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Introduction to Fiber Reinforced Polymer (FRP) Composites In Infrastructure

Rhode Island DOT

July 21, 2016

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ACMA

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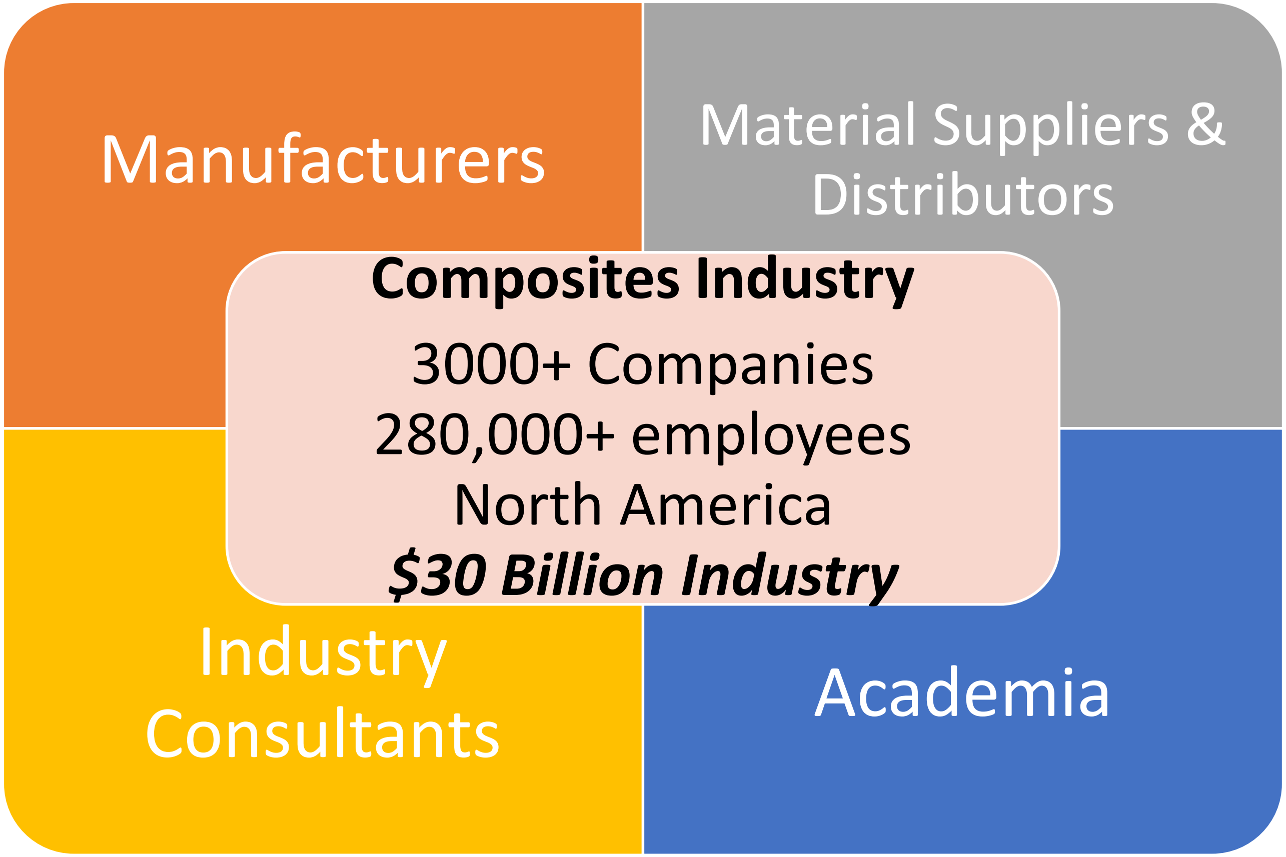
Outline

- About ACMA
- FRP Materials
- Products Used Today
- Installations Today
- Durability
- Standards & Specifications

American Composites Manufacturers Association

About ACMA

- World's largest composites trade association representing the entire composites industry supply chain:



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ACMA's Industry Councils

- Transportation Structures Council (TSC)
- FRP Rebar Manufacturers Council (FRP-RMC)
- Members represent the supply chain: material suppliers, manufacturers, distributors, consultants, and academia.

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TSC Manufacturers

- Composite Advantage
- Creative Pultrusions, Inc.
- Kenway Corporation
- Gordon Composites, Inc.
- Marshall Composite Technologies, LLC
- Sika Corporation
- Strongwell

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FRP-RMC Manufacturers

- BP Composites (TUFF-Bar)
- C1 Pultrusions, LLC (XBar™)
- Composite Rebar Technologies, Inc. (HollowBar)
- Hughes Brothers, Inc. (AslanFRP)
- Marshall Composite Technologies, Inc. (C-Bar™)
- Pultrall, Inc. (V-ROD)
- Raw Energy Materials Corporation (RockRebar™)

FRP Materials

Why are composites different?

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FRP Materials

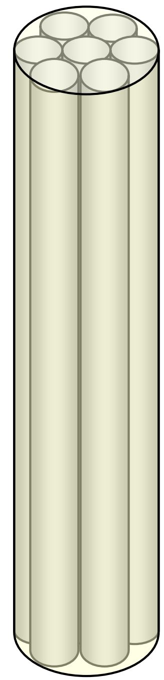
What is FRP?

Constituents

Fibers

Provide strength and stiffness

Glass, Basalt, Carbon, Aramid



Matrix (polymer)

Protects and transfers load between fibers

Polyester, Epoxy, Vinyl Ester, Urethane

Creates a material with attributes superior to either component alone!
fibers **and** matrix both play critical roles in the composites material...

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Factors Affecting Material Characteristics in Composites

- Type of fiber
- Fiber volume
- Type of resin
- Fiber orientation
- Quality control procedures during manufacturing
- Rate of curing
- Void content
- Service temperature

