UHPC FOR STEEL BRIDGE REPAIR AND HOUSTON SHIP CHANNEL BRIDGE CASE STUDY

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1. Introduction of Ultra-High Performance Concrete - What is UHPC?

FHWA Definition:

U.S. Department of Transportation
Federal Highway Administration

Se

About FHWA Progra

- Explore Research and Technology
- Bridges and Structures
- Ultra-High Performance Concrete
- Deployments
- Projects
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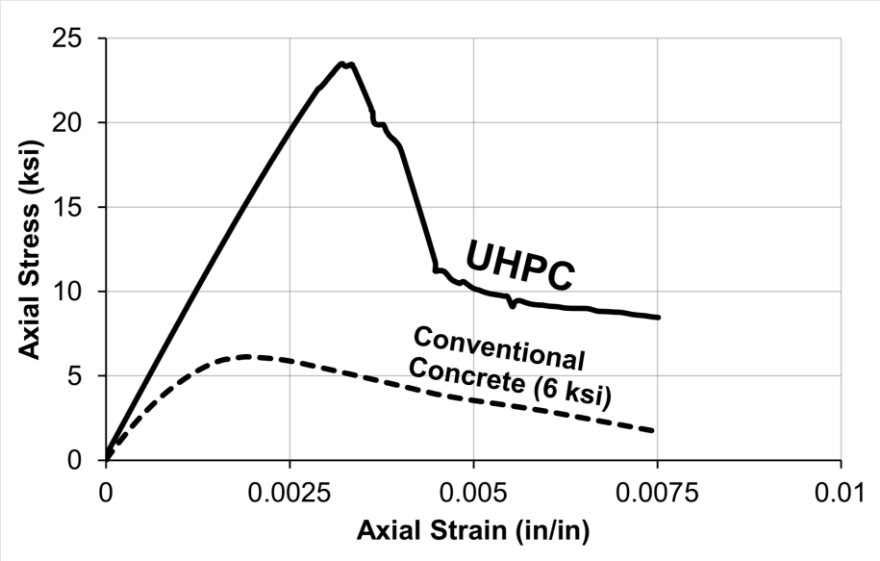
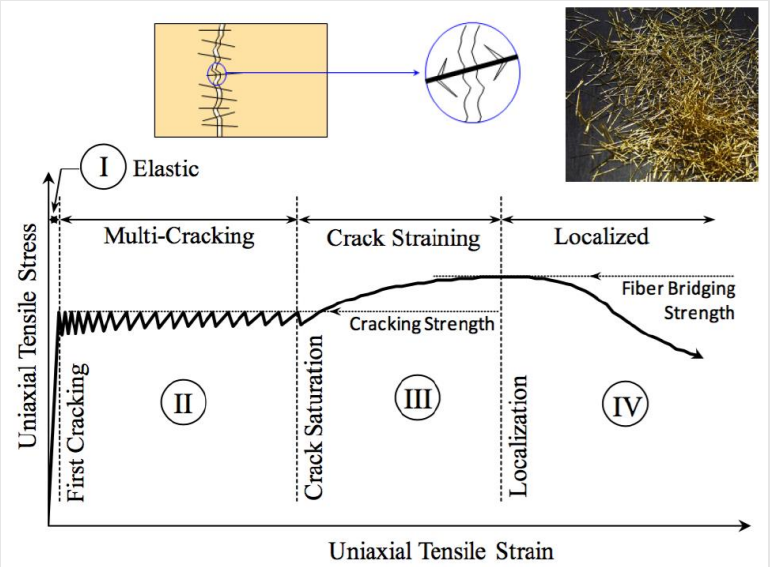
- UHPC FAQs

UHPC is a cementitious composite material composed of an optimized gradation of granular constituents, a water-to-cementitious materials ratio less than 0.25, and a high percentage of discontinuous internal fiber reinforcement. The mechanical properties of UHPC include compressive strength greater than 21.7 kilopounds per square inch (ksi) (150 Megapascals (MPa)) and sustained postcracking tensile strength greater than 0.72 ksi (5 MPa). Ultra-high performance concrete has a discontinuous pore structure that reduces liquid ingress, significantly enhancing durability compared to conventional and high-performance concretes.

UHPC Properties



Compression Behavior

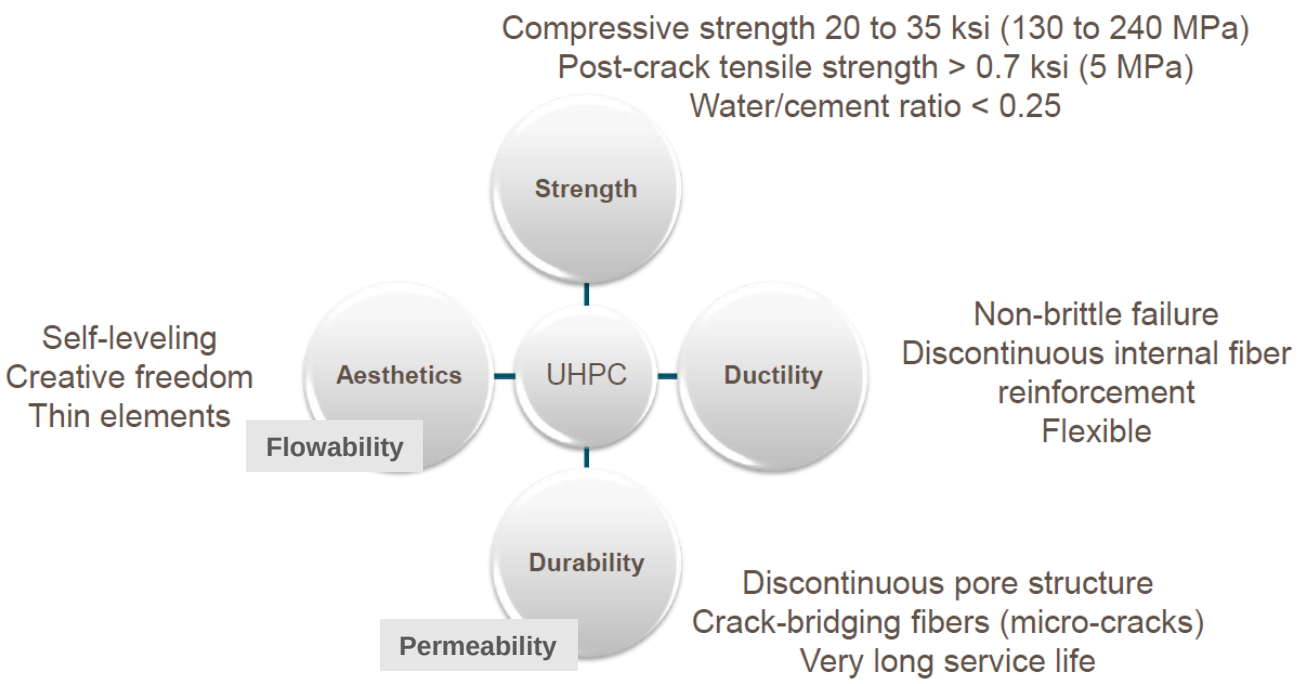


Tension Behavior

Ductility!

