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Ultra-High Performance Concrete (UHPC) Bridge Deck Overlays as a Corrosion Mitigation Strategy to Ensure Longer Service Life

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Source: FHWA.

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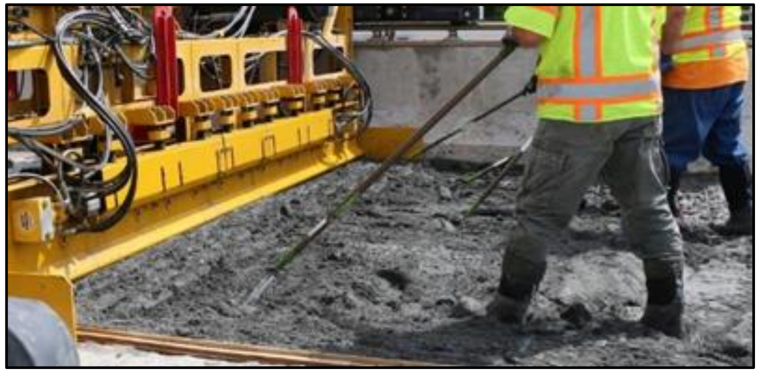
UHPC Overlays as a Bridge Preservation Method



Source: FHWA.

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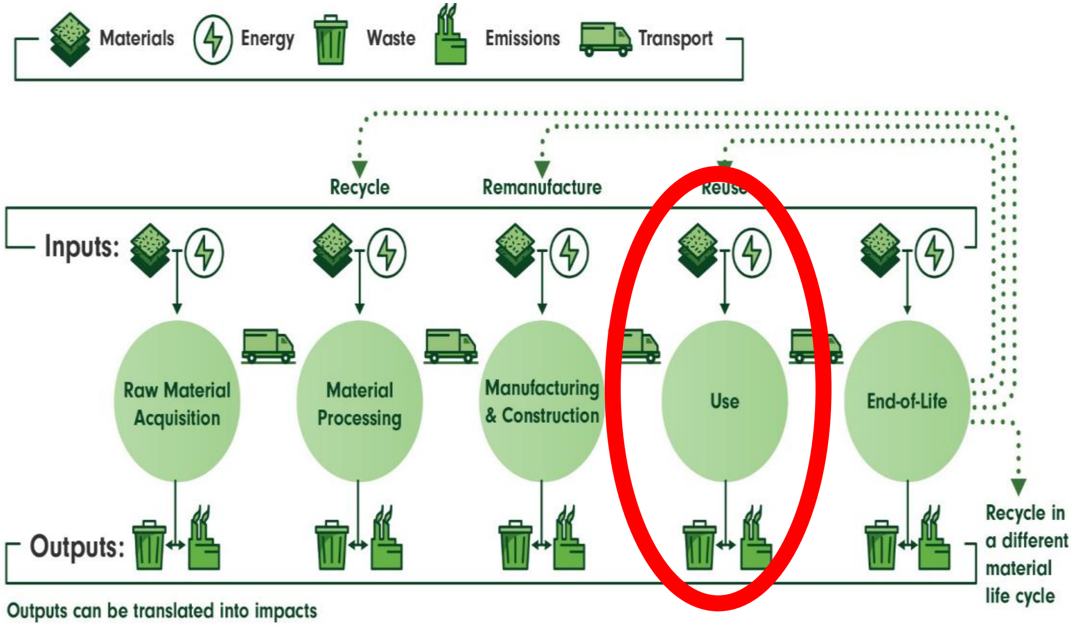
UHPC overlay properties (FHWA 2019):

- Cement-based composite with an optimized gradation of granular constituents.
  - **High cementitious contents.**
  - **Water-to-cementitious materials ratio <0.25.**
  - **Increased admixture dosages.**
  - **Fiber reinforcement dosage of 3.25 percent.**
- High compressive strength (>18,000 psi).
- High sustained tensile strength (>720 psi).
- Thixotropic in nature.
- Reduced overlay thickness compared to conventional overlays.

Approach to Sustainability and Cost Analysis

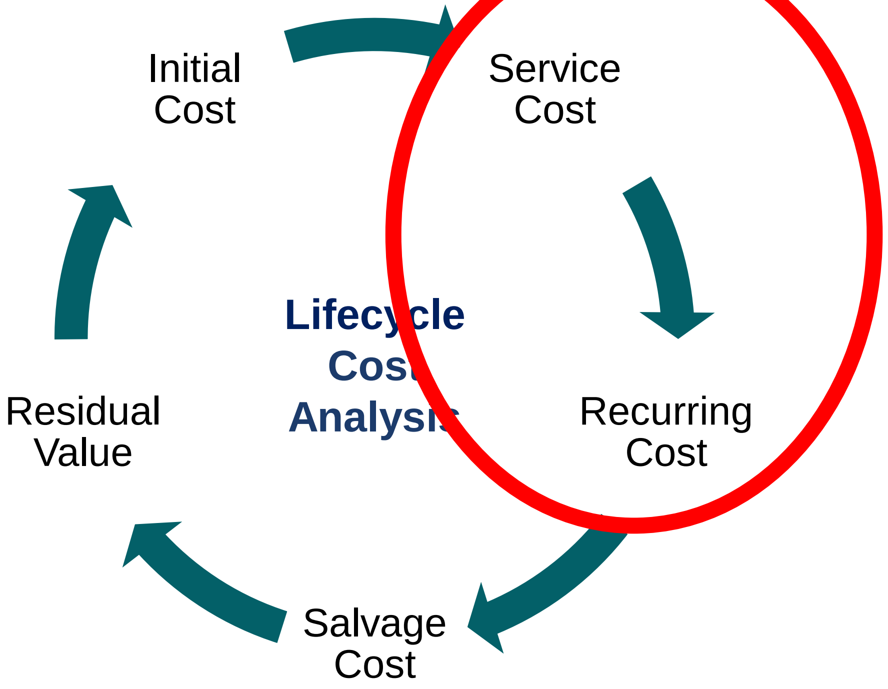
Affected by the Performance of the Material

LCA



Source: FHWA (2020).

