers work
- Not everyone will be on the same page, they might not even be in the same book, but you have to get the job done

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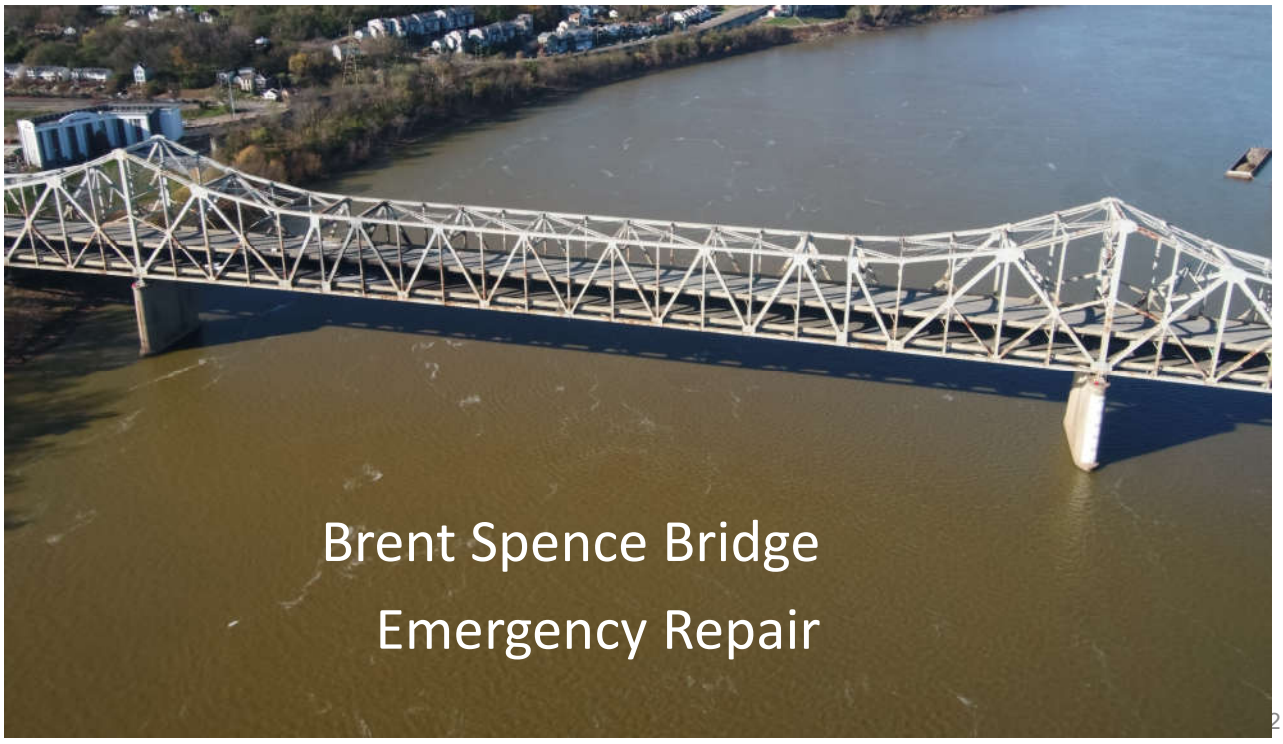

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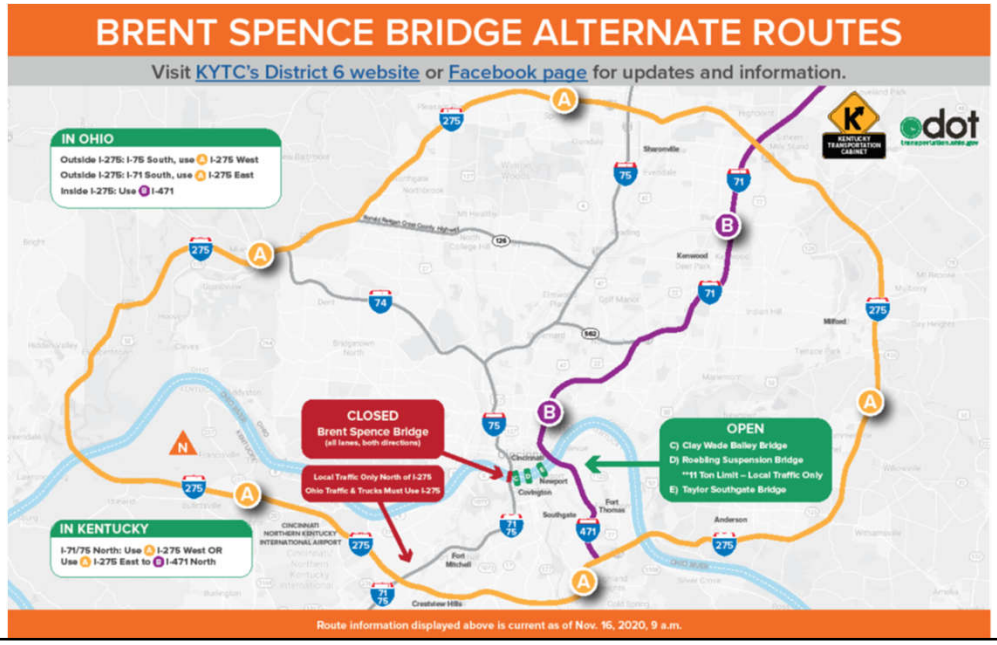
It's still 2020…

Critical Interstate Route



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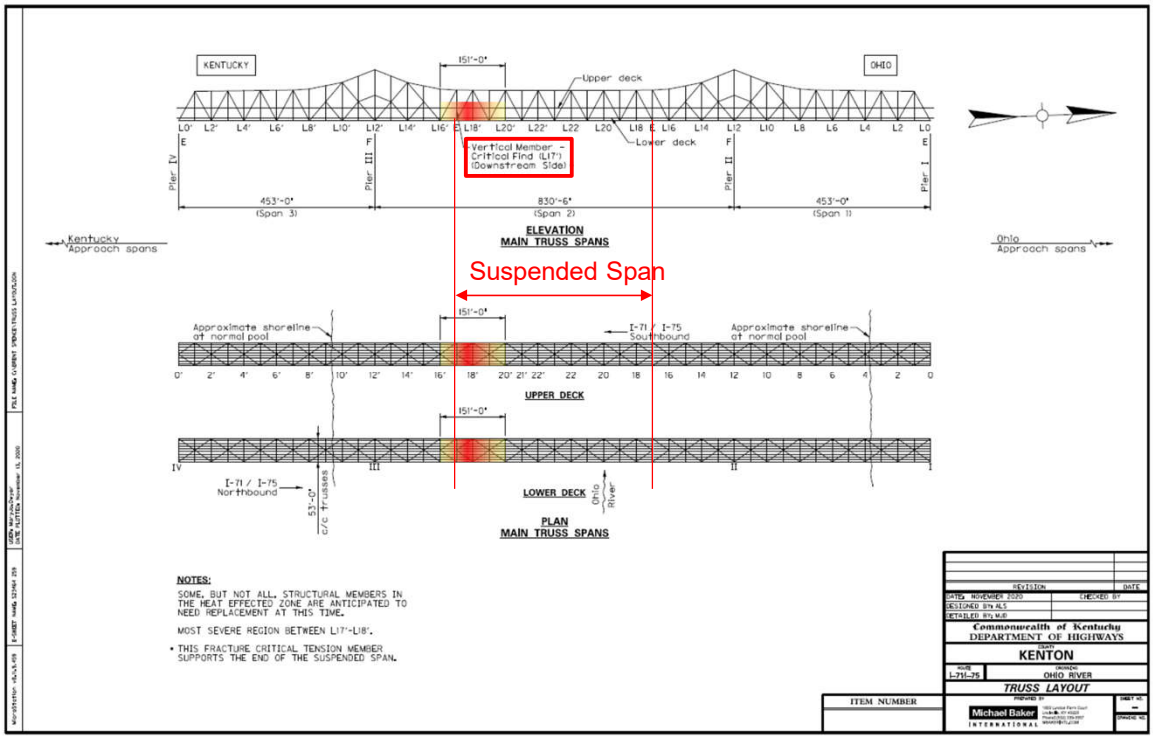

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The Aftermath

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Fire Damage



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TIMELINE

W	Th	F	Sat	Sun	M	
NOV. 11	NOV. 12	NOV. 13	NOV. 14	NOV. 15	NOV. 16	NEXT STEPS

INSPECTION AND TESTING

REPAIR PLAN DEVELOPMENT

CONSTRUCTION PROCUREMENT

CONSTRUCTION

9-5

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Leadership Challenges

- Similar to prior experiences
  - Mobilize field and office staff for 24-hr support
  - Assess critical damage in the field, confidently
    - Identify scope of work
    - Provide measurements and detail confirmation
  - Provide full-time project management support to two owners
  - Provide complete contract documents within days

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Everyone Working to a Common Goal

Never tell people how to do things. Tell them what to do and they will surprise you with their ingenuity.

