Use of Externally Bonded FRP Systems for Rehabilitation of Bridges in Western Canada

Robin Hutchinson, Gamil Tadros, Jadwiga Kroman, Sami Rizkalla

Synopsis:

Since its inception in 1995, the ISIS Canada research network has developed design procedures and innovative techniques for the rehabilitation and repair of existing concrete structures using fiber reinforced polymer (FRP) materials. In co-operation with various industrial partners, ISIS Canada has conducted many field application projects, successfully transferring ISIS technology into practice in the field.

This paper provides a review of four recent field applications in Western Canada, utilizing externally bonded FRP for the repair and strengthening of bridges. The projects include flexural strengthening of a bridge deck under lateral bending, shear strengthening of I-shaped AASHTO girders for two bridges, and the repair and strengthening of concrete corbels supporting a single girder pedestrian bridge. Some construction costs and the time required to complete each project are presented, as well as practical details specific to each application.

Keywords: Bridge, deck, carbon fibers, fiber reinforced polymer, repair system, strengthening

Robin Hutchinson *is an Engineer-In-Residence and Senior Instructor with the Dept. of Civil Engineering at the University of Manitoba, Canada. She received her Ph.D. from the University of Manitoba in 1999.*

Gamil Tadros, MACI, *is Technical Applications Consultant, ISIS Canada and Structural Consultant, Speco Engineering Ltd. Dr. Tadros is an active member in Canadian codes for the use of FRP. His field of activity includes bridge analyses, rehabilitation, and design, structural analysis, prestressed concrete, and FRP design. He is a member of ACI Committee 440, Fiber Reinforced Polymer Reinforcement*

Jadwiga Kroman, MACI, *is Senior Engineer with The City of Calgary, Canada. Ms. Kroman's field of activity includes managing, design and analyses of bridges and parking structures. Ms. Kroman's particular interests include advancement of methods for concrete structure upgrading and restoration using FRP, as vehicles for optimization of bridge structure life cycle and efficiency.*

Sami Rizkalla, *FACI, is Distinguish Professor of Civil Engineering and Construction, Director of the Constructed Facilities Laboratory, North Carolina State University. He is a chairman of ACI Committee 440, Fiber Reinforced Polymer Reinforcement, and a member of Joint Committee 550, Precast Concrete Structures.*

INTRODUCTION

The ISIS Canada research network has developed design procedures and standards for the rehabilitation and repair of existing concrete structures using fiber reinforced polymer (FRP) materials. Through various field applications across Canada, this technology has been successfully transferred into practice. This paper provides a review of four recent field applications in Western Canada, utilizing externally bonded FRP for the repair and strengthening of bridges.

Flexural strengthening of the Country Hills Boulevard Bridge in Calgary, using CFRP laminates is presented, followed by the shear strengthening of I-shaped AASHTO girders using CFRP sheets. This shear strengthening technique is described for two projects, the Maryland Bridge in Winnipeg, Manitoba and the John Hart Bridge in Prince George, British Columbia. And finally, the repair of concrete bridge corbel supports using CFRP sheets for the Jacques Lodge Pedestrian Bridge in Calgary Alberta, is discussed.

Visual monitoring of these bridges has been conducted in a regular basis. The increase in capacity due to FRP strengthening was limited to 50% of the original capacity. The criteria and design procedures used in these projects are consistent with those included in ISIS Canada Design Manual No. 4 (Neale 2001).

DECK STRENGTHENING: COUNTRY HILLS BRIDGE, CALGARY

This two-lane bridge, shown in Fig. 1, was constructed in 1975 to carry Secondary Road 564 over Highway 2, between Edmonton and Calgary, however it became a busy and important connection between Northwest Calgary and Calgary International Airport.

Fig. 1: Country Hills Boulevard Bridge over the Deerfoot Trail

The City of Calgary appointed CH2M Limited to analyze the bridge and determine appropriate strengthening measures. Design and construction criteria included the need to strengthen the bridge to carry current design live loading, and to maintain one-lane traffic on the bridge at all times during construction.

The bridge is a two-span composite steel box-girder structure with a 44-degree skew. Each span is 57.9m long, the overall width is 10.06m and the clear roadway is 8.53m. There are three 1.575m wide by 1.67m deep box girders supporting a 140mm thick reinforced concrete deck slab. The bridge was designed for AASHTO HS20-44 loading.

