Completed UHPC Overlay on the Delaware Memorial Bridge: A Sustainable Solution for Prolonging the Deck Service Life

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WSP

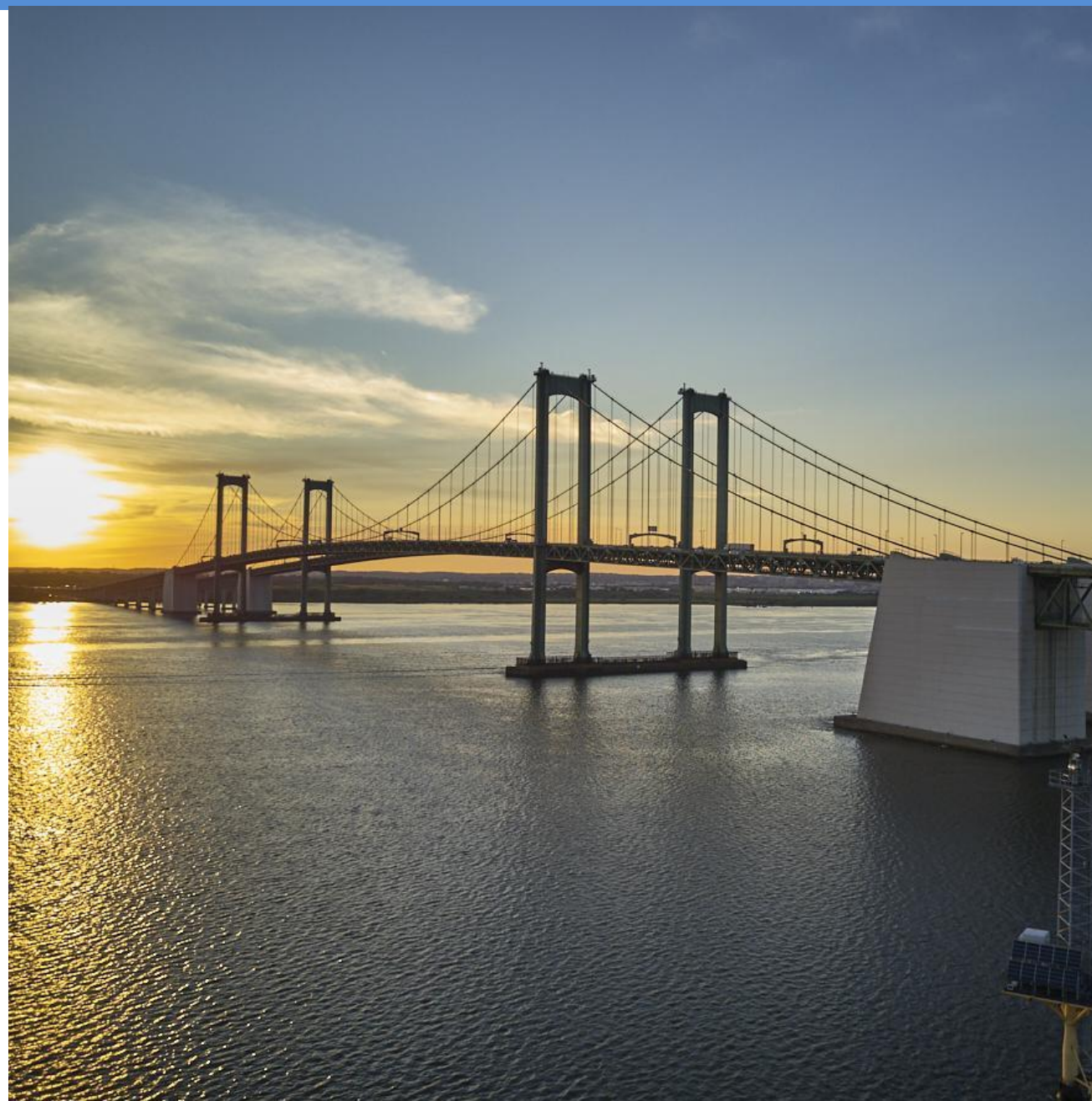
DRBA DELAWARE RIVER & BAY AUTHORITY

THE WORLD'S GATHERING PLACE FOR ADVANCING CONCRETE

aci CONCRETE CONVENTION

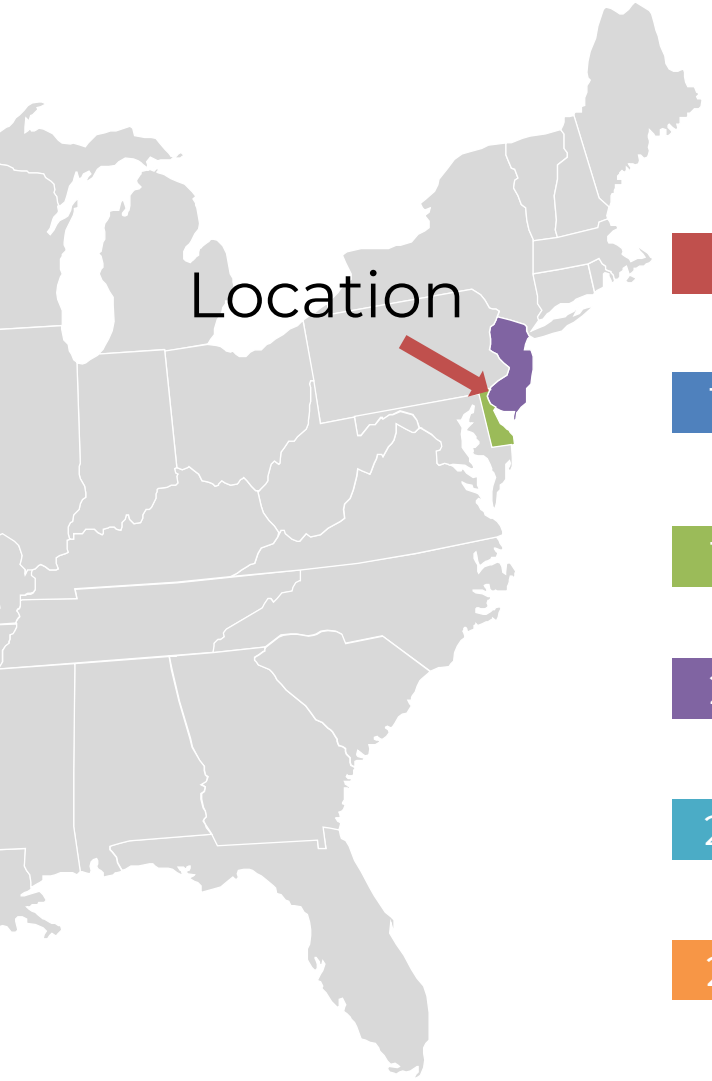
Agenda

- Bridge Overview
- Project Need
- Replace/Rehabilitate LCCA
- Pilot Project
- Sustainability
- Full Overlay Project Execution
- Challenges and Lessons Learned
- Recommendations
- Conclusions



