Steel Bridge Rehabilitation Using UHPC to Repair Corroded Steel Beam Ends

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1

2

Overview

- Background on Repair and Research
- Overview of Pilot Bridges
- Full-Height Repair Implementation
- Partial-Height Repair Implementation
- Key Findings
- Acknowledgements

2

3

Background – Corrosion of Beam Ends

- Extensive corrosion of beams occurs beneath leaking joints
- Corrosion can significantly reduce bearing capacity
- US spends **$8.3 billion annually** to repair or replace corrosion damaged bridges

3

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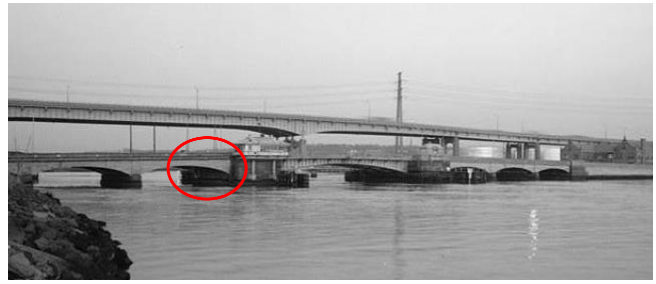
Current Rehabilitation Methods

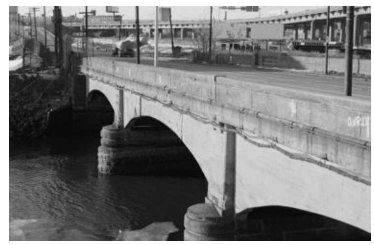
- Addition of steel shapes with painting
- May require jacking to relieve load
- Jacking may require lane closures
- Long and costly process
- Does not stop future corrosion from occurring

4

Genesis of this Idea

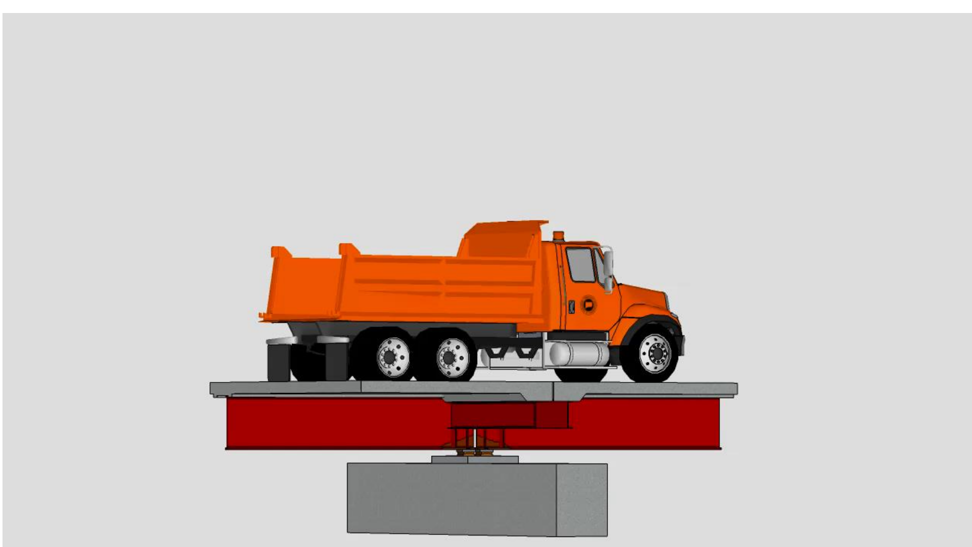
- Tomlinson Bridge, New Haven CT, 1990±
- Approach span beams were corroded at the bascule span counterweight pier
- 100% section loss in the webs
- Solution:
  - Encase the last 10 feet of the beam in concrete
  - Converted the beam end into reinforced concrete
- UHPC is like liquid steel
  - Can we use a similar approach with UHPC?
  - Goal: Eliminate jacking, bolting, and welding of plates
- CTDOT decided to fund a research project
- UConn was selected to execute the research





Concrete-encased riveted steel girders

Background – UHPC Beam End Repair



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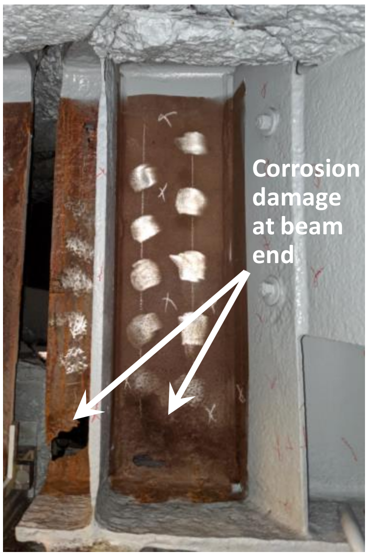

