Beam End Repair with Ultra-High Performance Concrete Webinar

February 17, 2023

10:30 a.m. EST

Zoom Meeting Platform User Information

- Participants are currently muted
- Question and Answer Session will follow presentations
- Use Chat function to ask questions or raise your hand to be unmuted
- The meeting is being recorded and the recording will be shared on the AII website

AASHTO
Innovation Initiative

Agenda

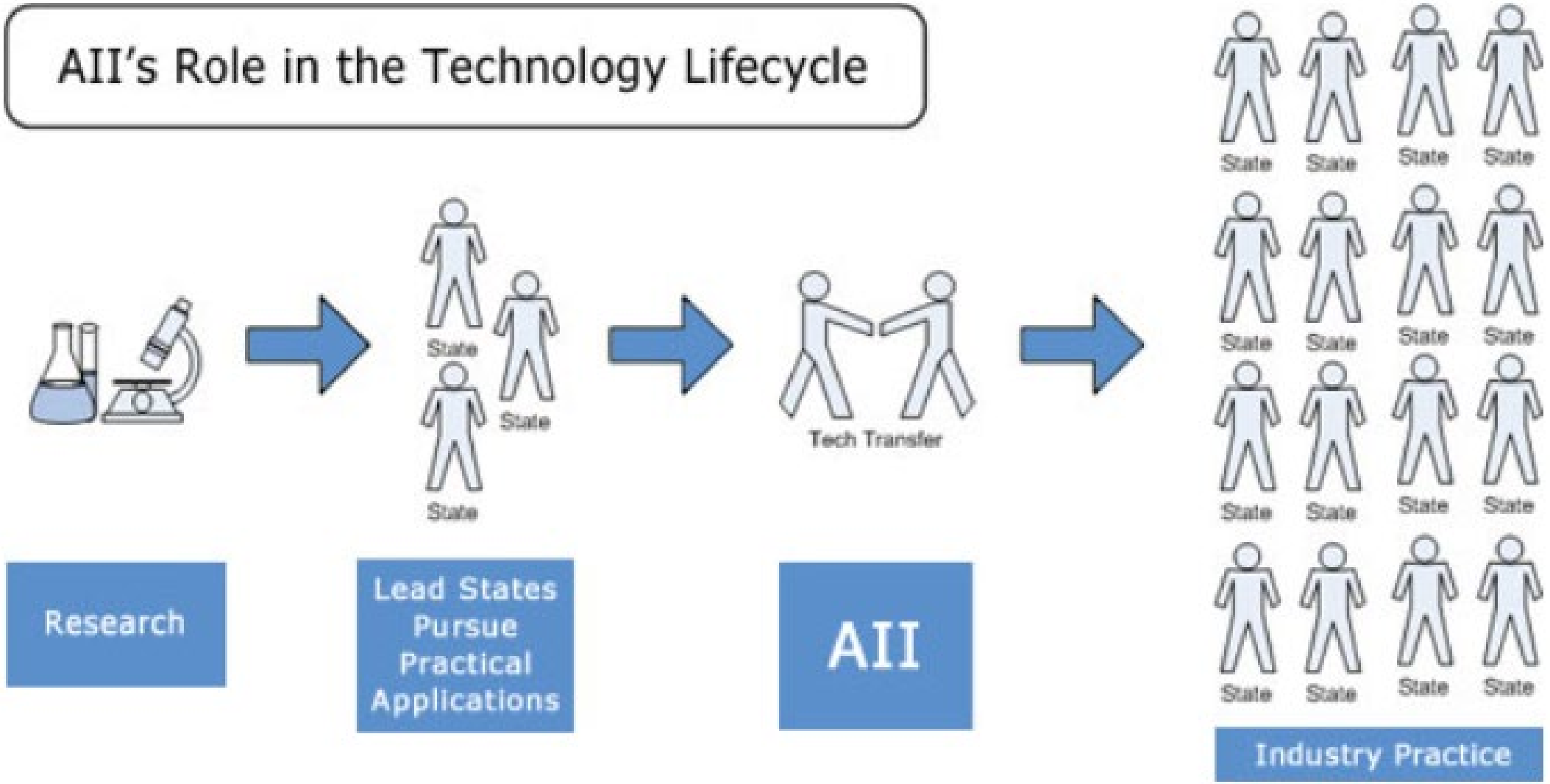
1. AII Program Overview
2. Beam End Repair with UHPC: An Introduction
3. Connecticut DOT's Implementation Experience
4. New York State DOT's Implementation Experience
5. Texas DOT's Implementation Experience
6. Questions and Answers

All about All – *The AASHTO Innovation Initiative*

- AASHTO's Technical Services Program
- Established in 1999 & Operating since 2000
- Previously called the *Technology Implementation Group (TIG)*
- Facilitate the implementation of **high-payoff**, **ready-to-use**, **innovative technologies**

Support the implementation of 100+ technologies since 2001

AII's Role in the Technology Lifecycle



Current Active Focus Technologies

- Beam End Repair Using UHPC
- Steel Press-Brake-Formed Tub Girder
- On-Demand Microtransit
- Improved Project Delivery with GIS & Surveying
- Laser Ablation Coating Removal
- Wrong Way Driving
- Electrically Conductive Concrete Heated Pavement System

Newly Selected Technologies

- Natural Hazard Risk Management
- Strides 2 Zero
- Freight Operations eXchange
- Plow Blade Installer Cart
- Sawcut Vertical Curb
- Hydrogen Fuel Cell Technology as Emergency Power
- ADA Data Collection System

Bridge Related Innovations

- Steel Press-Brake-Formed Tub Girder
- Beam End Repair Using UHPC
- Natural Hazard Risk Management
- Laser Ablation Coating Removal
- Carbon Fiber Reinforced Polymer Strands

Beam End Repair using UHPC

Beam End Repair Using Ultra-High Performance Concrete

Per the ASCE 2021 Infrastructure Report Card, nearly 42 percent of the nation's 600,000 plus bridges are at least 50 years old, and 7.5% of them are rated as structurally deficient. Faced with the growing backlog of bridge repair needs amidst chronic funding shortages, highway agencies are continually exploring innovative maintenance techniques to cost-effectively extend of the life of bridges. With approximately one-third of the nation's 600,000 plus bridges being made of steel, agencies are expending nearly $8.3 billion annually to address corrosion damage in steel bridges through various preservation and repair strategies. The structural repair of steel beam ends is one of them.

The conventional repair techniques for steel bridge beam ends entail the following: lifting of bridge members through jacking, installation of temporary supports, removal of the damaged beam sections, and welding with new steel. The conventional techniques are typically labor-intensive, costly, and time consuming, and furthermore, require lane closures for bridge repair, and frequent maintenance as the new steel continue to be susceptible to corrosion damage.

A new method for repairing deteriorated steel beam ends is to use Ultra-High Performance Concrete (UHPC) as a way to restore structural capacity lost through corrosion. The repair technique involves welding shear studs to the intact portions of the web plate and encasing the beam end with UHPC. This technique creates an alternate load path for bearing forces to bypass the corroded portion of the beam.

UHPC offers a cost effective and structurally efficient alternative to conventional techniques providing structural redundancy, superior mechanical and durability characteristics to protect against future deterioration. In addition, the significant versatility of UHPC allows it to be used on any geometry and deterioration level while expediting the time of repair and minimizing disruption caused by bridge closures to the traveling public.

Resources

- NYSDOT UHPC Beam End Repair Example Details
- NYSDOT UHPC Material Specification
- CTDOT UHPC Beam End Repair Design Guidelines
- CTDOT Typical Details of UHPC Beam End Repair - Partial Height Schematics
- CTDOT Typical Details of UHPC Beam End Repair - Partial Height

aii.transportation.org

Today's Speakers



Bartholomew Sweeney, Andrew Cardinali, Bao Chuong
Connecticut DOT

Jim Scarlata
New York DOT

Tom Fan
Texas DOT

Participant Poll #1

Beam End Repair Using UHPC
An Introduction

Bartholomew Sweeney, P.E.

Andrew Cardinali, P.E.

Bao Chuong, P.E.

Connecticut DOT

Background

- 59% of Connecticut bridges are 50 years or older, fourth highest rate in the nation.
- 1800+ single-span steel bridges and numerous simply supported multi span bridges
- Challenge of maintaining an aging infrastructure
- ConnDOT must develop strategies to extend the life and reduce the cost of repairs that will otherwise place great burden on the State's budget

Typical Steel Deterioration

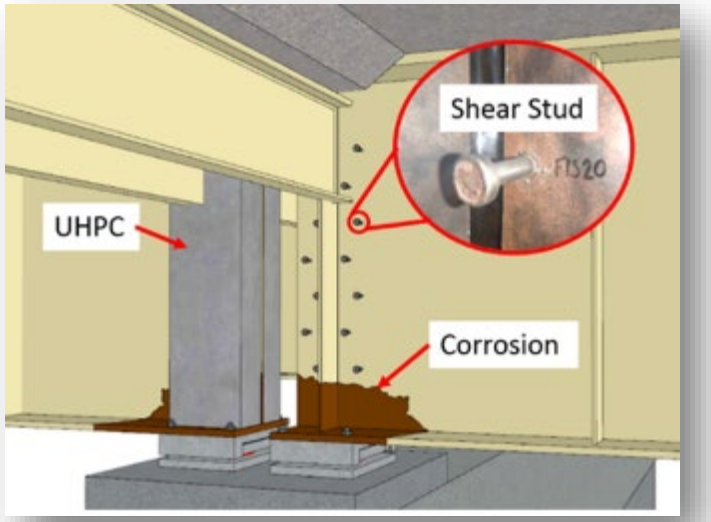
Conventional Repair Method

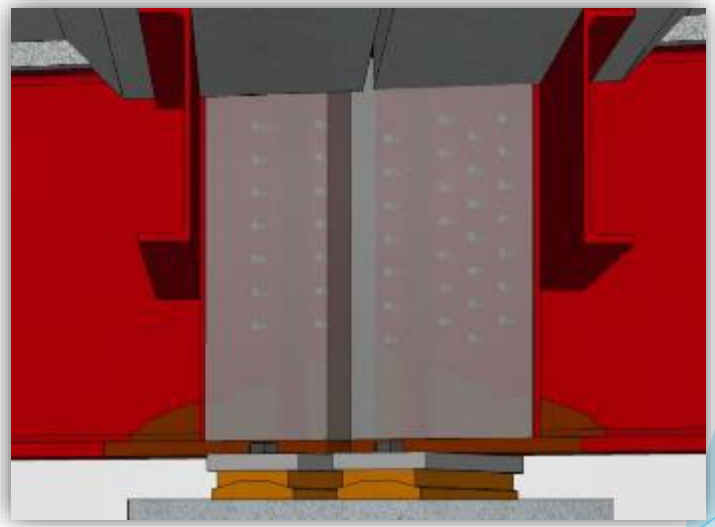
- Conventional repair method using new steel plates is still susceptible to future corrosion.
- Jacking is sometimes required to minimize in-situ member stress:
  - Costly
  - Disruptive to traffic
- Surface Preparation: extensive surface prep and lead paint removal may be required

UHPC Beam End Repair Concept

- Welding shear studs to un-corroded sections of steel web plate

- Encase repair regions in Ultra-High Performance Concrete





- Provide alternate load path for bearing forces through composite action

Research Project

PHASE 1: “Repair of Steel Beam/Girder Ends with UHPC”

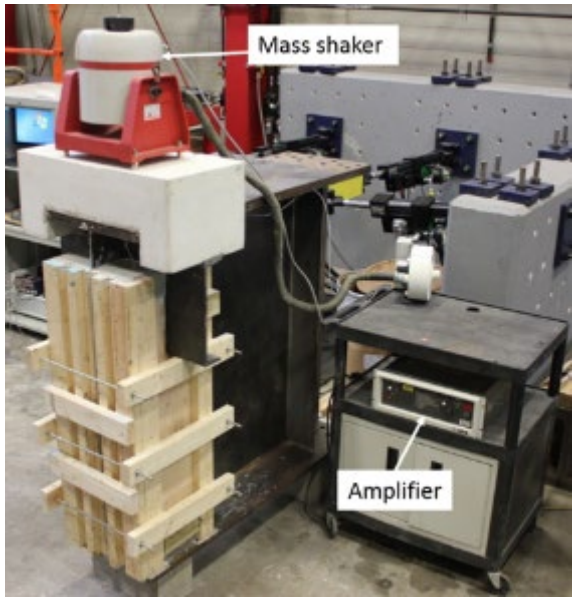
- Started in 2013
- CTDOT Partnered with UConn
- Conceptual

