Innovative Field Cast UHPC Joints for Precast Deck Panel Bridge Superstructures - CN Overhead Bridge at Rainy Lake, Ontario

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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. This paper presents the development, testing and installation of precast, ultra-high performance concrete (UHPC) bridge elements, specifically designed for the Ministry of Transportation of Ontario, to repair deteriorated bridge decks.

A project overview, the fundamentals of the technology, material properties, design details, manufacturing, prototyping, load testing, erection and economics are included.

By utilizing the UHPC material's unique combination of superior properties in conjunction with glass fibre reinforced plastic (GFRP), precast bridge deck panel design is advanced. Benefits include reduced joint size and complexity, improved durability, improved continuity, speed of construction and extended usage life.

Keywords: Precast, Bridge Repair, Ultra-High Performance Concrete, UHPC, Lafarge North America, Composite, Durability, Impermeability, Full Depth, Precast Deck Panels

INTRODUCTION

In North America today, there are thousands of bridges that are structurally deficient or obsolete and more than 3000 new bridges are added each year.[1] State, provincial and municipal bridge engineers are seeking new ways to build better bridges, reduce travel times and improve repair techniques; thereby reducing maintenance costs which are diverted from capital budgets required for building much needed new highways and bridges. Bridge owners are frequently faced with the need to replace critical bridge components during strictly limited or overnight road closure periods.

The introduction of new methodologies and innovative material technologies facilitates the implementation of new solutions. One new technology being developed to help solve the problem with North America's deteriorating bridges is an ultra-high performance, fibre 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. Ultra-high performance concrete (UHPC), used in conjunction with glass fibre reinforced plastic (GFRP) reinforced high performance concrete (HPC) provides a synergistic, new approach for reconstruction of bridge superstructures.

In 2004, the Ministry of Transportation of Ontario (MTO) implemented a new solution for replacement of deteriorating highway bridge decks. The solution was to use a precast concrete deck and approach slab panels with GFRP in the top mat and curbs. Field cast UHPC was used in the infill portions to develop continuity in the deck panels. The project selected to introduce this new solution was a highway bridge over the Canadian National Railway (CNR) at Rainy Lake, near Fort Francis, Ontario.

Utilizing the superior characteristics of the material technology enabled the designer to greatly simplify the precast panel fabrication and installation processes. This simplified design provided the Owner with improved tolerances, reduced risk, an overall cost savings in construction and a more durable solution.

THE PROJECT

The existing bridge, CN Overhead at Rainy Lake, was constructed in 1962 on Ontario Highway 11 over the CN rail lines near Rainy Lake, ON. The bridge was designed as a 24.384 meter (80′) single span x 10.972 meters (36′) wide, skewed (Figure 2) with steel plate girders and a 178 mm (7″) thick cast-in-place, reinforced concrete deck with an 80 mm (3″) thick asphalt wear surface (Figure 1). The existing deck had reached its useful life and was in need of major reconstruction. A staged method of construction was utilized to maintain one lane of traffic during deck reconstruction.