Bridge Overview

Bridge Overview



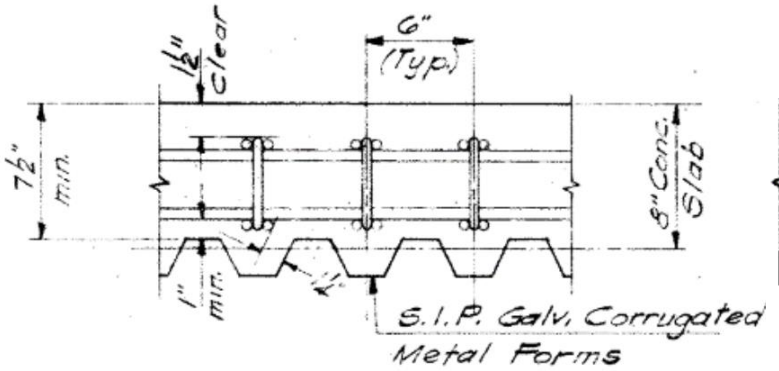
- 1951 — Structure 1 Completed
- 1968 — Structure 2 Completed
- 1969 — Structure 1 Deck Replacement
- 2018 — Deck Assessment and Studies (Structure 1)
- 2020 — UHPC Overlay Pilot Project (Structure 1)
- 2023 — Full UHPC Deck Overlay (Structure 1)

Bridge Overview (Structure 1)

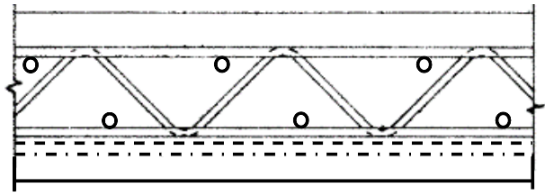
- Girder spans (2 sets), Truss Spans, (2 sets) and Suspension Bridge
- 2 miles long
- 4 lanes of traffic

Bridge Overview

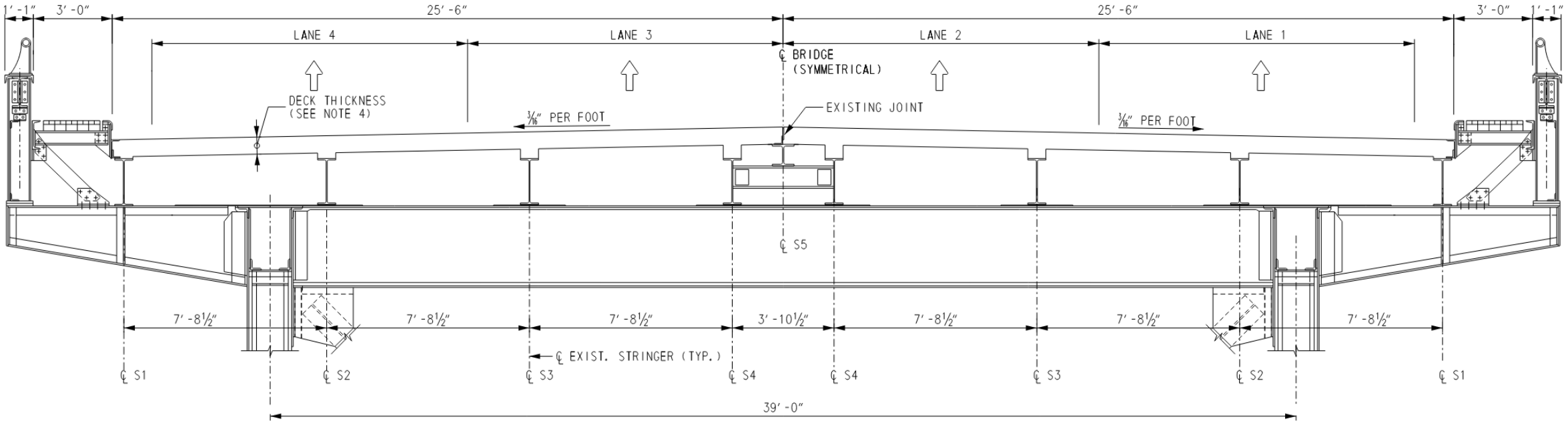
- 550,000 square feet of deck
- 8-inch reinf. concrete deck
- Trussed smooth transverse reinf.



Longitudinal Section
(Looking Transverse Direction)



Transverse Section
(Looking Longitudinal Direction)



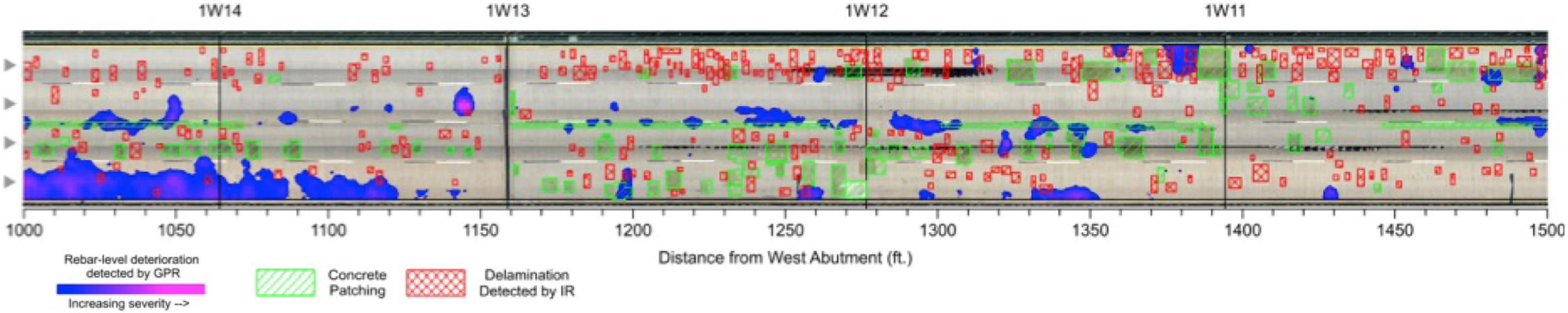
Project Need

Project Need

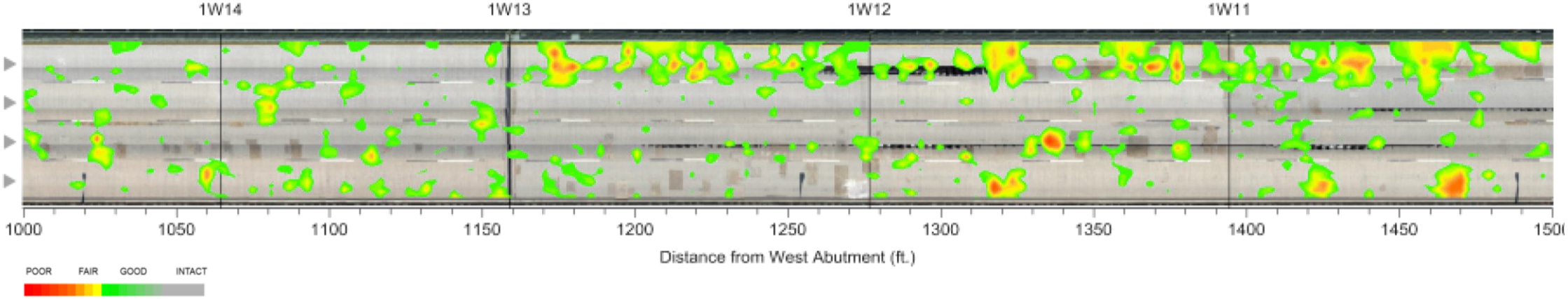
- Maintenance costs were skyrocketing
- 2018 study concluded deck would need to be replaced within five to fifteen years
- Mobile Nondestructive Testing
  - Infrared Thermography (IR)
  - Ground Penetrating Radar (GPR)
  - Deck Acoustic Response (DAR)
  - High Resolution Video (HRV)
- Coring and laboratory testing

