AISC Live Webinars

Thank you for joining our live webinar today.
We will begin shortly. Please standby.

Thank you.

Need Help?
Call ReadyTalk Support: 800.843.9166

The Use of NDT in the Rehabilitation of Major Steel Bridges: Two Case Studies

October 22, 2018

Smarter. Stronger. Steel.

AISC Live Webinars

Today's live webinar will begin shortly. Please stand by.

As a reminder, all lines have been muted. Please type any questions or comments through the chat feature on the left portion of your screen.

Today's audio will be broadcast through the internet.
Alternatively, to hear the audio through the phone, dial:

(888)-378-4398
Passcode: 240120

Smarter. Stronger. Steel.

AISC Live Webinars

Audio Options

Today's audio will be broadcast through the internet.

Alternatively, to hear the audio through the phone, dial:

(888)-378-4398
Passcode: 240120

Smarter.
Stronger.
Steel.

AISC Live Webinars

AIA Credit

AISC is a Registered Provider with The American Institute of Architects Continuing Education Systems (AIA/CES). Credit(s) earned on completion of this program will be reported to AIA/CES for AIA members. Certificates of Completion for both AIA members and non-AIA members are available upon request.

This program is registered with AIA/CES for continuing professional education. As such, it does not include content that may be deemed or construed to be an approval or endorsement by the AIA of any material of construction or any method or manner of handling, using, distributing, or dealing in any material or product.

Questions related to specific materials, methods, and services will be addressed at the conclusion of this presentation.

Smarter.
Stronger.
Steel.

AISC Live Webinars

Copyright Materials

The information presented herein is based on recognized engineering principles and is for general information only. While it is believed to be accurate, this information should not be applied to any specific application without competent professional examination and verification by a licensed professional engineer. Anyone making use of this information assumes all liability arising from such use.

Smarter.
Stronger.
Steel.

AISC Live Webinars

Course Description

The Use of NDT in the Rehabilitation of Major Steel Bridges: Two Case Studies
October 22, 2018

This webinar focuses on the rehabilitation of two major steel bridges, the Sherman Minton Bridge in Louisville and the Delaware River Bridge in Bristol, PA, each of which were rehabilitated and repaired using a combination of nondestructive testing, materials sampling and testing, engineering analysis, and emergency construction contracts. The two case studies show how major steel bridges can be quickly assessed and returned to service using a combination of tools.

Smarter.
Stronger.
Steel.

AISC Live Webinars

Learning Objectives

- List various non-destructive testing options for rehabilitation of existing steel structures.
- Describe the process of qualifying a unique ultrasonic testing procedure.
- Explain the communication techniques that can facilitate coordination between designers and the inspection team, when assessing the rehabilitation of an existing structure.
- Name steps that can be taken to perform a full forensic assessment of a steel structure.

Smarter.
Stronger.
Steel.

The Use of NDT in the Rehabilitation of Major Steel Bridges: Two Case Studies

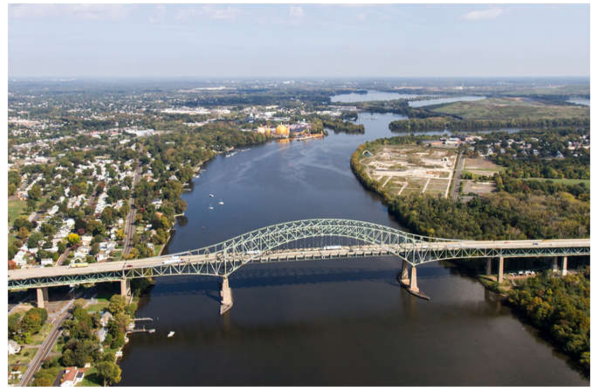
Frank Russo, PhD, PE
Technical Director, Bridge Engineering
Michael Baker International
Philadelphia, PA

Smarter.
Stronger.
Steel.

Two Case Studies....with very different outcomes

Sherman Minton Bridge

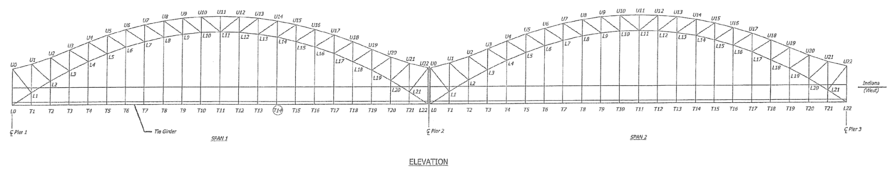
PA NJ Turnpike Delaware River Bridge



9

Sherman Minton Bridge over the Ohio River at Louisville

Sherman Minton Bridge – Structure Details



- Structure Information
  - Tied Arch
  - 2 – 800 foot spans
  - Double-deck structure
  - Navigable waterway underneath

11

Bridge History

- Prior inspections revealed visual cracks in isolated welds
- Prior NDT inspections documented multiple internal weld defects
- No comprehensive assessment of the bridge condition was ever conducted
- Large amount of unknowns

12

Contributing Factors

Type of Material

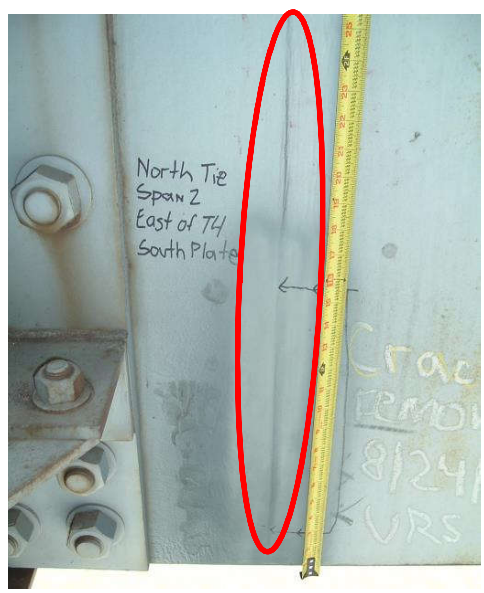
- "T-1" Steel
  - VERY high strength steel
  - Limited ductility
  - Susceptible to FRACTURE at cold temperatures and with small cracks

Sensitive Details

- Tie girder welds
- Diaphragm plates
- Lateral bracing details

Tie Girder Welds

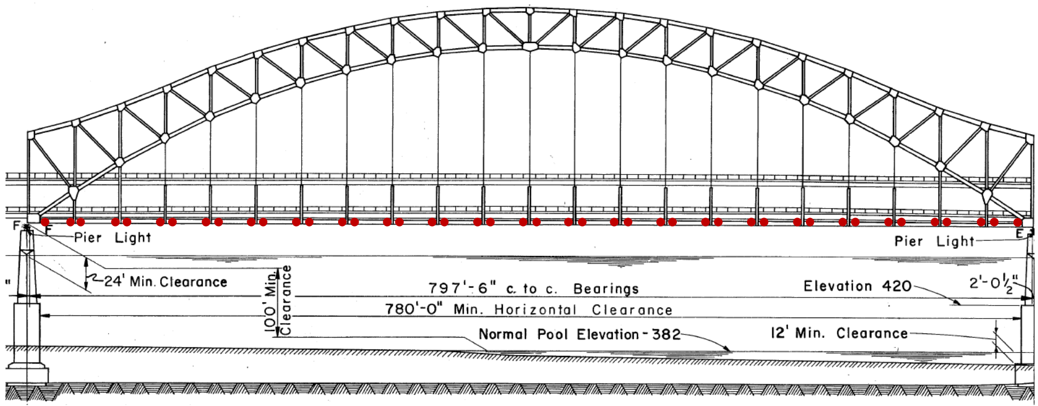
- T-1 Steel (known issues with welding)
- Tie girder butt-welded thin to thick plates to allow for drilling of tie girder splices, i.e. to maintain the section capacity



14

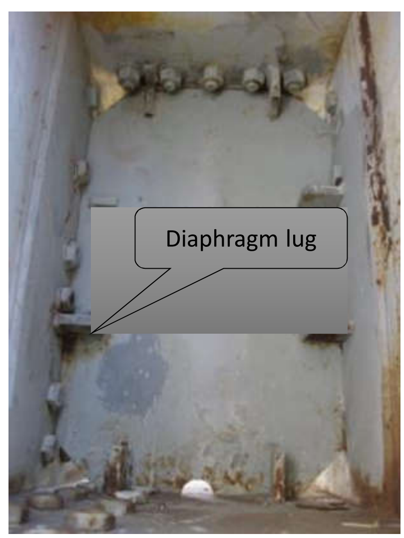
Tie Girder Welds

176 Individual welds per tie x 2 ties x 2 spans = 704 potential fracture sites



15

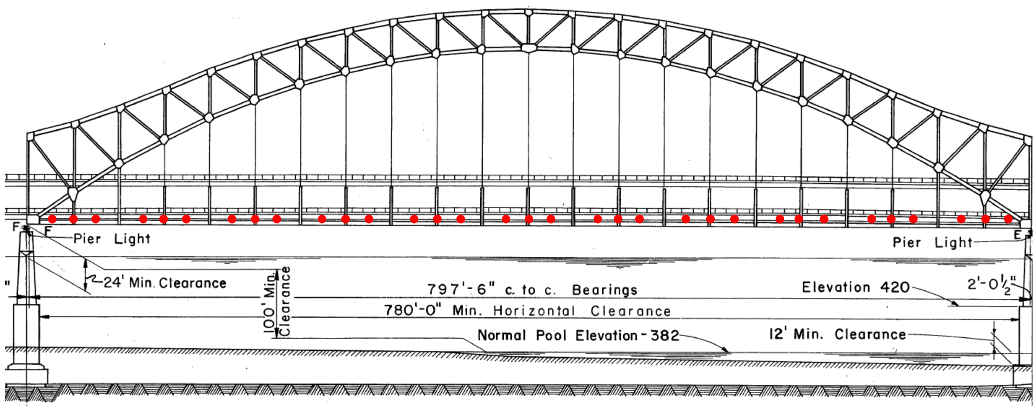
Diaphragm Lugs



16

Diaphragm Lugs

33 diaphragms per tie x 2 ties x 2 spans x 8 lugs per diaphragm x 2 legs = 2112 welds



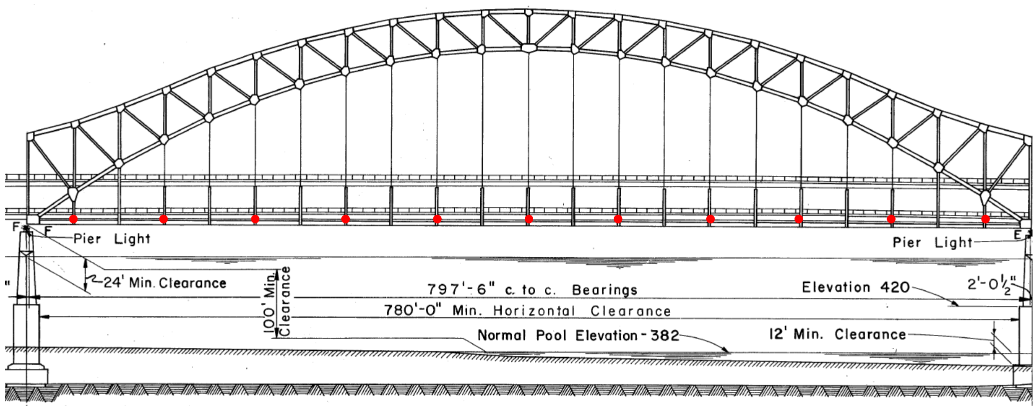
17

Lateral Bracing Plates

18

Lateral Bracing Plates

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



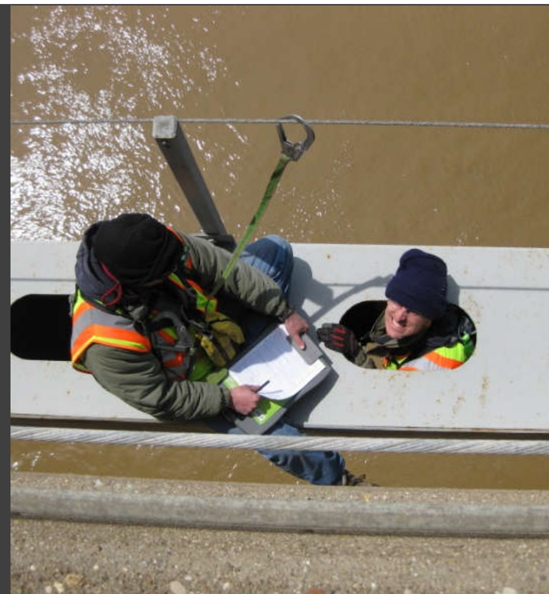
19

Enhanced Bridge Inspection

20

Inspection & Testing

- COMPLETE hands-on visual inspection of EVERY INCH of weld metal on the tie girder
  - What can we find?
- Nondestructive testing (UT, MT, RT, X-Ray)
  - What can we find that we can't even see?
- Extensive sampling of bridge materials – over 100 cores taken
  - How strong, how tough, how big of a crack is "too big"?
- The MOST comprehensive visual, NDT & physical testing program ever conducted on this bridge



21

Non-Destructive Testing (NDT)

Performance testing of NDT technicians

22

Initial Repairs

Initial Repairs – Lugs & Lateral Bracing Plates

- Retrofit diaphragm lugs and lateral bracing connection plates
  - Why?
    - Nearly impossible to inspect thoroughly
    - Each could serve as a fracture initiation site


Diaphragms – Before & After

25

Diaphragms – Bolted Retrofit

26

Lateral Bracing Plates - Existing

27

Lateral Bracing Plates – Bolted Retrofit

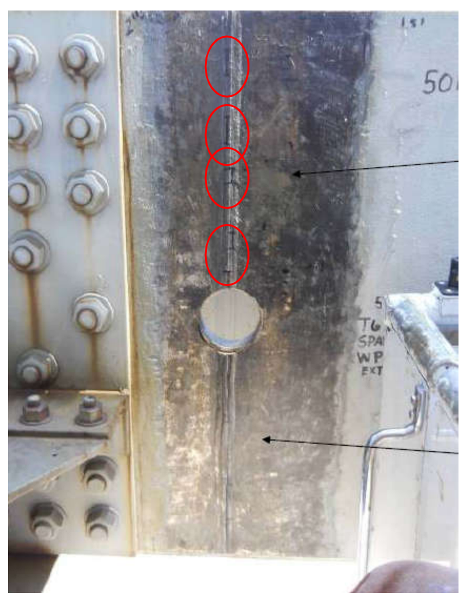
28

Tie Girder Welds

- It's what we CAN'T see that's the problem....

