THE USE OF HIGH PERFORMANCE CONCRETE IN BRIDGES AND ITS APPLICATION IN PRECAST CONCRETE INTEGRATED DECK SYSTEMS

Adel R. Zaki
SNC-LAVALIN Inc., Canada

Mohamed Lachemi
Ryerson University, Canada

Abstract

In recent years, the accelerated deterioration of bridge superstructures and the cost of their rehabilitation have been a major concern. The use of high performance concrete (HPC) became a suitable solution from a durability point of view. Moreover, its application in precast concrete integrated deck systems became the state-of-the-art for a comprehensive design in short and medium span bridges and for the optimization of life-cycle cost. The main objectives are to reduce on-site construction time for bridges subjected to high traffic volume, to produce durable elements and to achieve a better performance in aggressive environment. The aim of this paper is to share information and experience gathered by the authors relating to the use of HPC technology in bridges and its application in integrated deck system for highway, railway and pedestrian bridges.

1. Introduction

Extensive research programmes on different aspects of high performance concrete (HPC) have been carried out in Canada during the last 20 years [1,2]. This research effort resulted in a rapid growth in the use of HPC in different areas of civil engineering structures. The trend towards the wide use of HPC in bridges started in the early nineties with the construction of the Portneuf Bridge near Quebec City [3-6]. In 1997, a further step has been made in Sherbrooke, Quebec, with the construction of the world's first bridge to be built with a new generation of ultra high performance concretes called reactive powder concrete (RPC) [7-8].

Now, concrete having specified compressive strengths of up to 100 MPa can be produced in all areas of Canada [9]. Higher strengths can also be achieved by special means as in the case of RPC for which compressive strengths exceeding 200 MPa have been reached [10, 11]. The high strength and more importantly the durability of HPC provide an attractive technical and economical solution for both designers and owners. In many regions of Canada where bridges are subjected to severe and aggressive environments, the durability of this material results in lower service life costs. Moreover, initial costs can also be lower if designers take the strength benefits into consideration.

This paper is a brief review of some projects that have been completed using HPC and its application in integrated deck systems. It aims to share information and experiences gathered by the authors relating to the use of such a material for bridges in Canada.

2. Case Studies

Instead of giving a detailed historical background of the use of high-performance concrete for bridges in Canada, a number of selected projects familiar to the authors and involving the successful use of HPC are presented. These projects are used to illustrate different factors, including higher strength and durability, which have influenced the use of HPC for economic reasons. In each case, a general description that touches, among other things, the suitability of using HPC for that particular application is given.

2.1 Montreal's Jacques-Cartier Bridge

Opened to traffic in 1930, the Jacques Cartier Bridge spans the St. Lawrence River between Longueuil and Montreal, Quebec, Canada. Composed primarily of steel truss approach spans and a cantilever type main span, the bridge was originally built with a reinforced concrete deck. With five lanes and a traffic signaling system for reversing the direction of traffic flow in the centre lane, this bridge carries more than 43 million vehicles every year making it one of the busiest bridges in North America on a per lane basis.

The combined effects of age, heavy vehicles and the extensive use of deicing chemicals since the 1960's has led to undertake the replacement of the existing reinforced concrete deck. The new deck system is made of prefabricated, prestressed HPC panels (60 MPa) with integral deck system, subjected to transverse and longitudinal post-tensioning after being installed on the bridge. This major deck replacement project which extends over a distance of more than 2.7 km and over a width of 23 m, including a sidewalk and bicycle path, represents a deck area of more than 60,000 m^2 to be replaced.

The new deck for north and south bridge approaches consist of series of spans having 7.67 m long. Each span is made of four precast prestressed concrete panels installed side-by-side (Fig. 1). Each panel has a slab thickness of 180 mm and possesses three integral stems with variable moment of inertia reinforced with four draped prestressing 15-mm strands. The concrete barriers are also integrated with the panels. Following the installation of a certain number of panels, over the steel floor beams, the transverse and longitudinal post-tensioned were applied and stressed through ducts in order to eliminate all tensile stresses at the top fibre at joints located between panels. Finally, a rubberized asphalt waterproofing membrane was installed followed by the asphalt paving.