Research Project

PHASE 2 (SPR-2295): “Repair of Steel Beam/Girder Ends with UHPC – Phase 2”

1. Full-Scale Testing of Plate Girder

2. Simulation of Vibration due to vehicle traffic during repair



Research Project

PHASE 2 (SPR-2295): “Repair of Steel Beam/Girder Ends with UHPC – Phase 2”

Research Findings

- Bearing forces were successfully transferred from steel web to the UHPC repair

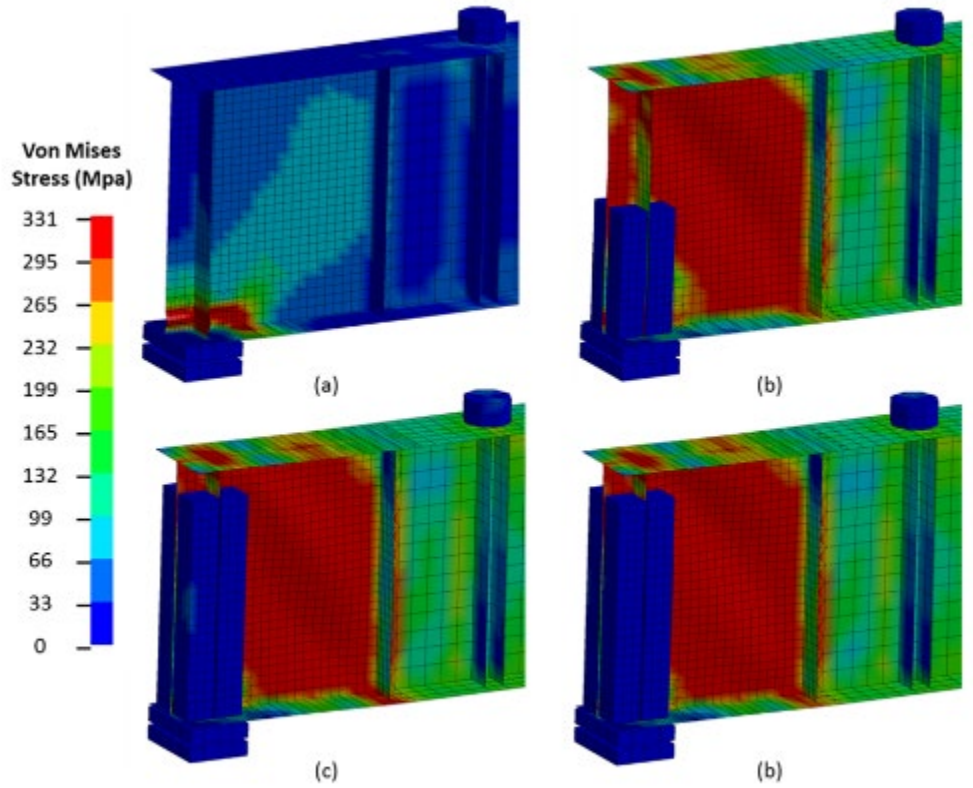


Figure 5.24: Von Mises stress contours and deformed shape for the analytical plate girder models: a) Baseline; b) Half Height; c) Full Height 1; d) Full Height 2

UCONN
SCHOOL OF ENGINEERING

Research - Benefits

- Durability of repair
- Low Maintenance
- No Jacking is needed

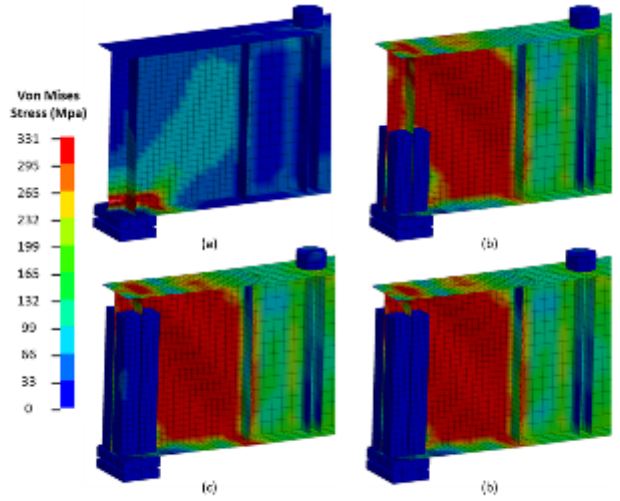


Figure 5.24: Von Mises stress contours and deformed shape for the analytical plate girder models: a) Baseline; b) Half Height; c) Full Height 1; d) Full Height 2

- Minimize disturbance to travelling public
- Surface preparation: UHPC repair requires minimal surface preparation (Power-Tool Cleaning SSPC-SP15)
- More versatile for complex geometries

Research Conclusions

- Capacity of repaired girder exceeded design capacity of undamaged girder by over 30%.
- UHPC repair significantly reduces force demand and strain accumulation on damaged portions of web and stiffeners
- Vibration induced on girders during curing has negligible effect
- Pilot Projects
  - Project 092-675
  - Project 42-325

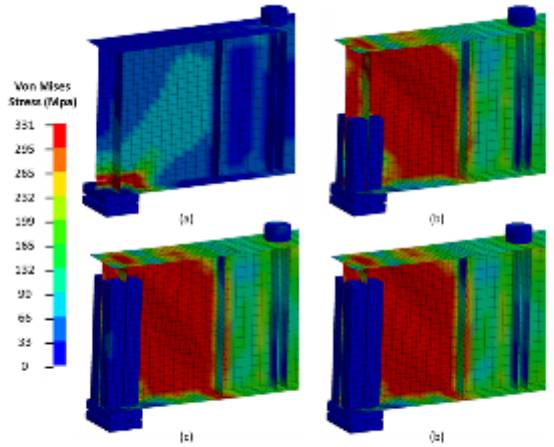


Figure 5.24: Von Mises stress contours and deformed shape for the analytical plate girder models: a) Baseline; b) Half Height; c) Full Height 1; d) Full Height 2

UHPC Beam End Projects following research findings:

Project 92-675

Rehabilitation of Bridge No. 03094, Carrying I-91 over Amtrak Railroad, New Haven.

Awarded: 1/2019 ($4.9M)

Const complete: 9/2020

Project 42-325

I-84 EB over RT-15SB, East Hartford

Awarded: 5/2021 ($4.3M)

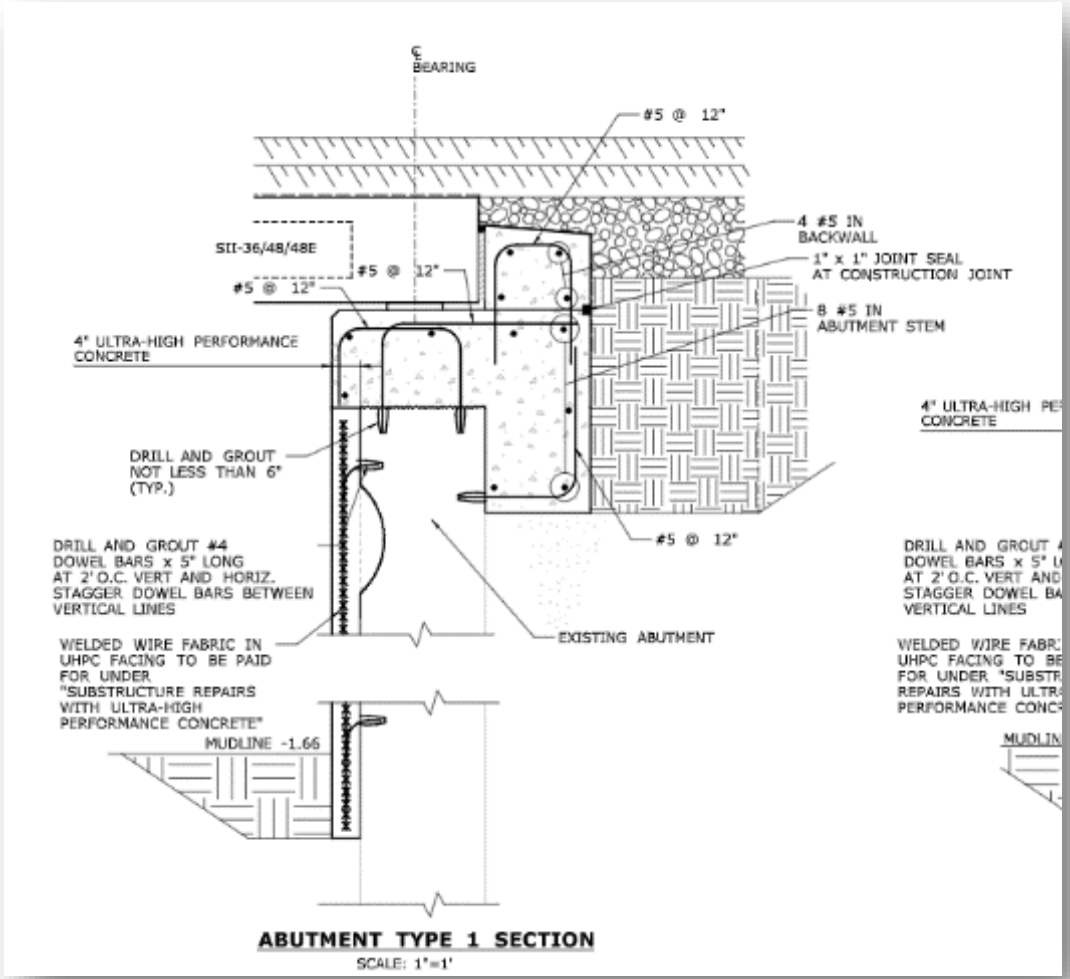
Const complete: 10/2022

Other Projects Using UHPC Solutions

Substructure Rehabilitation

- Project No. 113-107
- Existing Condition:

