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Mackenzie River twin bridges

North America's largest field-cast ultra-high-performance concrete connections project

- The Mackenzie River bridges, part of the TransCanada Highway realignment near Thunder Bay, ON, Canada, comprise twin, two-lane bridges, each with three spans, for a total length of 180 m (590 ft).
- Continuous steel-plate girders support full-depth precast concrete deck panels that extend the full width of the bridge.
- Precast concrete approach slabs and 130 precast concrete deck panels were connected at transverse joints and attached to the steel girders using field-cast ultra-high-performance concrete.

The Mackenzie River twin bridges project near Thunder Bay, ON, Canada, is the largest field-cast ultra-high-performance concrete (UHPC) project in North America in terms of bridge size and total volume of UHPC joint fill material used (**Fig. 1**). Completed in 2011, the bridges cross a deep gorge of the Mackenzie River and form part of the new TransCanada Highway realignment. Each bridge has two lanes and consists of three spans for a total length of 180 m (590 ft). They are constructed with variable-depth continuous steel plate girders with 130 full-depth precast concrete deck panels (2.99 m [9.6 ft] wide × 14.5 m [47.6 ft] long × 225 mm [9 in.] thick). The panels are lightly prestressed and extend the full width of the bridge. The transverse joints between the panels and the shear pockets and haunches between the underside of the deck panels and steel girders are filled with UHPC. Precast concrete approach slabs with UHPC field-cast connections were also used.

This paper presents the project design and details as well as the advantages and future potential for precast concrete bridge deck systems with UHPC connections (that is, accelerated bridge construction). Also discussed are UHPC's superior properties compared with conventional concrete, along with the batching, field casting, and installation techniques.

Figure 1. Mackenzie River twin bridges near Thunder Bay, ON, Canada. Courtesy of Lafarge.

The precast concrete deck concept

Every day engineers face the challenge of increasing traffic volume and loading on aging bridge infrastructure—with reduced budgets and public demand for less inconvenience during maintenance or repairs. Transportation authorities are also faced with replacing or repairing these critical bridge components during strictly limited road closures.

One of the greatest challenges is the durability and resiliency of bridge decks, which receive continuous impact loading from trucks and changing environmental conditions. Years of continuous flexural and thermal stresses cause deterioration.[1] While cast-in-place concrete decks with high-performance concrete (HPC) and corrosion-resistant reinforcing can significantly extend deck life, this type of construction creates user inconvenience and is problematic for bridge deck replacement in high-traffic areas or in remote areas with limited access to ready-mixed concrete. The use of precast HPC deck panels is a common method to speed construction and alleviate user inconvenience; however, jointing of the precast concrete system necessitates maintenance.

While it is recognized that precast concrete bridge components can be durable, conventional joints are often the weakest link in the system. One fairly new technology that is helping to solve the problem of deteriorating bridges is a UHPC that offers superior ductility, strength, and durability compared with conventional concrete, while providing highly moldable products with a high-quality surface 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 the construction or reconstruction of bridge superstructures.

Early development of UHPC joint fill began in 2004. The first project to use this solution was completed in 2006 at Rainy Lake on a highway bridge over the Canadian National Railway.[2] To expand on the Harryson joint[3] (to eliminate field formwork and simplify the reinforcing details), a concrete deck and approach slab panels with glass-fiber-reinforced polymer (GFRP) bars were used in the top mat and curbs and UHPC joint fill was used in the infill portions to develop continuity in the deck panels.

