Bridge Expo 2014
OGRA

New Materials in Bridge Construction - MTO’s Perspectives
Presented by: David Lai
Head of Bridge Rehabilitation
Bridge Office

Outline of presentation
- Update of GFRP
- Prepackaged high early strength concrete
- FRC
- UHPC
- Polyester concrete overlay
- New composition for weathering steel
- A1010 steel

Revised corrosion protection policy issued in April 2013
GFRP can be used in:
- PL2 and PL3 Barrier walls with AADT < 100000
- Not mandatory in waterproofed decks, but could be considered for AADT >50000 with justification by financial analysis
- Sidewalks and curbs
- Not in circular columns
- Not in integral abutment and rigid frame negative reinforcement

GFRP Suppliers
- Pultrall in Grade 1 and 3
- Aslan by Hughes Bros. available in Grade 1
- Schöck supplies Combar in Grade 3
Bent Bars vs. Headed Bars

<table>
<thead>
<tr>
<th>COST</th>
<th>TENSILE STRENGTH</th>
<th>CONSTRUCTION ISSUES</th>
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<tbody>
<tr>
<td>$2 TO $3 per bend for 15mm diameter.</td>
<td>Strength at bend is 40% to 55% of straight and $\Phi_{\text{FRP}} = 0.55$</td>
<td>No site adjustment of hooks (length can be adjusted by cutting). Made by wet layup in factory and could have large variation in surface finish and quality. Difficult to do QC/QA tests.</td>
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<tr>
<td>$2 per head for 15mm diameter.</td>
<td>No reduction in strength of bar; long term tensile capacity of head is around 60 KN.</td>
<td>More costly than bent bars. Detailing must use only straight bars. Difficult to do QC/QA tests.</td>
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COST

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New products under review

- Tuf Bar from BP Composite, Alberta currently undergoing long term durability tests.
- Temcorp from Stoney Creek, Ontario has just completed their prequalification tests according to CSA S806 and will be submitting for our review soon.

Conclusion on short and long term pullout capacity of headed anchors based on lab evaluation

- Short Term $T_u \geq 100 \, \text{KN}$
- Long Term $T_u \geq 60 \, \text{KN}$ (conservative since lab specimens were loaded 3000 microstrain sustained tension)
- Slippage under short term loading
  - At 100 N, slip (Combar) = 0.15 mm
  - slip (Vrod) = 0.2 mm
- Creep slippage under high sustained load could be excessive.
  - We recommend the same $F_{\text{SLS}} \leq 0.25$ to be applied
  - $T_{\text{SLS}} < 25 \, \text{KN}$

b. (60 days Exposure)

**Vrod Headed Anchor Pullout Test after 60 days in wet concrete at 60 degree C**
• GFRP bars shall be protected from contamination of concrete during adjacent placements. Any concrete contamination shall be removed immediately while the concrete is still fresh without damaging the GFRP bars. Removal of other materials present on the bars shall be according to the materials and methods recommended by the bar manufacturer.

**A Testing**

At the discretion of the Owner, the following tests shall be performed by a laboratory designated by the Owner, according to the test methods and requirements listed in Table 2:

i) Longitudinal tensile strength
ii) Longitudinal tensile modulus and ultimate elongation
iii) Fibre content
iv) Water absorption—twenty-four hour immersion and long-term immersion
v) Cure ratio
vi) Transverse shear strength

**Challenges for A testing**

• Shortlisted 10 labs but not all can do all of the tests:
  - **Cure ratio test requires DSC machine**
  - **Transverse shear needs special device**
  - **Tensile test of bent bars cast in concrete block**

• Tensile test of 25mm diameter and larger difficult to conduct due to length of bars required and high load
• Size and shape of bent bars may not be suitable for tensile testing
• Concrete blocks take time and space
On-going Development

- Research in post-installed epoxy dowels using GFRP at Ryerson University
- MTO funded research at U of Waterloo on simplified QA test methods
- MTO funded research at Queen’s University on fire resistance of GFRP internal reinforcement
- MTO/MTQ Task Force Guidelines for Repair of components with GFRP
- Pultrall planning crash testing of barrier wall with bent bars instead of headed anchors