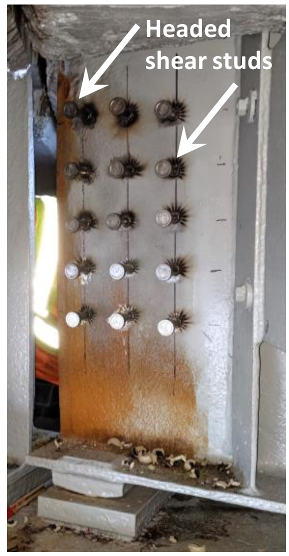

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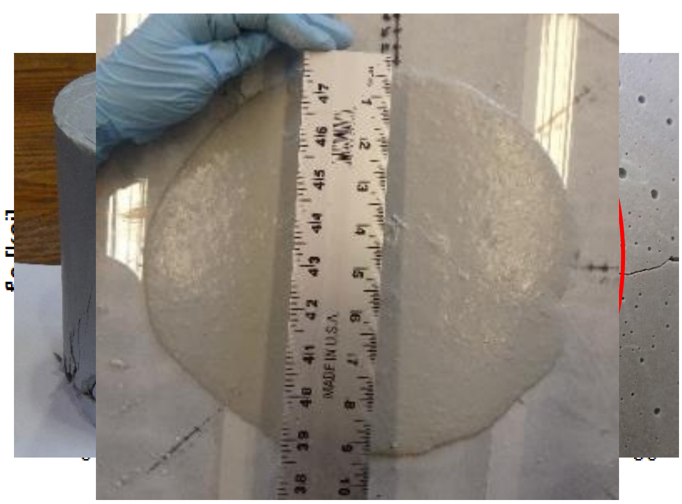
Background – UHPC Material

1. Compression strength
2. Sustained post-cracking tensile strength
3. Proven durability
4. Crack resistance
5. Flowability



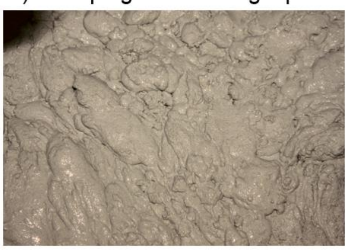
8

Background – UHPC Material

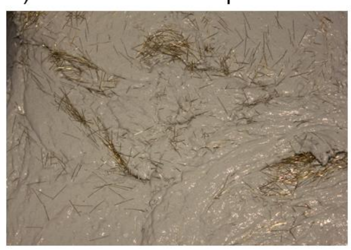
a) Clumping after adding liquids

b) 10 Minutes after liquids added

c) Larger clumps developing



d) Final clumping stage



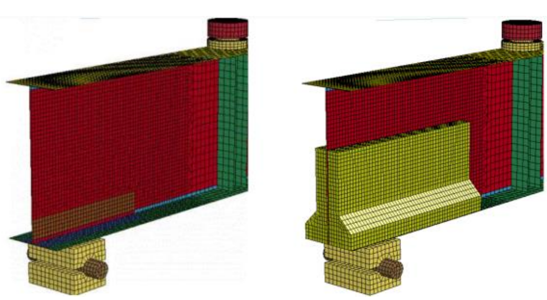
e) Addition of fibers

f) Final consistency

Background – Previous Research

Phase 1
2013-2015

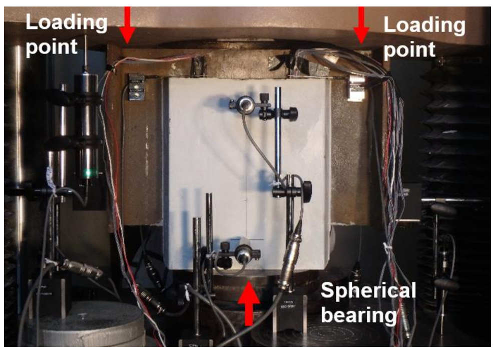
- Proof-of-concept experiments on third-scale girder specimens
- Developed finite element models to identify design parameters



Background – Previous Research

Phase 2
2015-2018

- Investigation of stud capacity embedded in UHPC
- Experimental study on 3 full-scale plate girder repairs



11

Background – Previous Research

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12

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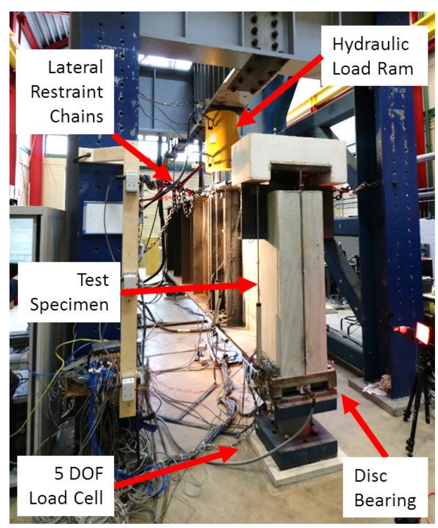
Background – Previous Research

13

14

Background – Previous Research



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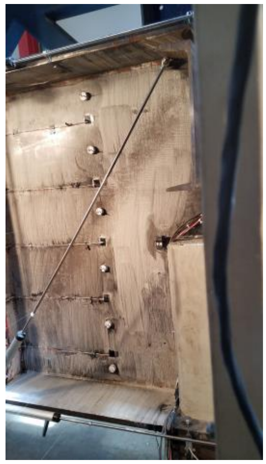
15

Testing

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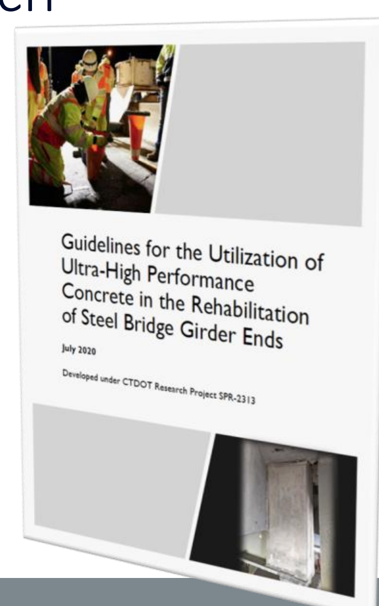
Background – Previous Research



Phase 3, 2018-2023

- Develop tools that can be used by CTDOT to quickly design repairs
- Support design, construction and inspection processes as well as instrument and monitor field implementations of the repair.

