MACKENZIE RIVER TWIN BRIDGES – THE LARGEST FIELD-CAST UHPC CONNECTIONS PROJECT IN NORTH AMERICA

Vic H. Perry, FCSCE, MASc, P.Eng, Lafarge North America, Inc., Calgary, Canada
Raymond Krisciunas, P.Eng, Ministry of Transportation of Ontario, Thunder Bay, Canada
Bob Stofko, P.Eng, McCormick Rankin Corporation, Mississauga, Canada

ABSTRACT

The Mackenzie River Bridges are part of the new TransCanada Highway realignment near Thunder Bay, Ontario, Canada. The project consists of twin, two-lane bridges, each with three-spans for a total length of 180 m (590 ft-6 in). The bridges cross a deep gorge of the Mackenzie River using variable depth, continuous steel plate girders with full-depth precast deck panels that are lightly prestressed and run the full-width of the bridge. Precast approach slabs and 130 precast deck panels (2.99 m [9 ft-7 in]wide x 14.5 m [47 ft-7 in] long x 225 mm [9 in) thick) were jointed together in transverse joints and attached to the steel girders through shear pockets and haunches, using field-cast ultra-high performance concrete (UHPC). With a total of 175 m^3 (229 yd^3), this application is the largest UHPC field-cast project in North America.

This paper presents: a completed project profile; precast deck panel details; and design of precast deck panel joints that utilize UHPC's unique combination of superior properties in conjunction with precast deck panels. The benefits, such as improved resiliency and durability, reduced joint size, elimination of post-tensioning and extended usage life, are discussed. Additionally, the advantages realized by the owner (when using a precast bridge system with UHPC joints) are illustrated.

The material properties, plus batching, casting and installation of this large field-cast UHPC project are illustrated. The advantages of using this system and other UHPC field-cast connections for future bridge projects (especially for ABC construction) are also explored.

Keywords: UHPC, In-field Connections, Joints, Composite, Ductile, Durability, Fiber-reinforced, Impermeability, Resiliency.

INTRODUCTION

The Mackenzie River Twin Bridge project near Thunder Bay, Ontario is (to date), the largest field-cast Ductal® Ultra-High Performance Concrete (UHPC) bridge project in North America. Constructed during 2010/11, it is part of the new TransCanada Highway realignment for the Ministry of Transportation of Ontario (MTO) and consists of twin, two-lane bridges; each consisting of three-spans for a total length of 180 m (590 ft 6 in). The bridges cross a deep gorge of the Mackenzie River, using variable-depth continuous steel plate girders with full-depth precast deck panels that are lightly prestressed and run the full-width of the bridge. There are 130 precast deck panels, 2.99 m (9 ft 7 in) wide x 14.5 m (47 ft 7 in) long x 225 mm (9 in) thick. The transverse joints between the panels are filled with UHPC as well as the shear pockets and haunches between the underside of the deck panels and the steel girders. Precast approach slabs with UHPC field-cast connections were also used.

THE PRECAST DECK CONCEPT

Every day, engineers face the challenge of increasing traffic volume and loadings on aging bridge infrastructure - with reduced budgets and public demand for less inconvenience during maintenance or repairs. Additionally, transportation authorities are faced with replacing or repairing these 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 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 of 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.

While it is recognized that precast bridge components can provide high durability, conventional joints are often the weakest link in the system. The introduction of new methodologies and innovative material technologies facilitates the implementation of new solutions. One new technology that is helping to solve the problem with deteriorating bridges is an ultra-high performance, fiber reinforced cement composite material ("Ductal®") 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. UHPC, when used as a jointing material in conjunction with reinforced HPC panels, provides a synergistic, new approach for reconstruction of bridge superstructures.

Since 2005, the Ministry of Transportation of Ontario has implemented the use of UHPC joint fill with full precast bridge decks for the replacement of deteriorating highway bridges and on new bridge construction[2]. 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 joint design, the precast panel fabrication and installation processes. This simplified design provides the owner with improved tolerances, reduced risk, increased speed of construction, a potential overall cost savings in construction and a more resilient/durable, longer lasting bridge deck solution.