Tie Girder Welds – Repairs

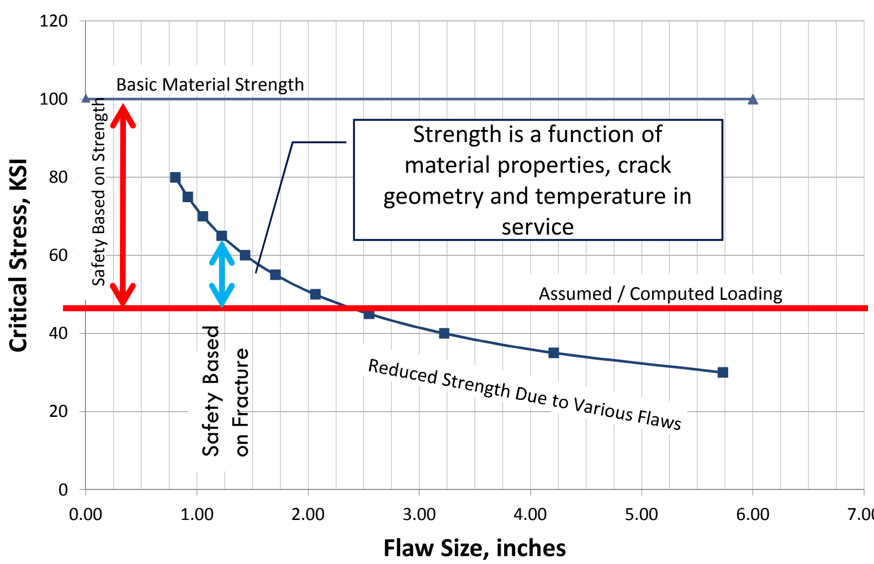
- Use of selected coring repairs



Engineering Approach

31

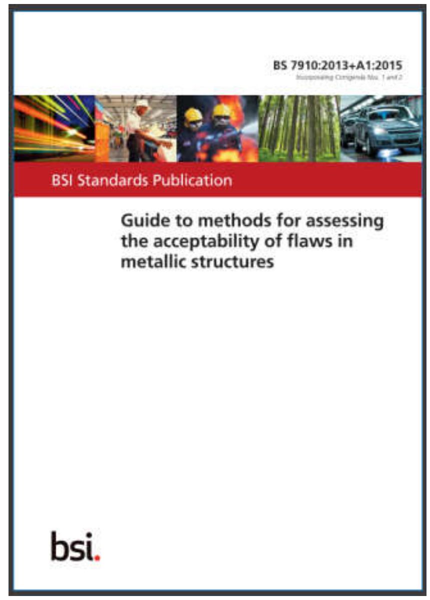
Why Even Small Cracks Can Matter



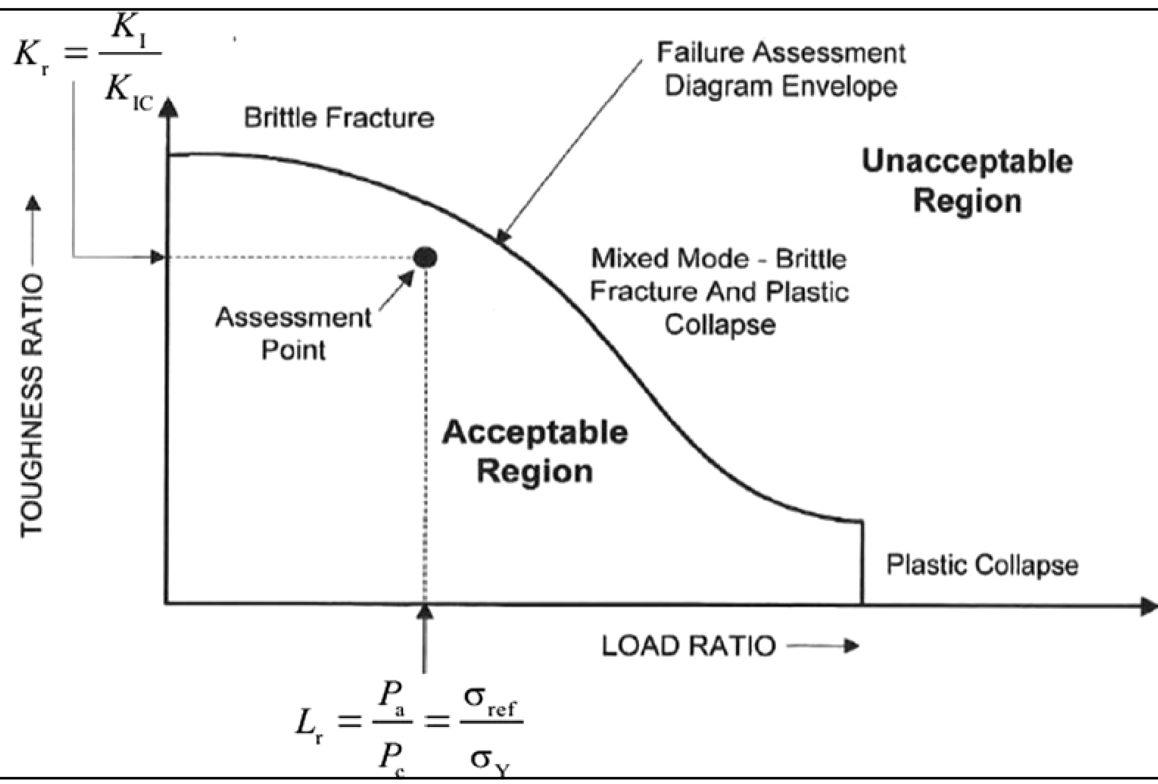
32

Fitness for Service Evaluation

- **BS 7910:2005 ---** *GUIDE TO METHODS FOR ASSESSING THE ACCEPTABILITY OF FLAWS IN METALLIC STRUCTURES*
  - Hypothesize combinations of temperature, load and flaws
  - Determine if the bridge can be kept open

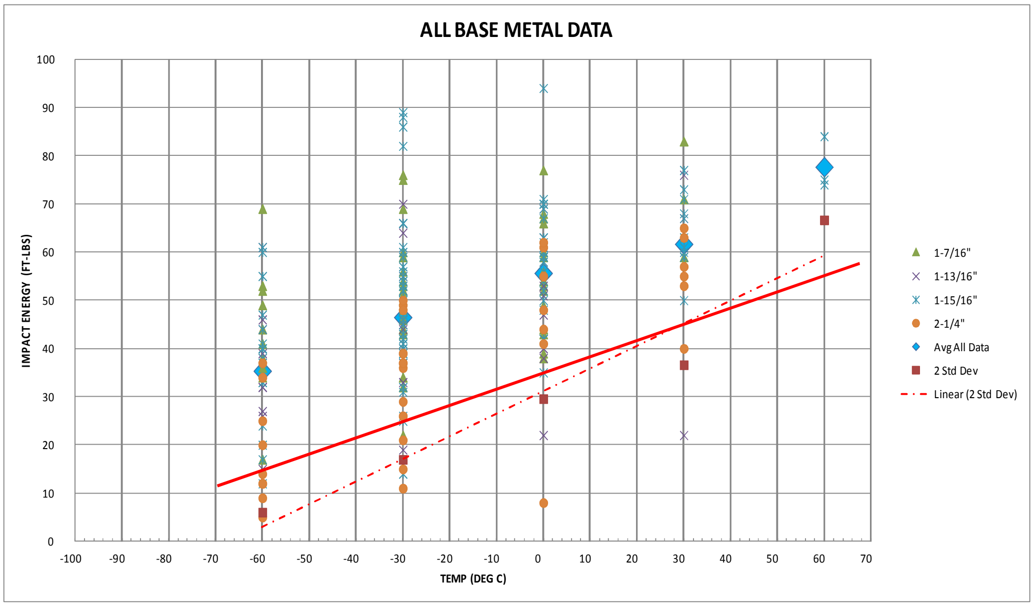


33



34

Material Assessment



35

Fitness for Service Conclusions

Some initial concern about allowing the bridge to remain in service at temperatures around 30F.

Bridge closed Friday September 9th 2011 @ 4 PM after a crack that should not have been stable at ambient temperatures was found.

Next steps…now what to do ????

36

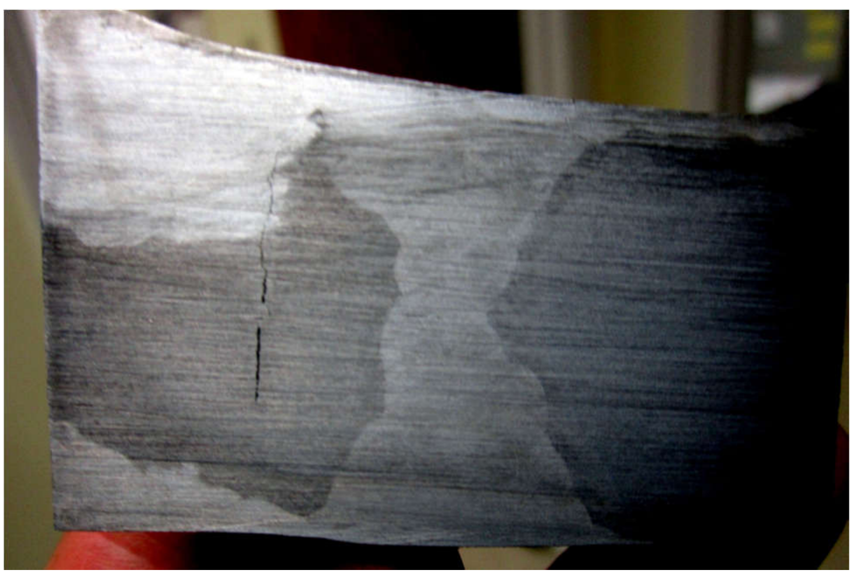
Emergency Bridge Closure

During removal of the 3rd lateral bracing plate, a critical flaw was discovered.

Problem detected Thursday evening – bridge ordered closed Friday afternoon

37

Why we closed the bridge …



38

Dog-Bone Retrofit

- Isolate potential crack propagation

39

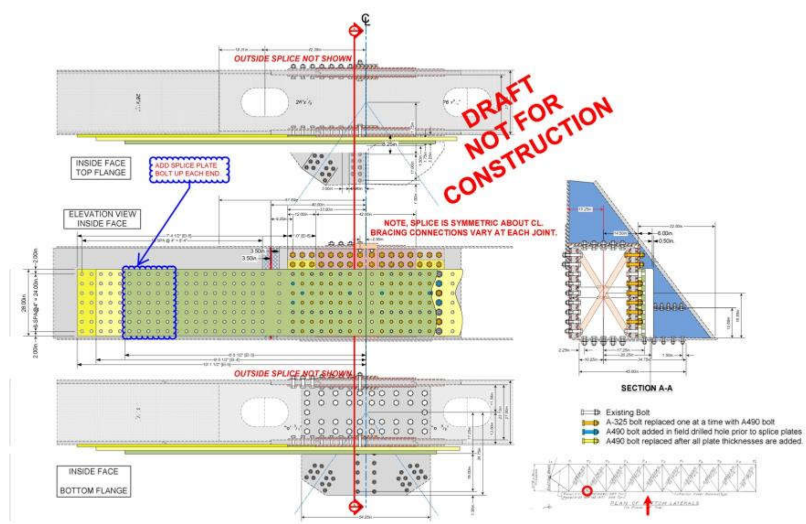
Retrofit Design Considerations

40

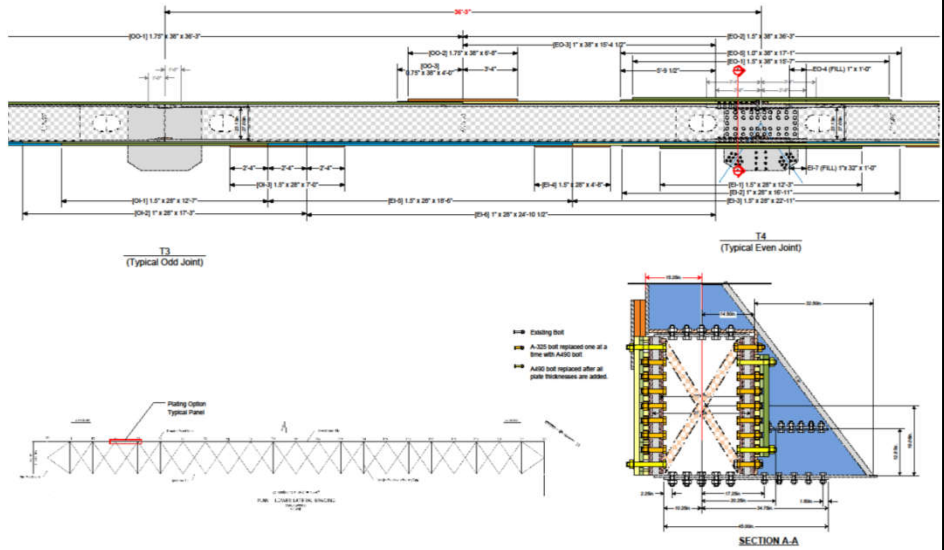
Retrofit Options Considered

Option 1	Option 2	Option 3	Option 4
Local Plating • 50 / 100 ksi local plating of joints	**Global Plating** • Extension of Option #1 with extra full length plates	**Tie Post Tensioning** • Full length PT of the tie to fully or partly decompress the section	**Tie Replacement** • Sequential replacement of the tie in place

