DECK RECONSTRUCTION OF JACQUES CARTIER BRIDGE USING PREFABRICATED HIGH PERFORMANCE CONCRETE PANELS

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ABSTRACT

Involving the reconstruction of more than 645, 800 ft² (60,000 m²) of bridge deck on one of Canada's busiest bridges, this project made extensive use of precast, prestressed, high performance concrete (HPC) deck panels. This case study demonstrates a good example of the benefits of using a precast deck replacement method to rapidly reconstruct a highly durable deck while maintaining normal rush hour traffic.

This paper describes the technical design and construction techniques that were developed and implemented in order to successfully reconstruct the deck of this major 1.7 miles (2.7 km) long urban bridge. Presented are the design, material selection and construction techniques adopted to satisfy the following main objectives; construct a highly durable deck, ensure safety of workers and users, minimize negative impacts to the environment, satisfy a challenging two-year construction schedule and, most importantly, to minimize the inconveniences to as many users as possible.

The use of high performance concrete combined with a precast, prestressed, post-tensioned modular multi-stem integral slab and girder system as implemented and presented in this paper reflects the state-of-the-art in regards to bridge deck reconstruction when durability, speed of construction, structural efficiency, life-cycle costs and impact to users are considered.

Keywords: Bridge, Integral deck system, Prestressed, Post-tensioned, High performance concrete

INTRODUCTION

Opened to traffic in 1930, the Jacques Cartier Bridge spans the St. Lawrence River between Longueuil and Montreal, Quebec, Canada and also provides access to St. Helen's Island (former Expo 67 site) situated in the middle of the St. Lawrence River. In Montreal, the Jacques Cartier Bridge is more than just a means of transportation, it is a landmark structure and forms an important part of the city's image.

Measuring 1.7 miles (2.7) km with five lanes of traffic, this bridge carries more than 43 million vehicles every year making it one of the busiest bridges in North America when considering traffic densities per lane.

Over the last 70 years, the bridge deck had taken its toll due to the combined effects of age, increase in weight and number of truck transits, and the extensive use of de-icing salts in order to maintain the bridge operational under Montreal's harsh winter conditions. Because of this deterioration, the owner, The Jacques Cartier & Champlain Bridges Inc., a Canadian Crown Corporation and subsidiary of the Federal Bridge Corporation Limited, decided in 1997 to undertake a complete replacement of the existing deck.

The deck reconstruction method was developed on the basis of following main objectives:
- Minimize inconveniences to as many users as possible.
- Construct a new highly durable deck (design service life to be greater than 50 years).
- Ensure safety of both users and workers.
- Minimize negative impacts to the environment.
- Complete the deck replacement during two construction seasons (April to October 2001 and 2002).

These constraints drove the decision to undertake the replacement of the existing non-composite reinforced concrete deck originally supported by steel stringers by a new deck system made of precast, prestressed, high performance concrete (HPC) integral deck panels.

With a total project cost of approximately $120 million (Canadian), this two-year deck reconstruction work represents the biggest bridge rehabilitation project ever carried out in Canada. Uncommon for an existing bridge, the design-build method of delivery was retained to carry out this project.

This paper describes the technical challenges and corresponding solutions developed and implemented in order to successfully reconstruct the deck of this major urban bridge while maintaining full rush hour traffic.

BACKGROUND AND HISTORY

Originally known as the "Montreal-South Shore Bridge" this bridge was officially inaugurated in 1930 as the "Montreal Harbour Bridge" and renamed in 1934 as the "Jacques Cartier Bridge".

Construction of the bridge began in May of 1925 and three lanes were opened to traffic in May of 1930[1]. Tramway rail tracks installed in the outer lanes which were never used were gradually replaced by vehicular traffic lanes in 1956 and 1959 when the fourth and fifth lanes respectively became operational.

In 1959, an exceptional feat of engineering was accomplished when a portion of the south approach of the bridge was raised in order to increase the 40.0 ft (12.2 m) original clearance to 120 ft (36.5 m) and hence provide adequate navigational clearance for the new St. Lawrence Seaway shipping canal opened in that year. The total increase in clearance was achieved by both raising the existing piers and by replacing the deck truss superstructure by a through truss span over the Seaway[2].

After more than 70 years of operation, the concrete deck slab, support beams and many other bridge deck components had suffered severe damage and had thus reached their useful service life.

In-depth investigations were conducted in 1992 and 1994 using several non destructive testing methods including; ground penetrating radar, infrared thermography, half-cell potential measurements, chloride content measurements, corrosion rate measurements as well as traditional assessment methods such as chain drag, coring and ground truth testing. These investigations confirmed that major reconstruction of the deck was required.

Finally, in January 2000, a two stage tendering process was launched to replace the entire deck and on October 12, 2000 a contract in the amount of $109 236 606 (Canadian) was awarded to a consortium composed of two Canadian firms, SNC-LAVALIN Inc. (lead member, design, construction and project management) and Montacier Inc. (erector), and Demathieu & Bard SA of France (major precaster).

BRIDGE DESCRIPTION (EXISTING CONDITIONS)

GEOMETRY

The bridge measures 1.7 miles (2.7 km) between abutments located on the north and south shores (see Fig. 1). In its pre-reconstruction configuration, the bridge had five traffic lanes totaling 60.0 ft (18.228 m curb to curb) and two sidewalks each measuring 5.0 ft (1.524 m).