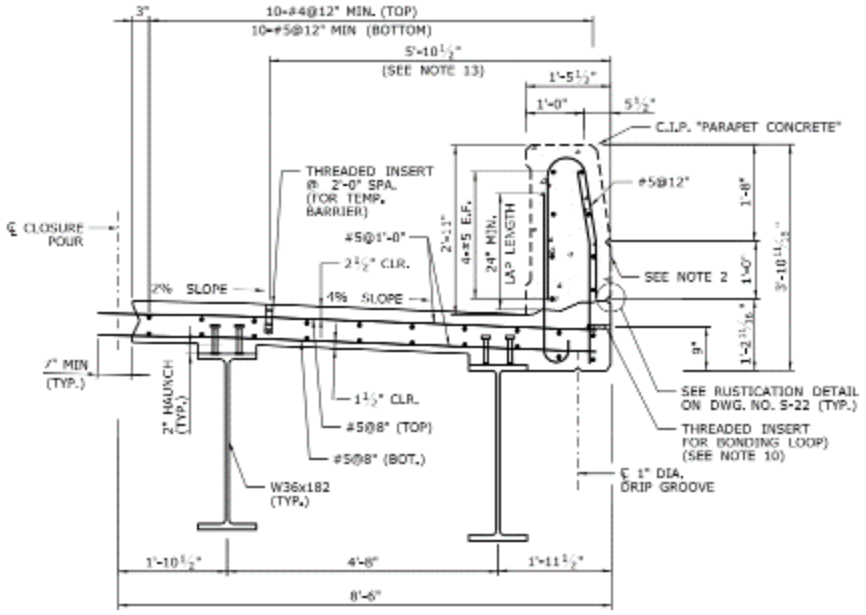
Typical Abutment Section



Finished Structure

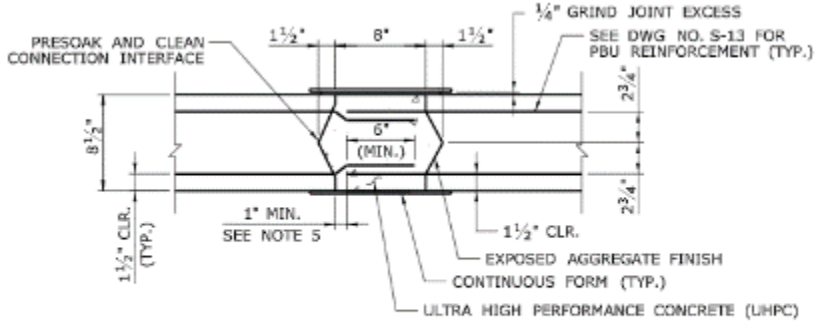
Precast Beam Connections

Project 58-336
Prefabricated Beam Unit (PBU) Closure Pours



EXTERIOR MODULE E REINFORCING DETAIL

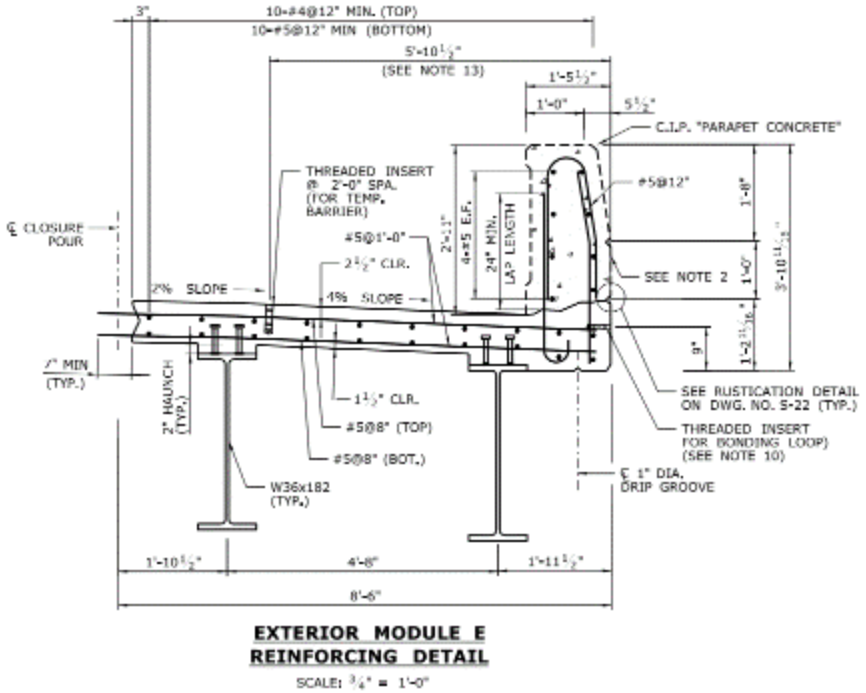
SCALE: ¾" = 1'-0"



LONGITUDINAL CLOSURE POUR DETAIL

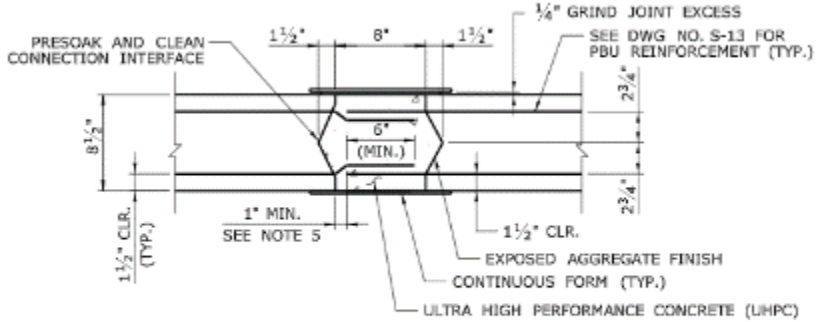
SCALE: 1½" = 1'-0"

Prefabricated Beam Unit (PBU) Closure Pours



EXTERIOR MODULE E REINFORCING DETAIL

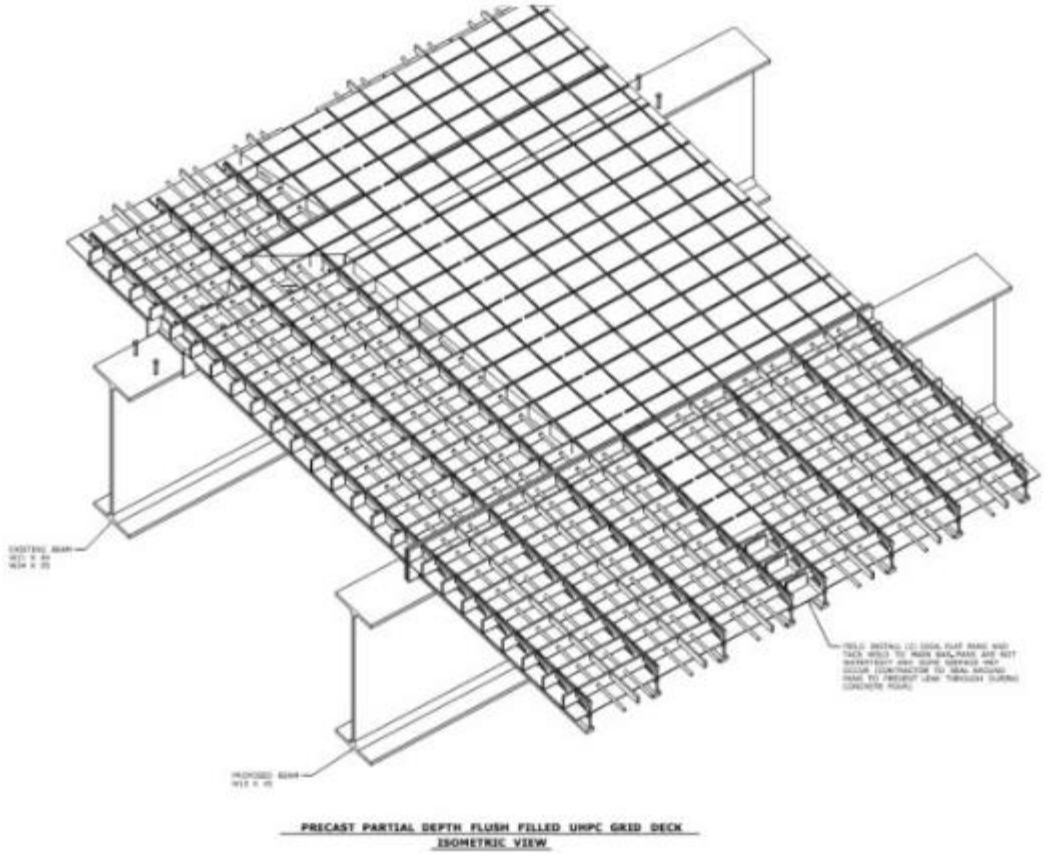
SCALE: ¾" = 1'-0"



LONGITUDINAL CLOSURE POUR DETAIL

SCALE: 1½" = 1'-0"

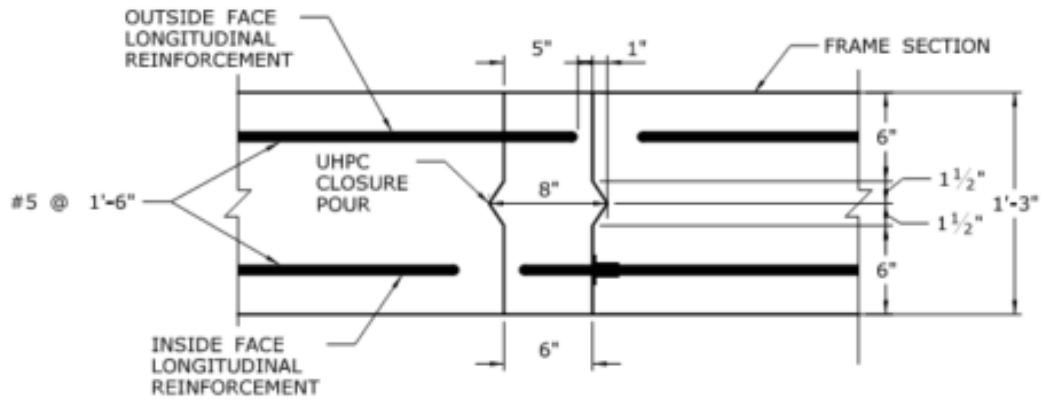
Half Filled Grid Deck Bridge 00327
US Route 1 over Housatonic River



- Project No. 083-267

Three-Sided Frame Closure Pours

Three-Sided Frame Connections



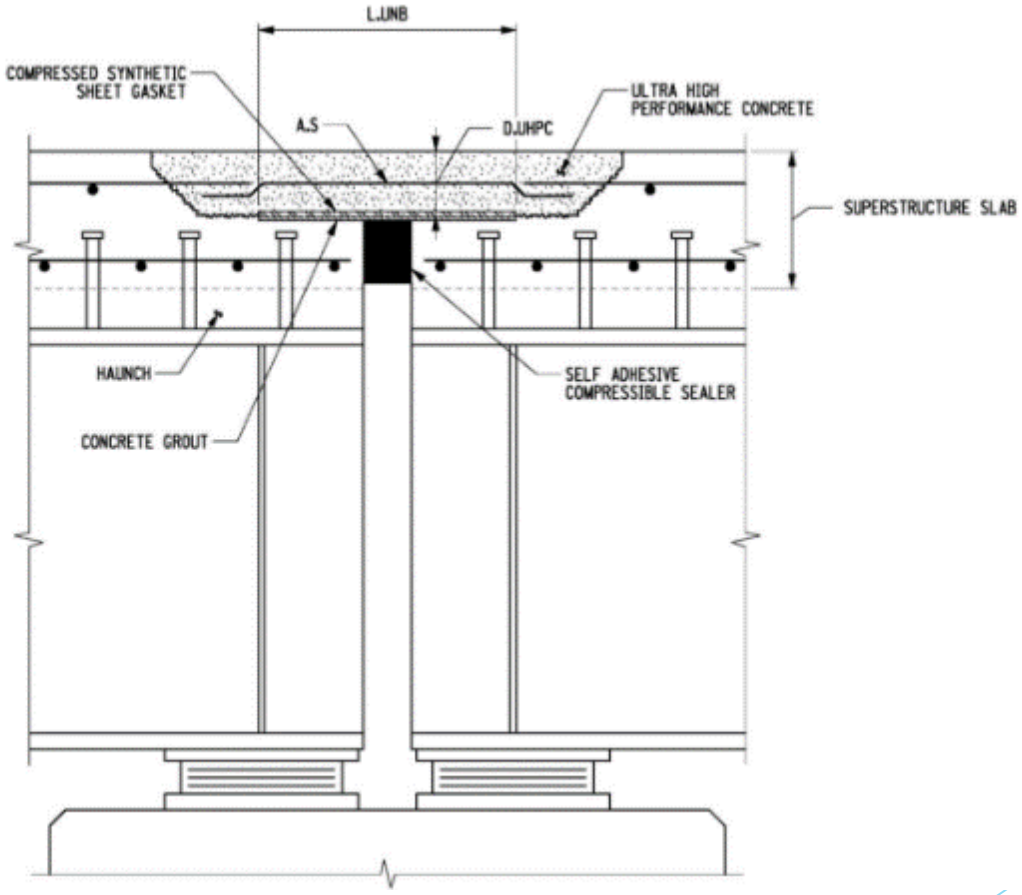
UHPC CLOSURE POUR BLOCKOUT - LEGS

TOP SLAB AND LEGS UHPC BLOCKOUT A

SCALE: 1½" = 1'-0" -

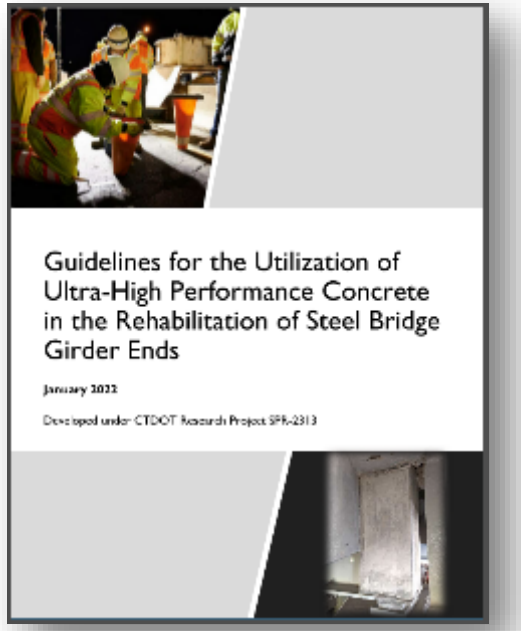
UHPC Link Slabs

- Project No. 171-484:



Institutionalized Implementation for UHPC

- Standard details
- Design Guide
- Design Calculation Template
- Bridge Design webpage