Local Plating Alternate



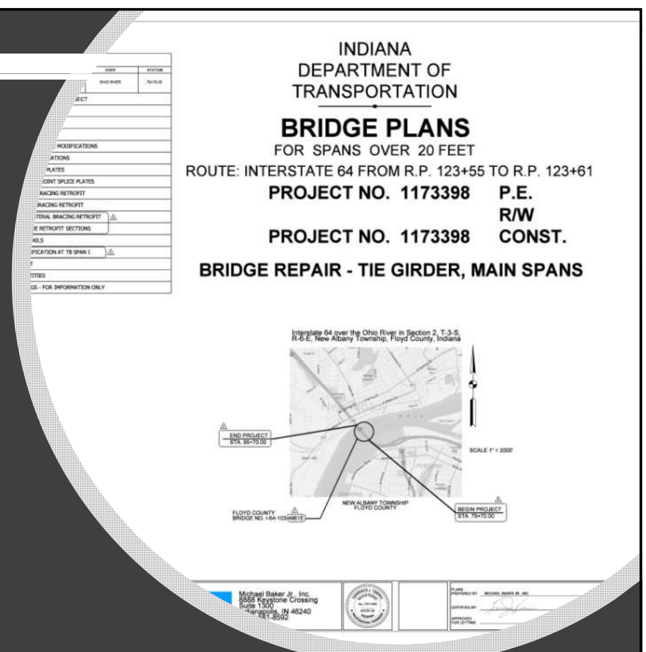
Global Plating Alternate



43

SOLUTION

- **Sherman Minton Bridge Solution**
  - Global plating
    - Bolt supplemental/alternate tie (plates) along side both sides of ties
    - Complete redundancy / alternate load path
    - $13.8 Million (+/-)
    - 4.5 months (+/-)
    - Open bids 18 October 2011

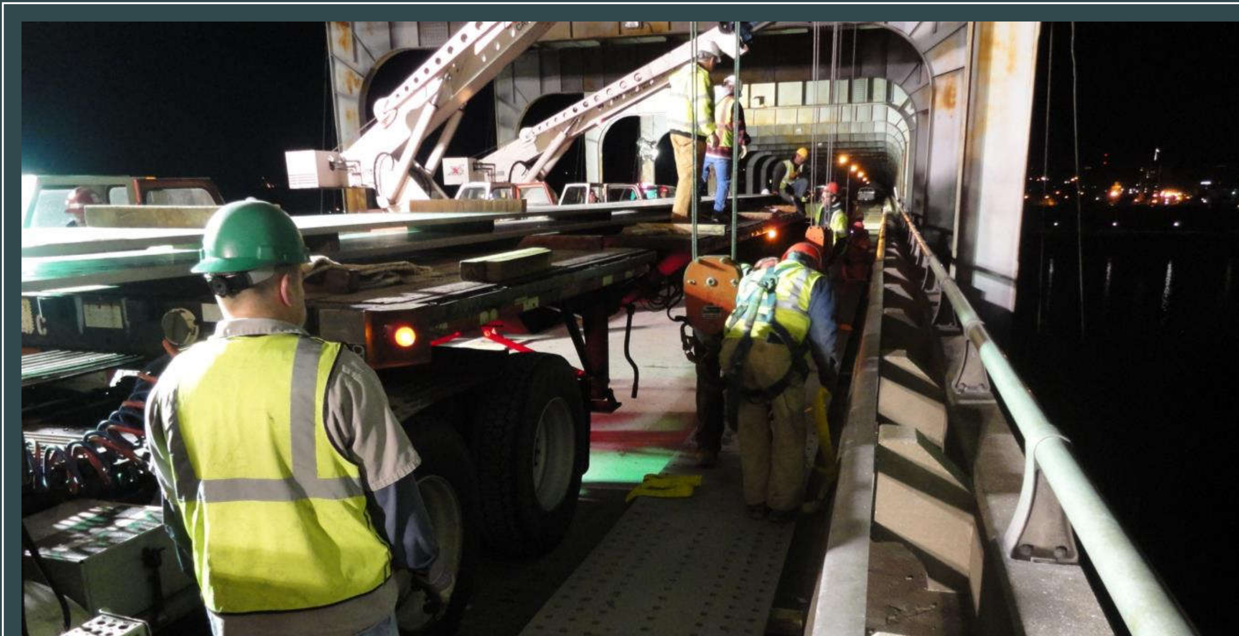


44

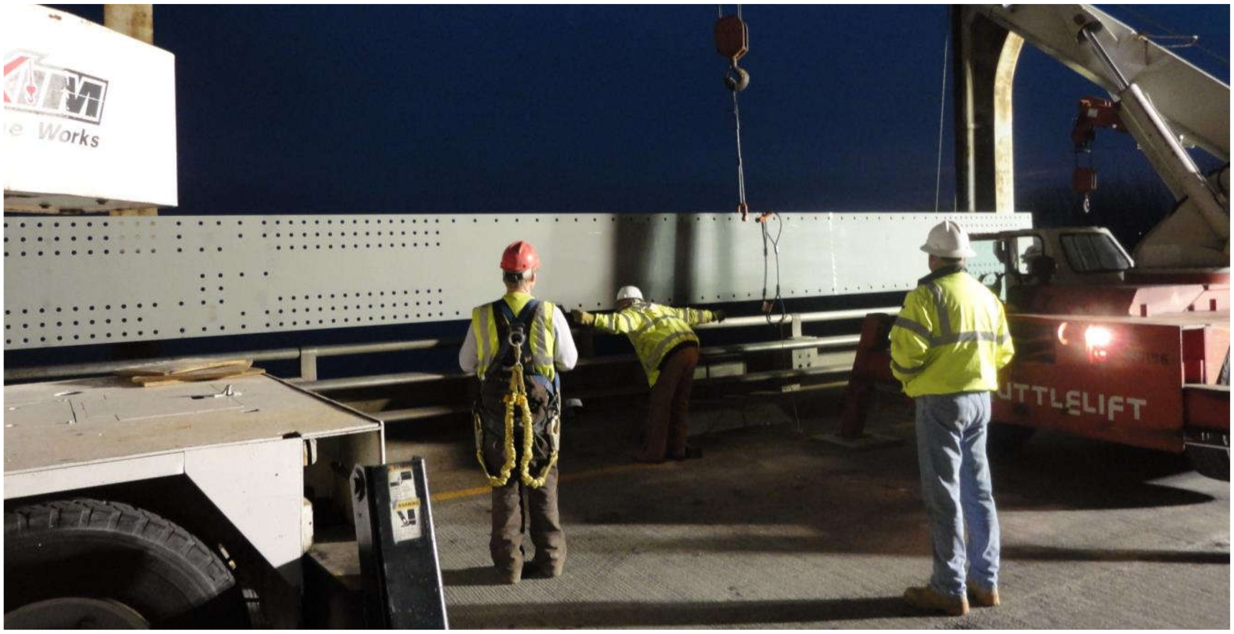
Discovery & Solution Timeline

Inspection NTP to Intermediate Repair	• 3.5 months
Intermediate Repair to Finding which closed the bridge	• 3 weeks
Bridge Closure to Complete NDT work	• 3 weeks
Bridge Closure to Advertisement of Contract Documents	• 3 weeks