Taking advantage of UHPC's superior characteristics simplifies joint design, precast concrete panel fabrication, and installation. The simplified design provides improved tolerances, reduced risk, increased speed of construction,

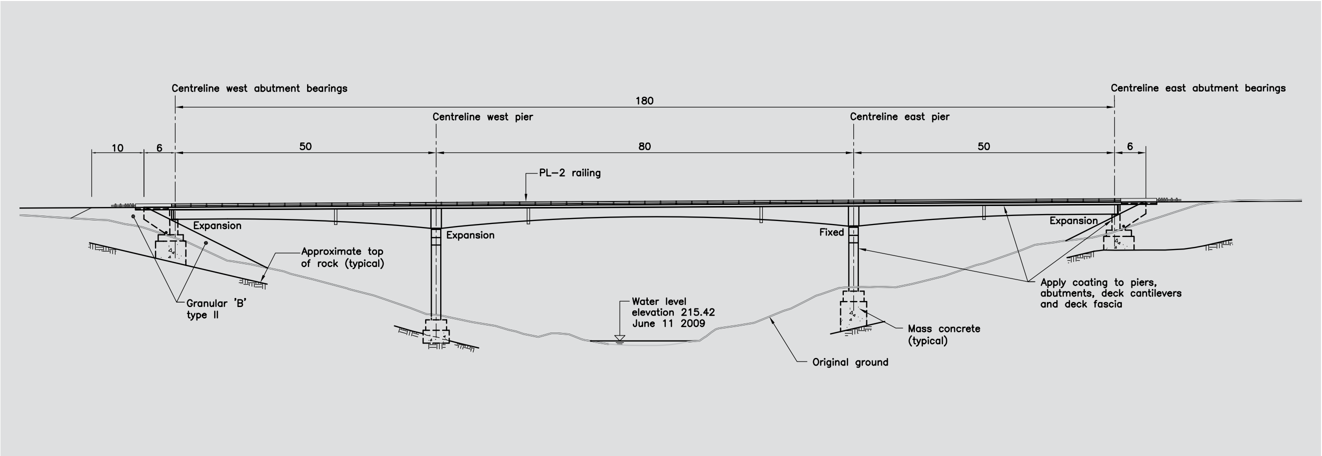

Figure 2. Elevation of eastbound bridge. Note: All measurements are in meters. 1 m = 3.28 ft. Courtesy of MMM Group Ltd.

a potential overall cost savings in construction, and a resilient, longer-lasting bridge deck.

The project

The Mackenzie River twin bridges cross a deep gorge of the Mackenzie River as part of a new TransCanada Highway realignment and twinning project near Thunder Bay. The bridge is a three-span, variable-depth steel plate girder supported by abutments on the river bank and two intermediate cast-in-place concrete piers on spread footings, all founded directly on bedrock (**Fig. 2**).

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 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, steel girders with a precast concrete deck offered the best combination of economy, expediency, and aesthetics. Extensive previous experience with this structural form, specifically the use of precast, prestressed HPC deck slabs with UHPC joint fill, was also a contributing factor. These materials, used 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 advance procurement of materials. All deck panels and structural steel elements were purchased under separate contracts and made available to the bridge general contractor, thereby shaving many months off the final completion schedule.

Foundations

The cast-in-place concrete abutments and piers are supported on cast-in-place concrete spread footings, which are, in turn, supported by mass concrete on rock.

Girders

Each bridge has five variable-depth, atmospheric corrosion-resistant steel plate girders with spans of 50 m (160 ft), 80 m (260 ft), and 50 m (160 ft), spaced at 3.0 m (10 ft) center to center, providing an overall bridge width of 14.5 m (47.6 ft). The continuous steel plate girders vary in depth from 1.8 m (5.9 ft) at the abutments and midspan of the main span to 3.8 m (12.5 ft) at the piers. Only the three interior girders are supported on the two piers; each exterior girder is supported by a heavy transverse steel diaphragm at the piers composed 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 concrete deck panels that are lightly prestressed and extend the full width of the bridge (**Fig. 3**).

There are 130 precast concrete deck panels, 2.99 m (9.6 ft) wide × 14.5 m (47.6 ft) long × 225 mm (9 in.) thick. The panels also contain GFRP bars as passive reinforcing, which project into the joints to develop the panel-to-panel connections. The transverse joints between 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 two shear pockets per girder line to accommodate shear studs. These pockets vary in size from 300 × 430 mm (12 × 17 in.) to 300 × 730 mm (29 in.) to accommodate from 12 to 32 studs per pocket. The reinforcing steel in the deck panels passes through the pockets and is detailed 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 then filled with UHPC.