THE PROJECT

The Mackenzie River twin bridges cross a deep gorge of the Mackenzie River, on a new TransCanada Highway realignment and twinning near Thunder Bay, ON. The bridge is a three-span, variable-depth steel plate girder (Figure 1), supported by abutments on the high river bank and two, intermediate high-level CIP concrete piers on spread footings; all which are founded directly on bedrock (Figure 2)[3].

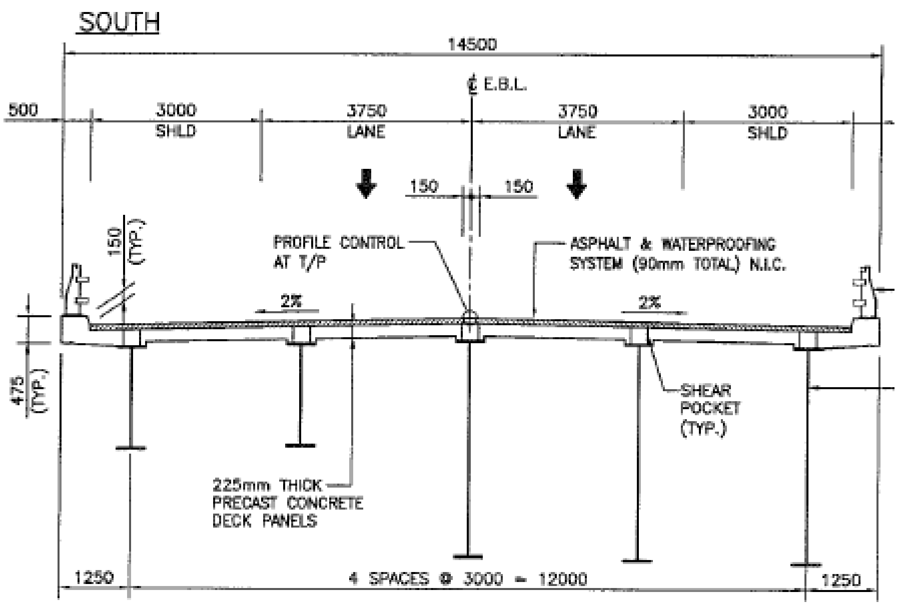

Fig. 1 Cross-Section of East Bound Bridge

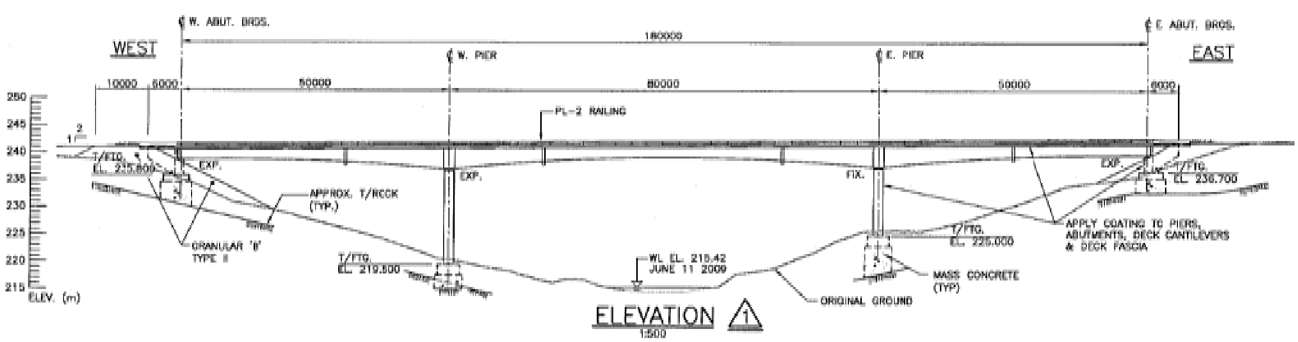

Fig. 2 Elevation of East Bound Bridge

Once the decision was made to twin Highway 17, there was considerable pressure to construct the two bridges as quickly as possible, to prevent use of the existing congested highway by heavy construction vehicles. The rugged site conditions and extremely tight timelines posed both challenges and opportunities for the design team. Various structural forms were considered, including segmental girders and concrete arches. In the end, the steel girder with a precast deck option offered the best combination of economy, expediency and aesthetics. The Region's extensive, previous experience with this structural form, specifically the use of precast, prestressed HPC deck slabs with UHPC joint fill, were also contributing factors. These materials, in combination with state-of–the-art fiber reinforced polymer reinforcing throughout, result in an expected life in excess of 75 years for the bridge deck.

