TN TDOT Department of Transportation

Michael Baker INTERNATIONAL

Emergency Repair of the Hernando de Soto Bridge

Presented to Minnesota Structural Engineering Series

1

Today's Speakers

Ted Kniazewycz, PE, F. ASCE
Tennessee Department of Transportation
Director | Structures Division

Aaron Stover PE, SE
Michael Baker International
Regional Bridge Lead

Daniel Baxter, PE, SE
Michael Baker International
Technical Manager – Bridge

We Make a Difference 2

2

Today's Agenda

- Immediate Response
- Phase I – Stability of Structure
- Modeling and Analysis
- Phase II – Long Term Repair of Fracture
- Phase III – Re-Opening to Traffic
- Forensic Evaluation
- Lessons Learned

We Make a Difference 3

3

TN TDOT Department of Transportation

4

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

We Make a Difference 5

5

Regional Importance

We Make a Difference 6

6

Agenda - *Swift and Critical Decisions*

- Immediate Closure
- Three-Phase Approach
  - Assess / Stabilize the Structure
  - Repair of the Fracture
  - Inspect and Assess the rest of the Tie Girder
- Fracture Analysis
- Lessons Learned

We Make a Difference 7

7

Immediate Response

Early Actions in the days immediately following the critical find

8

8

Timeline of Events

Day 0

- TDOT has responsibilities for repair project development
  - Selected Michael Baker International on Tuesday - May 11th
    - Qualification
    - Related Project Experience (Sherman Minton Bridge on I-64)
    - Availability of Team and Equipment (Inspection Staff on-site)
    - Contractual Relationship with TDOT was already in place
  - Initial task was to evaluate bridge in current state
  - Develop preliminary plan to stabilize structure
  - Work with CM on approach to complete fracture repair
- TDOT and ArDOT collaborated on a three-phase approach
  - Evaluate for resumption of river traffic
  - Evaluate and complete repairs for initial fracture
  - Evaluate existing bridge tension members and complete any repairs needed to open bridge

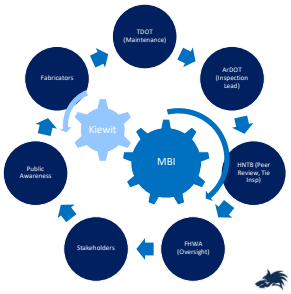
We Make a Difference 9

9

Critical Startup Activities

Day 0

- Communication IS Critical
  - 9:00 AM - Detailed design call
    - (DOT Engineers, Consultants, Contractor)
  - 1:00 PM – Media and Social Media updates issued
  - 3:00 PM – Project status call
    - (DOT's leadership, USCG, design and contractor)
  - 3:30 PM – Traffic update call
    - local EMS, USCG, DOT's
  - 4:00 PM – Engineering & Construction update
    - with partner agencies
- Daily Work Summaries



We Make a Difference 10

10

Timeline of Events

Day 1

- TDOT & ArDOT supplied bridge data to MBI
  - Plans, Shop Drawings & Weld Inspection Report (TDOT)
  - Inspection Reports (ArDOT)
  - Approved development of Phase 1 plating plans & model development

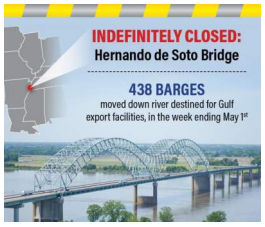
We Make a Difference 11

11

Impact on Traveling Public

Day 1

- 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



We Make a Difference 12

12

Propagation of Fracture

- TDOT did not ask for recommendations on safety/risk. **Day 2**
- MBI provides FEA model results to TDOT
  - TDOT does a risk assessment using model data, historic photos & former staff
  - Construction photos suggest favorable sequence of loading during construction **Day 3**
  - **TDOT provides risk evaluation to USCG who opens river to traffic.**

Media Attention on Inspection

- Reports of Prior Fracture
- Traffic Snarls
- TDOT Media Coordination

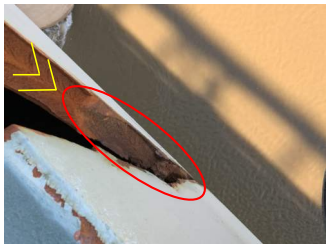
"It's so simple and so shocking to see a literal split in a steel beam on which millions of pounds of pressure and countless thousands of lives depend."

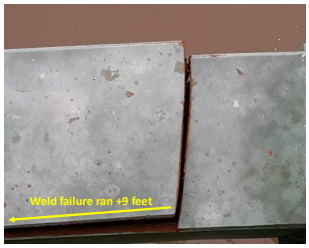
Sec. of Transportation Pete Buttigieg, while touring the Hernando de Soto Bridge

We Make a Difference 13

13

Fracture Details





We Make a Difference 14

14

Phase 1 Repairs

Stabilizing the Structure

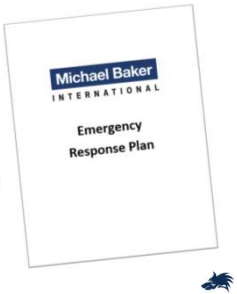
15

15

Critical Startup Activities

Day 0

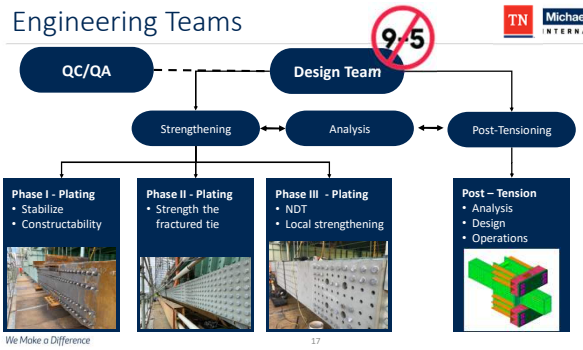
- Gathering Data
  - Bridge Plans, Shop Drawings, Inspection Reports, Models, Test Data…
- Mobilize Engineering Staff and Teams
  - Analysis team
  - Phase 1 Repairs
  - Phase 2 Repairs
- Other activities
  - Project Management
  - Communication / Meetings
  - BIM Modeling



We Make a Difference 16

16

Engineering Teams



We Make a Difference 17

17

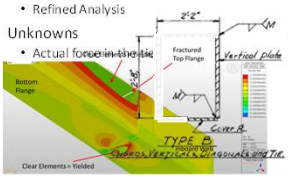
Hernando de Soto – Mobile Command Center

We Make a Difference 18

18

How Bad is it?