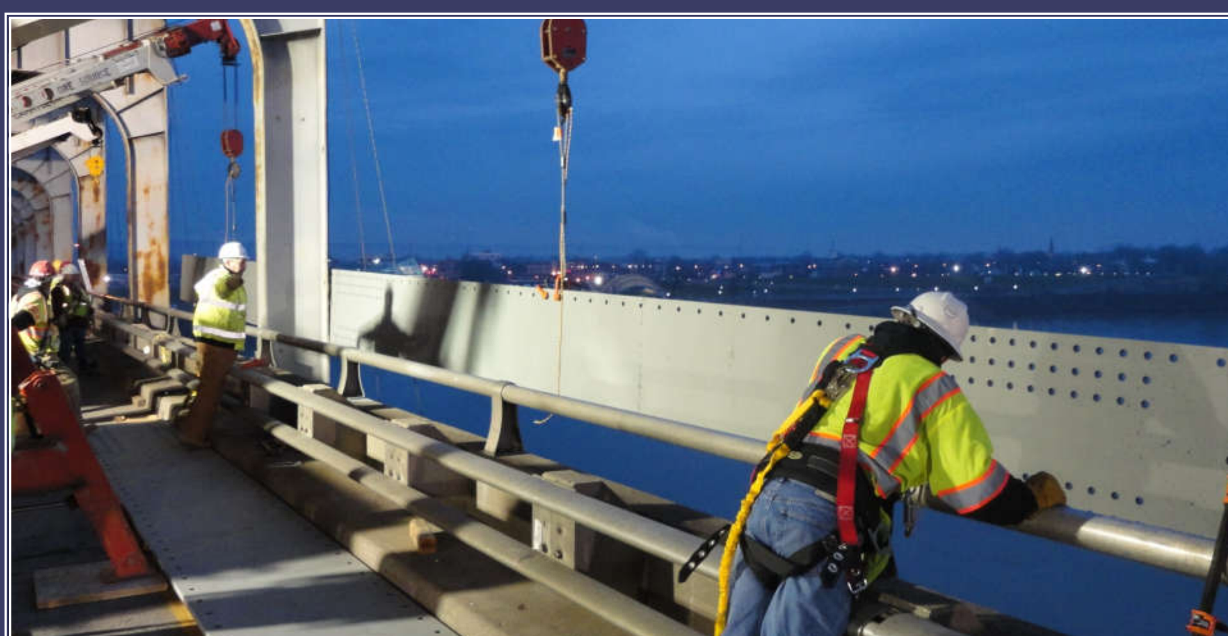
45



46

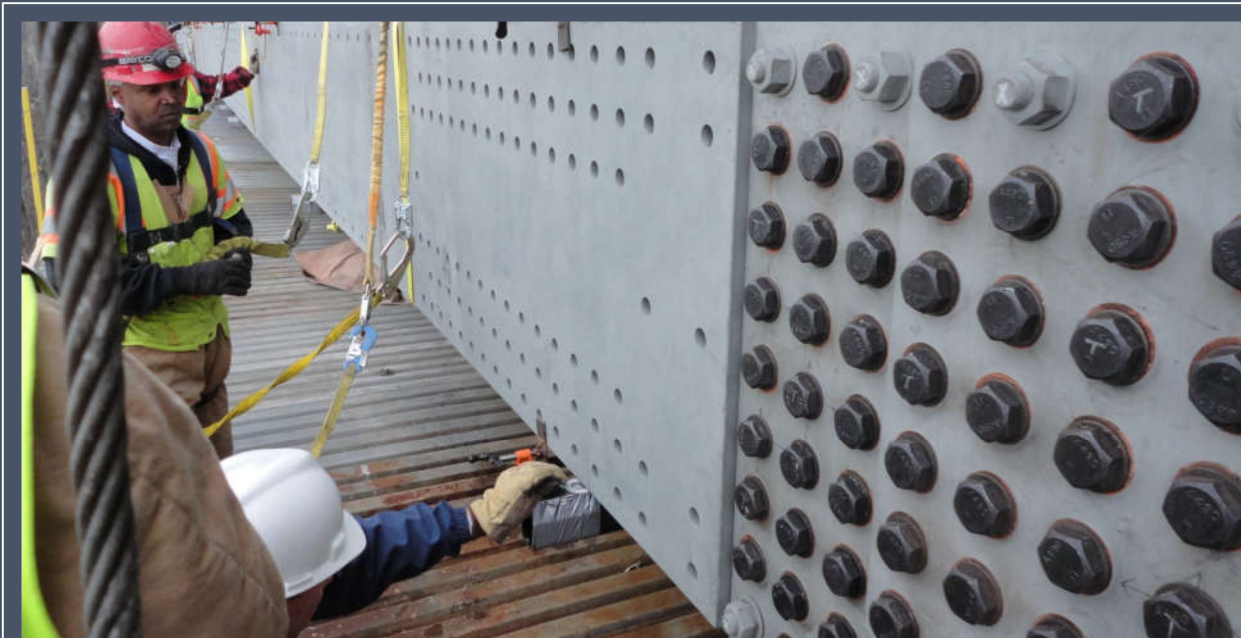


47



48

49

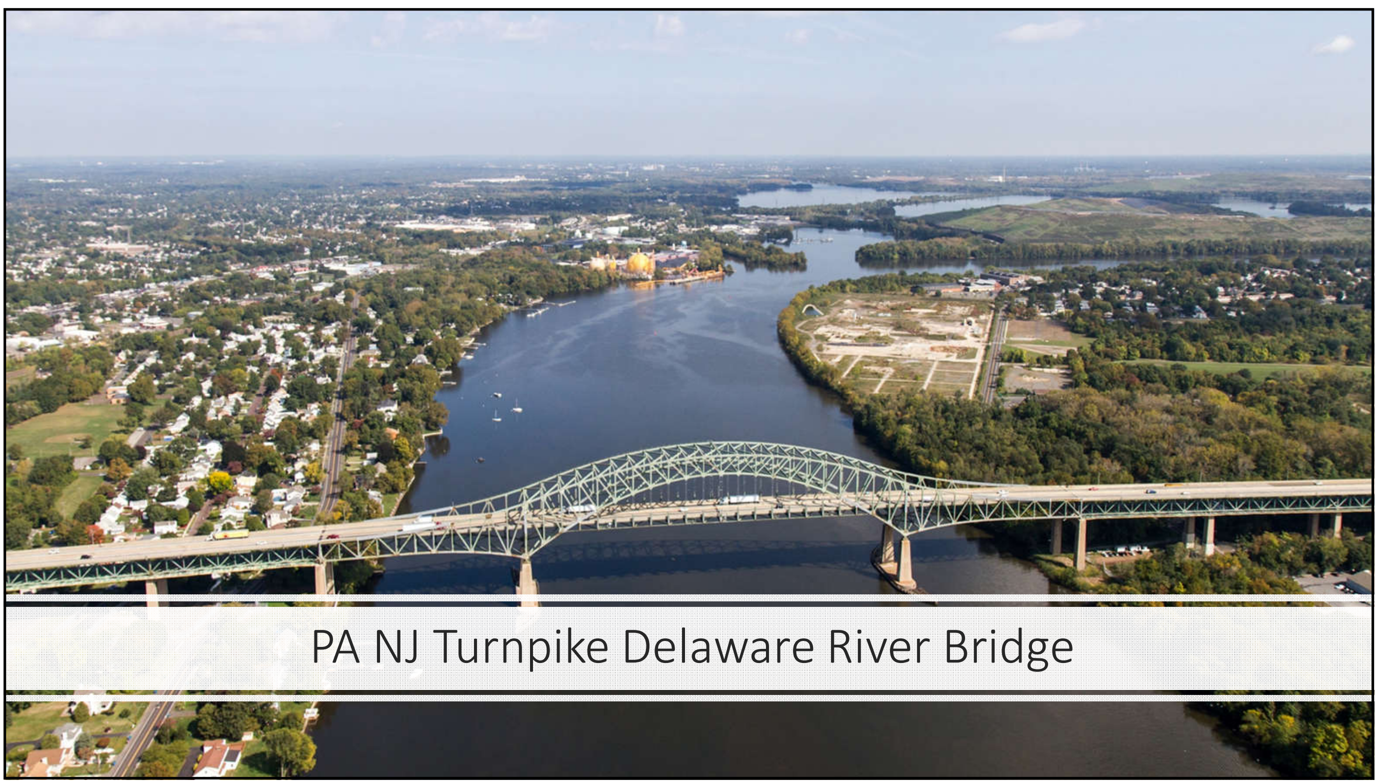


50

Sherman Minton Conclusions

- Detailed inspection including NDT is sometimes warranted, especially for bridges where cracking problems have been noted
- NDT plus material sampling are key elements to a Fitness for Service Analysis
- Sometimes a major retrofit is unavoidable. This is not always the case, i.e. Fremont Bridge in Oregon

51



PA NJ Turnpike Delaware River Bridge

Day 1: January 20

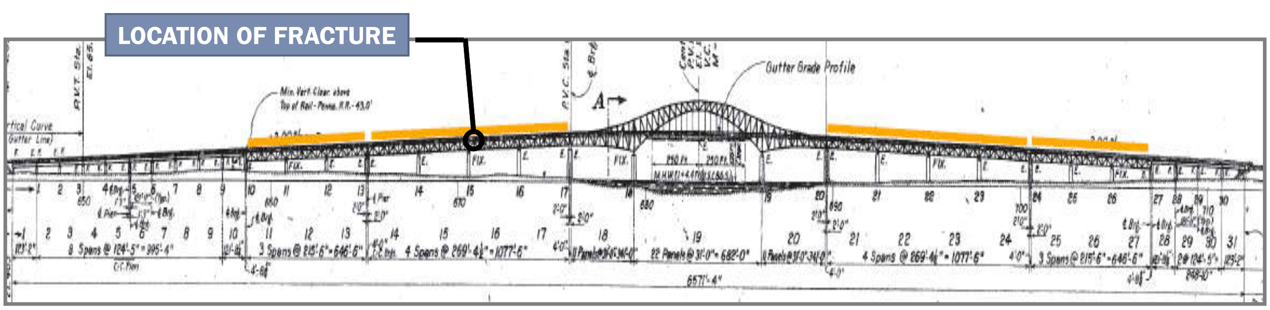
Fracture discovered by painting contractor

Immediate Action

- Remove Traffic on and below bridge.
- Clearing the Unit of Contractor Material
- Stabilize Truss

53

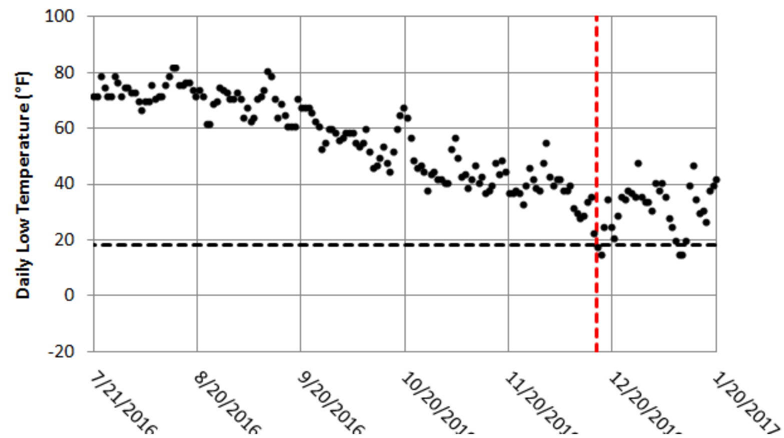
Location of Fracture



- 3 Span Continuous Unit: Piers 10 – 13. Total Length ≈ 647’
- 4 Span Continuous Unit: Piers 13 – 17. Total Length ≈ 1078’

54

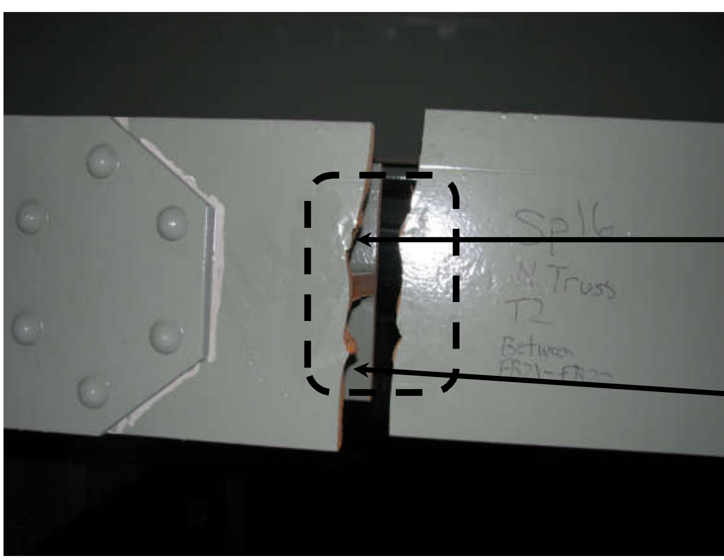
Temperature History

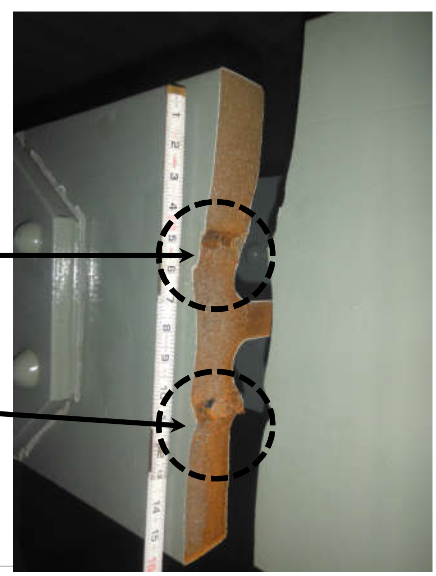


- Fracture occurred prior to January 20th
- Neighbors heard loud noise on or about December 16th, 2016
- “Shook the ground”
- 35 days before fracture discovered

55

Fracture and Evidence of “Plug Welds”





56

Fractured Chord After Removal

- W 14x314 Man-Ten Steel
- tf=2.28”
  tw = 1.41”

57

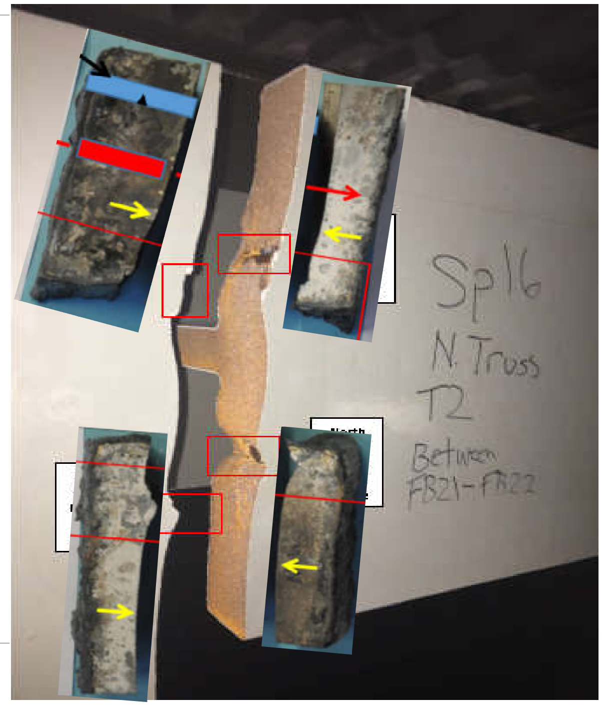
Fracture Cause

- Mis-drilled holes during fabrication
- Attempt to fill holes with weld metal
- 1” diameter, 2.3” deep hole
- Hole not completely filled
- Slag, cracks in weld metal, lack of fusion, etc.
- HAZ around edge of hole
- Brittle fracture initiated at hole edge, propagated through member
- No fatigue crack growth seen

58

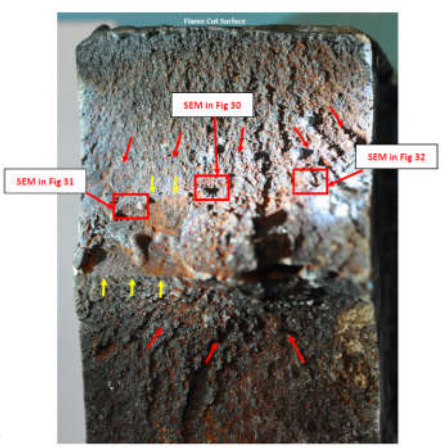
Sample Orientation

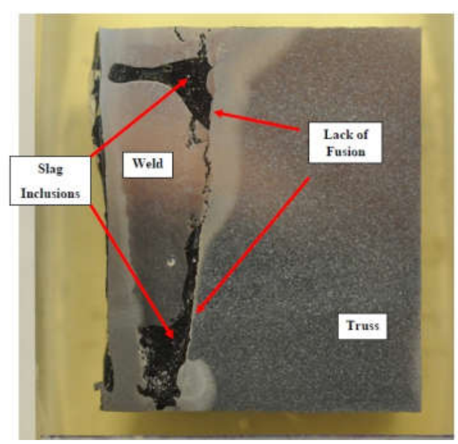
- Photos of samples overlain on the fractured U20-U19' chord



59

Lehigh's Investigation





60

UT Testing Approach

Phase I	Phase II	Phase III
Phase I • Development of UT testing protocols • Preparation of test plates • Onboarding of technicians • Qualification testing	**Phase II** • Expansion of connection testing • Additional qualification testing	**Phase III** • Selective full length member testing

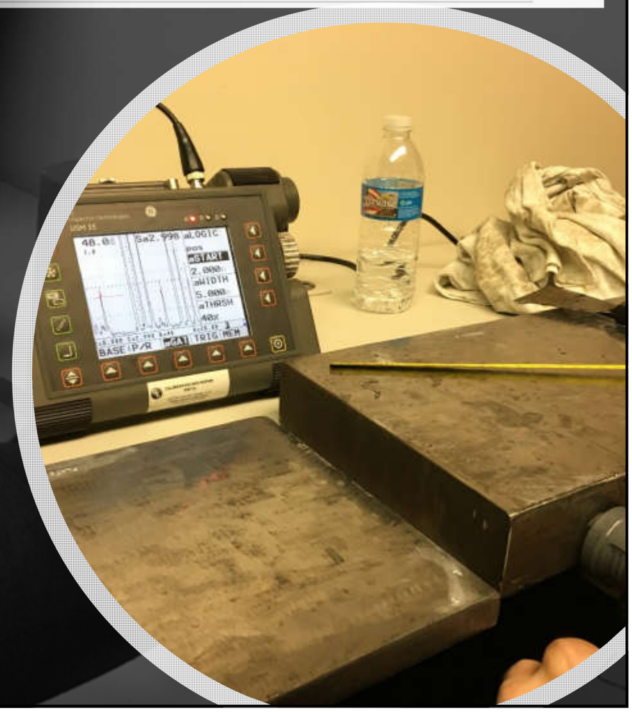
61

Phase I UT NDT Testing

- Development of UT approach and objectives
- *"To establish a uniform Ultrasonic Testing approach for the discovery of major weld defects remaining in plug welded hole repairs, made during the bridge construction. Potential areas for defective weld sites being investigated, are in the flanges of W shaped rolled members."*