Conventional grout in the blockouts would have been impractical, considering that UHPC was necessary for the field joints. The blockouts had to be completed simultaneously, necessitating UHPC. The superior durability of UHPC was an additional benefit.

The 14.5 m (47.6 ft) long precast concrete deck panels were lightly prestressed to minimize the potential for cracking during handling and in service, enhancing the durability of the deck. The panels were prestressed with 13 mm ($^1/_2$ in.) diameter CFRP tendons.

Deck joints

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

The UHPC used for the joints is an ultra-high-strength, ductile formulation made with portland cement, silica fume, quartz flour, fine silica sand, high-range water reducer, water, and steel fibers.[4] 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 (2200 to 5800 psi). Bond development lengths for 15M (no. 5) bars are less than 75 mm (3 in.), resulting in narrow joints approximately 150 mm (6 in.) to 210 mm (8 $^1/_4$ in.) wide.

The width of deck panel joints varies depending on the owner and designer. Narrow joints are more optimized but reduce construction tolerances for the installation of the panels. According to the Federal Highway

Figure 3. Full-width precast concrete deck panels ready for ultra-high-performance concrete joint fill. The concrete buggy in the upper portion of this photo is traveling along a previously completed section. Courtesy of Lafarge.

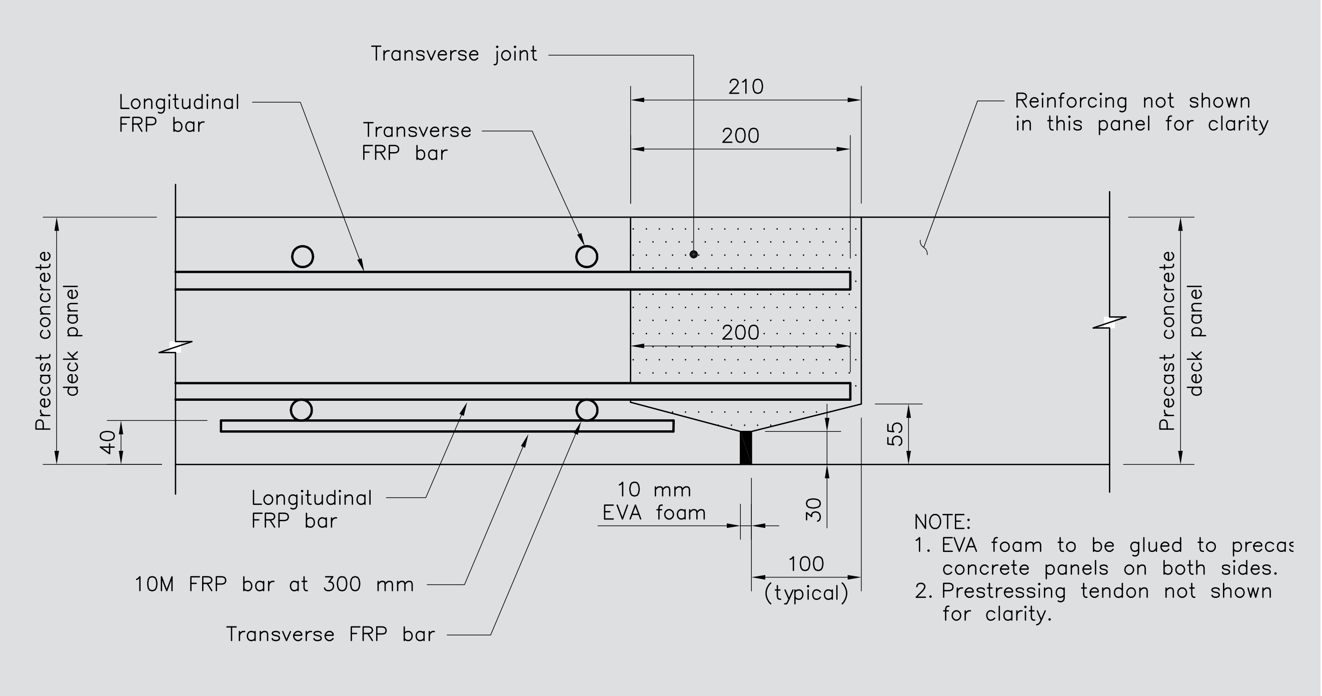

Figure 4. Typical section through a transverse panel joint. All dimensions in millimeters. Note: EVA = ethylene-vinyl acetate; FRP = fiber-reinforced polymer. 1 mm = 0.0394 in. Courtesy of MRC.

