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THE CITY OF CALGARY 12 STREET S.E. BRIDGE PREFABRICATED DECK PANELS

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Abstract: The City of Calgary's 12 Street Bridge is a new 170 m-long bridge carrying 12 Street S.E. over the Bow River, connecting St. George's Island (home of the Calgary Zoo) to the historic community of Inglewood. The three spans of the bridge are composed of three variable depth (arched) rectangular steel box girders, and supported by conventional cast-in-place concrete abutments and piers. To minimize the amount of work required over the river, the design team chose to use full-depth, full-width, precast concrete deck panels. This represents the first time this type of construction has been used in Alberta in a continuous vehicular bridge. The panel-to-panel and panel-to-girder connections were cast-in-place using Ultra High-Performance Concrete (UHPC). Although a first in Alberta, this solution has been used thus far on 200+ North American bridges. Many projects require Accelerated Bridge Construction (ABC) materials and methods, to ensure minimized user disruption and road closures. For this project, ABC methods allowed for a higher level of quality control on the deck construction and minimized the construction risk of placing a large volume of wet concrete over the Bow River. While deck panels joints can be detailed using standard HPC concrete (with compressive strengths around 45 MPa), the high compressive strength (160-200 MPa) and ductility of UHPC, simplifies the detailing, fabrication, and installation process. The paper includes a description of the 12 Street bridge structure with focus on design, detailing, and construction of the precast deck panels and their cast-in-place UHPC connections.

1. INTRODUCTION

The City of Calgary (The City) recently completed construction of the new 12 Street S.E. Bridge over the Bow River. The new structure replaces the 100-year-old St. George's Island Bridge and connects St. George's Island (home of the Calgary Zoo) with the historic community of Inglewood. The bridge crosses the southern channel of the environmentally sensitive Bow River. A key project goal was to explore ways to minimize environmental risks through the construction process. One of the solutions the design team adopted was the use of full-depth, full-width precast concrete deck panels in lieu of a fully cast-in-place (CIP) concrete deck. An Ultra High-Performance Concrete (UHPC) was used to effectively and efficiently transfer forces through the panel-to-panel and panel-to-girder connections. The use of precast panels and the small-batch UHPC limited the volume of wet concrete placed over the river, significantly reducing the impact of a concrete spill or formwork blowout into the river during construction. While the combination of full-depth, full-width precast concrete deck panels and UHPC have been used in other jurisdictions, to the authors knowledge, this represents the first time this technique has been used on a continuous span vehicular bridge in Alberta.

2. PROJECT BACKGROUND

2.1 Bridge Geometry

The new 12 Street bridge has a total length of 170 m with 3 spans of 50, 70, and 50 m. The bridge width of 14.3 m allows for two 3.5 m-wide lanes of traffic as well as a 4 m-mixed use pathway for pedestrians and cyclist. The overall deck width widens locally at the piers to 15.8 m to accommodate viewing platforms that afford pedestrians a place to stop and admire the City's downtown skyline. The two external spans carry a linear 3% vertical slope towards the central span. The centre span has a vertical curvature with the crest at mid-span. The deck has a constant 2% cross-fall from east-to-west for drainage. The horizonal alignment is mainly straight with a short curved and skewed portion at north end for connection to existing roads.

2.2 Bridge Structure

The bridge superstructure consists of three lines of rectangular steel box girders made composite with 250 mm-thick full-depth, full-width precast deck panels. At each abutment, the end of the deck was completed with a short (1.0 – 1.5 m long) CIP infill section. The steel box girders are nominally identical to each other and have a variable depth (arched) profile along their length. The steel box girders were constructed from steel plates using CAN/CSA G40.20/G40.21M Grade 350 AT, Category 3 weathering steel. Groups of shear studs (3 x 4) were welded to the top flanges during fabrication to facilitate composite action with the precast deck panels.

The girders are supported on conventional cast-in-place concrete abutments and piers. Vertical loads are transferred from the girders to the substructure through 24 polyether urethane disc bearings. More information on the overall bridge structure is presented in Azarnejad et al., 2018.