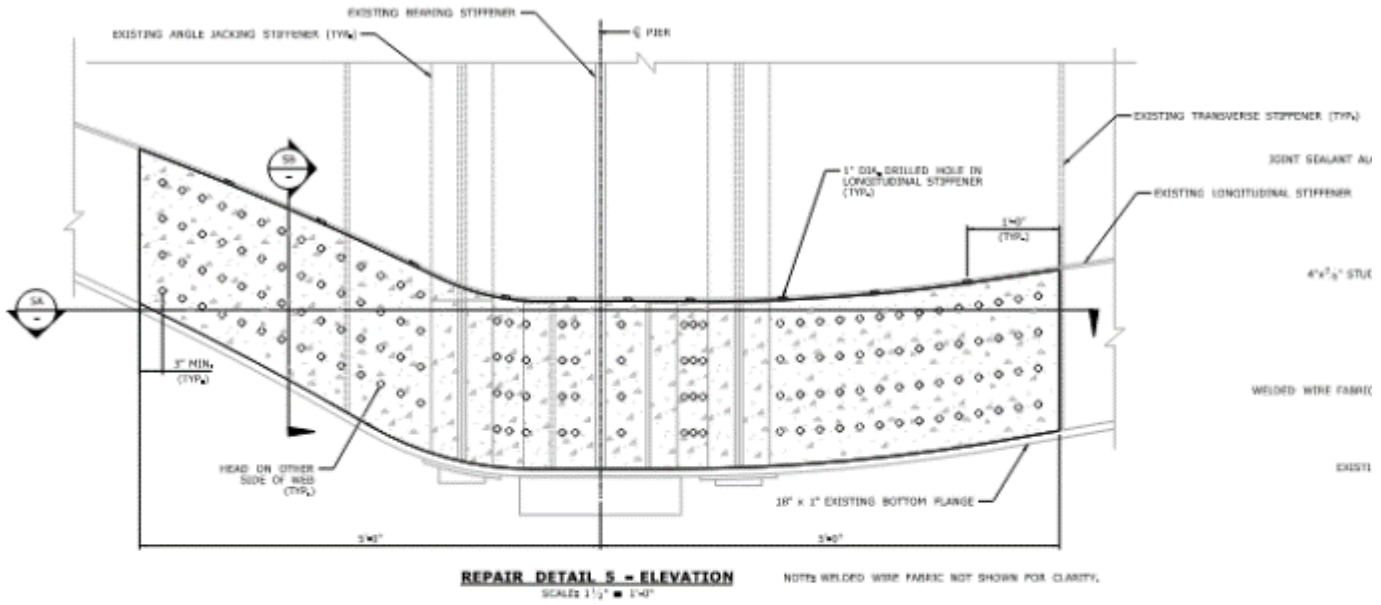
https://portal.ct.gov/DOT/State-Bridge-Design/State-Bridge-Design-Publications

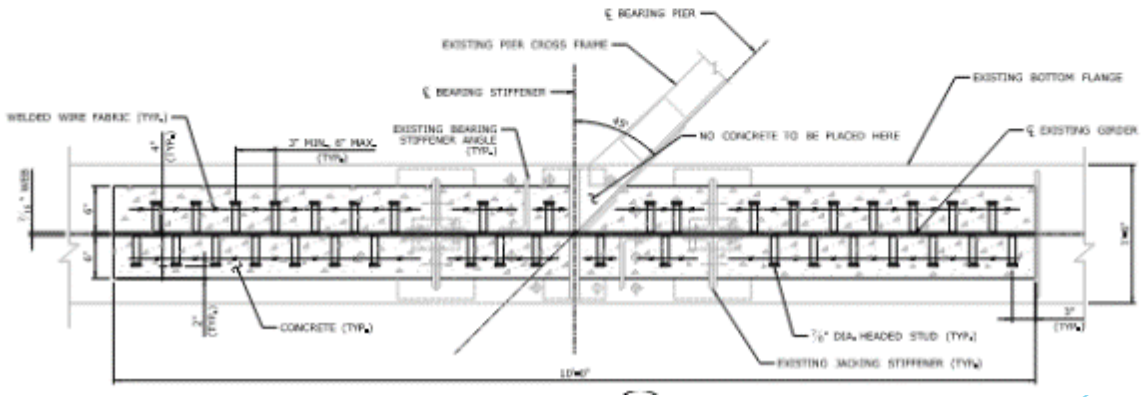
Bridge (Beam End) Bundling

- UHPC bridge bundles- CT has initiated an annual UHPC beam end repair program as part of the Bipartisan Infrastructure Law (BIL).
- Recently awarded (12/2022) a bridge bundle project with 16 Bridges using the UHPC Beam end repair methodology
- UHPC material cost trend 
- Contractors are getting accustomed to repair methodology
- CTDOT intends to continue advertising annual UHPC beam end bridge bundles. Annual programs for FFY23-FFY26 estimated at $36 Million/year.

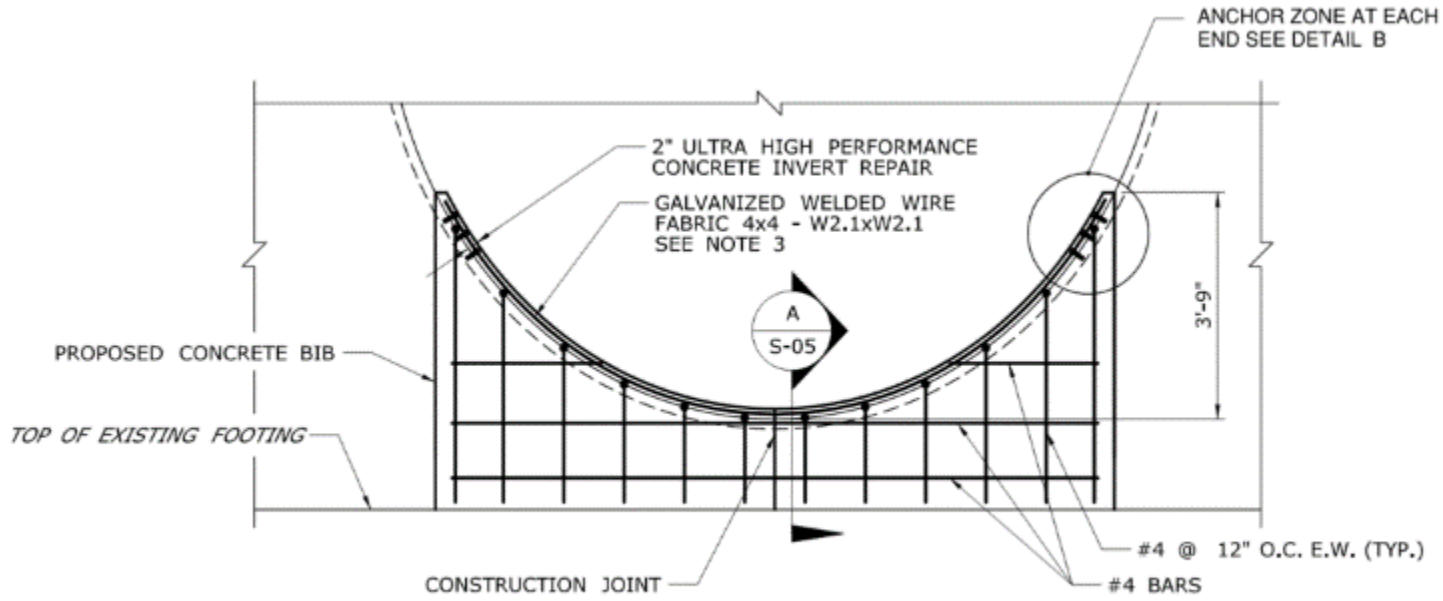
Future Uses of UHPC

Compression Flange Strengthening





UHPC Invert Lining



INVERT REPAIR DETAIL

SCALE: ½" = 1'-0"

Participant Poll #2

Beam End Repair Using UHPC
Connecticut DOT's Implementation Experience

Andrew Cardinali, P.E. and Bao Chuong, P.E.

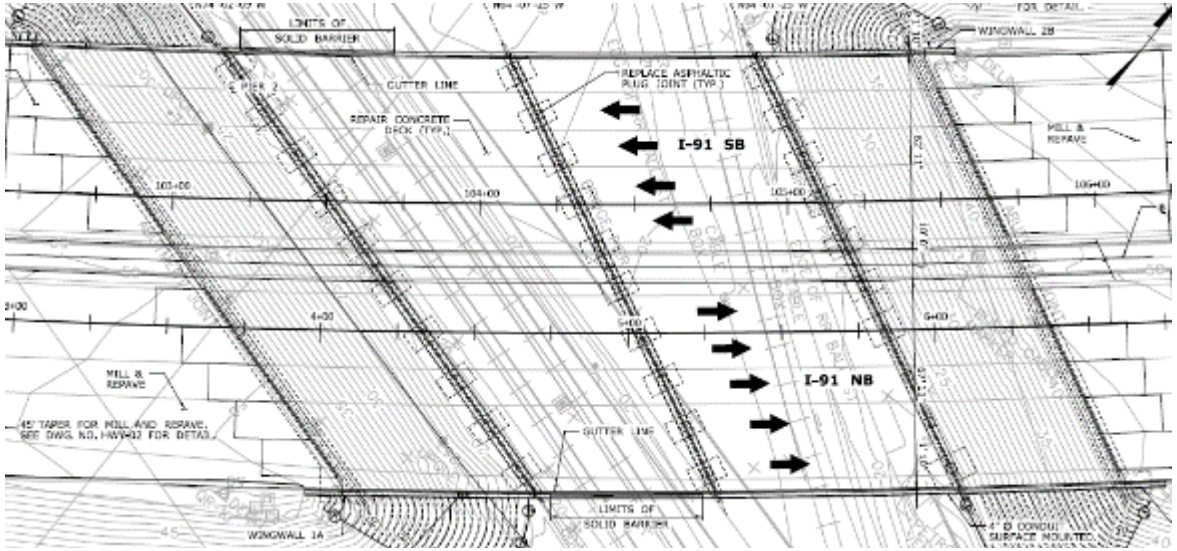
Project 92-675

Rehabilitation of Bridge No. 03094, Carrying I-91 over Amtrak Railroad, New Haven.

Project 92-675

Design Challenges for the Project

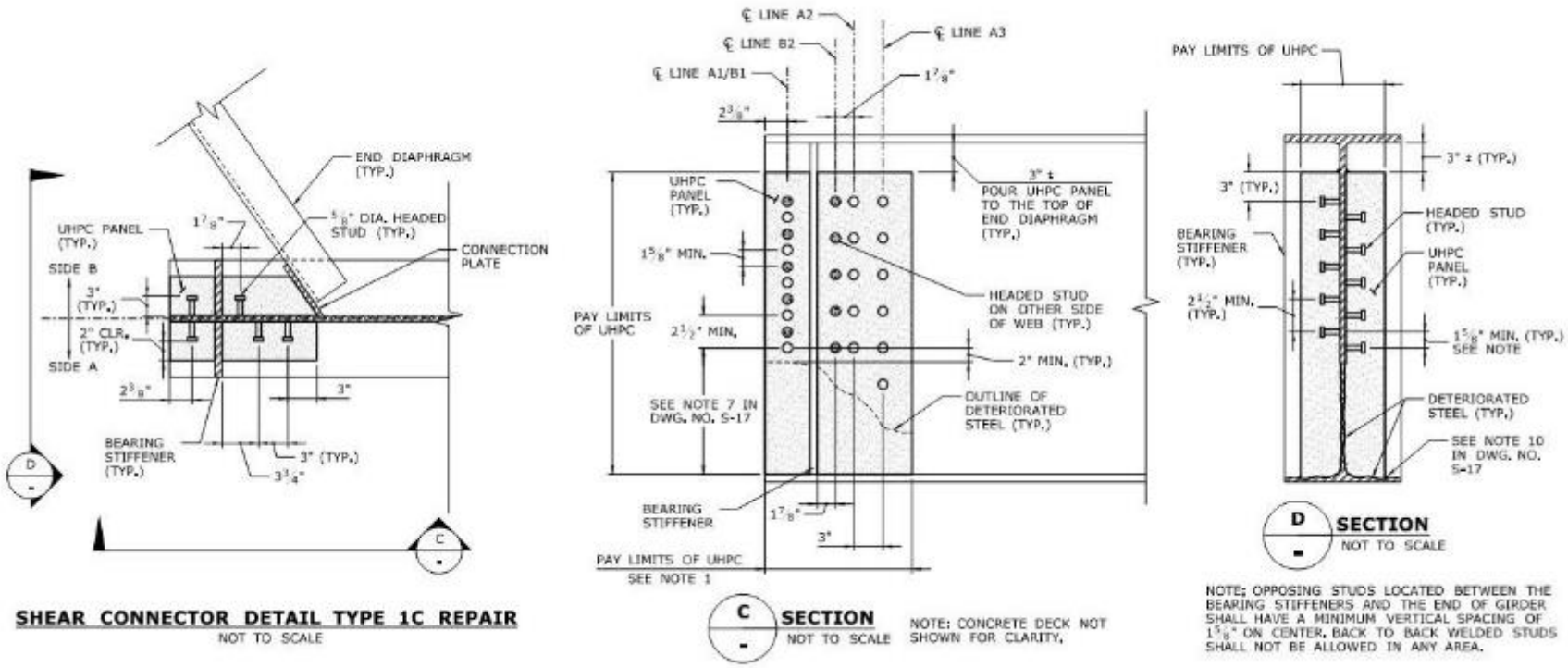
1. Complex geometry due to varying skew (25.9° and 35.9°)
2. Diversity of beam end details
3. Severity of corrosion damage
4. ADT, 67,000 vehicles/day in one direction
5. Limited access due to RR



Existing Steel Deterioration




UHPC Repair Details



SHEAR CONNECTOR DETAIL TYPE 1C REPAIR
NOT TO SCALE

C SECTION
NOT TO SCALE

NOTE: CONCRETE DECK NOT SHOWN FOR CLARITY.