- T1 steel = 100 ksi (+)
  - P/A design = 38ksi
- Fracture 113 in2 -> 51.5in2 (**45%!**)
  - P/A after Fracture = 83ksi
- Eccentric Loading
  - Refined Analysis
- Unknowns
  - Actual force in bin tie



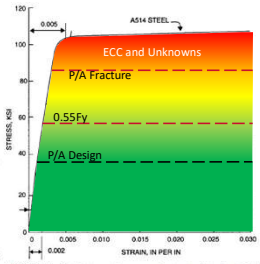
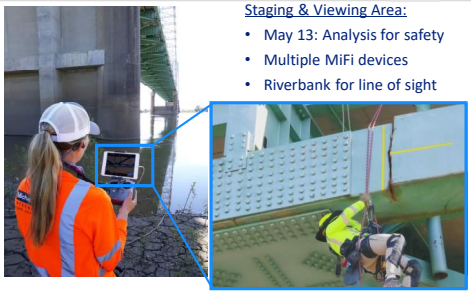


FIGURE 1.4 Partial stress-strain curves for structural steels strained through the plastic region into the strain-hardening range. (*From R. L. Brockenbrough and B. G. Johnston, USS Steel Design Manual, R. L. Brockenbrough & Associates, Inc., Pittsburgh, Pa., with permission.*)

We Make a Difference

19

Hernando de Soto – Combined RA & UAS Live Feed



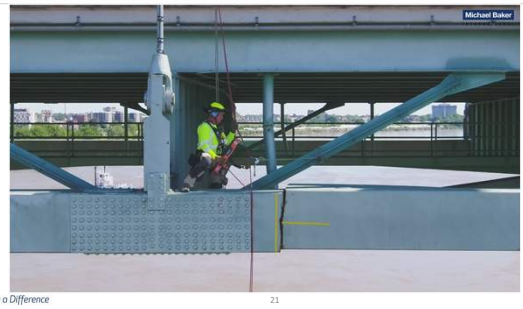
Staging & Viewing Area:

- May 13: Analysis for safety
- Multiple MiFi devices
- Riverbank for line of sight

We Make a Difference 20

20

Hernando de Soto – UAS Live Feed Inspection



We Make a Difference 21

21

Hernando de Soto – UAS Live Feed Inspection

22

Phase 1: Stabilize the Structure

How do you fix it?

- Tie w/ 4,500 kips +/-
- Displaced laterally and rotated
- Limited reserve capacity

And…

- **Time is of the Essence**

Plates of truss tension members are to be thickened by butt welding a heavier plate at joints and splices (upset fingers) where shown or noted on truss details. This is required to maintain minimum section. Thickened plates are to have the same min. yield strength as that of the member unless noted. See Vertical plate upset details.

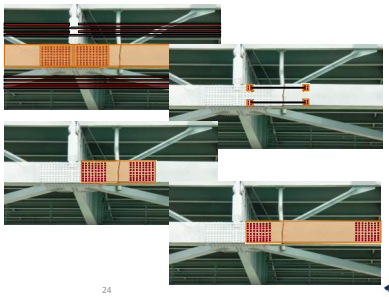
We Make a Difference 23

23

Phase 1: Stabilize the Structure

How do you fix it?

- Permanent Fix
  - *Duration too long*
- Shoring Towers
  - *Navigation / Duration*
- Temporary PT
  - *High Loads*
  - *Long lead time / fabrication*
- Adjacent Splice
  - *Distortion of the box*
- Lengthen Splice
  - Showed promise



We Make a Difference 24

24

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 in Bowling Green, KY

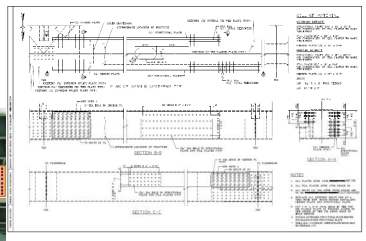
We Make a Difference 25

25

Phase 1 Preliminary Plans

Day 3

- 5/14 – Draft Plans Available, TDOT Advertises for CM/GC



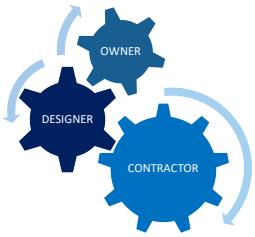
We Make a Difference 26

26

CM/GC Procurement

Day 3

- Repair Project – CM/GC Contractor Selection Process
  - Advertised on Friday - May 14th
  - 8 Contractors were invited to provide submit interest packages
  - Preliminary plating plans were provided as part of the invitation
  - Selection of CM/GC was based on the following
    - Qualification
    - Related Project Experience
    - Availability of Team and Equipment
    - Approach on Repair Options



We Make a Difference 27

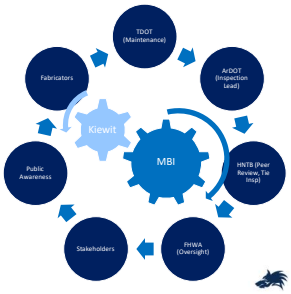
27

CM/GC Procurement

Day 6

Michael Baker INTERNATIONAL

- Repair Project – CM/GC Contractor Selection Process
  - Qualification-Based – not awarded to low bidder
    - Phase 1 work based on Force Account (Time & Materials)
    - Phase 2 work was bid / negotiated
    - Phase 3 work was determined based on NDT Inspection Results
- Awarded to Kiewit Infrastructure Group on Monday - May 17th



We Make a Difference

28

28

CM/GC Benefits

Michael Baker INTERNATIONAL

- Contractor selection driven mostly by qualifications selection
- Promotes discovery and resolution of key risks prior to construction
- Provides upfront value engineering and wisdom leading to smoother and more reliable construction phase expectations
- Optimizes schedules
- Enhances collaboration
- Fosters innovation driven by Construction Manager insights
- Allows flexibility
- Improves cost control and certainty
- Allows for fewer change orders and overruns
- Enhances design quality
- Improves constructability

We Make a Difference

29

29

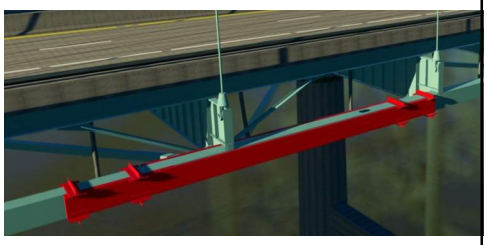
Phase 1: Stabilize the Structure

Day 6

TN Michael Baker INTERNATIONAL

CM/GC

- **Reduce Risk…**
  - Add capacity
  - low impact operations (drilling not bolt removal)
  - No attempt to straighten the tie



We Make a Difference

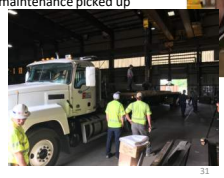
30

30

Phase 1: Fabrication

Fabrication

- **DAY 6** - Design Finalized 5/18
- **DAY 8** - Shop drawings created and approved 5/20
- **DAY 10** - Fabrication began 5/21
- **DAY 11** - TDOT maintenance picked up the steel 5/22



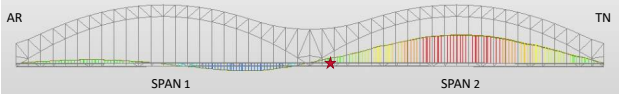
We Make a Difference 31

31

Loading of the Bridge

Tie Axial Influence Line @ Fracture

- Contractor requested options for construction from the deck of the bridge rather than from a barge on the river
- Loading in Span 1 results in minimum axial load
- Loading in Span 1 near Pier B results in some beneficial compression
- No loads in Span 2



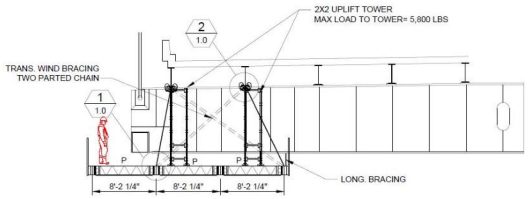
We Make a Difference 32

32

Phase 1: Work Platform

Day 9

- Kiewit Infrastructure installed a specially designed work platform and chain hoists instead of barges from the river. This was a lower risk and less impact option.