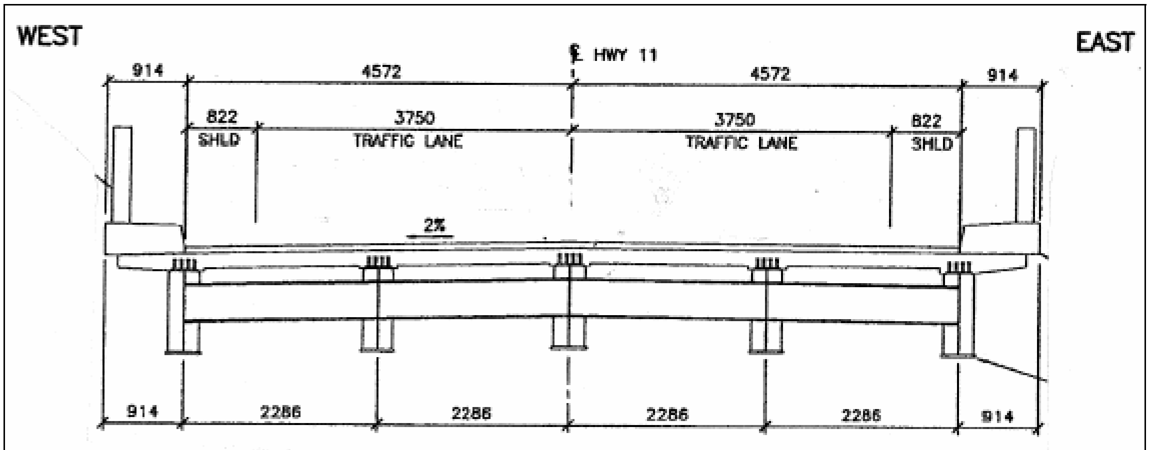

Fig. 1 Transverse Section of existing bridge – CN Overhead at Rainy Lake, ON(4)

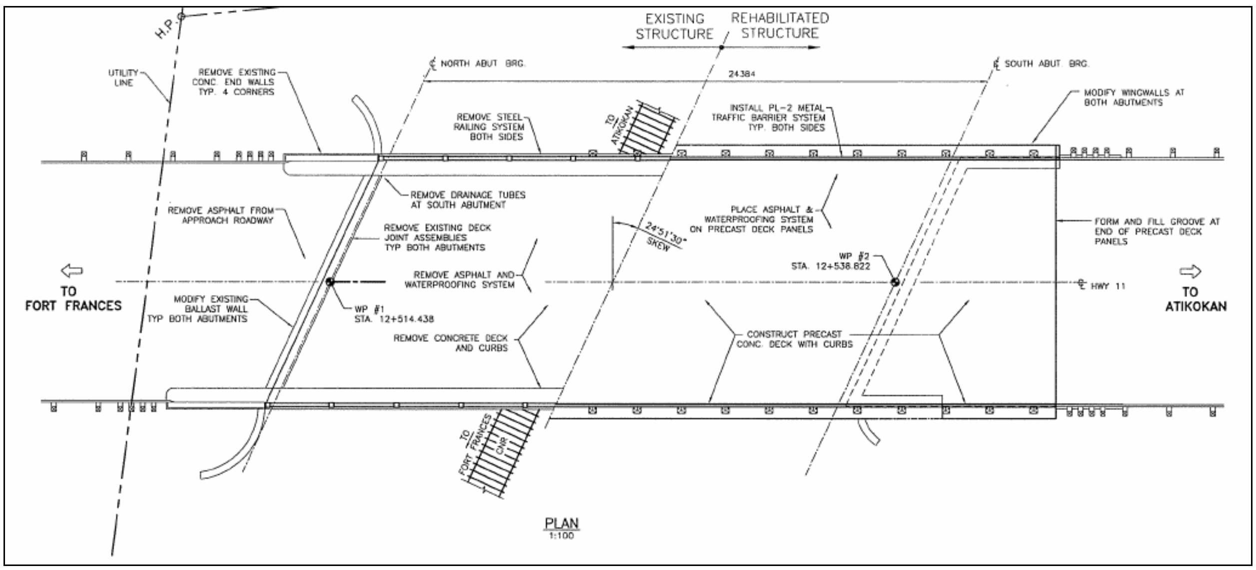

Fig. 2 Plan of existing and rehabilitated bridge

THE DESIGN

The material supplier, consultant and owner worked closely together to develop a new, innovative solution for reconstructing the bridge deck. The existing reinforced cast-in-place deck was removed transversely, one-half at a time while maintaining full traffic volume and replaced one-lane at a time with a new precast deck panel system. The new precast deck panels (Figure 3) were rectangular, 225 mm (9″) nominal thickness and 5775 mm x 3600 mm (19′ x 12′) reinforced with GFRP bars (top mat only), each way, top and bottom (conventional steel rebar). The deck panels were manufactured with 35 MPa (5000 psi) concrete. GFRP bars were selected as top slab reinforcing since they do not corrode and therefore provide excellent durability characteristics. Highway bridges are traditionally susceptible to corrosion, primarily from the top surfaces due to their exposure to deicing salts. The designers and owners decided to provide a non-corrosive reinforcing medium such as GFRP bars.