Project Need

GPR+IR+HRV



DAR



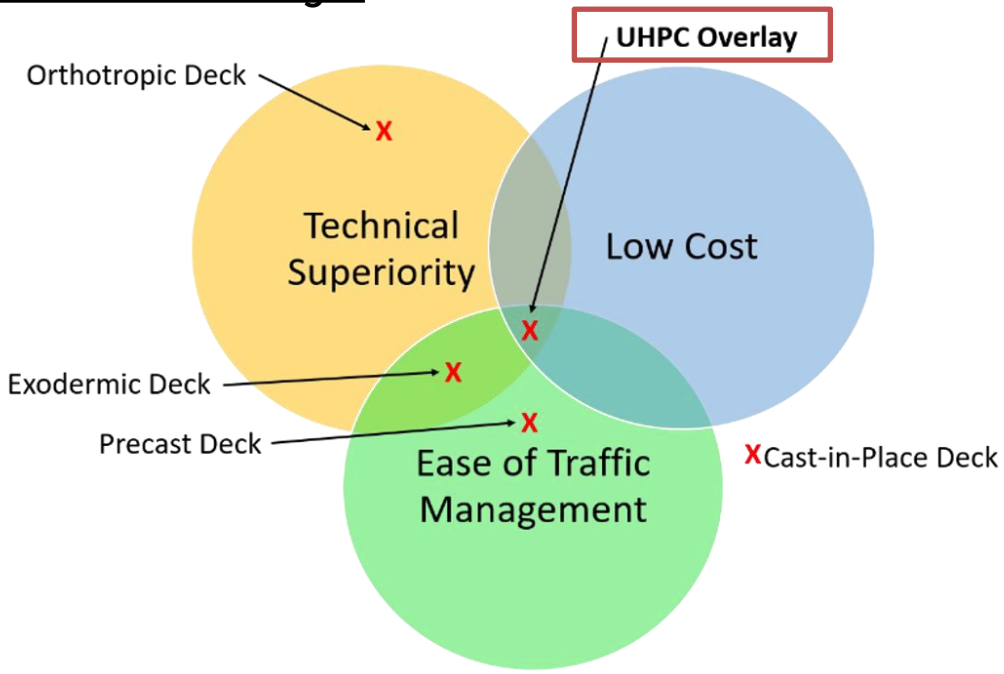
Replace/Rehabilitate LCCA

Replace/Rehabilitate LCCA

- Replace with precast deck and stainless steel rebar for 75-year service life

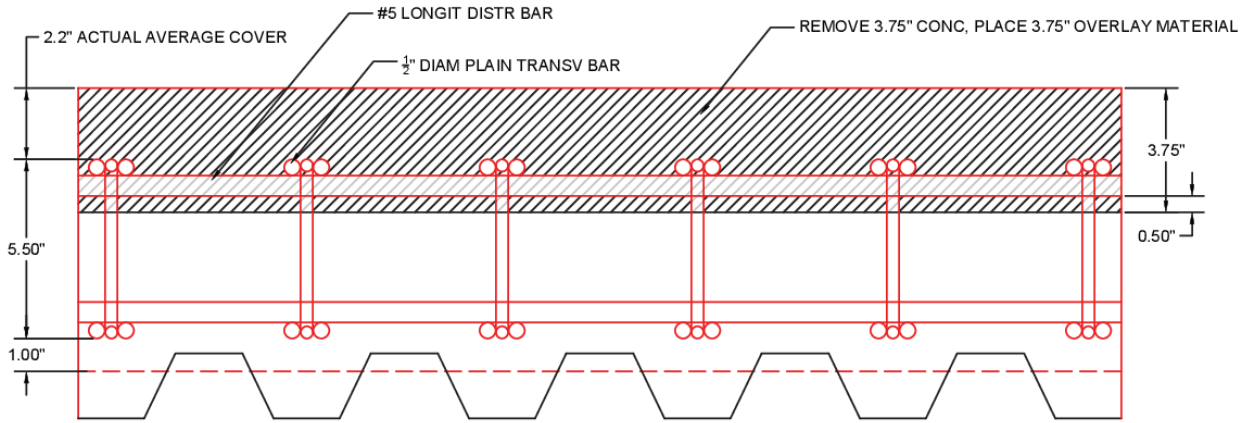
OR

- Rehabilitate with <u>partial-depth replacement "overlay"</u>:
  - Several depth options
  - LMC with 12- to 25-year service life
    - (based on DRBA experience)
  - UHPC with 30- to 50-year service life



Replace/Rehab LCCA

Year	UHPC			LMC		New Deck
	Method 1	Method 2	Method 3	Method 1	Method 2	Precast
Life Span (years)	30	50	45	12	25	75
Thickness	1.75 inch	3.75 inch	2.5 inch (plus asphalt)	1.75 inch	3.75 inch	8.0 inch
NPC compared to lowest	171%	100%	121%	255%	193%	300%



OVERLAY METHOD 2

Pilot Project

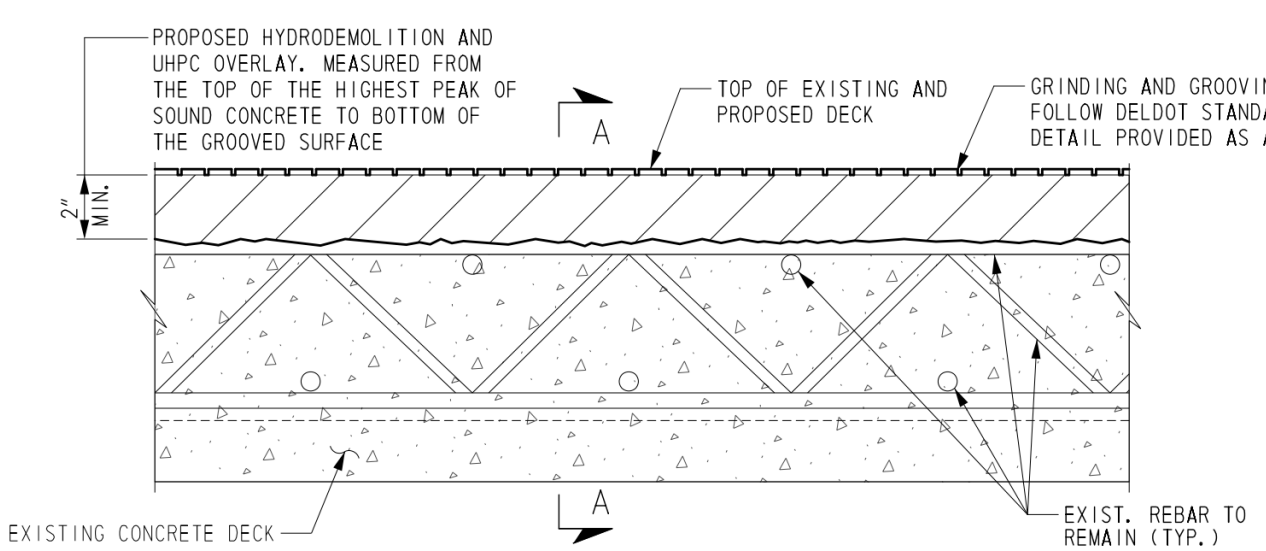
Pilot Project

- Fall 2020
- 3 areas of the deck
- 25,560 SF total
- Rebar shadowing during hydrodemolition made uniform removal below rebar very labor intensive and impractical

