NEW APPLICATIONS OF FIELD CAST UHPC CONNECTIONS FOR PRECAST BRIDGES

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ABSTRACT

Bridge owners are frequently faced with the need to replace critical bridge components during strictly limited or overnight road closure periods. Previous papers[4,5] have presented the development, testing and installation of precast, high performance concrete bridge elements connected with field cast ultra-high performance concrete (UHPC) Joint Fill, specifically for the replacement of deteriorated bridge decks in New York State and the Province of Ontario.

This paper explores and presents promising new applications for field cast UHPC connections, specifically for precast bridge parapet to decks, precast pile cap to piles, thin bonded overlays for repairs and high early strength UHPC for accelerated bridge construction. The fundamentals of the technology, material properties, design details, manufacturing, prototyping, testing, erection, completed project profiles and upcoming project overviews are included.

By utilizing the UHPC material's unique combination of superior properties in conjunction with precast bridge elements, the bridge performance is advanced and improved. Benefits include: reduced joint size and complexity, improved durability, improved continuity, speed of construction, elimination of post-tensioning and extended usage life. These new, promising field cast connections eliminate historical problems associated with the joints in precast bridges. With UHPC Joint Fill, the connections in precast bridge systems can now become the "strongest link".

Keywords: UHPC, Joints, Connections, Abrasion, Composite, Ductile, Durability, Fatigue, Fiber-Reinforced, Impermeability, Field Casting.

INTRODUCTION

Every day, bridge engineers face the challenge of ever increasing traffic volume and loadings on aging bridge infrastructure with reducing budgets and users demanding less inconvenience during maintenance or repairs. The result of not being able to fully meet these challenges is demonstrated by the USA Federal Highway Administration (FHWA) data which rates over 150,000 bridges that are categorized as structurally deficient or obsolete[1]. Transportation authorities are faced with replacing or repairing these critical bridge components during strictly limited or overnight road closures.

One of the largest and specific challenges facing bridge authorities is the long-term durability and resiliency of bridge decks which receive continuous impact loading from trucks and changing environmental conditions. The years of continuous flexural and thermal stresses create long-term deterioration and maintenance issues for bridge decks. While Cast-In-Place (CIP) concrete decks with High-Performance Concrete (HPC) and corrosion resistant reinforcing can significantly extend the deck life, it creates high user inconvenience and is problematic for bridge deck replacement in high traffic areas or in remote areas with limited access of ready-mix concrete. The use of HPC precast deck panels is a common method to speed construction and address the user inconvenience; however the jointing of the precast system is a source of potential maintenance.

While it is well recognized that precast bridge components can provide highly durability, the joints have been the weakest link in the system in the past.

The introduction of new methodologies and innovative material technologies facilitates the implementation of new solutions. One new technology helping to solve the problem with deteriorating bridges is an ultra-high performance, fiber reinforced cement composite material ("Ductal®") by Lafarge North America[2,3], which offers superior technical characteristics including ductility, strength and durability while providing highly moldable products, with a high quality surface aspect and a short bond development length. Ultra-high performance concrete (UHPC), used as a jointing material in conjunction with reinforced high performance concrete (HPC) panels provides a synergistic, new approach for reconstruction of bridge superstructures.

Since 2005, several US state[4] and Canadian Provincial highway departments[5] have implemented the use of UHPC Joint Fill with full precast bridge decks for the replacement of deteriorating highway bridges. The solution is to use a precast concrete deck with field cast UHPC joints to develop the continuity in the deck.

Utilizing the superior characteristics of the material technology enables the simplification of the precast panel fabrication and installation processes. This simplified design provides the owner with improved tolerances, reduced risk, increased speed of construction, an overall cost savings in construction and a more resilient/durable, longer lasting bridge deck solution.

CHARACTERISTICS AND SUPPLY OF THE UHPC JOINTING MATERIAL TECHNOLOGY

The UHPC technology utilized for the joints is an ultra-high-strength, ductile material formulation made with constituent ingredients such as: Portland Cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water and steel fibers. The family of products utilized for this application, is Ductal® JSXX00, and is covered by one of many patents in a range of ultra-high performance concretes, all under trademark (Ductal®). Compressive strengths for bridge applications can range from 17,400 to 29,000 psi (120 to 200 MPa) and flexural strengths range from 2,200 psi to 5,800 psi (15 to 40 MPa).

