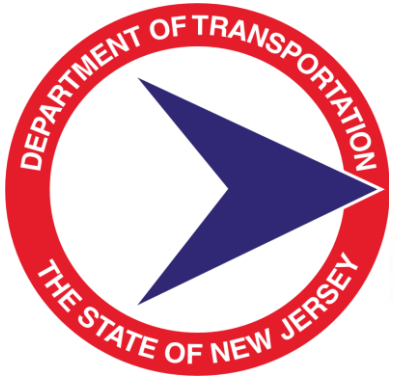
Design, Construction, and Evaluation of UHPC Bridge Deck Overlays for NJDOT

Samer Rabie - New Jersey Department of Transportation

Jess Mendenhall, P.E. - New Jersey Department of Transportation



Introduction

- Pilot project to install and evaluate Ultra-High-Performance Concrete (UHPC) bridge deck overlays.
- Focus on use as a strategy for preserving existing bridge decks.

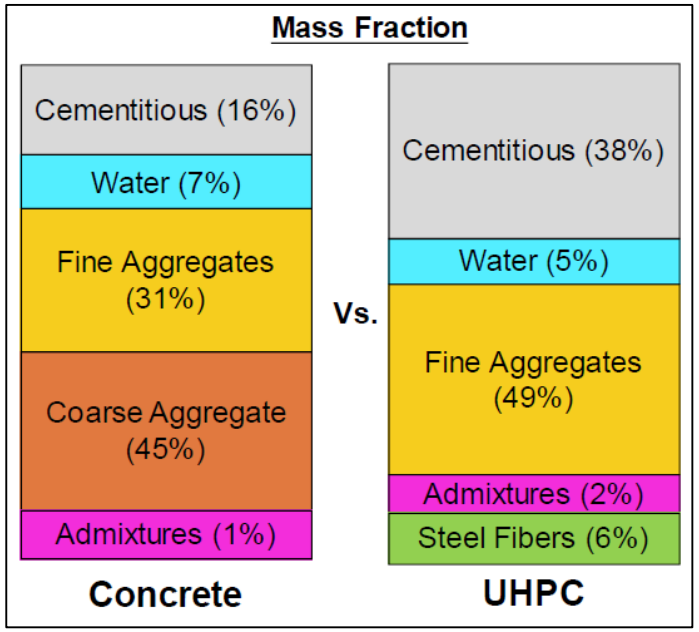
<u>Project Overview:</u>

- 4 bridges
- 48,000 SF total deck area
- 2 Construction contracts (North/South)

UHPC

- Cementitious composite
- Optimized gradation
- Steel Fibers
- Superior mechanical & durability properties
- Self-leveling vs semi-thixotropic mixes

Image Source: FHWA



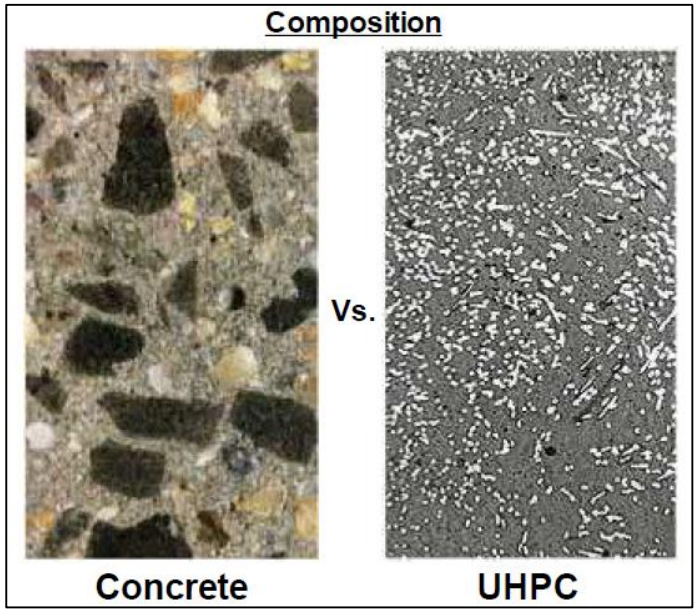


Image Source: FHWA

Program Background

- Past use of overlays for rehabilitation and new decks
- Preservation vs. Reconstruction

<u>UHPC Overlay Advantages</u>:

- Mechanical and durability properties
- Service life, potential life cycle cost savings

<u>UHPC Overlay Disadvantages:</u>

- Cost $ (project avg. cost $30-$45/SF, overlay only)
- Contractor experience with use as an overlay
- Workability of overlay mix

Conventional Overlay (40 years service)

Preservation vs. Reconstruction

- Deck Preservation (UHPC Overlay) vs Deck Reconstruction/Replacement
- Consider remaining service life of primary structural components (deck, superstructure, substructure)
- Consider Life Cycle Cost Analysis (LCCA)

Preservation vs. Reconstruction

LCCA Details:

- Example Bridge:
  - Year Constructed: 1990
  - Footprint: 8000 SF
  - Single Span, Multi-Girder

- **Alternative 1**: UHPC overlay now (w/ super. & sub. Rehab.)

- **Alternative 2**: Do nothing, replace deck in 10 years (w/ super. & sub. rehab.)

