First International Workshop on Glass Fiber Reinforced Polymer (GFRP) Bar for Concrete Structures (IWGFRP-1)

TECHNICAL PROGRAM

July 18, 2017, 8:00 to 17:45

Delta Hotel, Sherbrooke (Quebec) CANADA

ORGANIZERS

Chair: Brahim Benmokrane, Professor and Tier-1 Canada Research Chair, and NSERC/Industry Research Chair, Department of Civil Engineering, University of Sherbrooke, Sherbrooke, QC, CANADA

Co-Chair: Antonio Nanni, Inaugural Senior Scholar Professor and Chair Dept. of Civil, Arch. & Environ. Engineering, University of Miami, FL, USA

SPONSORS

UNIVERSITÉ DE SHERBROOKE
DEPARTMENT OF CIVIL ENGINEERING

NSERC CRSNG

CRC Canada

UNIVERSITY OF MIAMI

ConSEA

MESSAGE FROM THE CHAIR AND THE CO-CHAIR

The deterioration of concrete infrastructure owing to corrosion of reinforcement steel is one of the major challenges facing the construction industry today. Worldwide, governments and industrial firms are looking for infrastructure systems that are stronger, last longer, are more resistant to corrosion and cost less to build and maintain. Engineers all over the world are searching for new and affordable construction materials as well as innovative approaches and systems to solve problems. As a result, in the last decade, there has been a rapid increase in using **innovative noncorrosive glass fiber-reinforced polymers (GFRP)** reinforcing bars for concrete structures due to enhanced properties and cost-effectiveness. The GFRP bars have been used extensively in different applications such as bridges, parking garages, water tanks, tunnels and marine structures in which the corrosion of steel reinforcement has typically led to significant deterioration and rehabilitation needs. Many significant developments from the manufacturer, various researchers and Design Codes along with numerous successful installations have led to a much higher comfort level and exponential use with designers and owners. After years of investigation and implementations, public agencies and regulatory authorities in North America have now included GFRP as **a premium corrosion resistant reinforcing material** in their corrosion protection specifications. Currently, Canadian Highway Bridge Design Code and the *AASHTO* LRFD Bridge Design Specifications contain design provisions for the design of concrete bridge members reinforced with FRP bars. As a result, over 400 bridges across Canada and USA have been designed and constructed using GFRP bars.

This workshop will provide a unique opportunity for end-users/DOT's, contractors, consultants, engineers firms, GFRP bar manufacturers, and researchers to **exchange up-to-date knowledge** on the use of GFRP bars in concrete structures (bridges, buildings, marine structures) including **challenges and opportunities**. The workshop consists of presentations by government authorities such as the Ministry of Transportation of Ontario, the Ministry of Transportation of Quebec, Florida Department of Transportation, Prince Edouard Island Transportation, Infrastructure, and Energy, Missouri Department of Transportation and Texas Department of Transportation, consultants, manufacturers of resins and glass fibers, GFRP reinforcing bar manufacturers, researchers and open discussions.

Topics and perspectives of the workshop presentations:

1. End-User Perspective & Experience
2. North American & International Codes (CSA, ACI, AASHTO, fib), Standards, and Specifications Perspective
3. GFRP Bar Industry Overview & Future
4. Ongoing research and new applications

We would like to thank all participants – without them this workshop would not be successful.

Sincerely,

Brahim Benmokrane, PhD, PE
Chair IWGFRP-1
Professor
Canada Research Chair in Advanced Composite Materials for Civil Structures
NSERC/Industry Research Chair in Innovative FRP Reinforcement for Concrete
Director, Quebec-FQRNT Research Centre on Concrete Infrastructure (CRIB)
Director, The University of Sherbrooke Research Centre on FRP Composites (CRUSMaC)
Department of Civil Engineering
University of Sherbrooke
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Antonio Nanni, PhD, PE
Co-chair IWGFRP-1
Inaugural Senior Scholar
Professor and Chair
Dept. of Civil, Arch. & Environ. Engineering
University of Miami
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Coral Gables, FL 33146-0630
Phone: 305-284-3461
E-mail: Nanni@miami.edu

Tuesday July 18, 2017	Session 1: Owner's Perspective on the Use of GFRP Bars	8:00 - 10:30	Sherbrooke B

Session Chairs: **Brahim Benmokrane and Antonio Nanni**

8:00	*Brahim Benmokrane & Antonio Nanni* – Welcoming Remarks
8:10	*Sam Fallaha, Chase Knight, and Steve Nolan*, FDOT (Florida Department of Transportation) State Structures Design Office – **FDOT GFRP Implementation - Current Status, Projects, and Challenges**
8:50	*David Lai*, MTO (Ministry of Transportation Ontario) Head Bridges Rehabilitation Section, Bridge Office, Highway Standard Branch – **MTO's Policies, Projects, Specifications, and Practices for the Use of GFRP Bar**
9:10	*Darrell Evans*, PEI (Prince Edouard Island) Transportation, Infrastructure, and Energy, Capital Projects Division – **Use of GFRP Bar in PEI Transportation and Infrastructure Projects**
9:30	*Tim Bradberry*, TxDOT (Texas Department of Transportation) Engineering Support Lead of Bridge Division, Bridge Design Section – **Past Use and Future Plans for GFRP Rebar in Texas Highway Construction**
9:50	*Steve Arsenault and Gérard Desgagné,* MTQ (Ministry of Transportation Quebec) Bridge Structures Department – **Quebec Current Status and Practices for the Use of GFRP Bar in Bridges**
10:10	*Bryan Hartnagel*, MoDOT (Missouri Department of Transportation) Bridge Division – **Use of GFRP Bar and Project Experiences in Missouri**
10:30	**Refreshment break** — **Foyer ABC**

Tuesday July 18, 2017	Session 2: Codes, Standards & Specifications Perspective on the use of GFRP Bars	10:50 - 12:30	Sherbrooke B

Session Chairs: **Sam Fallaha and David Lai**

10:50	*William Gold*, BASF Corporation & Chair ACI 440 Committee – **Development of 440 H Design Code on Concrete Structures Reinforced with GFRP Bars and ASTM Specifications for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement**	
11:10	*Brahim Benmokrane*, University of Sherbrooke – **Development of New Editions of CSA Standards Related to GFRP Bar for Concrete Structures**	
11:30	*Antonio Nanni*, University of Miami – **Trends and Standards Development for FRP bars in New Construction in the US**	
11:50	*Allan Manalo*, University of Southern Queensland – **Trends and Standards Development for GFRP as Internal Reinforcement in Australia**	
12:10	*Emmanuel Ferrier*, University of Lyon 1 – **Trends and Development of Codes and Specifications on GFRP Bars for Concrete Structures in Europe**	
12:30	**Lunch**	**Sherbrooke C**

Tuesday July 18, 2017	Session 3: GFRP Bar Manufacturer's Installer's, & Supplier's Perspective	13:30 - 15:30	Sherbrooke B

Session Chairs: **Tim Bradberry and Darrell Evans**

13:30	*John Busel*, Vice-President, Composite Grow Initiative, American Composites Manufacturers Association – **FRP Rebar Manufacturers Council**
13:45	*Amol Vaidya*, Global Innovation Leader, Owens Corning – **The Role of Glass Fibers & Sizing in the Glass-Fiber (GFRP) Rebar Applications**
14:00	*Joy Bennett*, Global Business Development Manager – Specialty Ashland Performance Materials – **Resin Manufacturing/QC for the GFRP Rebar Industry**
14:15	*Christian Witt*, General Manager, AGF Steel Inc (Ottawa Division) – **GFRP Experiences from the Point of View of the Rebar Fabricators/Installers**
14:30	*Bernard Drouin*, President, Pultrall Inc– **Quality Assurance for Raw Materials and Quality Control of GFRP Bar Manufacturing**
14:45	*Doug Gremel*, Director, FRP Composites Transportation Infrastructure, Hughes Brothers Inc – **Manufacturing Process Monitoring**
15:00	*Dritan Topuzi*, Product Manager, Fiberline Composites Canada Inc – **GFRP Bar Testing for Enhanced Quality Control**
15:15	*Jeff Rothchild*, Pultrusion Product Leader, AOC – **Best Practices for Providing Consistent Vinyl Ester Resins for the GFRP Rebar Industry**
15:30	**Refreshment break** — **Foyer ABC**

Tuesday July 18, 2017	Session 4: Ongoing Research and New Applications	15:50 - 17:10	Sherbrooke B

Session Chairs: **John Myers and Steve Arsenault**

15:50	*Brahim Benmokrane*, University of Sherbrooke – **Driven Field Test of Precast Concrete Piles Reinforced with GFRP Bars in Arthur Drive Bridge**
16:10	*Antonio Nanni*, University of Miami – **Halls River Bridge**
16:30	*Mark Green*, Queen's University – **Fire Resistance of Concrete Slabs Reinforced with GFRP Bars**
16:50	*Lawrence Bank*, City College of New York City – **Are GFRP Reinforcements Sustainable?**

Tuesday July 18, 2017	Closing Session	17:10 - 17:45	Sherbrooke B

Session Chairs: **John Busel and William Gold**

17:010	Question and Answers
17:45	**Closure of the Workshop**

Tuesday July 18, 2017	CDCC-2017 Welcoming Reception	18:00 - 20:00	Foyer C

2017 First International Workshop on GFRP Bar for Concrete Structures

July 18, 2017

Sherbrooke, QC, CANADA

FDOT GFRP-RC Implementation - Current Status, Projects and Challenges

Prepared by:

Sam Fallaha[1], Chase Knight[2] & Steven Nolan[1]

[1] FDOT State Structures Design Office

[2] FDOT State Materials Office

FDOT

Current Status, Projects and Challenges

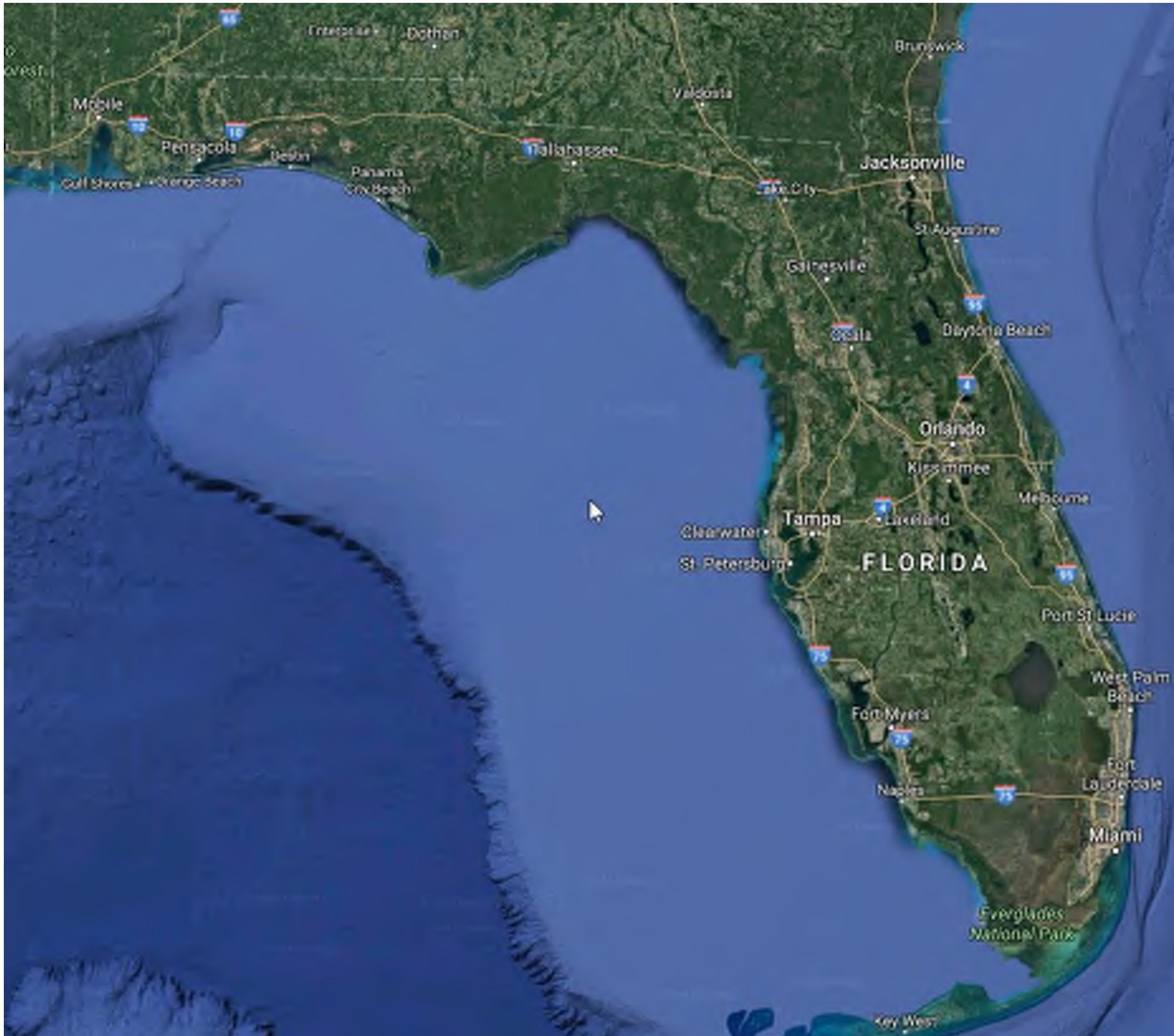
Part 1:

- The Need – Why Composites?
- Available Documentation
- FDOT Research
- Projects
- Looking Forward

Part 2:

- Challenges
- Focus Areas

The Need – Why Composites?



The Need – Why Composites?

- Avoiding Corrosion
  - Durability/Service Life
  - Cost/Benefit Analysis
  - Mitigating Risks


New and Old Seven-Mile-Bridge, (Florida Keys)


Old St. George Island Bridge Piling


Gandy Blvd. seawall, (Tampa Bay)

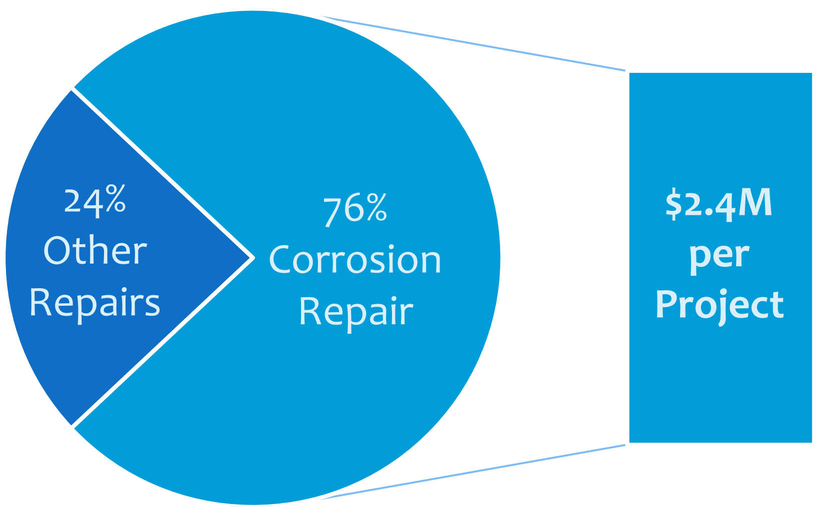

Courtney Campbell Causeway, seawall (Tampa Bay)

The Need – Why Composites?

- Avoiding Corrosion
  - Durability/Service Life
  - Cost/Benefit Analysis
  - Mitigating Risks

The Need – Why Composites?

- Example Costs of Corrosion
  - FDOT District 7 Study
    - Repair cost of bridges
    - 54 Bridge Projects Studied (02/03 to 12/13)
      - 20 Steel and 34 Concrete Bridges



Source: FDOT D7 District Structures Maintenance Office & T.Y. Lin

Available Documentation

Design Documentation

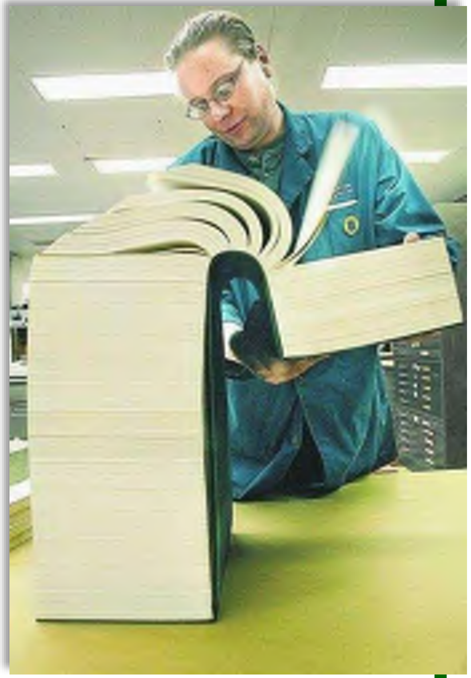
What's available from FDOT?

1. Design criteria –
   a) ***Fiber Reinforced Polymer Guidelines (FRPG)***
   b) ***Structures Design Guidelines (SDG)***;

2. Detailing criteria – ***Structures Detailing Manual (SDM)***;

3. ***Design Standards*** *(drawings)*;

4. ***Specifications*** *(Construction and Materials).*

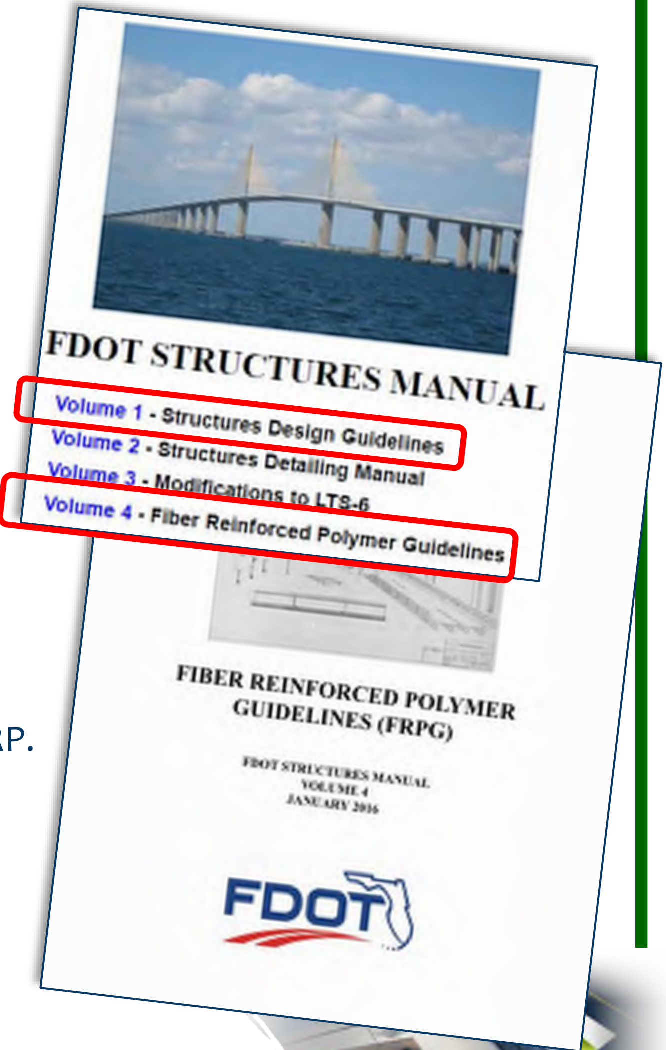


Available Documentation

Design Documentation

1. Design criteria –
   a) ***Fiber Reinforced Polymer Guidelines (FRPG)***
      - Overall commentary on FRP;
      - Specific design criteria, plan content and Specification requirements;
      - Design review requirements;
      - Approval of use process;
      - Permitted uses for each type of FRP.

   b) ***Structures Design Guidelines (SDG)***
      - Overall design criteria;
      - Revised and/or supplemented by ***Fiber Reinforced Polymer Guidelines (FRPG)*** for given applications of FRP.

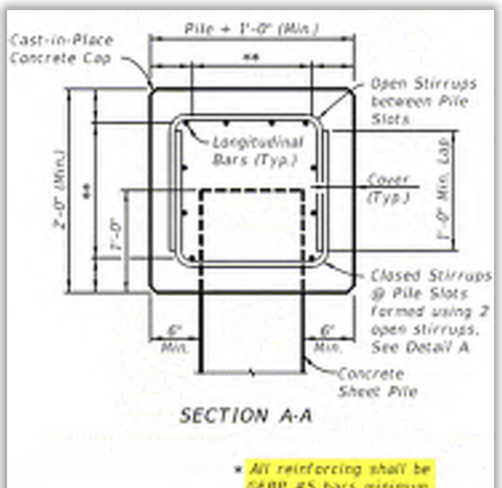


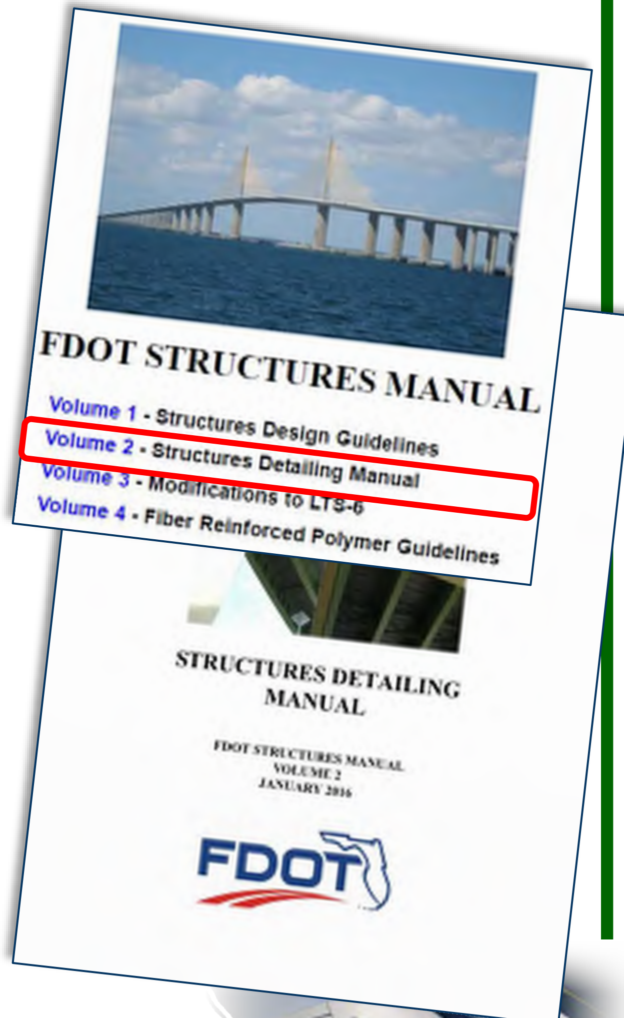
http://www.fdot.gov/structures/StructuresManual/CurrentRelease/StructuresManual.shtm

Available Documentation

Design Documentation

2. Detailing criteria – ***Structures Detailing Manual (SDM)***:
   a) Overall detailing criteria;
   b) Revised and/or supplemented by ***Fiber Reinforced Polymer Guidelines (FRPG)*** for given applications of FRP.





Available Documentation

Design Documentation

3. ***Design Standards:***

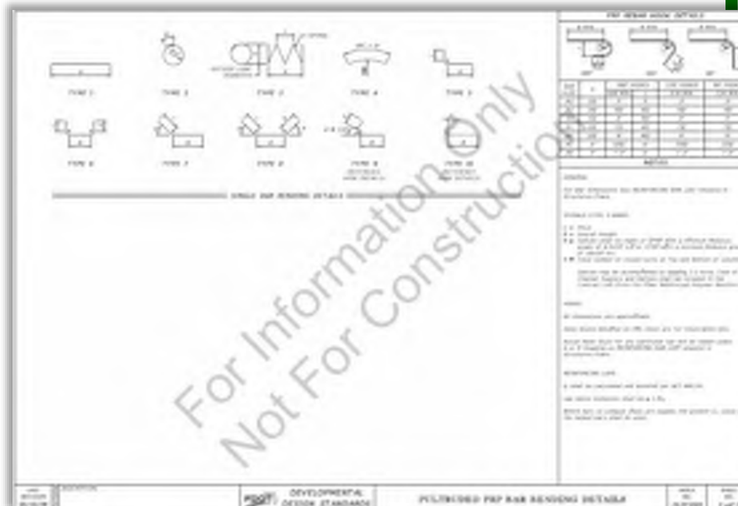
a) FY2017-18 Design Standards:

- ***Index 22600 series*** – Square CFRP & SS Prestressed Concrete Piles;
- ***Index 22440*** – Precast Concrete CFRP/GFRP & HSSS/GFRP Sheet Pile Wall

b) Developmental Design Standards:

- ***Index D6011c*** – Gravity Wall – Option C (GFRP reinforced);
- ***Index D21310*** – Pultruded FRP Bar Bending Details;
- ***Index D22420*** – GFRP reinforced 32" F-Shape Traffic Railing;
- ***Index D22900*** – GFRP reinforced Approach Slab;

http://www.fdot.gov/roadway/DesignStandards/Standards.shtm



http://www.fdot.gov/roadway/DS/Dev.shtm

Available Documentation

Design Documentation

4. *Construction & Material Specifications*

a) Standard Specifications (effective July 2016+):

- Implemented previous FRP ***Developmental Specifications.***
- ***400*** Concrete (includes FRP Bar construction considerations);
- ***415*** Reinforcing for Concrete (FRP Bars construction considerations);
- ***450*** Precast Prestressed Concrete Construction (FRP Bars construction considerations);
- ***932*** Nonmetallic Accessory Materials for Concrete Pavement and Concrete Structures (GFRP & CFRP Bars material specs);
- ***933*** Prestressing Strand (CFRP Strand material specs);

(Photograph) Hughes Bros. *Coated tie wire.*

http://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm

Available Documentation

Material & Producer Requirements

State Materials Office Oversight Role:

- ***Material Specifications***
- ***Sampling and Testing Requirements***
- ***Quality Control Program – Production Facility Approvals***
- ***Conduct and Facilitate Research – Durability/Service Life***

State Materials Office

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   a) ***Specifications Section 105***
   b) ***Materials Manual Chapter 12.1***
   c) ***Specifications Section 932 & 933***

2. Acceptance at the Project Level
   a) ***Certification***
   b) ***Sampling and Testing***

3. Materials Acceptance and Certification System (MAC)

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   a) ***Section 105 – Contractor Quality Control***
      - FRP producers must meet requirements of Materials Manual

   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

Producers of Fiber Reinforced Polymer Composites shall meet the requirements of Section 12-1, Volume II of the Department's Materials Manual, which may be viewed at the following URL:
http://www.dot.state.fl.us/programmanagement/Implemented/URLinSpecs/Section121V2.shtm.

2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*

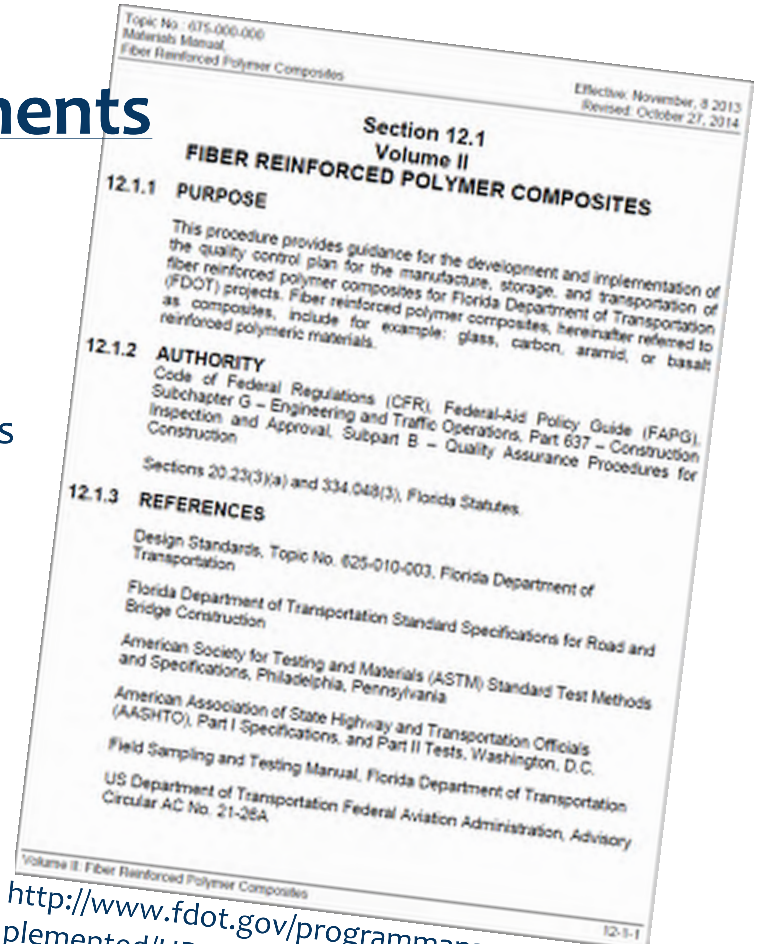
3. *MAC*

http://www.dot.state.fl.us/programmanagement/Implemented/SpecBooks/default.shtm

Available Documentation

Material & Producer Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) ***Materials Manual Chapter 12.1***
      - Production Facility Qualification Process
      - Producer Responsibilities
      - Incoming raw material control
      - Manufacturing quality control
      - QC inspection
      - Handling, Storage, Shipment
      - Documentation and Record Retention
   c) *Specifications Section 932*


Topic No.: 675-000-000
Materials Manual
Fiber Reinforced Polymer Composites

Effective: November, 8 2013
Revised: October 27, 2014

Section 12.1
Volume II
FIBER REINFORCED POLYMER COMPOSITES

12.1.1 PURPOSE

This procedure provides guidance for the development and implementation of the quality control plan for the manufacture, storage, and transportation of fiber reinforced polymer composites for Florida Department of Transportation (FDOT) projects. Fiber reinforced polymer composites, hereinafter referred to as composites, include for example: glass, carbon, aramid, or basalt reinforced polymeric materials.

12.1.2 AUTHORITY

Code of Federal Regulations (CFR), Federal-Aid Policy Guide (FAPG), Subchapter G – Engineering and Traffic Operations, Part 637 – Construction Inspection and Approval, Subpart B – Quality Assurance Procedures for Construction

Sections 20.23(3)(a) and 334.048(3), Florida Statutes

12.1.3 REFERENCES

Design Standards, Topic No. 625-010-003, Florida Department of Transportation

Florida Department of Transportation Standard Specifications for Road and Bridge Construction

American Society for Testing and Materials (ASTM) Standard Test Methods and Specifications, Philadelphia, Pennsylvania

American Association of State Highway and Transportation Officials (AASHTO), Part I Specifications, and Part II Tests, Washington, D.C.

Field Sampling and Testing Manual, Florida Department of Transportation

US Department of Transportation Federal Aviation Administration, Advisory Circular AC No. 21-26A

Volume II: Fiber Reinforced Polymer Composites

12-1-1

http://www.fdot.gov/programmanagement/Implemented/URLinSpecs/Section121V2.shtm

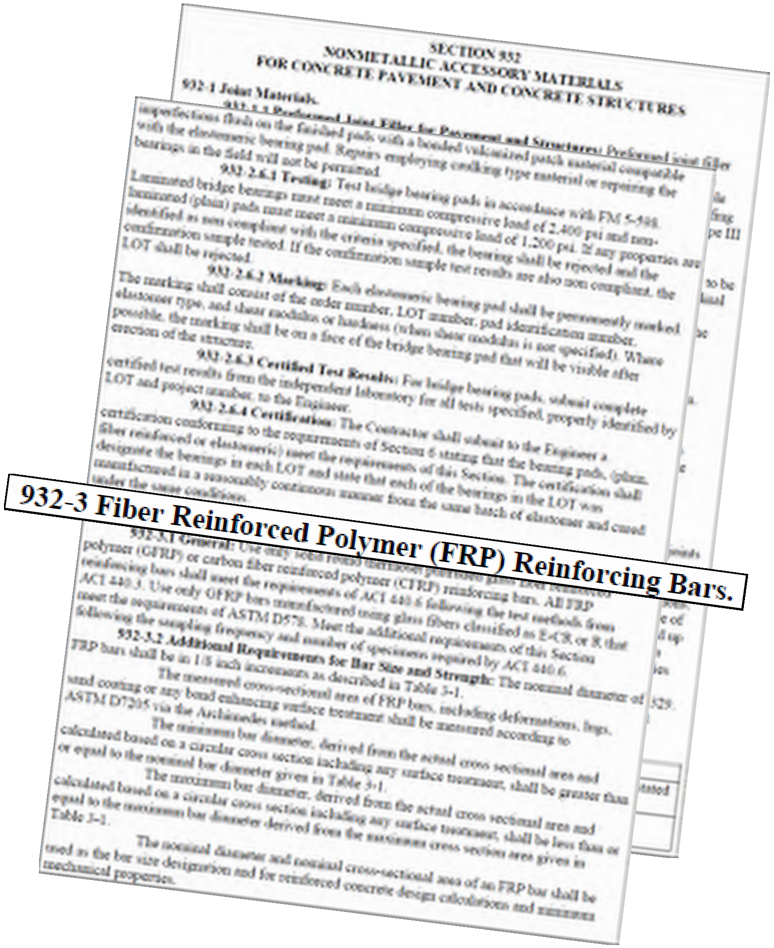
2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*

3. MAC

Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) ***Specifications Section 932***
      - Since July 2016
      - Sizes and Strengths
      - Physical Property Requirements for Producer Qualification
      - Requirements for Acceptance at the Project Level
2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*



http://www.fdot.gov/programmanagement/Implemented/SpecBooks/default.shtm

3. *MAC*

Available Documentation

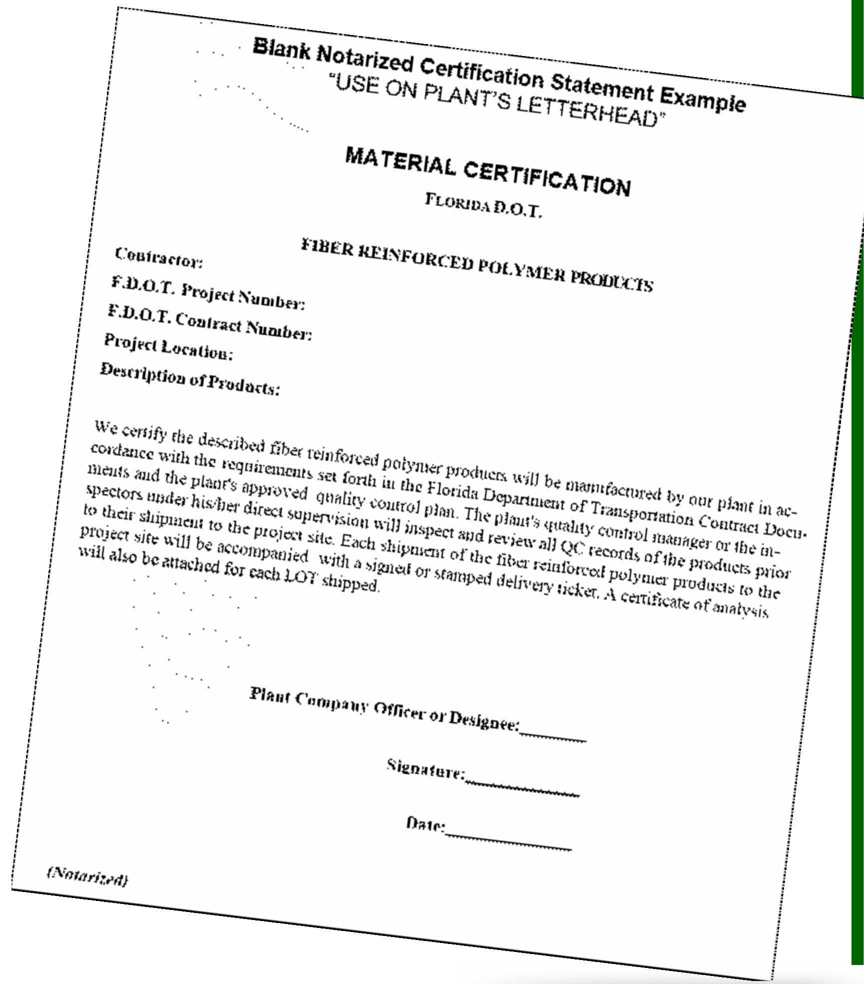
Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

2. Acceptance at the Project Level
   a) Certification
   - Notarized Statement from FRP Producer sent **prior to shipment**
   - Certificate of Analysis for each LOT sent with each shipment

   b) Sampling and Testing

3. *MAC*


Blank Notarized Certification Statement Example
"USE ON PLANT'S LETTERHEAD"

MATERIAL CERTIFICATION

FLORIDA D.O.T.

FIBER REINFORCED POLYMER PRODUCTS

Contractor:
F.D.O.T. Project Number:
F.D.O.T. Contract Number:
Project Location:
Description of Products:

We certify the described fiber reinforced polymer products will be manufactured by our plant in accordance with the requirements set forth in the Florida Department of Transportation Contract Documents and the plant's approved quality control plan. The plant's quality control manager or the inspectors under his/her direct supervision will inspect and review all QC records of the products prior to their shipment to the project site. Each shipment of the fiber reinforced polymer products to the project site will be accompanied with a signed or stamped delivery ticket. A certificate of analysis will also be attached for each LOT shipped.

Plant Company Officer or Designee:________

Signature:________

Date:________

(Notarized)

Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.1*
   c) *Specifications Section 932*

2. Acceptance at the Project Level
   a) *Certification*
   b) ***Sampling and Testing***
      - Samples selected by Engineer after delivery to project
      - Contractor responsible for verification testing using independent ISO Lab

3. *MAC*

Laboratory Test Report

1. REBAR SAMPLE INFORMATION

Sample No.	ID/Ref.	Nominal Rebar Denomination	Material type*
1	N° 342 RWB-A-#4 SUPERSTR. SPANS 1-5 4-451 (P0728T23CB L=32.36 LF) P.D. (02-08/01/17)	#4	Glass fiber reinforced polymer (GFRP)

Sample No.	ID/Ref.	Nominal Rebar Denomination	Material type*
2	N° 221 RWB-A-#5 SUPERSTR. SPANS 1-5 5-551 (P0708T23CB L=25.00 LF) P.D. (16-18/11/16)	#5	Glass fiber reinforced polymer (GFRP)

Laboratory Test Report

3.5. TENSILE PROPERTIES

Test Standard Method: ASTM D7205/D7205M - 06 (2011) Standard test method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars.

Test Description: Determine the ultimate tensile load carrying capacity, tensile modulus of elasticity and computed ultimate strain based on an assumed linear elastic behavior.

Technician/s:

Specimen Preparation: The specimens were cut to the prescribed dimensions. Steel pipe type anchors were installed as indicated in ASTM D7205 using expansive grout after machining the ends of the rebar as to center the bars in the anchors.

Test Data:

Nominal Rebar Denomination	SPECIMEN ID	Peak Load P_{max} lbs	Nominal Area A in²	Ultimate Tensile Strength, UTS f_{fu} ksi	Modulus of Elasticity, E Msi
#4	TNS1-01	27993	0.196	142.6	8.835
	TNS1-02	27963		142.5	8.875
	TNS1-03	29567		150.7	8.963
	TNS1-04	27133		138.3	9.808
	TNS1-05	27352		135.4	8.991
	Average	**28001**		**143**	**9.095**
	S_{n-1}	952		4.85	0.40
	CV (%)	3.4		3.4	4.4
#5	TNS2-01	43959	0.307	143.4	8.593
	TNS2-02	42914		139.9	8.058
	TNS2-03	42517		138.7	8.186
	TNS2-04	42894		139.9	8.203
	TNS2-05	42474		138.5	8.199
	Average	**42951**		**140**	**8.248**
	S_{n-1}	599		1.95	0.20
	CV (%)	1.4		1.4	2.4

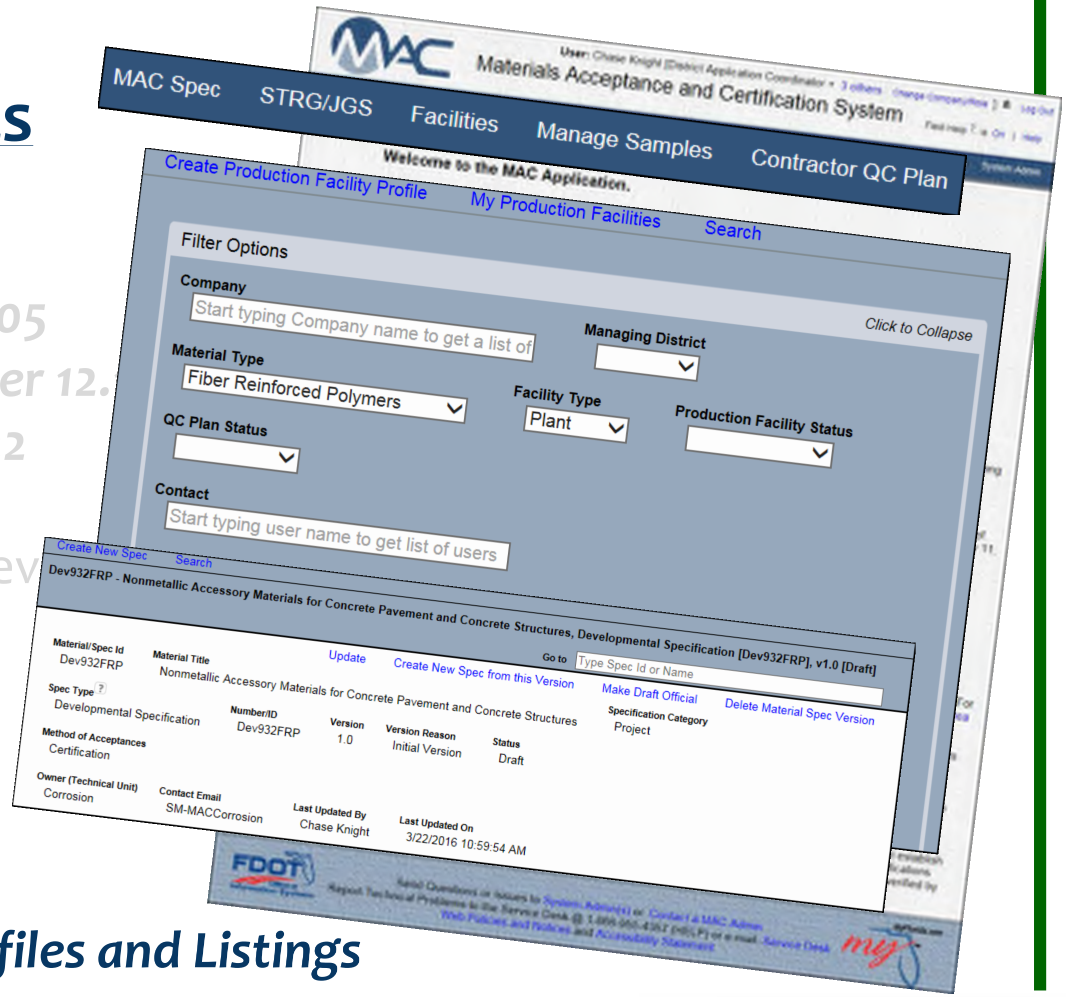
Available Documentation

Material Requirements

1. Producer Quality Control
   a) *Specifications Section 105*
   b) *Materials Manual Chapter 12.*
   c) *Specifications Section 932*

2. Acceptance at the Project Lev
   a) *Certification*
   b) *Sampling and Testing*

3. MAC
   a) ***Specifications***
   b) ***Production Facility Profiles and Listings***



https://mac.fdot.gov/smoreports

Available Documentation

Material and Producer Requirements

1. Producer Quality Control
   a) *Specification Section 105*
   b) *Materials Manual Ch. 12.1*
   c) *Specifications Section 932, 933, and 973*

2. Acceptance at the Project Level
   a) *Certification*
   b) *Sampling and Testing*

3. MAC
   a) ***Specifications***
   b) ***Production Facility Profiles and Listings***

Current Research

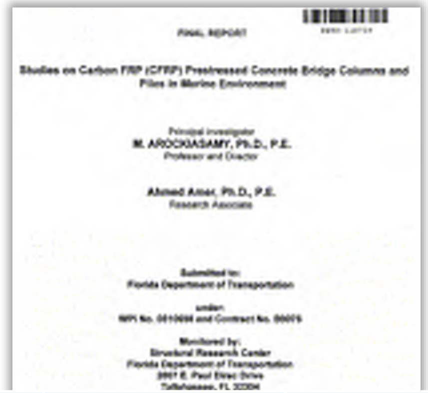
<u>Projects</u>

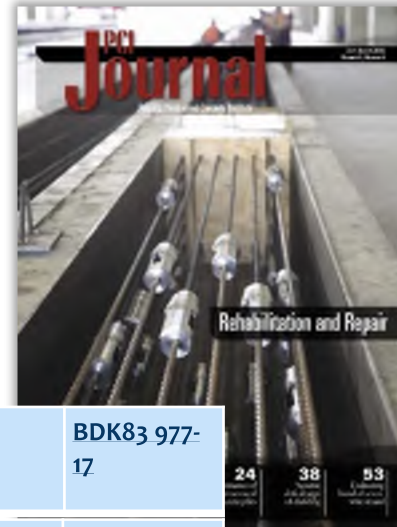
- **BDV30-977-18**: "Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments"
  (https://rip.trb.org/view/2016/P/1406946), Est. Completion: 5/31/2018
- **BDV34-977-05**: "Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements"
  (https://rip.trb.org/view/2015/P/1352376), Est. Completion: 3/31/2018
- **BDV30-706-01:** "Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement"
  (Sample testing and 2 year post-construction monitoring; Est. Completion 11/31/2019)

Past Research
– CFRP Prestressed Concrete Piles

http://www.fdot.gov/structures/structuresresearchcenter/CompletedResearch.shtm


Department of Civil Engineering and Mechanics
The University of South Florida
Durability of CFRP Pretensioned Piles
in Marine Environment
Volume II
Rajan Sen, Satya Sukumar and Ana Rosas
Department of Civil Engineering and Mechanics

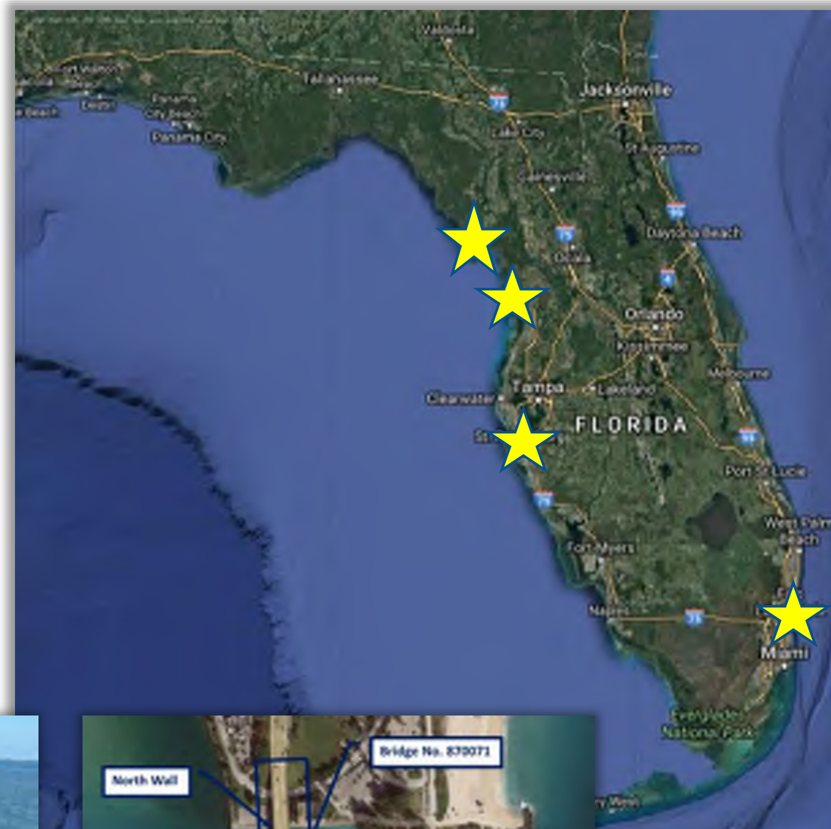

FINAL REPORT
Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment
Principal investigator
M. AROCKIASAMY, Ph.D., P.E.
Professor and Director
Ahmed Amer, Ph.D., P.E.
Research Associate
Submitted to:
Florida Department of Transportation
Monitored by:
Structural Research Center
Florida Department of Transportation



4/16/2014	Investigation of Carbon Fiber Composite Cables (CFCC) in Prestressed Concrete Piles	M. Roddenberry, P. Mtenga	Florida State University	BDK83 977-17
11/30/1998	Studies on Carbon FRP (CFRP) Prestressed Concrete Bridge Columns and Piles in Marine Environment	M Arockiasamy	Florida Atlantic University	B-9076
8/1/1995	Durability of CFRP Pretensioned Piles in Marine Environment Volume II	R. Sen	University of South Florida	0510642

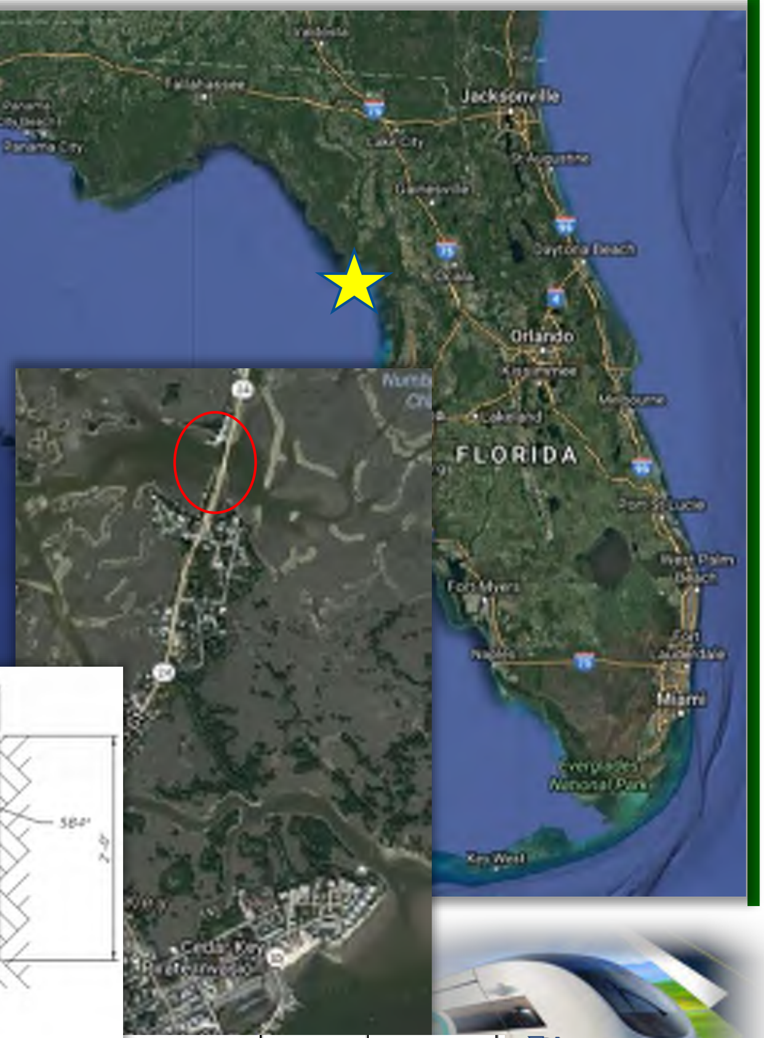
FDOT Construction Projects Status

1. ***Cedar Key Bulkhead Cap Rehab.***
   - FPID 432194-1 construction completed June 2016; SMO monitoring.
2. ***Halls River Bridge Replacement***
   - Construction started 1/9/2017;
   - Astaldi Construction Corp.
3. ***Bakers Haulover Cut Bridge Rehab.***
   - Construction started 1/9/2017;
   - Kiewit Infrastructure South Co.
4. ***Skyway South Rest Area Seawall Rehab.***
   - Design Build Procurement;
   - Awarded 2/10/2017;



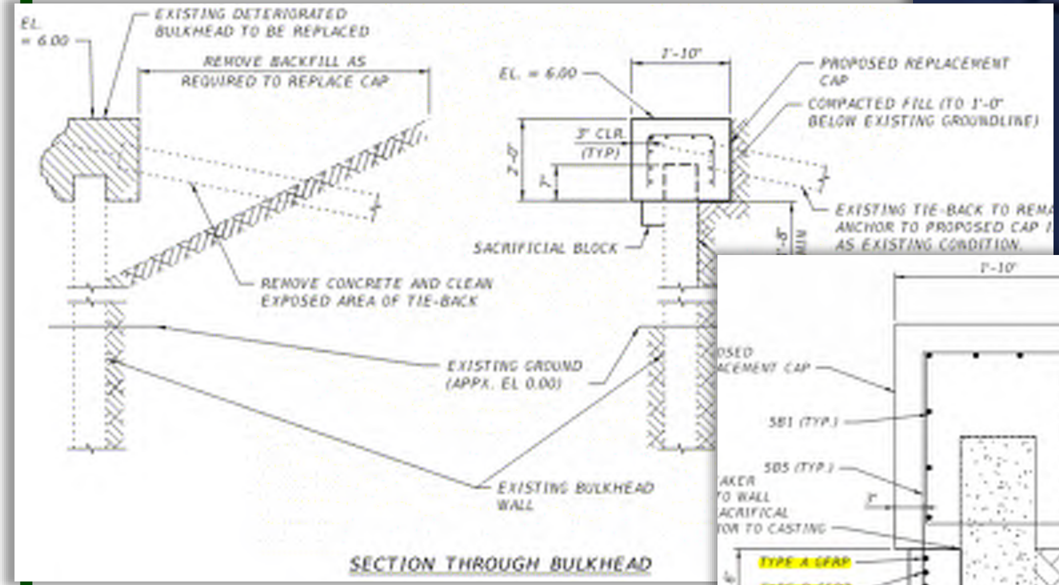
Project Example 1 – *Cedar Key SR24 Bulkhead Rehabilitation*

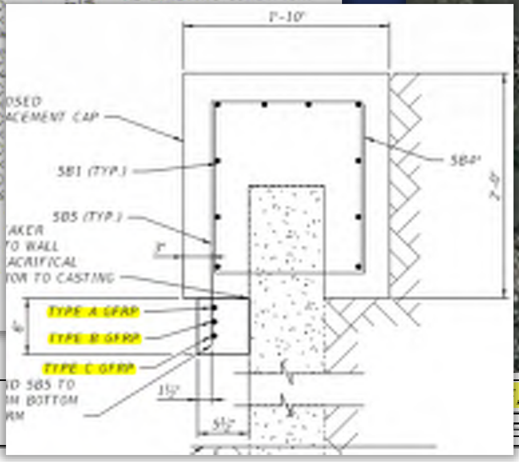
FPID# 432194-1



GFRP BAR TYPE CHART	
TYPE A	SIZE 5 GFRP BAR COATED WITH GRANULAR MATERIAL AND WITH SURFACE INDENTATIONS/DEFORMATIONS CREATED BY HELICAL WRAPPING.
TYPE B	SIZE 5 GFRP BAR COATED WITH GRANULAR MATERIAL AND WITHOUT SURFACE INDENTATIONS/DEFORMATIONS.
TYPE C	SIZE 5 GFRP BAR COATED WITH POLYMER (NO GRANULAR COATING) AND WITH SURFACE INDENTATIONS/DEFORMATIONS CREATED BY SHAPING THE POLYMER COATING (NO EXTERNAL WRAPPING).