The material's high mechanical properties are a result of proportioning the constituent ingredients to produce a modified compact grading with a nominal maximum coarse aggregate size of 400 μm, and a fiber geometry of ½" x 0.08" (12 mm x 0.2 mm). The ratio of maximum coarse aggregate size to fiber is important to facilitate random orientation of fibers and a ductile behavior. These performance characteristics result in improved micro-structural properties of the mineral matrix, especially toughness and control of the bond between the matrix and fiber.

With a carbonation depth penetration of 0.02″ (0.5 mm), there is almost no carbonation or penetration of chlorides or sulphides and a high resistance to acid attack. The superior durability characteristics are due to low porosity from a combination of fine powders, selected for their relative grain size (maximum 0.02″ [0.5 mm]) and chemical reactivity. The net effect is a maximum compactness and a small, disconnected pore structure.

The ultra-high strength properties and low permeability also provide for excellent protection of the rebar against corrosion and improved bond with the rebar, thereby provide short bond development lengths.

The following is an example of the range of material characteristics for Ductal® JS1000[6].

Strength		**Durability**	
Compressive (28 days)	20000 psi (140 MPa)	Freeze/thaw (after 300 cycles)	100%
Compressive (48 hours)	14500 psi (100 MPa)	Salt-scaling (loss of residue)	<0.10 g/m^2
Flexural	4300 psi (30 MPa)	Carbonation depth	<0.5 mm
Young's Modulus (E)	7200 ksi (50 GPa)		

The materials are supplied to the site in a three-component premix (pre-blended powders in 50 lb [22 kg] bags or 2420 lb [1100 kg] super-sacks plus superplasticizer and fibers), along with portable mixers (Figure 1) and technical support from the supplier.

The mixers are set up in pairs to provide a continuous supply of material for the joint filling operation. The mixers are normally set up at the end of the bridge to provide direct access to the bridge deck.

IMER Mortarman 750 mixers are capable of batching 8 ft^3 (0.23 m^3) per 20 minute batch cycle time for a volume of 1.77 yd^3 (1.36 m^3) per hour per pair of mixers. The number of mixers delivered to the site is determined based on the contractors schedule. Larger, Ryan Industries 2500 mixers of 0.65 yd^3 (0.5 m^3) batches (26 yd^3 [20 m^3] per day capacity are also available. For even higher volume supply, ready-mix truck batches of 7.85 yd^3 (6 m^3) are available.

Fig. 1: UHPC Portable Mixers

The UHPC joint material is transported to the joints by power buggy or wheel barrow then placed directly into the joints (Figure 2). The UHPC material was batched with a mini-slump of 8″ (200 mm) to 10″ (250 mm) (self consolidating and self-leveling). The rheology of material permitted the UHPC to be poured directly into the joints without any vibration.

Fig. 2 Filling the joints with UHPC.

The joints are covered with form grade plywood strips, and then allowed to cure until reaching 14,500 psi (100 MPa) before opening to traffic. The time to reach 14,500 psi (100 MPa) will vary, depending on ambient and curing temperatures. At ambient temperatures of 70°F (20°C) without accelerators, this would be approximately 3 days. This can be reduced with accelerator and heat or the use of rapid strength product.

FULL SCALE TESTING OF UHPC JOINTS

In 2008, the owner (NYSDOT), the material supplier (Lafarge North America Inc.), precaster (Fort Miller Company) and the FHWA agreed to undertake a prototyping and testing program to validate the full depth precast panel and UHPC joint design.

The prototypes to be cast and tested were pairs of precast panels with Joint Fill (Figure 3) and small samples of UHPC with rebars for direct pullout tests[7].