16

Field Implementations in CT

Implementation 1

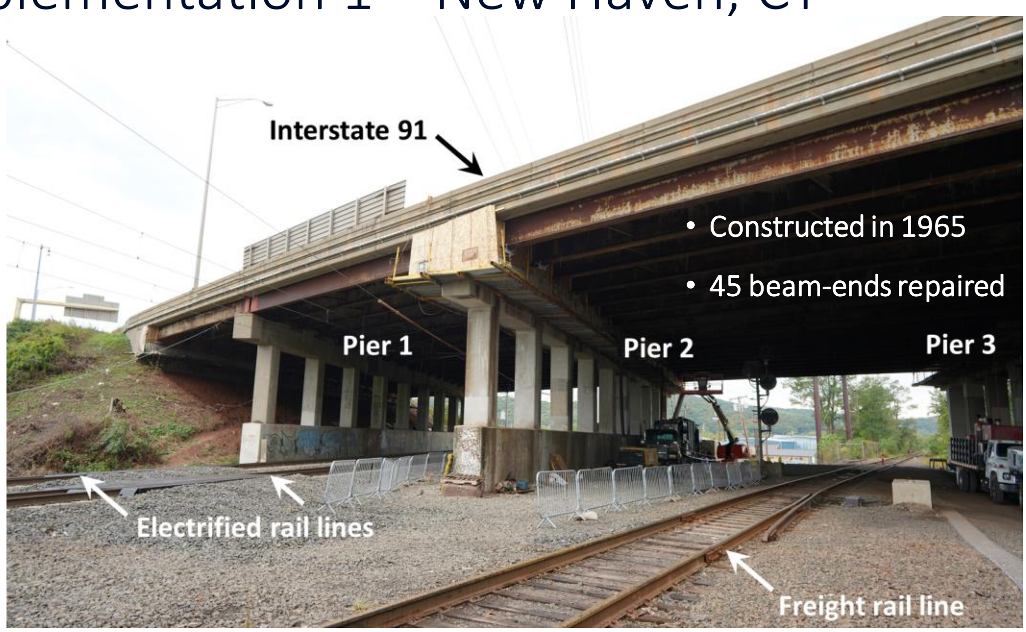
- Rolled beam bridge
- Built in 1965
- Full-height repair
- Plain carbon steel
- Casting October 2019-May 2020
- Cast from top of deck
- Consultant-led design

Implementation 2

- Plate girder bridge
- Built in 1983
- Partial-height repair
- Weathering steel
- Casting October 2021
- Cast from below deck
- CTDOT In-house design

17

Implementation 1 – New Haven, CT



18

Implementation 1 – New Haven, CT

- Composite concrete deck
- Four simple spans, 273 ft
- Ranging skews 25° -35°
- Variable beam sizes, depths ranging from 33-36 in
- Different end conditions

Implementation 1 – Condition of Bridge

- Rated as structurally deficient
- Beam ends, end diaphragms, and connection plates were severely corroded
- Web ends and bearing stiffeners have substantial section loss
  - Max bearing capacity loss: 72%
  - Max shear capacity loss: 15.5%

21

Implementation 1 – Contracting

Key to success during design was continued sharing of information between research team, owner, and designer

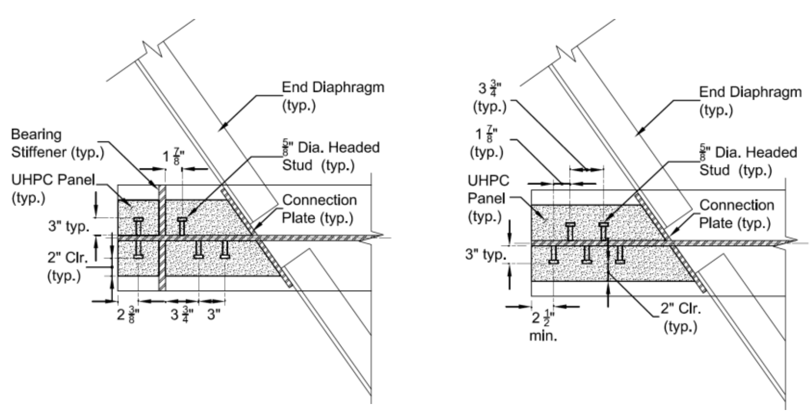
- Designer worked closely with UConn team to get the research data and capacity estimations for the studs
- Unique components in specification for contractor:
  - Requiring pre-bid meeting for all contractors bidding the project
  - UHPC material manufacturer was specified
  - Including mockup to practice casting UHPC
  - Providing access for research team for instrumentation

