CDOT Rapid Response to Hydrogen Cracking in Grade 100 Steel Welds at Blue Mesa Reservoir Bridges

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CDOT Overview

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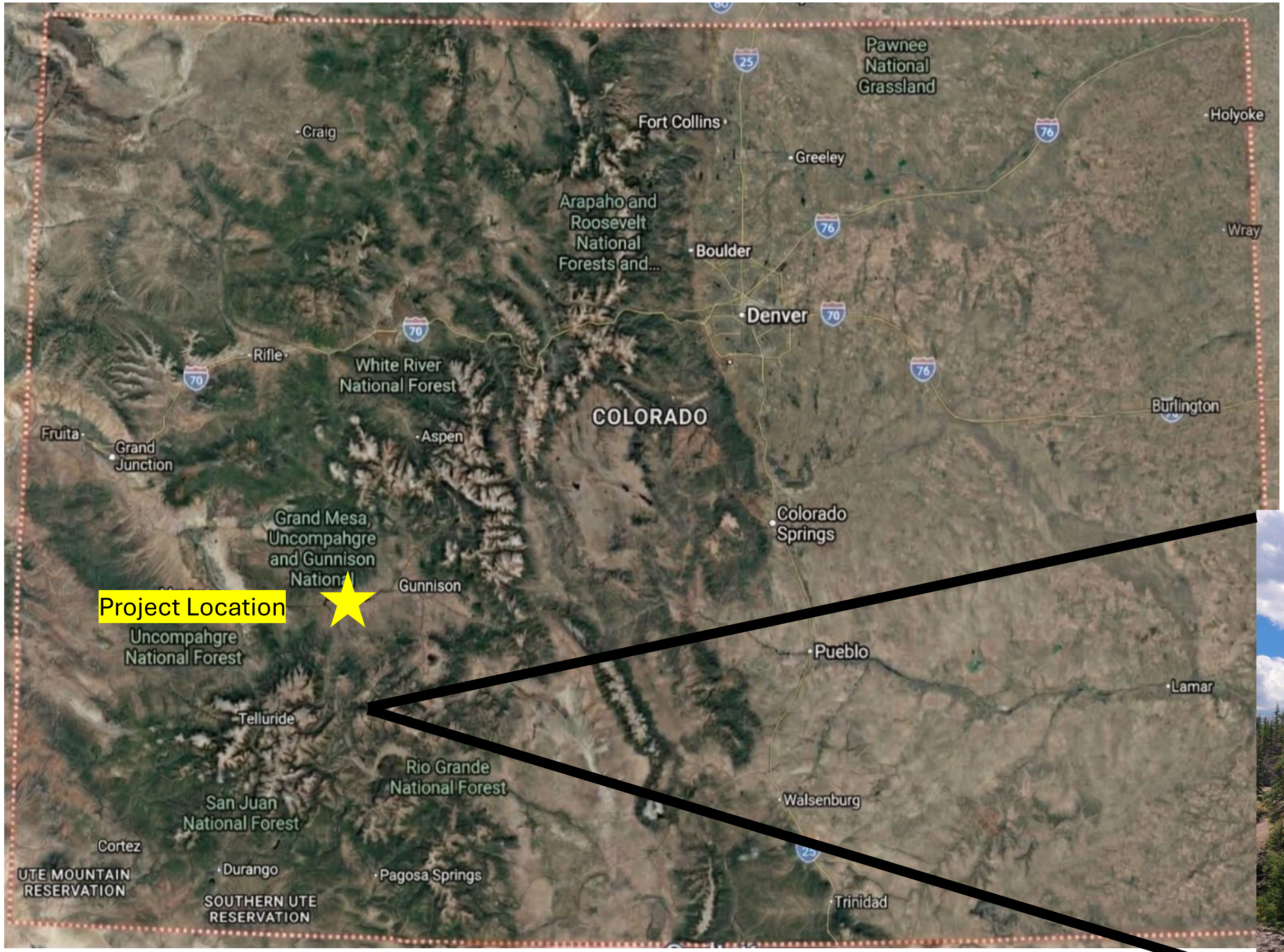
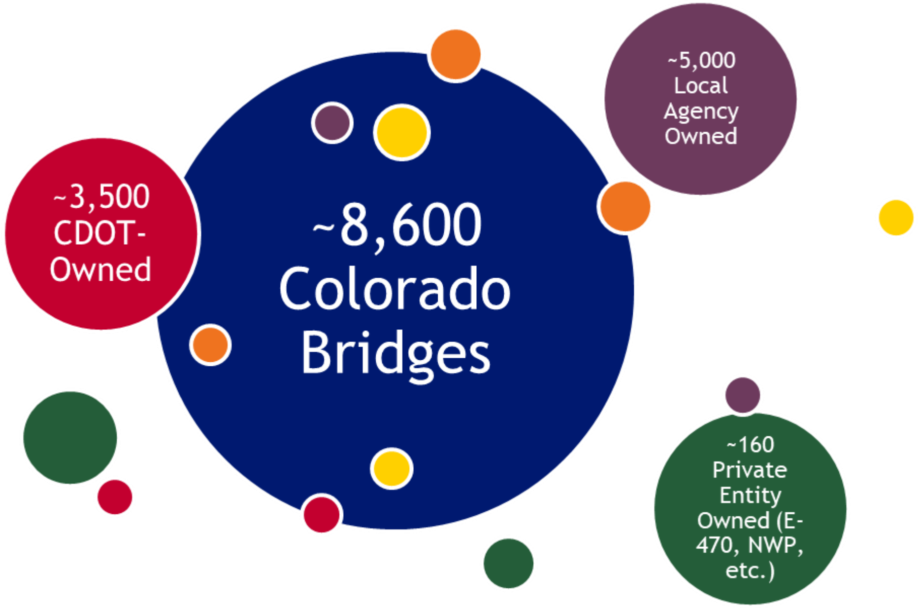
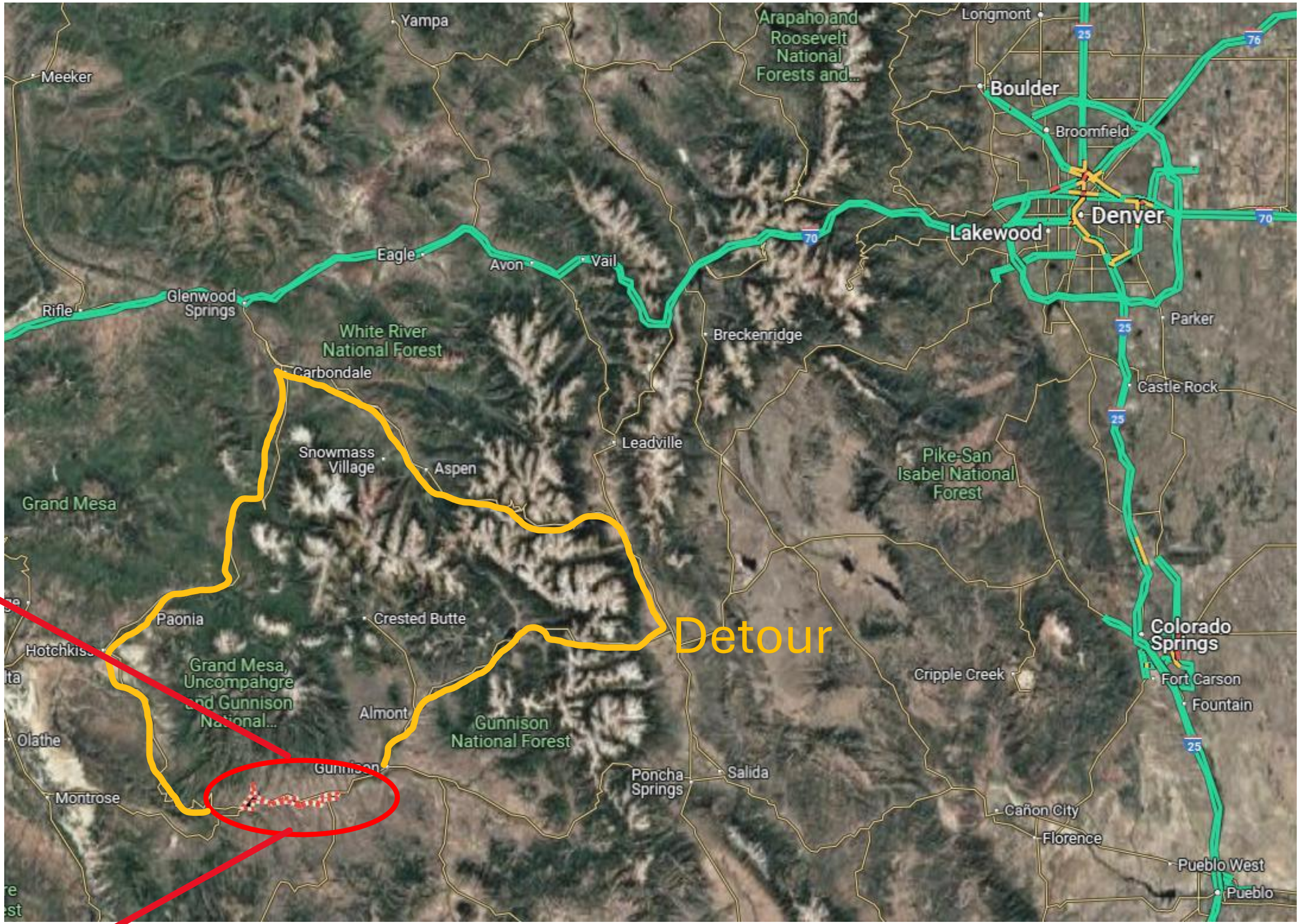