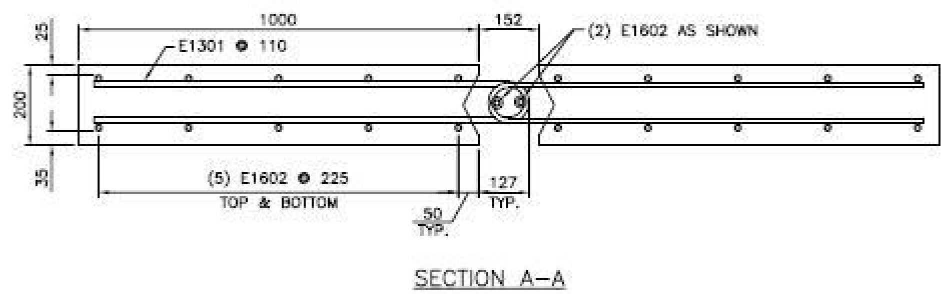

Fig. 3 Prototype Panel (Pairs) for Testing Joint Fill Performance[7]

The precast panel pairs were manufactured with three rebar joint configurations (straight bars, hairpins, and stud head) and three types of rebar (epoxy coated, galvanized and black) and for a total of nine configurations. Note, Figure 3 shows only the hairpin joint configuration.

Pullout test specimens were manufactured with 1/2″ (13 mm), 5/8″ (16 mm) and 3/4″ (19 mm) bar sizes in epoxy coated and black steel bars. Embedment lengths were 3″ (75 mm) for the 1/2″ (13 mm) Ø bar; 4″ (100 mm) for the 5/8″ (16 mm) Ø bar; and 5″ (125 mm) for the 3/4″ (19 mm) Ø bar. Failure behavior of the pullout tests conducted on all samples was rebar failure.

To validate the joint's ability to remain water tight during the life of the bridge, the precast panel pairs were loaded with a simulated wheel impact loading while water was ponded on the joint (Figure 4). The pairs of panels were simply-supported with the joint arrangement in both a parallel and perpendicular direction in order to simulate both a transverse joint and a longitudinal joint. The test panels manufactured at the Fort Miller Company, NY were shipped to the US Federal Highway Administration's (FHWA) Turner-Fairbanks laboratory for fatigue testing in a field simulated, wet condition[8].

The HPC precast deck panels (Figure 4) with the UHPC Joint Fill showed no signs of leakage or degradation at 9 million cycles of a simulated wheel loading (cycling from 1 ton to 8 tons).

Fig. 4 Bridge deck panels with water ponding under fatigue loading (courtesy of FHWA)

PREVIOUS EXPERIENCE WITH UHPC FIELD CAST JOINTS

FULL DEPTH PRECAST DECK PANELS

The Rainy Lake Bridge, Ontario (Figure 5) constructed in 2006 was the first UHPC Joint Fill project; part of an innovative field cast joint solution for a bridge superstructure/precast deck panel system specially developed for the Ministry of Transportation of Ontario[5]. UHPC was used for all joints including shear pockets and haunches. Through its design, testing and construction, this project validated a precast bridge deck with an 8″ (200 mm) wide joint and led the way to other, repetitive joint fill projects.

Fig. 5 Rainy Lake, Ontario bridge deck prior to receiving asphalt wearing surface

Oneonta**,** New York was constructed in 2009 with 22 precast slabs jointed on top of 5 steel girders (slab thickness: 8″ [200 mm]). The bridge was 130 ft (38.8 m) in length, with a deck surface area of 5420 ft^2 (504 m^2). Joint cross-section was 6″ x 8″ (152 mm wide x 200 mm) thick. The deck was reinforced with galvanized bars and received a bonded concrete overlay riding surface.

The Chukuni River Bridge**,** Ontario**,** (Figure 6) was completed in the summer of 2010. It was constructed with four – 11 ft (3.7 m) deep steel beams and 54 precast concrete deck panels. UHPC Joint Fill was used to interconnect the precast concrete panels to each other as well as provide the shear connection to the steel structure. This bridge is 331 ft (101 m) long with a clear span of 275 ft (83.5 m); the longest single span bridge in Canada.

Fig. 6 Chukuni River Bridge, Ontario

SIDE-BY-SIDE BOX GIRDERS

During the period from 2007 to 2010, seven bridge projects *(Sunshine Creek, Hawk Lake, Buller Creek, Log River, Eagle River, LaVallee River and Wabigoon River)* have been competed with UHPC Joint Fill (Figure 7) between side-by-side box girders. The projects ranged in length from 70 ft (21 m) to 285 ft (87 m) and from single to three span continuous (Figure 8). For all of these bridges lateral connections was with UHPC only (no post-tensioning was applied).