Courtesy of LafargeHolcim

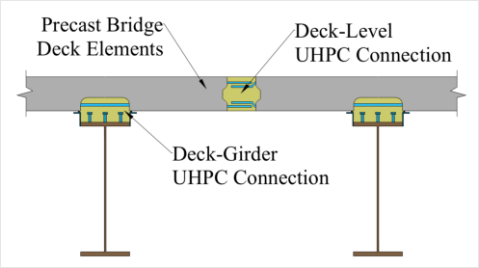
UHPC Characteristics



Courtesy of LafargeHolcim

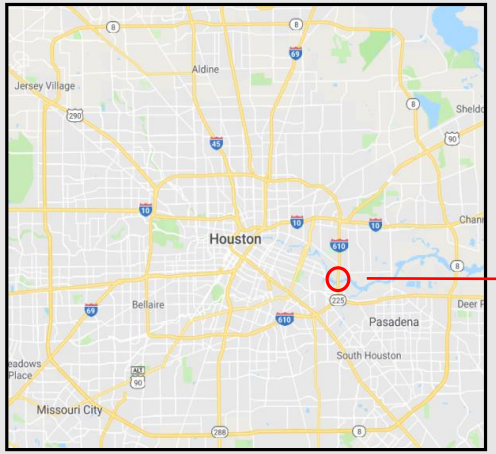
UHPC Typical Bridge Applications

Joint connections/closure pours between prefabricated members



Courtesy of LafargeHolcim

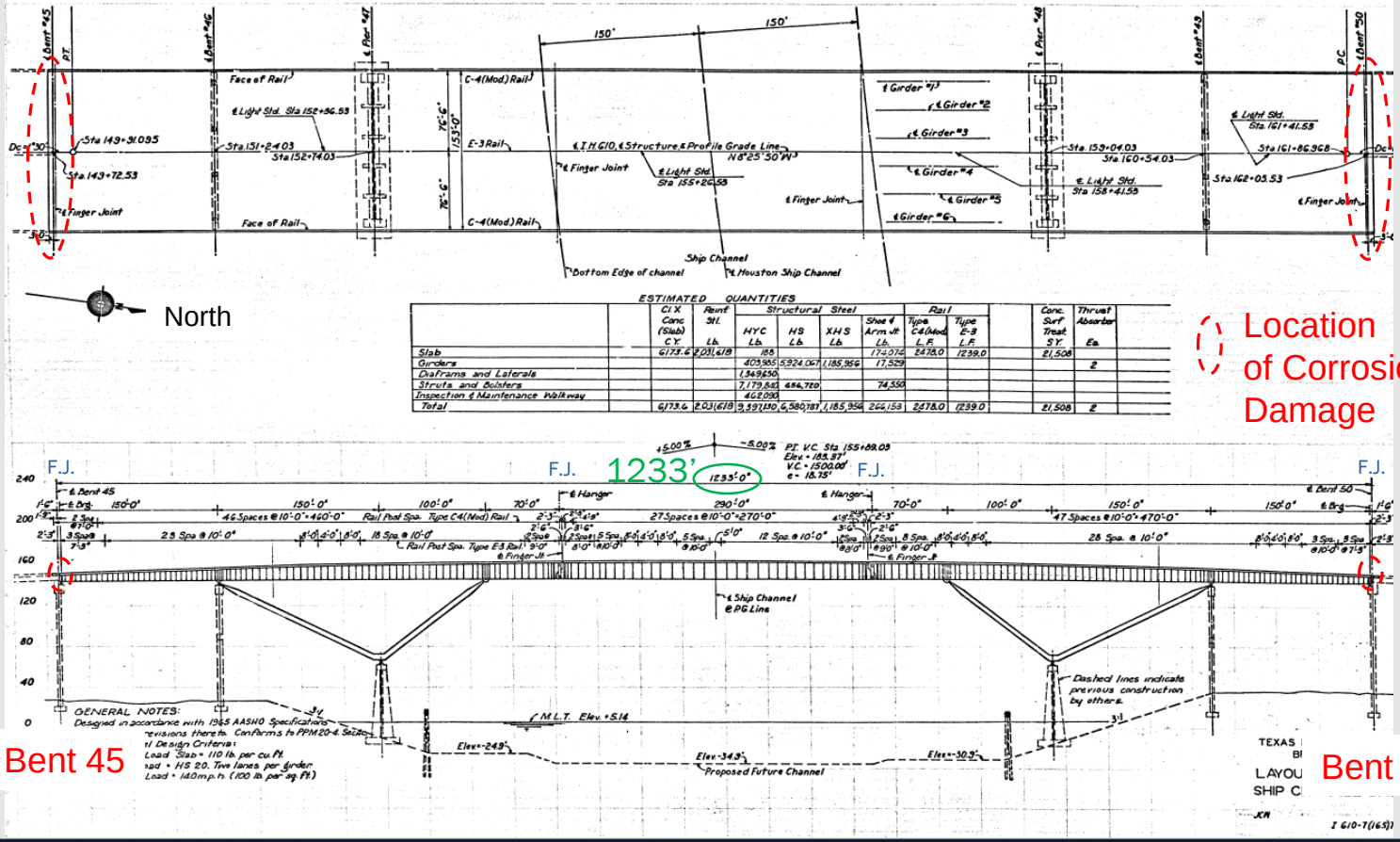
2. IH 610 Houston Ship Channel Bridge



Built in 1969.
Repaired previously for wearing and collisions.

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

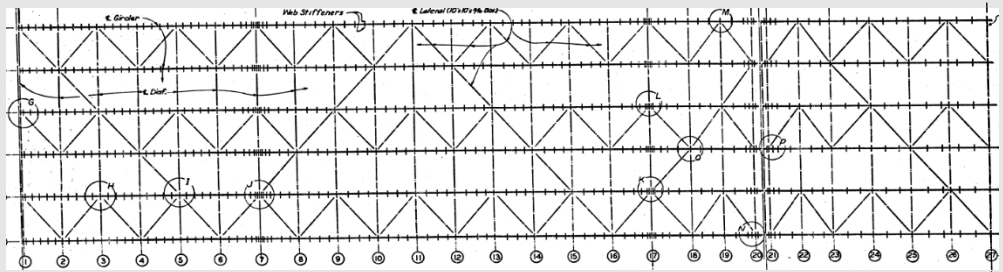
Bridge Overview



Bridge Overview

Girders and Braces:

Symmetric



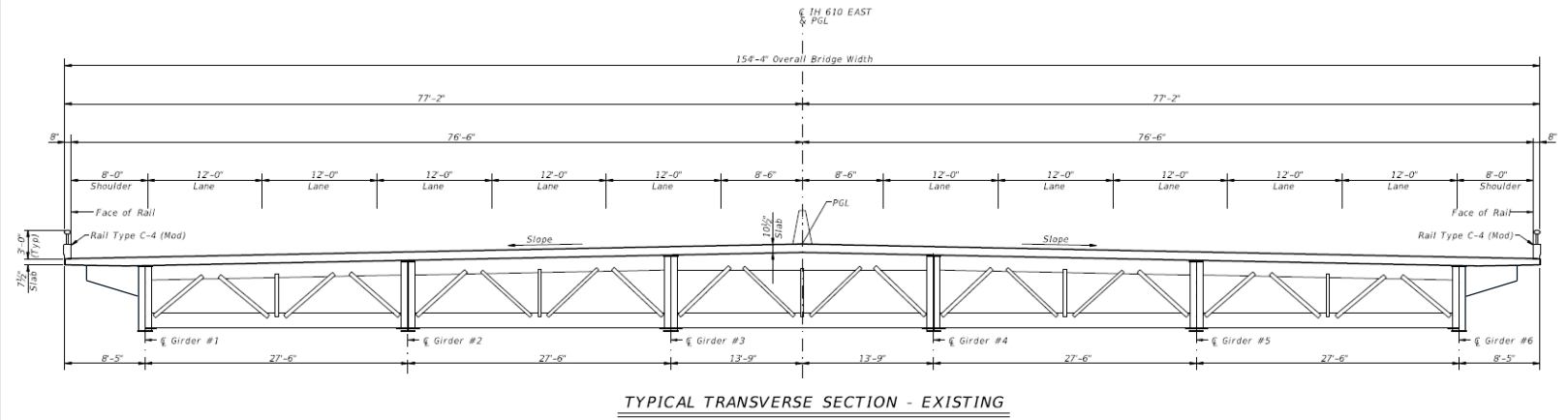
Bent 45

Framing Plan

Center of the Ship Channel

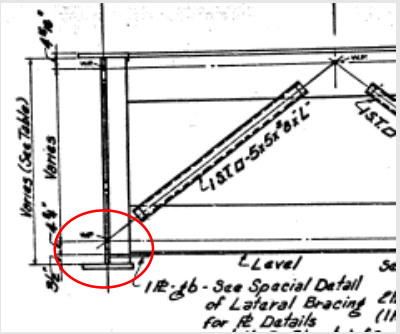
Features…

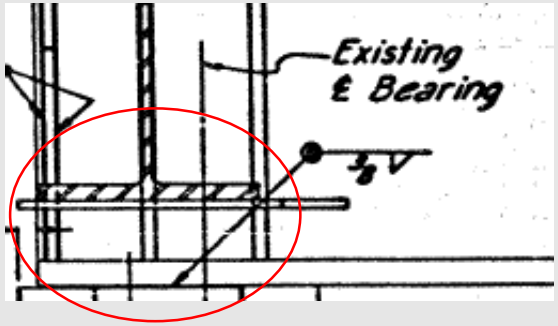
- Six (6) Steel Girders, spaced at 27’-6” , with varying depth.
- Large deck overhang: 8’-5”.
- Truss diaphragms spaced at 25’.
- Rocker bearings under girders.



(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 is 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

Temporary Repair (February 2019)

At Bent 50, Girder 2 (B50G2) only:

Emergency repair bridged the flange hole with a piece of welded steel plate.

(Temporary Repair was led by Roger Lopez, PE, Kevin Pruski, PE, and Steven Austin, PE)

3. Permanent Repair Concept Development – Bearing Repairs

Goal: Provide Minimum 15 Years Additional Service Life

Must Do --- Bearings at Bent 45:

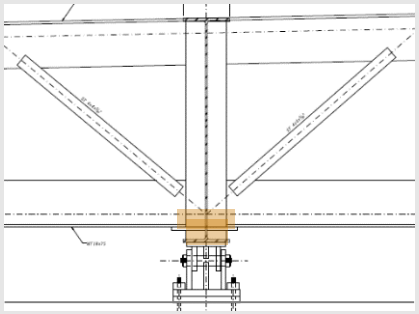
Girder 6 rocker position must be corrected.

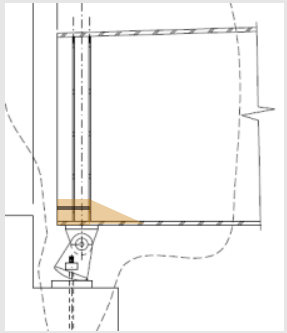
Deteriorated bearing base plates and anchor bolts for Girders 3 through 6 must be replaced.

⇨ Girder Jacking Is Needed at Bent 45

Repair Items for Girders and Diaphragms

- Repair the corroded and damaged plates at the girder ends 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 eliminate the small spaces that trap water and debris.

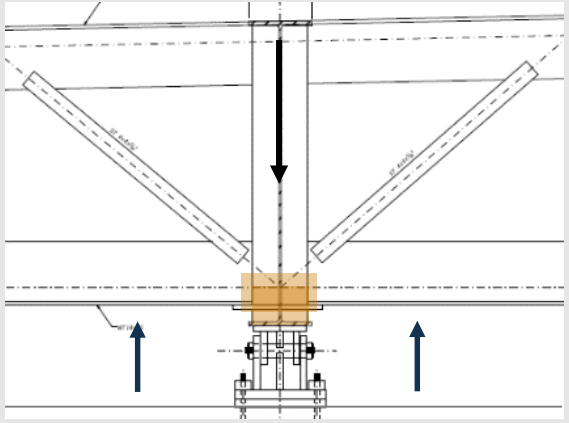
Typical Corrosion Repair Methods

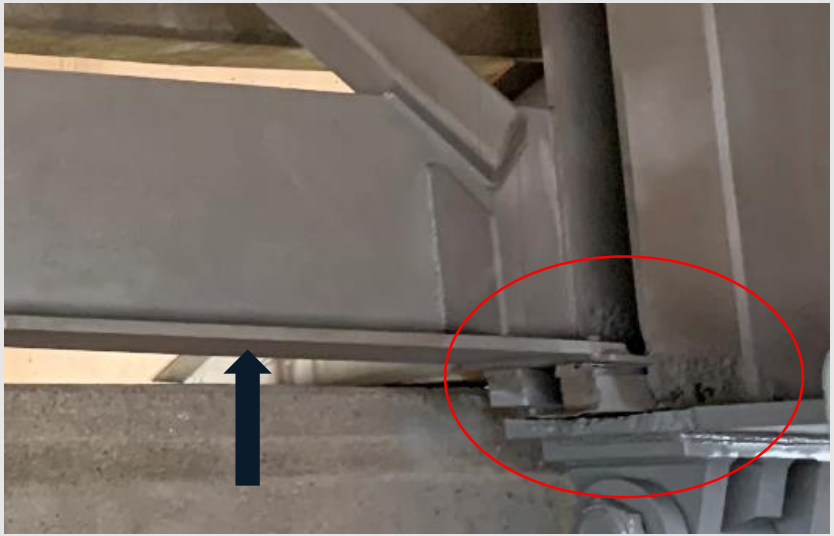
- Cut-and-Replacement Method
- This Method Requires either:
  - Installing Temporary Supports (Shoring), or
  - Unloading of Dead Loads from Structure

Initial Permanent Repair Ideas

Can the cut-and-replacement method be used here?

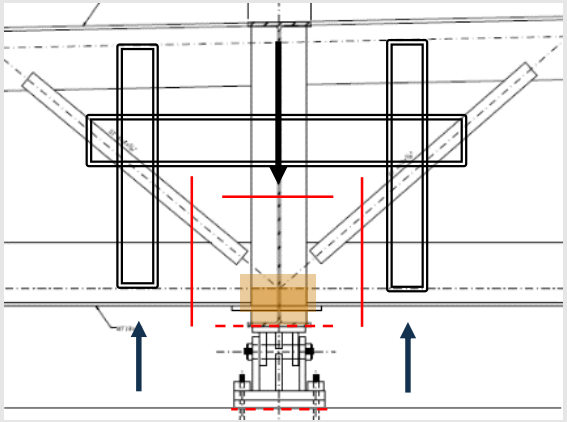
Jacking / Temporary Support through diaphragms ?

