FIFTEEN YEARS OF UHPC CONSTRUCTION EXPERIENCE IN PRECAST BRIDGES IN NORTH AMERICA

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Abstract

Constant flexing from heavy truck loadings, climatic exposures (freeze/thaw) and deicing compounds – all present challenges for bridge designers and owners who want to provide durable, low maintenance structures. Owners are frequently faced with the need to replace critical bridge components during strictly limited or overnight road closures in order to minimize traffic interruptions and public inconvenience. Ultra-high performance concrete (UHPC), with its ultra-high strength and durability, is a technology that provides new solutions for these challenges. This paper presents a historical perspective of UHPC use in North American bridges and explores promising new applications for precast UHPC components combined with field cast UHPC connections. This paper presents a review of bridges built with UHPC components over the past 7 years and their current condition evaluations. The fundamentals of the technology, material properties, design details and project profiles are included. By utilizing UHPC unique combination of superior properties in conjunction with precast bridge elements, the bridge performance is advanced, accelerated and improved. Benefits include: minimum interruption, reduced maintenance, reduced joint size and complexity, improved durability, improved continuity, speed of construction, extended usage life and improved resiliency.

Résumé

Assurer une bonne capacité portante sous trafic lourd, résister aux expositions climatiques (gel / dégel) et aux conditions d'exploitation (salage) forment des défis pour les concepteurs et les maîtres d'ouvrages dans une optique de développement de structures durables à faible coût d'entretien. En effet, les maîtres d'ouvrages ne peuvent remplacer des composants critiques de leurs ouvrages que durant des périodes de fermeture de l'itinéraire strictement limitées ou durant la nuit afin de minimiser les interruptions de trafic et les désagréments pour le public. Les bétons fibrés à ultra-hautes performances (BFUP), avec leur haute résistance et grande durabilité, est une technologie qui offre de nouvelles solutions à ces défis. Cet article présente une perspective historique de l'utilisation des BFUP pour les ponts en Amérique du Nord et explore de nouvelles applications prometteuses pour les composants préfabriqués en BFUP combinés avec des connexions BFUP coulées sur site. Cet article présente un panorama des ouvrages construits avec des composants BFUP au cours des 7 dernières années et l'évaluation de l'état actuel. Les principes fondamentaux de la technologie, les propriétés des matériaux, les détails de conception et des projets sont également donnés. En utilisant les BFUP, grâce à la combinaison de propriétés accrues associée à des éléments préfabriqués, la performance est améliorée et obtenue plus rapidement. Les avantages incluent notamment un minimum d'interruption de service, une maintenance réduite, une réduction de complexité et de dimension, une durabilité améliorée, une amélioration de la vitesse de construction, une durée d'utilisation prolongée et une meilleure résilience.

1. INTRODUCTION

Every day, bridge engineers, owners and operations personnel face the challenge of increasing traffic volumes and loadings on aging infrastructure - with reduced budgets and public demand for less inconvenience during maintenance and repairs. Additionally, authorities are faced with replacing or repairing critical bridge components during strictly limited or overnight road closures. One of the largest challenges is the long-term durability and resiliency of bridge decks which receive continuous impact loading from trucks and changing environmental conditions. Years of continuous flexural and thermal stresses create long-term deterioration and maintenance issues [1]. While Cast-In-Place (CIP) concrete decks and bridge elements with High-Performance Concrete (HPC) and corrosion-resistant reinforcing can significantly extend deck life, this type of construction creates high user inconvenience and is problematic for bridge deck replacement in high traffic areas or in remote areas with limited access to ready-mix concrete. The use of HPC precast deck panels is a common method to speed construction and alleviate user inconvenience; however jointing of the precast system is a source of potential maintenance. Additionally, new technologies, materials and methods can significantly extend the usage life of critical infrastructure and reduce maintenance or user inconvenience.

This paper presents a preliminary, limited evaluation concerning the use and performance of a relatively new technology, Ultra-High Performance Concrete (UHPC); to build better bridges, extend usage life, reduce maintenance costs and user inconvenience during bridge replacements, rehabilitation or repair. The paper also provides a brief, historical overview of the development and implementation of UHPC bridge solutions in North America, involving the use of precast UHPC elements and field cast UHPC connections (between precast bridge elements).