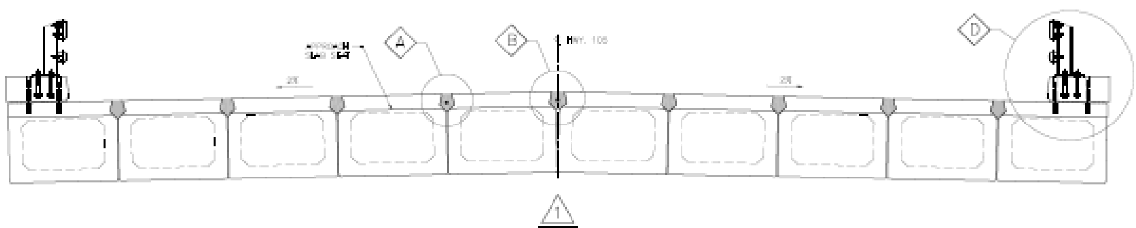

Fig. 7 Typical cross section of side-by-side box girders with UHPC Joint Fill

Fig. 8 Eagle River Bridge, Ontario is a multiple span, side-by-side box girder bridge[9]

SIDE-BY-SIDE DECK BULB-TEES

The Village of Lyons Bridge, New York constructed in 2009, is a side by side, single Bulb-Tee girder project. The bridge consists of eight – 85 ft (26 m) long, side by side Single Bulb-Tee Girders (Figure 9) with UHPC Joint Fill connecting the flanges between the bulb-tees. The deck received an asphalt overlay for a riding surface.

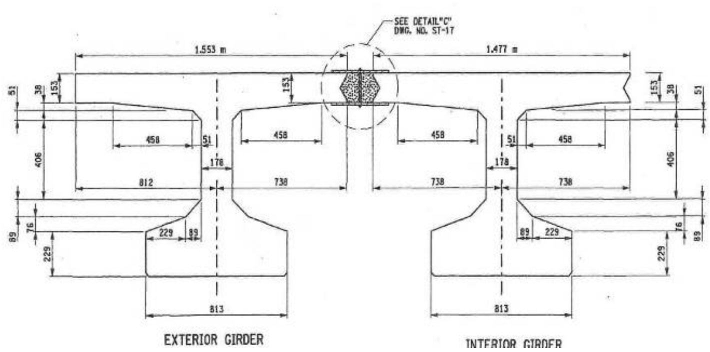

Fig. 9 Section showing Side-by-side Bulb-Tees with UHPC Joint Fill connecting the flanges[10]

FIELD CAST JOINT FILL FOR LIVE-LOAD CONTINUITY

During 2010 two bridge projects (Eagle River [Figure 10] and Wabigoon River, ON) utilized UHPC field cast joints for live-load continuity over internal piers in precast bridges. This joint design (Figure 11) completely eliminated the need for post-tensioning and provide for fast and simple field connections of precast bridge elements.

Fig. 10 Wabigoon River Bridge, Ontario, Canada

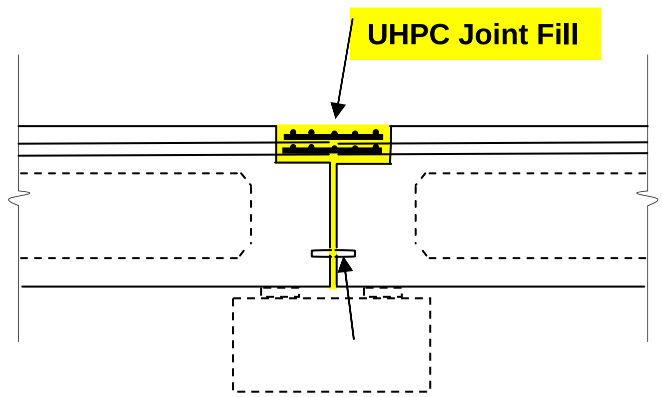

Fig. 11 Section through a live-load continuity joint

FIELD CAST JOINT FILL FOR PRECAST APPROACH SLABS

To date, ten precast bridges have utilized UHPC field cast joints for precast approach slabs. The use of UHPC field cast joints (Figure 12) completely eliminate the need for post-tensioning, contribute to further reductions in construction time and provide a more durable solution.