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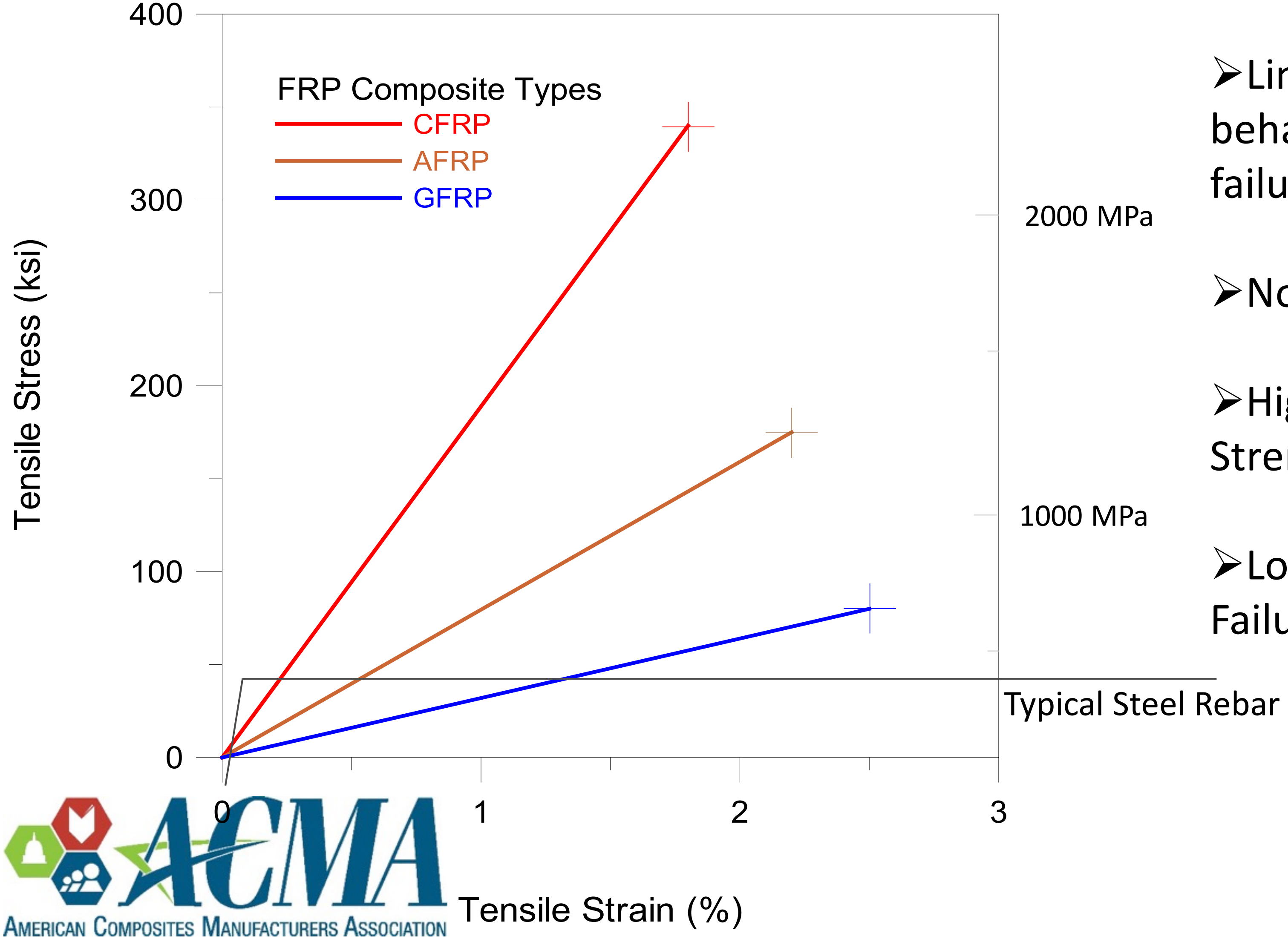
Tensile Stress-Strain Characteristics of Reinforcement Fibers



- Linear elastic behavior to failure
- No yielding
- Higher Ultimate Strength
- Lower Strain at Failure

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Why is FRP different from steel?

- FRP is **Anisotropic**
  - High strength in the direction of the fibers
  - This anisotropic behavior affects the shear strength, dowel action, and bond performance
- FRP does not exhibit yielding: the material is linear elastic until failure
  - Design should account for lack of ductility
  - Member does have substantial deformability
- You design FRP different than steel

Products Used Today

Historical and new

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From the beginning…infrastructure

- 1st FRP rebar – early 1970’s - USA
  - 2nd company, more R&D – early 1980’s
  - Bridges – 1980’s – Japan
- 1st FRP dowel bar - concrete pavements – USA – 1977
- 1st FRP Vehicular Bridge – China – 1982
- 1st FRP Pedestrian Bridge – China – 1986
- 1st FRP tendon, prestressing – Germany - 1986
- 1St CFRP tendon – Canada -1991
- 1st FRP Glulam beams – USA – early 1990’s

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More firsts…

- 1st FRP Strengthening System
  - Experimental work, 1978, Germany
  - 1st application, RC columns, 1980’s, Japan
  - 1st application, flexural strengthening of RC bridges, 1987
- 1st Bridge “Wind Fairing” – USA – 2003
- Movable bridges
- Long spans…..
- …and more to come

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FRP Products Used in Infrastructure

- Vehicular & Pedestrian Bridge Decks
- Deck Superstructures
- FRP Rebar
- Girders
- Concrete Strengthening Systems (blast mitigation)
  - Thousands of installations (column, bent, slab, girder)
  - Blast hardening of cables
- Marine Piles (fender, bearing, sheet)
- Cables, tendons (carbon fiber)
- Other: Parapets, Sidewalks, Guardrails, Bridge Enclosures / Fairings, drainage pipe

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Composites Products for Prefabricated Bridge Elements & Systems (PBES)

- FRP composites deck panel systems
    - Sandwich construction, vacuum infusion (foam/structural reinforcement)
    - Full thickness, pultruded, 1-piece, bonded panel joints
- FRP composites deck superstructure systems
    - Sandwich construction (foam/structural reinforcement)
- Girders
    - pultruded structural shape
    - vacuum infused box systems

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Composites Products for Prefabricated Bridge Elements & Systems (PBES)

- FRP rebar - reinforced precast concrete deck panels
- FRP grid - reinforced concrete structural stay-in-place deck panel systems

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FRP Composites Benefits

- **Prefabrication of deck panels**
  - Manufacturing in a plant to ensure quality
  - Minimizes installation on site
- **High strength**
  - Design loads are tailored to meet the requirements of the job/application
- **Lightweight**
  - Reduces installation time
  - Reduces the number of trucks to carry products to site as more products can be transported per truck
  - Lighter duty equipment needed to lift and place panels
  - Increases the live load capacity of weight restricted bridges with FRP deck replacements.

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FRP Composites Benefits

- **Corrosion resistance**
  - Long durable life
- **Design flexibility**
  - Infinite shapes and sizes can be designed to meet the requirements of the job
- **Color matching**
  - Meet needs of blending into surrounding environment
- **Enhanced Safety**
  - Solid surface for traction
  - Non-skid surface for safety of pedestrian traffic

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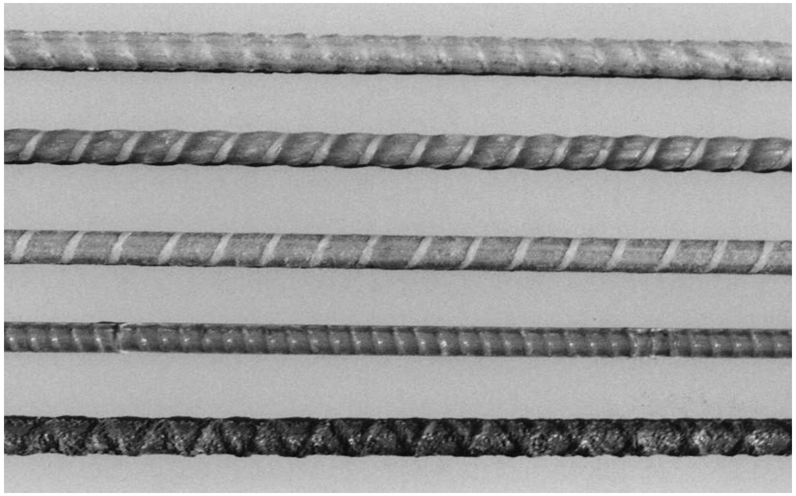
FRP Bar Types

- **Materials**
  - Glass/vinylester (most used)
  - Glass/polyurethane
  - Basalt/epoxy
  - Carbon/vinylester
- **Forms**
  - Solid
  - Round