- Assumptions:
  - Overall fair condition (Deck/Super/Sub)
  - Assume superstructure or substructure repairs for either alternative to increase remaining component service life
  - Assume 40-year service life of UHPC overlay
  - Structural Cost Only
  - Consider major routine maintenance/rehabilitation

Preservation vs. Reconstruction

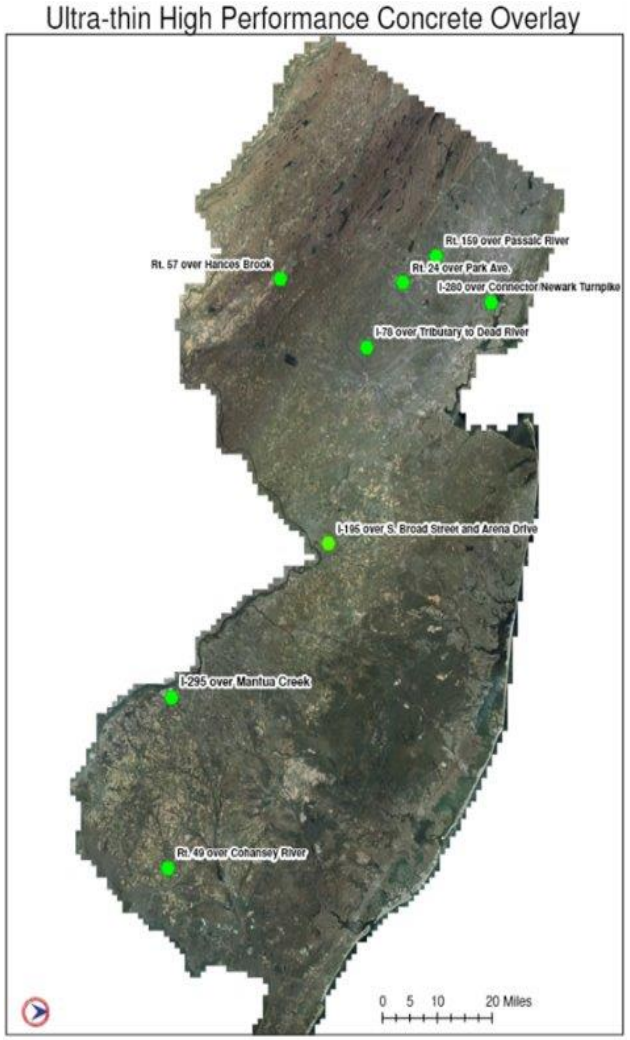
- Initial Construction Cost:
  - UHPC Overlay (deck work only): $480,000
  - Deck Replacement (deck work only): $1,100,000

- Life Cycle Cost (100-year):
  - **Alt. 1:** UHPC Overlay (now): $7.3M
  - **Alt. 2:** Deck Replacement (in 10 years): $7.7M

Bridge Selection

Bridge Selection

- 8 structures fully evaluated and tested
- 4 structures advanced into design and construction
- Considerations:
  - Component condition ratings
  - Deck chloride content
  - Existing overlay depths
  - Need for superstructure and substructure repairs
- Elimination:
  - Chlorides
  - Traffic impacts
  - Load ratings



Bridge Selection

Structure	Structure Type	Deck Area (SF)	Deck Age (yr)
I-295/US 130 NB over Mantua Creek	Steel Multi-Girder	20300	33
NJ 57 over Hances Brook	Prestressed Adjacent Slab	850	<10
I-280 WB over Newark Turnpike (CR 508)	Steel Multi-Girder	15200	40
NJ 159 WB over Passaic River	Prestressed I-Beam	11500	<10

- Deck slab ages: 10 - 40 years
- Deck slab areas: 800 - 20,000 SF
- All bridges existing asphalt overlay
- Deck/Super/Sub Condition - Good or Better

Existing Conditions & Testing

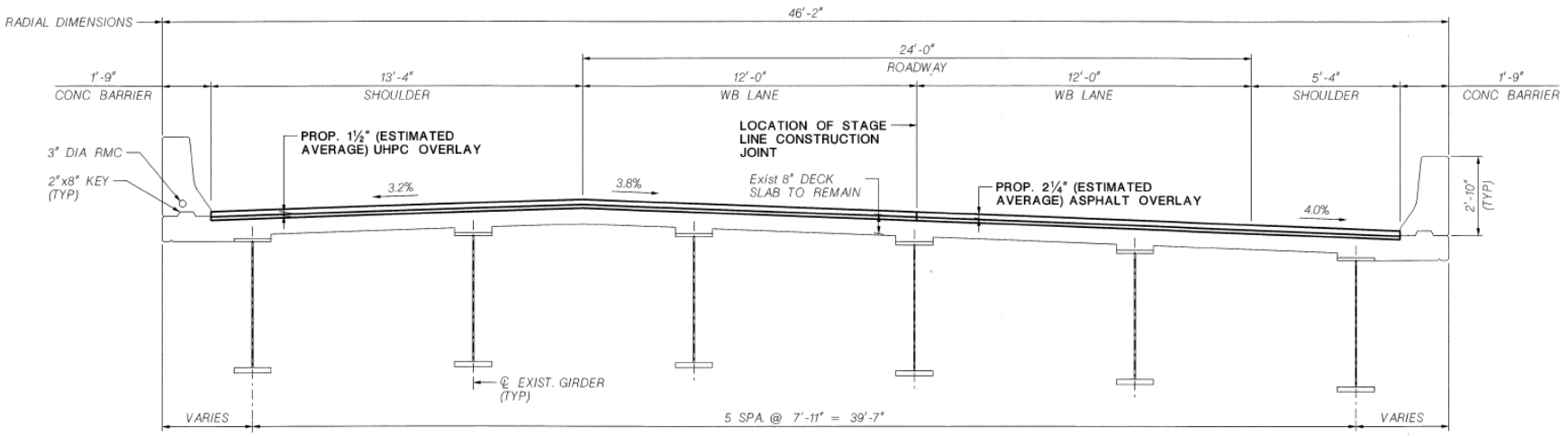
- Core samples were taken at each bridge:
  - Existing overlay thickness
  - Chloride content

- Chloride content:
  - Contamination of deck concrete to remain
  - Baseline data for future testing

- Ground penetrating radar (GPR):
  - Estimate area of deck spall repairs
  - Confirm overall condition of the deck.