LCCA



Source: FHWA.

Previous Research on UHPC LCA/LCCA*

Material Constituents	Material Performance	LCA/LCCA Outcomes
High environmental impact and high materials costs	**Improved durability and mechanical performance**	
High cementitious content	Longer service life for critical durability	**Potential reduction in environmental impact and lifecycle costs when service life is considered**
Steel fibers	Optimized structure geometry from improved mechanical performance	
High-quality filler material	Less maintenance costs	
High admixture dosage		


TECHNOTE

Ultra-High Performance Concrete (UHPC) Overlays: An Example of Lifecycle Cost Analysis

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INTRODUCTION

In the United States, ultra-high performance concrete (UHPC) is a nascent solution for thin bonded overlays and highway bridge deck partial-depth replacements. In the United States, UHPC has been used for this purpose since 2016. The first adopter, Switzerland, has used UHPC in this manner since 2004.[1,2] UHPC overlays are expected to add decades of service life to existing bridge decks. The expectations for enhanced service life are based on the following key properties of UHPC-class materials: very low permeability, strong bond strength to conventional concretes, and post-cracking tensile ductility through the formation of uniformly distributed microcracks.[2–4] Additionally, an investigation into the first UHPC bridge deck overlay in Switzerland revealed that the deterioration of the bridge deck, which was visible from the soffit of the bridge deck prior to installation of UHPC overlay, had not worsened in more than decade since the installation of the overlay.

OBJECTIVE

There are two challenges to broader adoption of UHPC overlays: lack of long-term in-service performance data and high initial material cost of UHPC relative to other bridge deck overlay materials. This document provides information addressing the latter challenge. The lifecycle cost analysis (LCCA) can be used to counter arguments against the high initial material costs of UHPC overlays. This document presents a summary of an LCCA study that was performed by a signature bridge owner evaluating different overlay options for one of their bridges. The analysis compared UHPC overlays with several thicknesses with conventional concrete overlay solutions and complete deck replacement. The findings show the net present cost of the different solutions and a break-even analysis. Lastly, the study also represents an example of what bridge owners could do to create a project-specific cost comparison.

BACKGROUND

Formed by an interstate compact in 1968, the Delaware River and Bay Authority (DRBA) is a bi State government agency that provides transportation links between Delaware and New Jersey. DRBA operates two ferry ways, five regional airports, and most notably, in the context of this document, the Delaware Memorial Bridge (DMB) structures, which are shown in figure 1; this document focuses on the First Structure. The First Structure carries northbound I–295 from Newcastle, DE into New Jersey, and onto the New Jersey Turnpike. The First Structure bridge includes a 3,650-ft suspension bridge with a 2,150-ft main span, plus elevated approach structures composed of girder-supported spans and deck-truss spans at each end, for a total bridge length of 10,795 ft. The DMB structures are a key component of the I–95 corridor connecting the Washington, DC-area with New York, NY, carrying

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Image Source: FHWA (Haber et al. 2023).

*See Harvey et al. (2020) and Haber et al. (2023).

UHPC Bridge Deck Overlay Performance

UHPC overlays are used to extend the lifespan of a bridge deck; however, a long service life for the overlay must still be ensured:

- Part I: Structural Performance of Joints in UHPC Bridge Deck Overlays to Ensure Longer Service Life.
- Part II: UHPC Bridge Deck Overlays as a Corrosion Mitigation Strategy to Ensure Longer Service Life.

Source: FHWA.

Source: FHWA

Part I: Structural Performance of Joints in UHPC Bridge Deck Overlays to Ensure Longer Service Life

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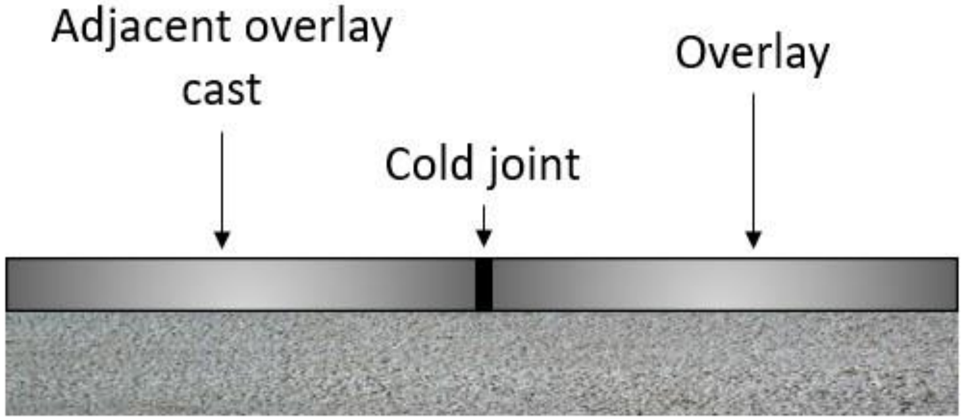
Cold Joints in Overlays

UHPC overlays are commonly constructed in phases:

- Cold joint occurs between adjacent phases.
- Cold joints may allow water and chlorides to permeate the substrate deck concrete.
- Cold joints may be the weak link from a structural standpoint.

Source: FHWA.

Schematic



Source: FHWA.