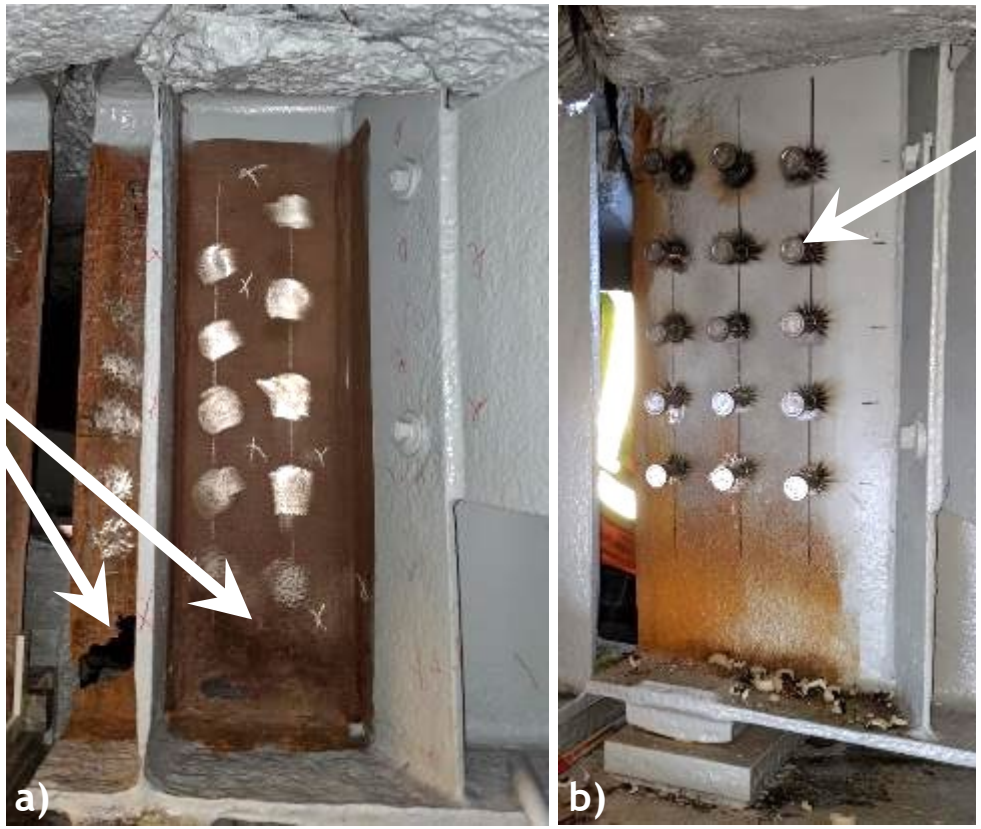
D SECTION
NOT TO SCALE

NOTE: OPPOSING STUDS LOCATED BETWEEN THE BEARING STIFFENERS AND THE END OF GIRDER SHALL HAVE A MINIMUM VERTICAL SPACING OF 1⅝" ON CENTER. BACK TO BACK WELDED STUDS SHALL NOT BE ALLOWED IN ANY AREA.

TYPE 1C BEAM END REPAIR

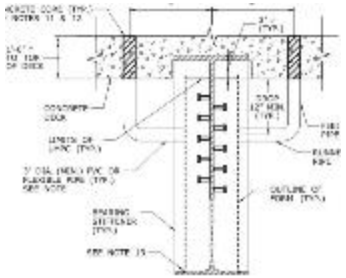
Contractor Mock Up

Repair Progression



Distribution of UHPC

- Core 3” holes through bridge deck
- 3” PVC pipe from bottom of bridge deck to formwork



Mixing and Pouring Operation

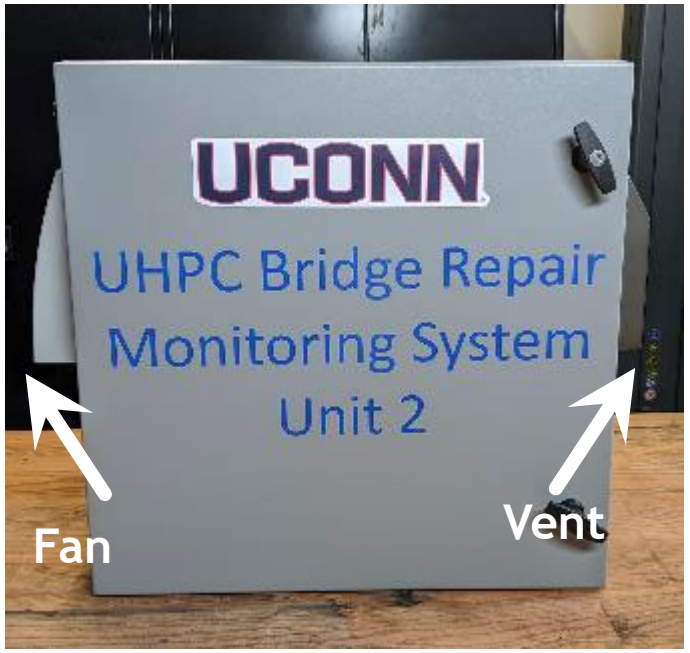
Testing: Performed by Lafarge Holcim

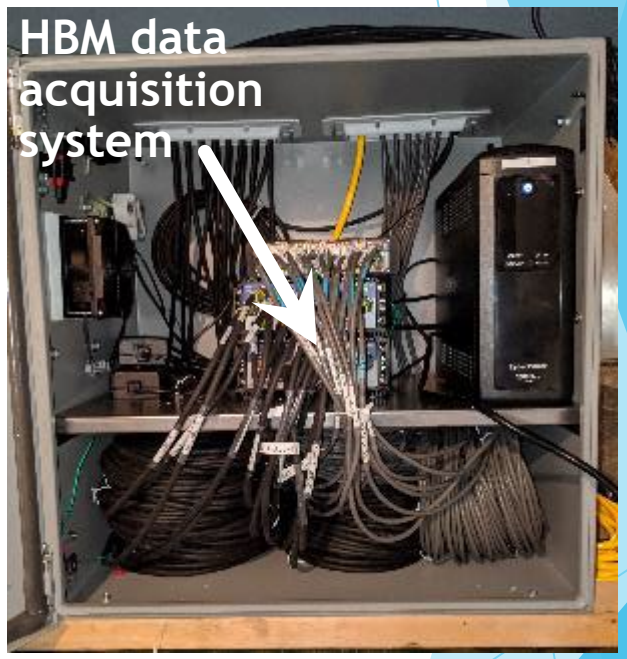
- Mix Temperature – 60 degrees F
- Flow Table – 7 – 10 inches
- Cylinders: 3” x 6” – 4 at 48 Hours, 4 at 7 days, 4 at 28 days, and 4 spare
  - Cylinder breaks to be performed at the CAP Lab at UCONN
  - 28 Day design strength – 18 ksi

Final Product




Post Construction Monitoring System

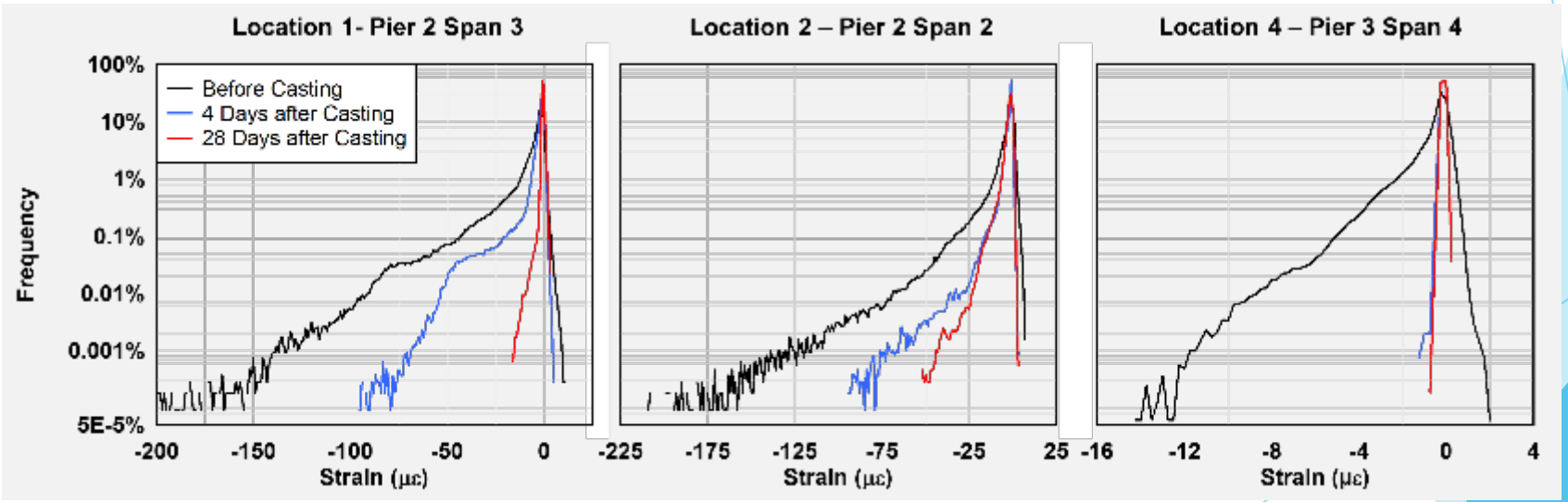




Surge protector and battery backup

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.