62

Procedure Validation / Inspector Testing

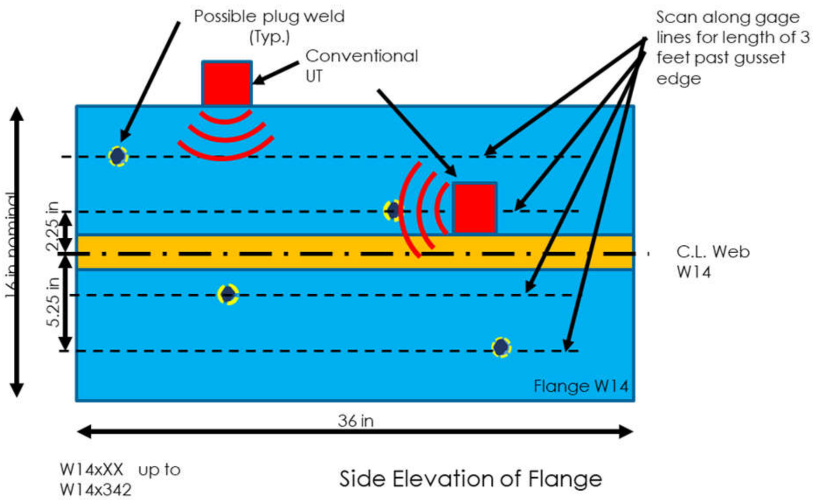


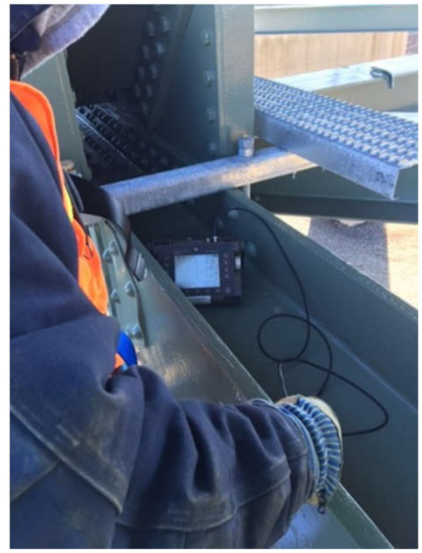
Ultrasonic Testing Program

- Needed a method that could find weld-filled holes
- Straight wave scan from flange edges
  - Down from top edge
  - Up from bottom edge

64

UT Testing Procedure Schematic



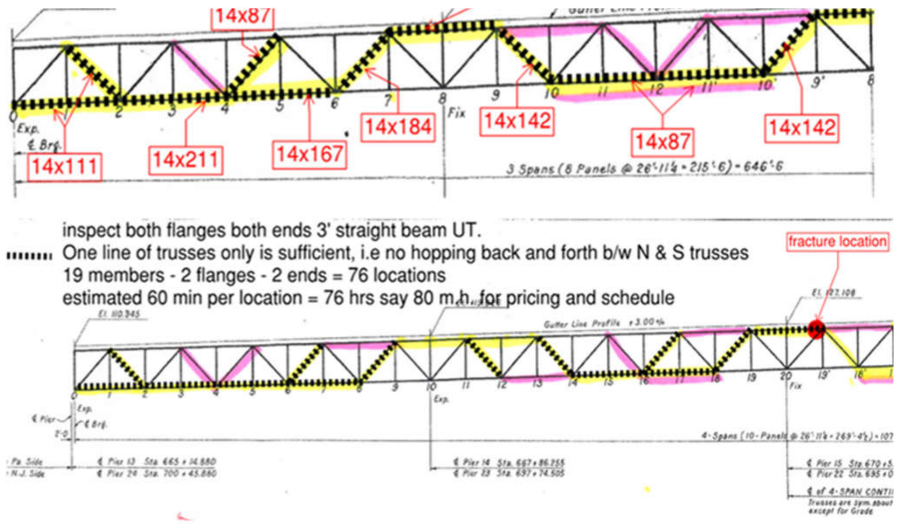


65

All Inspectors Performance Tested

Development of UT Testing Approach

- Develop limits of testing
- Test “dashed” members on North truss, PA side only as first screening (i.e. about 1/8th of tension members)



Phase II NDT UT Testing

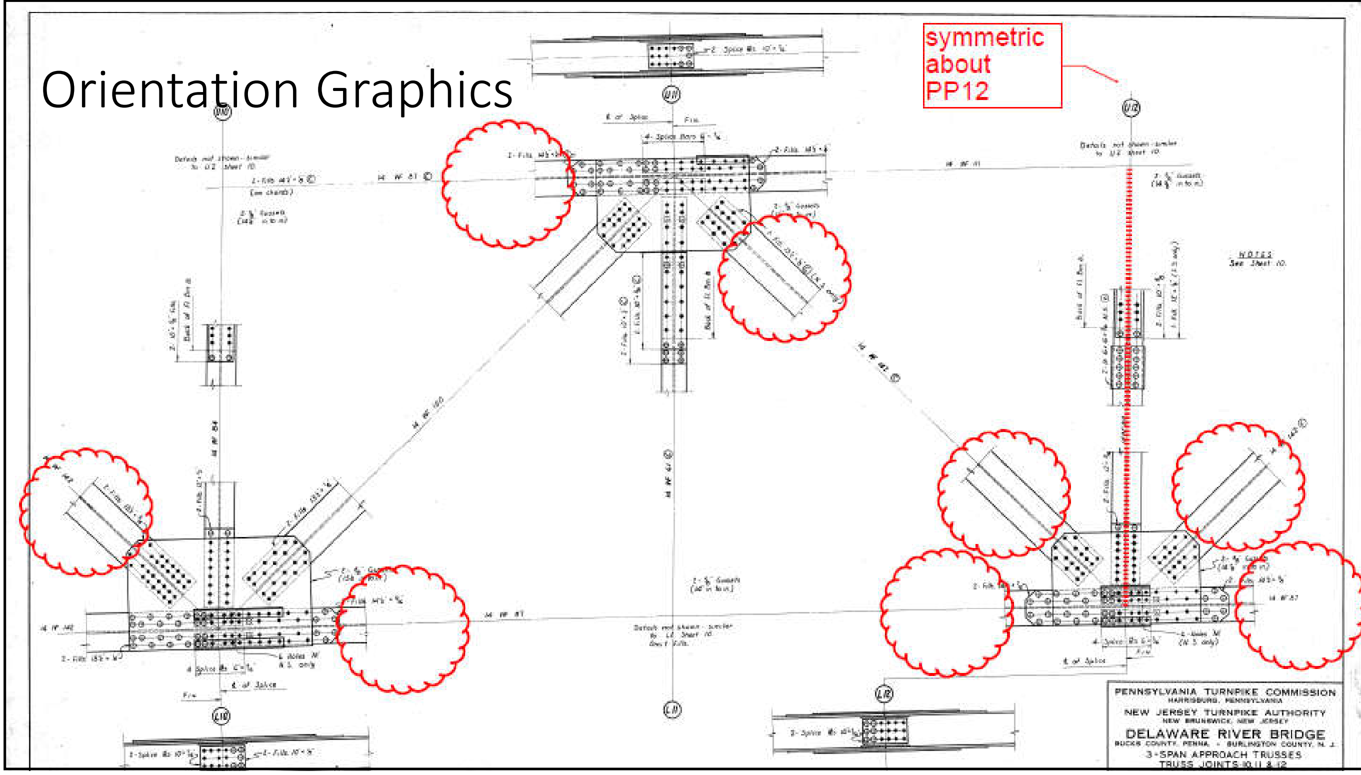
Expand the testing 8-fold to include all tension and reversal members on the PA and NJ deck truss approach spans

Continue pattern of testing end 3-ft. regions adjacent to main gusset plate connections

On-board many new inspectors from numerous firms

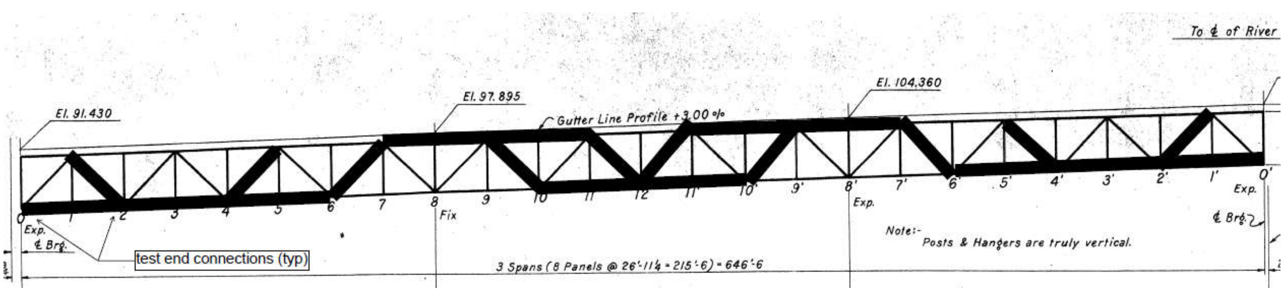
- Continue process of technician testing
- Develop orientation graphics to enhance project communication
- Require mandatory end-of-day reporting and consistent report format preparation

Orientation Graphics



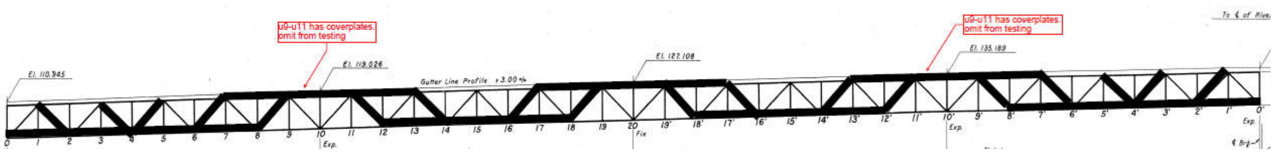
3-Span NDT UT scope

- 88 total members tested at 2 ends
  - 22 members per truss line, 2 trusses, 2 states



4-Span NDT UT scope

- 156 total members tested at 2 ends (up from 14 members at 2 ends)
  - 41 members per truss, 2 trusses, 2 states



71

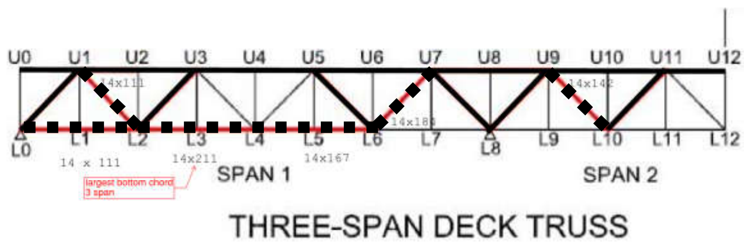
Phase III NDT UT Testing

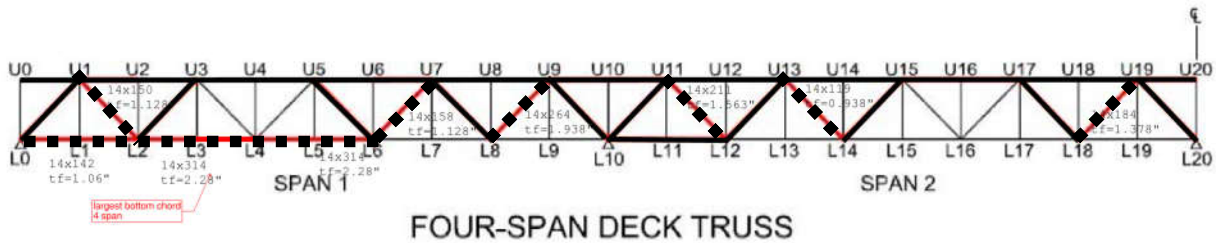
- Expand the testing to a fraction of members for the full length
- Members met several criteria
  - Tension members only
  - Defined as “failure critical” in a prior study of the bridge by another consultant
- Chose 21 members in each state for testing

72

Combined Full Length Plan

- 21 members, each state





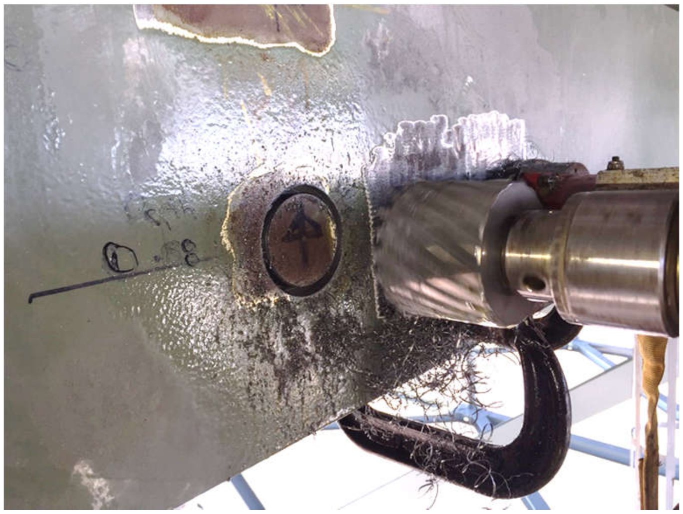
73

UT Program Results

- Mobilized numerous Level 2 UT technicians from many firms
- Scanned flanges 3 feet out from edge of gussets on every tension and reversal member in PA and NJ
- Scanned full length of 42 tension members
- No additional weld filled holes found
- However, when you look, you will find things