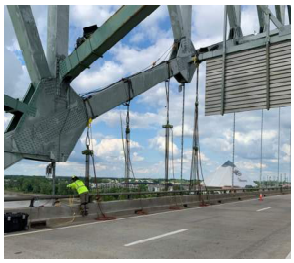
We Make a Difference

33

Phase 1: Stabilize the Structure

Construction

- Trucks come from west end of the bridge
- Use chain fall to move plates on Span 2 and into place
- No work barges or river access was used during the duration of the project



We Make a Difference 34

34

Phase 1: Plate Installation

- Kiewit Infrastructure began installing the plates Saturday, May 22nd. **Day 11**
- Phase 1 plate installation was completed on Tuesday, May 25th. **Day 14**
- Completing Phase 1 allowed for starting the Phase 3 inspection work

We Make a Difference

35

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

We Make a Difference 36

36

Phase 1: Stabilize the Structure

Eccentricity

- Eccentric connections highly loaded would try to crush box
- Thin cover plates attached with poor welds
- External frame added to account for moment developed by eccentricity

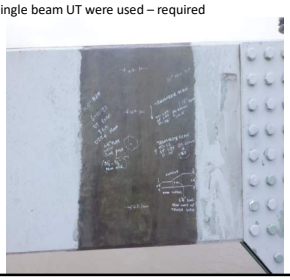
We Make a Difference

37

Phase 3: Inspect & U/T all welds

- 484 tie girder weld locations + statistical sample of welds on high truss.
- Phased Array and single beam UT were used – required paint removal.
- More details later

Day 15

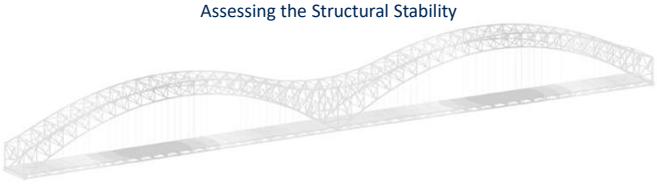


We Make a Difference

38

Modeling and Analysis

Assessing the Structural Stability



39

39

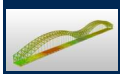
Model Development

Analysis Team

MIDAS

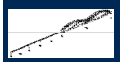
LARSA 4D

Global Modeling
- 3D Model
- Midas Civil



Local Modeling
- Shell Element of the fracture area
- FEA NX

Other
- QC team
- Pier model
- 2003 seismic retrofit design



Global Modeling
- 3D Model

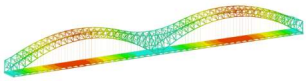
We Make a Difference 40

40

Model Development

2D Model
- Simple model – existing plan geometry

3D Model
- Adjusted for any design/shop drawing discrepancy
- Steel DL Calibration
- 2003 Seismic rehab

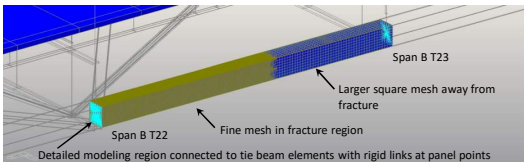


We Make a Difference 41

41

Model Development

Local Model
- Modeled T22 and T23 upstream tie with shell elements
- Integrated in full 3D model – captures out-of-plane force effects and boundary conditions
- Connected using rigid links
- Capacity and stability assessment of the current condition – needed for Phase 1 repair activities



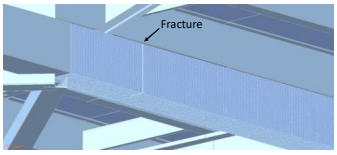
We Make a Difference 42

42

Model Development

Local Model – Material Nonlinear Analysis

- 1" square mesh in fracture region – fracture modeled with 1" gap
- Compromise between analysis speed and accuracy
- Elastic-perfectly plastic material model
- Von Mises initial uniaxial yield stress of 100 ksi
- Load incremented in steps of 0.05 up to 1.25 times the service dead load



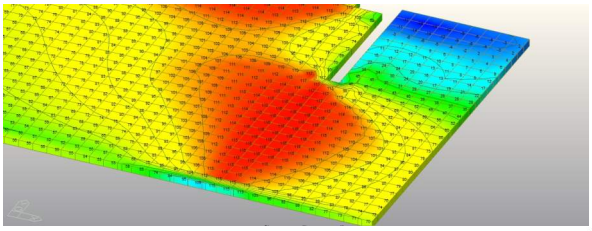
We Make a Difference 43

43

Model Development

Local Model Results

- Remaining bottom flange was fully yielded through the plate due to dead load



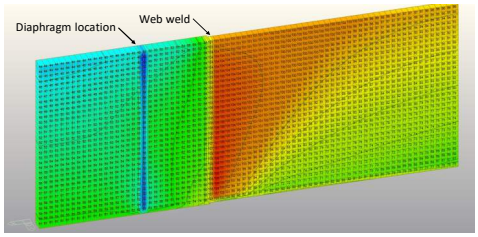
We Make a Difference 44

44

Model Development

Local Model Results

- Inboard web was fully yielded on the inner face of the plate under dead load



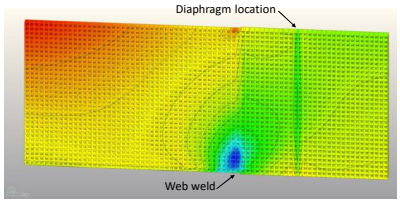
We Make a Difference 45

45

Model Development

Local Model Results

- Inboard web had not reached yield on the outer face of the plate under dead load – web did not entirely yield
- Provided resistance to live load after fracture prior to bridge closure
- Resistance during Phase 1 repairs

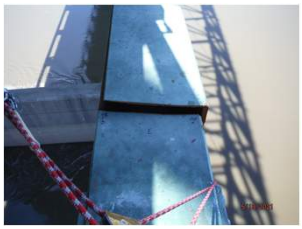


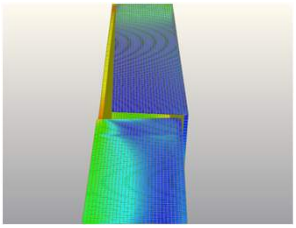
We Make a Difference 46

46

Model Development

Actual Deflected Shape Versus Model



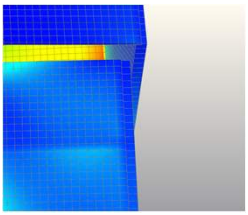


We Make a Difference 47

47

Model Development

Actual Deflected Shape Versus Model

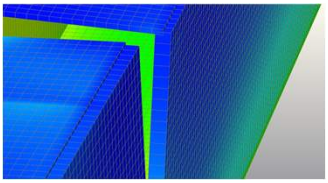


We Make a Difference 48

48

Model Development

Actual Deflected Shape Versus Model

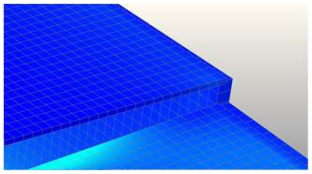


We Make a Difference 49

49

Model Development

Actual Deflected Shape Versus Model

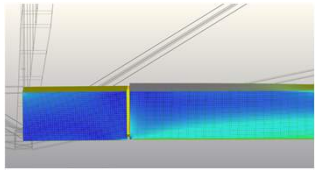


We Make a Difference 50

50

Model Development

Actual Deflected Shape Versus Model



We Make a Difference 51

51

Model Development

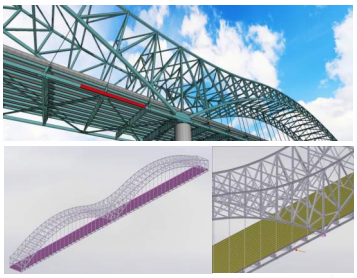
TN Michael Baker INTERNATIONAL

QC Process

- Checklists used for efficient verification of Midas Civil model
- Each updated version of the model was checked again

LARSA 4D FEA Model

- Independent model with independent team
- Comparable results



We Make a Difference 52

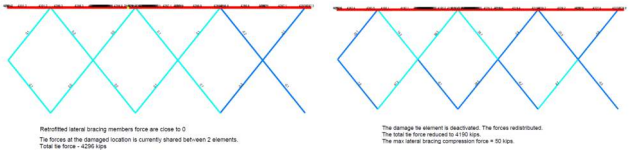
52

Model Development

TN Michael Baker INTERNATIONAL

Where did the Load go?