TABLE APPLIES ONLY TO REBAR IN SACRIFICIAL BLOCK





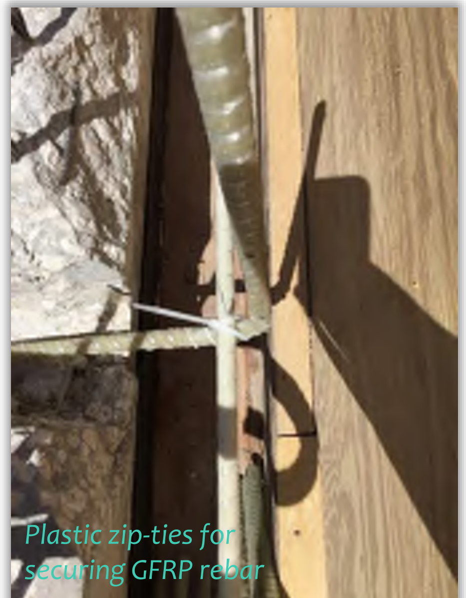
914-415-105	GLASS FIBER REINFORCING POLYMER BAR		
	...ADS	LF	5088
	...ED	LF	131

GFRP Deployment Train

Project Example 1 – *Cedar Key SR24 Bulkhead Rehabilitation*

Installing 2-piece stirrup bars in bulkhead cap

Installing 2-piece stirrup bars in bulkhead cap

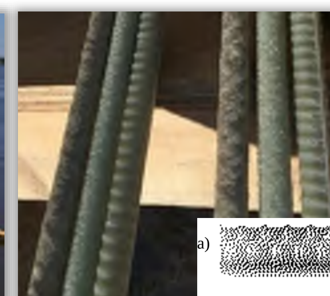


Plastic zip-ties for securing GFRP rebar

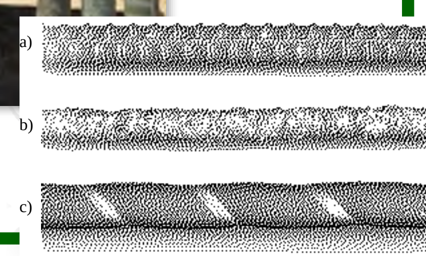
Curing concrete bulkhead cap prior to form removal

Temporary UV protection for bulkhead cap reinforcing

Forming bulkhead cap



3 bar-surface types:
a) Ribbed
b) Sand-coated
c) Helically wrapped and sand-coated

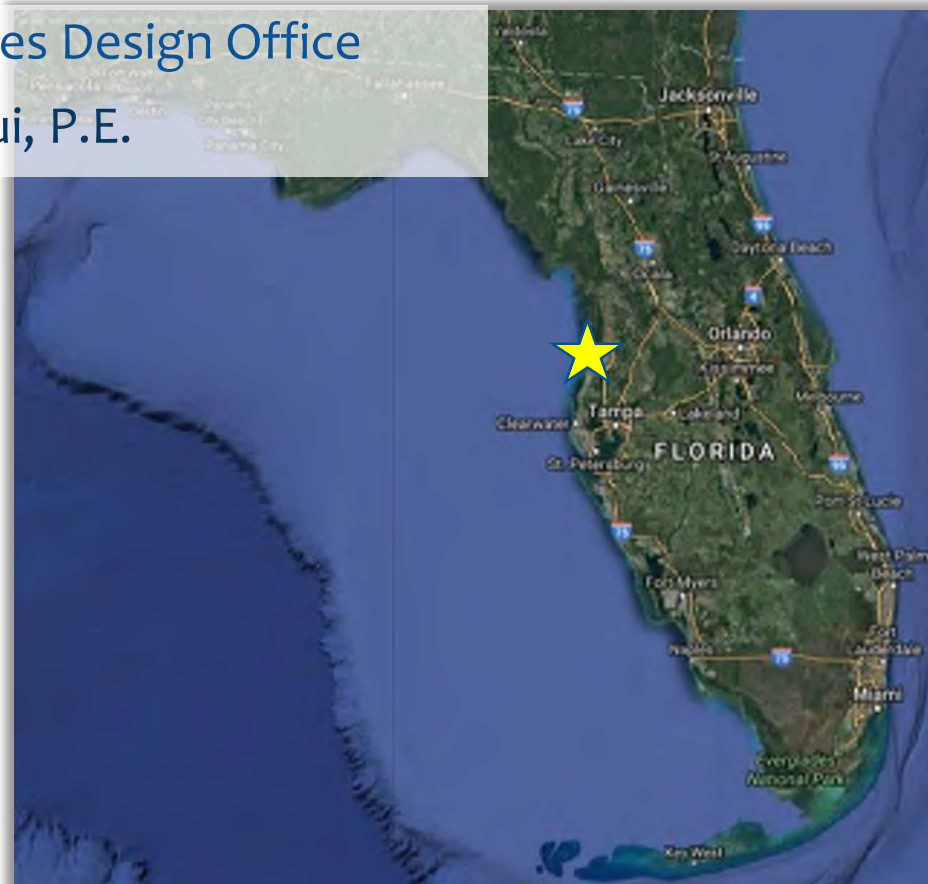


Project Example 2 – *Halls River Bridge Replacement Project*

FPID# 430021-1

Designer: FDOT District 7 Structures Design Office

Structures EOR: Mamunur Siddiqui, P.E.



Owner & Maintaining Agency

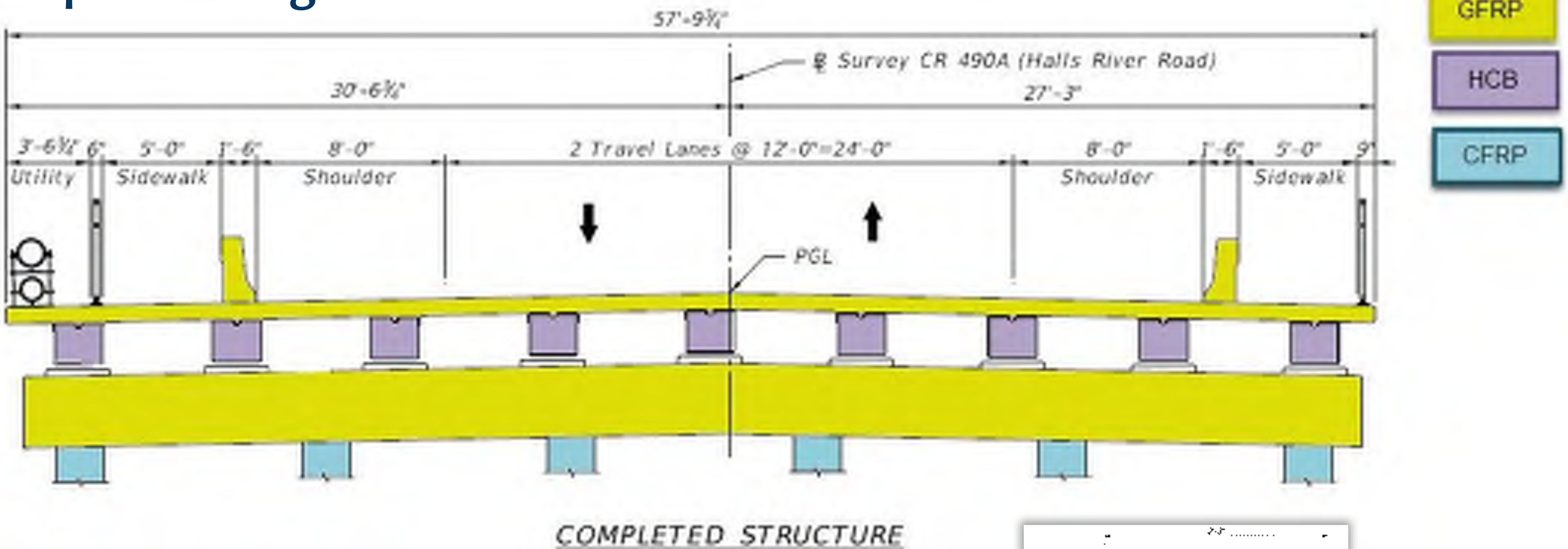
Design & Bi-Annual Inspection

Funding & Monitoring

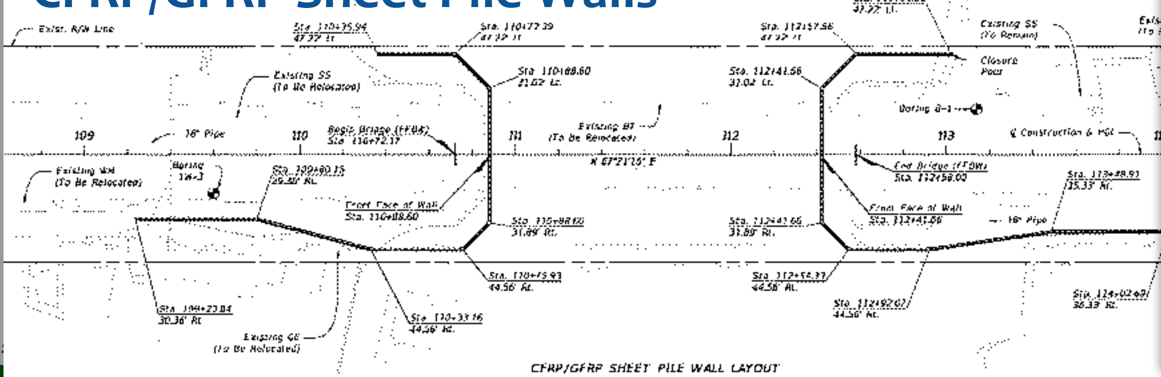
Collaboration Research

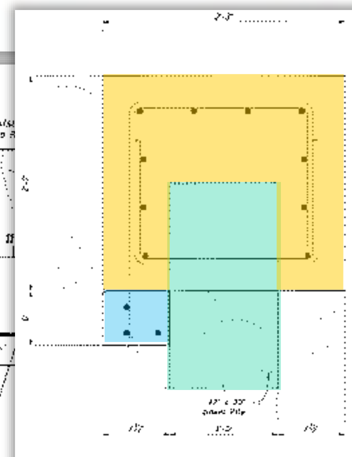
Project Example 2 – *Halls River Bridge Replacement Project*

Proposed Bridge Section



CFRP/GFRP Sheet Pile Walls

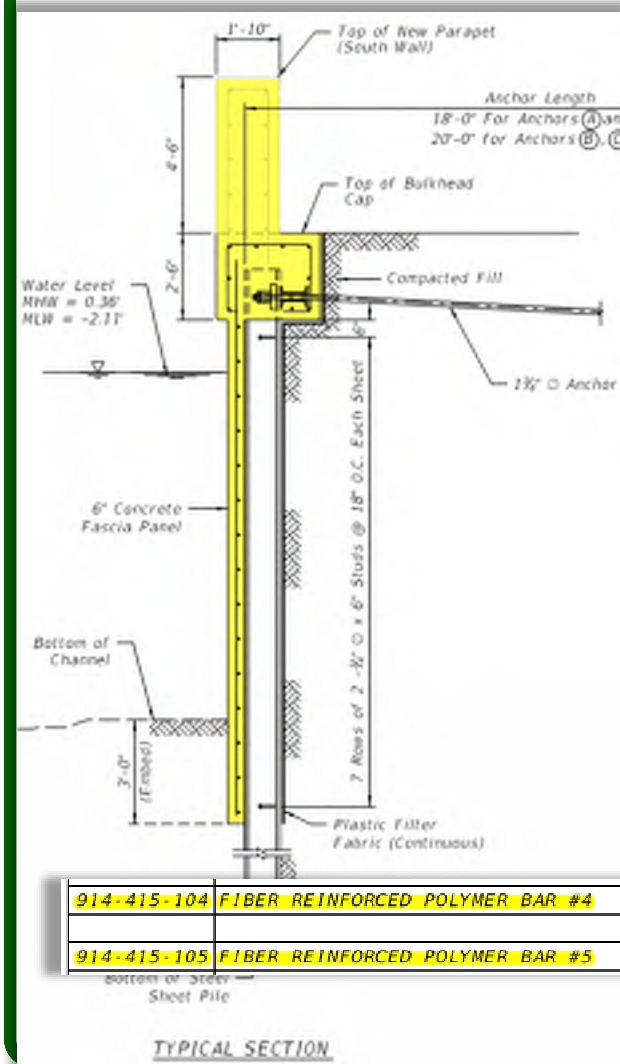




FDOT GFRP Deployment Train

Project Example 3 – *Bakers Haulover Cut Bridge Bulkhead Replacement*

FPID# 433378-1



914-415-104	FIBER REINFORCED POLYMER BAR #4	BULKHEAD CAP, PARAPET & FASCIA PANEL	LF	12,199.32
914-415-105	FIBER REINFORCED POLYMER BAR #5	BULKHEAD CAP, PARAPET & FASCIA PANEL	LF	7,071.14

Project Example 4 – *Skyway South Rest Area Seawall Rehabilitation* FPID# 437973-1 & 438528-1

Design-Build Contractor: *David Nelson Construction Co.*

Example RFP language:

- **FPID 437973-1, South Rest Area Site:**

  - The existing seawall and handrail shall be raised.

  - Extend the seawall southward 285’ from the end.

  - Fill behind the seawall to provide for a grassed area and grade for drainage.

  - Metallic reinforcement is not allowed.

  - Non-metallic Reinforcement must meet design criteria and specification

- **FPID 438528-1, Seawall:**

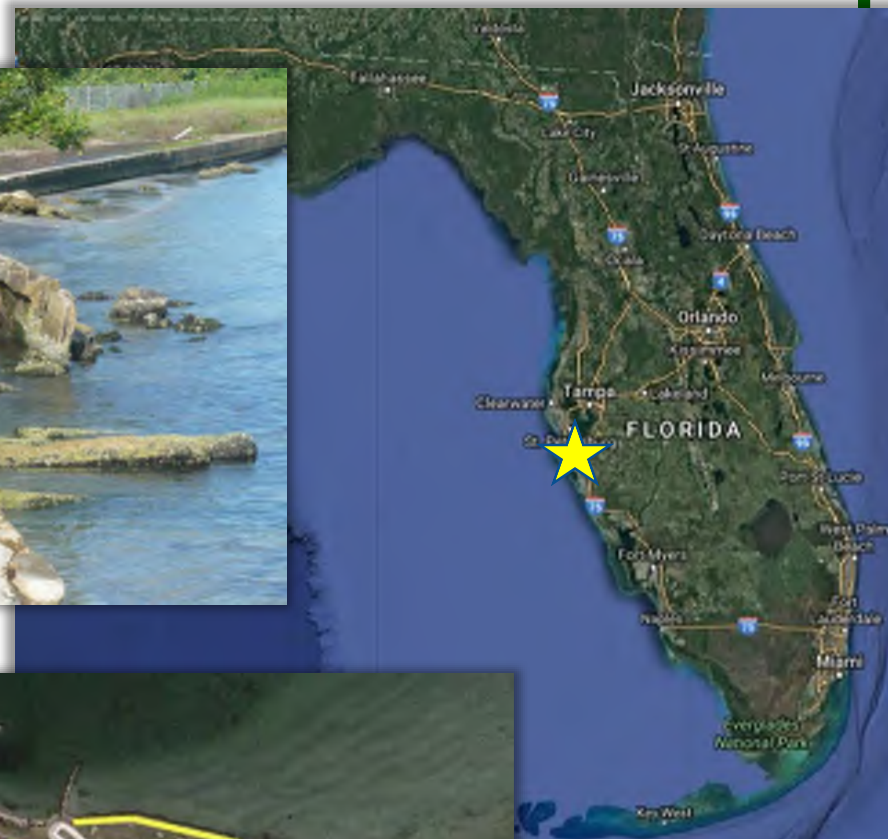
  - Remove and replace the existing seawall cap.

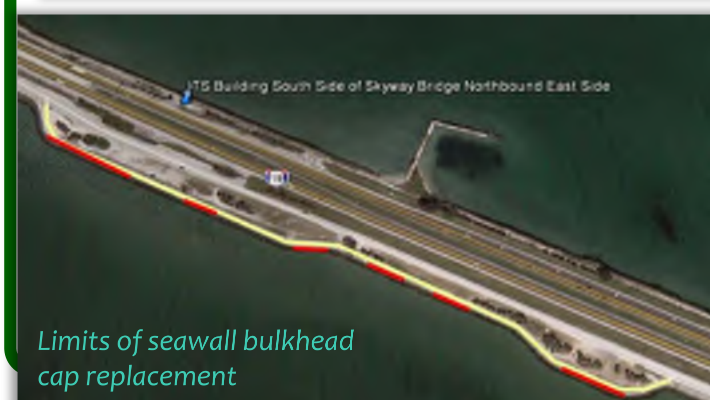
  - Metallic reinforcement is not allowed.

Source: Request for Proposal (Revised August, 2016)

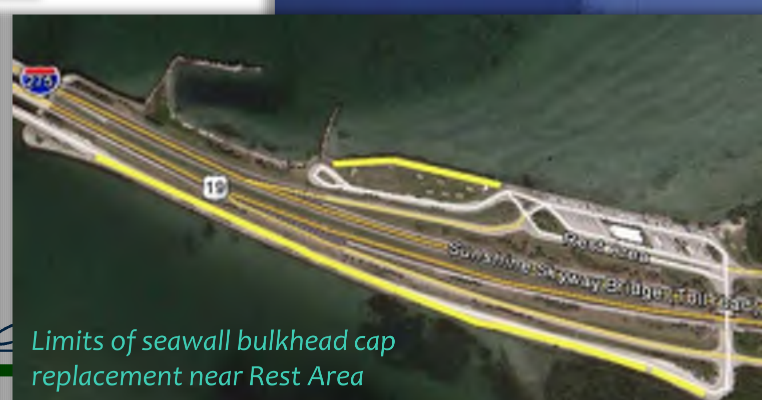
Project Example 4 – *Skyway South Rest Area Seawall Rehabilitation*

Cracking of existing seawall bulkhead cap





Limits of seawall bulkhead cap replacement



Limits of seawall bulkhead cap replacement near Rest Area

FDOT GFRP Deployment Train

Looking Forward

Promote the Use of FRP – Use it where you need it

FDOT Transportation Innovation Challenge

Structures Design Office

Curved Precast Spliced U-Girder Bridges
Fiber Reinforced Polymer Reinforcing
Geosynthetic Reinforced Soil Integrated Bridge System
Geosynthetic Reinforced Soil Wall
Prefabricated Bridge Elements and Systems
Segmental Block Walls

Structures Design - Transportation Innovation
Fiber Reinforced Polymer (FRP) Reinforcing Bars and Strands

Overview
Usage Restrictions / Parameters
Design Criteria
Specifications
Standards
Producer Quality Control Program
Technology Transfer (T^2)
Contact

http://www.fdot.gov/structures/innovation/FRP.shtm

Technology Transfer (T^2)

The following links to FDOT meetings, seminars and workshops are provide as background information for potential users and industry partners:

- FDOT/FHWA Corrosion-Resistant Rebar (CRRB) Seminar (July 17, 2012)
- FHWA/NCHRP 20-68A U.S. Domestic Scan 13-03 meeting with FDOT (June 4-5, 2015)
- FDOT-FRP Rebar Industry Workshop (June 15, 2016)
- Composites-Halls River Bridge Promotional Video for CAMX 2016 (September 26-29, 2016)
- CAMX 2016: FDOT-FRP Deployment for Structural Applications (for new construction) (September 29, 2016)
- ACMA-Transportation Structures Council (TSC) Meeting - FDOT Presentation (Sept. 29, 2016)
- FDOT/FTBA Construction Conference - FRP Presentation Schedule Pending (Feb. 2-3, 2017)
- FDOT-CO Winter FRP-RC Workshop (Feb. 3, 2017)
- Halls River Bridge Replacement FRP Demonstration Project Workshop (May 3, 2017)

Challenges & Focus Areas

See to Part 2 – Do we need a Roadmap for further deployment?

- Challenges to expanded FRP Implementation;
- FDOT Priorities
- Potential Focus Areas;

SDO (RR's) priorities (2/28/2017)

Priority Focus Areas:

1. Increase the variability in bent shapes. The goal would be to duplicate every shape on the FDOT ***Design Standard*** Index 21300;
2. Methods/tests to determine expected life of the products in place, durability modeling and predictions;
3. Maintenance inspection of rebar embedded in concrete;
4. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections;
5. Updating of all design factors (FDOT will approach NCHRP with a recommendation to pursue this as a parallel effort);
6. Continue to coordinate with AASHTO and ACMA-TSC to develop design codes and test protocols (FDOT will continue to participate in all related AASHTO activities);

Questions ?

FDOT Contact Information:

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(850) 414-4296
Sam.Fallaha@dot.state.fl.us

Steven Nolan, P.E. (Structures Standards Coordinator)
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Steven.Nolan@dot.state.fl.us

State Materials Office:

Chase C. Knight, PhD. (FRP Coordinator)
(352) 955-6642
Chase.Knight@dot.state.fl.us

Ivan Lasa, B.S.C.E. (Corrosion Lab.)
(352) 955-2901
Ivan.Lasa@dot.state.fl.us

Part 2

Do we need a Roadmap?

- **Challenges to expanded FRP Implementation**
- **FDOT Priority Focus Areas**
- **Potential Focus Areas**

Roadmap

Challenges to expanded FRP Implementation:

1. **Material Cost**
    - First cost should include benefits of reduced cover, reduction of concrete additives for durability, and labor/installation savings due to lightweight.
    - Life-Cycle Cost Analysis should to be utilized.
    - SEACON is generating LCC/LCA data that may be helpful.
    - Consider developing example cost comparisons

Roadmap

Challenges to expanded FRP Implementation (cont.):

2. **Lack of confidence in durability for submerged environments (FDOT seeking 75 - 100 year service life)**
   - Accelerated testing could address this issue. OC could update previous tests using samples subjected to sustained load+saltwater+60ºC (may need to consider alkalinity also)? The outcome could be a new set of creep-rupture curves that account for environmental effects.
     - *FDOT doing some accelerated testing investigation under BDV30-977-15 "Performance evaluation of glass fiber reinforced polymer (GFRP) reinforcing bars embedded in concrete under aggressive environments" (FSU-UM)*
   - Look at quality of bends compared to straight bars for these conditions.
     - *FDOT proposed SMO research was not advanced last year.*

Roadmap

Challenges to expanded FRP Implementation:

3. **Limitations on the strength due to degradation of properties over time (currently C_E factor = 0.7 for GFRP exterior environments)** ***[goes with Challenge #2]***
   - Use tests on field-retrieved bars and correlate to accelerate-conditioning tests to develop reliable knockdown factors for 100 years of service life (See Ali & Benmokrane, ***Recommended Value for the Environmental Reduction Factor (C_E) for GFRP Bars in ACI 440-H XXX Code***, for **C_E** = 0.9, for 100 year service life GFRP with VE resin, July 2017);
   - Existing sustained stress limit is 0.20 of guaranteed times C_E to account for creep-rupture and fatigue under service loads. *Is the creep-rupture limit actually affected by long-term environmental exposure?*
   - Current FDOT research project: *BDV34 977-05* *"Degradation Mechanism and Service Life Estimation of FRP Concrete Reinforcements"*, may provide some answers.

Roadmap

Challenges to expanded FRP Implementation:

4. **Limitations on strength due to low design resistance factors (ϕ factors) related to lack of ductility and strength variability in the FRP materials (currently 0.55-0.65 for tensioned-control to compression-controlled flexural failure modes)**
    - This is a design issue that could be tackled immediately based on reliability.
    - For flexure, revisit existing data and verify proposal by Jawaheri and Nanni (see Table 9).

Table 9—Recommended strength reduction factors for FRP reinforced beams

Limit state	Strength reduction factor (ϕ)
FRP rupture*	0.70
Concrete crushing*	0.75
Shear†	0.75

*Conservatively: ϕ=0.70 for both modes; †Shear reinforcement limit is modified as $V_f \leq 3V_c$.

Roadmap

4. Limitations on strength… (continued)

Code comparison prepared by SSDO:

Action	Failure Mode	Phi (AASHTO)	Phi (ACI)	Comment
Conventional Steel Reinforcing:				
Shear	Brittle	0.75	0.75	
Flexure-CC	Brittle	0.75	0.75	
Flexure-TC	Ductile	0.90 (1.00)	0.90	() = prestressed
FRP Reinforcing:		(AASHTO-GS)	(ACI -440)	
Shear	Brittle	0.75	0.75	
Flexure-CC	Brittle	0.65	0.65	non-prestressed
Flexure-TC	Brittle	0.55	0.55	non-prestressed
Flexure-CC	Brittle	N/A	0.65	CFRP-prestressed
Flexure-TC	Brittle	N/A	0.85	CFRP-prestressed

- Prestress resistance factors might be reduced for TC = 0.75 & increased for CC = 0.80 based on new reliability study by Kim & Nickle *(ACISJ Tile 113-S89, Sept-Oct 2016)*
- Could also consider eliminating minimum flexural reinforcing limits when excesses Mcr capacity is provided (maybe 1.5Mcr ??) .

Roadmap

Challenges to expanded FRP Implementation:

5. Limitations on the service limit states due to creep-rupture:

- Existing sustained stress limit is 0.20 of guaranteed strength times C_E to account for fatigue and creep-rupture under service loads.
    - *Is 0.20 f_u too low?*
- Same 0.20 limit for both fatigue (range) and creep (sustained).
    - *New ACI 440.1R-15 under 7.4.2 implies that sustained+range $\leq$ 0.2 f_u, is this valid? If so why even check creep at 0.2fu ?*
    - Is the AASHTO-Fatigue I load case (1.5 x design truck – for infinite life) consistent with the intention under ACI 440.1R for fatigue?
    - AASHTO-GS 2.7.3 creep-rupture limit loading is unclear (should this be just Dead Load at Service I, since what portion of the Live Load would be considered sustained load?)
- Need endurance testing based on modern bar properties.

Roadmap

Challenges to expanded FRP Implementation:

6. **Low Elastic Modulus, resulting in greater deflections and larger crack openings**
   - Not likely we can increase MoE significantly, so…
   - Revisit default k_b factor = 1.4, for crack width estimation, or require testing in Spec 932 to establish a lower value for design (maybe 1.0).
   - Consider combining with FRC to control crack size openings. Would need tools to quantify effect of FRC on crack width (0.02” max.) and deflections.
7. **Shear design:**
   - Shear provisions could be reconciled with Canadian standards method which is much less conservative.

Roadmap

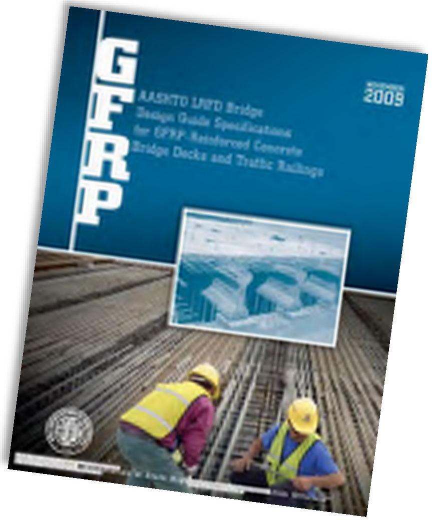
Challenges to expanded FRP Implementation:

8. **Restrictions in bar bending capabilities, and challenges with field modifications to bar shapes**
   - Manufacturers could propose standardized shape of higher quality revisiting minimum radius of curvature and 60% efficiency.
     - *For design, clarify how the 40% strength reduction is applied for bent shear stirrups?*
   - Continuous close stirrups/ties are now possible and allow tight corners, and do not rely on GFRP-concrete bond.
     - *Would test methods differ for these types of stirrups?*
     - *What is the maximum leg length before surface bonding would be required?*
   - Consider combining GFRP stirrups/ties with carbon or steel strand in PC applications.
     - *Would need to quantify confinement effect.*

Roadmap

Challenges to expanded FRP Implementation:

9. **Update AASHTO Guide Specification (2009)**
   - This work is underway
10. **Maintenance Inspection Methods**
11. **Repair Methods**



SDO (RR's) priorities (2/28/2017)

Priority Focus Areas:

1. Increase the variability in bent shapes. The goal would be to duplicate every shape on the FDOT standard index ***(Challenge #8)***
2. Methods/tests to determine expected life of the products in place, durability modeling and predictions ***(Challenge #2 & 5)***
3. Maintenance inspection of rebar embedded in concrete ***(Challenge #10)***
4. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections (***Challenge #11)***
5. Updating of all design factors (FDOT will approach NCHRP with a recommendation to pursue this as a parallel effort) ***(Challenge #2, 3, 4, 5, 6, 7 & 9)***
6. Continue to coordinate with AASHTO and ACMA-TSC to develop design codes and test protocols (FDOT will continue to participate in all related AASHTO activities) ***(Challenge #9+)***

Roadmap

Expanded list of Potential Focus Areas:

1. **(Challenge# 2) Resolution of durability question especially in submerged environments;**
   - SMO projects. (Do we need other testing ?)
     1. BDV34-977-05 Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements, A. El-Safty (UNF), due 3/31/2018
     2. BDV30-977-18 Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments, R Kampmann (FSU), Due 5/31/2018
2. **(Challenge# 3) Refinement of Environmental Reduction factors (CE);**
3. **(Challenge# 4) Rationalization of Resistance Factors (ϕ factors)** used to address lack of ductility and variability in material strength properties;
4. **(Challenge# 5) Endurance limits** – refine fatigue and creep-rupture design limits and loading;
5. **(Challenge# 6) Mitigation of lower elastic modulus effects** as related to member deflections and concrete crack widths;
6. **(Challenge# 8) Advancement in bent bar fabrication;**

Roadmap

Expanded list of Potential Focus Areas (cont.):

7. **(Challenge# 9) Improved FRP Industry coordination** especially between ACMA-TSC and AASHTO SCOBS-T6 (FRP) & T10 (Concrete);
8. **(Challenge# 10) Maintenance Inspection/Test methods**
   1. Maintenance inspection of rebar embedded in concrete;
   2. Non-Destructive Test Methods for identifying deterioration preferable.
9. **(Challenge# 11) Repair Methods**
   1. Repair of damaged FRP rebar during construction and when discovered during maintenance inspections
10. **Investigate hybrid designs –** using GFRP stirrups/rebar with Carbon or Steel prestressing strands;

Roadmap

Expanded list of Potential Focus Areas (cont.):

11. Continued Standardization through:

i. Design Specifications
   - AASHTO Guide Spec update (T5) –> LRFD Chapter 5 inclusion (T10);
   - ACI 318-GFRP design companion document/address column design;

ii. Material Specifications
   - FDOT Specification Sections 932 & 933;
   - ACI 440-K/ASTM D30.10: new Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement, WK43339;

iii. Pre-Fabrication
   - Cages (ACP, Sheet Piles, Traffic Railings, Precast Caps)
   - Closed stirrups
   - 2D-Grids/Mats (e.g. Decks and Noise Wall Panels);
   - Closed Stirrups/Hoops;
   - Headed Anchors;

iv. Pre-designed of Structural Elements (such as **FDOT** ***Design Standards*** Indexes);

Roadmap

Expanded list of Potential Focus Areas (cont.):

13. Guidance on the use of Life Cycle Cost Analysis for FRP justification:

i. Coordinate with SEACON-WP6;

ii. Utilize FHWA/& NCHRP Report 483;

iii. Consider Leveraging Sustainability angle if permitted:

- From **2016 National Bridge Conference**: Jianwei Huang and Chris Strazar, “Sustainability of GFRP RC Bridge Deck: Materials Cost”, Southern Illinois University Edwardsville: *This research clarifies the concern of the high initial cost for GFRP RC bridge deck as compared to conventional steel RC deck;*
- **USDOT to require emissions-reduction goals for funding recipients** The US Department of Transportation is working on plans to require highway and transportation funding recipients to set and track carbon dioxide emissions-reduction goals as a condition of receiving money;
- **FHWA proposal: Emissions could gauge success of transportation projects** The amount of emissions, along with congestion, traffic reliability and freight movement, could be used to evaluate the success of a transportation project under new rules proposed by the Federal Highway Administration. The agency has started a 90-day comment period in the proposal.

Roadmap

Expanded list of Potential Focus Areas (cont.):

14. Project Monitoring

i. SMO monitoring Cedar Key Bulkhead rehab – Test Beams under cap (3 surface coatings of GFRP bars);
ii. FSU-UM monitoring Halls River bulkheads, piles, bent caps and deck – Test beams under bulkhead (GFRP, CFRP, and BFRP);
iii. Coordinate with FHWA for monitoring FRP under ***Fixing America's Surface Transportation (FAST) Act***.

15. Outreach and Technology Transfer:

i. FDOT Transportation Innovation - FRP website;
ii. FDOT Design Expos;
iii. Project Case-Studies & Workshops.

****

New items from FDOT-FRP Workshop (Feb 3, 2017)…

ACMA/FRP-RMC Industry Concerns

1. Necessary and required testing today versus years of test data compiled from other installations
2. Identification and selection process of testing laboratories which are ISO qualified. *(Comment: This has been proposed to be changed to "an independent laboratory approved by the Department" for the January 2018 Specs*.)
3. Government agencies and engineers that use products that may be interpreted by some as questionable, un-tested and does not meet the expected standards generated by ASTM, ACI, others
4. First costs versus cost premium impact to overall project cost. How is this handled from the owners stand point. Do life cycle costs play a role as identified in MAP-21?
5. Durability testing: field versus accelerated testing. Which will the DOT feel gives them the results they need? What is the DOT looking for?

Questions ?

CDCC Conference Sherbrooke, Quebec July 19- 21, 2017

MTO's Policies and Practices for the Use of FRP Reinforcement

Presented by: David Lai, P. Eng
Head, Rehabilitation Section
Bridge Office

Outline of presentation

- Current MTO corrosion protection policy
- Draft future corrosion protection policy
- DSM and Standard Special Provision
- Q A Testing Protocol and implementation
- Design and Research Issues
- Construction Issues and visual inspection
- Conclusions

Current use of GFRP rebar

Component	Acceptable	Remarks
Top mat in waterproofed decks with AADT > 50000	Yes	Based on financial
Negative reinforcement in rigid frame and integral abutment	No	Uncertain stress- strain behaviour of bent bars
PL2/TL4 barrier or parapet wall	Yes	Based on equivalent static design, crash testing not required
PL3/TL5 barrier wall with AADT < 100000	Yes	Only crash tested products
Curbs and sidewalk	Yes	
Stirrups in precast girders	No	Bent bars QC/QA issues, strength reduction.

Draft Future Policy

50000< AADT < 100000	Single span slab on girder with waterproofing	GFRP top mat, black steel bottom mat except as required in Section 12 of Structural Manual and use MMFX at integral abutment for top longitudinal. (See Note 3)
50000< AADT < 100000	Multi-span slab on girder and integral abutment bridges with waterproofing.	Option 1: MMFX top mat, black steel bottom mat except as required in Section 12 of Structural Manual. Use plastic chairs and ensure minimum 25mm separation between top and bottom mat. (See Note 4) Option 2: GFRP top mat, black steel bottom mat except as required in Section 12 of Structural Manual and use MMFX at integral abutment for top longitudinal. (See Note 3) Two alternative designs should be conducted for cost comparison and bid competitively.

GFRP in decks

- Since 2008, MTO has constructed a significant number of bridge decks with GFRP, including:

  - precast deck panels between girders

  - cast in place slab on girders (simply supported or semi-continuous)

- Progressed beyond trial stage
- Not favourable for integral abutment due to large sustained negative moment and uncertain stress-strain behavour of bent bars

3rd Concession / Hwy 401

GFRP Reinforcement Top and Bottom Mat 2008

3rd Concession/ Hwy 401

Rainy Lake Precast Deck

Rainy Lake Precast Deck

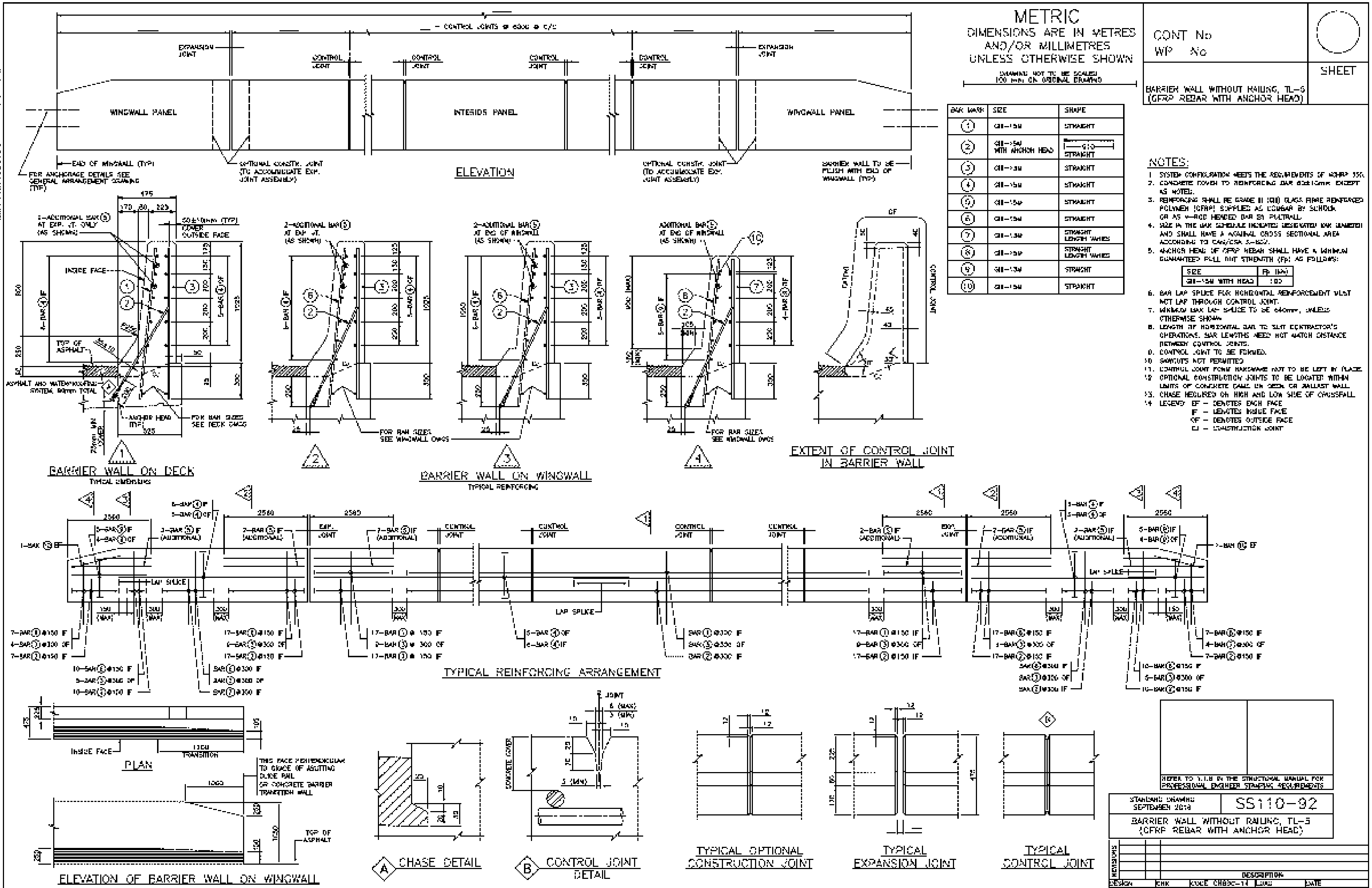
Examples of GFRP in decks

- Whiteman's Creek Precast Deck, Hwy 24
- Humber River Bridge Hwy 401
- Nestor Falls Hwy 71 Precast Deck
- Rainy Lake/Noden Causeway PC Deck
- Chukuni River Bridge Precast Deck Hwy 105
- Ottawa Queensway bridges
- Warden Avenue Hwy 401 overlay
- Nipigon River Bridge

PL3/TL5 Barrier Wall

- MTO accepts crash test result for PL3/TL5 barrier with Combar and Vrod, Standard Drawing has been issued. TemBar being reviewed.
- All other manufacturers will have to go through similar crash test in order to have their product/design qualified for PL3 /TL5 barrier.

PL3 /TL5 Barrier Wall Standard Drawing with Combar Headed Anchor



PL2/TL4 Barrier and Parapet Walls

- MTO already has two standards for each, one using Grade 1 (40 GPa) with bent bars and another using Grade 3(60 GPa) with headed anchors.
- With only Grade 3 in DSM, the Grade 1 standard will be withdrawn.

DSM and Standard SP

- MTO has recently implemented the DSM for GFRP
- Only Grade 3 (60 GPa) products are listed
- Distinction made between pre-qualifed and conditionally pre-qualified products
- NSSP has become a SSP
- A policy memo has been issued to advise designers only Grade 3 to be used.

Structural
Reinforcement
Glass Fibre Reinforced Polymer - Reinforcing Bar

Date: 25-May-2017

SPECIFICATIONS: SSP 999S02
DRAWINGS: n/a
CUSTODIAL OFFICE : Bridge Office - (905) 704-2351

Company	Product Name	Product Grade / Type	Status
Fiberline Composites Canada Inc. 1009-30 Duke Street West Kitchener ON N2H 3W5 Canada Email: drto@fiberline.com Web: www.fiberline.com	ComBAR GFRP	Grade III straight bar. Grade III bent bar. Grade III straight bar with anchor head.	OK
Pultrall Inc. 700 9th Street North Thetford-Mines QC G6G 6Z5 Canada Tel: 418-335-3202 Fax: 418-335-5117 Web: www.pultrall.com	V-Rod (GFRP Reinforcing Bar)	Grade III straight bar. Grade III bent bar. Grade III straight bar with anchor head.	OK
TemCorp Industries Ltd. 332 Glover Road Stoney Creek ON L8E 5M3 Canada Email: switts@temcorp.ca Web: www.temcorp.ca	TemBar	Grade III straight bar. Grade III bent bar.	Conditional Qualification
Ontario Source: **TUF-BAR Canada Inc.** 7 Erin Park Drive Erin ON N0B 1T0 Canada Tel: 519-833-5050 Email: info@tuf-bar.com Web: https://www.tuf-bar.com/	TUF-BAR	Grade III straight bar. Grade III bent bar.	Conditional Qualification
TUF-BAR Inc. 5522 36 St NW Edmonton AB T6B 3P3 Tel: 1-780-462-8100 Email: info@tuf-bar.com Web: https://www.tuf-bar.com/	TUF-BAR	Grade III straight bar. Grade III bent bar.	OK

Major changes implemented in SSP

QA Testing Protocol and Implementation

Design and Research Issues

- Currently there is no standard yet for rehab of barrier/parapet walls using GFRP dowels with epoxy grout in drilled holes:

  - uncertainty in long term performance due to freeze thaw and loss of bond
  - research at Ryerson University funded by MTO to evaluate GFRP dowels in epoxy grout and long term effects to be completed soon
  - Pull test in the field requires steel sleeve

Design and Research Issues

- No more use of Grade 1
- No more use of bent bars in precast girders
- MTO is funding a research project at U of Waterloo to investigate the stress-strain behaviour of bent bars, hopefully design provisions could be developed for integral abutments.
- MTO is also funding a research project at U of Toronto to develop design provisions for spirals in columns.

Design and Research Issues

- Research by Dr. Mark Green at Queens University on Fire Resilience of GFRP reinforced components is almost completed and has shown very interesting results.
- Research on combined bending and shear effect at closure joints using UHPFRC is in progress at U of Waterloo and Ryerson U.
- Code issues
  - Negative reinforcement over piers for composite steel girders
  - Phi factor for deformability
  - Strain limit of GFRP at ULS when tension control

Conclusion and Challenges

- We have come a long way in the use of FRP reinforcement; but new products are still being developed and introduced and it is a challenge for practising engineers, spec writers and owners to keep up with it.
- There could potentially be five suppliers in the near future and some have more than one grade. Actual properties could be quite different from nominal. Keeping track of them in construction for future management is a problem.

Conclusion and Challenges

- Once the revised corrosion protection policy is implemented, we would likely see some increase in use of GFRP in bridge decks.
- QA testing is quite onerous and requires knowledgeable staff to administer.
- Pending research results.

CDCC Conference Sherbrooke, Quebec July 19- 21, 2017

MTO's Policies and Practices for the Use of FRP Reinforcement

Presented by: David Lai, P. Eng
Head, Rehabilitation Section
Bridge Office

Outline of presentation

- Current MTO corrosion protection policy
- Draft future corrosion protection policy
- DSM and Standard Special Provision
- Q A Testing Protocol and implementation
- Design and Research Issues
- Construction Issues and visual inspection
- Conclusions

Major changes implemented in SSP

- For bent bars and anchor headed bars, a lot shall consist of no more than 2000 bars
- A lot shall consist of no more than seven (7) days of continuous production
- For QC testing,the actual number of samples tested for each lot shall be reported if more than 5.
- Submit protect plan to prevent contamination of placed or partially embedded GFRP bars from concrete splatter from an adjacent concreting operation.

Major Changes implemented in SSP

- GFRP bars shall be grade III.
- Companies and products that are conditionally prequalified might not have been in full production yet; it is the responsibility of the contractor to ensure that the contractual requirements can be met, including all QC tests and delivery schedule.
- The physical and durability properties of GFRP bars shall meet or exceed the requirements for a durability classification of D1 as per CSA S807

Major Changes implemented in SSP

- **8.02 Sampling**

Prior to placing the GFRP, the Contract Administrator shall randomly select 5 samples for quality assurance testing from each lot. The straight bar samples shall be cut to a length of 2.2 m by the Contractor. If a lot of straight bars does not contain any pieces that may be cut down to a length of 2.2 m, then the length requirement shall be waived and samples shall be taken from the available lengths as supplied. For bent bars and anchor headed bars, the Contract Administrator shall select 5 samples at random from each lot.

Random Sampling for QA Testing

- The intent is that the CA would advise the contractor early in contract which bar sizes and shapes would require extra bars for QA testing; the extra bars should therefore be shown in the bar schedule but randomly delivered with the rest so that it is not prepackaged.

8.04.02 Visual & Dimensional

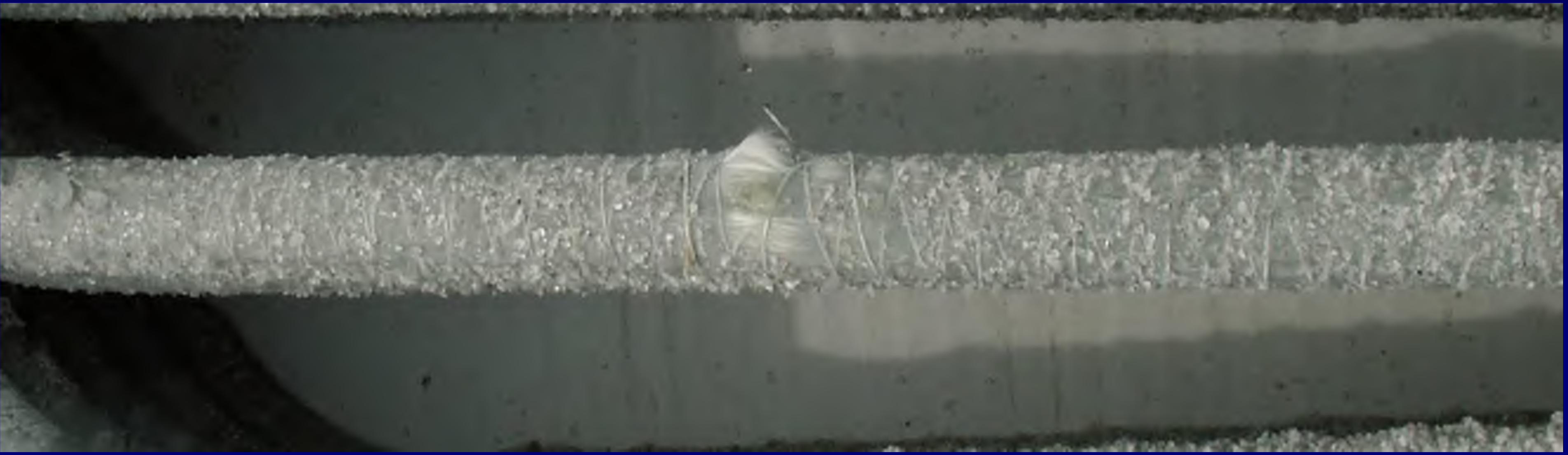
GFRP that does not meet the specified finishing, surface conditions, or dimensional tolerances shall be rejected.

The MTO "Guidelines for Inspection and Acceptance of Glass Fibre Reinforced Polymer (GFRP) Reinforcing Bars" shall also be used as a basis for field inspection and rejection of GFRP bars.

Unacceptable bent bar with excessive resin

Unacceptable rebar with kink and rough finish

Unacceptable bar with poor finish and no sand



Unacceptable bar with exposed dry fibre

Unacceptable bar with rough, non-uniform finish and voids

Unacceptable bar with bulging and dry fibre

Unacceptable bar with loose helical wrap, voids and kinks in fibre

QA Testing Protocol and Implementation

- A RFQ was sent to a list of labs and universities to perform QA testing for MTO; following tests to be included:
  - tensile strength and modulus
  - cross sectional area
  - fibre content
  - water absorption
  - transverse shear strength
  - cure ratio and Tg
  - modified pullout test of bent bars

Challenges to implementation

- Very few commercial labs can do all the specified tests
  - not all labs have DSC
  - tensile test of larger diameter bars require long specimen and therefore large vertical clearance
  - transverse shear test requires good fit up of device to specimen, but each product's actual diameter is different

Challenges

- Costly to do
- Timely turn around during construction
- Need dedicated knowledgeable staff to administer the program
- Need to keep track of lot numbers from same supplier for multiple contracts

Nevertheless, Senior Management has given the approval to implement the QA testing program.

Contract and Construction issues

- Finishing quality and consistency of bent bars continue to be an issue.
- Rejection of bent bars may cause significant project delay due to delivery schedule of additional bars.
- Completion of all QC test reports and certified by QVE to meet construction schedule could sometimes be difficult.

Contract and Construction issues

- Not all CA and QVE are familiar with the products and know how to interpret the test results.
- Frequent change proposals and technical issues to be resolved.

DSM Issues

- Intent is to have listed products going through testing again every three to five years.
- Very soon, MTO might require the GFRP suppliers to provide finger printing scan of the resin for record and comparison with actual products supplied in the future.

Thank you.

- Questions?






PAST USE AND FUTURE PLANS FOR GFRP REBAR IN TEXAS HIGHWAY CONSTRUCTION

Timothy E. Bradberry, P.E.

July 18, 2017

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The Problem – Deterioration of Reinforced Concrete Infrastructure

The Problem – Deterioration of Reinforced Concrete Infrastructure

The Problem – Deterioration of Reinforced Concrete Infrastructure

Bridge at US 385 and the Canadian River, in Oldham County, TX

Corrosion induced concrete deck deterioration.

An Experiment with Something New

In 1999 TxDOT was awarded a $580,000 Transportation Equity Act for the 21st Century (TEA-21) Innovative Bridge Research & Construction Program project to construct and perform research a concrete bridge deck using GFRP bars as reinforcement:

- $180,000 to offset the cost of the innovative material; and
- $400,000 to instrument and perform other research regarding its use in bridge decks.

Construction Project Selected

Potter County

CSJ 1245-02-029

Project BR 99(15), etc.