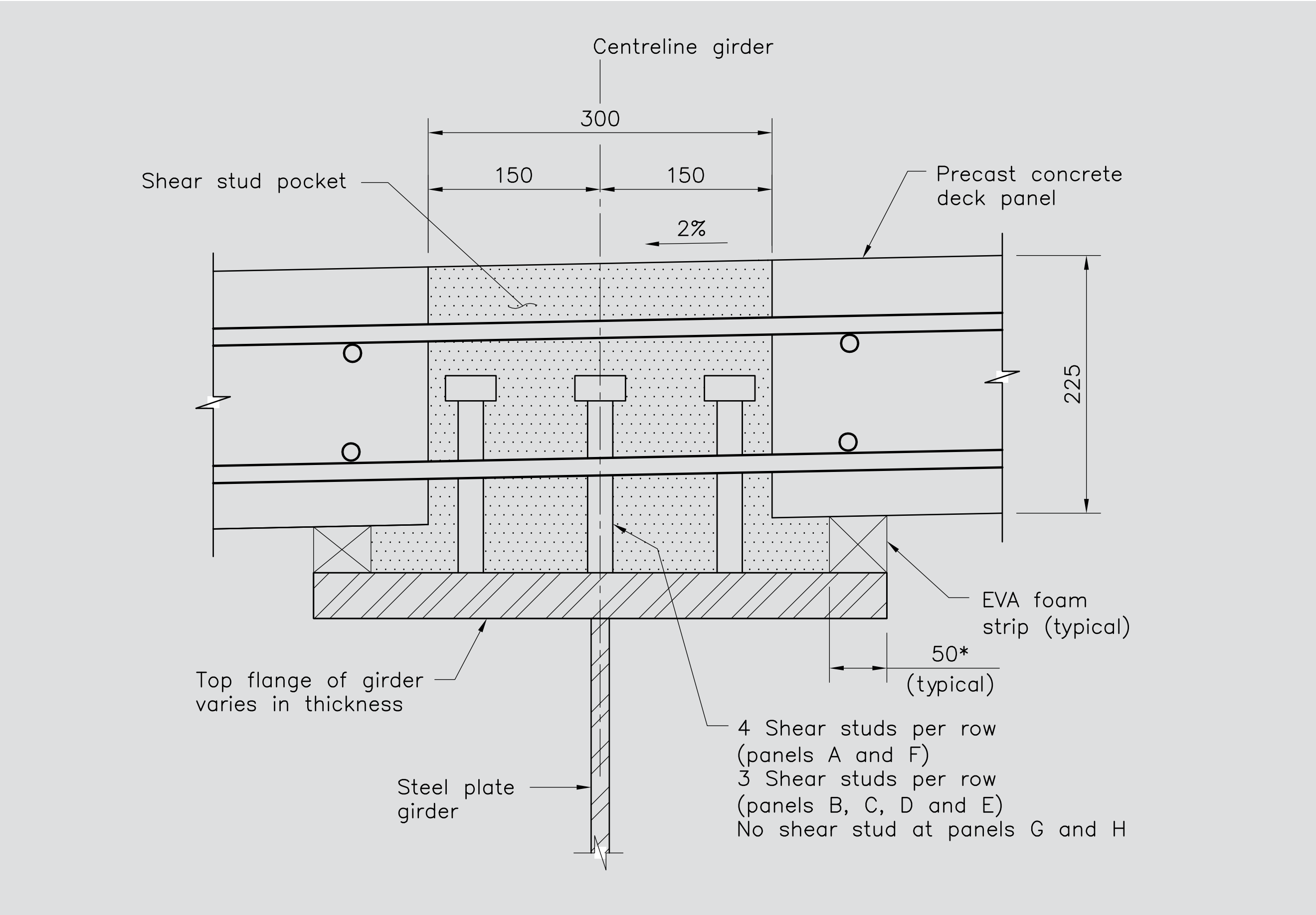

Figure 5. Typical section through a shear pocket connection and haunches. Note: All measurements are in millimeters. EVA = ethylene-vinyl acetate. 1 mm = 0.0394 in. Courtesy of MMM Group Ltd.

Administration's[5] full-scale testing of the pullout capacity of reinforcing bars in UHPC, with an embedment length of 200 mm (8 in.), the panel-to-panel connections provide full continuity across the joint (Fig. 4).

Casting the joints

To complete the work, all of the UHPC materials and twin 0.5 m^3 (18 ft^3) mixers were supplied to provide more than 20 m^3 (706 ft^3) per day of production for a total of 175 m^3 (6250 ft^3). The casting of the joint fill material was completed with an 18-person crew in just 10 days. The crew consisted of two people 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, four guiding the buggies, one floating the material (**Fig. 6**), and six on the forms.

The dry UHPC premixture was supplied in 1116 kg (2460 lb) super sacks and added first to the mixer. Then the water and liquid high-range, water-reducing admixtures were introduced. Once the batch became fluid, the weighed fibers were added manually. When placing this self-leveling UHPC into joints, it is important to take advantage of its fluid characteristics. UHPC's fluid characteristics ensured that the narrow gaps between the underside of deck and top flange of the girders were completely filled, leaving no voids. After placement, any exposed surfaces were covered to prevent dehydration. For each on-site batch, quality control was performed by measuring the rheological properties to confirm that the material was batched and placed properly. Compressive strength tests were also performed each production day.

Barrier walls

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

