FIBER REINFORCED POLYMER (FRP) COMPOSITES REBAR

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Director, Composites Growth Initiative
American Composites Manufacturers Association
July 17, 2012

American Composites Manufacturers Association

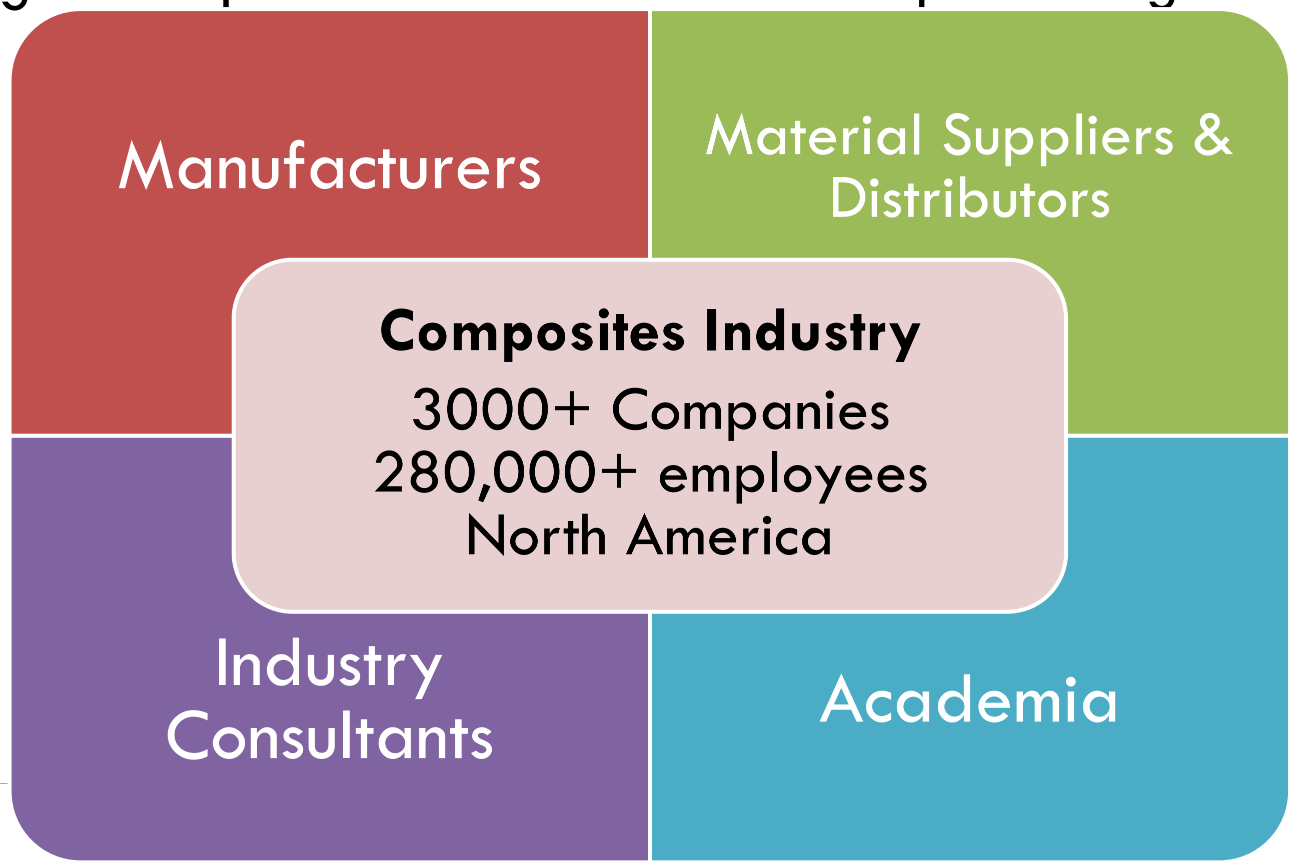
FL-DOT, Tampa

Outline

- About ACMA
- Introduction
- FRP Materials
- FRP Bars
- Standards & Specifications
- Applications
- Summary

About ACMA

- Formed in 1979
- World's largest composites trade association representing:



ACMA Industry Council

- **Mission** - Promote the use and growth of FRP reinforcement (rebar, tendons & grids) in concrete and masonry applications through development of quality procedures, industry specifications, performance standards, and field application guidelines.

FRP-RMC

FRP Rebar Manufacturers Council

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FRP-RMC Manufacturers

- BP Composites (TUFF-Bar)
- Composite Rebar Technologies, Inc.
- Hughes Brothers, Inc. (AslanFRP)
- Marshall Composite Technologies, Inc. (C-Bar)
- Pultrall, Inc. (V-Rod)

Introduction

- The Problem - Corrosion
  - Corrosion and deterioration of steel reinforced concrete
  - Mitigation techniques - High costs to rehabilitate and remediate structures
  - Safety - Construction zones and detours
- The Solution – FRP Rebars
  - Non corrosive concrete reinforcement
  - Increase service life (durability)
  - Hundreds of applications in service in North America

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Traditional Approach to Corrosion Problems

- Reduce, Eliminate, or Negate the Current Flow of the Electrochemical Corrosion Cell Inherent With Steel Reinforced Concrete
  - ✓ Admixtures
  - ✓ Increase Concrete Cover
  - ✓ Efforts to reduce permeability & mitigate cracking - HPC
  - ✓ Alter Concrete Mix
  - ✓ Membranes & Overlays
  - ✓ Epoxy coated steel
  - ✓ Cathodic protection
  - ✓ Sacrificial anodes

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FRP Materials

Why are composites different?

FRP Materials

What is FRP?

Fibers

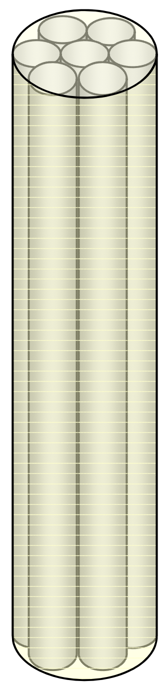
Provide strength and stiffness

Carbon, glass, aramid

Matrix

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

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

What is different?

- 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

Composites Features

- Impervious to chloride ion and chemical attack
- Tensile strength is greater that steel
- ¼ the weight of steel
- Transparent to magnetic fields and radar frequencies
- Electrically non-conductive
- Thermally non-conductive

Where should FRP rebar be used?

- Any concrete member susceptible to corrosion by chloride ions or chemicals
- Any concrete member requiring non-ferrous reinforcement due to Electro-magnetic considerations
- As an alternative to epoxy, galvanized, or stainless steel rebars
- Where machinery will "consume" the reinforced member ie. Mining and tunneling
- Applications requiring Thermal non-conductivity

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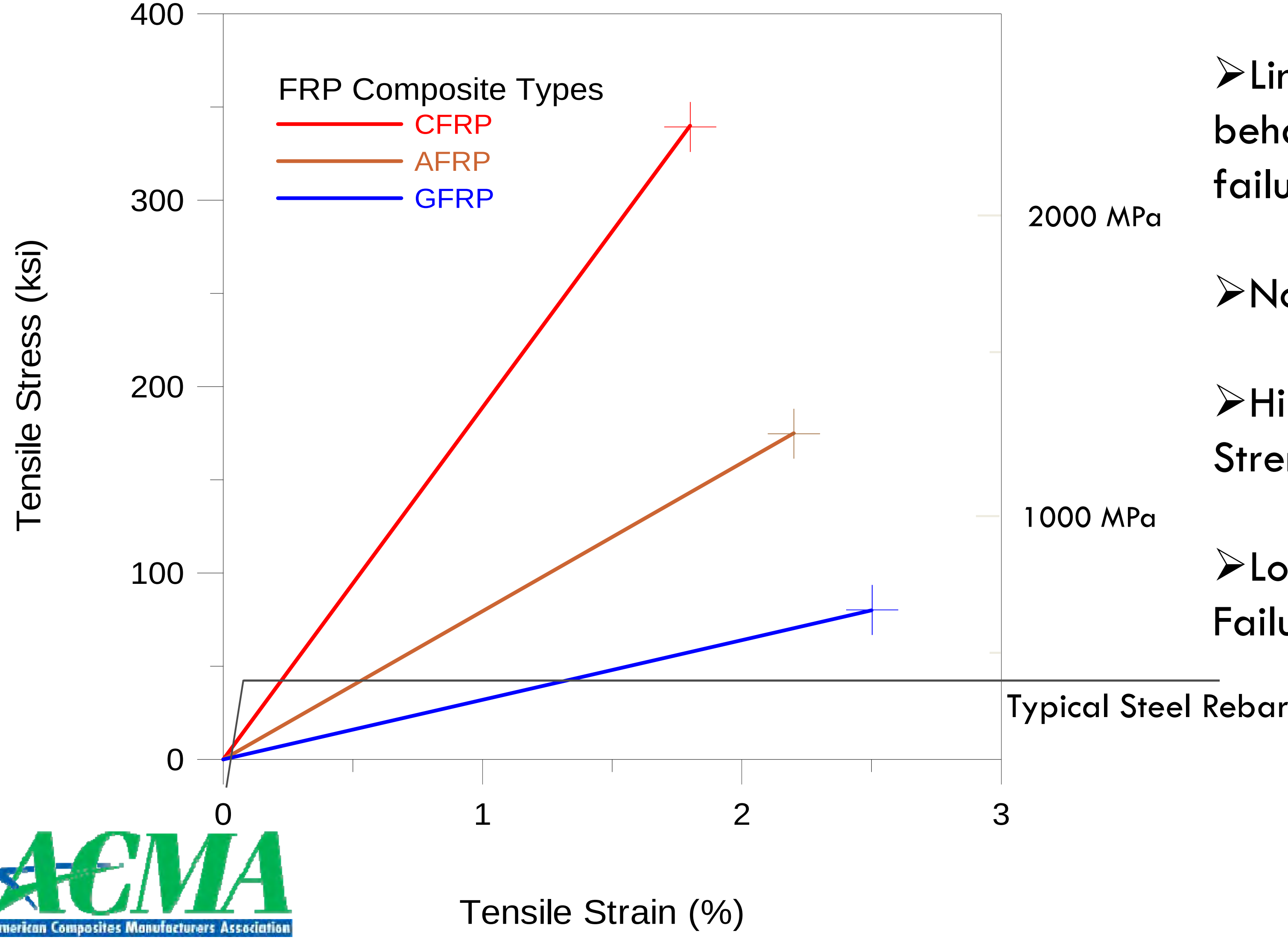
Tensile Stress-Strain Characteristics