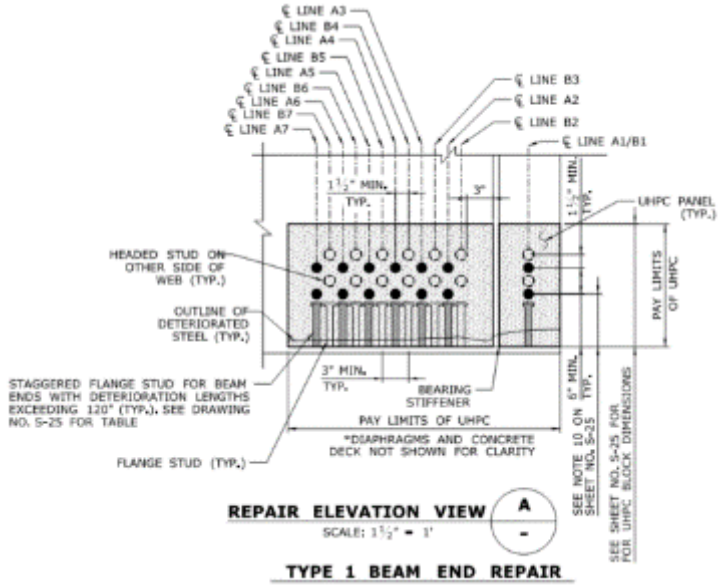
Project 42-325

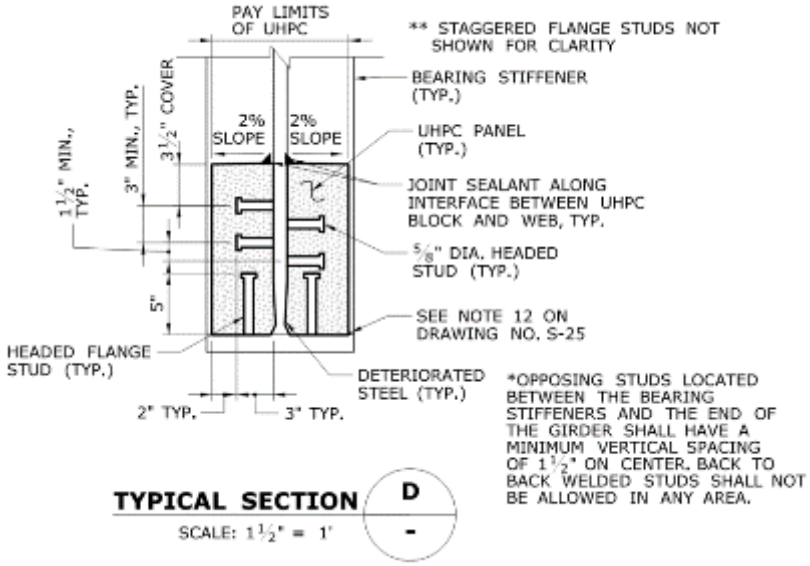
I-84 EB over RT-15SB, East Hartford

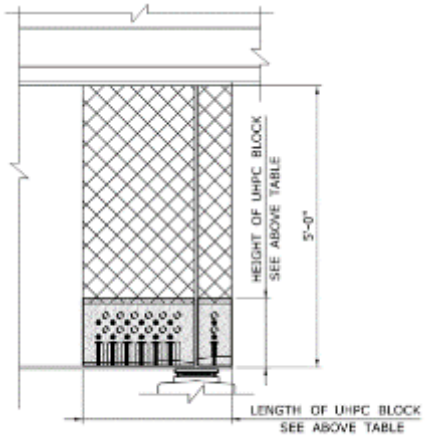
Project 42-325

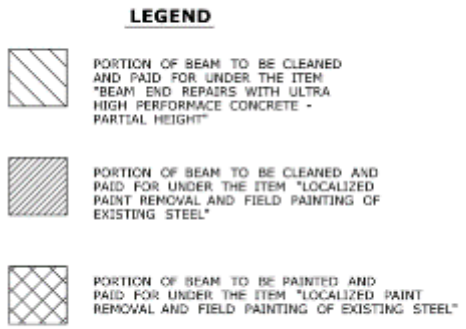
84 EB over RT-15SB, East Hartford

Partial Height Repair









UHPC Casting

UHPC Casting

Repaired UHPC Beam End

Lessons Learned From Two Pilot Projects

- Be flexible with stud layout due to differing site issues
- QC on stud welds is critical, use Stud gun wherever possible
- Contractor pre-bid meeting and mockup was beneficial for pilot project
- Having the Manufacturer representative onsite was crucial
- Critical to have watertight forms and deck core holes
- Skew angle can impact placement of studs and forms
- Consideration needs to be taken with end diaphragm future maintenance
- There was a large amount of UHPC discarded in the distribution pipes for the full height repair

Ultra High Performance Concrete
NYSDOT's Implementation Experience

Jim Scarlata, P.E.

New York State DOT's Experience with UHPC

- 2009 Connections for Prefabricated Bridge Elements

New York State DOT's Experience with UHPC

- 2009 Connections for PBE
- 2013 Link Slabs

New York State DOT's Experience with UHPC

- 2009 Connections for PBE
- 2013 Link Slabs
- 2019 Overlays

New York State DOT's Experience with UHPC

- 2009 Connections for PBE
- 2013 Link Slabs
- 2019 Overlays
- 2022 Beam End Repair

Motivation for Using UHPC Beam End Repair

- Already familiar with UHPC
- Beam end deterioration is a major issue due to heavy usage of deicing agents and leaky joints
- Convention methods of repair can be expensive and still susceptible to corrosion.

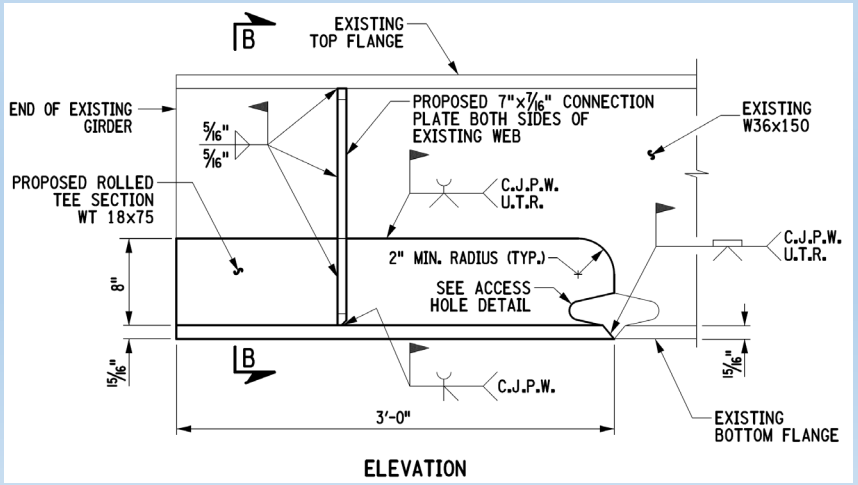
NYSDOT Self-Consolidating UHPC Specification

- Based on internal testing and FHWA recommendations
- Able to be produced by anyone
  - Meet minimum performance characteristics
  - No specific materials required
  - Steel must meet ‘Buy-America’ Requirements
- Currently have four approved suppliers
- Installation drawings required – approved by the Department
- Supplier representative required to be on site

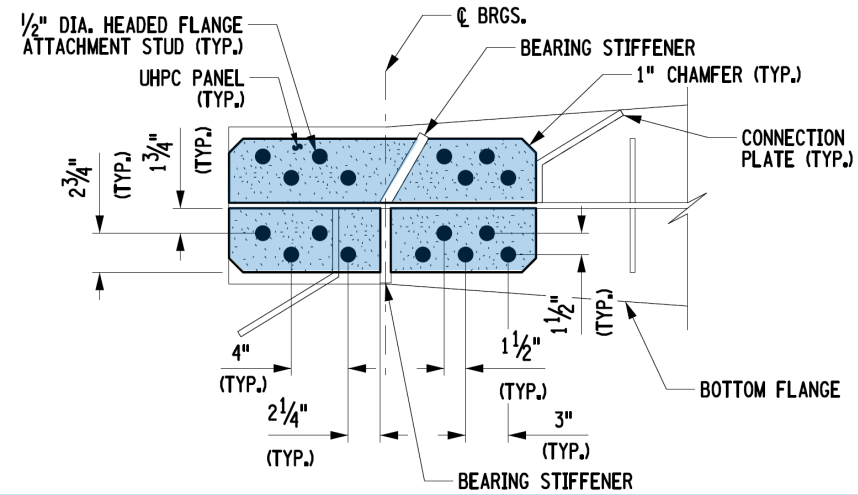
NYSDOT Self-Consolidating UHPC Specification

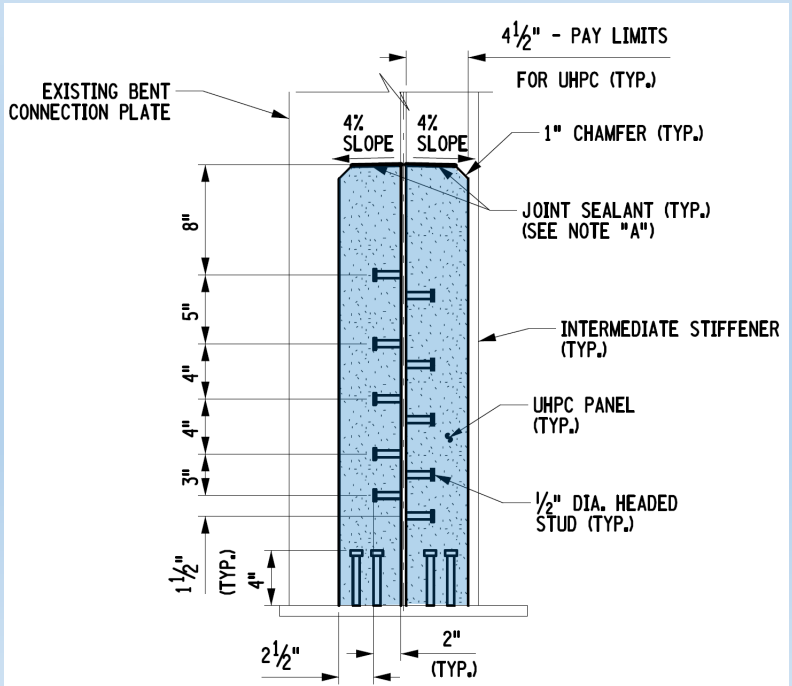
- Maturity testing required for estimating real-time compressive strength
  - Validated with compressive tests
  - Form removal 10 ksi
  - Opening to traffic 12 ksi

Conventional Steel Beam End Repair Solutions



UHPC Beam End Repair Pilot Project





UHPC Beam End Repair Pilot Project

UHPC Beam End Repair Pilot Project

UHPC Beam End Repair Pilot Project

UHPC Beam End Repair Pilot Project

UHPC Beam End Repair Pilot Project

Lessons Learned

- No issues to report!
  - Past experience with UHPC
  - Assistance from Connecticut DOT

Future Plans

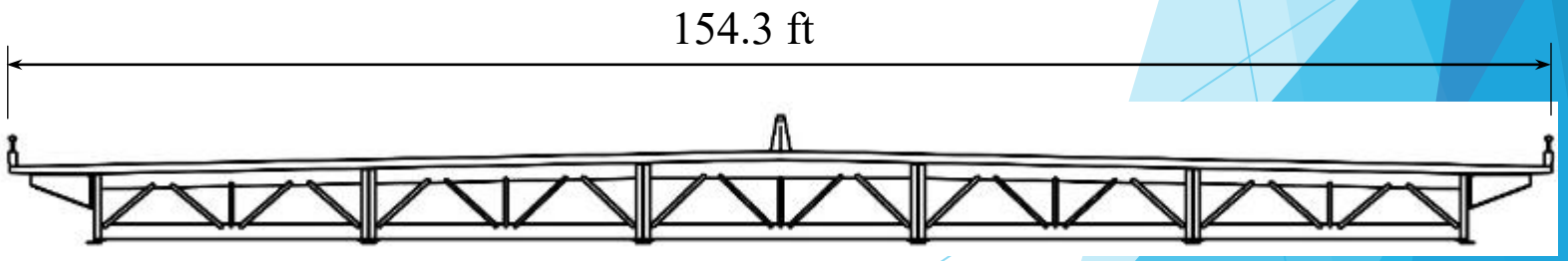
- Being considered on several rehabilitation projects

Beam End Repair Using UHPC
Texas DOT's Implementation Experience

Zhanfei "Tom" Fan, PhD, P.E.