The precast deck panels were designed to be fully composite with the existing steel girders. This was accomplished by providing standard Nelson shear studs welded to the top flanges of the girders at the precast panel pockets, which were subsequently fixed with UHPC. Precast continuity was provided by reinforcing embedment/development with the field cast UHPC construction joints. The higher strength/E-Modulus UHPC joint material also improved the stiffness of the connection between the panels and the Nelson studs, thereby enhancing the composite section between the deck and beams.

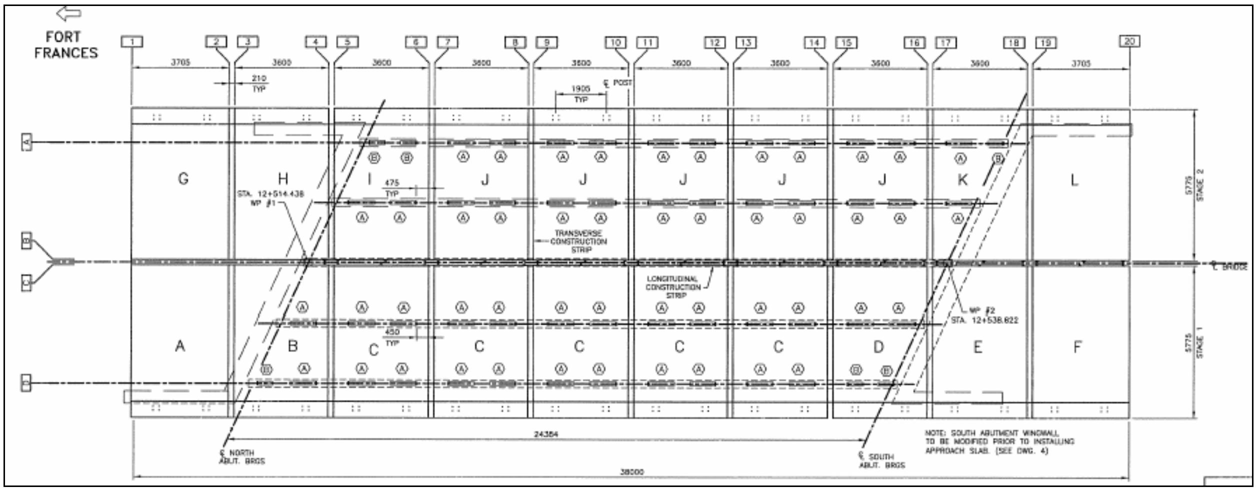

Fig. 3 Precast panel layout

Traditional closure strips between panels usually involve complex reinforcing arrangements, e.g. looped bars and a large quantity of transverse reinforcement in the joint. To reduce the complexity during fabrication and installation of the precast deck panels a new, simpler joint was developed - based on research conducted at Chalmers University of Technology, Sweden(8). This study focused on using UHPC in a 100 mm (4″) wide closure strip, without any complicated hooked or bent bars. At the Rainy Lake CNR Overhead, UHPC was selected in order to achieve a much simpler 210 mm (8″) wide joint.

To eliminate the need for installing forms on the transverse closure strips, a small concrete lip was fashioned on the bottom part of the panel. During installation, a small strip of Evazote (foam backer rod) was glued to the edge of this lip so that when two panels were butt together, a watertight seal was formed. This eliminated the need for additional forms on the underside of the transverse closure strips (Figure 4). Because of the small closure strips, these lips were more robust and durable than traditional configurations.

Tensile pullout tests were carried out and it was decided that full bar development could be realized in the field-cast joints, using a bar embedment length of approximately 190 mm (7½″) (Figure 5).