Full Project

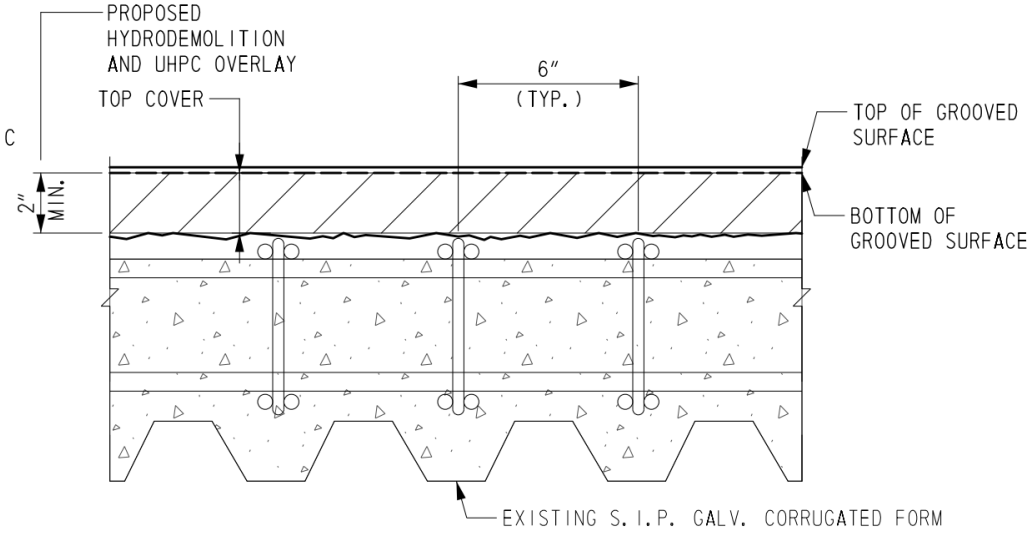
Full Project

- 3 Phases: Fall 2022, Spring 2023, and Fall 2023
- 550,000 SF (minus pilot areas)
- Reduced UHPC thickness to 2 inches minimum (cover depth)



DETAIL 2

TYPICAL DECK REMOVAL AND UHPC OVERLAY



SECTION A–A

Sustainability

Sustainability

- Compared 8-inch new concrete deck with plain rebar to:
  - 8.0-inch new concrete deck with galvanized rebar
  - 8.0-inch new concrete deck with stainless steel rebar
  - 1.5-inch thick LMC overlay
  - 2.0-inch thick UHPC overlay with 0.25-inch overfill
  - 1.5-inch thick UHPC overlay with 0.25-inch overfill

Sustainability

- Simplified analysis
- Considered material production only (“Cradle to gate”)
  - Did **not** consider construction phase emissions:
    - No demolition activities
    - No construction activities
    - No deck forms, temporary or permanent (SIP)
    - No traffic congestion
    - No material transportation
    - No waste material disposal

Sustainability

- Only considered major carbon contributing ingredients:
  - Cement
  - Steel rebar
    - Plain, galvanized, and stainless
  - Steel fiber
  - Synthetic latex

Carbon Emissions (Day 1)

	Rel. CO_2
Data Source	EPDs
8.0-inch Concrete Deck (uncoated reinf.)	**100%**
8.0-inch Concrete Deck (galvanized reinf.)	144%
8.0-inch Concrete Deck (stainless reinf.)	313%
1.5-inch LMC	22%
2.25-inch UHPC	74%
1.75-inch UHPC	58%

Carbon Emissions (Long Term)

	Rel. CO_2 (EPD)	Service Life (years)	Rel. CO_2 per year	Plus More…
8.0-inch Concrete Deck (uncoated reinf.)	**100%**	**50**	**100%**	Demolition, construction duration, traffic disruption, material transportation, bottom forms, waste disposal
8.0-inch Concrete Deck (galvanized reinf.)	144%	75	96%	
8.0-inch Concrete Deck (stainless reinf.)	313%	100	156%	
1.5-inch LMC	22%	15+	74%	Demolition/construction cycles, traffic disruption, material transport, waste disposal
2.25-inch UHPC	74%	40+	93%	Grinding
1.75-inch UHPC	58%	30+	96%	

Carbon Emissions (Long Term) – What if?

	Rel. CO_2 (EPD)	Service Life (years)	Rel. CO_2 per year	Plus More…
8.0-inch Concrete Deck (uncoated reinf.)	**100%**	**50**	**100%**	Demolition, construction duration, traffic disruption, material transportation, bottom forms, waste disposal
8.0-inch Concrete Deck (galvanized reinf.)	144%	75	96%	
8.0-inch Concrete Deck (stainless reinf.)	313%	100	156%	
1.5-inch LMC	22%	20	55%	Demolition/construction cycles, traffic disruption, material transport, waste disposal
2.25-inch UHPC	74%	**50**	**74%**	Grinding
1.75-inch UHPC	58%	**50**	**58%**	

Carbon Emissions (Long Term) – What if?

	Rel. CO_2 (EPD)	Service Life (years)	Rel. CO_2 per year	Plus More…
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8.0-inch Concrete Deck (stainless reinf.)	313%	100	156%	
1.5-inch LMC	22%	25	44%	Demolition/construction cycles, traffic disruption, material transport, waste disposal
2.25-inch UHPC	74%	**80**	**46%**	Grinding
1.75-inch UHPC	58%	**80**	**36%**	

