FIELD APPLICATION OF FRP COMPOSITE BARS AS REINFORCEMENT FOR BRIDGE DECKS

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ABSTRACT: A new girder type concrete bridge, at the Municipality of Wotton (Quebec, Canada), was constructed using FRP bars as deck reinforcement. Both carbon and glass FRP bars were used as reinforcement for the concrete deck slab. The bridge is well instrumented at critical locations for internal temperature and strain data collection using fiber optic sensors. A data acquisition system attached to a modem is installed on-site to allow remote monitoring of the deck behaviour from the time of construction to several years after completion of construction. Also, the bridge was tested for service performance using a standard truckload as specified by the new CHBDC (2000). This project allows field evaluation and long-term assessment of using different types of FRP composite bars as deck reinforcement as well as direct comparison to steel reinforcement under the same real service and environmental conditions. This paper presents the constructability issues and the field performance test results.

1. INTRODUCTION

Fiber reinforced polymer (FRP) rods are used as reinforcement for concrete structures such as bridges, parking garages and marine structures in which the corrosion of steel reinforcement has typically led to significant deterioration and rehabilitation needs. Bridge decks deterioration is one of the most common deficiencies in a bridge system. Concrete bridge decks deteriorate faster than any other bridge component because of direct exposure to environment, deicing chemicals and ever-increasing traffic loads. The magnitude of deck cracking and delamination due to corrosion is a major problem when measured in terms of rehabilitation costs and traffic disruption. In Quebec, half of the maintenance budget of the Ministry of Transportation is spent in concrete structures damaged by corrosion of steel. Within Europe, the annual cost of corrosion related problems has been estimated at £1.0 billion pounds per year. To overcome the corrosion-related problems, the steel reinforcement should be protected form elements causing corrosion, or be replaced with alternative non-corrosive materials in new structures. One of these alternatives, fiber reinforced polymers (FRP) composite reinforcement, has been used successfully in many industrial applications and more recently has been introduced as concrete reinforcement in bridge decks and other structural elements. The use of FRP composites as reinforcement for concrete bridge decks provides a potential for increased service life, economic, and environmental benefits (Benmokrane, B., and Rahman, H., eds.1998, Japan Concrete Institute, ed. 1997, Saadatmanesh, H., and Ehsani, M.R., \textit{eds}. 1996, Neale, K.W., and Labossière, P., \textit{eds}. 1992, GangaRao et al 1997, Rizkalla, S. et al 1998, Rizkalla, S., and Tadros, G. 1994).
The new Canadian Highway Bridge Design Code (CAN/CSA-S6-00 2000), recently published (December 2000), includes a new section (Section 16) about using FRP composites as reinforcement for concrete bridges.

This research project, in collaboration with the Ministry of Transport of Quebec, includes three phases. In Phase I (Laoubi et al 2000), preliminary tests were carried out on the sand-coated carbon FRP ISOROD™ bar, which was under development (Pultrall, Inc., 2000). These tests were aimed to optimize the mechanical and structural properties of the new FRP bar in two directions. First, determining of the optimum carbon fibre content. Second, developing a new process for the external coating of the bar in order to ensure a good bond with concrete. These preliminary tests included uniaxial tensile tests, durability tests (CFRP bars under tension in alkaline solutions), pullout tests (using concrete blocks), and flexural tests (on reinforced concrete beams). The obtained preliminary results were very satisfactory, which allowed the continuation of the research project.

In Phase II (Kassem, C. et al 2001), a series of tests were carried out on the optimized CFRP, which resulted from phase I. These tests included tensile tests, pullout and bond tests, and flexural tests (carried out on one-way concrete slabs reinforced with the new CFRP bars). For comparison purposes, identical slabs reinforced with conventional steel were also constructed and tested. The test results of this phase were very encouraging where it showed good performance of the composite bars as reinforcement for concrete slabs (bridge decks). This research project thus continued for the field implementation of this type of FRP bars in a pilot project as deck bridge reinforcement. The bridge, which was chosen for this project by the Ministry of Transportation of Quebec (MTQ), is located on the 6th Rang Ouest, above Nicolet-Center river in Wotton (Quebec). This project includes the use of the composite material reinforcement in a part of the deck slab and monitors the behaviour of the bridge from the moment of completing the construction to several years. The construction of the bridge was completed and opened for traffic on October 2001 and the first static and dynamic tests were carried out on November 16, 2001.

This paper presents phase III of this research project, which includes construction details and some results of the first static and dynamic tests.