74

UT Indications at U7-U9 PA 3-Span



- Several indications in one area
- One class A – rejectable
  - Criteria doesn't make much sense, it was developed for welds
- Cores taken of 2 worst indications
- Sectioned, RT'd, MT'd

75

Removed Cores - Sectioned

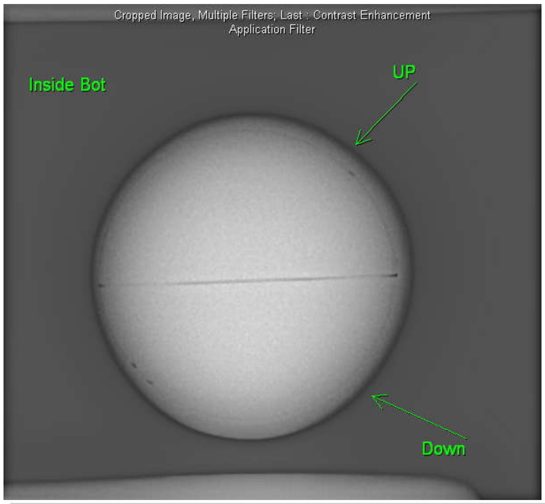
- Two cores shipped to Purdue

- Sectioned. No plug welds found

76

Radiographic Testing at High Steel

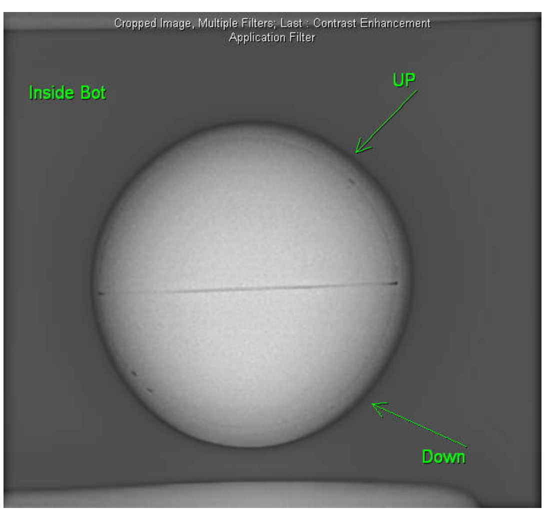
- Clean RT test result – inside flange

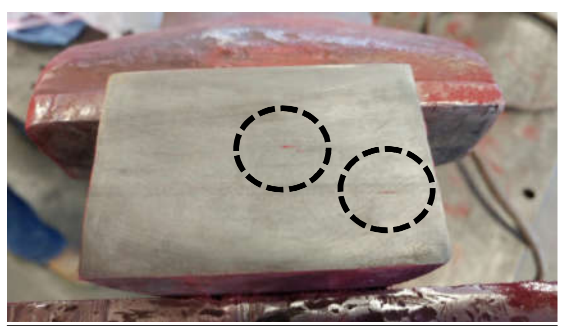


- Original orientation

77

Radiographic and MT Testing





- Small indications noted by MT testing
- No idea if that is what UT detected

78

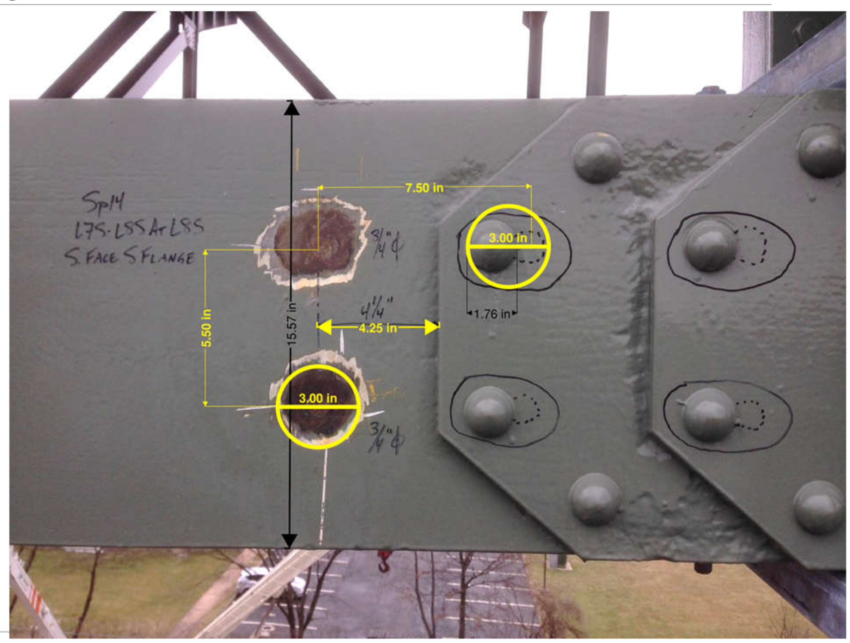
UT Indications @ L6-L8 PA 4-Span

- Possible filled holes found
- Gage line indicates possible filled holes

79

Remedial Actions

- Removed paint. Holes are filled…with something
- Core two locations to verify no welding at these filled holes
- Confirmed left-most hole is a mistake. Right holes (2 and 3) are mis-drilled then shifted shop fasteners.



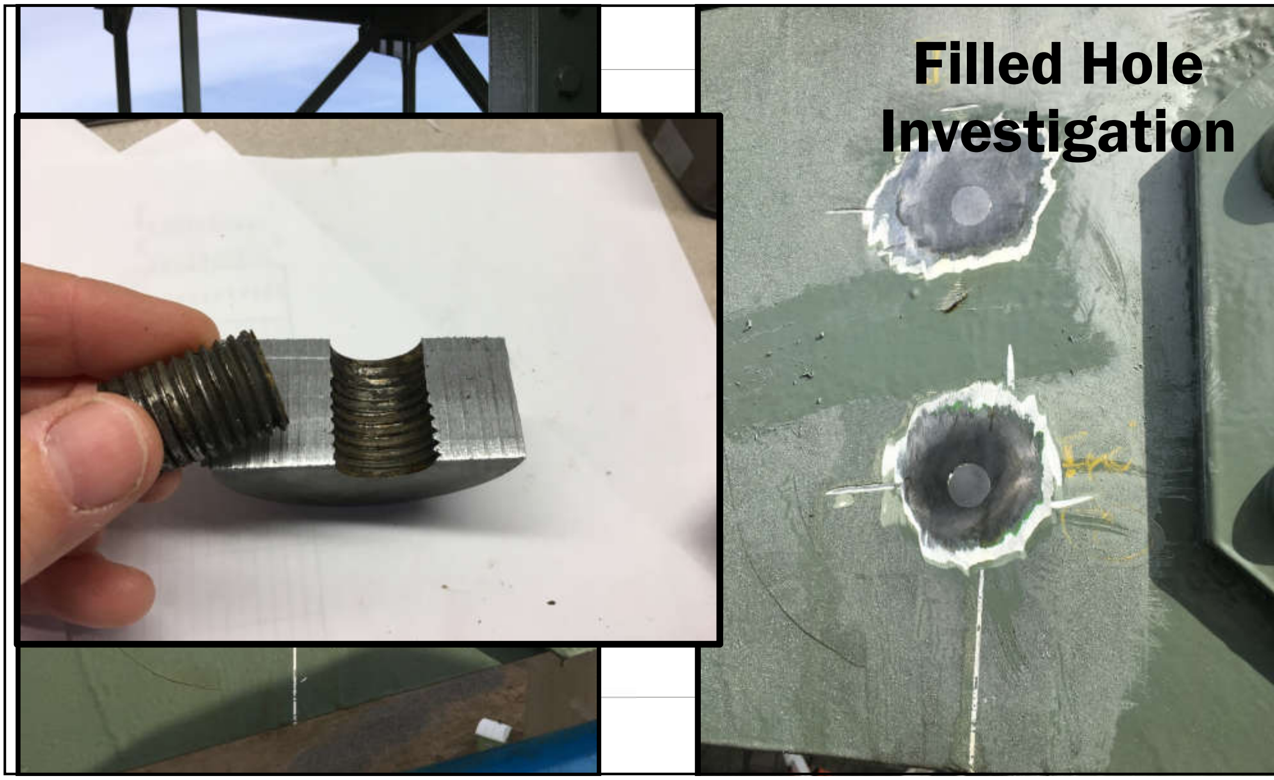
80

Filled Hole Investigation

81

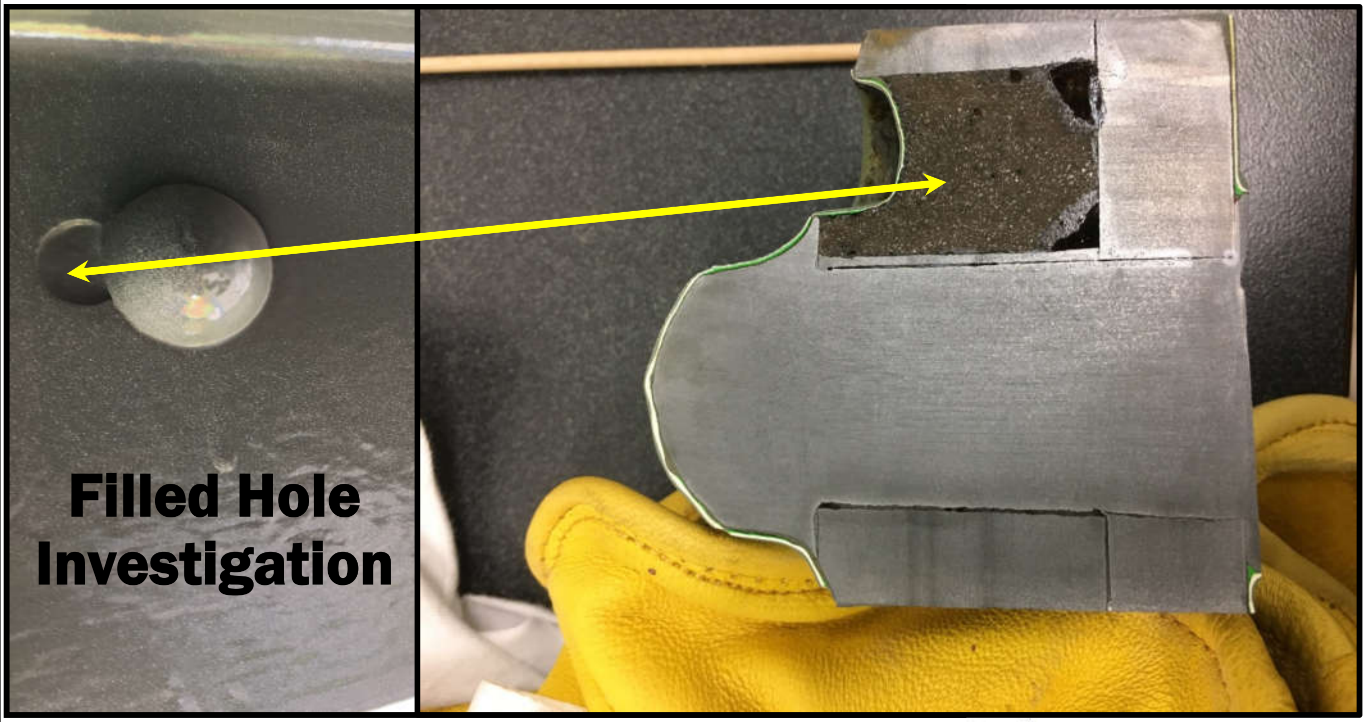
Filled Hole Investigation

82



83

84



Summary of UT

- 277 members tested. 3 ft. limits each end
  - Zero weld-filled-holes were found
  - Some odd mechanically filled holes
  - One location (U7-U9) with strong UT indications cored. No welding and virtually no internal discontinuities
- Removed chord scanned prior to delivery to Lehigh. No other plugs present

86

Material Testing / Forensics

Material Testing Program

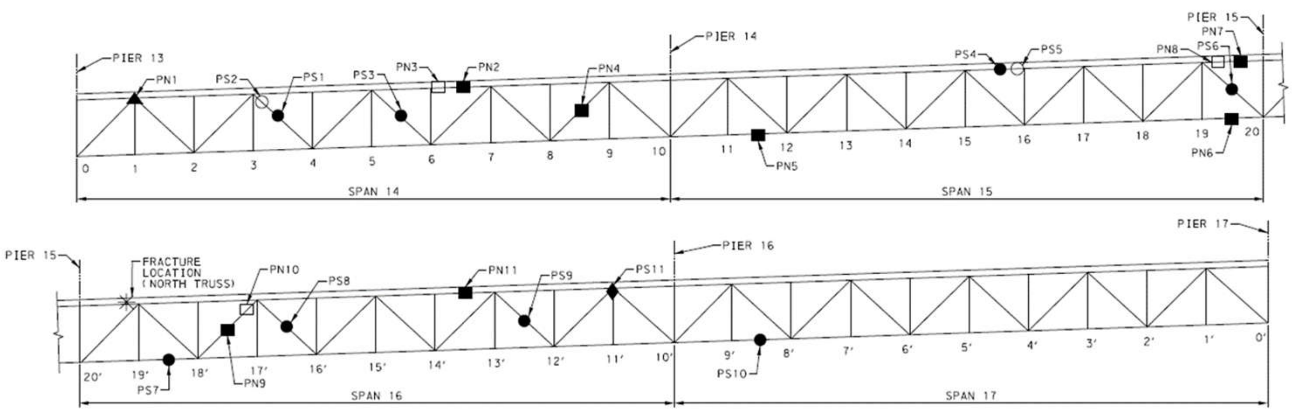
- Portions of fracture surface cut out of member and shipped to Lehigh
- Lehigh investigation included:
  - Chemical and mechanical tests
  - Optical microscopy
  - SEM
  - Etc.
- Comprehensive material testing program
- Intended to characterize material throughout the deck truss side spans
  - Gussets
  - Jumbo members
  - Man-Ten
  - Carbon Steel
  - Etc.