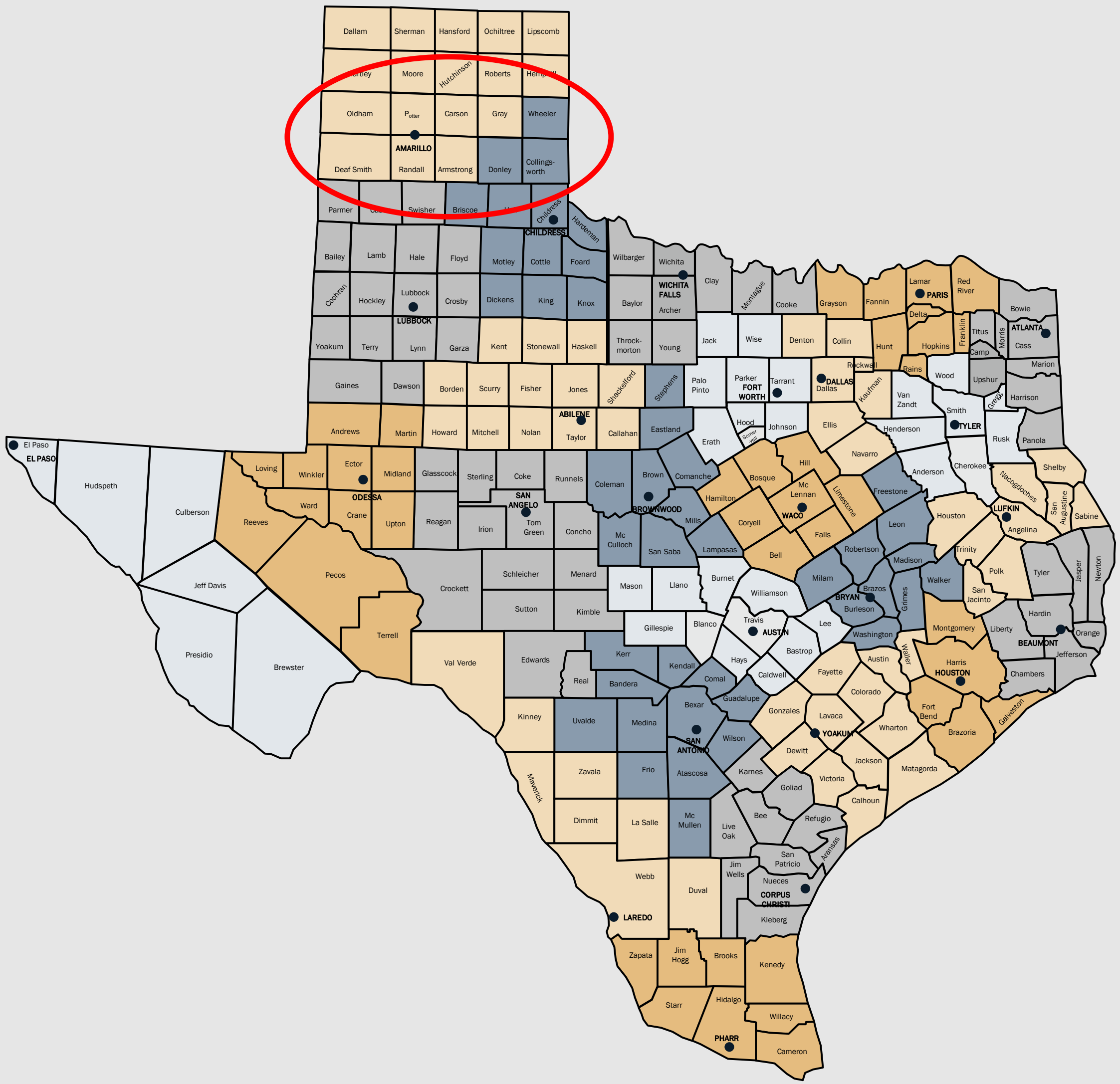
RM 1061

Sierrita de la Cruz Creek Bridge

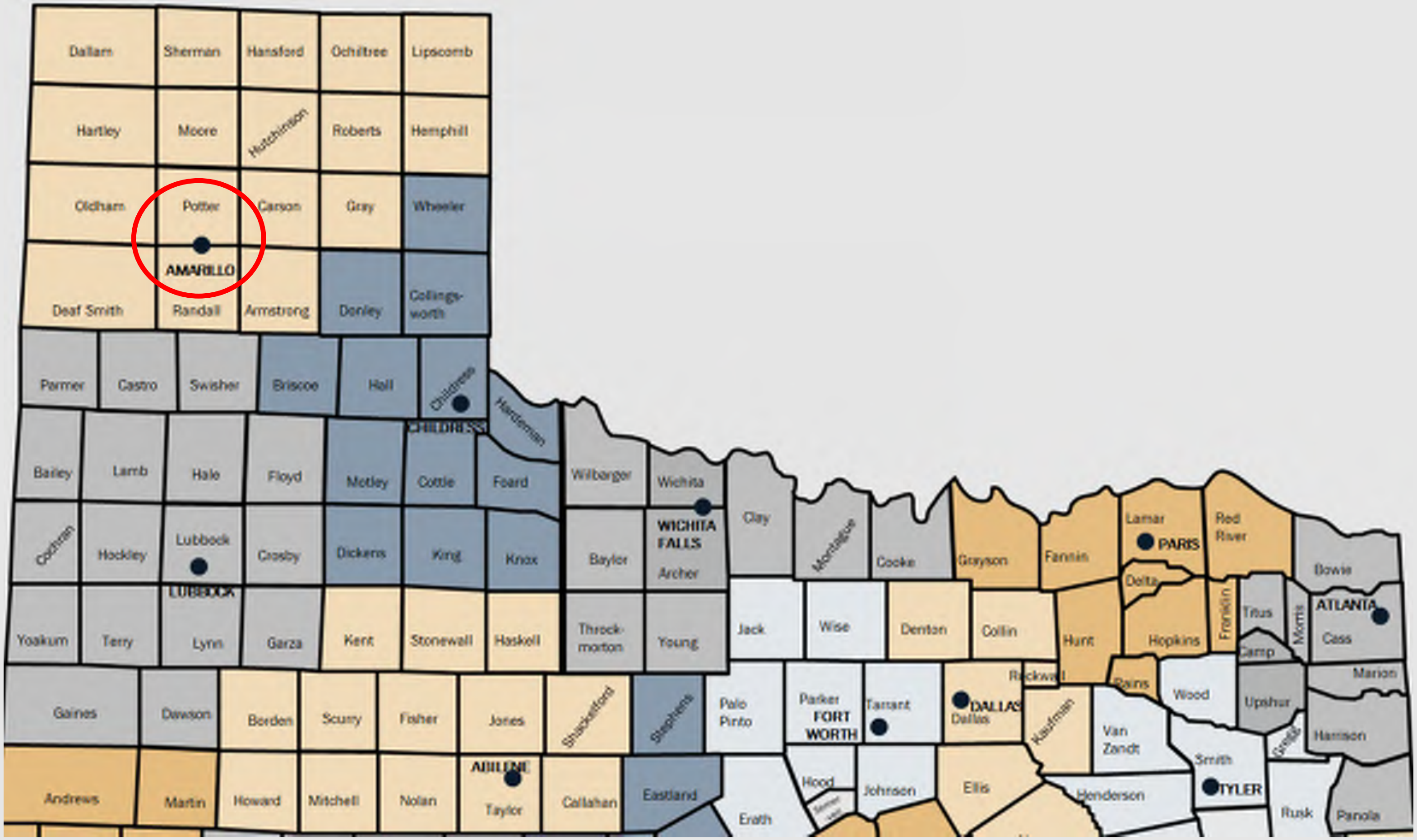
NBI Structure Number

04-188-0-1245-02-007

The Past



The Past



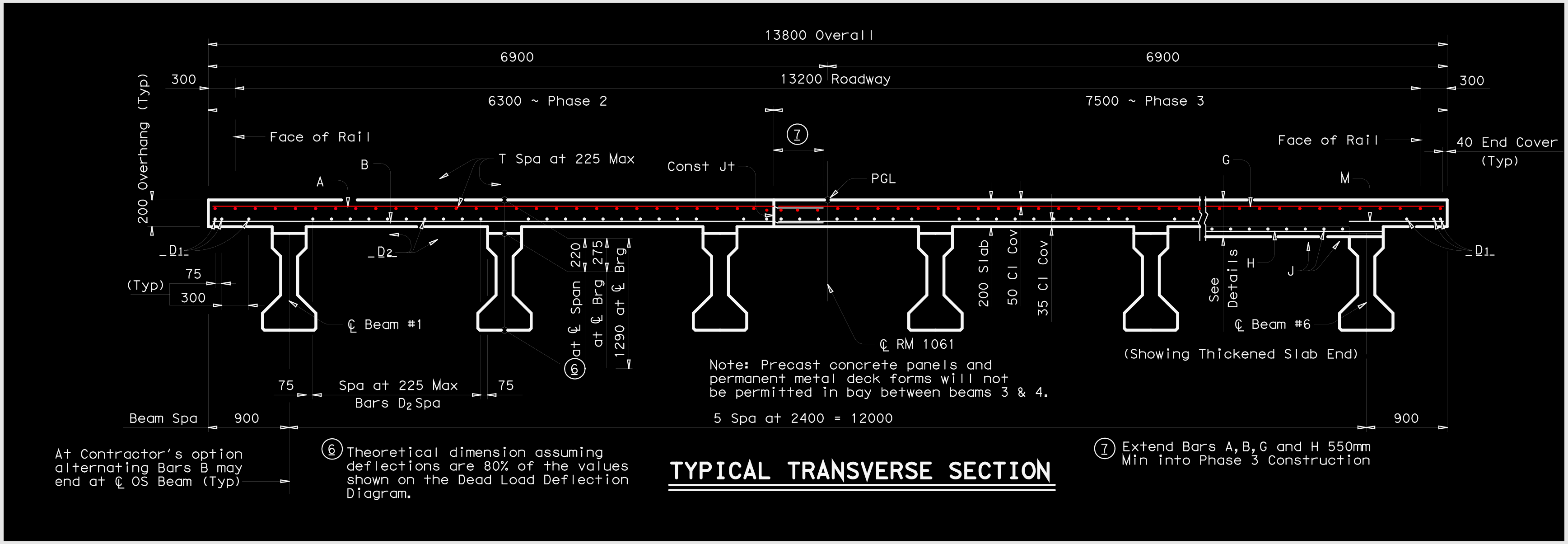
Dallam
Sherman
Hansford
Ochiltree
Lipscomb
Hartley
Moore
Hutchinson
Roberts
Hemphill
Oldham
Potter
Carson
Gray
Wheeler
AMARILLO
Deaf Smith
Randall
Armstrong
Donley
Collings-
worth
Parmer
Castro
Swisher
Briscoe
Hall
Childress
CHILDRESS
Hardeman
Bailey
Lamb
Hale
Floyd
Motley
Cottle
Foard
Wilbarger
Wichita
Clay
Cochran
Hockley
Lubbock
LUBBOCK
Crosby
Dickens
King
Knox
Baylor
WICHITA
FALLS
Archer
Montague
Cooke
Grayson
Fannin
Lamar
PARIS
Red
River
Bowie
Delta
Yoakum
Terry
Lynn
Garza
Kent
Stonewall
Haskell
Throck-
morton
Young
Jack
Wise
Denton
Collin
Hunt
Hopkins
Franklin
Titus
Morris
ATLANTA
Cass
Camp
Marion
Gaines
Dawson
Borden
Scurry
Fisher
Jones
Shackelford
Stephens
Palo
Pinto
Parker
FORT
WORTH
Tarrant
DALLAS
Dallas
Rockwall
Kaufman
Rains
Van
Zandt
Wood
Upshur
Harrison
Smith
Gregg
Andrews
Martin
Howard
Mitchell
Nolan
ABILENE
Taylor
Callahan
Eastland
Erath
Hood
Johnson
Ellis
Henderson
TYLER
Rusk
Panola

The Sierrita de la Cruz Creek Bridge

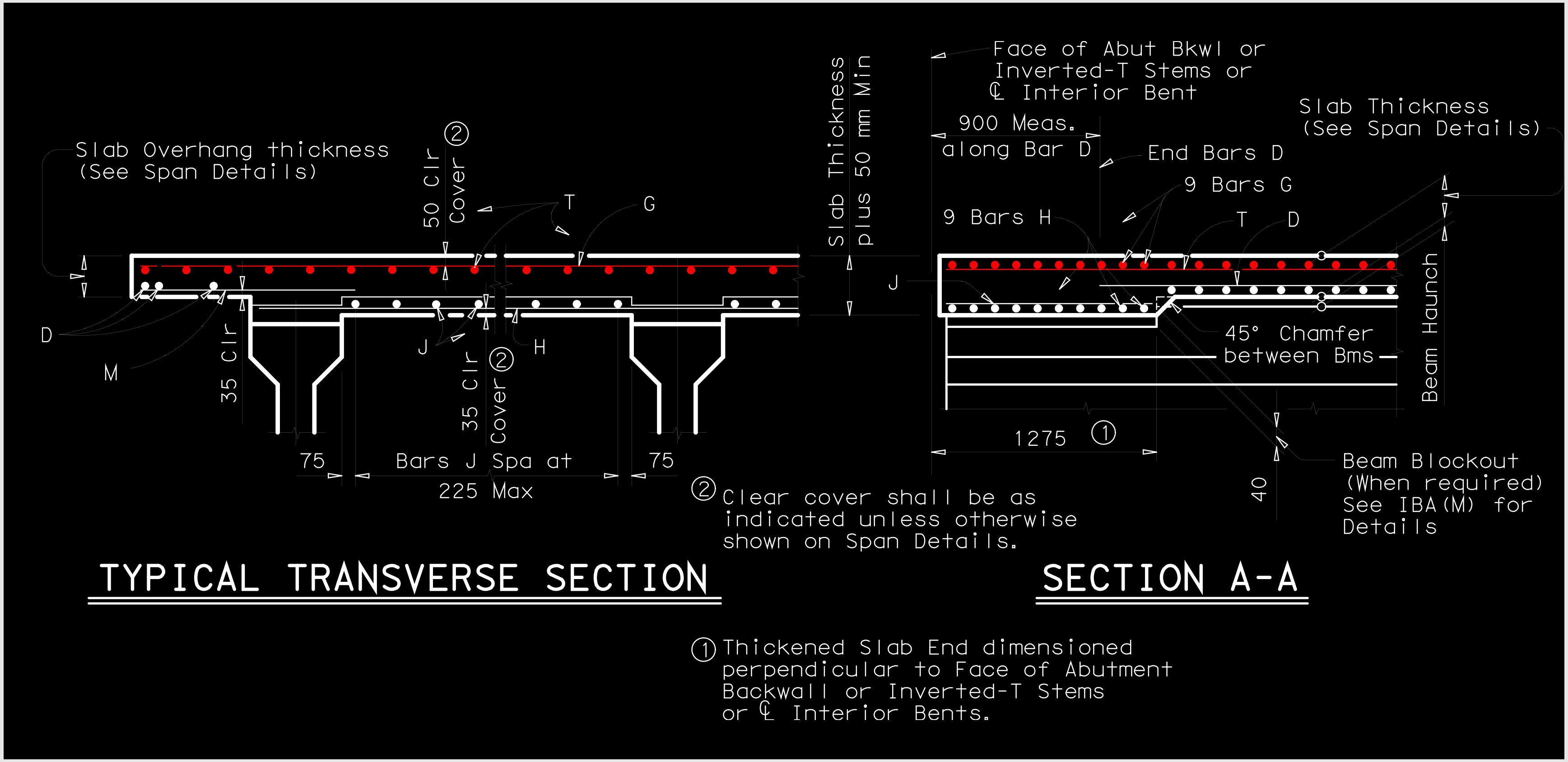
Sierrita de la Cruz Creek Bridge
Basic Dimensions

Roadway Width	Overall Width	Bridge Length	Span Lengths	Poor Boy Continuous Unit s Arrangement
13.2 m (43.3 ft)	13.8 m (45.3 ft)	168.553 m (553 ft)	7 ~ 24.079 m (79 ft)	2 Span – 3 Span – 2 Span

The Past

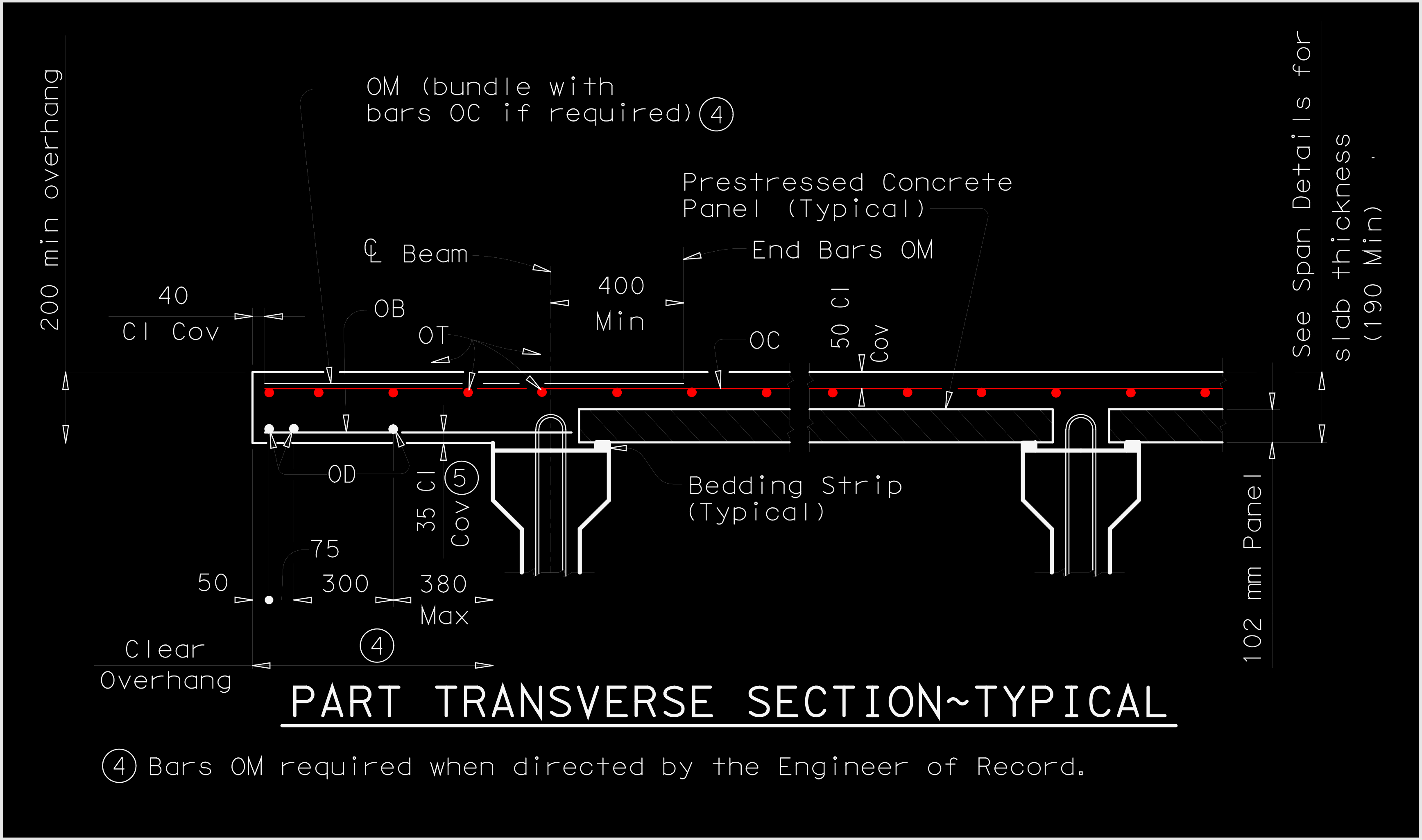


13800 Overall
6900
6900
300
13200 Roadway
300
6300 ~ Phase 2
7500 ~ Phase 3
200 Overhang (Typ)
Face of Rail
Face of Rail
40 End Cover (Typ)
T Spa at 225 Max
Const Jt
PGL
A
B
G
M
D1
D2
D1
75
(Typ)
300
220 at ℄ Span
275 at ℄ Brg
1290 at ℄ Brg
200 Slab
50 Cl Cov
35 Cl Cov
See Details
H
J
℄ Beam #1
℄ Beam #6
℄ RM 1061
(Showing Thickened Slab End)
Note: Precast concrete panels and permanent metal deck forms will not be permitted in bay between beams 3 & 4.
75
Spa at 225 Max
75
Bars D2 Spa
Beam Spa
900
5 Spa at 2400 = 12000
900
At Contractor's option alternating Bars B may end at ℄ OS Beam (Typ)
6 Theoretical dimension assuming deflections are 80% of the values shown on the Dead Load Deflection Diagram.
TYPICAL TRANSVERSE SECTION
7 Extend Bars A, B, G and H 550mm Min into Phase 3 Construction



Slab Overhang thickness
(See Span Details)
2
50 Clr Cover
T
G
D
M
35 Clr
J
2
35 Clr Cover
H
75
Bars J Spa at
75
225 Max
Slab Thickness plus 50 mm Min
J
Face of Abut Bkwl or
Inverted-T Stems or
℄ Interior Bent
900 Meas.
along Bar D
End Bars D
Slab Thickness
(See Span Details)
9 Bars G
9 Bars H
T
D
45° Chamfer
between Bms
Beam Haunch
1275
1
40
Beam Blockout
(When required)
See IBA(M) for
Details
2 Clear cover shall be as
indicated unless otherwise
shown on Span Details.
TYPICAL TRANSVERSE SECTION
SECTION A-A
1 Thickened Slab End dimensioned
perpendicular to Face of Abutment
Backwall or Inverted-T Stems
or ℄ Interior Bents.

The Past



OM (bundle with bars OC if required) 4
Prestressed Concrete Panel (Typical)
℄ Beam
End Bars OM
200 min overhang
40
Cl Cov
OB
OT
400 Min
OC
50 Cl Cov
See Span Details for slab thickness (190 Min)
OD
35 Cl Cov 5
Bedding Strip (Typical)
75
50
300
380 Max
4
Clear Overhang
102 mm Panel
PART TRANSVERSE SECTION~TYPICAL
4 Bars OM required when directed by the Engineer of Record.

The Past

The Past


The Past

The Past

The Past

The Past

The Past

Maximum Bar Spacing Required for Strength and Serviceability

Limit State	#5 ~ ECS	#6 ~ GFRP (k_b = 1.22)	#6 ~ GFRP (k_b = 1.0)
Strength	158 mm (6.22 in)	268 mm (10.55 in)	268 mm (10.55 in)
Allowable Stress	>158 mm (6.22 in)	251 mm (9.88 in)	251 mm (9.88 in)
Crack Width (~0.02 in)	>158 mm (6.22 in)	140 mm (5.51 in)	171 mm (6.73 in)

k_b = bond-dependent coefficient (which accounts for the difference between crack width of black steel and FRP reinforcement attributable to bond slip adjacent to the crack).

Use of a more realistic / less overly-conservative k_b factor will result in a design that can compete head to head with ECS in terms of spacing of reinforcement required when designing for the same slab moment (empirical design not considered).

The Past

County	CSJ	Letting	Usage
[1]Williamson	0683-06-015	05/2003	11" JCP w/ GFRP dowels and transverse deformed bars in the region of toll gantries
[1]Travis	3136-01-126	06/2003	11” JCP w/ GFRP dowel and transverse deformed bars in the region of toll gantries 8" concrete bridge deck w/ GFRP bars in top n the region of a toll gantry (2nd usage in TX)
[1]Williamson	0683-01-070	08/2003	11" JCP w/ GFRP dowels and transverse deformed bars in the region of toll gantries
[1]Williamson	0683-01-069	09/2003	11” JCP w/ GFRP dowel and transverse deformed bars in the region of toll gantries
[1]Williamson	0683-06-024	01/2004	11” JCP w/ GFRP dowel and transverse deformed bars in the region of toll gantries
[1]Travis	0683-07-003	03/2004	11” JCP w/ GFRP dowel and transverse deformed bars in the region of toll gantries
[2]Cameron	3622-01-001	03/2010	GFRP Reinforced CRCP
[3]Randall	0168-09-108	07/2010	Alternate bid was 8" concrete deck w/ top mat of GFRP bars

GFRP Bar Usage Summary

During the first decade of service of the Sierrita de la Cruz Creek Bridge at least eight TxDOTconstruction projects employed GFRP bars in some capacity. All but one project used the bars for magnetic transparency in pavements at electronic tolling locations, including: (1) jointed concrete pavement; (2) a bridge deck supporting a toll plaza; and (3) GFRP bar continuously reinforced concrete pavements.

Of particular interest is the last listed project let in July 2010 in which a GFRP bar reinforced concrete deck design was offered as an alternative to the standard steel reinforced deck design. This was TxDOT’s first attempt to let GFRP bars compete directly with steel reinforcement. Not unsurprisingly the winning bidder based their bid on the standard steel reinforced concrete deck.

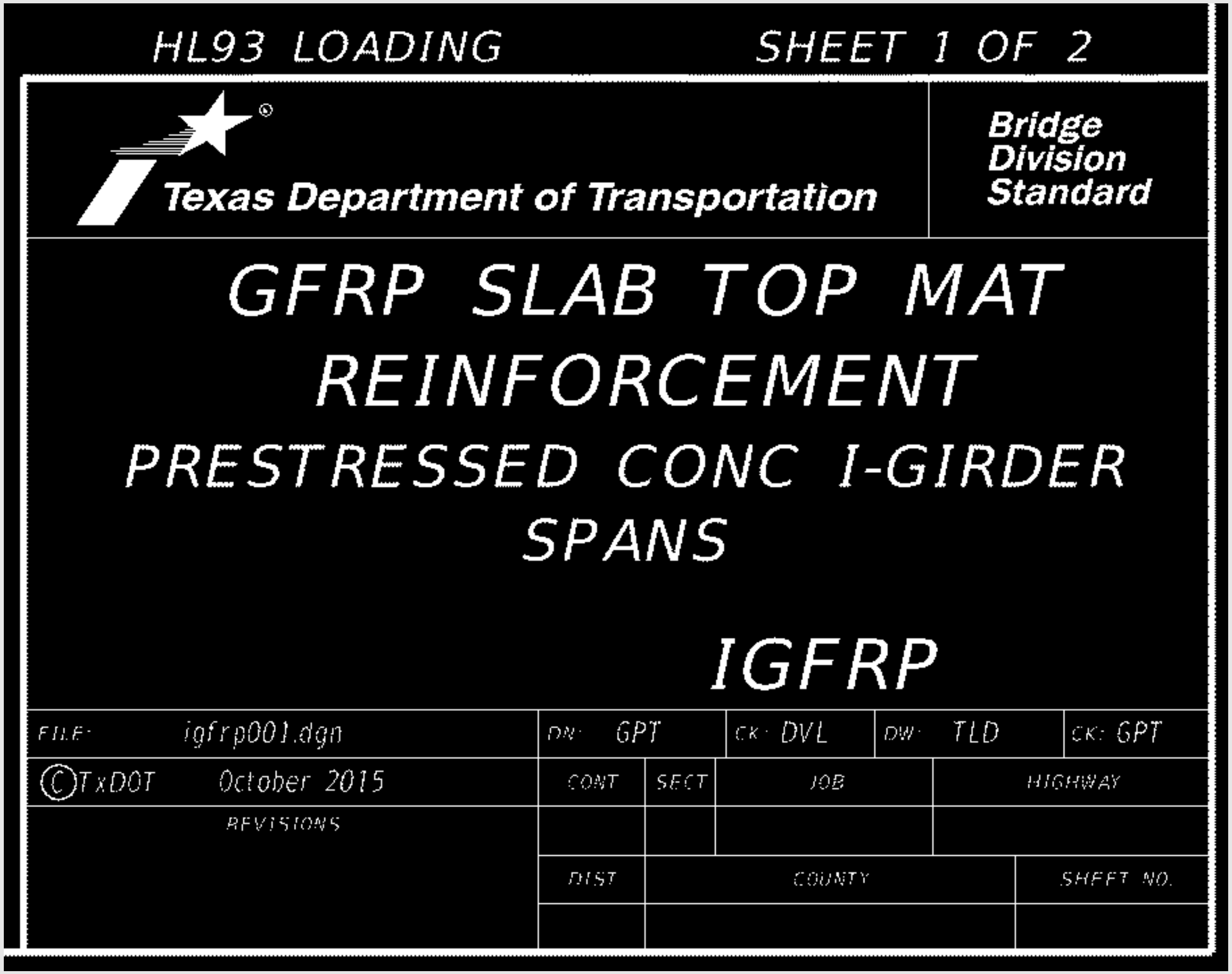
Recommendations for GFRP Bar CRCP

Evaluating the Use of Fiber-Reinforced Polymer Bars in Continuously Reinforced Concrete Pavement
URL: https://www.fhwa.dot.gov/pavement/concrete/pubs/hif09012/hif09012.pdf

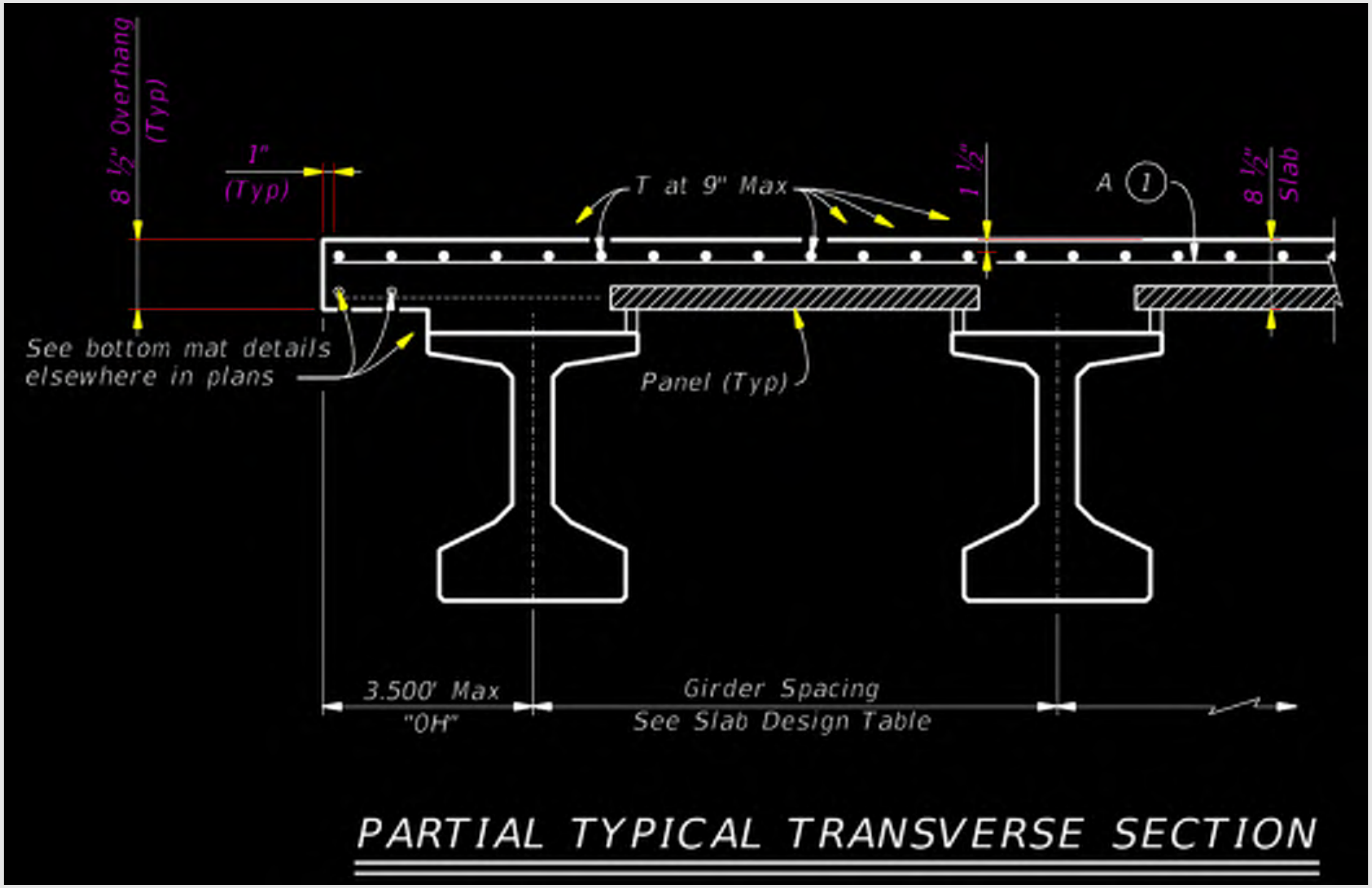
Walton, S., and T. Bradberry. 2005. "Feasibility of a Concrete Pavement Continuously Reinforced by Glass Fiber Reinforced Polymer Bars." Proceedings, Third International Conference on Construction Materials, Vancouver, British Columbia, Canada
URL: https://ftp.dot.state.tx.us/pub/txdot-info/library/pubs/bus/bridge/feasibility_concrete.pdf

The Past

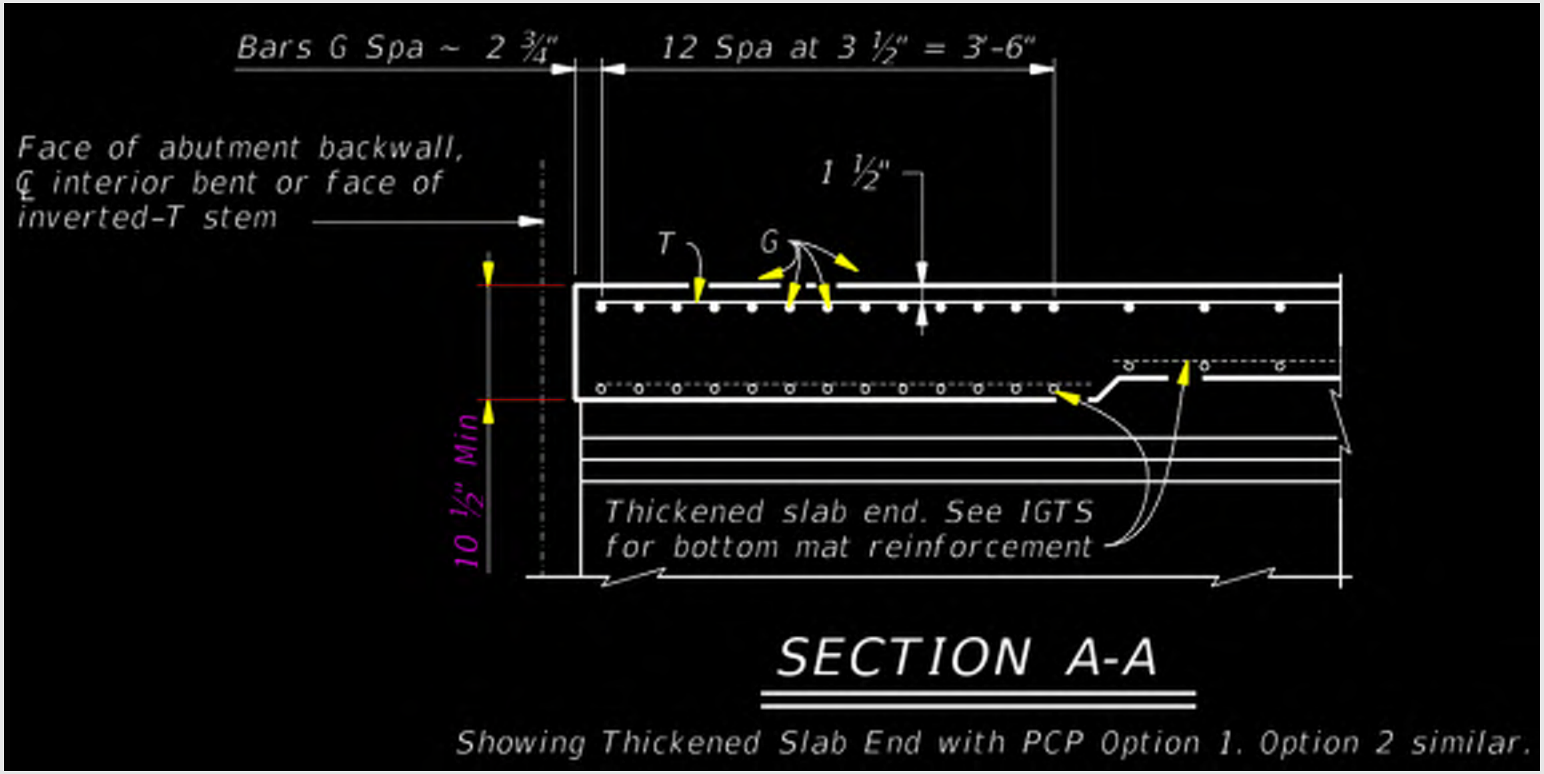
The Present – 1st Generation IGFRP Standard Bridge Deck



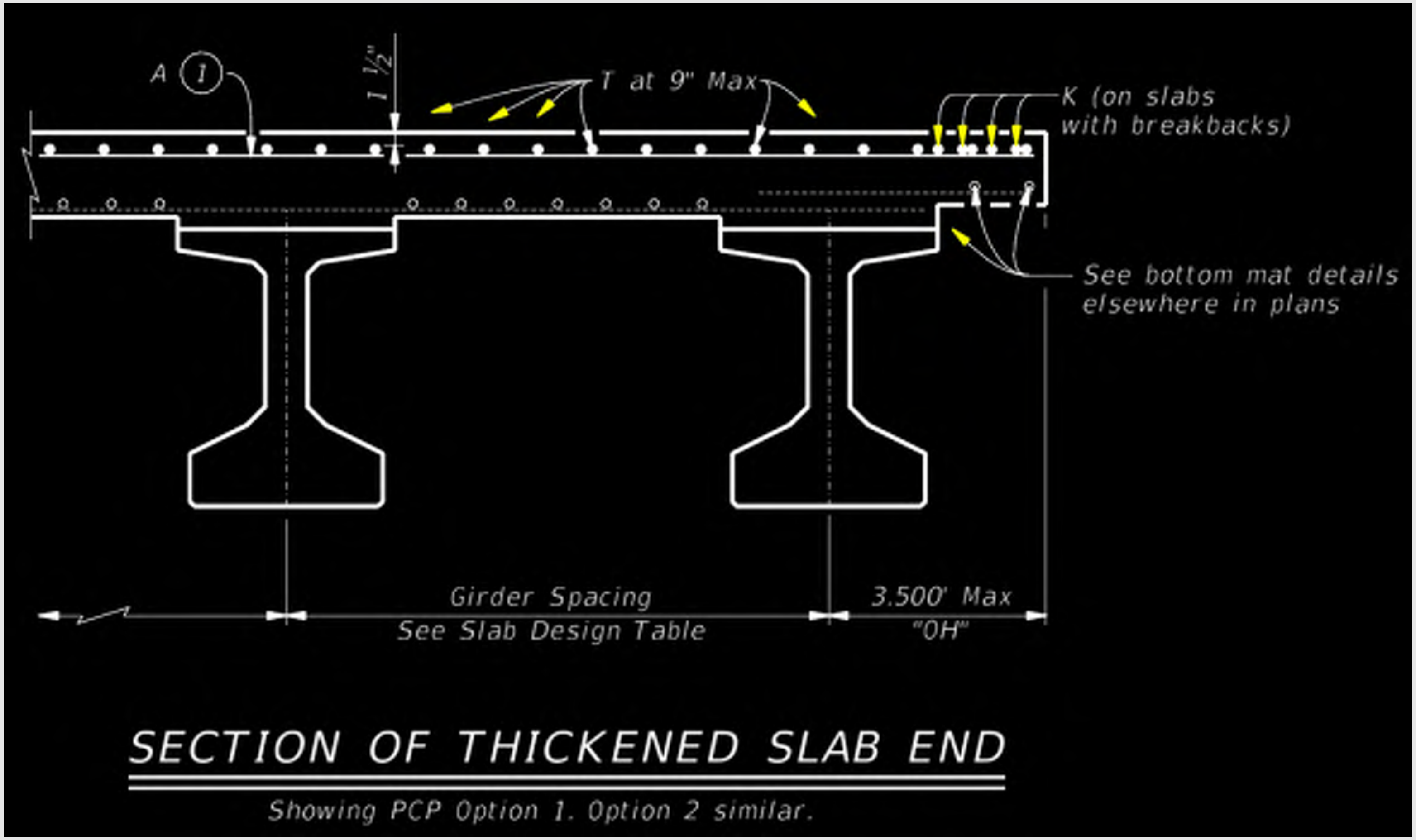
The Present – 1st Generation IGFRP Standard Bridge Deck



The Present – 1st Generation IGFRP Standard Bridge Deck



The Present – 1st Generation IGFRP Standard Bridge Deck



The Present – 1st Generation IGFRP Standard Bridge Deck

Transverse Bars →

Longitudinal Bars →

BAR TABLE

BAR	SIZE
A	#6
AA	#6
G	#6
K	#5
T	#5

SLAB DESIGN TABLE

Girder Spacing	Max Bar A Spa	Length of #5 GFRP bar per Sq Ft	Length of #6 GFRP bar per Sq Ft
7.500' or less	7"	1'-4"	1'-9"
8.500' or less	6 ½"	1'-4"	1'-10"
9.500' or less	5 ¾"	1'-4"	2'-1"
10.000' or less	5 ½"	1'-4"	2'-2"

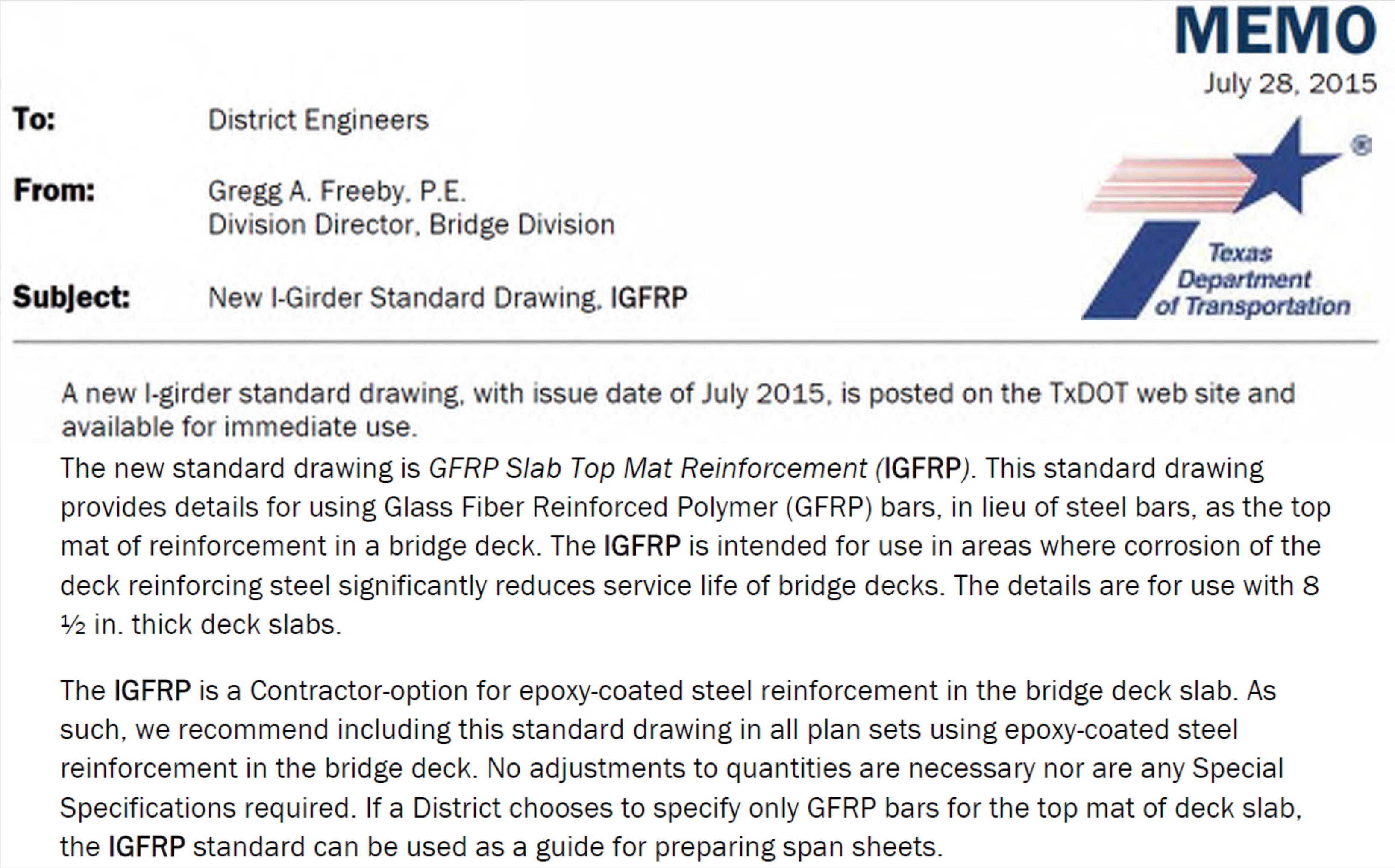
DESIGN PROPERTIES TABLE (8)

Bar Size	E_f	f_{fu}	C_E	k_b
#5	5.7×10^3	95	0.7	0.9
#6	5.7×10^3	90	0.7	0.9

(8) GFRP properties assumed for design.

E_f = Modulus of elasticity (ksi)
f_{fu} = Tensile strength for product certification (ksi)
C_E = Environmental reduction factor
k_b = Bond coefficient

The Present – 1st Generation IGFRP Standard Bridge Deck



MEMO

July 28, 2015

To: District Engineers

From: Gregg A. Freeby, P.E.
Division Director, Bridge Division

Subject: New I-Girder Standard Drawing, IGFRP

A new I-girder standard drawing, with issue date of July 2015, is posted on the TxDOT web site and available for immediate use.

The new standard drawing is *GFRP Slab Top Mat Reinforcement (***IGFRP***)*. This standard drawing provides details for using Glass Fiber Reinforced Polymer (GFRP) bars, in lieu of steel bars, as the top mat of reinforcement in a bridge deck. The **IGFRP** is intended for use in areas where corrosion of the deck reinforcing steel significantly reduces service life of bridge decks. The details are for use with 8 ½ in. thick deck slabs.

The **IGFRP** is a Contractor-option for epoxy-coated steel reinforcement in the bridge deck slab. As such, we recommend including this standard drawing in all plan sets using epoxy-coated steel reinforcement in the bridge deck. No adjustments to quantities are necessary nor are any Special Specifications required. If a District chooses to specify only GFRP bars for the top mat of deck slab, the **IGFRP** standard can be used as a guide for preparing span sheets.

Memo link – ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/memoi51e.pdf

Drawing link– ftp://ftp.dot.state.tx.us/pub/txdot-info/cmd/cserve/standard/bridge/igfrp001.pdf

The Future – Specify GFRP Bars for One or Two Large Projects

Suggested revisions to the IGFRP Standard

- Flip the top mat reinforcement back to the traditional orientation of transverse bars on top of longitudinal bars to increase *d* from 6 to 6.625 inches (~10% increase in flexural capacity).
- Reduce, if possible, the amount of reinforcement in the thickened slab ends.
- Use a more realistic deck analysis method or use something like an empirical deck design.

The Future – Specify GFRP Bars for One or Two Large Projects

Demonstration Projects

- Specify GFRP bars on a limit basis for bridge projects in the Pan Handle or other areas of Texas with a history of steel corrosion induced concrete deterioration.
- The purpose would be to determine if the GFRP bars can be supplied in the quantities needed at reasonable prices.
- Assuming a favorable outcome, more projects would follow.

Conclusions

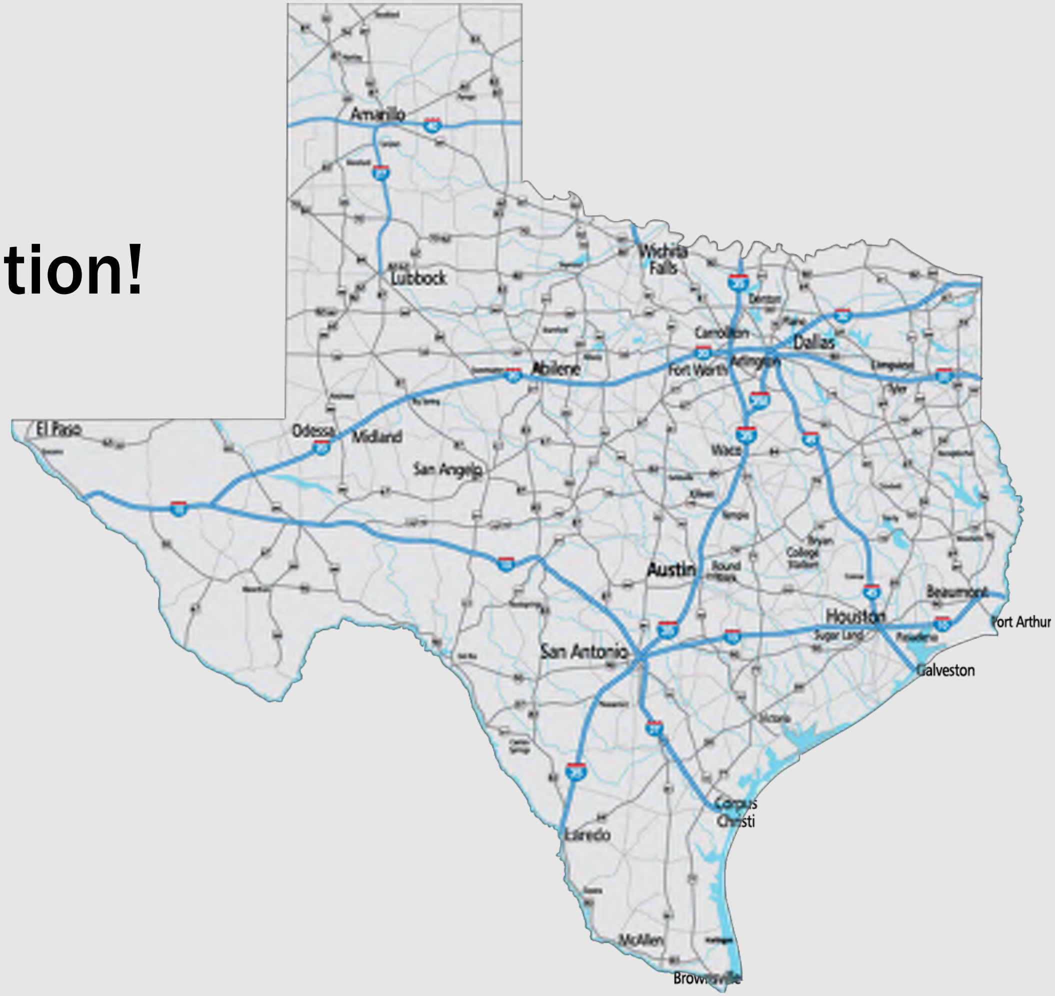
- De-pacified steel reinforcement will corrode, return to the iron oxide from which it came and in the process deteriorate the concrete.
- GFRP rebar cannot corrode and thus does not deteriorate concrete.
- Texas built a GFRP bar reinforced bridge deck on an experimental basis in 1999-2000.
- Texas has used GFRP dowels and rebar in JCP and CRCP for magnetic transparency. No performance issues have been reported.
- Texas issued a standard in 2015 for GFRP reinforced bridge deck for use with its popular prestressed I-Girders as a Contractor option, but contractors have not opted to use the standard. Engineers plan to explore ways to reduce the amount of GFRP required by the standard to make it more competitive with steel reinforced decks.
- Because TxDOT engineers are gaining confidence in GFRP bars as reinforcement for bridge decks they plan to let one or two large projects where GFRP rebar will be specified. The question will be: Can the material be supplied and placed in the quantities required at a reasonable price?

17 Years of GFRP Reinforcement Involvement

17 Years of GFRP Reinforcement Involvement

Thanks for your attention!

Questions?



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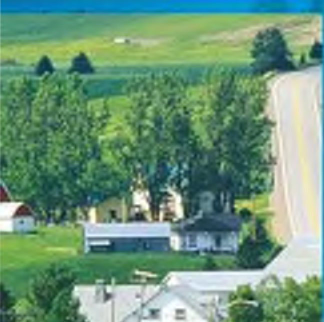
MINISTÈRE DES TRANSPORTS, DE LA MOBILITÉ DURABLE
ET DE L'ÉLECTRIFICATION DES TRANSPORTS

First International Workshop on Glass Fiber Reinforced Polymer (GFRP) Bar for Concrete Structures

Quebec's Current Status and Practices for the Use of GFRP Bar in Bridges

By Steve Arsenault, Eng., M. Sc. and Gérard Desgagné, Eng., M. Sc.
Direction générale des structures

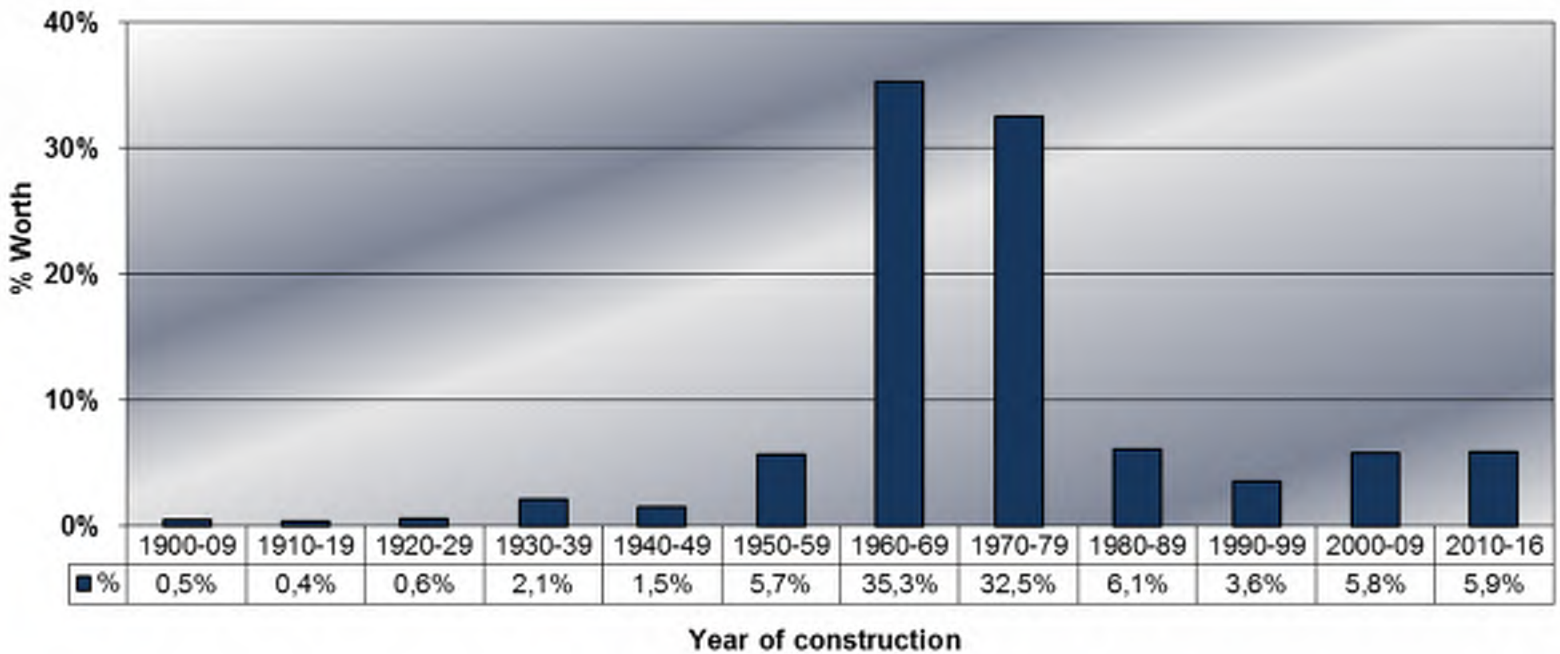
July 2017



ENSEMBLE on fait avancer le Québec

Québec

Percentage of Superior Road Network Structures Built per Decade (4.5 m or more)



Transports, Mobilité durable et Électrification des transports
Québec

Structures Inventory

Network	Quantity	Area (m^2)	Worth of structures (G$)
Superior	5 465	5 234 984	26.33
Municipal	4 247	744 004	3.46
Total	9 712	5 978 988	29.79

Transports, Mobilité durable et Électrification des transports
Québec

Current Applications in Bridges

- Deck slab reinforcement
- Barrier wall reinforcement

Transports, Mobilité durable et Électrification des transports
Québec

Current Applications in Bridges
Deck Slabs and Barrier Walls

Transports, Mobilité durable et Électrification des transports
Québec

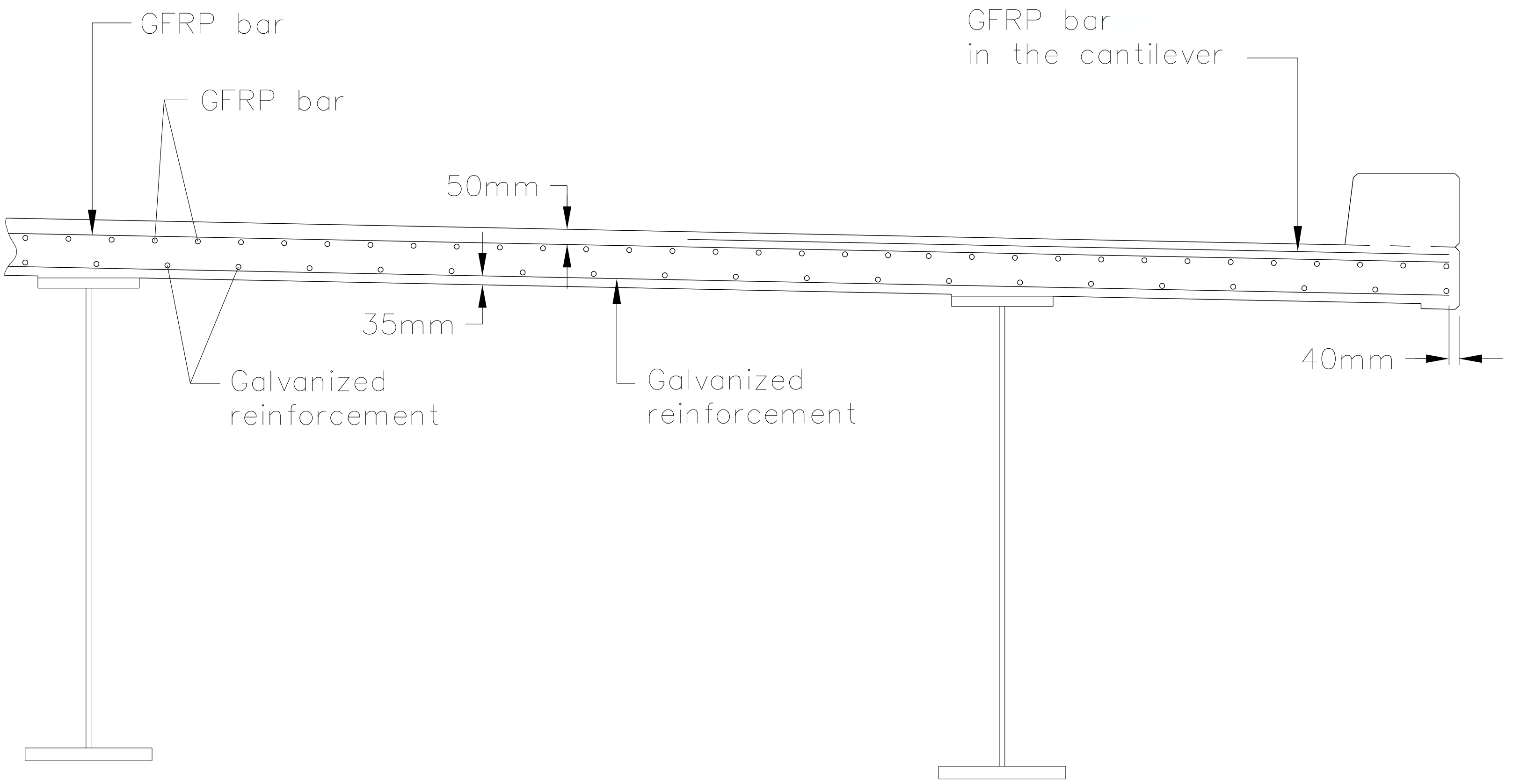
Deck Slab Reinforcement

- Replacement of galvanized rebar when AWDT > 2 500

- Top reinforcement only transversely and longitudinally, except near the deck joint

- Single span bridges not part of the superior network

Deck Slab Reinforcement



Transports, Mobilité durable et Électrification des transports
Québec

Barrier Wall Reinforcement

- Replacement of galvanized rebar when AWDT > 500
- Static tests
- Pendulum tests

Transports, Mobilité durable et Électrification des transports
Québec

Barrier Wall Reinforcement

Static Tests

Transports,
Mobilité durable
et Électrification
des transports
Québec

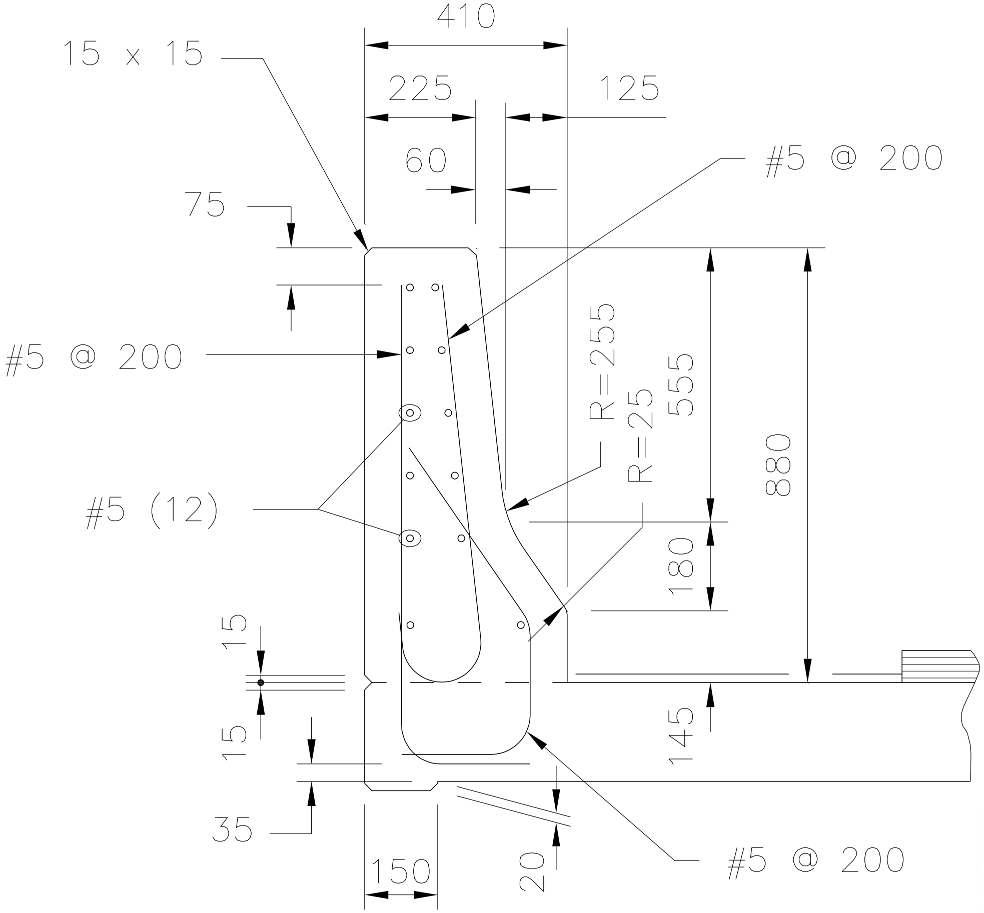
Barrier Wall Reinforcement

Pendulum Tests

Transports,
Mobilité durable
et Électrification
des transports
Québec

Barrier Wall Reinforcement

GFRP Bent Bars — TL4



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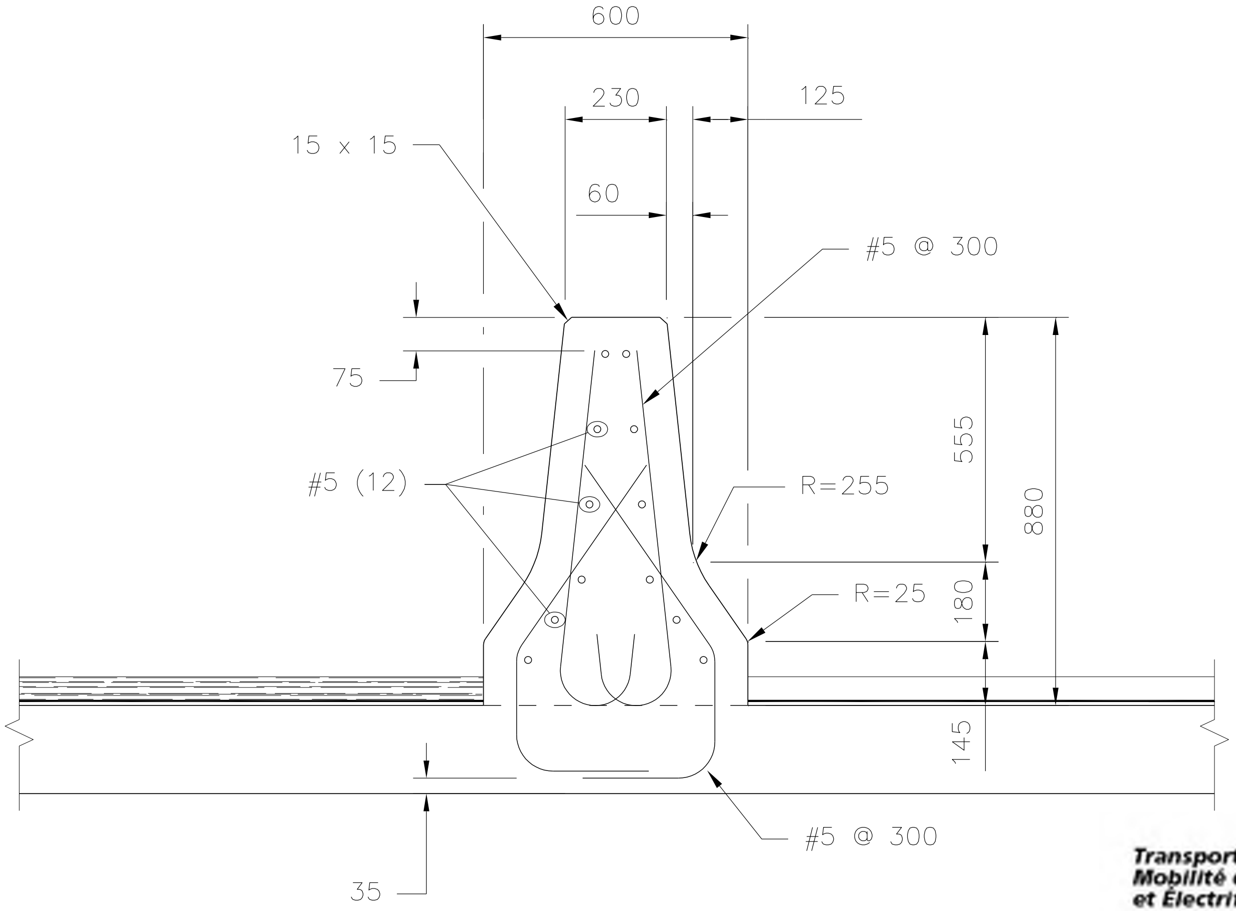
Transports, Mobilité durable et Électrification des transports
Québec