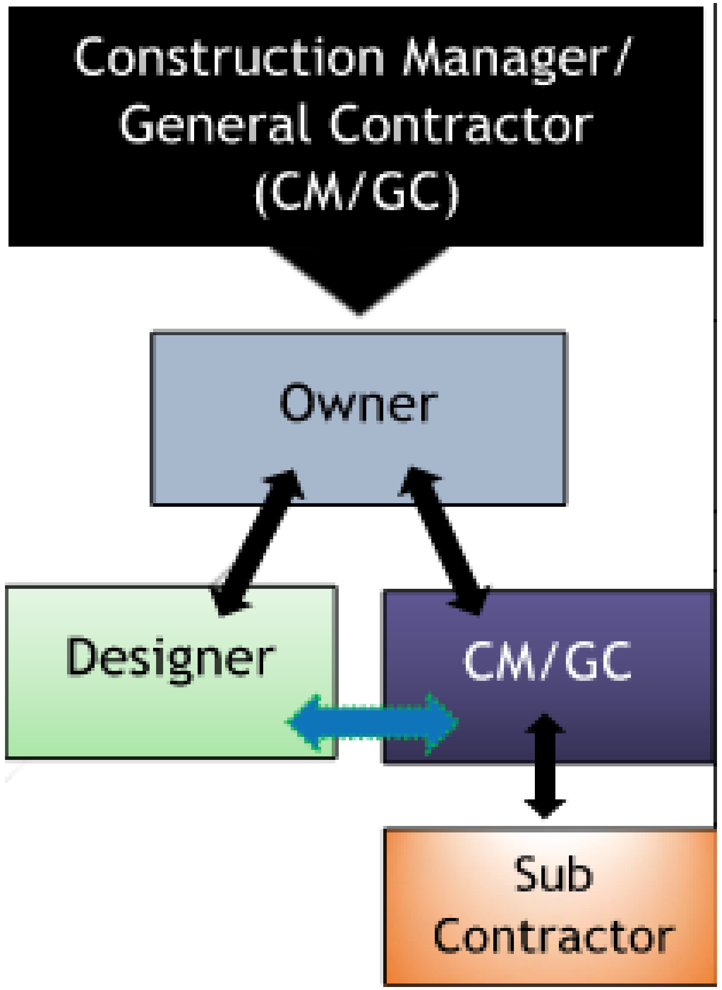
Project Location

- Blue Mesa Reservoir
- 3.5-4 hours from Colorado Springs or Denver
- Located in a very remote part of the mountains



Blue Mesa CM/GC Overview

- CDOT holds contracts with the Designer, CM, and ICE (Independent Cost Estimator)
- Blue Mesa Benefits
  - Material availability and pricing
  - Risk identification
  - Schedule
  - Constructability feedback
  - Resource allocations
  - Plans and specifications quality review
  - Phasing and construction access worked into design



Blue Mesa Bridges - General Information

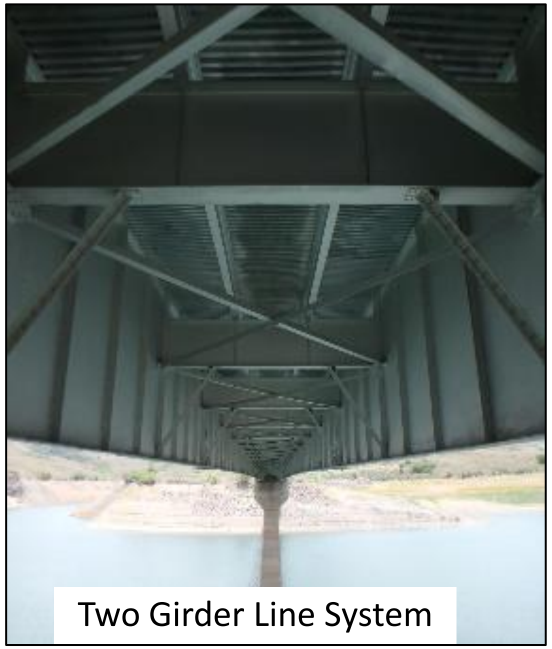
- Both bridges built 1963, FAIR condition
- K-07-A
  - US 50 over the Lake Fork at mile marker 132.69
  - Six span, continuous composite welded girder bridge. 993ft, 300ft max span
  - Spans 3, 4, and 5 are Non-Redundant Steel Tension Members (NSTM).
- K-07-B
  - US 50 over the Blue Mesa Reservoir at mile marker 136.16
  - 10 span, continuous composite welded girder bridge. 1,532ft, max span 360ft
  - Spans 5, 6, and 7 are NSTM.
- 1 lane each direction

K-07-A

K-07-B

Blue Mesa Project

- On December 31, 2021, FHWA issued a memo requiring the identification, testing, and repair of T1 steel bridges with NSTM (Non-redundant Steel Tension Members)
- Colorado identified two Blue Mesa bridges as having main spans are composed of 100 ksi T1 Steel built-Up (welded) NSTM members

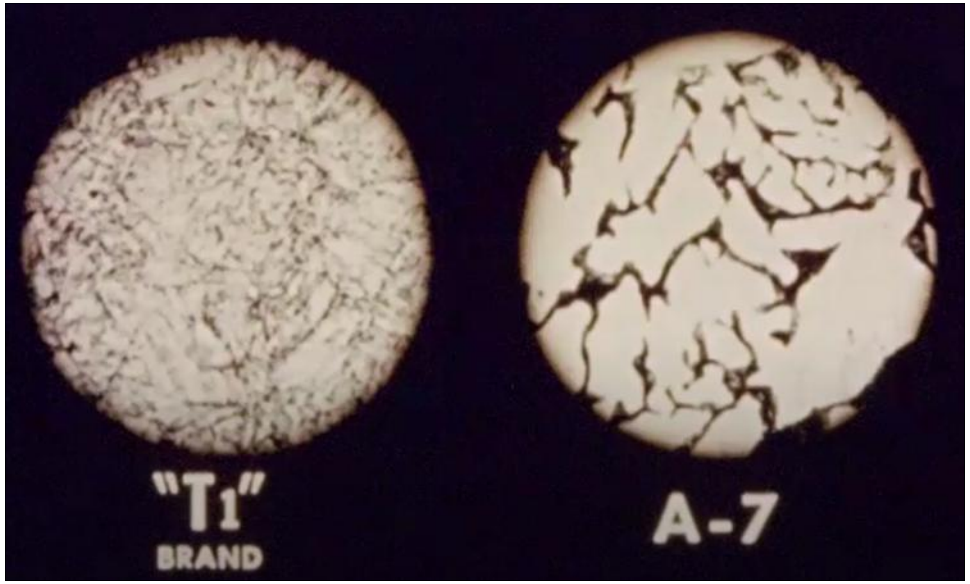


Two Girder Line System

Pin and Hanger

What Is T1 Steel?