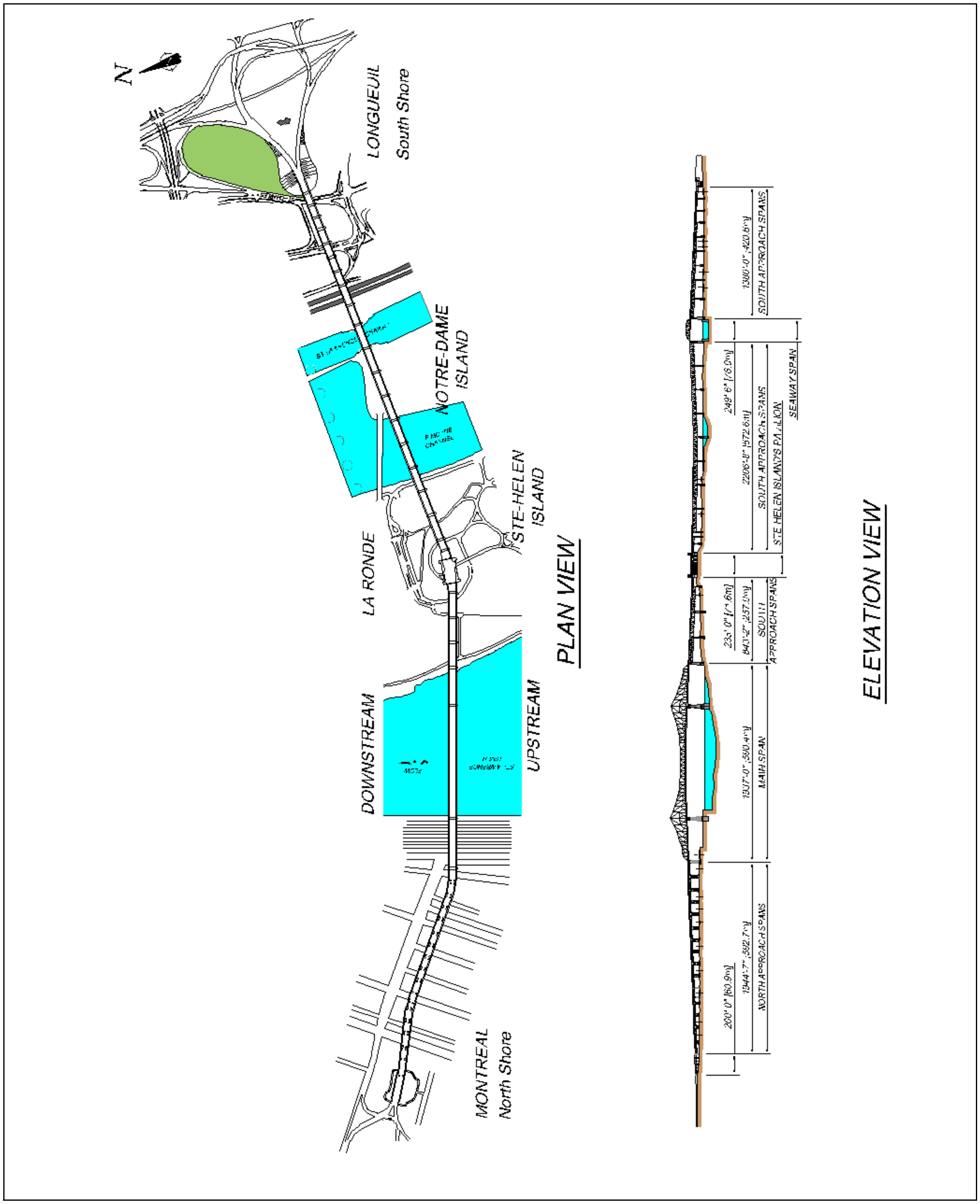

Fig. 1. General Layout of Bridge Showing Plan and Elevation Views

The horizontal alignment includes three major curves. One is located at St. Helen's Island Pavilion (the roof of the pavilion acts as the bridge deck), the other two, including a 292.0 ft (89.0 m) stretch just north of the Main Span, called the Craig curve which was originally built with a radius of only 250.0 ft (76.2 m), are located along the north approach.

The bridge is composed of several different structural systems including; the South Abutment span, the North and South Approach Spans, the St. Helen's Island Pavilion, the Seaway Span and the Main Span. These different configurations required different decking systems, which added to the complexity of this reconstruction project.

NORTH AND SOUTH APPROACH SPANS

The North and South Approach Spans consist of steel deck truss spans with a non-composite concrete deck. In general, North Approach Spans are supported by steel towers whereas the South Approach Spans are supported by concrete piers.

The concrete deck was supported by steel longitudinal stringers spanning between transverse steel floor beams, which in turn span from one top truss chord to the other. A cantilevered portion of the floor beam projects outboard beyond the truss chords and supports part of the deck and the sidewalks.

The structural configurations of the North and South Approach Spans are similar. However, along the north approach, a single transverse floor beam supports stringers located on each side of an expansion joint. This difference had a significant impact on the sequence of work for the north approach, since the new panels located on one side of an expansion joint had to be in place before the panels located on the adjoining side of the expansion joint could be installed due to the particular bearing arrangement.

MAIN SPAN

The Main Span measures 1937 ft (590.4 m) in length and is a steel through truss with two anchor spans, two cantilever spans and a central suspended span (see Fig. 8). The deck was a non-composite reinforced concrete slab supported by transverse stringers spanning over longitudinal beams. The longitudinal beams span between floor beams located at each truss panel point. The floor beam spacing is variable ranging between 20.25 ft (6.174 m) and 37.0 ft (11.287 m).

The sidewalks are located outboard of the trusses and are mounted on cantilevered brackets attached at each truss vertical.

SEAWAY SPAN

The Seaway Span measures 248.0 ft (75.6 m) and consists of a steel Warren type through truss system, with a concrete deck (see Fig. 10). The deck was a non-composite reinforced concrete slab supported by transverse stringers spanning over castellated longitudinal beams.

The longitudinal beams span between built-up trussed floor beams located at each truss panel point. The floor beam spacing is consistent at 31.0 ft (9.449 meters).