Barrier Wall Reinforcement

GFRP Bent Bars — TL4

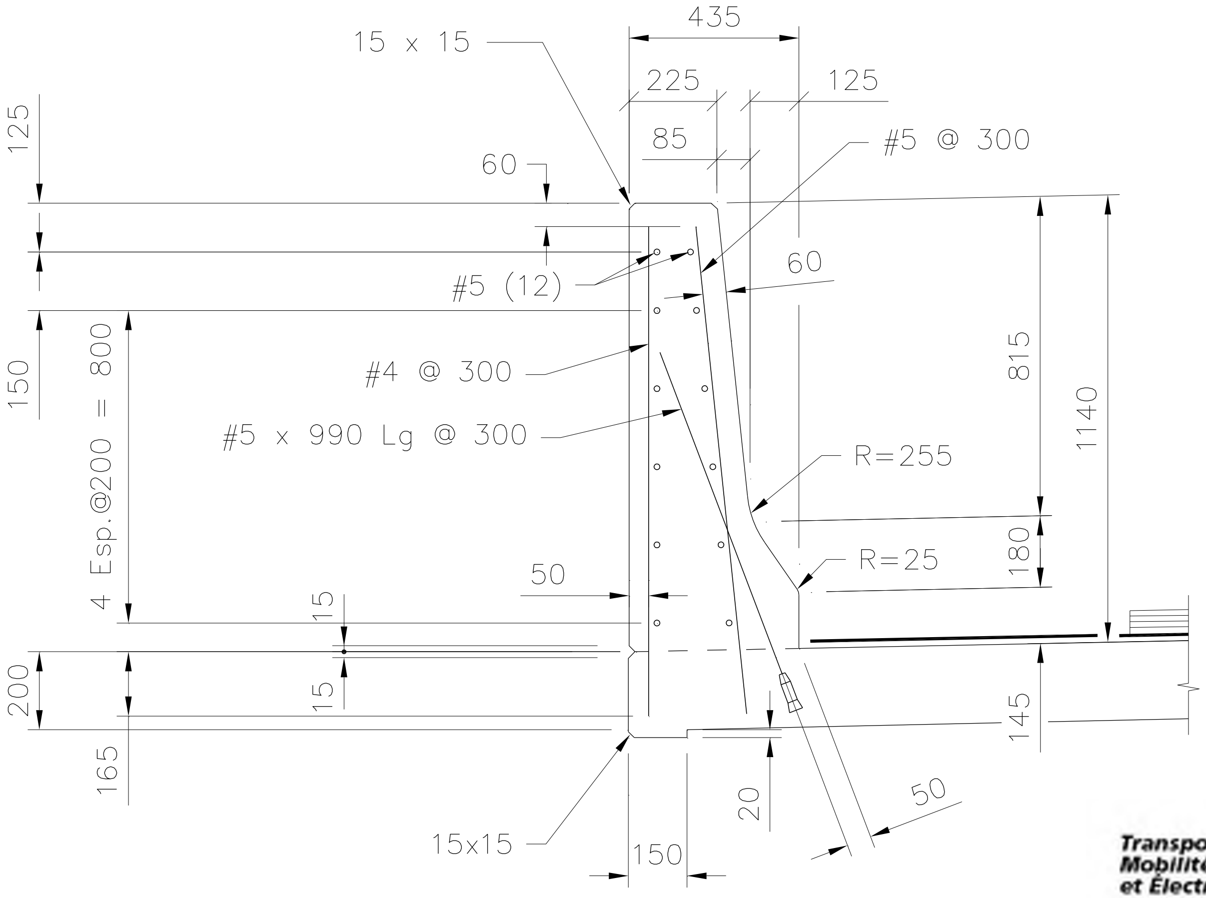


201M

Transports, Mobilité durable et Électrification des transports
Québec

Barrier Wall Reinforcement

GFRP Straight Bars with Headed Ends — TL5

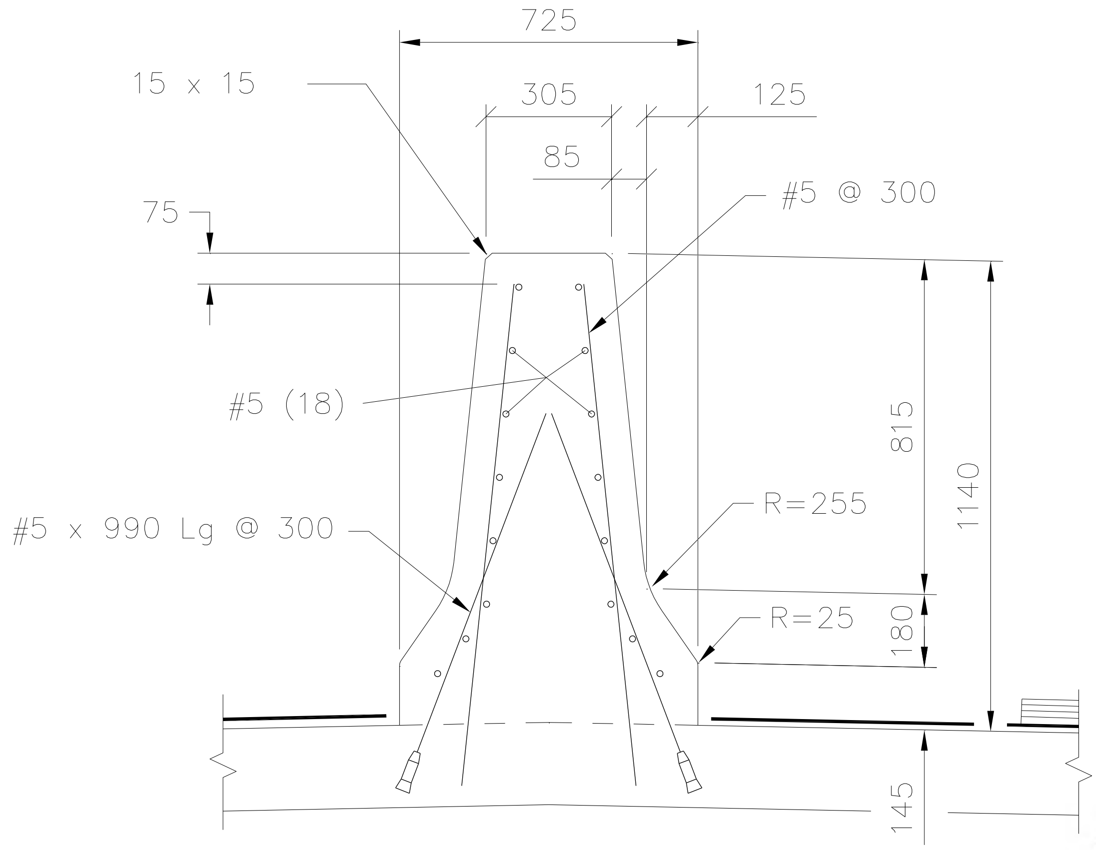


301

Transports, Mobilité durable et Électrification des transports
Québec

Barrier Wall Reinforcement

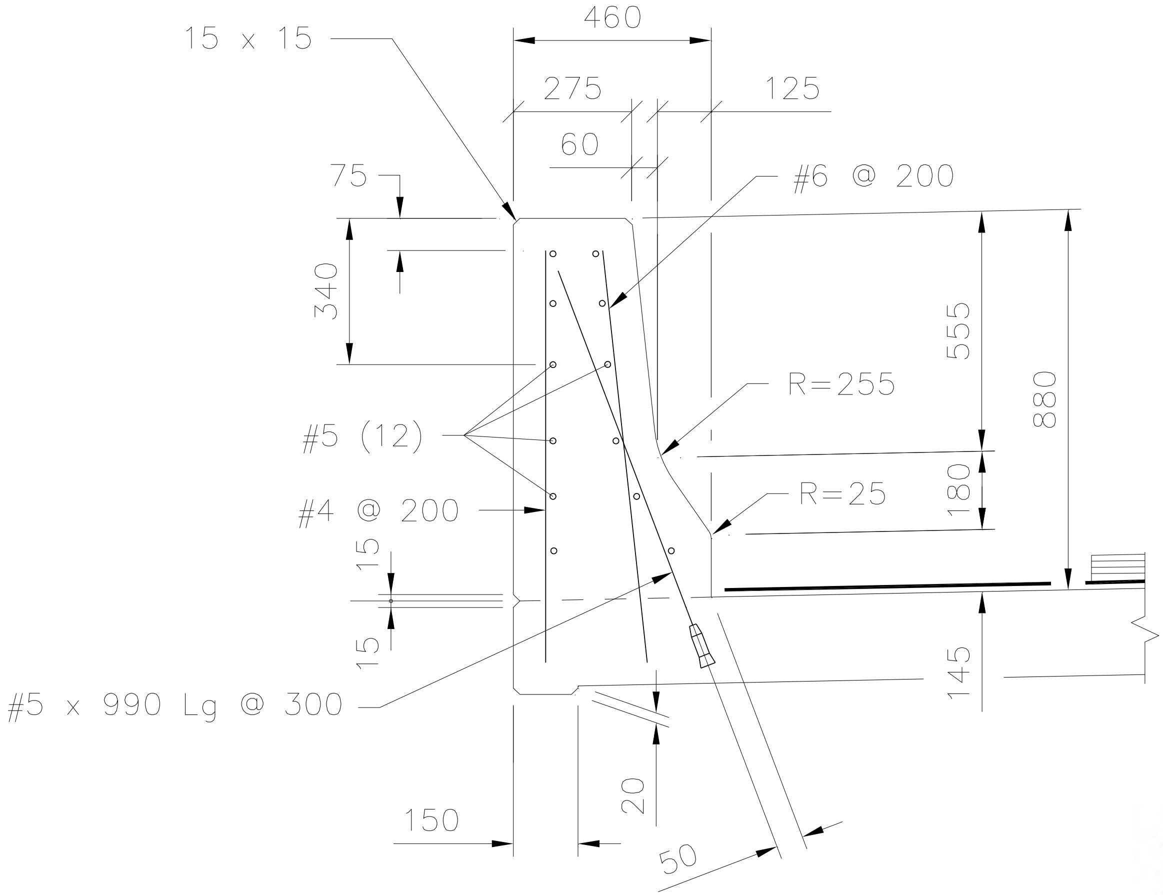
GFRP Straight Bars with Headed Ends — TL5



301M

Barrier Wall Reinforcement

GFRP Straight Bars with Headed Ends — TL5



311B

Transports, Mobilité durable et Électrification des transports
Québec

Status of the Projects with GFRP Led by the MTMDET

Fifty structures are currently in service:

- 8 projects before 2008
- 7 projects in 2009
- 7 projects in 2010
- 10 projects in 2012
- 7 projects in 2013
- 7 projects in 2014
- 4 projects in 2016

Projects to come (2017):

- 9 projects approved to date
- Other projects are planned until 2022

Current Applications in Bridges

Status

- Good structural behaviour
- Good short-term durability (≈ 20 years)

Current Applications in Bridges

Main Concerns

- Repair techniques
- Long-term durability
- Life cycle cost vs galvanized or stainless

Transports, Mobilité durable et Électrification des transports
Québec

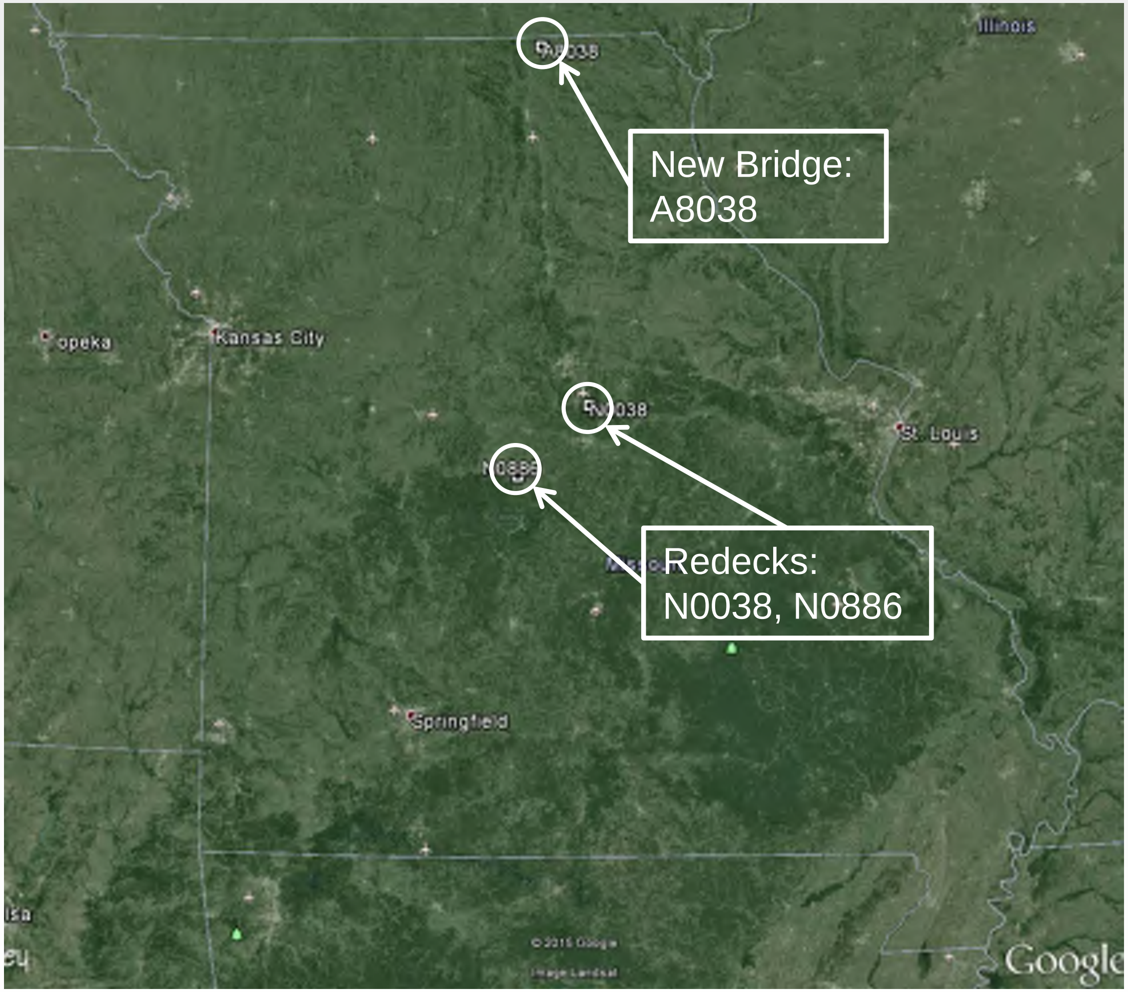
Transports,
Mobilité durable
et Électrification
des transports
Québec

Use of FRP Bar and Project Experiences in Missouri

Bryan A. Hartnagel, PE, Ph.D.
Structural Resource Manager
Missouri Department of Transportation
July 18, 2017

MoDOT History with FRP bars in Bridge Decks

- Locations with FRP reinforced bridge decks on State maintained bridges
- Two redecks
- One new bridge



Two Steel Girder Bridge Redecks in 2007

- Based on research conducted at the University of Missouri – Columbia and University of Missouri – Rolla (now Missouri University of Science and Technology)
- Hybrid approach using GFRP and CFRP bars to enhance ductility and limit crack width
- http://library.modot.mo.gov/RDT/reports/Ri02002/or06014.pdf

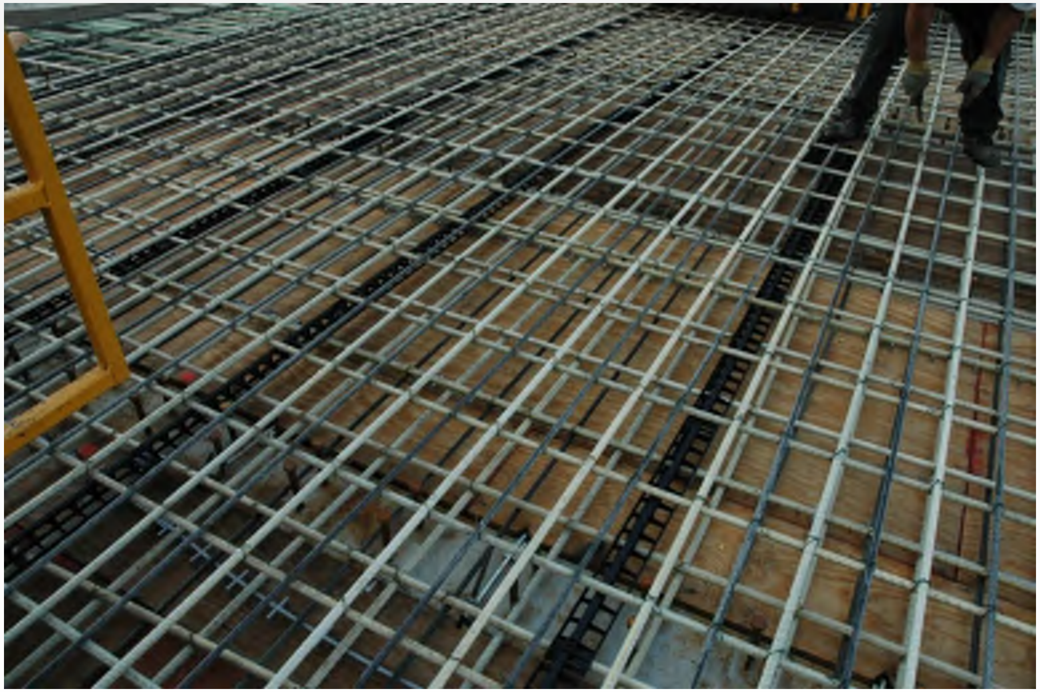
MoDOT History with FRP bars in Bridge Decks

- Bridge Redeck: N0038
- Location: Boone Co., Rte. Y over Cedar Creek
- ADT = 2450
- Let 3/30/2007

N0038 Details cont…

- (65'-80'-65') Steel Girder Spans
- 22' Wide Roadway
- CFRP and GFRP bars used in the deck only
- Epoxy coated steel rebar used in barrier curb and abutments

- 20,721 ft of #4 CFRP ($6.25/ft)
- 23,548 ft of #6 GFRP ($1.90/ft)
- Fiber Reinforced Concrete (FRC)



N0038 – Carbon FRP Bars with Sand Coating

N0038 – Glass FRP Bars with Sand Coating

Fiber Reinforced Concrete Mix

MoDOT History with FRP bars in Bridge Decks

- Bridge Redeck: N0886
- Location: Miller Co., Rte. OO over S. Moreau Creek
- ADT = 152
- Let 3/30/2007

N0886 Details cont…

- (50’-65’-50’) Steel Girder Spans
- 22’ Wide Roadway
- CFRP and GFRP bars used in the deck only
- Epoxy coated steel rebar used in barrier curb
- 14,226 ft of #4 CFRP ($6.30/ft)
- 17,833 ft of #6 GFRP ($2.00/ft)
- Fiber Reinforced Concrete (FRC)

MoDOT History with FRP bars in Bridge Decks

- New Bridge: A8038
- Rte. C over South Fork of North Fabius River
- ADT = 292

A8038 Details cont…

- In-House Design
- (41'-59'-41') P/S Concrete I-Girders
- 24' Roadway
- Let 3/21/2014
- GFRP bars used in the deck
- Epoxy coated steel rebar used in barrier curb and concrete diaphragms
- 24,776 ft of GFRP (Bid as SQYD of slab)
- #4, #6 & #7 GFRP bar sizes used.
- Class B-2 Concrete Mix

A8038 Objectives

- Non-corrosive “steel free bridge deck” alternative to our current practice (epoxy coated steel rebar).
- Implement GFRP bar design using the “AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings - 2009”
- Keep costs within our budget constraints.
- Track performance for future project development.

Scoping Process

We had some experience with a prior design that got scrapped and partially led to the following criteria.

- 200’ maximum overall length
- Jointless superstructure (no expansion joints)
- Low volume/rural route
- Use FHWA crash tested Open GFRP (Corral) Railing?
- Stream crossing required for open railing design
- No stage construction

Previous GFRP Deck Design (Scrapped)

- 2-77’ Spans with 4 - 27”x48” spread box beams (Girder depth needed for vertical clearance).
- Designer ran into issues with fitting enough GFRP rebar in the deck over the pier to account for flexural tension stresses (negative moment steel). Various “solutions” were discussed.
- Tight deadline, limited resources and a tight budget forced a switch back to an epoxy steel deck.

Lesson learned:

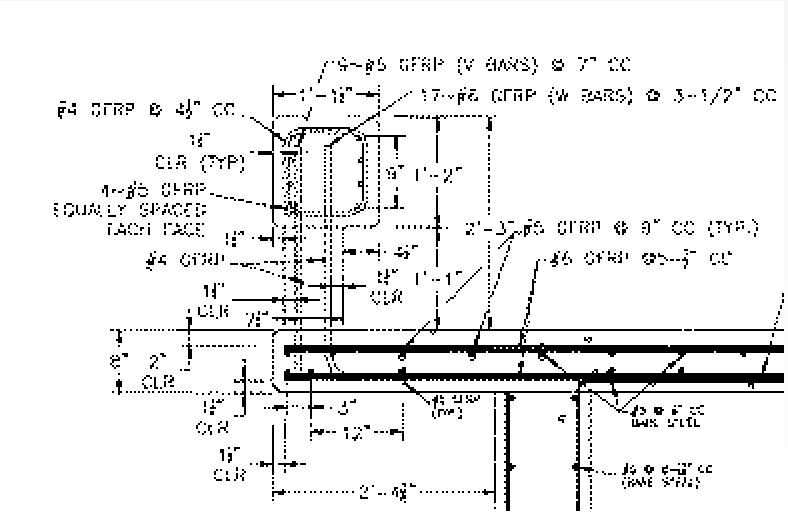
- Reduce scope to either single span bridges or bridges with three or more spans where moment over the pier is less controlling.

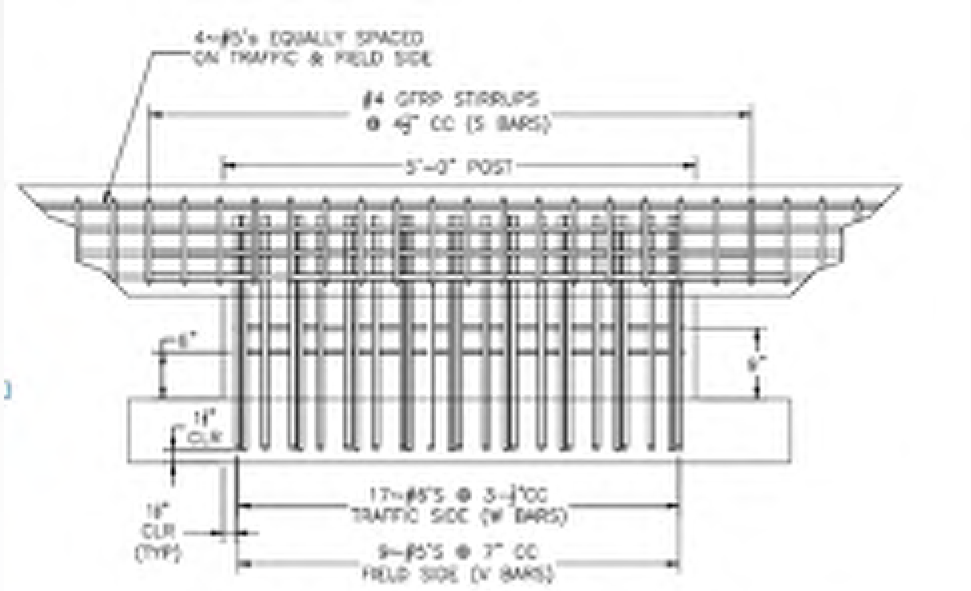
Preliminary GFRP (Corral) Railing

- Proposed railing actually uses a wider post than shown below. 5 ft wide post and opening.

Preliminary GFRP (Corral) Railing – Too Costly

- Cost of GFRP Rebar per ft of barrier curb = $30. Incudes a $0.75 per bend premium. Cost estimate is for rebar only.
- MoDOT standard Epoxy steel reinforced curb is $11.60/ft.
- Installation costs are not included and would likely drive costs up further since slip-forming cannot be used and field bends are not allowed.

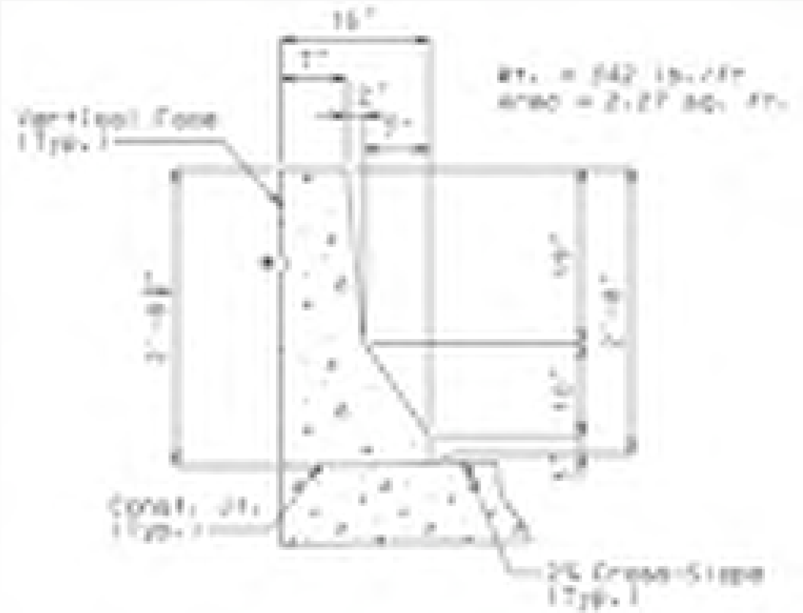




POST ELEVATION ~ Ce=0.7 CASE

Standard MoDOT Curb

- Epoxy steel reinforced double sloped "Jersey" curb.
- There is no crash-tested GFRP reinforced Jersey Curb available.
- Requires slab drain installation (Fiberglass).



Scoping Result

- New Bridge: A8038, Schuyler Co.
- (41'-59'-41') span lengths with integral abutments.
- Prestressed concrete (39") MoDOT Type 3 Girders
- Standard Jersey Curb
- Fiberglass Drains
- SIP Steel Forms (Option)

Design Concerns

- "AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings - 2009"
- Strength and modulus of bars vary with suppliers
- Stringent environmental factors (Ce = 0.7)
- GFRP bars do not yield (linear elastic until failure) resulting in stringent resistance factors (0.55 – 0.65)

Design Concerns

- GFRP bars have higher tensile strengths than steel, but the environmental concerns and non-ductile failure mechanism results in larger bar sizes and makes the product difficult to implement on longer span bridges.
- Unlike steel, larger bar sizes have smaller unit tensile strengths. This results in diminishing returns for increasing the bar size.
- Crack sizes are larger than steel reinforced decks.
- GFRP availability is non-proprietary, but still a limited number of suppliers.

Design Summary

GFRP		Transverse		Longitudinal	
		Top	Bottom	Top	Bottom
	Bar Size	7	6	6	6
	Spacing, s	6"	6"	12"	8"

- In addition #4 bars were used over the piers
- Note that #7 transverse bars were placed on top of the longitudinal bars with a 2” cover.

Design Summary cont…

Design Summary cont…

- Epoxy steel is still present in the slab!!!

Cost (Epoxy Steel vs. GFRP)

Cost Breakdown for Bridge A8038

A8038	Epoxy Steel Estimate	GFRP Awarded	GFRP Low*
Bid Item Price**	$260	$370	$335
Deck Area (sq. yd.)	425	425	425
Bid Item Total	$110,500	$157,250	$142,375
Est. Cost Increase	**$0**	**$46,750**	**$31,875**
Total Bridge Cost		$353,791	$336,569
Est. Cost Increase		**15.2%**	**10.5%**
Total Project Cost		$578,678	$598,533
Est. Cost Increase		**8.8%**	**5.6%**

*Lowest qualifying bid for Bid Item

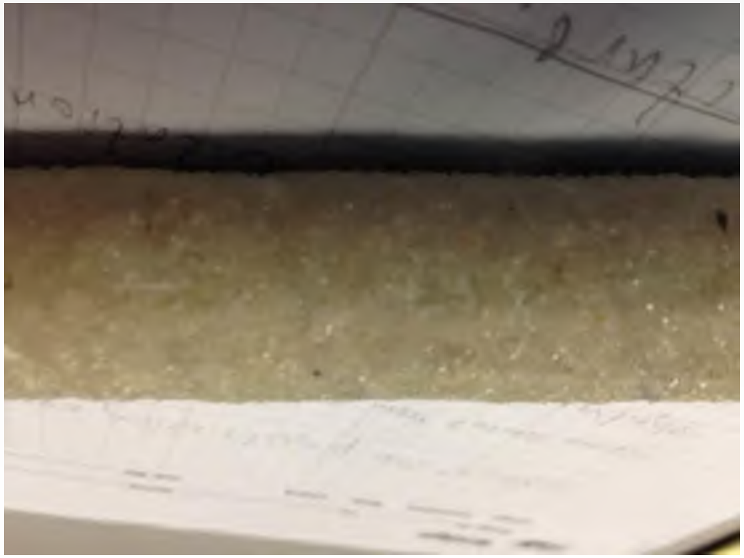
**Bid Item - Misc. Slab on Concrete I-Girder (GFRP Rebar)

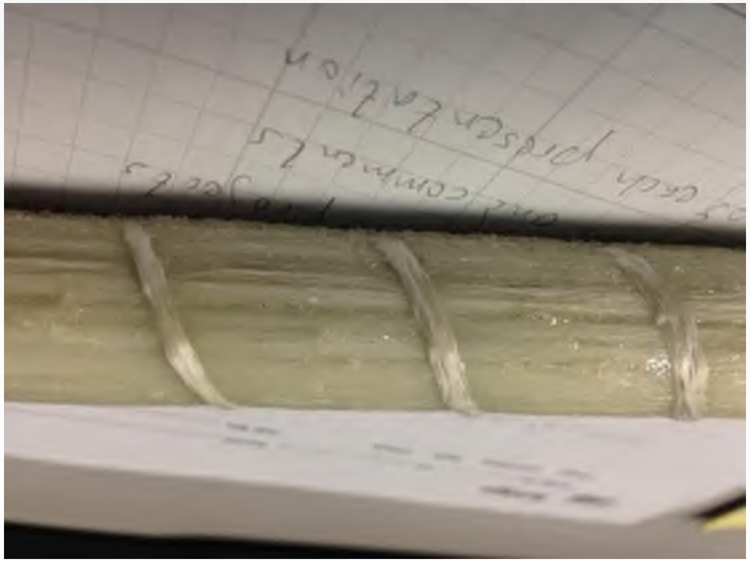
Material Testing

- Testing requirements are laid out in the aforementioned AASHTO GFRP design guide spec.
- Be wary of uniformity issues with application of sand coating. No current spec guidance.

Material Inspection

- Sample bars were given to our materials inspectors and passed on to the Bridge office.
- The #6 bars showed issues with application of the sand coating. Approximately 1/3 of the surface was smooth uniformly along the length of the bar.
- After their own review the supplier replaced all of the bars for the project (including the #4 and #7 bars)





Material Inspection

- Looking for a uniform application of sand coating

Sand Coating Issues cont…

- CFRP bars from the N0038 Redeck. Too much and too little.

Construction Concerns

- Bar mats must be restrained to prevent floating during concrete placement.
- Field bends for GFRP bars are not allowed.
- Bars should not be cut using shearing methods. Follow manufacturers recommendations.

Construction Feedback

- Bars are much lighter (25% of steel). More bars can be carried in each trip.
- Bars are more stable when walking on the mats. Ties did not come loose which was attributed to the sand coating. This leads to less re-work.
- Gloves are required when handling the bars. Gloves were provided by the manufacturer for this project.
- Harder to clean dirt off of the bars due to sand coating
- Overall the construction crew preferred the use of GFRP to epoxy steel.
- Note that all GFRP bars used in the deck were straight bars so any fit-up issues that may occur from bent bars were not tested.

Construction Misc…

- Workers required multiple gloves due to wear from sand coating.

- Same ties used for Epoxy steel and GFRP bars. (Plastic coated tie wire)

Construction Misc…

- Steel Galvanized Stay-In-Place (SIP) forms were chosen by the Contractor.

Construction Misc…

- Fiberglass Drains anchored by galvanized steel bolts.

Product Familiarity

- Familiarity…Our materials inspectors and lab testers are not used to working with the product.
  - More stringent Job special provision (JSP)
- Familiarity…Contractors are used to working with Epoxy steel
  - Factors into the bid prices (likely driving them up)
- Familiarity…Designer's have a guide spec but they are used to following certain guidelines
  - Designs may not fully utilize the advantages of GFRP.

Future Plans/Research

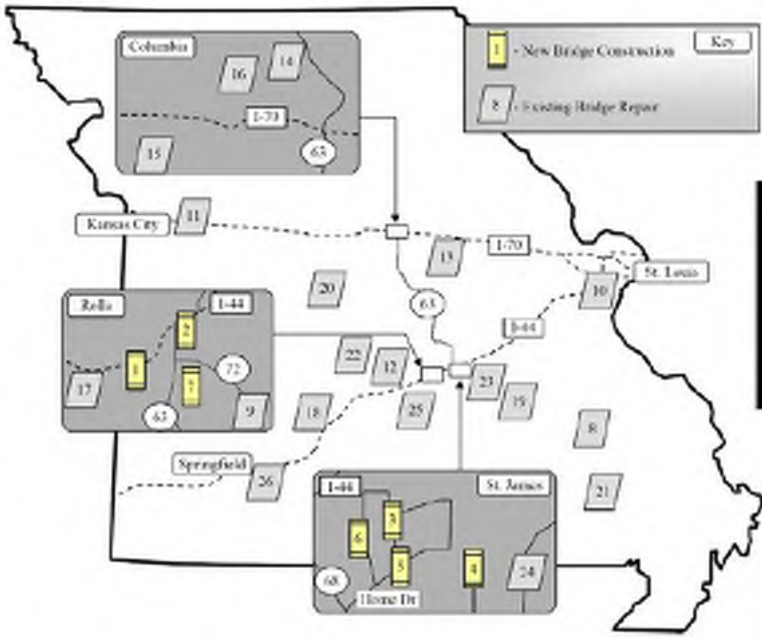
- No set plan to use GFRP on any upcoming projects.
- Would like to see a MASH TL-4 crash tested and FHWA approved GFRP barrier curb design.
- Midwest Roadside Safety Facility (MwRSF), part of NU, has proposed a research project to test a single slope barrier curb.
- This research is vital before we can achieve a “steel free bridge deck”.

Other Missouri FRP Related Projects

Other Sample Off-system FRP Bridge Applications and Historic First Application Use of FRP in the State of Missouri, USA

Slides provided by Dr. J.J. Myers, Missouri S&T

Missouri FRP Related Projects



Fully Composite Manual Lay-up and Pultruded FRP Applications (New Construction)

Internally Reinforced Concrete FRP Bridge Applications (New Construction)

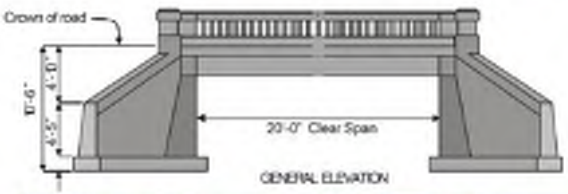
Externally Bonded, Near Surface Mounted and Mech. Fastened FRP (Repair)

Missouri's First Application of FRP Applications Date Back to 1998 and include FRP used for both new construction and repair. To date, approximately **50 projects** have used FRP in some capacity.

Slide Content Provided by J.J. Myers, Missouri S&T

http://transportation.mst.edu/media/research/transportation/documents/C23_2008_Myers.pdf

Strengthening of Bridge G-270 in Missouri



First Bridge Strengthened In Missouri: **Year 1998** Bridge G270, Iron County, Missouri. Repair Technique: Externally Bonded Manual Wet-Layup CFRP Sheets.

Project to Address Load Posting Restrictions

Application of Saturant and CFRP Fabric

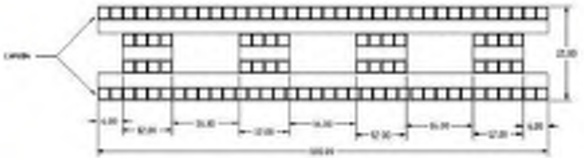
Concrete Distress Due to Corrosion Prior to Strengthening

Post-Installation Bond Validation

Slide Content Provided by J.J. Myers/A. Nanni, UMR/Missouri S&T

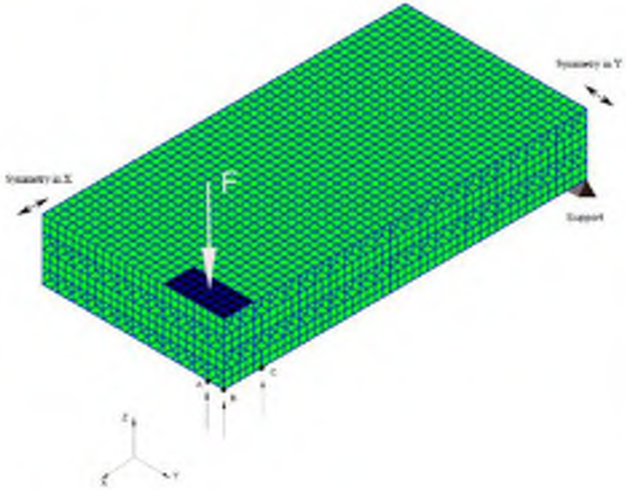
Pedestrian Bridges in Missouri – S&T Campus

First Composite Bridge Built In Missouri: **Year 1999** Pedestrian Bridge on the Missouri S&T Campus. Photo Taken 17 years after Installation: Composed of Pultruded GFRP and CFRP Tubes.



Theoretical Finite Element Modeling

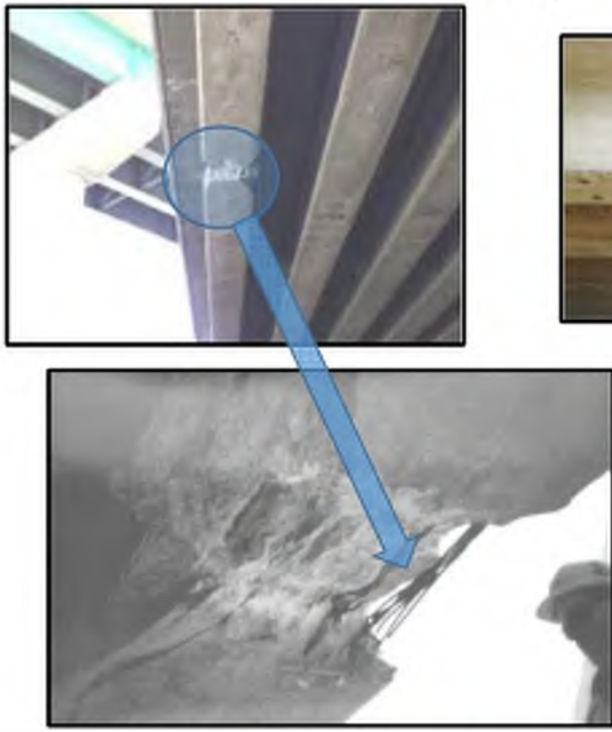
Laboratory Validation of FRP Sectional Structural Behavior



Site Installation

Slide Content Provided by J.J. Myers/A. Nanni, UMR/Missouri S&T

Strengthening of Impacted Bridge A10062 in Missouri



First Bridge Strengthened with FRP in Missouri due to Impact Damage: **Year 2000** Bridge A10062, St. Louis County, Missouri. Repair Technique: Externally Bonded Manual Lay-up using CFRP Sheets.

Project to Restore Original Prestressed Concrete Girder Capacity

a) Overall View

b) Surface Sandblasting

c) Conc. Repair/Putty Application

d) Saturant Application

e) Manual Lay-up of CFRP Sheet

f) Strip Manual Lay-Up CFRP Sheet

General Repair Procedure on Impacted PC Girder Repair

Slide Content Provided by J.J. Myers/A. Nanni, UMR/Missouri S&T

Pedestrian Bridges in Missouri – Rolla, MO

Use of FRP Reinforced Precast Concrete for Accelerated Construction: **Year 2009** Pedestrian Bridges built in Rolla, Missouri. Use of Advanced HPC and GFRP in Precast Deck Panels.

Bridge Instrumentation and Panel Fabrication

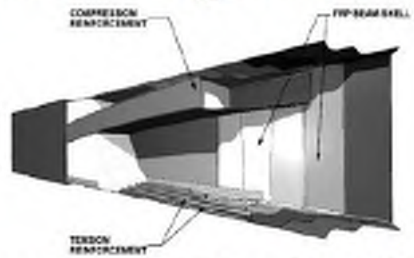
Location Map in Rolla, MO

Site Installation: Two Bridges Each Erected in Less than 4 Hours

Slide Content Provided by J.J. Myers, Missouri S&T

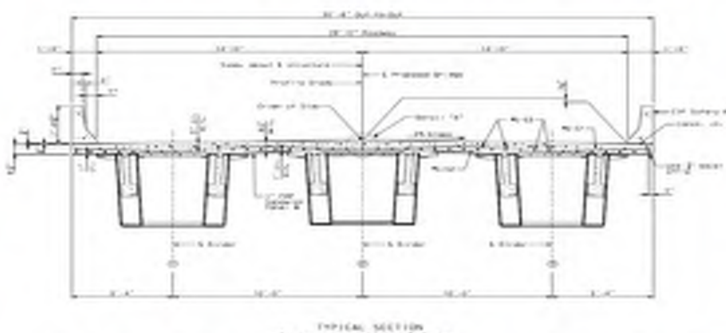
FRP Hybrid Composite Beam Bridges in Missouri

Hybrid Composite Bridge: **Year 2011** Bridge built in Ava, Missouri. Use of GFRP Shell with RC Arch and Galvanized Tension Tie.



Conceptual HCB Closed Loop System

Project Location Map



2nd HCB Missouri Bridge: Longest Spanning HCB Bridge to Date Located in Lockwood, MO

Slide Content Provided by J.J. Myers, Missouri S&T

Any Questions?

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(573-751-0267)

American Concrete Institute
Always advancing

Development of 440 H Design Code on Concrete Structures Reinforced with GFRP Bars

William J. Gold, P.E., FACI
Engineering Services Manager, BASF Corporation
Chair, ACI Committee 440

First International Workshop on Glass Fiber Reinforced Polymer (GFRP) Bar for Concrete Structures

17 July 2017

Sherbrooke, QC
Canada

ACI 440.X-XX

- The need for standardization
  - Previous design documents from ACI Committee 440 are guides. They cannot be adopted into other standards.
  - ACI standards can be adopted by other organizations (e.g., the International Code Council) making them legally binding in some cases
  - It removes obstacles to adopting FRP reinforcement and makes us "mainstream"

American Concrete Institute
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ACI 440.X-XX

- 440.X Design Code
  - Being led by ACI Subcommittee 440H chaired by Dr. Vicki Brown and Dr. Carol Shield
  - When complete, will be the first standardized design code for FRP reinforcement published by ACI
  - Standardization is the most rigorous consensus process used by ACI

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ACI 440.X-XX

- Scope
  - ACI 440.X-XX will focus narrowly on round, solid, GFRP bars as the sole reinforcement in concrete elements
  - Focuses specifically on building-type structures

ACI 440.X-XX

- ACI 318 Dependent Code
  - Replace specific provisions of ACI 318-14 where changes are required for GFRP Bars
  - Can also omit portions of ACI 318-14 that may not be applicable to GFRP bars

ACI 318 Chapters

Black = Not much change

Green = Phase 1

Blue = Phase 2

Red = N/A

- Ch 1 – General
- Ch 2 – Notation/Terminology
- Ch 3 – Referenced Standards
- Ch 4 – Structural System Requirements
- Ch 5 – Loads
- Ch 6 – Structural Analysis
- Ch 7 – One-way Slabs
- Ch 8 – Two-way Slabs
- Ch 9 – Beams
- Ch 10 – Columns
- Ch 11 – Walls
- Ch 12 – Diaphragms
- Ch 13 – Foundations
- Ch 14 – Plain Concrete
- Ch 15 – Beam/Slab-Column Joints
- Ch 16 – Connection between Members
- Ch 17 – Anchoring to Concrete
- Ch 18 – Earthquake-Resistant Structures
- Ch 19 – Concrete: Design & Durability
- Ch 20 – Rebar Properties, Durability
- Ch 21 – Strength Reduction Factors
- Ch 22 – Sectional Strength
- Ch 23 – Strut & Tie Models
- Ch 24 – Serviceability Requirements
- Ch 25 – Reinforcement Details
- Ch 26 – Construction Documents & Inspection
- Ch 27 – Strength Evaluation of Existing Structures
- 318.2 – Thin Shells

ACI 440.X-XX

- Borrowing from ACI 440.1-R
  - Flexural provisions
  - Shear provisions
- But…
  - Need compatible shear and torsion provisions
  - C_E and Creep rupture factors
  - Phi factors
    - Look at flexure calibration in light of advances made in materials
    - Need calibration of shear and torsion phi factors

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ACI 440.X-XX

- Have never developed provisions for
  - Columns
  - Beam-Column Joints
  - Torsion

ACI 440.X-XX

- And need to address issues such as
  - Fire
  - Crack width criteria
  - Bond
    - K_b factor
    - Do we allow bond failures?
  - Do we allow light-weight concrete?
  - Do we allow bundled bars?

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ACI 440.X-XX

- Reference Standards
  - Design codes require a reference material specification and construction specification
  - A construction specification has been developed and is currently being updated (ACI 440.5-XX).
  - A material specification has also been developed (ACI 440.6). However we are hoping to have this migrated to an ASTM material standard.

ASTM D30.X-XX

- Material Standard
  - ASTM standard for solid, round GFRP bars
  - Specifies minimum material properties, methods of measurement, and manufacturer labeling and quality control requirements.
  - Will serve as the basis for the 440.X design code and also allow adoption into other design standards and codes

Current Status

- Work completed to date
  - Initial chapters of the design code have been successfully balloted by ACI Committee 440
    - Ch 1 – General
    - Ch 4 – Structural Systems
    - Ch 5 – Loads
    - Ch 19 – Concrete Design and Durability Requirements
    - Ch 26 – Construction Documents and Inspection
  - Balloted Ch 21 – Strength Reduction Factors (still awaiting consensus)
  - Several iterations of ballots on the ASTM D30.X material specification have been completed. This document is close to a consensus.

The Road Ahead

- ACI Committee 440 Work
  - Must complete drafting of
    - Ch. 7 One-Way Slabs
    - Ch. 8 Two-Way Slabs
    - Ch. 9 Beams
    - Ch. 10 Columns
    - Ch. 11 Walls
    - Ch. 13 Foundations
    - Ch. 15 Beam-Column Joints
    - Ch. 16 Connections
  - Must successfully ballot all of these chapters and come to committee consensus on this work
- Reviews
  - ACI-TAC review and committee response
  - Public review and committee response

Development of 440 H Design Code on Concrete Structures Reinforced with GFRP Bars

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First International Workshop on Glass Fiber Reinforced Polymer (GFRP) Bar for Concrete Structures

17 July 2017

Sherbrooke, QC Canada

Development of New Editions of CSA Standards Related to GFRP Bar for Concrete Structures

Dr. Brahim Benmokrane, P.Eng.

Professor of Civil Engineering

Tier-1 Canada Research Chair

NSERC/Industry Research Chair

University of Sherbrooke, Sherbrooke, QC, CANADA

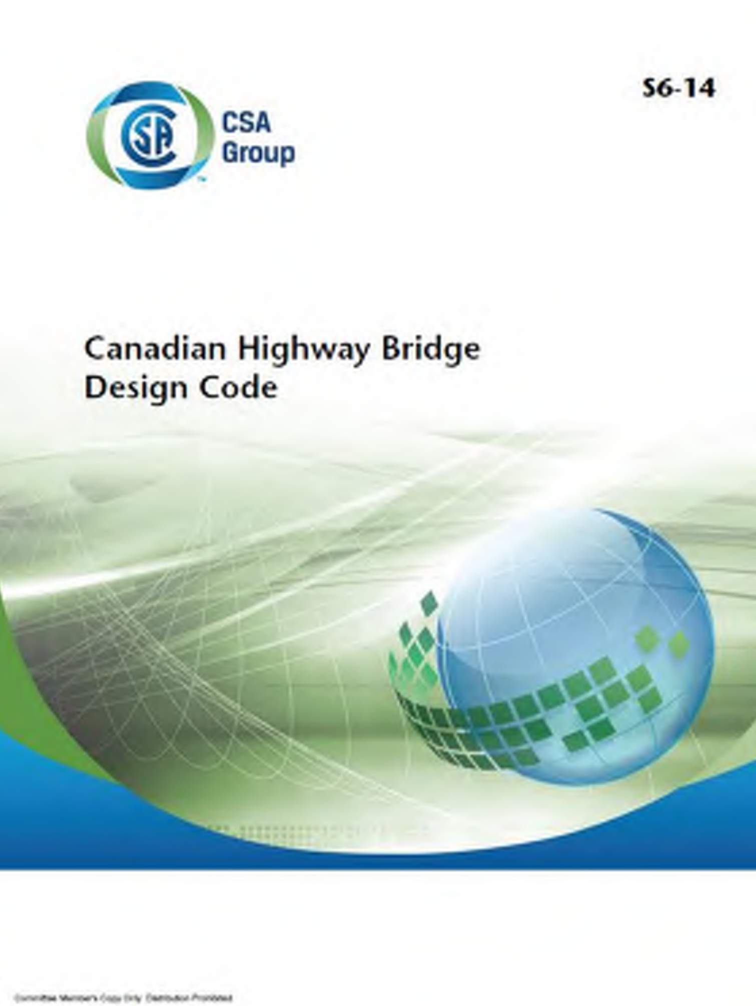
Codes, Standards & Specifications in Canada on GFRP Bars (CSA)

1. **CAN/CSA S6**: "Canadian Highway Bridge Design Code", Section 16 "Fibre Reinforced Polymers (FRP) Structures". *1st Edition in 2000; 2nd Edition in 2006; Supplement S1, 2010; 3rd Edition in 2014; New Edition in 2019 - DRAFT*

2. **CAN/CSA S806**: "Design and Construction of Building Components with FRP". *1st Edition in 2002; 2nd Edition in 2012*

3. **CAN/CSA S807**: "Specifications for Fibre Reinforced Polymers". *1st Edition in 2010; Re-approved in 2015; New Edition in 2018 - DRAFT*

Codes, Standards & Specifications in Canada on GFRP Bars (CSA)



Codes, Standards & Specifications in Canada on GFRP Bars (CSA)

- Design principles of GFRP-RC structures are well established through extensive research and field practice
- Provisions governing testing and evaluation for certification and QC/QA
- Standard Describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements
- Specific properties of GFRP reinforcement, design algorithms and resistance factors, detailing, material and construction specifications
- FRP bar preparation, placement (including cover requirements, reinforcement supports), repair, and field cutting are specified.

CSA Design Codes (CSA S6 and CSA S806)

- **Serviceability Limit State** (stress limit, crack-width, short & Long term deflection).
- **Ultimate Limit State** (resistance factor, strength).

Design Considerations with GFRP Bars

- The designer should understand that a direct substitution between GFRP and steel bars is not possible due to differences in mechanical properties of the two materials
- One difference is that GFRP are linear up to failure and exhibit no ductility or yielding- Deformability.
- Due to it's lower modulus of elasticity, serviceability limit state of GFRP reinforced concrete sections (such as deflection and crack widths) will govern the design.

CSA Design Codes (CSA S6 and CSA S806)

The current CSA design codes address the durability issue in design of GFRP reinforced sections through a common way considering the following:

- The material resistance & environmental reduction factors based on fiber type and exposure conditions
- Limitation of maximum stress under service load
- Limitation of maximum crack-width under service load
- Limitation of maximum stress/strain level under sustained load
- Concrete cover (fire resistance)
- Creep rupture stress limits
- Fatigue stress limits
- Factor for long-term deflection calculation

CSA Design Codes (CSA S6 and CSA S806)

As an example for the Canadian Highway Bridge Design Code (CSA S6), the specified values are:

Design Parameter	Design Value
Resistance factor	0.55 for GFRP bars
Stress under service load	Less than 25% of the specified tensile strength for GFRP bars
Crack-width	0.5 mm

CSA S807

Table of Contents of S807

List of Tables

List of Annexes

A. Test Method for determination of cure ratio for FRP bars by DSC (normative)

B. Marking (informative)

C. Example of manufacturer’s quality control plan (informative)

CSA S807 - Technical Committee

Brahim Benmokrane	**Université de Sherbrooke, Sherbrooke, Québec**	**Chair**
Baidar Bakht	JMBT Structures Research Inc., Scarborough, Ontario	
Nemkumar Banthia	University of British Columbia, Vancouver, British Columbia	
Bernard Drouin	Pultrall, Thetford-Mines, Québec	
Garth Fallis	Vector Construction Limited, Winnipeg, Manitoba	
Marc-Antoine Loranger	Transports Québec Direction des Structures, Québec, Québec	
Dritan Topuzi	Fiberline Composites Canada, Kitchener, Ontario	
David Lai	Ministry of Transportation of Ontario, St. Catharines, Ontario	
Rolland Heere	Metro Testing Laboratories Ltd, Vancouver, British Columbia	
Ghani Razaqpur	McMaster University, Hamilton, Ontario	
Martin Krall	Ministry of Transportation of Ontario	
Shamim Sheikh	University of Toronto, Toronto, Ottawa	
Jonathan Clavet	Sika Canada Inc., Pointe-Claire, Québec	
Allan Manalo	University of Southern Queesland, Australia	
Didier Hutchison	BP Composites, Edmonton, Alberta	
Ahmed Mostafa	Tem Corp, Toronto, Ontario	
Claude Nazair	Transports Québec Direction des Structures, Québec, Québec	
Ken Phu	**CSA Manager**	

CSA Material Specifications (CSA S807)

Describes permitted constituent materials, limits on constituent volumes, and minimum performance requirements .

Provides provisions governing testing and evaluation for product qualification and QC/QA.