Full Project

Full Project

- Mechanical Milling 1.0 inch
- Hydrodemolition Containment

Full Project

- Hydrodemolition

Full Project

- Hydrodemolition finish

Full Project

- Mixing Equipment

Full Project

- Transport Equipment

Full Project

- UHPC Placement
- Only 2 lanes closed

Full Project

- Curing without Plastic Sheeting

Full Project

- Grinding and Grooving

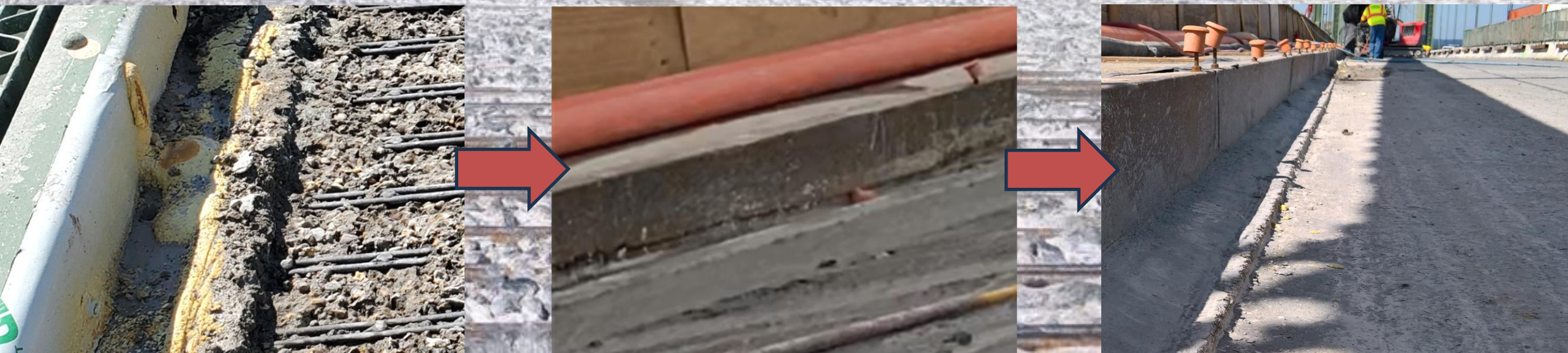
Full Project

- Finished Surface

Challenges and Lessons Learned

Challenges and Lessons Learned

- Challenge to fully contain hydrodemolition slurry with open gutters
  - Containment system required multiple layers of protection
  - Spilled slurry should be washed off structure immediately



Challenges and Lessons Learned

- Deck grinding
  - Quality grinding is important for ride quality

Challenges and Lessons Learned

- Air holes in deck surface
  - Many widespread surface holes on some placements
  - Very few surface holes on other placements
  - About 50% > 5/8-inch deep
  - A small minority of holes 1.5 inch to 2 inches deep
  - Holes were opened up, if necessary, and filled with UHPC slurry with no fiber

Challenges and Lessons Learned

- Air holes in deck surface
  - Many were very small at the surface and easy to overlook.
  - Very small holes were often wider below the surface

Challenges and Lessons Learned

- Fiber balling due to never-before-used automated mixing equipment.
  Addressed by:
  - Slowing down mixing process
  - Adjustments to mixing equipment
  - Removal of fiber balls from fresh mix
  - Areas with many fiber balls on finished surface had surface removed and replaced with new UHPC
  - Isolated fiber balls were cleaned out and filled with UHPC slurry

Challenges and Lessons Learned

Fire Damage

COMPLETED UHPC OVERLAY ON THE DELAWARE MEMORIAL BRIDGE: A SUSTAINABLE SOLUTION FOR PROLONGING THE DECK SERVICE LIFE

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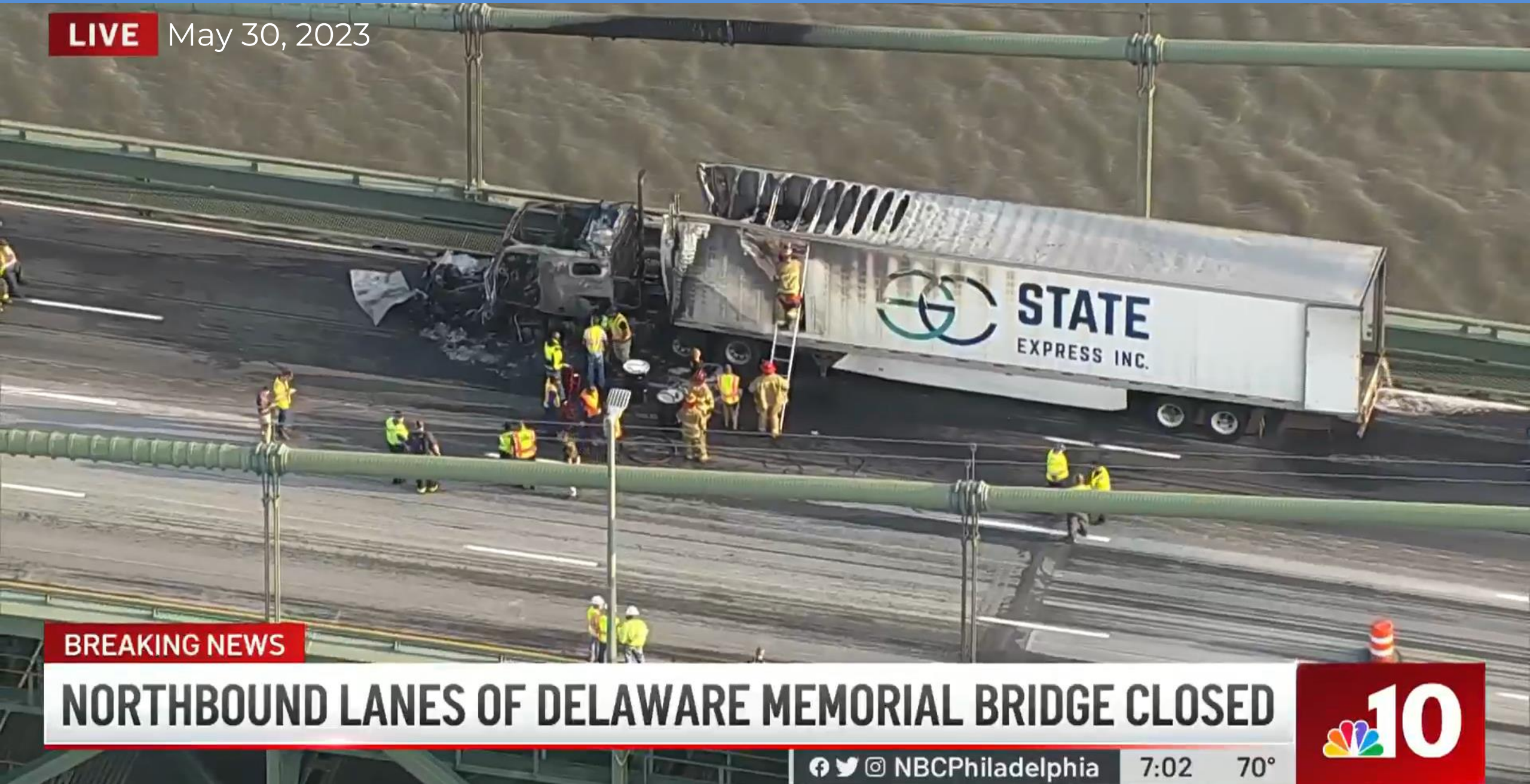


Fire Damage

Fire Damage

- Multiple spalls ≈ 0.75-inch deep
- No evidence of explosive spalling other than very small bits of fiber and UHPC on top of parapet.

Fire Damage Emergency Repair

- Schibeci grinder used to remove area to 1-inch depth
- Left lots of exposed fiber on bottom suface

Fire Damage Emergency Repair

- Bicycle screed used to place UHPC
- No overfill

Fire Damage Emergency Repair

- 14 months later

Challenges and Lessons Learned
UHPC Replacement
(Yes you can!)