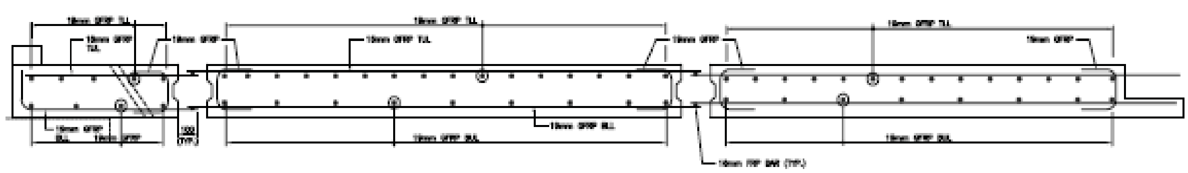

Fig. 12 Section through approach slabs and joints

FIELD CAST CONNECTIONS FOR PRECAST CURBS

UHPC field cast joints for precast curbs (Figure 13) have been used on eight (Wabigoon River, Current River, Eagle River, Sunshine Creek, Hawk Lake, LaVallee River, Log River and Buller Creek) precast bridge projects between 2007 and 2010. The use of UHPC connections ensures continuity in the curb-deck system, simplifies the deck precasting operations and contributes to speed of construction (Figure 14).

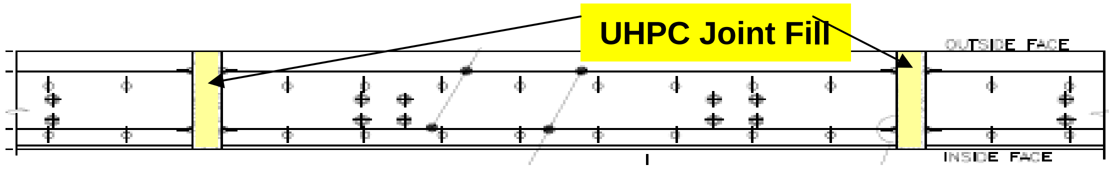

Fig. 13: Plan view of precast curbs and UHPC connections

Fig. 14 Forming and finished view of UHPC curb joints

PROMISING NEW APPLICATIONS FOR UHPC FIELD CAST JOINTS

The use of UHPC field cast connections is a relatively new solution, only have been implemented since 2006 and used in fewer than 20 bridges. However, this early adoption has provided excellent field experience and validation of the methodology. It has also provided exposure and confidence in the technology which has led to innovations for the use of UHPC for other types of field connections for precast bridge systems.

FIELD CAST CONNECTIONS FOR PRECAST WAFFLE DECK PANELS AND HIDDEN SHEAR POCKETS

The use of UHPC for Precast Waffle Deck Panels (Figure 15) provides a light weight durable bridge deck system suitable for new or the rehabilitation of bridges. Installing UHPC Joint Fill (Figure 16) between the UHPC Waffle Deck panels provides an entire deck made from UHPC. To further reduce dead load and improve the deck durability the waterproofing and wearing surface are removed, thereby leaving the entire UHPC deck exposed in order to provide the highest durability, where it is most needed, at the riding surface.

Removing the wearing surface and membrane not only exposes the deck panels, but also the field cast Joint Fill and shear pocket openings. Obtaining a high quality riding surface on exposed field cast UHPC requires additional field work. One option is reduce the quantity of exposed fields cast Joint Fill. To further minimize the exposed surface of Joint Fill, hidden shear pockets maybe introduced into the precast panel. The UHPC filled hidden or conventional shear pockets and haunches provide a fully composite action with the supporting beams.