An additional feature of this structural form was the high degree of prefabrication which enabled pre-procurement of materials. All deck panels and structural steel was pre-purchased under separate contracts and made available to the bridge general contractor, thereby shaving many months off the final completion schedule.

FOUNDATIONS

The CIP abutments and piers are supported on CIP spread footings which are, in turn, supported by mass concrete on rock

GIRDERS

Each bridge has 5 variable-depth, atmospheric corrosion-resistant steel plate girders with spans of 50 m (164 ft), 80 m (262 ft) and 50 m (164 ft), spaced at 3000 mm (9 ft 10 in), center to center, providing an overall bridge width of 14,500 mm (47 ft 7 in).

The continuous steel plate girders vary in depth, from 1800 mm (5 ft 11 in) at the abutments and mid-span of the main span, to 3800 mm (12½ ft) at the piers. Only the 3 interior girders are supported on the two piers; each exterior girder is supported by a heavy transverse steel diaphragm at the piers comprised of twin plate girders. This enabled a much narrower pier than what would normally be designed for a girder bridge.

DECK PANELS

The bridge deck consists of full-depth precast deck panels that are lightly transversely prestressed and run the full-width of the bridge. There are 130 precast deck panels, 2.99 m (9 ft 7 in) wide x 14.5 m (47 ft 7 in) long x 225 mm (9 in) thick (Figure 3). The panels also contain Glass Fiber Reinforced Polymer bars (GFRP) as passive reinforcing, which project into the joints to develop the panel to panel connections. The transverse joints between the panels are filled with UHPC. The haunches (between the top flange of the girders and the underside of the deck panels and the shear pockets) are filled with UHPC, to provide fully composite action between the steel girders and precast concrete deck panels.

Each deck panel has 2 shear pockets per girder line to accommodate shear studs. These pockets vary in size, from 300 x 430 mm (11 ft 8 in x 16 ft 9 in) to 300 x 730 mm (11 ft 8 in x 28 ft 7 in), to accommodate between 12 and 32 studs per pocket. The reinforcing steel in the deck panels passes through the pockets and is detailed in order to avoid interference with the studs. Shear studs were welded to the top flanges of the girders after installation of the deck panels and the pockets were filled with UHPC.

Grout in the blockouts could have worked however it would have been impractical, considering that UHPC was necessary for the field joints. The blockouts had to be completed simultaneously, thereby necessitating UHPC. Consequently, superior durability (with UHPC) was a bonus in that respect.

The 14.5 m (47 ft 7 in) long precast deck panels were lightly prestressed, to minimize the potential for cracking during handling and in service, thereby enhancing the long term durability of the deck. The panels were prestressed with 12 mm (1/2 in) diameter carbon-fiber-reinforced polymer (CFRP) tendons.

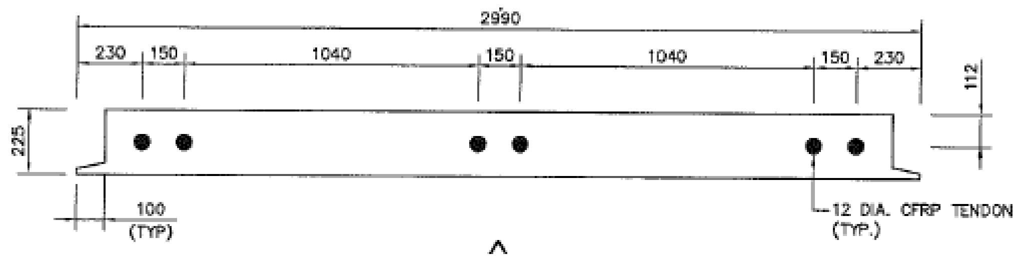

Fig. 3 Typical Cross Section through a panel

DECK JOINTS

The deck joints (Figure 4) are filled with UHPC, as are the shear pockets and haunches between the underside of the deck panels and the steel girders (Figure 5). Precast approach slabs with UHPC field-cast connections were also used.