UHPC Replacement

- Called for 1 inch removal and replacement
- UHPC was one year old
- UHPC surface was removed by hydrodemolition

UHPC Replacement

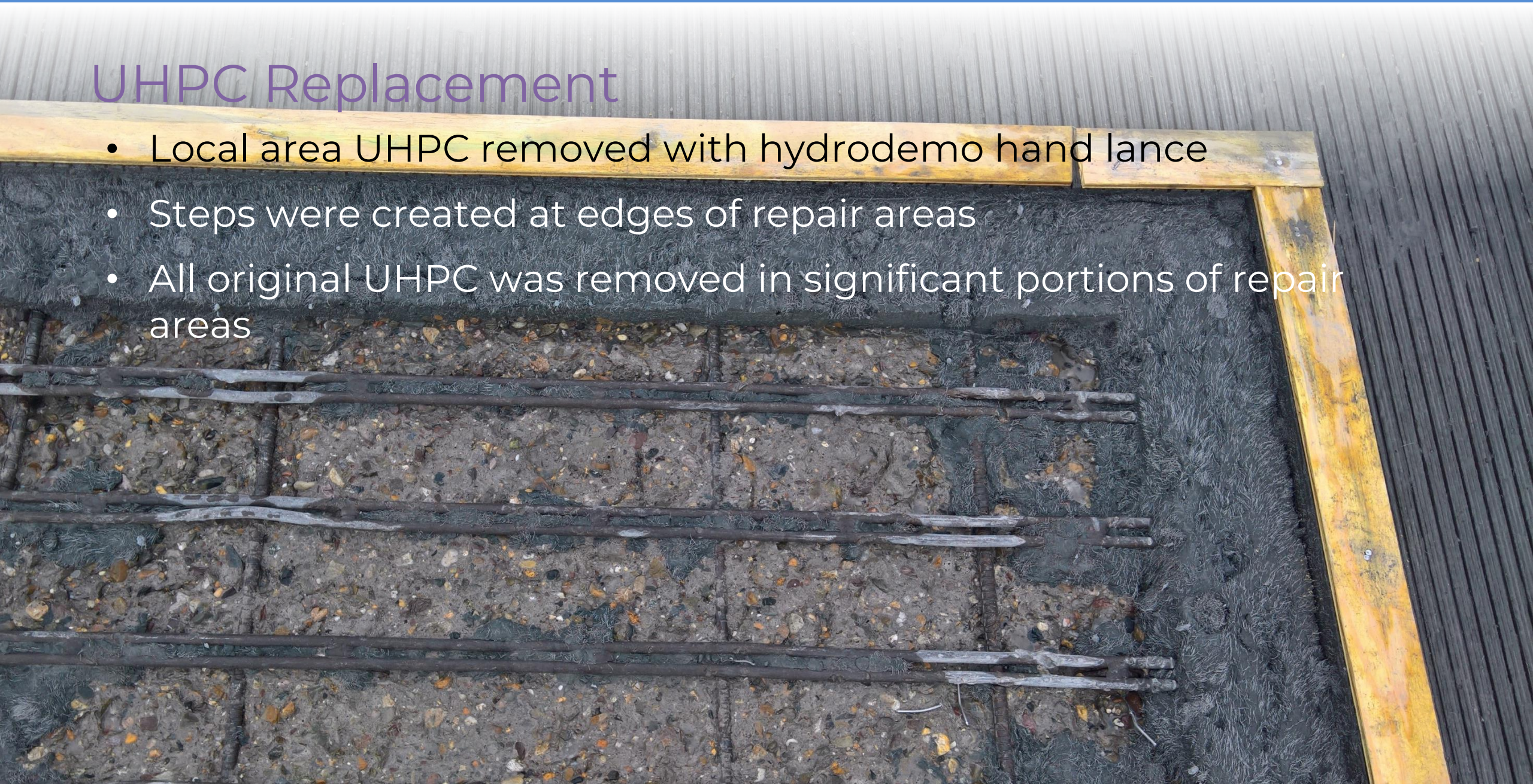
- Hydrodemolition left exposed fiber

UHPC Replacement

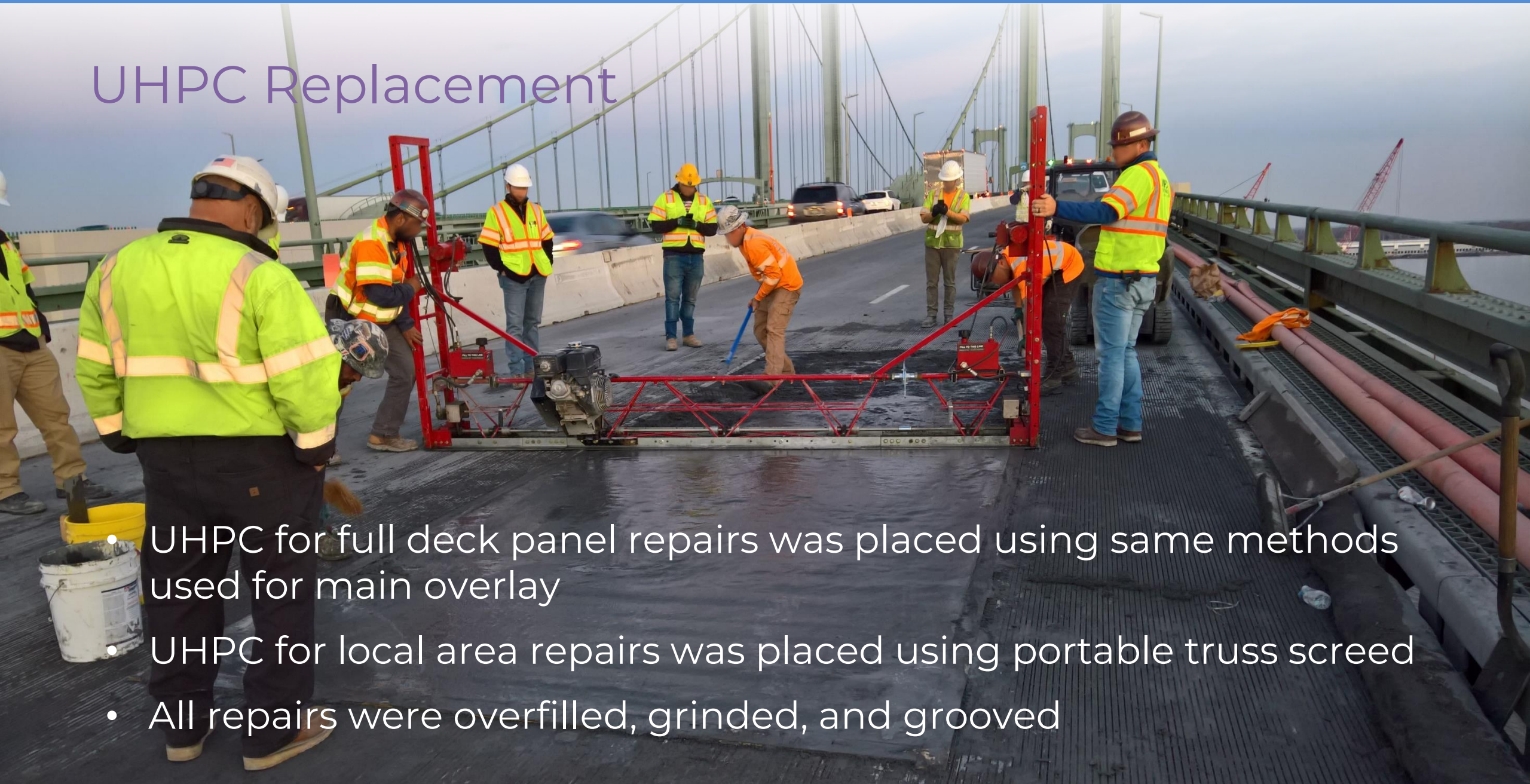
- Hydrodemolition removed all UHPC in some areas
- No blow throughs

