Inspection and Non-Destructive Testing and Load Rating of Hernando De Soto Bridge

HNTB

2023 TEAM Conference,
Branson, MO
March 16th, 2023

ARDOT
ARKANSAS DEPARTMENT OF TRANSPORTATION

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  - SPRAT/IRATA Level 1

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Agenda:

- Main Span Unit Inspection & NDT
- West Approach Unit Inspection & NDT
- Load Rating West Approach Unit
- Conclusions

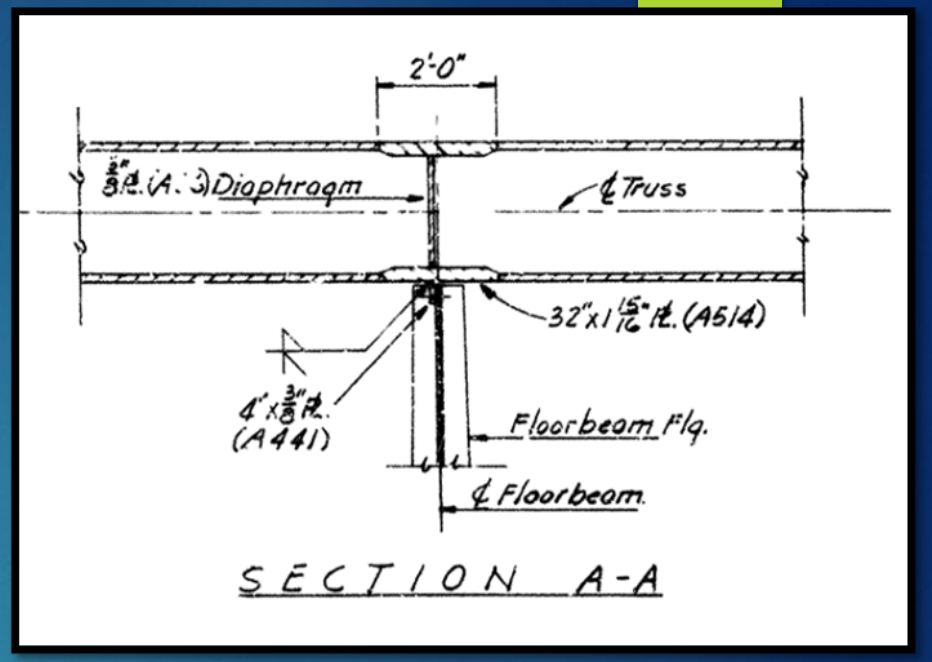
Hernando De Soto Bridge-Main Span Unit

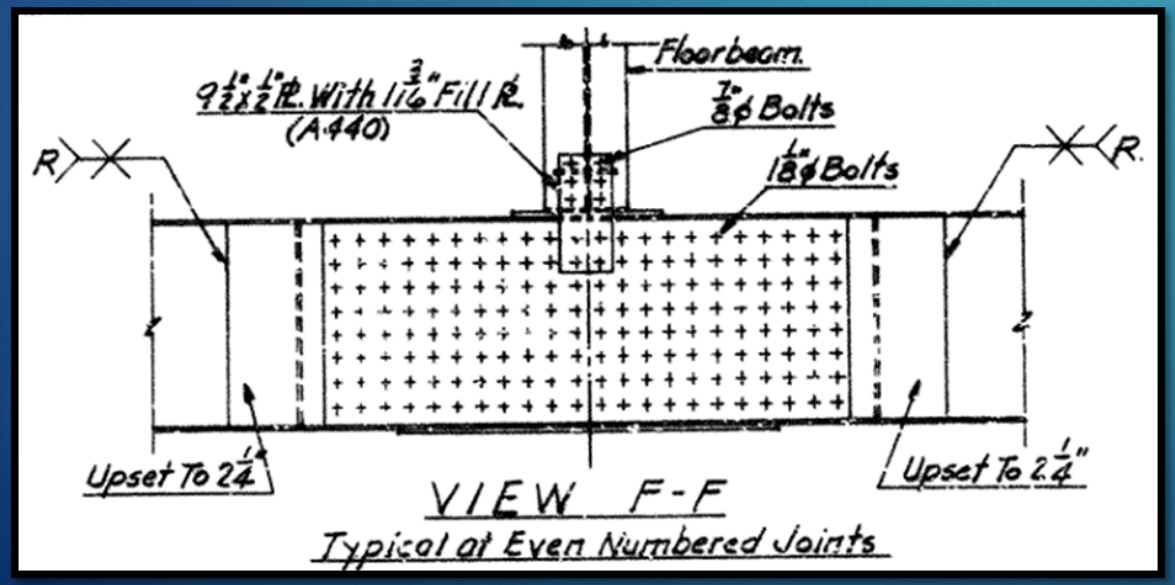
- Constructed 1973-Designed by Hazelet & Erdal in 1967
- Two 900' Span Tied Arch connecting West Memphis, AR to Memphis, TN over the Mississippi River
- 45,000 ADT

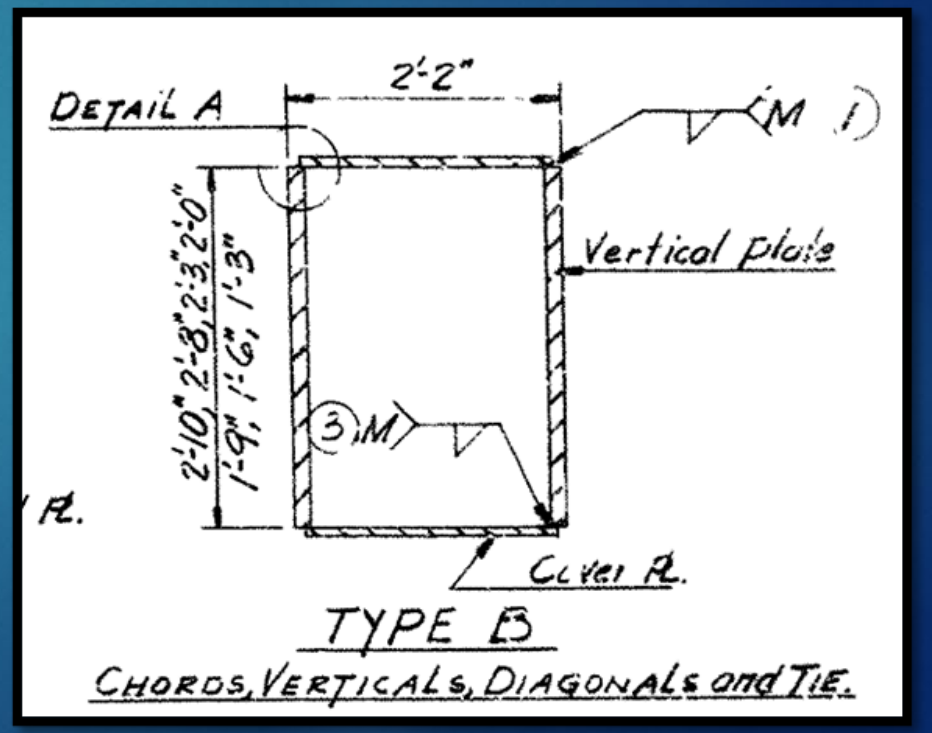
- ASTM A-514/A517 Steel
- Fy = 100 ksi, Fu = 115 ksi
- Allowable Stress = 45 ksi
- Design Stress = 44 ksi

Tie Girder Details

- Welded built-up box
  - Full penetration butt welds at web transitions
  - Fillet Welds in corners
- 32" x 26" box with 1/2" top cover plates and 1-3/8" web plates
- Thickened to 1-15/16" and 2-1/4"

