EMERGING UHPC-BASED BRIDGE CONSTRUCTION AND PRESERVATION SOLUTIONS

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Abstract

UHPC has emerged as a class of materials capable of addressing a variety of shortcomings commonly encountered in the U.S. bridge sector. As with any constructed facility, bridges are recognized to be comprised of components whose performance and resiliency vary thus often necessitating preservation actions to address premature deterioration. By focusing on developing innovative solutions that address immediate needs, the weak links in the structure's performance can be mitigated and the overall structure's performance can be improved.

The U.S. Federal Highway Administration continues to investigate optimal uses of UHPC in the highway sector and work with partners to deploy promising solutions. Recent advancements include assessments of performance of a range of available UHPCs and the development of novel field-cast UHPC connection details. Owners across the country are becoming aware of the benefits of UHPC and are beginning to press forward with innovative solutions such as deck rehabilitation overlays, link slabs to replace joints over interior piers, and deteriorated steel girder web encasement.

Résumé

Le Béton fibré à ultra-hautes performances (BFUP) a émergé comme une gamme de matériaux capable de fournir une réponse à une variété de défauts couramment rencontrés dans le domaine des ouvrages d'art aux Etats Unis. Comme pour toute construction, les ponts sont constitués de composants dont la performance et la résilience évoluent dans le temps, et nécessitent des actions de réhabilitation préventives. En mettant l'accent sur le développement de solutions innovantes qui répondent aux besoins immédiats, les maillons faibles de la performance de la structure peuvent être atténués et leurs performances globales améliorées.

L'administration fédérale américaine des autoroutes (FHWA) poursuit les recherches pour une utilisation optimale des BFUP dans le secteur des infrastructures autoroutières et collabore avec de nombreux partenaires afin de déployer des solutions prometteuses. Des avancées récentes comprennent des évaluations de la performance d'une gamme de BFUP disponibles et l'élaboration de nouveaux détails de joints de connexion en BFUP coulés *in situ*. Les maîtres d'ouvrage à travers le pays prennent conscience des avantages du BFUP et commencent à déployer des solutions innovantes comme le renforcement de dalles de pont, l'attelage des travées indépendantes par des dallettes en BFUP, et enfin le renforcement par chemisage en BFUP des âmes de poutres métalliques.

1. INTRODUCTION

UHPC has emerged as a class of materials capable of addressing a variety of shortcomings commonly encountered in the U.S. bridge sector. As with any constructed facility, bridges are recognized to be comprised of components whose performance and resiliency differ thus often necessitating preservation actions to address premature deterioration. By focusing on developing innovative solutions that address immediate needs, the weak links in the structure's performance can be mitigated and the overall structure's performance can be improved. The growing awareness of UHPC across the US infrastructure community is facilitating a movement toward a more resilient transportation network.

2. UHPC USAGE IN THE UNITED STATES AND CANADA

The usage of UHPC in the North American bridge market is continuing to grow. From the first pilot projects that were being completed a decade ago, the number of deployments has steadily grown. As of early 2017, there were more than 180 bridges open to traffic in the US and Canada. The large majority of these bridges used UHPC in field-cast connections between prefabricated bridge components; however, a handful used UHPC in prefabricated elements (e.g., beams, decks) and others used UHPC to rehabilitate deteriorated components (e.g., joint replacement, deck overlay). Recent years have seen dozens of projects being completed, and the pipeline of pending projects indicates that future years will continue the trend.

Figure 1 shows the locations of completed projects throughout much of the US and southern Canada. A large number of owners have completed first projects, and even more are working toward that goal. A few US transportation agencies, including New York State Department of Transportation, Pennsylvania Department of Transportation, and New Jersey Department of Transportation, are institutionalizing specific UHPC applications into their normal bridge design, construction, and rehabilitation practices. An interactive map that allows self-directed investigation of completed UHPC bridge projects can be found at https://www.fhwa.dot.gov/research/resources/uhpc/bridges.cfm.

3. UHPC AVAILABILITY

The U.S. Federal Highway Administration (FHWA) defines UHPC as a cementitious composite material with a water-to-cementitious materials ratio of less than 0.25 and a high percentage of discontinuous internal fibre reinforcement. UHPC exhibits mechanical properties including a compressive strength greater than 150 MPa and a sustained post-cracking tensile strength greater than 5 MPa. UHPC also exhibits significantly enhanced durability as compared to conventional concrete [1].