UHPC Replacement

- Local area UHPC removed with hydrodemo hand lance
- Steps were created at edges of repair areas
- All original UHPC was removed in significant portions of repair areas



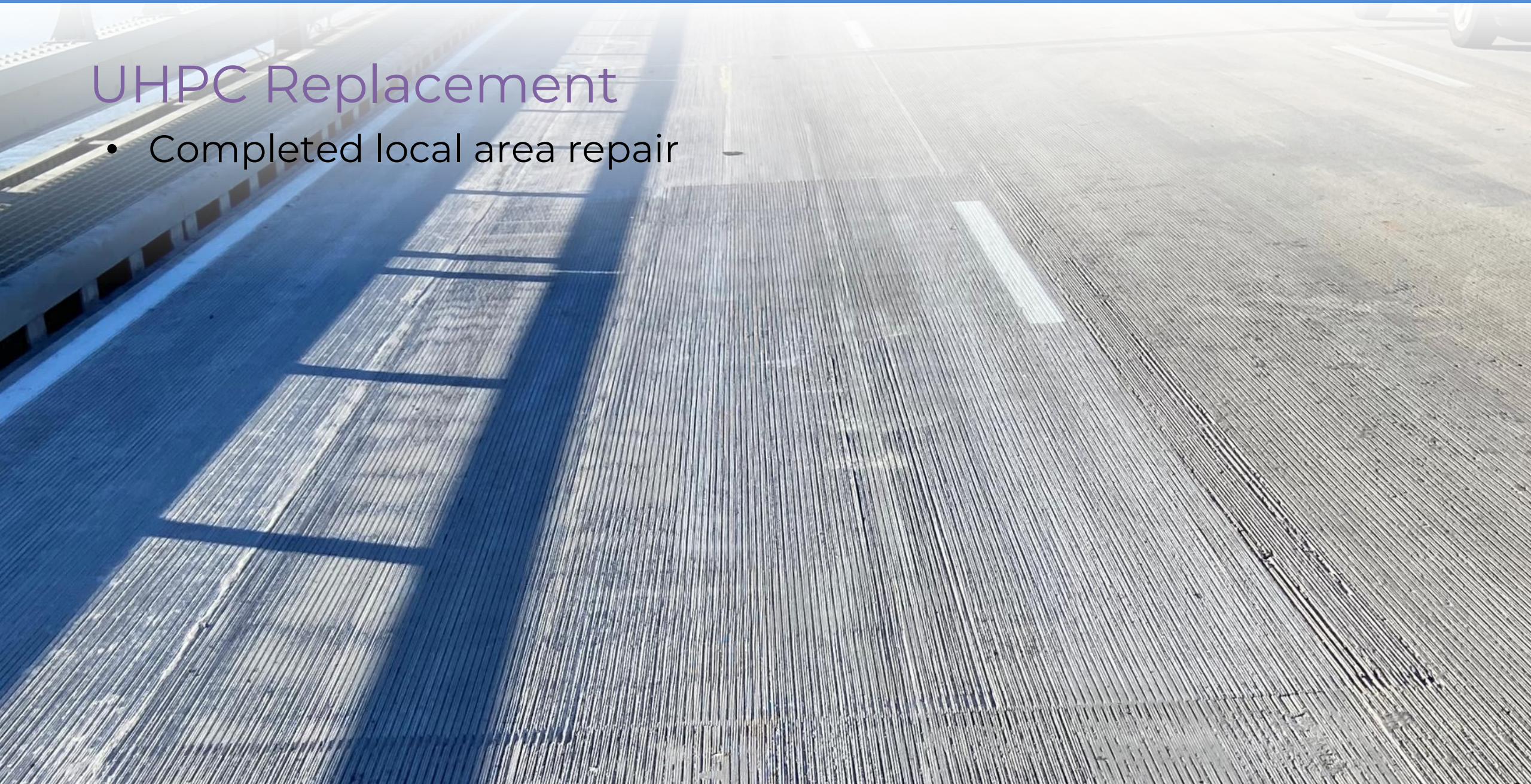
UHPC Replacement



- UHPC for full deck panel repairs was placed using same methods used for main overlay
- UHPC for local area repairs was placed using portable truss screed
- All repairs were overfilled, grinded, and grooved

UHPC Replacement

- Completed local area repair



Challenges and Lessons Learned

Successes

Challenges and Lessons Learned

- Successful placement adjacent to live traffic
- Successful placement in downhill direction

Challenges and Lessons Learned

- UHPC overlays can be successfully installed on major bridges

Recommendations

Recommendations

- **Design**
  - Limit removal/replacement thickness to the concrete cover
    - UHPC will waterproof the deck which should stop corrosion, regardless of chloride levels
    - Reduces cost and maximizes sustainability
- **Demolition**
  - Mill as much as possible to minimize hydrodemolition
  - Ensure tight wastewater containment and wash off spills ASAP
  - Explore alternatives to hydrodemolition such as shotblasting

Recommendations

- **UHPC Mockup**
  - Perform full-size mockup with actual production equipment
  - Use mockup substrate with roughness to mimic bridge deck prep
  - Grind the cured mockup to expose any fiber balls and air holes
  - Repeat, if necessary, until no fiber balls and minimal air holes
- **QC Specifications**
  - Include spec language to ensure surface defects are repaired.
  - Include ride quality criteria if not already part of standard specs.

Conclusions

Conclusions

- Installation of a 2-inch-thick UHPC overlay on the entire deck of the Delaware Memorial Bridge first structure was a success
- First UHPC overlay on an entire long-span bridge in North America
- Largest UHPC overlay in North America by surface area and by volume
- Methods for temporary and permanent repairs of UHPC overlay were successful
- UHPC is expected to extend the service life of the deck by 40 years
- Lifecycle cost analysis indicates that the UHPC overlay is the most cost-effective option for deck rehabilitation/replacement
- Simplified calculation suggests that a UHPC overlay is the most sustainable option for deck rehabilitation/replacement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Thank you
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Appendix