—General George Patton

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Inspection & Testing

Inspection

- 20 + Inspectors
- Structural Stability
- Damage in Heat Affected Zone
- Condition of Remaining Bridge

Testing

- Concrete Cores
- Steel Cores (Microscopic Eval)
- Laser Induced Breakdown Spectroscopy
- Telebrineller hardness

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Bridge Repairs

Lower Deck

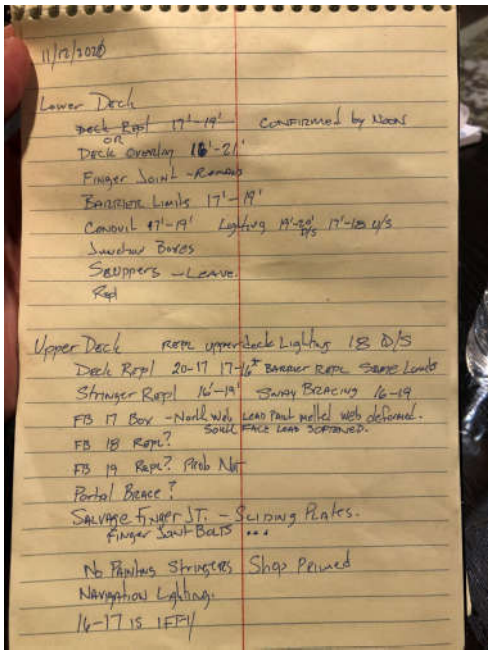
- No damage below deck
- Deck Overlay (5 Panels)
- Barrier Replacement (2 Panels)

Upper Deck

- Stringer Replacement (2 Bays)
- Deck/Barrier Removal and Replacement (4 Bays)
- Finger Joint Removal and Reinstallation
- Electrical & Drainage Replacement

Challenges/Setbacks/Opportunities

- Devil in the Details



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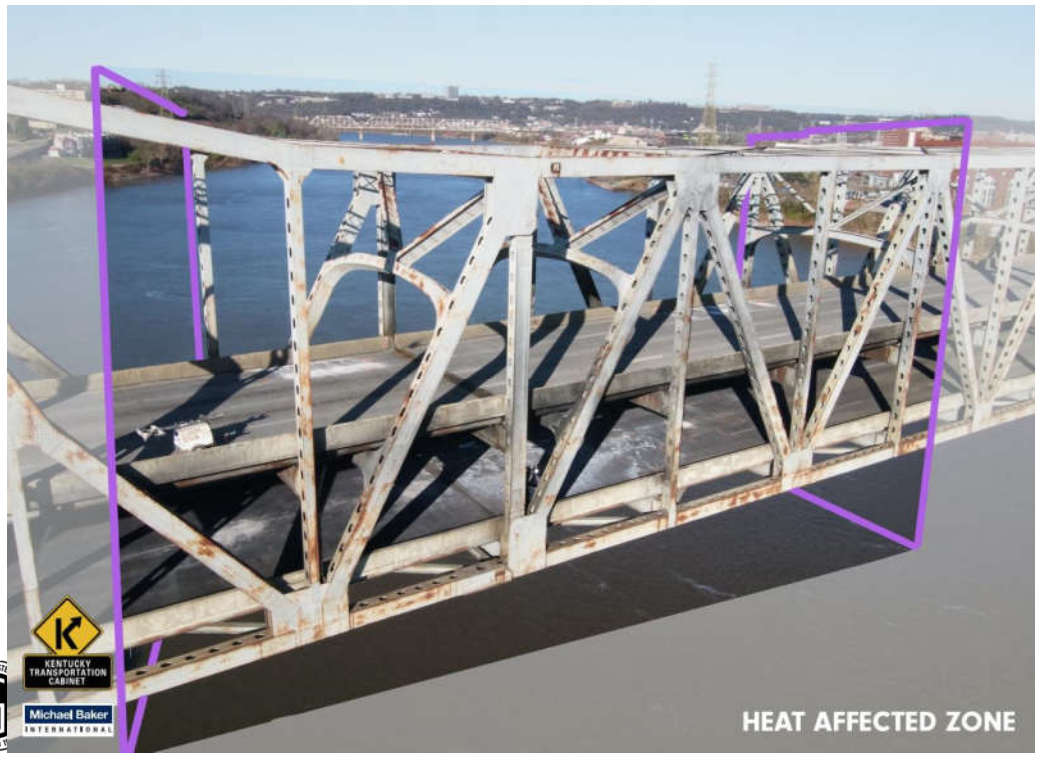

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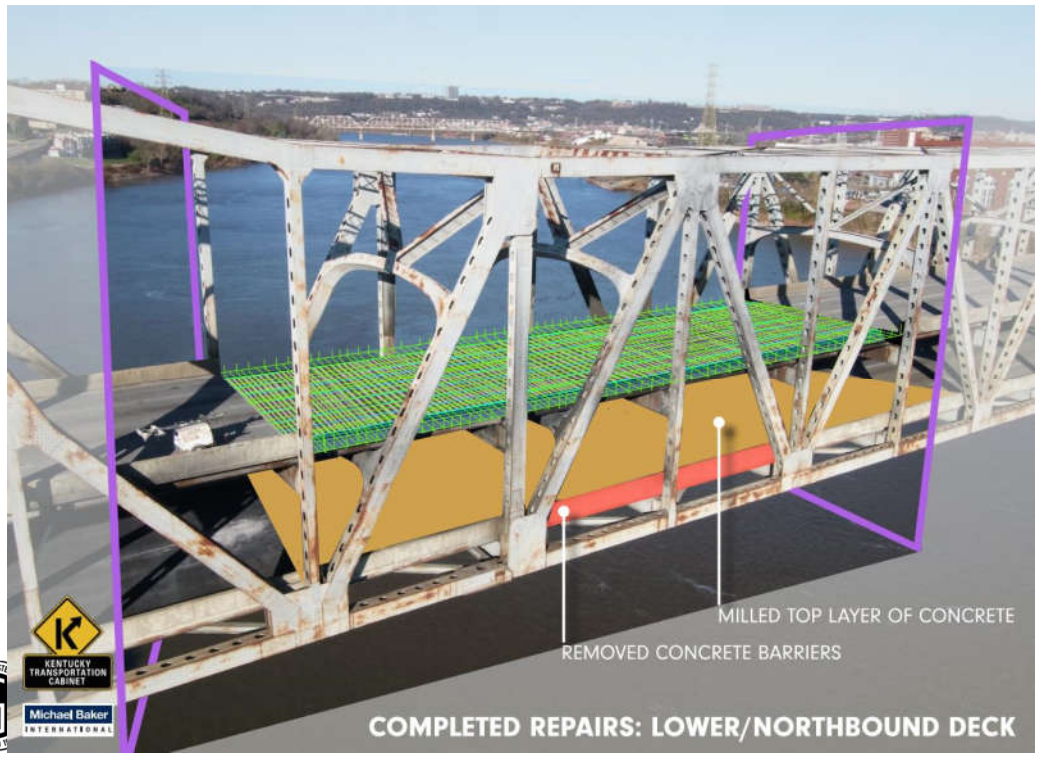

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Leadership Lessons

Many Groups => Common Goal

- Establish Leadership at all Levels
- Redundancy of Leadership
- Communication is Critical – Internal / External

Expect the Unexpected - Manage Changes

- Identify Potential Roadblocks and Setbacks
- Shifting Schedules
- Identify Additional Resources

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Hernando de Soto Emergency Repair

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Bridge History

- Hernando de Soto
- Constructed 1967-1973
  - Opened August 2, 1973
- Two Span Continuous Tied Arch Bridge
  - 2 – 900ft spans
  - 109ft above the water
  - Designed by Hazlett and Erdall

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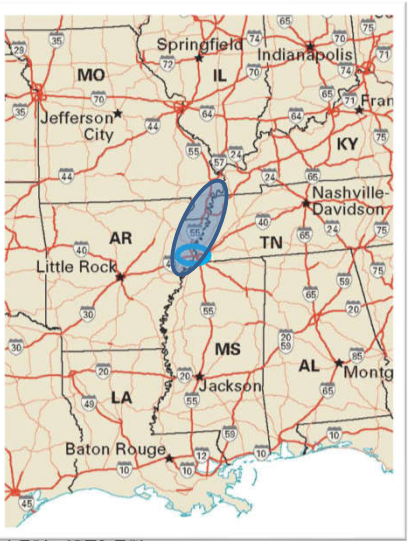
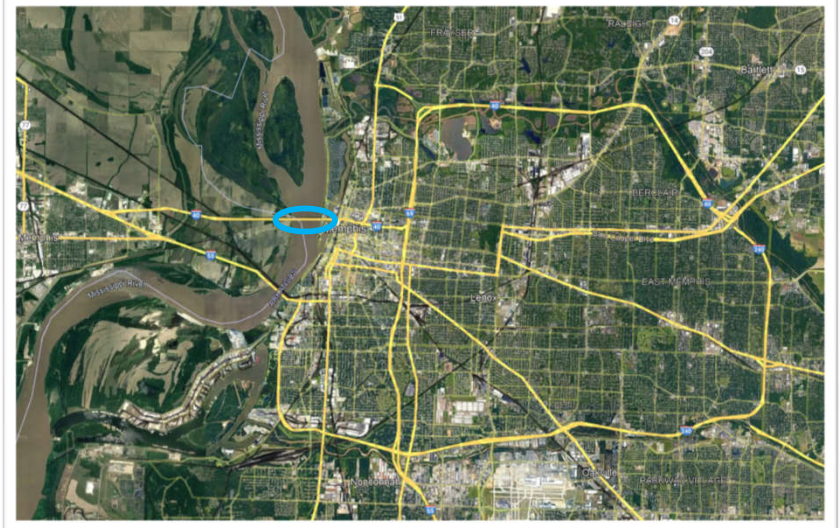
Regional Importance