CSA Material Specifications (CSA S807)

Example of Durability Related Provisions:

1. **Limit on Constituent Material, e.g.**
   - Limits on diluents and certain fillers
   - Limits on low-profile additives
   - No blended resins
2. **Lower Limit on Glass Transition Temperature (Tg) & Cure Ratio**
   - Minimum cure ratio and Tg
3. **Material Screening Through Physical & Durability Properties**
   - Maximum void content
   - Maximum water absorption
   - Limits on mechanical property loss in different environment conditioning (Alkali)

CSA Material Specifications (CSA S807)

As an example, the specified limits (acceptance/rejection criteria) are:

Property	Specified Limit
Void Content	Less than 1%
Water absorption	Less than 0.75%
Cure Ratio	Greater than 95%
Glass Transition Temperature	100 ^{o}C (DSC)
Alkali Resistance in High pH Solution	Greater than 80% (without load); Greater 70% (with load)
Creep Rupture	greater than 35% of UTS for GFRP bars

CSA Material Specifications (CSA S807)

Table 1: Designation of GFRP individual bars

Fiber	Designated diameter of bar with circular cross-section or width of bar with nominally square cross-section mm	Nominal cross-sectional area (mm^2)	Minimum specified tensile strength Mpa	Designation
Glass	6	32	750	*Ga-Eb-Dc*
	8	50	750	
	10	71	750	
	13	129	650	
	15	199	650	
	20	284	600	
	22	387	550	
	25	510	550	
	30	845	500	
	32	819	450	
	36	1006	450	

CSA Material Specifications (CSA S807)

Table 2 (Grades of FRP bars and grids corresponding to their minimum modulus of elasticity, GPa)

Designation	Grade I		Grade II		Grade III	
	Individual bars	Bars in a grid	Individual bars	Bars in a grid	Individual bars	Bars in a grid
AFRP	50	40	70	60	90	80
CFRP	80	70	110	100	140	130
GFRP	40	30	50	40	60	50

CSA Material Specifications (CSA S807)

Table 4 (Determining physical and durability properties of FRPs (all bars sizes for qualification and manufacturer's QC))

Property	No. and details of test specimens required				Test method	Specified limits
	Qualification test	Manufacturer's QC	Owner's QA	Provided at request		
Fibre content	9 tests from 3 production lots 10, 15, 20, and 25 mm or only the sizes manufactured by the supplier	3 tests for each bar size used on project	5 tests for each bar size used on project	N/A	The relevant of the following: (a) bars with glass fibre: ASTM D2584 or ASTM E1131; (b) bars with carbon fibre: ASTM E1131; or (c) bars with aramid fibre: no method is available; provide the theoretical content	Fibre volume fraction ≥55% for FRP bars; fibre volume fraction ≥35% for FRP grids; for ASTM D2584, glass Fibre fraction ≥70% by Weight
Longitudinal coefficient of thermal expansion	N/A	N/A	N/A	5 tests on bar size requested	ASTM E831 at temperature = 0.1-0.3 T_g; or ASTM D696	N/A
Transverse coefficient of thermal expansion	9 tests from 3 production lots 10, 15, 20, and 25 mm or only the sizes manufactured by the supplier	N/A	5 tests for each bar size used on project	N/A	ASTM E831 at temperature = 0.1-0.3 T_g; or ASTM D696	Transverse coefficient of thermal expansion ≤40 x 10-6 °C-1

CSA Material Specifications (CSA S807)

Qualification Tests Per GFRP Bar Size

1. Tensile Strength: 24 specimens
2. Bond Strength: 24 specimens
3. Transverse Shear Strength: 24 specimens
4. Strength of bent bars: 24 specimens
5. Tensile Strength at cold temperature: 24 specimens
6. Fibre Content: 9 specimens
7. Transverse Coefficient of Thermal Expansion: 9 specimens
8. Void Content: 9 specimens
9. Water Absorption: 15 specimens
10. Cure Ratio: 15 specimens
11. Glass Transition Temperature: 15 specimens
12. Alkaline Resistance without/load: 24 specimens
13. Alkaline Resistance with/load: 24 specimens
14. Creep Rupture : 24 specimens

CSA Material Specifications (CSA S807)

At least five Canadian GFRP bar manufacturers qualified their products and obtained approvals from end-users and government authorities (such as MTO and MTQ):

1. **B&B FRP MANUFACTURING INC.** (MSTBAR)
2. **BP COMPOSITES INC.** (TUF-BAR)
3. **FIBERLINE COM POSITE CANADA INC.** (COMBAR)
4. **PULTRALL INC.** (V-ROD)
5. **TEMCORP INC.** (TEMBAR)

Hughes Brothers Inc., Marshall Composite Technologies Inc., Composite Rebar Technologies Inc., No Rust Rebar Inc., (USA), FiReP International AG (Switzerland), Asamer (Austria), Pultron Composites Ltd. (New Zealand), Magmatech Ltd (United Kingdom), Galen (Russia), etc.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

- The standard will cover FRP bars made of basalt fibres. Consequently, new values for mechanical properties of BFRPs will be added in the Tables.
- For GFRPs, only E-CR glass fibres will be permitted. The E-CR glass fibres shall meet the requirements of ASTM D578. The first edition of CSA S807 did not specify the glass fibre type.
- Headed GFRP bars will be included in the new edition of CSA S807. Therefore, new tables for mechanical properties will be created in order to separate straight bars from bent and headed bars.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

- The new edition will limit the **quantity of straight, bent and headed bars** that the manufacturers can produce **for each production lot** (Quality Control Tests.)

- A lower and an upper limit for **cross-sectional area of GFRP bars** have been defined. The lower limit will be **95 %** of the nominal cross-sectional area. The upper limit will be ≤ **120 %** of the nominal cross-sectional area for bars of **20 mm** and smaller; and ≤ **115 %** for bars larger than 20 mm.

- New tables for mechanical properties (minimum **modulus of elasticity** and minimum **tensile strength**) with distinction between straight and bent bars.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

- New tests for the evaluation of durability characteristics of bent and headed GFRP bars are added such as interlaminar shear strength in high pH solution at 60°C and tensile strength retention of headed GFRP bars after conditioning in alkaline solution under sustained load for 120 days at 60°C.

- A new testing method for determining the strength of the bent portion of GFRP bars has been proposed for qualification & quality control testing. This method is viewed as more convenient than the ACI 440.3R B.5.

- Others small changes and/or clarifications have been made for some mechanical and physical properties concerning the test method to be used, the number of specimens required or the specified limits. For example, for alkali resistance in high pH solution (without load), the tensile capacity retention ≥ ~~80%~~ 85% UTS; for alkali resistance in high pH solution (with load), the tensile capacity retention ≥ ~~70%~~ 75% UTS.

CSA Material Specifications (CSA S807)

Summary of the major changes in the upcoming edition of CSA S807

Annex A (normative)
Test Method for determination of cure ratio for FRP bars by DSC

Annex B (informative)
Handling and Storage

Annex C (informative)
Marking

Annex D (informative)
Example of manufacturer's quality control plan

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars

Annex F (normative)
Evaluation of Durability Characteristics of Headed Glass Fiber–Reinforced Polymer Bars

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars

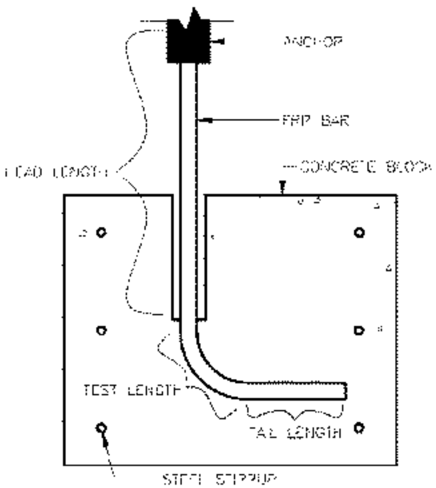


Figure 1 – General Arrangement

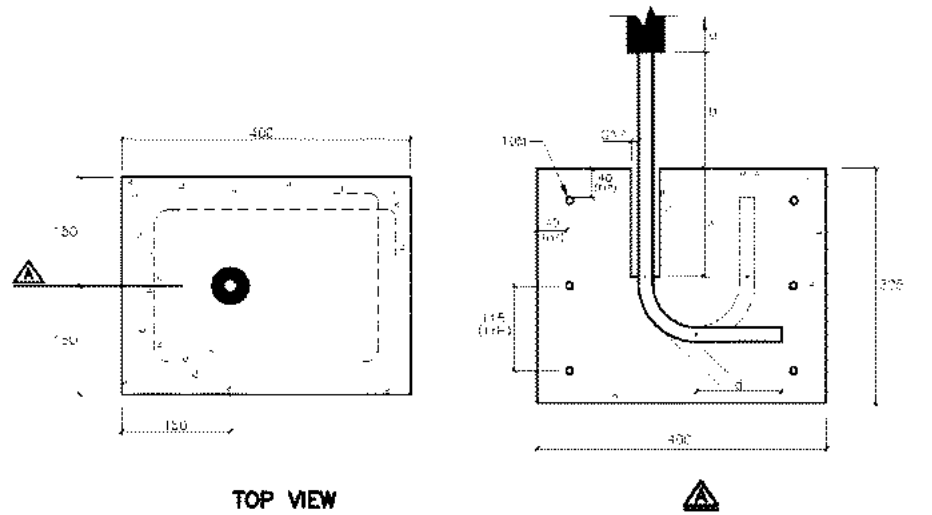
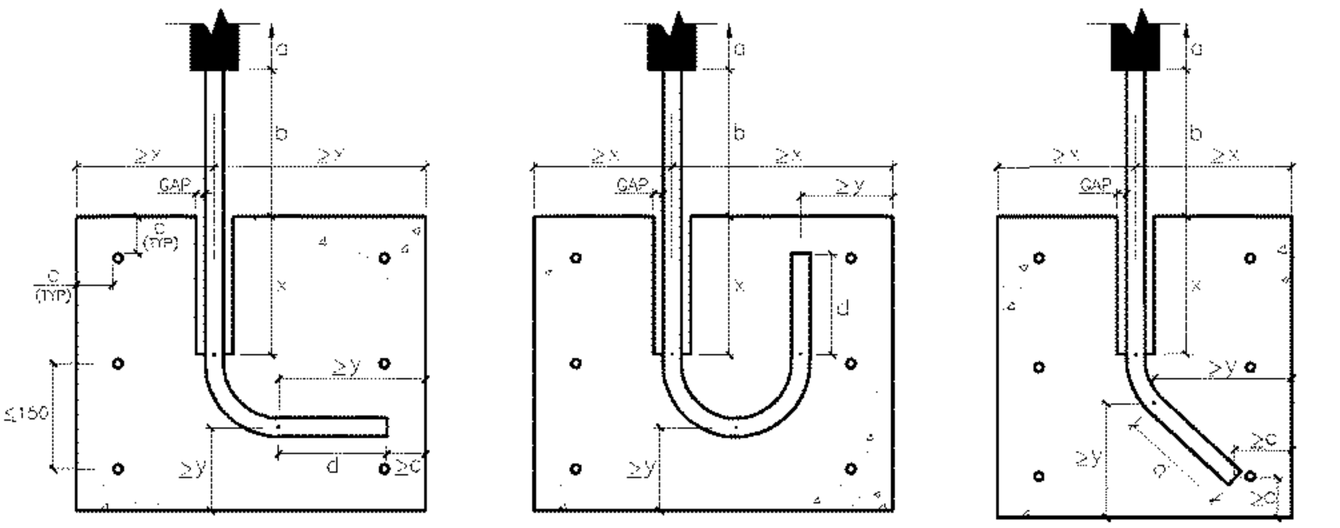


Figure 2 – Dimensional Arrangement of the Block
(nominal diameter of 20 mm or less, bent at an angle between 0 and 180 degrees, and manufactured with a bend-radius-to-bar-diameter ratio of 4 or less)

Annex E (normative)
Method of Test for Determining the Strength of the Bent Portion of FRP Reinforcing Bars



A custom block shall be made for large sizes of bars and bent

Annex F (normative)
Evaluation of Durability Characteristics of Headed Glass Fiber–Reinforced Polymer Bars

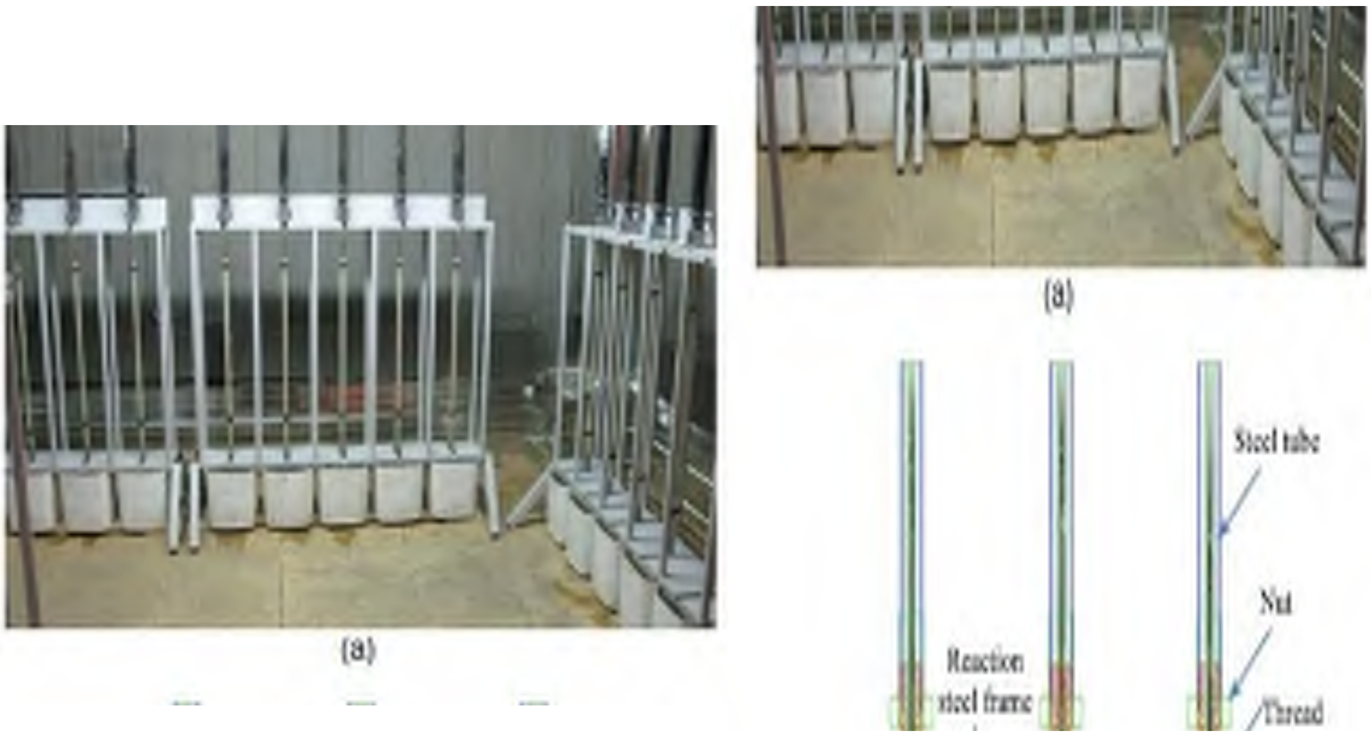
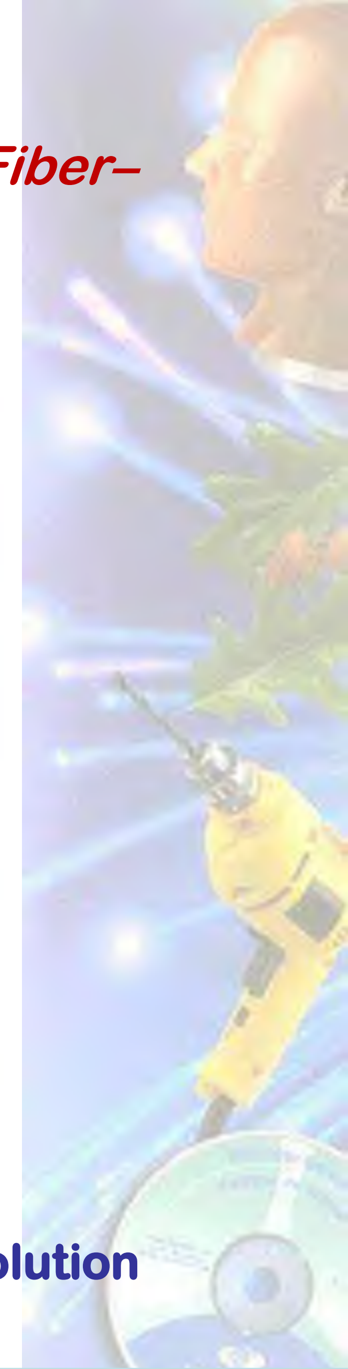
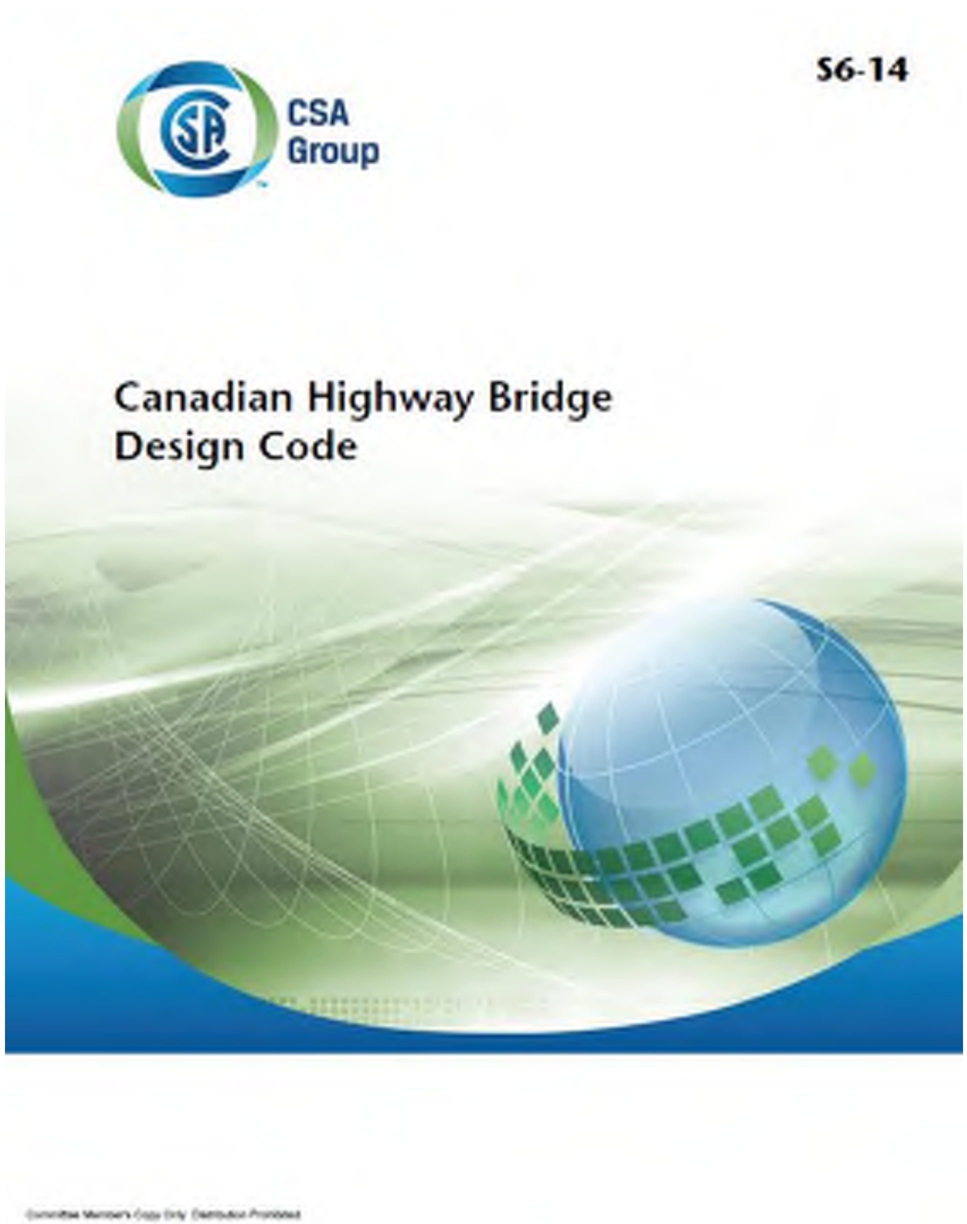


Figure F1. Conditioning of headed GFRP bars in alkaline solution under sustained load (a) test setup; (b) schematic diagram



CSA S6



CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 – DRAFT.* Chair: S. Sheikh

1. **Durability/Material properties/New structural materials**
   (Lead: Benmokrane, Lai, Ben Huh, Mostafa)

2. **Concrete bridge components reinforced internally with FRP reinforcement**
   (Lead: Benmokrane, Sheikh, Bakht, Mufti, Salib, Lai, Galipeau)

3. **Concrete bridge components reinforced externally with FRP reinforcement**
   (Lead: Green, Sheikh, Bakht, Benmokrane, Mostafa, Schaefer)

4. **Concrete bridge components prestressed with FRP**
   (Lead: Svecova, Benmokrane, Green)

5. **Wood bridge components reinforced with FRP**
   (Lead: Bakht, Svecova)

6. **FRP only structures**
   (Lead: Almansour, Benmokrane, Salib, Wight)

7. **FRP formwork**
   (Lead: Almansour, Fam, Green)

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 – DRAFT. Chair: S. Sheikh*

Durability/Material properties/New structural materials

16.5.1 FRP bars and grids

FRP bars and grids shall be manufactured and qualified in accordance with CSA S807.

The properties of FRP bars and grids shall be provided by the manufacturer in accordance with CSA S807.

All of the design properties of FRP bars and grids shall be obtained from tests conducted in accordance with CSA S807.

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 – DRAFT. Chair: S. Sheikh*

Durability/Material properties/New structural materials

16.5.3 Resistance factor (phi factor)

We increased the phi factor of GFRP bar from 0.55 to 0.65

Rational:

Durability of GFRP bars has been enhanced during the last few years:

1. Better manufacturing process and quality control
2. Better constituents : 1) ECR-Glass versus E-Glass; Most of the GFRP bar manufacturers are using boron-free glass fibres (ECR, commercial name Owens Corning), 2) High-performance resins (advances in polymer chemistry)
3. Durability tests in alkaline solution show high strength retentions without load and under loads (CSA S807): 1) greater than 90-95% (without load), 2) greater than 83-90% (with load).
4. Recently the MTQ took cores for in-service bridges (more than 15 years). No degradation.
5. Durability of GFRP versus durability of concrete? The phi for concrete in the CHBDC is 0.75.

CAN/CSA S6: « CHBDC, Section 16 "Fibre Reinforced Polymers (FRP) Structures". *New Edition in 2019 – DRAFT. Chair: S. Sheikh*

Concrete bridge components reinforced internally with FRP reinforcement

16.8 Concrete beams, slabs and columns reinforced with GFRP bars

New provisions:

1. Development length of FRP bundled bars
2. Development length of FRP bent bar
3. Splice length for FRP bars
4. Anchorage of headed FRP bar
5. Design for shear and torsion
6. Compression components (combined flexure and axial)
7. Strut-and-tie model
8. Barrier walls
9. Recommended practice for repair of damaged bridge barrier walls, curbs, and slabs reinforced with FRP bars

Thank you for your attention

Trends and Standards Development for FRP Bars in New Construction in the US

Prof. **Antonio Nanni**
University of Miami (USA)
Università di Napoli Federico II (Italy)

International Workshop on
Glass Fiber Reinforced Polymer Bar
18 July 2017, Delta Hotel, Sherbrooke, QC, CANADA

Presentation Flow

(three parts)

PART I

- With focus on **buildings** and **US**, address the role of standards
- Introduce **International Building Code** (**IBC**) part of I-Code family and mechanism for addressing innovation via **Acceptance Criteria** (**AC**)

Presentation Flow

PART II

FRP composites for **internal reinforcement** of concrete structures

- Buildings
  - Role of **ASTM International Subcommittee D30-10**
  - Role of **ACI Committee 440** (Covered by W. Gold)
- Transportation infrastructure
  - Role of **AASHTO**
  - Role of **DOTs** (Covered by Others in Session 1)

PART III

- Conclusions
- Acknowledgements

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Role of Standards

What distinguishes construction from other industries is the role played by **building codes** in regulating its activities

Building codes are collections of **mandatory provisions** that specify minimum acceptable levels of service and safety

The practice of developing, approving, and enforcing building codes **varies among countries**

Code of Hammurabi
1772 B.C.

Role of Standards

The number one rule in real estate is location, location, location. Similarly, in **the construction industry it is all about standards**, would they be:

– **design codes**
– **materials and construction specifications**
– **inspection protocols**
– **test methods**

We have not fully understood this and when we do, we lack the ability to remain open to innovation (**prescriptive** vs. **performance** standards)

Role of Standards

Recalling differences as we make progress….

Document types:

CODES

vs.

GUIDELINES

Codes

- Adopted by regulatory agencies
- Mandatory language (shall not should)
- Establish required practice

Guidelines

- Non-mandatory language (should not shall)
- Establish recommended practice

Within codes:

PROVISIONS

vs.

COMMENTARY

Provisions

- Mandatory language (shall not should)
- Requirements to be followed
- Only codes and standards as references

Commentary

- Guidance on how to satisfy code
- Non-mandatory language; why and how
- Any references can be used

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Agencies responsible for writing model codes and acceptance criteria

International Code Council (**ICC**) is a member-focused association; dedicated to developing model building codes and standards for use to design and construct safe, sustainable, affordable and resilient structures

ICC-ES, a subsidiary of ICC, performs **product certification** using codes and standards in the built environment.

Accredited by the American National Standard Institute (ANSI) to the requirements of ISO/IEC 17065.

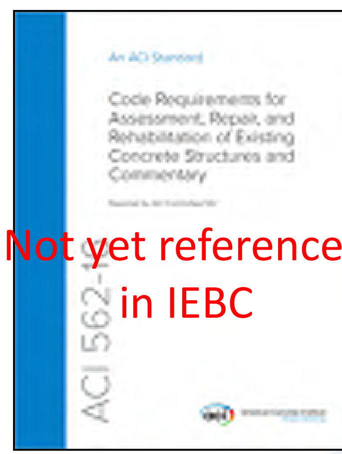
Expert in developing and interpreting **acceptance criteria** (**AC**) for innovative products

US model code for new buildings

IBC – International Building Code

- IBC is the model building codes, published by International Code Council (ICC)
- First published in 2000, it is published every other third year (2015 is the latest edition)
- Adopted by all 50 states
- Use of internal FRP reinforcement is NOT included
- **ACI 318** is referenced for reinforced concrete requirements

Applicable Building Codes in the US

	General (Model) Building Code	Concrete Building Code
New Construction		
Existing Construction		 Not yet referenced in IEBC

ICC-ES acceptance criteria

What happens if there is a new material or system not covered (or referenced) in the model codes (I-Codes)?

Sections 104.11 and 104.11.1 of IBC (and equivalent ones in the other I-Codes) allow alternative materials when a "research report" is available for building official's approval

104.11 Alternative materials, design and methods of construction and equipment; The provisions of this code are not intended to prevent the installation of any material or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been *approved*……………….

104.11.1 Research reports: Supporting data, where necessary to assist in the approval of materials or assemblies not specifically provided for in this code, shall consist of valid research reports from *approved* sources.

ICC-ES acceptance criteria

Existence of a set of protocols and provisions is necessary to conduct tests, analysis of results, design, and installation of the product on which to base the "Research Report"

ICC-ES develops with proposers of new technology specific documents called "**Acceptance Criteria (AC)**" for the purpose of issuing "Evaluation (Research) Reports (ESR)"

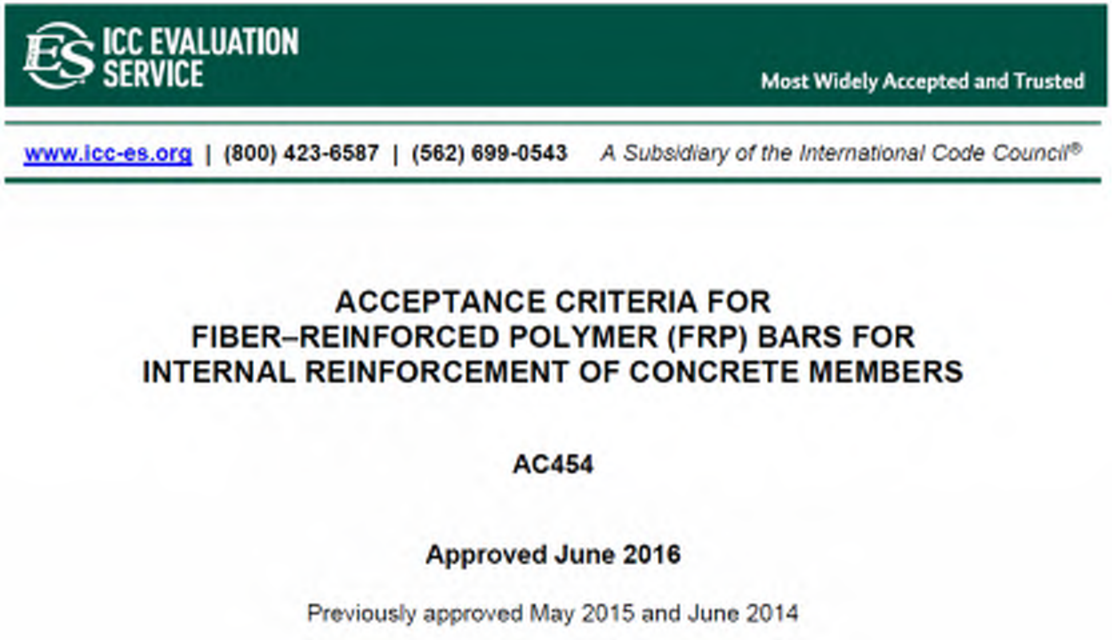
ICC-ES issues an ESR when manufacturer demonstrates an approved QC program and the research program outlined in the AC is successfully conducted by a certified independent laboratory

Role of Standards - Buildings

The case of new concrete construction for buildings

Tools **now available** for implementation of GFRP bars as internal reinforcement (alternative approach only)

1 – IBC


ICC EVALUATION SERVICE
Most Widely Accepted and Trusted

www.icc-es.org | (800) 423-6587 | (562) 699-0543 A Subsidiary of the International Code Council®

ACCEPTANCE CRITERIA FOR
FIBER–REINFORCED POLYMER (FRP) BARS FOR
INTERNAL REINFORCEMENT OF CONCRETE MEMBERS

AC454

Approved June 2016

Previously approved May 2015 and June 2014

2 – AC454-16

Summary of PART I

- In the US today, we have the mechanism to use FRP to reinforce concrete in building structures
- This is done by showing compliance with the building code via research reports based on Acceptance Criteria
- As of today and 24 years after the creation of ACI Committee 440, FRP bars are not included in US building codes

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PART II

FRP composites for **internal reinforcement** of concrete structures

- Buildings
  - Role of **ASTM International Subcommittee D30-10**
  - Role of **ACI Committee 440** (Covered by W. Gold)
  - Summary
- Transportation infrastructure
  - Role of **AASHTO**
  - Role of **DOTs** (Covered by Others in Session 1)

ASTM International

The following standards already produced by Subcommittee **D30.10** related to **FRP reinforcement for concrete** structures:

- **D7205/D7205M** Standard Test Method for Tensile Properties of FRP Matrix Composite Bars
- **D7290-06(2011)** Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications
- **D7337/D7337M-12** Standard Test Method for Tensile Creep Rupture of FRP Matrix Composite Bars
- **D7617/D7617M** Standard Test Method for Transverse Shear Strength of FRP Matrix Composite Bars

ASTM International

- **D7705/D7705M** Standard Test Method for Alkali Resistance of FRP Matrix Composite Bars used in Concrete Construction
- **D7913/D7913M** Standard Test Method for Bond Strength of FRP Matrix Composite Bars to Concrete by Pullout Testing
- **D7914/D7914M** Standard Test Method for Strength of FRP Bent Bars in Bend Locations

The most relevant standard is currently under development, anticipated for release in 2017, and titled:

- **WK43339** Specification for Solid Round Glass FRP Bars for Concrete Reinforcement (addressed by W. Gold)

Role of ACI Technical Committee 440

- ACI 440 documents and current efforts addressed in the presentation by current chair:

William Gold, BASF Corporation & Chair ACI 440 Committee – Development of 440 H Design Code on Concrete Structures Reinforced with GFRP Bars and ASTM Specifications for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

Role of Standards

In summary, for **internal FRP reinforcement** in buildings:

Desirable Approach

IBC (2021?)

↓

ACI 440-18?

↓ ↘

440.5 Constr.   440.6 Mats.

↙ ↓ ↘

ASTM standards

Alterative Approach

IBC (2015 and previous)

↓

AC454-14

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FRP composites for **internal reinforcement** of concrete structures

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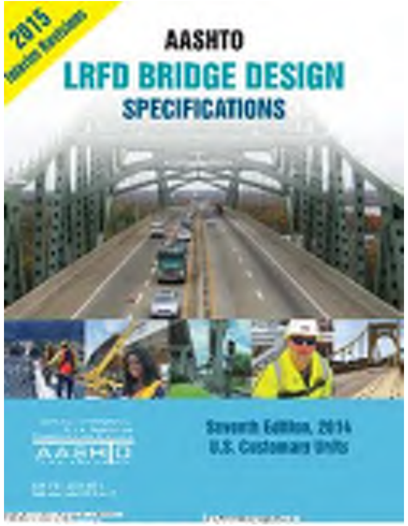
- Transportation infrastructure
  - Role of **AASHTO**
  - Role of **DOTs** (Covered by Others in Session 1)

Role of Standards - Transportation

The case of new concrete construction for bridges

Among many documents that AASHTO develops, most relevant to the design of bridges is **AASHTO LRFD Bridge Design Specifications**, currently in the **Seventh Edition** (no reference to FRP internal reinf.)



Specification intended for use in design, evaluation, and rehabilitation of bridges, and mandated by **FHWA** for use on all bridges using federal funding

Document prepared and approved under oversight of Subcommittee on Bridges and Structures (**SCOBS**)

Role of Standards - Transportation

The case of new concrete construction for bridges

State Transportation Agencies or other government agencies currently need to provide supplemental design and construction criteria for safe and consistent implementation of FRP for reinforced concrete

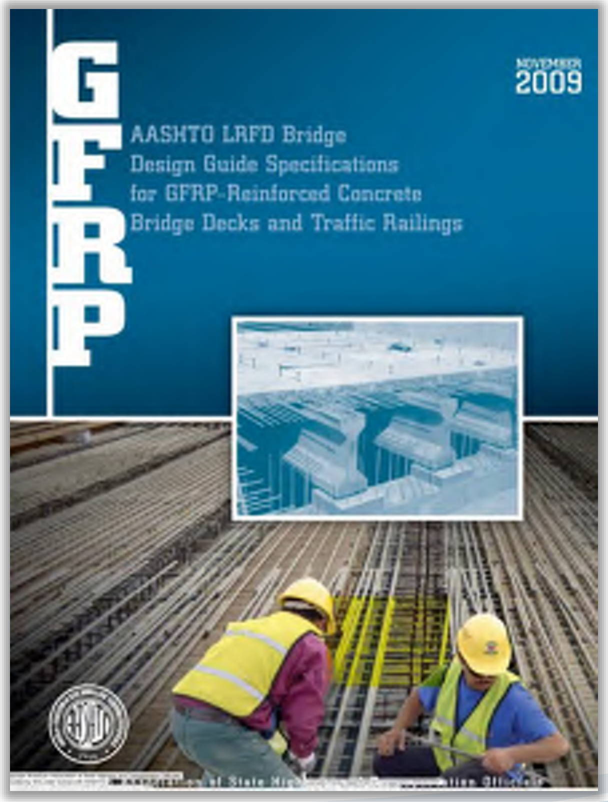
Presentations by bridge owners have addressed this topic:

Session 1: Owner's Perspective on the Use of GFRP Bars

Role of Standards - Transportation

The case of new GFRP-concrete construction for bridges

Tool **now available** for implementation of GFRP bars as internal reinforcement (AASHTO Guide Specification)



Guide is limited to decks and railings. No other structural element is covered

Revision of 2009 GFRP Guide

Task force charged by ACMA Rebar Council to develop the draft to be submitted to Subcommittee T6 for their consideration

Timothy E. **Bradberry** (Texas DOT, Tim.Bradberry@*txdot.gov*)

Jamal **Elkaissi** (FHWA-Resource Center, Jamal.Elkaissi@dot.gov)

*Jim **Gutierrez** (Cal Trans, Jim.Gutierrez@dot.ca.gov)*

Mark **Henderson** (Bridge consultant, CT Cons., OH, mhenderson@ctconsultants.com)

Fabio **Matta** (University of South Carolina, fmatta@sc.edu)

Antonio **Nanni**, (University of Miami, *nanni@miami.edu*) – *Chair*

Steven **Nolan** (FDOT, Steven.Nolan@dot.state.fl.us)

*Will **Potter** (FDOT/T6, william.potter@dot.state.fl.us)*

Revision of 2009 GFRP Guide

Rationale/Scope of revision

- update due to availability of new knowledge and field experiences beyond decks and railings
- only address the use of GFRP round solid bars as longitudinal and transverse reinforcement of concrete members reflecting the material specifications now being balloted in ASTM. (Designers should not view this narrowed material scope as a limitation, but rather the nexus point for future expansion to other fiber and resin technologies as well as other forms of reinforcement, once validated)
- PC application outside the scope of Edition 2

Revision of 2009 GFRP Guide

Key features

- Compliance with provisions of AASHTO LRFD Bridge Design Specifications Eighth Edition
- Harmonization not only with ACI 440 documents but also other international standards such as those from CSA
- When documented by R&D, include provisions not yet adopted in other guides

What we have and do not have

In summary, for **internal FRP reinforcement** in transportation :

Desirable Approach

AASHTO BDS (2021?)
(Chapter 5)

↓

(DOTs specs)

↙ ↓ ↘

ASTM standards

Alterative Approach

AASHTO LRFD Guide Spec.
(2009 and 2018rev?)

↓

AC454-16

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PART III

Conclusions

- Discoveries and deployment of the last quarter century have made composites for construction a reality here to stay
- Full deployment can only occur if composites are recognized in standards similarly to traditional construction materials
- According to I-Codes, we have a process in place to adopt innovation. Compliance with code provisions can be demonstrated by means of protocols established in ad-hoc Acceptance Criteria

Conclusions

- ACI technical committees need to continue efforts in the development of standards in addition to guides and other non-mandatory language documents
- International collaboration can expedite the safe deployment of innovation and produce time and resource savings
- After more than two decades of incubation time, FRP reinforcement is now being considered as another tool in the design/construction toolbox. Some challenges in characterization and full-exploitation remain

ACKNOWLEDGEMENTS

National Science Foundation (NSF) Industry/University Center for Integration of Composites into Infrastructure (CICI) under Grant IIP-1439543

Center for Integration of Composites into Infrastructure

Infravation under grant 31109806.005-SEACON

Qatar Foundation under Grant NPRP9-110-2-052

الصندوق القطري لرعاية البحث العلمي
Qatar National Research Fund
Member of Qatar Foundation

University Transportation Center RE-CAST under Grant Agreement DTRT13-G-UTC45

THANK YOU

Questions?

Trends and Standards Development for GFRP as Internal Reinforcement in Australia

Dr Allan C Manalo
Senior Lecturer, School of Civil Engineering and Surveying
Centre for Future Materials
University of Southern Queensland, Toowoomba, Qld 4350, Australia

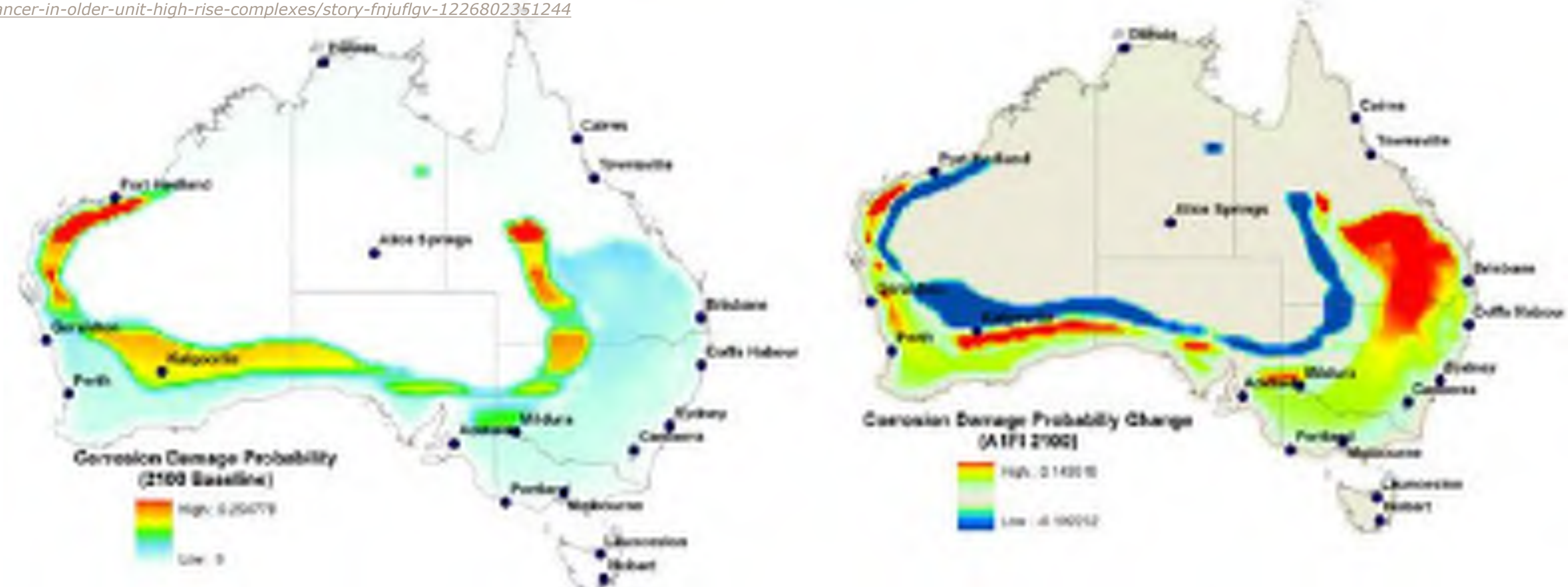
First International Workshop on Glass Fiber Reinforced Polymer (GFRP) Bar for Concrete Structures (IWGFRP-1)
18 July 2017

The need

http://www.cairnspost.com.au/realestate/warning-to-check-for-concrete-cancer-in-older-unit-high-rise-complexes/story-fnjuflgv-1226802351244

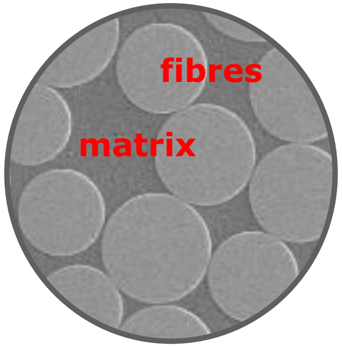
Corrosion of steel reinforcement

- Repair or replacement costs associated with steel corrosion in Australia are estimated at **AU$26 billion per year**.
- The risk of corrosion is likely to increase significantly due to climate change (Wang et al. 2012).



Probability of corrosion damage by 2100 (Wang et al. 2012)

The solution



Fibre reinforced polymer (FRP) bars

Advantages

- Impervious to chloride ion and chemical attack
- Tensile strength greater than steel
- 1/4th weight of steel reinforcement
- Transparent to magnetic fields and radio frequencies
- Electrically and thermally non-conductive

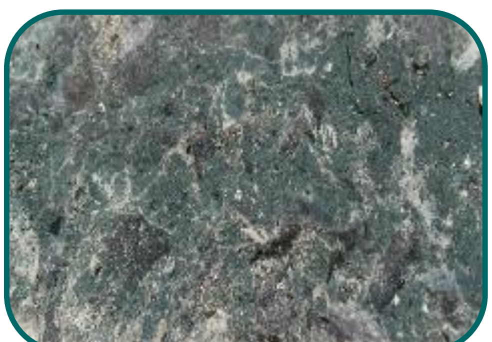
Research at CFM

UNIVERSITY OF SOUTHERN QUEENSLAND AUSTRALIA

Research
Centre for Future Materials

FRP reinforced geopolymer concrete

- Bond performance
- Behaviour of beams (flexure/shear)
- Behaviour of columns
- Behaviour of precast concrete elements
- Development of design specifications/standards



Collaborators:

- Inconmat Australia
- Pultrall Canada
- University of Sherbrooke
- University of Melbourne
- Qld Department of Transport and Main Roads

Bond-slip behaviour

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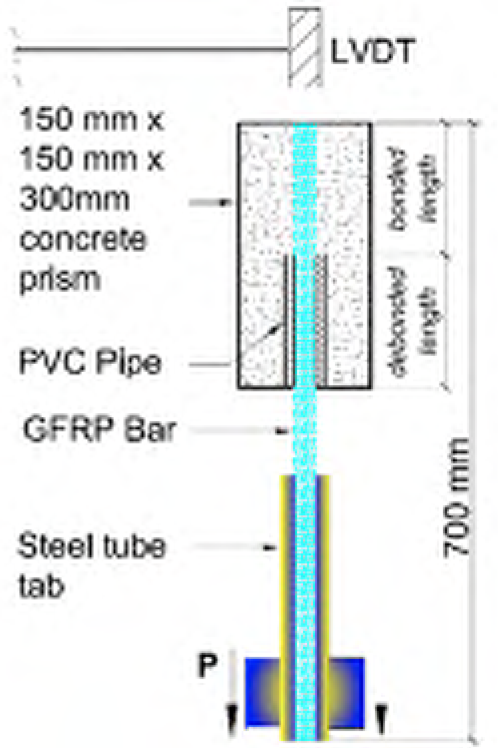
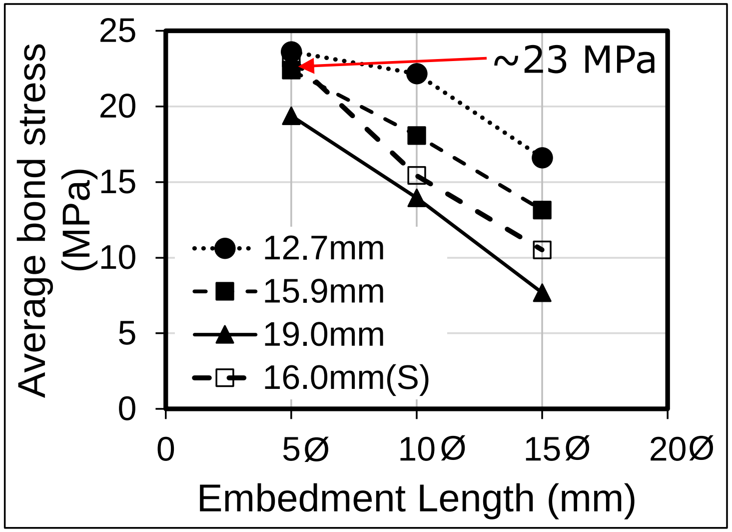
Actual Setup

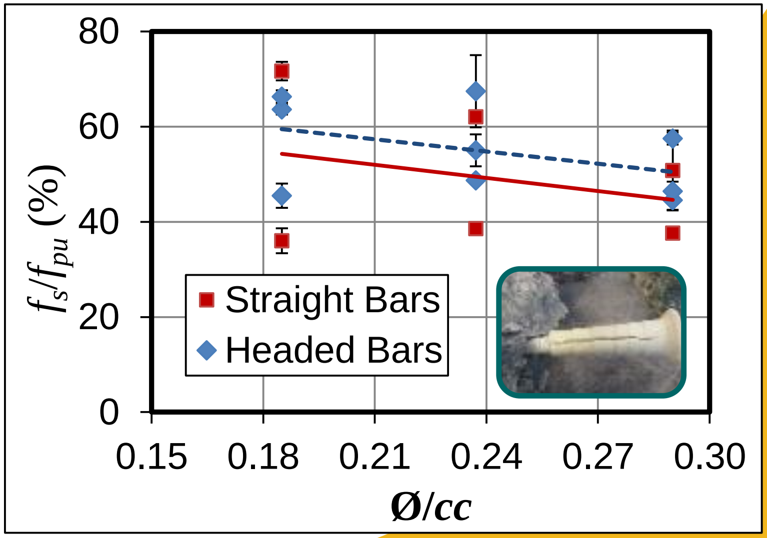


Schematic diagram

Direct Pullout Test Setup

(ACI 440.3R-04)





Flexural behaviour

Experimental Program: Test Set-up

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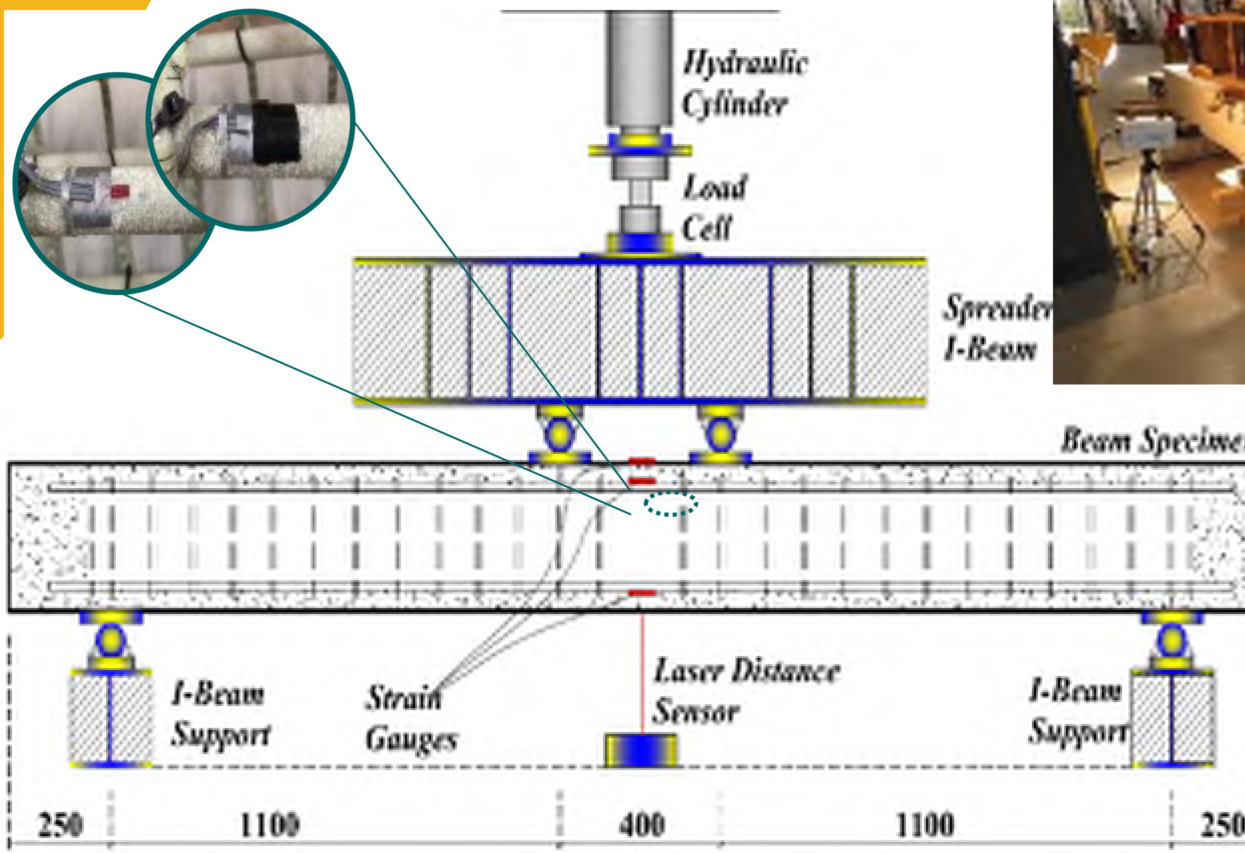


Four-point static bending test setup

Actual Set-up

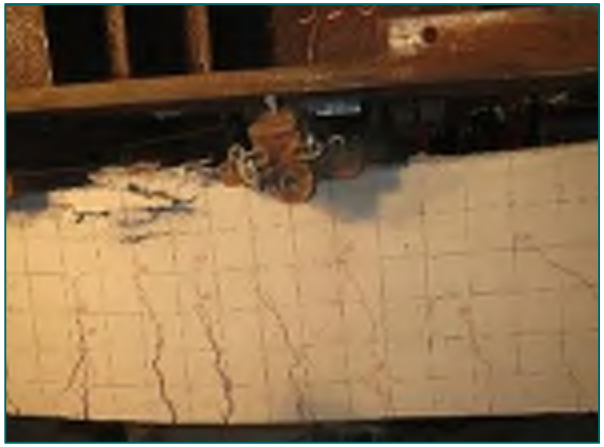
Parameters:

Bar diameter	12.7 mm, 15.9 mm, 19.0 mm
Reinforcement ratio	1.1%, 2.1%
Anchorage system	With and without anchor head

Flexural behaviour
Results

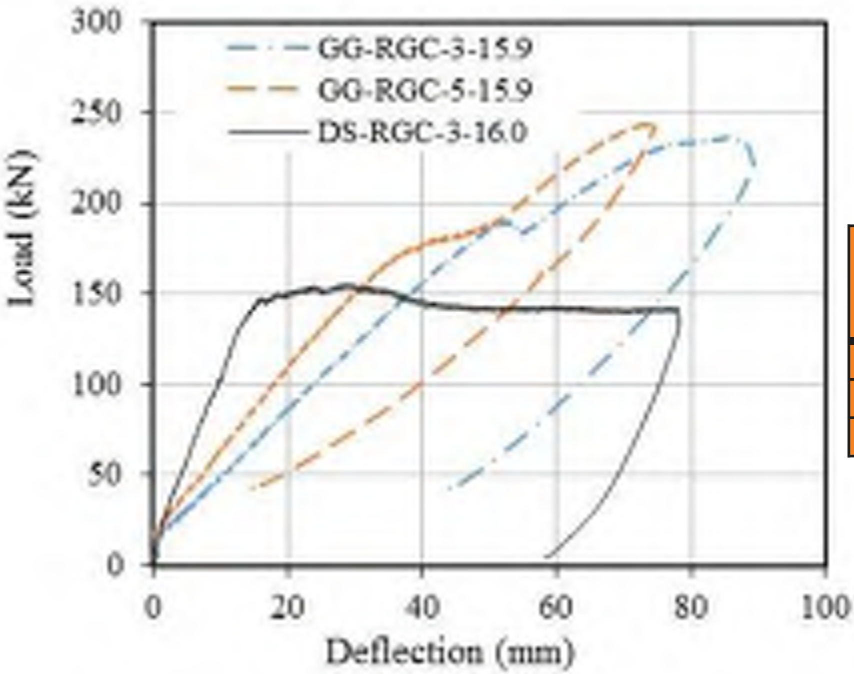
Concrete crushing at the top followed by compression buckling of top bars

(**FRP bars**)



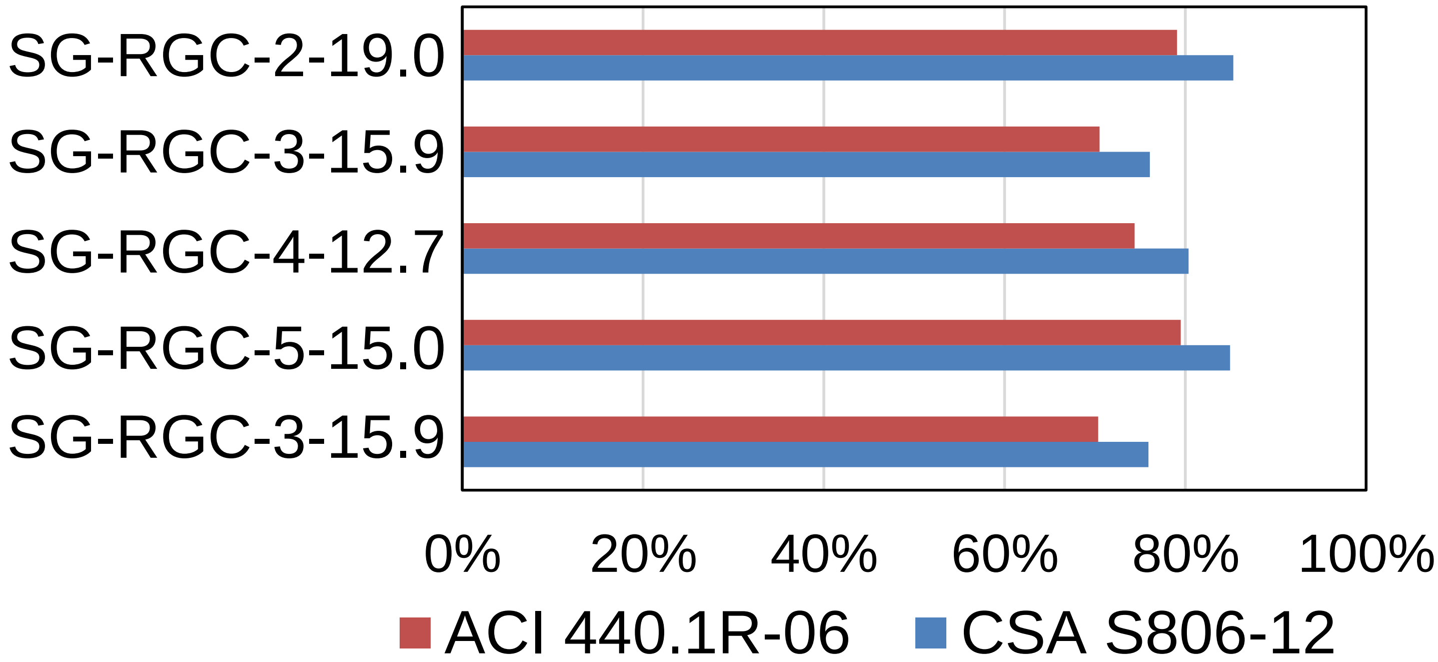
Flexural cracking at the bottom that signified steel yielding

(**Steel**)



Specimen	M_{cr} (kN-m)	M_s (kN-m)		M_u^* (kN-m)	M_{peak} (kN-m)
		At 2000 με	At $0.3M_u$		
SG-3-15.9	11.5	21.3	31.4	104.8	130.4
SG-5-15.9	10.4	27.7	29.8	99.3	134.2
DS-3-16.0	10.8	48.6	25.6	85.4	74.1

Flexural behaviour
Theoretical predictions

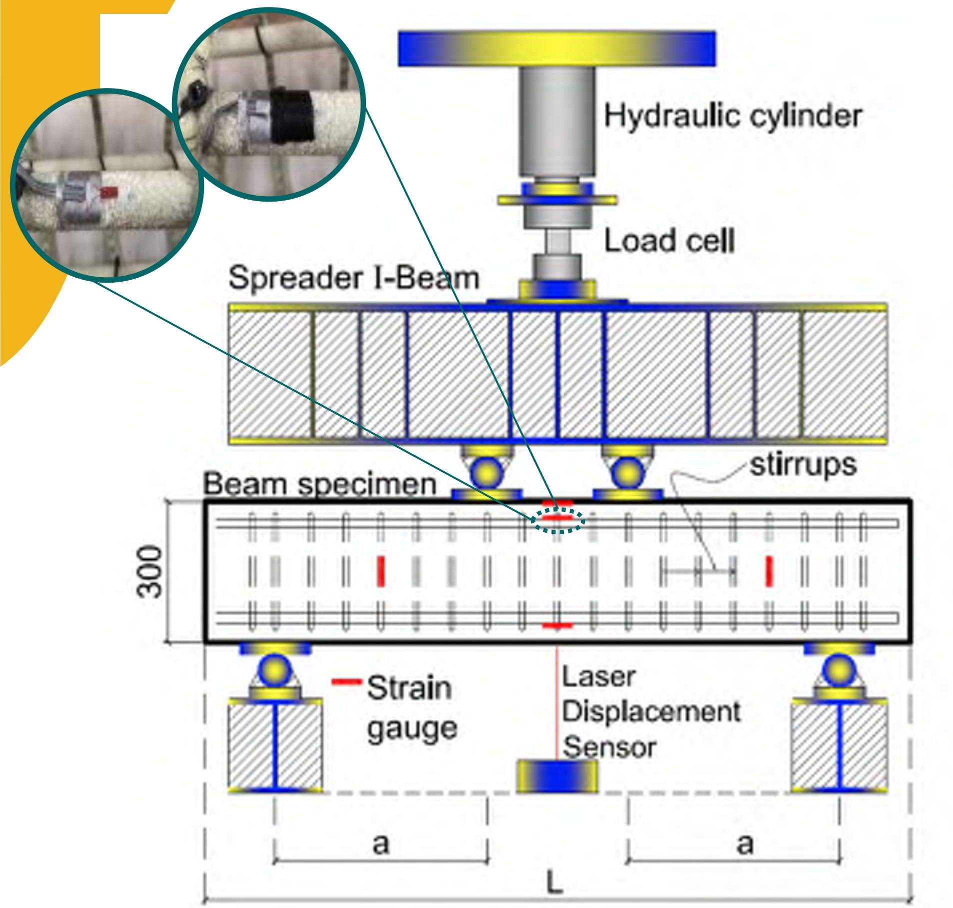


The ratios between the theoretical (using ACI 440.1R-06 and CSA S806-12) and experimental ultimate bending moment capacities (M_u)

CSA S806-12 can reliably predict the capacity of geopolymer concrete beams internally reinforced with FRP bars.

