HODDER AVENUE UNDERPASS

Precast Concrete

PROJECT CREDITS

OWNER
The Ministry of Transportation of Ontario – Northwestern Region

ENGINEER OF RECORD
Hatch Mott MacDonald

GENERAL CONTRACTOR
Teranorth Construction & Engineering Limited

MATERIAL SUPPLIER
Lafarge Canada Inc.

ADDITIONAL PARTICIPANTS
- BASF Canada Inc.
- Harris Rebar
- Ironworkers Local 759
- Lafarge
- LIUNA Local 607

PROJECT FACTS

LOCATION Thunder Bay, Ontario

COMPLETION July 2012

TONNAGE
- Precast high strength concrete – 1,200 m^3
- Ductal ultra-high performance concrete – 50 m^3

QUICK PROJECT FACTS
- The width of the bridge is 20 m and the total length is 85 m, including two 33.5 m spans and two 9 m wingwall section at both ends of the bridge.

2013 Ontario Concrete Awards

The Owner, The Ministry of Transportation of Ontario (MTO), has embarked on an aggressive four-lane project in Northwestern Ontario that involves construction of about 30 km of new highway and up to 30 structures in an area with extremely rugged terrain, from deep swamps to massive rock cuts. A part of this project is a new 'parclo' (partial cloverleaf) interchange including a new underpass bridge required at the intersection of Highway 11/17 and Hodder Avenue in Thunder Bay, Ontario. The bridge is a two span structure spanning over six lanes of traffic and founded on a combination of hard till and bedrock. The spans, each 33.5 m long, are supported on a centre pier and two false abutments.

Due to the remote location and harsh environment of the project in northwestern Ontario, the owner's priorities were enhanced quality and durability of the final structure and a speedy execution of the construction work. Equally important for the owner was the aesthetics of the design. Since the interchange is the first structure that drivers encounter when approaching the city of Thunder Bay, and with close proximity to the Terry Fox monument, MTO wanted to elevate the structural design from the utilitarian style frequently encountered in urban highway settings, and create a structure that would complement the surrounding landscape.

To meet these quality, durability and aesthetic goals, the project team utilized an innovative modular construction approach with extensive use of fibre reinforced ultra-high-performance concrete (UHPC). Almost all structural elements were pre-fabricated in a controlled environment and assembled on site using UHPC joints. Hodder Avenue Underpass is the first project in North America to incorporate precast UHPC pier cap and pier column shells, together with precast high-performance concrete (HPC) box girders, abutment caps, ballast walls, sidewalks/parapet walls, slope paving panels and approach slabs. All field connections were cast using UHPC, resulting in smaller joints with high durability and strength, and low complexity. The innovative precast UHPC design for the unique pier cap and pier column shells contributed to the overall aesthetic quality and durability of the structure.

Modular Construction with UHPC

A two-span precast prestressed concrete box girder configuration with no top slab was developed as the most practical and cost-effective solution. Considering the location and exposure to harsh climates, use of precast elements throughout was a necessity to satisfy the quality and durability requirement of the project. Consequently, a modular construction approach was utilized where almost all structural elements are precast. The precast elements in the project include:

- UHPC pier cap and pier column shells
- HPC box girders, abutment caps, ballast walls, sidewalk panels, parapet walls, slope paving panels, and approach slabs

Although UHPC and HPC precast bridge elements are highly durable, conventional jointing materials are often the weakest link in the bridge system. Introducing new methodologies and innovative material technologies

provided the solution which involved the use of UHPC with superior technical characteristics such as ductility, strength, durability and bond development. This resulted in improved tolerances; reduced risk; increased speed of construction; a potential overall cost savings; and a more resilient, longer lasting bridge superstructure.

When field-casting UHPC, materials are batched in pairs of onsite mixers or ready-mix concrete trucks. For this project, all premix materials were shipped in 1,116 kg sacks and mixed in two 0.5 m^3 high-shear onsite mixers. UHPC requires significant energy to mix and to lubricate all of its raw material constituents (i.e. cement, silica sand, ground quartz, and silica fume) within the powder matrix. Higher energy completes the mixing process more quickly, resulting in a self-levelling UHPC.

After batching, the plastic UHPC was placed into all the joints using buggies and chutes. To control hydro-static pressures throughout all connections, the joints were isolated to ensure complete filling. When placing the self-levelling UHPC material into joints, it is important to take advantage of its fluid characteristics. When discharged from the concrete bucket into the joints, UHPC spreads itself throughout.

By moving the discharge point at a rate such that it always stays behind the 'leading edge' of the flow, the joint was filled in one continuous motion. Due to its self-levelling characteristics, UHPC was placed at the lowest of end of the joint using a top form to contain the concrete and moving toward the high end of the joint where a 'chimney' was placed. This chimney ensures proper hydrostatic pressure within the joint and prevents any low spots. All joints were immediately covered with resin-coated plywood (top form) to avoid dehydration of the UHPC. After the initial hardened strength of the UHPC was reached, the joints were ground flush to the precast elements.