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Immediate Response

Early Actions in the days immediately following the critical find

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Impact on Traveling Public

- Interstate Traffic
  - 60,000 vehicle ADT
  - 2-3 hour backups
  - Estimated $2.4M/day impact to trucking industry
- Mississippi River
  - 470,323 short tons of freight every day
  - soybeans, distillate fuel oil and corn

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Hernando de Soto – UAS Live Feed Inspection

Staging Area

Viewing Area

Fracture Location

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Closer Look at Fracture

- Condition
- Measurements

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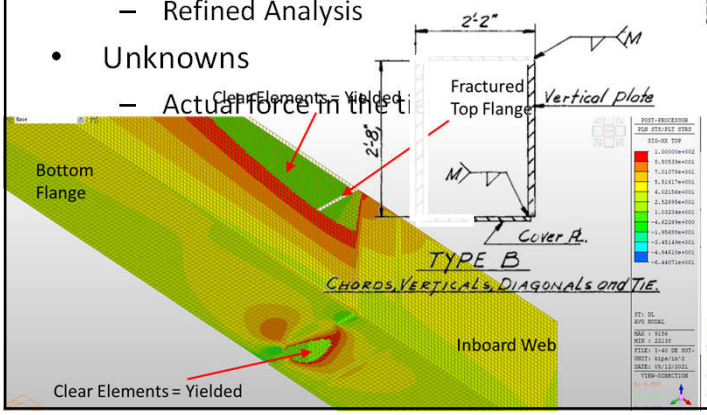
How Bad is it?

- T1 steel = 100 ksi (+)
  - P/A deadload = 38ksi
- Fracture 113 in^2 -> 51.5in^2 (**45%!**)
  - P/A after Fracture = 83ksi
- Eccentric Loading
  - Refined Analysis
- Unknowns
  - Actual force in the ti



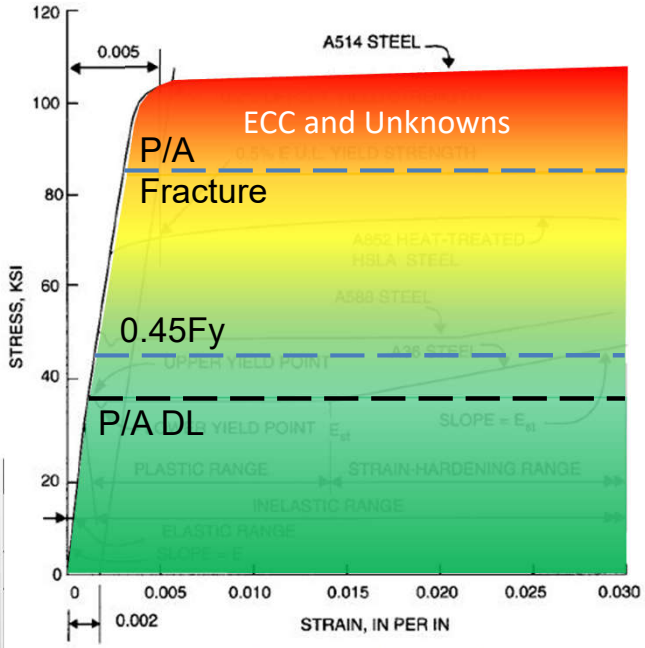


FIGURE 1.4 Partial stress-strain curves for structural steels strained through the plastic region into the strain-hardening range. (*From R. L. Brockenbrough and B. G. Johnston, USS Steel Design Manual, R. L. Brockenbrough & Associates, Inc., Pittsburgh, Pa., with permission.*)

Swift and Critical Decisions

- Immediate Closure
- ArDOT – Inspection
- TDOT – Maintenance/Repair
- Contracted Michael Baker
  - Previous Experience
  - Accessible and Available
- Three-Phase Approach
  - Assess / Stabilize the Structure
  - Repair of the Fracture
  - Inspect and Assess the rest of the Tie Girder

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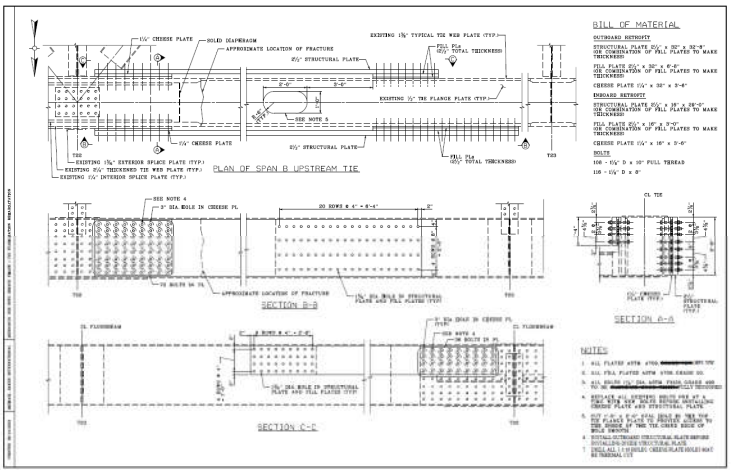
Week 1 Timeline

- 5/11 – Closure of Bridge
- 5/12 – Data Gathering, Model development
- 5/13 – Preliminary Analysis, Historical information, Navigation resumes
- 5/14 – Draft Plans Available, TDOT Advertises for CM/GC
- 5/17 – Kiewit Selected as CM/GC



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Modeling and Analysis

Answering the question of how serious is the situation

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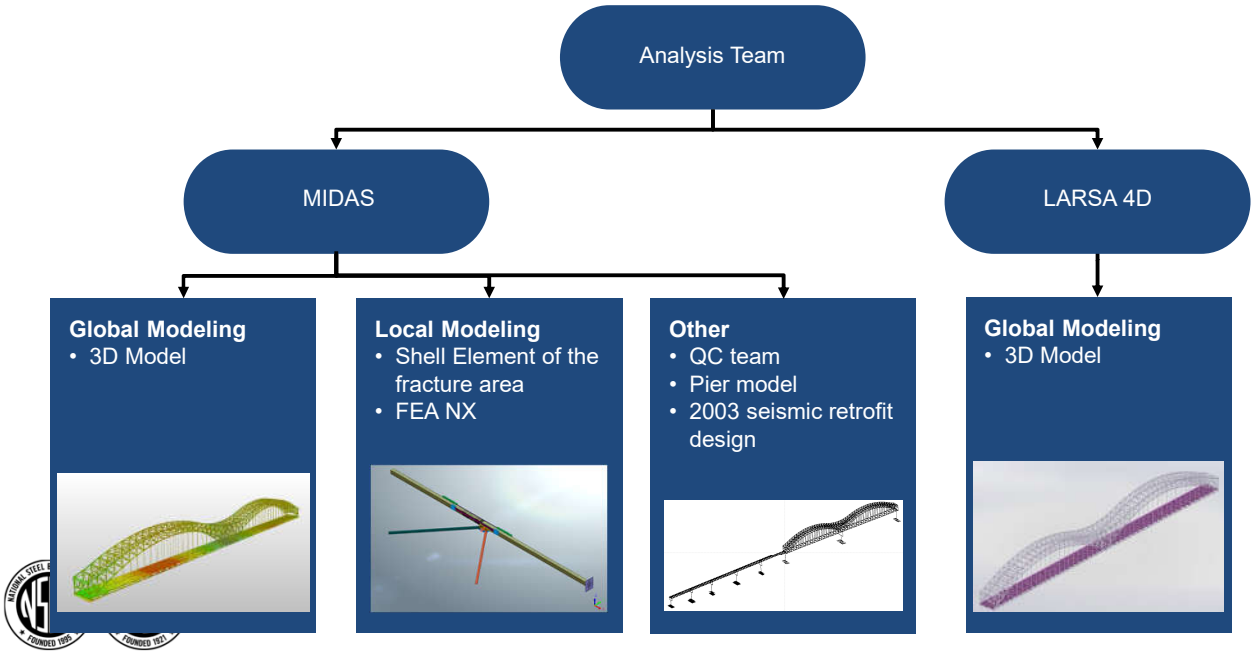
Model Development



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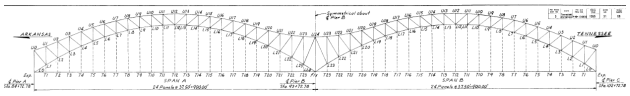
Model Development