Benefits of UHPC joints in a precast concrete bridge deck

Concrete is one of the most durable construction materials. In North America, most precast concrete plants are within 200 miles (300 km) of a building site. Using

Figure 6. Placing the ultra-high-performance concrete material into a joint. Courtesy of Lafarge.

local materials reduces the transportation required to ship heavy building materials and the associated energy and emissions.[6] Furthermore, the cement, concrete, and construction industries provide employment for people in local communities. Durable and local products are fundamental elements to sustainability.

UHPC further extends the sustainability and resiliency of our infrastructure. For field-cast UHPC joint fill applications, the quantity of raw materials is typically low in volume, shipped from the nearest blending facility directly to the construction site. With a carbonation depth of 0.5 mm (.02 in.),[7] there is almost no carbonation or penetration of chlorides.[8,9] These characteristics are due to low porosity from a combination of fine powders, selected for their relative grain size (maximum 0.5 mm [.02 in.]), and chemical reactivity. The net effect is maximum compactness and a fine, discontinuous pore structure.

A series of UHPC prisms (152 × 152 × 533 mm [6 × 6 × 21 in.) was placed in 1996 and 2004 at the U.S. Army Corps of Engineers (USACE) Marine Exposure Station (a long-term exposure test site in Treat Island, Maine) (**Fig.** 7).

The prisms were placed on the wharf deck located at mean tide in the Bay of Fundy.The samples were subjected to two tide cycles of wet/dry in seawater each day and, during winter at low tide, to freezing and thawing for13 years. The samples were removed and measurements taken to record the depth of chloride penetration.