The increased usage of UHPC in the North American market is spurring growth in the range of UHPC-class products that are available. FHWA is in the process of assessing the performance of five different UHPC-class products, each of which is or appears likely to soon be available in the U.S. market. The study investigates compressive and tensile behaviours, creep and shrinkage, freeze-thaw resistance, chloride penetration, UHPC bond to precast concrete, UHPC bond to reinforcing bars, and performance in prefabricated bridge deck connections. Preliminary results on material properties, bond to reinforcing bars, and performance in prefabricated bridge deck connections are reported by De la Varga et al. (2016), Yuan and Graybeal (2016), and Haber and Graybeal (2016), respectively [2, 3, 4].

Given that public sector owners in the bridge market are accustomed to locally sourced concretes, a number of owners are funding research at their local universities to develop non-proprietary UHPC-class materials. Although these efforts do serve to increase competition, equally important is the role that they play in broadening the institutional knowledge base of all parties associated with designing, procuring, constructing, and testing UHPC-based solutions. One notable study, which was funded by FHWA, both developed non-proprietary mixes while also delivering a process through which these mixes could be developed [5]. Other examples include mix design development studies in Michigan and Montana [6, 7].

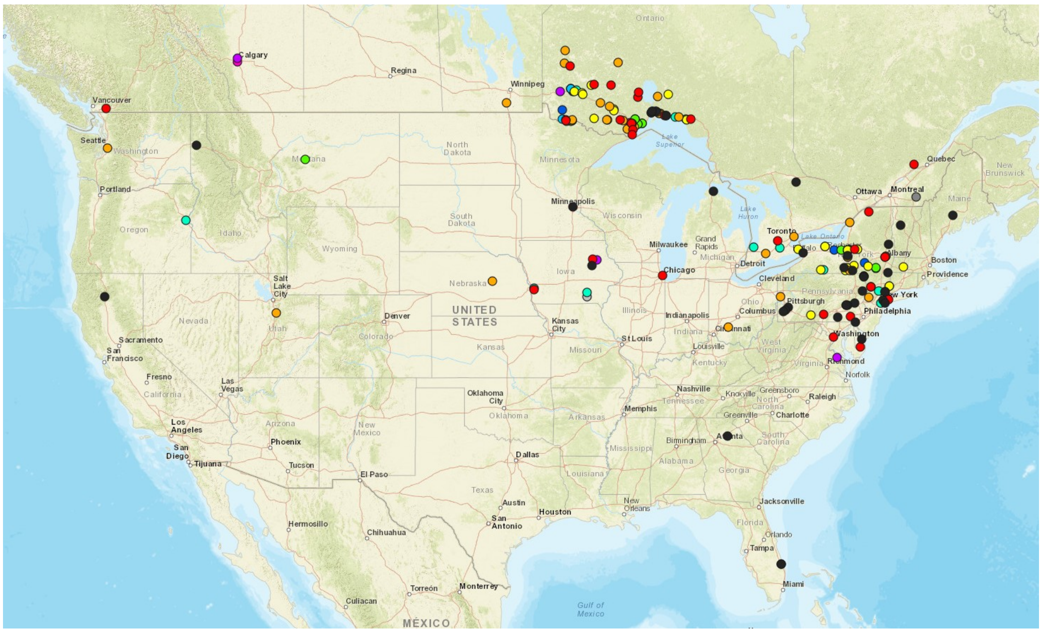

Figure 1: Usage of UHPC in bridges in the US and Canada as of December 2016

4. FIELD-CAST UHPC CONNECTIONS

Prefabricated elements offer advantages in terms of component quality, construction site safety, and construction timeline; however, their use presents challenges in terms of field assembly of elements and performance of field-installed connections. Using field-cast UHPC in place of conventional cementitious grout-like materials for closure pours can simultaneously address multiple concerns with the use of prefabricated elements. The advanced mechanical properties of UHPC allow field-cast connections to be smaller, to contain less expensive connectors, and to outperform the connected elements thus eliminating the connections as a weak link in the structure. The fresh properties of UHPC allow tight and potentially hidden connection spaces to be filled with little concern of honeycombing or unintended voids. The durability properties of UHPC allow the field-cast connections to withstand the aggressive environments that have in the past caused field-cast grouts and conventional concretes to prematurely degrade.

The U.S. Federal Highway Administration produced design and construction guidance for these connections [1]. This document provides guidance and commentary on the structural design of these connections. It also provides example connection details, insight on construction considerations, and included a set of case studies on bridges constructed using this technology.