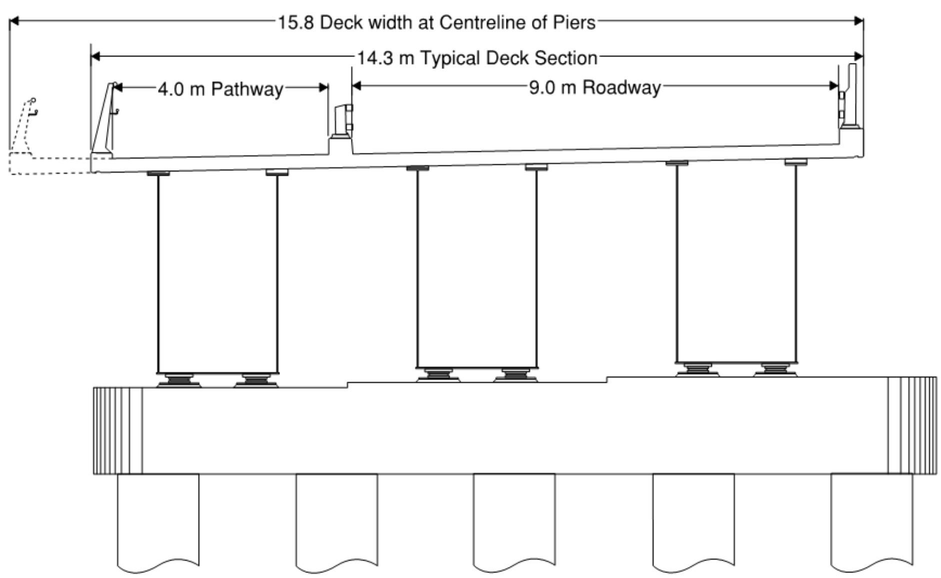

Figure 1: Typical Bridge cross-section at Pier

3. PRE-CAST DECK PANEL DESIGN

One of the environmental concerns raised by The City on this project was the potential risk of a major concrete spill or formwork blowout while placing the concrete deck over the sensitive Bow River ecosystem. Full-depth, full-width, precast deck panels were selected primarily to mitigate this risk. Precast panels also reduced the need for onsite formwork and temporary work platforms and allowed for accelerated construction by reducing the amount of on-site work. Panel fabrication was completed in a controlled plant environment, leading to a higher level of quality and tighter construction tolerances over cast-in-place methods.

3.1 Materials and Geometry

The 170-m long deck was subdivided into sixty, 250 mm-thick precast deck panels. A typical precast panel is 2.78 m long (when measured parallel to the centreline of the bridge) and 14.3 m wide. Each panel contained 18 shear pockets (3 rows of 6 pockets) so the panels could be made composite with the steel girders. Internal shear pockets were typically 300 x 360 mm while external shear pockets were 300 x 420 mm to accommodate hardware for a leveling bolt. The plan view geometry of a typical panel is shown in Figure 2.