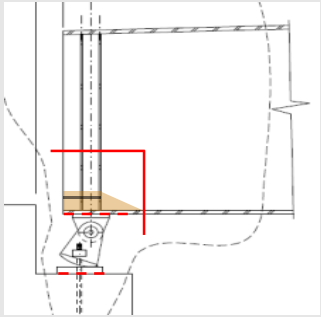




Not with the weakened joints!

Initial Permanent Repair Ideas





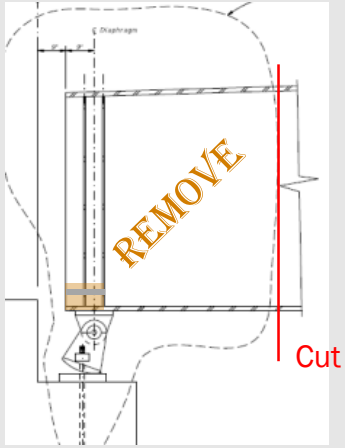
Even if the diaphragms could be reconfigured for jacking,

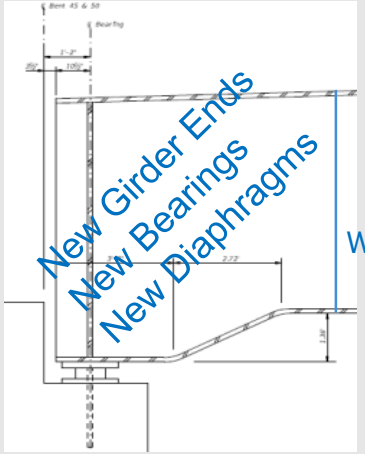
- Need to cut/disconnect many plates and members.
- Need *Significant and Complex Welding* to connect the new steels to these members and plates.
- The bridge/lanes need to be closed for long time (for welding).
- New joints likely still geometrically complex and trapping water and debris.

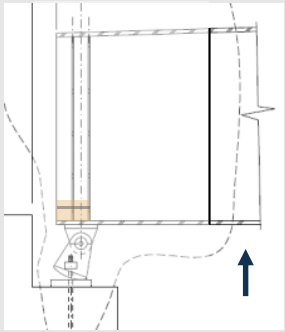
Initial Permanent Repair Ideas

To reduce field welding and simplify connection details ---

Cut and replace the entire girder ends along with diaphragms and bearings?





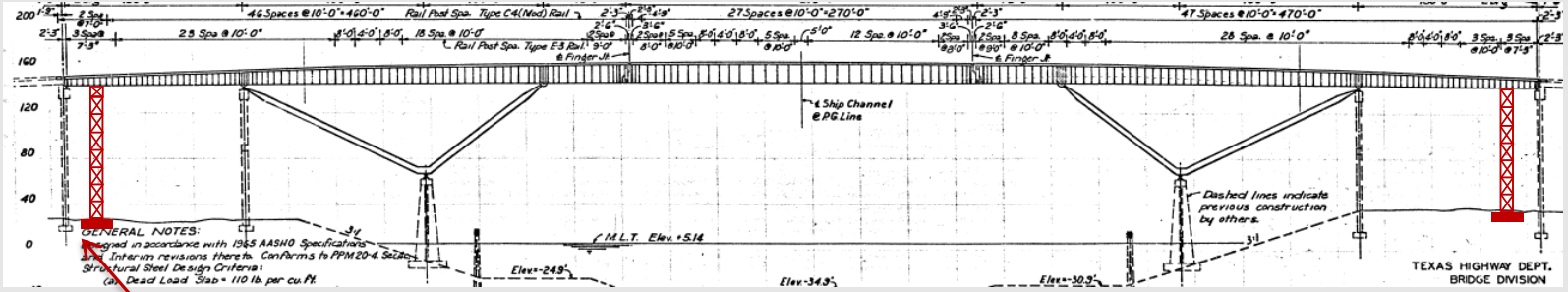


To do so, the girders need to be shored / jacked directly, not through diaphragms.

Jack the Girders Using Shore Towers?

Restrictions on Using Shore Towers:

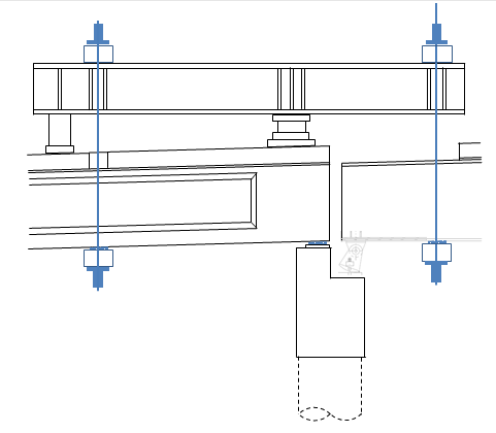
- High elevations (120’) above the ground.
- Ground occupied by railroad tracks under Bent 45.
- Girder webs too weak to resist reaction forces at shoring points.
- Weak soil and utilities for temporary foundations.

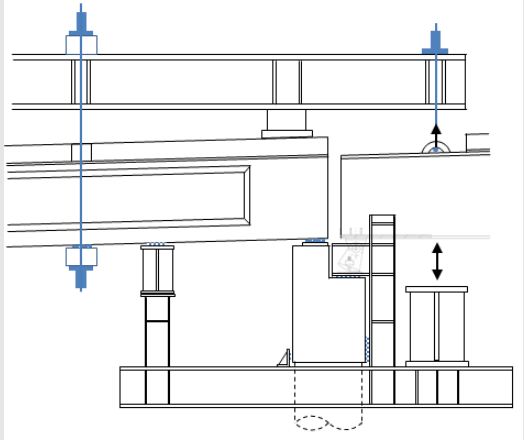


Railroad tracks under Bent 45

Lift the Girders from the Top?

Many great ideas were proposed but all with limitations.





- Strongbacks redistribute girder loads, causing large load concentrations on the bent caps' weak spots.
- Strongbacks will occupy the bridge service areas for long periods of time.

Encasing, Instead of Cutting?

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

.... *Encasing,* instead of Cutting?

To be a valid idea, the encasing material (grout?) must possess certain desired properties. The "grout" must

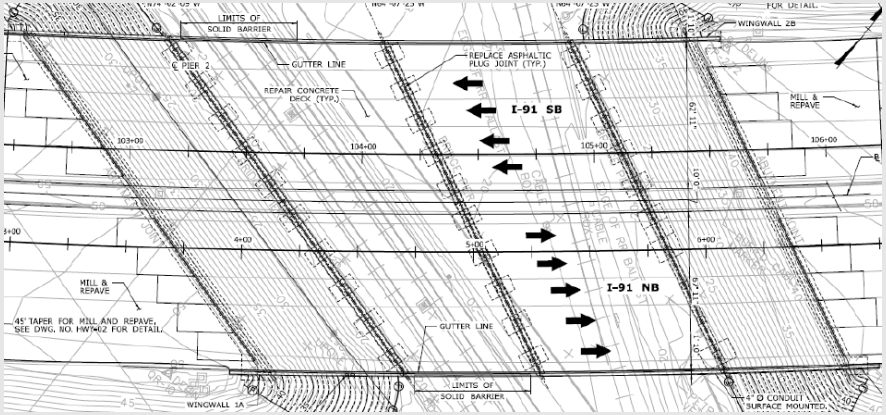
- be flowable enough to fill the small spaces around the corroded steel and the shim plates.
- not only insulate and strengthen existing members, but also reshape the joints to enable girder jacking.
- be strong and ductile enough after cured to survive the stress variation and reversal during jacking.