Like the Main Span, the sidewalks are located outboard of the trusses and are mounted on cantilevered brackets attached at each truss vertical.

NEW DESIGN FOR BRIDGE DECK RECONSTRUCTION

In general, the new bridge deck is made of precast HPC panels [8,700 psi (60 MPa)] which form a modular multi-stem integral deck system, and are subjected to transverse and longitudinal post-tensioning after being installed on the bridge to provide high durability. The deck reconstruction over a distance of 1.7 miles (2.7 km) and a width of 77.0 ft (23.5 m), including a sidewalk and a bikeway, represents an area of more than 645,800 ft^2 (60 000 m^2).

The precast concrete panels were designed to suit the various structural systems of the existing steel superstructure along the bridge. The new deck structural configuration was mostly driven by construction constraints and by the existing steel bridge components.

The live load used for design was the Canadian standard QS-660 kN (148.5 kips corresponding to a total weight of 74 tons) truck load (see Fig. 2) and a uniform load of 5.0 kPa (104 psf) for sidewalks. The new deck system was designed to carry the full live load for all stages of construction while a section of deck was open to traffic.

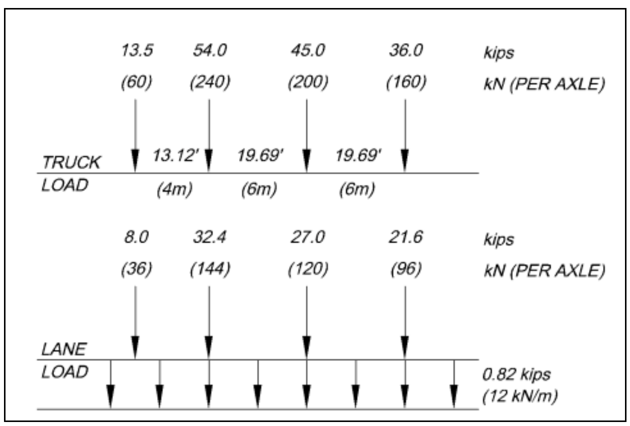

Fig. 2. QS-660 Truck Load Configuration

APPROACH SPANS

The new deck for the North and South Approach Spans consists of a series of deck spans, typically 24.34 ft (7.42 m) long. Each span is made up of four precast, prestressed concrete panels installed side-by-side (see Fig. 3 and 4). Each panel has a 7 in. (180 mm) thick slab and possesses three integral stems with variable depth which are reinforced with four 0.6 in. (15 mm) diameter harped prestressing strands (see Fig. 5 and 6). The concrete barriers were also integrated with the panels (see Fig. 7). Following the installation of a specific number of panels which are supported by existing floor beams, the transverse and longitudinal post-tensioning was applied.

The deck panels for the approach spans represent 67 percent of the entire surface which was reconstructed.