- High strength steel developed in the 1950's and used 1950s - 1980s
- ASTM A514 or A517 designation
- Fy = 100 ksi : Fu = 110 ksi
- T-1 is US Steel marketing name
- Weldability issues



Low Carbon Tempered Martensite

Proven Engineering Material: T1 Steel (youtube.com)

Timeline

Inspection and Design
April 8 - Start of visual inspection
April 11 - Visual finding of first crack
April 18 - Visual finding of second crack
April 18 -Bridge closed to traffic
April 20 - Benesch, BDI, Michael Baker & Kiewit retained
April 22 - Begin NDE inspection & design

April

K-07-B Inspection and Design
May 24 - UT Butt weld inspection completed
May 25 - K-07-B MT fillet weld testing
May 31 - Critical repair plans issued

May

Inspection and Design
K-07-B MT fillet weld testing

June

Construction
June 5 - Shop drawings & fab start
June 11 - Begin critical repairs

K-07-A Inspection and Design
July 8-Aug 3 - K-07-A MT fillet weld testing
Aug 1 - K-07-B permanent repairs plans issued
Aug 11 - K-07-A permanent repairs plans issued

July-December

July 2 - Critical repair complete
July 3 - K-07-B open to limited traffic
July 6 - K-07-B begin permanent repairs
August 12 - K-07-A begin permanent repairs
November 12 – Last bolt installed

Timeline

Inspection and Design

April 8 - Start of visual inspection

April 11 - Visual finding of first crack

April 18 - Visual finding of second crack

April 18 -Bridge closed to traffic

April 20 - Benesch, BDI, Michael Baker & Kiewit retained

April 22 - Begin NDE inspection & design

April

May

Inspection and Design

K-07-B Testing and Design

Timeline

<u>K-07-B Testing and Design</u>

May 24 - UT Butt weld inspection completed

May 25 - K-07-B MT fillet weld testing

May 31 - Critical repair plans issued

Site Constraints

- Weight restrictions
- Access
- Paint
- Wind
- Remote location

May

June

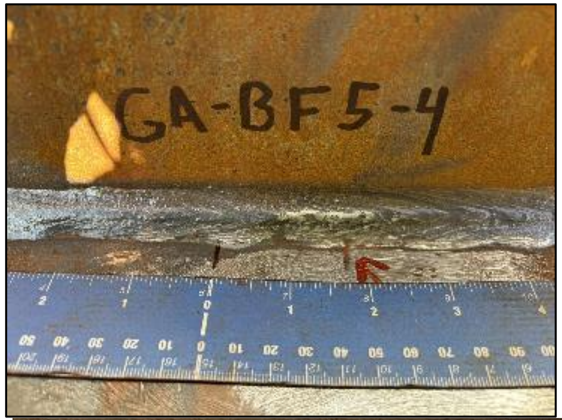
<u>K-07-B Testing and Design</u>

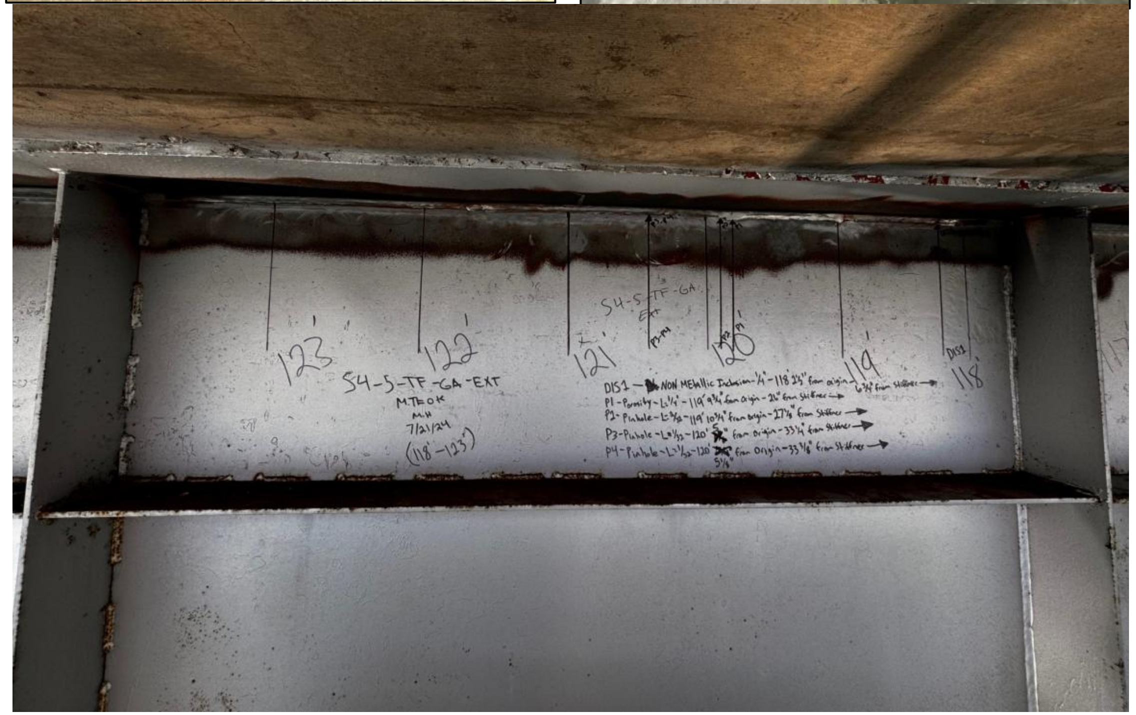
Design and Construction

Timeline

<u>Inspection and Design</u>
On-going K-07-B MT fillet weld testing

<u>Construction</u>
June 5 - Shop drawings & fab start
June 11 - Begin critical repairs





June

<u>Design and Construction</u>

K-07-A Inspection and Design

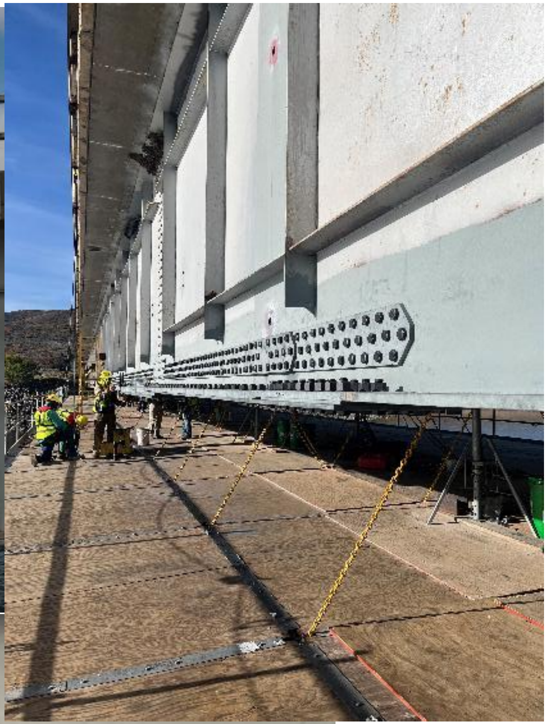
Timeline

K-07-A Inspection and Design

July 8-Aug 3 - K-07-A MT Fillet weld testing
Aug 1 - K-07-B Permanent repairs plans issued
Aug 11 - K-07-A Permanent repairs plans issued

Construction

July 2 - Critical repair complete
July 3 - K-07-B open to limited traffic
July 6 - K-07-B Begin Permanent Repairs
August 12 - K-07-A Begin Permanent Repairs
November 12 – Last Bolt Installed