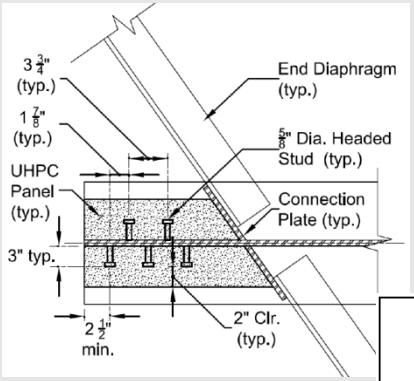
Sounds familiar? Sounds **UHPC!**

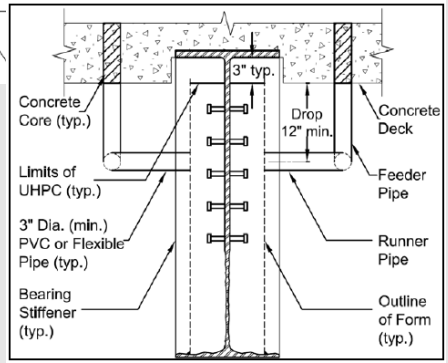
Thank you FHWA for the UHPC Class in Austin in 2018.

Tried in Connecticut

Connecticut DOT (CT) was repairing a corroded steel bridge in IH 91 using UHPC





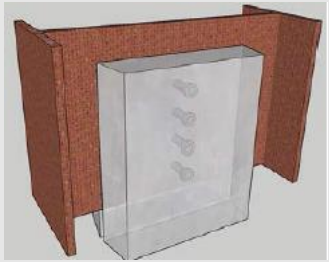


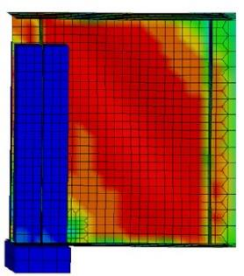
New Haven, CT

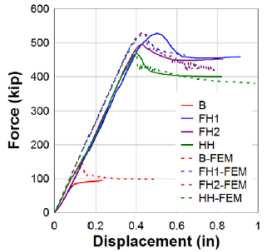
Picture Courtesy of Dr. Arash E. Zaghi, Univ. of Connecticut

UConn Research

- CT sponsored research on the idea at the University of Connecticut led by Dr. Arash E. Zaghi.
- UConn investigated in great depth on shear studs in UHPC, capacities of the UHPC encased beam ends, etc.
- They also studied durability and constructability of the UHPC repair.





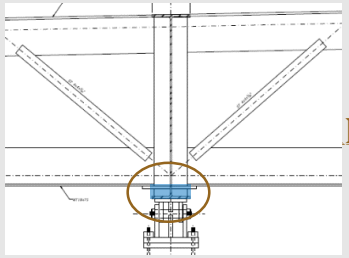


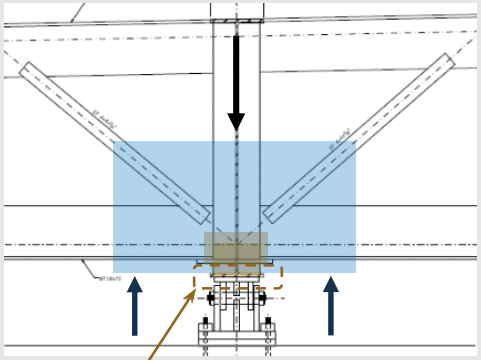
Picture Courtesy of Dr. Arash E. Zaghi, Univ. of Connecticut

4. Innovative Permanent Repair Plan Using UHPC

Encase just the corroded areas with shim plates?

- Too small to hold everything together and to jack





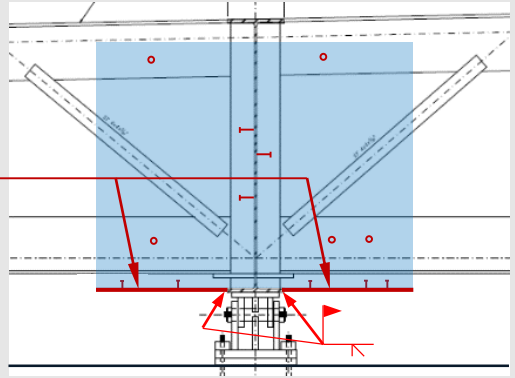
High Jacking Stress Area

Use larger encasements. Can we jack now?

- Bonding between steel and UHPC too weak to resist jacking stresses

Introducing Plates A

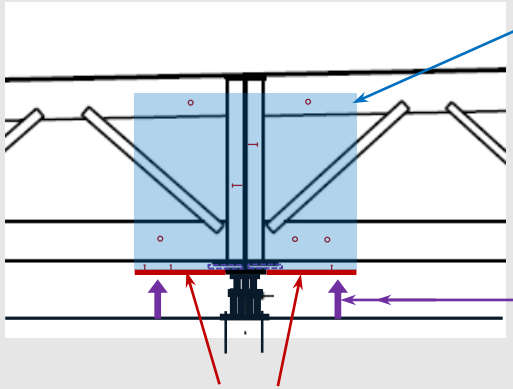
Weld New Steel **Plates A** to Girder Flanges



(Jacking-induced stresses at the bottom resisted by continuous steel)

Permanent Repair Steps

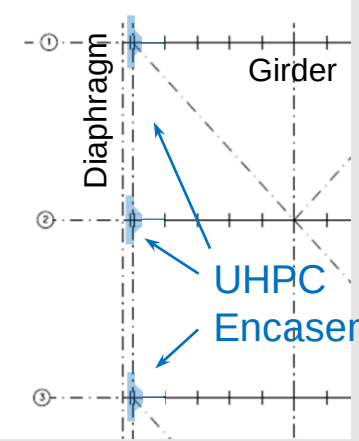
- Step 1: Weld Plates A to the side edges of girder flanges to create continuous steel along the diaphragms. Also weld the shear studs.
- Step 2: Pour UHPC to encase the joint areas between the girder ends and the diaphragms.
- Step 3: After UHPC hardening, jack the girders under the UHPC encasements and perform the bearing repair.