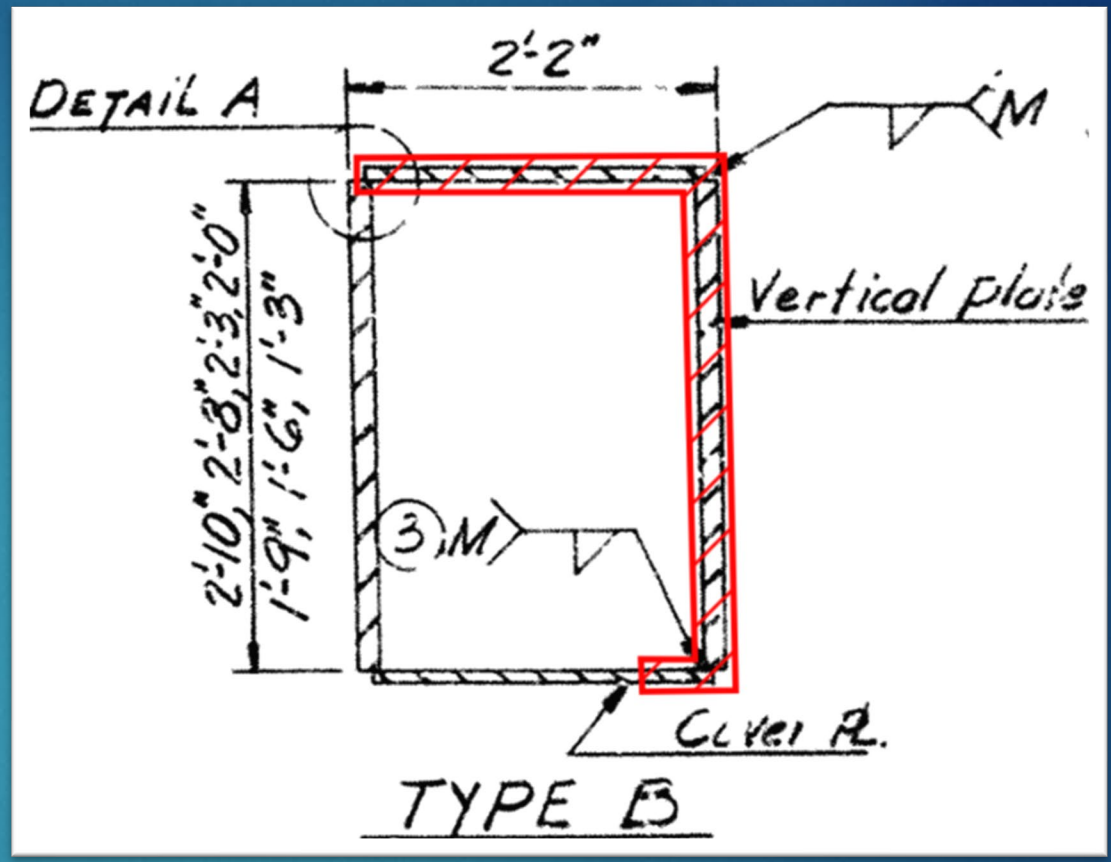


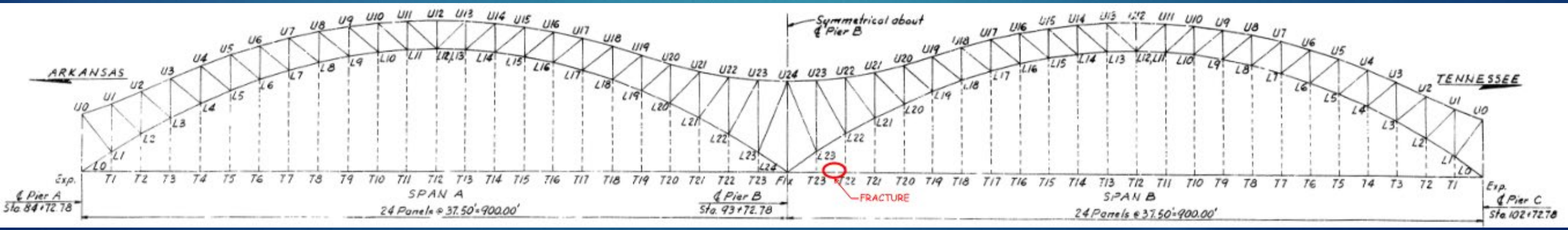




The Fracture

- Span B, North Tie Girder near T22 between T22 and T23
- 54% of Tie Girder Fractured
- Effective Area Reduced from 113 sq. in. to about 52 sq. in.





The Fracture

- Estimated Stress in Tie Girder After Fracture
  - DL = 87 ksi
  - DL + LL = 95 ksi (95% of Yield Strength of Steel)


10"
9.0"

Visual Inspection

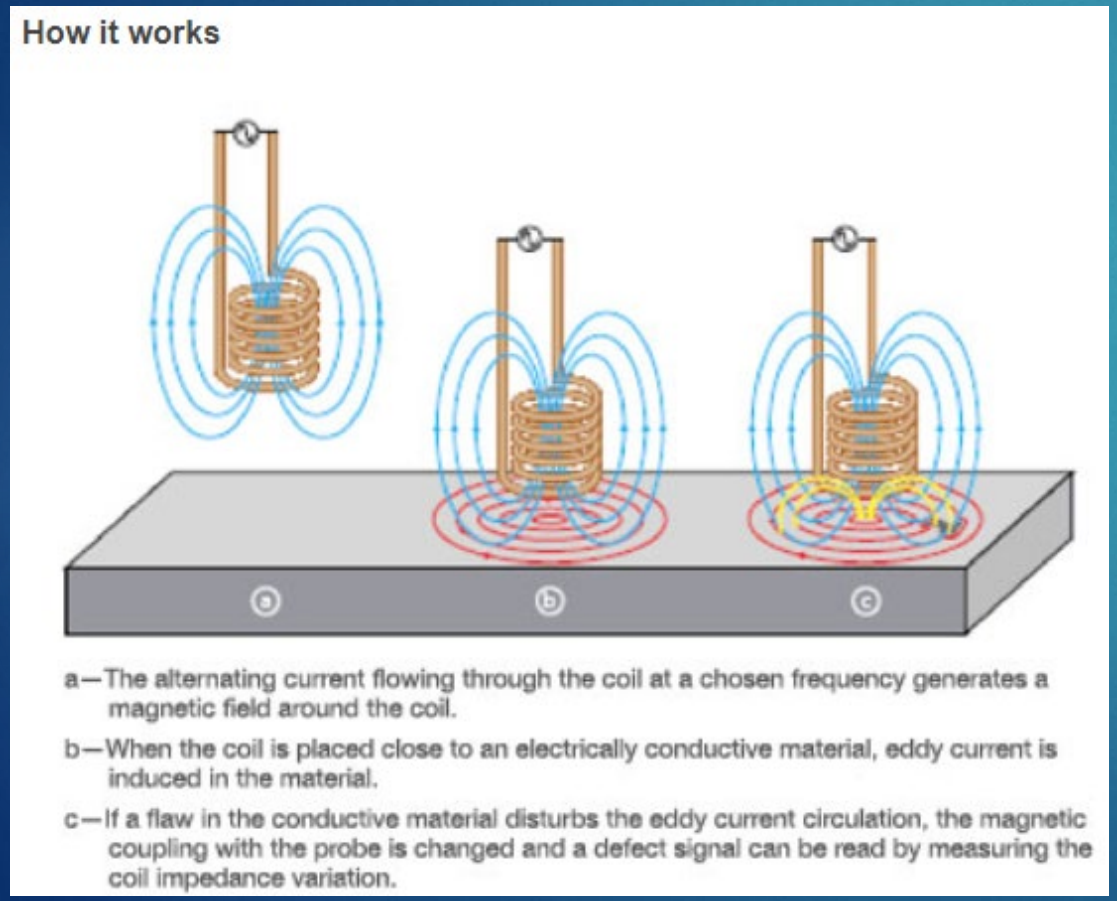
- In-Depth/FCM Inspection
  - 20 engineers and rope access technicians
  - Tie girders, Floor system, Cables and Sockets
  - Included deck and substructure

Non-Destructive Evaluation-Main Span Unit

- Utilized Eddy Current (ECT) and Phased Array Ultrasound (PAUT)
  - 484 butt welds totaling 1,200'
  - Possible cracks at other fatigue prone detail
- Also performed UT for 92 pins