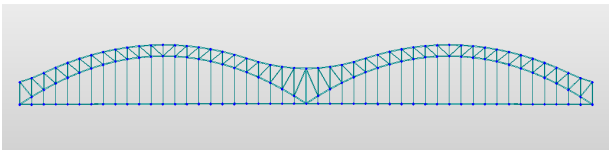
2D Model

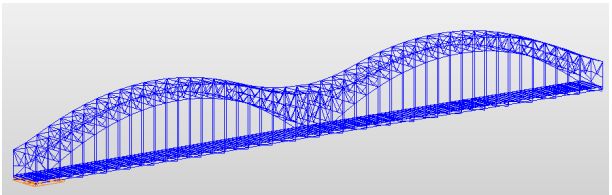
– Simple model – existing plan geometry



3D Model

– Adjusted for any design/shop drawing discrepancy
– Steel DL Calibration





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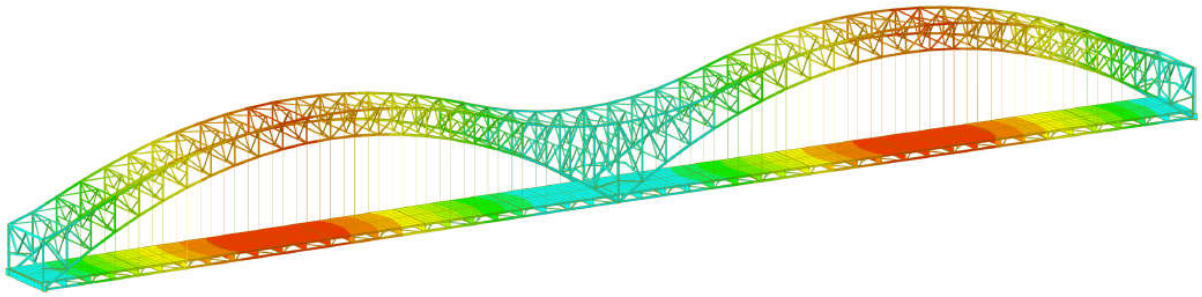
Model Development

2003 Seismic rehab

- Incorporate the retrofit details
- Seismic bearing
- Model staging
- Recalibrate the steel DL



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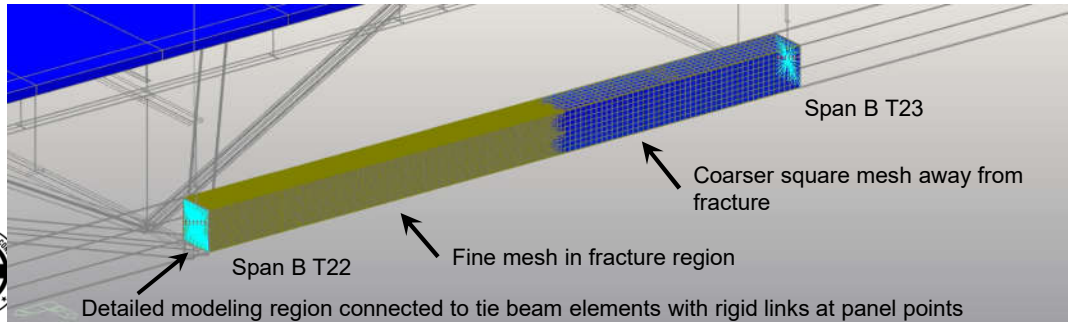
Model Development

- Local Model
  - Modeled T22 and T23 upstream tie
  - Integrated in full 3D model
  - Connected using rigid links
  - Stability assessment of the current condition



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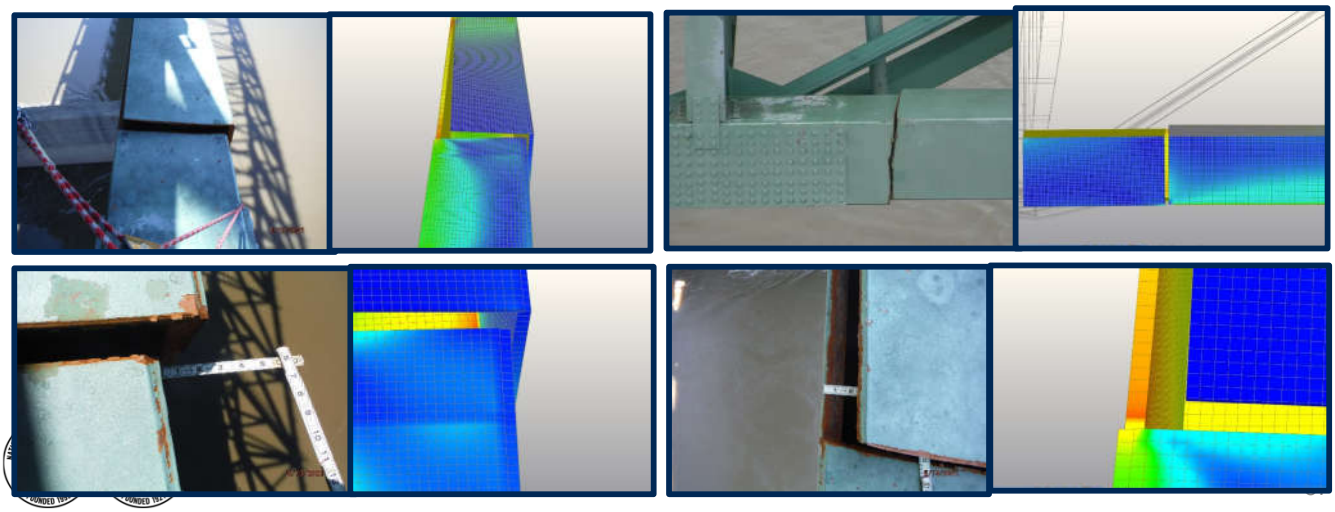
Stability Evaluation

- Stability assessment of the current condition



Phase 1 Repairs

Stabilizing the structure for future repair

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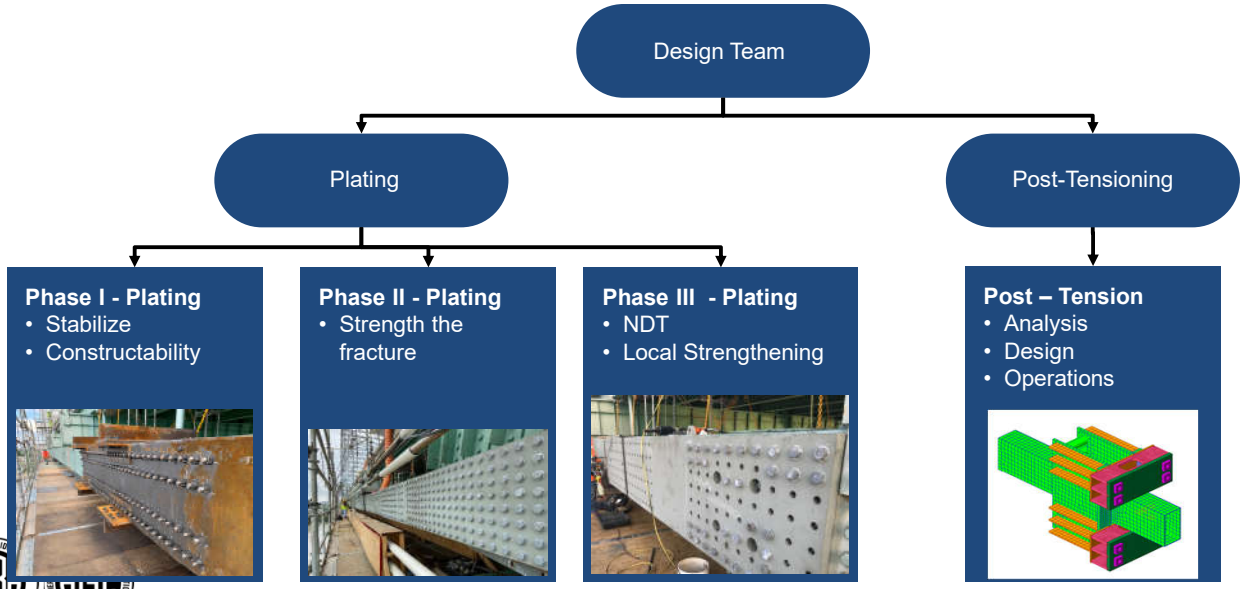
Design Development



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Phase 1: Stabilize the Structure

How do you fix it?

- Tie w/ 4,000 kips +/-
- Displaced laterally and rotated
- Limited reserve capacity

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Phase 1: Stabilize the Structure

BUT HOW MUCH?

Option 1

- Use the existing splice to attach new stabilizing plates
- Perform work from river on work barges
- Hippocratic oath: Do no harm!

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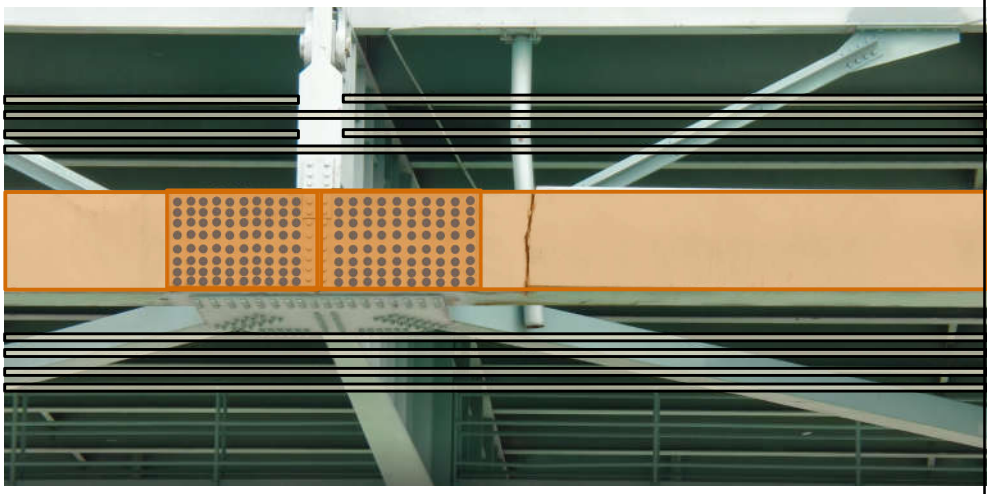
Phase 1: Stabilize the Structure

BUT HOW MUCH?