Design – UHPC Overlay

- Environmental constraints limited the design to match existing elevations.
- Thin UHPC Overlay:
  - UHPC Overlays can be a minimum of 1” .
  - Average of 1.5” was specified to account for construction tolerances.
- Structures with existing overlay > 3” were designed for a 1.5” UHPC Overlay with an Asphalt topping
- NJ-159 bridge was designed with 2.75” UHPC Overlay, no asphalt topping



PROPOSED TYPICAL SECTION

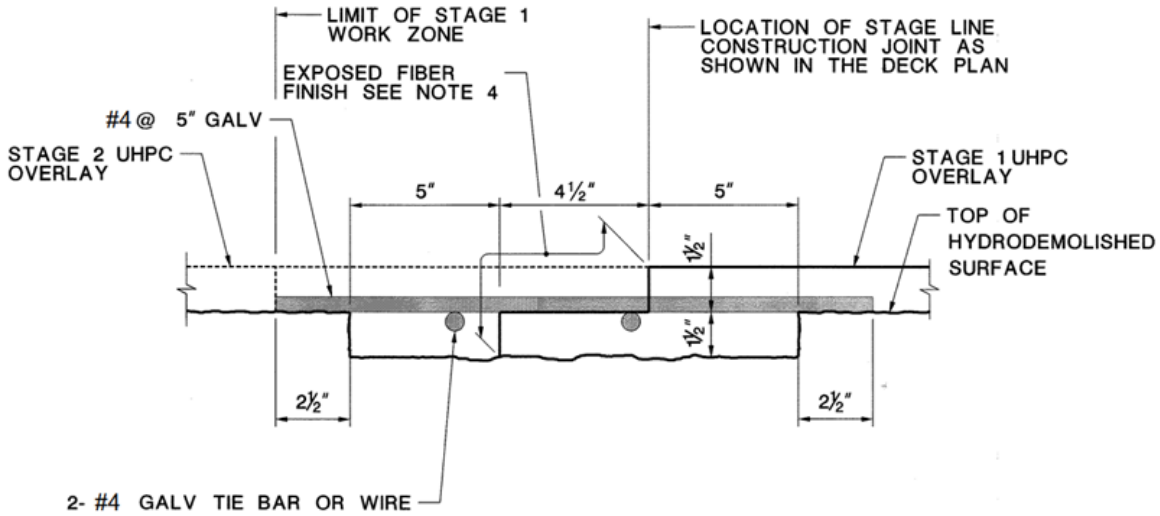
Design – Hydrodemolition

- Hydrodemolition is the preferred removal method for UHPC Overlays.
- Roughened surface with no microfractures creates ideal bonding surface with UHPC.
- The design called for 0.5” removal of the top surface of the deck