- Alternate Load Paths?
  - Sensitivity Analysis
- Stiffness of the structure
- Field Observations



We Make a Difference 53

53

Analysis Summary

TN Michael Baker INTERNATIONAL

Phase 1

- Safe Load evaluation
- Stabilizing plate analysis
- Construction support

Phase 2

- PT analysis
- PT cookbook
- Additional construction support
- Moving load analysis

Phase 3

- Moving load analysis
- Seismic analysis

Post Phase 3

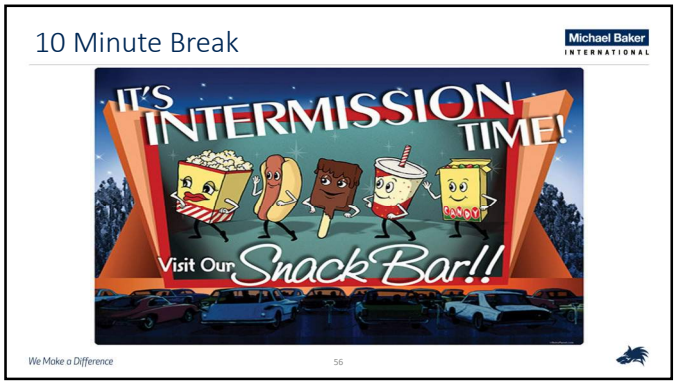
- Load Rating
- Redundancy Analysis

We Make a Difference 54

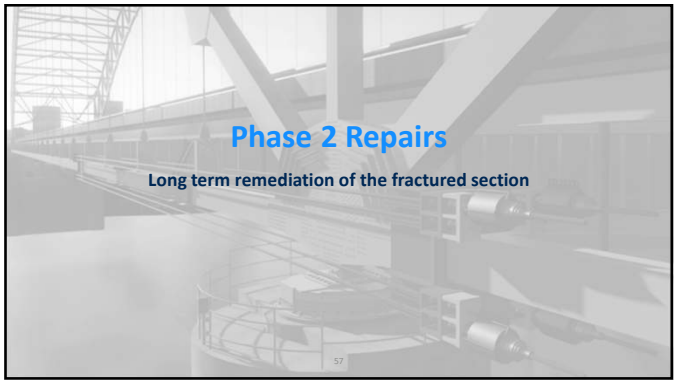
54


Questions ?
55

55


10 Minute Break
Michael Baker
INTERNATIONAL
IT'S INTERMISSION TIME!
Visit Our Snack Bar!!
We Make a Difference
56

56


Phase 2 Repairs
Long term remediation of the fractured section
57

57

Phase 2 Repair Design

Day 0

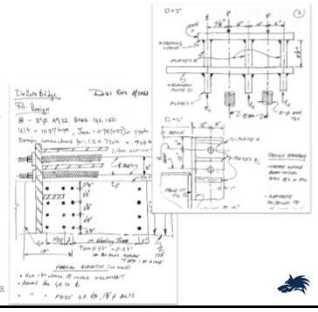
Initial Calc 8:44 PM on 5/11

Design Philosophy

- Preserve capacity of original tie
- How much post-tensioning ?
- How much of the gap do we need to close?
- Effects on Secondary Members?
- How effective will the Post-Tensioning actually be?

Multiple concepts considered

- Ultimately, load path to the tie girder dictated design

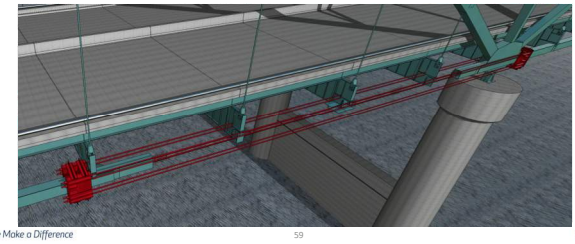


We Make a Difference 58

58

Tie Girder Complete Replacement

- Initial direction: completely remove the old/fractured tie
- End Result: Cut out Fracture and Plate back to connections



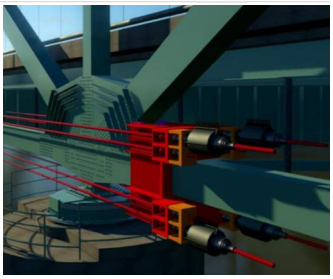
We Make a Difference 59

59

Post-Tensioning System Design

P/T System

- 8 - Cold-rolled 150 ksi 3” diameter PT bars
- Allowance for fitment/eccentric loads
- Staged PT
- Monitoring Plan including direct force measurement



We Make a Difference 60

60

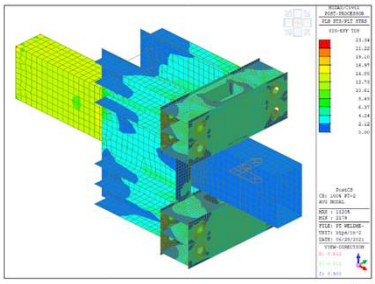
Post-Tensioning System Design

Anchorage

- Designed to remain elastic
- Self-Reacting – Don't crush the box
- Constructability Coordination
- Fabrication Coordination
- Cheese PL, with Double nut bolts

Sequence

- Install anchorage (walers, struts etc)
- Install Bars
- Disconnect/Remove Lateral bracing
- Post-Tension
- Remove Phase I Plating
- Install Phase II Plating



We Make a Difference

61

61

3D Model

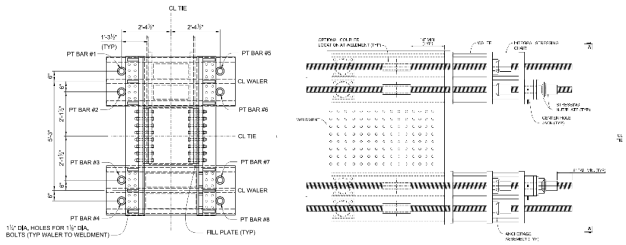
- Detailed Model used to find conflicts

We Make a Difference

62

62

Post-Tensioning System Design



We Make a Difference

63

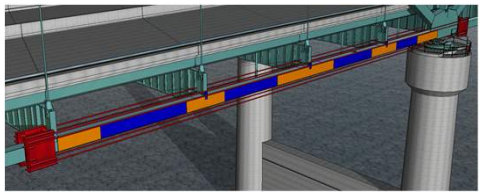
63

Phase 2 - 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

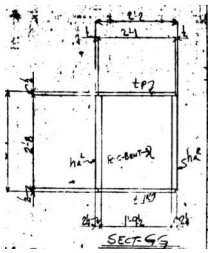


We Make a Difference 64

64

Phase 2 – Design Philosophy

- Target design resistance
  - Existing Tie STR (Pex = 10396 kips)
  - Fracture Net Section ALWAYS controls
    - Ag = An
    - Yield: 0.9*100ksi = 95ksi
    - Fracture: 0.8*115ksi = 92ksi
- Any reduction in x-sect area → Proposed Capacity < Existing Capacity
- Design strategy (Do no harm)
  - Use of Existing Holes
  - Splices at Tie Joints