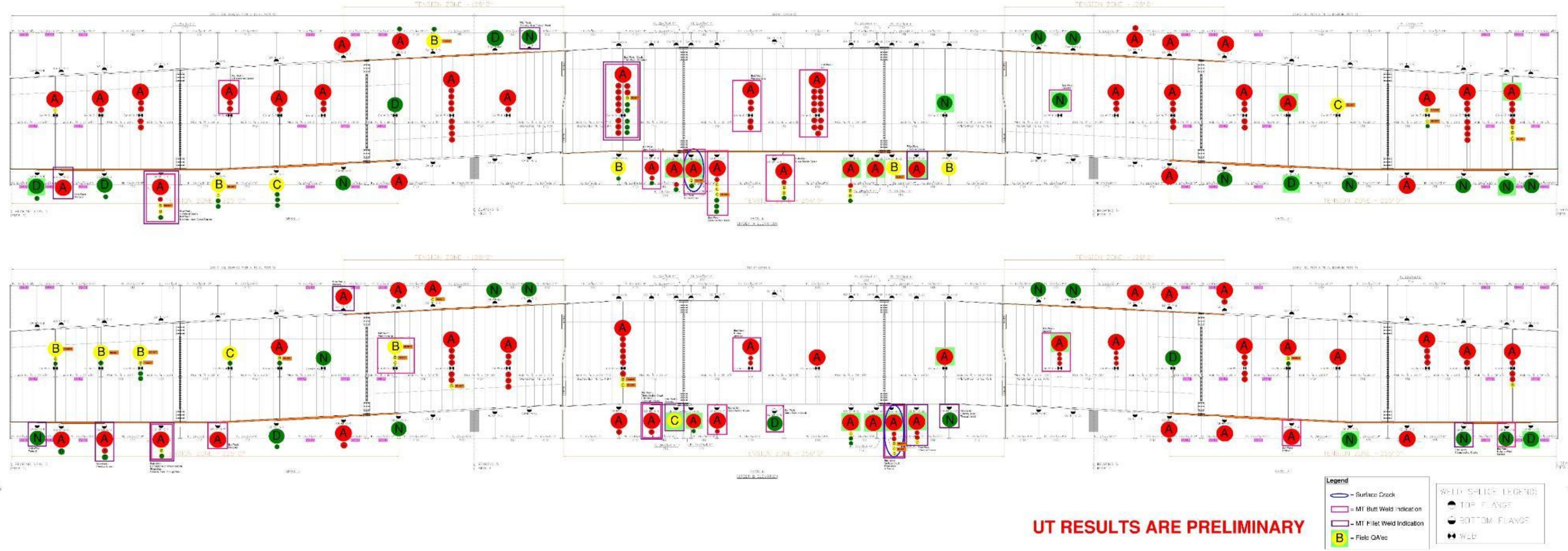


July-December

K-07-A Inspection and Design

Bridge B - T1 Butt Weld Defects Map

UT RESULTS ARE PRELIMINARY



Class A indications

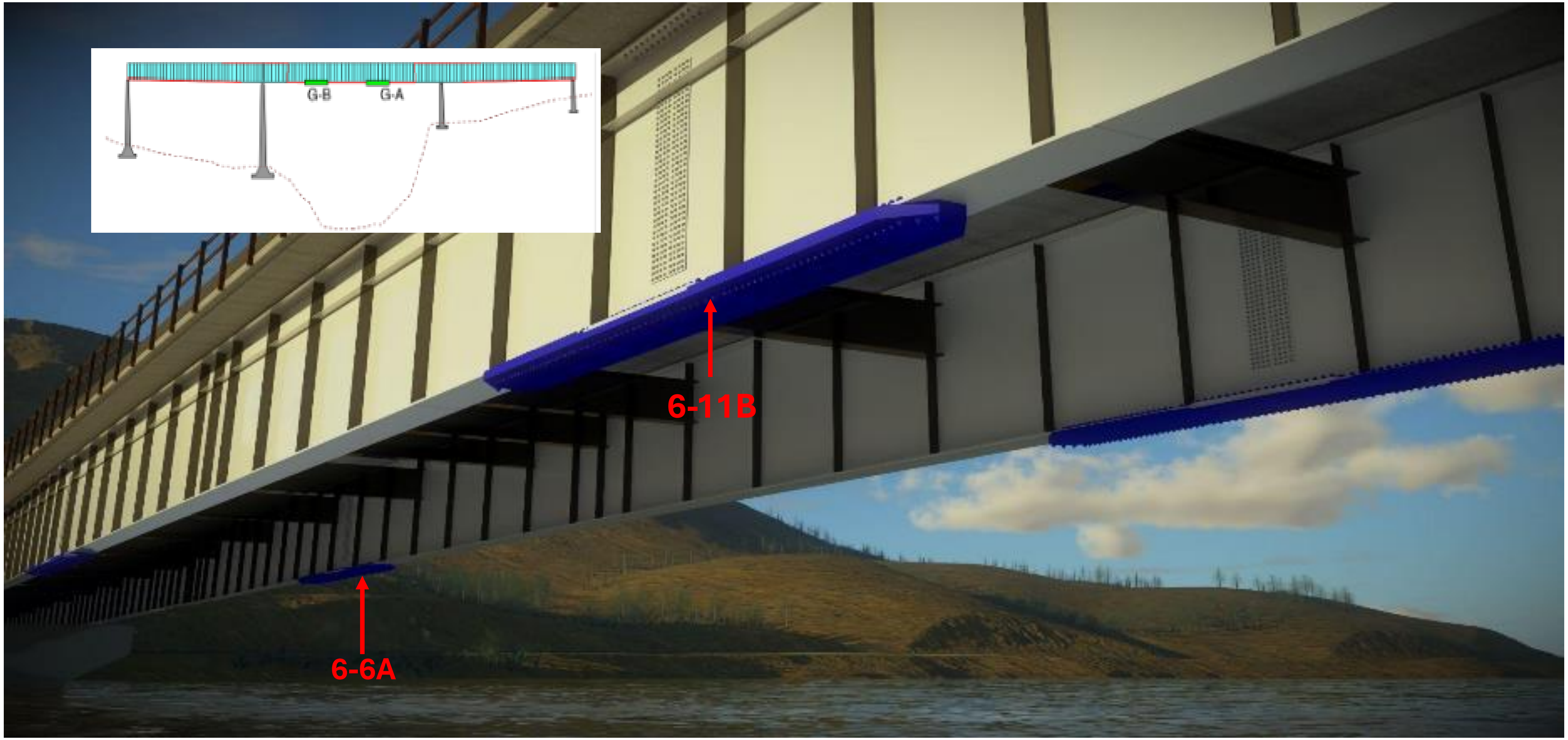
Class B and C Indications

Class D indications and None

Bridge B - T1 Butt Weld Defects Map

Bridge Item (Span 5,6 & 7)	5/21/2024
Total Tension Splices	118
Tension Splices UT Tested	118
Indications Found in Welds	289
Repair Locations (estimates)	118
Number of Surface Cracks	5 (2 Flange)

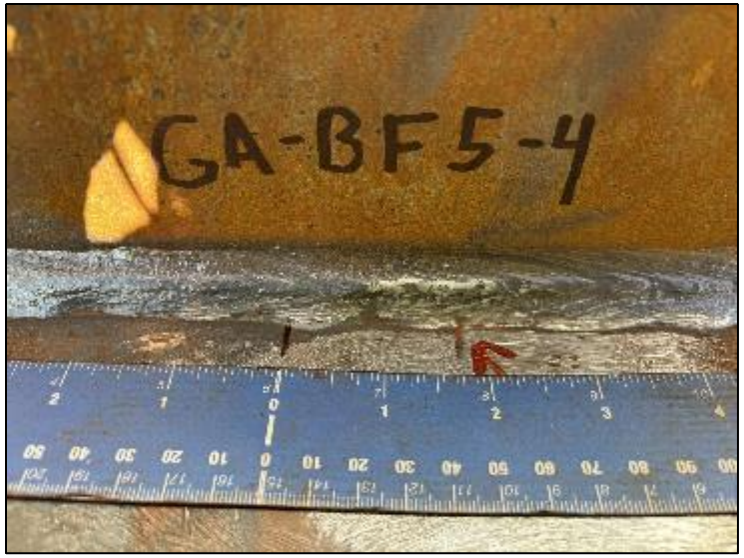
Bridge B Critical Repairs - Designed for Speed