The principle focus of this paper is to present visual inspections of UHPC bridge projects with over 7 years of service, in order to provide an introductory validation on the material performance, for the improvement of the resiliency of highway bridges.

2. HISTORY OF UHPC IN NORTH AMERICA

"Ultra-High Performance Concrete (UHPC) is a concrete material that has a minimum specified compressive strength of 150 MPa, with specified durability, tensile ductility and toughness requirements; fibres are generally included to achieve specified requirements"[2]. The material matrix is typically manufactured from combining fine materials such as sand (< 400 microns), ground quartz, Portland cement and silica fume. The matrix typically contains small fibres (12 mm x 0.2 mm diameter) in a very high dosage rate of 2% by volume. The matrix provides a very dense and low permeability (Chloride ion diffusion <0.02 x 10^{-12} m^2/s) to prevent the ingress of chlorides or other aggressive agents [3]. UHPC is a family of products with different formulations that are used for different applications. These UHPC formulations vary in raw material ingredient dosages, fiber types and curing regimes.

The first time that UHPC was used for a bridge in North America was in 1997, for construction of the Sherbrooke Pedestrian Bridge (Fig. 1), in Sherbrooke, Quebec, Canada [4]. This 60 m, clear span bridge was constructed from 6 precast 3-D space truss UHPC elements, post-tensioned together on site. Although not a highway bridge, it has been exposed to severe freeze/thaw conditions, deicing salts and light vehicle loadings (for snow removal) for 16 years.

Figure 1: Sherbrooke Pedestrian Bridge, Sherbrooke, Quebec, Canada

Early introduction and testing of UHPC for use in the bridge and marine environments in North America began almost 20 years ago, in 1994. Raw material sourcing and formulating resulted in the preparation and placement of UHPC test prisms under the US Army Corp of Engineers' Long-Term Exposure program [5]. In 1995, three UHPC prisms were cast and placed on the Army Corp Exposure Site at Treat Island, Maine to monitor long-term weathering (Fig. 2). Subsequently, several additional sets of UHPC prisms have been cast and placed on the dock (elevation mean tide), subject to twice daily tides of wet/dry and winter freeze/ thaw cycles.

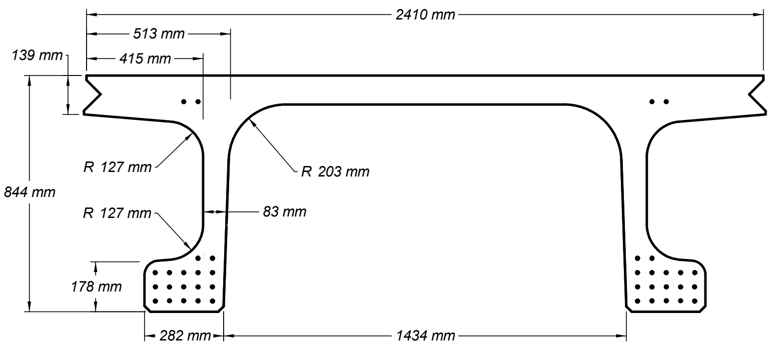
Figure 2: UHPC Prism at US Army Corps Long-Term Exposure Site, Treat Island, Maine, USA

Each year, the Civil Engineering Department at the University of New Brunswick, Fredericton, New Brunswick, Canada visits the Treat Island site to collect data on the performance of the UHPC samples on the dock. To date, all specimens show no evidence of surface scaling, mass loss, cracking or strength regression. Additional testing on chloride ion penetration has shown that UHPC is significantly lower in permeability and that it is an order of magnitude better than HPC.

In 2001, the US Federal Highway Administration (FHWA) initiated a comprehensive research program to evaluate and introduce UHPC into the US Highway Department of Transportation system [6]. Since then, significant progress has been made on the validation of this material technology for highway bridges. The FHWA has been instrumental in developing precast UHPC elements such as I & PI-girders and waffle decks, as well as utilizing the material for field cast connections between precast bridge elements.

As a result of the FHWA's research and a collaboration with the Iowa Department of Transportation, Wapello County, Iowa State University and the Center for Transportation Research & Education in Ames, Iowa, the first North American highway bridge with UHPC elements was completed in 2006, on the Mars Hill Bridge in Wapello County, Iowa, USA.[7]. The bridge is a 34 m single span, two-lane rural structure subject to frequent farm-to-market loadings (Fig. 3). The bridge has 3 – 34 m long UHPC I-Girders with a conventionally reinforced cast-in-place concrete deck.

