Structural Performance of UHPC Overlays

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Abstract

The use of ultra-high performance concrete (UHPC) as an overlay is quickly becoming a viable option in the maintenance and repair of bridge decks. This method of bridge preservation is advantageous when a bridge deck is structurally sound but the surface of the deck is beginning to exhibit excessive deterioration. In such an event, the use of conventional repair techniques may not be adequate because water and deleterious chemicals can still penetrate the concrete and result in further degradation. The process of installing a UHPC overlay typically involves removing a layer of the deteriorated concrete and replacing it with thixotropic UHPC. The very low permeability of the UHPC provides a durable top surface to the deck and significantly reduces the water and chloride ingress to the substrate concrete, thus extending the lifespan of the bridge deck. These durability advantages make UHPC overlays an intriguing option for bridge owners; however, the structural advantages and limitations of UHPC overlays are less acknowledged. The research presented herein considered a series of structural tests on conventional concrete slabs with UHPC overlays. Several variables were considered in the research such as positive or negative moment bending, cold-joint detailing, lap-splice detailing, and overlay depth. Both cyclic and monotonic tests were performed. The results indicate that UHPC overlays can increase the structural capacity of bridge decks. Additionally, adequate cold-joint detailing within the UHPC overlay must be considered to maintain the improved structural performance.

Keywords: UHPC; bridge deck overlays; thixotropic UHPC; structural testing; cyclic testing; overlay detailing.

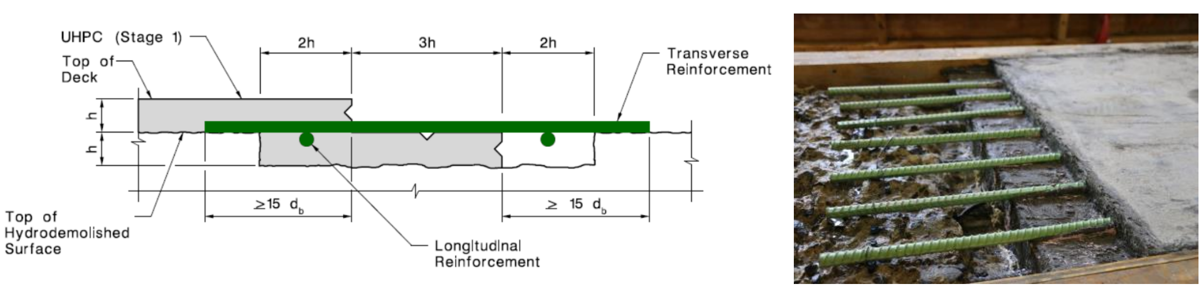
1. Introduction

The use of UHPC overlays has been gaining attention as an option for extending the lifespan of bridge decks (Seibert, Brindley, and Reece 2021; Seibert, Scinida, and Twelde 2021). Removing a portion of the often-deteriorated concrete cover at the top surface of the deck and replacing it with UHPC is advantageous because UHPC is a robust structural material with very low permeability. The low permeability slows the ingress of deleterious chemicals such as chlorides into the bridge deck, thus reducing the likelihood that these chemicals will reach the reinforcing steel layer and cause or accelerate corrosion. Recognizing that if significant corrosion in the steel is present there is a higher likelihood of complete deck replacement, UHPC overlays are more commonly considered when the deck deterioration is concerning but not yet severe.

UHPC overlays systems are highly durable but may also provide some structural advantages. UHPC provides significantly higher compressive strengths compared with conventional concrete and provides sustained post-cracking tensile capacity whereas conventional concrete is often assumed to have no tensile capacity. There are scenarios wherein engagement of these behaviors may be advantageous when considering the structural capacity of the retrofitted bridge deck. However, there is some uncertainty in how designers can take advantage of the improved mechanical behaviors offered by UHPC overlays. Questions arise as to whether the conventional concrete and UHPC act compositely at higher loads or after cyclic loading. In some installations of UHPC overlays, the deteriorated conventional concrete may be removed to a depth which exposes the top layer of reinforcement thus creating uncertainties with the bonding of the UHPC to the steel reinforcement and/or the required cover for the UHPC to fill in below this layer of reinforcement. In instances where the top layer of reinforcement is not exposed, uncertainties may arise as to whether additional steel reinforcement within the UHPC is required. Finally, the cold joints between phased construction of multiple lanes of UHPC overlays may create weak links from both a structural and durability standpoint. Different detailing of these interfaces may significantly affect the structural performance. These aspects must be addressed in order for designers to efficiently utilize UHPC overlay systems, maintain structural integrity, and eliminate the possibility of the UHPC experiencing localized cracks that would reduce its durability.

2. Summary of Experimental Program

The experimental program within this study was intended to address many of the problems discussed in the previous section. Structural testing of ten conventional concrete slabs with UHPC overlays is presented herein. These slabs were 2.5 ft. (0.76 m) wide, 9.5 ft. (2.90 m) long, and 8 in. (203 mm) deep. Cyclic tests were performed on five of these specimens. This included cyclic flexural loading of the full depth conventional concrete slab prior to removing a layer of concrete from the top surface of the deck via hydro-demolition then installing the UHPC overlay. The cyclic loading was intended to induce cracking that would commonly be present in a bridge deck that was being considered for a UHPC overlay. Once the UHPC overlay was cast, further cyclic loading was applied based on moments listed in the American Association of State Highway and Transportation Officials LRFD Bridge Design Manual Table A4-1 (2020) for design of bridge decks. These cyclic tests were performed in both positive and negative bending scenarios and considered joint detailing as variables. An example of this joint detailing can be seen in Figure 1.



a b

Figure 1. a) detailing of cold-joint between staged UHPC construction (Haber et al. 2022) and b) photograph of cold-joint tested within this study

Additionally, five UHPC overlay slabs were tested through monotonic loading to failure with a negative bending moment as seen in Figure 2. These slabs were not pre-cycled and were created by casting a partial height conventional concrete slab with a surface retarder to produce a roughened interface between the conventional concrete and UHPC. UHPC was then placed on top the conventional concrete to produce an 8-in. (203 mm)-deep slab. Variables considered with monotonic tests include the depth of the UHPC, detailing of lap splices and cover, and the addition of cold joints.

Figure 2. Example of conventional concrete slab with UHPC overlay in test frame

3. Summary of Results

Results of structural testing indicate that UHPC overlay systems act compositely with the conventional concrete substrate and that the structural capacity can be designed using fundamental engineering practices based on the engineering properties of the conventional concrete, reinforcing steel, and UHPC. The predicted structural response based on these fundamental practices closely matched the tested responses. Also, the use of lap-splice and cover details at or slightly below existing UHPC overlay design guidance, as described in Haber et al. 2022, had little effect on the response. Cyclic positive bending moment tests demonstrated that when the UHPC is in compression, no structural deterioration is present. Cyclic negative bending moment tests demonstrated that UHPC did not exhibit any structural deterioration prior to its design cracking moment, but at higher moments and higher cyclic counts, localization cracks may develop at the tensile strain limit of the material thus limiting the structural capacity. Finally, results indicated that proper detailing of the joints between phased construction can maintain the structural integrity of the system. Overall, structural testing of UHPC overlays indicated that the structural capacity of a retrofitted bridge deck may be increased, especially in negative bending moment scenarios, if adequate detailing is provided.

4. References

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