Option 2

NO! Not enough

- Ultimate solution and fix it right first.
- PT & use the existing splice location to attach new stabilizing plates
- Time to complete unknown



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Phase 1: Stabilize the Structure

BUT HOW MUCH?

Option 3

NO! Too Much Risk

- Take out a few bolts and add rods to provide some added capacity
- Limited risk

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Phase 1: Stabilize the Structure

BUT HOW MUCH?

- Contractor (Kiewit):

NO! Too Much Risk

- Onboard 5/17
- Add capacity, but perform low impact operations (drilling not bolt removal)
- No attempt to straighten the tie
- No Live load on Span 2

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Phase 1: Stabilize the Structure

Availability

- Initial contact with several fabricators looking for plate availability
- HPS 70W in stock and able to be used for the repairs
- 2+" Thickness? Length?
- <u>You can't install what you can't get!</u>

Stupp Bridge
Bowling Green, KY

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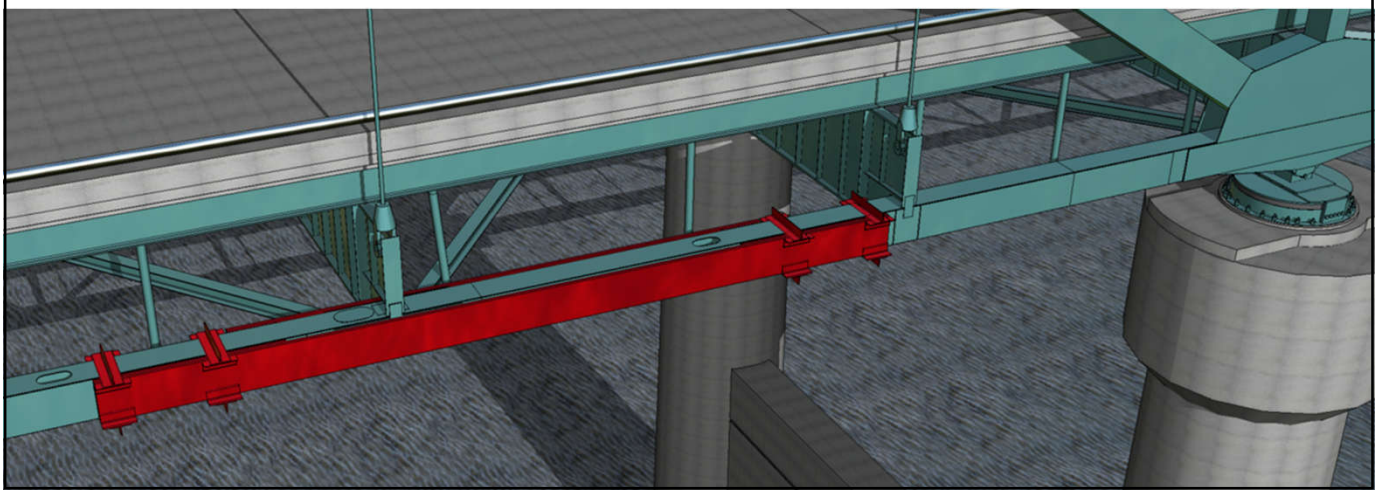
Phase 1: Stabilize the Structure

Design

- Several iterations to meet field conditions and enhance constructability



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Phase 1: Stabilize the Structure

Fabrication

- Design Completed 5/18
- Shop drawings created and approved 5/20
- Fabrication began 5/21 10 days after discovering the fracture
- TDOT maintenance picked up the steel 5/22

Phase 1: Stabilize the Structure

Construction

- Outboard plate placed w/ 3” of fill plates
- Eliminate any interference or straightening of the tie.
- Inboard plate required hole cut into the floorbeam web
- Anchored beyond the girder twist as measured in the field

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Phase 2 Repairs

Long term remediation of the fractured section

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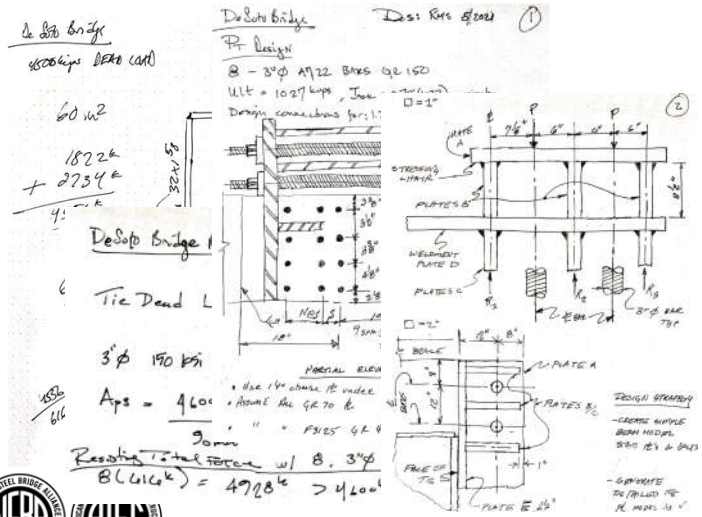
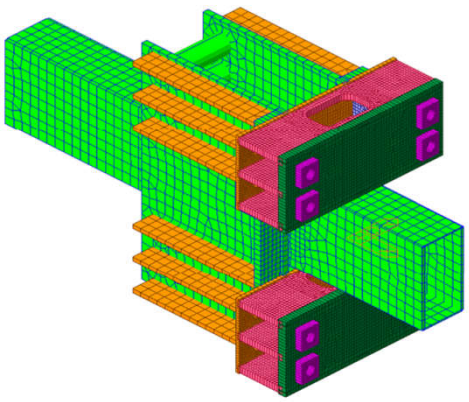
Evolution of the Design

Initial Calc 8:44 PM on 5/11



Final Design



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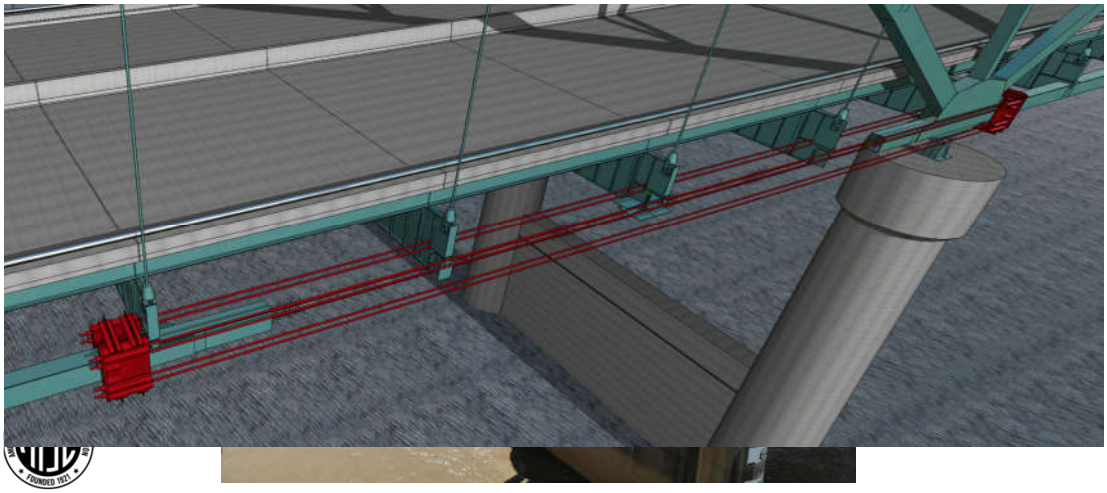
Tie Girder Complete Replacement

- Initially assumed we would completely remove the old/fractured tie
- But after design, we left the tie largely in-place and plated around it



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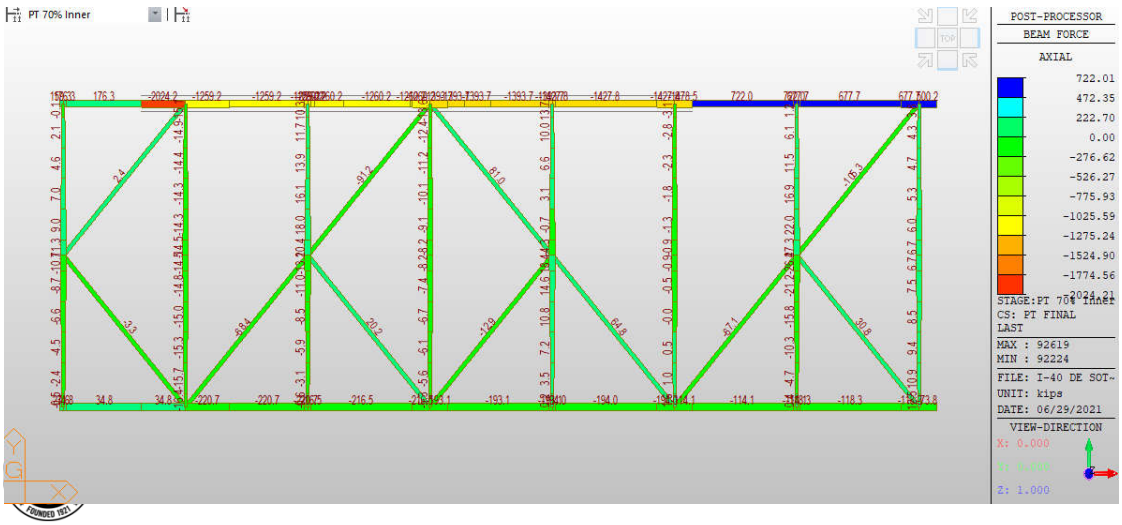
“Drag” Force