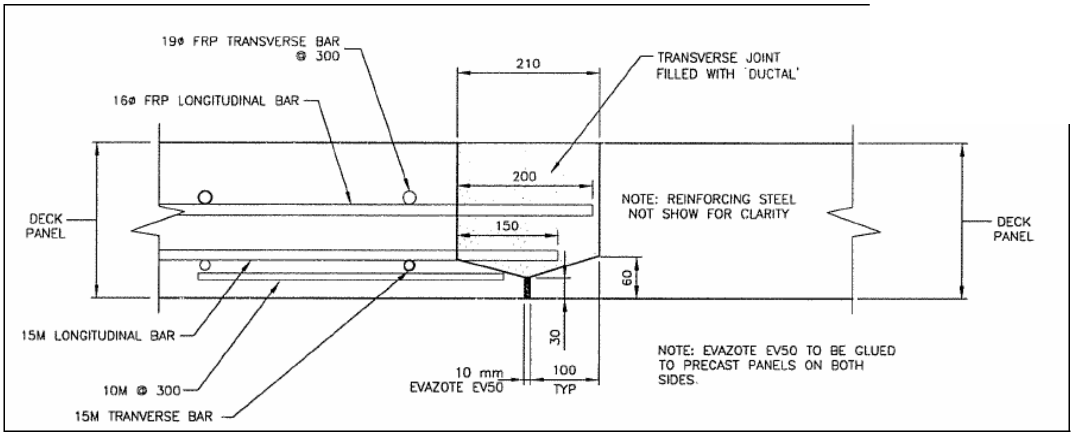

Fig. 4 Typical transverse field joint

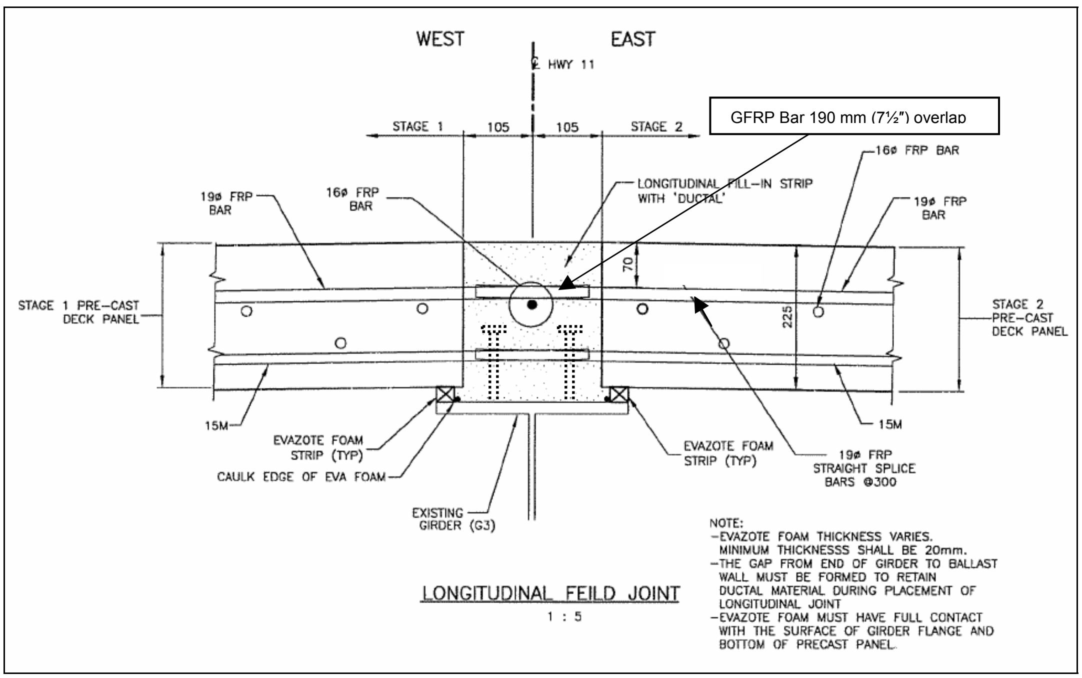

Fig. 5 Section through longitudinal field cast joint

CHARACTERISTICS OF THE UHPC JOINTING MATERIAL TECHNOLOGY

The UHPC technology utilized for the joints in this project 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 fibres. The material 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 120 to 200 MPa (17,400 to 29,000 psi) and flexural strengths range from 15 to 40 MPa (2,200 psi to 5,800 psi).