Strengthening Criteria and Analysis

The strengthening criteria was to review the strength of the superstructure and bearings for the CS-750 truck which applies 750 kN of live load according to The Canadian Standard CAN/CSA-S6-88 (1988). A finite-element grid analysis program was used to model bridge behavior under a moving CS-750 live load. The model was analyzed for the effects of self-weight, superimposed dead load, and truck or lane load. The CS-750 truck was applied at different locations across the bridge. Combined truck loading was also considered.

Deck Slab

The deck slab is 140mm thick with a 50mm asphalt-wearing surface. It spanned five equal lengths of 1.575m, between girder flanges and it proved to be the main problem area in the bridge rehabilitation work.

In the analysis, it was assumed that the 50mm of asphalt over the deck slab would be removed and replaced with heavier overlay concrete. Over most of the slab area, analysis showed that applied factored bending moments, M_f, were in the order of 42 kN.m/m'. Strength was therefore not a factor for most of the slab, but crack avoidance, or minimization, in the negative moment region was an important issue. In two specific areas in each span, the factored negative bending moments in the slab (53 kN.m/m') exceeded the moment capacity provided by the existing reinforce concrete section (Fig. 2). Two alternatives were considered to strengthen the deck slab. The first alternative was to provide slotted strips in sections of deck slab and strengthen these sections with additional reinforcement. The other was to add epoxy bonded carbon fiber strips on the top of the deck slab. The CFRP strips were applied in the capacity deficient tension zone and anchored in the adjacent compression zone (Fig. 3)

CFRP Strip Strengthening

The deck strengthening involved the installation of Carbon Fiber Reinforced Polymer (CFRP) strips, 100mm Sika Dur as shown in Fig. 3. The 100mm wide x 1.2mm thick strips were applied at 500mm centers across the bridge in areas requiring additional deck strengthening. The CFRP strips have a tensile strength of 2,400MPa, Modulus of Elasticity of 150,000MPa, and elongation at break of 1.4%(min).

The design for the number of strips to be used per meter is based on limiting the stress in the strips at ultimate loads, to less than 25% of the ultimate capacity of the strips. The cut off of the strips were chosen, as shown in Fig. 3, to be in the compression zone of the deck slab to avoid peeling of the strip at its end according to Saadatmanesh and Malek (1998). The cost of CFRP including the installation is $160.00 per meter of the CFRP plates.

General contractor for the rehabilitation project was Walter Construction (Canada) Ltd., with the CFRP application completed by Van Mason Coating Ltd. Engineers for the project were CH2M Limited, of Calgary, and ISIS Canada was consultant for the project.