Fire resistance research of GFRP internal reinforcement at Queen’s University funded by MTO to be completed in 2015.
Prepackaged High Early Strength Concrete

- A necessary choice of material to go with expeditious bridge construction technology.
- MTO lab evaluation conducted in 2007 and found favourable material properties.
- Since then has been used in many projects involving: closure pour of prefab bridges, link slab and deck end of ABC, patches of deck top for holding strategy.
Deck end pour of prefabricated deck girder system using high early strength concrete
Westminster Rd Hwy 401 underpass, 2014

High early strength concrete for link slab over pier
Westminster Rd Hwy 401 underpass, 2014

High early strength concrete for closure pour of precast abutment
Westminster Rd Hwy 401 underpass, 2014

Expansion Joint Replacement using high early strength concrete, Rouge River Hwy 401
Special Provision in MTO contracts

Hardened concrete shall have minimum compressive strength of 20 MPa before opening to traffic, and a minimum 28-day compressive strength of 50MPa.

The prebagged rapid hardening concrete, HP-S10 Concrete, shall not be used when ambient air temperature is 30°C or higher.

Concrete may be produced either at the job site or at a ready mix facility within 15 minutes travel time of the job site. The maximum size of batch to be mixed at one time shall be more than 1 cubic metre, but shall not exceed 50 % of the mixing capacity of the truck mixer.

The Contractor shall cast 100mm diameter and 200mm long cylinders for compressive strength determinations from three loads of concrete per lot. From each of the three loads of concrete the Contractor shall cast 12 cylinders for strength determinations at 4, 6, and 8 hours, and 28 days. A compressive strength result will be an average of three cylinders.

Fibre Reinforced Concrete (FRC)

- Addition of macro fibre to normal concrete to enhance structural performance, usually for post cracking toughness and residual tensile strength.
- MTO started using synthetic macro fibre for debonded link slab construction in 2006.
  Typical 0.5% by volume = 2 MPa
  Residual tensile strength

Use of FRC for Debonded Link Slab

What is a Link Slab?

- Replaces traditional expansion joints
- Deck made continuous while girders remain simply supported
- Link slabs withstand bending and tensile forces without forming large cracks
- Require large density of reinforcement bars

![Image of Link Slab](image-url)
How FRC can Improve Link Slab Design

- Reduce steel reinforcement required to withstand load effects
- Control crack growth and propagation
- Often cast with ultra-high performance fibre-reinforced concrete (UHPFRC)

Photos from University of Michigan ACE-MBL
Research Project at U of Waterloo

Structural Aspects of FRC Link Slab

Research Objectives

- Develop an FRC mixture:
  - Using common macro fibres
  - Using common concrete mixture ingredients
  - With sufficient workability for ease of placement
  - With higher strength than standard concrete
  - With increased ductility and crack control
  - With sufficient long-term durability

<table>
<thead>
<tr>
<th>Fibre Types Tested</th>
<th>Length (mm)</th>
<th>Aspect Ratio</th>
<th>Specific Gravity</th>
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<tr>
<td>Polypropylene polyethylene (PP)</td>
<td>61</td>
<td>74</td>
<td>0.92</td>
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<tr>
<td>Crimped steel (St)</td>
<td>50</td>
<td>45</td>
<td>7.7</td>
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<tr>
<td>Hooked-end steel (HS)</td>
<td>50</td>
<td>50</td>
<td>7.7</td>
</tr>
<tr>
<td>Deformed carbon steel (BS)</td>
<td>25</td>
<td>41</td>
<td>7.7</td>
</tr>
<tr>
<td>Deformed stainless steel (SS)</td>
<td>25</td>
<td>41</td>
<td>7.7</td>
</tr>
<tr>
<td>Polyvinyl alcohol (PVA)</td>
<td>30</td>
<td>45</td>
<td>1.3</td>
</tr>
</tbody>
</table>

- Develop analytical model for debonded link slab
- Investigate effects of dosage and type of fibre on structural performance:
  - Crack width
  - Stresses of normal reinforcement
  - Contribution of fibre to link slab capacity
MTO funded research at Ryerson University to investigate the feasibility of using FRC in barrier walls to reduce/optimize the amount of premium reinforcement and geometric size of barrier.