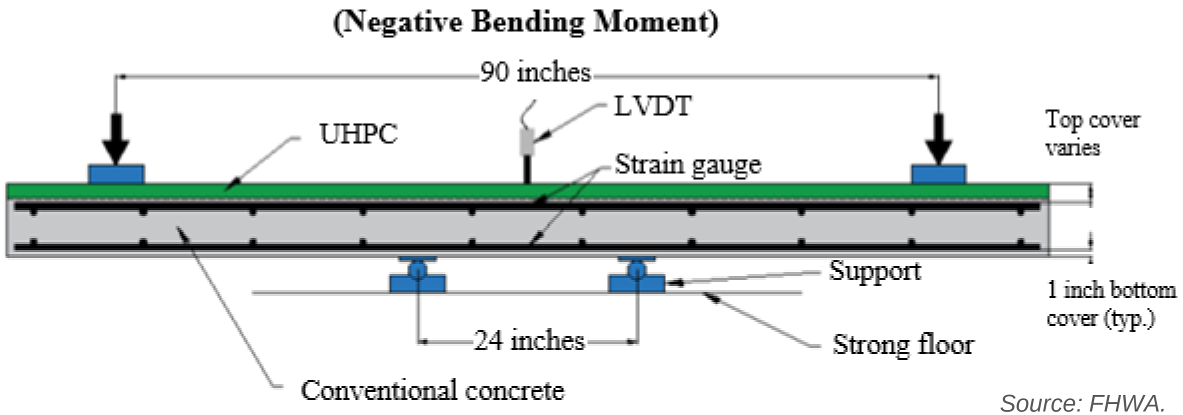
Cyclic Structural Testing

- Negative moment bending (UHPC is in tension).
- Conventional concrete substrate precycled to represent mature deck.
- Roughened surface produced by hydro-demolition.
- Specimens cycled at incrementally increasing moments corresponding to the UHPC's cracking stress and localization strain.

Source: FHWA.

Source: FHWA.

Cold Joint Detailing (1 of 3)



Source: FHWA.

Three scenarios were considered for structural testing:

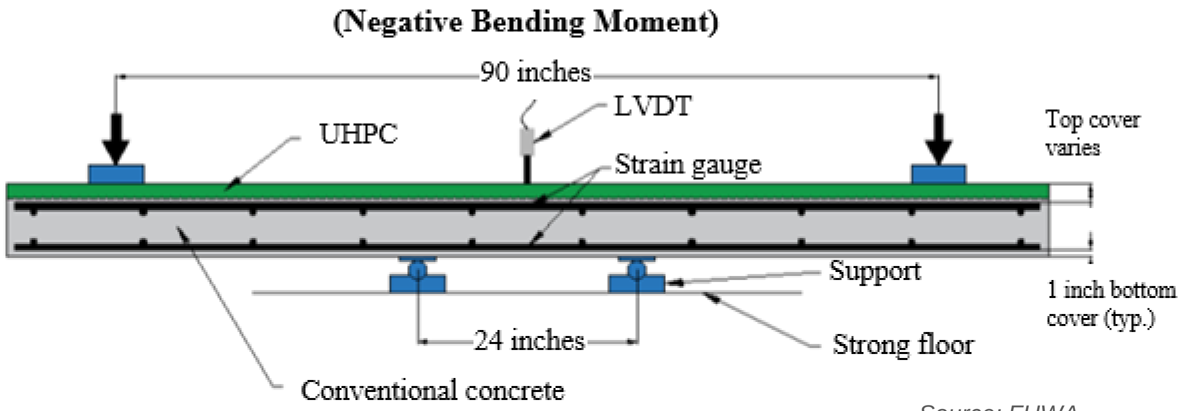
- ***Reference (no cold joint).***
- Cold joint with bonding agent.
- Stepped cold joint.

Source: FHWA.

Cold Joint Detailing (2 of 3)

Three scenarios were considered for structural testing:

- Reference (no cold joint).
- ***Cold joint with bonding agent.***
- Stepped cold joint.



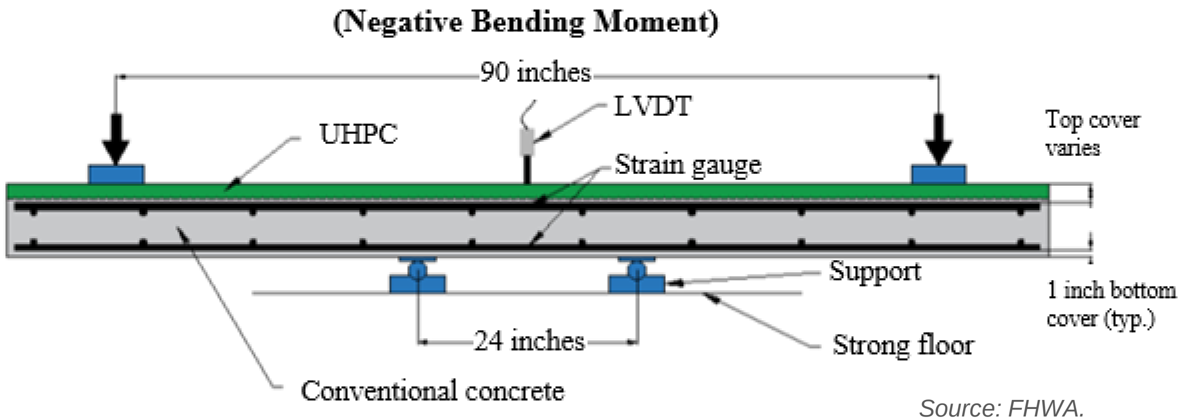
Source: FHWA.

Source: FHWA.