Eddy Current

- At or near surface defects
- Utilized an array probe for efficiency

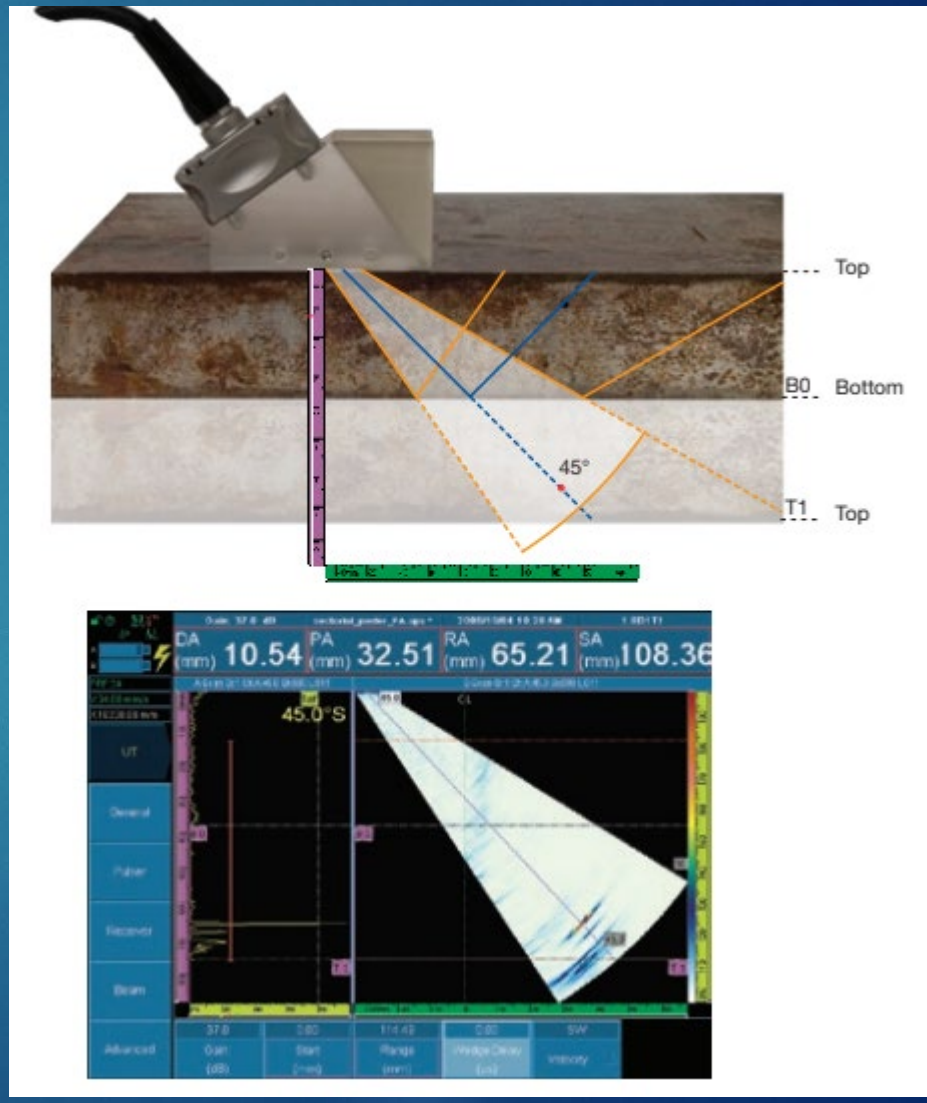


Eddy Current

- Scanned all 484 welds
- Three passes to cover Heat Affected Zone
- No paint removal required
- Findings confirmed with Magnetic Particle Testing (MPT)
- Discovered indications 0.05” deep and shallower-Even piece mark stamps!

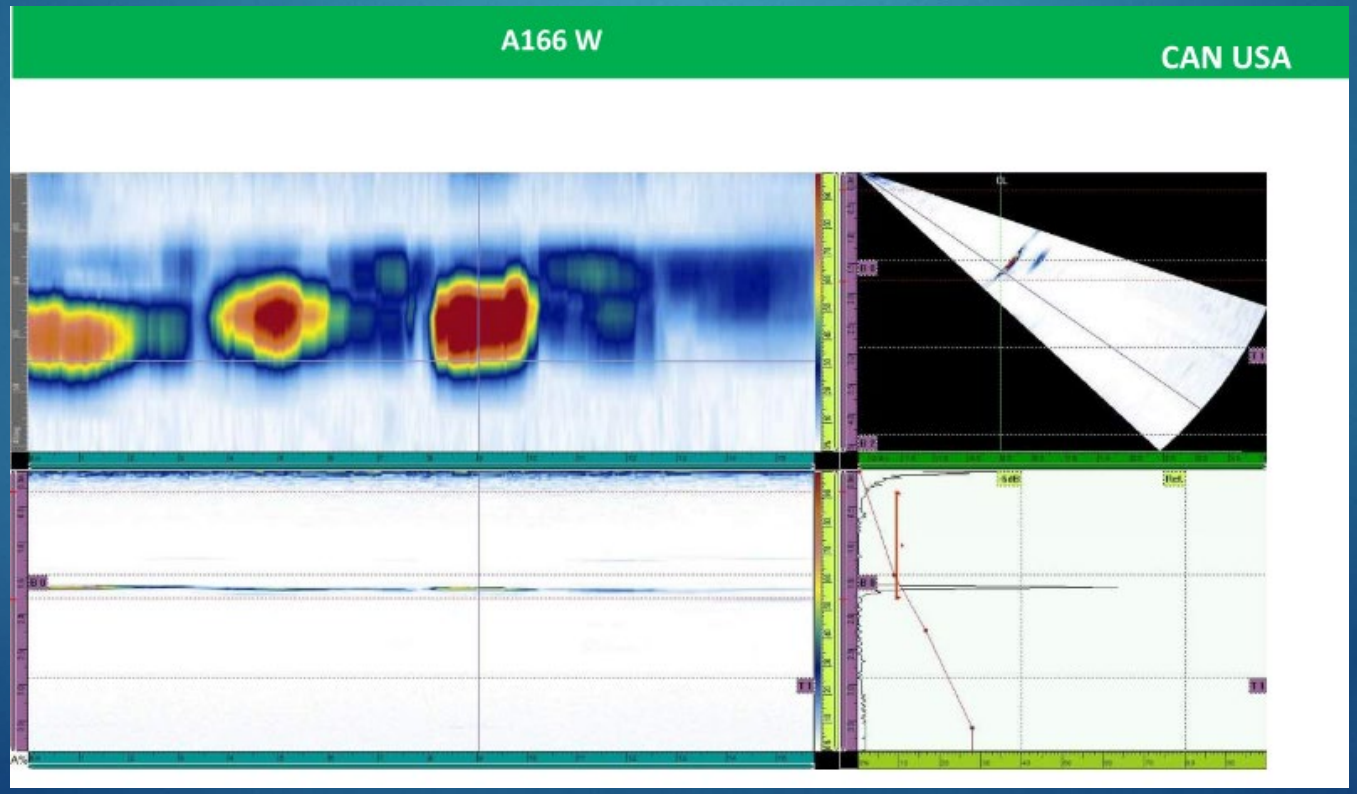
Phased Array Ultrasonic

- Below surface and through the thickness
- From both sides of weld



Phased Array Ultrasonic

- Paint removal recommended
- AWS D1.5 criteria
- Utilized “re-interpretation” process with the fractured portion