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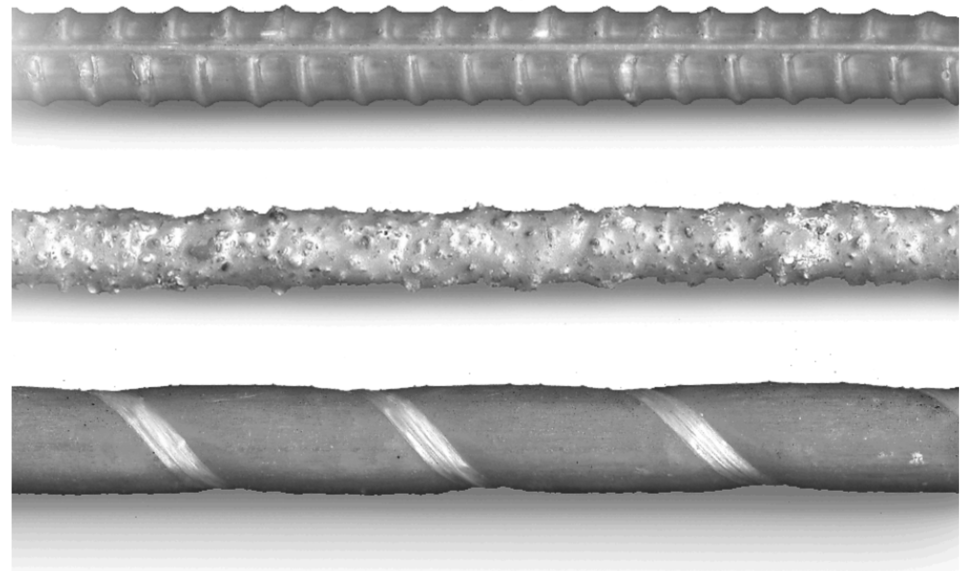
FRP bar types

- **Surface**
  - ➢ Ribbed (a)
  - ➢ Sand Coated (b)
  - ➢ Helically Wrapped and Sand Coated (c)

a)
b)
c)



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Installations Today

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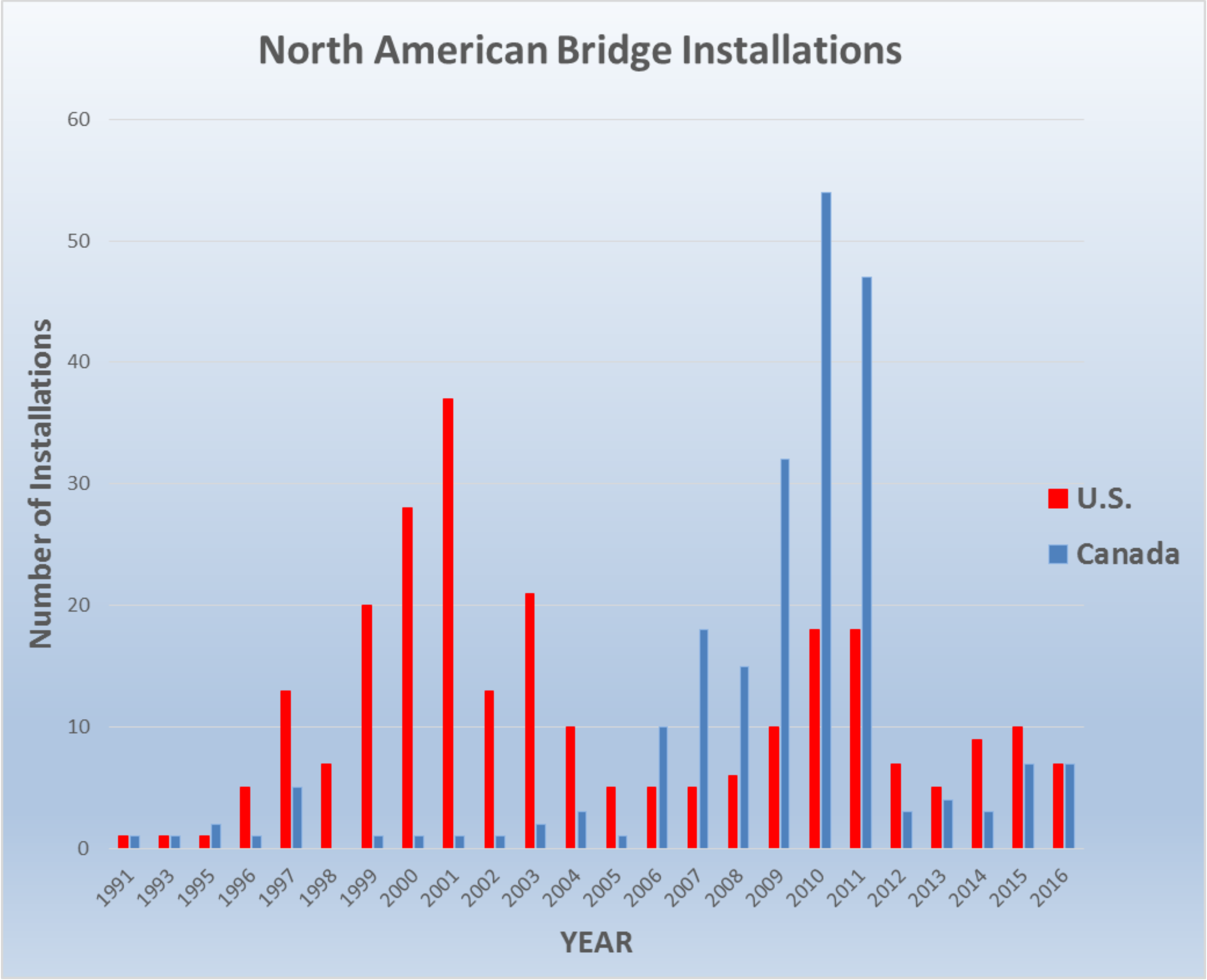
Bridge Installations	Canada	U.S.
1991	1	1
1993	1	1
1995	2	1
1996	1	5
1997	5	13
1998	0	7
1999	1	20
2000	1	28
2001	1	37
2002	1	13
2003	2	21
2004	3	10
2005	1	5
2006	10	5
2007	18	5
2008	15	6
2009	32	10
2010	54	18
2011	47	18
2012	3	7
2013	4	5
2014	3	9
2015	7	10
2016	7	7
	220	**262**



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Source: ACMA, 2016

FRP Products Used in North American Installations

Product Applications	Number of Installations	
	USA	Canada
Deck Panel System	70	2*
Deck Superstructure	49	0
Girder/Beam	54	9
Concrete Deck with rebar/grid	65	202
Tendon/Cable	13	7
Panel	18	1
Abutment / Footing	3	4
Parapet, Barrier, Enclosure, sidewalk	9	41
Piling / Column	3	1
Pier (Column) Fendering Systems	14	0
FRP / Glulam Beam	9	0
Carbon Fiber/Glass Concrete Filled Arch	17	0

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Source: ACMA, 2016

Note: Does not include repair/strengthening

FRP Rebar Use in USA
65 Bridges – 27 States

Colorado	2
Connecticut	1
Florida	8
Georgia	2
Indiana	1
Iowa	2
Kansas	1
Kentucky	2
Mass	1
Maine	4
Michigan	2
Minnesota	1
Missouri	6
Nebraska	1

New Hampshire	1
New York	3
North Carolina	1
Ohio	4
Oregon	1
PA/NJ	1
Pennsylvania	1
Texas	3
Utah	2
Vermont	1
Virginia	1
West Virginia	9
Wisconson	3

Applications		
Deck only	Deck, parapet, barrier, enclosure, and/or sidewalk	Parapet, barrier, enclosure, and/or sidewalk
56	5	4

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Source: ACMA, 2016

FRP Rebar Use in Canada
202 Bridges – 4 Provinces

	Rebar	Deck only	Deck, parapet, barrier, enclosure, and/or sidewalk	Parapet, barrier, enclosure, and/or sidewalk
Bridges in Canada	202	167	23	12