Shear behaviour

Experimental Program: Test set-up



Four-point static bending test setup

Actual Set-up

Parameters:

Stirrup Spacing	75 mm, 100mm, 150 mm
Reinforce	GFRP, steel

Shear behaviour

Results

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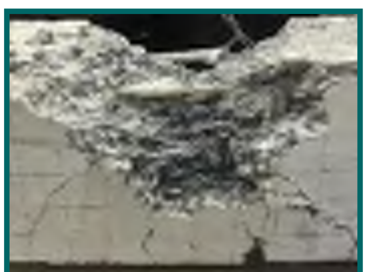
Research

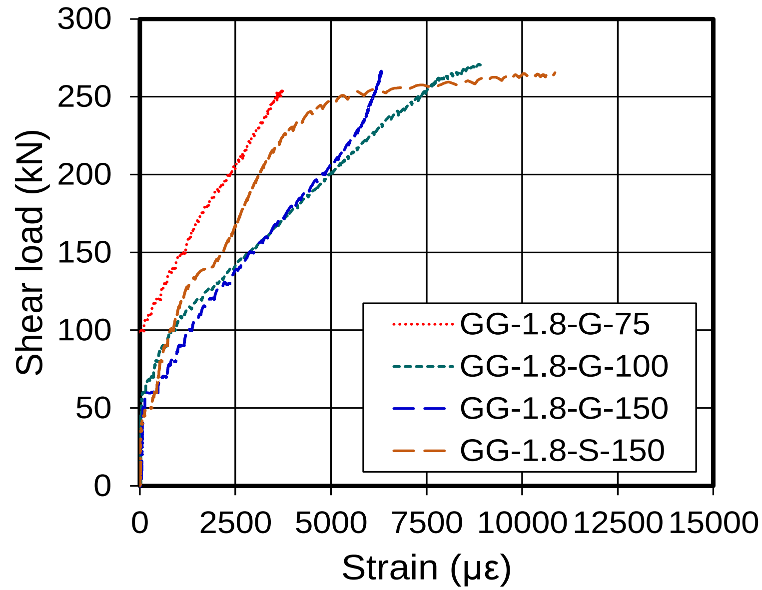
Centre for Future Materials

Diagonal strut tension failure (GG-1.8)

Diagonal strut compression failure (GG-1.8-G & -S)



Concrete crushing (GG-4.7-G-100)

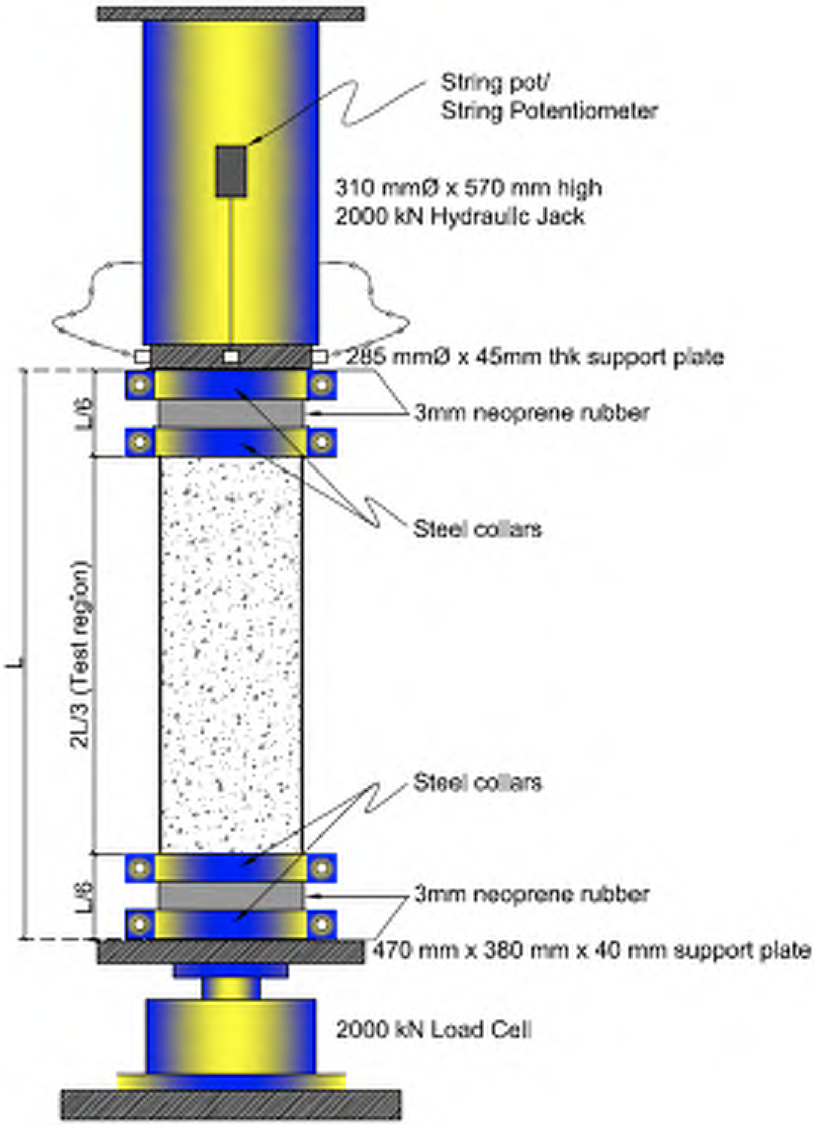


Shear load-stirrup strain relationship

Beam	$V_{2500\mu\varepsilon}$, kN	V_{n}, kN	V_{s}, kN	Δ_{n}, mm
GG-1.8	--	147	-	11
GG-1.8-G-75	205	256	109	20
GG-1.8-G-100	142	273	126	19
GG-1.8-G-150	138	**267**	**120**	19
GG-1.8-S-150	160	**266**	**119**	19
GG-4.7-G-100	--	122	-	11

Compression behaviour

Experimental Program: Test set-up



Compression test setup

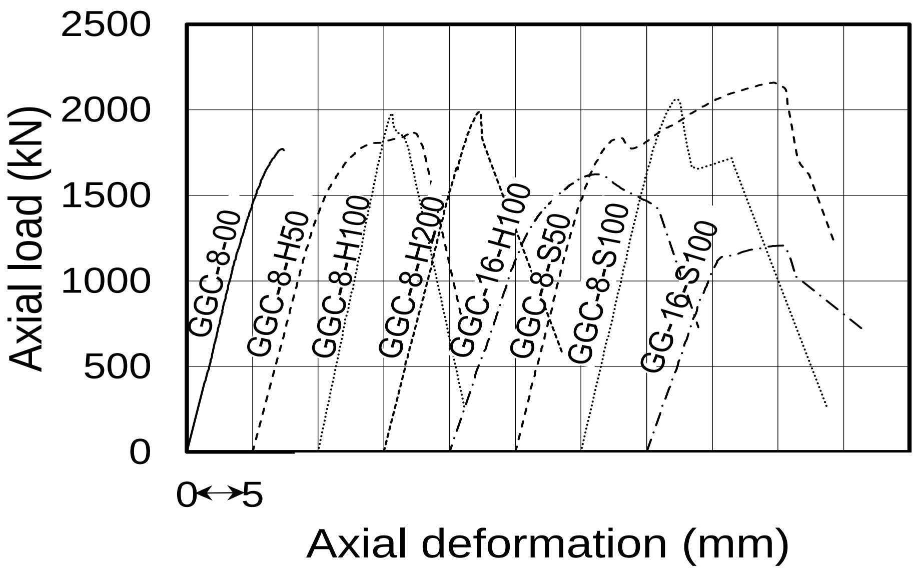
Actual set-up

Parameters:

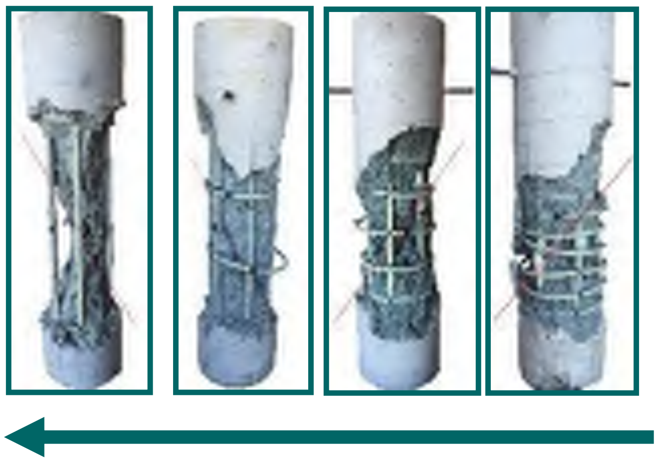
Tie configuration	Hoops, spirals
Spacing	50 mm, 100 mm, 200 mm
Slenderness ratio	8, 16

Compression behaviour

Results



Load-deformation response



Increasing degree of concrete crushing failure

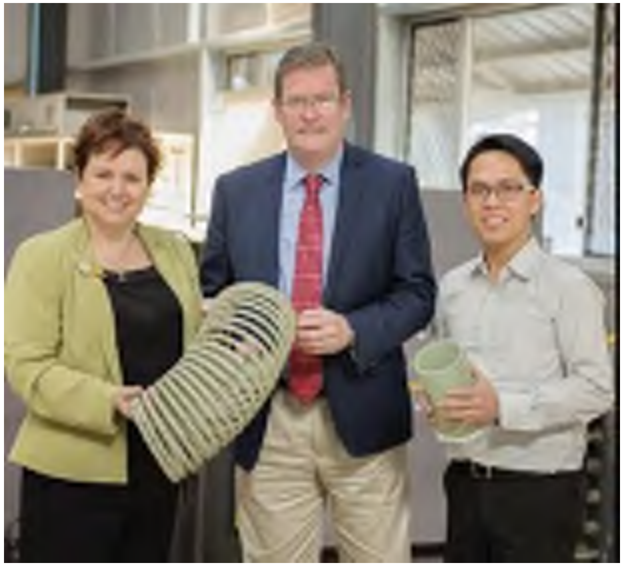
Column	P_g (kN)	P_c (kN)	Δ_g (mm)	Δ_c (mm)	P_{fg} (kN)	P_{fc} (kN)
GGC-8-00	1772	-	7.2	-	123	-
GGC-8-H50	1791	1872	8.6	12.1	188	451
GGC-8-H100	1981	1763	5.6	6.9	133	444
GGC-8-H200	1988	-	7.3	-	134	-
GGC-8-S50	1838	2160	8.0	19.7	158	645
GGC-8-S100	2063	1717	7.2	11.4	147	587
GGC-16-H100	1624	-	11.1	-	107	-
GGC-16-S100	1208	-	10.4	-	143	-

Applications

- Built in or close to sea water
- With low electric conductivity
- Soil with high moisture content
- Storage for (corrosive) liquid
- Precast concrete elements

Opportunities

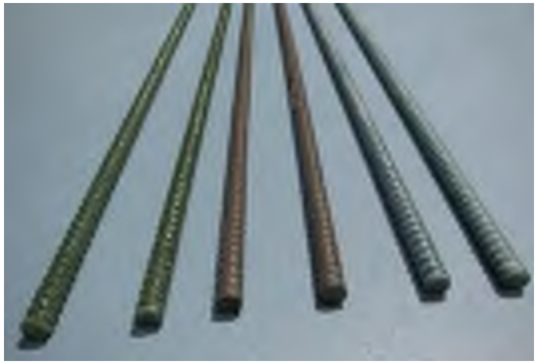
- New and novel applications, i.e.
  Precast concrete marine infrastructure (boat ramps, pontoons and floating walkways), railway sleepers, etc.
- New generation of bars (and forms)
- Durability and long-term performance in Australian environment
- Education and training
- Development of ***materials*** and design standards



FRP bars in Australia

V-Rod

http://mateenbar.com/products-and-specifications/mateenbar/



Firep International AG (Switzerland)

climb0917.en.made-in-china.com/product/BKLEGiZvhtha/China-Fiberglass-Bar-FRP-Bar-GRP-Bar-Glass-Fiber-Bar.html

Every bar is different!

- Type and amount of fibres
- Type of resin systems
- Fillers and additives
- Manufacturing method
- Handling and storage

- ***Qualification test***
- ***Quality control test***

There is a need to establish a material specification for FRP bars!

Standards Australia (PP 1581)

Design of Concrete Structures using Fibre-Reinforced Polymer (FRP) Bars

Part 1: FRP reinforcement material

Part 2: Design of concrete internally reinforced with FRP bars

Interested stakeholders:

- University of Southern Queensland
- IRC Pty Limited
- VicRoads
- Qld Dept. Transport and Main Roads
- University of Melbourne
- University of Wollongong
- Monash University
- Australian Institute of Building
- Composites Australia
- Inconmat Australia
- Pultrall Canada
- Pultron Composites Ltd
- Schöck Bauteile GmbH (ComBAR)
- University of Sherbrooke, Canada
- City College of New York, USA
- University of Western Australia
- AustRoads
- Engineers Australia
- Cement Concrete & Aggregates Australia
- CSA Group (Canadian Standards Association)

BD-108 *Fibre-Reinforced Polymer (FRP) Bars*

new Australian Standard for 'Design of concrete structures using Fibre-Reinforced Polymer (FRP)'

AS 5204-20XX Specification for fibre-reinforced polymer bars

Development of international standards and specifications to **ensure structural quality and grade of FRP bars** for use in internal reinforcement of concrete components and structures.

Safe and effective usage of composite reinforcing material in Australian civil infrastructure and construction.

AS 5204-20XX

Specification for fibre-reinforced polymer bars

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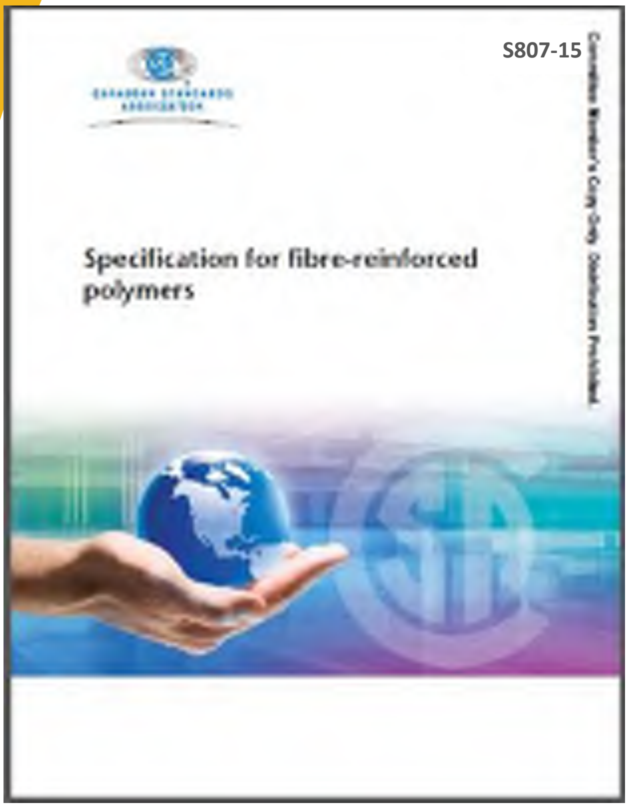
Research Centre for Future Materials



Canadian Standards Authority (CSA) **CSA807-15 (2015)** *Specifications for fibre-reinforced polymers.*

■ *Adoption by reference*

An Australian Standard which references a suitable international standard such as the CSA 807-15 in its entirety with Australian specific modifications as required.

■ *Complete re-write*

Merits of having a unique standard but there exist no bar manufacturer in Australia.

Thank you!

e-mail: *manalo@usq.edu.au*
www.researchgate.net/profile/Allan_Manalo

SHERBROOKE

CDCC' 2017

July 19-21, 2017
Delta Hotel
Sherbrooke, Quebec, Canada

Université Claude Bernard Lyon 1

Trends and Development of Codes and Specifications on GFRP Bars for Concrete Structures in Europe

Emmanuel FERRIER

LMC² - Université LYON 1

Laboratoire des Matériaux Composites pour la Construction
EA 7427

Outline

- Codes and specification in Europe
- Use of FRP bars in Europe
- Curent research
- Conclusions

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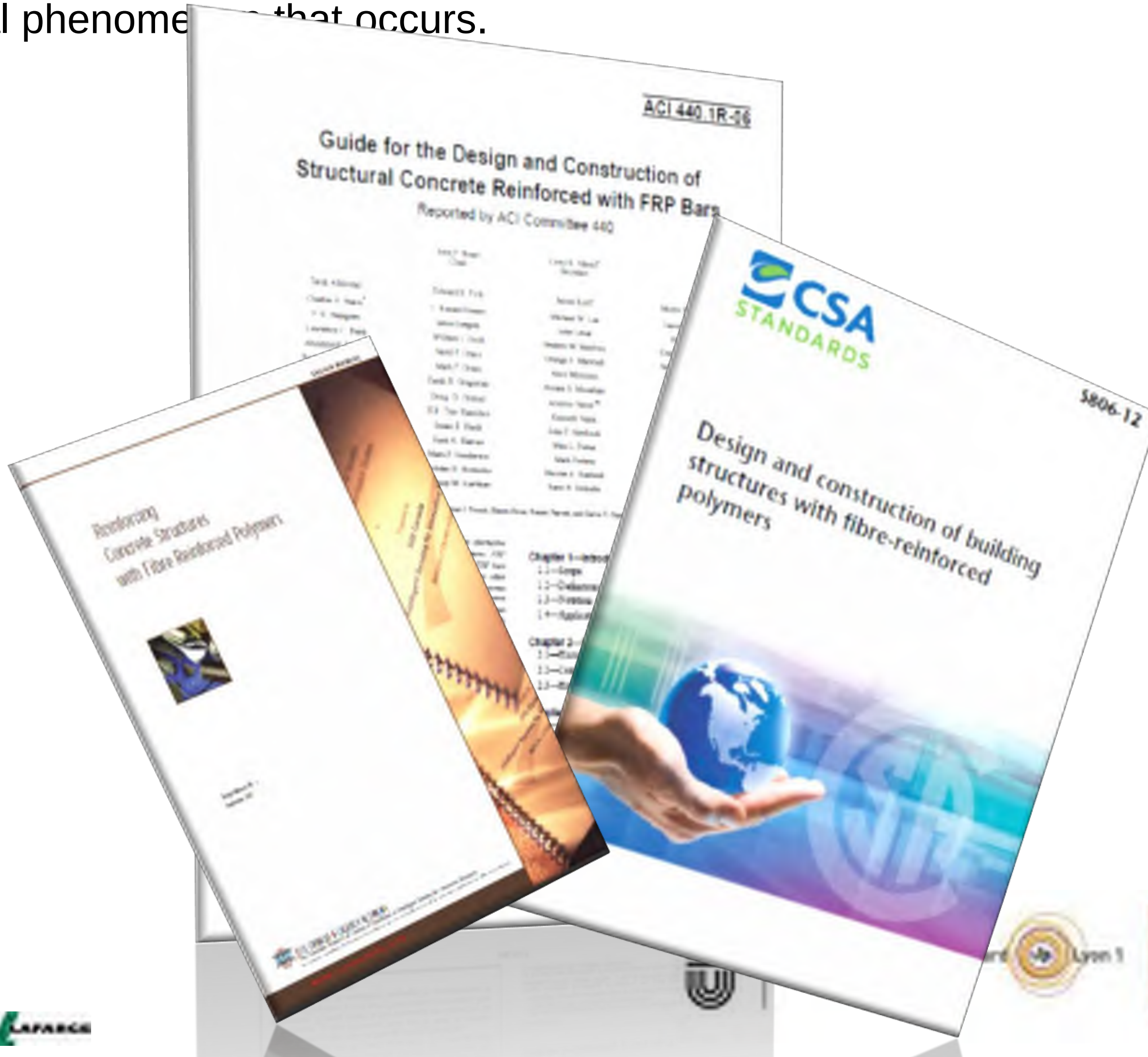
Codes and specification in Europe

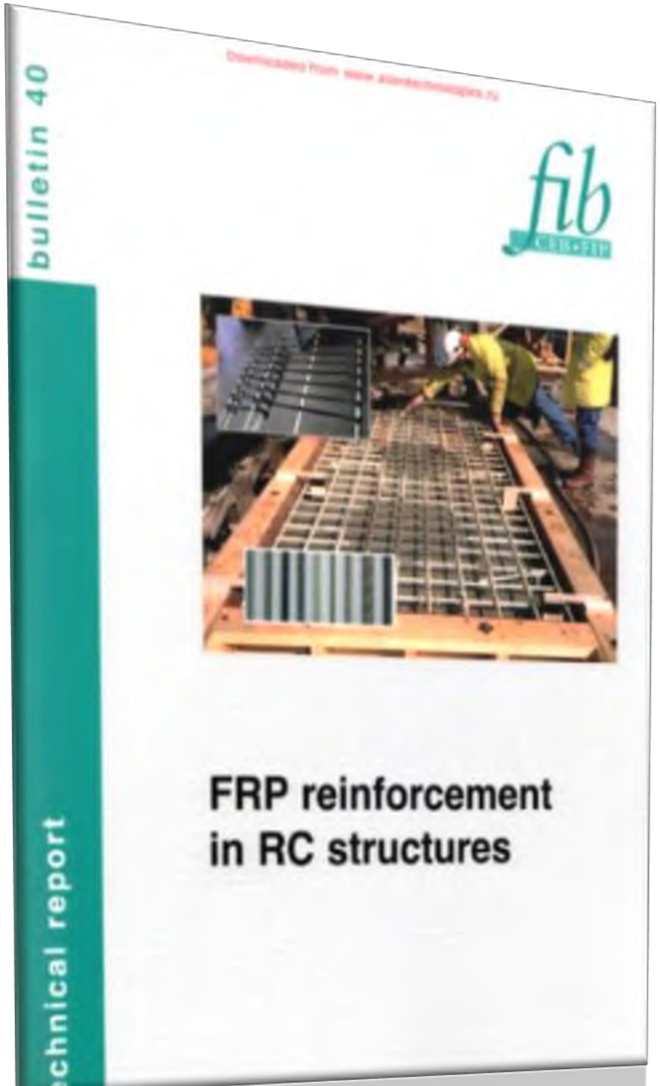
FRP codes are based on steel codes

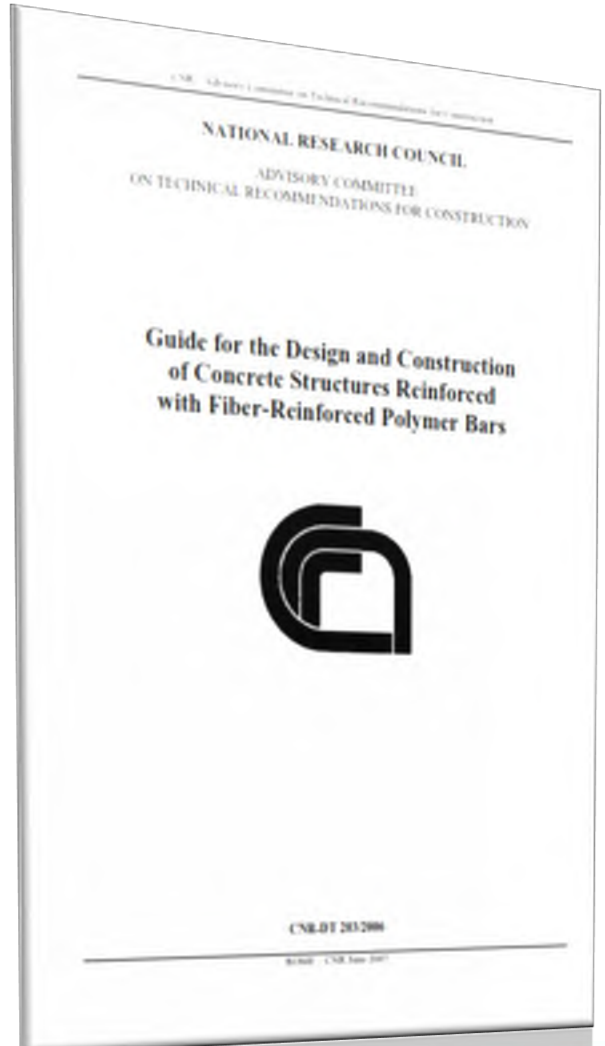
- Equations are derived from steel codes equations but don't match always the physical phenome[na] that occurs.



4

Codes and specification in Europe





Materials design value

$$X_d = \eta \frac{X_k}{\gamma_m},$$

Exposure conditions	Type of fiber / matrix*	η_a
Concrete not-exposed to moisture	Carbon / Vinylester or epoxy	1.0
	Glass / Vinylesters or epoxy	0.8
	Aramid / Vinylesters or epoxy	0.9
Concrete exposed to moisture	Carbon / Vinylesters or epoxy	0.9
	Glass / Vinylesters or epoxy	0.7
	Aramid / Vinylesters or epoxy	0.8

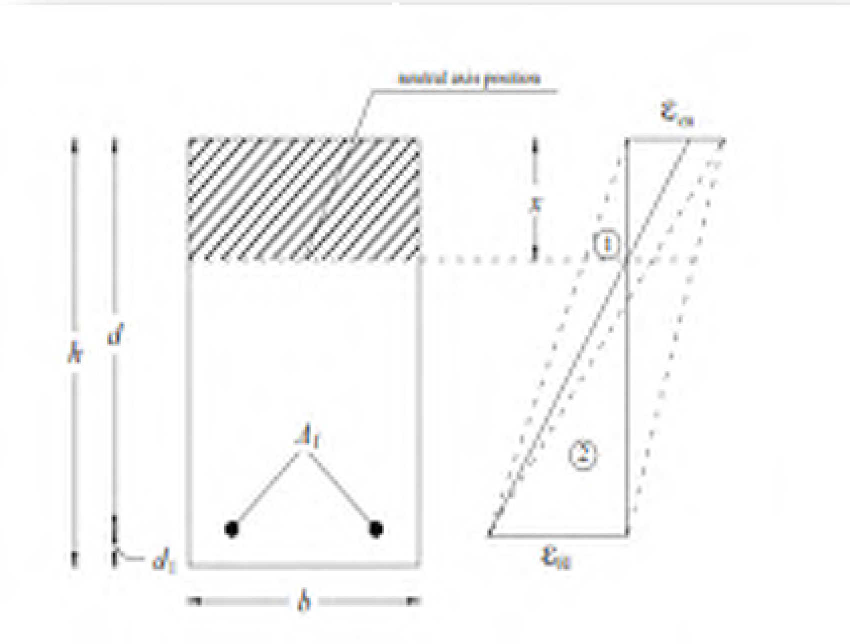
* The use of a polyester matrix is allowed only for temporary structures.

(1) For ultimate limit states, the partial factor γ_m for FRP bars, denoted by γ_f, shall be set equal to 1.5.

(2) For serviceability limit states, the value to be assigned to the partial factor is $\gamma_f = 1$.

(3) The partial factor prescribed by the current building code shall be assigned for concrete.

ULS calculation hypothesis



$$M_{Sd} \le M_{Rd} \,.$$

$$\varepsilon_{fd} = 0.9 \cdot \eta_a \cdot \frac{\varepsilon_{fk}}{\gamma_f} \,,$$

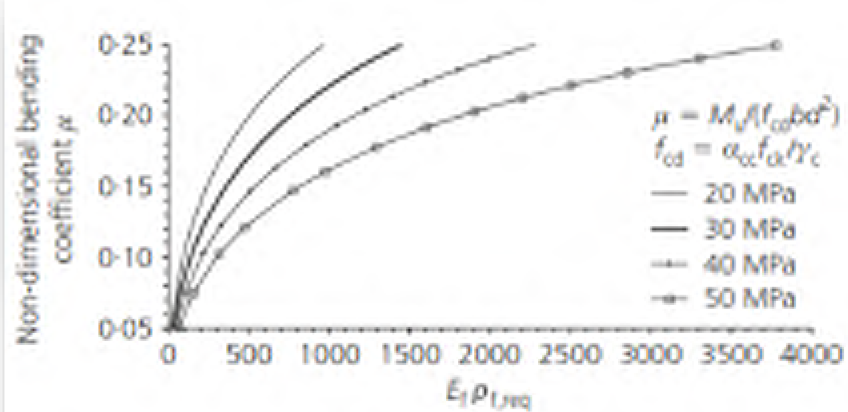


Figure 4. Design chart for flexural capacity of constant-width FRP RC elements

SLS : Deflection limit

Code	Type of structures	Limit
Eurocode 2	Aesthetic and functionality conditions (quasi permanent loads)	L/250
	Damage limitation of non-structural elements sustained or attached (quasi permanent loads)	L/500
ACI 318-05	Roofs and floors supporting or attached to non-structural elements (Sum of long term deflection due to all sustained loads and immediate deflection due to any additional live load):	
	Not likely to be damaged by large deflections	L/240
	Likely to be damaged by large deflections	L/480
	Elements not supporting or attached to non-structural elements likely to be damaged by large deflections (immediate deflection due to live loads): Floors	L/360
	Flat roofs	L/180

$$f = f_1 \cdot \beta_1 \cdot \beta_2 \cdot \left(\frac{M_{cr}}{M_{max}} \right)^m + f_2 \cdot \left[1 - \beta_1 \cdot \beta_2 \cdot \left(\frac{M_{cr}}{M_{max}} \right)^m \right]$$

- f_1 is the deflection of the uncracked section;

- f_2 is the deflection of the transformed cracked section;

- $\beta_1 = 0.5$ is a non-dimensional coefficient accounting for bond properties of FRP bars;
- β_2 is a non-dimensional coefficient accounting for the duration of loading (1.0 for sh
loads, 0.5 for long time or cyclic loads);

- M_{max} is the maximum moment acting on the examined element;

- M_{cr} is the cracking moment calculated at the same cross section of M_{max} ;

- m is a coefficient to be set equal to 2.

SLS : Crack opening limit

$$w_k = \beta \cdot s_{rm} \cdot \varepsilon_{fm}, \qquad s_{rm} = 50 + 0.25 \cdot k_1 \cdot k_2 \cdot \frac{d_b}{\rho_r}, \qquad \varepsilon_{fm} = \frac{\sigma_f}{E_f} \cdot \left[1 - \beta_1 \cdot \beta_2 \cdot \left(\frac{\sigma_{fr}}{\sigma_f}\right)^m\right],$$

- k_1 is a coefficient accounting for the bond properties of the FRP bars, to be set equal to 1.6;

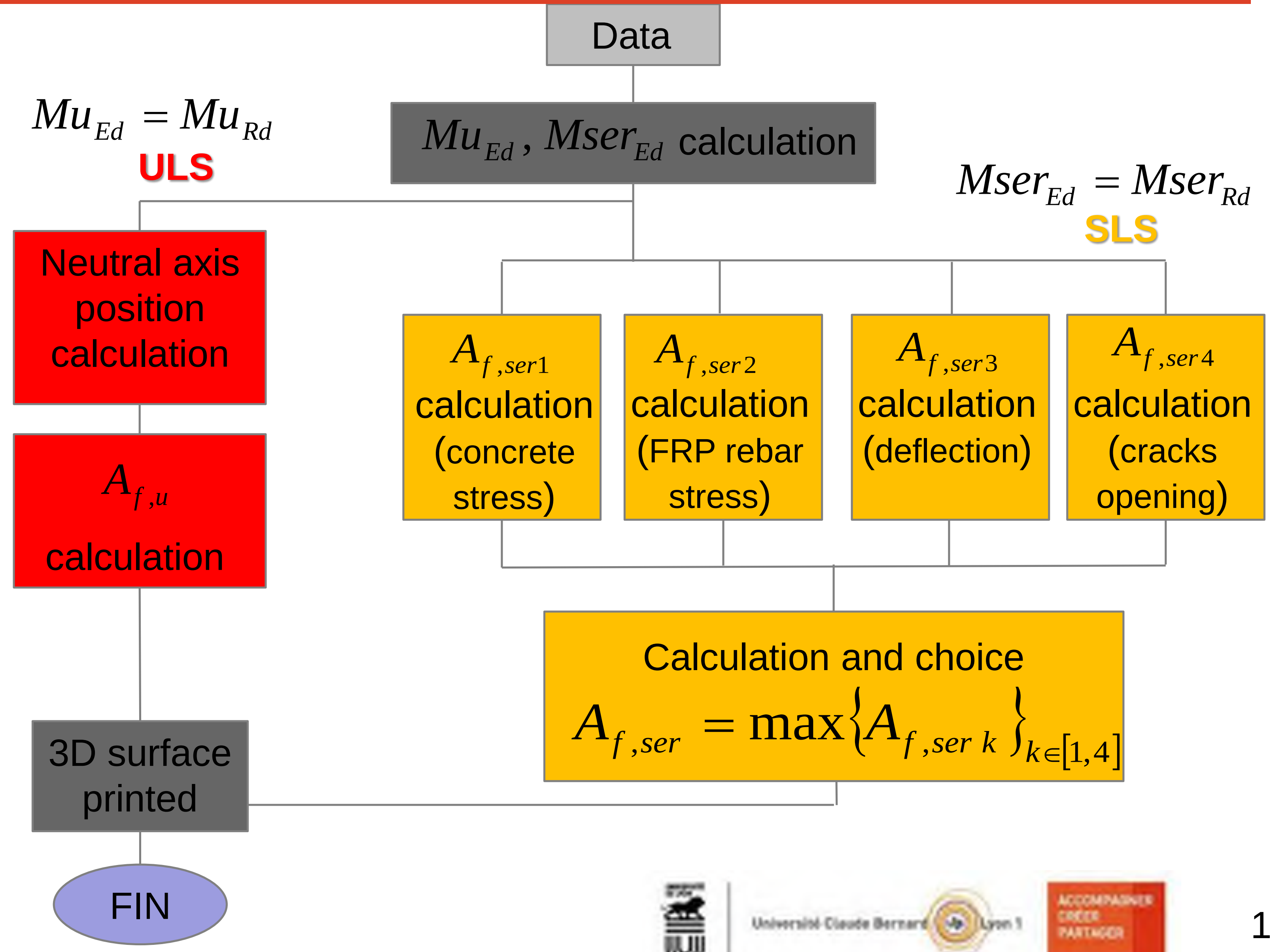
- k_2 is a coefficient depending upon the strain diagram (0.5 for flexure, 1.0 for pure tension);

- d_b is the equivalent diameter of the FRP bars, in mm; if bars of different diameter are used, their average value can be considered;

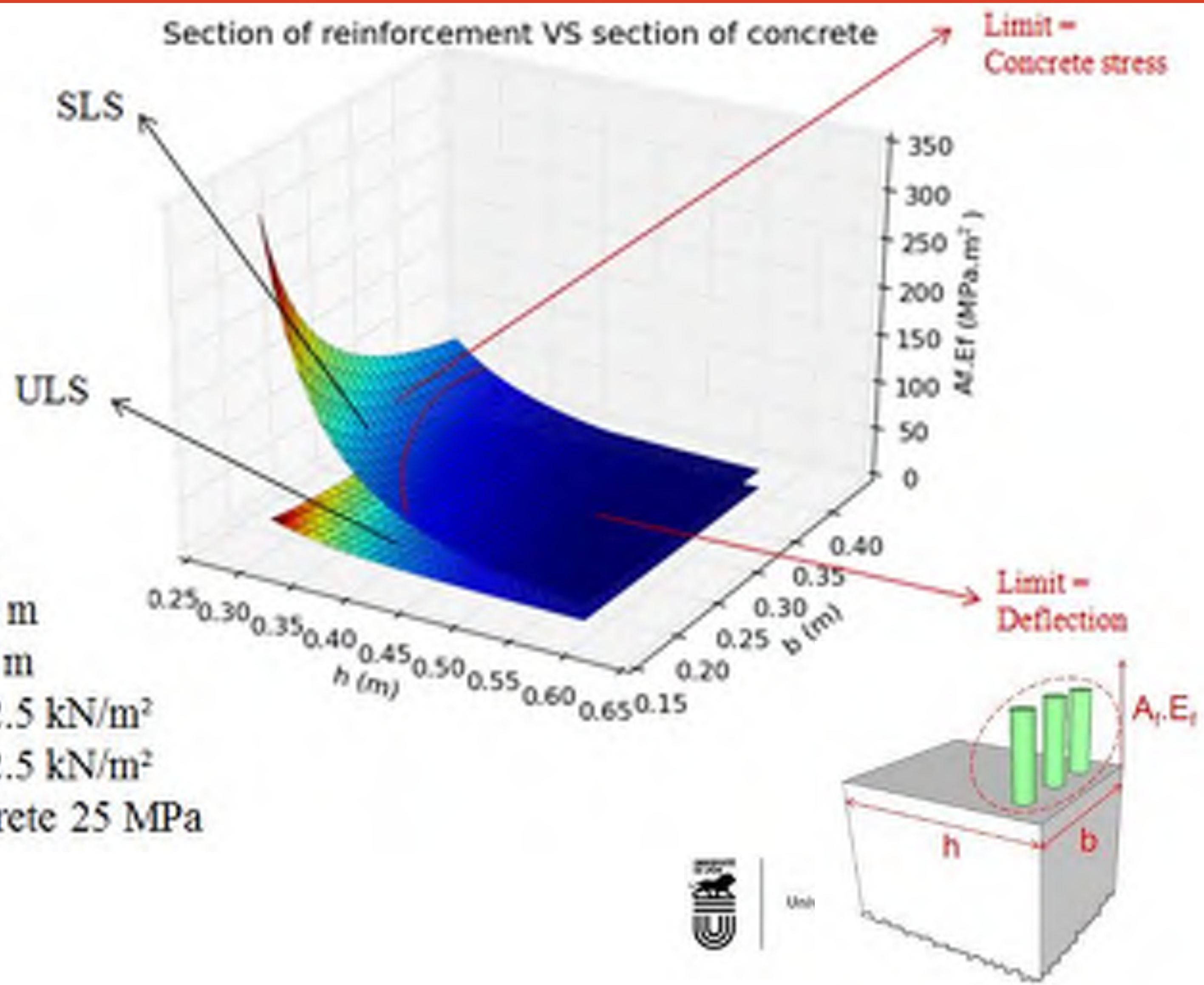
- ρ_r is the effective reinforcement ratio, equal to $A_f / A_{c,eff}$, where $A_{c,eff}$ is the effective area in tension defined as the concrete area surrounding the tensile FRP reinforcement, having depth equal to 2.5 times the distance between tension fiber and bars centroid (EC2).

Eurocode 2	Steel	Normal	0.3 mm
Model Code 1990	Steel	Normal	0.3 mm
JSCE (1997)	FRP		0.5 mm
ACI 440.1R-06 CSA (2002)	FRP	Interior	0.7 mm
ACI 440.1R-06 CSA (2002)	FRP	Exterior	0.5 mm
IStuctE (1999)	FRP	Close to observer Away from observer	0.3 mm >0.3 mm

Algorithm for CSA code



Design trends results based on CSA S806-12



Data
L = 4 m
e = 3 m
Q = 2.5 kN/m²
G = 2.5 kN/m²
Concrete 25 MPa

Outline

- Codes and specification in Europe
- Use of FRP bars in Europe
- Curent research
- Conclusions

Pavement on seaside

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Pavement on road : electromagnetic field

Gare de Péage

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Soft eye FRP reinforcement

Figure 1-3: Soft eye FRP reinforcement

Soft eye FRP reinforcement

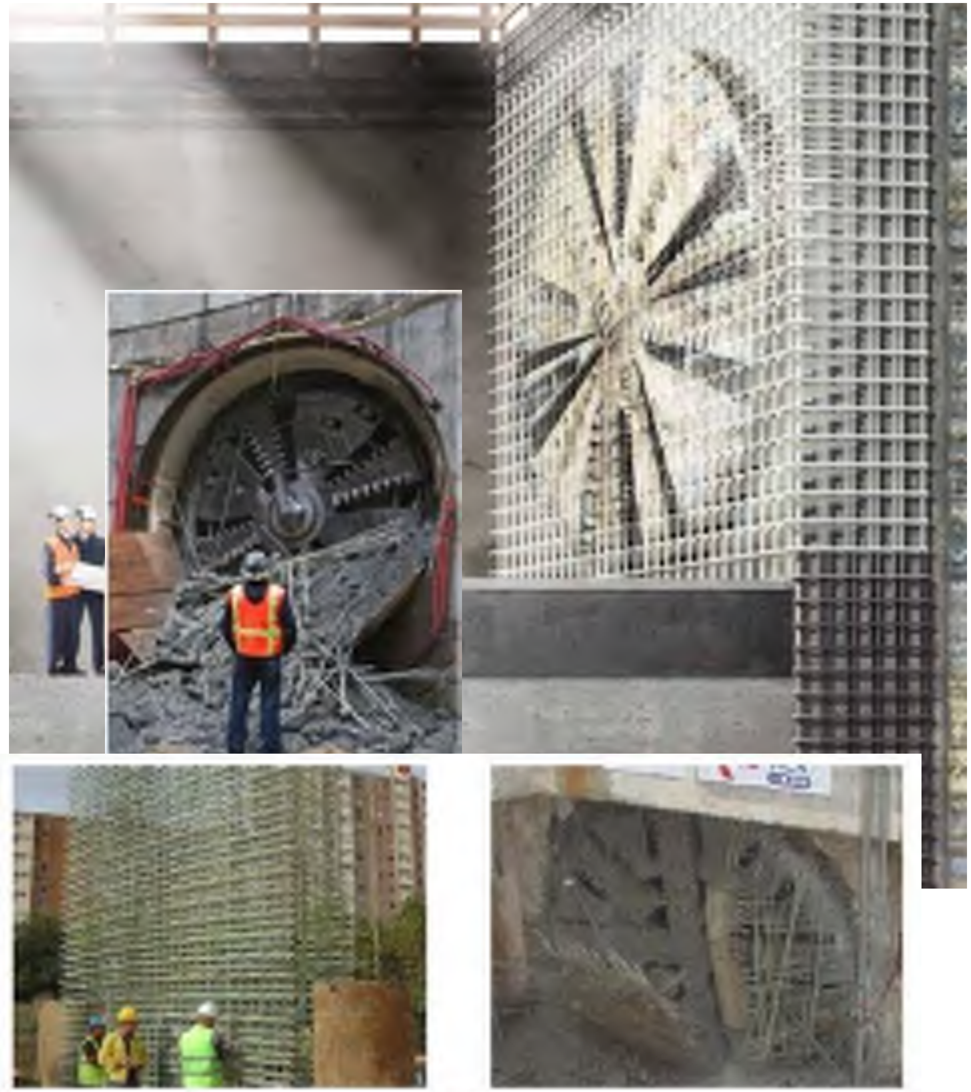

Figure 1-1: Soft eye FRP reinforcement

- Faster and safer penetrations
- Suitable for:
  - ✓Soft-eyes in shaft walls at tunnelling projects
  - ✓Diaphragm walls
  - ✓Drilled pile walls
  - ✓Temporary concrete buildings

Pile foundation FRP reinforcement

sireg

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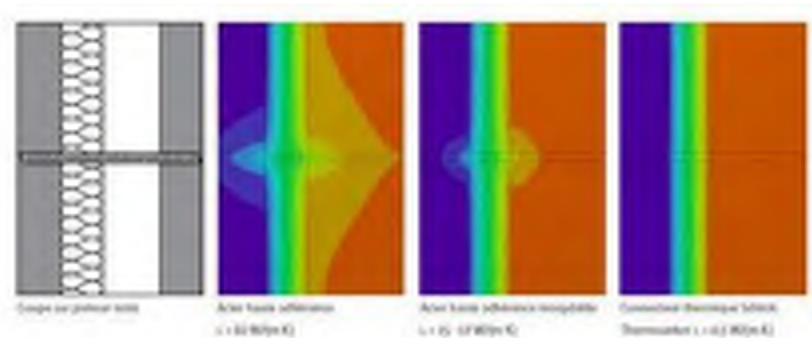
Soft Precast wall bolt



Soft Precast wall bolt


FFB

La FFB

Le Bâtiment et vous

Bâtimétiers N° 8 - 2007 | Gros oeuvre/structure

LE PRÉMUR, ALTERNATIVE AU BÉTON BANCHÉ ?

Livré sous forme de panneaux sur le chantier, le prémur peut être intéressant pour réaliser certains types d'ouvrages ou certaines parties de bâtiment. Sous Avis technique du CSTB, sa mise en oeuvre est exigeante et les entreprises doivent se poser la question de son coût.

Depuis une dizaine d'années, il existe une alternative au béton banché pour construire des murs porteurs : le prémur. Prébétonné en usine, il se compose de deux parois minces en béton armé (4,5 à 7,5 cm), généralement sans acier en attente, maintenues espacées par des raidisseurs métalliques horizontaux. Une fois positionnés et stabilisés, les panneaux de prémur font office de coffrage : on y glisse des armatures de liaison et on y coule du béton prêt à l'emploi, ce qui garantit la stabilité de la construction. Cette technique peut être employée pour réaliser différents murs porteurs de bâtiments industriels, de bureaux ou d'habitations, pouvant comporter plusieurs niveaux de sous-sols, ou pour des murs de soutènement ; elle répond aux exigences de la construction en zone sismique. En fonction des contraintes qui lui sont demandées, l'épaisseur du prémur varie de 16 à 40 cm, tandis que sa hauteur varie de 1 à 10 m, pour une largeur de panneaux allant jusqu'à 2,80 m. S'il s'agit encore d'un marché de niche, avec un petit nombre de fabricants, l'intérêt des entreprises de maçonnerie pour cette technique va croissant. Avec 1,2 million de m2 en 2006, le prémur représente 7 % du total des murs construits.

With 1,2 million of m2 in 2006, precast wall represent 7 % of the total building wall.

Source FFB

If all conector are made of FRP that make 6 million of conector or 1,2 million of linear meter per year!

Soft Precast wall bolt

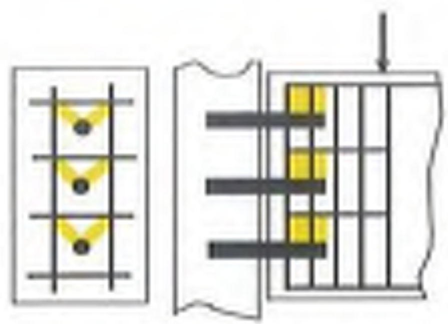

Avis Technique 3/15-817

Goujons SCHÖCK

CSTB

Logements Bellerive


Figure 2-6: FRP rebars (Schöck Bauteile GmbH)



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Outline

- Codes and specification in Europe
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Composite structures using FRP bars

-Used of full system effect on mechanical behaviour

- mixing material with FRP bars

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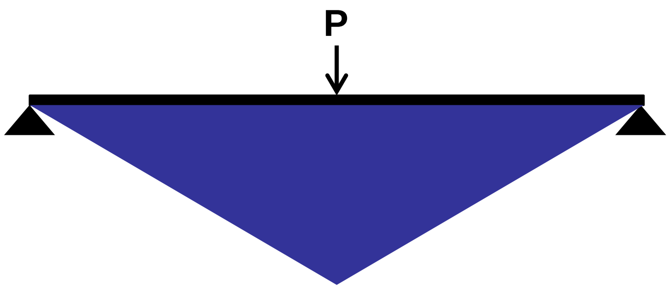
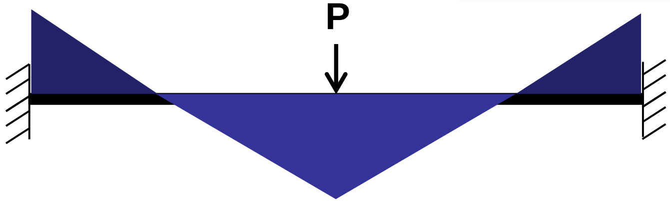
Difference between simply supported and fixed beams deflection

Simply supported beam



Fixed beam



$$\delta_s = \frac{PL^3}{48EI}$$

$$\delta_e = \frac{PL^3}{192EI}$$

$$\delta_e = \frac{\delta_s}{4}$$

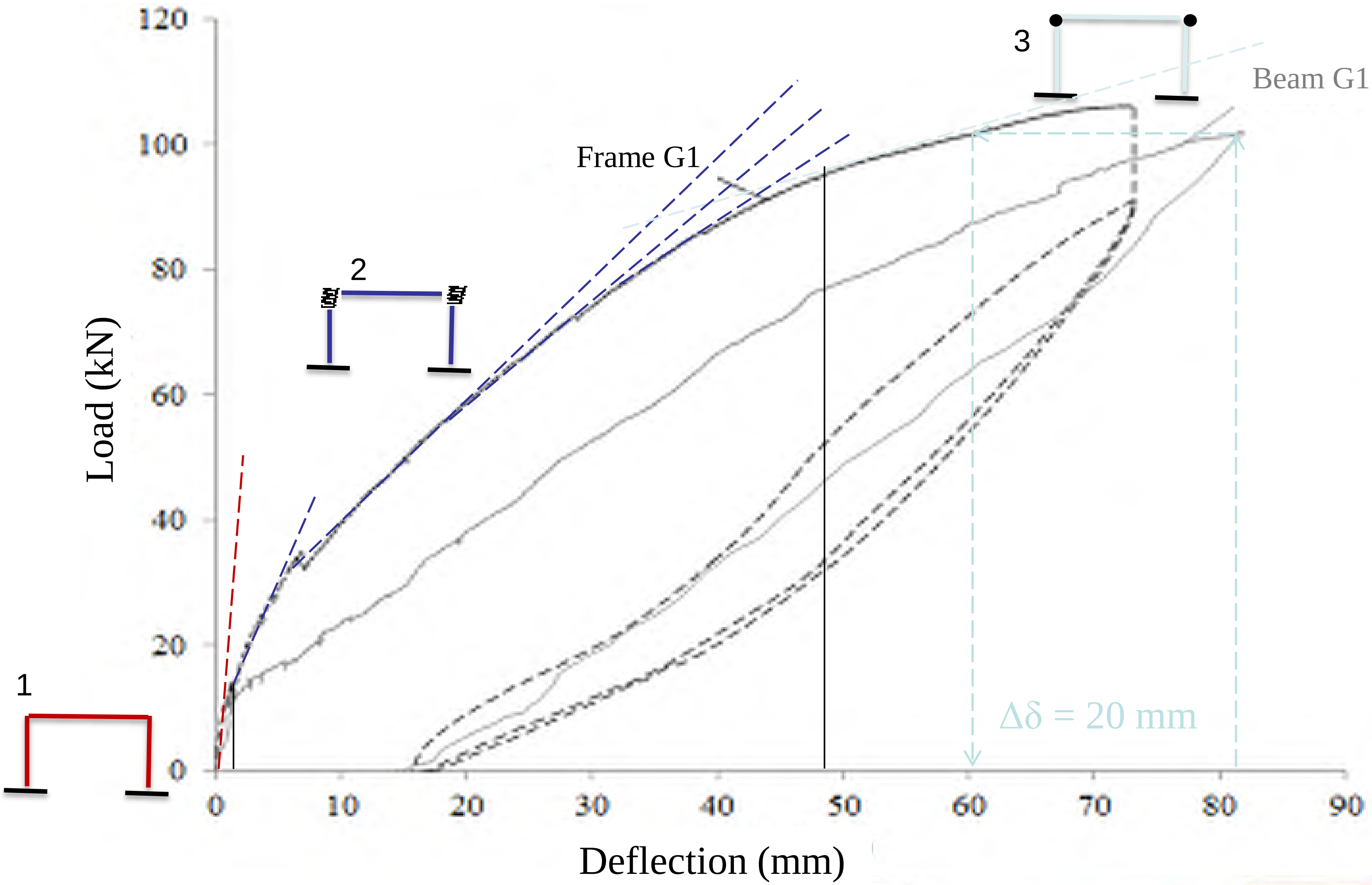
The moment distribution will change according to boundary conditions.