A notable example of UHPC connections serving to change the way bridges are constructed occurred during the summer of 2016 in Minneapolis, Minnesota. The Franklin Avenue Bridge, shown in Figure 2, was completely re-decked during a 3.5 months closure. Precast concrete deck panels spanning between spandrel beams were connected together using field-cast UHPC connections. The non-contact lap splice connections of both mats of reinforcing bar within the UHPC connections allowed for easy fabrication of the components and easy assembly in the field.

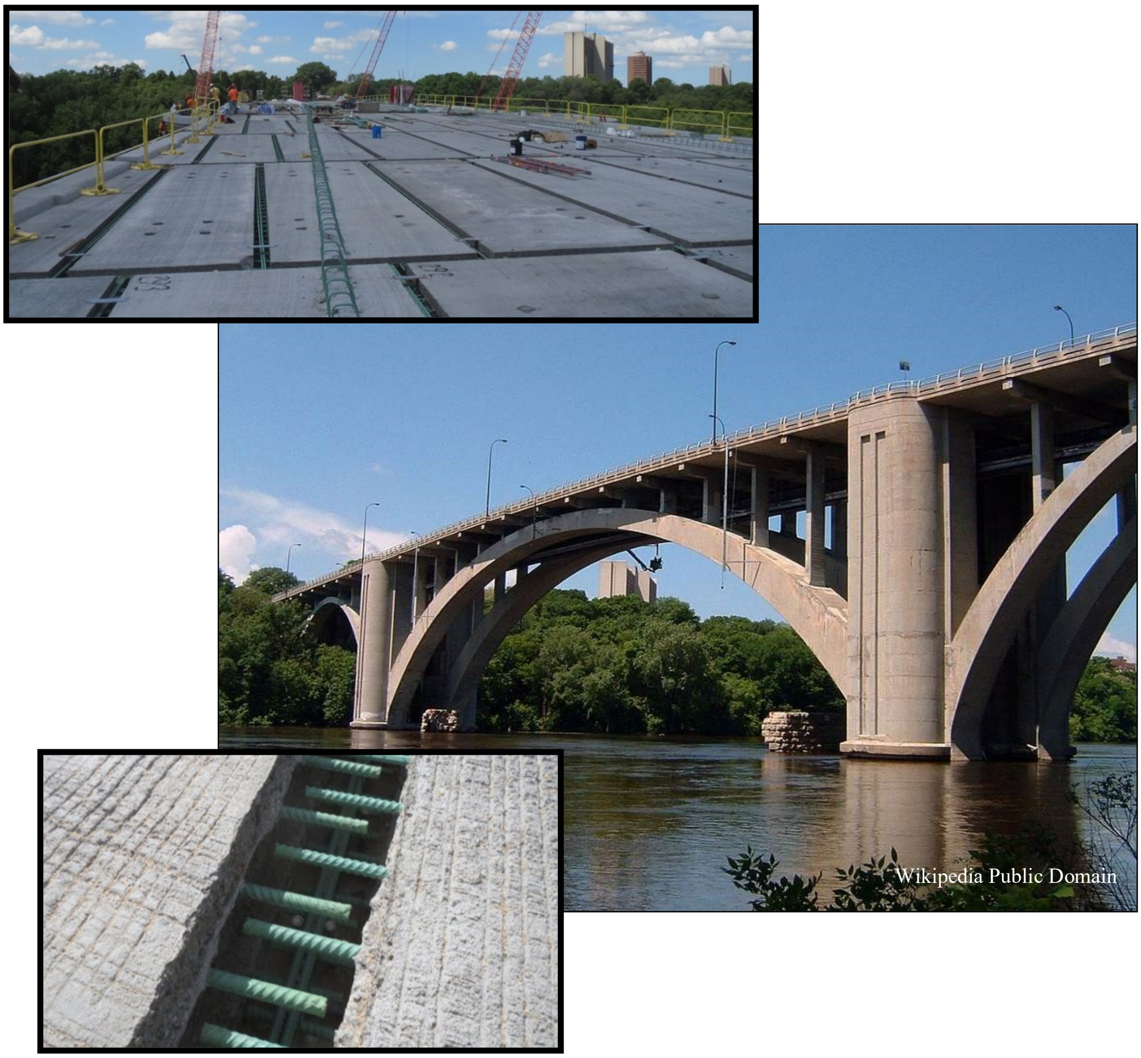

Figure 2: Accelerated replacement of the deck of the Franklin Avenue Bridge

5. EMERGING REHABILITATION SOLUTIONS

As the bridge community in the U.S. has become more familiar with UHPC, the opportunities to use UHPC to address longstanding bridge performance issues have become more plentiful. Bridge owners spend a significant portion of their budget each year on rehabilitating deteriorated bridges. Bridge decks, which inherently exist in an aggressive environment and serve as the roof of the underlying structure, are recognized to be deteriorating prematurely and thus constricting the use of the facility, while exposing the underlying structure to accelerated degradation. Three new UHPC-based bridge rehabilitation solutions are being considers for use in the U.S.