Fig. 15 Waffle Deck Panels for Wapello County Bridge, Iowa, USA

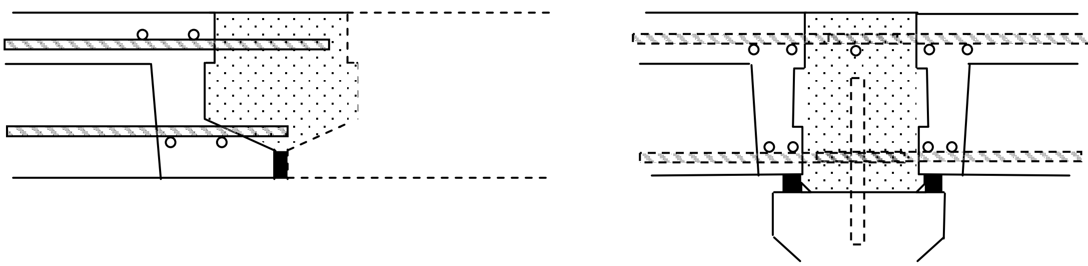

Fig. 16 Jointing Details between Waffle Deck Panels

FIELD CAST CONNECTIONS FOR PRECAST PARAPETS / BARRIER WALLS

As an alternative to cast-in-place, precast parapets or barrier walls maybe supplied to the bridge already integral with the deck (Figure 17) or as separate units (Figure 18) to be field attached. In both cases the precast parapet units need to become fully composite with the bridge deck system in order to carry the traffic barrier loadings.

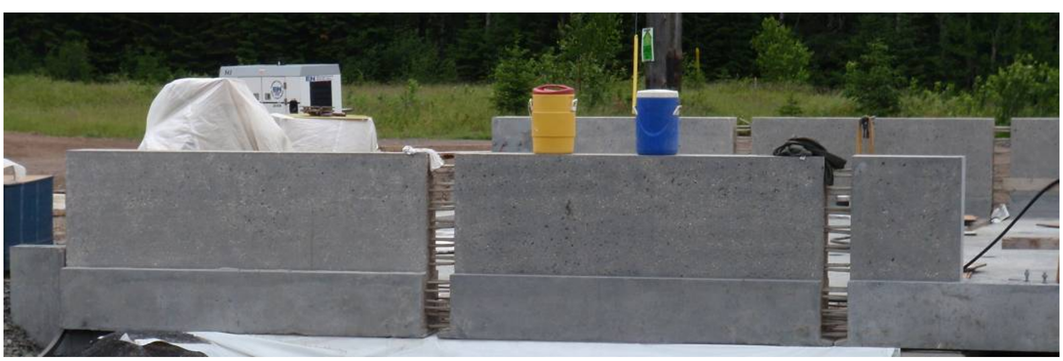

Fig. 17 Integral Deck and Parapets

Field cast UHPC connections for precast parapets and barriers provides the integral continuity and further aids in speeding the construction of the bridge.

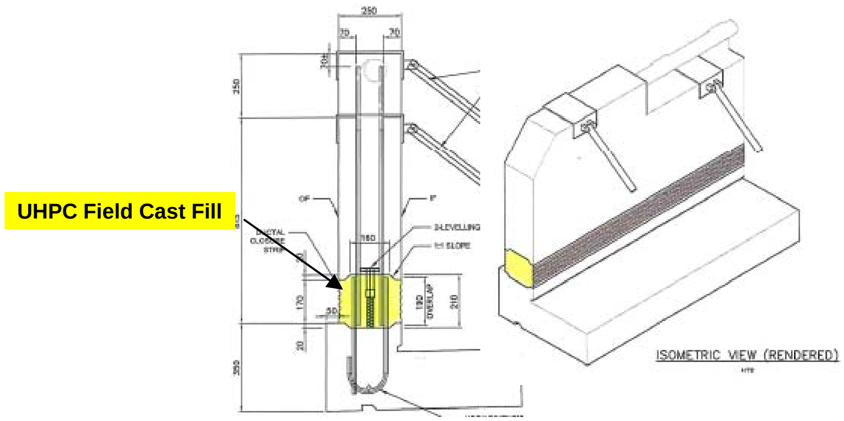

Fig. 18: Separate Precast Parapets (sketch courtesy of MTO)

FIELD CAST CONNECTIONS FOR PILES TO ABUTMENTS

As bridge engineers look for more innovative methods to further speed bridge construction, precast abutments (Figure 19) placed on piling and connected with UHPC[11] provides a further reduction in construction time. The Whiteman Creek project (Figure 19) was under construction at the time of writing this paper.