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

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FRP Properties

	Steel	GFRP	CFRP	AFRP
Yield Stress ksi (MPa)	40 - 75 (276 - 517)	N/A	N/A	N/A
Tensile Strength ksi (MPa)	70 - 100 (483 - 690)	70 - 230 (483 - 1600)	87 - 535 (600 - 3690)	250 - 368 (1720 - 2540)
Elastic Modulus X 10^3 ksi (MPa)	29 (200)	5.1 - 7.4 (35 - 51)	15.9 - 84 (120 - 580)	6.0 - 18.2 (41 - 125)
Yield Strain %	.14 - .25	N/A	N/A	N/A

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Source: ACI 440.1R-06

Coefficient of Thermal Expansion

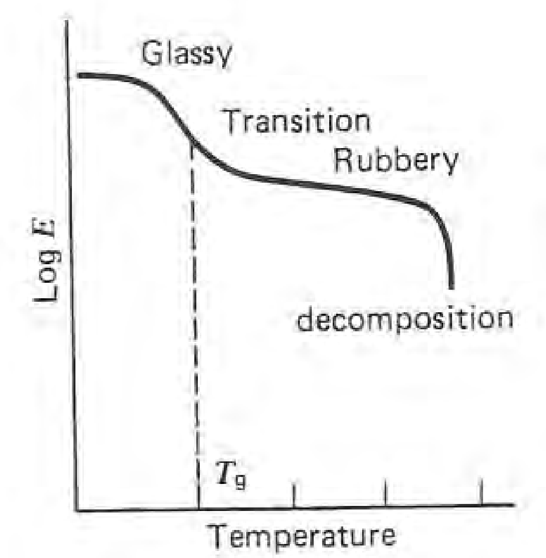
CTE (10^{-6}/ °F)

Material	Longitudinal Direction	Transverse
Concrete	4 ~ 6	4 ~ 6
Steel	6.5	6.5
GFRP	3.5 ~ 5.6	» 12
CFRP	- 4 ~ 0	41 - 58
AFRP	- 3.3 ~ - 1.1	33 - 44

- Values of CTE differ between FRP materials and concrete.

Effect of High Temperatures

- Resins will soften due to excessive heat
- The tensile, compressive, and shear properties of the resin diminish when temperatures approach the Glass Transition Temperature, T_g
- T_g values are approximately 250°F (120°C) for vinylester resins which are typically used with GFRP rebars
- T_g lowers as a result of moisture absorption



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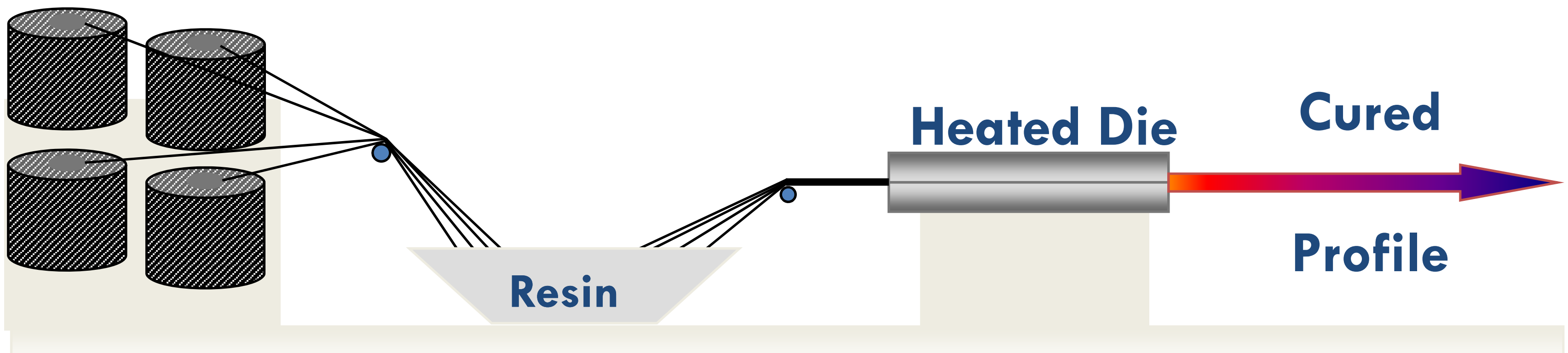
FRP bars

Looks are deceiving

Pultrusion Process

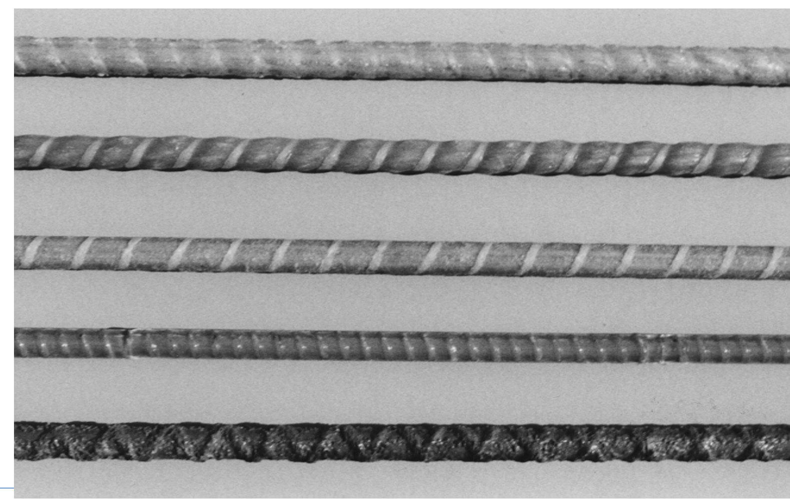


Most products are manufactured with this process

FRP Bar Types

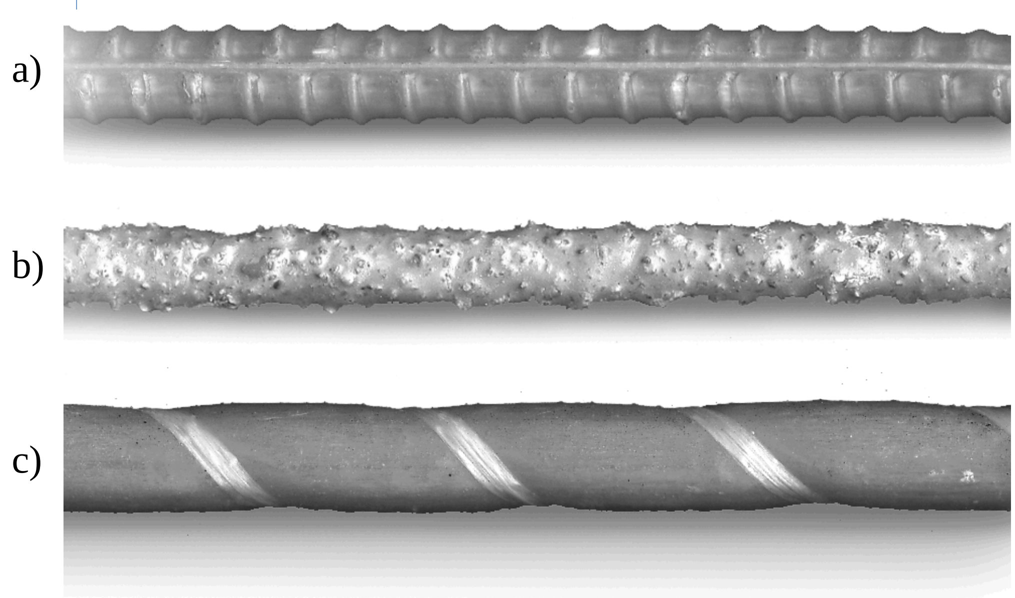
- Materials
  - Glass/ vinylester
  - Carbon/ vinylester

- Forms
  - Solid



FRP bar types

- Surface
  - Ribbed (a)
  - Sand Coated (b)
  - Wrapped and Sand Coated (c)
  - Deformed
  - Helical



Innovation – hollow bar - coming soon

Courtesy of Composite Rebar Technologies, Inc.