5.1 UHPC Overlays to Rehabilitate Deteriorated Bridge Decks

The use of UHPC as a field-applied overlay to rehabilitate a deteriorated reinforced concrete bridge deck is an emerging solution that can potentially afford decades of renewed bridge service without the expense of a full bridge deck replacement. The research and development behind this concept was pioneered in Switzerland, and has been deployed on a number of Swiss highway bridges [8-10]; a notable deployment of this concept was on the 2.1 km-long Chillon viaduct which borders the shores of Lake Geneva. [11]

This concept saw its first deployment in the U.S. in May 2016 on a three-span reinforced concrete slab bridge located in Brandon, Iowa, USA. This bridge was designed and constructed in the 1960s, and although it has a low ADT, it carries large trucks with agricultural loads. The deck was beginning to show signs of significant deterioration, and a UHPC overlay was chosen to extend the service life of the structure. The concept, as shown in Figures 3 and 4, is to prepare the existing deck by removing all deteriorated concrete then roughening the surface, followed by the casting of a 38 mm thick layer of UHPC. Experience to date has shown that these UHPC overlays can be constructed using common bridge deck construction techniques, and that the installed UHPC is capable of bonding well to the substrate concrete.

Six months after completing of the overlay a research team from FHWA conducted a field study to assess the bond between the UHPC over and underlying concrete deck. Bond was assessed using the direct tension pull-off test method.[12] This test method entails gluing a steel disc on the test surface, and partially coring the deck to create a test sample. A direct tensile load is then applied to the steel disc. If the bond between the overlay material and the substrate is sound, then failure will occur by fracture of the substrate or bonded material. A photo of a test sample is shown in Figure 5. At all tested locations, good bond between the UHPC overlay and the underlying concrete deck was found.

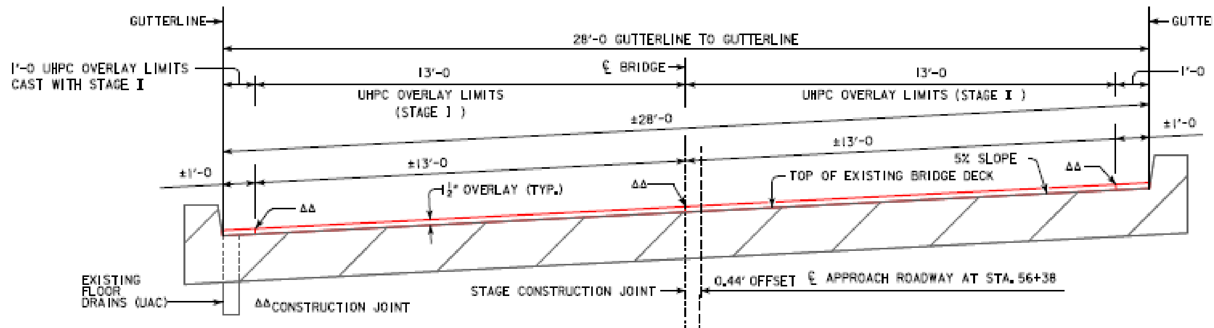

Figure 3: Schematic of a UHPC bridge deck overlay (courtesy of Buchanan County Iowa)

Figure 4: Installing a UHPC overlay to repair a deteriorated bridge deck

(a) Front (b) Back (c) UHPC-Concrete Interface

Figure 5: Photo of a test sample for testing the UHPC overlay-to-concrete bond

5.2 UHPC Link Slabs to Rehabilitate Deteriorated Bridge Expansion Joints

In the past, it was not uncommon to construct multi-span bridges with numerous expansion joints located above intermediate piers. Over time, these expansion joints have often failed to redirect chloride-laden water off of the deck, resulting in leakage and the need for continual maintenance of both the joint and the underlying structure. One emerging remediation solution is to replace the leaking joint with a field-cast UHPC link slab designed to provide a durable seal without attracting significant structural loads.