Cold Joint Detailing (3 of 3)

Three scenarios were considered for structural testing:

- ▶ Reference (no cold joint).
- ▶ Cold joint with bonding agent.
- ▶ ***Stepped cold joint.***



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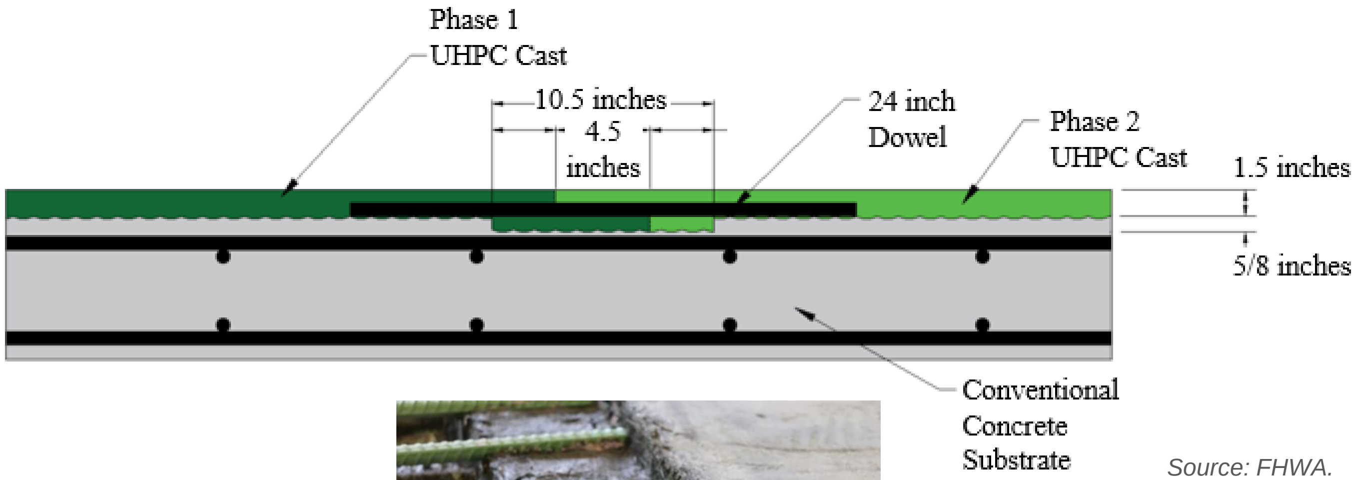
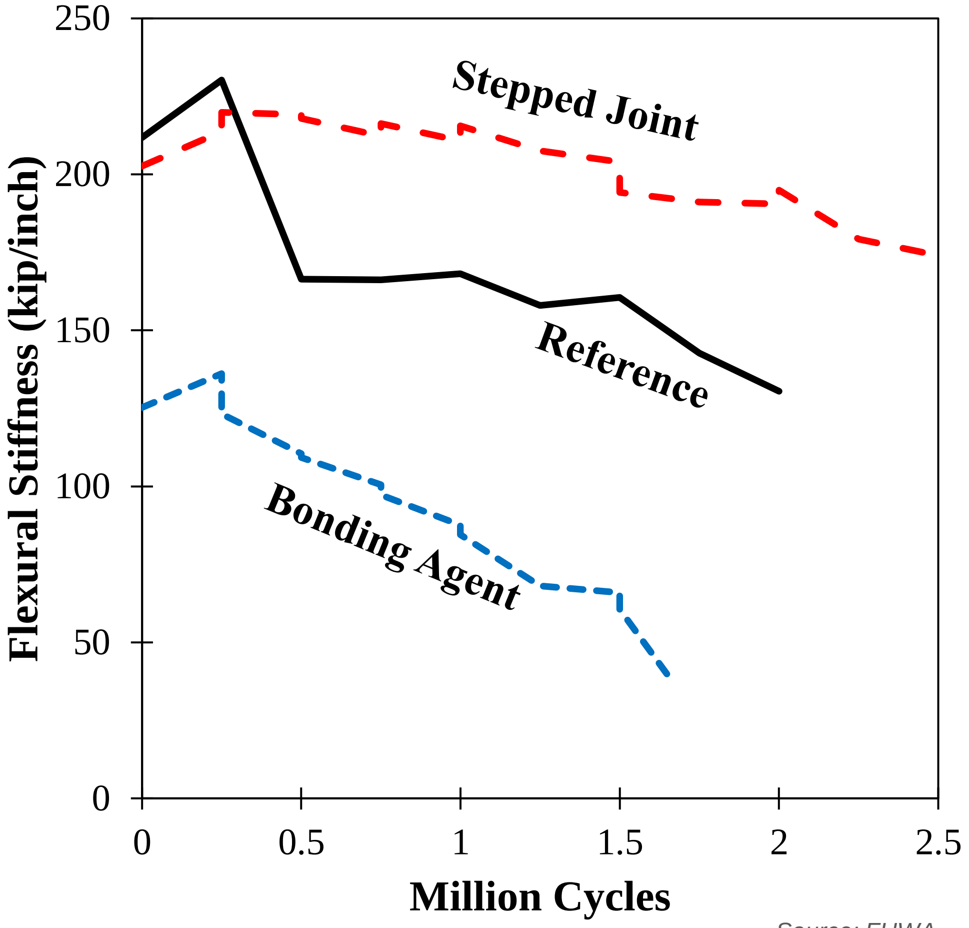


Source: FHWA.

Source: FHWA.

Flexural Stiffness During Cycling

- Reference sample:
  - Flexural stiffness was maintained below the tensile cracking moment.
  - Some reduction in stiffness was observed when cycled beyond the tensile cracking limit.
- Cold joint with bonding agent:
  - Flexural stiffness began to reduce during cycling.
  - Joint opening continued to expand during cycling.
- Stepped cold joint:
  - Flexural stiffness was maintained throughout cycling.
  - Joint width did not appear to expand.