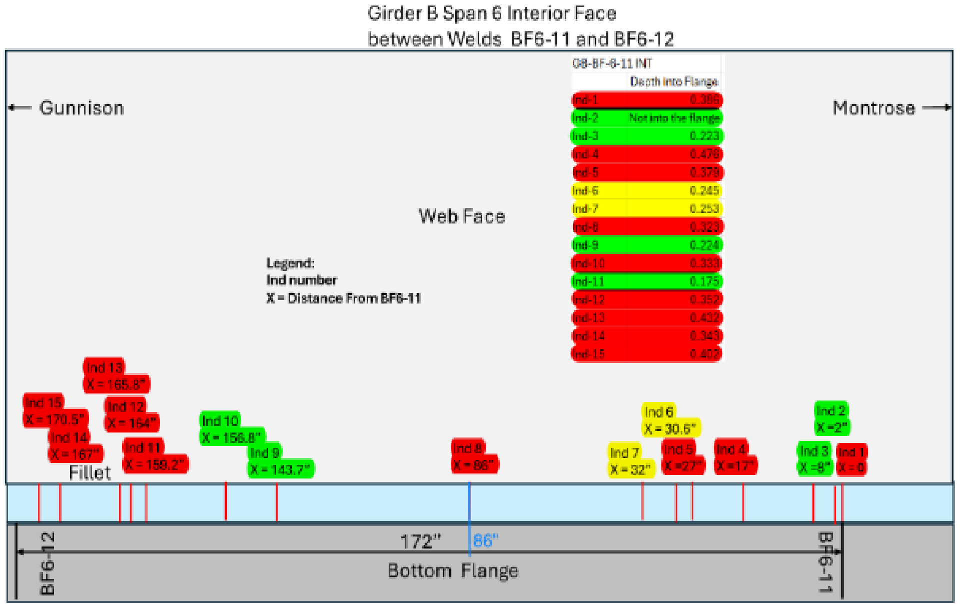


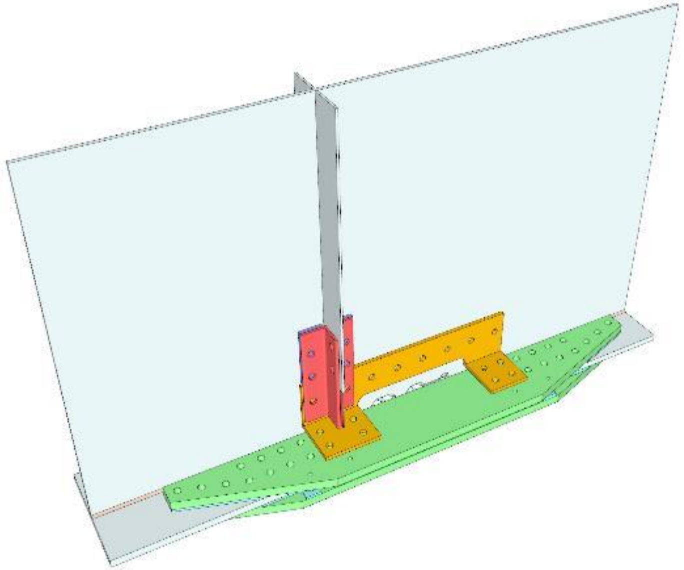
Bridge B – Critical Repairs

- Open for July 4th
- Address flange to flange surface indications
- Use material that is immediately available
- Detail considering the loading limitations

Web-Flange Fillet Weld Cracking



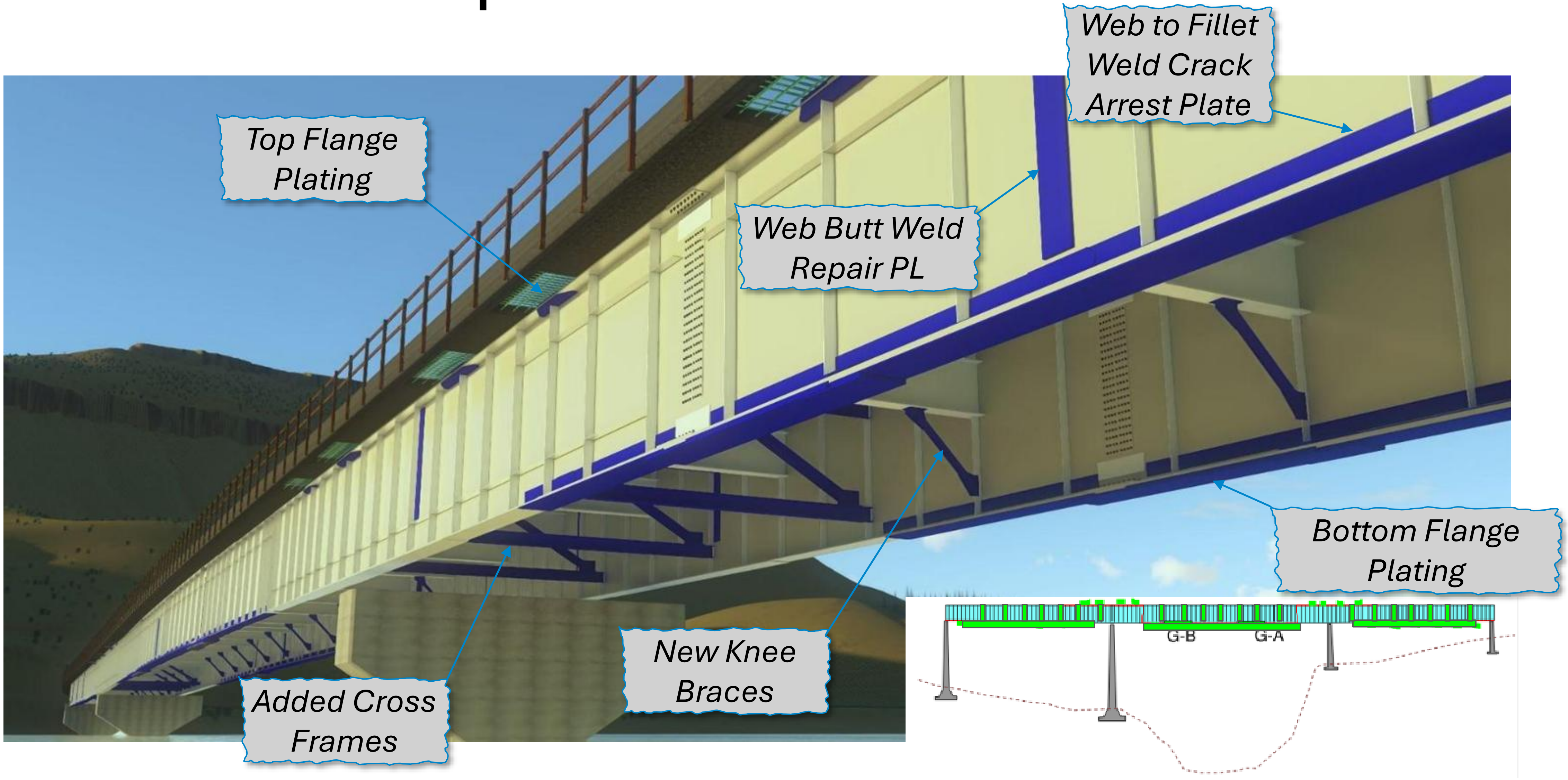




Bridge B Permanent Repair Options Drivers

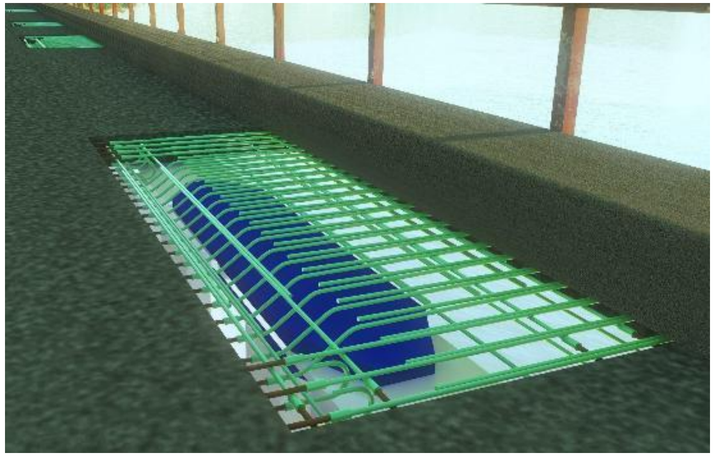
- Prevalence of fillet weld cracks
- Availability 100 ksi material
- Substructure capacity
- Schedule risk
- Historic bridge