After comparable exposure, HPC had more than 5 times the chloride content and 2.5 times the depth of penetration of UHPC. In accordance with Fick's law of diffusion, the rate of penetration depth of chlorides in concrete is proportional to the square of time. It takes four times as long to double the depth of penetration. **Figure 8** shows the predicted rate of chloride ion penetration of UHPC versus HPC.[10]

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 show rounding of the corners due to freezing and thawing after one season.

Conclusion

This project demonstrates that the use of a precast HPC deck panel with CFRP tendons, GFRP bars, and

Figure 7. Test prisms on the wharf at a long-term exposure test site in Treat Island, Maine. Courtesy of Lafarge.

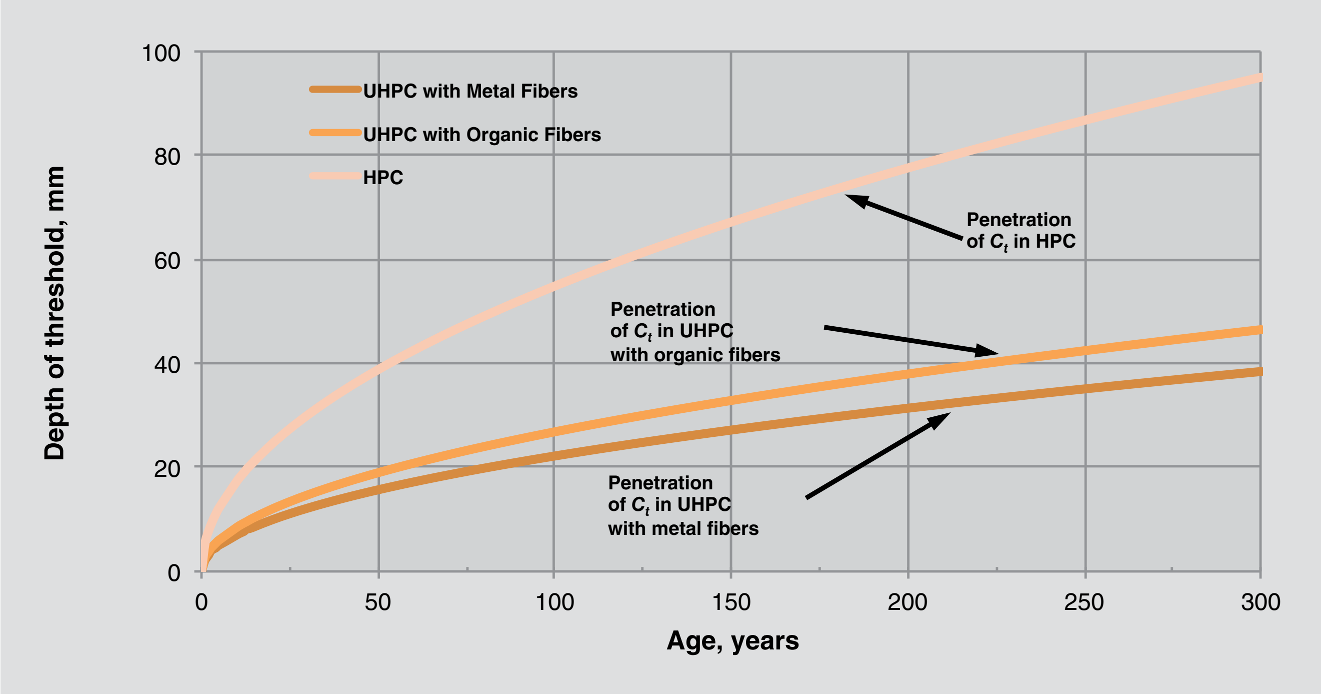

Figure 8. Predicted service life with chloride ion transportation threshold predictive modeling: (UHPC versus HPC)[8] Source: Reproduced by permission from Lafarge. Note: C_t = chloride ion concentration at 0.05%; HPC = high-performance concrete; UHPC = ultra-high-performance concrete.1 mm - 0.0394 in.

UHPC joints results in a potentialy highly durable bridge deck system with extreme resistance to corrosion that may be constructed in rural areas by regular bridge contractors.