Bar Sizes

Bar Size		Nominal Diameter	
Imperial	*Metric*	*Imperial*	*Metric*
Inches	mm	inches	mm
#2	6	0.25	6.35
#3	10	0.375	9.53
#4	13	0.4	12.7
#5	16	0.625	15.88
#6	19	0.75	19.05
#7	22	0.875	22.23
#8	25	1	25.4
#9	29	1.125	28.65
#10	32	1.25	31.75

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Strength and Modulus Grades

- Strength grade is based on ultimate tensile strength of the bar.
- Lowest grade is 60 ksi
- Strength is provided on 10 ksi increments

Grade F 60 $\rightarrow$ f^*_{fu} **>60 KSI**

Grade F 300 $\rightarrow$ f^*_{fu} **>300 KSI**

- Modulus grade corresponds to minimum modulus of the selected bar.

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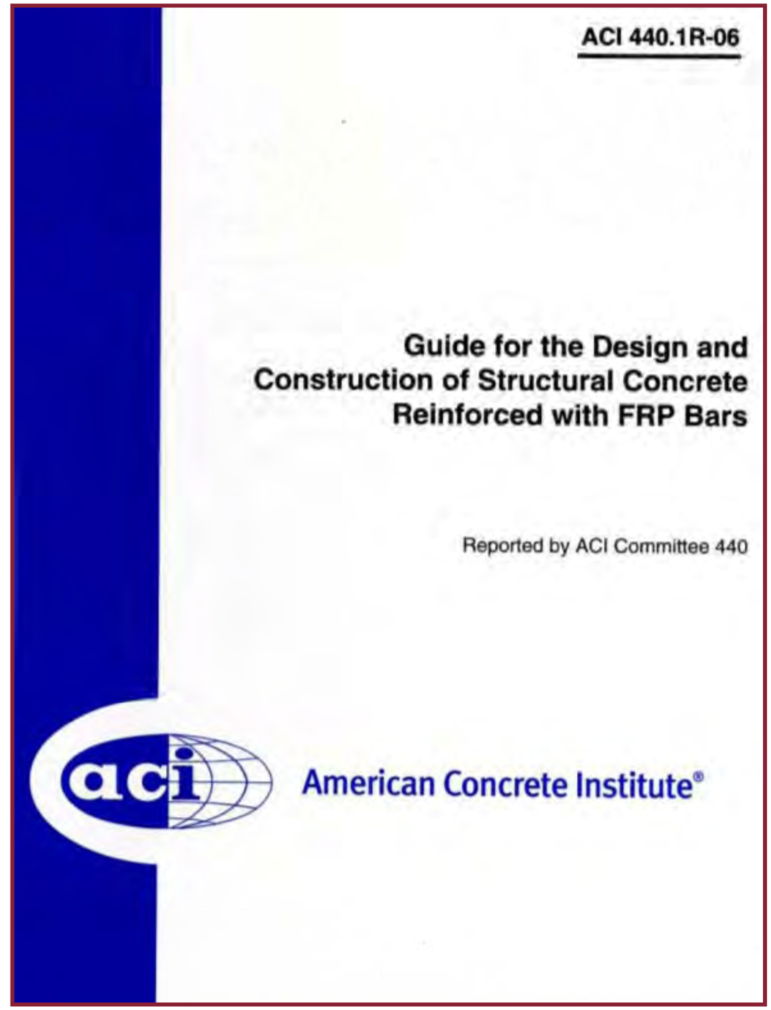
Standards & Specifications

Translating research into industry standards

ACI – rebar design guideline

- Design principles well established through extensive research
- Guideline documents published in North America, Europe, Japan
- Non-mandatory language


ACI 440.1R-06

Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars

Reported by ACI Committee 440

aci American Concrete Institute®

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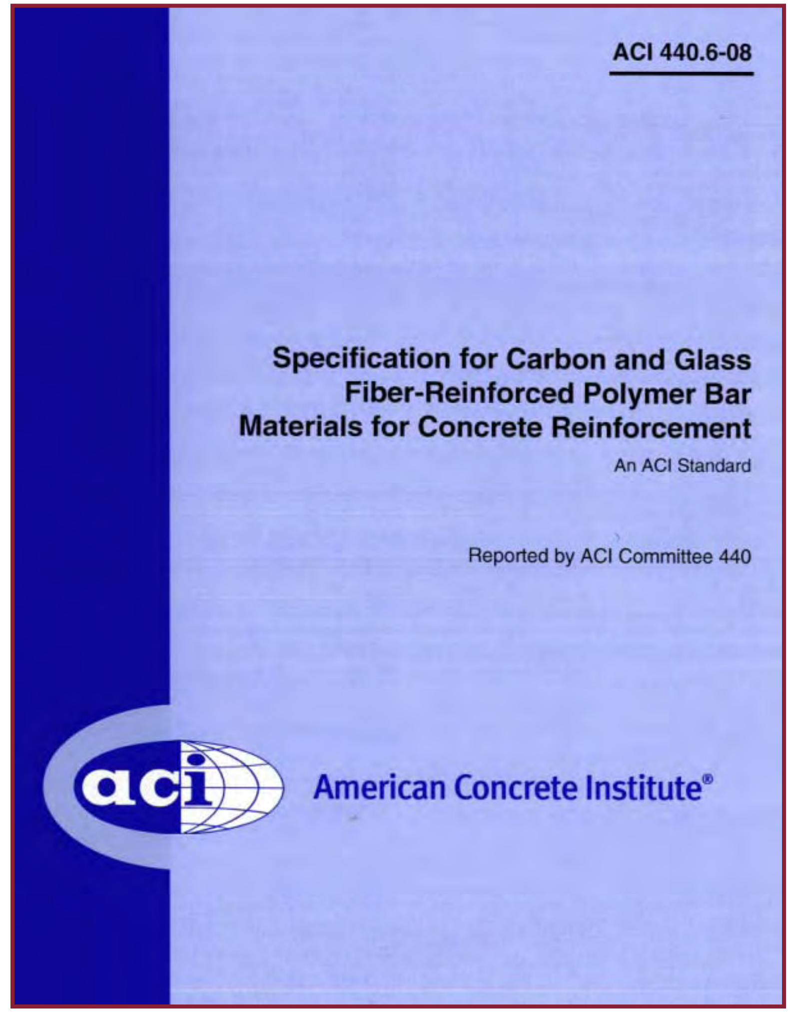
ACI – rebar, materials spec

- ACI 440.6-08, **mandatory language** (standard document)
- Provisions governing testing and evaluation for certification and QC/QA
- Describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements


ACI 440.6-08

Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement

An ACI Standard

Reported by ACI Committee 440

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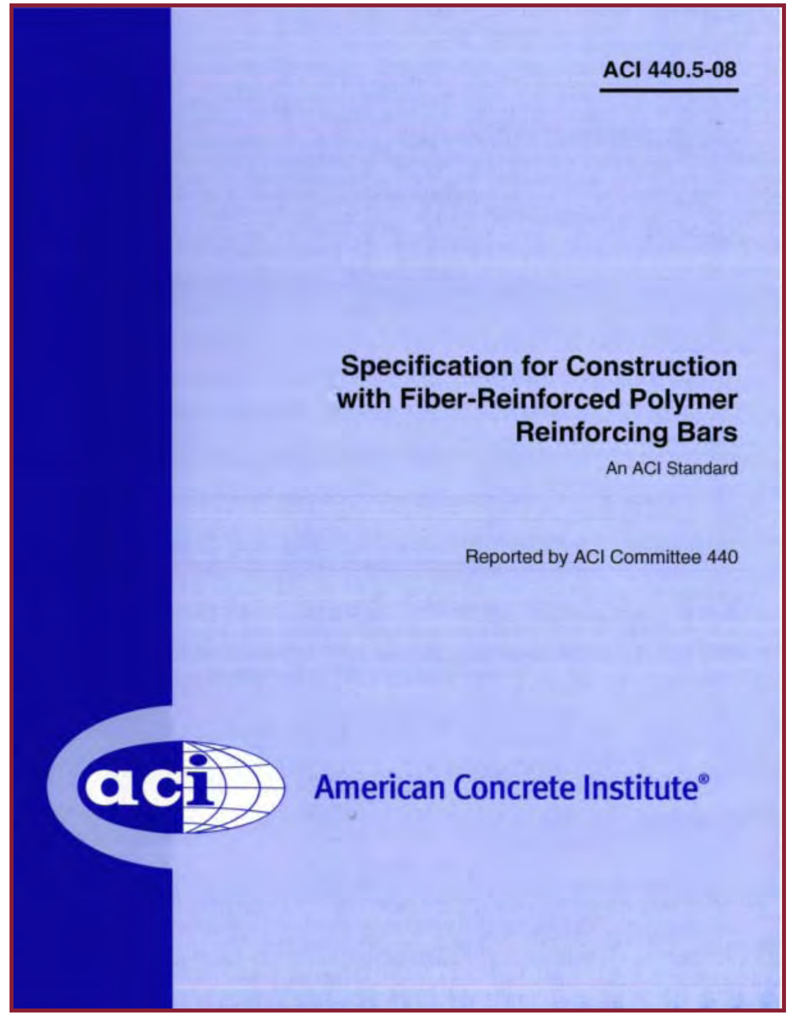
ACI – rebar, construction spec