21

22

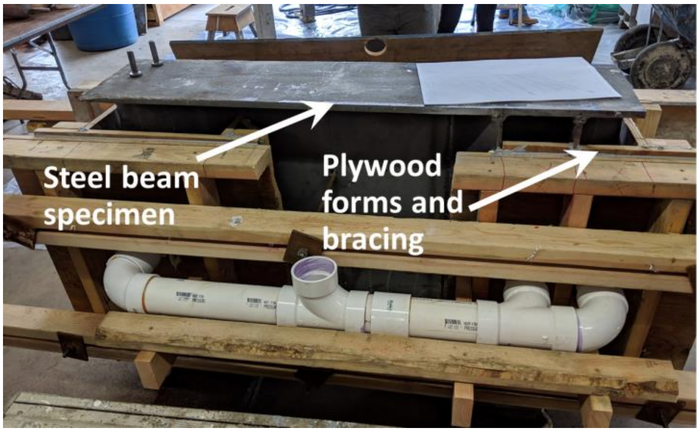
Implementation 1 – Repair Design

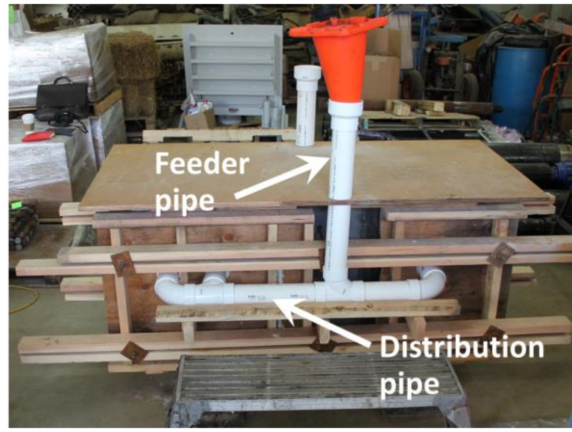
- Capacity design method was used, i.e. restoring original capacity
- Studs: 5/8” diameter
  - 20-40 per end
- UHPC
  - Ductal JS1000
  - 2% fibers
  - Minimum 28-day strength: 18 ksi