2. OBJECTIVES OF THE PROJECT

The objectives of this research project are:
1. To implement the technology and design of FRP composite reinforcement in the construction of bridges.
2. To assess the short and long-term performance of FRP reinforcement under different service loading and environmental conditions.
3. To make direct comparison with steel bars under identical loading and environmental conditions.
4. To improve/validate the current design guidelines and codes such as the new Canadian Highway Bridge design Code (CAN/CSA-S6-00 2000).
5. To enhance the confidence of engineers, governmental authorities and end-users to use these new technologies, which introduce a potential solution to the corrosion problems of reinforced concrete structures.

3. BRIDGE CONSTRUCTION

The construction of the bridge started on July 29, 2001 and it was opened for traffic on October 25, 2001. The design and preparation procedure for the bridge reconstruction started few months before and it involved the following stages:
1. Establish the location and the dimensions of the part of the bridge deck, which will be reinforced with FRP composite bars. This stage of the project was carried out in collaboration with the engineers of the Ministry for Transport of Quebec and the consultant in charge of the project of rebuilding of the bridge.
2. Make the necessary arrangement with the contractor to facilitate and accelerate the procedures of handling and placement of the composite material reinforcement as well as not to damage it.
3. Deal with the installation of instrumentation through the formwork of the deck slab during construction. Also, the installation of the instrumentation wires for long-term monitoring of the bridge.
3.1 Details of the Bridge

The bridge is located in the Municipality of Wotton (the 6° Rang Ouest, Western Bank, above the Nicolet-Center river in Quebec). The new bridge is a girder type with four main girders simply supported over a span of 30.60 m. The deck is a 200 mm thickness concrete slab continuous over three spans of 2.65 m each with an overhang of 1.15 m on each side. Standard Type IV AASHTO pre-stressed concrete beams were used as main girders. Bridge barriers, sidewalks, and top layer of the deck slab for half the bridge was reinforced with glass FRP composite bars. Within the same half of the bridge, a 5-m width portion of the bottom layer of the deck slab was reinforced with carbon FRP composite bars. Both glass and carbon FRP bars, which were used as reinforcement in this bridge, are sand-coated ISOROD™ bars. Glass FRP bars (No.16 - 15.9 mm) were used in all directions except in the short direction at the bottom where carbon FRP bars (No.10 - 9.5 mm) were used. The other half of the bridge, including bridge barriers, sidewalks, and top layer of the deck slab as well as the rest of the bottom layer of the deck slab, was reinforced with No. 15M steel bars.

The design of the part of the bridge deck reinforced with FRP composite bars was made according to Clause 16.8.7 of the new Canadian Highway Bridge Design Code (CAN/CSA-S6-00). This design led to the following reinforcement configuration as shown in Figure 1 and 2.

Figure 1. Deck slab top reinforcement

- Glass FRP bars No 16 @ 150 mm in the transverse main direction
- Glass FRP bars No 16 @ 165 mm in the longitudinal direction
This reinforcement covers half of the deck slab (15.3 m long). The other half of the deck slab was reinforced with conventional steel reinforcement.
Bottom layer:
- Three (bundled) carbon FRP bars No 10 @ 90 mm in the transverse main direction
- Glass FRP bars No 16 @ 165 mm in the longitudinal direction
This reinforcement covers a 5-m wide strip of the deck slab. The remainder of the deck slab was reinforced with conventional steel reinforcement.

Normal weight concrete (Type V MTQ) with an average 28-day compressive strength of 37 MPa was used in the bridge deck. Figure 3 and 4 show photos of the bridge during different stages of construction. The construction crew reacted positively saying that more FRP bars could be handled and placed in less time due to their lightweight. Plastic chairs were spaced at 1.0 m apart in both directions to support the FRP bars and maintain a clear concrete cover of 35 mm at the bottom and 65 mm at the top. The FRP bars withstood all on-site handling and placement problems.
3.2 Instrumentation of the Bridge

The bridge is well instrumented at critical locations for internal temperature and strain data collection using fiber optic sensors (FOS). A total of 44 Fabry-Perot FOS were used to monitor strains and temperature, 30 of them were glued on reinforcing bars and 6 were embedded in concrete for strain measurements (Figure 3). Two thermocouples (FOS) were embedded in concrete to measure temperature changes. Also, six 80-mm long FOS were installed on the surface of the concrete girders to measure strains (Figure 4).

In addition, during testing, deflections of concrete slabs and girders were measured using a system of rulers and theodolites as shown in Figure 7. This instrumentation will enable the acquisition of data and long term monitoring of the bridge behaviour under all possible loading and environmental conditions. Therefore, it will be possible to evaluate the effect of each stress type (dynamic, vibration, impact, thermal,...etc.) and the most critical parameter causing maximum stresses in the bridge. On the other hand, the selected instrumentation will allow a direct comparison between the behaviour of the composite material reinforcement and that of the steel reinforcement under identical traffic and various environmental conditions.