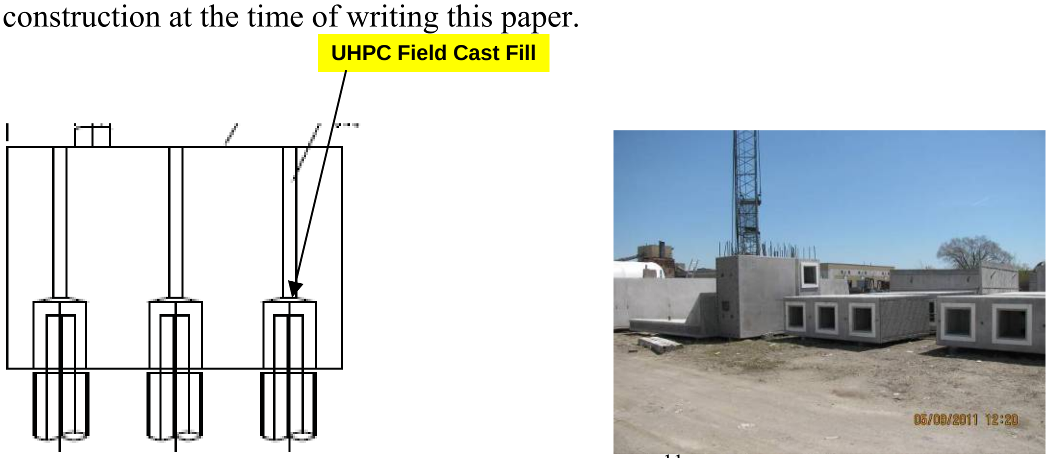

Fig. 19 Precast Abutment for Whiteman Creek, ON[11]

FIELD CAST UHPC FOR EXPANSION JOINTS

UHPC field cast expansion joints (Figure 20) provide strong and durable solutions to solve the durability problems with freeze/thaw, deicing, the constant impact/abuse from trucks and snow ploughs crossing the expansion joints. The use of UHPC for expansion joints eliminates the need for embedded steel edges or casting of field concrete between the precast deck and steel embed.

The expansion joint is formed (Figure 21) and the UHPC is cast through a chimney (Figure 22) in order to maintain a constant head on the filled portion of the joint. Once the UHPC has gained 11,600 psi (80 MPa) it is ground (Figure 23) to exact grade and profile to match the asphalt wearing surface.

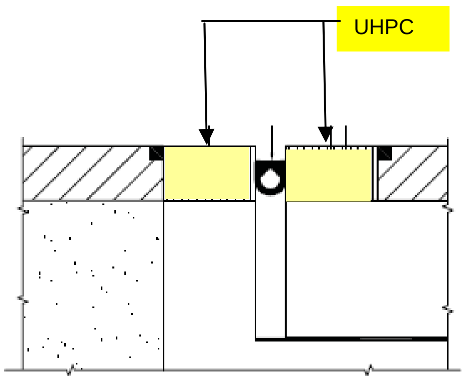

Fig. 20 Section through expansion joint

Fig. 21 Expansion joint ready for UHPC

Fig. 22 Forming & Casting the UHPC Joint

Fig. 23 Finished Joint

This type of UHPC Expansion Joint has been used on several bridge projects in the province of Ontario.

FIELD CAST UHPC FOR THIN BONDED OVERLAYS

Another promising use for UHPC field cast rehabilitation is thin bonded overlays (or "Hybrid") to re-strengthen deteriorating bridge decks (Figure 24). Several State DOTs cooperatively with Universities are investigating the use of UHPC as a cost effective method to significantly extend the life of bridge decks approaching their service life. Early research work undertaken by several universities[12,13] has shown that the inter-facial bond between post cast UHPC onto hardened HPC has provide excellent bond. In all testing conducted to date the failure has always occurred in the base HPC material and not in the interface between the UHPC and HPC. This ongoing research is a further validation of the fatigue testing conducted by the FHWA[8] on the pairs of precast slabs with UHPC Joint Fill, where the joints did not fail or leak after 10,000,000 load cycles.