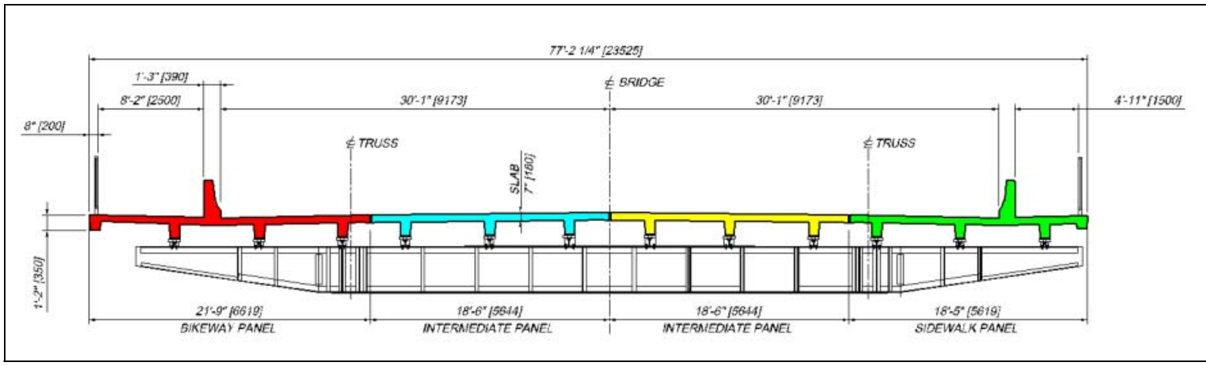

Fig. 3 Approach Span – Typical Deck Cross-Section

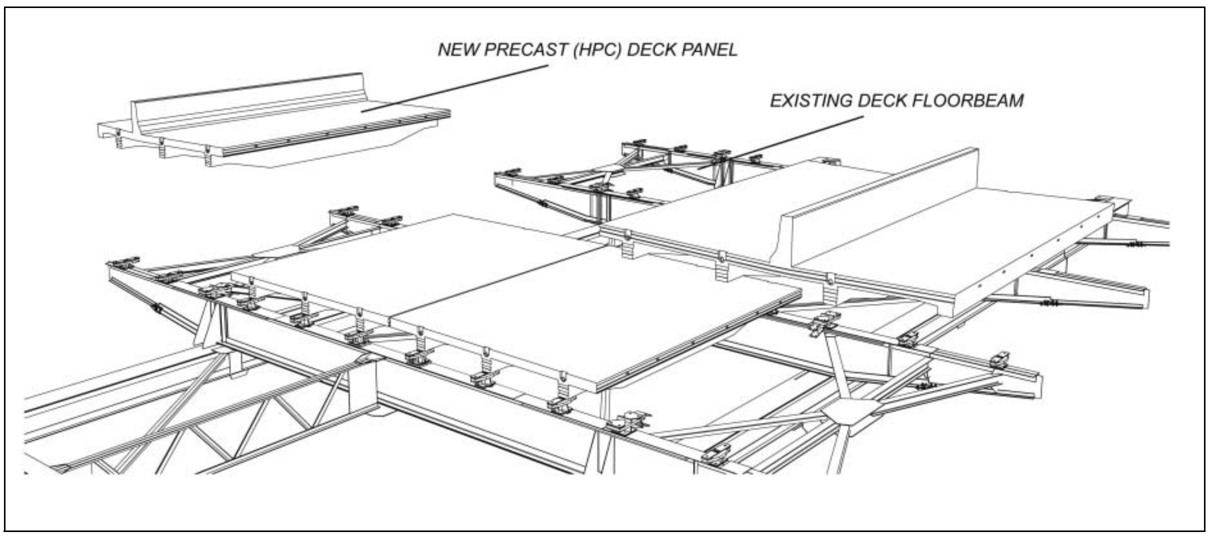

Fig. 4 Approach Span Panels Configuration

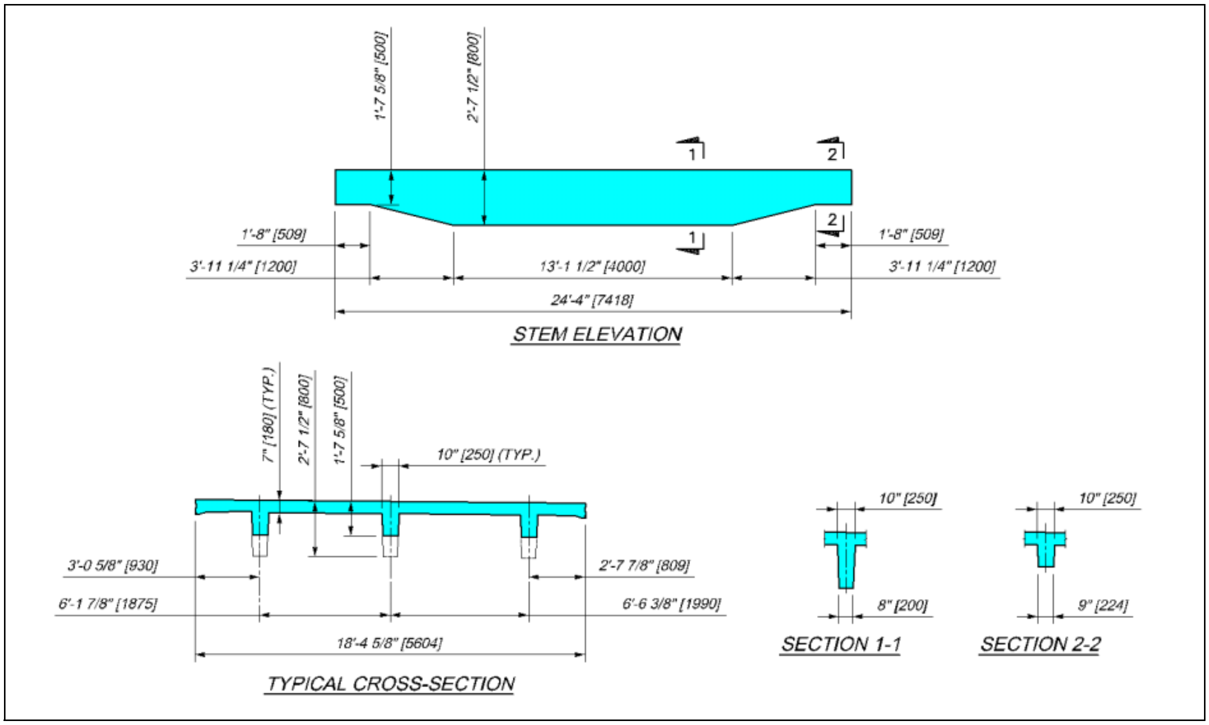

Fig. 5 Typical Approach Span Deck Panel

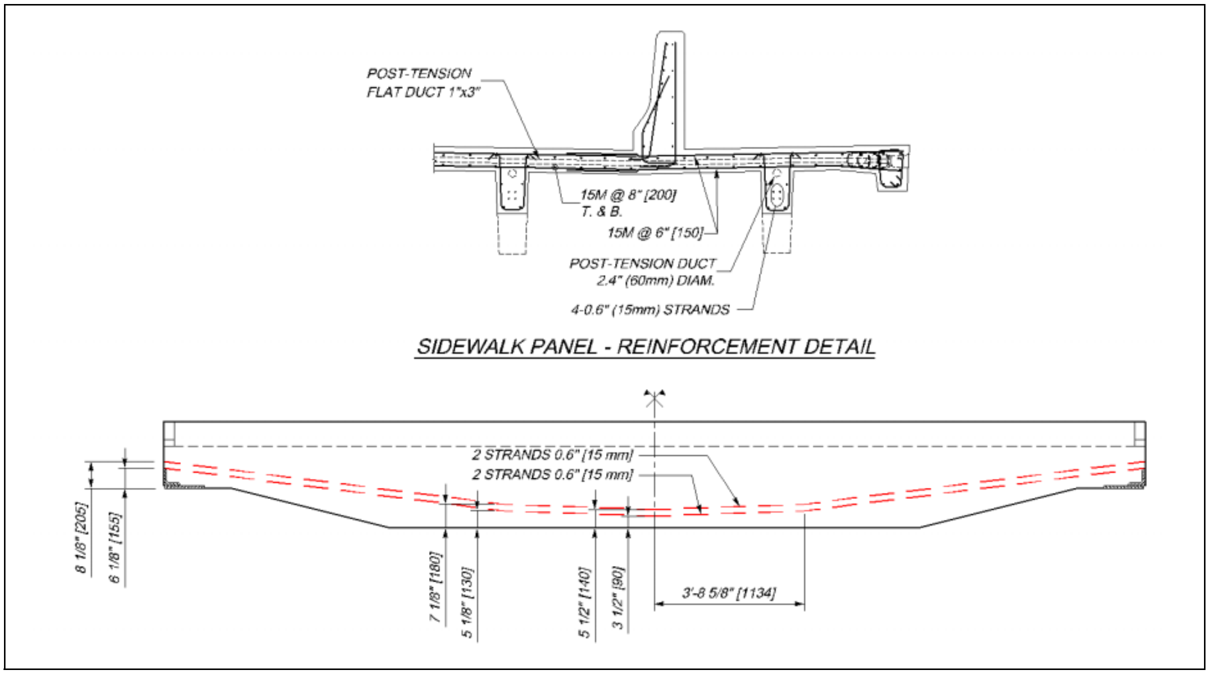

Fig. 6 Prestressing Strands

Fig. 7 Precast Prestressed Concrete Bikeway Panels

MAIN SPAN

The new deck consists of a series of precast concrete panels supported by the existing steel longitudinal beams. Each panel comprises two stems of variable depth, which are integrated with the slab. In the initial construction phase, a series of precast panels were installed and this was followed by the application of post-tensioned tendons on-site which was executed in a second phase, to provide continuity.