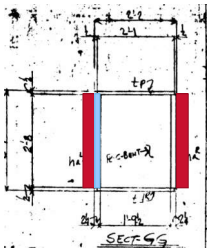


We Make a Difference 65

65

Phase 2 – Critical Design Assumptions

- Proposed Tie Capacity
  - Inboard Existing Web PL 1 $^3/_8$" (A514)
  - 2 Proposed Web PL (GR70)
- Plating installed under PT loading
- Repair effective for
  - DL = PT load
  - LL
  - Future Loading
- → 32" high x 2.25" thk
- Passes Yield on Gross and Net Section, so far so good…



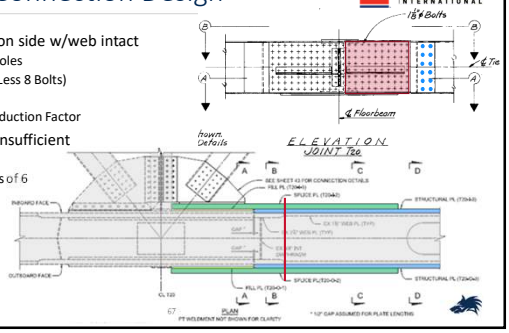
A514
GR70

We Make a Difference 66

66

Phase 2 – Connection Design

- Check bolt shear on side w/web intact
  - Utilize Existing Holes
  - Avoid Conflicts (Less 8 Bolts)
  - Single Shear
  - 0.76 Fill Plate Reduction Factor
- # Bolts Available Insufficient
  - Need 7 more EF
  - Added 2 columns of 6



We Make a Difference 67

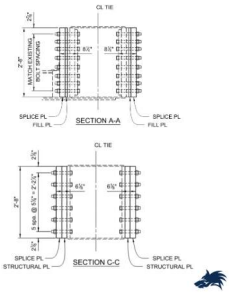
67

Phase 2 – Connection Design

- Net Section Capacity w/8 holes @ Joint = 3366 k
- Net Section Capacity w/6 holes elsewhere = 3749 k

We can't fully develop strengthening plate for composite tie due to limited capacity @ Joint

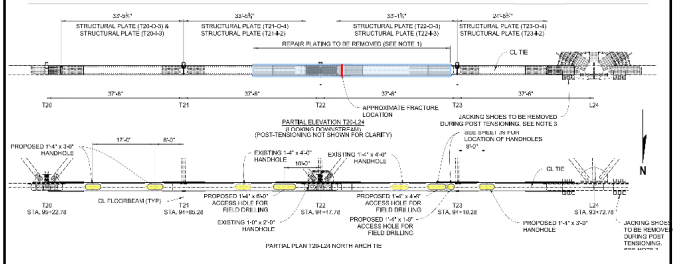
Therefore, increase plate thickness to 2.5"



We Make a Difference 68

68

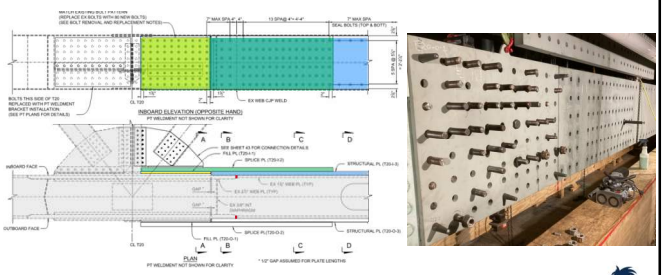
Phase 2 – General



We Make a Difference 69

69

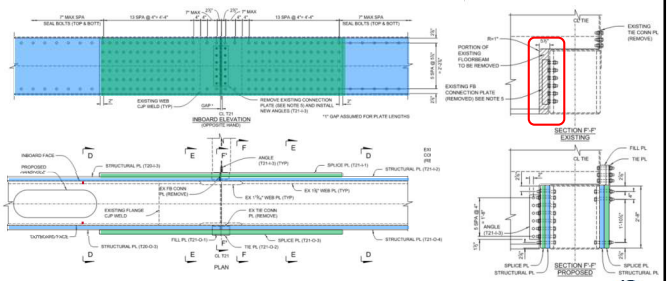
Phase 2 – Plating T20



We Make a Difference 70

70

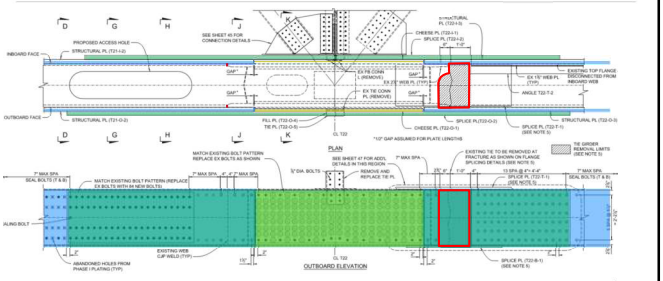
Phase 2 – Plating T21/T23



We Make a Difference 71

71

Phase 2 – Plating T22

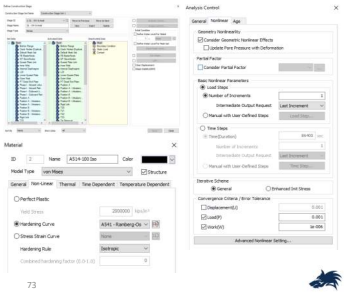


We Make a Difference 72

72

Why was FEA NX used?

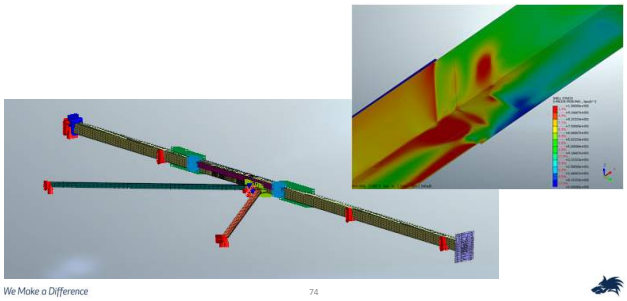
- Non-linear geometry
  - Need to include large deformation theory to capture buckling – PT force applied to an asymmetric cross-section
- Non-linear material
  - Need to include metal plasticity with hardening to capture yielding
- Incremental analysis
  - Need to include construction/ retrofit sequence



We Make a Difference 73

73

Unloading effects on Tie

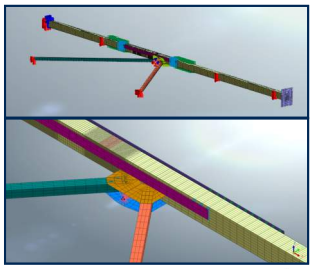


We Make a Difference 74

74

Model Summary: Geometry

- Geometry originally developed in Midas Civil then imported in FEA NX
- Geometry comprised:
  - Tie segment between L24 and T20
    - Including internal stiffening plates
  - Diag. bracing @ T22 incl. conn. plates
  - Plating installed during fracture retrofit
- Boundary conditions:
  - Fixed @ L24
  - Translational constraints to model effect of floorbeams and brace framing