Experimental setup

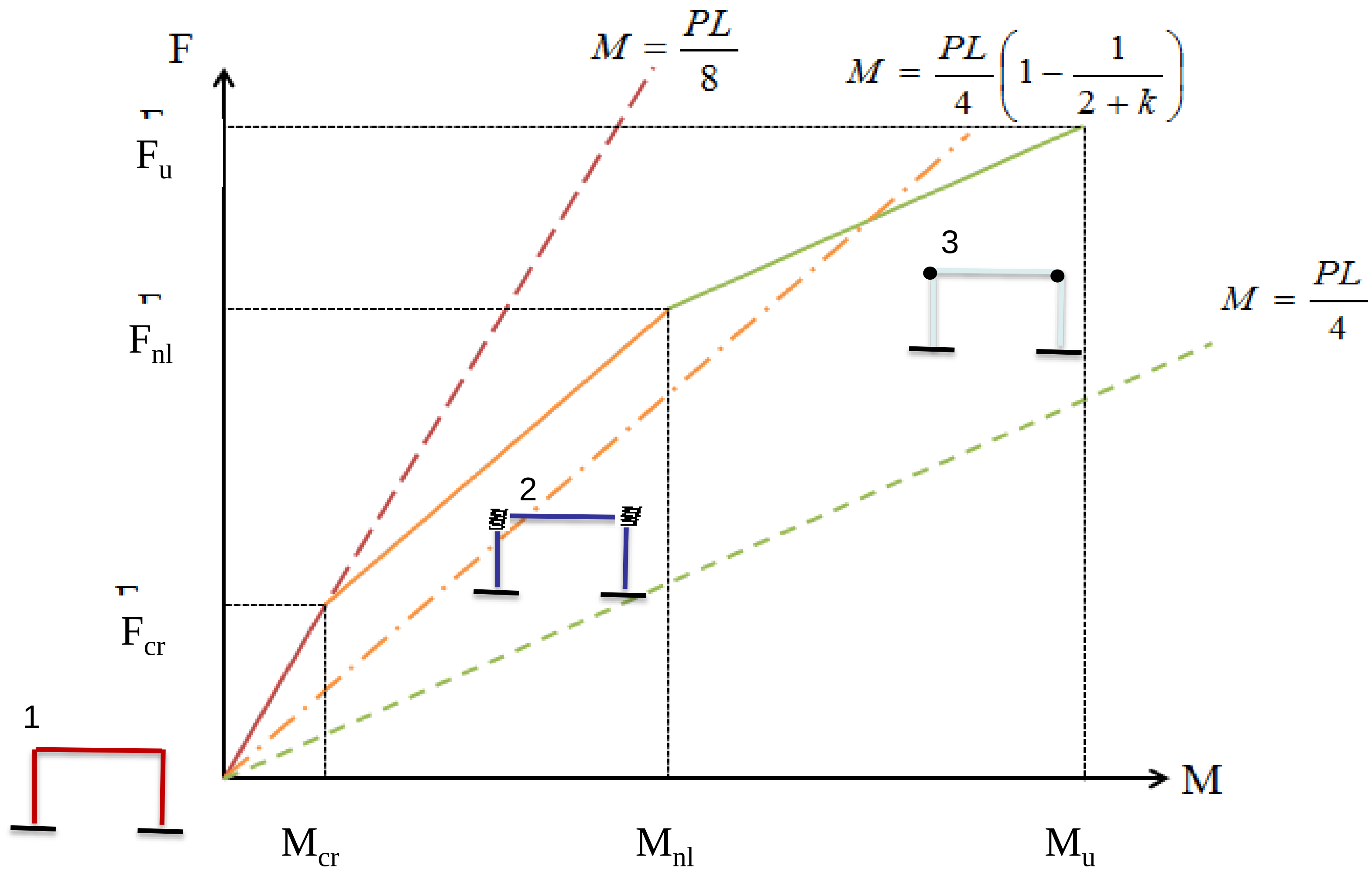
- 3-points bending test

Experimental results

Difference of deflection between isostatic and hyperstatic system



Force deduced from calculated features moments



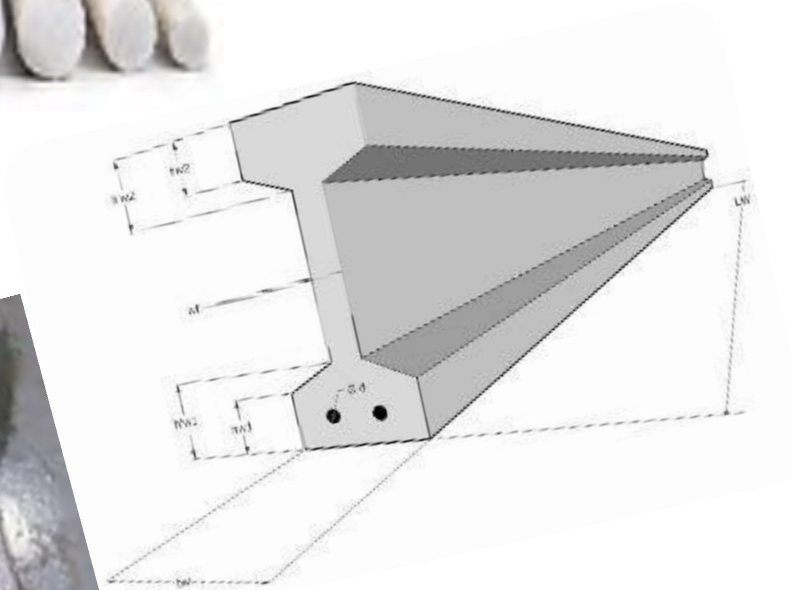
« …get the best of each material for new product… »

Ultra high performance concrete

Seonyu, Seoul pedestrian bridge

Sherbrooke pedestrian bridge

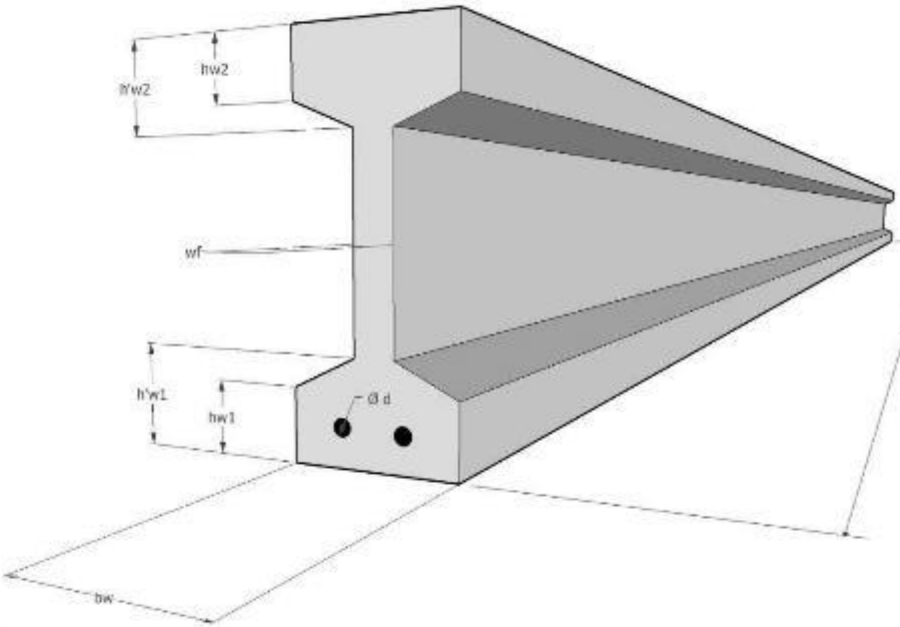
FRP bars



<u>FRP</u>
Young modulus: 70 GPa to 200 GPa
strenght : 1500 to 2800 MPa

<u>BFUP</u>
Young modulus: 200 MPa
Strength: 15 MPa

« ...UHPC and FRP... »



	h_{w1}	h'_{w1}	h_{w2}	h'_{w2}	b_w	b_f	h_w	L_w	FRP TYPE	Diameter	number	Area
	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[mm]	[m]	CF/GF	[mm]	[u.]	[mm²]
Beam 1	23	40	32	48	90	22	200	4	Glass	16	1	201
Beam 2	17	33	10	21	90	22	176	4	Carbon	9.6	3	217
Beam 3	17	33	10	21	90	22	192	4	Carbon	9.6	2	144
Beam 4	38	55	35	50	90	22	215	2	Glass	16	2	402
Beam 5	38	55	35	50	90	22	215	2	Glass	16	2	402


Beam 1

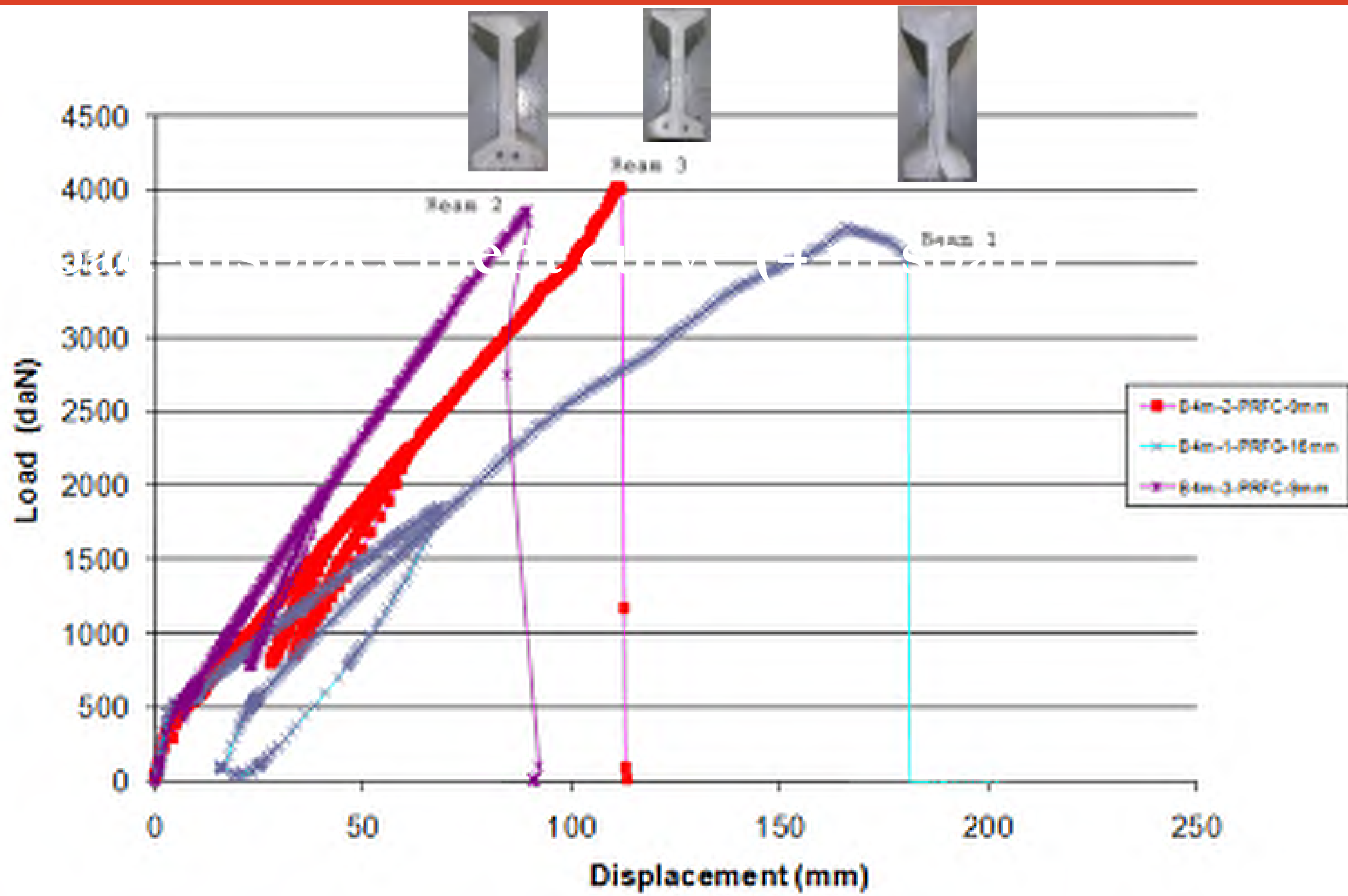

Beam 2


Beam 3


Beam 4

Beams section after testing

Load deflection curve



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CRÉER
PARTAGER

Choice of the sections

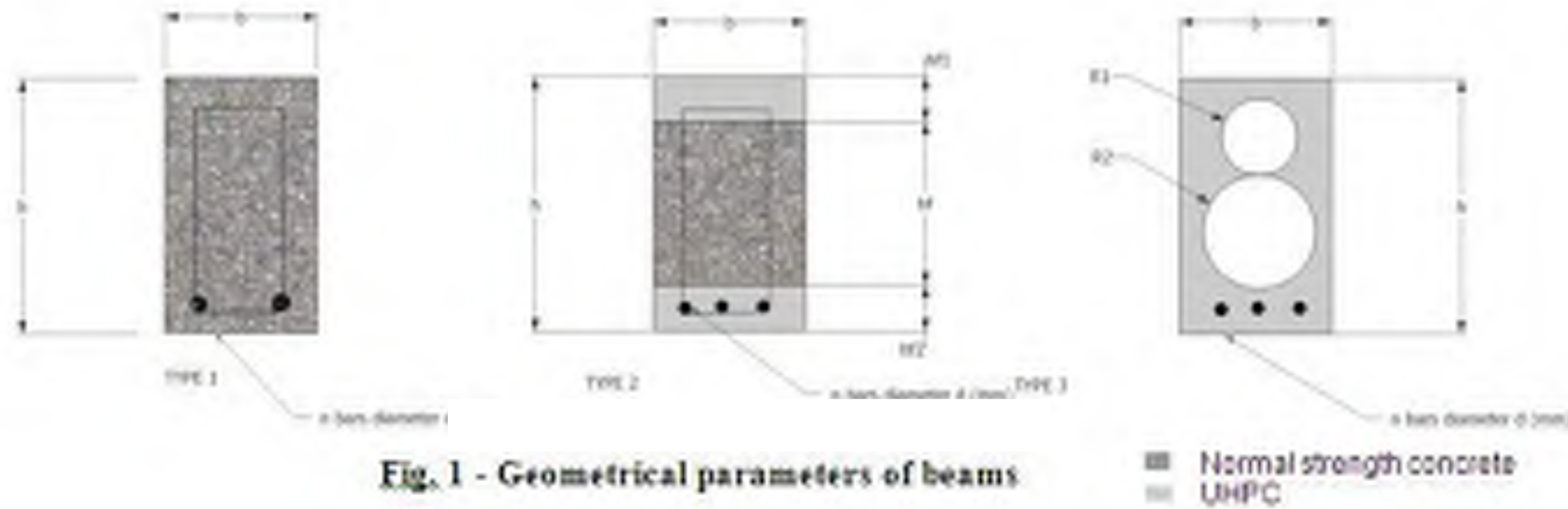

Fig. 1 - Geometrical parameters of beams

Material		Parameter	Value
Ultra-high-performance concrete	Tension	f_{ctj} [MPa]	13.4
		e_e [%]	0.02
		f_{ct} [MPa]	25.9
	Compression	e_{bc} [%]	0.3
		f_{cc} [MPa]	171
	Young's modulus	E_c [MPa]	53900
CFRP rebars	Tension	$f_{FRP\ r}$ [MPa]	1890
		e_{re} [%]	1.35
	Young's Modulus	E_r [MPa]	130000

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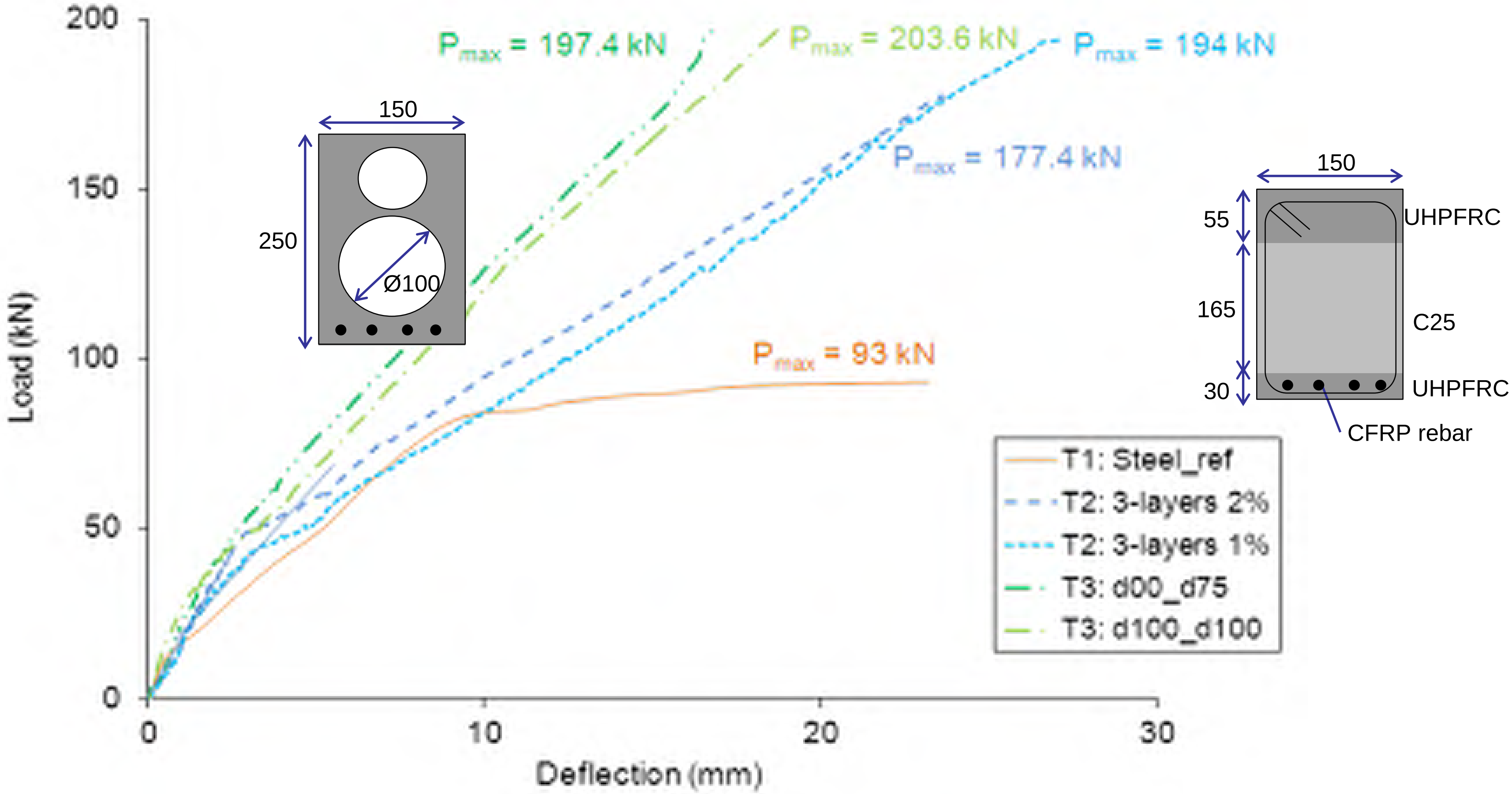
Experimental results

- Beams 2m-long, section 0.15x0.25



Conclusions

- FRP bars used start to be used in Europe
- Codes are based on North American aproach
- Specific used may be found in building and road pavement
- Original research have been done combining FRP and UHPC

MERCI de votre attention

Des questions ?

Laurent MICHEL, Emmanuel FERRIER

LMC² - Université LYON 1

ACMA
FRP Rebar Manufacturers Council

1st International Workshop on GFRP Bar for Concrete Structures (IWGFRP-1)

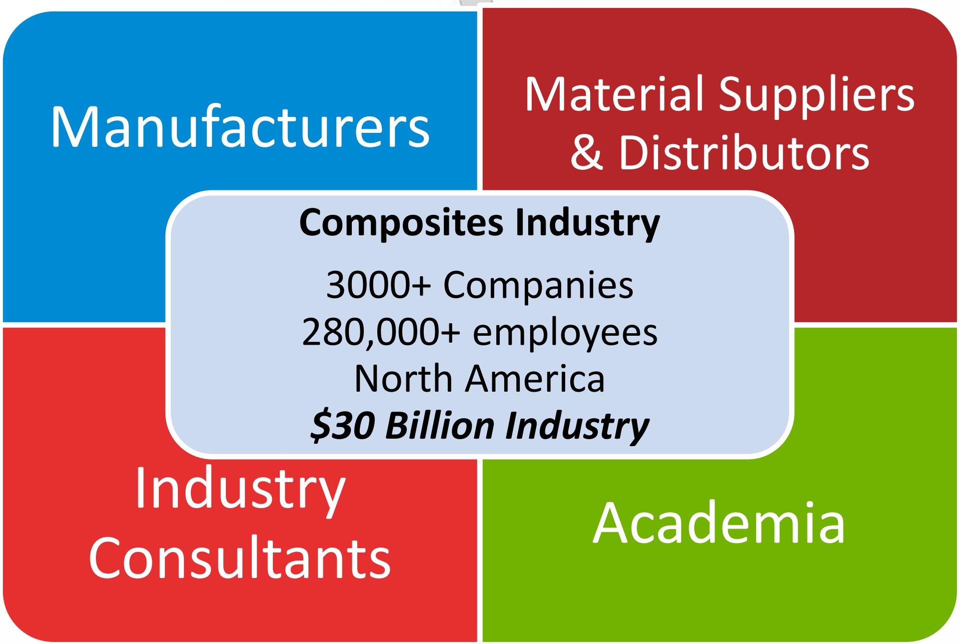
July 18, 2017

Sherbrooke, Quebec CANADA

John P. Busel, FACI

About ACMA

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



ACMA's Infrastructure Councils

- Architectural Division (Arch)
- Corrosion Control Division (CCD)
- Transportation Structures Council (TSC)
- Pultrusion Industry Council (PIC)
- FRP Rebar Manufacturers Council (FRP-RMC)
- Fiberglass Grating Manufacturers Council (FGMC)
- Utility & Communication Structures Council (UCSC)

Members represent the supply chain: material suppliers, manufacturers, distributors, consultants, and academia.

FRP Rebar Manufacturers Council

Established in 2002

Vision

- To create a forum for composites industry manufacturers that ensures FRP rebars, tendons, and grids, are accepted by designers, engineers, and specifiers in construction and civil engineering applications

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

ACMA
American Composites Manufacturers Association

FRP Rebar Council Members (23)

Manufacturers	Suppliers	Consult/Academic
Composite Rebar Technologies, Inc.	AOC, LLC	GAZ Consulting, LLC
Marshall Composite Technologies, LLC	Arkema, Inc.	Ryerson University
Owens Corning Infrastructure Solutions	Ashland, LLC	University of Miami
Pultrall, Inc.	Dixie Chemical	University of Sherbrooke
Pultron Composites	Interplastic Corp.	University of Mass – Lowell
Raw Energy Materials Corp.	Olin Blue Cube, Inc.	West Virginia University
Strongwell	Owens Corning	
TekModo Industries	Toho Tenax	
TUF-BAR, Inc.		

Council Leadership

- **Co-Chair**
  - Tom Hershberger, Composite Rebar Technologies, Inc.
- **Co-Chair**
  - Doug Gremel, Owens Corning Infrastructure Solutions
- **Treasurer**
  - Robert Gibson, Tom Hershberger, Composite Rebar Technologies, Inc.

ACMA
American Composites Manufacturers Association

What does the Council Do?

American Composites Manufacturers Association

Strategic Goals

- **Standards Development -** Develop new or modify existing standards to assist engineers in design and specification of FRP rebar.
- **Education -** Provide basic education on the use and specification of FRP rebar that is targeted at designers, engineers in consulting firms or DOTs.
- **Marketing -** Promote the FRP rebar industry to a broad audience of users in the transportation infrastructure and building industry.
- **Outreach & Advocacy -** Work together as a cohesive industry to represent the needs that will remove barriers resulting in greater acceptance by educating and partnering with end-users, federal agencies, and legislators.

ACMA
American Composites Manufacturers Association

Standards

- **ACI**
  - Committee 440
- **ASTM D30.10**
- **CSA**
- **AASHTO**

AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

Education

- **Professional**
  - FHWA Corrosion Resistant Rebar Seminars
  - International Bridge Conference – ACMA's Technical Workshops on FRP Composites
- **Student**
  - Support ACI FRP Concrete Beam Competition
- **User**
  - Maintain project database of installations
  - Website

http://www.compositesinfrastructure.org/frp-rebar/

AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

Education

Marketing

- International Bridge Conference - Exhibit

Outreach & Advocacy

- FHWA
- AASHTO SCOBS T-6
- State DOTs
- Engineers
- Capitol Hill – Washington, DC

American Composites Manufacturers Association

Council Strategic Focus

- **Standards Development**
  - Update AASHTO Design Standard
  - ACI Rebar Code
- **Education**
  - Collaboration with State DOTs
- **Marketing**
  - International Bridge Conference
- **Outreach**
  - State DOTs
  - AASHTO
  - Capitol Hill – ACMA Infrastructure Day (Feb. 2018)

American Composites Manufacturers Association

Conclusion

- Strong Council that represents the composites supply chain
- Collaboration and focus on the needs of the industry
- Dedication and successful accomplishments in standards development
- Importance on professional and student education

ACMA
American Composites Manufacturers Association

Thank you!

AMERICAN COMPOSITES MANUFACTURERS ASSOCIATION

The Role of Glass Fibers & Sizing in the Glass-Fiber (GRFP) Rebar Applications

JULY | 2017

1st International Workshop on GFRP bar for Concrete Structures (IWGFRP-1)

Amol Vaidya, Dave Hartman, Mala Nagarajan, John Amonett, Mikhail Vorobiev
Owens Corning

OWENS CORNING

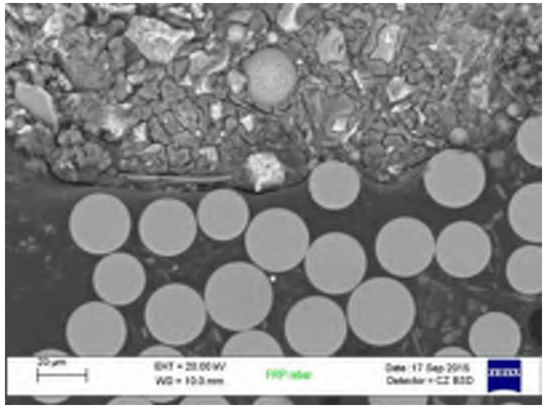
- Founded in 1938
- 2016 Sales $5.7 billion
- 17,000 Employees in 33 countries
- 3 Businesses based on fiber glass
    - Composite Solutions
    - Roofing & Asphalt
    - Insulation Solutions
- A leading producer of fiberglass in the world
- Fortune 500® company for 63 consecutive years
- Component of the Dow Jones Sustainability index

MEGATRENDS IN THE CONSTRUCTION INDUSTRY

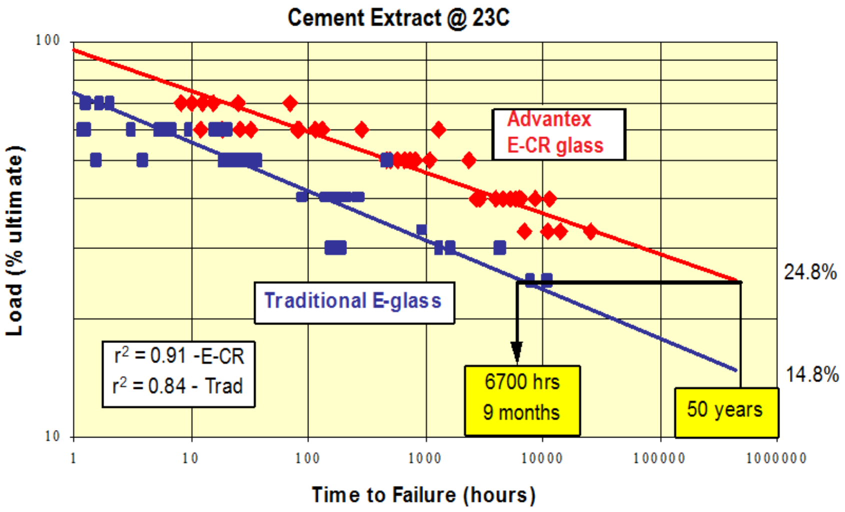
- Markets
  - Ageing Infrastructure
  - Big & Complex Projects
- Sustainability
  - Resource Scarcity
  - Resilience Challenge
- Society
  - Urbanization
  - Talent & Workforce

Source: Press Reports; “Shaping the Future of Construction: A Breakthrough in Mindset and Technology ” World Economic Forum; The Boston Consulting Group

WHY COMPOSITES?



Images courtesy of ATP Italy and/or University of Mian



- Corrosion resistance
- High strength-to-weight ratio
- Ease of application and installation
- ¼ the weight of steel
- >2.5x less expensive over 100 years of service life

Source: CFRP Prestressing by *Matthew J. Chynoweth, P.E. Michigan Department of Transportation 2015 AASHTO Subcommittee on Bridges and Structures Technical Subcommittee T-6, Composites.*
Owens Corning creep test data

OPPORTUNITIES FOCUS ON DURABILITY

6.2—Design material properties

Material properties provided by the manufacturer, such as the guaranteed tensile strength, should be considered as initial properties that do not include the effects of long-term exposure to the environment. Because long-term exposure to various types of environments can reduce the tensile strength and creep rupture and fatigue endurance of FRP bars, the material properties used in design equations should be reduced based on the type and level of environmental exposure.

Equations (6.2a) and (6.2b) give the tensile properties that should be used in all design equations. The design tensile strength should be determined by

$$f_{fu} = C_E f_{fu}^*$$

The design rupture strain should be determined as

$$\varepsilon_{fu} = C_E \varepsilon_{fu}^* \qquad (6.2b)$$

The design modulus of elasticity will be the same as the value reported by the manufacturer as the mean elastic modulus (guaranteed value) of a sample of test specimens ($E_f = E_{f,ave}$).

The environmental reduction factors given in Table 6.2 are conservative estimates, depending on the durability of each fiber type, and are based on the consensus of ACI Committee 440. Temperature effects are included in the C_E values. Fiber-reinforced polymer bars, however, should not be used in environments with a service temperature higher than the T_g of the resin used for their manufacturing. It is expected

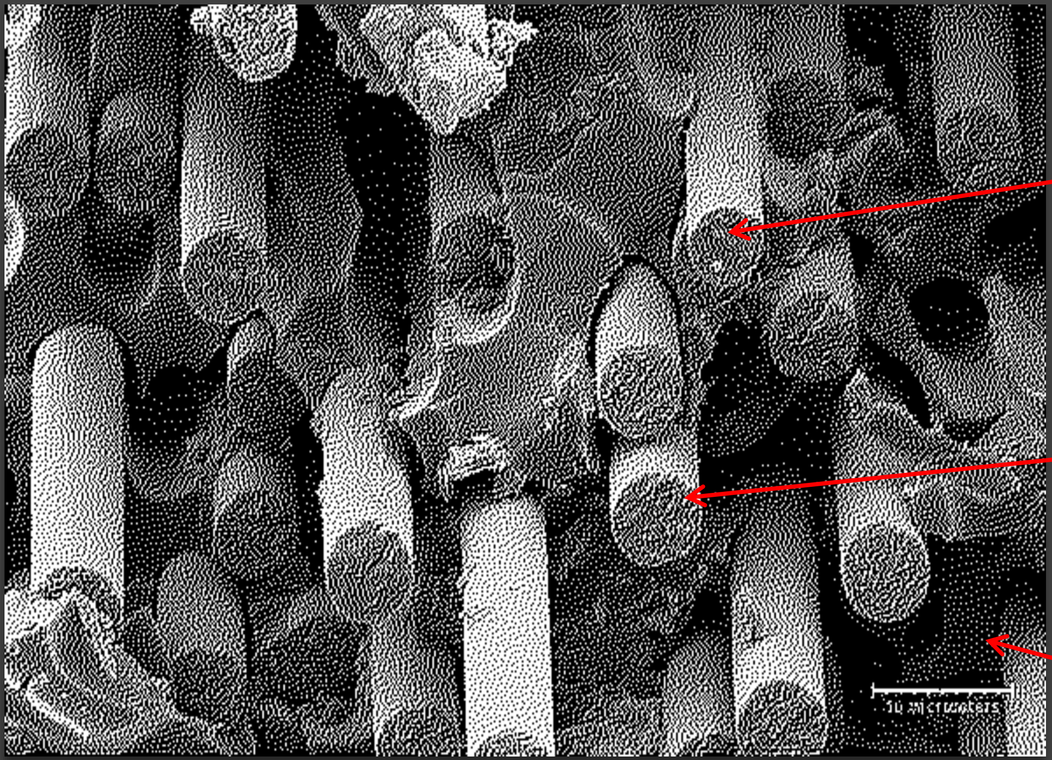
aci American Concrete Institute – Copyri

Table 6.2—Environmental reduction factor for various fibers and exposure conditions

Exposure condition	Fiber type	Environmental reduction factor C_E
Concrete not exposed to earth and weather	Carbon	1.0
	Glass	0.8
	Aramid	0.9
Concrete exposed to earth and weather	Carbon	0.9
	Glass	0.7
	Aramid	0.8

OPPORTUNITIES MATERIAL ADVANCEMENTS

OC believes that following advancements in the material space will help to improve the degradation factor for GFRP rebar to support the industry



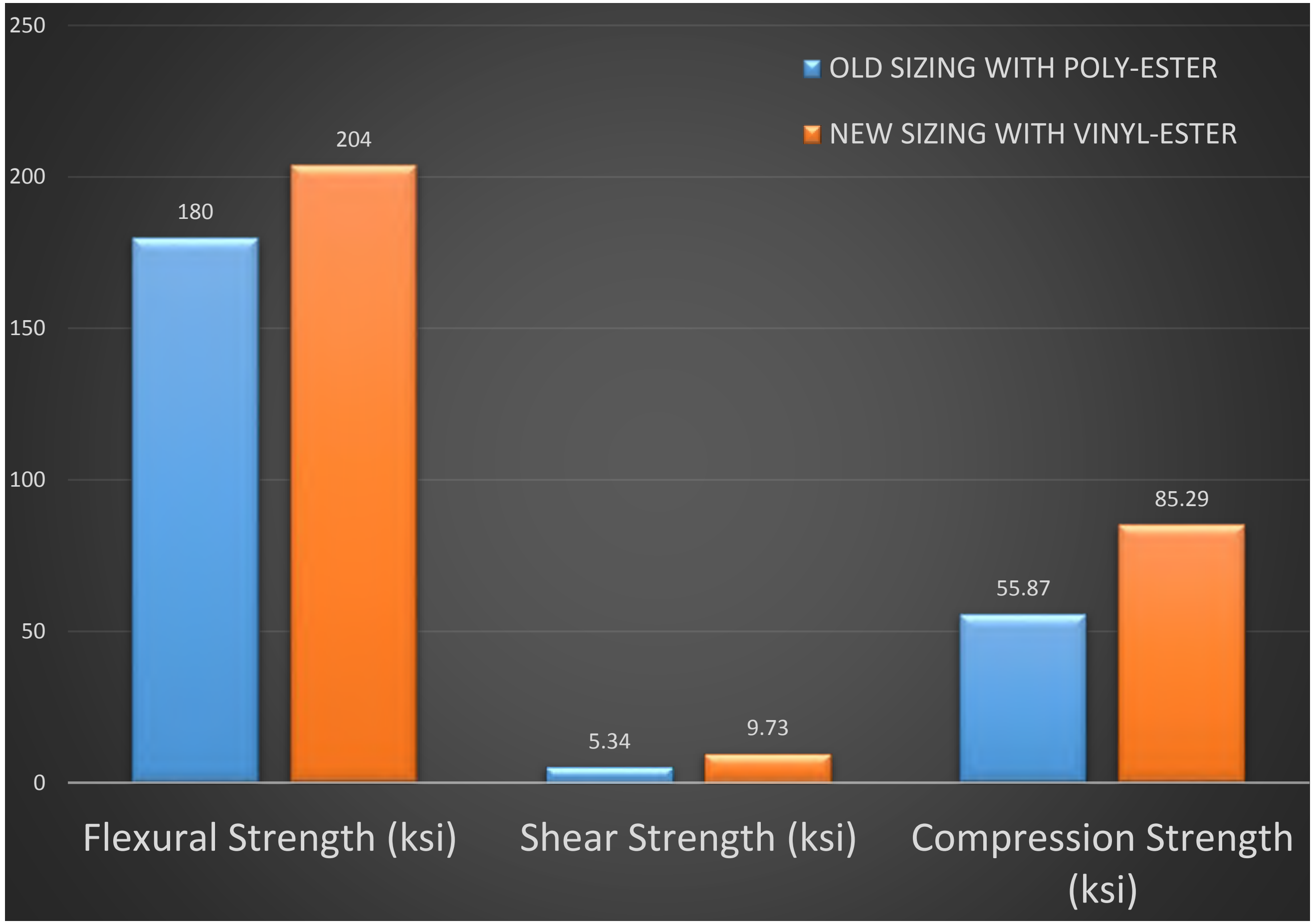
- Controlling glass science to deliver superior performance characteristics
(E.g. H-Glass / S-Glass / Advantex®)

- Advancements in Resin Chemistries (PolyEster, VinylEster)

- Understanding key interfacial science to drive the performance of composite structures
(E.g. Windstrand® / Pipestrand®/ Pulstrand®)

- Developing new characterization metholdologies to underpin future applications of composite materials (e.g. corrosion performance)

OPPORTUNITIES MATERIAL ADVANCEMENTS



Influence of Sizing and Resin:-

- **~11% Higher flexural strength** – Higher retention after applying reduction factors
- **~45% Higher shear strength** – Better interlinear & interfacial bond- reduced delamination
- **~34% Higher compressive strength-** Compressive strength is ~55% of tensile strength for GFRP rebars* (per ACI-440)

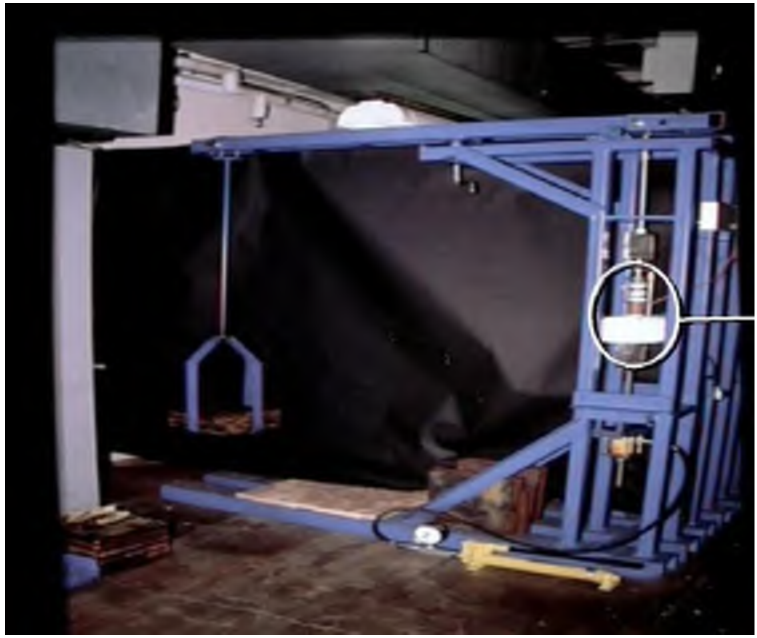
OVERALL WE BELIEVE THIS WILL TRANSLATE INTO HIGHER STRENGTH RETENTION POST DURABILITY TEST

Source: Owens Corning Internal testing and benchmark study

OPPORTUNITIES DEMONSTRATE 75-100 YEARS OF SERVICE LIFE

OBJECTIVE- Developing creep rupture data with new material systems:-

- E-CR GLASS
- NEW SIZING
- NEW RESIN



Tensile Testing: Per ASTM D7205

Item	Material	# of Samples	Report
1	3/8" pultruded bar	5	Strength, strain, modulus
2	#5 rebar-A	5	Strength, strain, modulus
3	#5 rebar-B	5	Strength, strain, modulus

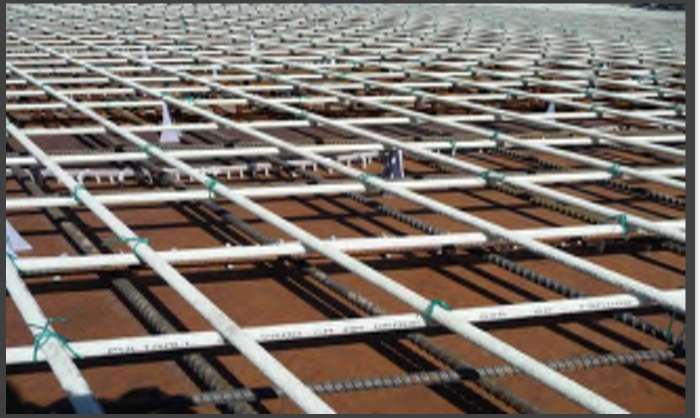
Creep rupture testing: Per ASTM D2990. Expose all samples to alkaline solution of pH 12.5 for entire duration of loading

Item	Material	# of Samples/Load Level	Exposure Temperature (C)	Loading (% of UTL measured in Item #1, 2 &3)					Report
4	3/8" pultruded bar	5	40	40	60	70	80	90	Time to failure
5	#5 rebar-A	5	40	x	x	70	x	90	Time to failure
6	#5 rebar-B	5	40	x	x	70	x	90	Time to failure
7	3/8" pultruded bar	5	50	40	60	70	80	90	Time to failure
8	#5 rebar-A	5	50	x	x	x	x	x	Time to failure
9	#5 rebar-B	5	50	x	x	x	x	x	Time to failure
4	3/8" pultruded bar	5	60	40	60	70	80	90	Time to failure
5	#5 rebar-A	5	60	x	60	x	80	x	Time to failure

Source: Owens Corning Internal testing and benchmark study

KEY TAKEAWAYS

- GFRP REBARS OFFERS DURABILE SOLUTIONS OVER STEEL REBARS

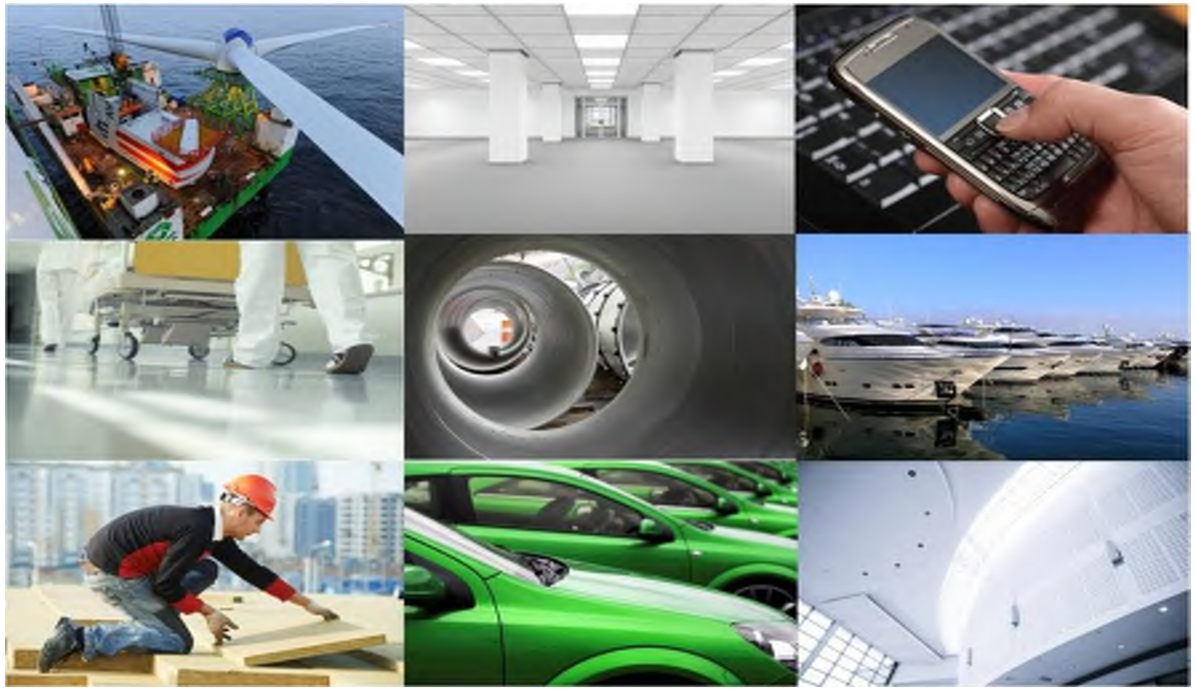


- SIGNIFICANT ADVANCEMENTS HAVE BEEN MADE IN
  - E-CR GLASS- Superior corrosion resistance over E-Glass
  - NEW SIZING- Better Interface- Higher strength & retention
  - NEW RESINS – Superior Corrosion resistance

NEED FOR INDUSTRY-WIDE ADVANCEMENT OF COMPOSITE SOLUTIONS:-

- Develop creep test data with new products
- The technology could advance faster with publicly available test data
- Industry feedback on the test protocol

Focused on meeting key Composite challenges through



Partnership

with customers

Innovation

for new solutions

Sustainability

of our products and operations

THANK YOU!

Resin QA/QC for GFRP Rebar Applications

University of Sherbrooke – GFRP Bar for Concrete Structures

Joy Bennett
Business Development Manager
jbennett@ashland.com

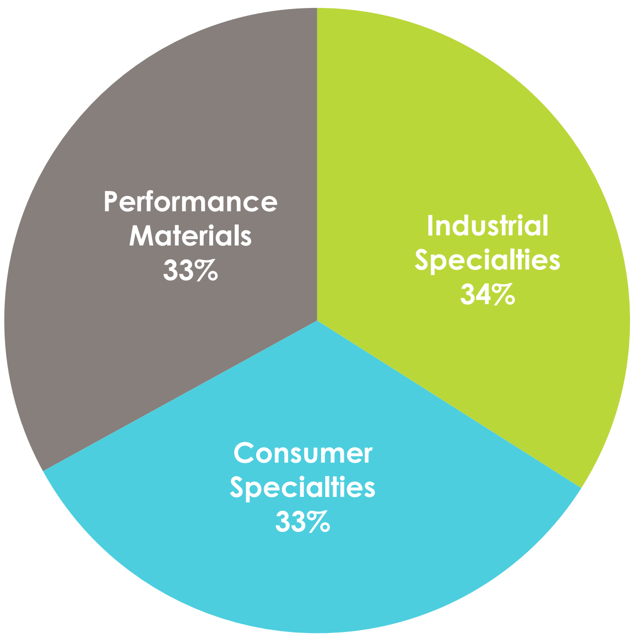
Ashland™
always solving

Agenda

- Ashland Introduction
- Resin Selection Basics
- QA/QC for Resin Supply

Ashland: leading specialty chemicals business

Ashland
in sales

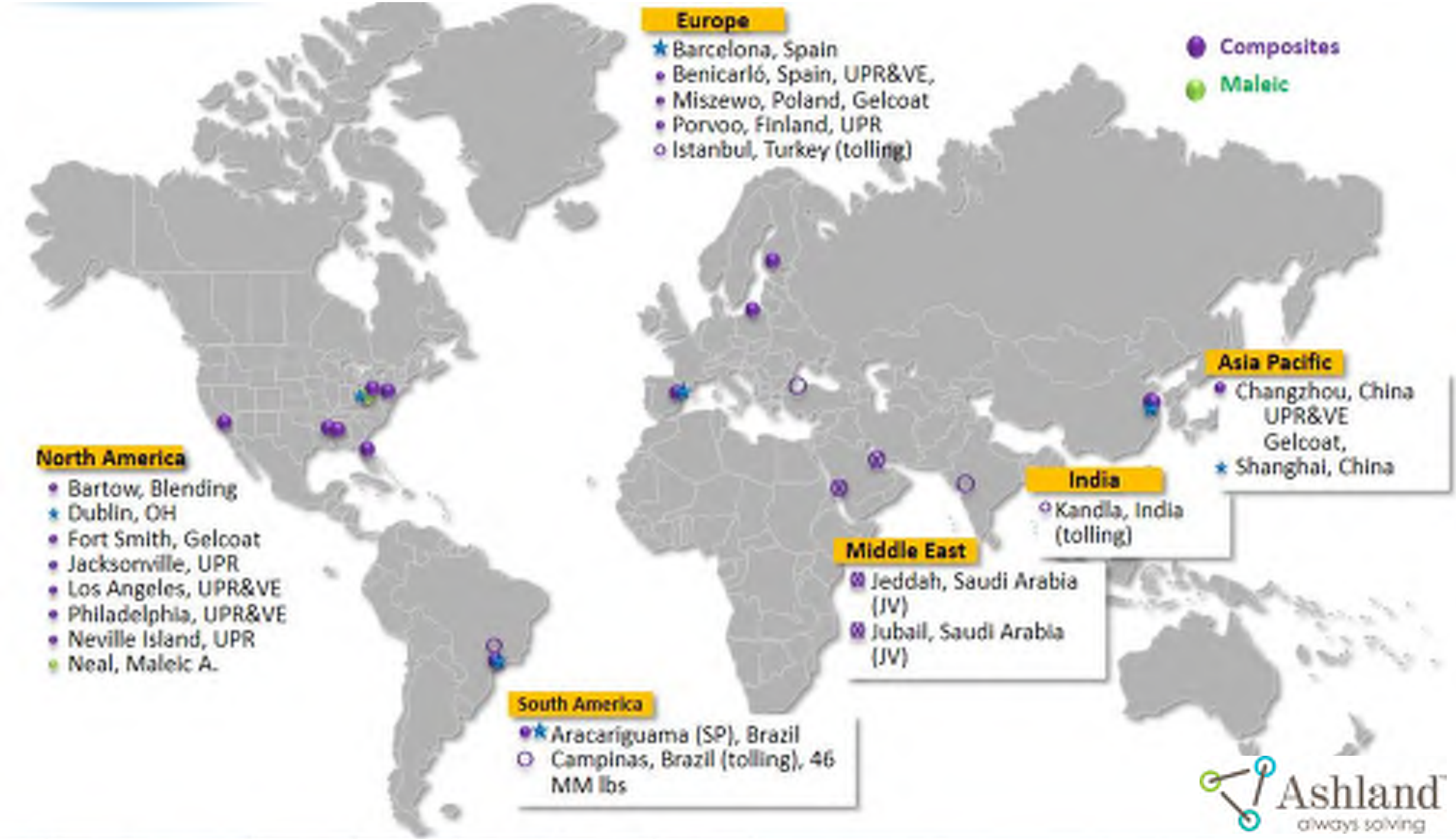


- $3.4 B in Sales
- 5,000 Employees, 60+ global facilities, sales in >100 countries
- Key end markets for our products:
  - Pharmaceuticals
  - Personal Care
  - Architectural Coatings
  - Nutrition
  - Automotive
  - Construction

Differentiated technology and deep customer relationships in attractive and growing end markets

Ashland
always solving

Ashland Performance Materials
Global Reach



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Composites Overview








Definition of FRP Composite

Resin
+
Glass or carbon fiber
+
Additives & Fillers

Benefits of FRP Composites

- Design flexibility
- Lightweight
- Corrosion resistant
- Durable
- Low Maintenance
- Longevity

$9BN market, growing at 5% per annum driven by material substitution trends

FRP – Basics components

- Thermoset Resin
  - Locks Fibers in Place Preserving Orientation
  - Determines Corrosion Resistance, Heat Resistance, Flame Retardance, and Toughness
- Glass Fibers
  - Provides Strength and Modulus
  - Orientation Maximizes Directional Properties
  - Composites are non-isotropic
    - Properties differ greatly based on glass orientation
    - Provide design flexibility and optimization
- Factors Affecting Resin Selection
  - Equipment Design
  - Thermal Conditions
  - Food Contact Requirements
  - Corrosion Environments
  - Test Data, Case History, Experience & Trust

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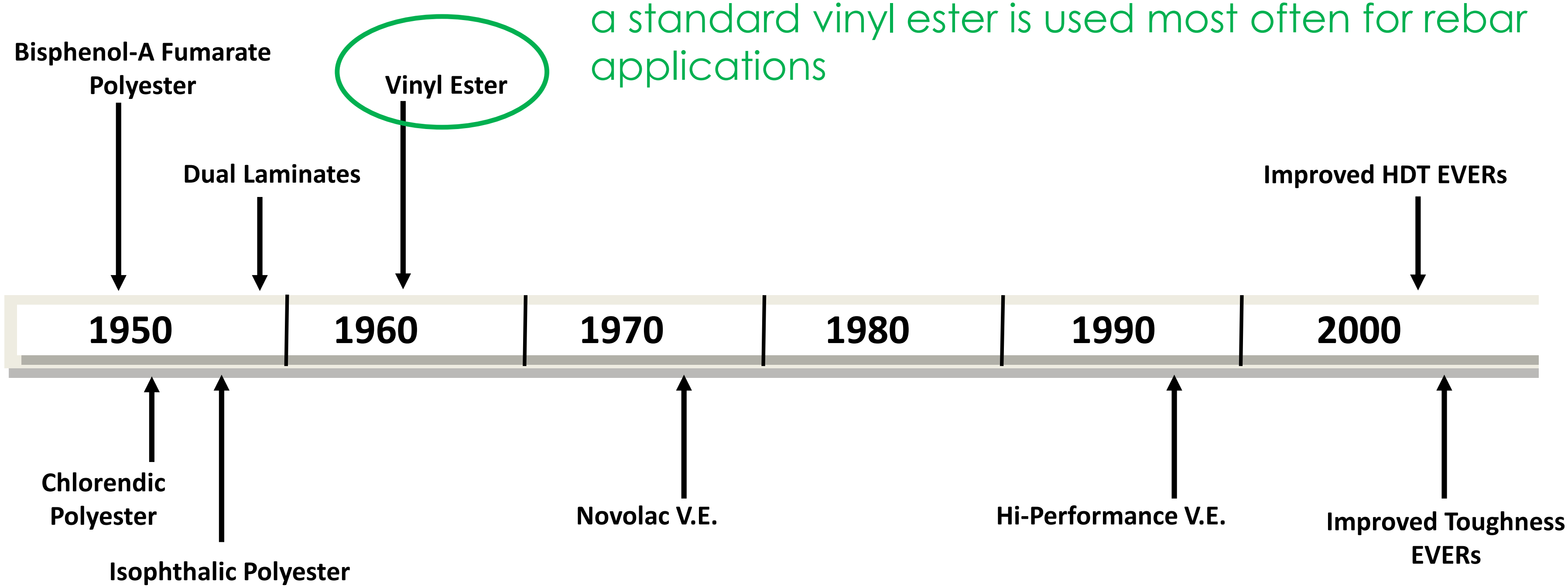
History Of Corrosion Resistant Resins Development Timeline

Due to its strong performance with acids & salts, a standard vinyl ester is used most often for rebar applications



"50 Years of Proven Performance"

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Chemical Resistance Testing

- The static resistance of a VER resin can be evaluated by ASTM C-581, but nothing replaces in situ testing.
  - Acts as a guide
  - Need combination of stress + corrosion
  - Stress & corrosion is difficult to simulate
- Documented performance through a real world case study is best practice

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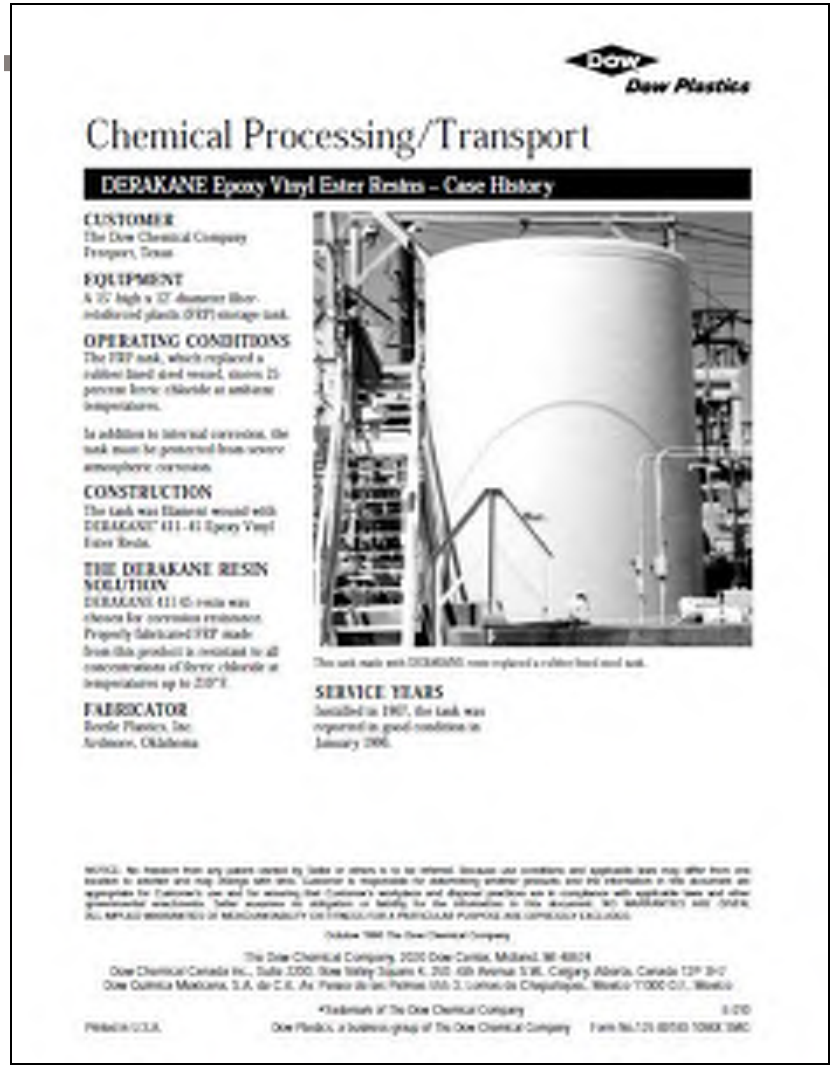
Hundreds of Case Histories – 1967 to 2017



Dow Plastics

Chemical Processing/Transport

DERAKANE Epoxy Vinyl Ester Resins – Case History

CUSTOMER
The Dow Chemical Company
Freeport, Texas

EQUIPMENT

OPERATING CONDITIONS

CONSTRUCTION

THE DERAKANE RESIN SOLUTION

FABRICATOR
Ardmore, Oklahoma

SERVICE YEARS
Installed in 1967, the tank was reported in good condition in January 1996.