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 fibre geometry of 12 mm x 0.2 mm (½" x 0.08"). The ratio of maximum coarse aggregate size to fibre is important to facilitate random orientation of fibres 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 fibre.

With a carbonation depth penetration of 0.5 mm (0.02″), 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 0.5 mm [0.02″]) and chemical reactivity. The net effect is a maximum compactness and a small, disconnected pore structure.

The joint fill for the precast deck panel was Ductal® JS1000. The following is an example of the range of material characteristics for Ductal® JS1000:(6)

Strength		**Durability**	
Compressive (28 days)	140 MPa	Freeze/thaw (after 300 cycles)	100%
Compressive (48 hours)	100 MPa	Salt-scaling (loss of residue)	10 g/m^2
Flexural	30 MPa	Carbonation depth	0.5 mm
Young's Modulus (E)	50 GPa		

The materials are supplied to the site in a three-component premix (pre-blended powders in 35 kg (80 lb) bags plus superplasticizer and fibres), along with a mixer and technical support from the supplier.

TESTING

Previous work and various tests have been conducted to demonstrate the pullout capacity of steel strands in UHPC(7), to determine that significantly shorter bond development lengths would be required to fully develop the bars. However, since bond development lengths for GFRP in UHPC had not been tested, a test program was undertaken in the labs of EBA Engineering Consultants Ltd. (Calgary), in order to develop a design recommendation.

Single GFRP bars were embedded into UHPC blocks at lengths of 100 mm (4″) and 150 mm (6″) (Figure 6). The bars were loaded to failure, in accordance with Annex B of CAN/CAS-S806-02(8). Test results (Table 1) show that the mode of failure for the 150 mm (6″) embedment was a tensile force induced fracture of the GFRP rod, with no discernible slippage nor any detectable UHPC fracturing. For the 100 mm (4″) embedment, the failure was a delamination of the epoxy sand layer to the bar. Both embedment lengths failed in the bond of the epoxy sand coating however, the force applied was significantly greater than the design requirement.

Table 1. Pullout test data – GFRP in UHPC

Sample #	Embedment Length	Failure Load (N)	Failure Method
1	100 mm (4″)	67,110	GFRP Rod Rupture
2	150 mm (6″)	95,684	GFRP Rod Rupture

This test result validated the design, which allowed for a precast bridge deck with a 210 mm (8″) wide joint compared to a conventional design of a 600 mm (24″) wide joint.

Fig. 6 Test set-up for pullout capacity of GFRP in UHPC block

DESIGN CONSIDERATIONS FOR DURABILITY OF THE JOINT

One challenge facing highway authorities when utilizing full depth precast bridge deck panels is durability of the joints due to the constant flexing from truck loadings and corrosion from salt of the rebar crossing the joints. The design for this project focused on balancing a joint detail that provided deck continuity for loads, minimizing traffic disruption, speed of construction and long-term durability.

Regardless of the materials used, shrinkage across the joint is a potential problem that results in a joint interface between the panel and joint fill, which is an area for the ingress of salts. To minimize this corrosion potential, a non-corrosive rebar (GFRP) was used in the top mat and the joint size was minimized to provide the least possible total shrinkage across the joint. Minimizing the joint size also reduced the quantity of jointing material to be cast on-site and simplified the precast panel manufacturing.

The JS1000 joint fill material has a superior freeze/thaw resistance, extremely low porosity, higher than normal flexural strength and superior toughness, which provides improved resistance to climatic conditions and continuous flexing from truck loadings across the joints.

The improved durability of GFRP concrete bridge decks has also been shown in a recent study by ISIS Canada[9]. The ISIS study of cores taken from bridge decks, wharf decks and parapets constructed of GFRP in concrete during the periods of 1997 to 2000, showed no signs of deterioration.