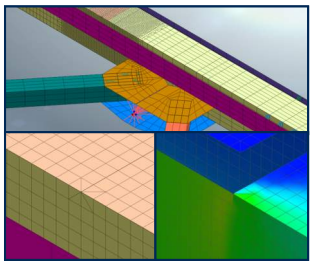
We Make a Difference 75

75

Model Summary: Mesh

Michael Baker INTERNATIONAL

- All elements are:
  - Shells used to model plates
  - Elastic links to model bolts
    - Linear elastic with stiffness representative of bolt shear stiffness
- Mesh size based on 8 elements across tie height and width
- Mesh aspect ratio less than 5
- Detailed mesh around fracture:
  - 1" x 1" elements
  - Collapsed mesh around crack tips



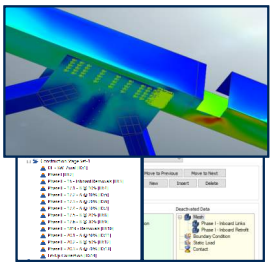
We Make a Difference 76

76

Effect of Retrofit Operations

Michael Baker INTERNATIONAL

- Incorporate different alternatives considered in retrofitting
  - Removing gusset plates connections
  - Cutting diagonals, etc.
- Main use was to estimate local effect of unbalanced PT forces
  - Effects are negligible

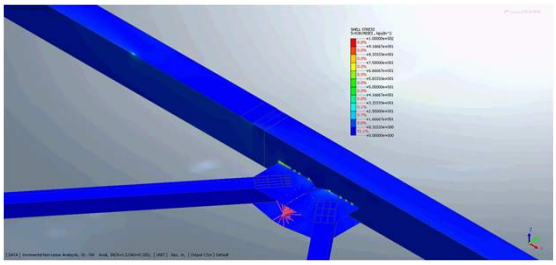


We Make a Difference 77

77

Final Retrofit Sequence Modeling

Michael Baker INTERNATIONAL

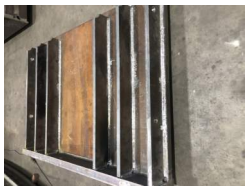


We Make a Difference 78

78

Phase 2: PT Weldment Fabrication

- Each weldment is 8 foot tall and 20,000 pounds
- Fabricated by G&G Steel in Russellville, Alabama
- Weldments were delivered to the job site June 11th Day 31

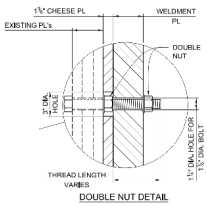


We Make a Difference

79

Cheese Plate & Double Nut

Day 32



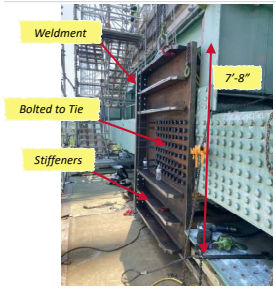
We Make a Difference

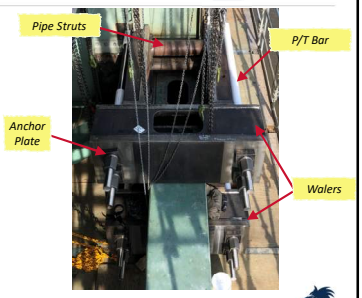
80

80

Post Tensioning Anchorage

Day 32





We Make a Difference

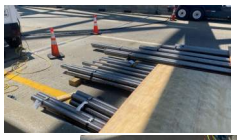
81

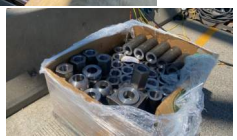
81

Phase 2: PT System

Day 39

- PT jacks and hydraulics pumps were delivered and installed





We Make a Difference

82

Stressing

Day 42

PT Stressing began Sunday, June 20th and was completed June 22nd

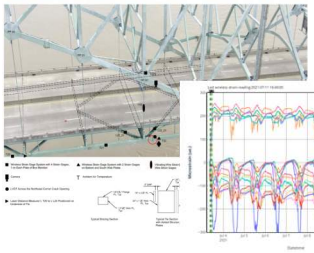
We Make a Difference

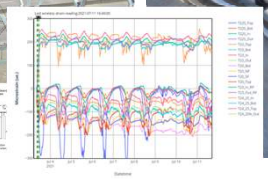
83

83

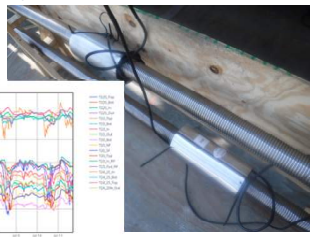
PT Monitoring

Strain Gauges





Dyna Force Sensors



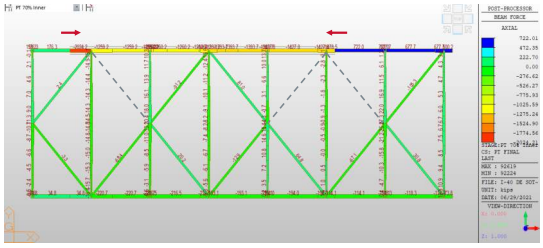
We Make a Difference

84

84

"Drag" Force

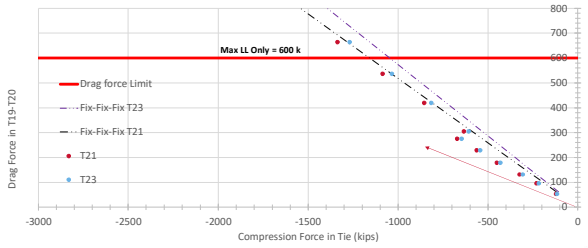
Force in the Tie outside the limits of the PT



We Make a Difference 85

85

Actual Drag Force vs Compression in Tie

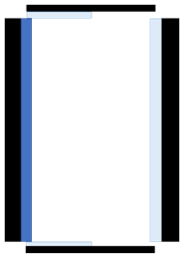


We Make a Difference 86

86

As-Built Conditions

- Plate stresses fractured section:
  - Post Fracture: 100 ksi
  - After PT: 75 ksi
  - Current: 80 ksi
- New plates ALONE installed can handle full LRFD Design loading
- Conclusion, there is a large reserve capacity in these members
- Crack tip brought together and removed
- Geometry *partially* restored



We Make a Difference 87

87

Removing the Fracture

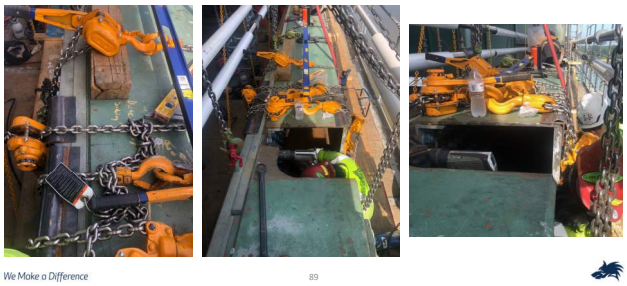
Day 43

We Make a Difference

88

88

Squaring of the Box



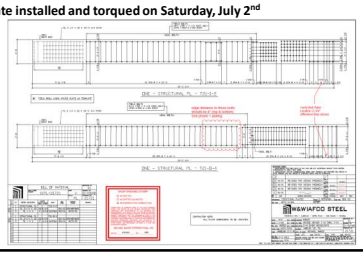
We Make a Difference

89

89

Phase 2: Final plating fabrication

- Plating fabrication by W&W /AFCO in Little Rock, Arkansas — Day 43
- 70 ksi material with A325 bolts
- Partial submittals / approvals for speed of fabrication
- Last Plate installed and torqued on Saturday, July 2nd — Day 51