- ACI 440.5-08, **mandatory language** (standard document)
- GFRP bar preparation, placement (including cover requirements, reinforcement supports), repair, and field cutting


ACI 440.5-08

Specification for Construction with Fiber-Reinforced Polymer Reinforcing Bars

An ACI Standard

Reported by ACI Committee 440

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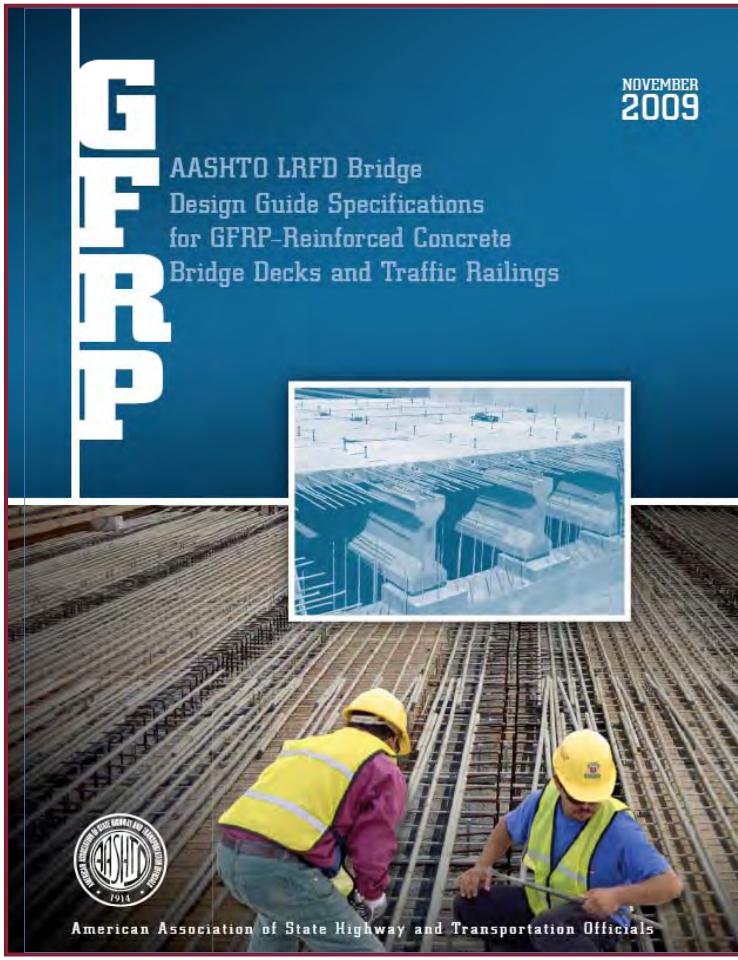
AASHTO design guide



- New AASHTO LRFD design guide specifications published 11/2009
- Bridge decks and traffic railings, glass FRP (GFRP) bars
- Specific properties of GFRP reinforcement, design algorithms and resistance factors, detailing, material and construction specifications

ACI Test methods

ACI 440.3R-04

Guide Test Methods for Fiber-Reinforced Polymers (FRPs) for Reinforcing or Strengthening Concrete Structures

Reported by ACI Committee 440

aci international

american concrete institute
P.O. BOX 9094
FARMINGTON HILLS, MICHIGAN 48333-9094

Designation: D 7205/D 7205M – 06

Standard Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars[1]

This standard is issued under the fixed designation D 7205/D 7205M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This test method determines the quasi-static longitudinal tensile strength and elongation properties of fiber reinforced polymer matrix (FRP) composite bars commonly used as tensile elements in reinforced, prestressed, or post-tensioned concrete.

NOTE 1—Additional procedures for determining tensile properties of polymer matrix composites may be found in test methods D 3039/D 3039M and D 3916.

1.2 Linear elements used for reinforcing Portland cement concrete are referred to as bars, rebar, rods, or tendons, depending on the specific application. This test method is applicable to all such reinforcements within the limitations noted in the method. The test articles are referred to as bars in this test method. In general, bars have solid cross-sections and a regular pattern of surface undulations and/or a coating of bonded particles that promote mechanical interlock between the bar and concrete. The test method is also appropriate for use with linear segments cut from a grid. Specific details for preparing and testing of bars and grids are provided. In some cases, anchors may be necessary to prevent grip-induced damage to the ends of the bar or grid. Recommended details for the anchors are provided in Annex A1.

1.3 The strength values provided by this method are short-term static strengths that do not account for sustained static or fatigue loading. Additional material characterization may be required, especially for bars that are to be used under high levels of sustained or repeated loading.

1.4 *This standard does not purport to address all of the safety problems, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

1.5 The values stated in either SI units or inch-pound units are to be regarded separately as standard. Within the text, the inch-pound units are shown in brackets. The values stated in each system are not exact equivalents; therefore, each system must be used independently of the other. Combining values from the two systems may result in nonconformance with the standard.

2. Referenced Documents

2.1 *ASTM Standards:* [2]

A 615/A 615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
D 792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D 883 Terminology Relating to Plastics
D 3039/D 3039M Test Method for Tensile Properties of Polymer Matrix Composite Materials
D 3171 Test Methods for Constituent Content of Composite Materials
D 3878 Terminology for Composite Materials
D 3916 Test Method for Tensile Properties of Pultruded Glass-Fiber-Reinforced Plastic Rod
D 5229/D 5229M Test Method for Moisture Absorption Properties and Equilibrium Conditioning of Polymer Matrix Composite Materials
E 4 Practices for Force Verification of Testing Machines
E 6 Terminology Relating to Methods of Mechanical Testing
E 83 Practice for Verification and Classification of Extensometer System
E 122 Practice for Calculating Sample Size to Estimate, With a Specified Tolerable Error, the Average for a Characteristic of a Lot or Process
E 456 Terminology Relating to Quality and Statistics
E 1012 Practice for Verification of Test Frame and Specimen Alignment Under Tensile and Compressive Axial Force Application
E 1309 Guide for Identification of Fiber-Reinforced Polymer-Matrix Composite Materials in Databases
E 1434 Guide for Recording Mechanical Test Data of Fiber-Reinforced Composite Materials in Databases
E 1471 Guide for Identification of Fibers, Fillers, and Core

[1] This test method is under the jurisidiction of ASTM Committee D30 on Composite Materials and is the direct responsibility of Subcommittee D30.05 on Structural Test Methods.

Current edition approved March 15, 2006. Published April 2006.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

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Rebar Test Methods

- ACI 440.3R-04 – (12) test methods for FRP rebars
- ASTM D30 (Composite Materials) and D30.05 (Structural Test Methods) committees, now D30.10

Test Method	ASTM Standard
B.1. Bar Cross-Section	D7205-06 (R11)
B.2. Bar Tension	D7205-06 (R11)
B.4. Bar Transverse Shear	D7617-11
B.6. Bar Alkaline Tension	WK27200
B.8. Bar Creep Rupture	D7337-07
App. A. Bar Anchors	D7205-06 (R11)

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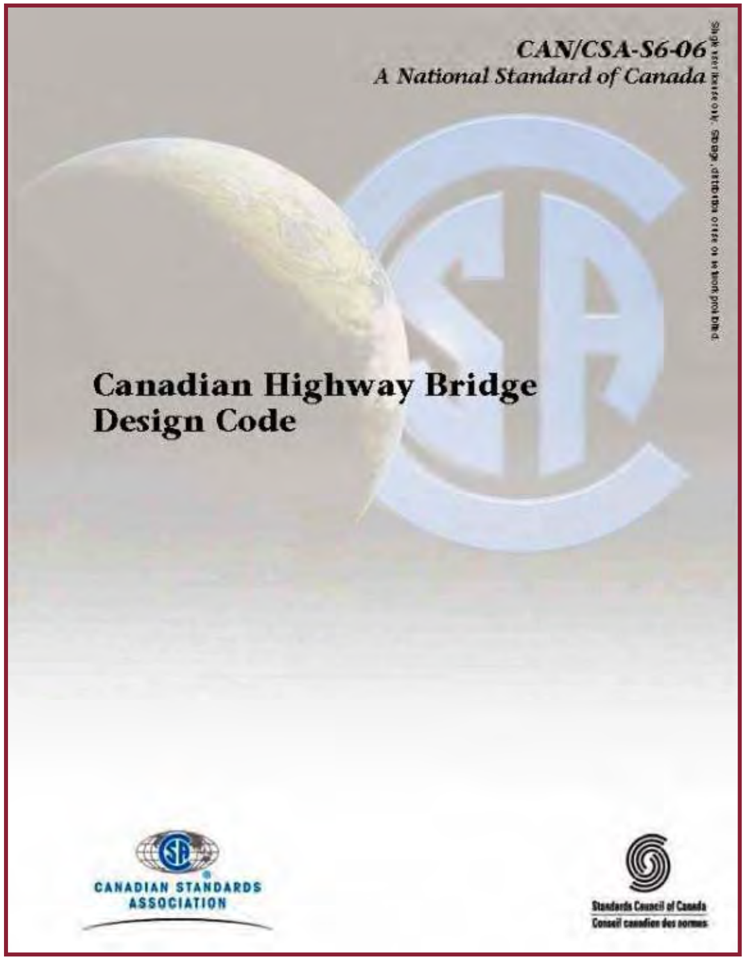
Canada - Highway Bridge Design Code