It should be noted that the measuring instruments used in this project are similar to those used previously during the reconstruction of Joffre Bridge located in downtown Sherbrooke city (Québec) in 1997 (Benmokrane et al 2001).
4. FIRST STATIC TEST OF THE BRIDGE

The bridge was tested for service performance on November 16th, 2001, using a standard truckload (three axle truck having 102 kN on the front axle and approximately 116 kN per each back axle) as specified by the new CHBDC (CAN/CSA-S6-00). The bridge was tested under static loads using two trucks (see Figure 7). A high-speed system of data acquisition (1000 Hz) was installed underneath the bridge to collect data from FOS during testing as shown in Figure 8. During all static and dynamic tests, deflections of concrete slabs and girders were measured using a system of rulers and theodolites.

Three different paths symmetrically in each direction (total of six paths) were marked on the bridge as shown in Figure 9 and 10. Nine stations (truck stops) were also marked along the longitudinal direction of the bridge at distances such that to give maximum strains in the instrumented bars and concrete sections. The first stage of the test was carried out using one truck only such that total of 54 (9 stations × 6 paths) readings were recorded for each gauge. In the second stage of the test, two trucks were used simultaneously. Only two paths were used, A-A1 and C1-C1 such that total of 18 (9 stations × 2 paths) readings were recorded for each gauge.

Figure 11 to 13 show comparisons between maximum measured strains in reinforcing bars, both FRP and steel bars, and concrete against truck position along the bridge. In these figures, the zero value on the horizontal axes represent the point at which the longitudinal midpoint of the front axle is directly over a given gauge. Maximum strain values do not coincide with the abscissa zero value due to the dual back axle assembly and the influence of the front axle on the strain readings. The strain values depend on the case of loading, namely truck position and path. Therefore, for each graph, the truck path, which gives the maximum strain readings is considered.

In Figure 11, it can be seen that a change in strain of only 12 micro-strain was measured in the concrete as the truck moves across the gauge. It is noted here that the concrete gauges were embedded, between two bars, in the deck slab at the same level as top and bottom reinforcement, which is 60 mm and 35 mm, respectively. Using simple bending theory, it can be shown that the tensile strain at the top and bottom surfaces of concrete reached a maximum of 10 and 25 micro-strain, respectively at these gauge locations. These strain values at concrete surfaces of the deck slab are well below the cracking strain of concrete, \( \varepsilon_{cr} = 125 \mu\varepsilon \) (for \( f'_c = 35 \) MPa and \( E_c = 28 \) GPa).
In Figures 12 and 13, it can be seen that a change in strain of only 4 and 15 micro-strain were measured in the top glass FRP and bottom carbon FRP bars, respectively as the truck moves across the gauge. These strain values are less than 1% of the ultimate strain of the material. Figure 14 shows the strain distribution across the depth of the girder at mid span due to truckloads at different paths. The maximum tensile concrete strain was approximately 45 micro-strain.

During static tests, deflections of concrete slabs and girders were measured. Recorded deflections of the bridge deck and girders were less than 5 mm and 10 mm, respectively for the entire load duration.

5. CONCLUSIONS

Based on the construction details and the results of the static field tests, the following conclusions can be drawn:

1. No obstacles to construction were encountered due to the use of the FRP bars. The FRP bars withstood normal on-site handling and placement problems.
2. The performance of FRP sand-coated bars is very similar to that of the steel bars.
3. Due to truck loading, the maximum tensile strain values in concrete were very small, 10 to 25 micro-strain, as the truckload moves over the gauge. These strains are well below cracking strain for concrete, which is in the range of 100 to 125 micro-strain for normal weight concrete with compressive strength of 30 to 35 MPa (E_c = 28 GPa).
4. During the entire test, the maximum tensile strain in FRP bars was 15 micro-strain. This value is less than 0.1% of the ultimate strain of the material.
5. Deflections of the bridge deck and slab were well below AASHTO allowable limits.
6. The long-term monitoring of strains and temperature using Fiber Optic Sensors will generate valuable data, which will allow direct comparison with steel reinforcement under actual service conditions.
Figure 12. Maximum tensile strains in top reinforcement

Figure 13. Maximum tensile strains in bottom reinforcement
Figure 14. Strain distribution in the intermediate main girder at mid span

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7. REFERENCES


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