22

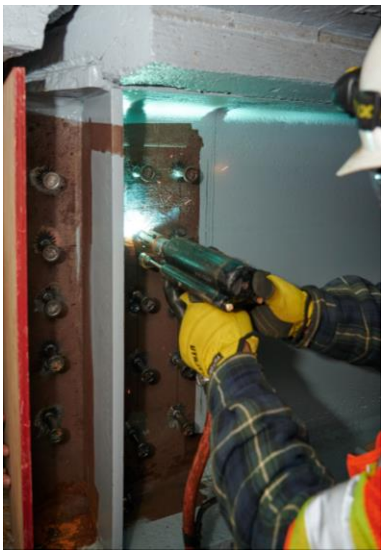
Implementation 1 – Mock-up

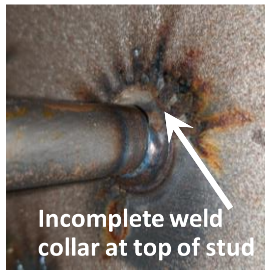




Implementation 1 – Mock-up

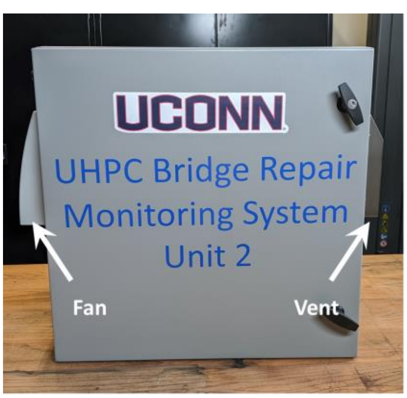
Implementation 1 – Stud Welding

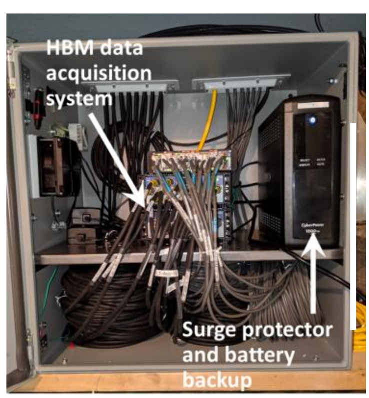




25

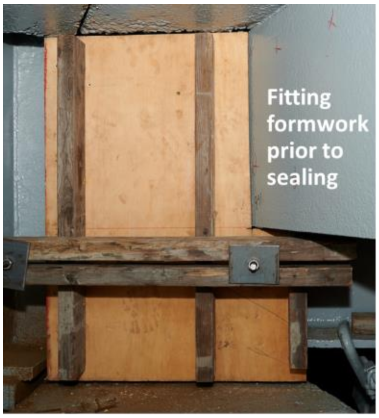
Implementation 1 – Monitoring

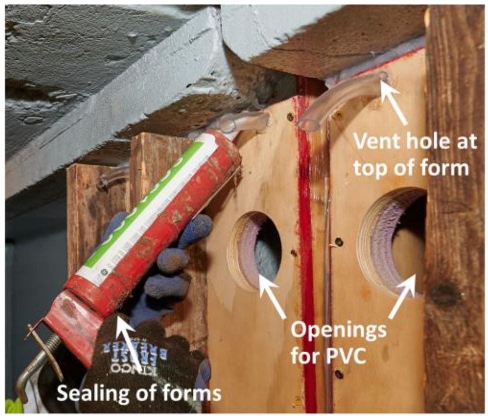


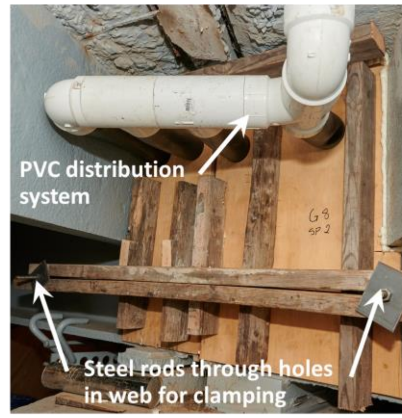


26

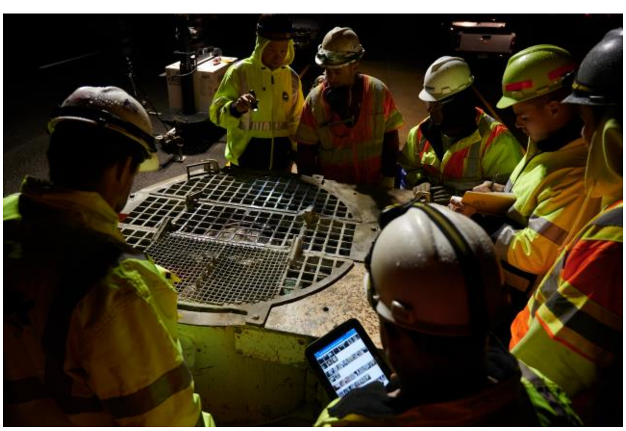
Implementation 1 – Forming

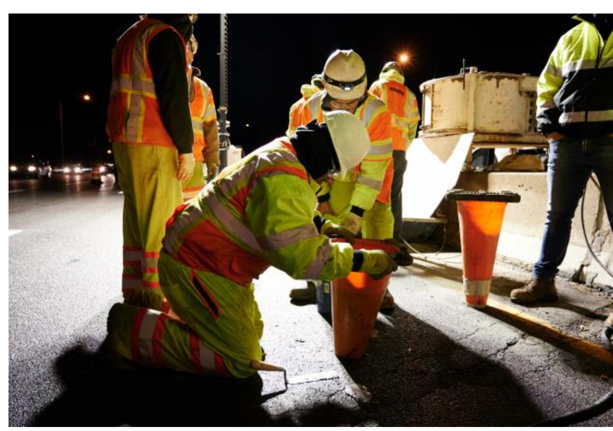






Implementation 1 – Mixing and Casting

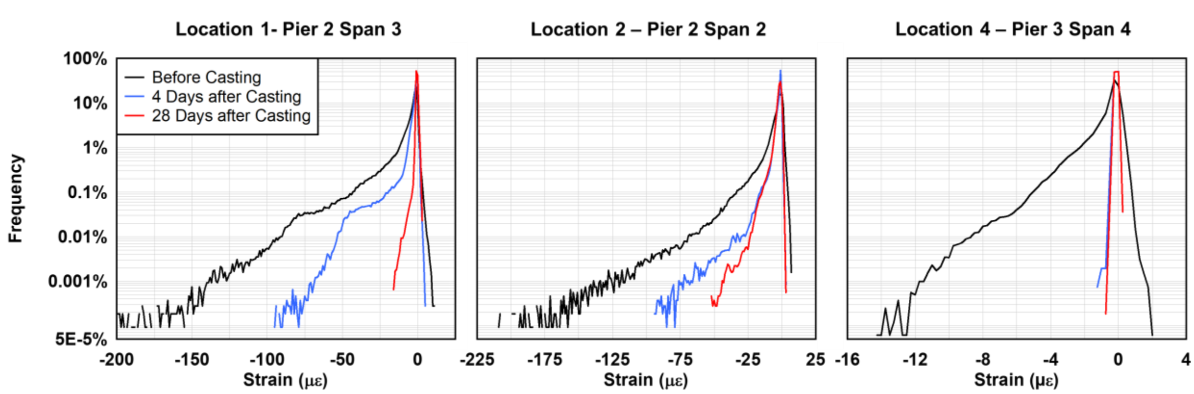




Implementation 1 – Cured Beam Ends

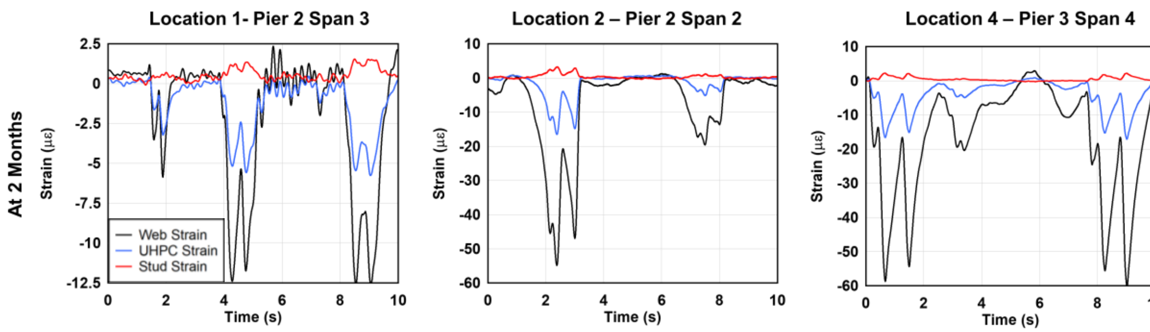
Data Collection on Repaired Beam Ends

- If the UHPC panels are engaged, there should be a reduction in the magnitude of web strain under live load events.
- The repair reduced the maximum web strain from the baseline condition as well as the frequency of high-magnitude strain events.



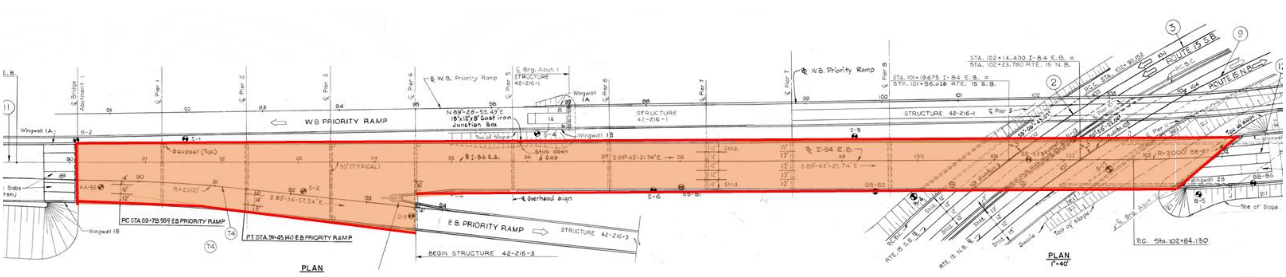
Data Collection on Repaired Beam Ends

- The results showed clear peaks in all strain responses under live load events.
- Prior to repair, the magnitude of web strain under live load was larger while the UHPC and stud strains were zero.