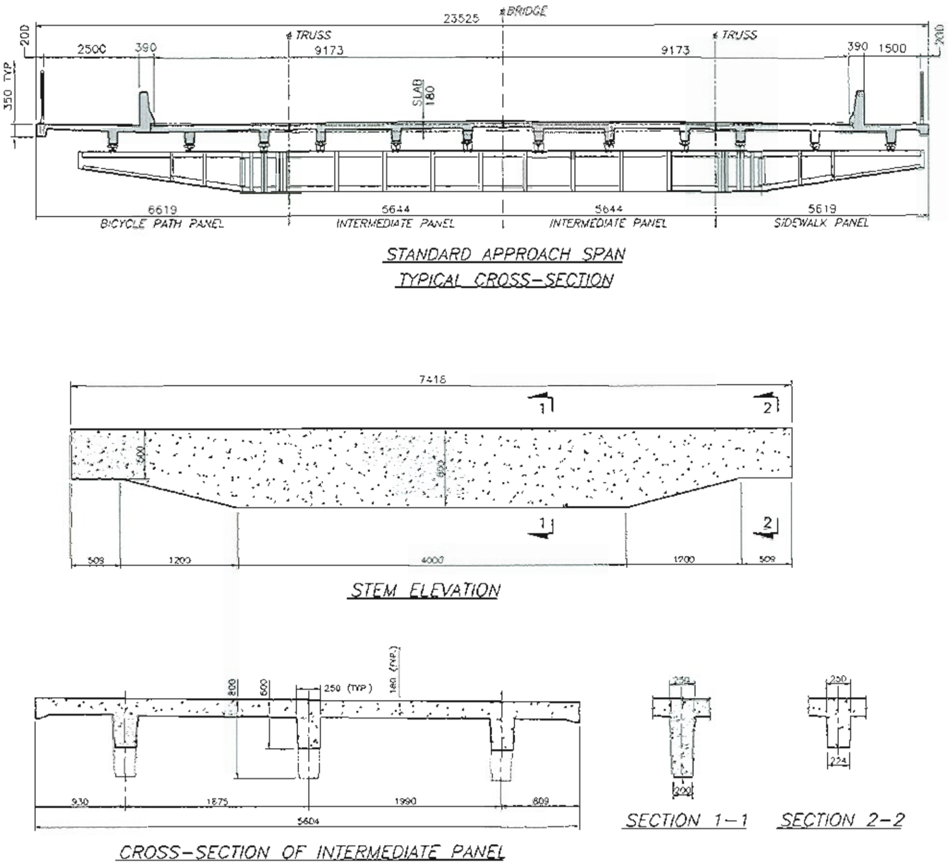

Fig. 1. Schematic representation of Jacques-Cartier Bridge Deck

The live load that has been used for design is QS-660 truckload and a uniform load of 5.0 kPa for sidewalks. The new deck system was designed to carry the full live load for every stage of construction for which the portion of deck under consideration is open to traffic. The deck panels for the approach spans represent 70% of the whole reconstruction area.

The use of prestressed precast concrete integral deck system for the deck reconstruction revealed to be a successful alternative to insure long-term durability (design life greater than 50 years). The use of HPC is insuring a low permeability and higher strength, which should result in extending the service life. It is also achieving substantial economy, by minimising the disruption of traffic during construction.

2.2 Laval's Pedestrian Bridge

In 1992, an existing pedestrian bridge, crossing a six-lane highway (3 lanes in each direction plus a central median and 2 shoulders), was examined in Laval, Québec, Canada. The original concrete pedestrian showed signs of significant concrete deterioration and reinforcement corrosion. A decision was taken to replace the bridge and HPC precast elements solution offered the most economical solution.

Fig. 2 shows the cross section of the new pedestrian bridge made with HPC [4]. The bridge spans 35 m centre-to-centre of the neoprene bearings. The cross section consists of two Z-shaped precast girders with the shape providing a bottom ledge for supporting the precast panels for the deck slab. Each of the Z-shaped girders was pre-tensioned with 40 – 15-mm ϕ strands. The depth of the precast pre-tensioned girders is 1370 mm and the widths are 250 mm.