The UHPC technology utilized for the joints is an ultra-high-strength, ductile material formulation made with constituent ingredients including: Portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water and steel fibers. Compressive strengths for bridge applications range from 120 to 200 MPa (17,400 to 29,000 psi) and flexural strengths range from 15 to 40 MPa (2175 to 5800 psi). Bond development lengths for 15M (49 ft 3 in) bars are less than 75 mm (3 in), resulting in very narrow joints of approximately 150 mm (6 in) to 210 mm (8 in) in width.

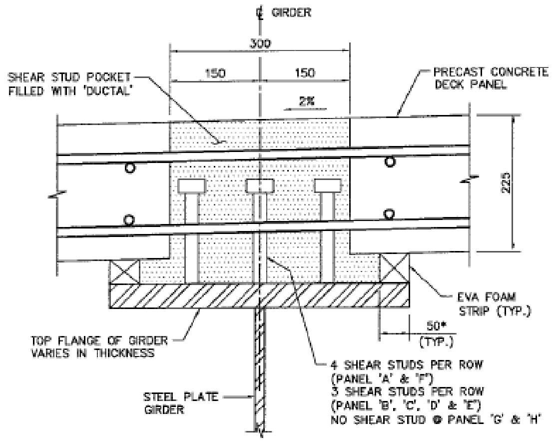

Fig. 4 Typical Section through a Transverse Panel Joint

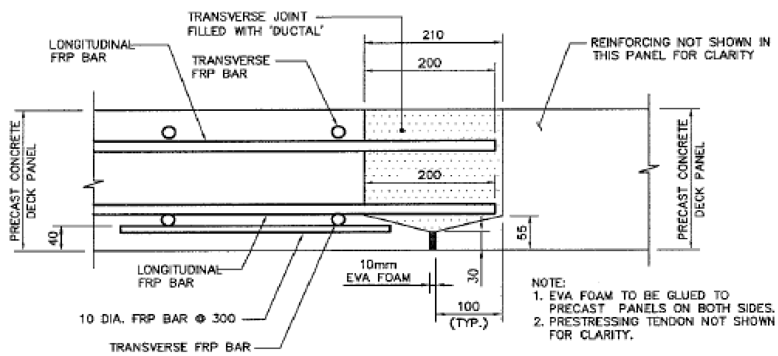

Fig. 5 Typical section through a shear pocket connection & haunches

The width of the joints used by various owners and designers varies, based on experience and projects. Narrow joints are more optimized but reduce construction tolerances for the installation of the deck panels. Based on testing of pullout capacity of bars in UHPC, full scale panel testing conducted at FHWA[5] and the 200mm (7 ft 9 in) bar embedment length (Figure 4), the panel to panel connections provide full continuity across the joint, as if the reinforcing is continuous through the joint.

BARRIER WALLS

An added feature of the bridge is the use of UHPC panels as aesthetic facing over top of the barrier wall transitions (Figure 6). Conventional concrete would have been prone to the effects of salt and snow plow damage. Therefore, a unique, textured bolt-on UHPC panel protective system was developed.

Fig. 6 UHPC Barrier Wall Facing Panels

CASTING THE JOINTS

To complete the work, Lafarge supplied all of the UHPC materials and twin 0.5 m^3 (18 ft^3) mixers (Figure 7), providing over 20 m^3 (706 ft^3) per day of production for a total of 175 m^3. The casting of the joint fill material was completed with an eighteen-man crew in just ten days. The crew consisted of two men on the mixers, one on the scales, one to load the mixers, one to guide the loader, two on power buggies - transporting the material from the mixer to the bridge (Figure 8), four guiding the buggies, one floating the material and six on the forms.