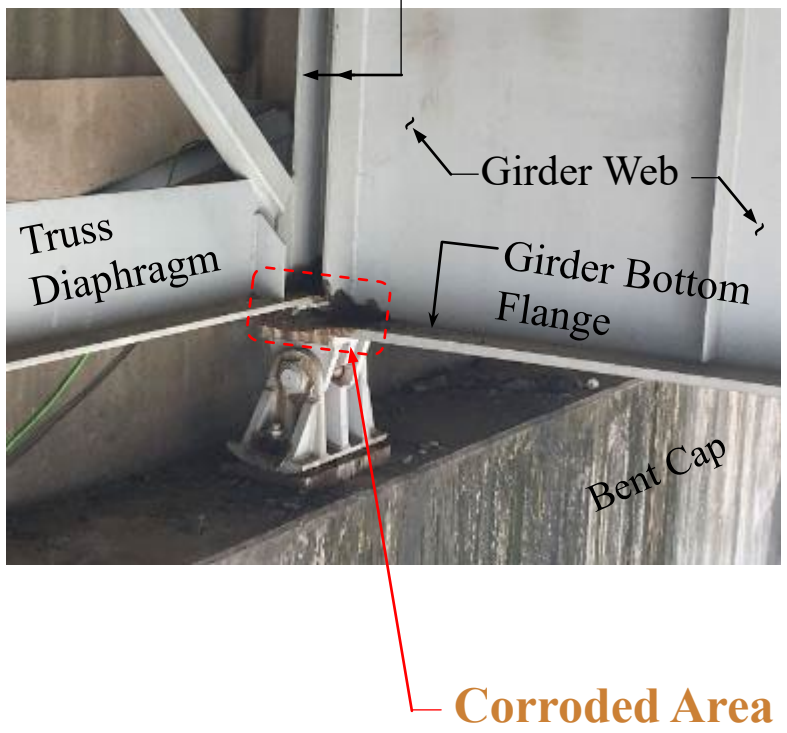
Sidney Sherman Bridge in IH 610 over Houston Ship Channel

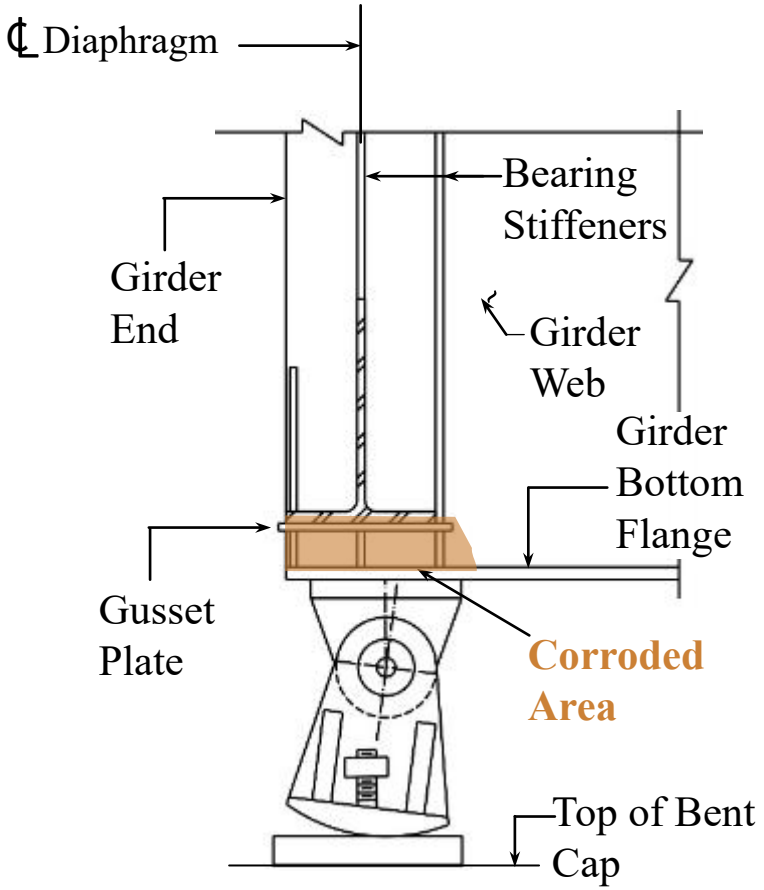
ADT: 165,000 VPD (2019). High Percentage of Truck Traffic



Diaphragm at Bent 45 and Bent 50

Problems: Significant Corrosion Damages to Girders and Diaphragms





Problems: Rocker Bearing Deterioration

Corrosion of Steel Plates and Bolts

Large Rocker Rotation. Base Plate Movement. Anchor Bolt Shear-off.

(The rocker condition was most severe at Bent 45, Girder 6, and moderate at other locations.)

Temporary Repair (December 2018)

Shim Plates Installed

(All Bearings)

Stiffening Plates Welded (At Some Bearings)

At B45G6: Base Plate Extended

Permanent Repair Scope: Rocker Bearings

Urgent Repair--- Bearings at Bent 45:

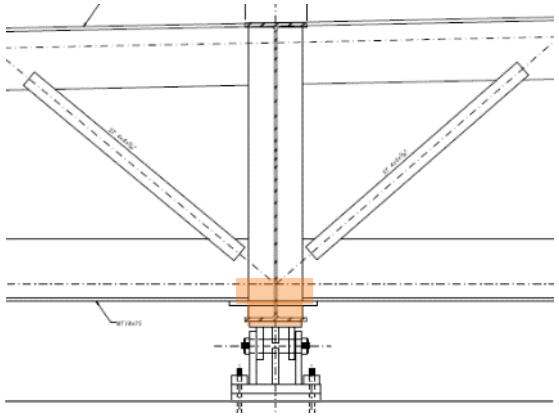
Girder 6 rocker position must be corrected.

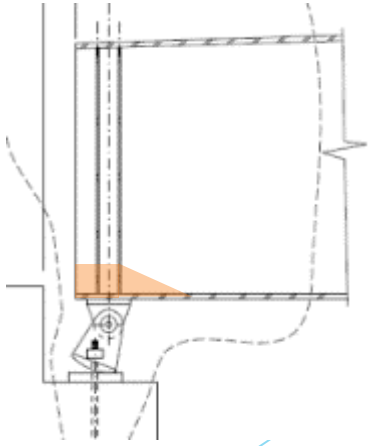
Deteriorated bearing base plates and anchor bolts under 4 girders at Bent 45 must be replaced.

⇨ Girder Jacking Is Needed at Bent 45

Permanent Repair Scope: Girders and Diaphragms

- Repair the corroded and damaged plates to restore the load paths for DL and LL.
- Provide a safe load path for jacking the girders to perform bearing repairs.





- Improve details to minimize future corrosion.

How to Repair Corroded Steel Beams?

Conventional repair method is to *cut* the corroded steel and *replace* with new steel.

Cut-and-Weld for Sidney Sherman Bridge?

Drawbacks:

- *So many* plates and members to be cut and welded in complex geometry and working space.
- Prolonged and widespread lane closure.
- New joints still geometrically complex.

Picture Courtesy of Dr. A. Zaghi, University of Connecticut

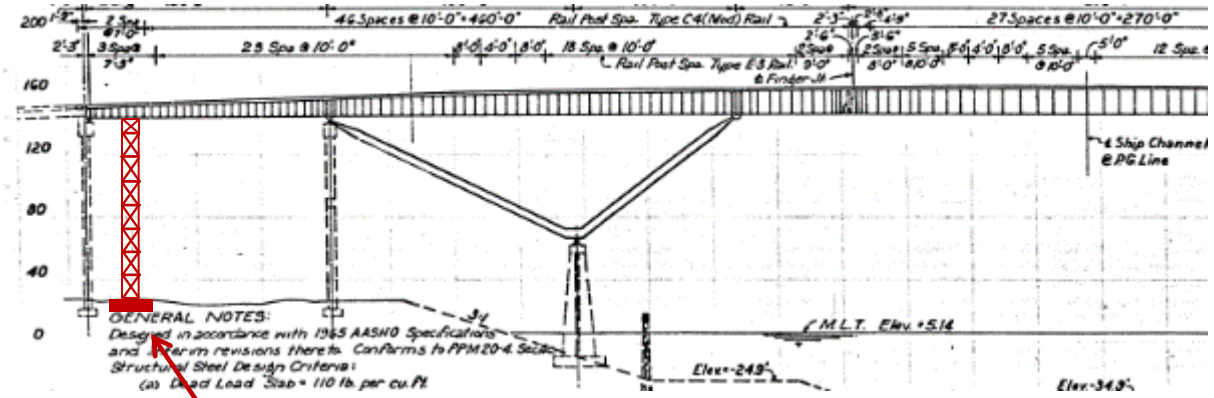
Major Problem:

The structure further weakens during the cut and weld.

➡ The girders need temporary support (jacking) ***before*** joint repair

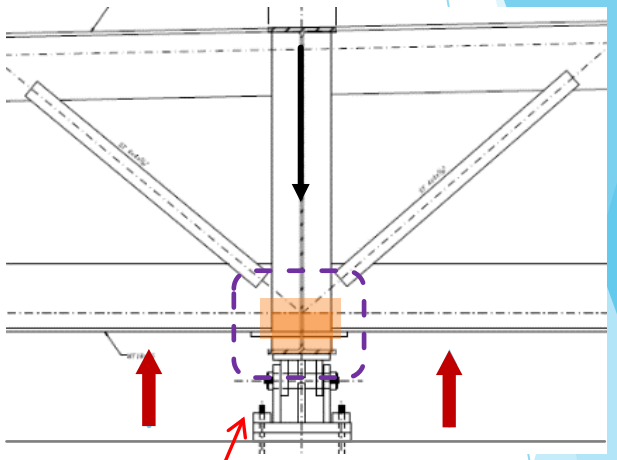
Permanent Repair Plan Development

Jack Directly on Girders from Ground?



- 110+ ft tall
- Railroad underneath
- Weak Girder Webs

Jack thru Diaphragms from Cap?



Jacking must be *AFTER* joint repair.

Risky with weakened joints.

Encasing, Instead of Cutting?

Conventional repair methods were found difficult…. Need to think out-of-box.

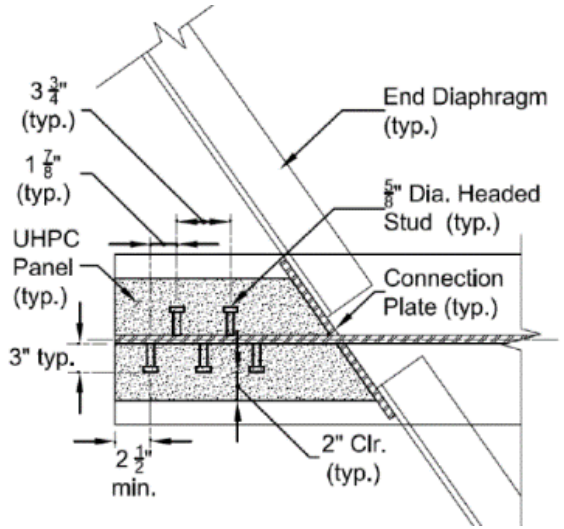
…. *Encasing,* instead of Cutting, would repair the corroded joints without weakening them in the process.

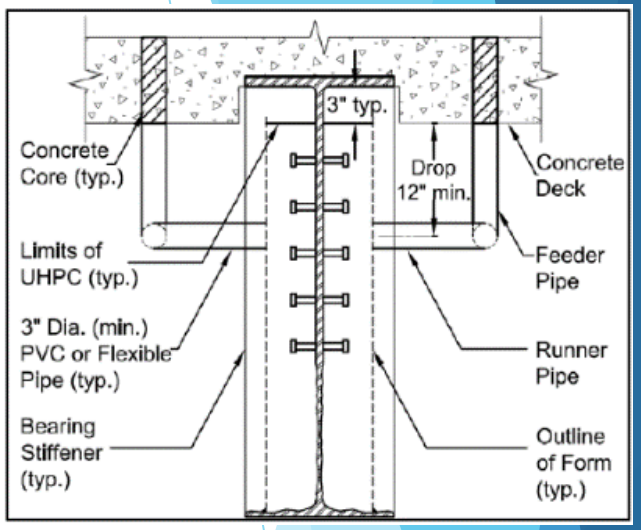
To be a valid idea, the encasing material must possess certain *desired properties*, such as high flowability, high strength, high ductility, etc.

Traditional concrete would be too brittle for this application

UHPC turned out to be an ideal material that possesses the desired properties.

Innovative Permanent Repair Plan Using UHPC





Picture Courtesy of Dr. A. Zaghi, Univ. of Connecticut

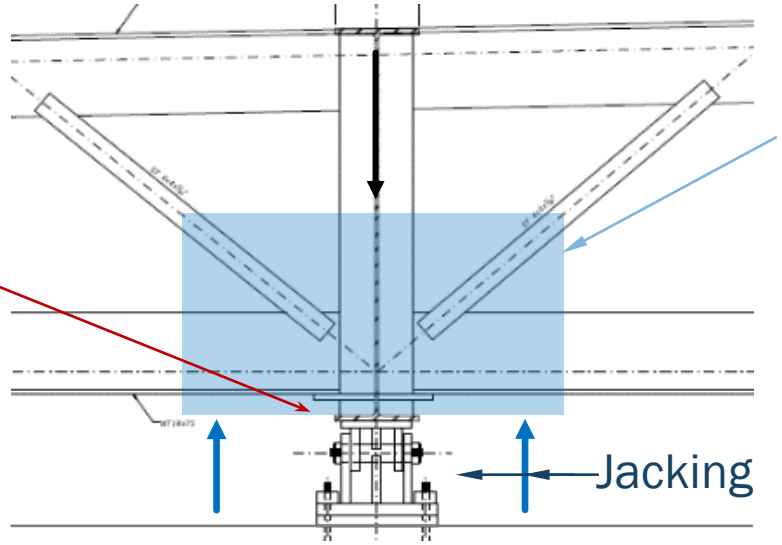
Thank You Connecticut DOT!