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Source: ACMA, 2016

Installations by State

- Several States have many installations which range in size, ADT, and complexity
- States like Ohio and West Virginia made commitments to integrating composites technology

Installations by State	Total
ME	43
WV	35
OH	34
NY	20
MO	18
FL	10
VA	9
NJ	8
OR	8
PA	7
KS	6
KY	6
MA	6
DE	5
IA	5

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Source: ACMA

Bridge Tour

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Beddington Trail Bridge, Canada

Calgary, Alberta
Opened 1993
2 spans (22.8 and 19.2 meter)

First Bulb-Tee bridge girder pretensioned with CFRP tendons, CFRP stirrups, and monitored by FBG sensors

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McKinleyville, WV (1996)

1st Bridge with FRP Rebar

Courtesy of West Virginia Univ. CFC

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Smith Road, Tech21

- **All Composite Short Span Bridge**

- 1997 - Tech21 - Butler County Ohio

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Smith Road, Tech21

- **All Composite Short Span Bridge**

- 1997 - Tech21 - Butler County Ohio

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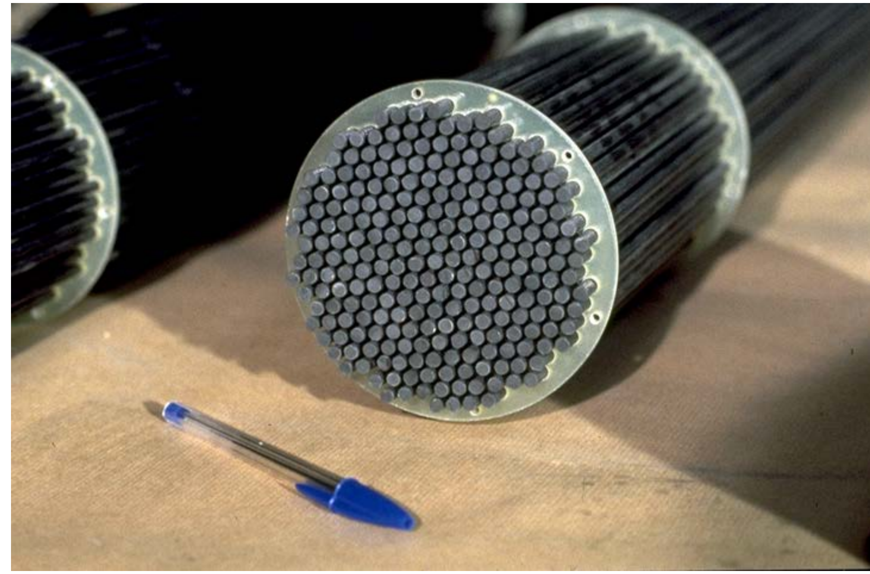
FRP Tendons: Cable-Stayed Bridges



Stork bridge (124 m span, 2 lanes)

241 wires (each 0.2 in)
ultimate load: 2700 kips

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Pierce Street over Ottawa River (1999)

- **Concrete reinforcement**

- Pierce Street over the Ottawa River - Lima Ohio
  - –Glass fiber reinforcing bars

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Bridge Street Bridge, USA

Bonded and unbonded CFRP Tendons in both Longitudinal and Transverse Directions

Southfield, Michigan
Opened 2001
2 parallel independent bridges (A and B)
3-spans (21.3, 20.4 and 21.4 meters)
2-lanes

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Bridge Street Bridge

- Two parallel independent bridges:
  - Structure A: 5 conventional AASHTO-I beams
  - Structure B: 12 beams (each prestressed using pretensioned CFRP Leadline tendons and post-tensioned in the longitudinal and transverse directions using CFCC strands

Erection of 12 CFRP Pretensioned and Post-tensioned DT Beams, (Courtesy of LTU)

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Fairgrounds Road over Little Miami River

- Installation: 2002 Span Length: 221’
- Location: Greene County
- Bridge Owner: Greene County
- Designer: LJB
- FRP Application: FRP Deck – DuraSpan™
- FRP Manufacturer: Martin Marietta Composites
- Performance History:
  - Live load tests in 2002 and 2004, FRP deck performing properly
- Of Interest:

High Volume Rural – average daily traffic 15,200

7,072 sq. ft. of FRP deck installed in under three days

Fairgrounds Road, Greene County

Installation Pictures

Morristown Bridge Vermont 2002

Concrete cast-in-place
May 2002

Bridge opened to traffic
July 2002

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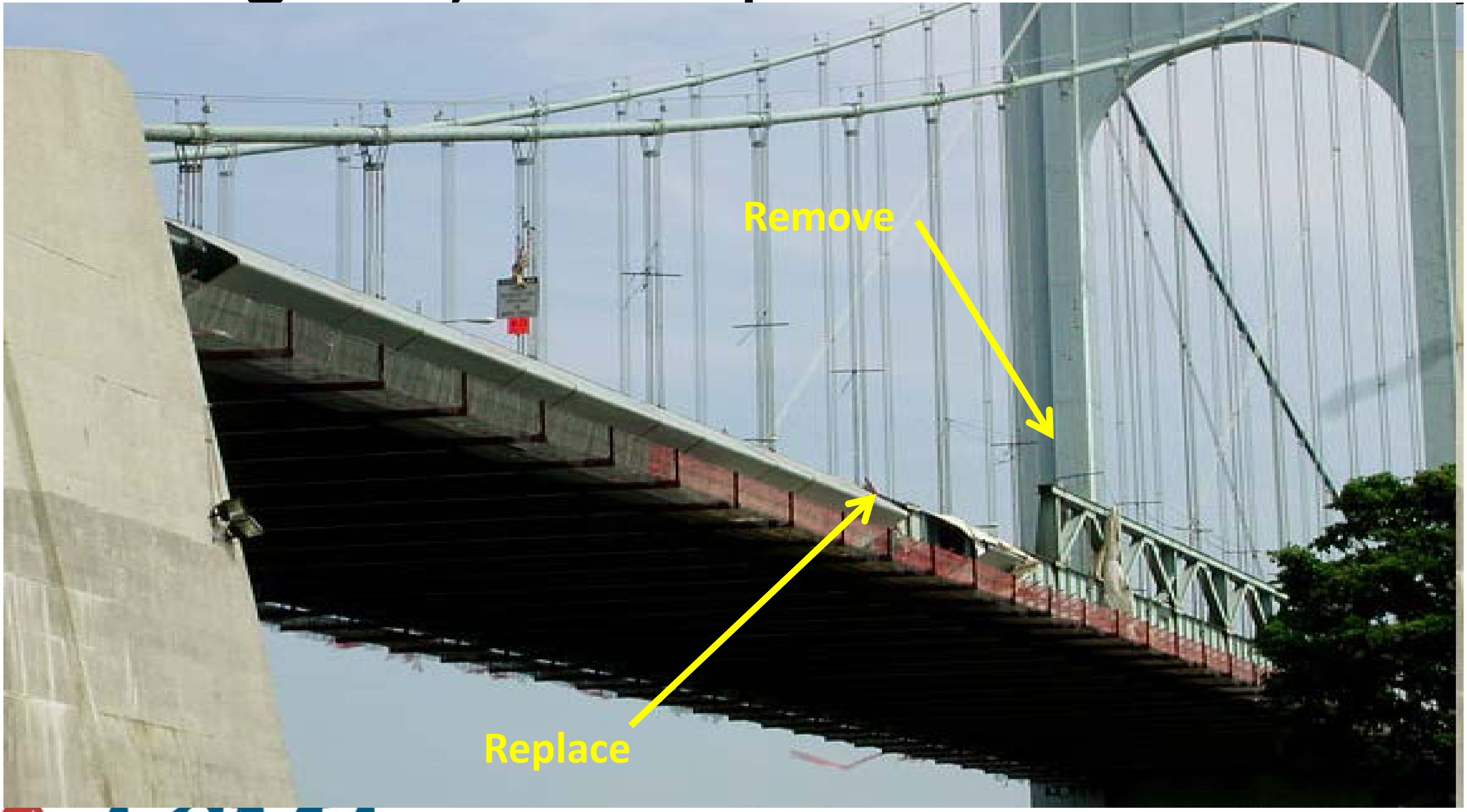
Courtesy of Pultrall, Inc.