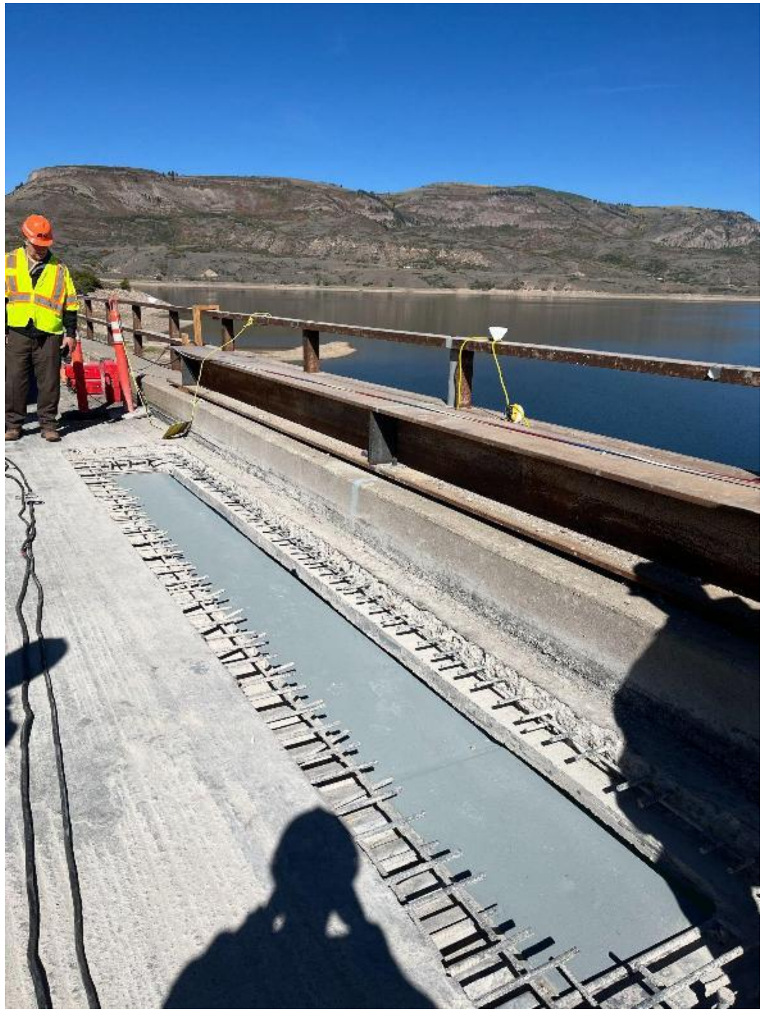
Permanent Repair Schematic



Top Flange Repairs

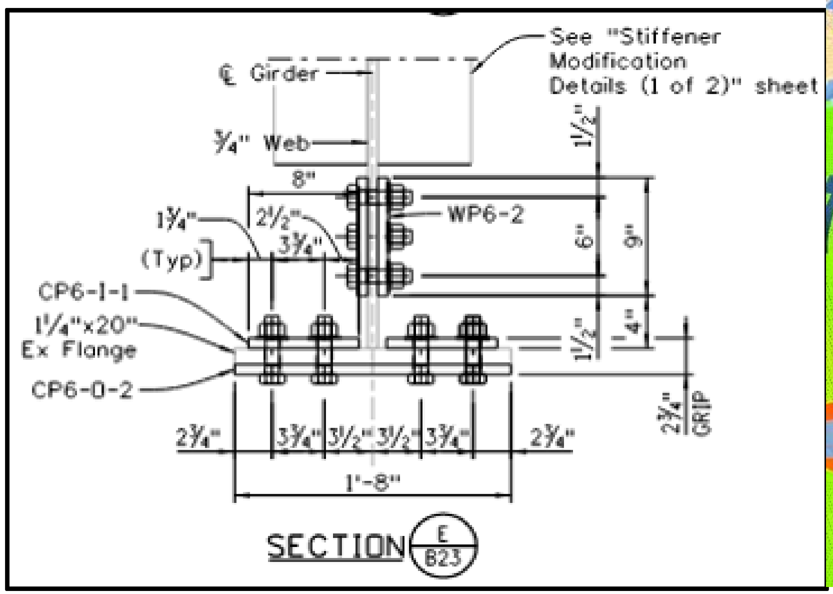
- Local splice
- Minimize deck removal
- Minimize duration
- Grade 50 for speed