- 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

Canadian Standards

- CSA S807 – 09
- Qualification and QA criteria

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Quality Assurance - Verification and traceability of bar properties

Tensile Testing of GFRP Rebar

AslanFRP
Hughes Brothers

TEST MACHINE
Baldwin Model 120 CS S/N: 1005
Electromechanical
120,000 lbs Capacity Tension/Compression
Certification Number 148082709080420
By Instron 27-August-09
Operating System - MTEST Windows
Grip V Style

Lot Type: ⦿ Production ○ Experimental ○ Durability

Tested By	R Colberg
Test Date	2/22/2010
Rebar Size	RB5
Stock Order	5040
Work Order	1
Date Produced	2/17/2010
Lot Color Code	Yellow D9810
Matrix	VE
Formulation	RBVEIP2567-25 FA
Test Temp	71.8°F
Test R/H	19%
Load Rate	0.50"/min
Reinforcement	ECR-Glass
Filament Diameter	23 Micron
Sizing	Silane
Yield	113
# of Ends	68
Sample Length	48.00"
Free Length	27.375"
Anchor Length	10.00"
Potting Material	M-183

Sample #	Load @ Failure (lbs)	Tensile Strength (psi)	Tensile Strength (MPa)	Ultimate Strain (in/in)	Modulus of Elasticity (psi)	Modulus of Elasticity (GPa)
1	35,252.6	114,904.2	792.3	0.0164	6,987,036	48.2
2	34,147.0	111,300.5	767.4	0.0162	6,860,213	47.3
3	35,208.9	114,761.7	791.3	0.0163	7,031,870	48.5
4	34,454.6	112,303.1	774.3	0.0162	6,925,616	47.8
5	34,082.0	111,088.7	766.0	0.0163	6,825,419	47.1
6	33,924.3	110,574.6	762.4	0.0161	6,862,768	47.3
7	35,901.9	117,020.5	806.9	0.0169	6,905,709	47.6
8	35,991.8	117,313.6	808.9	0.0173	6,772,467	46.7
			Averages	0.0165	6,896,387	47.5

	PSI	MPa	Strain
Tensile Strength Average	113,658.4	783.7	
Sigma	2,523.5	17.4	0.0004
3 Sigma	7,570.4	52.2	0.0012
σ -3 Sigma	106,088.0	731.5	0.0153

Extensometer Epsilon Model 3543

Distance from Anchors	10.688"
LBS of Load at Removal	14,573
Percent of Load at Removal	50%
Span	6.0"

Lot Comments

Sample	Mode of Failure
1	Delam Center
2	Delam Bottom
3	Delam Center
4	Delam Center
5	Delam Center
6	Delam Center
7	Delam Center
8	Delam Center

Surface: Undulated Externally Wrapped
Spacing of Wrap .75 - 1.0"
Silica Sand applied to Surface During Process
* Samples cut using Diamond Blade Cutoff Saw
** Anchorages are cut to length and wheel abrated
Schedule 40 Pipe

Additional Lab Test Data

% Glass to Matrix	74.71 / 25.29	ASTM D2584 By Weight
Barcol Hardness	61.6	ASTM D2583
Wicking	Not Continuous	ASTM D5117
Transverse Shear	32,652.4 psi	ACI 440 B.4
Apparent Shear	8,227.1 psi	ASTM D4475
Water Absorption Average 24 Hour	0.1446 %	ASTM D570 P7.7

Rebar Size	Required Tensile Strength psi / MPa	Load Cell Min (lbs / N)	Nominal Ø (in / mm)	Standard CSA A_b (in / mm)
5	95,000	29,148	0.6250	0.3068
16	655.0	129,650	15.88	197.9

Metric References

Hughes Brothers, Inc. Seward, NE

Per ASTM D7205-06

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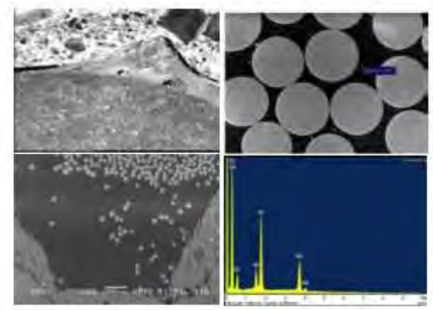
Durability

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

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

NO Degradation of GFRP bars found !

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

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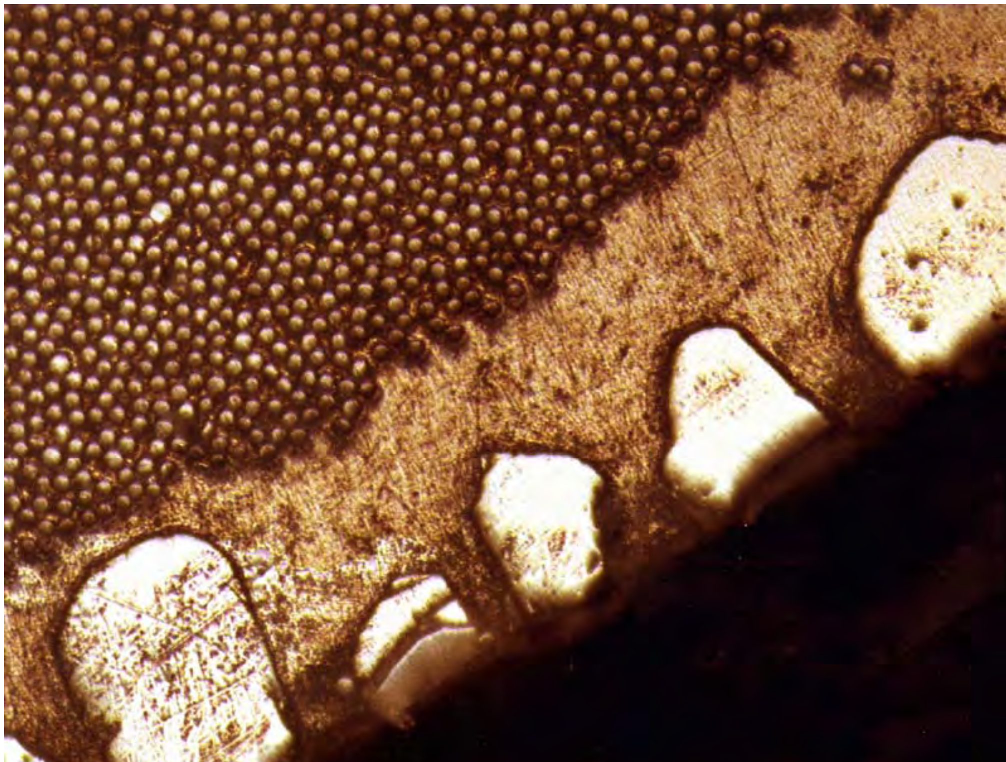
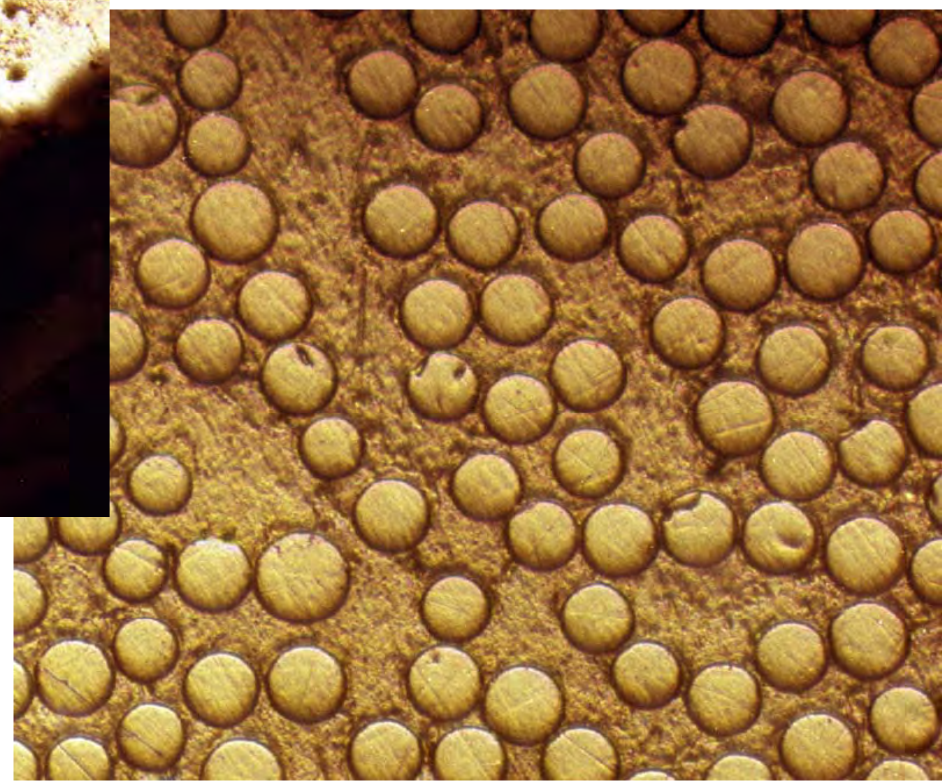
…..a closer look