Material Testing Program

- Purpose was to characterize the material used in the bridge
- Was the fractured member substantially different than the material in the rest of the bridge?
- Compare with historical information on similar material
- Compare Heavy shapes to others
- Compare Man-Ten to carbon steel.

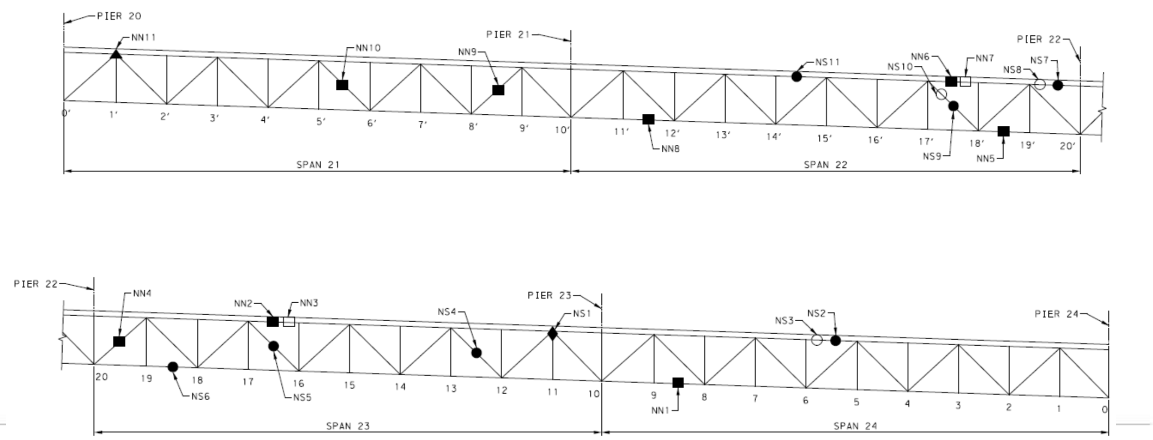
89

PA Testing Plan



90

NJ Testing Plan



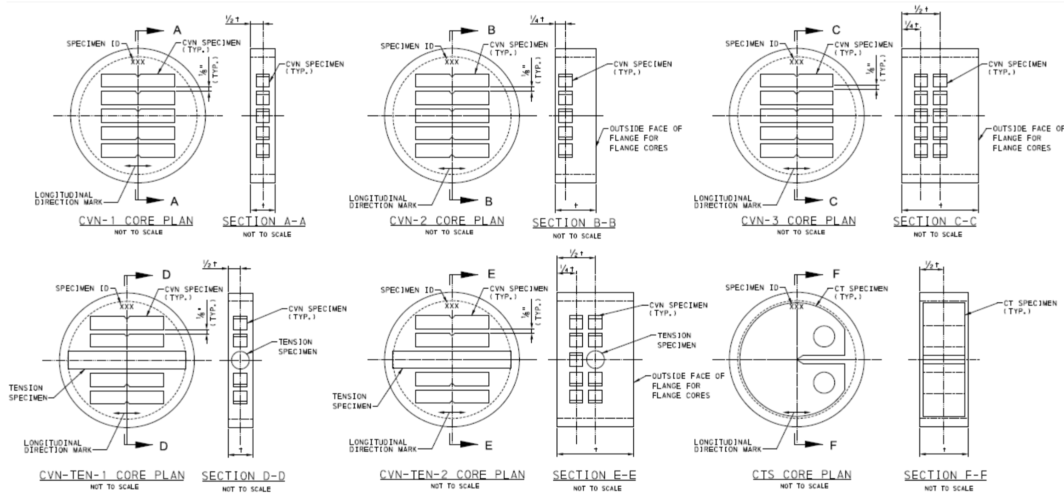
91

Material Testing

- 240 Charpy V-notch samples – fracture toughness
- 10 Tension samples – yield and ultimate strengths
- 4 compact tension samples – fracture toughness directly
- Chemical analysis
- Samples shipped to laboratory for machining of specimens

92

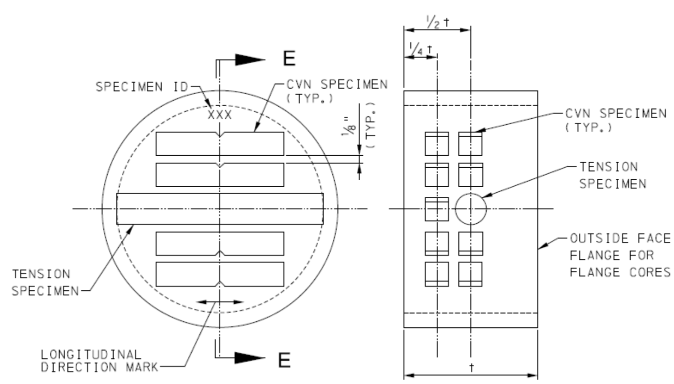
Sampling from Cores



93

Core Sampling Detail

- Various Specimens from Thick Cores



94

Material Callout on Shop Drawings

"Do no tack welding or welding on Manten – A242"

Do no tack welding or welding on Manten - A242 steel except where welding is detailed. Use Class E7016 electrodes when welding is detailed.

WORKMANSHIP NOTES

Rivets - 1" dia. Unless Noted
Holes - 1-1 16" dia. Unless Noted
Material - "CC" - Copper Bearing Carbon Steel - BILLING SUBDIV. [A]
"MT" - Manten Steel - BILLING SUBDIV. [B]
Rivets 1" dia. - Copper Bearing Manganese Steel [B]
Rivets 7/8" and 3/4" dia. - Copper Bearing Carbon Steel [A]
Reaming - Subpunch or subdrill 13/16" dia. and ream to size as per Drawing P1.
Edge - "FC" - Flame Cut
Preparation - "FCS" - Flame Cut and Flame Soften. All flame cut edges of Manten Steel, shall be flame softened.
See Drawing P1 for complete material and workmanship specifications.

1" thick & Over

Flanges to in flanges

162 APPENDIX

USS DESIGN MANUAL FOR HIGH STRENGTH STEELS 1962

USS MAN-TEN STEEL

A high-strength manganese-copper steel intended primarily for weight reduction by means of greater strength in applications involving moderate forming. It is considered a weldable grade provided mild steel electrodes are used and good welding technique and workmanship are maintained. It is not considered suitable for spot welding.

MECHANICAL PROPERTIES	½ in. and Under in Thickness	Over ½ to 1½ in. incl.	Over 1½ to 3 in. incl.
Yield Point, min, psi	50,000	45,000	40,000
Tensile Strength, min, psi	75,000	70,000	65,000
Elong. in 2 in., min, per cent	20	—	22
Elong. in 8 in., min, per cent 0.180 in. and heavier	18	19	19
Cold Bend	180°D = 1t	180°D = 2t	180°D = 3t

The minimum yield point and tensile strength requirements will be reduced by 5,000 psi when annealing or normalizing is specified, or when furnished in coils.

ASTM Standard Specimens, minimum number of tests and ductility modifications apply.

CHEMICAL COMPOSITION (For information purposes only)	C	Mn	P	S	Si	Cu
Composition Range, per cent	.25 max	1.10/1.60	.045 max	.05 max	.30 max	.20 min
Typical Composition, per cent	.22	1.40	.020	.036	.07	.27

USS DESIGN MANUAL FOR HIGH STRENGTH STEELS 1962

164 APPENDIX

USS MAN-TEN (A242) STEEL

FOR RIVETED AND BOLTED BRIDGES, BUILDINGS AND TOWERS

A high-strength steel intended primarily for use in structural members of riveted and bolted bridges, buildings, and towers. The characteristics of USS MAN-TEN (A242) Steel make it particularly applicable for structures of riveted construction requiring high strength with atmospheric corrosion resistance equal to that of copper steel.

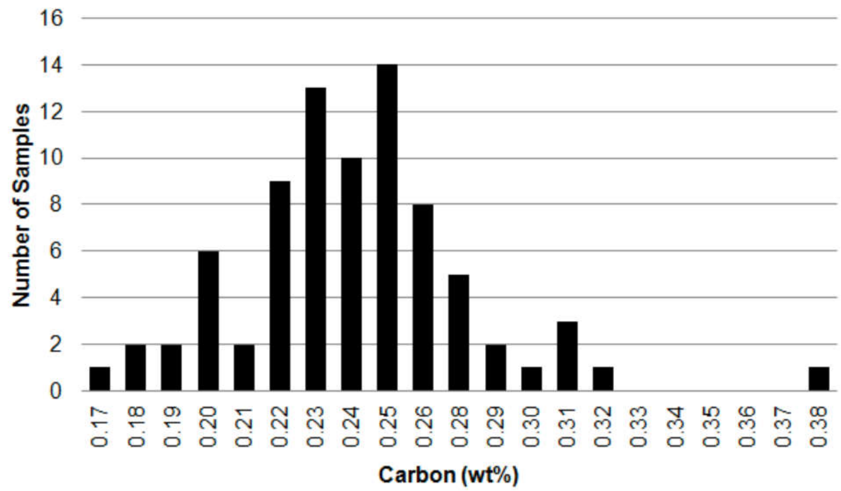
MECHANICAL PROPERTIES	THICKNESS RANGES		
	¾ in. and under	Over ¾ to 1½ in. incl.	Over 1½ to 4 in. incl.
Yield Point, min, psi	50,000	46,000	42,000
Tensile Strength, min, psi	72,000	70,000	65,000
Elong. in 8 in., min, per cent	18	19	19
Elong. in 2 in., min, per cent	—	—	24
180° Cold Bend	D=1t for thicknesses to ¾ in. incl. D=1½t for thicknesses over ¾ to 1 in. incl. D=2t for thicknesses over 1 to 1½ in. incl. D=2½t for thicknesses over 1½ to 2 in. incl. D=3t for thicknesses over 2 to 4 in. incl.		

ASTM Standard Specimens, minimum number of tests and ductility modifications apply.

CHEMICAL COMPOSITION, PER CENT (For information purposes only)		C	Mn	P	S	Si	Cu
ASTM A242	Ladle	.22 max	1.25 max	—	.05 max	—	—
	Check	.26 max	1.30 max	—	.063 max	—	—
USS MAN-TEN A242	Ladle	.27 max*	1.10/1.60*	.04 max	.05 max	.30 max	.20/.35
	Check	.31 max*	1.65 max*	—	.063 max*	—	—

*Deviations from ASTM A242

Carbon Content As-Tested



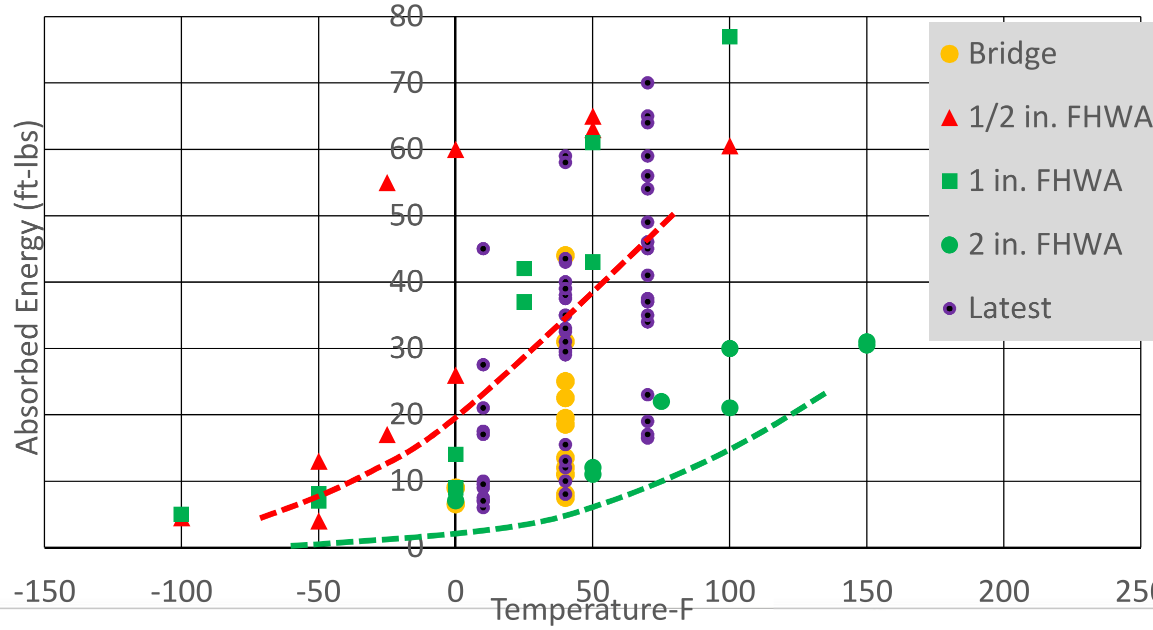
97

Mechanical Properties

Property	Test Results	ASTM A242 (1952 - Tentative)	USS Man-Ten (A242 Modified) (1954)	ASTM A440 (1959 - Tentative)
Yield Strength t ≤ 1.5 in.	43.8 min 45.1 avg 47.0 max	45.0 min	46.0 min	46.0 min
Ultimate Strength t ≤ 1.5 in.	83.0 min 85.9 avg 88.1 max	66.0 min	70.0 min	67.0 min
Yield Strength t > 1.5 in.	40.0 min 42.2 avg 44.0 max	40.0 min	42.0 min	42.0 min
Ultimate Strength t > 1.5 in.	77.1 min 80.0 avg 82.2 max	63.0 min	65.0 min	63.0 min