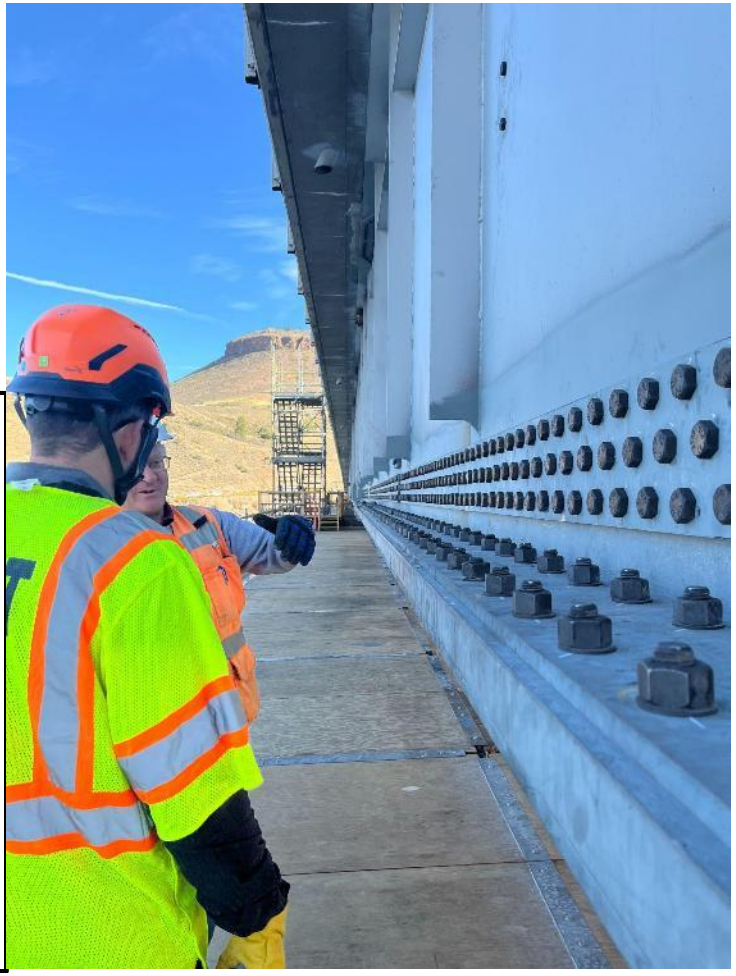




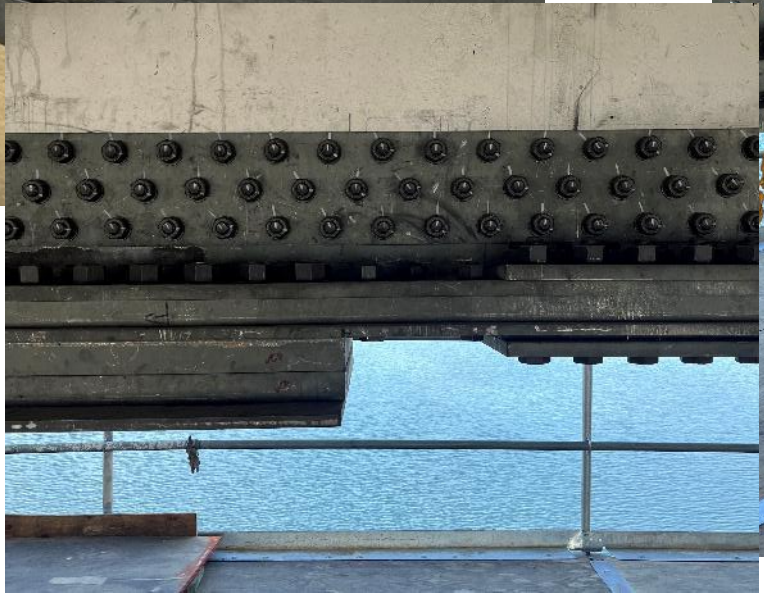
Bottom Flange Repairs

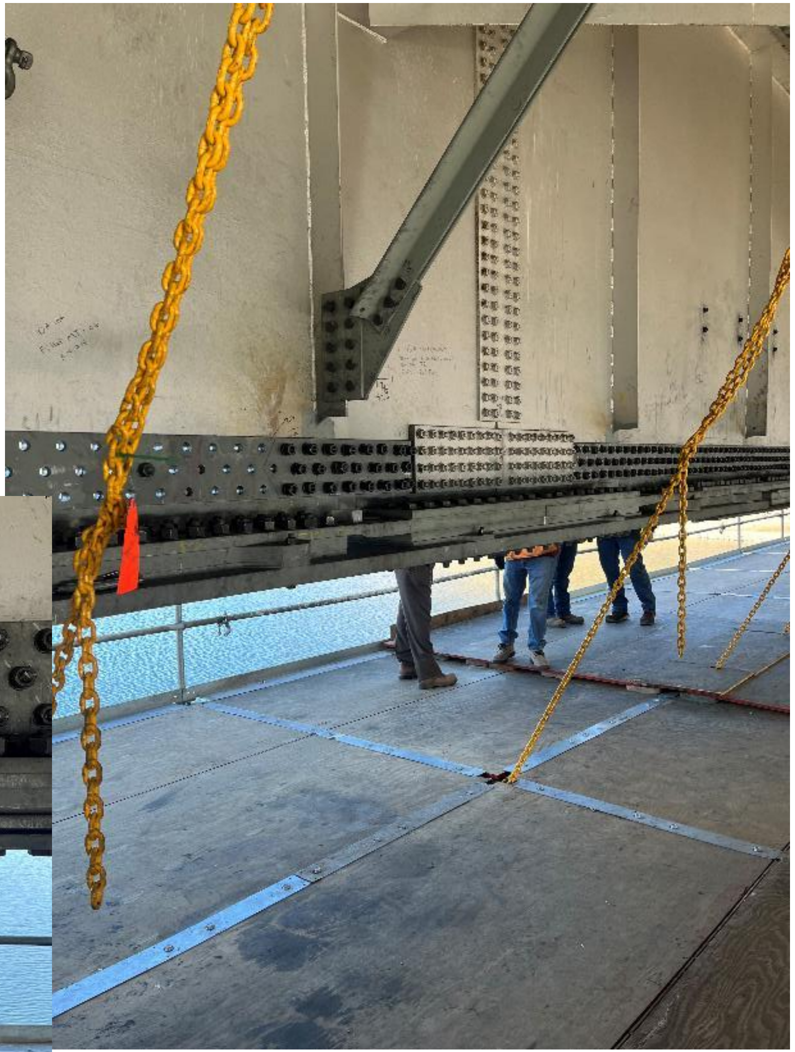
- Cont. plating, for weld defects/fracture
- Not a redundant section
- Sourced A514 (GR100) plates
- Minimize dead load impacts
- Standardized bolting





Connection to Initial Repairs



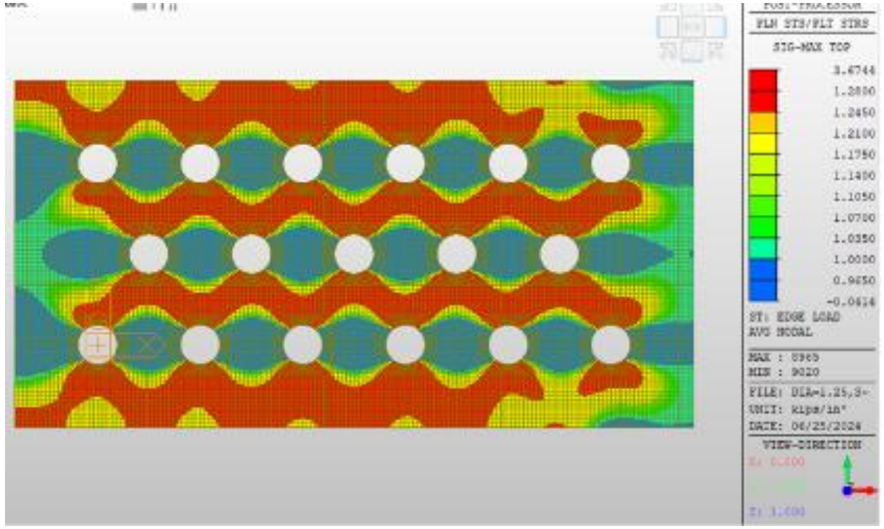


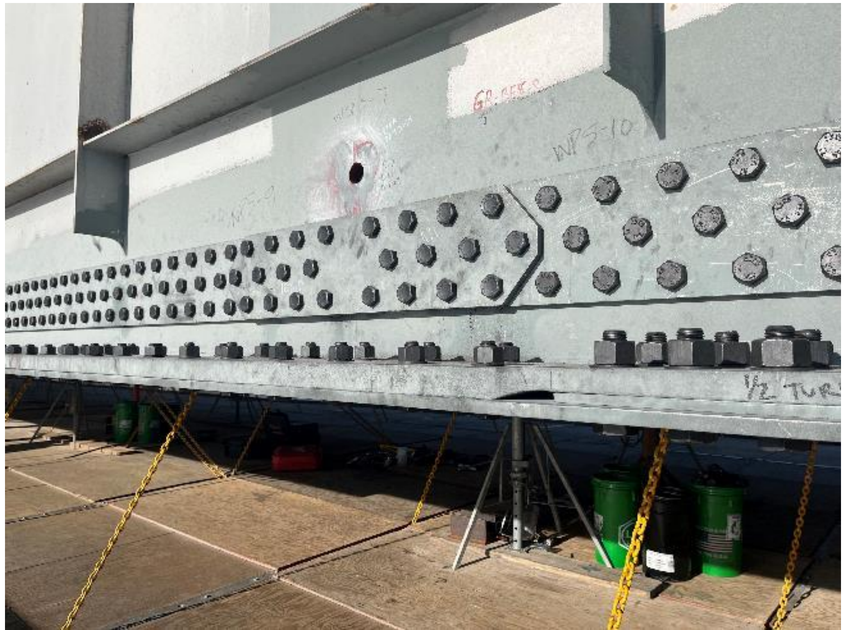
Collaboration with S-BRITE Center

- Steel Bridge Research, Inspection, Training and Engineering (S-BRITE) Center
  - Led by Dr. Robert Connor at Purdue University
- Provides expertise and resources to partners: 24 states and FHWA
  - Training, courses, research, inspection, expertise network (DEN), etc.
- Currently developing a bridge engineering program within the Lyles School of Civil and Construction Engineering
- Plans for a bridge engineering education center