UHPC Overlay Service Life Basis

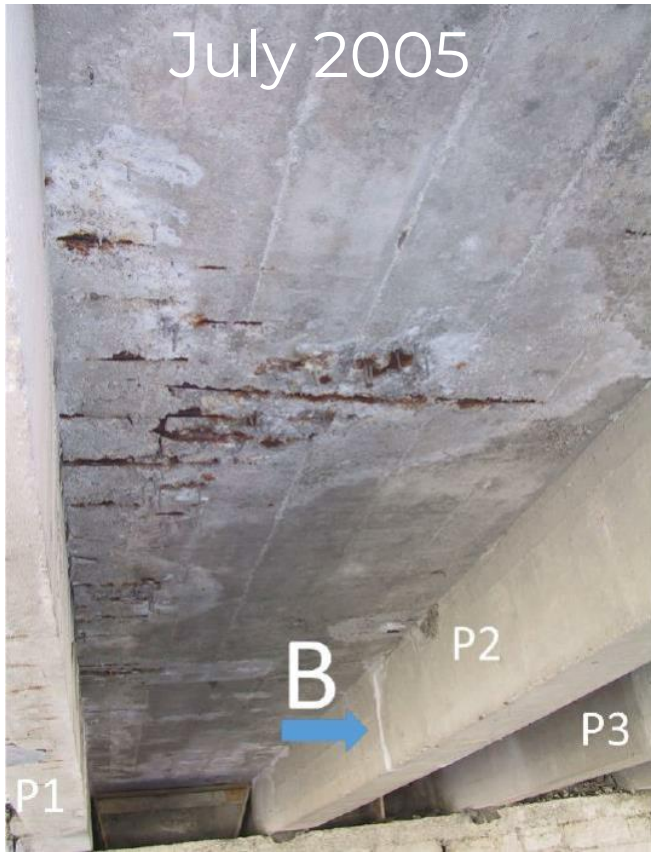
UHPC Overlay Service Life Basis

- 21-year long studies on Treat Island, Maine by Dr. Michael Thomas
  - Chloride penetration after 21 years < 0.25 inch
  - Time to initiate rebar corrosion with 2-inch cover ≥ 400 years

All Photos Credit Michael Thomas and Sean Hayman, University of New Brunswick

UHPC Overlay Service Life Basis

- Morge River Bridge Rehabilitation, Switzerland
  - UHPC placed in 2004
  - Deck soffit left unrepaired
  - No soffit deterioration or water infiltration since then

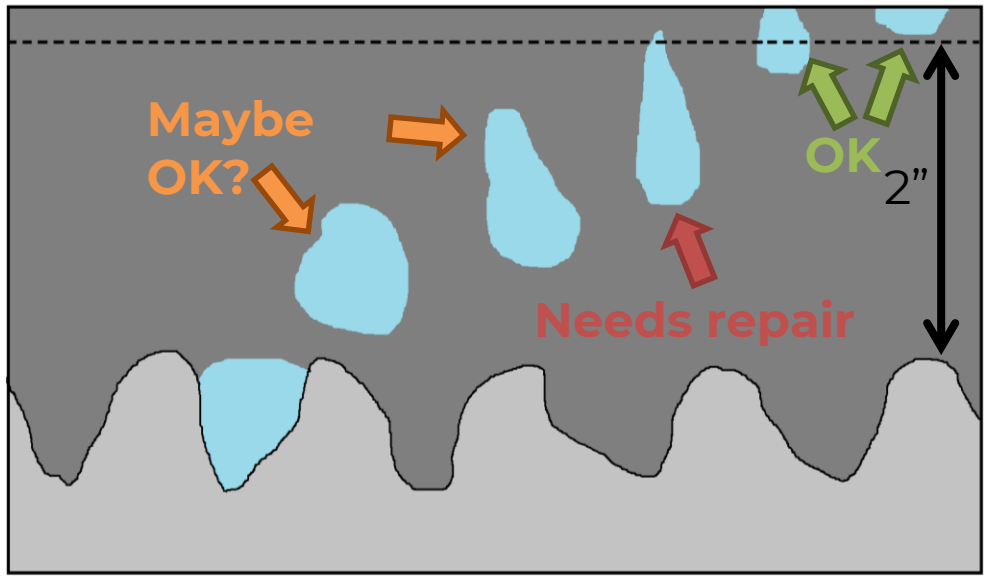


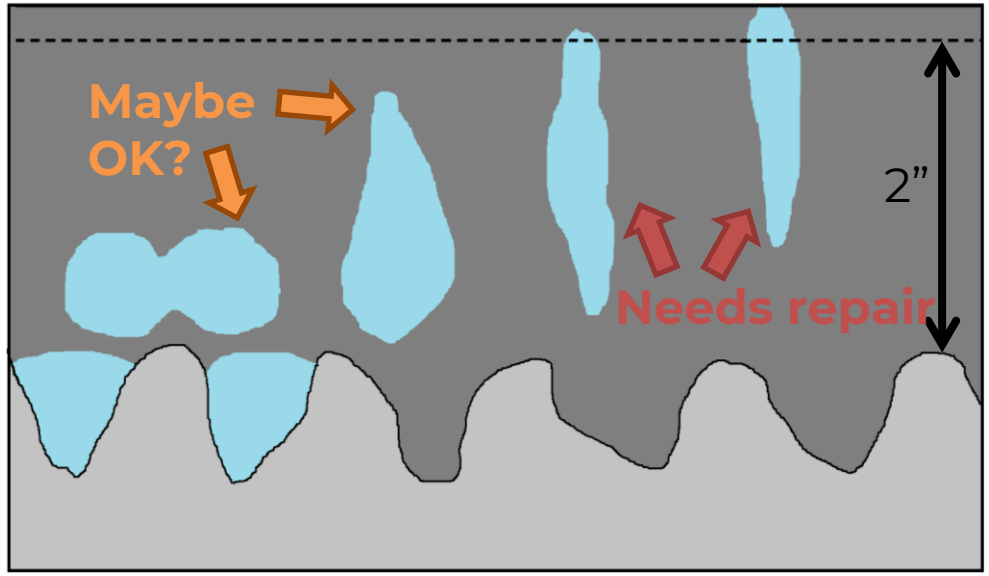
All Photos Credit E. Denarié, EPFL

Challenges and Lessons Learned

Challenges and Lessons Learned

- Air holes in deck surface
  - Indicates less than 100% consolidation
  - Not isolated to this project
  - Industry needs to improve understanding and techniques





Challenges and Lessons Learned

- UHPC overlay surface can be removed and replaced
  - Fire damage
  - Fiber balls
  - Removed 1-inch+ with methods that leave exposed fiber
  - Steps at construction joints

Sustainability

Sustainability

Stage	Product			Construction		Use					End-of-life				Beyond
	A1	A2	A3	A4	A5	B1	B2	B3	B4	B5	C1	C2	C3	C4	D
Embodied	Raw material supply	Transport	Manufacturing	Transport	Construction and installation	Use	Maintenance	Repair	Replacement	Refurbishment	Demolition and deconstruction	Transport	Waste processing	Disposal	Credit for Reuse, Recycling and Recovery Potential
Operational						B6	Energy use								
						B7	Water use								

Cradle-to-gate →
Cradle-to-handover →
Cradle-to-grave →
Cradle-to-cradle →

Graphic Credit EC3, https://buildingtransparency.org

Carbon Emissions

	Rel. CO_2 V1	**Rel. CO_2 V2**	**Rel. CO_2 V3**
Data Source	Various	Winnipeg	EPDs
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8.0-inch Concrete Deck (stainless reinf.)	251%	235%	313%
1.5-inch LMC	16%	14%	22%
2.25-inch UHPC	36%	38%	74%
1.75-inch UHPC	28%	30%	58%