CONSTRUCTION/INSTALLATION

In order to maintain critical traffic flows during reconstruction of the bridge deck replacement, the project was phased, with one lane always open to traffic (Figure 7). Temporary Jersey barriers enabled the contractor to safely work on the bridge deck, adjacent to moving traffic.

Following removal of the existing cast-in-place reinforced concrete deck and shear studs, new studs were added in joints and slab pockets. The existing steel beams were then cleaned and painted. The half-width precast deck panels were set to grade, spanning between the steel girders and leveled with integrally cast leveling bolts. At the panel bearings on the beams, an Evazote foam strip was installed to provide a water-tight seal between the precast panels and steel beam bearings (Figure 5).

Once all panels were installed, leveled and tested for water tightness (Figure 8), the joints were filled with the UHPC material.

The material was also utilized as a bedding substance for the precast slabs (flowing beneath the previously installed slabs), providing a 13-20 mm (½–¾") continuous UHPC interface between the bottom of the precast slab and steel support girder, in order to precast the HPC slab gap (Figure 5).

Fig. 7 Maintaining one lane open to traffic at all times during the deck reconstruction

It should be noted that no specific detail or preparation was required on the face of the precast panels. The design assumption was that there would be a minimal amount of shrinkage across the joint. The use of the GFRP bars and extremely small shrinkage would not negatively impact the durability of the joint.

Fig. 8 Joints ready for filling with UHPC

The UHPC material was batched on site with an IMER Mortarman 720 Mixer, in 0.2 cubic meter (0.7 cubic foot) batches. Two mixers were used in parallel, alternating to provide for batching and placing in a continuous basis. A four-person crew was able to run both mixers and produce 0.5 cubic meters (1.7 cubic feet) per hour. Casting time to complete the filling of all joints for one half of the bridge took approximately 8 hours.

Following batching of the UHPC, the material was placed in a power buggy and transported across the precast panels to the joint location and poured into the joints (Figure 9). The self-leveling UHPC material was then covered with form grade plywood to protect against moisture loss. The UHPC should not be vibrated so as not to disrupt the random orientation of the fibres. Following a 4-day field cure, the UHPC material was ground smooth, in the area of any high spots.

Fig. 9 Filling the joints with UHPC placed from the power buggy

The joints were covered and left to cure for 96 hours, at which time the compressive strength exceeded the 100 MPa (14,500 psi) requirement to open the bridge to traffic (Figure 10). The traffic was transferred onto the new precast deck and the second phase of the bridge was re-constructed with the same system. A waterproof membrane and asphalt overlay were then placed on the entire new deck surface after the second phase was completed.

During casting of joints, 75 mm x 150 mm (3″ x 6″) cylinders were cast. The cylinders were field cured beside the cast joints then transported to a lab for end grinding and testing. Due to UHPC's higher strengths, special procedures for cylinder preparation must be followed in order to ensure that test results represent the actual material properties.

Construction was completed during summer of 2006 and the bridge opened to traffic in September, 2006.

Fig. 10 CN Overhead at Rainy Lake Bridge with precast deck panels and UHPC joint fill

CONCLUSIONS

The UHPC material's combination of superior properties including strength, durability, fluidity and increased bond capacity, in conjunction with the GFRP reinforced precast panels, provides engineers with the ability to create new, optimized solutions for bridge construction. By utilizing the combined material properties in this application, precast bridge deck panel design is advanced. Direct benefits include reduced joint size and complexity, improved continuity and speed of construction while indirect benefits include improved durability, lower maintenance and extended usage life.

This project's design, testing and construction validated a precast bridge deck with a 210 mm (8″) wide joint compared to a conventional design with a 600 mm (24″) wide joint. The precast deck panel system enabled the bridge to be opened to traffic in 48 hours after the joint pour (closure).

While there are still technical challenges when implementing this solution on a wide scale basis, the real challenge ahead is to identify the optimized shapes for precast deck panels and joints for various deck arrangements. When the optimized configurations are determined, precasters, manufacturers and contractors can invest in the formwork and equipment to economically produce these solutions. The true economics of these systems will eventually bring value to highway users through standard mass production of optimized UHPC shapes and systems.

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