Figures 6 and 7 show a bridge whose strip seal above the intermediate pier was replaced by a 0.4-m wide by 100 mm thick UHPC link slab. This link slab lap spliced the top mat of reinforcement from the adjacent bridge decks as shown in the detail in Figure 8. It was installed at the same time that the bridge deck was replaced through the use of prefabricated deck panels and field-cast UHPC connections. The girder bearings were also modified to ensure that the rotations and strains experienced by the bridge superstructure above the intermediate pier could be accommodated.

Figure 7 shows how the steel girders had begun to deteriorate under the leaking joint. It is expected that this link slab, which has been in service since 2013, will offer consistent service with no maintenance throughout the life of the overall bridge deck.

Figure 6: Bridge with UHPC deck level connections and a UHPC link slab
(photo courtesy of New York State DOT)

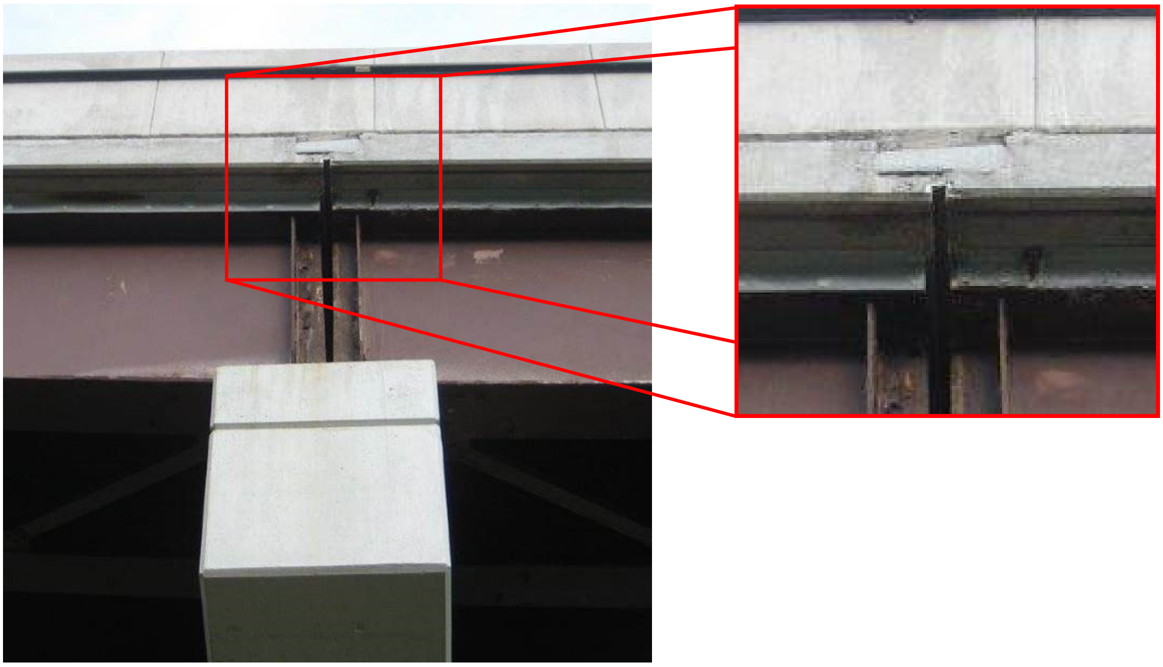

Figure 7: Elevation view of UHPC link slab

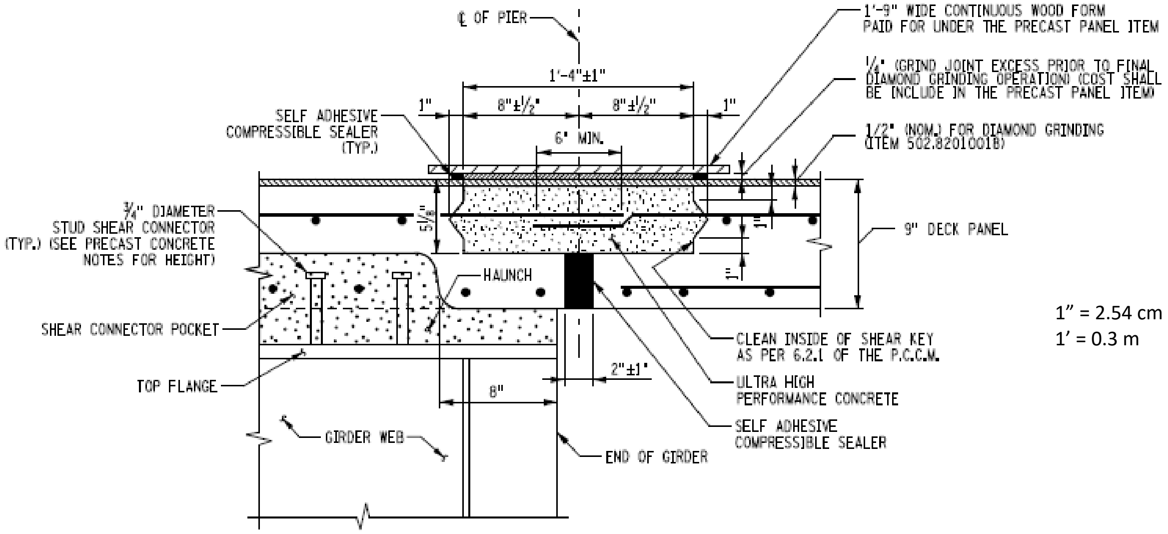

Figure 8: UHPC link slab detail (image courtesy of New York State DOT)

5.3 UHPC Encasement to Rehabilitate Deteriorated Steel Beams at Leaking Joints

An emerging rehabilitation solution is the use of UHPC to remediate decades of unmitigated deterioration of steel beams located under leaking bridge deck expansion joints. Situations such as that shown in Figure 9 are commonplace in some parts of the U.S., particularly in states where the inventory includes a large number of short span steel superstructure bridges that were constructed prior to the 1970s.

Figure 9: Deteriorated steel beams in need of repair