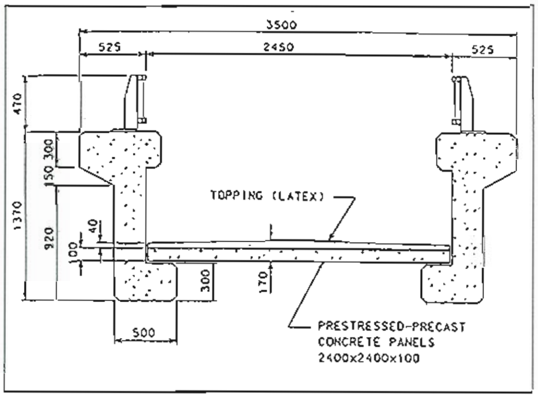

Fig. 2. Laval's pedestrian Bridge cross section

One of the key features of the design was the need for rapid erection to cause the least amount of disturbance to the traffic flow under the pedestrian bridge. The girders were erected in one evening to limit the disruption of traffic. The Z-shaped girders are structurally interconnected at both supports and at mid-span by casting concrete in 300-mm thick reinforced concrete closure strips. These closure strips produce a U-shaped cross section at these locations and serve as structural diaphragms. The diaphragms served to connect the girders to enable sharing of vertical loading and to interconnect the Z-shaped girders to aid in resisting torsion. The precast concrete panels were pre-tensioned with 13-mm ϕ strands and were supported by the lower ledge of the girders.

The specified 28-day compressive strength of the concrete for the girders and the panels was 70 MPa. For this bridge, there were several advantages to using a 70-MPa HPC:

- There were smaller long-term losses in the prestressing due to the larger modulus of elasticity, the smaller creep strains and the smaller long-term shrinkage strains;
- The higher strength concrete resulted in larger permissible stresses in the concrete;
- The smaller section, made possible by using HPC resulted in a practical precast concrete section;
- The use of HPC resulted in smaller deflections due to the larger modulus of elasticity.

2.3 Sherbrooke's RPC Bridge

Another outstanding and innovative example of the use of ultra high performance concrete in Canada is the world's first reactive powder concrete (RPC) bridge. This innovative pedestrian and bicycle bridge that has been built entirely with a 200-MPa RPC without any steel rebars, has been erected in the summer of 1997 over the Magog River in downtown Sherbrooke, Quebec, Canada [7,8]. This project has involved participants from Canada, France, Switzerland and the USA. The aim of this project was to explore first full size applications for RPC in structures. The main advantages of using RPC in bridges are the improvements to durability and structural performance. During the construction of the bridge, special attention was devoted to the quality control of the RPC used to prefabricate the match-cast segments of the superstructure.

Reactive powder concrete is a material made with particles smaller than 800 μm. It is formulated from Portland cement, silica fume, crushed quartz, sand, superplasticizer, water and steel fibers. The name RPC reflects the high percentage of hydraulically reactive components in the material and the small size of the granular particles used.

The 60-m span bridge is a prestressed concrete open-web-space truss. composed of six match-cast segments. The truss is made of RPC confined in thin stainless steel tubes. Significantly, no passive reinforcement is used in the structure. The main tensile stresses due to bending are counterbalanced by post-tensioning, whereas secondary tensile stresses are directly resisted by the steel fibers in the mix.

The cross section is composed of two 380 × 320 mm bottom chords and a 30 mm upper slab with 70 mm deep transverse stiffening ribs embedded in two 300 × 200 mm longitudinal ribs (Fig. 3). Total height of the truss is 3.0 m and overall width is 3.3 m, so that the 10-m long segments could be transported by normal trucks. Truss diagonals are joined to the top and bottom chords through two greased-sheathed anchored monostrands. These very small anchorages were especially developed for this technique. They are fully encapsulated and have neither bearing plate nor local zone spirals. The anchor head is directly in contact with the concrete, the mechanical characteristics of RPC being able to withstand the high compressive stresses beneath the anchor head.