Bronx-Whitestone Bridge – Wind Fairings – 2,300 ft span



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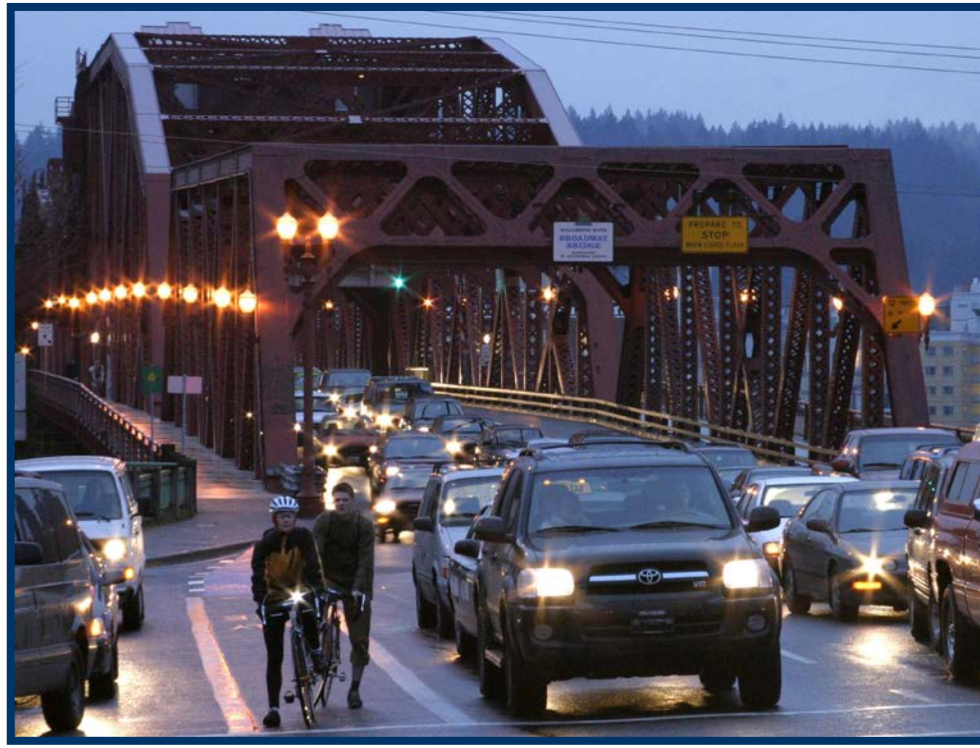
Bridge deck - Broadway Bridge, 2005

- Located in the heart of the Portland harbor
- 30,000 vehicles per day
- Bascule bridge
- Vital to all types of traffic
  - Vehicular
  - Pedestrian
  - ***Marine (4 shifts)***



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Decorative architectural composites for bridge applications

Source: DEC Architectural Composites

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Wolf Trap National Park
Vienna, Virginia

- Pedestrian bridge connecting parts of the park
- Crosses main access to Dulles Airport
  - Ten lanes of highway and one passenger rail line
- Safe access to amphitheater from one parking lot
- Visitors were walking on vehicle bridge with minimal sidewalk

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Span 1

FRP Deck Enables Accelerated Construction of Truss Bridges

- Enabled fully assembled spans to be erected with minimal road closure
  - No deck installation over the road
  - Precast concrete would have added 74,000 lb to the 132,000 lb lift
- 15 minutes in the middle of the night is Minimal
- FRP Benefits
  - Prefabricated Elements
  - Ease of installation - Light Weight

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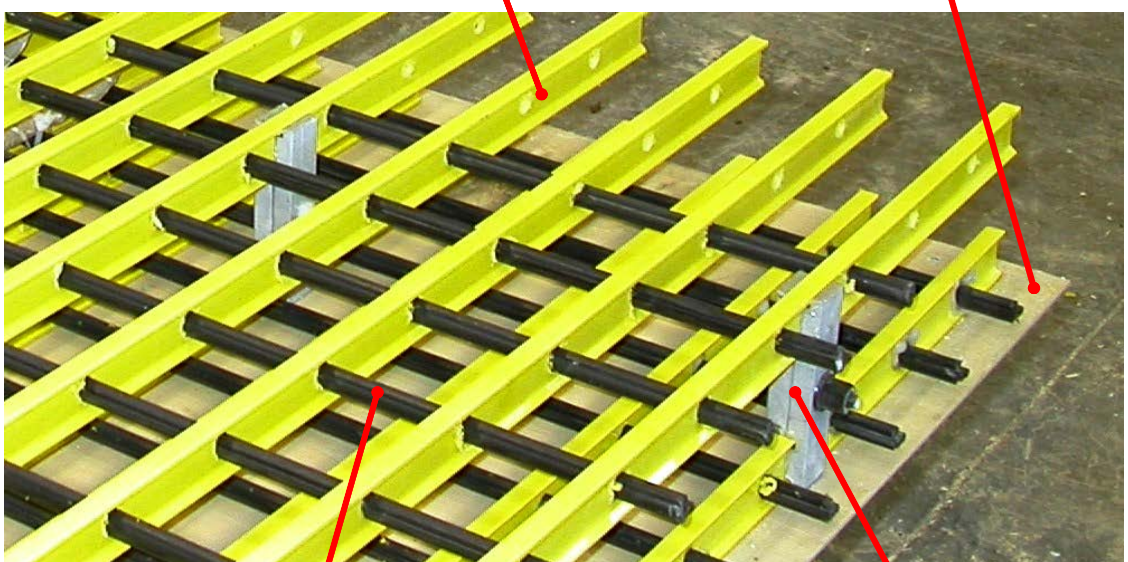
Penobscot Narrows Cable Stayed Bridge (2007/08)

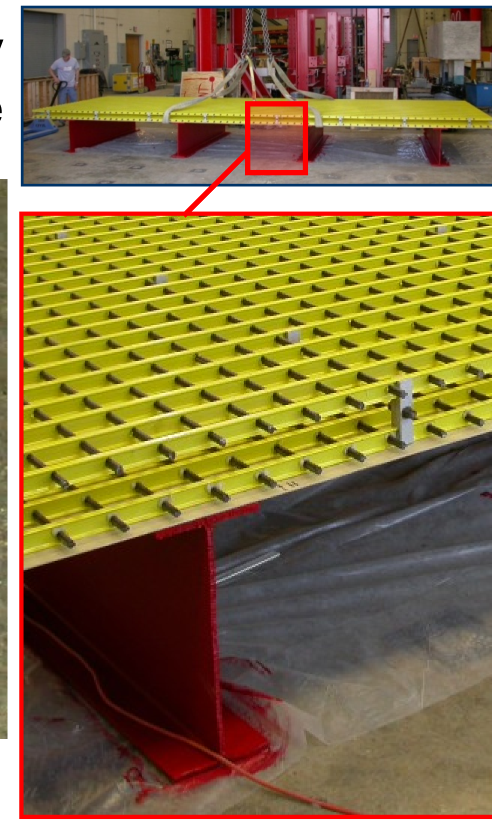
Prefabricated FRP stay-in-place panels

Double-layer stay-in-place (SIP) reinforcing panels pre-assembled using off-the-shelf pultruded GFRP components