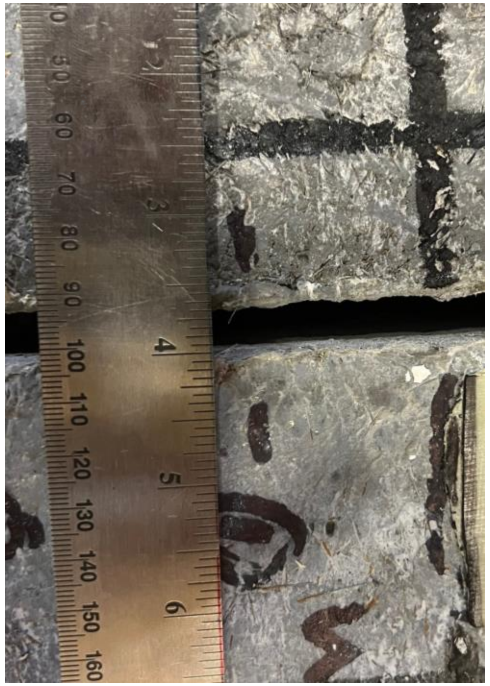


Source: FHWA.

Crack/Joint Opening During Cycling

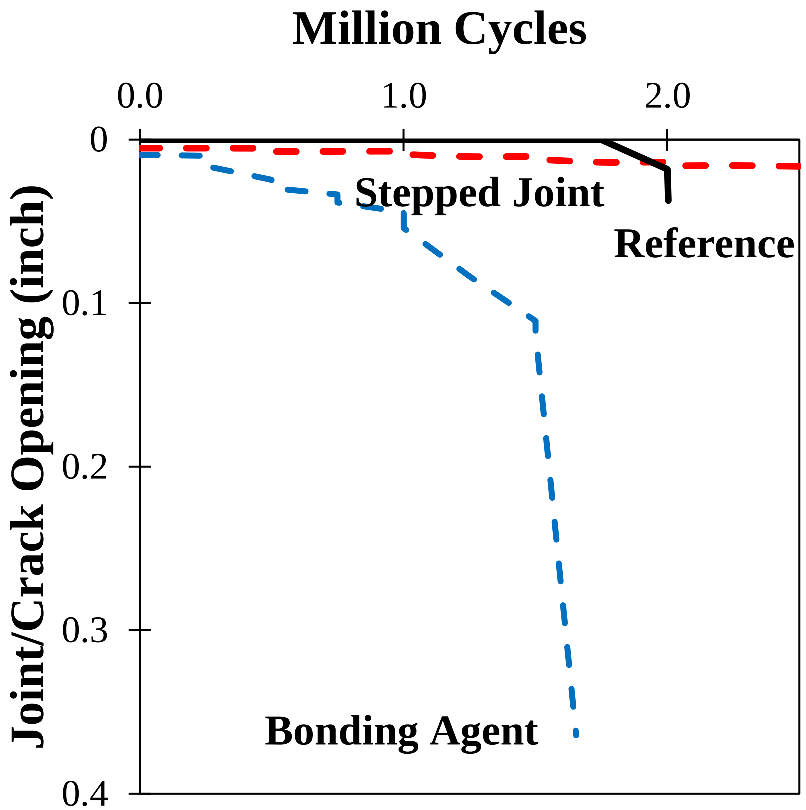
Reference

Bonding Agent



Stepped Joint

All images source: FHWA.



Source: FHWA.

Summary

- Cyclic loading when a UHPC overlay is in tension (beyond the UHPC cracking limit but before the localization limit) may result in reduced flexural stiffness and an increased crack opening.
- Cold joints created with a bonding agent at the interface were unable to sustain flexural stiffness at higher flexural moments and extended cyclic testing.
- Stepped cold joints were able to sustain flexural stiffness and maintain a low joint opening throughout cyclic testing.

Part II: UHPC Bridge Deck Overlays as a Corrosion Mitigation Strategy to Ensure Longer Service Life

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Statements and Objective

- Statements:
  - Corrosion has become one of the leading contributors to bridge deck deterioration.
  - Corrosion of reinforcing steel can result in a reduced deck capacity.
  - Effective corrosion mitigation strategies are necessary to ensure longer service life of bridge decks.
  - Bridge deck overlays and corrosion mitigation chemicals (CMC) are of interest in this study.
- Objective: Evaluate the performance of the UHPC overlay by itself or in conjunction with different corrosion mitigation strategies.