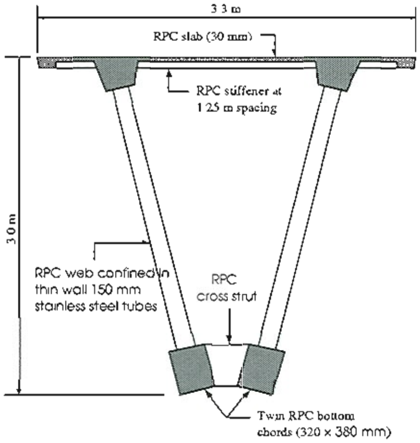

Fig. 3. RPC Bridge cross-section

2.4 Ontario's Railway Bridge

The bridge is crossing the Seal Creek, District of Kenora, Ontario, Canada, over the main track of the Canadian National Railway. Further to an overall evaluation and a bridge rating of the existing timber pile trestle bridge, it has been decided to replace it by a multi-stemmed high performance concrete ballasted deck span, with concrete cap bents (Fig. 4).

The single-span simply supported bridge spans 11.40 m, and designed for cooper E-90 Railroad Loading plus diesel impact, in conformity with AREMA Standards. It is composed of 2-precast prestressed multi-stemmed girders installed side-by-side (Fig. 5). Each girder has a slab thickness of 230 mm, an overall depth of 1100 mm and possesses three integral stems reinforced with 60 straight pre-tensioned 15 mm ϕ stress-relieved strands having an ultimated tensile strength of 1860 MPa.

The curbs were casted in plant and integrated with girders, including inserts. The lifting weight of each girder is 40 600 kg, including curb. Following the installation of the span over the bent, a steel trainmen's walkway and handrailing were connected to the curbs through the inserts.

The use of an integral precast prestressed HPC for railway bridge reconstruction revealed to be a successful alternative to insure long term durability and to achieve the most economic solution 12].