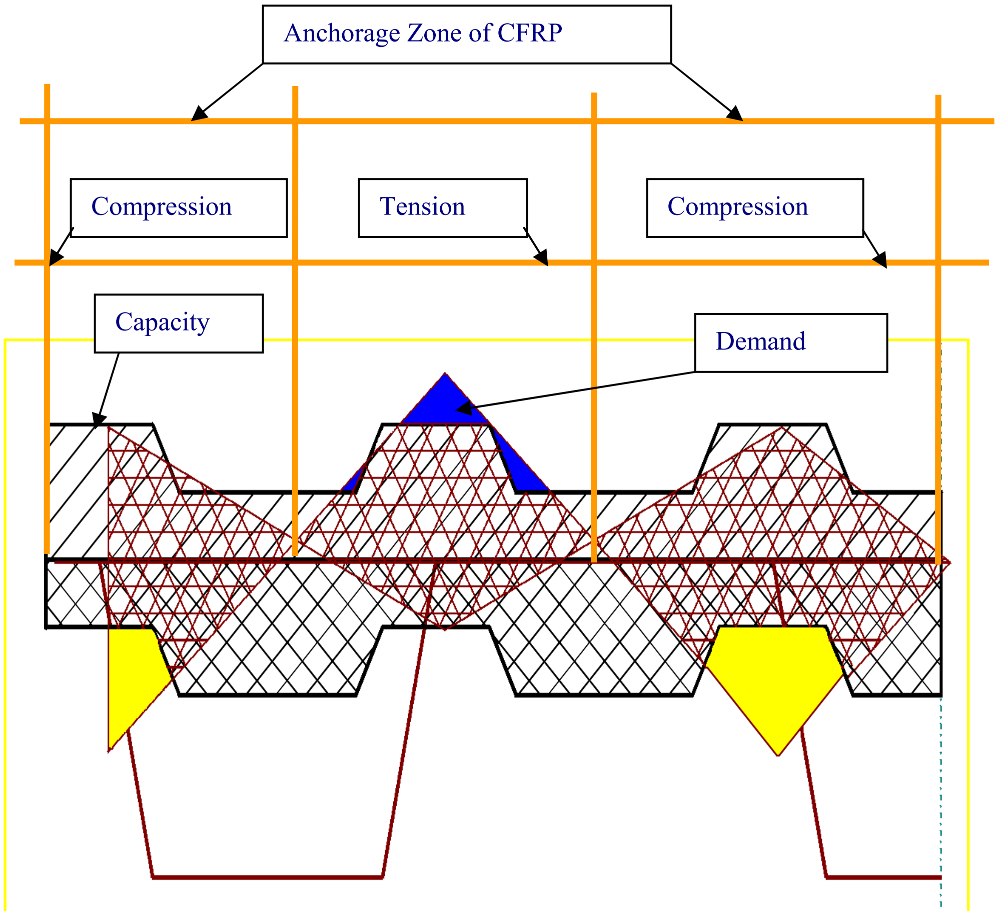

Fig. 2: Extent of Moment Demand/Capacity of Deck Slab

Fig 3: Placing CFRP Strips on Deck Slab

GIRDER SHEAR STRENGTHENING:
JOHN HART AND MARYLAND BRIDGES

Externally bonded CFRP sheets have been used to upgrade the shear capacity of two concrete bridges in Western Canada. The John Hart Bridge in Prince George, British Columbia (BC), and the Maryland Bridge in Winnipeg, Manitoba both consist of I-shaped prestressed concrete AASHTO girders which do not meet current code requirements for shear strength under today's heavier truck loads. In fact, the industrial traffic Gross Vehicle Weight (GVW) has increased 3-fold since the construction of the bridges in the early 1960's. These bridges are both located on main arterial roadways and continue to be heavily used. In both cases, the fact that the bridges remained completely accessible to traffic during construction was a major factor in selecting this particular shear strengthening method.

The John Hart Bridge is owned by the BC Ministry of Transportation Central Northeast Region, and consists of 7 simply supported 33 m spans with six 1500 mm deep prestressed concrete girders per span. Diagonal CFRP sheets were applied over a 4 m length at each end of all 42 girders, resulting in one of the largest strengthening applications of its kind.

The shear capacity of the girders was increased by 15 to 20% using a single diagonal layer of Replark™ CFRP sheets. The CFRP sheets are manufactured by the Mitsubishi Corp. of Japan, and were supplied by Specialty Construction Products of Winnipeg, Manitoba. The specialty contractor responsible for preparing the concrete surface of the girders and applying the CFRP sheets was Retro of Vancouver, BC. Fig. 4 (b) shows the application of the diagonal CFRP sheets. The final component of the externally bonded CFRP sheet system is a 2 to 4 mm thick protective coating.

Fig. 4 (a): John Hart Bridge, Prince George BC *Fig. 4(b): CFRP Application*

Scouten and Associates of Prince George BC were consultants for the project, with Sure Span of Vancouver BC as general contractors. The shear strengthening of all 84 girder ends was completed within a 6 week period in September and October of 1999.

The City of Winnipeg, Manitoba, Canada has implemented a trial application of CFRP sheets as a first step in the plan to upgrade the shear capacity of the Maryland Bridge. The bridge consists of two five-span continuous prestressed concrete structures with 7 girders per span. Consultant for the bridge rehabilitation project is Dillon Consultants Ltd., of Winnipeg.

In October 1999, two girder ends were strengthened by Vector Construction Ltd. using the MBrace™ system manufactured by Master Builders Inc., and two girder ends were strengthened by Concrete Restoration Services Ltd. using the Replark™ system manufactured by Mitsubishi. The total time for construction was 1 week for each pair of two girder ends, and the total cost of approximately $30,000 was similar for each pair of girder ends.

Based on experimental test results and recommended design procedures, the configuration of the CFRP sheets selected for the Maryland Bridge girders includes vertical sheets with a horizontal layer at the top and bottom of the thin web, as shown in Fig. 5 a) and b). The shear capacity of the girders was increased by 20 to 25 %.