1.5” I-bars
(4” o.c. perpendicular to traffic)

1/8” thick epoxy bonded form plate



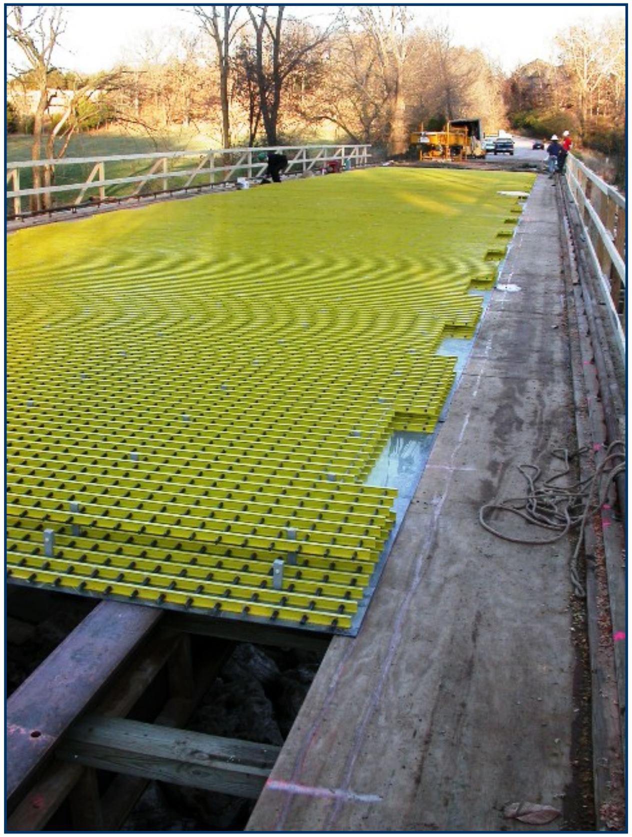


Three-part cross rods
(4” o.c. parallel to traffic)

Vertical connectors

Deck construction, Missouri

- Setting Panels of Reinforcement



Floodway Bridge Winnipeg

One of the largest uses of GFRP bars

150 tons of GFRP = 1.2 million lbs of steel rebar or 30 truckloads
Largest “steel free deck”
Largest FRP reinforced bridge
8 truckloads of GFRP bar

Seawall - Honoapiilani Highway 2012

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Courtesy of Hughes Brothers

Box Girder / Column

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Four 70 ft. Beams – One Truck

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Bridge in a Backpack

- Carbon Fiber shell, prefabricated in the plant
- Shipped to site – installed – lightweight, carried by workers - concrete poured
- Finished with composites panels

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Historic Powder Point Bridge *(Duxbury, MA)*

Nipigon River Cable-Stayed Bridge (2012-2017)

Canada’s First Deck Slab Reinforced with GFRP Bars in Cable Stayed Bridge: Nipigon River Bridge

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Traditional Looking Pedestrian Bridge

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Innovative Pedestrian Bridge – Internal Structure

Innovative Pedestrian Bridge
Exterior Finishing

Innovative Pedestrian Bridge
Lifting into place

Pont y Ddraig, Wales, 2013

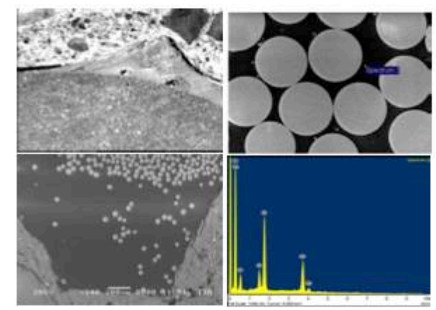
Durability - Canada

- ISIS Canada reports on Durability performance of GFRP bars in Bridge Decks in Service for 8-10 years
- Multiple reports from several institutions
- Follow-up reports after 15 years

GFRP Durability Study (Project 5.17) – University of Manitoba

DURABILITY OF GFRP REINFORCED CONCRETE FROM FIELD DEMONSTRATION STRUCTURES

Final Report



Prepared by:

Dr. Maria Onofrei

Adjunct Professor University of Manitoba
Consultant ISIS Canada

May 2005

1 Dr. M. Onofrei - Final Report, May 2005

NO Degradation of GFRP bars found !

Additional studies are being performed on US bridges with service over 15 years – Preliminary results – the same

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Composites in Construction 2005 – Third International Conference, Hamelin et al (eds) © 2005 ISBN xxxxx

Lyon, France, July 11 – 13, 2005

REPORT ON THE STUDIES OF GFRP DURABILITY IN CONCRETE FROM FIELD DEMONSTRATION STRUCTURES

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ABSTRACT: In 2004, ISIS Canada studied the durability of GFRP in concrete by removing concrete cores containing GFRP from five Canadian field demonstration structures built during the last 5 to 8 years. Three teams working independently at several Canadian universities used a variety of analytical methods to (a) investigate whether or not the GFRP in concrete field structures had been attacked by alkali, and (b) compare the composition of GFRP removed from in-service structures to that of control specimens, which were saved from the projects and not exposed to the concrete environment. The analytical results have confirmed that the GFRP in concrete has not suffered any discernible damage during the last five to eight years. As a result of this study, the Technical Subcommittee of Fibre Reinforced Structures of the CHBDC has recommended that GFRP can now be used as primary reinforcement and prestressing tendons in concrete structures. The paper reports on the findings of the durability study conducted by the ISIS Canada Research Network.