To ensure proper quality control of all field-cast UHPC material, the flow characteristics of each batch were tested using a modified version of ASTM C.1437 (*Standard Test Method for Flow of Hydraulic Cement Mortar)*. This was completed immediately after mixing to ensure consistency within all batches. Compressive strengths were also validated daily.

Unique Precast UHPC Pier Cap

The structure's overall aesthetic quality is attributed to its slenderness and open form. The superstructure has a span-to-depth ratio of 29, which is well above the conventionally recommended 20 for voided slabs or 22-25 for precast multiple-cell box girders, making the bridge appear strikingly slender.

To accentuate the slender appearance of the superstructure and to create visual openness, the design incorporated a unique inverted-T shaped pier cap, prestressed and precast fully with UHPC. Instead of the traditional approach of supporting the girders from below, this pier cap is recessed between the two spans and is visually and structurally integral with the superstructure, providing a frame that seems to go directly into the superstructure. This appearance may be achieved with conventional post-tensioned cast-in-place superstructures, but extremely difficult to achieve using pre-fabricated elements. In this case, the team pushed the envelope by precasting the pier cap entirely with UHPC and creating a design that takes full advantage of this advanced concrete material.

Geometrically, the girders have dapped ends that sit on the ledges of the inverted-T beam. The pier cap and girders are made composite using field-cast UHPC joints reinforced with stainless steel bars and threaded bolts. This joint assembly is subjected to a complicated set of forces because it serves not only to join the pier cap with the girders, but also to longitudinally connect the two spans together over pier support. The relatively shallow cross-section of the cap beam as a result of the geometric constraints posed major design challenges, which were overcome by strengthening the pre-tensioning design to take full advantage of the ultrahigh strength of the material.

Due to the amount of prestressed strands, steel embedments and other perforations, the precaster used building information modelling (BIM) to identify conflicts between the main pier cap beam (inverted-T section) and box girders. This analysis concluded that once the stresses were released into the main pier cap, the element would significantly deflect under the prestress effects and would not sit flush on the seats at the top of the pier columns. This problem was resolved by anchoring and jacking to straighten the precast element. Any minor gaps were filled with high-performance epoxy grout.

The main pier cap was cast in a precast plant using a steel form, manufactured in the exact same shape as the inverted T-section, prestressed and filled with UHPC. The UHPC material was placed from the top of the stem and gradually flowed to the top of the inverted T-section. No vibration was applied.

Unique Pier Columns with Precast UHPC Shells

The use of advanced material for the pier cap – UHPC with compressive strength up to 200 MPa allowed the optimization of the pier design. The number of pier columns was reduced from four in the concept design to three in the final design, opening up the structural frame and lightening up the space.

The unique design of the piers entailed prefabricating the aesthetically-shaped UHPC shell and then filling it with concrete in the field. Each column has an octagonal shape which transitions from a smaller constant dimension at the bottom to a flaring larger dimension towards the top. This 'flower vase' column feature contributes to an overall sleek and elegant appearance of the structure.

During the long winter season, the bridge columns would be frequently exposed to winter de-icing salt sprays which cause considerable damage. Since UHPC is extremely low in porosity and has a high durability against chloride ingress, its incorporation into the pier columns results in far more durable elements. A customized UHPC shell was designed to act as a non-structural form which could be filled with standard reinforced concrete on-site.

Manufacturing the three precast UHPC pier column shells proved to be a challenge due to their height (8.35 m) and complex shape. They were cast on an angle, using an inner and outer steel formwork. The inner steel mould was self-collapsing to allow for initial shrinkage of the UHPC during setting. The transition of the octagon shape from the constant cross-section to the flared cross-section created challenges for: form manufacturing; casting of the UHPC; initial shrinkage allowances; and stripping of the UHPC precast element. During casting, the form was positioned on an approximate 15 degree angle. The material was placed slowly from the top of the column through an inlet funnel. When casting a long, thin and slender UHPC element, the pouring process was carefully monitored to ensure proper fibre dispersion throughout the plastic material.

Conclusion

The Hodder Avenue Underpass is a 'leading-edge' project utilizing an advanced modular construction approach made possible by the extensive use of UHPC. The innovative design and construction method, taking advantage of the superior properties of UHPC, effectively achieved the owner's requirement for enhanced quality, durability and aesthetics. The result is a resilient and elegant bridge structure that is built to last. A strong collaborative partnership among the Owner, the UHPC supplier, precaster and the engineering firm resulted in the successful design and construction of this project that met and exceeded MTO's goals, setting a new standard for bridge design and execution.