Furthermore, when used with precast concrete bridge deck systems, this solution can help to minimize traffic disruption and user costs through accelerated bridge construction.

The UHPC product used on this project has been commercially available in North America for 13 years and used as a field-cast joint-fill solution for almost a decade. Although the UHPC technology may still be in its infancy (particularly in terms of deployment), numerous joint fill projects have been successfully completed,[11] demonstrating that acceptance and demand are growing rapidly.

Acknowledgments

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References

1. Bhide, S. 2008. "Material Usage and Condition of Existing Bridges in the U.S." Skokie, IL: Portland Cement Association.
2. Perry, V., P. Scalzo, and G. Weiss. 2007. "Innovative Field-Cast UHPC Joints for Precast Deck Panel Bridge Superstructures — CN Overhead Bridge at Rainy Lake, Ontario." In *PCI National Bridge Conference Proceedings, Phoenix, AZ, 2007*. Chicago, IL: PCI. CD-ROM.
3. Harryson, P. 2003. "High Performance Joints for Concrete Bridge Applications." *Structural Engineering International* 13 (1): 69–75.
4. Lafarge Canada Inc. "Field-Cast Joint Fill Solutions for Precast Deck Panel Bridges." Ductal JS1000 Product Data Sheet. Accessed August 2013. http://www.ductal-lafarge.com/JS1000_2009.pdf.
5. Graybeal, B. 2010. "Field-Cast UHPC Connections for Modular Bridge Deck Elements." TechBrief FHWA-HRT-11-022. Federal Highway Administration. Accessed August 2013. http://www.fhwa.dot.gov/publications/research/infrastructure/structures/11022/11022.pdf.
6. PCI. "Precast Concrete and Sustainable Design." Accessed January 2014. https://www.pci.org/Design_Resources/Sustainability_Resources/Precast_Concrete_and_Sustainable_Design/.
7. ASTM Subcommittee C09.65. 2013. *Standard Practice for Petrographic Examination of Hardened Concrete*. C856-13 (Modified). West Conshohocken, PA: ASTM International.
8. AASHTO (American Association of State Highway and Transportation Officials). 2006. *Standard Method of Test for Resistance of Concrete to Chloride Ion Penetration*. T259-02-UL. Washington, DC: AASHTO.
9. Thomas, M., B. Green, E. O'Neal, V. Perry, S. Hayman, and A. Hossack, A. 2012. "Marine Performance of UHPC at Treat Island." In *Proceedings of HiPerMat 2012 3rd International Symposium on UHPC and Nanotechnology for High Performance Construction Materials*, 365–370. Kassel, Germany: Kassel University Press.
10. Thomas, M. D. A. "Performance of Reactive Powder Concrete in a Marine Environment." Paper, ACI Annual Conference, Chicago, IL, 2010.
11. Lafarge Canada Inc. "North American Ductal Bridge Projects as of December, 2012." Accessed August 2013. http://www.ductal-lafarge.com/Ductal_Bridge_Portfolio_December_2012.pdf.

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Abstract

The Mackenzie River bridges are part of the TransCanada Highway realignment near Thunder Bay, ON, Canada. The project consists of twin two-lane bridges, each with three spans, for a total length of 180 m (590 ft). The bridges cross a deep gorge of the Mackenzie River using variable depth, continuous steel plate girders with full-depth precast concrete deck panels that are lightly prestressed and extend the full width of the bridge. Precast concrete approach slabs and 130 precast concrete deck panels (2.99 m [9.6 ft] wide × 14.5 m [47.6 ft] long × 225 mm [9 in.] thick) were connected at transverse joints and attached to the steel girders through shear pockets and haunches using a total of 175 m^3 (229 yd^3) field-cast ultra-high-performance concrete (UHPC).

Keywords

CFRP, composite, ductile, durability, fiber reinforced, GFRP, HPC, impermeability, joint, resiliency, UHPC.

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