- Force in the Tie outside the limits of the PT



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3D Model

- Detailed Model used to find conflicts

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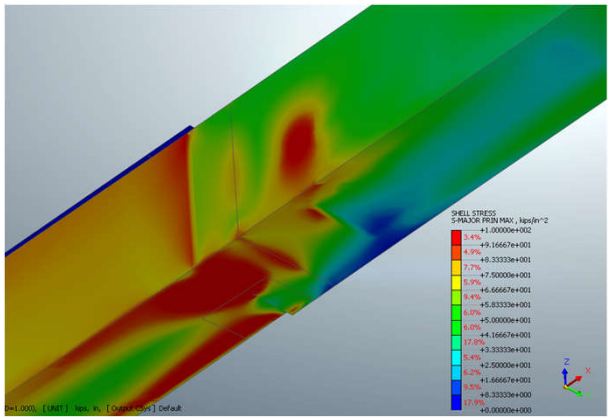
Unloading effects on Tie



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Stressing

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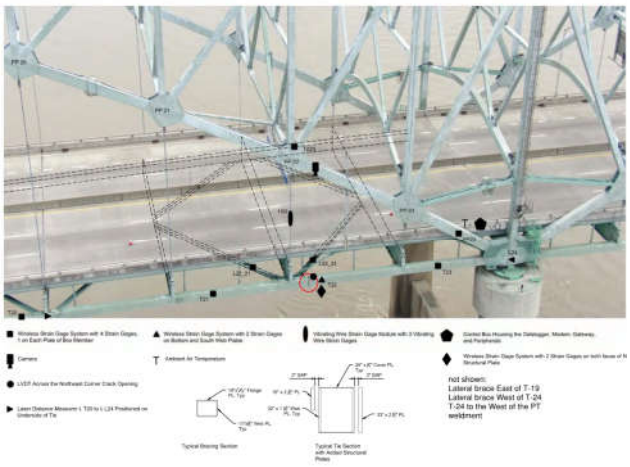
PT Monitoring

Strain Gauges



Dyna Force Sensors

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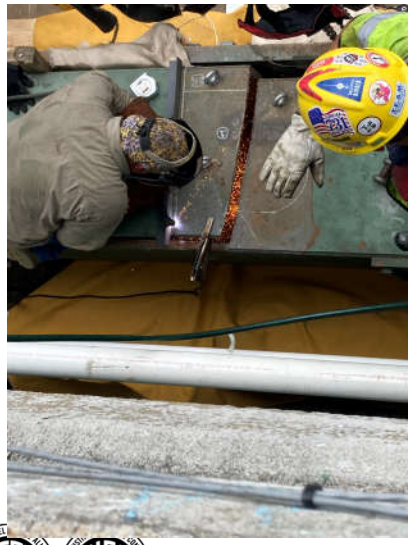
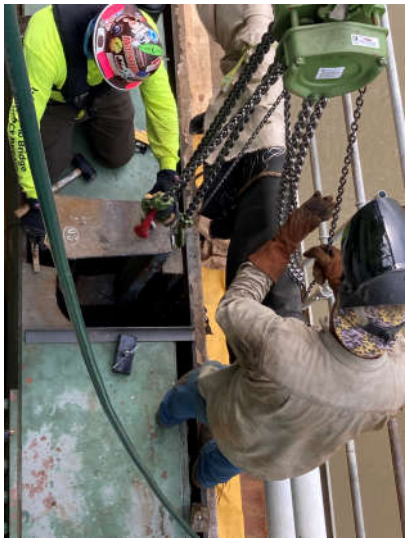
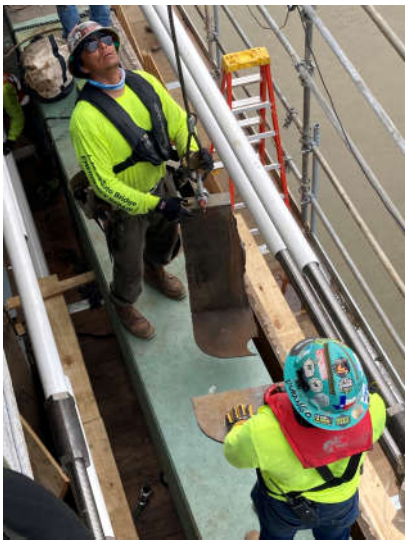
Removing the Fracture

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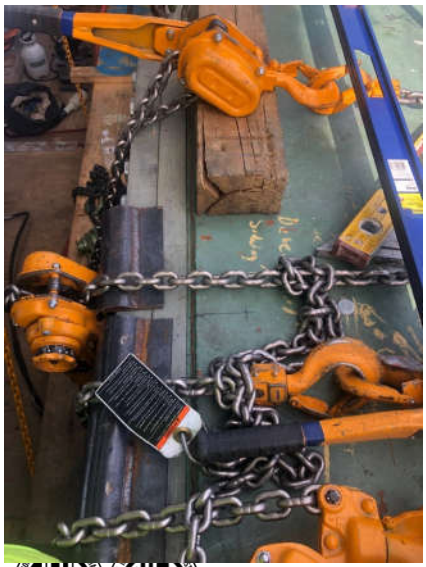
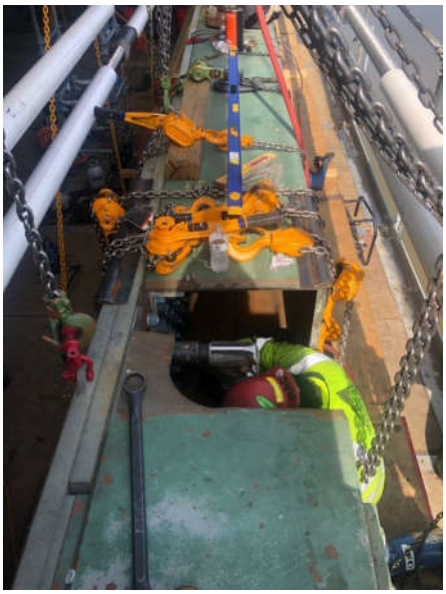
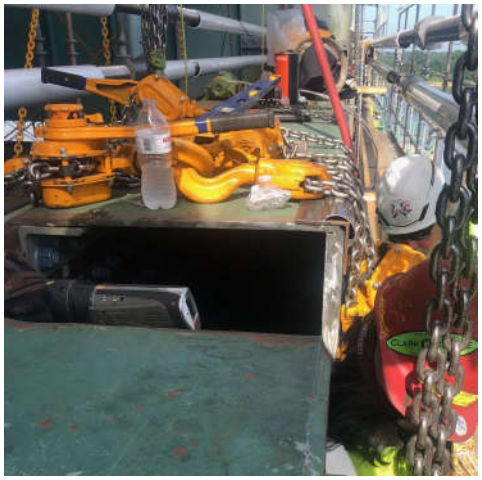
Squaring of the Box

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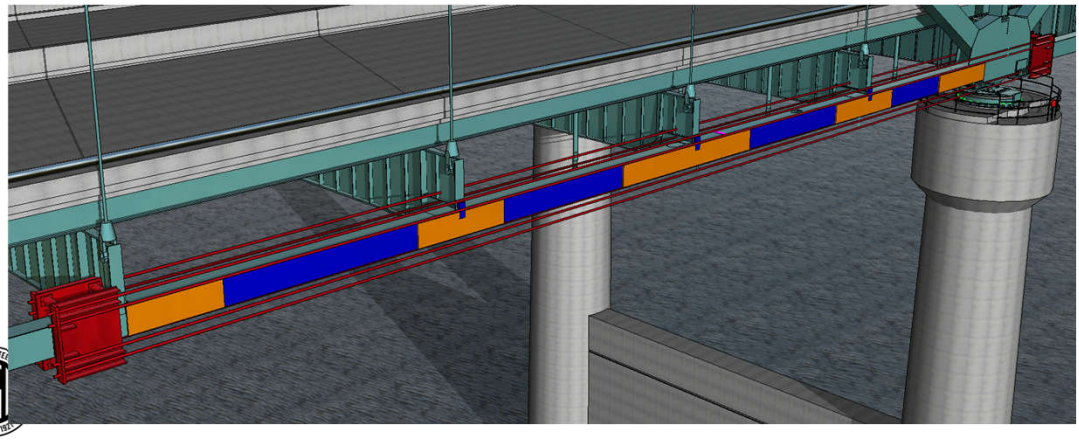
Plating Design

- Original ASD Design: $f_{allowable} = 0.45\ f_y$ (DL = 4500 k LL = 900 k)

  $f = 0.9\ DL + (LL+IM) + Wind$
- Retrofit Design LRFD: Gross and net sections checks



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Phase 2 Plating

- Plating fabrication by W&W /AFCO in Little Rock, Arkansas
- 70 ksi material with A325 bolts
- Partial submittals / approvals for speed of fabrication
- Last bolt installed and torqued on Saturday, July 2nd