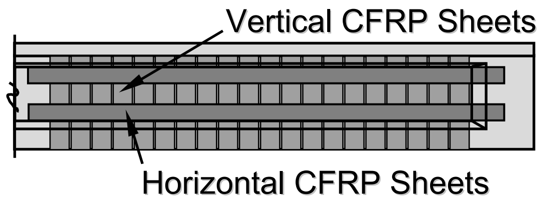

Fig. 5 (a) – Configuration of CFRP Sheets for the Maryland Bridge

Fig. 5 (b) – Shear Strengthening of the Maryland Bridge

Fig. 6 illustrates the tendency for the CFRP sheet to peel and straighten due to the shape of the girder. Based on experimental results, this outward peeling force was accounted for in the design of the strengthening scheme for both the Maryland and John Hart bridges. For design, strain in the CFRP sheets is limited to 2 millistrain based on both bond and scale model beam tests. Test results indicate that the shear contribution of the CFRP sheets can be added to the contributions from the concrete and the internal steel stirrups, in order to predict the overall shear capacity of the girder. (Hutchinson and Rizkalla, 1999)

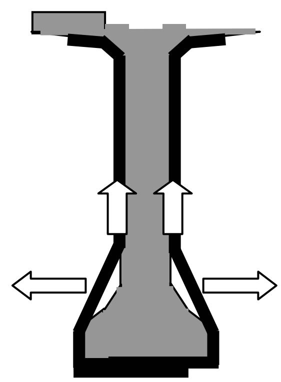

Fig. 6 - Peeling and Straightening of CFRP Sheets Due to Girder Shape

REPAIR OF CONCRETE BRIDGE CORBEL SUPPORT: JAQUES LODGE BRIDGE, CALGARY

The Jacques Lodge Pedestrian Bridge in Calgary, Alberta, consists of a precast concrete "drop-in" girder supported by a cantilevered girder at each end. As shown in Fig. 7, the concrete corbels supporting the main girder exhibited cracking due to unexpected friction forces and a lack of sufficient internal diagonal steel reinforcement. The direction of the fibers in the applied sheets was consistent with the ordination of the deficient reinforcing steel.

Fig. 7: Jacques Lodge Bridge Corbel Support Prior to Repair

A strut and tie model was used to design the CFRP strengthening scheme. The configuration of the CFRP sheets is shown in Fig. 8 (a). Since the outer faces of the corbel are vertical, a maximum strain of 4 millistrain was used for design, based on the work of various researchers. (Maeda et. al. 1997; Hutchinson and Rizkalla 1999; Neale 2001) A single horizontal layer and a diagonal layer of CFRP sheets were required for each side of the corbel, as shown in Fig. 8 (a).

In order to repair the concrete corbels, the entire main span was jacked up. After cleaning and preparing the concrete surface, Replark™ CFRP sheets were applied as shown in Fig. 8 (a). After curing of the epoxy impregnating the CFRP sheets, a protective coating was applied, and the jacks supporting the main span were removed, as shown in Fig. 8 (b).

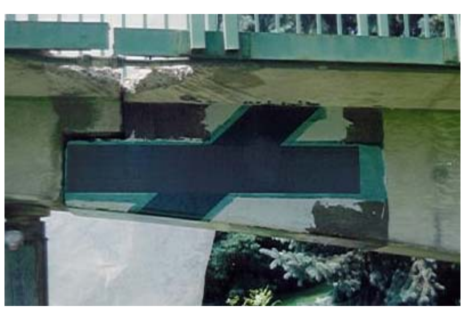

Fig. 8 (a): Application of CFRP Sheets

Fig. 8 (b): Bridge After Repair

Repair of the Jacques Lodge Bridge was completed in 6 weeks at a total cost of $20,000. The consultant for the project was HMS Structural Engineering, and the contractor was JAMOR Engineering Ltd. The bridge is owned by the Metro Calgary Foundation.

CONCLUSION

Externally bonded CFRP has been used to strengthen four bridge structures in Western Canada. For all of the rehabilitation projects described in this paper, the ease of handling of the CFRP materials resulted in reduced construction time, when compared with conventional repair techniques. For the three heavily used highway bridges, at least one lane of traffic remained open at all times during construction. The four projects described in this paper demonstrate a successful transfer of ISIS technology into practice in Western Canada.

The methods of strengthening the above bridges developed by ISIS Canada researchers and were instrumental for the development of ISIS Canada Design Manual No. 4 (Neale 2001)

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