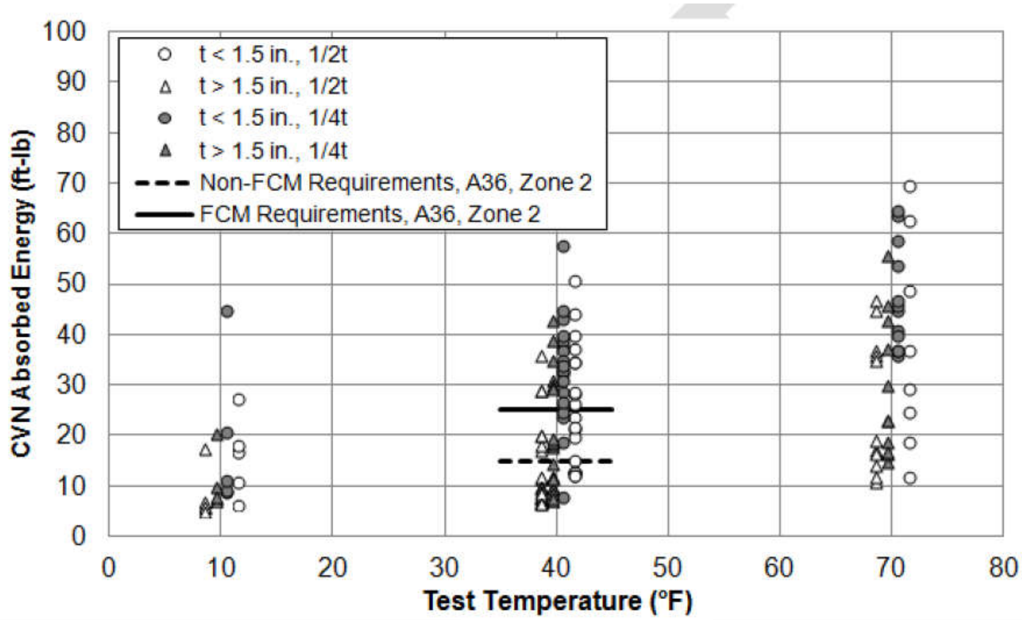
98

Initial Test Data (March 2017) – Compared to Historical Materials



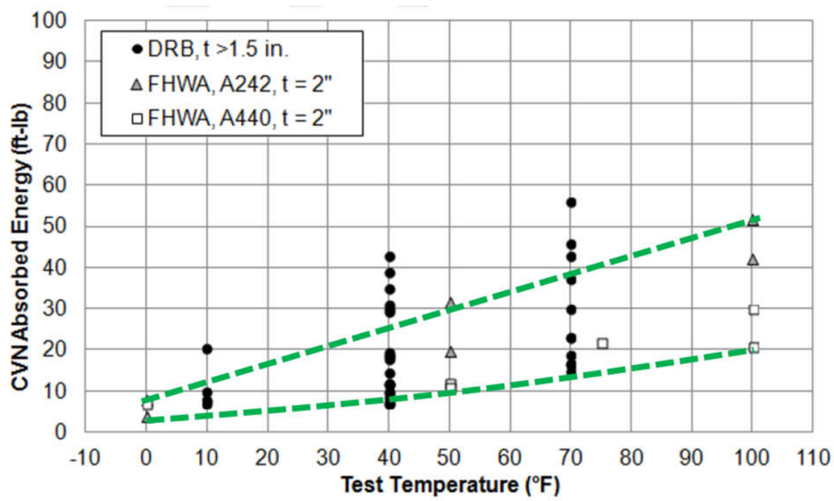
99

Final ManTen CVN Results



100

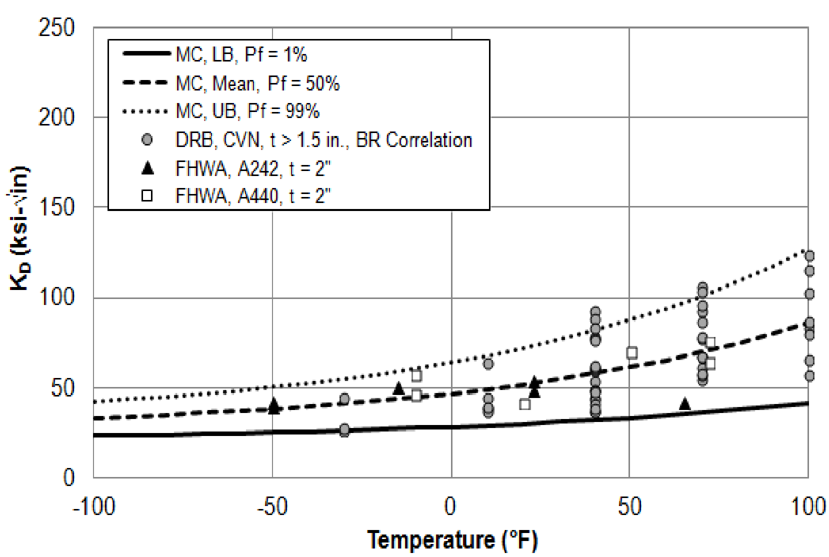
Delaware River Bridge vs. Historical Data



101

Results

- Better classification of Man-Ten provided
- 1970's test data for A440 found
- Properties were consistent
- Lower fracture toughness than modern steels



102

Conclusions Based on Material Testing

- ¼ thickness CVN tests for "non jumbo" shapes meet modern CVN requirements
- ¼ thickness CVN tests for "jumbo" shapes do not always meet the CVN requirements for FC and non-FC members
- This steel was produced at a time when no such FC requirements existed
- The steel is consistent with other A242 and A440 steels tested nearly twenty years later (1970's research)
- Steel was deemed as not unusual for the time of construction and not fundamentally flawed.

103

Conclusion … Why now?

- Defect present since initial fabrication in 1954
- No sign that anything changed in 63 years
- Dead load increase about 17 years ago
- Safespan added ~ 1 ksi to DL
- Low temperature on assumed day of fracture
- HAZ around edge of hole
- Brittle fracture initiated at hole edge, propagated through member
- No fatigue crack growth seen

104

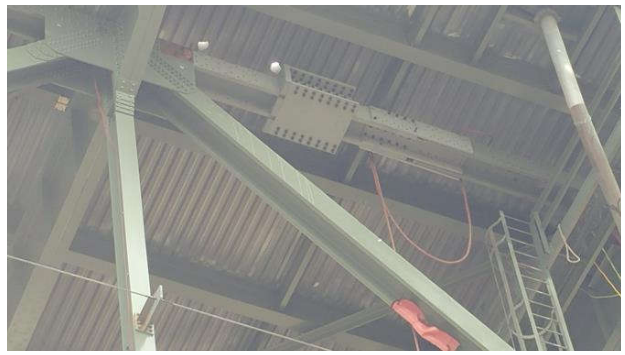
Final Repair Photos

105

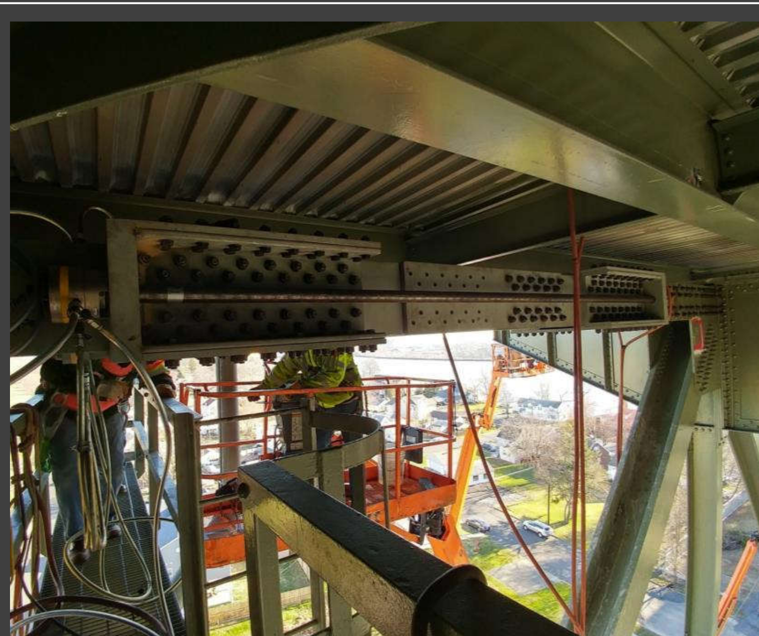
Vertical Jacking

106

Post-Tensioning and New Chord Segment



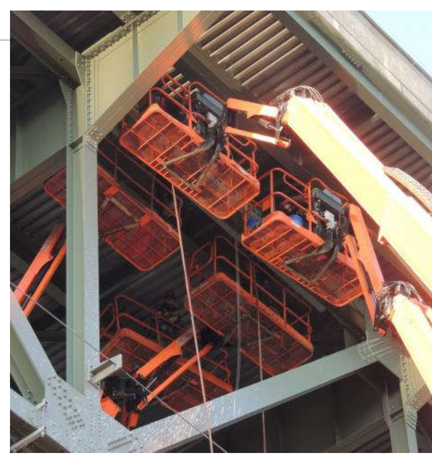
107

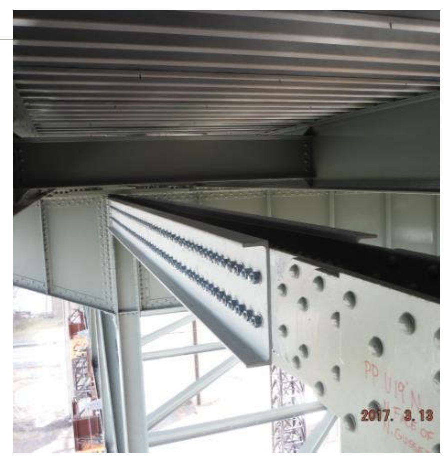


108

Final Splice

109





Additional Repairs

110

Load Testing of Repaired Structure

111

Delaware River Bridge Conclusions

- NDT is a tool when "something goes wrong"
- Useful for searching for other similar defects
- Standard testing procedures and technician testing are essential
- Helping owners understand what they should and shouldn't be looking for, or be able to expect to find, is important

112

Questions?

Smarter.
Stronger.
Steel.

CEU / PDH Certificates

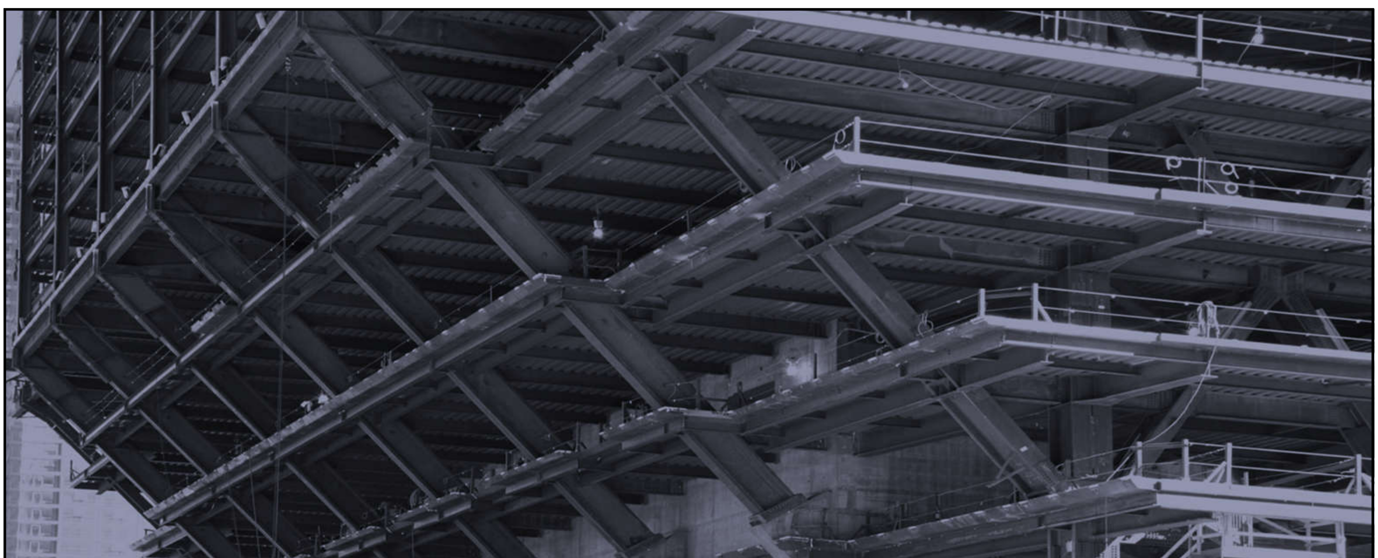
- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Smarter.
Stronger.
Steel.

CEU / PDH Certificates

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

Smarter.
Stronger.
Steel.



Thank you.

Smarter.
Stronger.
Steel.