Abstract

The high strength and light weight of fibre reinforced polymer (FRP) and the fact that they are now available in the form of very thin sheets, provide an attractive and economical solution for strengthening existing concrete bridges and structures to increase their ductility, flexure and shear capacity in response to the increasing demand to use heavier truck loads. This paper reviews some of the Canadian projects which have been completed using these materials. The paper presents a new technology for remote monitoring of bridges to minimize the need for frequent site inspections, as well as new material being developed for the rehabilitation of wood bridges. Monitoring is based on using a new generation of fibre optic sensors which have already been implemented in the construction of new bridges in Canada, as well as in the strengthening of existing ones.

Introduction

The Canadian Network of Centres of Excellence on Intelligent Sensing for Innovative Structures (ISIS Canada) was established in 1995 to conduct research and development on the innovative use of FRPs for bridges as a solution for deterioration of concrete due to corrosion of steel reinforcements, as well as the development of structurally-integrated fibre optic sensing technologies that will allow engineers to monitor the bridge from a remote location. One of the other main thrusts of ISIS Canada is to use FRPs for the repair and strengthening of bridges in response to increased demand for heavier truck loads and to increase ductility of existing bridges for earthquake resistance. This paper reviews the use of FRPs for strengthening existing bridges. In both cases, the experience gained from using a new generation of fibre optic sensors, remote monitoring and intelligent processing of the collected data are discussed.

More than 40 percent of the bridges operating in Canada were built over 30 years ago and most are in urgent need of replacement or rehabilitation. Many of the structural deficiencies are due to deterioration of the concrete as a result of corrosion of the steel. Other bridges have become functionally obsolete due to an increase in service loads and traffic volumes which exceed those for
which they were designed. FRPs provide an excellent solution to repairing and/or strengthening bridges. For bridge piers, wrapping can significantly improve the strength and ductility. FRPs are also used for strengthening the superstructure of the bridge by strengthening the flexure and shear capacity of the girders and slab. The following are selected demonstration projects illustrating the use of FRP for strengthening bridges.

1. Champlain Bridge

In October 1996, the Jacques Cartier and Champlain Bridges Inc. proceeded with the rehabilitation of a concrete pier of the Champlain Bridge located in Montreal. The pier is 1.37 meters in diameter and was repaired over a 4 meter length measured from the base. The rehabilitation began with restoration of the column surface using shotcrete. After curing, the surface was prepared using a sand blast technique followed with a resin application. Nine layers of glass fibre, type E (SEH51/TYFO S), from Composite Retrofit International Inc. were used, see Figure 1. FRP was needed in this case to increase the confinement of the concrete, as well as providing a protective surface to the crumbled and cracked concrete surface(1).

![Figure 1: Strengthening of the pier of the Champlain Bridge.](image)
2. **Maryland Bridge**

Carbon FRP is planned to be used to strengthen the shear capacity of the I-shaped concrete AASHTO girders of the Maryland Bridge in Winnipeg, Manitoba. The bridge was built 27 years ago. Analysis of the precast prestressed concrete girders indicates a deficiency in the shear capacity using the current AASHTO code. A 1:35 scale model of the bridge girder was tested using three different types of CFRP and six configuration schemes, as shown in Figure 2. The diagonal configuration for the carbon FRP was found to be the most effective configuration in reducing the tensile force in the stirrups(2).

*Figure 2: Proposed configuration of CFRP sheets for Maryland Bridge.*
3. Webster Parking Garage

Carbon and glass fibre sheets were used for rehabilitation of the Webster parking garage built in 1959 in Sherbrooke, Quebec, Canada(3). The rehabilitation included strengthening the main beams for flexure and shear, as well as the columns which had lost their carrying capacity due to severe corrosion of the steel reinforcements. High-performance self-leveling concrete was used to replace the severely damaged and cracked concrete for some of the beams and columns before applying the external FRP sheets as shown in Figure 3. Wrapping of the columns provided a confinement effect and was used to increase both strength of the concrete and ductility of the columns. Sheets used for the main beams increased the flexural capacity by 15 percent and the shear capacity by 20 percent. Depending on the degree of deterioration, some of the beams needed strengthening for the negative moment region, especially in the rigid frame system and other needed strengthening in the positive moment regions.

Figure 3: Webster parking garage.
4. **Country Hills Boulevard Bridge**

In 1996, CH2M Gore & Storrie Limited, with the assistance of Dr. Gamil Tadros of ISIS Canada, put a material testing program together at the University of Calgary to review the strengthening effects of carbon fiber reinforced polymer (CFRP) strips on existing bridge beams. In 1997, CH2M Gore & Storrie Limited was appointed by the City of Calgary to strengthen the bridge carrying Country Hills Boulevard over the Deerfoot Trail in north-east Calgary.

One of the main problems with the bridge was that its thin deck would be over-stressed in lateral bending under full CS-750 loading. Conventional strengthening with the addition of reinforcement would have required breaking into the deck in strips, adding reinforcement, and re-concreting each strip. Hit and miss strip construction would have been required since the bridge had one lane open at all times and it was feared that to do otherwise would weaken the deck such that failure could occur. To avoid this problem and to strengthen the deck in a non-destructive way, the contract alternative of applying CFRP strips was chosen.