Fig. 24: Thin Bonded UHPC Overlay[12]

The use of this system is being investigated as both a field cast topping for in-situ deck repairs and as a precast system. The precast "Hybrid" would be cast top surface down where the UHPC is first cast in a textured form liner and then the HPC as a structural back-up. Then panels would be cured, flipped and ready for delivery to site. The precast "Hybrid" panels would be connected with field cast UHPC. Hidden shear pockets may also be used with this system.

FIELD CAST UHPC FOR ACCELERATED BRIDGE CONSTRUCTION

UHPC is a family of products where the mix designs can be formulated to provide a wide range of slump flows, hardened mechanical properties and rate of strength gain. One UHPC product formulated specifically for ABC construction is Ductal® JS1100RS, which provides a high early strength of 8000 psi (55 MPa) in 12 hours at normal ambient temperatures (Figure 25). The product has similar fluid workability to other UHPCs.

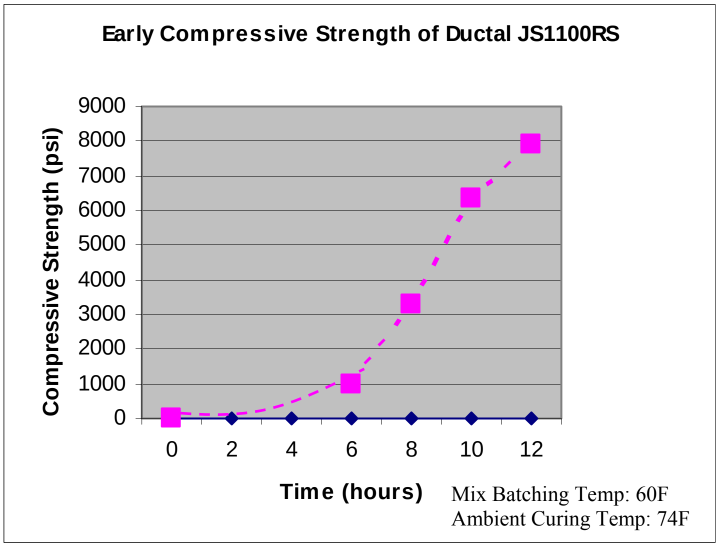

Fig. 25 Strength vs Time Curve for Rapid Strength UHPC

This UHPC rapid strength product is designed for ABC projects executed during weekend closures or other time limited type repairs.

CONCLUSIONS

The UHPC material's combination of superior properties including strength, durability, resiliency, fluidity and increased bond capacity, in conjunction with reinforced precast panels, provides engineers with the ability to create new, optimized and innovative solutions for bridge construction, repair and rehabilitation. Direct benefits may include: improved bridge deck performance through the reduction of joint size and complexity; improved continuity and speed of construction and; elimination of field post-tensioning, while indirect benefits include: improved durability; lower maintenance, reduced user inconvenience and; extended usage life.

Examples were highlighted and testing presented from several DOTs and universities currently involved in precast bridge decks and UHPC programs. The early testing to date indicates that rebar in UHPC has a much shorter bond development length and that the interface bond between UHPC and HPC is stronger than the base HPC. This provides opportunities for bridge engineers to design narrower joint widths for precast deck systems without the use of post-tensioning, improved jointing between precast bridge deck systems, improved horizontal shear transfer systems for fully composite decks, and improved rehabilitations for bridges near their design service life.

The use of UHPC for field connection between precast bridge elements has shown promising results and opportunities for expanding its usage. Full scale laboratory testing and early field perusals have indicated that to date the results of using this technology is providing improved bridge systems; however the authors also recognize that 5 years of performance is rather short compared to the desired service life of hundreds of years. While the feedback from bridge owners using this system has been very positive with respect to performance, the authors plan to conduct an in depth field study of the joint performances and publish a future paper detailing the results.

The projects presented indicate that this material can be successfully batched on site in a range of batch sizes and provide high early strengths during typical field curing conditions. This experience also shows that local contractors can easily adapt to using UHPC material in bridge projects.

While there are still challenges when implementing new material technologies on a wide scale basis, the real challenge ahead is to identify the optimized shapes for precast decks, shear pockets, joints for various deck arrangements and to disseminate on a wide basis the 'know-how' to the engineering community.

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