We Make a Difference

90

Phase 2 Summary

Day 51

- Phase 2: Final plating fabrication and installation complete

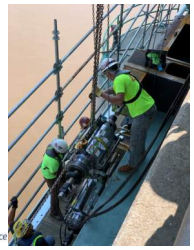
We Make a Difference

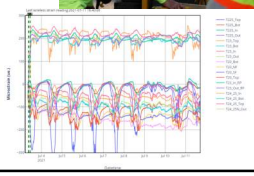
91

Phase 2 - PT Unloading

Day 52

- **PT work by DSI completed on July 2nd**
- **PT bridge monitoring by WJE**





We Make a Difference

92

Phase 2 Completion

- Final Painting
- Phase 2 Complete

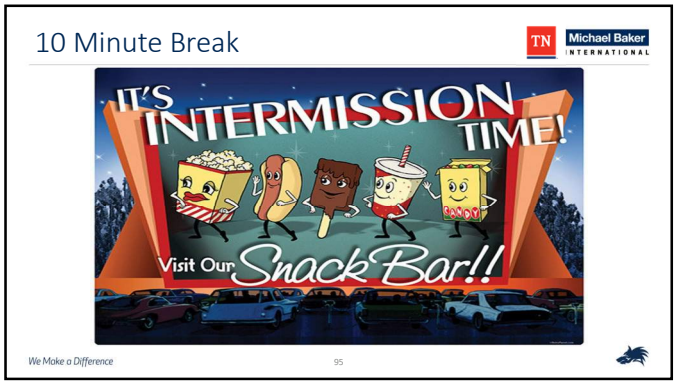
We Make a Difference

93

93


Questions ?
94

94


10 Minute Break
TN
Michael Baker
INTERNATIONAL
IT'S INTERMISSION TIME!
Visit Our Snack Bar!!
We Make a Difference
95

95


Phase 3 Repairs
Inspection, Testing, and Repair for long-term reliability
96

96

Phase 3 – Inspection

Day 15 - Day 59

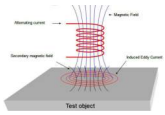
- Full Penetration Butt Weld detail typical throughout structure
  - Potential for similar defects
  - Prevent future failure
- Arch Tie Members and Hanger Pins (Approx. 500 welds)
  - HNTB contracted CAN-USA
  - June 1st to June 23rd
- Arch Truss Members (Sampling)
  - MBI contracted Fickett
  - June 7th to June 11th and June 23rd to 25th

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

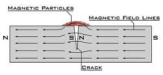
We Make a Difference 97

97

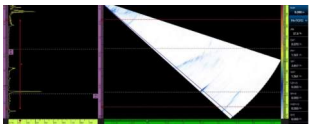
Phase 3 – Inspection Methods



Eddy Current Inspection
(Wermac)



Magnetic Particle Inspection
(NBBI)



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

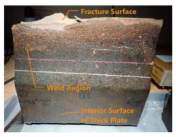
- Visual
- Eddy Current (EC)
  - Near Surface Defects for MP Verification
  - Exact Location of Butt Welds for PAUT
- Magnetic Particle (MP)
  - After EC, prior to Paint Removal for PAUT
  - Utilized to verify EC indication findings
- Phase Array Ultrasonic Testing (PAUT)
  - Paint Removal
  - Embedded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

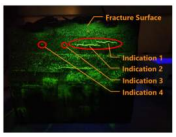
We Make a Difference 98

98

Phase 3 – PAUT Recalibration

- WJE Examination of Fracture
  - Verify CAN-USA system setup sensitivity as QA/QC measure
  - Utilize confirmed defects from extracted fractured section for PAUT data reinterpretation
  - Not much data available for ASTM A514 Steel
- WJE concluded CAN-USA original setup accurate for data collection
- CAN-USA identified additional 17 rejectable welds for a grand total of 46



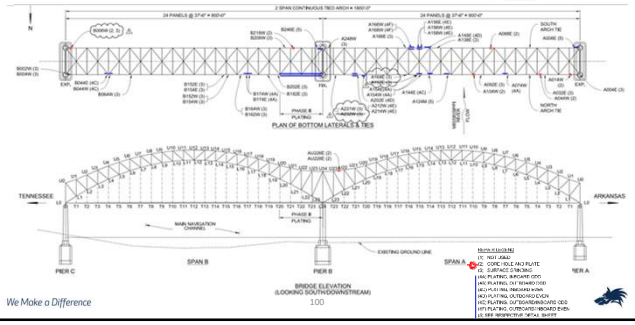


WJE Recalibration Testing
(WJE PAUT Calibration and Verification Testing Memo)

We Make a Difference 99

99

Phase 3 – Repair Summary



We Make a Difference

100

100

Phase 3 – Design Philosophy

- Target design resistance debate continues
  - Recurring Yield on Gross vs. Fracture on Net Section
  - What is "good enough"?
  - Feasibility/Economics of existing capacity
- EXT-I (50% LL) & STR-I Load Combo
- Effective only for future loading or after additional fracture
- Standardization for Present & Future

And if you ever DID catch your tail, are you sure it would make you happy?

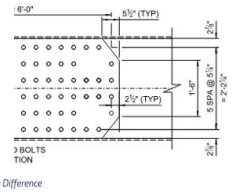
We Make a Difference

101

101

Phase 3 – Design Aspects

- Plate Chamfer
  - "Incremental Loading" – 8 bolt holes max
  - All splice ends with holes into thin web
  - Req'd for double plating but utilized for single plating in case of future plating



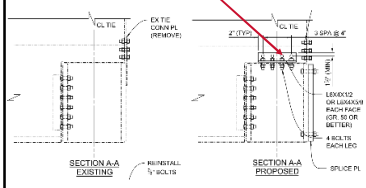
We Make a Difference

102

102

Phase 3 – Constructability Aspects

- Contractor Input on Constructability
  - Even Joint – 4 bolts to remain
  - Odd Joint – Floorbeam/Tie Connection

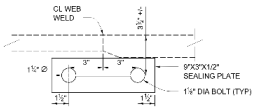


We Make a Difference 103

103

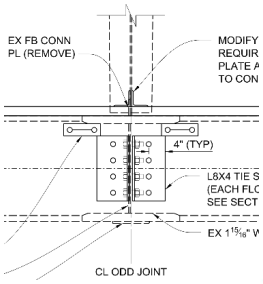
Phase 3 – Design/Constr. Aspects

- Dogbone detail for potential crack arrest



FLANGE DOGBONE
RETROFIT DETAIL

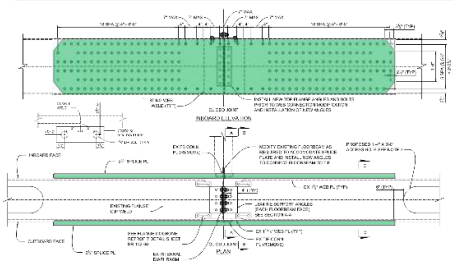
(SEE NOTE 5 FOR PROCEDURE)
NOTE: INSTALL ON TOP AND BOTTOM
FLANGE AT EACH LOCATION.