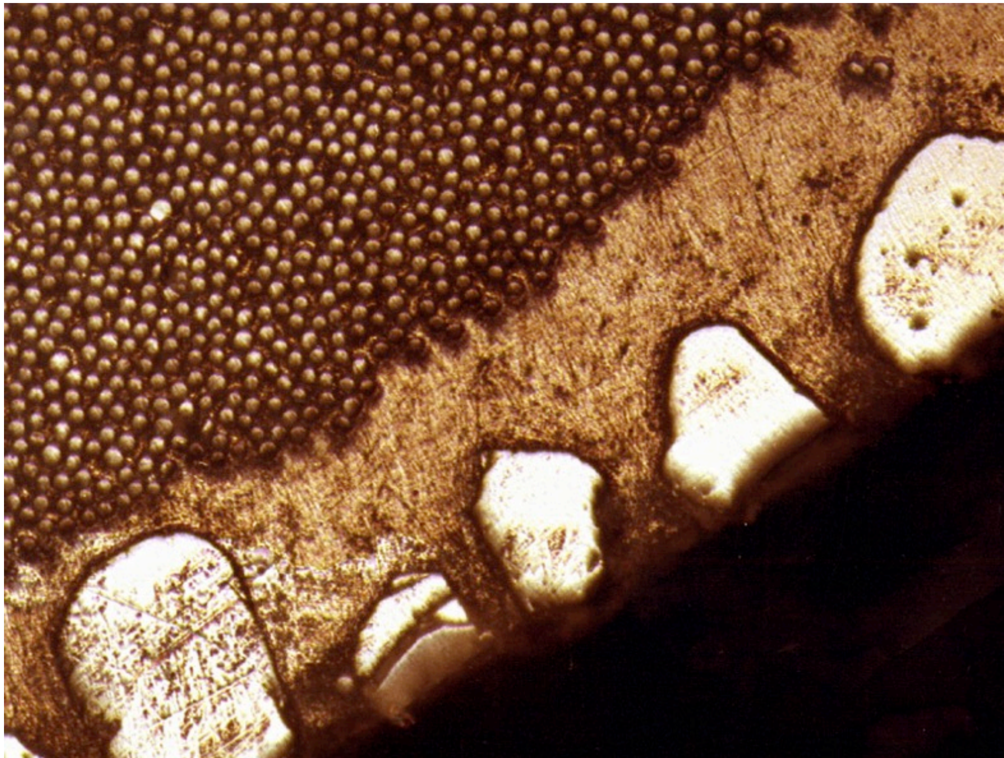
1. INTRODUCTION

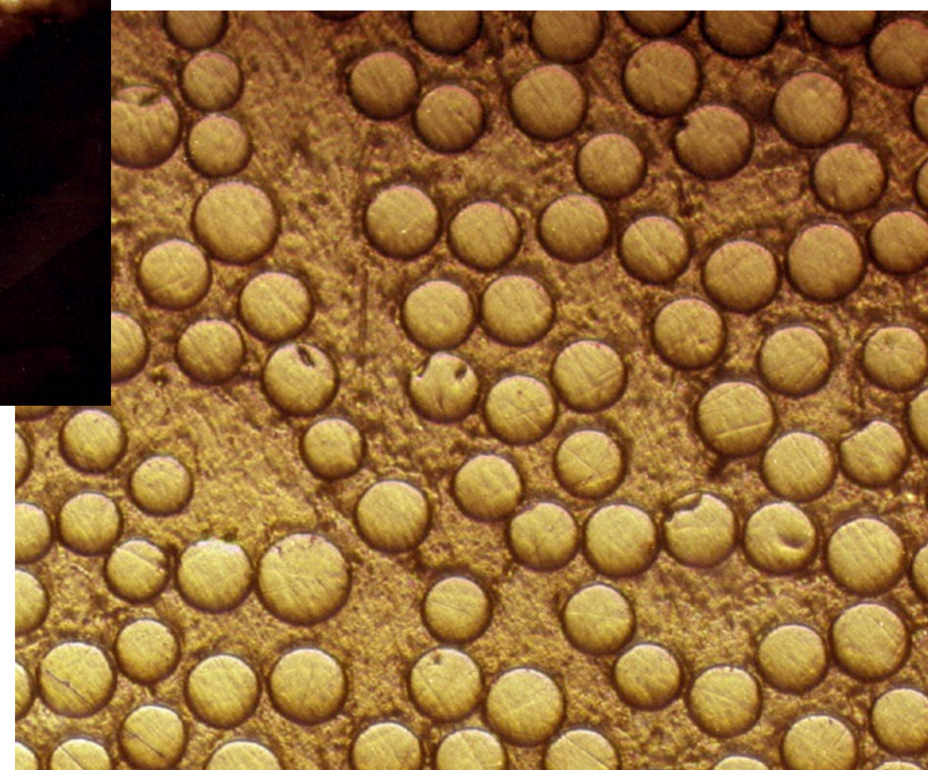
Recently, Professor U. Meier reviewed the activities of ISIS Canada [1]; he recommended that Canada, having invested significantly in innovative concrete structures with GFRP, should study the durability of GFRP in concrete. Following his advice, ISIS Canada initiated in 2004 a project, in which concrete cores containing GFRP were removed from five Canadian structures, and analyzed the GFRP for its composition at a micro level. Since previous simulated studies of the durability of GFRP in concrete [e.g., 2,3] had indicated that GFRP is not stable in the alkaline environment of concrete, the Canadian Highway Bridge Design Code (CHBDC) [4] restricted the use of GFRP as only secondary reinforcement. It has been argued in [5] that the simulated tests, whether accelerated or non-accelerated, were conducted in an alkaline environment, which is likely to be different from the concrete environment found in field structures. The objective of the study described in this paper was to provide data on the performance of GFRP in several Canadian concrete demonstration structures built during the past five to eight years. The paper reports on the findings of the durability study conducted by the ISIS Canada Research Network. The names of the authors are those of the project team that conducted the study with the President of the ISIS Canada Research Network as the project leader.

2. ANALYTICAL STUDIES

Five field demonstration projects were chosen for the study under consideration, these being the Hall's Harbor Wharf, the Joffre Bridge, the Chatham Bridge, the Crowchild Trail Bridge, and the Waterloo Creek Bridge; these structures, exposed to a wide range of environmental conditions, are well

…..a closer look





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Review – Standards & Specifications

Translating research into industry standards

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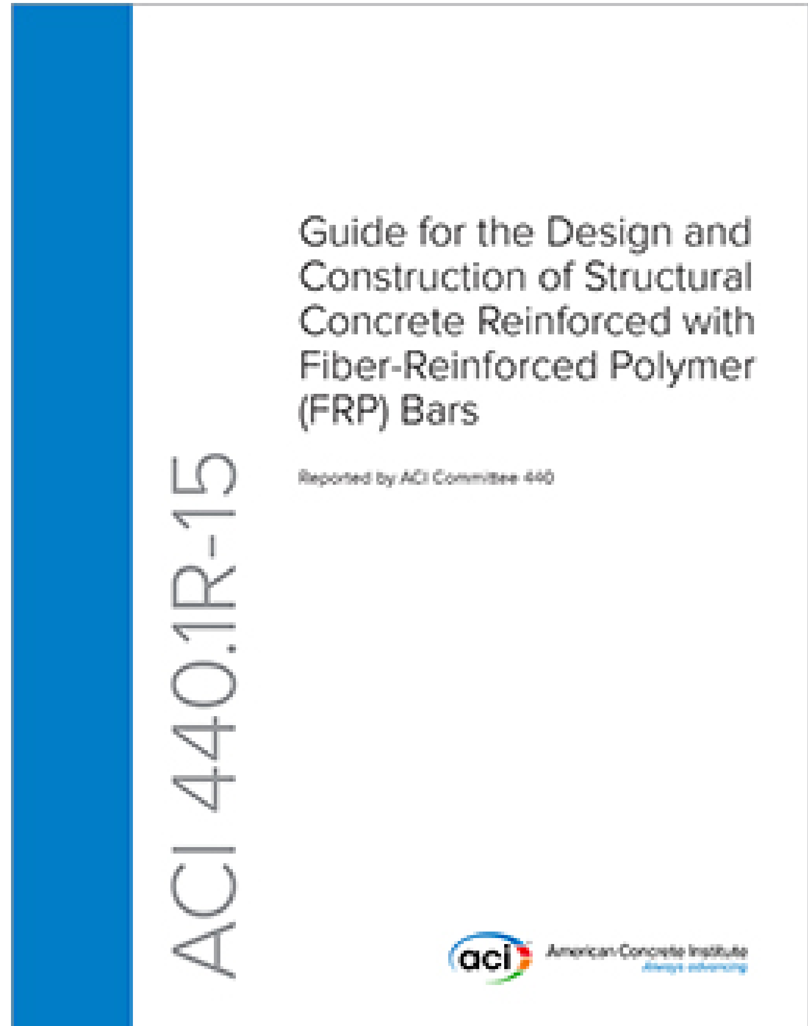
ACI – rebar design guideline

- Design principles well established through extensive research
- <u>Non-mandatory language</u>
- ACI 440.1R-15
  - 4th update to document
  - Current research added
  - Added direction on high temperature and fire effects
  - Design examples enhanced and reorganized.