Innovative Crack Arrest Strategy

- T1 steel with weld embrittlement issues
- Widespread defect indications in web-to-flange welds
- The extent of the indications made traditional repairs (grinding/coring) infeasible
- Nonredundant Steel Tension Member (NSTM, old FCM)
- The high number of defects also raised the likelihood of undetected cracks
- These conditions required a continuous retrofit, effective regardless of crack location, rather than localized repairs at each indication



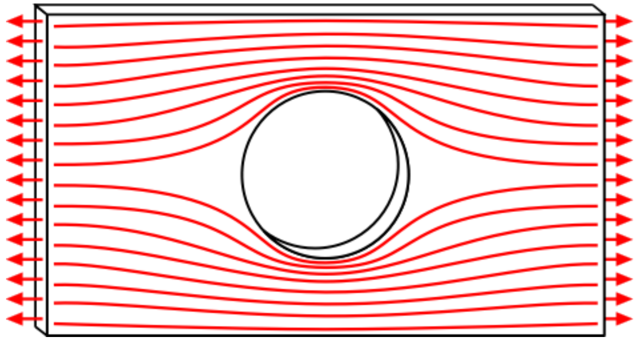


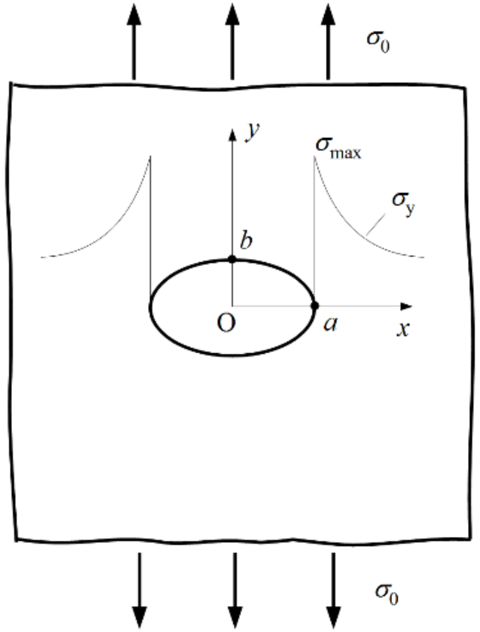
Typical Approaches and Limitations

- Common retrofit methods: coring and dogbone details
  - Dogbones were impractical due to extensive overlap and risk of flange-web separation
- Web-splicing (plates on both sides + angle connections) was unsuitable because:
  - Excessive added weight,
  - Fabrication and fit-up with other repairs
- Widespread cracking meant localized strategies would be ineffective
- Inspection uncertainty required a location-independent crack-arrest mechanism

Preliminary Retrofit Development

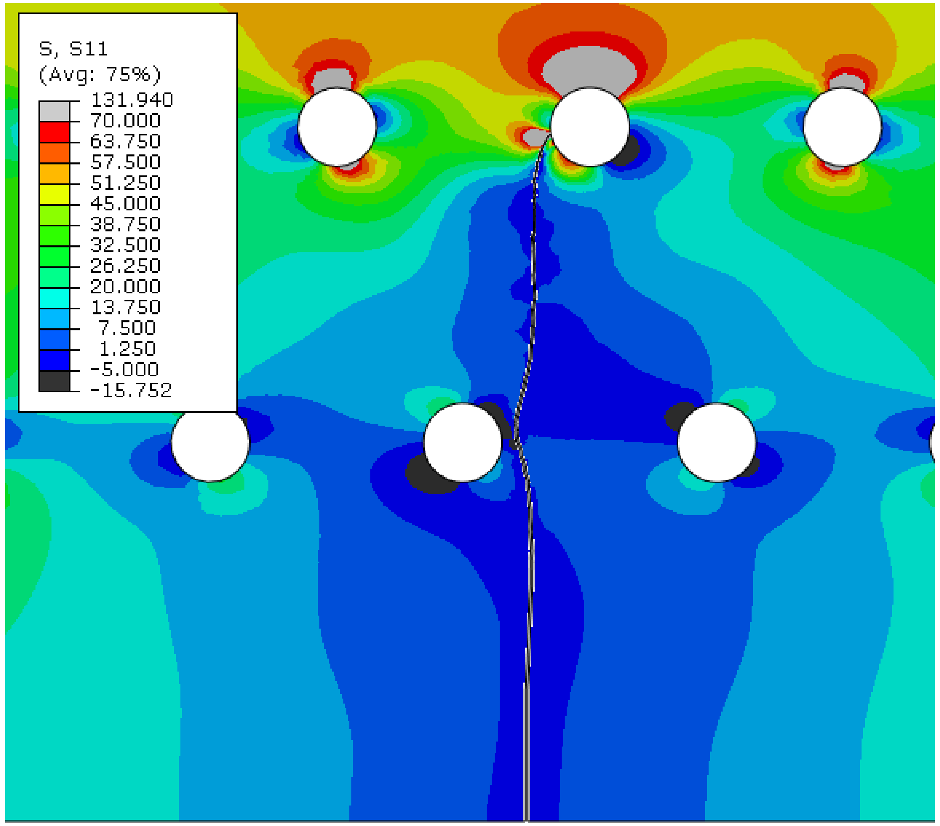
- Retrofit concept based on understanding stress-field changes caused by bolt holes and how cracks respond to them
- Cracks tend to grow toward bolt holes due to stress concentrations and away from stress-vacuum regions
- Hole size chosen to match bolts used in other repairs
- Spacing (gage/pitch) evaluated using the infinite-plate stress model, ensuring cracks redirect toward the holes when tensile stress normal to propagation ≥ applied stress
- Focused on the region between bolts closest to the tension flange, where cracks would "avoid" the first bolt row
- A third row was added for redundancy
- Multiple spacing patterns were developed and then prepared for analytical validation





Retrofit Validation

- Validation performed at Purdue University by Dr. Korkmaz and Dr. Connor using Abaqus FEA
- Crack behavior modeled using Extended Finite Element Method (XFEM)
- XFEM employs enrichment functions enabling:
  - Heaviside discontinuity modeling,
  - Accurate crack-tip stress fields through stress-intensity functions
- XFEM's key benefit: no remeshing required as cracks grow
- Bolt-pattern performance tested using cracks initiated at various distances and directions from bolt holes
- Multiple crack-propagation criteria evaluated (energy-release rate, mode mixity, etc.)
- All simulations showed cracks arresting in the first or second bolt row, with no propagation beyond row two



Fit-up Modifications

- Final retrofit: three bolt rows with defined minimum and maximum spacing limits
- Web reinforcement plates placed on both sides to maintain capacity if cracks arrested at bolt holes
- Retrofit required compatibility with other repairs, including:
    - Cored web-crack locations,
    - Existing flange splice retrofits
- Where bolt spacing conflicted with prior repairs, dogbone crack-arrest details were used instead of altering spacing
- These adjustments preserved consistent crack-arrest performance across the structure

Fun Facts

Repairs at a glimpse

- **118 splices tested**
- **289 indications found**
- **35,207 SF of primer**
- **410 tons of additional steel**
- **51,504 bolts (57 tons)**

Acknowledgements

- CDOT Region 3 and Staff Bridge
- Kiewit
- Michael Baker International
- Benesch
- Bridge Diagnostics, Inc.
- Dr. Robert Connor
- Dr. Cem Korkmaz
- S-BRITE Center at Purdue University
- FHWA
- Coating Specialists
- eO
- ICE
- KTA
- Stantec
- Ulteig
- W&W AFCO
- Gunnison County
- Brand Safway
- CIG
- Rocksol

Lessons Learned

- Collaboration - *Everyone has a common goal*

- Girder bridges offered some very unique challenges

- Bridge A – Forgo Testing and went straight to repair/reinforcement.

- Communication
  - Internal and externally
  - Many moving pieces and parts

- CM/GC benefits
  - Improved constructability
  - Material procurement / schedule


Thank You