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Phase 3 Repairs

Inspection, Testing, and Repair for long-term reliability

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Phase 3 – Inspection

- Full Penetration Butt Weld detail typical throughout structure
  - Potential for similar defects
  - Prevent future failure
- Arch Tie Members and Hanger Pins (Approx. 500 welds)
  - HNTB contracted CAN-USA
  - June 9th to June 17th
- Arch Truss Members MBI contracted Fickett
  - June 7th to June 11th and June 23rd to 25th

NDT Inspection of Arch Tie Member
(HNTB Final Inspection and NDT Results Report)

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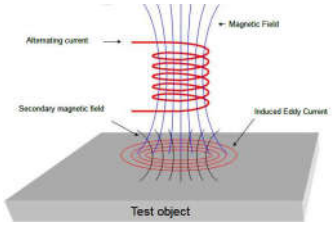
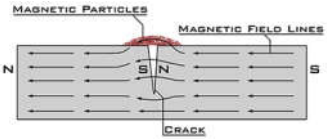
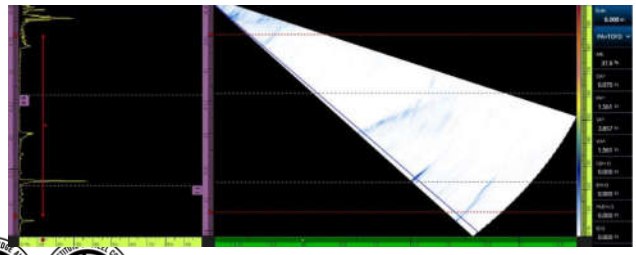
Phase 3 – Inspection Methods



Eddy Current Inspection
(Wermac)



Magnetic Particle Inspection
(NBBI)



PAUT Sample Data Output
(HNTB Final Inspection and NDT Results Report)

- Visual
- Eddy Current (EC)
  - Near Surface Defects for MP Verification
  - Exact Location of Butt Welds for PAUT
- Magnetic Particle (MP)
  - After EC, prior to Paint Removal for PAUT
  - Utilized to verify EC indication findings
- Phase Array Ultrasonic Testing (PAUT)
  - Paint Removal
  - Embedded Indications

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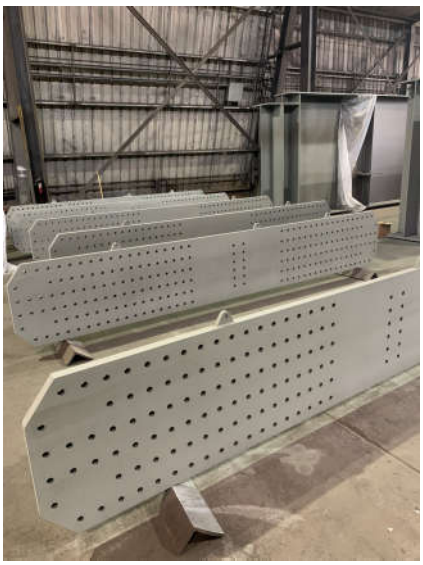
Phase 3 – Fabrication

W&W/AFCO
Little Rock, AR



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Phase 3 – Installation

Odd Joint Plating

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Phase 3 – Installation

Even Joint Plating

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Phase 3 – Bridge Reopening

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Forensic Evaluation

Assessment of the Fracture

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Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

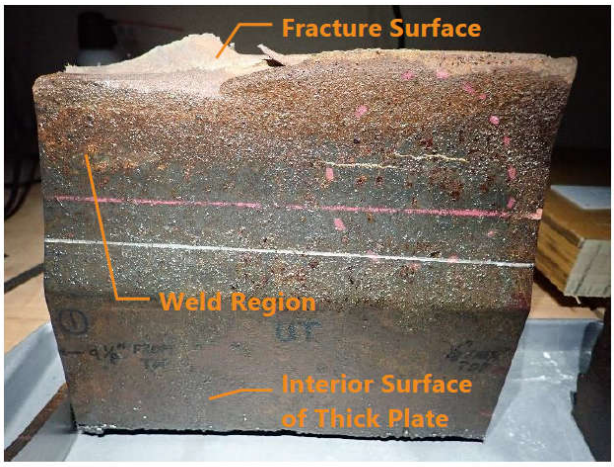

Figure 1. Sample under white light showing MT filings at crack locations.

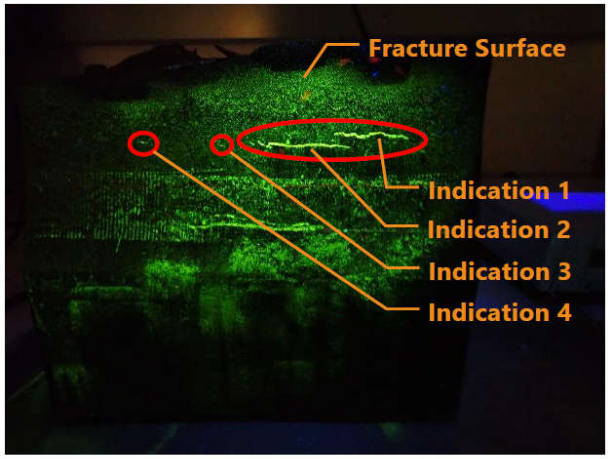

Figure 2. Sample under black light during wet fluorescent MT inspection with four MT indications (red circles)

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Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

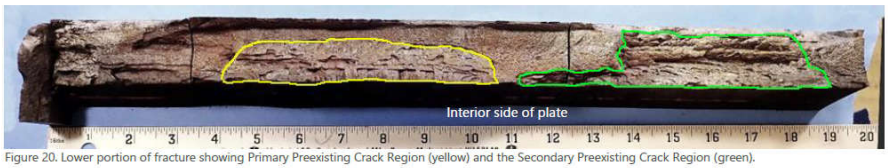

Figure 20. Lower portion of fracture showing Primary Preexisting Crack Region (yellow) and the Secondary Preexisting Crack Region (green).

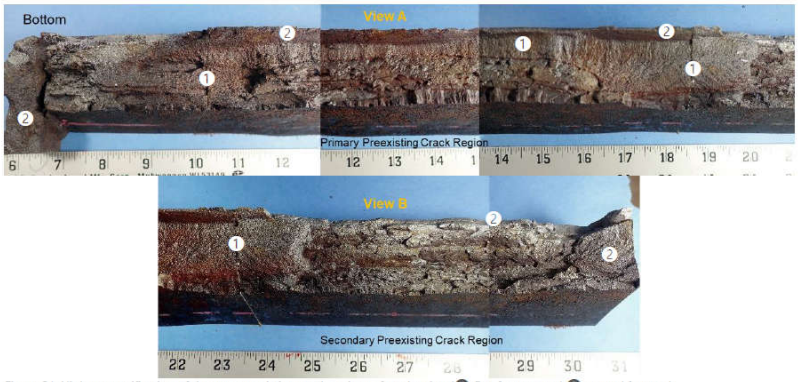

Figure 21. Higher magnification of the two preexisting crack regions after cleaning (❶ first fracture and ❷ second fracture).

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Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

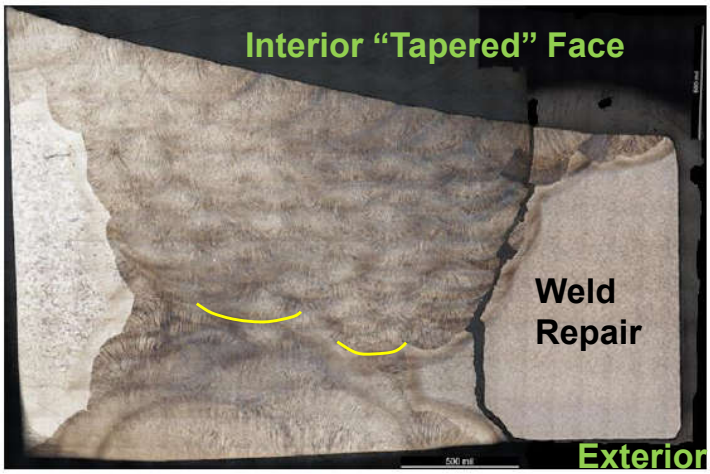

Figure 39. Primary preexisting crack weld profile.

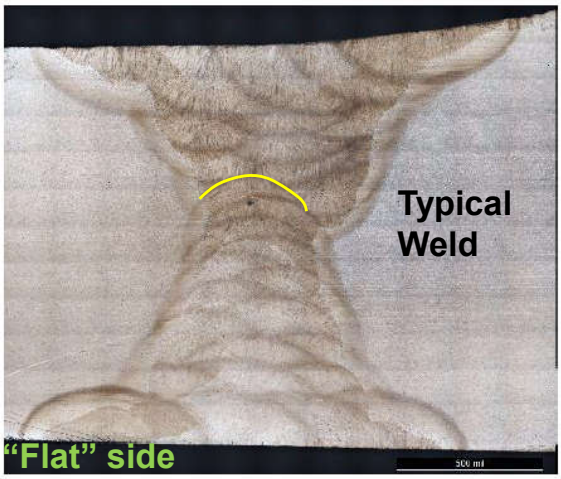

Figure 40. Core Sample SA008E weld profile.