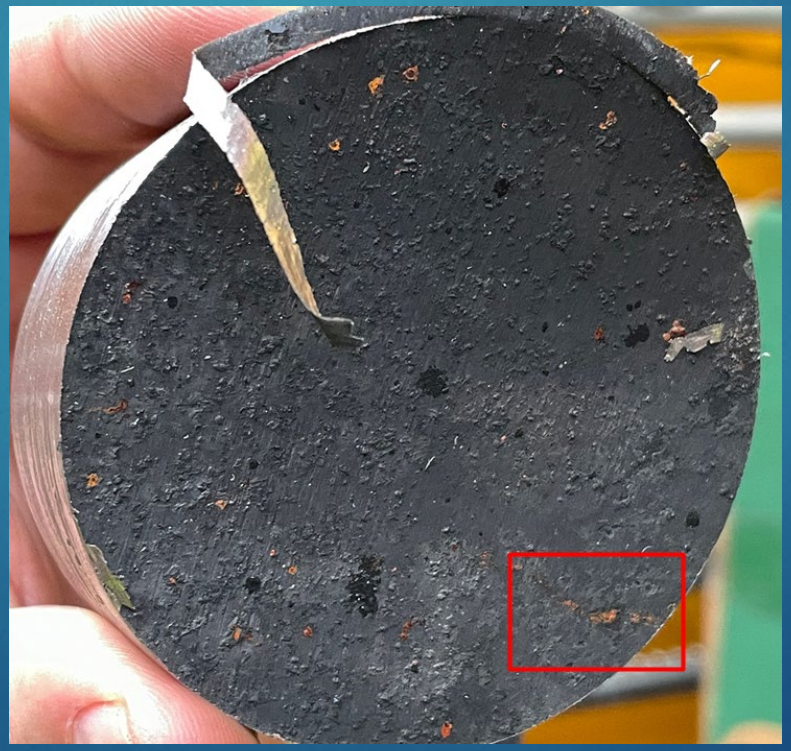


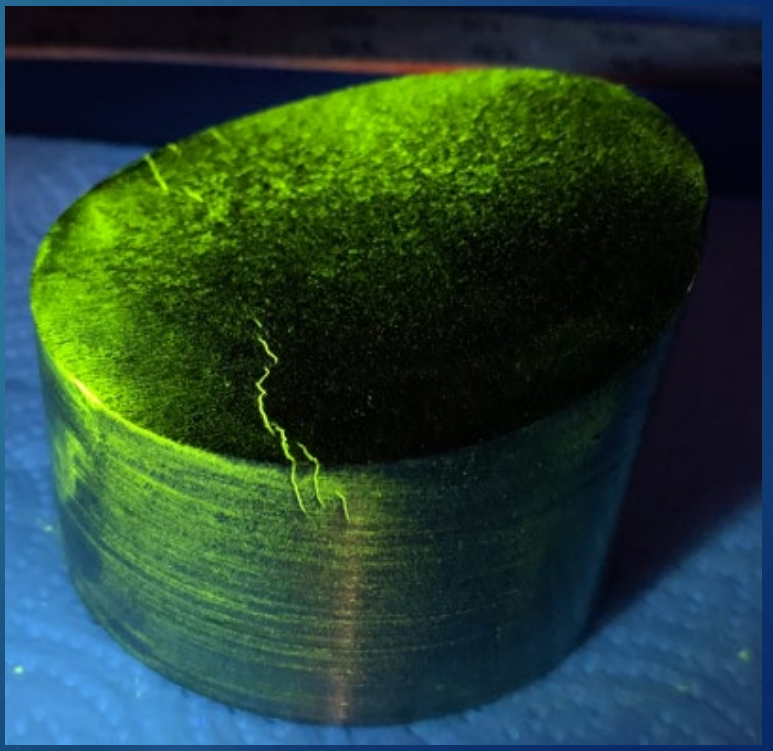
Repairs and Results

- Destructive Evaluation
- 17 additional repair locations
- FHWA Memorandum

Destructive Evaluation

- WJE engaged to core butt welds
- Initial prognosis is hydrogen cracking





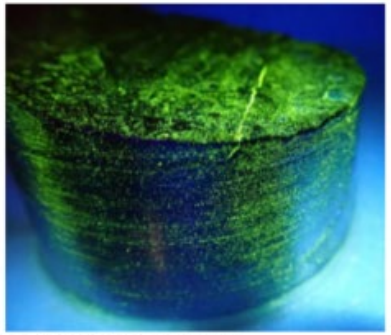


Figure 7. Specimen No. SA008E

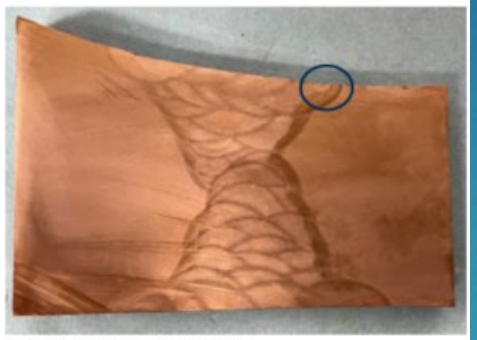


Figure 8. Specimen No. SA008E

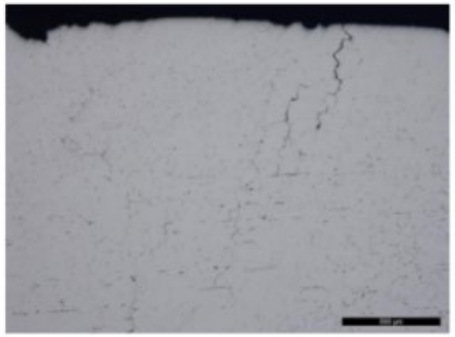


Figure 9. Specimen No. SA008E (50x)

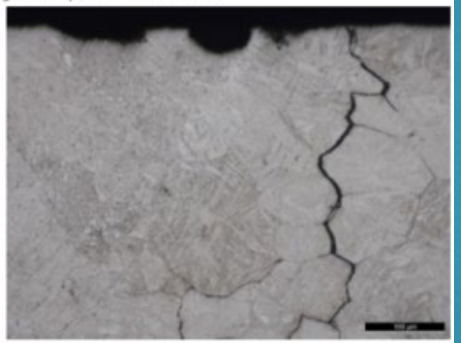


Figure 10. Specimen No. SA008E (200x etched)

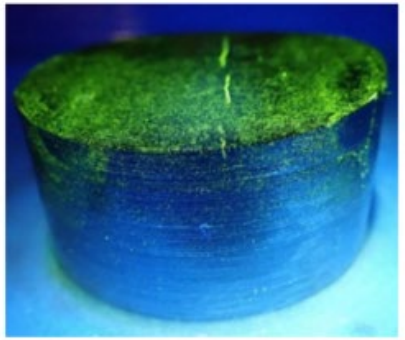


Figure 11. Sample No. SA158W

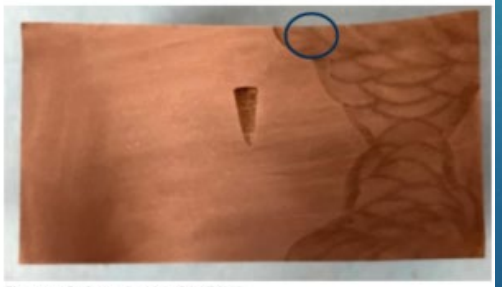


Figure 12. Sample No. SA158W

WJE
Hernando de Soto Bridge Fracture Investigation
Core Samples from NDE Inspection

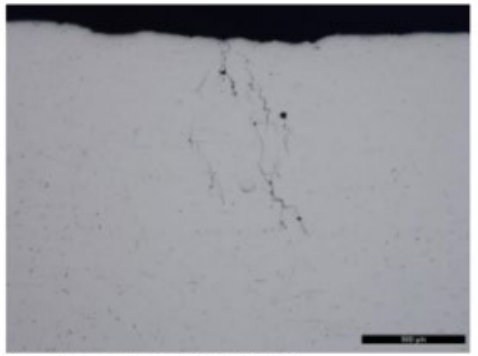


Figure 13. Sample No. SA158W (50x)

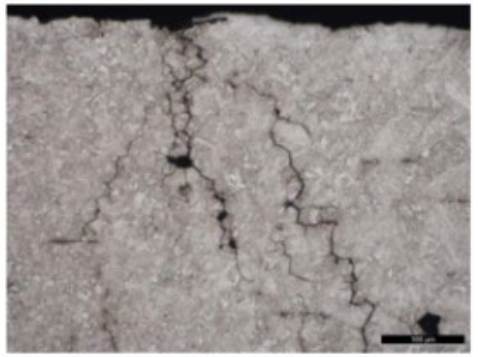


Figure 14. Sample No. SA158W (200x etched)

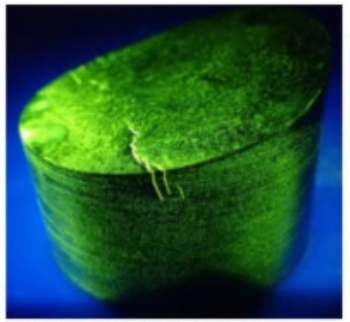


Figure 15. Sample No. SA166W


Figure 16. Sample No. SA166W

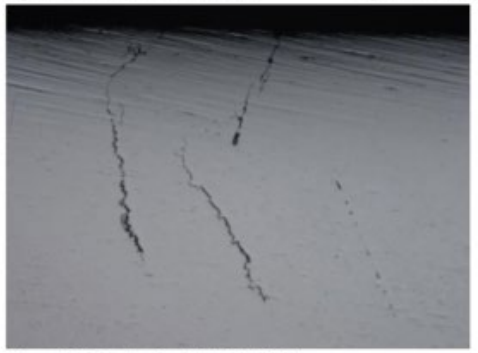


Figure 17. Sample No. SA166W (25x)


Figure 18. Sample No. SA166W (100x etched)

Figure 1. 2 ¼-inch thick plate side of fracture with cracks highlighted by yellow filings.

Figure 2. Crack highlighted by yellow filings in 1 3/8-inch thick plate at fracture.

Hydrogen Cracking

- Fabrication defect-usually at time of welding or shortly thereafter
- Normally originate in heat affected zone but can extend into weld metal
- Improper pre-heating
- Contaminated electrodes
  - I-40 fracture appears to have originated from repair welds
- Weld metal hydrogen
  - Can be as simple as moisture on electrodes or steel
- Stresses on weld due to external restraint, material thickness, joint geometry and fit-up
  - Poor fit-up greatly increases risk due to excessive root gap
  - Restraint due to lack of proper pre-heating likely cause
- Parent material-higher Carbon Equivalent value increases risk

FHWA Memorandum:

Non-Destructive Testing of Fracture Critical Members Fabricated from AASHTO M244 Grade 100 (ASTM A514/A517) Steel

- Sherman-Minton Bridge over Ohio River near Louisville, KY
  - T-1 steel fabrication with several cracks in butt welds
  - Discovered during 2011 inspection
  - Hydrogen cracking
- Memorandum added Hernando De Soto
  - T-1 steel fabrication
  - Hydrogen cracking
- Both bridges fabricated prior to adoption of "Fracture Control Plan for Fracture Critical Bridge Members"

FHWA Memorandum (Cont'd)

- Requires DOTs
  - Review inspection records to identify FCMs fabricated with T-1 steel
  - Document the members identified
  - Ensure they have been **appropriately** inspected including:
    - Adequate hands-on inspections and NDT
    - Any rejectable indications using AASHTO/AWS considered critical findings
  - Report to FHWA structure information and NDT findings
  - NDT to be complete by March 31, 2024