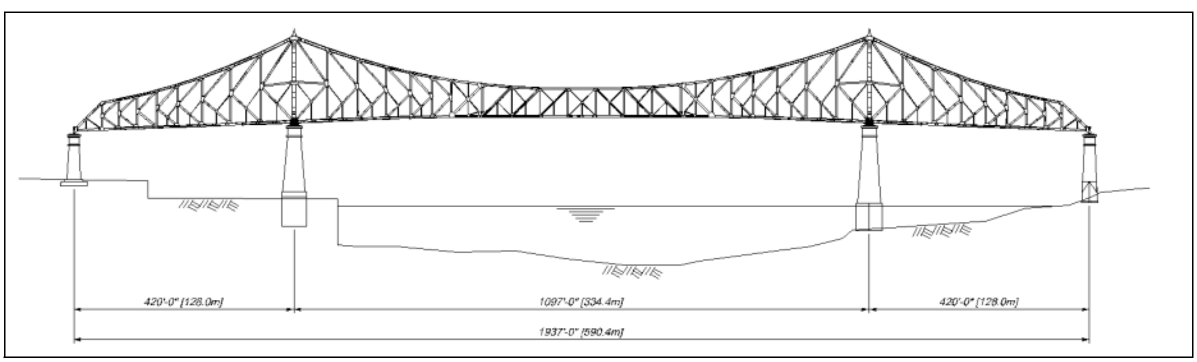

Fig. 8 Main Span - Elevation

The sidewalk and bikeway panels are independent of the roadway deck, and are supported over steel brackets connected at each truss vertical member. Each panel consists of a precast

HPC channel type section (see Fig. 9), prestressed with 0.6 in. (15 mm) diameter straight strands. After installation on the bridge, longitudinal post-tensioning was applied.

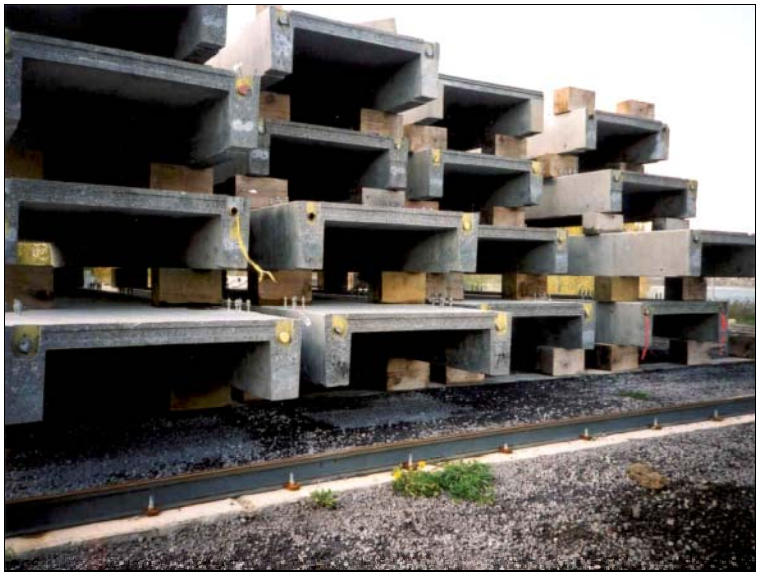

Fig. 9. Main Span Sidewalk and Bikeway Panels

SEAWAY SPAN

The new deck comprises a series of precast HPC panels supported by the existing steel castellated longitudinal beams. The design and construction procedure for the roadway deck, sidewalk and bikeway panels were in general similar to that of the Main Span (see Fig. 10 and 11).