2. Pour UHPC to Encase and Fill the Damaged Areas

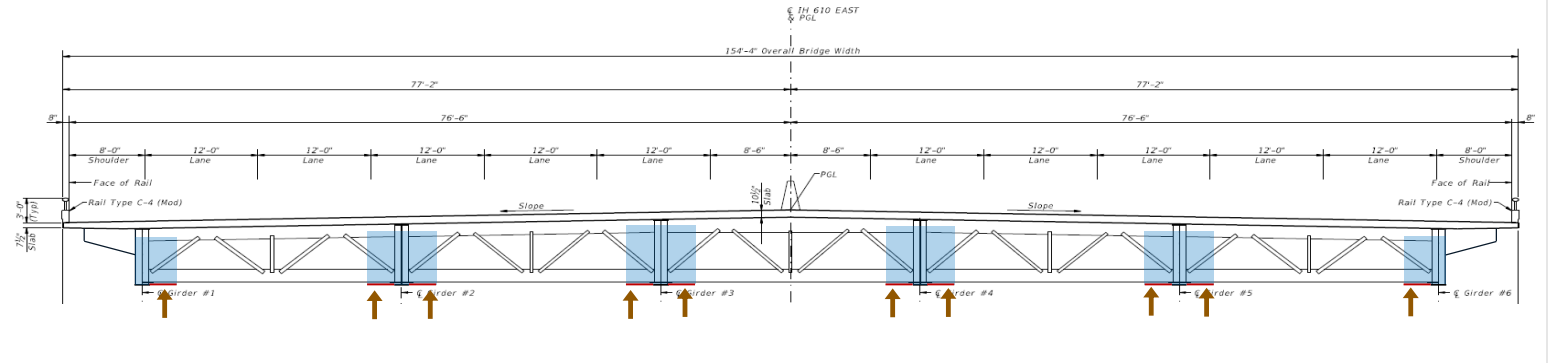
3. Jack the Hardened UHPC and Repair the Bearings

1. Weld New Steel Plates A to the Girder Flange



Plan View:

UHPC Encasement Solution: Many Benefits



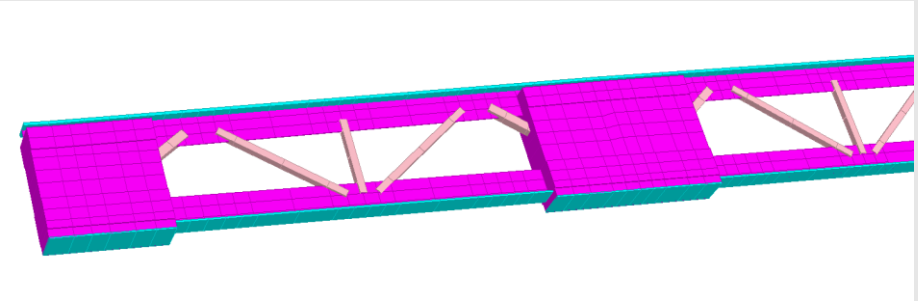
- Avoiding intensive cutting & welding, minimizing bridge closure time.
- Avoiding shore towers or strongbacks.
  - ❖ Creating solid load paths to transfer loads from girders to bearings.
  - ❖ Strengthening diaphragms to enable jacking of girders for bearing repair.

➢ Sealing the corroded areas of steel girders to stop further corrosion.

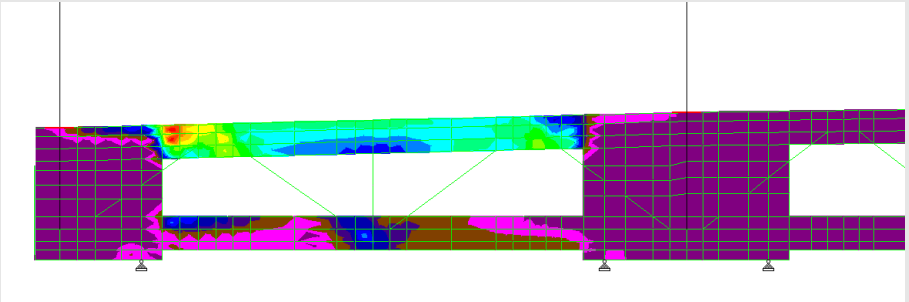
➢ Eliminating the water and debris trapping details.

UHPC Design Features in This Project

- Our encasements cover mostly diaphragms, not longitudinal girders.
- Our encasements cover mostly trusses, not continuous webs.
- The greatest loads on our encasements are jacking loads.
  - ❑ Finite Element Analysis was performed for stress estimation during jacking.
  - ❑ Stresses were checked in Plates A, UHPC blocks, and in diaphragm members.



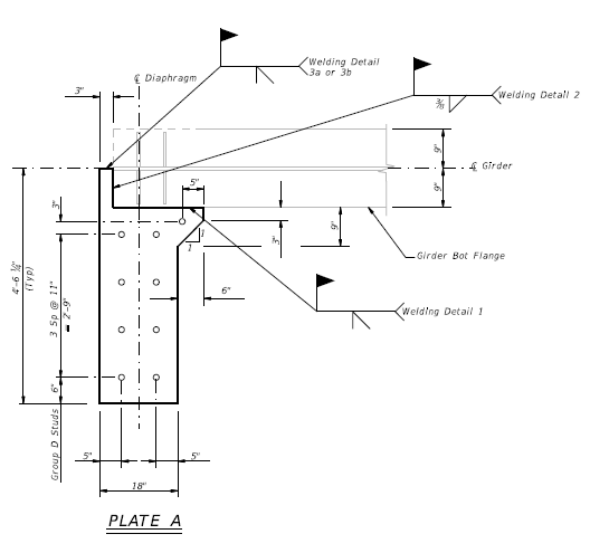
FEA Model including steel diaphragm members and UHPC encasements