Implementation 2 – East Hartford, CT

- I-84 in East Hartford over RT 15
- Constructed in 1983
- 49 beam-ends repaired
- 12 spans, 1,390 ft
- Simple and continuous spans
- Weathering steel



Implementation 2 – East Hartford, CT

Implementation 2 – Condition of Bridge

- Rated as structurally deficient.
- Section loss extended an average of 7 ft from the end of the girders.
- The height of the deterioration was 4-8 in, localizing the damage to the bases of the webs.
- Interface shear strength was a concern.

Implementation 2 – Contracting

- Design was completed internally by CTDOT Bridge Design Unit
- Unique components in specification for contractor:
  - UHPC shifted to a perfromace-based specification
  - Partial height repair required finishing top surface of UHPC to prevent pooling of water on top of the repair panel
  - Including mockup to practice casting UHPC
  - Providing access for research team for instrumentation

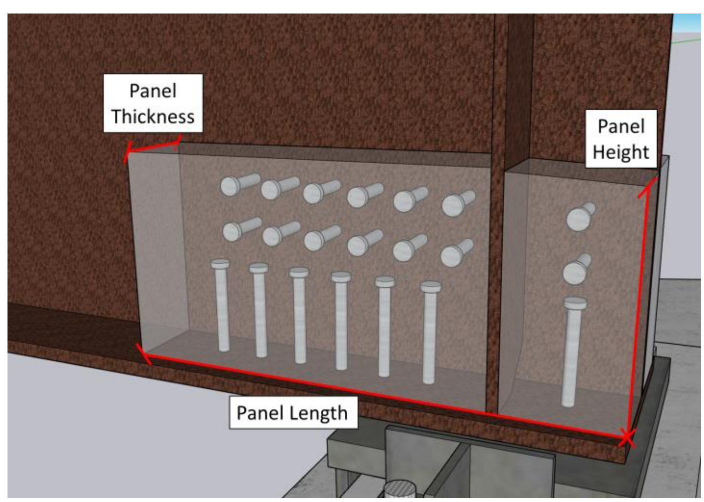
Implementation 2 – Repair Design

- Strength I Load combination was selected
- Studs: 5/8” diameter
- Capacity determined by:

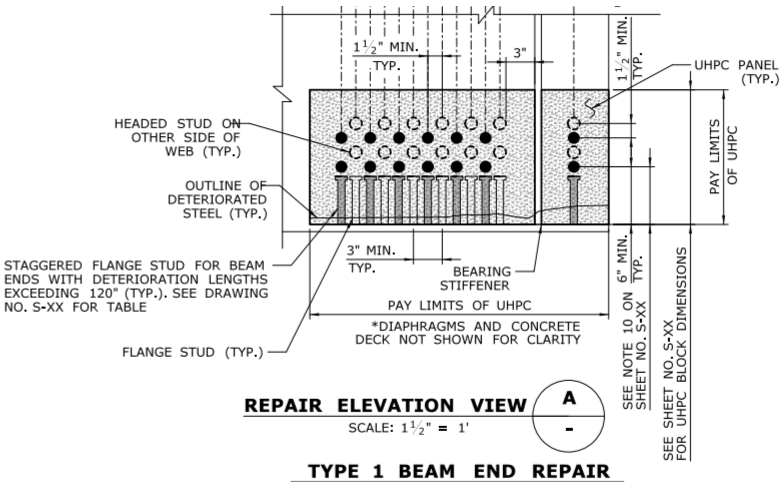
$$P_u = \phi_s P_n$$

$$P_n = 0.7 A_s F_u$$

  - Selected two standard stud layouts
- UHPC
  - CorTuf
  - 2% fibers
  - Minimum 28-day strength: 18 ksi