We Modified This Idea and Used Wider Encasements.

Jacking is possible through the UHPC encasements !

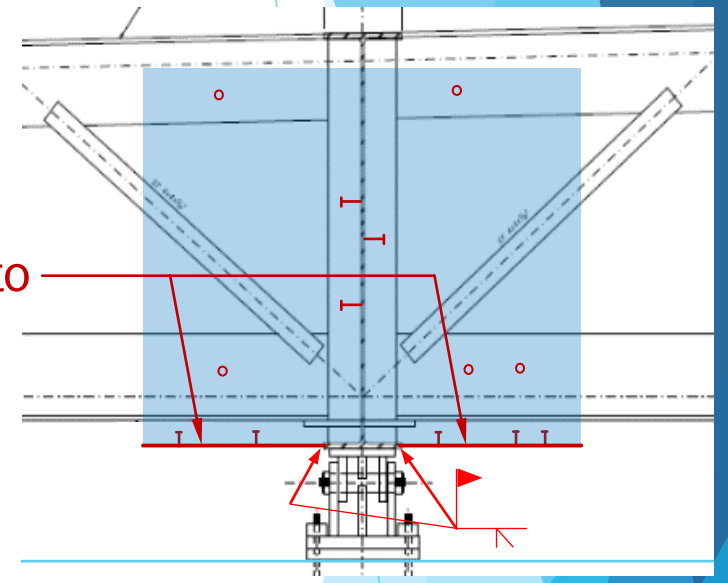
Innovative Permanent Repair Plan Using UHPC

Tensile Jacking Stresses



UHPC Encasement

Weld New Steel Plates to Girder Flanges



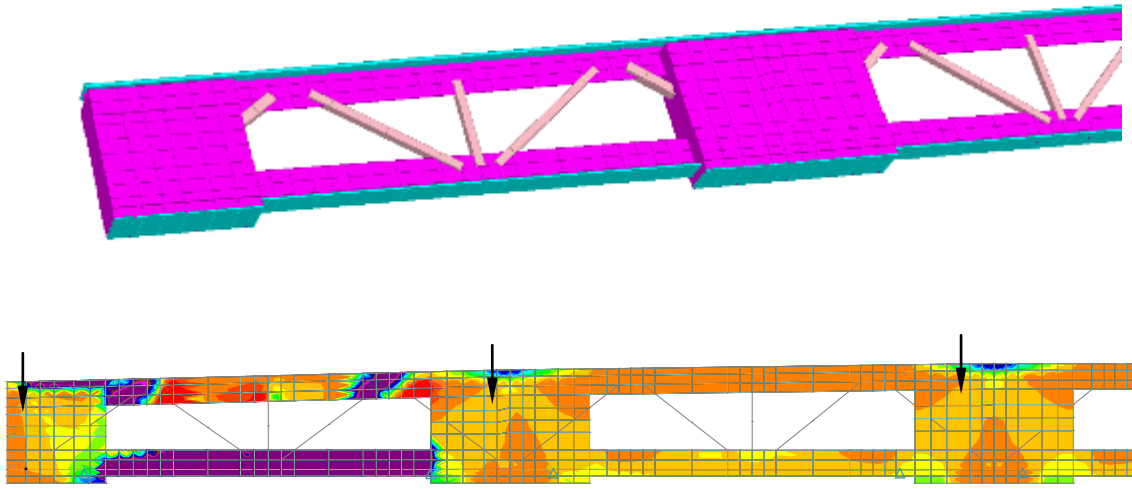
Bonding between steel and UHPC not reliable for resisting jacking stresses

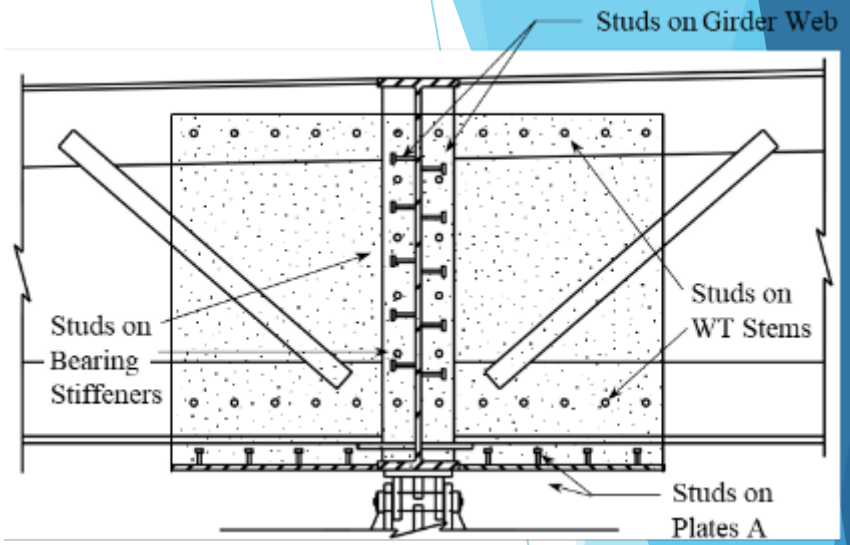
Jacking-induced stresses at the bottom resisted by continuous steel

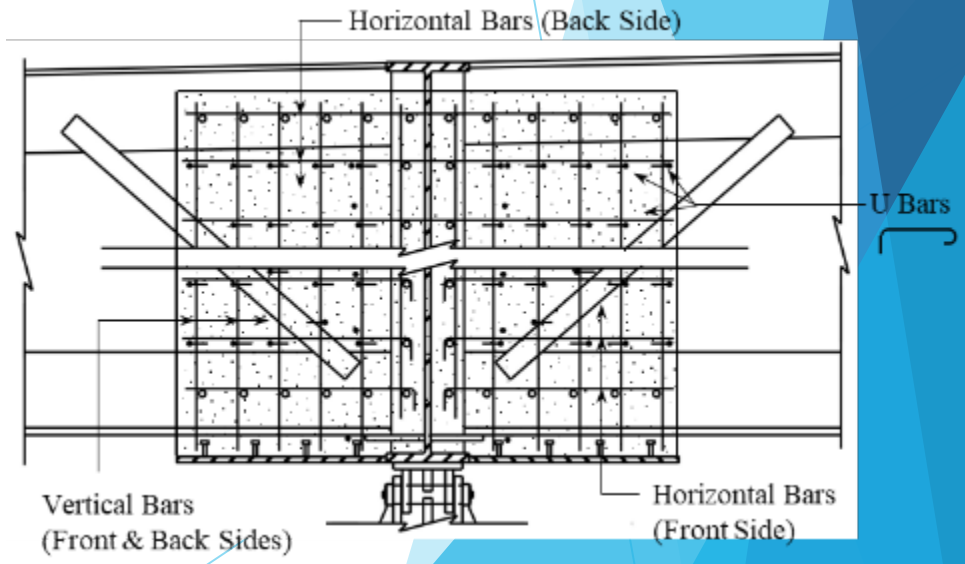
Design Features and Details

The UHPC in this project

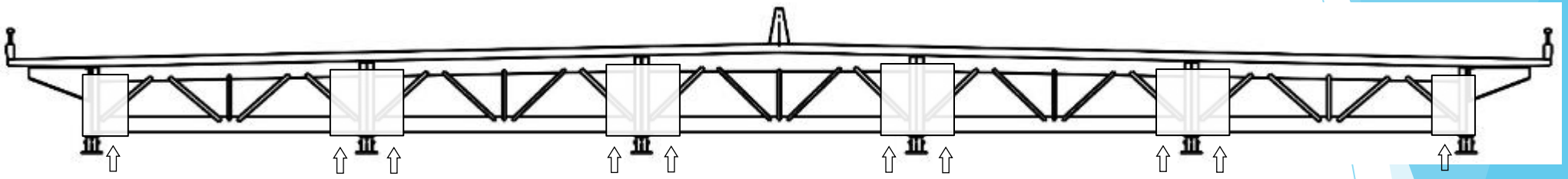
- encases mostly diaphragms, not longitudinal girders.
- encases over mostly trusses, not continuous webs.
- is subject to jacking load as its greatest load.







UHPC Encasement Solution: Many Benefits



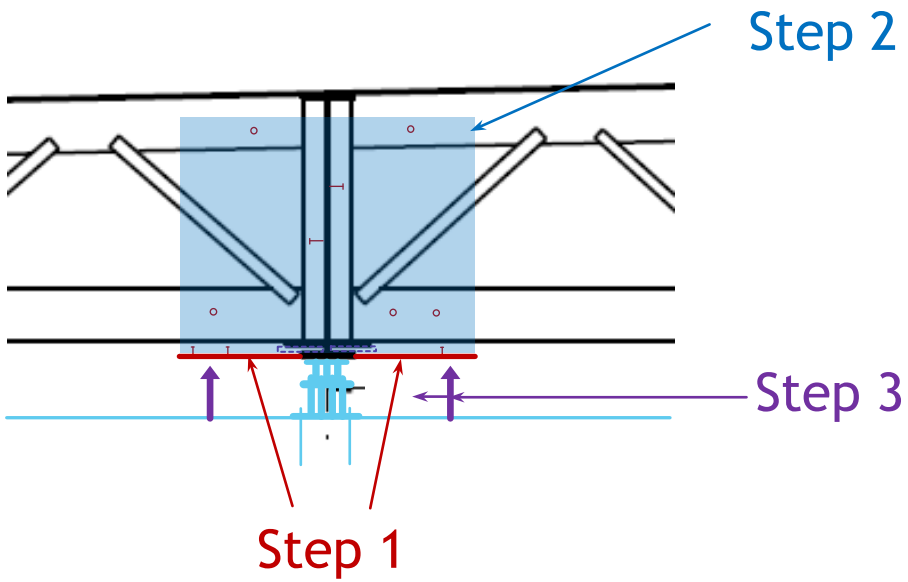
- Avoiding intensive cutting & welding, minimizing bridge closure time.
- Avoiding shore towers .

  - ❖ Creating solid load paths to transfer loads from girders to bearings.
  - ❖ Strengthening diaphragms to enable jacking of girders for bearing repair.

- ➢ Sealing the corroded areas of steel girders to stop further corrosion.
- ➢ Eliminating the water and debris trapping details.

Construction Sequence

- Step 1: Weld New Steel Plates and Shear Studs.
- Step 2: Pour UHPC to Encase the Joints
- Step 3: Jack the Girders under UHPC Encasements and Repair the Bearings.



Construction started in February 2020,

and was completed in September 2020.

Install Stair Towers/Platforms and Sandblast

Sandblasting with Lead Abatement

Weld New Steel Plates and Shear Studs. Install Reinforcement.

Mock-Up

- Mock-up UHPC pour with real size prototype in April 2020.
- Major leak occurred, indicating challenges on forming tightly around steel with high hydrostatic pressure.

Forming. Testing. Reforming.

Forming on the Bridge

Pouring UHPC

Poured through temporarily drilled holes on bridge deck, using funnels and PVC pipes

Pour UHPC

Under the Deck

Fixing Leaks

Completing One

UHPC Form Removed

UHPC filled all the intended space!

Solid load path established.

Jacking and Bearing Repair

UHPC Delivered!

Encasements performed very well during jacking operation.

Girder Ends and Bearings Repaired

Other Highlights of UHPC Repair

Minimal Bridge Closure:

- Total Full Bridge Closure: **Only One Weekend**
- Total NB Or SB Closure: **One Weekend Each**

Lower Costs:

- Lower immediate repair cost.
- Lower life-cycle cost.

Superior UHPC Properties Used

- High Strength
  - Strengthening and confining the corroded steel joints.
- High Ductility and Reliable Tensile Strength
  - Preventing/minimizing cracking in varying stresses by live and jacking loads.
- High Flowability
  - Filling the small spaces around the corroded steel and the shim plates.
- Low Permeability
  - Improving corrosion resistance in future service.

Conclusion and Acknowledgements

Conclusion:

UHPC is a powerful material that can be effectively used to repair corroded steel beam ends.

Acknowledgements:

Texas Department of Transportation:

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Question and Answer Session

Thank you!

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