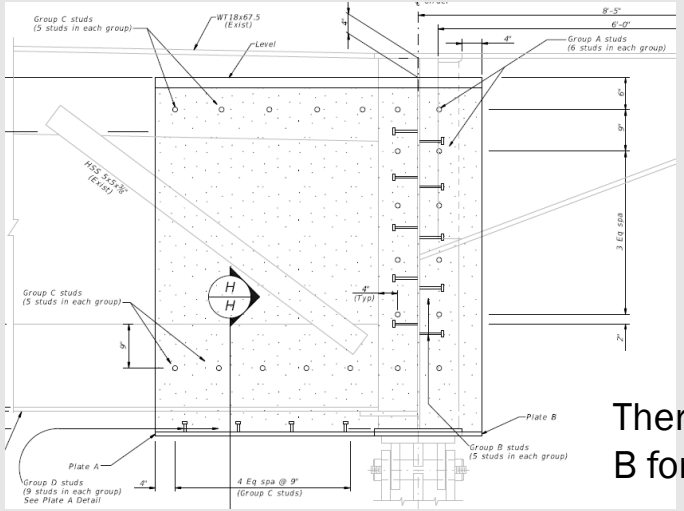
Stress contours during jacking

5. Repair Details

Field Weld Steel Plates and Shear Studs



Plan View

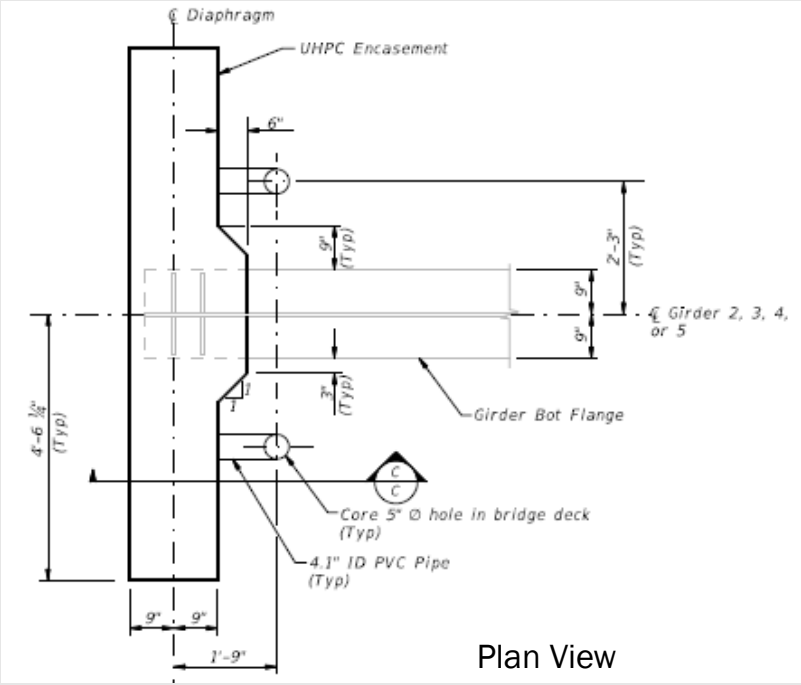


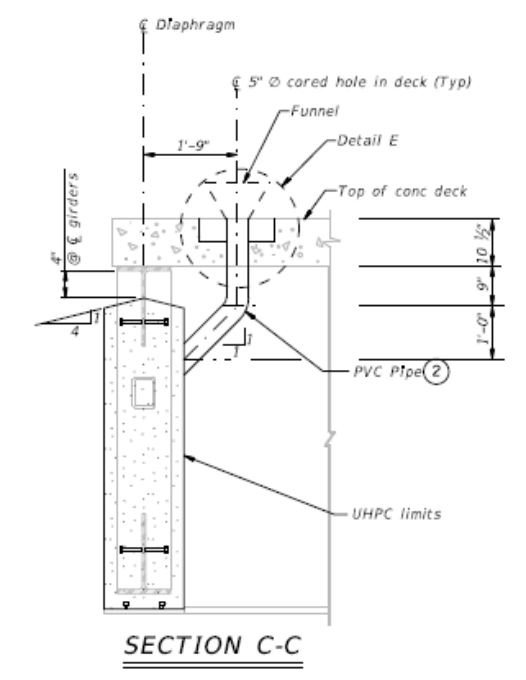
Elevation View, Exterior Girder

There are also Plates B for exterior Girders

Geometric restrictions and constructability were the main considerations for the welding design

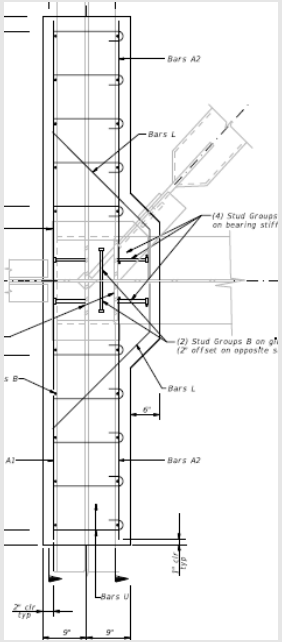
UHPC Encasement Sizes and Construction Methods

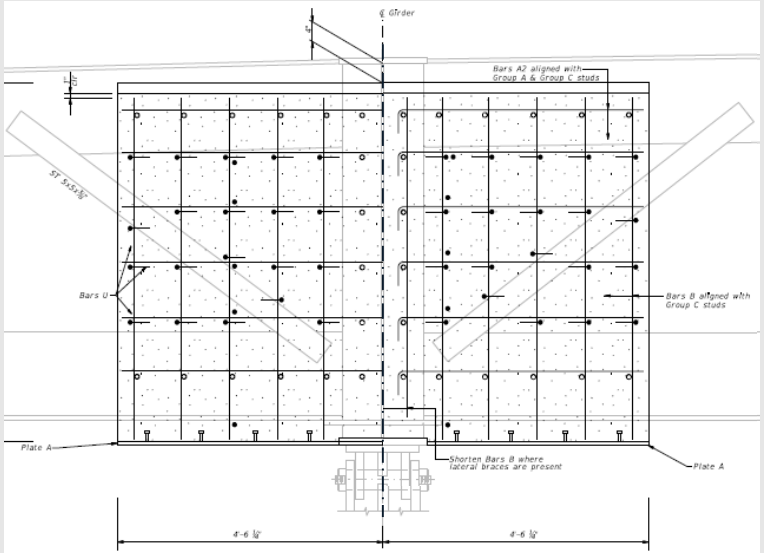




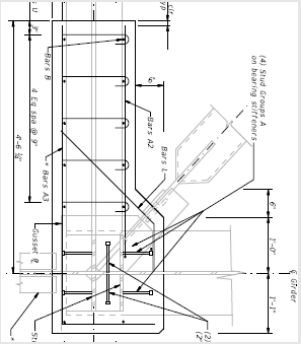
- Encasement sizes governed mainly by constructability & jacking operation.
- UHPC to be poured from the top of deck through cored holes and PVC pipes.

Encasement Details





Encasements for Interior Girder



Encasements for Exterior Girder

Light reinforcement was used

Special Specification on UHPC and Workshop

Special Specification 4154

Ultra-High Performance Concrete (UHPC) for Steel Girder End Encasement

Texas Department of Transportation

1. DESCRIPTION

Furnish and place ultra-high performance concrete (UHPC) where shown on the plans.

2. MATERIALS

2.1. **UHPC.** Provide a proprietary UHPC product with independent test data showing the proposed UHPC product meets the requirements of Table 1.

Table 1
UHPC Requirements

Property	Test Method	Requirement
28-Day Compressive Strength[1], Min (psi)	ASTM C 1856	21,000
4-Day Compressive Strength[1], Min (psi)	ASTM C 1856	14,000
28-Day Shrinkage, microstrain	ASTM C 157	≤ 800
Permeability[2], coulombs	ASTM C 1202	≤ 250
Scaling Resistance	ASTM C 672	y < 3
Freeze-Thaw Resistance, 300 cycles, % RDM	ASTM C 666A	> 96
Alkali Silica Reactivity,% Max expansion at 14 days	ASTM C 1260	< 0.1

1. Use 3 in. x 6 in. cylindrical specimens
2. After 7 days of standard curing and 21 days of water curing at 100°F

2.2. Water. Furnish water meeting the requirements of Item 421, "Hydraulic Cement Concrete."

- SS4154 defines material properties, construction methods, testing requirements.
- It is supplemented by many design notes on the contract plans.
- A mock-up was required before the UHPC cast.

A UHPC Workshop was held in Houston on Oct. 17, 2019 for contractors, engineers, inspectors and testers.

6. Construction and Lessons Learned

1. Build Platforms and Stair Towers.
2. Sandblast to Remove Existing Paints and Rusted Steel.
3. Weld Plates A and B.
4. Weld Shear Studs.
5. Install Reinforcement.
6. Form.
7. Test Forms, and Re-Form.
8. Pour UHPC.
9. Jack Girders at Bent 45. Repair Bearings.