FRC could absorb a lot more energy than normal concrete after cracking.

The material's high mechanical properties are a result of proportioning the constituent ingredients to produce a modified compact grading with a nominal maximum coarse aggregate size of 400 µm, and steel fibers measuring 0.008 x ½” in size. The ratio of maximum coarse aggregate size to fiber is important to facilitate random orientation of fibers and a ductile behavior. These performance characteristics result in improved micro-structural properties of the mineral matrix, especially toughness and control of the bond between the matrix and fiber.

Developed in France during the 1990s, ultra high-performance concrete (UHPC) has seen relatively limited use in North America. UHPC consists of fine sand, cement, and silica fume in a dense, low water-cement ratio (0.15) mix. Compressive strengths of 18,000 psi to 30,000 psi can be achieved, depending on the mixing and curing process.

The material has a low permeability and high durability. To improve ductility, steel or polyvinyl alcohol (PVA) fibers (approximately 2% by volume) are added, replacing the use of mild reinforcing steel.

The material's ultra-high strength properties and low permeability also provide excellent protection of the rebar against corrosion and improved bond with the rebar, thereby providing short bond development lengths.
Whiteman’s Creek Bridge
Hwy 24
Precast Deck Panels and Other Precast Bridge Components

Typ. Transverse Joint Detail

Typ. Longitudinal Closure Joint

Typ. Between Shear Fockets

Typ. Precast Concrete Details At Girder

Whiteman’s Creek Bridge Precast Deck Panels 2011
UHPC for shear pockets and closure strips

2014 Westminster Road / Hwy 401 Ductal Closure Strip
## Compressive Strength (cylinders)

<table>
<thead>
<tr>
<th>Age (days)</th>
<th>Compressive Strength (MPa)</th>
</tr>
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<tbody>
<tr>
<td>1</td>
<td>49.9</td>
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<tr>
<td></td>
<td>57.1</td>
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<tr>
<td>4</td>
<td>114.5</td>
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<td></td>
<td>108.1</td>
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<td>7</td>
<td>133.8</td>
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<td>127.8</td>
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<tr>
<td>28</td>
<td>170.2</td>
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<tr>
<td></td>
<td>161.8</td>
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<td>160.7</td>
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</tbody>
</table>
Research Needs for HPC

- Combined bending and shear effect at closure joints with GFRP
  - MTO funded research at Waterloo U (2 years starting 2013) and Ryerson U (3 years starting 2013)
- Encourage industry to develop alternative products (not single source)

Polyester Concrete Overlay

- An option for rapid deck rehabilitation
- A non-proprietary material developed by Caltran in the 1980’s
- Advantages:
  - Fast cure: Traffic can be put back within 2 hrs at 5 degree C
  - Low temperature curing (degree C)
  - Much thinner than normal concrete (20-25mm)
  - Low permeability (0 to 200 coulombs) so can be used as exposed wearing surface
  - Low modulus and shrinkage due to polymer curing

Polyester Concrete Overlay

- MTO is currently planning for trial in two bridges carrying Hwy 401 near Napanee
- Sites chosen due to small time window allowed for work on Hwy 401 as a holding strategy for 10 to 15 years
Development of New Composition for Weathering Steel
Current Status & Future Plans

David Pai

Background

- Weathering steel, a low alloy steel, has been used in highway bridges in the US since mid-60's and in Ontario since 1968.
- In the 80's, accelerated corrosion in ACR steel structures were observed at localized areas:
  - Near leaking expansion joints and
  - Areas subjected to constant wetting e.g. interior sections of box girders in some bridges, splice locations of plate girders.