Figure 3: Placing a 34m UHPC I-Girder -Mars Hill Bridge, Wapello County, Iowa, USA



(2006).

Figure 4: Cross-section of the second Generation Pi-girder [6].

The most significant aspect of this first UHPC highway bridge was the use of three UHPC I-Girders without any stirrups for shear reinforcing. This was a major milestone and a significant step towards the introduction of UHPC into the North American highway system. Two years later, the Virginia Department of Transportation completed a similar bridge (Cat Point Bridge, Richmond, Virginia, USA) with UHPC I-girders and a cast-in-place concrete deck. During this same period of time, the FHWA was working on an "optimized" precast bridge profile, named the "Pi-Girder" (Fig. 4). The first generation of this girder was prototyped and installed on a test track in the FHWA's Turner-Fairbank Research Center near Washington, DC. In 2008, Buchanan County, Iowa completed the Jakway Park Bridge using the second generation UHPC precast Pi-girder.

3. OVERVIEW OF BRIDGES CONSTRUCTED WITH UHPC IN NORTH AMERICA

As of February 2013, fifty bridges with UHPC bridge elements (precast and/or field cast connections) have been completed in North America.

3.1 Precast UHPC Elements for Bridges

From 1997 to 2012, UHPC precast bridge elements were used on the following 9 projects:

<u>Pedestrian Bridges</u>

- Sherbrooke, Quebec, Canada – 3-D space Truss – 60m span (1997).
- Glenmore/Legsby Bridge, Calgary, Alberta, Canada – single T-Section, 33.6 m span (2007).
- Sanderling Drive, Calgary, Alberta, Canada – single T-Section, 33.6 m span (2008).

<u>Highway Bridges</u>

- FHWA Pi-girders – Langley, Virginia, USA –twin Pi-Girder, 23 m span (2003).
- Mars Hill Bridge, Wapello County, Iowa, USA – 3 I-girders, 33.5 m span (2006)
- Jakway Bridge, Buchanan County, Iowa, USA – 3 Pi-girders, 15.3 m span (2008).
- Cat Point Bridge, Richmond, Virginia, USA – 5 I-girders, 24.3 m span (2008).
- Hodder Avenue Underpass, Thunder Bay, Ontario, Canada – Pier cap, leave-in-place column covers and joint-fill (2012) [8]

Various equipment and manufacturing techniques for batching, forming, placing and curing of UHPC precast components were successfully applied to the above precast elements [9].

3.2 Field Cast UHPC Connections for Precast Bridge Elements

While it is recognized that precast bridge components can provide high durability, conventional joints are often the weakest link in the system. UHPC offers superior technical characteristics including ductility, strength and durability while providing highly moldable products with a high quality surface aspect also has a very short bond development length. When used as a jointing material in conjunction with reinforced HPC precast bridge components, UHPC provides a synergistic, new approach for the reconstruction of bridge superstructures.

Between 2006 and 2012, more than 40 precast bridges were completed utilizing UHPC field cast connections. In 2006, an initial bridge at Rainy Lake, Ontario, Canada, was constructed using this technology (Fig. 5) and, during each subsequent year, the number of projects has grown significantly. In 2012, 13 bridges were completed using this technology in multiple state and provincial jurisdictions in both the USA and Canada.

UHPC field cast connections have been used to connect bridge precast elements, such as, full depth precast deck panels, side-by-side box girders, side-by-side Deck Bulb-Tees, live-load continuity connections, precast approach slabs to abutments, curbs to decks, piles to abutments and in the haunches to provide horizontal shear for composite construction [10].

