RECENT INNOVATION FOR CONCRETE HIGHWAY BRIDGES IN CANADA

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ABSTRACT

A brief description of three concrete highway bridges, which have recently been built in Canada using new design concepts and advanced materials for reinforcing and prestressing concrete, is reported. The first smart concrete highway bridge (Centre Street, Beddington Bridge, Calgary, Alberta) is prestressed by carbon fiber reinforced plastic (CFRP) tendons and instrumented by fiber optical sensors. The second bridge is the Salmon River Bridge in Halifax, Nova Scotia, where a reinforcing steel-free concrete deck slab was constructed based on the research work conducted at the Technical University of Nova Scotia. The third bridge, under construction in Manitoba, has straight and draped CFRP tendons for prestressing the girder, CFRP stirrups for shear reinforcement, CFRP for flexural reinforcement of the deck slab and GFRP for the bridge curbs.

All bridges are instrumented with a new generation of optical fiber sensors monitored remotely from a central station through telephone lines, thereby eliminating the need for costly site inspections.

1. INTRODUCTION

In Canada, the Canadian government initiated in September 1995 a new Network of Centres of Excellence for Intelligent Sensing for Innovative Structures (ISIS Canada). The main objective of the centre is to develop unique advanced technology that will lead to a new generation of sophisticated civil engineering structures. These structures are classified as smart by virtue of their integrated fiber optic sensors and innovative through the use of advanced composite materials to solve the corrosion problem which is considered one of the main causes of deterioration of concrete structures.

This paper discusses the design and construction of two bridges opened to traffic in 1993 and 1995 and a third one currently under construction in Winnipeg, Manitoba, Canada.
2.0 CENTRE STREET/BEDDINGTON BRIDGE IN CALGARY

This bridge is the first smart bridge constructed in Canada using two different types of carbon fiber reinforced plastic (CFRP) tendons and the optical fiber sensor technology (Rizkalla et al., 1994). The bridge is a two-span continuous skew bridge of 22.9 m and 19.2 m spans, each consisting of 13 bulb T-section precast pretensioned concrete girders. A typical girder is shown in Figure (1).

![Figure 1 - Typical Pretensioned Girder of Calgary Bridge](image1)

The two different types of CFRP used were carbon fiber composite cables (CFCC) 16 mm in diameter produced by Tokyo Rope of Japan and two 8 mm in diameter leadline rods per tendon. Fiber optic Bragg grating sensors were used to monitor the behaviour during the construction and under serviceability conditions. The City of Calgary sponsored an experimental program at the University of Manitoba to examine the proposed design and the various limit states behaviour include the failure mode (Abdelrahman et al., 1995). The 1:3.3 scale model beams were pretensioned by the same type, size and anchorage used for the bridge. Behaviour of the beams was bi-linear with reduced stiffness after cracking and up to failure. All beams pretensioned by CFRP exhibited large deflection and uniformly distributed crack pattern as shown in Figure (2). This behaviour is considered acceptable to provide sufficient warning before failure which normally can be measured by the ductility ratio for steel reinforced concrete structures. Figure (3) shows the completed bridge.

![Figure 2 - Crack Pattern of Calgary Bridge Test Beams Before Failure](image2)

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3.0 SALMON RIVER BRIDGE

Construction of the deck slab of this bridge was based on an innovative concept using polypropylene fiber reinforced concrete and new construction details to provide lateral restraint of the supporting steel girders. Use of this concept allowed the bridge deck to be constructed totally devoid of all internal steel reinforcements. The lateral restraint was achieved by providing transverse steel straps regularly spaced and welded to the top flange of the steel girder (Bakht et al. 1996, and Newhook et al. 1996). This concept relies on the arch action mechanism and punching shear failure mode rather than the traditional flexural behaviour normally used for slab as illustrated in Figure (4).

The Salmon River Bridge consisted of two simply supported spans of 31 m each and was constructed on the Trans Canada Highway, 150 km from Halifax, Nova Scotia, Canada. One span was constructed with steel-free deck slab while the other used conventional deck to compare the behaviour under the same environmental and traffic loading conditions. Construction of the steel straps with one welder and casting of the concrete without reinforcing the deck can be seen in Figures (5) and (6).
Figure (5) - Welding of the Steel Straps to the Girder

Figure (6) - Casting of the Steel-free Deck

The curbs of the same span used for the steel deck was reinforced by glass fiber reinforced plastic reinforcements as shown in Figure (7).

Figure (7) - GFRP Reinforcements for the Bridge Curb
The deck slab is remotely monitored by using a combination of conventional electronic resistance foil gauges and Bragg grating fiber optic sensors. Some of the optic sensors were structurally integrated in the NEFMAC grid used to reinforce the curb.

4.0 HEADINGLEY BRIDGE IN MANITOBA

Due to the severe environmental conditions and use of salt for de-icing, the Manitoba Department of Highways and Transportation has approved the use of carbon fiber reinforced plastic (CFRP) reinforcements for the shear and prestressing of four girders of Headingley Bridge. CFRP as reinforcement for a portion of the deck slab and glass fiber reinforced plastic (GFRP) reinforcement for one side of the bridge barrier. The bridge consists of five 30 m simple spans. The 200 mm deck slab in each span is carried by six AASHTO girders spaced 1.8 m. Due to the lack of codes and standards, an experimental program was undertaken at the University of Manitoba to examine the behaviour of six 10 m long beams pretensioned by straight and draped CFRP tendons and reinforced by various size and diameter CFRP stirrups (Fam et al, 1996).

Reinforcement details and the completed test beams are shown in Figures (8) and (9). The experimental program indicated that the concrete shear contributions, $V_c$, is gradually reduced after cracking. Due to the relatively high elastic modulus of CFRP in comparison to other FRP reinforcements, the induced strain in the stirrups and the diagonal crack width were comparable to steel stirrups. The test beams exhibited significant deflection and cracking before failure as shown in Figure (10). This behaviour is considered to be sufficient to provide the required warning before failure, thus safety of the public. A full-scale test of the bridge deck using CFRP reinforcements was tested at the Structures Laboratory of the University of Manitoba as shown in Figure (11). The bridge will be remotely monitored, as sketched in Figure (11), using conventional electric foil gauges and Bragg grating optic sensors using an intelligent processing system.

Figure (8) - Reinforcement Details of the Test Beams for Headingley Bridge
Figure (9) - Test Beams at Con-Force Ltd., Winnipeg, Manitoba

Figure (10) - Extensive Cracking Pattern Before Failure of a Typical Test Beam

Figure (11) - Full-scale test of the deck slab.
Figure (12) - Remote Monitoring of Headingley Bridge

4. CONCLUSION

This paper briefly describes three bridges constructed using new innovative concepts and fiber reinforced plastic reinforcements for flexure and shear. All bridges included structural details and sensing technology to ensure safety of the public. The use of fiber reinforced plastic reinforcements, remote monitoring and intelligent processing were used as innovative technology for these bridges. The new structures are characterized as innovative and intelligent which are the focus of the new Canadian Network of Centres of Excellence in this field.

5. REFERENCES