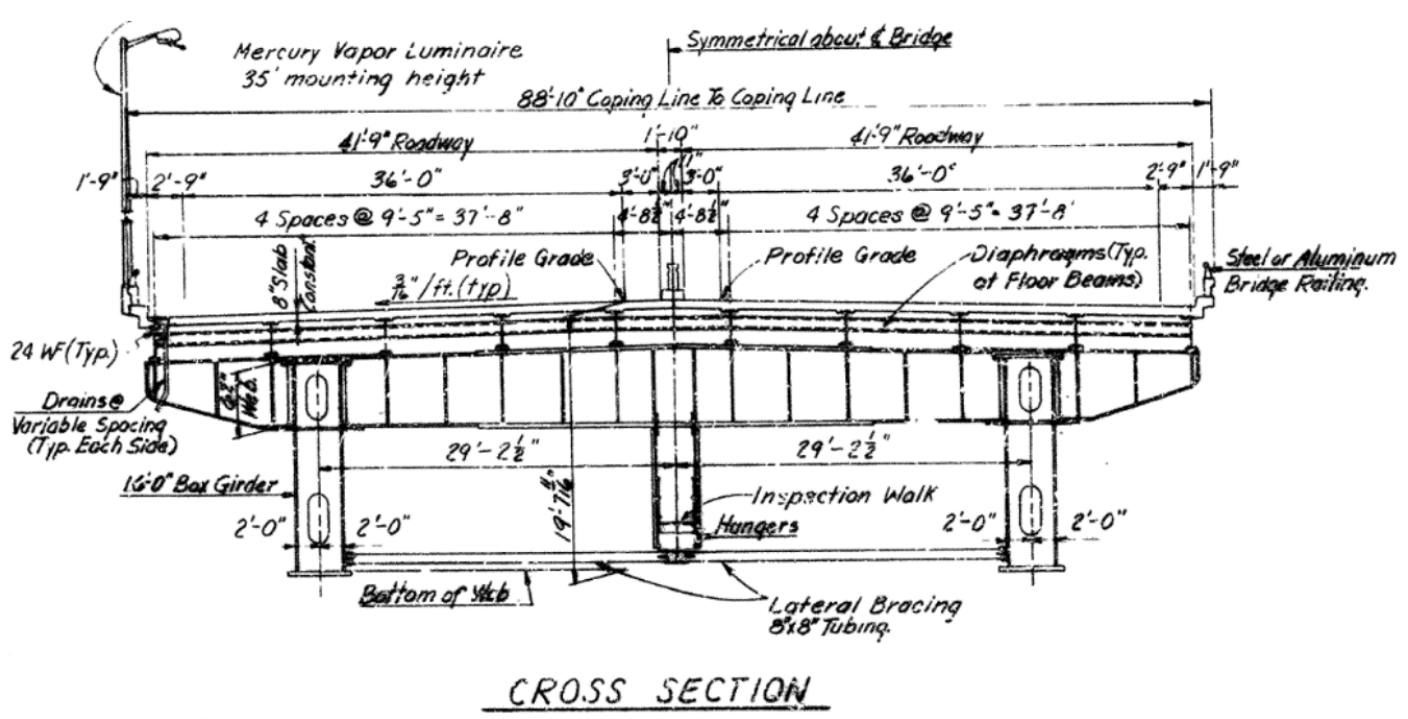
Hernando De Soto Bridge-West Approach Unit

- Five Span, Continuous, 1,855’ long
- Spans vary from 330’-400’
- Two girder system with stringers and floorbeams

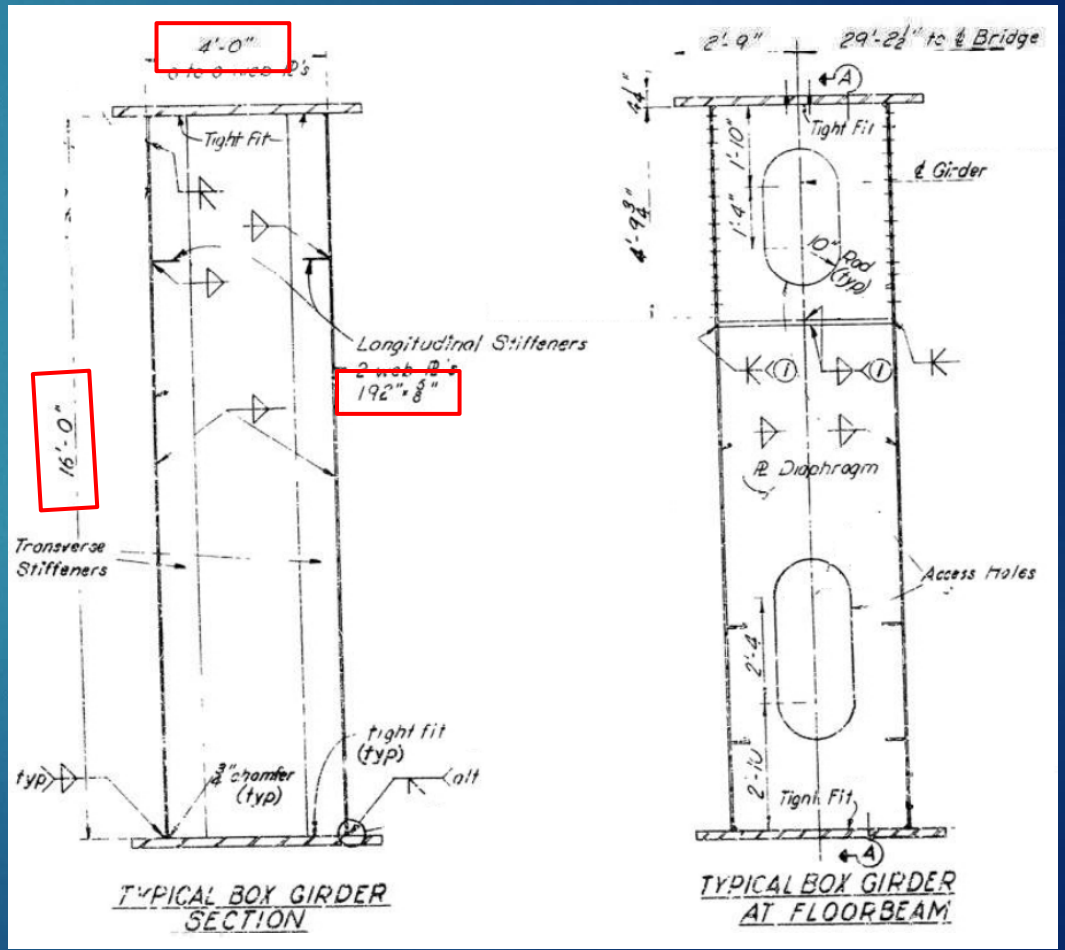
- Steel grades utilized in unit
  - A36
  - A441
  - A-514/A517

Approach Unit Details

- Welded built-up boxes
  - 16' x 4'
  - Flanges varied from 66"-74" wide, 1.75"-4" thick
  - Webs 16' tall, 5/8" thick with transverse and longitudinal stiffeners along the length
- 10 lines of stringers
- 5'-6" tall Floorbeams spaced at 25'