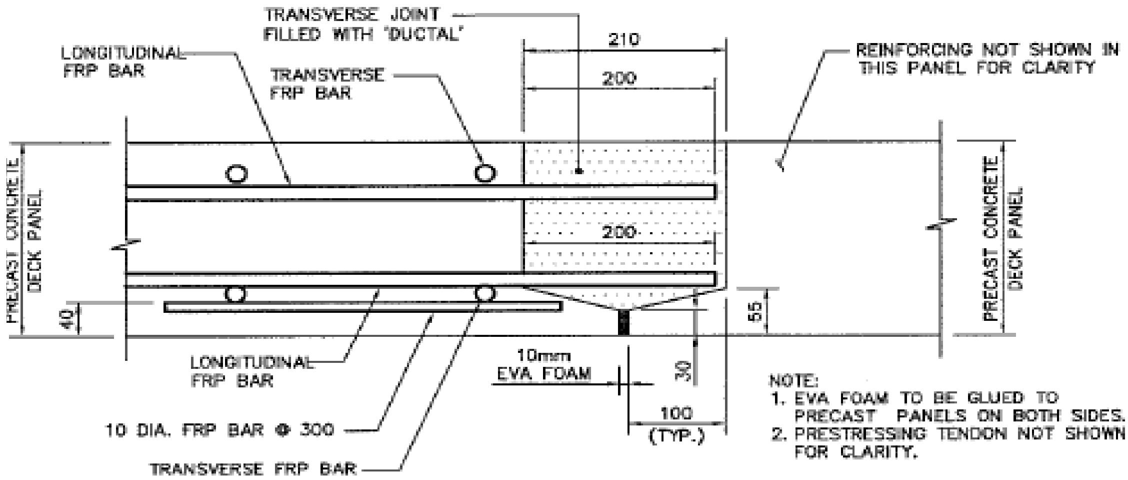


Figure 5: Typical Section through a Transverse Full Depth Precast Panel Joint

4. CONDITION SURVEY OF SELECT UHPC BRIDGES IN NORTH AMERICA

During 2012, site inspections were conducted on numerous UHPC bridges in service across Canada and the USA in order to conduct a visual condition survey. The following 8 bridges were selected and are presented herein:

4.1 Mars Hill Bridge, Wapello County, Iowa, USA

The 3 UHPC I-girders cast for this project in 2005 were visually inspected and showed no evidence of scaling or cracking. The surface aspect of the girders appeared to be same as the day they were placed in the field. (Fig. 6). There were no visible signs of any delamination at the horizontal shear interface of the CIP Deck and the UHPC girders [11].

4.2 Jakway Park Bridge, Buchanan County, Iowa, USA

This second generation Pi-girder bridge was completed in 2008 (Fig. 7). The 3 side-by-side Pi-girders are connected with a HPC grout and the deck was covered with a tar and gravel (chip seal) to provide an anti-skid surface texture. The chip seal is in good condition with no evidence of scaling or peeling. The UHPC Pi-girders show no visible evidence of scaling or cracking. The surface aspect of the girders appeared to be same as the day they were placed in the field.

Figure 6: Mars Hill Bridge:
View along UHPC I-Girder (Photo 2012)

Figure 7: UHPC Pi-Girders, Jakway Park Bridge
Buchanan County, Iowa, USA (Photo 2012)

4.3 Rainy Lake Bridge (over CNR), Fort Francis, Ontario, Canada

The full depth HPC precast deck panels on steel girders utilized UHPC field cast connections in the panel to panel connections, in the haunches (panel to girder connections), in the curb connections and in the connections of the precast approach slabs. The bridge has a waterproofing membrane plus a protective asphalt wearing surface (Fig. 8). This was the first bridge to use this technology; completed in 2006 [12]. During a walking visual inspection of the asphalt surface there was no evidence of reflective cracking. This would indicate that, after 6 years of service, the UHPC joints are performing well and providing full continuity in the deck slab, as if the joint does not exist.

4.4 Otego Creek Bridge, Oneonta, New York, USA

This project was the first use of full depth precast HPC deck panels on steel girders, with UHPC field cast connections by the New York State Department of Transportation. The bridge received a 50 mm (2 in) thin bonded HPC overlay. UHPC was only used in the panel to panel deck level connections. The project was completed and put into service in 2009. A visual inspection and water ponding test was conducted on the bridge deck in 2012. The visual inspection showed random plastic shrinkage cracking in the thin bonded overlay. There was no evidence of any reflective cracking in the thin bonded overlay over the UHPC panel to panel joints. There was a full depth (panel + overlay), full width transverse crack adjacent to each abutment approximately the depth of the steel girders away from the abutment (Fig. 9). The bridge was constructed with a semi-integral abutment and it is believed that this construction method provides sufficient rotational restraint so as to induce tensile cracking in the deck panels.

Figure 8: Rainy Lake over CNR Bridge,
Rainy Lake, Ontario, Canada (photo: 2012)

Figure 9: Otego Creek Bridge, Oneota, NY,
USA (Photo 2012)

A water ponding test was conducted on the deck. The only evidence of leaking through the deck occurred at the full depth crack, adjacent to each abutment.