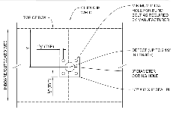
We Make a Difference 104

104

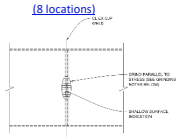
Phase 3 – Repair Types (Typical Odd)



Plating with "Dogbone"
(17 locations)



Core & Plate
(8 locations)

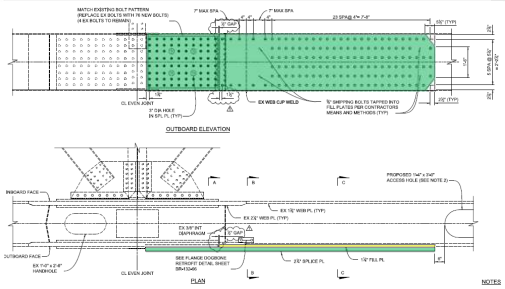


Grinding
(21 locations)

We Make a Difference 105

105

Phase 3 – Repair Types (Typical Even)



We Make a Difference 106

106

Phase 3 – Fabrication

W&W | AFCO STEEL

We Make a Difference 107

107

Phase 3 – Installation

Odd Joint Plating

We Make a Difference 108

108

Phase 3 – Installation

Even Joint Plating

We Make a Difference

109

109

Phase 3 – Bridge Reopening

We Make a Difference

110

110

Forensic Evaluation

Examination of the Fracture Surface

111

111

Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

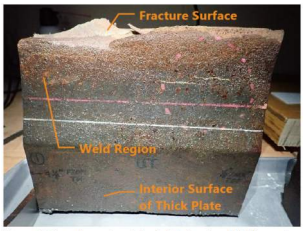


Figure 1. Sample under white light showing MT filings at crack locations.

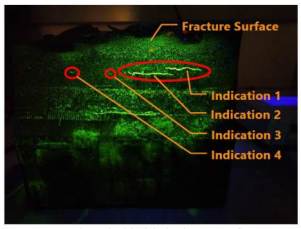


Figure 2. Sample under black light during wet fluorescent MT inspection with four MT indications (red circles)

We Make a Difference 112

112

Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

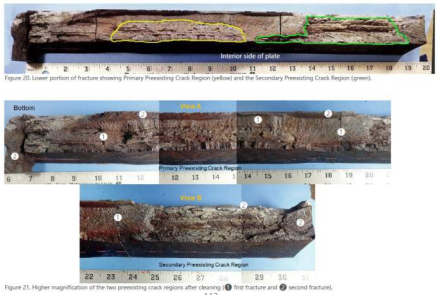


Figure 20. Lower portion of fracture showing Primary Preexisting Crack Region (yellow) and the Secondary Preexisting Crack Region (green).

Figure 21. Higher magnification of the two preexisting crack regions after cleaning (1 first fracture and 2 second fracture).

We Make a Difference 113

113

Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

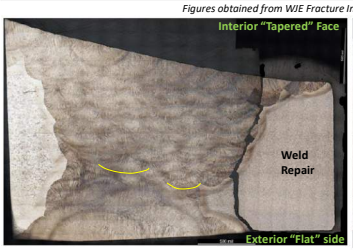


Figure 39. Primary preexisting crack weld profile.

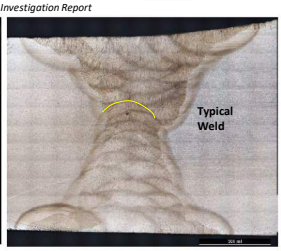


Figure 40. Core Sample SA008E weld profile.

We Make a Difference 114

114

Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

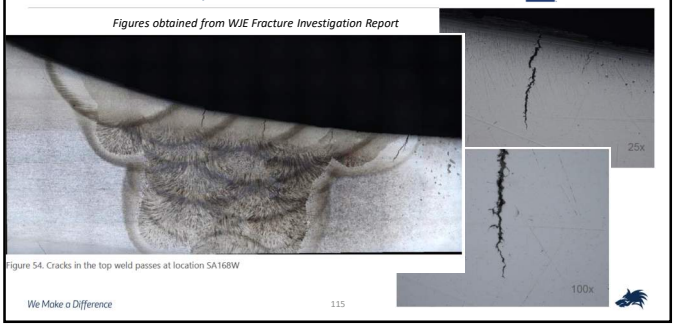


Figure 54. Cracks in the top weld passes at location SA168W

We Make a Difference 115

115

Fracture Analysis

Figures obtained from WJE Fracture Investigation Report

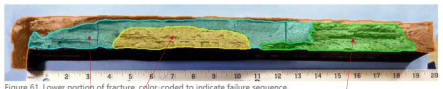


Figure 61. Lower portion of fracture, color-coded to indicate failure sequence.

Fracture Event #1

Secondary Pre-existing Crack

Primary Pre-existing Crack

Fracture Event #2

Fracture Event #3

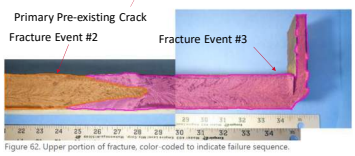


Figure 62. Upper portion of fracture, color-coded to indicate failure sequence.

We Make a Difference 116

116

Lessons Learned

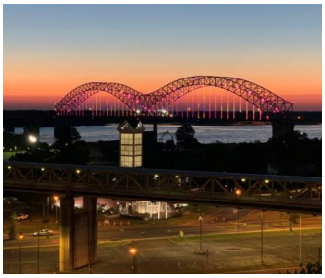
Keys to success

117

117

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



We Make a Difference 118

118

Lessons Learned

- Ensuring Quality is Critically Important!
  - Multiple Teams working simultaneously
  - Appropriate staff expertise
  - Check and Re-Check – checklists are valuable
  - No time to back track
- Be Prepared for Challenges and Setbacks
  - Don't assume field conditions = plans
  - Always revisit your assumptions!
- Check your Ego at the door
  - Many opinions, some of them are right
  - All ideas have value
- Keep Calm

We Make a Difference 119

119

By the Numbers

PHASE 1	30,000 LBS of structural steel redundancy plating to stabilize the Tie Girder	448 Temporary bolts required to install the plates	Total Repair Cost = $9.7M	
PHASE 2	108,000 LBS of structural steel redundancy plating added to the Tie Girder	Over 4,400 Permanent Bolts used to connect the plates	1,424 Feet of 3" diameter High-strength Post tensioning rods utilized in the repair procedure	1.2Million + Pounds of tension removed from the fractured section and put on the composite section
PHASE 3	17 Welds were plated for a total of 78,000 LBS of structural steel	Over 4,000 Permanent Bolts used to connect the plates	1,202 ft of welds inspected and tested in the 472 but welds of Tie Girders	29 Additional weld defects ground or cored out

We Make a Difference 120

120

National Spotlight

TN Michael Baker INTERNATIONAL

We Make a Difference

121

121

122

122

Michael Baker INTERNATIONAL | *We Make a Difference*

TN TDOT Department of Transportation

123