Hydrodemolished Surface – Typical

Design – Construction Joint

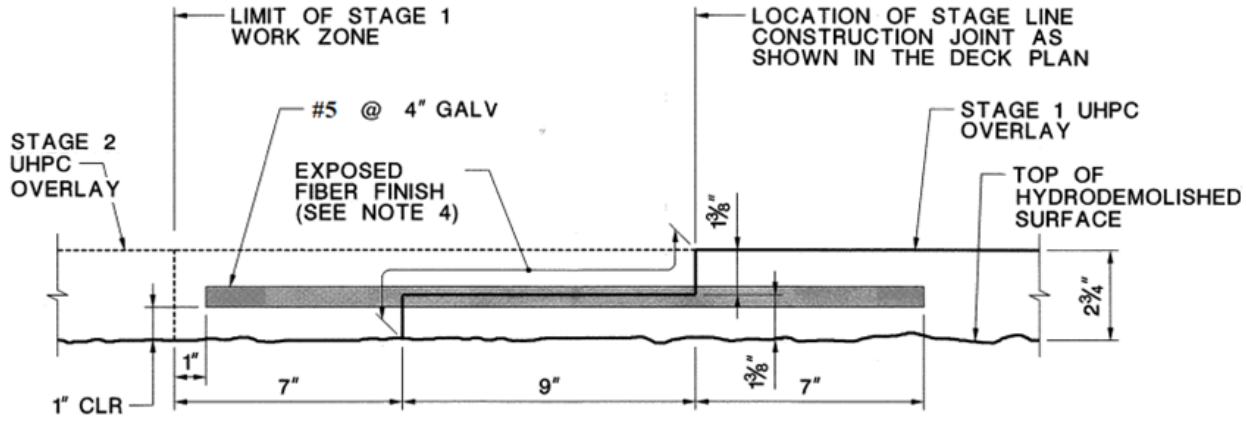
Construction Joint – 1.5” UHPC Overlay



UHPC OVERLAY CONSTRUCTION JOINT DETAIL

NTS

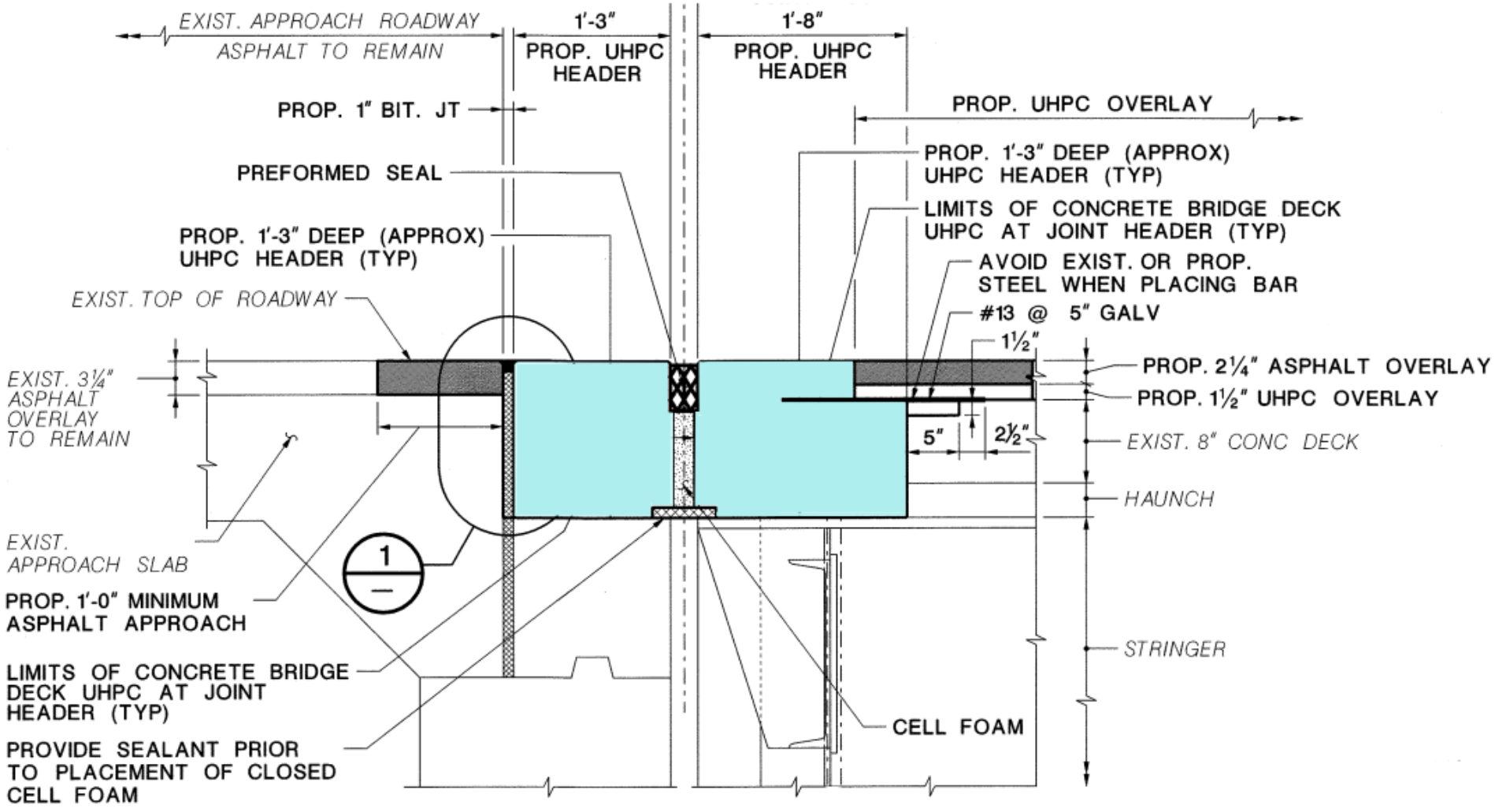
Construction Joints – 2.75” UHPC Overlay



UHPC OVERLAY CONSTRUCTION JOINT DETAIL

NTS

Design – Headers (Deck Joints)



Material Testing

- Performance Specifications
- Verification Testing
- Acceptance Testing
- Fresh Properties
- Both contractors choose to use proprietary UHPC mixes

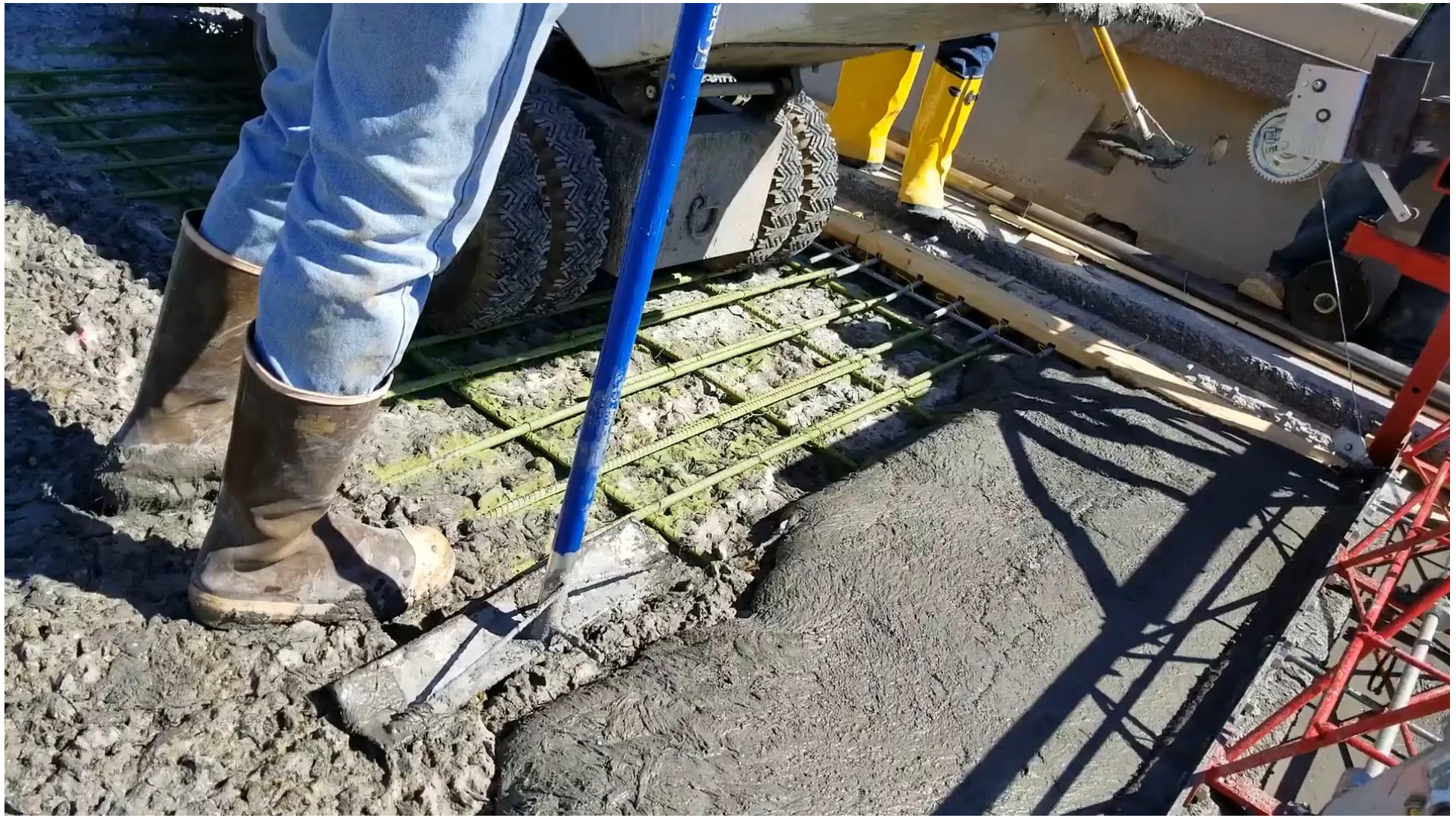
UHPC Material Properties		
Description	**Test Method**	**Acceptance Criteria**
Compressive Strength	C39 as modified by ASTM C 1856	-18,000 psi at 28- day moist cure
Direct Tension 1st Cracking Strength	AASHTO T 397	fcr > 1,000 psi
Direct Tension Post-Cracking Hardening Ratio	AASHTO T 397	Fp/fcr ≥ 1.25
Bond Strength	ASTM C 1583, Bonded to an Exposed Aggregate Concrete Surface	100% failure in substrate concrete with concrete compressive strength ≥ 4ksi, or > 400 psi
Modulus of Elasticity	C469 as modified by ASTM C 1856	≥ 6,500 ksi
Long-Term Shrinkage	C157, initial reading after set, as modified by ASTM C 1856	≤ 800 micro-strain
Rapid Chloride Ion Penetrability	AASHTO T277/ASTM C1202	≤ 250 coulombs (w/o steel fibers)
Scaling Resistance	ASTM C672	≤ 3
Freeze-Thaw Resistance	C666A, 600 cycles, as modified by ASTM C1856	Relative Dynamic Modulus of Elasticity > 95%
Alkali-Silica Reaction	ASTM C1567	Innocuous