Stair Towers and Platforms

Sandblast with Lead Abatement

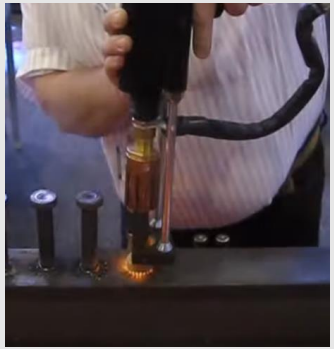
Steel Before and After Sandblasting

Before:

After:

Weld Plates A and B

Install Shear Studs

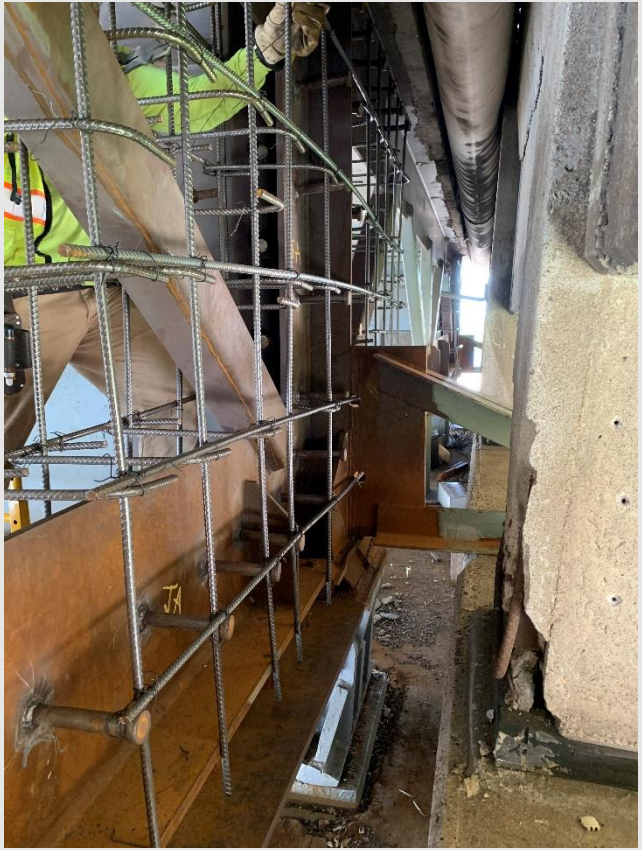


Molten weld metal lost at the top due to gravity

Stud welding gun unable to deliver continuous weld on vertical surfaces.

Repaired by manual welding.

Reinforcement And Forming



Mock-Up

- Mock-up UHPC pour with real size prototype on April 16, 2020.
- Major leak occurred, indicating challenges on forming tightly around steel with high hydrostatic pressure.

Forming. Testing. Reforming.

Forming on the Bridge

Pour UHPC

Pre-pour meeting

Plan B?

Pour UHPC

Two mixers

Pour through funnels and PVC pipes

Pour UHPC

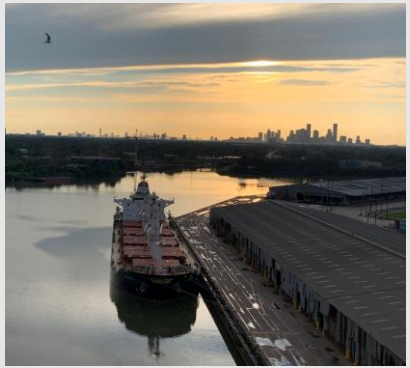
Under the Deck

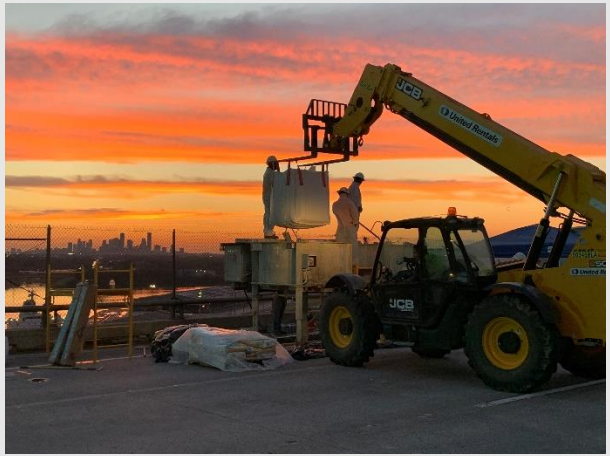
Fixing Leaks

Completing One

Pour UHPC 2

Rain Delayed. But the view was worth it.



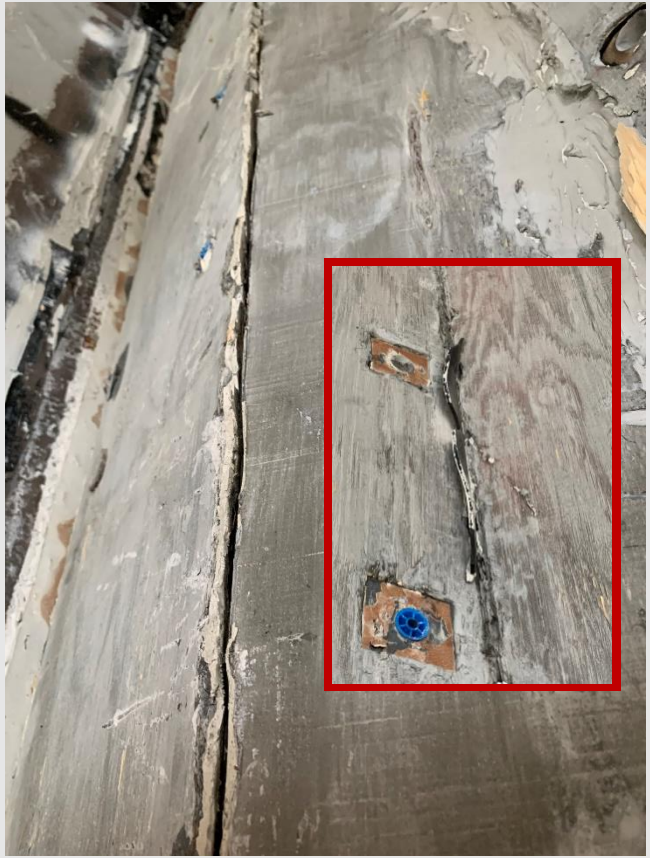


UHPC Form Removed

UHPC filled all the intended space!

Solid load path established.

UHPC Forming Lessons



There were lessons, however:

Sealing materials used in form joints invaded into the forms and caused voids in the encasements.

Fortunately the voids are relatively small and not widespread.

Prepare for Jacking

- Prepared per jacking plan approved earlier.
- The platform must be allowed to move up with girders during jacking.

Jacking and Bearing Repair

UHPC Delivered!

Encasements performed very well during jacking operation.

7. Summary - Bent 45, Girder 5 Repaired

2018
Corroded Steel on
Top of Rocker Bearing

2018 & 2019
Temporary Repair
Using Shim Plates

August 15, 2020

UHPC Encasements Sealing
Corroded Steel and Ready to
Serve in Jacking Stresses

Bent 50, Girder 2 Repaired

2018
Corroded and Broken Steel

2018 & 2019
Welded and Shimmed
In Emergency Repair

September, 2020

UHPC Sealing Corroded
Steel and Reestablishing
Robust Load Path

Bent 45, Girder 6 Repaired

2018
Anchor Bolts Corroded and
Base Plate Walking Away

2018 & 2019
Temporary Repair to Prevent
Total Bearing Failure

September, 2020
Rocker Standing Straight Again
on New Base Plate after UHPC
Encasements Enabled Jacking

Other Highlights

Minimal Bridge Closure:

- Total Full Bridge Closure: Only One Weekend
- Total NB Or SB Closure: One Weekend Each
- Other Closures: One-lane & shoulder closures during sandblasting

State of Texas, UHPC-wise:

- This was the first major UHPC application in Texas
- TxDOT has hosted demos & sponsored research, including an active project at TTI

Closing

Conclusion: UHPC is indeed a powerful material that lives up to its promise.

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