Implementation of Advanced Technology in Canadian Bridges

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# Progress

<table>
<thead>
<tr>
<th></th>
<th>1995</th>
<th>2009</th>
</tr>
</thead>
<tbody>
<tr>
<td>Universities</td>
<td>10</td>
<td>15</td>
</tr>
<tr>
<td>Principal Investigators</td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>Researchers</td>
<td>59</td>
<td>286</td>
</tr>
<tr>
<td>Research Projects (cumulative)</td>
<td>17</td>
<td>170</td>
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<tr>
<td>Demonstration Projects (cumulative)</td>
<td>2</td>
<td>50</td>
</tr>
<tr>
<td>Industry &amp; Govt Partners</td>
<td>17</td>
<td>100+</td>
</tr>
<tr>
<td>HQP Studies Completed</td>
<td>0</td>
<td>750</td>
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</table>
The mandate of ISIS Canada

- is to revolutionize the design
- and construction
- of civil engineering structures

- So structures will last 100 years+ instead of 50 years
Mandate Realization

- We do this through
  - Fibre Reinforced Polymers - FRPs
  - Fibre Optic Sensors - FOSs
  - Structural Health Monitoring - SHM
  - Innovative design and rehabilitation concepts
VARIOUS FIBRES AND FRPS

carbon fibre reinforced polymer (CFRP)

Aramid Fiber Reinforced Polymer (AFRP)

Glass Fiber Reinforced Polymer (GFRP)
Sensor Development

FOSs

Bragg Grating

Fabry-Perot

Brillouin Scattering

Long Gauge FOS

Column Structure

Piezo/Chemo Resistive Sensors

MW NanoTubes
Corrosion of Top Steel in Bridge Decks
Corrosion-Free Deck Slabs

First Generation
- Salmon River Bridge, NS 1995
- Chatham Bridge, ON 1996
- Crowchild Trail Bridge, AB 1997
- Waterloo Bridge, BC 1998
- Lindquist Bridge, BC 1998
- Hall’s Harbour, NS 1999

Second Generation
- North Perimeter Bridge, MB 2003
- Iowa, USA 2004
- South Perimeter Bridge, MB 2006
- Floodway Bridges, MB 2009
### Foil Gauges

- **Main Girder**
- **Continuous Drop-in Span**

### ISIS Canada Research Network

- **Strain Sensors**
- **Fiber optic sensors bonded**

### Field Monitoring Projects

- **Remote monitoring system with CDPD modem**
- **Instrumentation Inside the Concrete Deck**
- **Instrumentation on Girders**

### Instrumented Pier No. 2

- **Position of Sensors**
  - **Top View**
  - **Counter View**
- **Antenna for CDPD service**

### Sensors

<table>
<thead>
<tr>
<th>Conventional Sensors</th>
<th>Innovative Fiber Optic Sensors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Strain</td>
<td>Strain</td>
</tr>
<tr>
<td>• vibrating wire</td>
<td>• Bragg grating</td>
</tr>
<tr>
<td>• thermocouple</td>
<td>• long gauge</td>
</tr>
<tr>
<td>• thermistor</td>
<td>• Brillouin scattering</td>
</tr>
<tr>
<td>Temperature</td>
<td>“smart patches”</td>
</tr>
<tr>
<td>• thermocouple</td>
<td>• low coherence interferometry</td>
</tr>
<tr>
<td>• thermistor</td>
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</table>

### FRP Wrapping

- **Five layered FRP (Tyfo SHE 51A) wrapping on**
- **North Pier No. 1**
- **2630 (8') mm from center line of bearings at north abutment**
  - **9030 mm from center line of bearings at Pier # 1**
- **2800 (9') mm from center line of bearings at Pier # 1**
- **3790 (12') mm from center line of bearings at north abutment**
- **4115 (13') mm from center line of bearings at north abutment**

### FRP-Reinforced Area

- **Golden Boy**
- **Provencher Bridge**
- **Beddington Trail Bridge**
- **Leslie Street Bridge**

### Conventional Sensors

- **Bragg grating**
- **thermocouple**
- **thermistor**
- **Bragg grating**
- **long gauge**
- **Brillouin scattering**
- **“smart patches”**
- **low coherence interferometry**

### Innovative Fibers

- **Fiber optic sensors bonded**
- **3-D accelerometer**
- **Remote monitoring system**
- **Brillouin scattering**
- **Bragg grating**
- **Fabry-Pérot**
- **Brillouin scattering**
- **long gauge**
- **low coherence interferometry**

### Additional Information

- **Portage Creek Bridge**
- **Taylor Bridge**
- **Laurier-Taché East Wing**
- **Laurier-Taché West Wing**
- **Crowchild Trail Bridge**
- **Leslie Street Bridge**
- **Confederation Bridge**
- **Salmon River Bridge**
- **Joffre Bridge**
- **Gentilly Nuclear Station**
Because of ISIS Canada research and influence, the 6 new highway bridges over the Winnipeg Floodway have GFRPs in the decks (20,000 square metres). Some of these bridges also have SHM. Almost completed.

This is a mega project estimated to cost $700 million, and is therefore, comparable to the one billion dollar Confederation Bridge project completed in 1995.
Is GFRP Durable in Concrete?