Applications

Many installations and growing

TEA-21

- FY 98-03 - IBRC Program
- 124 FRP Projects - $87M funded
  - 44 decks
  - **14 rebar**
  - 33 repair
  - 6 tendons
  - 27 others (i.e. FRP glulam)
- 19 states with FRP decks
- Future funding - uncertain

Installations Today

- In the U.S.
  - >190 installations that use FRP composites
  - >50 installations where FRP bars are used in bridge decks
  - 15 states (CO, FL, IA, IN, KY, MO, NC, NY, OH, OR, TX, UT, VT, WI, WV) use FRP bars in bridge decks
- In Canada,
  - >195 installations that use FRP composites
  - 190 installations use FRP bars in bridge decks, parapets, barriers, sidewalks

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Applications

- Cast in Place
- Precast
- Top mat
- Top and bottom mat
- Decks, parapets, sidewalks
- Other applications: tunneling (soft eye, seawalls, MRI rooms, light rail foundations, railway girders, culverts, and many more.

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FRP Rebar for Decks & Approach Slabs

Applications

Sierrita de la Cruz Creek Bridge,
Amarillo, TX
2000, USA

Taylor Bridge
Manitoba
Canada

Pierce Street Bridge,
Lima OH
USA

Wotton, Quebec
Canada

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Morristown Bridge Vermont 2002

Concrete cast-in-place
May 2002

Bridge opened to traffic
July 2002

Courtesy of Pultrall, Inc.

Emma Park Bridge, Pleasant Grove, Utah DOT, 2009

(Courtesy of Hughes Brothers, Inc.)

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Emma Park Bridge

- Full Depth Precast – top & bottom mat
- Cost premium in 2009 to use GFRP over Epoxy bar
    - 14% greater deck cost – due in large part to additional girders
    - On a 1:1 basis, GFRP bars equal in unit price to epoxy steel

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53rd Ave Bridge Bettendorf, IA 2001

Courtesy of
Hughes Bros.

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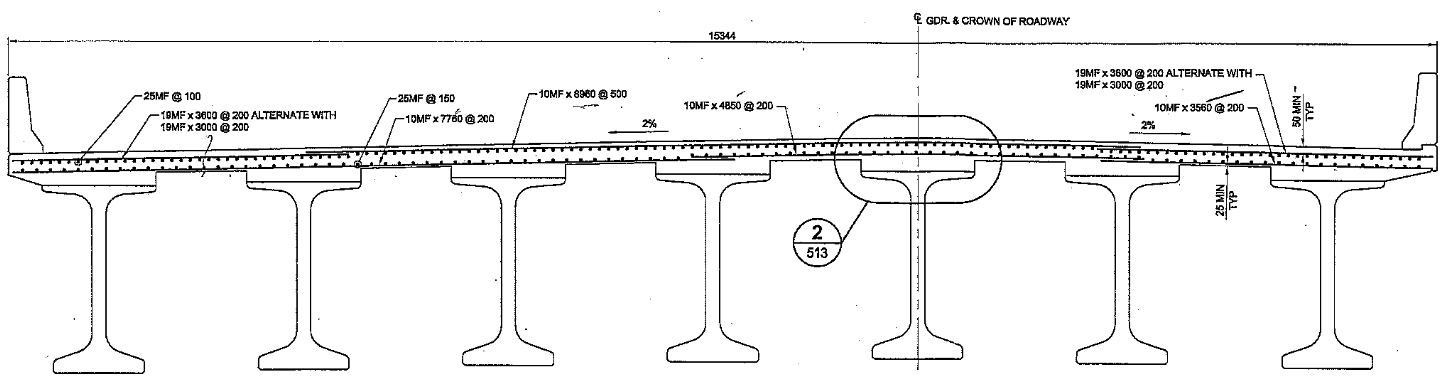
Floodway Bridge, Manitoba, Canada (2005)

- 2 Bridges 8 spans each
- 2 Lanes Each Bridge
- 142 feet typical span
- 1136 feet total length (1/5 mile)
- 50 foot Wide
- 9 inch thick Deck Slab
- 8 feet Girder Spacing



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Floodway Bridge, Manitoba, Canada

- Largest Steel Free Deck Project
- Largest FRP reinforced bridge in the world
- 8 Truckloads of GFRP Rebar
- 150 Tons of GFRP = 1.2 million lbs of steel rebar (30 truckloads)
  - Primarily #8 and #3 Longitudinal
  - #6 Transverse
- 3200 CY concrete (6400 tons

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Floodway Bridge, Manitoba, Canada

Courtesy of
Hughes Bros.

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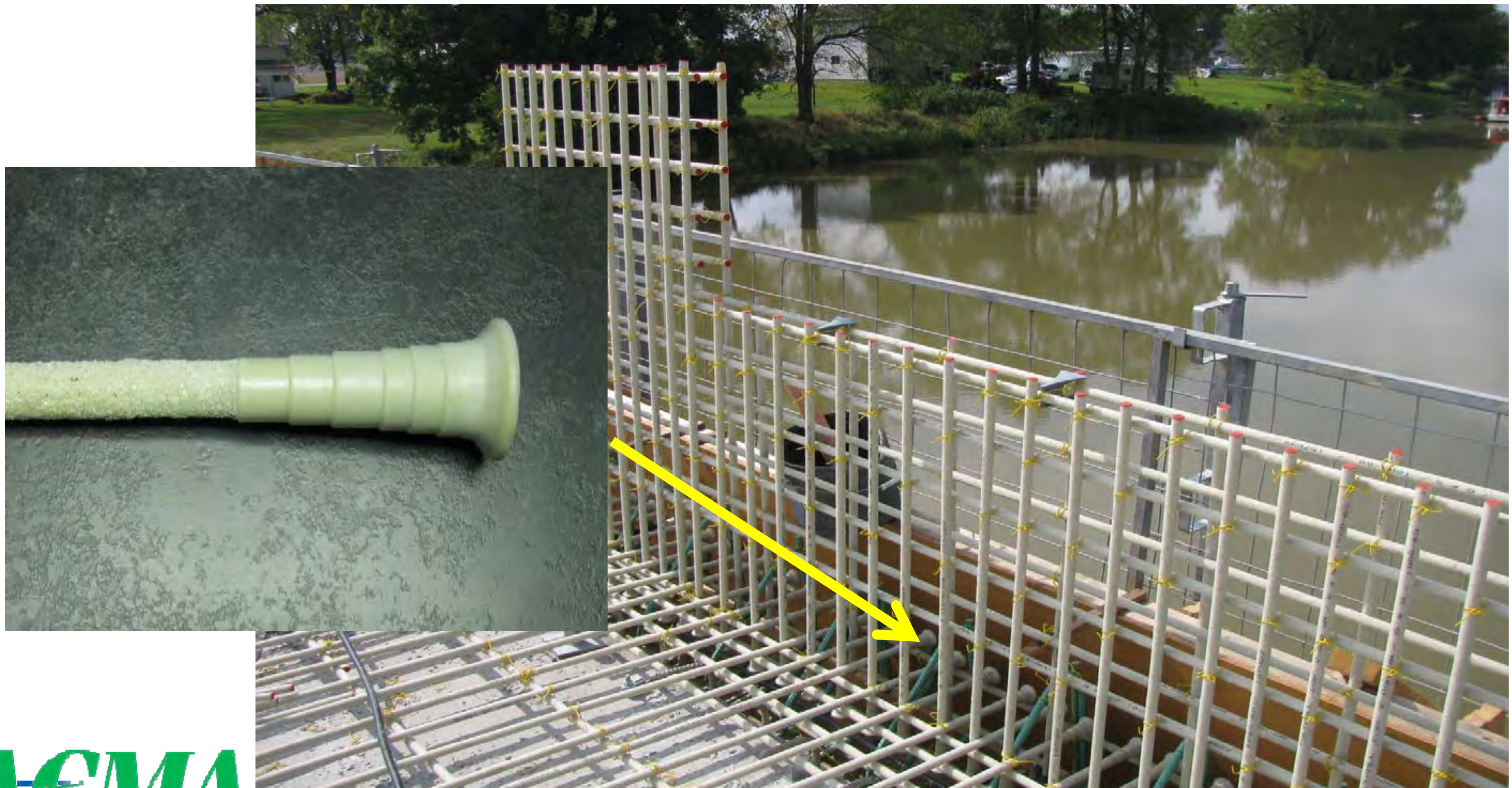
American Composites Manufacturers Association

O’Reilly Bridge - Canada

New anchor head used

Courtesy of Pultrall, Inc.