Fig. 7: Loading premix into 0.5m^3 mixers

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Fig. 8: Pouring a UHPC joint

The premix was supplied in 2,460 lbs (1116 kg) super sacks and added first to the mixer. Then, the water and liquid superplasticizers were introduced. Once the batch became fluid, the weighed fibers were manually added to the mixer. When placing this self-levelling UHPC into joints, it is important to take advantage of its fluid characteristics. After placement, any exposed surfaces were covered in order to prevent dehydration. For each onsite batch, QA/QC was performed by measuring the rheological properties to confirm that the material was batched and placed properly. Compression tests were also performed on a regular basis.

ADVANTAGES/BENEFITS OF A PRECAST CONCRETE BRIDGE DECK SYSTEM WITH UHPC JOINTS

Concrete is one of the most durable building materials on the earth and, in North America, it is usually available locally. Durability means longevity and local availability means a reduction in transportation of resources. Furthermore, the cement, concrete and construction industries provide employment for people in local communities, also relating to reduced transportation impacts. Durable, long lasting and local products are fundamental elements to approaching sustainability.

UHPC further extends the sustainability and resiliency of our infrastructure. With a carbonation depth penetration of 0.5 mm (.019 in), 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 [.019 in]) and chemical reactivity. The net effect is a maximum compactness and a small, disconnected pore structure

To better understand UHPC's long-term durability and life expectancy, a series of prisms (152 mm x 152 mm x 533 mm [6 in x 6 in x 21 in) were placed in 1996 and 2004, at the long-term exposure test site of the US Army Corp of Engineers, in Treat Island, Maine, USA (Figure 9)[6].

Fig. 9 Wharf at US Army Corp of Engineers long-term exposure site, Treat Island, Maine, USA

The prisms are placed on the wharf deck which is located at mean tide in the Bay of Fundy, Maine (Figure 10). The samples are subjected two tide cycles of wet/dry in sea water each day and, during winter at low tide, are subject to freeze/thaw. After 13 years of exposure, the samples were removed and measurements taken for the depth of chloride penetration.

Fig. 10 Prisms on the wharf at exposure site

After 13 years of similar exposure, HPC has more than 5 times chloride content and 2.5 times the depth of penetration compared to UHPC. In accordance with *Fick's Law for Chloride Ion Diffusion*, the rate of penetration depth of chlorides in concrete is proportional to the square of time. It takes 4 times as long to double the depth of penetration. Figure 11 shows the predicted rate of penetration of UHPC vs HPC.

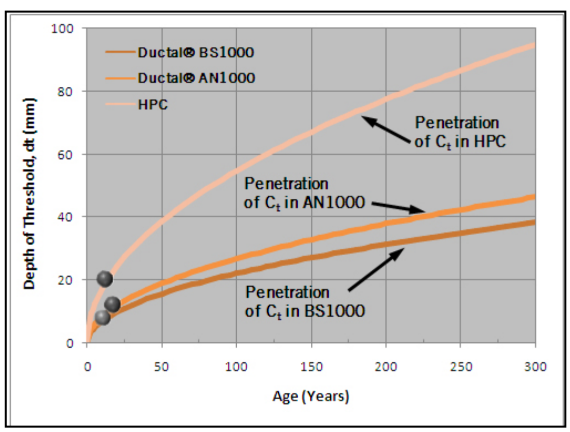

Fig. 11 Depth of chloride vs time for UHPC vs HPC

Extrapolating the data suggests that UHPC requires 1,000 years to have the same level of chloride penetration that HPC would have in less than 100 years. Another observation is that, after 13 years, the UHPC prisms at the exposure site still have corners that are as clean and sharp as the original samples. Most other concrete samples, after one season, show rounding of the corners due to freeze/thaw durability.

CONCLUSIONS

This project demonstrates that the use of a precast HPC deck panel with CFRP tendons, GFRP bars and UHPC joints provides a corrosion-free, highly durable bridge deck system that can be constructed in non urban areas by regular bridge contractors.

UHPC technology is not new, but relative to concrete, this 20 year-old technology is still in its infancy, particularly relative to its deployment. This material technology shows very promising results for building better 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.

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