Five field demonstration projects were chosen for this study:

- Hall’s Harbour Wharf
- Joffre Bridge
- Chatham Bridge
- Crowchild Trail Bridge
- Waterloo Creek Bridge

The demonstration structures perform in a wide range of environmental conditions, and were designed for normal use (i.e., heavy truck traffic).
Core Specimens
Analytical Methods

• Optical Microscopy (OM)
• Scanning Electron Microscopy (SEM)
• Energy Dispersive X-ray Analysis (EDXA)
• Fourier Transformed Infrared Spectroscopy (FTIR)
• Differential Scanning Calorimetry (DSC)
Chatham Bridge – BEI

Cross Section of Core Specimen

EDS Plot – Shows the Chemical Composition of the Glass Fibre
EDX Plot – shows no evidence of fibre dissolution or penetration of ions from the concrete pore solution into the polymer matrix.
EDX Plot – shows no evidence of fibre dissolution but suggests penetration of Cl ions from concrete pore solution into the polymer matrix.

Cross Section of Core Specimen

<table>
<thead>
<tr>
<th>Event</th>
<th>Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>Initiation ($T_i$)</td>
<td>8 years</td>
</tr>
<tr>
<td>Propagation ($T_p$)</td>
<td>6 years</td>
</tr>
<tr>
<td>Time to 1st Repair ($T_r$)</td>
<td>14 years</td>
</tr>
</tbody>
</table>
Conclusions

- No evidence of de-bonding between GFRP and Concrete.
- No chemical degradation processes occurred within the GFRP reinforcement due to alkalinity in concrete.
Durability of Externally Bonded FRP for Strengthening

Four in-service Bridges
1. Safe Bridge with sprayed FRP in British Columbia;
2. Maryland Bridge in Manitoba;
3. Leslie Street Bridge in Ontario;
4. St-Étienne-de-Bolton Bridge with four different FRP wrap products in Quebec;
Bond Durability of Externally Bonded FRP in Four *in-service* Bridges

**Criteria for Selecting Bridge Sites**
- Variation in Environmental Conditions
- Length in Service
- Type of Strengthening
- Type of FRP product
1. Safe Bridge (Youbo, BC)

- Constructed in 1955
- Repaired and Strengthened in 2001 with Spray GFRP
- 8 Precast Concrete Channel Beams (PCCB) with a 10m Span
- Mild Climatic Conditions
- Heavy Trucks
2. Maryland Bridge, Winnipeg, Manitoba

-Built in 1969; Consists of two five-span continuous concrete structures each supported by seven precast pre-stressed girders;
-Shear Strengthening in 1999 with externally bonded CFRP sheets;
-Relatively dry climate with temperatures from -22.8° to 25.8° C.
3. Leslie Street Bridge (Toronto, ON)

- Built in 1960s as part of HW 7.
- Columns (dim~1 m) are repaired/strengthened with GFRP in 1996.
- Steel flexural members are corroded.
- Located in an urban area
- Harsh cold Temperatures.
3. Leslie Street Bridge (Toronto, ON)
4. St-Étienne Bridge (St-Étienne-de-Bolton, QC)

- Constructed in 1962.
- 4 Spans Over Autoroute 10
- Supported by 18 Columns in 3 rows (D ~ 760mm)
- Extremely Cold Climate
- Remote Location -> Significant Snowfall
- 9 of 18 columns were Repaired with 4 different FRP products.
Bond Durability Study

NDT
- IR Thermography
- Impact-Echo

Semi-Destructive
- Mechanical Pull-off
Impact-Echo

- Operates based on the principle of mechanical wave movement.
- Uses steel spheres as impactors.
- Allows for detection of material discontinuity in material.
Impact-Echo

Ampl. vs. Frequency

Spectrum

Ampl. vs. Frequency

Peak Frequency of 4.9 kHz
## Pull-off Results

<table>
<thead>
<tr>
<th>Location</th>
<th>Ultimate Pull-off Strength</th>
<th>Age of Repair (Years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Safe Middle Span</td>
<td>1.45</td>
<td>8</td>
</tr>
<tr>
<td>Safe End Spans</td>
<td>1.06</td>
<td>8</td>
</tr>
<tr>
<td>Maryland</td>
<td>3.25</td>
<td>10</td>
</tr>
<tr>
<td>Leslie Street</td>
<td>1.89</td>
<td>11</td>
</tr>
<tr>
<td>St-Ètienne (Column 1)</td>
<td>0.72</td>
<td>12</td>
</tr>
<tr>
<td>St-Ètienne (Column 2)</td>
<td>2.53</td>
<td>12</td>
</tr>
<tr>
<td>St-Ètienne (Column 3)</td>
<td>1.94</td>
<td>12</td>
</tr>
<tr>
<td>St-Ètienne (Column 4)</td>
<td>3.60</td>
<td>12</td>
</tr>
</tbody>
</table>

- **Mean (MPa)**
- **Stand. Deviation (MPa)**
- **Maximum (MPa)**
- **Minimum (MPa)**
- **Type of Fiber**

Typical “virgin” average bond values: 5.00–6.00 MPa (from unpublished results)
IR Thermography and Bond Strength

Numbers indicate Pull-Off Bond Strength in MPa
Conclusions

- IR Thermography proved to be very effective in detecting debonding and interface flaws;
- The direct pull-off tests indicated that while in most cases the bond between FRP and concrete was acceptable, in some instances, the bond showed severe deterioration, and measured only a small percentage of its “virgin” initial value. This is a major cause for concern.
ISIS Canada Design Manuals

1. Sensor Technology
2. Structural Health Monitoring
3. Concrete Reinforced with FRPs
4. Rehabilitation with FRPs
Canadian Codes

CAN/CSA-S6-06

Canadian Highway Bridge Design Code
A National Standard of Canada

CSA: Design and Construction of Building Components with Fibre-Reinforced Polymers

CHBDC

S806-02

Design and Construction of Building Components with Fibre-Reinforced Polymers
Thank You.

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