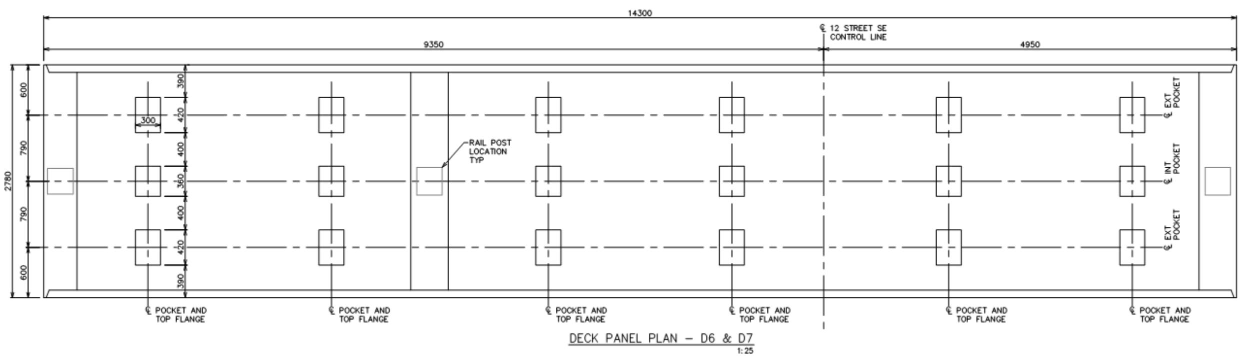

Figure 2: Typical Precast Deck Panel Plan View

The panels were constructed using stainless steel reinforcement, carbon steel prestressing strands and high-performance concrete (HPC) with a design 28-day compressive strength of 45 MPa. Curbs for the traffic and pedestrian barriers, including anchor bolts, were cast as a part of the panel.

At the lookout locations over the piers, the width of the panels varied from the base 14.3 m width to a maximum width of 15.8 m. The overall geometry of the panels and the location of the shear pockets remained consistent. The additional width was achieved by increasing the distance between the outside pedestrian pathway curb and the first line of shear pockets.

3.2 Panel Reinforcement

A key design requirement was the 100-year service life for the structure. Stainless steel reinforcement was selected for use in the precast concrete deck panels due to higher exposure to road spray and salts. It is The City's standard best practice to use reinforcing material with corrosion protections systems when designing with a 100-year service life in mind. Stainless steel has advantages over other corrosion protections systems (such as galvanized or epoxy coated steel) in that it is not as susceptible to handling damage, it has a smaller galvanic potential when paired with black steel and it can be exposed during partial depth concrete rehabilitations without needing to be recoated.

The panels were designed according to Canadian Highway Bridge Design Code (CHBDC) CSA S6-14 and City of Calgary Design Guidelines for Bridges and Structures. One of the primary challenges in the panel design was providing longitudinal continuity in negative moment areas where the panels and their connections are subjected to high tensile forces. Traditionally, precast elements forming a continuous member are connected using longitudinal post-tensioning system. While effective at transferring forces between individual elements, pre-stressed cables present a potential risk during future bridge deck rehabilitation efforts. The possibility of cutting one or more post-tensioned cable adds significant risk to typical partial depth repairs, potentially shortening the life-span of the structure. To overcome the need to use post-tensioned materials, in the original design the longitudinal continuity at the joints was provided by 180 degree hooks in the bars projecting from the panels. Ultra High Performance Concrete was also specified for the joints for its higher tensile strength and improved bar development characteristics. UHPC was not required for splicing as hooks were used for developing the projected bars in the joints. The design thickness of 250 mm for panels was primarily based on accommodating the hook diameter and required cover.

In the initial stages of panel fabrication, challenges were encountered with bending the stainless steel bars to the design bend diameter. The actual bent diameters came up larger than design, making it necessary to tilt the hooks. Although tilting the bars could be accommodated in the positive moment regions with less longitudinal bars, it would create conflicts in the regions over the piers where additional longitudinal reinforcement was required. It was therefore decided to take advantage of the properties of UHPC. The 180 degree hooks were eliminated as the high strength properties of UHPC reduced the required splice lengths for reinforcement and made it feasible to splice the longitudinal bars in the 200 mm wide panel-to-panel joints without using hooked bars. Splicing details specific to UHPC had to be followed to allow the fibres to develop the bars and transfer the force (FHWA, 2014).

To verify the efficiency of these connections, some of the panels and connecting joints are instrumented with wireless strain gauges. The instrumentation details are provided in a separate publication (Appelman et al. 2018).