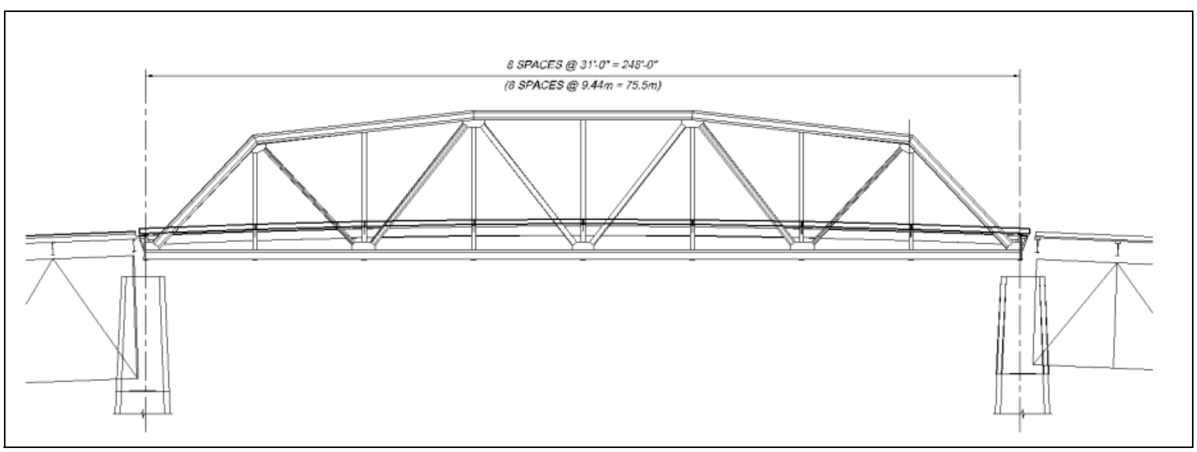

Fig. 10 Seaway Span - Elevation

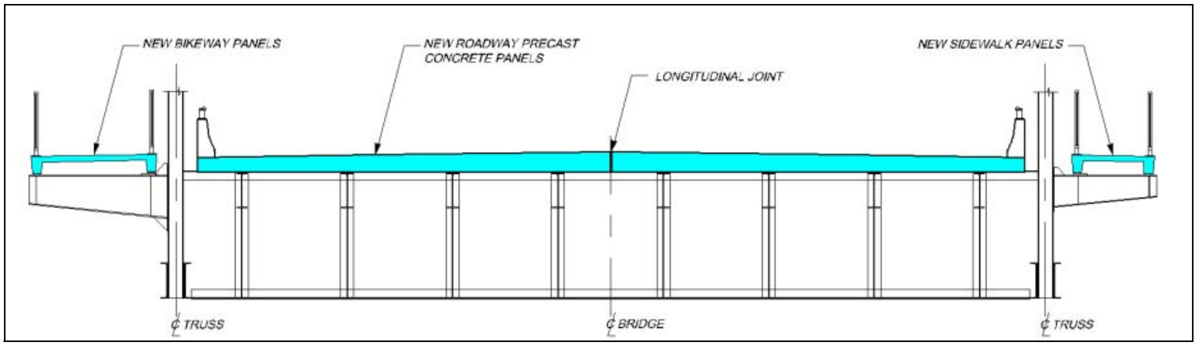

Fig. 11 Typical Cross-Section

DURABILITY

In order to satisfy a principal objective which was to construct a highly durable deck, the new deck system incorporated the following design features:

- A high performance concrete 8,700 psi (60 MPa) with a water-cementitious material ratio of 0.3 offering an excellent resistance to chloride penetration (ion penetration below 500 coulombs on average using the rapid chloride test method) and a mix design to provide good freeze-thaw and scaling resistance.
- The incorporation of galvanized rebar in some strategic areas of the deck which are directly exposed to de-icing chemicals (sidewalk, bikeway and barriers).
- Installation of a rubberized asphalt waterproofing membrane.
- Use of a high quality grout for post-tensioning ducts.
- Use of both longitudinal and transversal post-tensioning to eliminate all tensile stresses at the top fiber of all joints located between the panels.
- Incorporation of New-Jersey type barriers cast monolithically with the deck. In addition, the barriers were cast with a permeable form liner to improve surface properties of the concrete.

The combination of these design features was incorporated into the design to provide a durable deck system with a design service life in excess of 50 years.

FABRICATION AND CONSTRUCTION

CONSTRUCTION ACTIVITIES

The deck replacement work involved six principal types of construction activities which included:

- Steel works incorporating floor beam repair, strengthening and installation of new bearing assemblies to support the panels.
- Precasting of HPC deck panels.

- Removal of existing deck sections.
- Installation of new panels.
- Joint mortar placement and post-tensioning works.
- Installation of expansion joint armors, cast-in place expansion joint dams and paving work.

Because of the size of the project and the large number of precast deck panels to be installed during the two construction seasons (April to October of 2001 and 2002), it was deemed advantageous to construct a temporary precasting plant near the south approach of the bridge.

Built specifically for the project and certified to the requirements of CSA A23.4 – *Precast Concrete – Materials and Construction*[3], the precasting plant occupied an area of about 574 x 492 ft (175 m x 150 m) and was constructed in a three month period at a cost of approximately $6.5 million (Canadian). The plant encompassed five main areas for prefabrication, which were:

- Reinforcing Steel Pre-Assembly Area:
  Two bays, each 72 x 170 ft (22 m x 52 m) were dedicated to the assembly of reinforcing steel. Material handling was assisted by six overhead cranes with a capacity of 5.5 tons (5 tonnes) and spans ranging between 32.8 and 65.6 ft (10 and 20 m).

- Precasting Area:
  One large bay [89 x 269 ft (27 m x 82 m)] was used for the precasting area. This bay, at the heart of the plant, was linked to the different work areas. From this central location, the reinforcing steel staging area, three separate concreting areas, as well as the curing room could be accessed. Material handling was assured through the availability of three 22 tons (20 tonnes) overhead cranes, each with spans of 89 ft (27 m). One 44 tons (40 tonnes) capacity lift truck carried the cast elements to the curing room.

- Curing Room:
  The curing room occupied dimensions of 70 x 170 ft (21.5 m x 52 m) and was used to complete the initial 7-day required maturation period. The curing room communicated directly with the precasting area. To evacuate the cured product, access to the storage area was provided through a motorized sliding door. A twin hook overhead crane, with a capacity of 2 x 22 tons (2 x 20 tonnes) and a span of 65.6 ft (20 m) served the curing room by manipulating the elements while in the room, as well as by moving the finished product to the exterior storage yard. The curing room consisted of the following main components: a system of continuous sleepers to support the piles of precast deck elements, an air circulation system, a steam powered heating system to maintain constant temperatures, and finally a vapor distribution system which was used to maintain the humidity of the enclosure.