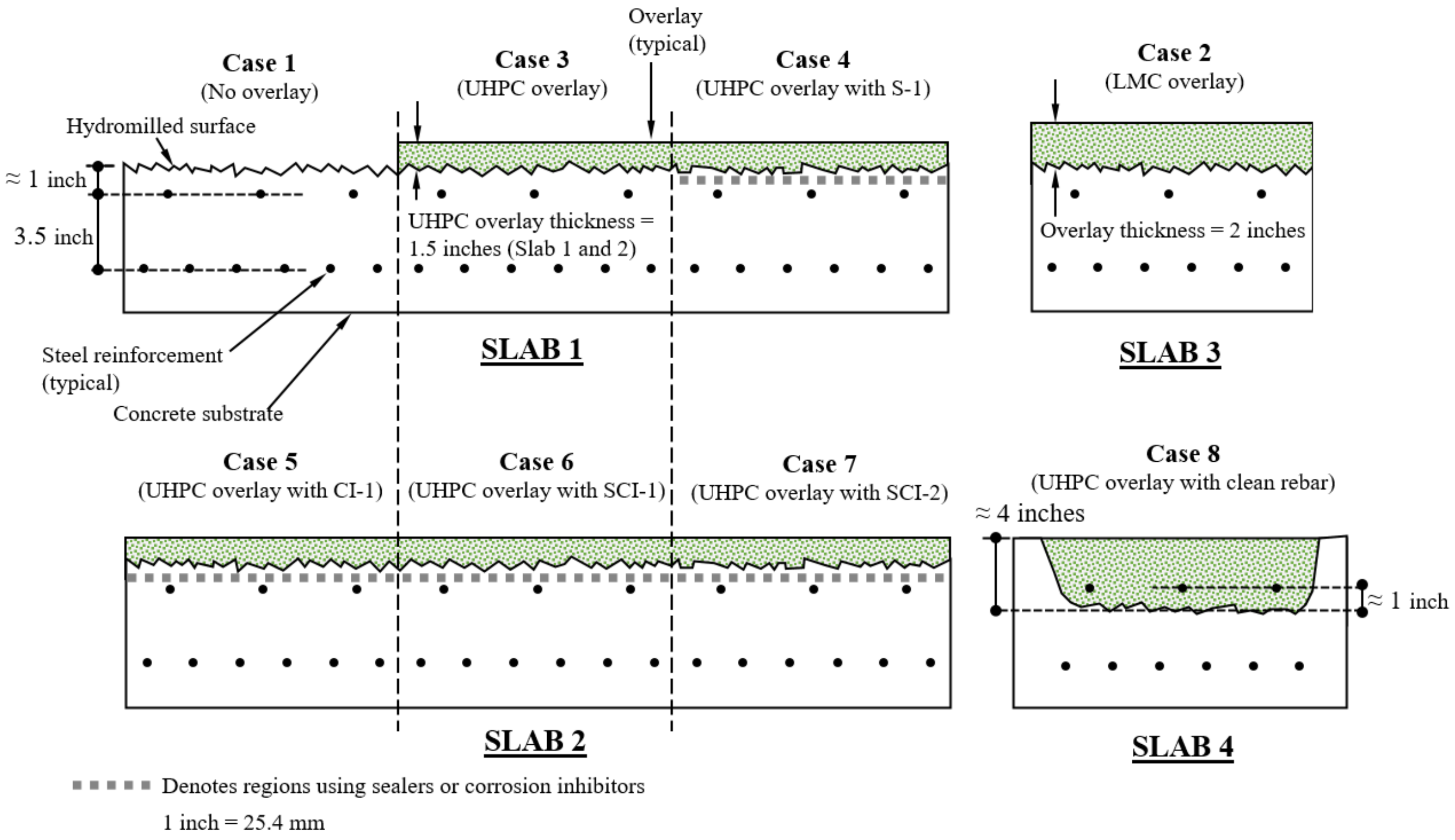
Materials

- Substrate concrete—A4 concrete (VDOT 2016).
- Steel—ASTM A615 grade 60 U.S. No. 4 (ASTM 2022a).
- Overlays:
  - Commercially available UHPC overlay (**1.5 inches thick**).
  - LMC overlay (**2 inches thick**).
- CMC:
  - Soy-based sealer (S-1).
  - Amino alcohol-based corrosion inhibitor (CI-1).
  - Hybrid silane-based sealer and corrosion inhibitor (SCI-1).
  - Hybrid silane-based sealer and corrosion inhibitor (SCI-2).

Specimen Preparation and Test Matrix

- Corrosion performance:
  - Corrosion potential (C876 (ASTM 2022b)).
  - Cyclic polarization (G61 (ASTM 2018)).
- Bond performance:
  Direct tension bond testing (C1583 (ASTM 2020)).

(FHWA-HRT-22-087)