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Noden Causeway

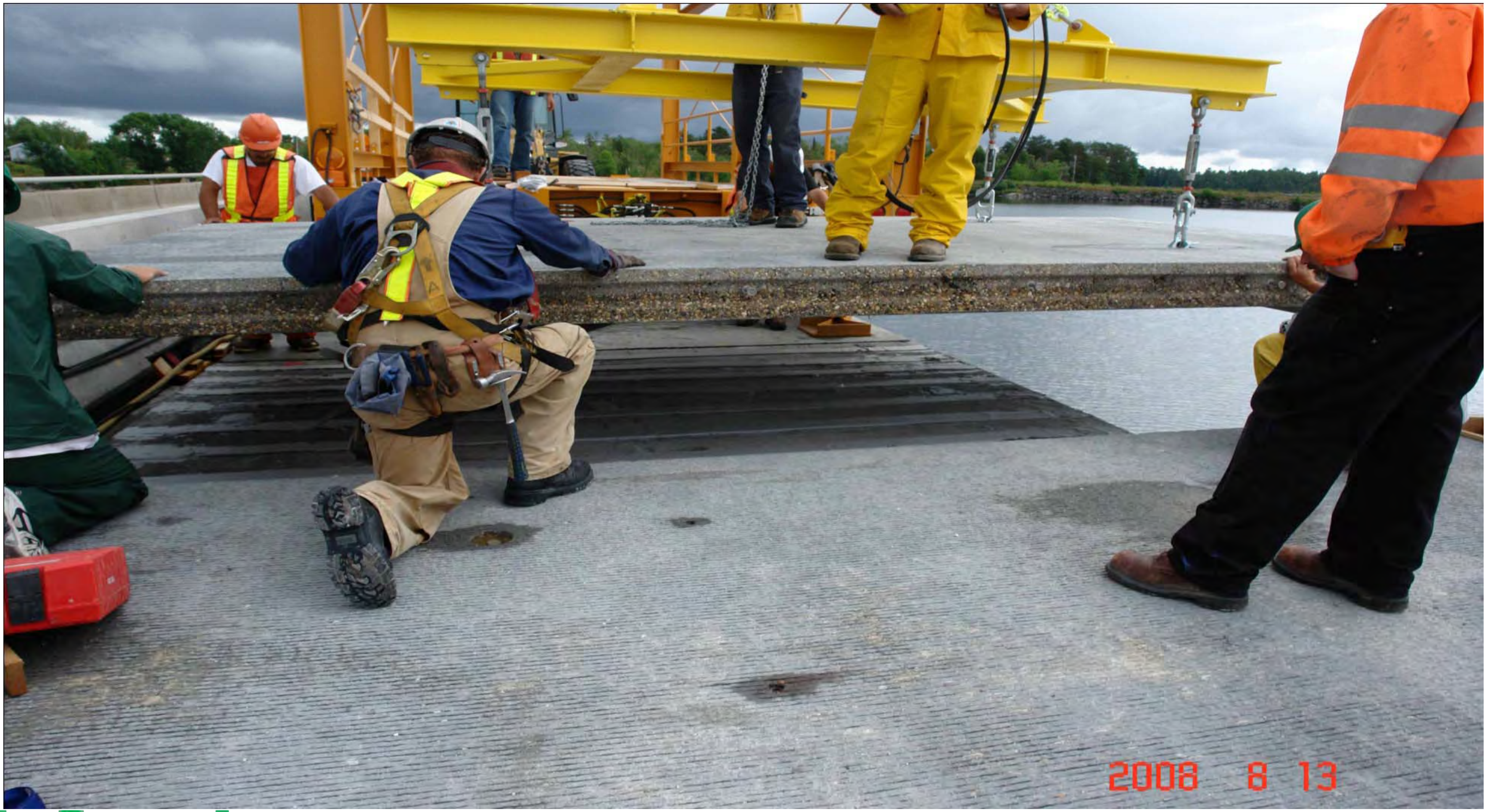
- Prestressed/precast deck

Courtesy of Pultrall, Inc.

Noden Causeway

Courtesy of Pultrall, Inc.

Noden Causeway



Courtesy of Pultrall, Inc.

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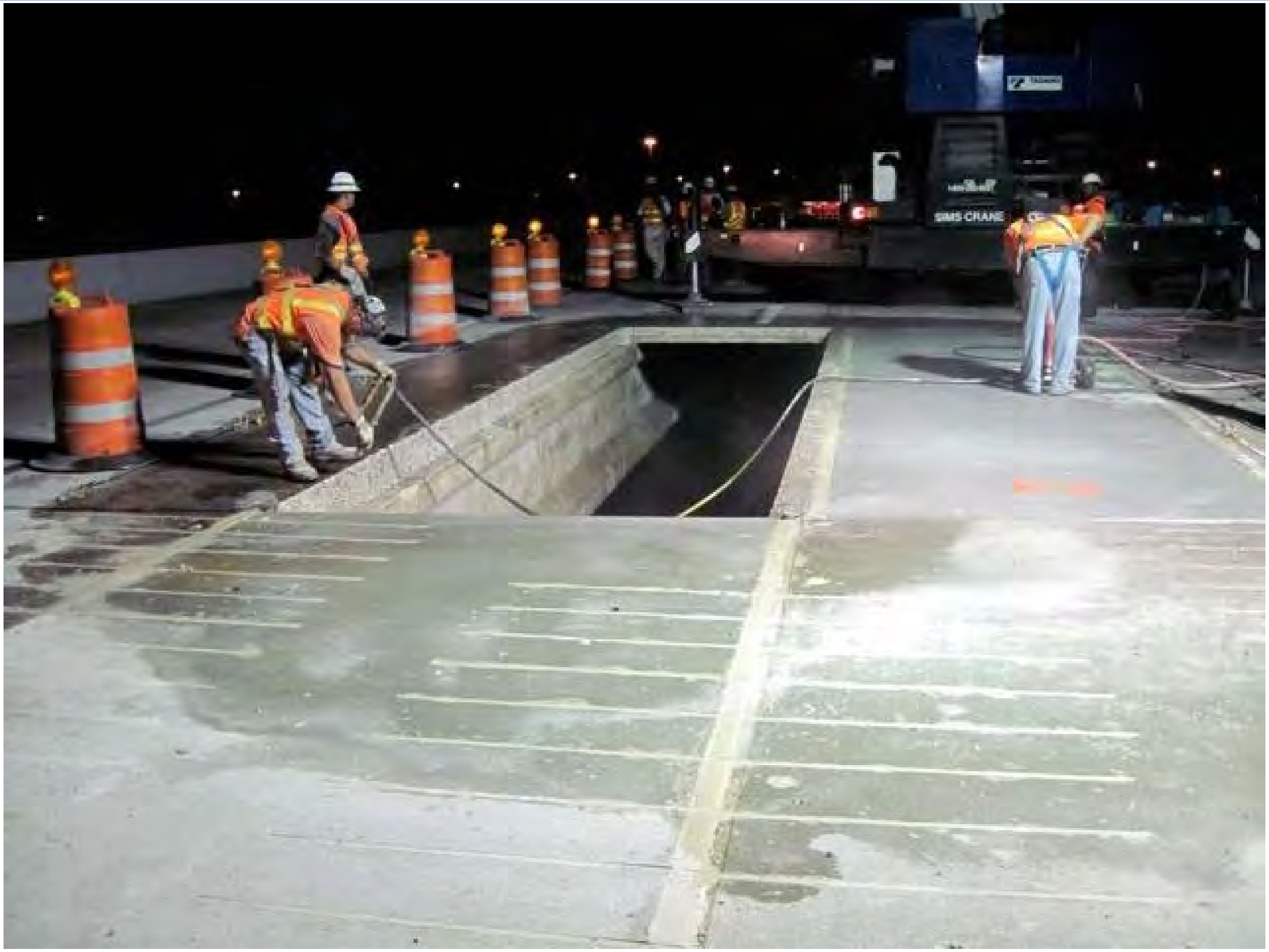
I-75- Tampa ~ Deck Replacement – NSM Stitching



Courtesy of Hughes Bros.