- Storage Yard:
  The plant storage area had many functions and was divided into different work zones. First, an unloading zone was used to handle the panels exiting the curing room. A second

zone was dedicated as a staging area for final touch-ups and corrections of any defects that were detected. The third zone was a storage yard (see Fig. 12) with a capacity to stockpile up to 400 precast elements. Here, the deck panels would sit until they reached their required compressive strength. Finally, once the elements were fully matured, they were moved to the loading dock. At the loading dock, tractor-trailers were loaded for the transport of the finished product to the work site. All of the storage yard's zones were serviced with a huge twin hook overhead portal crane with a 157 ft (48 m) clear span and a capacity of 44 tons [2 x 22 tons (2 x 20 tonnes)]. The portal crane traveled on two rails and was radio-controlled.

- Batch Plant:
  An automated portable concrete batch plant with a stationary horizontal pre-mixer and a capacity of 5.23 $yd.^3$ (4 m^3) was fed by an aerial conveyor. Three bins would feed the batch plant with the help of the aerial conveyor's load cells. The aggregate bins were filled with the help of a wheeled loader. The cement silo's capacity was 55 tons (50 tonnes). Other components of the system included a cement scale**,** and a volumetric dosage system which controlled the addition of water and admixtures at the pre-mixing stage. Two ready mix trucks were used to carry the concrete to the supply doors of the prefabrication dock.

Fig. 12 Storage Yard and Stockpile of HPC Precast Prestressed Panels

- Maintenance and Staff Facilities:
  The plant was also equipped with a maintenance workshop, a testing laboratory, premises for workers, and the plant office.

In the prefabrication process, reinforcing steel cages including prestressing strands were pre-assembled (see Fig. 13) then lifted as a complete unit using a lifting frame and an overhead crane and then deposited into one of several steel moulds. Strands were tensioned against the steel moulds which were specifically designed for this purpose.

Fig. 13 Preassembled Reinforcing Steel Cages

GENERAL FEATURES OF MOULDS USED FOR FABRICATION

The moulds included the following main features:

- Each mould had a rigid welded steel underframe (see Fig. 14), which for the prestressed elements, was capable of resisting the stresses and elastic deformations caused by the prestressing operations to the harped strands. Each mould was equipped with a system of external vibrators. The vibrators were strategically located and mounted on supports whereby a system of gussets would diffuse the vibration across the mould. The mould underframes were separated from the building slab through the use of anti-vibration supports and bushings.

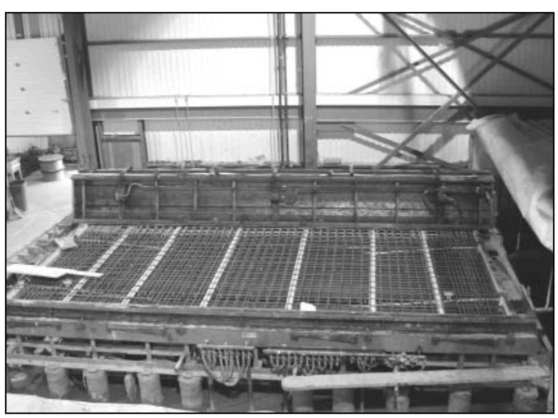

Fig. 14 Mould Set-up

- The mould's bottom surface formed part of the underframe. The mould sidewalls and endwalls were of welded steel construction. They were bolted into closed position using a system of auto-locking screws. The sidewalls were used as a leveling guide for the vibrating screeds used to smooth out the surface of the precast elements. Also, parts of the moulds were provided with recessed pockets, which allowed for future installation of inserts and accessories.

MIX DESIGN AND CONCRETE PLACEMENT

Concrete was batched in a stationary pre-mixer in quantities of approximately 3.9 $yd.^3$ (3 m^3). After mixing, each batch was then dumped into one of the two ready mix trucks, each with a 10.5 $yd.^3$ (8 m^3) capacity. If necessary, the concrete was cooled with nitrogen, before being transported to one of the plant's dock entrances. From there, the concrete was moved to the moulds using a 2.6 $yd.^3$ (2 m^3) traveling bucket, hauled by overhead cranes. The mix design for 1.3 $yd.^3$ (1 m^3) is shown in Table 1, and the properties are shown in Table 2.

Table 1. Concrete Mix Proportions

Cement type 10 SF : 450 kgs (SF designates blended cement with silica fume)	Superplasticizer (PS1248 by MBT) : 4500 ml
Water/cementitious materials ratio : 0.30	Air entraining admixture : 380 ml (Micro-air by MBT)
Aggregates (5/14) : 990 kgs	Set retarding admixture : 1000 ml (100XR by MBT)
Sand (0/5) : 760 kgs	

Conversion factors: 1 kg = 2.2 lb
1000 ml = 35.2 fl.oz.

Table 2. Properties of concrete mix

Slump : 200 mm	Strength after 16 hours : 32 MPa
Entrained air : 5%	Strength at 7 days : 55 MPa
	Strength at 28 days : 72 MPa

Conversion factors: 1 MPa = 145 psi

The concrete mix was placed in the moulds using concrete buckets, and consolidated into place using both external vibration of the moulds and internal vibration applied locally in congested areas. Concrete surface was finished using a vibrating truss screed and a broom finish was also applied to improve tire traction while the bridge was operated prior to placement of the asphalt wearing surface.

Accelerated curing was used which permitted releasing of the prestressing strands and stripping of forms 13 to 16 hours after casting once the concrete had attained a minimum compressive strength of 3,600 psi (25 MPa). Once stripped from moulds, panels were relocated to a maturity chamber for curing for a period of 4 days and then stockpiled outside using a 44 tons (40 tonnes) overhead crane.