CROSS SECTION



TYPICAL BOX GIRDER SECTION

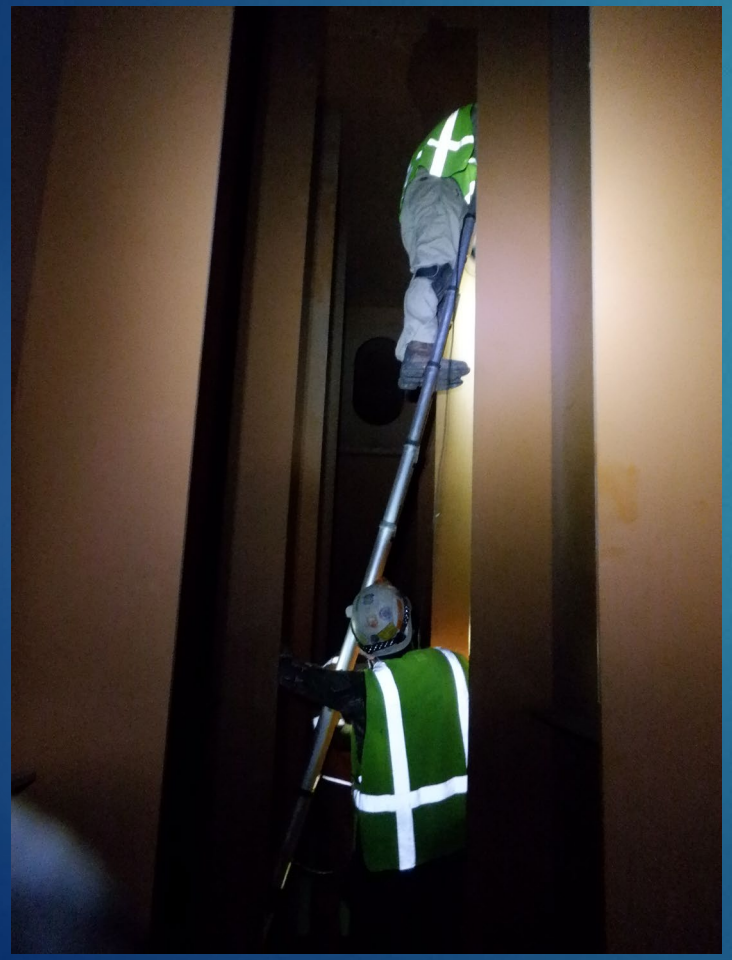
TYPICAL BOX GIRDER AT FLOORBEAM

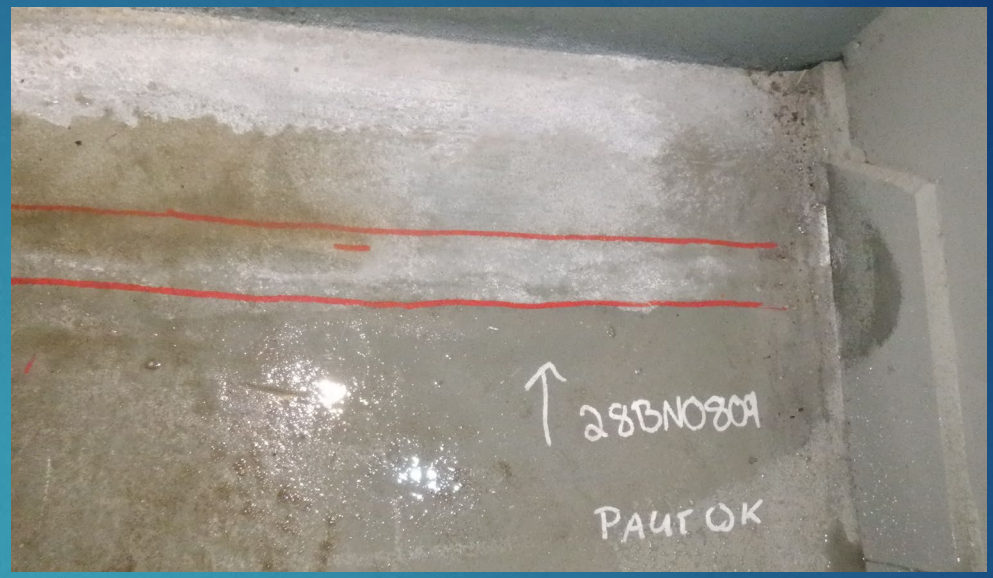
Visual Inspection - Approach Unit

- In-Depth/FCM Inspection
  - Snooper
  - Spelunking

Non-Destructive Evaluation - Approach Unit

- Utilized ECT and PAUT
  - 272 butt welds totaling 1,800'
  - ECT and MPT at possible cracks at other fatigue prone detail

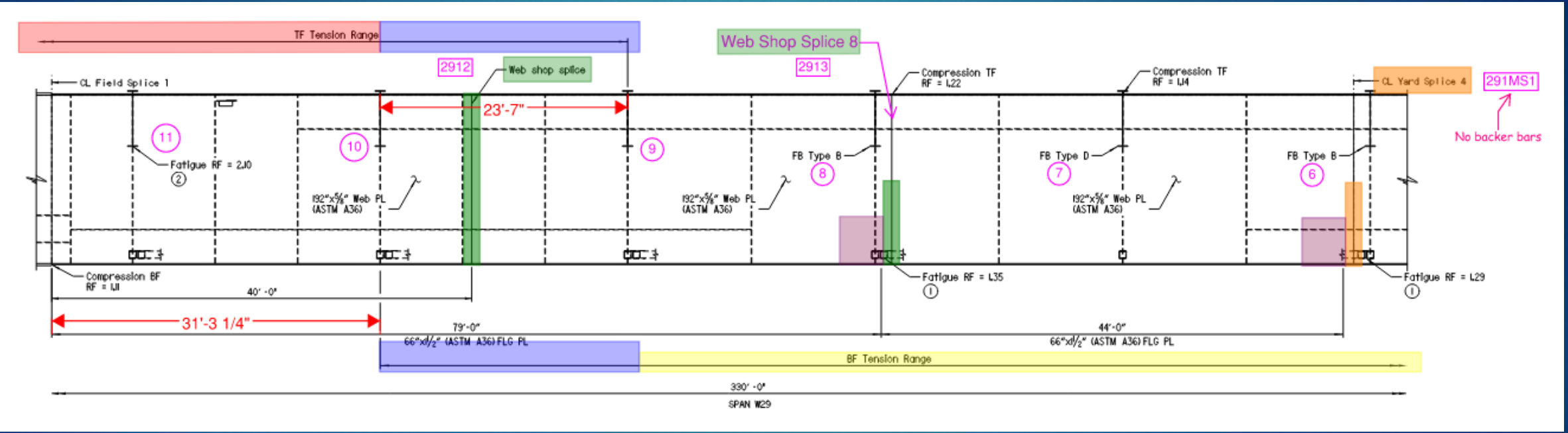




Rating Process

- Preliminary Rating (As-Built)
  - Only Design HL-93 Truck
  - Strength and Fatigue Limit States
  - Used as a baseline and for providing insight for inspectors on the critical areas
- Final Rating (As-Is)
  - Full suite of trucks analyzed
  - Section Properties Update for Section Loss

Preliminary Rating Map



Rating Methodology

- Structural analysis performed using CSI Bridge
- Box Web-Bend Buckling Coefficient
- Load rating calculations using excel spreadsheets
  - Stringers
  - Floorbeams
  - Box Girders

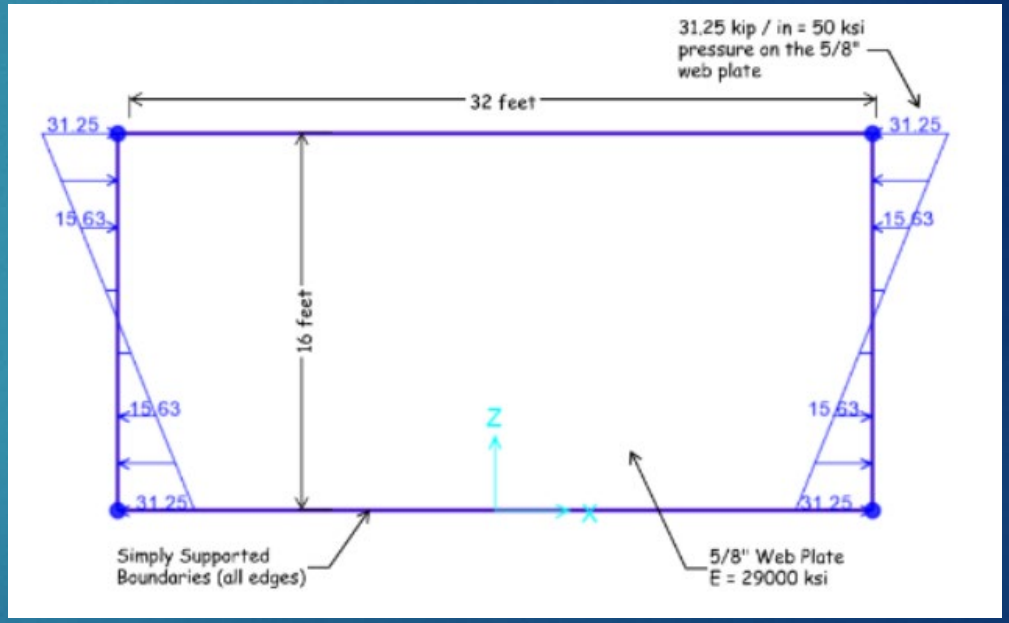
Box Web-Bend Buckling Coefficient

- AASHTO BDS Commentary in 6.10.1.9.2
  - Bend-buckling coefficient "k" may be calculated by a direct buckling analysis of the web panel
- CSi bridge used to perform buckling analysis
- Assumptions
  - Stiffeners are sufficiently stiff to prevent lateral translation of the web plates. Neglect transverse stiffeners.
  - A sufficiently long length of the web such that the up and down station boundary conditions of the plate do not matter.
  - Boundaries of the plate are simply supported (required by AASHTO for this type of analysis).
  - Web is in pure flexure (no axial force).