(photo courtesy of New York State DOT)

Short of replacing the entire bridge superstructure, existing repair solutions include field welding or bolting steel doubler plates onto the existing beams. This repair solution has proven to be costly given the number of beam ends in a bridge and the tight working conditions under the deck.

The Connecticut Department of Transportation has been leading efforts to develop a UHPC-based alterative repair solution through work at the University of Connecticut [13]. Concepts similar to that shown in Figure 10 have been studied through large-scale experimental testing and detailed analytically modelling. Corroded steel is removed from the beams and then short studs are welded to intact steel. A form is then placed around the beam and the UHPC is cast. The UHPC allows for both increased shear resistance of the beam as well as increased bearing resistance at the support. Experimental studies showed that beams ends repaired using this concept could meet or exceed their intended capacity at the ultimate limit state.

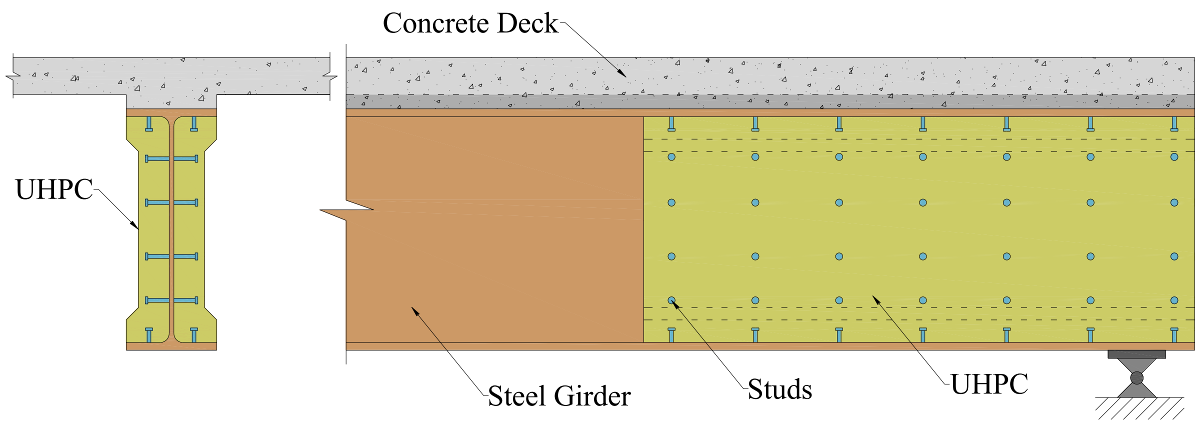

Figure 10: Steel beam repair using UHPC encasement

6. SUMMARY

UHPC is proving to be a material that is facilitating the development of innovative solutions to long-standing bridge construction and performance issues. From accelerating bridge construction to facilitating new rehabilitation strategies, UHPC is being recognized as a class of concrete that can be relatively easily implemented within existing construction processes while offering significant return on the invested effort.

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