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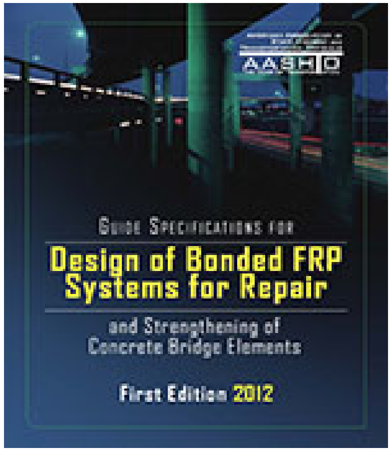
ACI – Standard Under Development

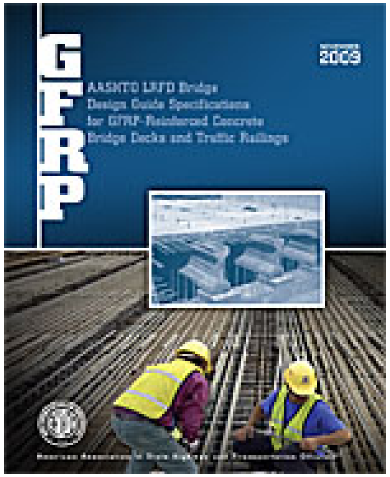
- New FRP Rebar Design Code
  - In 2014, ACI TAC approved a new standard development
- Dependent Code
  - Aligned with the exact chapters and structure ACI 318-14
  - Only chapters that impact FRP will be re-tooled to reflect the properties, characteristics, etc.
- This is expected to be a 3 year effort

AASHTO

- Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements, 1st Edition



- AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings, First Edition



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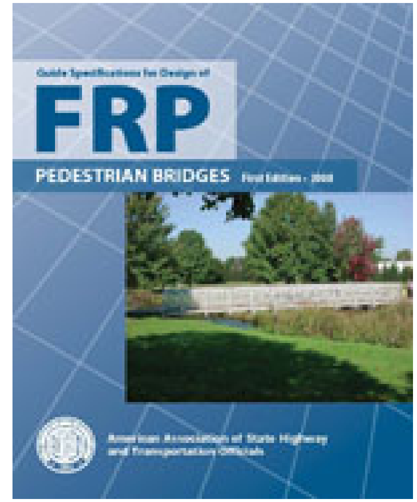
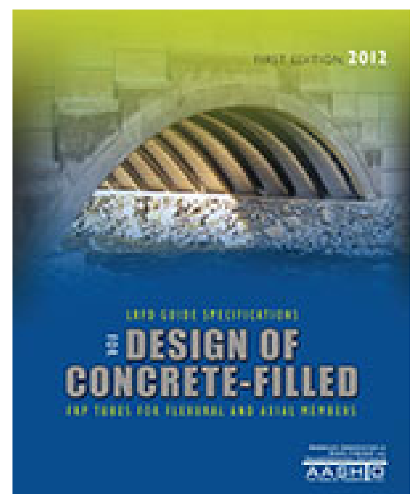
AASHTO

- Guide Specifications for Design of FRP Pedestrian Bridges, 1st Edition, 2008



- AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes, 1st Edition



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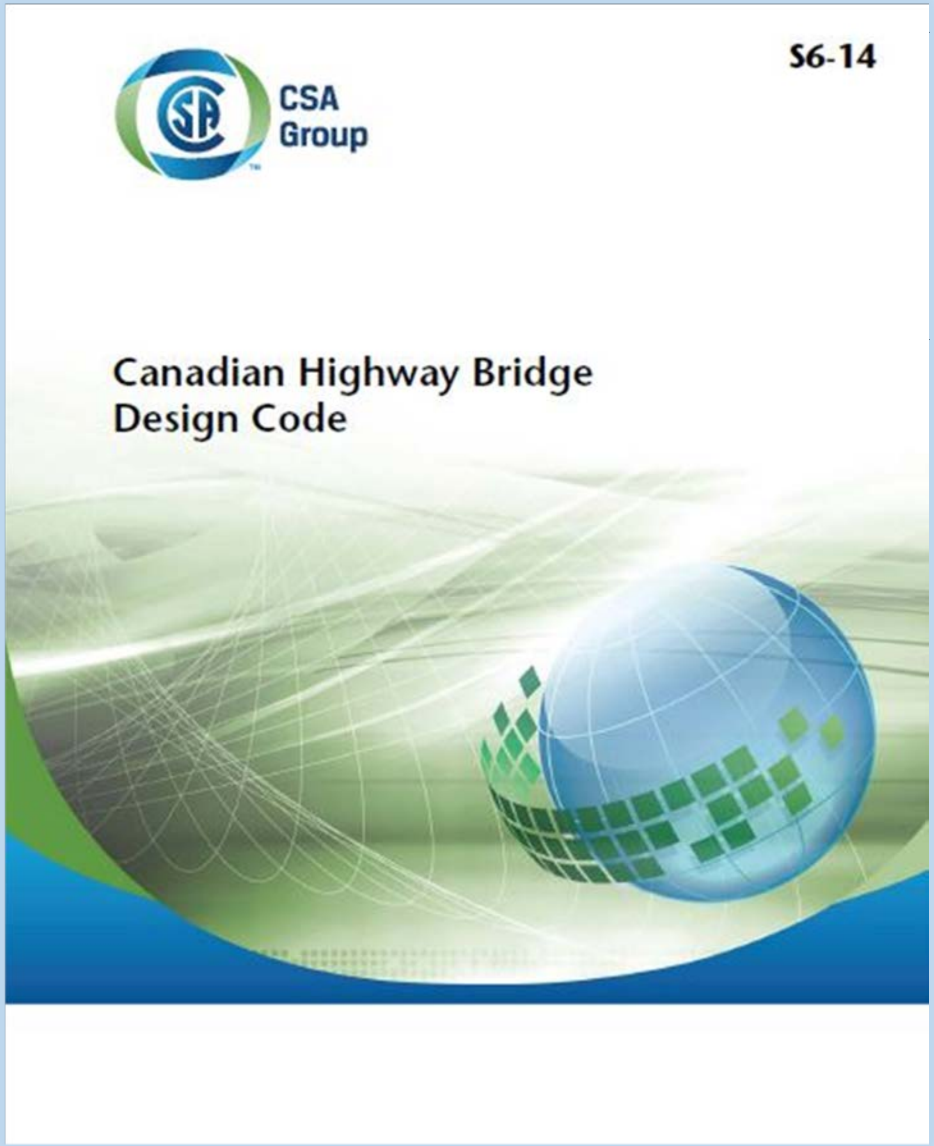
Canada - Highway Bridge Design Code



Technology transitioned from government-subsidized research projects to actual commercialization

Experience gained on viability of construction management practices where FRP reinforcement is adopted through traditional bid letting processes and competitive bidding from multiple FRP bar suppliers

Summary

- Engineered systems
- Prefabricated components, factory built, quality controlled
- ***Reduces*** the need for large, heavy, expensive equipment during installation
- ***Increases*** safety on site
- Lighter Weight for ***Reduced*** Shipping, Handling and Erection Time and Costs (Accelerated Bridge Construction)
- ***Reduced*** Carbon Footprint
- Greater Corrosion Resistance than Conventional Materials Providing Service Lives Beyond 100 Years
- ***LOWER OVERALL BRIDGE COST!!***

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4 – Eyes

- Composites inspire ***innovation*** with different designs using similar materials
- Composites encourage ***ingenuity*** because it allows you to think outside the box
- Composites facilitates ***invention*** by making existing techniques, systems, methods better
- Composites propels ***imagination*** into new frontiers to make an engineers or contractors vision a reality

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Thank You

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