Design of panels in the bridge transverse direction was based on flexural method in CHBDC. The empirical method could not be used as one of the requirements for using empirical design method for full-depth precast panels is longitudinal post tensioning which was not provided (as explained above). At 14.3 m, the typical panel width exceeds the maximum dimension recommended for full-depth panels in the existing references. 15.2 mm, 7-wire low relaxation strand lateral prestressed steel was used to reduce the risk of cracking during shipping and erection. The pretensioned force also acts to keep the panel stresses in compression under service loads. See Figure 3 for panel dimensions and transverse reinforcing details. The top transverse reinforcement was kept continuous at the stud pocket locations. It provides the negative moment resistance and does not have much conflict with the studs as it stays mainly above them. The bottom transverse reinforcement were only kept continuous in the middle pockets where the barrier posts were located. The shear pockets included leveling bolts which allowed for adjustment of the panel elevations after erection (but prior to being made composite). See Figure 4 for a picture of deck panel reinforcing prior to casting.

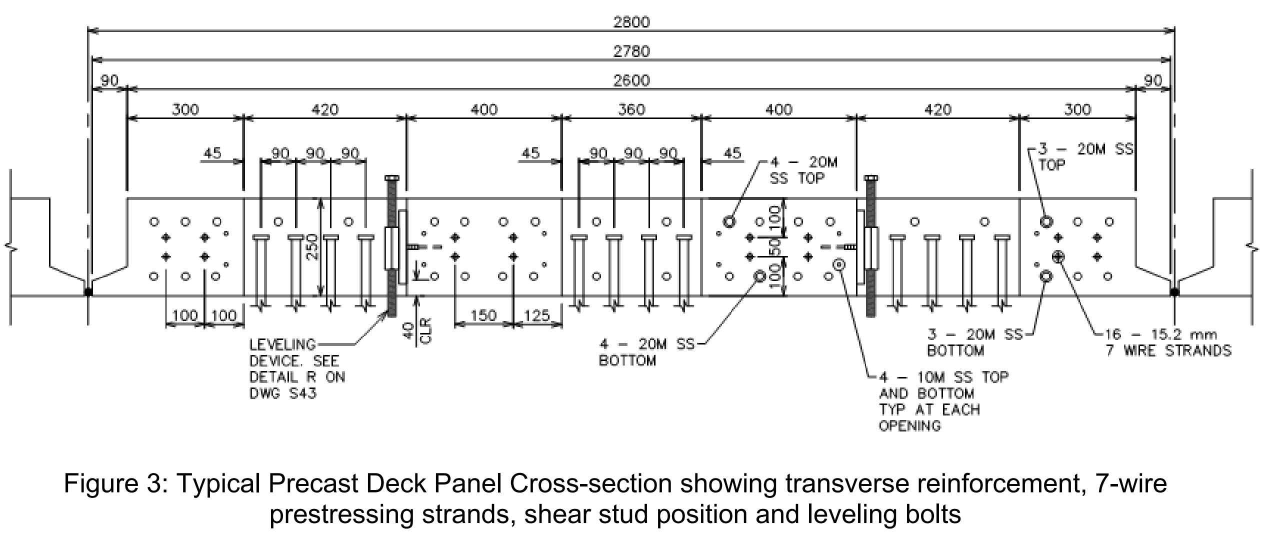

Figure 3: Typical Precast Deck Panel Cross-section showing transverse reinforcement, 7-wire prestressing strands, shear stud position and leveling bolts

Figure 4: Deck Panel Reinforcement prior to casting

3.3 Joint Geometry and Reinforcement

The joint geometry is shown in Figure 5. The shape was detailed to allow the panel to act as its own formwork. The surface of the concrete was roughened to a 6-mm amplitude to promote a strong surface bond with the UHPC. Figure 6 is a picture of a typical joint.

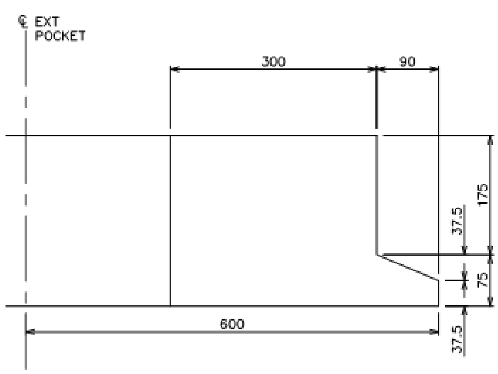

Figure 5: A) Typical panel joint geometry, and B) Joint reinforcement detail.