Box Web-Bend Buckling Coefficient

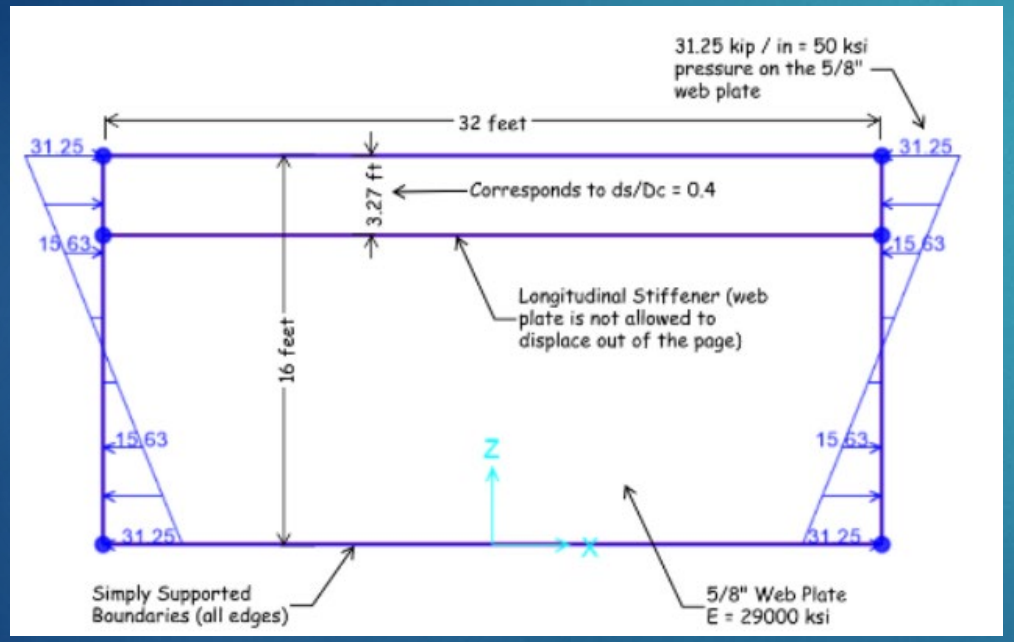
- Three plate conditions are analyzed.
  - Without a longitudinal stiffener
  - Single longitudinal stiffener positioned at the optimal position on the plate
  - The two longitudinal stiffeners in as-built condition

No Longitudinal Stiffener

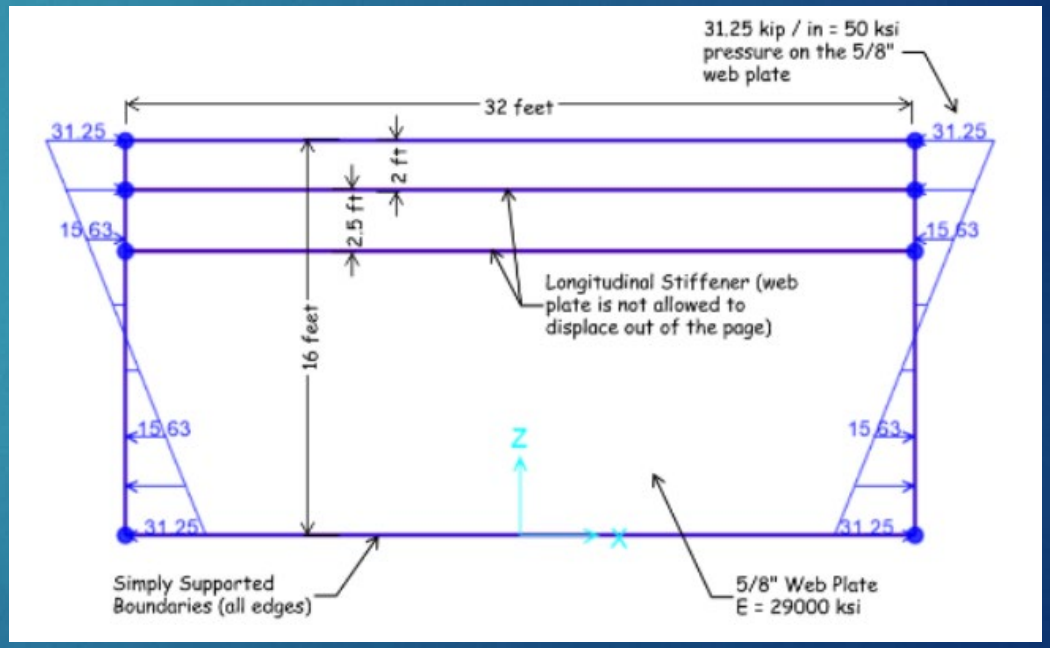


Box Web-Bend Buckling Coefficient

One Longitudinal Stiffener



Two Longitudinal Stiffeners



Box Web-Bend Buckling Coefficient

- Calculate buckling coefficient using AASHTO BDS Eq. 6.10.1.9.1-1

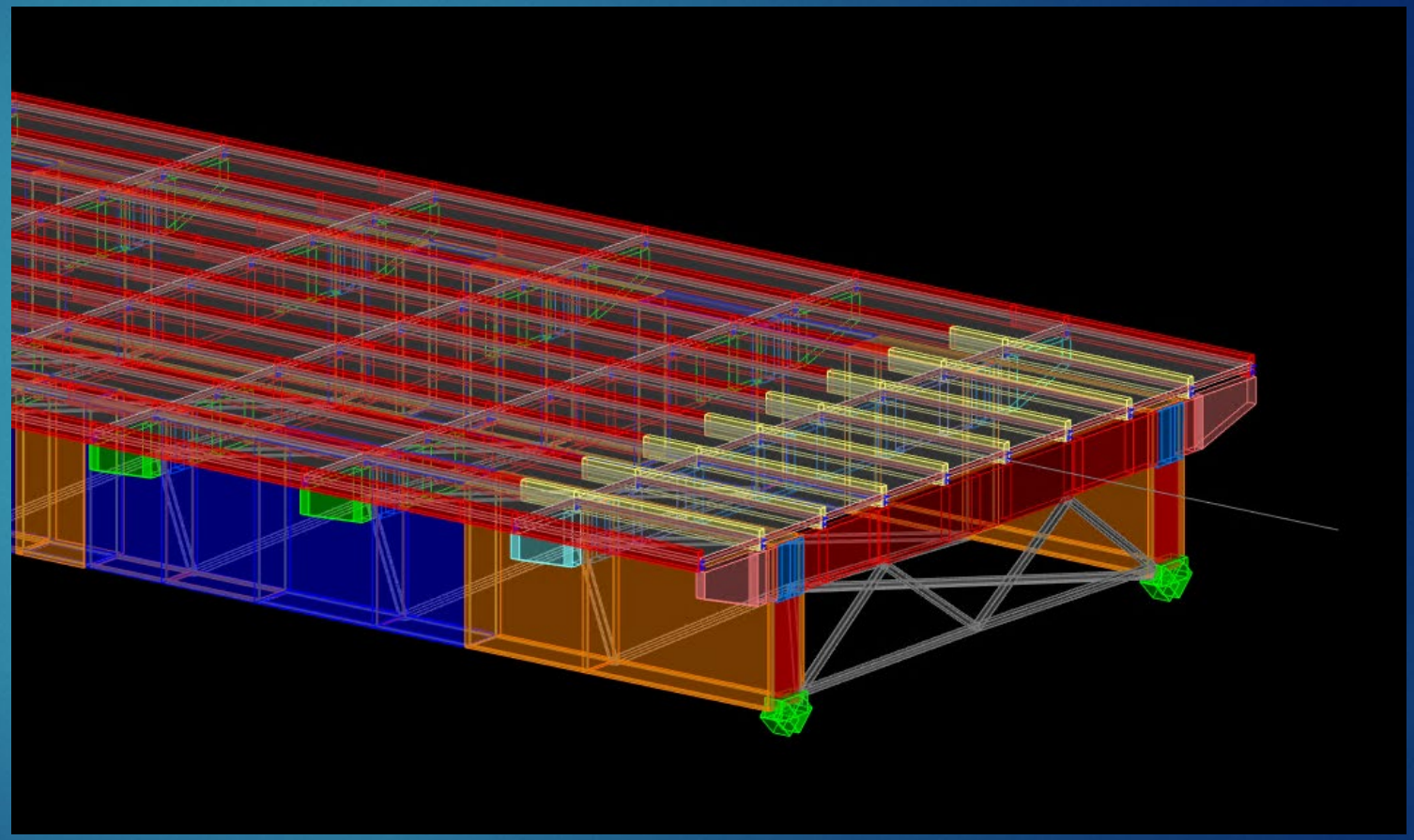
$$k := \frac{F_{crw} \cdot \left(\frac{D}{t_w}\right)^2}{0.9 \cdot E} = 24.949$$

- Buckling Analysis Results for the three plate conditions

Analysis Model	Eigenvalue	Fcrw		D/tw	k
Unstiffened	0.138	6.90	ksi	307.20	24.95
Stiffened - 1 stiffener (optimal)	0.767	38.35	ksi	307.20	138.67
Stiffened - 2 stiffeners (plans)	1.954	97.70	ksi	307.20	353.26