UHPC Overlay Mockup Tests : Per the contract documents, contractors were required to successfully place a 4’x12’x3” deep rectangular test slab of UHPC with a grade of 8% in the longitudinal direction.

Construction – Hydrodemolition

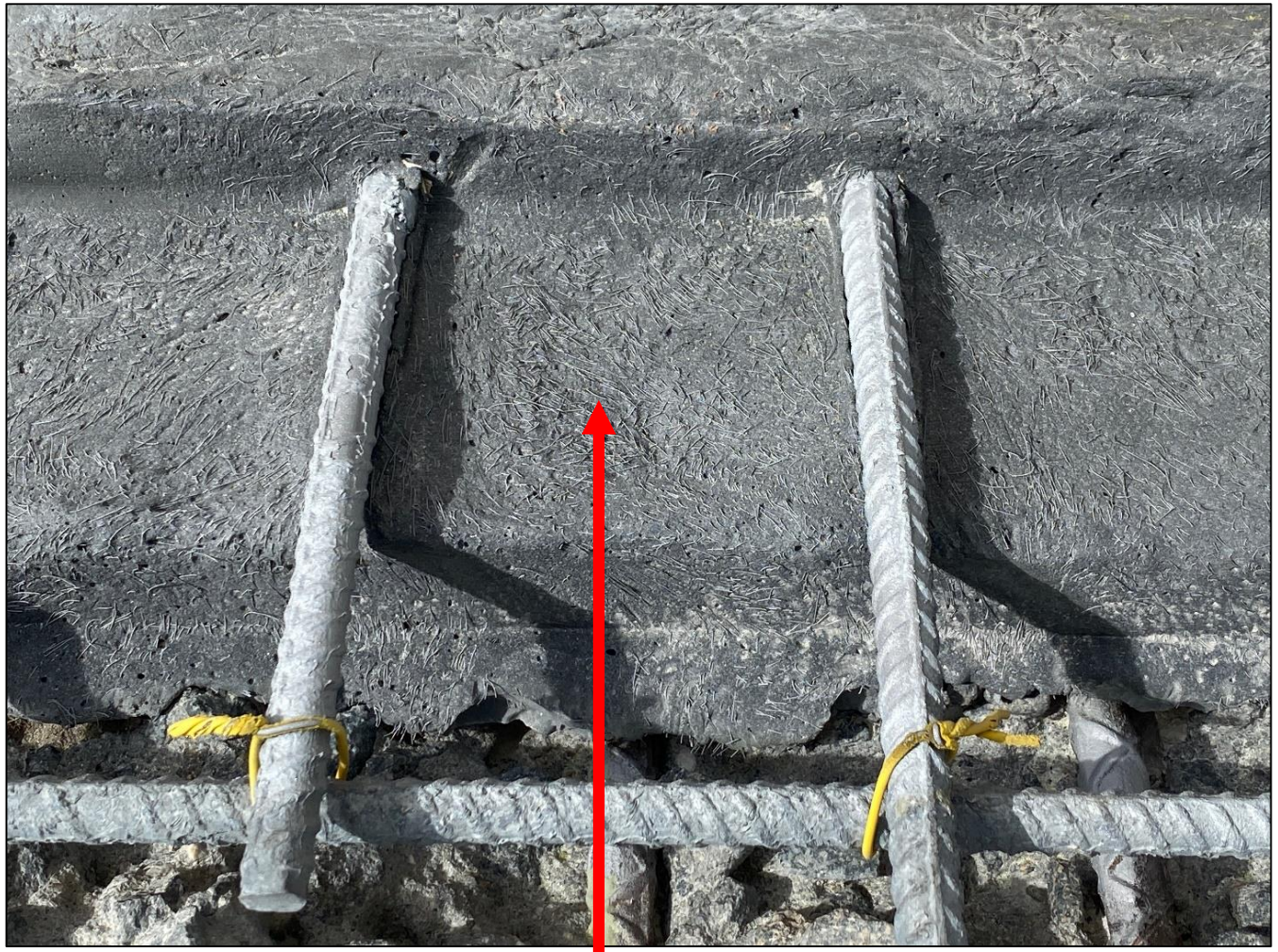
Construction – UHPC Placement

Construction – UHPC Placement



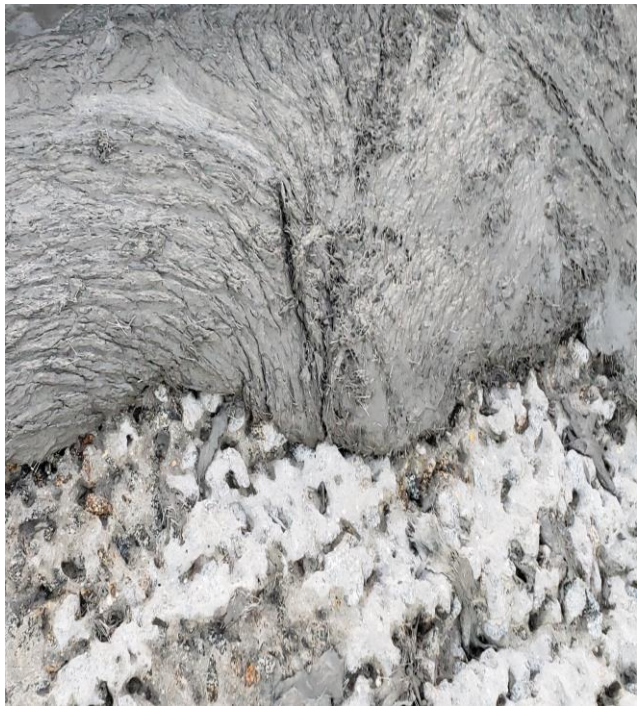
Construction – Construction Joint

Exposed Fiber



Step

Construction – Curing/Finishing



Lessons Learned

- If an overlay on top of the UHPC is required, consider BDWSC, curing materials must be removed.
- GPR to determine concrete cover, overlay thickness and reinforcement locations.
- Construction surveys for each interim stage.
- Specify watertight forms, top forms, minimum of ¼” to ½” overfill, and surface grinding.

Lessons Learned

- To replace deck joints use conventional HPC with UHPC at the surface.
- Self-consolidating UHPC is preferred for the full-depth UHPC header placement to ensure consolidation.
- Partial depth UHPC headers will be recommended with staging limitations.

Lessons Learned

- Surface defects were addressed before asphalt paving.
- UHPC slurry with no fibers was placed in air voids.
- Define proper repair methods in the contract documents for aesthetic or structural anomalies.

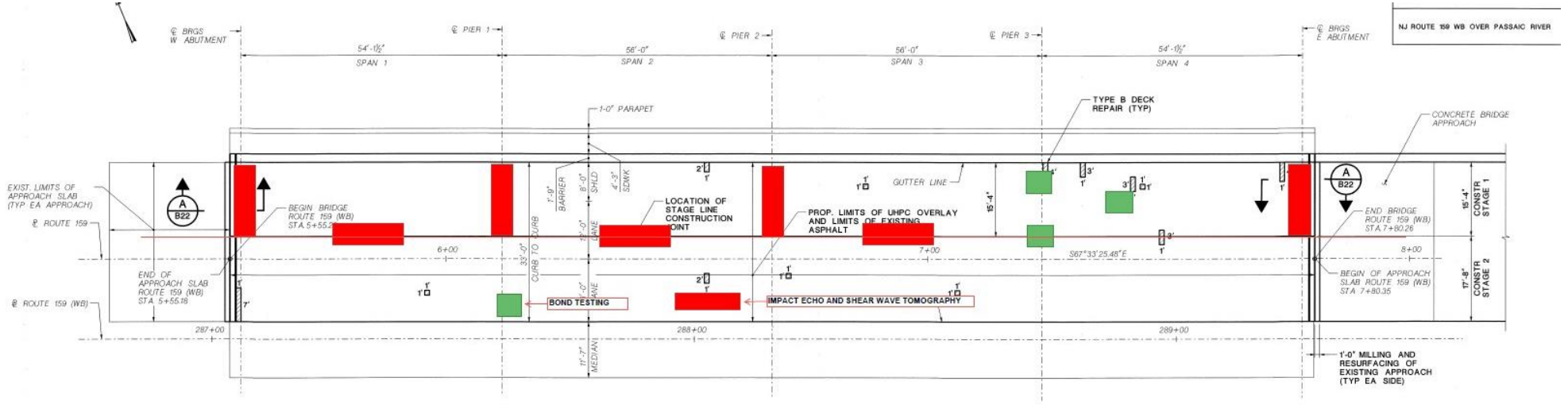
Evaluation

- Two Bridges selected for annual Evaluations :
  - I-295 NB & US 130 NB over Mantua Creek in Gloucester County
    - (UHPC with Asphalt Topping)
  - NJ 159 WB over Passaic River in Morris County
    - (UHPC diamond grinding)
- Objective is to ensure the bond is intact between UHPC and the existing concrete.
- Initial survey to establish baseline conditions followed by periodic monitoring over succeeding years.