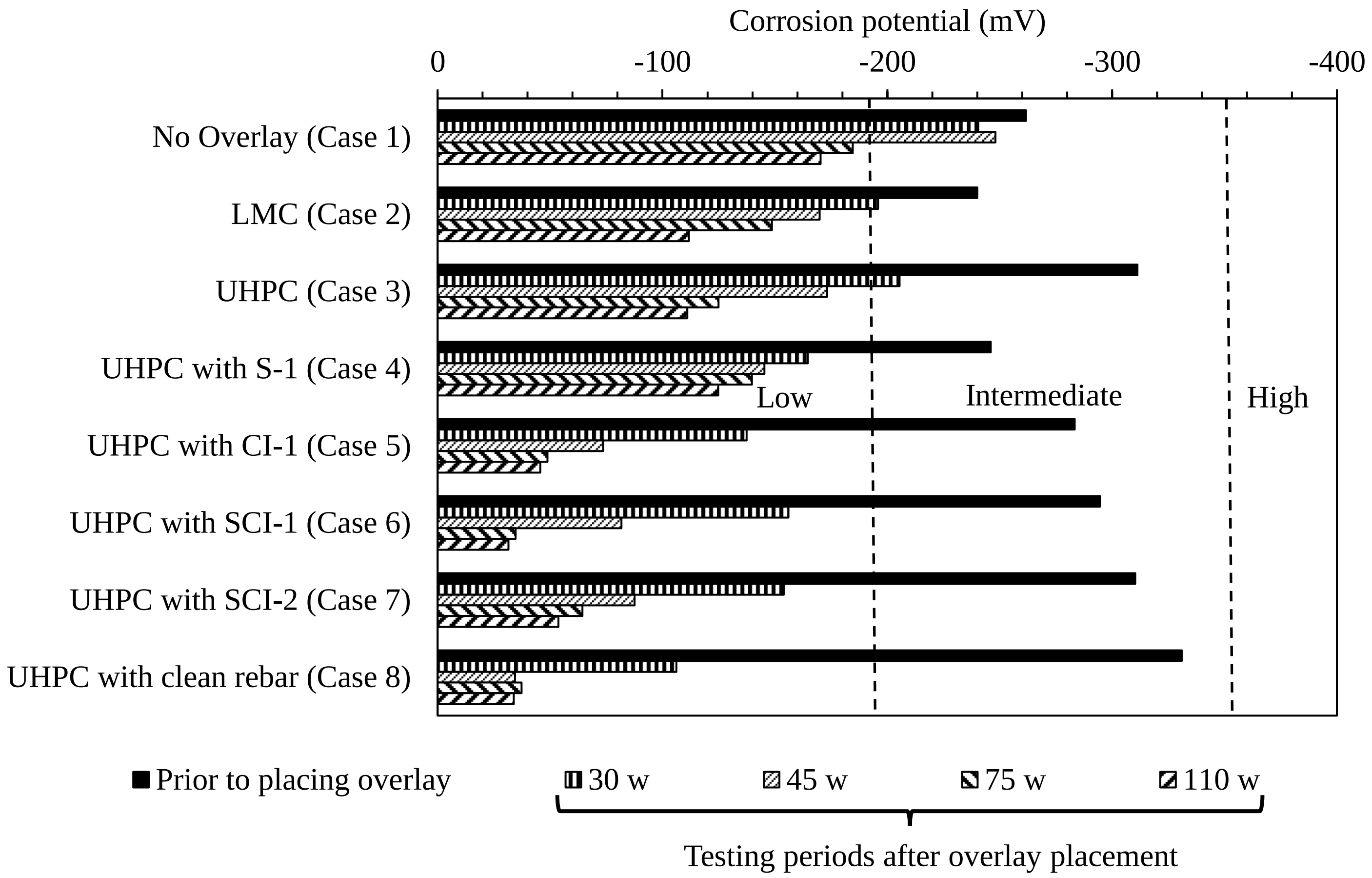


Source: FHWA.

Results—Corrosion Potential

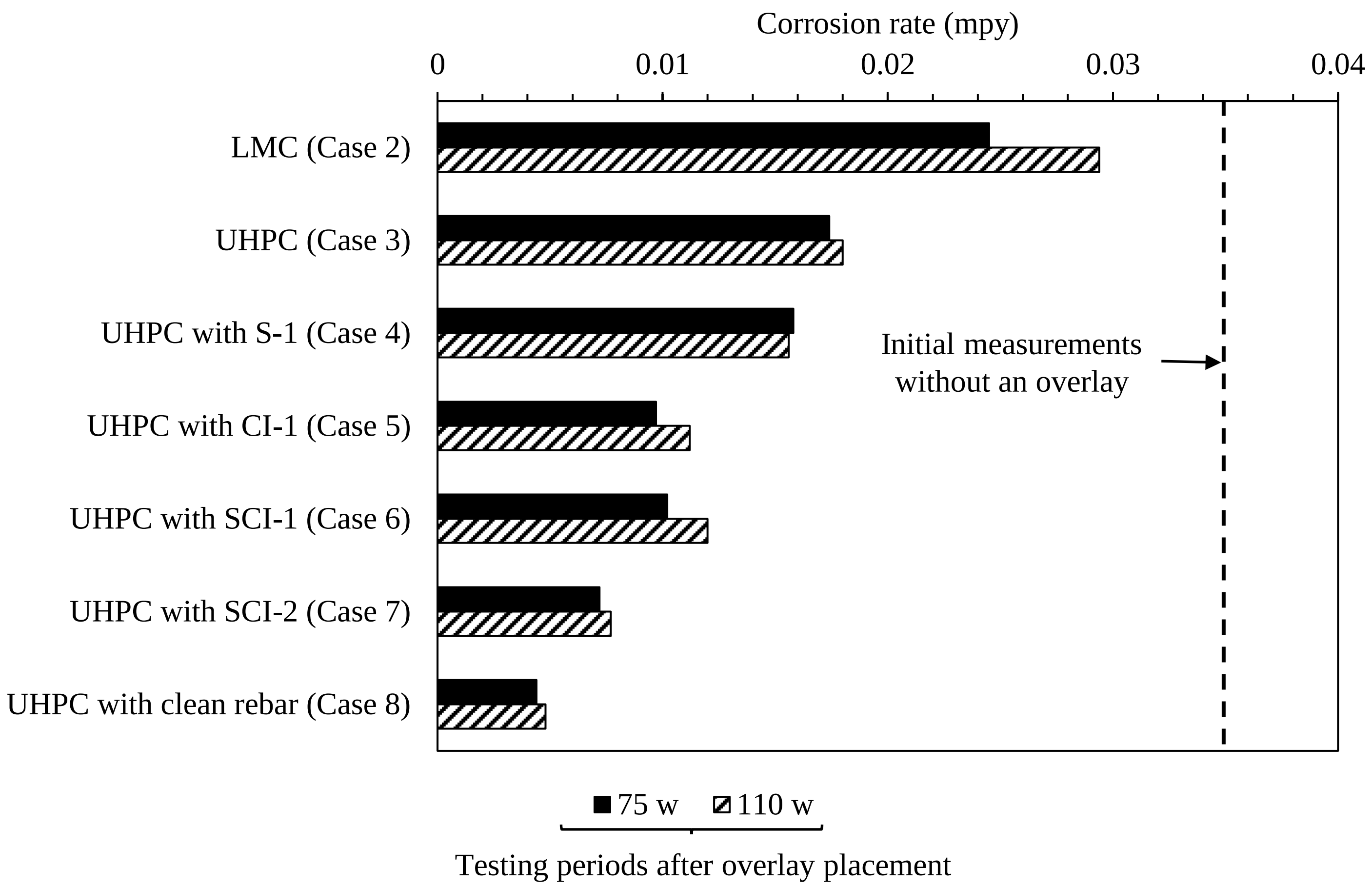
According to ASTM C876, the relationship between potential measurements and corrosion probability is as follows (ASTM 2022b):

