First Smart Highway Bridge in Canada

by

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The Beddington Trail/Centre Street, Calgary, Alberta, Canada, is the first prestressed concrete highway bridge built in Canada pretensioned by Carbon Fiber Reinforced Plastic, FRP, tendons. It is also the first bridge which has utilized a structurally integrated optical sensors system to monitor the behaviour. The bridge is completed and was opened to traffic on November 5, 1993. The project involved the cooperation from the following experts in the private sector, government and universities:

- The City of Calgary (Chris Wade, P.Eng. and Amit Guha-Thakurta)
- Strait Crossing Incorporated (Dr. G. Tadros, P.Eng.)
- Graham Construction Ltd.
- Con-force Structures Ltd, Canada (Leon Grant, P.Eng.)
- Mitsubishi Kasei, Japan
- Tokyo Rope Mfg. Co. Ltd., Japan
- University of Toronto Institute for Aerospace Studies (Dr. R. Measures, Dr. T. Alavie and Dr. R. Maaskant)
- University of Manitoba (Dr. S. Rizkalla and A. Abdelrahman)
- External Affairs and International Trade Canada
- National Research Council of Canada (Industrial Research Assistant Program)

The bridge is a two span continuous skew bridge 75 feet (22.83 m) and 63 feet (19.23 m) spans consisting of 13 bulb-Tee section precast prestressed concrete girders in each span. Two different types of carbon fiber plastic, FRP, tendons were used to pretension six precast concrete girders, typical of those shown in Figure (1). Carbon fiber composite cables, CFCC, 5/8"
(15.2 mm) in diameter, produced by Tokyo Rope, Japan were used to pretension four girders while the other two girders were pretensioned using two ¾” (8 mm) diameter Leadline rods tendons, produced by Mitsubishi Kasei. Distribution of the CFCC cables and Leadline tendons within the bottom flange, is shown in Figure (2). Continuity of the two spans was achieved by post-tensioned steel tendons extended along the entire length of the bridge.

Fiber optic Bragg grating strain and temperature sensors were used to monitor the behaviour during the construction and under serviceability conditions. The 4-channel Bragg grating fiber laser sensing system was developed at the University of Toronto Institute for Aerospace Studies.¹

Before construction of the bridge, an experimental program was conducted at the Structural Engineering and Construction R&D Facility, University of Manitoba, to examine the behaviour of a 1:3.3 scale model beams pretensioned by the same types size and anchorage of the two different tendons used for the bridge girders. The tests also used the same optic sensor as used for the bridge in addition to electric resistance strain gauges to compare the results. Tests results of the structural behaviour and optical sensors are discussed in detail in separate papers.²³

Structural Design

Flexural design of the girders, using carbon fibre reinforced plastics, CFRP, tendons was based on the strain compatibility and the materials characteristics of the CFCC, Leadline rods and the concrete. The material characteristics of CFRP is perfectly linearly elastic up to failure with a guaranteed tensile strength of 250 ksi (1750 MPa) and 285 ksi (1970 MPa) for the CFCC cables and Leadline rods respectively. The elastic models of CFCC and Leadline rods were 20,000 ksi (137 GPa) and 21,000 ksi (147 GPa) respectively. The girders were designed to provide identical behaviour to the other girders pretensioned by steel tendons under service loading conditions as shown in Figure (3). This design resulted in higher flexural strength of the girders pretensioned by CFRP, however, less deflection at ultimate in comparison to the girders pretensioned by conventional steel strands.

Special detail was implemented in the structural details to provide safety precaution features in the unlikely event of possible distress of the CFRP. Holes were provided at the thickened web at the end of the girders, as shown in Figure (4), to be used to bolt steel brackets.
on each side of the web to support external prestressing system, if needed, at the bottom flange of the girder to compensate any possible losses of the pretension system. The failure mechanism of the bridge ensured also that the catenary action provided by the steel tendons, used to provide the continuity over the middle support, is sufficient to carry the self weight of the bridge.

Due to the high bond characteristics of the CFRP, which could result in shorter transfer length and consequently possible split cracking, spiral reinforcements were provided at the end of the girders for each cable as shown in Figure (5).

The cables were located at three different layers to also provide significant safety and ductility to the bridge since any possible distress will take place gradually from the bottom layer to the second and the third layer, thereby providing sufficient warning effect. The bridge is continuously monitored using the built in optical sensors and electric resistance strain gauges. Collected data on the performance will also provide sufficient warning effect to avoid any possible accumulation of serious distressing, therefore helping engineers to take appropriate actions.

**Construction Details**

Prestressing of CFRP were adapted to practice of the precasters by using couplers to couple the CFCC and Leadline rods to conventional steel strands as shown in Figure (6.a, b) for the CFCC and Leadline respectively. Use of couplers were useful to minimize the length of CFRP tendons. The couplers were staggered to allow use of the same spacing used for the conventional steel tendons. The couplers system simplified the tensioning process by allowing the precasters to use the same jacking system typically used for steel tendons without any modifications. Details of the coupling system is shown in Figure (7). The CFCC and the Leadline rods were delivered to the precast plant in approximately 2 meter diameter rolls as shown in Figure (8) The Leadline rods were cut at the site, and two rods were used for each tendon. The CFCC were delivered precut to the specified length with 300 mm die cast at each end to distribute the stresses at the anchorage zone. Construction of the bridge and handling of the girders at the site were typical as shown in Figure (9). The completed bridge is shown in Figure (10).
**Optic Sensing System**

A 4-channel Bragg grating fibre laser sensor system, developed by University of Toronto Institute for Aerospace Studies, was used at different locations along the bridge girders pretensioned by the CFRP. This system involves 4 independent Bragg grating tuned fiber lasers that are multiplexed in order to be pumped by one semiconductor laser. Each fiber laser was attached to the surface of the tendon to serve as a sensor. The sensors were connected, through a modular system, to a laptop computer used at the construction site to record the measurements at different stages of construction and after the completion of the bridge as shown in Figure (11).

The optic sensor system measures the absolute state of strain rather than a strain relative to an initial calibration value such as the case for the electric resistance strain gauges and mechanical gauges.

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