Implementation 2 – Repair Design



https://portal.ct.gov/DOT/State-Bridge-Design/State-Bridge-Design-Publications

Implementation 2 – Mock-up

Step 3 – Mixing

39

Implementation 2 – Stud Welding

- This repair design was unique in that studs were welded to the bottom flange to carry shear between the web and bottom flange.

39

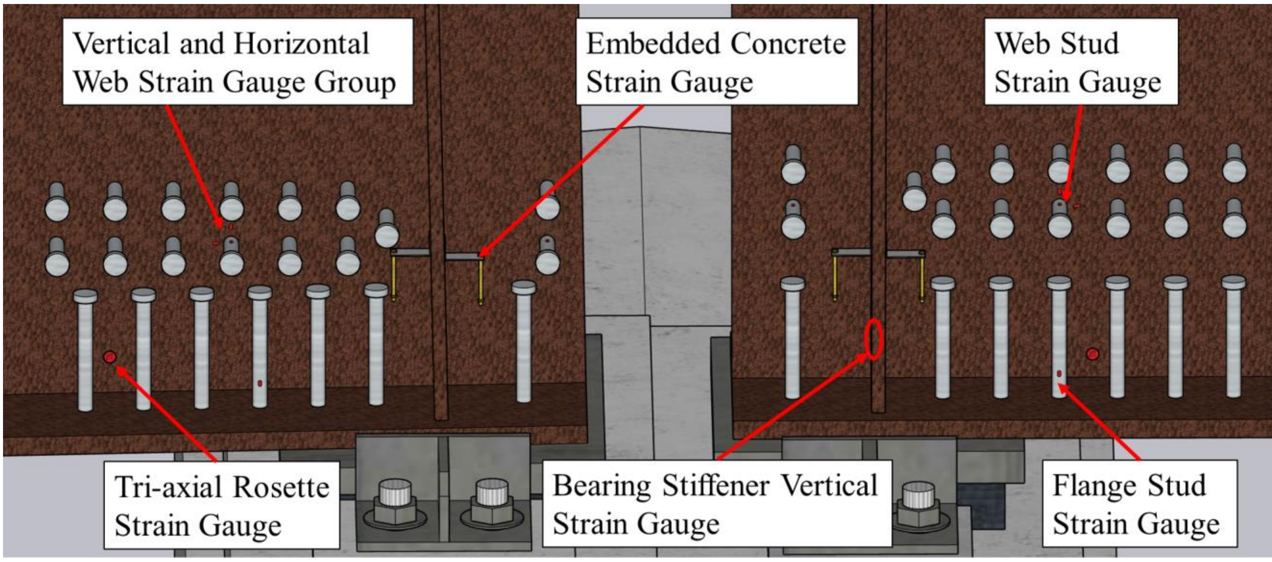
40

Implementation 2 – Monitoring

- Monitoring was based on learnings from previous implementation.
- Captured:
  - Accelerations
  - Temperature during curing
  - Strains on web, studs and in UHPC panels.

40

Implementation 2 – Monitoring



41

Implementation 2 – Forming

42

43

Implementation 2 – Forming

43

44

Implementation 2 – Mixing

44

45

Implementation 2 – Casting

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46

Implementation 1 – Cured Beam Ends

46

Data Collection on Repaired Beam Ends

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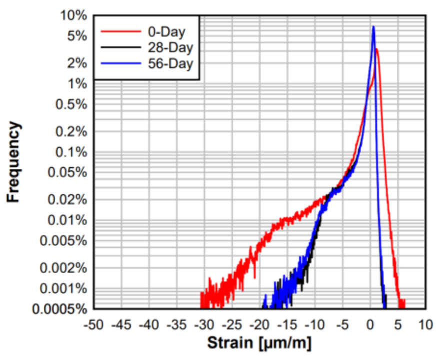

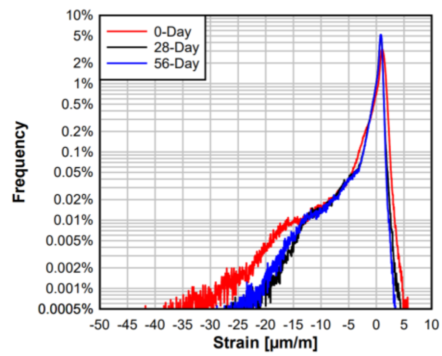

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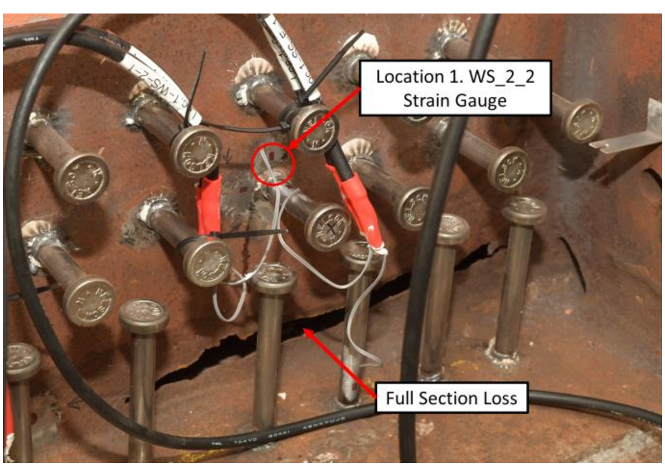