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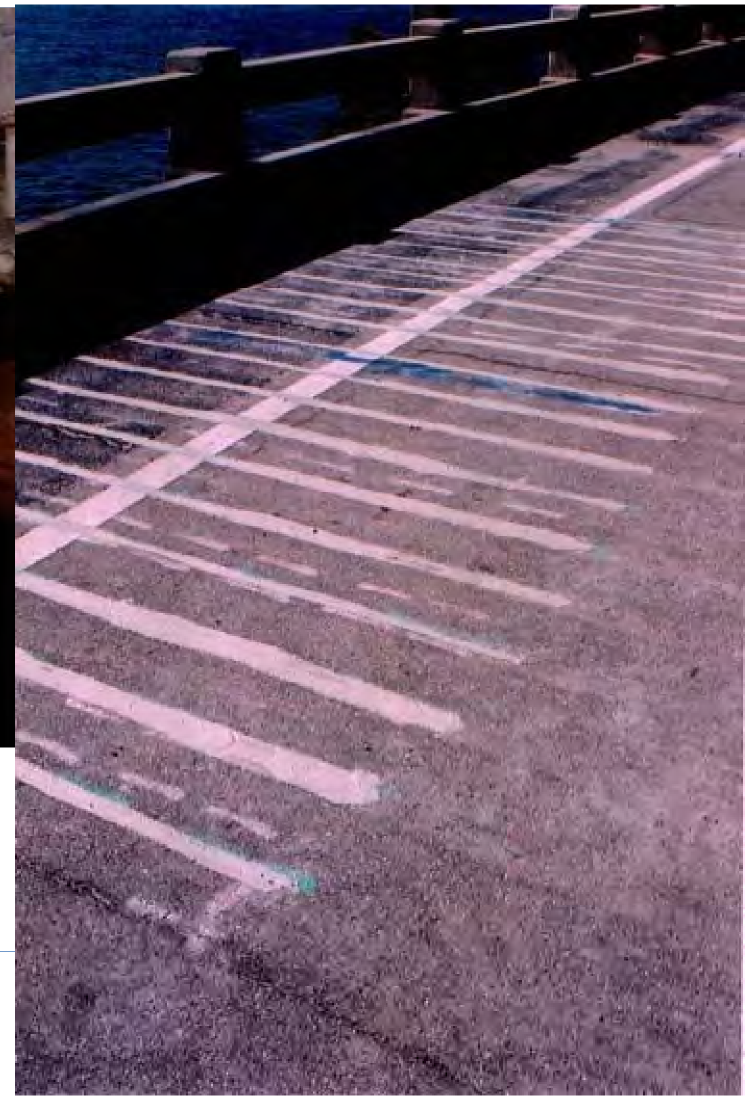
Courtesy of Hughes Bros.

New Precast deck panels , NSM stitched at night leaving bridge open to traffic during high volume use in daytime.

Structural Strengthening – Bridge Cantilever – Old Florida Keys Bridge



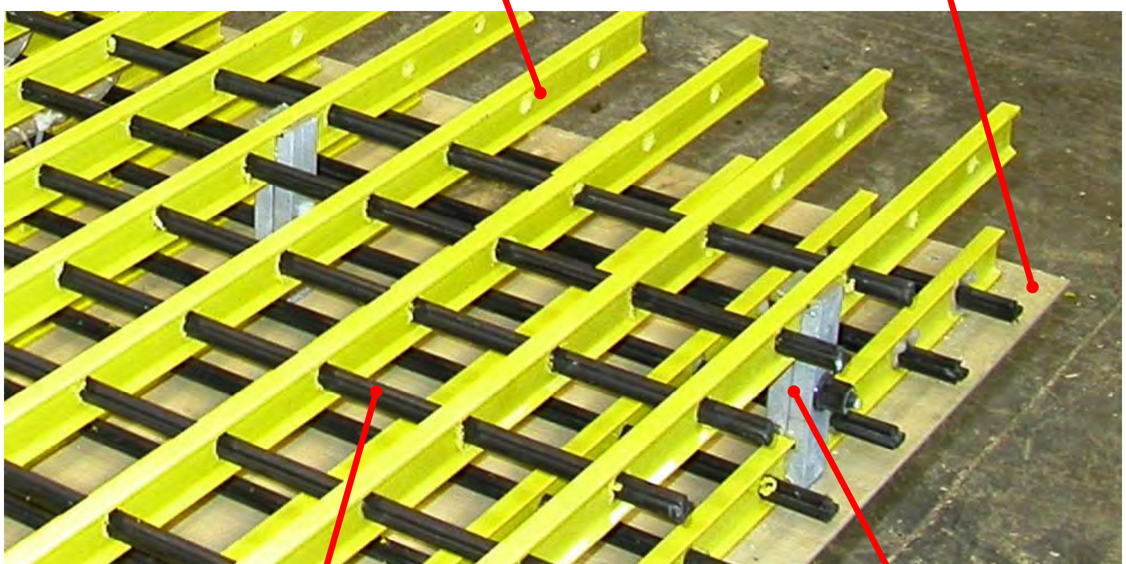
- Cast in place repair with GFRP & CFRP bars

Prefabricated FRP stay-in-place reinforcement panels

Large-size 24’ x 8’, double-layer stay-in-place (SIP) reinforcing panels pre-assembled using off-the-shelf pultruded GFRP components

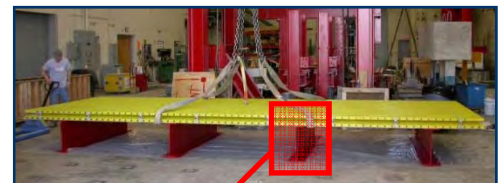
1.5” I-bars
(4” o.c. perpendicular to traffic)

1/8” thick epoxy bonded form plate



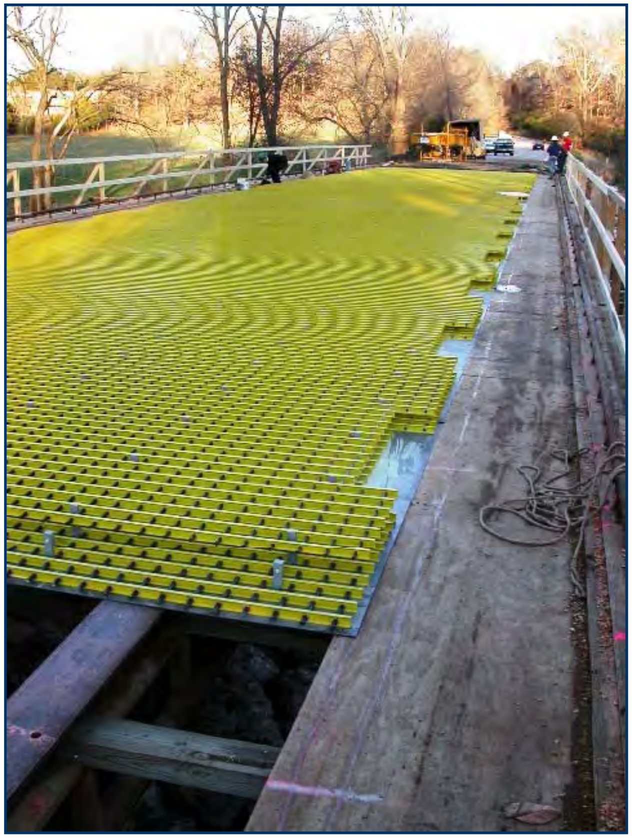
Three-part cross rods
(4” o.c. parallel to traffic)

Vertical connectors



Deck construction

- Day 1: SIP panels setting and anchoring



Heavy Rail – Miami MetroRail – MIA
2.4 Miles of elevated rail

- Rail Plinths 100% reinforced with GFRP Bars

Seawalls

Courtesy of Marshall Composite Tehnologies

Summary

- Complete set of guides, test methods and standards are available for GFRP bars
- Many bridges built with GFRP bars and performing well
- Non-proprietary solution, traditional supply chain acquisition & installation in place
- Extended service life of GFRP reinforced decks is expected
- Many practices adopted for corrosion protection are not necessary with FRP bars
- Holistic view of bridge deck construction makes FRP bars the best value proposition

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Composites Conference

www.compositesshow.org

- COMPOSITES 2013
- Orange County Convention Center, Orlando, FL
- January 29-31, 2013
- Over 4,000 attendees
- Technical papers and educational sessions on many topics including infrastructure and construction
- Expo with suppliers and manufacturers

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LRFD – Pultruded Composites

Pre-Standard for
Load & Resistance Factor
Design (LRFD) of Pultruded
Fiber Reinforced Polymer (FRP)
Structures
(Final)

Submitted to:
American Composites Manufacturers
Association (ACMA)

November 9, 2010

- **Pre-Standard released 2010**
  - Ch. 1 General Provisions
  - Ch. 2 Design Requirements
  - Ch. 3 Tension Members
  - Ch. 4 Compression Members
  - Ch. 5 Flexural and Shear Members
  - Ch. 6 Combined Forces & Torsion
  - Ch. 7 Plates and Built-Up Members
  - Ch. 8 Bolted Connections

Thank You

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Director, Composites Growth Initiative

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