Sika Carbodur strips were installed in eight areas of slab found to be in need of strengthening. Strips were installed at 500 mm centres. The hydromilled deck surface was rough and an initial levelling course of Sikadur 30 with sand aggregate was trowelled on. After one day, strips were applied (Figure 4). A 1 mm layer of Sikadur 30 epoxy was applied to the levelling course and a 2 mm layer to each strip using a convex application tool such that there was more epoxy at the middle of the strip initially. Each strip was rolled to remove the excess epoxy. After one day, the back of each strip to be in contact with the new deck overlay was cleaned, sanded, and given an application of Sika Armatec 110 bonding agent about four hours prior to installing the overlay.

![Figure 4: Repair of Country Hills Boulevard Bridge in Calgary, Alberta.](image)
5. **Roof Retrofit**

The Winnipeg North End Water Pollution Control Centre was built in the early 1930's and no information on the roof system capacity could be located. It was assumed that the roof structure was designed to carry its own weight and snow load, in addition to a live load specified by the Canadian Code for inaccessible roofs. The roof structure consists of 56 simply-supported precast concrete panels of 2,400 mm (94.5 in.) span and 450 mm (17.7 in.) width. Recent upgrading of the building demanded the installation of large equipment on the existing roof, which created significant snow drift load. To avoid costly replacement of the roof, it was decided to strengthen the existing roof using CFRP strips.

The CFRP strips used in this project were the heavy-duty Sika CarboDur strips bonded to the concrete surface by Sikadur-30 adhesive. This method was proven to be superior to the traditional methods, including external post-tensioning, section enlargement, and epoxy bonding of steel plates. Table 1 summarizes the advantages of the strengthening system in comparison to epoxy bonding of steel plates commonly used for strengthening of similar structures.

<table>
<thead>
<tr>
<th>Criteria</th>
<th>CFRP Strips</th>
<th>Steel Plates</th>
</tr>
</thead>
<tbody>
<tr>
<td>own weight</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>tensile strength</td>
<td>very high</td>
<td>high</td>
</tr>
<tr>
<td>overall thickness</td>
<td>very thin</td>
<td>small</td>
</tr>
<tr>
<td>corrosion</td>
<td>no</td>
<td>no</td>
</tr>
<tr>
<td>length of strips</td>
<td>unlimited</td>
<td>unlimited</td>
</tr>
<tr>
<td>handling</td>
<td>flexible, easy</td>
<td>difficult, rigid</td>
</tr>
<tr>
<td>load-bearing</td>
<td>in the direction of the fibres only</td>
<td>in any direction</td>
</tr>
<tr>
<td>laps</td>
<td>easy</td>
<td>complex</td>
</tr>
<tr>
<td>fatigue behaviour</td>
<td>outstanding</td>
<td>adequate</td>
</tr>
<tr>
<td>material costs</td>
<td>high</td>
<td>low</td>
</tr>
<tr>
<td>installation costs</td>
<td>low</td>
<td>high</td>
</tr>
<tr>
<td>application</td>
<td>no tools necessary</td>
<td>requires lifting equipment and clamping device</td>
</tr>
</tbody>
</table>

*Table 1: Comparison between CFRP strips and steel plates.*
The CFRP strips were placed onto the concrete surface. A roller was used to press the strip into the epoxy mortar until the adhesive was forced out on both sides of the strip. Figure 5 shows the final shape of the soffit of the roof panels after cleaning surplus epoxy mortar from the CFRP strips. The construction time for the entire roof was four days, the preparation for the surface was two days, and the application time of the CFRP strips was another two days. The new equipment was installed after the three-day epoxy curing.

![Figure 5: Roof panels after CFRP strip application.](image)

6. Rehabilitation of Wood Bridges

In cooperation with the Swiss Federal Laboratories for Materials Testing and Research (EMPA), ISIS Canada is undertaking a new research program to develop an innovative technique to strengthen highway timber bridges to carry the new design requirements specified by most Departments of Highways and Transportation. The research focuses on the use of FRP materials due to its non-corrosive characteristics, easy handling and high strength. More specifically, the research uses non-laminated FRP materials currently under development by EMPA to prestress the wood stringers as shown in Figure 6. The specific objective of the research is to optimize the post-tensioning technique and to determine details of the most convenient and economical connections which could be used to prestress these types of bridges.
The study consists of an experimental program using old timber bridge stringers of an abandoned and dismantled timber bridge. Manitoba Highways and Transportation has provided ten beams, 10.4 meters long with 200 x 600 mm cross section; six beams, 6.7 meters long with 500 x 150 mm cross section; and two beams, 2.75 meters long with 300 x 300 mm cross section for the experimental program. The project is currently in its preliminary stages and one beam was tested in November 1998.

**Conclusion**

In spite of the lack of codes and standards, several bridges have been built around the world using carbon FRPs for prestressing and/or reinforcing of the concrete structural girders, deck slab and barrier wall. The design is based on a rational approach of the material characteristics which was relatively simple due to the linear behaviour of the FRPs to failure. FRPs were also used to strengthen existing bridges due to the increased demand for heavier truck loads. The strengthening was in the form of wrapping columns to increase the strength and ductility as well as to increase flexure and shear capacity of the girders. Most of the field applications have been instrumented for continuous monitoring to provide data related to the material’s long-term behaviour and to ensure safety of the bridge by monitoring their performance under service loading conditions.
Acknowledgements

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References