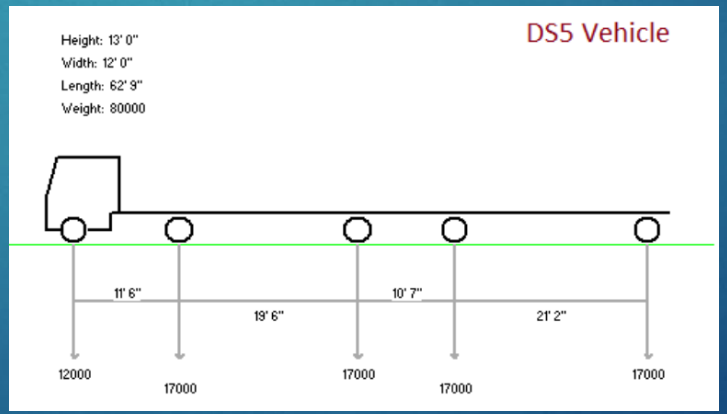
Analysis Model

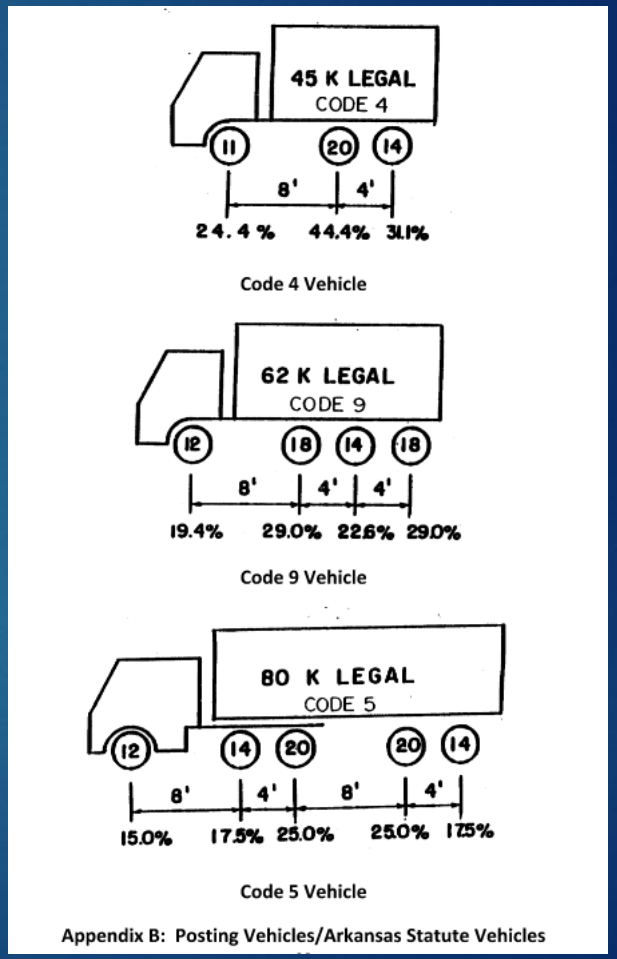
- Box member modeled using Shell elements
- Stringers and Floorbeams Modeled as frame elements
- Deck modeled Shell elements



Final Rating Trucks

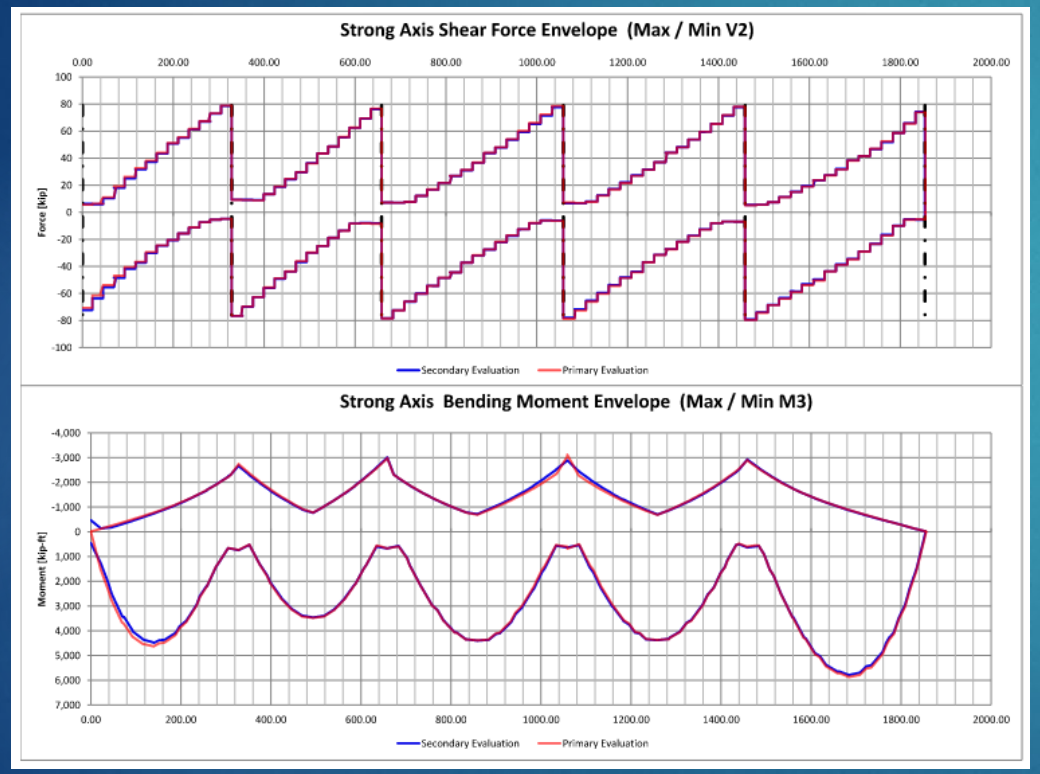
- HL-93 Design Truck
  - With lane load and Tandem with Lane load
- Legal Truck
  - Type 3, Type 3S2, and Type 3-3
- Special Haul Vehicles
  - SU4, SU5, SU6, and SU7
- Notional Truck
- Emergency Vehicles
  - EV2 and EV3
- Arkansas Legal Trucks
  - Code 4, Code 9, Code 5
- DS5 Vehicle



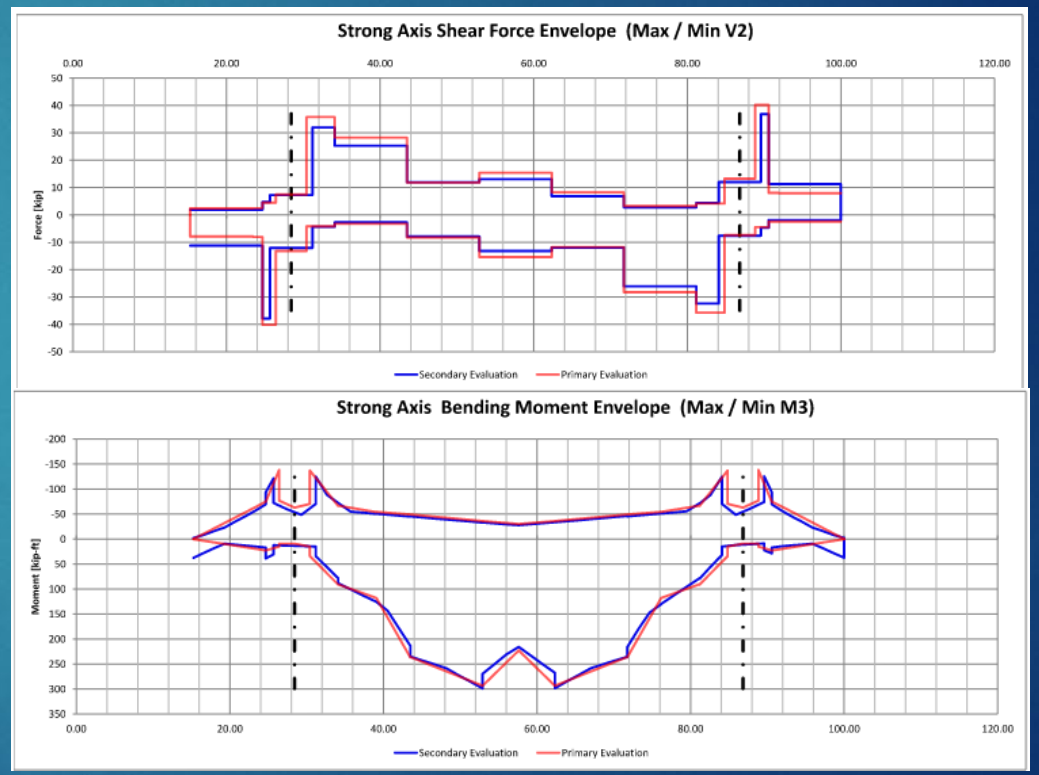


Shear and Moment Envelope

Box Girder



Floorbeam



Conclusions

- Combination of ECT and PAUT was effective in discovering flaws in various weld types
- NDT findings validated with destructive testing
- CSi an effective tool in analyzing the approach unit superstructure system and developing “k” factors for the slender web
- Controlling Load Ratings elements are Stringers and Floorbeams

Questions

- Later questions: ldickens@hntb.com and khawk@hntb.com
- References
  - *I-40 Hernando de Soto Bridge: Fracture Investigation* prepared by Wiss, Janney, Elstner Associates, Inc.
  - *Memorandum "Non-Destructive Testing of Fracture Critical Members Fabricated from AASHTO M244 Grade 100 (ASTM A514/A517) Steel* prepared by Hari Kalla from U.S. Department of Transportation/Federal Highway Administration