4.5 Steel River Bridge, Terrace Bay, Ontario, Canada

This 3 span bridge with full depth, half width HPC precast deck panels on steel girders, utilized UHPC field cast connections in the panel to panel joints, deck to girder haunches, precast curb joints and in the approach slab to abutment connections. A waterproofing membrane and asphalt wearing surface was applied. The new bridge, part of a TransCanada Highway realignment project in Ontario, was completed and open to traffic in 2011 (Fig. 10). A visual inspection of the deck surface showed <u>no</u> evidence of any reflective cracking in the asphalt wearing surface. A visual inspection of the deck underside showed <u>no</u> evidence of any deck leakage or efflorescence.

Figure 10: Steel River Bridge, Terrace Bay, Ontario, Canada (Photo 2012)

4.6 Sunshine Creek Bridge, Thunder Bay, Ontario, Canada

This 21 meter long single span bridge uses side-by-side box girders with UHPC field cast connections, and UHPC connections for the precast approach slab to abutment. The bridge has a waterproofing membrane and asphalt wearing surface. The side-by-side boxes are not laterally post-tensioned. All of the vertical load transfer is carried by the UHPC connections. The bridge was completed and opened to traffic in 2007. A visual inspection of the deck surface (Fig. 11) showed <u>no</u> evidence of any reflective cracking in the asphalt wearing surface. A visual inspection of the deck underside showed <u>no</u> evidence of any deck leakage or efflorescence.

Figure 11: Sunshine Creek, Thunder Bay, Ontario, Canada (Photo 2012)

4.7 Canandaigua Outlet Bridge, Lyons, New York, USA

This was the first structure to use side-by-side deck bulb tees with UHPC field cast connections. The single span bridge consists of 8 - 26 meter long deck bulb-tee girders. It has a waterproofing membrane and asphalt wearing surface [13]. The bridge took just 6 weeks to construct and was completed in 2009. A visual inspection of the deck surface (Fig. 13) showed no evidence of any reflective cracking in the asphalt wearing surface. A visual inspection of the deck underside showed no evidence of any deck leakage or efflorescence.


Figure 12 (left) and 13 (right): Canandaigua Outlet Bridge, Village of Lyons, NY, USA (Photos 2012)

4.8 Little Cedar Creek Waffle Deck Bridge, Wapello County, Iowa, USA

The introduction of a full depth precast UHPC waffle deck panel with UHPC field cast connections provides a full riding surface of UHPC. This design concept utilizes the true benefits of this material. It has the first structure in North America with a 100 % UHPC bridge deck. With a fully exposed UHPC deck, the surface should provide an extremely durable, long lasting and low maintenance bridge deck [14]. The 14 half width UHPC waffle deck panels are 2.4 m x 4.94 m x 200 mm thick, connected with UHPC joints and connected with UHPC to the standard Iowa Type B precast, prestressed concrete girders, spaced at 2.23 m. The bridge was completed and opened to traffic in 2011.

A visual inspection and water ponding test (Fig. 14) was conducted on the bridge deck in the fall of 2012. A water ponding test was conducted on the deck to check for signs of leakage at the interface of the UHPC panels and the UHPC joint fill. A visual inspection of the deck underside (Figure 14) showed no evidence of any deck leakage or efflorescence.


Figure 14: Little Cedar Creek, Wapello County, Iowa
UHPC waffle deck bridge with water ponding test (left) and underside view (right)

5. CONCLUSIONS

Ultra-high performance concrete technology is not new, but relative to concrete, this 20 year-old technology is still in its infancy, particularly relative to its 7 year deployment in highway bridges. This material technology shows very promising results for building better, more resilient and longer-lasting infrastructure. UHPC and precast bridge deck systems can minimize traffic impacts and user costs through rapid construction while providing highly durable and sustainable bridge decks. The authors recognize that the projects presented are not exhaustive nor do they prove that the material technology will provide bridges that last hundreds of years without maintenance. However, the projects, inspections and impressive results do provide an enhanced level of comfort with this “superior” UHPC technology. It should also be noted that the performance of the bridges presented do meet or exceed the design assumptions for the solutions. The absence of cracking, scaling, reflective cracking or other deterioration supports that the material is performing successfully, as required by the designers.

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