Figure 6: Joint picture.

The project team overcame some challenges during the erection process. The combination of the projected bars and concrete lip at the joints, shear studs pre-welded to the girders, and the tight dimensions of the shear pockets, left very little room to shift a panel forward or backward and still fit the studs within the pockets. Some of the studs had to be bent to allow for the erection of the panels. Some of the alternatives that could have made the panel erection easier include: welding the studs on site (not a preferred option for the City in this project), leaving were more space between the studs and the inside face of the shear pockets, and projecting bars from one side of the joint only and using couplers with coupled bars on the other side.

4. ULTRA HIGH-PERFORMANCE CONCRETE (UHPC)

4.1 UHPC Mix Characteristics

UHPC is a fiber-reinforced cementitious composite material composed of portland cement, quartz sand, quartz flour and silica fume. UHPC mixes have a low water-to-cement ratio, typically less than 0.25. The mixes typically incorporate a high strength steel or glass fibre to provide added tensile and flexural strength to the mix. For this project, steel fibers were used. The steel fibers were 0.2 mm in diameter by 13 mm long and had a yield strength of 2000 MPa. The quantity of the discontinuous fibers in the mix is typically 2% by volume. The mix properties used for this project are presented in Table 1.

Table 1: Mechanical Properties of UHPC Mix

Mechanical Property	Strength (MPa)
Compressive Strength, 28 Day	165
Modulus of Elasticity, 28 Day	48,000
Tensile Strength	9
Flexural Strength	20 – 50

4.2 Joints

Due to the high strength properties of UHPC, the joint size for connecting panels can be minimized. The development length for the precast panel reinforcement extended into the joint is 8 bar diameters. This also generally allows for the use of straight bars without bends (depending on the design requirements).

4.3 Splices

For lap splices of straight lengths of deformed steel reinforcement, the lap-splice length (Ls) is at least 0.75 times the development length. Clear spacing between adjacent bars should be less than or equal to Ls. To avoid congestion issue with the steel fibres, the minimum spacing between non-contact splices is 1.5 times the steel fiber length. While contact lap-splicing in UHPC connections is an acceptable practice, it can cause on-site installation problems with panel fit, due to the configuration of the dowels. For this project, non-contact splices were used as seen in the photo in Figure 6.

5. CONSTRUCTION

5.1 Panel Fabrication and Installation

The precast concrete deck panels were fabricated and installed over a four-month period in the Spring/Summer of 2017. The panels were fabricated three at a time and laid out end-to-end on a stressing bed. Prestressing strands were passed through the bulkhead formwork for all three panels which allowed the panels to be stressed simultaneously. Once the concrete had reached the release strength of 30 MPa, the prestressed strands were cut and the formwork was stripped. Care was taken to avoid chipping or cracking the slender joint toes. Any required patching or repairs were completed immediately after stripping and then the panels were moist cured for a minimum of 72 hours. Afterwards, the panels were then stored outside for a minimum of 30 days to allow most of the concrete shrinkage to occur before erection. Some of the panel details were tested using mock-ups before full-scale implementation.

The panels were erected on the bridge using a hydraulic crane and steel lifting loops that were cast into the panel (See Figure 7). Before being made composite, the panels were supported on the girders by a combination of Ethylene-vinyl acetate (EVA) foam and the panel leveling bolts. The EVA foam also acted as stay-in-place formwork for the concrete shear pockets and haunches. Once the final panel elevation was established, the leveling bolts and lifting loops were cut 25 mm below the deck surface and patched.

The installation sequence for the precast concrete deck panels was a critical loading stage for the steel girders. The girders were required to carry the full dead load and construction live load of the structure before they were made composite with the panels. The panels were placed first over the negative moment regions at the piers, then in the positive movement regions, starting from the south end of the structure and working north.