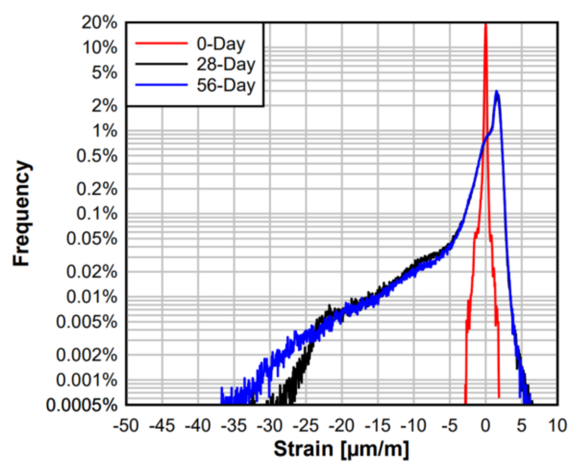

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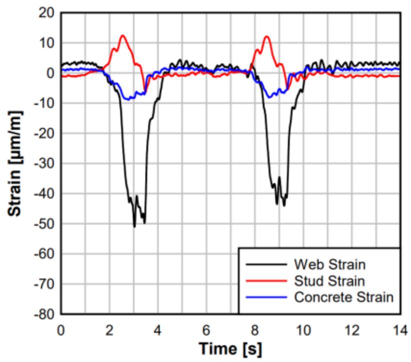
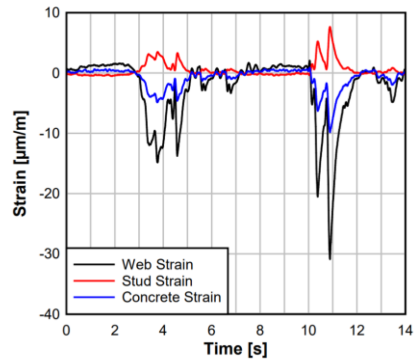
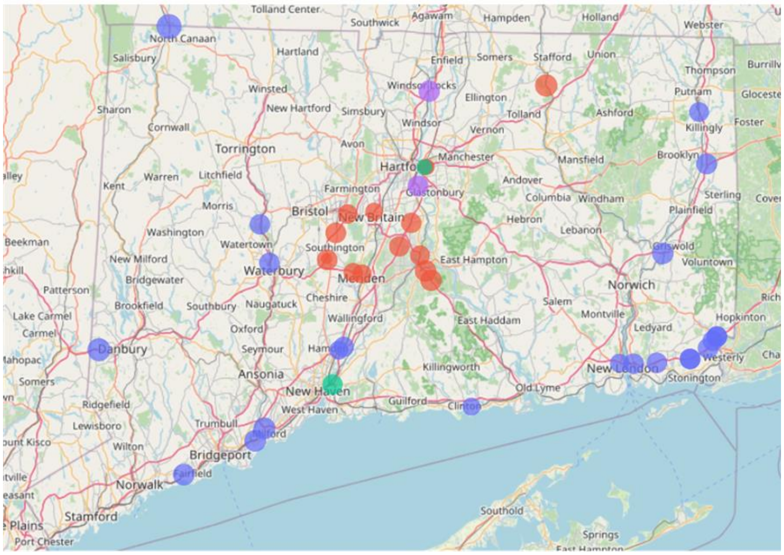




Key Lessons Learned

- A novel repair procedure for corroded steel beam ends using UHPC was developed and researched over the past 10 years.
- The involvement of the research team during design and construction ensured a smooth transition from research to practice.
- Crucial aspects of implementation include cleaning the area where the studs are to be welded, using the proper ferrules, and the inclusion of a mockup.
- It is critical that the owner, contractor, and inspector understand the structural performance of repair and material specific properties for UHPC prior to implementation.
- The two repairs used different designs, UHPC mixes, and casting procedures showcasing the flexibility of the repair.

Expanded Use in CT



- Design 22
- Construction 13
- Completed 2
- Strengthening 2

Available Design Tools

- The repair guideline and sample drawings can be found on the CTDOT website:

https://portal.ct.gov/DOT/State-Bridge-Design/State-Bridge-Design-Publications

- EDC-6 Materials:

https://www.fhwa.dot.gov/innovation/everydaycounts/edc_6/uhpc_bridge_preservation.cfm

- YouTube video summarizing New Haven Repair:

https://www.youtube.com/watch?v=wIU9CgIlTmI

53

Acknowledgements

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53

Thanks!
Questions?

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54