Evaluation

Testing Program :

- Non destructive testing (NDT)
  - Impact Echo (IE) : depth and location of potential debonding or voids.
  - Ultrasonic shear wave tomography (MIRA) : 3D representation to identify the location and orientation of embedded features.
- Physical Sampling and Lab Testing
  - Pull-off testing (ASTM C1583)
    Bond Strength and Failure Mode
  - Chloride profile (ASTM C1152)
    0.5 ” and ~ 1.0 ” below the UHPC Overlay
- Testing Plan:

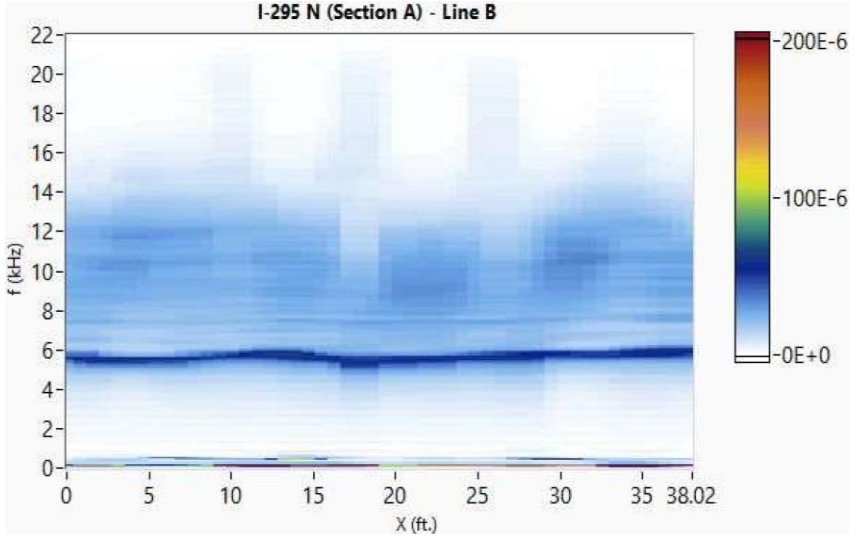


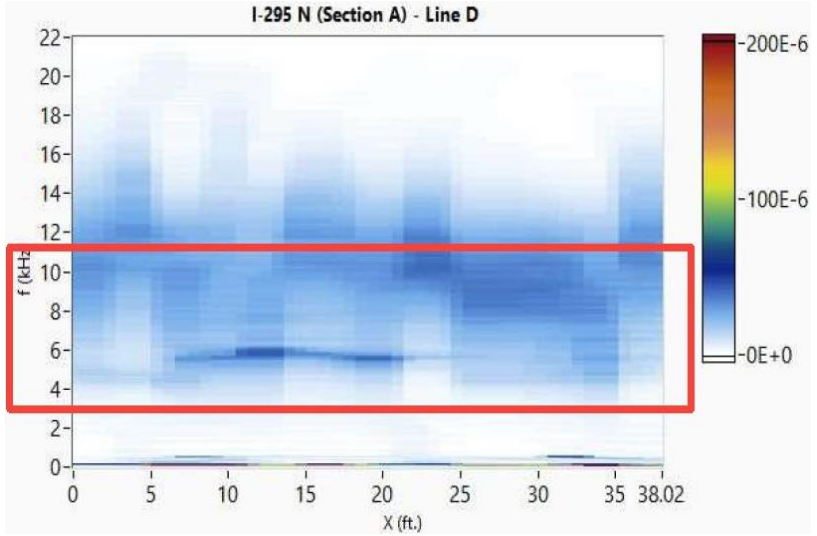
Evaluation

IMPACT ECHO

Impact echo is a commonly used NDE method for evaluating concrete and reinforced concrete elements for discontinuities, delamination, and thickness verification.

ASTM C1383-15 “Standard Test Method for Measuring the P-Wave Speed and the Thickness of Concrete Plates Using the Impact-Echo Method”