Panels were transported over a distance of 0.62 miles (1 km) from the plant to the bridge site, using tractor-trailers specially modified to support and transport the panels without damage (see Fig. 15).

Fig. 15 Tractor-trailer Used for the Transportation of Panels

SITE WORK SEQUENCE

On the bridge, the existing deck was removed by saw cutting the deck into sections which were similar in dimensions to the new panels. Existing deck sections, which included the slab, steel stringers, barriers and railings were removed using two 60.5 tons (55 tonnes) self-propelled telescopic cranes placed at opposite ends of a panel (see Fig. 16).

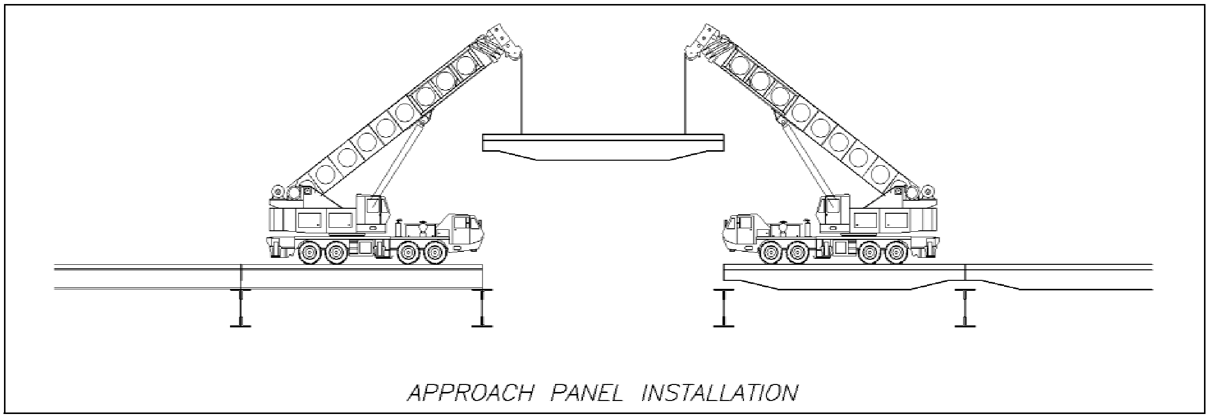

Fig. 16 Set-up for Removal and Installation of New Deck Panels

During the same lifting sequence and using the same cranes, the new panels [weighing between 22 and 42 tons (20 and 38 tonnes)] were lifted from the transport truck and lowered (see Fig. 17) onto the new bearing assemblies which were installed by other crews working in advance during the day.

Fig. 17 Installation of New Deck Panel

At peak productivity, a single crew was capable of installing six approach panels per night. In general, work was carried out using two crews which permitted the installation of 12 panels per night [representing about 5,380 ft^2 (500 m^2) of new deck area] between 8:30 pm and 5:30 am.

Joints between panels 1.56 in. (40 mm) wide were filled using a very rapid setting mortar, to which was added a 0.40 in. (10 mm) coarse aggregate and steel fiber, and designed to provide a 3,600 psi (25 MPa) compressive strength three hours after mixing. In order to improve bond between the mortar and concrete, panel edges received a special treatment which involved the use of a set retarder and water blasting to partially expose the coarse aggregate.

For typical north and south approach panels, transverse post-tensioning was completed a few hours after placement of the rapid setting mortar and once the four panels comprising a transverse section had been installed. Longitudinal post-tensioning was applied using multi-strand jacks placed in expansion joint block-outs (see Fig. 18) and could only be completed once all panels had been installed within a span (20 to 40 panels depending on the span length) (see Fig. 19).

The last major step in the reconstruction process involved the installation of new expansion joints armors and casting of expansion joint dams, installation of rubberized asphalt waterproofing membrane and the laying of a polymer modified asphalt wearing surface.

The bridge deck reconstruction project was organized so that half of the bridge's length would be closed to traffic at night during the first year of construction and the remaining half closed at night for the second year of construction.

The bridge closure was effective between 8:30 p.m. to 5:30 a.m. during each weekday while reconstruction operations were carried out.

Fig. 18 Longitudinal Post-tensioning Site Operations

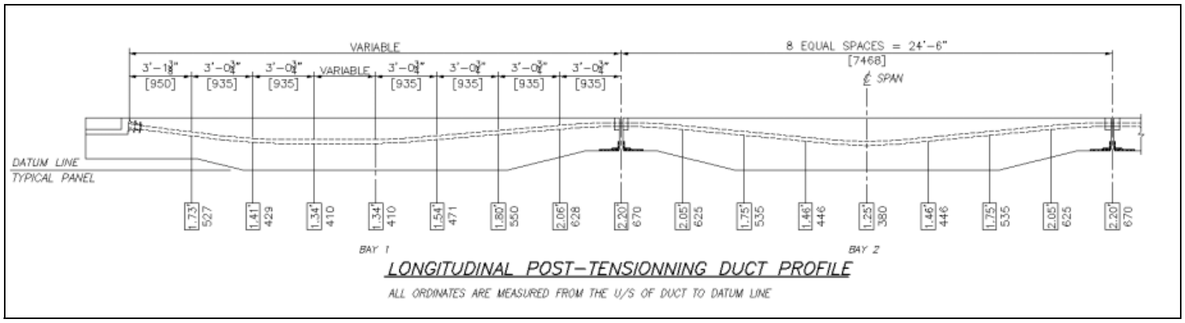

Fig. 19 Longitudinal Post-tensioning Duct Profile

CONCLUSION

The use of prestressed, precast HPC integral deck system for the Jacques Cartier Bridge deck reconstruction was selected and proved to be successful in meeting the main objectives which were to construct a durable and structurally efficient deck system while satisfying construction constraints and, most importantly, avoiding any disruptions to rush hour traffic on this major urban bridge.

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