Current Concerns

- Stable Patina is not formed when ACR in frequent humid and chloride environments
- Since early 2000s de-bonding of corrosion products in layers over driving lanes of box girders has been observed. A potential safety concern and an on-going maintenance problem.
- Service life expectancy
Weathering Steel Bridges - Concerns of Corrosion - Field Observations

- Higher rates of corrosion and de-bonding of corrosion products in layers over the driving lanes was seen in many bridges
Causes for Unstable Patina, Accelerated Corrosion & Debonding of Corrosion Products

- The Bridge Office initiated a research project.
- Steel core samples were taken from corroded areas and good areas of box girders (Hwy 11 & Hwy 402).
- Engaged Surface Science Western (SSW) to determine and confirm the causes for the formation of unstable patina, accelerated corrosion and debonding.
- Surface Science Western conducted the analyses using Raman, Mossbauer and SEM/EDX spectroscopic techniques.

Sampling and Corrosion Products Analysis

- Steel plug and loose rust samples were taken from heavily corroded regions and benign regions.
- Hwy 11 & Hwy 402 box girder Bridges.
- Kettle lake girders.
Development of New Composition Weathering steel

- There is a need to develop new composition which would form stable patina in saline environment.
- Industry collaboration was established in 2008 with Essar Algoma Steel and Canadian Institute of Steel Construction (CISC) to produce new compositions in Pilot Quantities at CANMET.
- The objective is to develop new compositions that could be produced by local steel mills like Essar Steel.
- Surface Science Western, University of Western Ontario was chosen to conduct accelerated corrosion resistance testing and corrosion product analysis under HIRF funding.

Pilot Scale Production of New Weathering Steel at CANMET Ottawa in 2009

- Cast ingots (6") after cutting off the top and bottom ends ready to be loaded into the furnace at 1150°C.
- Steel plates (1/2") at 1000°C allowed to air cool after rolling (9 passes).
- Please see the video clip on rolling.

Weight Gain per Area in ASTM G85-A5 Prohesion Test

<table>
<thead>
<tr>
<th>Steel</th>
<th>Weight Gain (g/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HPS70W</td>
<td>0.450</td>
</tr>
<tr>
<td>A1010 12% Cr Steel</td>
<td>0.440</td>
</tr>
<tr>
<td>3.5% Steel from Essar Algoma</td>
<td>0.430</td>
</tr>
<tr>
<td>9025 (Ni+Cr+Mo)</td>
<td>0.420</td>
</tr>
<tr>
<td>9026 (Ni+Cr+Mo)</td>
<td>0.410</td>
</tr>
<tr>
<td>9027 (Ni+Cr+Mo)</td>
<td>0.400</td>
</tr>
<tr>
<td>Control Weathering Steel</td>
<td>0.390</td>
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</tbody>
</table>

- HPS 20 — 0.210 g/cm² and Control steel — 0.150 g/cm².
Weight Loss per Area in ASTM G85-A5 Prohesion Test

Weight Gain per Area in GM 9540P Test

Weight Loss per Area in GM 9540P Test

Field Exposure of Test Panels at Hwy 404-Bloomington Rd

- 0.1673 g/cm² and Control steel - 0.2240 g/cm²

- 0.019 g/cm² and Control steel - 0.022 g/cm²

- 0.0243 g/cm² and Control steel - 0.0301 g/cm²
### Proposed compositions for 2014 casting at Canmet

<table>
<thead>
<tr>
<th>Element</th>
<th>#1</th>
<th>A1010</th>
<th>#2</th>
<th>#3</th>
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<th>#4</th>
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<tbody>
<tr>
<td>C</td>
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<td>0.10 max</td>
<td>0.10 max</td>
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<td>Si</td>
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**A1010 Steel**

- ASTM A1010 (Mittal Steel USA’s “Duracorr.”) is a 12% chromium structural steel.
- In 2002, FHWA funded Caltran to build the first demo bridge using A1010 steel for a county road bridge.
- Oregon and Washington DOT in collaboration further investigated the feasibility of A1010 steel for longer span bridge girders.
- Oregon DOT has built two A1010 steel girder bridges, the first was opened to traffic in 2012 and a second one in 2013.

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**Oregon DOT Mill Creek Bridge**

**Oregon DOT Dodge Creek Bridge**
**A1010 Steel**

- MTO is planning to do two pilot projects using A1010 steel—one in West Region in 2015 and one in Central Region possibly 2016.

- Need to develop a prequalified welding procedure in advance to address:
  - notch toughness category 2 in welded area and HAZ
  - choice of welding electrode and heat input rate