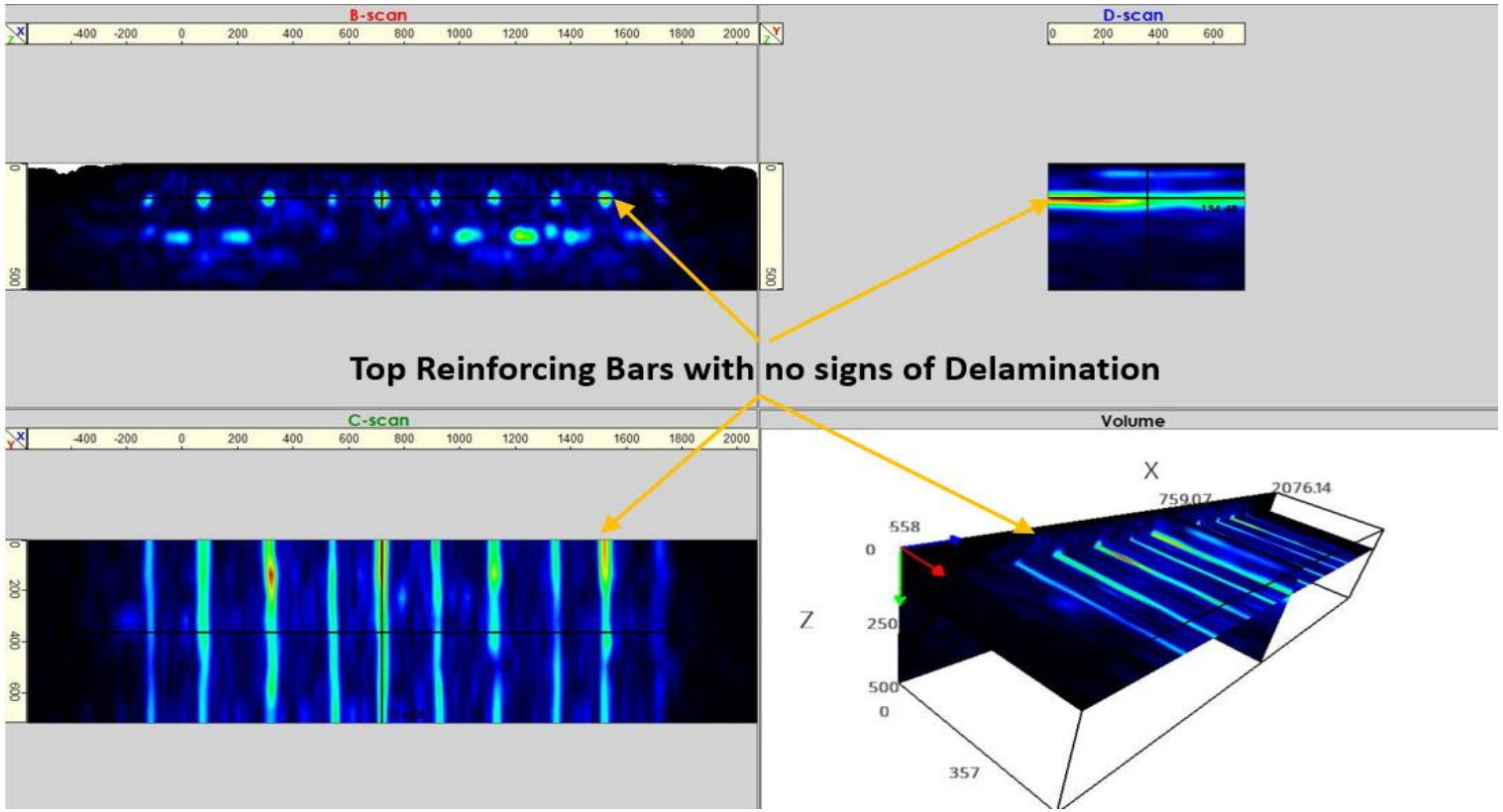


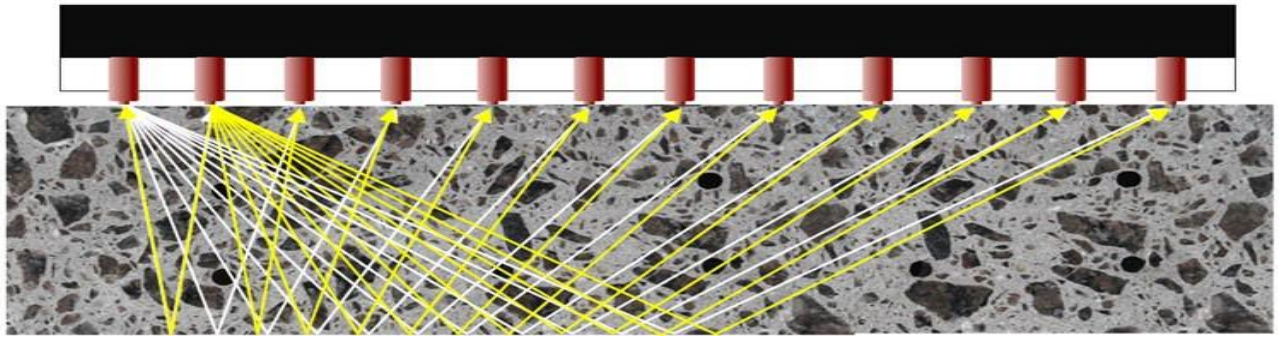


Evaluation

ULTRASONIC TOMOGRAPHY

Analysis of the signal times and angles of incidence between transducers allows for the construction of a 3-D representation of embedded features (tomograph).





Evaluation

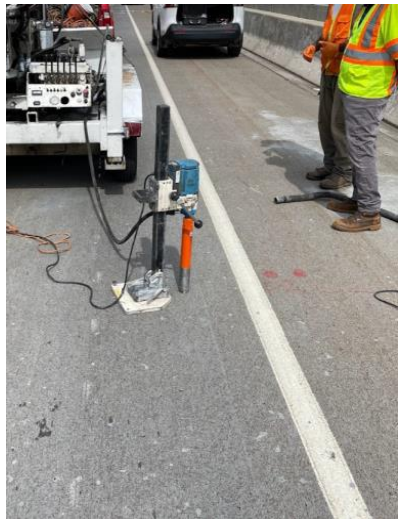
Pull-off Testing (ASTM C1583)

Bond Strength and Failure Mode

Location #	Bond Strength (PSI)	Failure Mode
P 11	184.7	c
P 12	376.7	a
P 13	200.9	a

Chloride Profile (ASTM C1152)

Within and below UHPC Overlay



Core Number	Depth (inches)	
	0.5” (Within UHPC)	1.0“ (Below UHPC)
	Chloride at Depth (PCY)	
C1	0.807	0.603
C2	3.221	0.519
C3	0.460	0.452
C4	0.464	0.44

Conclusions

- The ultrasonic tomography and impact echo testing indicated that the bond between UHPC and concrete substrate is sound.
- Bond strength test data demonstrates that the desired bond was achieved between UHPC and the substrate concrete.
- Chloride content is also within expectations.
- The baseline testing was successful, with no significant defects encountered
- Future monitoring at the same locations as well as different from the baseline to allow to maximize testing area.
- NJDOT is considering installing UHPC overlays on newly constructed decks as well as decks with lower condition ratings for future projects.
- A deeper overlay (with deeper existing deck removal) will be regarded as a viable alternative for structures that need a major deck rehabilitation.
- Incorporating UHPC for several applications in the new design manual, including P&R.

Thank You

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