Measured Potential (mV/CSE)	Probability of Nonnegligible Steel Corrosion Activity (percent)
> −200	<10
−200 to −350	Uncertain
< −350	>90



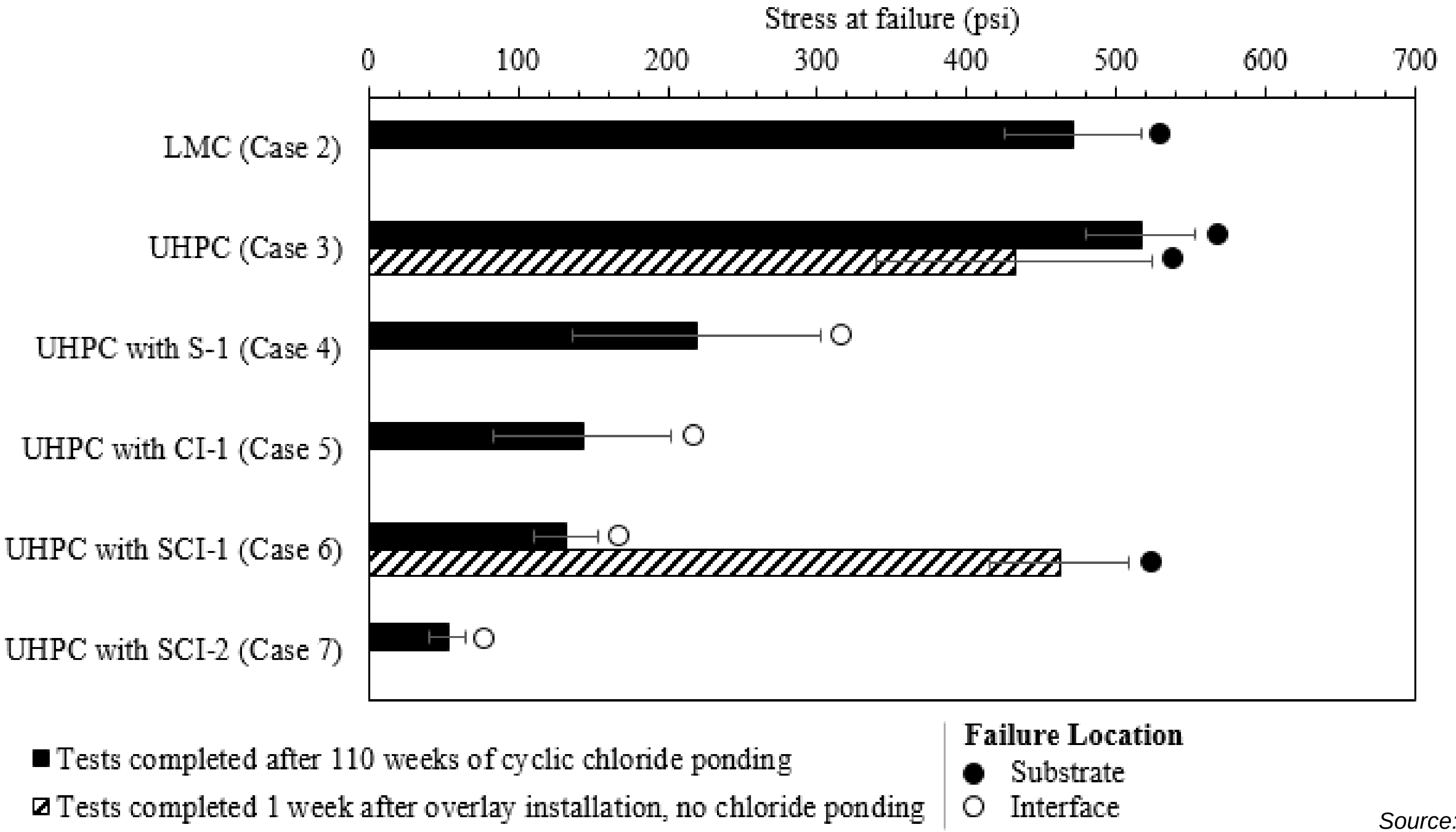
Source: FHWA.

Results—Cyclic Polarization



Source: FHWA.

Results—Direct Tension Bond Test



Source: FHWA.

Conclusions (1 of 2)

A commercially available UHPC overlay material used in combination with common CMCs was compared to a conventional LMC overlay in terms of corrosion propensity over time:

- Use of overlays by themselves or in conjunction with CMCs reduced corrosion propensity.
- LMC and UHPC overlays reduced corrosion rates by 20 and 50 percent, respectively, compared to no overlay.

Conclusions (2 of 2)

- Despite the reduced overlay thickness, lower corrosion rates were observed in UHPCs compared to LMC, potentially due to the lower permeability of UHPCs.
- Use of CMCs in combination with UHPC overlay reduced corrosion rates further. However, the presence of CMCs along the overlay-to-concrete interface had a clear, negative effect on the long-term bond performance.

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Questions?

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Abbreviations

ASTM	American Society for Testing and Materials
CI-1	corrosion inhibitor-1
CMC	corrosion mitigation chemicals
CSE	copper sulfate electrode
FHWA	Federal Highway Administration
LCA	lifecycle assessment
LCCA	lifecycle cost assessment
LMC	latex modified concrete
LVDT	linear variable differential transformer
mpy	mils per year
S-1	sealer-1
SCI-1 and SCI-2	sealer and corrosion inhibitor-1 and -2
UHPC	ultra-high performance concrete
VDOT	Virginia Department of Transportation