The last panel was placed at the midspan of the structure. The panel was fabricated with stainless steel threaded couplers cast flush in the joint face instead of protruding cast-in dowels. This detail allowed the panel to drop into place between the two adjacent panels without reinforcing conflicts. Threaded dowels were mated with the couplers in the joint after the panel was set down. See Figure 8 for a picture of panels after erection.

Figure 7: Panel erection

Figure 8: Full-depth, full-width, precast deck panels installed on the bridge

5.2 UHPC Batching and Placing

For this project, a pre-pour meeting was held to confirm the sequence and location of UHPC placement was in accordance with the design criteria. As UHPC was a new material for most of the project team, the meeting was a critical step to clarify the batching, placing and curing procedures. The meeting also helped to minimize or eliminate errors, and review good construction practices with the manufacturer.

High shear mixers are the most efficient way to properly mix the UHPC liquids, pre-mix powder, and fibers. For this reason, on-site portable high shear mixers, were used on this project. They are also the manufacturer's recommendation. A pair of mixers is used in sequence to avoid disruption in the process of batching and placing. It is also very important for the temperatures of the mix be maintained at the manufacturer's recommendations. For this project, ice was used instead of water to keep temperatures within range given the very hot weather during placement. To also ensure these temperatures stayed within range, the batching and placing was done at night.

Traditionally, transporting the UHPC from the mixers to the placement location is done with motorized buggies or non-motorized wheelbarrows. Prior to placing UHPC, it was important to condition the surfaces to saturated-surface-dry (SSD) so that the precast panel did not absorb the water out of the UHPC. The wet UHPC was poured directly from the buggies into the shear pockets and joints. Individual connections are filled consecutively, proceeding from areas of lower elevation to areas of higher elevation. Placing from low to high prevented air bubbles and pockets from getting trapped in the material. Each joint was poured as a discrete section while the shear pockets and haunches were filled in sections of 6-12 pockets.

Once the UHPC level in each connection reached the top panel surface, the pocket/joint was covered with a plywood form which was secured to the precast panel. Top forming after placement of the UHPC was required given the hydrostatic pressures exerted by the material in its fluid state. The plywood forms at the low end of a pour section had a small hole drilled through them and a 5-gallon bucket filled with UHPC placed on top. The UHPC maintained the head pressure in the poured section and ensured all the connections were completely filled. To keep the hydrostatic pressures within acceptable limits, pour breaks were introduced at regular intervals by placing plywood bulkheads within a row of shear pockets. The placement of the UHPC and the top formwork are shown in Figure 10.

5.3 UHPC Finishing

To reduce the risk of surface dehydration, the connections remained sealed from exposure to the external environment until after an initial set had occurred. To facilitate the ABC techniques employed on this project the contractor was allowed to remove the forms after the UHPC had reached a strength of 100 MPa. That enabled the contractor to quickly resume work on the deck and stay on schedule.

Figure 10: A) UHPC placement in a shear pocket and B) Top formwork and head buckets after placement

6. SUMMARY

Accelerated Bridge Construction (ABC) methods, such as using full-depth, full-width deck panels combined with Ultra High-Performance Concrete, are increasingly becoming common tools for bridge designers. There are several benefits from using precast ABC techniques, including a higher level of quality control compared to traditional cast-in-place elements, a reduced need for onsite formwork, reduced construction timelines, and lower risks corresponding to work over water or live heavy traffic. This technology, however, has not been used in Alberta on continuous vehicular bridges. The experience gained from this project provides long term value to the public as the experience can be applied for future designs and lead the way for more widespread adoption of full-depth, full-width precast deck panels and UHPC. There were several aspects of this project that used design techniques, materials, and methods not commonly used in Alberta or were being used for the first time in this application. The project received the 2018 Alberta Minister's Award for Transportation Innovation in Design.

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- Rapid Span: Girder fabrication
- Goal Engineering: Strain instrumentation and monitoring

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