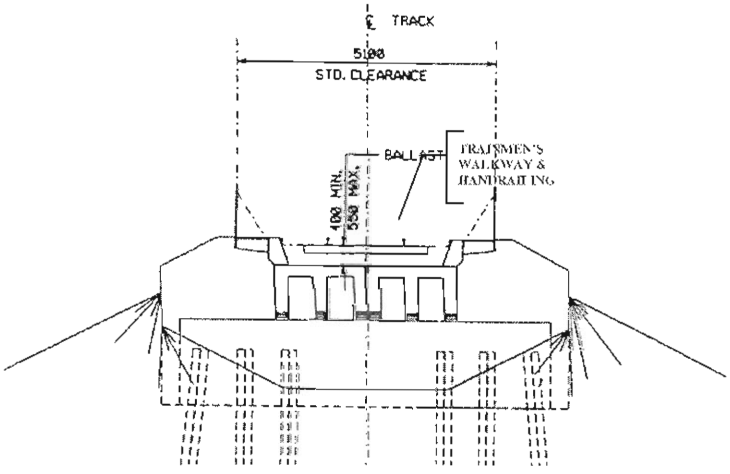

Fig. 4. Railway Bridge cross-section

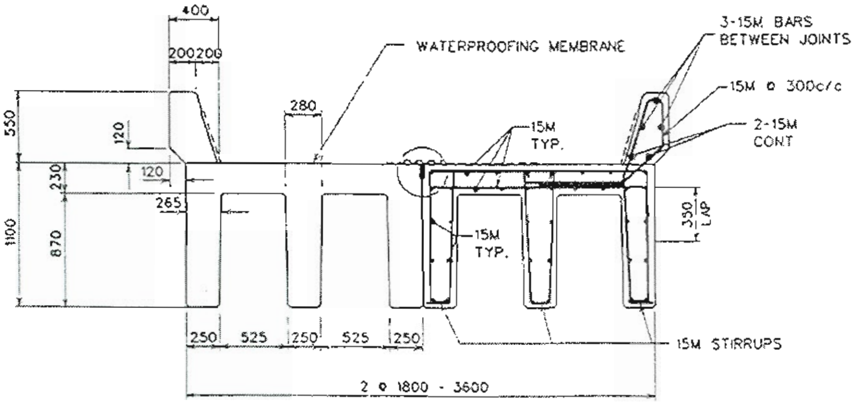

Fig. 5. Multi-stemmed girders

3. Conclusions

Premature deterioration of bridges has become a major problem during the last few decades. The use of high performance concrete to rehabilitate older superstructures or for new bridge constructions offers an attractive alternative to insure a long-term durability especially in areas subjected to aggressive environment. The improved durability of high performance concrete, due to its low permeability and higher tensile strength, should extend service life for bridges, which results in lower service life costs. Substantial economy can also be achieved due to the various structural advantages of using HPC, particularly when precast prestressed integral deck systems are used.

For the different bridge projects presented in this paper, high quality HPC was produced throughout the different projects despite very demanding production requirements. Some of these bridges have been instrumented to provide data related to the material's long-term behaviour under service loading and exposure conditions. It is too early to realistically highlight the real performance of the bridges after only a few years of monitoring, but it is hoped that this long-term monitoring programmes will help to demonstrate other advantages of using this material.

5. References

1. Aïtcin, P.-C. (1998), "High-Performance Concrete," E & FN SPON, London, 591 p.
2. Bickley, J.A. and Mitchell, D. (2001), "A State-of-the-Art Review of Hig Performance Concrete Structures Built in Canada: 1990-2000" Cement Association of Canada, Ottawa, Ontario, May 114p.
3. Aïtcin, P.-C., Ballivy, G. Mitchell, D., Pigeon, M. and Coulombe, L.-G. (1993), "Use of High-Performance Air-Entrained Concrete for the Construction of the Portneuf Bridge," SP-140, American Concrete Institute, Detroit, pp. 53–72.

4. Mitchell, D., Pigeon, M., Zaki, A.R. and Coulombe, L.-G. (1993), "Experimental Use of High-Performance Concrete in Bridges in Quebec," CFCA/CSCE Structural Concrete Conference Proceedings, May, pp. 63–75.
5. Mitchell, D. (1997), "An Overview of Canadian High-Performance Concrete Bridges," Technology Transfer Day: The Specifications and Use of HPC, University of Toronto, Toronto, Ontario, Canada, October, pp. 19–33.
6. Lachemi, M., Bois, A.-P., Miao, B., Lessard, M. and Aïtcin, P.-C. (1996), "First Year Monitoring of the First Air-Entrained High-Performance Bridge in North America," ACI Structural Journal, **93**(4), pp. 379–386.
7. Aïtcin, P.-C., Lachemi, M., Adeline, R. and Richard, P. (1998), "The Sherbrooke Reactive Powder Concrete Footbridge," Structural Engineering International (IABSE), **8**(2), pp. 140–144.
8. Lachemi, M., Dallaire, É., Adeline, R., Richard, P., Aïtcin, P.-C. (1998), "Innovative Use of Reactive Powder Concrete in 3D Space Truss Structure," The Structural Engineers World Congress, San Francisco, California, July 18–23, 9 p.
9. Bickley, J.A. (1999), "North American Trends in the Development of High-Strength Concrete," 5th International Symposium on Utilization of High Strength/ High Performance Concrete, Sandefjord, Norway, June, 13 p.
10. Bonneau, O., Lachemi, M., Dallaire, É., Dugat, J. and Aïtcin, P.-C. (1997) "Mechanical Properties and Durability of two Industrial Reactive Powder Concretes," American Concrete Institute Materials Journal, **94**(4), pp. 286–290.
11. Dallaire, É., Aïtcin, P.-C. and Lachemi, M. (1998), "High-Performance Powder," Civil Engineering (ASCE), January, pp. 48–51.
12. Goldberg, D. (1983), "Thirty Years of Prestressed Concrete Railroad Bridges," *PCI Journal,* **28**(5), Sept-Oct.