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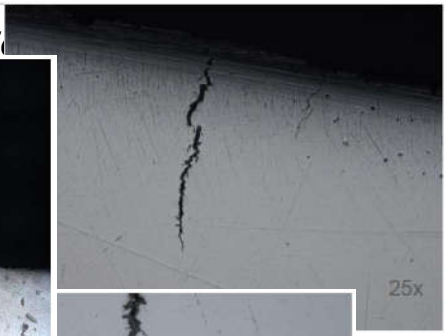
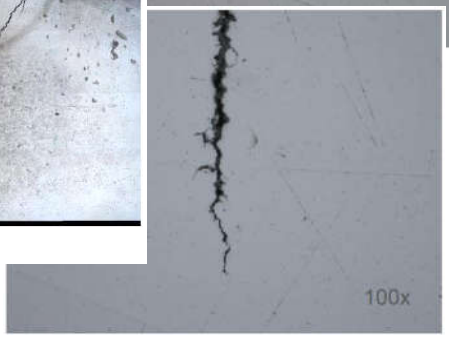
Fracture Analysis

Figures obtained from WJE Fracture Investi

Figure 54. Cracks in the top weld passes at location SA168W





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Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

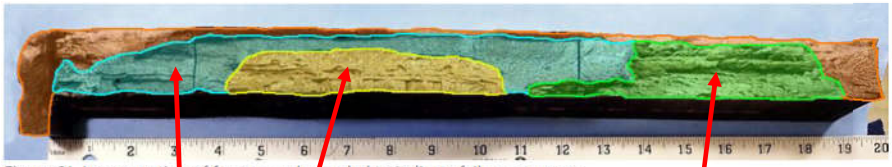


Figure 61. Lower portion of fracture, color-coded to indicate failure sequence.

Fracture Event #1

Secondary Pre-existing Crack

Primary Pre-existing Crack

Fracture Event #2

Fracture Event #3

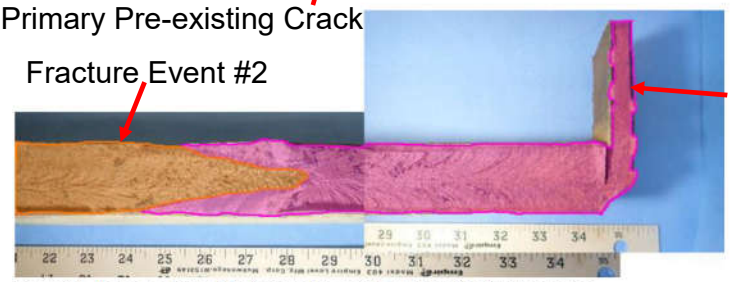
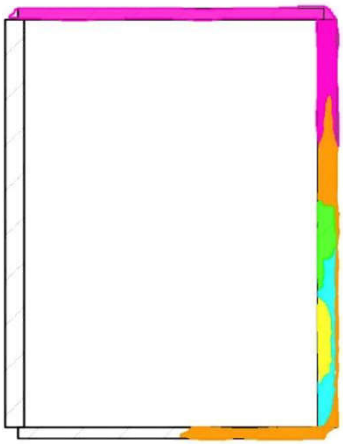


Figure 62. Upper portion of fracture, color-coded to indicate failure sequence.



4 MAY 2021
SCALE: NTS (LOOKING WEST)

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Lessons Learned

Keys to success

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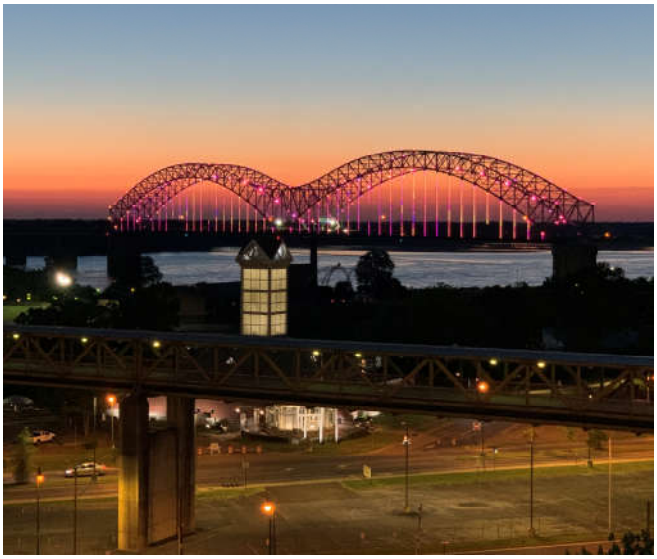
Lessons Learned

- Collaboration
  - Everyone with a Common Goal
- Communication
  - Internal and Externally
  - Many moving pieces and parts
- CM/GC Benefits
  - Risk Reduction
  - Improved Constructability
  - Material Procurement / Schedule
  - Contractor Risk Sensitivity



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Keys to success

- Simplicity
  - In spite of the crisis, simplicity is key
  - Sherman Minton and Hernando De Soto
    - Bolted splice plates is all it takes, just a lot of them
  - Delaware River and Brent Spence
    - Selected member replacement
  - Eggners Ferry
    - A new bridge composed of simple parts

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Observations

- Bridges w/ Fracture Critical Members
  - Designed, fabricated, and constructed before the Fracture Control Plan of 1978
  - Hernando De Soto and Delaware River Bridge are excellent examples of the “not so fracture critical bridge”
  - Sherman Minton
    - Real concerns – easily remedied
  - Quality of inspection is critical as is a design team that can work in theory and practical aspects

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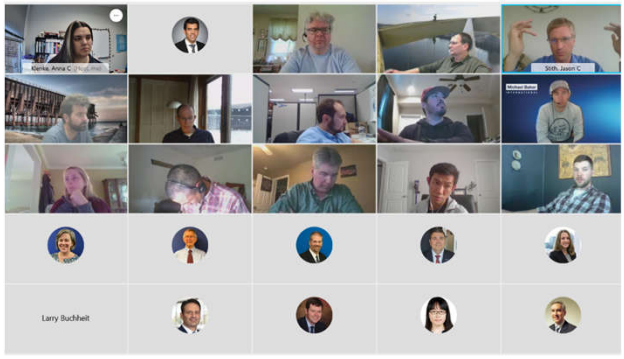
Are Steel Bridges Resilient?

- Redundancy is important
  - Structural member redundancy
  - Team member redundancy
  - Leadership redundancy
  - Industry redundancy



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Thank You

- A virtual toast to so many friends who helped along the way

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Questions?

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PDH Certificates

For those participating at their own connection…

- Reporting attendance is not necessary.
- Certificates will be issued based on AISC's attendance records.
- You will be receiving certificates via email from registration@aisc.org.

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PDH Certificates

For those participating at one connection with a group…

- Primary registrant will report attendance via an online form. (The link will be provided in an email from registration@aisc.org.)
  - Username: Same as AISC username
  - Password: Same as AISC password.
- Once attendance has been reported, you will be receiving certificates via email from registration@aisc.org.

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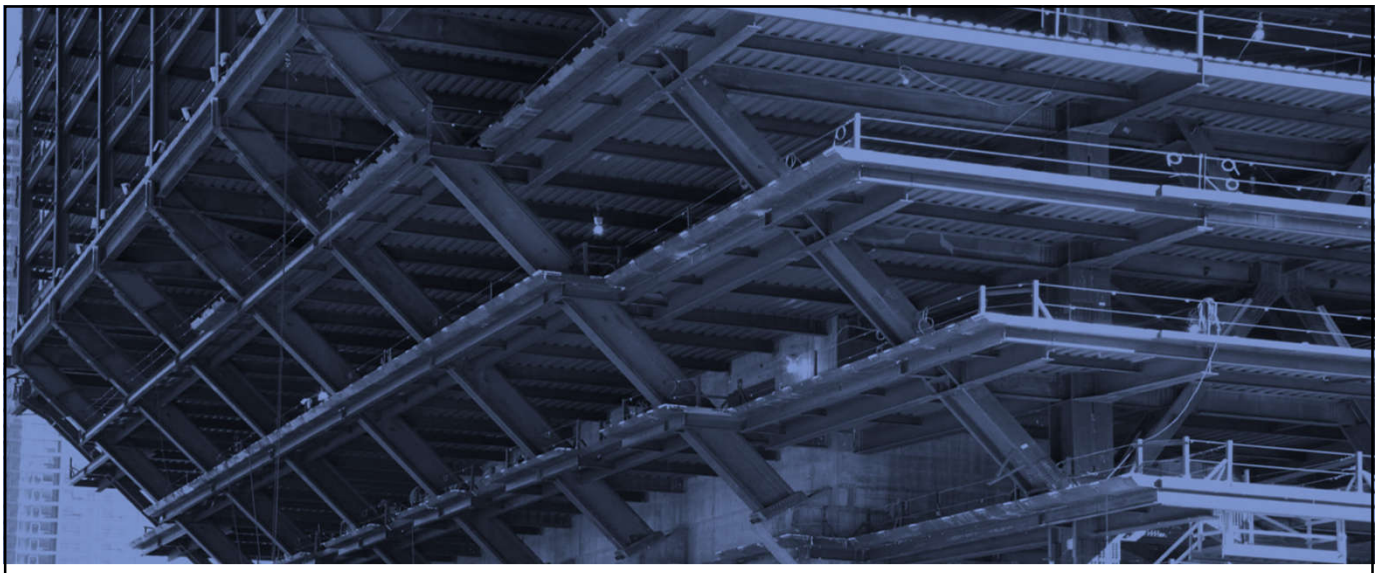

AISC | Thank you

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