DERAKANE™
EPOXY VINYL ESTER

Sodium Hypochlorite Tank from 1996

Derakane Epoxy Vinyl Ester Resins – Case History

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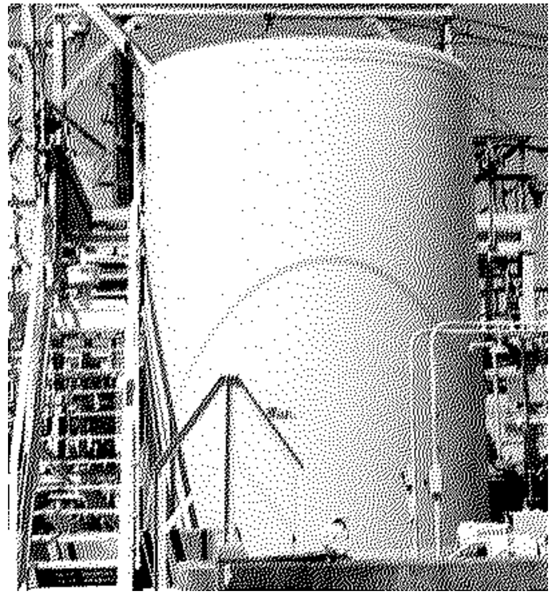
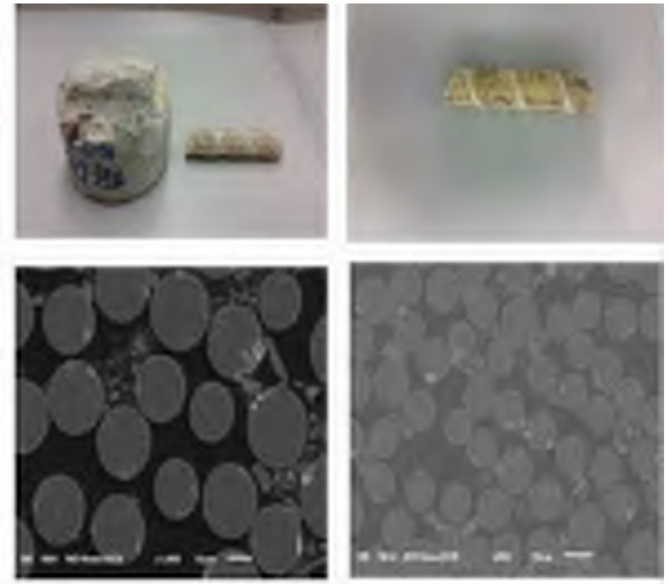
A History of Proven Performance

HCl Storage Tanks → **27 yrs**



25% Ferric Chloride → **30 yrs**



FRP Rebar → **20 yrs**

We now have multiple case studies with real use demonstrating no loss of properties for GFRP rebar

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Product Standardization

- Maintain Product Consistency Between Manufacturing Locations Within and Between Regions
  - Important for global Customers
  - Leverage Technology Development
    - Development in Dublin, OH; Porvoo, Finland and Changzhao, China
- More Than Just Review of Product QC Results
  - Includes comparison of RM specs, RM charges, processing equipment, processing conditions, control limits, spec limits, etc.
- Continuous Improvement Projects
  - Global Check Sample Program
  - ISO 9001:2000 processes
  - Delta-V control systems (Reactor Plants)
  - Test and spec requirements
  - SAP recipe management
  - Global procurement process and specifications

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QC lab capabilities

- %NV
- Viscosity
- APHA Color
- Gardner Color

- Weight Per Gallon
- % Water
- Barcol Hardness

- Gel Testing
    - RTG
    - SPIG
- Refractive Index

- Acid Value
- Epoxy Value
- Heat Stability
- Compatibility Studies

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QA/QC: Expected Results

- Global Product Standardization
  - Drives improvements in product capability.
    - Same Materials
    - Same Processes
    - **SAME PRODUCT**
    - **SAME PERFORMANCE**

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Derakane™ Resins: The Gold Standard in Fighting Corrosion for More than 50 Years and Counting





International Workshop on GFRP Bars for Concrete Structures

GFRP Experiences From the Point of View of Rebar Fabricators & Installers

AGF
Ottawa





Christian Witt B.
July 2017

Agenda

1. From GFRP Supplier to Rebar Fabricator
2. Experience as Rebar Fabricator (From Tender to Realization)
3. Advantages and Challenges of GFRP & Future Vision
4. GFRP in action – Pictures of AGF Projects
5. Acknowledgements and Thank-You Note
6. Summary & Questions



From GFRP Supplier to Rebar Fabricator

From the Eyes of a Former GFRP Supplier:

- Easier to install than steel rebar
- GFRP is the better option among premium materials
- Only High Grade should be used
- All rebar suppliers understand and think “GFRP”
- SS “is too expensive”, epoxy / galv. “doesn’t work”

To Reality of Rebar Suppliers & Fabricators:

- Not enough experience (shop drawings, placing, …)
- Lots of conditions to be aware of (storage, tie wire, etc)
- GFRP business much smaller than steel business
- Suppliers depend a lot on experts
- SS is expensive, but material is only “half” the job
- Epoxy and galvanized still very often specified

Experience as Rebar Fabricator

AGF Ottawa

From Tender:

- 3 approved products by MTO but more in the market
- Prices or qtys differ often among suppliers
- Good communication from suppliers very important
- GFRP to be priced as a lump sum
- Often combination of SS, Galv, GFRP in same job

To Realization:

- On time delivery and proper packaging & tagging
- Limited detailing information / standards
- Not all shapes are achievable
- Difficult to keep track of weights due to different "systems" (weight vs lengths)
- Close eye on budget and immediate info on extras

Advantages & Challenges of GFRP

AGF Ottawa

Advantages:

- Great products and renown companies in the market
- Less costly than Stainless Steel
- No remnants or waste since custom-tailored
- Long history of success with GFRP reinforced structures
- Truly non-corrosive, non-magnetic and non-conductive
- Clean & light (physically easier to handle)

Challenges:

- How to calculate the right installation costs
- More elaborate and costly tying ("flimsy" and $$$$ SS-ties)
- Which suppliers are "really" approved and for what products?
- How quick can changes be realized and material be shipped?
- Are GCs supportive of change proposals?
- How can we get all engineering firms and designers on board?

Future Vision from Our Perspective

AGF Ottawa

What should be developed?

- Next generation of GFRP bent bars
- Higher grade GFRP systems
- More standard drawings and standard details
- Training programs for users like AGF
- Alternative QA to minimize testing bars

What could be done better?

- Work on more standardization of bar shapes
- Gain more acceptance for GFRP (engineers, owners, …)
- Create a higher demand to help reduce the price
- Provide full range of services (estimate, tech. support, …)
- Work together to promote GFRP in the industry
- Understand the changing needs of rebar suppliers

GFRP in Action – Projects by AGF

AGF Ottawa

Highway 407 Stage 1

- AGF Rebar Inc. (DMC)
- Location: Toronto, Ontario
- Approx. Weight: 100 tons of GFRP
- Year: 2015 - 2016

GFRP in Action – Projects by AGF

AGF Ottawa

Sarnia Road Bridge

- AGF Rebar Inc. (Dietrich)
- Location: London, Ontario
- Approx. Weight: 1 Tonne of GFRP
- Year: 2011

GFRP in Action – Projects by AGF

AGF Ottawa

Rideau Canal Rehabilitation

- AGF Steel Inc. (Ottawa Division)
- Location: Ottawa, Ontario
- Approx. Qtys: 15,000 metres
- Year: 2016

GFRP in Action – Projects by AGF

Ottawa

LCBO Warehouse

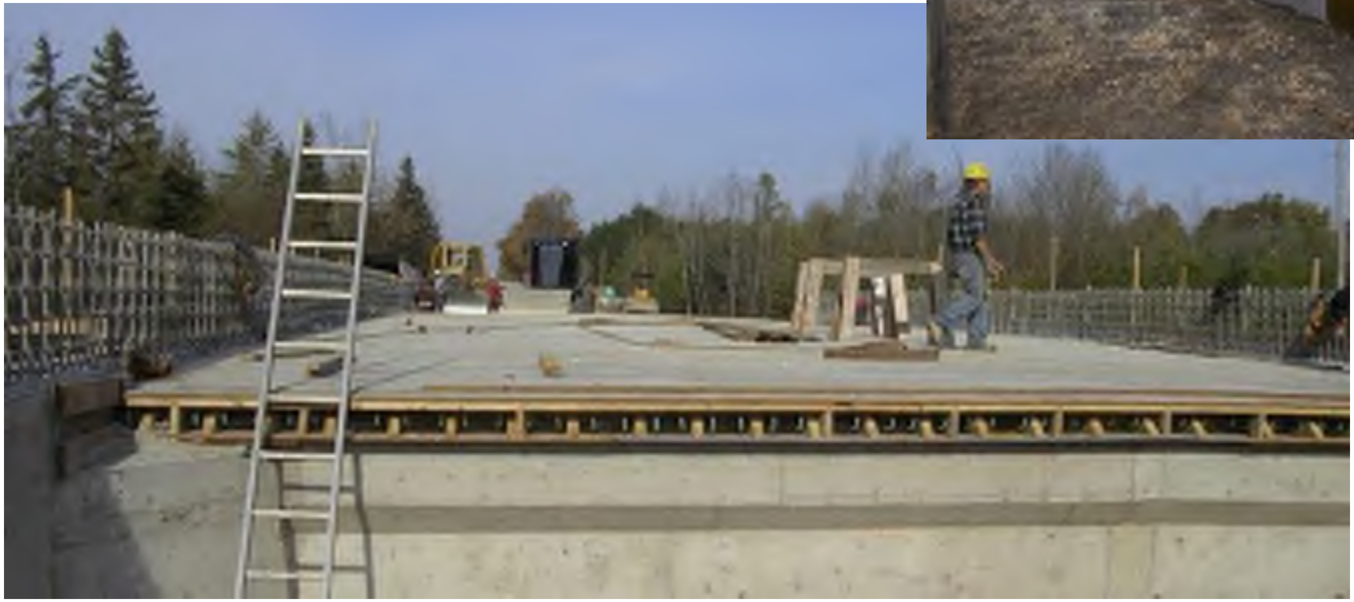
- AGF Rebar Inc. (Dietrich)
- Location: London, Ontario
- Approx. Qtys: 4,000 metres
- Year: 2015

GFRP in Action – Projects by AGF

AGF Ottawa

Rae Bridge

- AGF Rebar Inc. (Albrecht)
- Location: Kitchener, Ontario
- Approx. Qtys: 2,000 metres
- Year: 2009



GFRP in Action – Projects by AGF

OLRT – St Laurent Station, Blair Station, West Transitway, RSS Coping Walls

- AGF Steel Inc. (Ottawa Division)
- Location: Ottawa, Ontario
- Approx. Qtys: 10,000 metres
- Year: 2016 - 2017

GFRP in Action – Projects by AGF

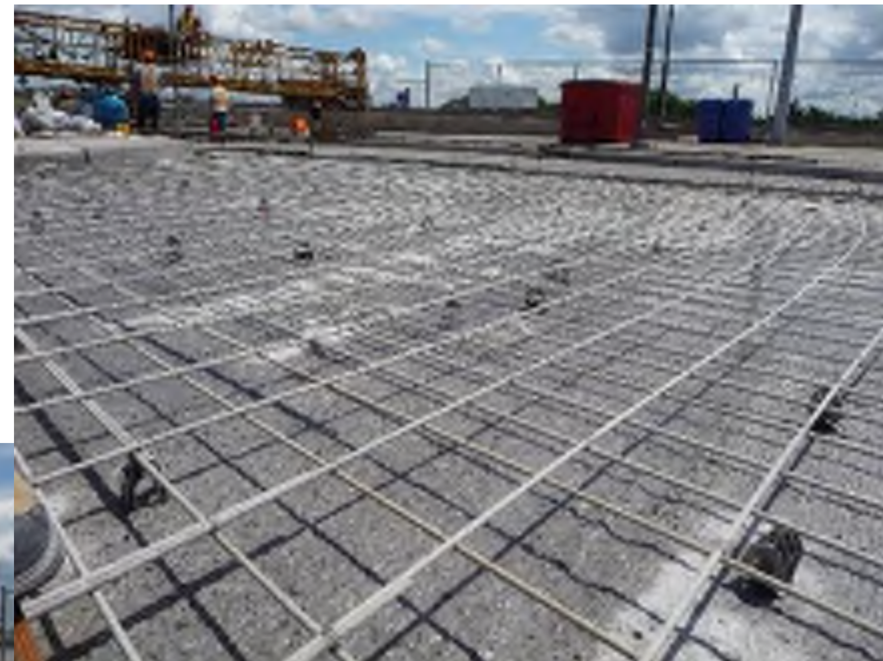
Durham Line Project

- AGF Rebar Inc. (Albrecht)
- Location: Toronto, Ontario
- Approx. Weight: 1.5 Tonnes of GFRP
- Year: 2011

GFRP in Action – Projects by AGF

East Transitway / St Laurent Station

- AGF Steel Inc. (Ottawa Division)
- Location: Ottawa, Ontario
- Approx. Qtys: 38,400 metres
- Year: 2009



GFRP in Action – Projects by AGF

AGF Ottawa

Steeles West Station

- AGF Rebar Inc. (C&T)
- Location: Toronto, Ontario
- Approx. Weight: 3.5 Tonnes of GFRP
- Year: 2011

GFRP in Action – Projects by AGF

Burnhampthorpe Bridge

- AGF Rebar Inc. (C&T)
- Location: GTA, Ontario
- Approx. Qtys: 133,700 metres
- Year: 2009

GFRP in Action – Projects by AGF

Ottawa

CAMH

- AGF Rebar Inc. (C&T)
- Location: Toronto, Ontario
- Approx. Qtys: Unknown
- Year: 2010

Acknowledgment and Thank You Note

Bernard Drouin, Gene Latour & Brad Smith

Dr. Brahim Benmokrane

Dr. Dritan Topuzi

Special acknowledgment to **Marc Fortin** (Superintendent) and **Christopher Wyatt** (Chief Detailer & PM), both at AGF Steel Inc. (Ottawa Division) for their important contribution to this presentation

And to all Sponsors of this prestigious event!

Summary of Presentation

1. GFRP is a viable and promising solution
2. GFRP is a small part of our business
3. More lobbying / acceptance required
4. 2-3 players in a relatively small market seems sufficient
5. There is still a lot to learn for us (installation, details, …)
6. Technical support from suppliers is needed
7. Some interesting projects have been realized by AGF
8. AGF has very good and positive experiences
9. Only a few challenges to be addressed by the industry

Questions

PULTRALL

STRONG and FLEXIBLE

Mission

With Passion :

- Develop
- Manufacture
- Bring to Market

Specific composite profiles using the pultrusion process.

Vision or how?

- Innovatively
- Competitively
- Profitably

Work hard at ensuring our customer's, our staff and our supplier's success, all in an environment friendly way.

Values

- Creativity
- Commitment
- Integrity

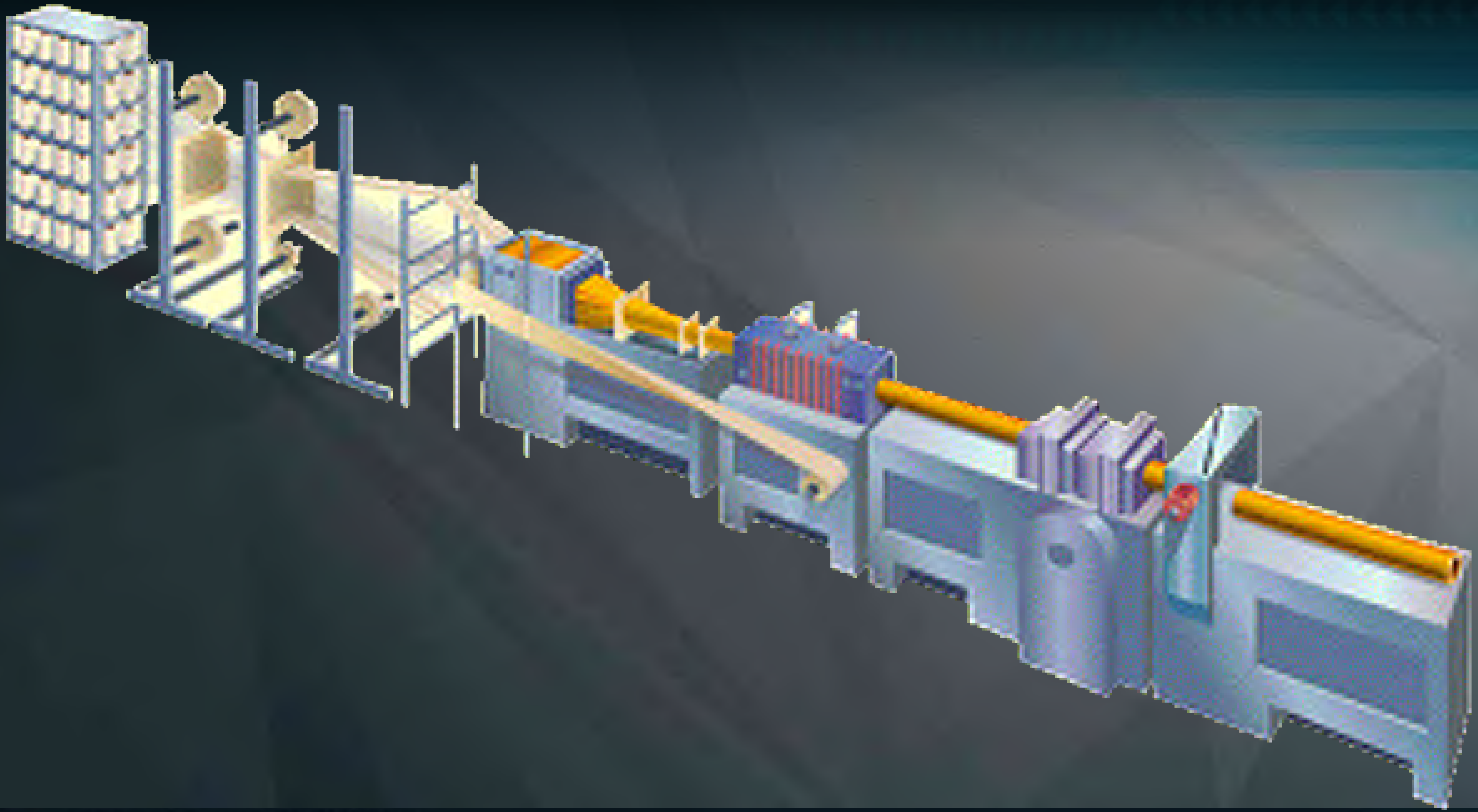
The quality system

- ISO9002-1994 since 1994
- ISO9001-2000 since 2003
- TS16949 since 2008
- ISO14001 since 2016

Certification

V-ROD is CSA-S807-10 certified (soon ASTM D30.10)

The process : Pultrusion



FRP Rebar Composition

Fibres (Reinforcements)
Resins (Polymers)
Fillers
Additives

Fibres – Mechanical strength
Resins – Chemical resistance

Manufacturing of V-Rod bars

↓

Inspection of raw material

↓

Resin mix

↓

Machine setup

↓

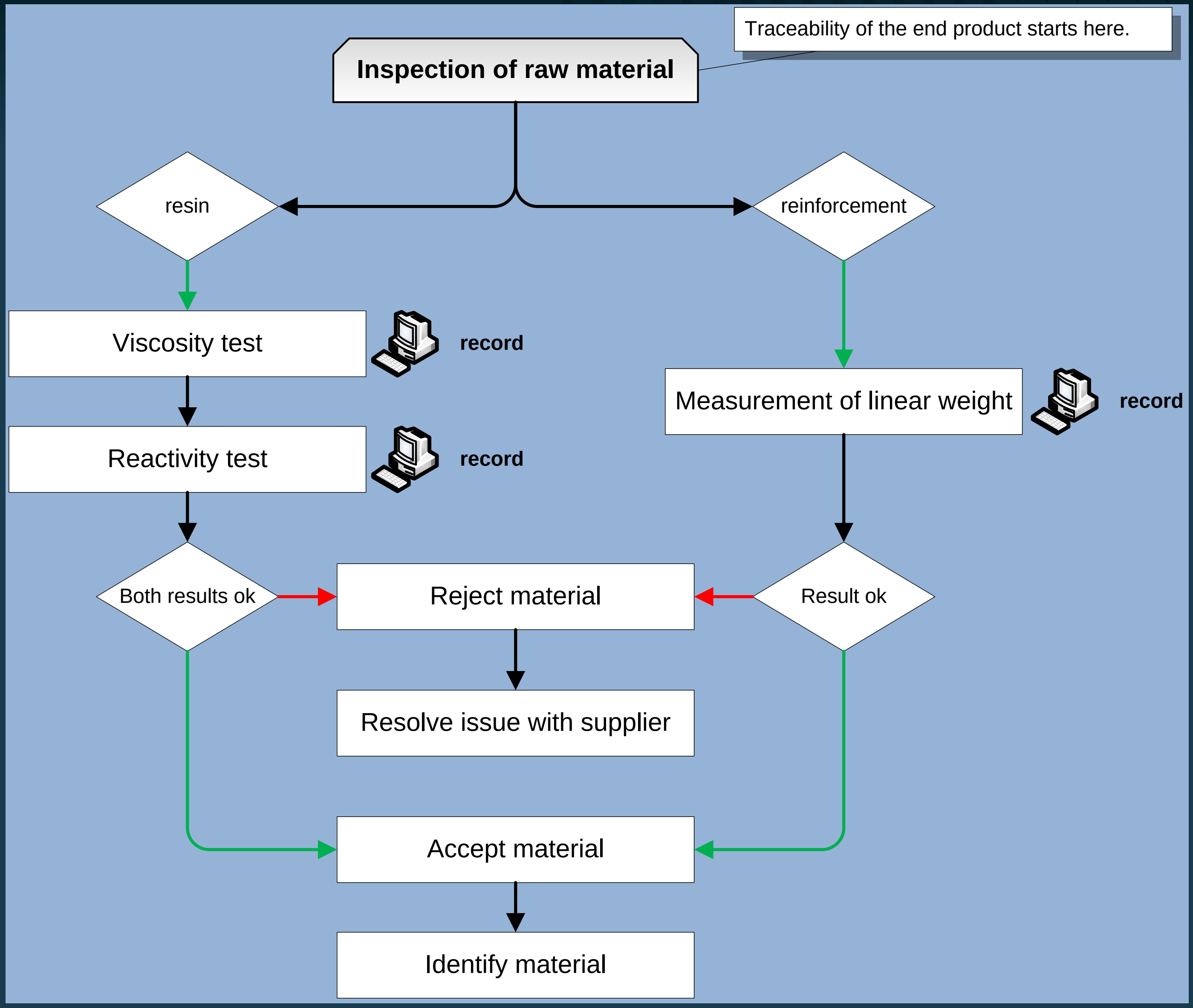
Start of production

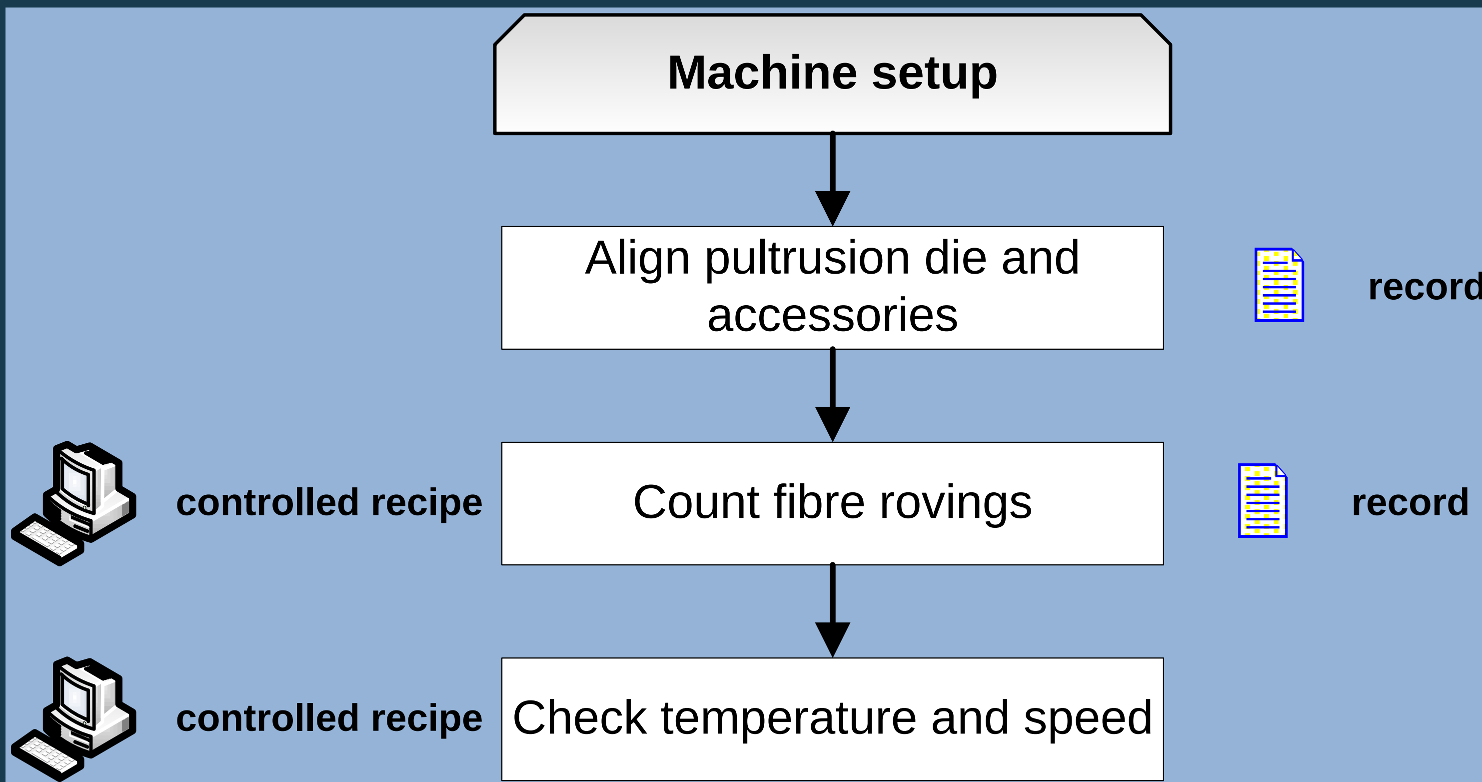
↓

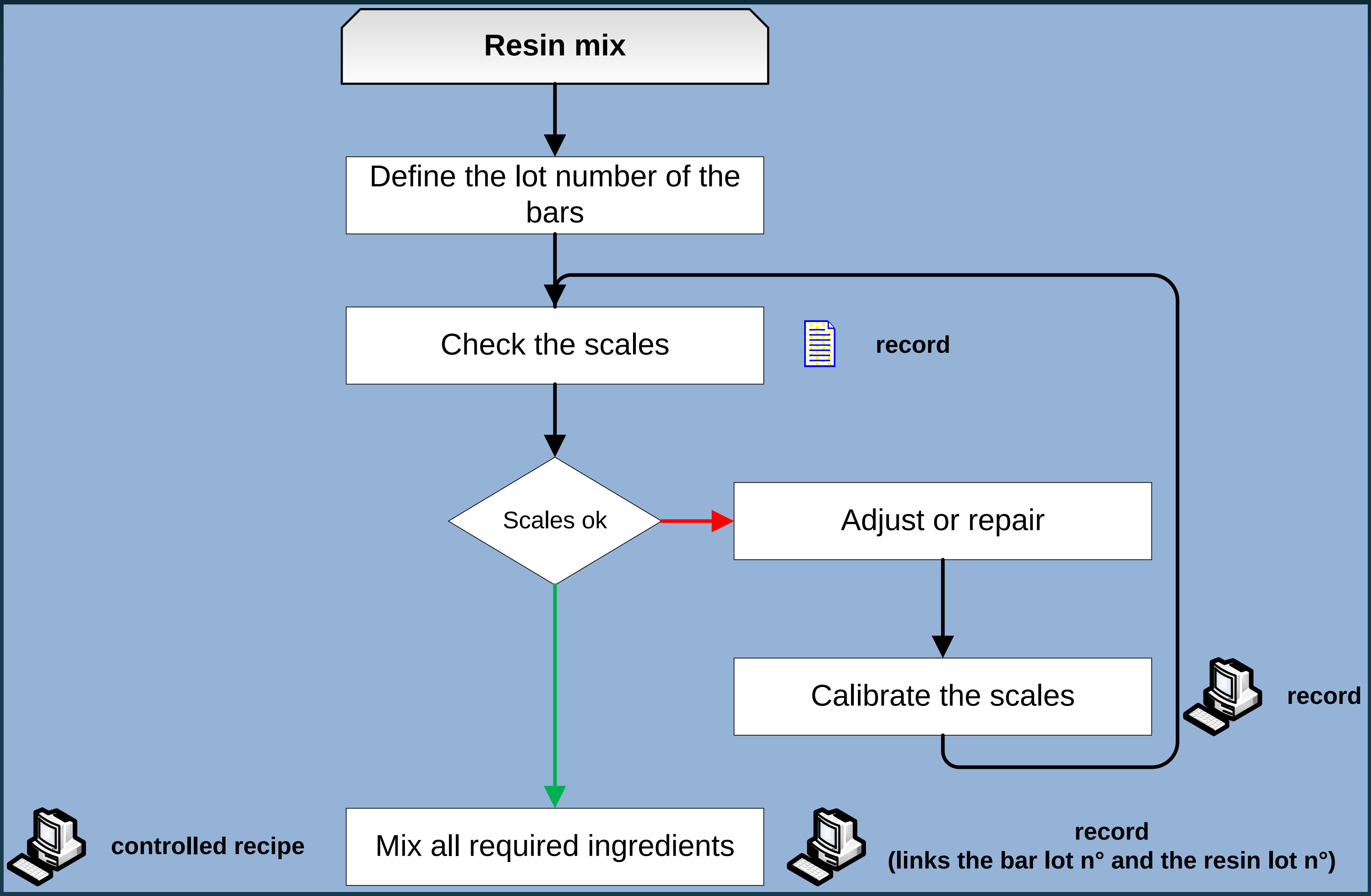
Production

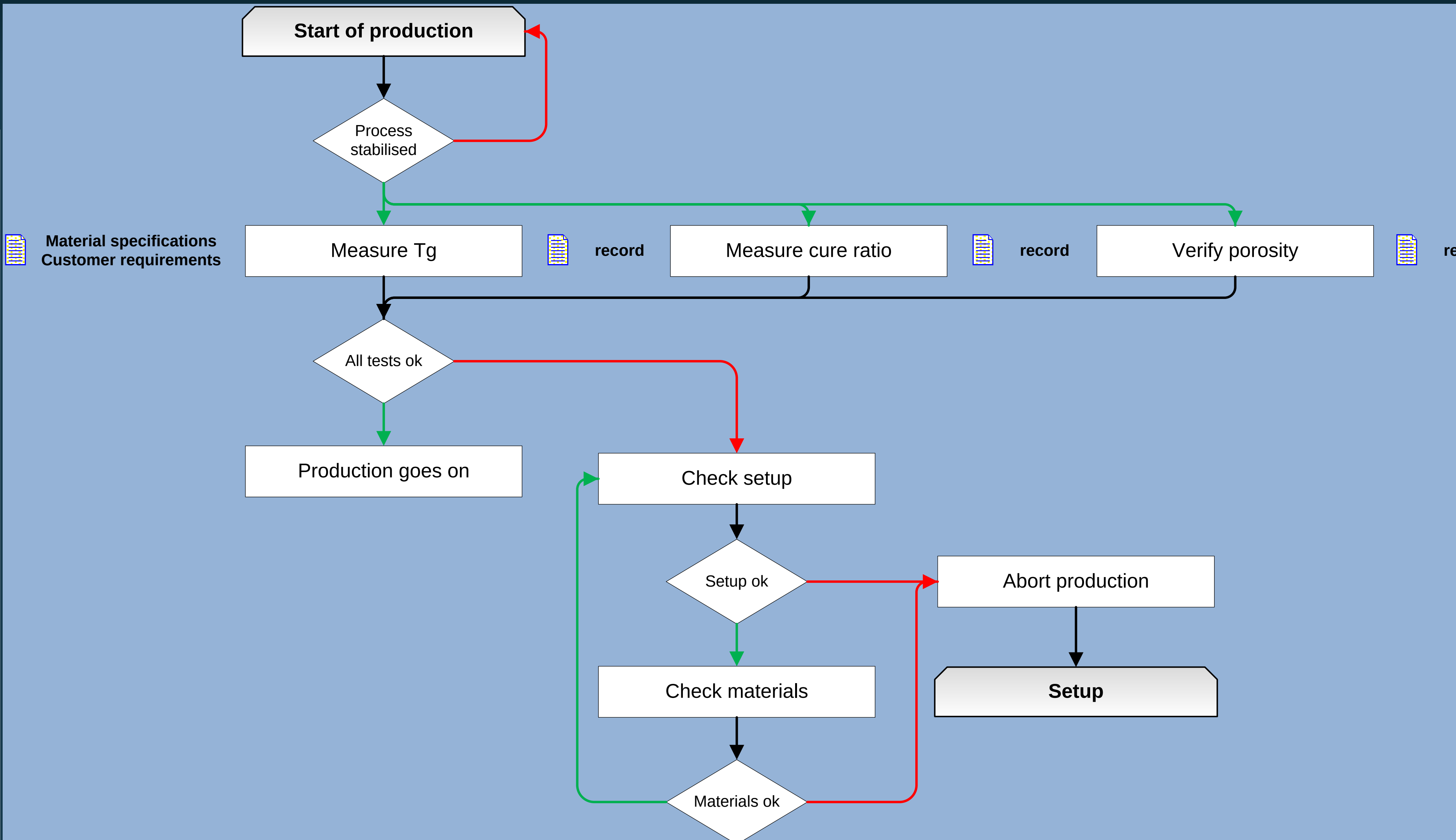
↓

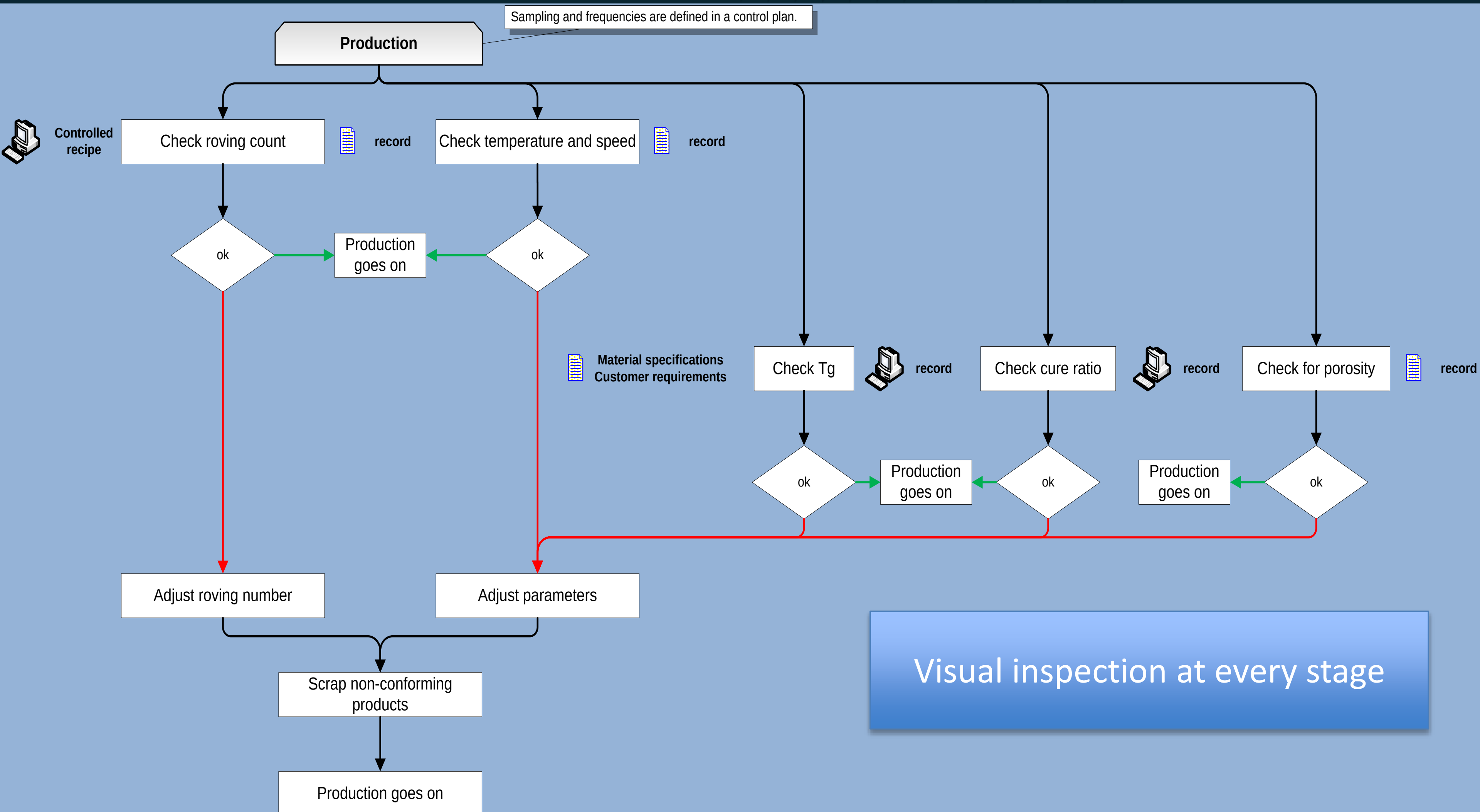
Final inspection


Traceability of the end product starts here.
Inspection of raw material
resin
reinforcement
Viscosity test
record
Reactivity test
record
Measurement of linear weight
record
Both results ok
Reject material
Result ok
Resolve issue with supplier
Accept material
Identify material

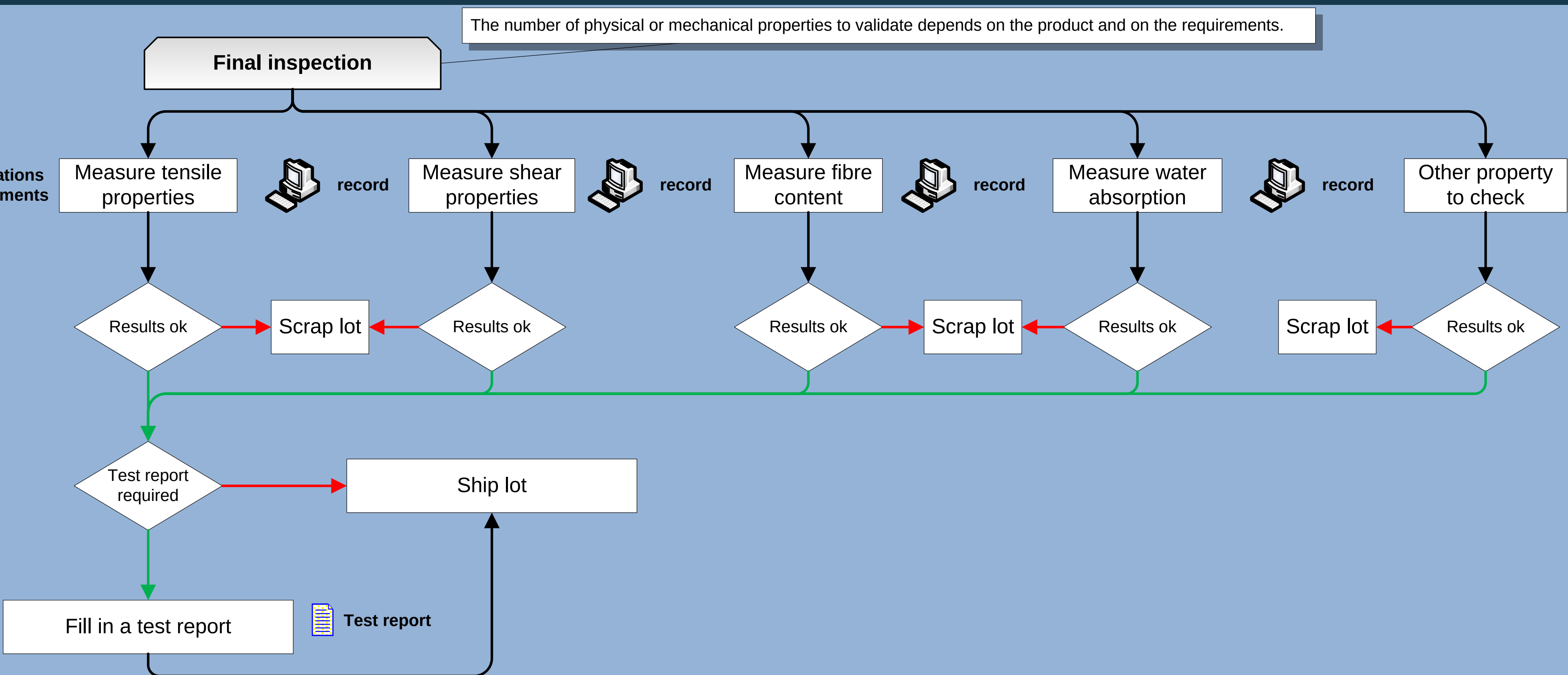

Machine setup
Align pultrusion die and accessories
record
controlled recipe
Count fibre rovings
record
controlled recipe
Check temperature and speed


Resin mix
Define the lot number of the bars
Check the scales
record
Scales ok
Adjust or repair
Calibrate the scales
record
controlled recipe
Mix all required ingredients
record
(links the bar lot n° and the resin lot n°)


Start of production
Process stabilised
Material specifications
Customer requirements
Measure Tg
record
Measure cure ratio
record
Verify porosity
All tests ok
Production goes on
Check setup
Setup ok
Abort production
Check materials
Setup
Materials ok



Visual inspection at every stage


The number of physical or mechanical properties to validate depends on the product and on the requirements.
Final inspection
ations
ments
Measure tensile properties
record
Measure shear properties
record
Measure fibre content
record
Measure water absorption
record
Other property to check
Results ok
Scrap lot
Results ok
Results ok
Scrap lot
Results ok
Scrap lot
Results ok
Test report required
Ship lot
Fill in a test report
Test report

Materials
bar #5 grade III
type of resin: vinylester, lot number 1702193P
type of fibre: glass

Production
manufacturing process: pultrusion
lot number: 1711002-5-60 with a total of m, started on and ended on .
a production lot is defined by a change of the lot number of the resin and/or a change of machine

Product characterisation
Cross sectional area:
test method CSA S806 Annex A

sample	mm²
1	226
2	225
3	227
4	224
5	224
average	225
std deviation	1,1
required minimum:	*189,1*
required maximum:	*238,8*

Longitudinal tensile properties:
test method CSA S806 Annex C

sample	load at break (kN)	strength (MPa)	modulus (MPa)	elongation (m/m)
1	279	1411,2	61670	2,3%
2	284	1435,3	61876	2,3%
3	293	1478,3	61526	2,4%
4	297	1499,2	62190	2,4%
5	282	1422,2	61624	2,3%
average	286,9	1449,2	61777	2,3%
std deviation	6,7	33,8	236	0,1%
required minima:	*200*		*60000*	*1,2%*

Transverse shear strength
test method ACI 440.3R test method B4

sample	load at break (kN)	strength (MPa)
1	96,6	244,0
2	99,9	252,4
3	97,9	247,3
4	97,1	245,4
5	97,0	245,2
average	97,7	246,8
std deviation	1,2	2,9
	required minimum:	*180*

Fibre content (per weight):
test method ASTM D2584 (temp 650°C, sand coating discarded from result)

sample	%
1	83,4%
2	83,8%
3	83,9%
4	83,4%
5	83,5%
average	83,6%
std deviation	0,2%
required minimum:	*70%*

Void content:
test method ASTM D5117 (15 min wicking with basic fuchsin)

sample	wicking
1	ok
2	ok
3	ok
4	ok
5	ok

Water absorption:
test method ASTM D570 (50°C)

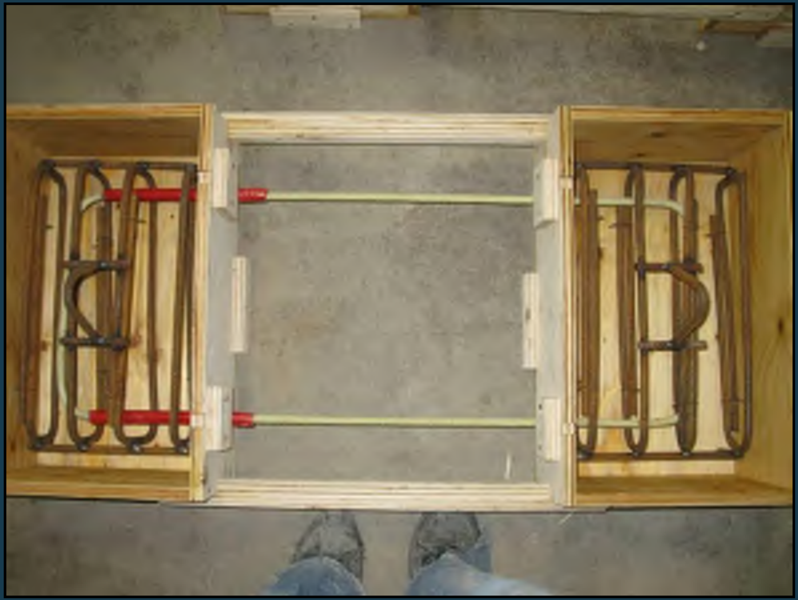
sample	weight variation 24h	weight variation long term
1	0,06%	0,12%
2	0,06%	0,10%
3	0,07%	0,11%
4	0,07%	0,11%
5	0,07%	0,12%
average	0,07%	0,11%
std deviation	0,00%	0,01%
required minima:	*0,25%*	*0,45%*

Cure ratio and glass transition temperature:
test method ASTM D3418 and CSA S807 Annex A (half-height @ 20°C/min)

sample	cure ratio (%)	Tg (°C)
1	99,90	138
2	99,61	134
3	99,68	129
4	99,73	131
5	99,51	127
average	99,69	131,7
std deviation	0,13	3,7
required minima:	*95*	*100*

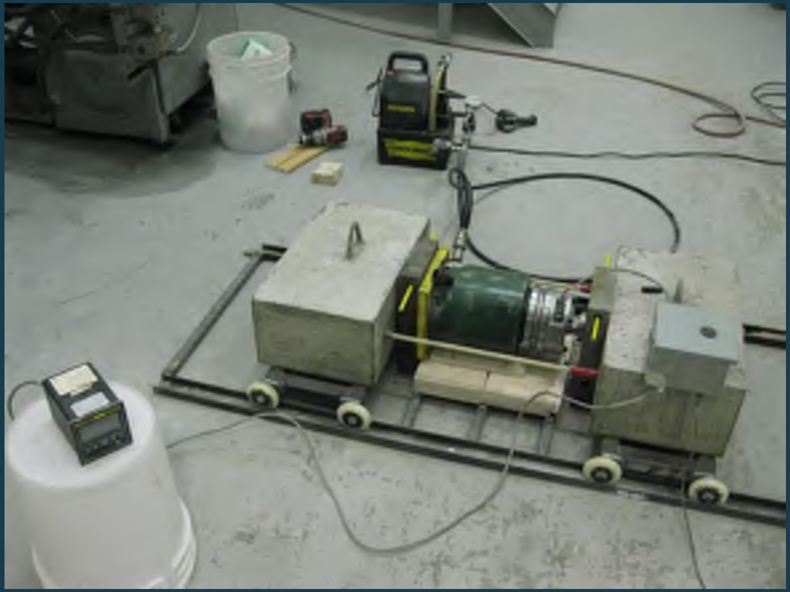
Bent bars

B5 testing method



B5 method

Testing fixtures



B5 method from ACI

Failure on one side

New method

- The use of quick plg type concrete
- Same as B5 with used confinement reinforcement around the bend

New Method

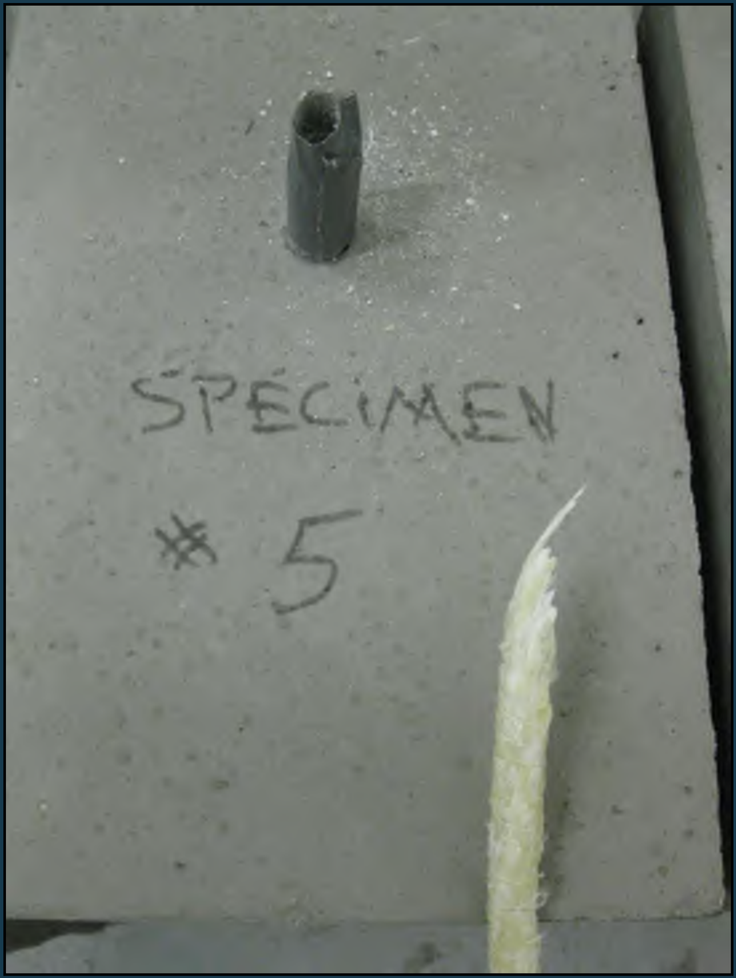
- Samples ready for testing

- **Testing on UTM**

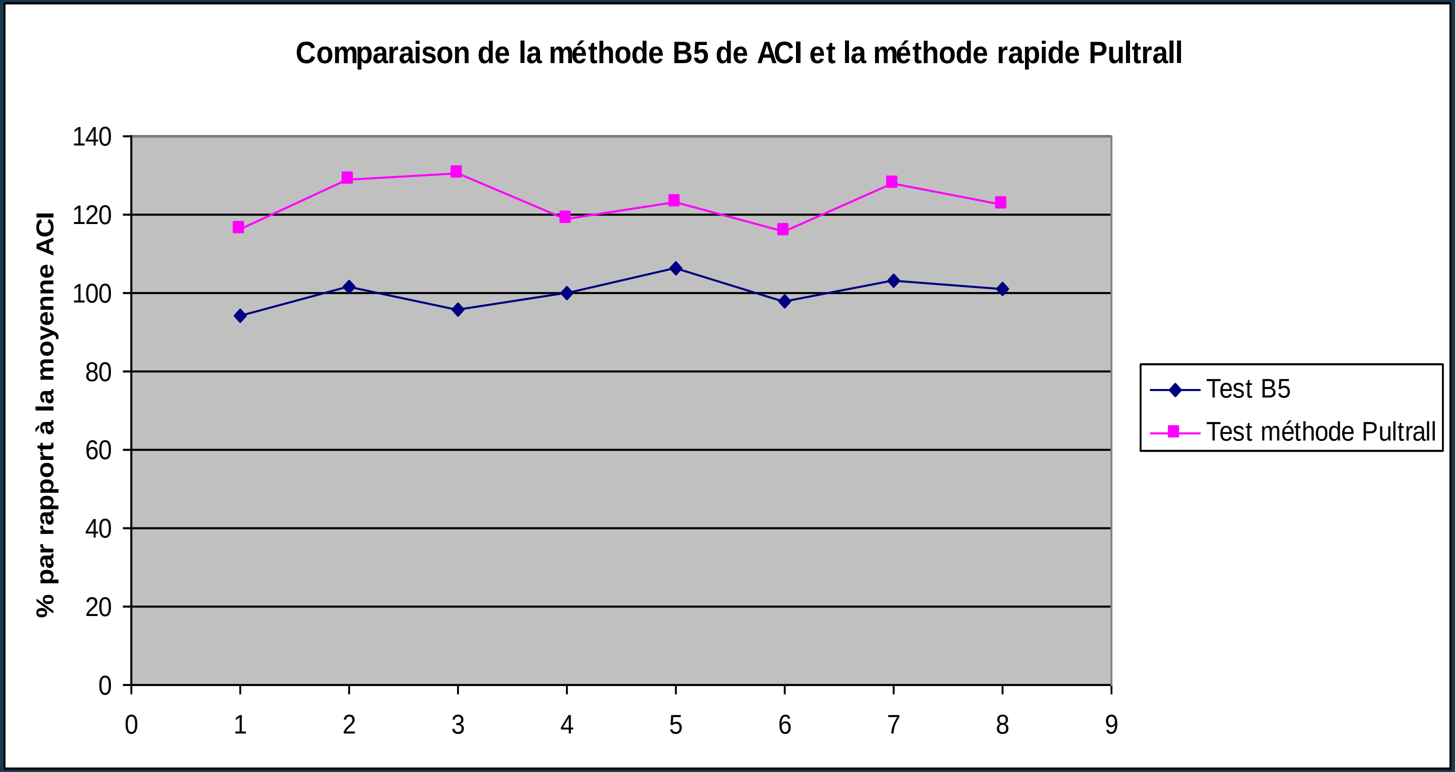
New method

B5 method failure mode

New method failure mode



Comparing the results



Conclusion

- The quality system should be independently audited annually
- The product range should comply with CSA-S807 and ASTM D30.10
- Every manufacturing step should be subjected to inspections
- We need to improve testing methods to make them quicker and reproducible:
    - Ex : Bent bars, pull out and shear

PULTRALL

STRONG and FLEXIBLE

Thank you

GFRP Bar Testing for Enhanced Quality Control

5522 – 36 Street
Edmonton, Alberta
T6B 3P3
T:780 – 448 – 9338

info@tuf-bar.com
1–888–997–3227

GFRP Bar Testing & Quality Control

- **Objective:**

To ensure the **consistent delivery** of a **high quality** product with to the industry.

TUF-BAR

GFRP REBAR Manufacturing and QC

- **Industry Standards**
- **Raw Materials**
- **Manufacturing**
- **Finished Goods**

TUF-BAR

INDUSTRY STANDARDS

- **CSA-S807-10:** Specification for Fibre-Reinforced Polymer
- **ACI-440.6-08:** Specification for Carbon and Glass Fiber-Reinforced Polymer Bar Materials for Concrete Reinforcement
- **ASTM GFRP Material Specification:** COMING SOON!
- **FRP-RMC:** FRP Rebar Manufactures Council

TUF-BAR

RAW MATERIALS

- **Code requirements**
  - VinylEster Resins
  - E-glass or ECR glass

- **Plant Quality Management program**
  - Inspection of incoming shipment
  - Vendor Certificate of Analysis
  - Verification of shelf life
  - Verification of resin properties

GFRP REBAR MANUFACTURING

- **Plant Quality Management program**
  - ISO certification or equivalent program
  - Definition of the production lot
  - Record of all lot controlled materials used
  - Record of all manufacturing parameters

TUF-BAR

PRODUCT QUALIFICATION

- **Standards list the acceptable values for:**
  - Mechanical Properties
  - Physical Properties
  - Durability Properties

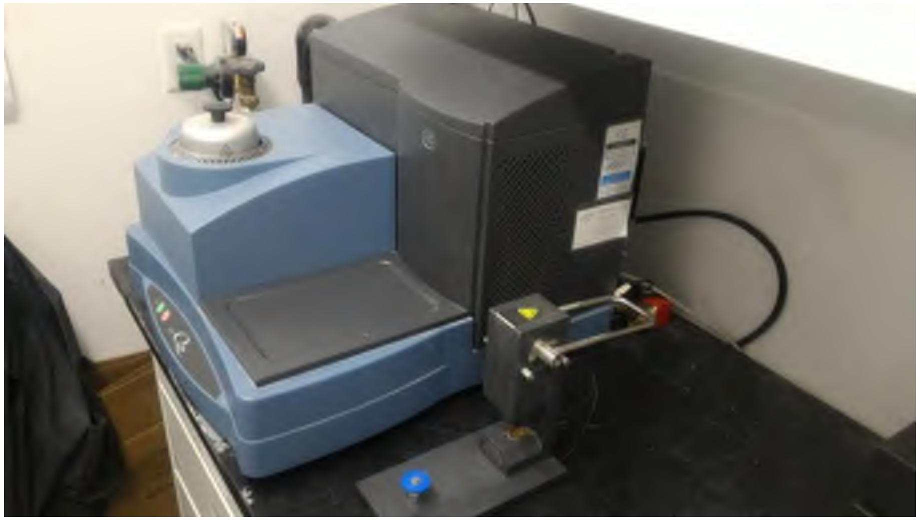
- **Samples required from 3 production lots**

University of Sherbrooke

TUF-BAR

PRODUCTION QC

- **Standards list the acceptable values for:**
  - Cross Section
  - Tensile Strength
  - Modulus of Elasticity
  - Ultimate Elongation
  - Transverse Shear
  - Fibre content
  - Void content / Die penetrant
  - Water absorption
  - Cure ratio
  - Glass Transition Temperature

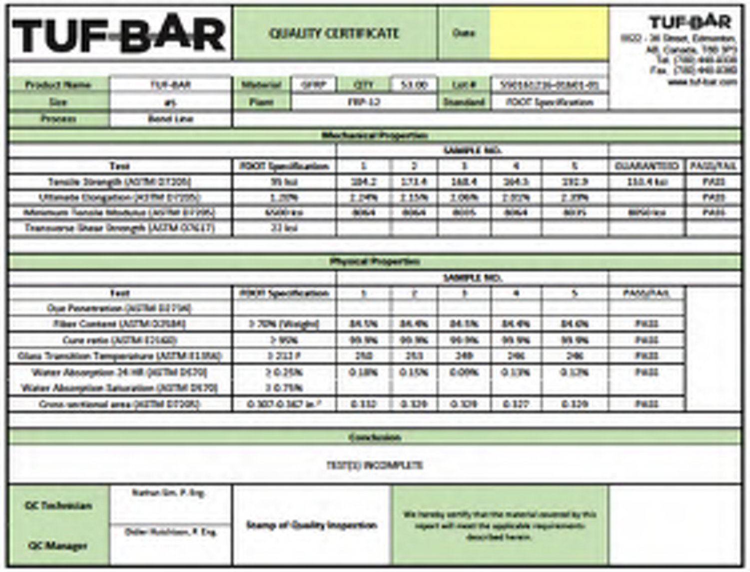


TUF-BAR

PRODUCTION QC

- **Tests conducted for each production Lot**
  - Random sampling (5)

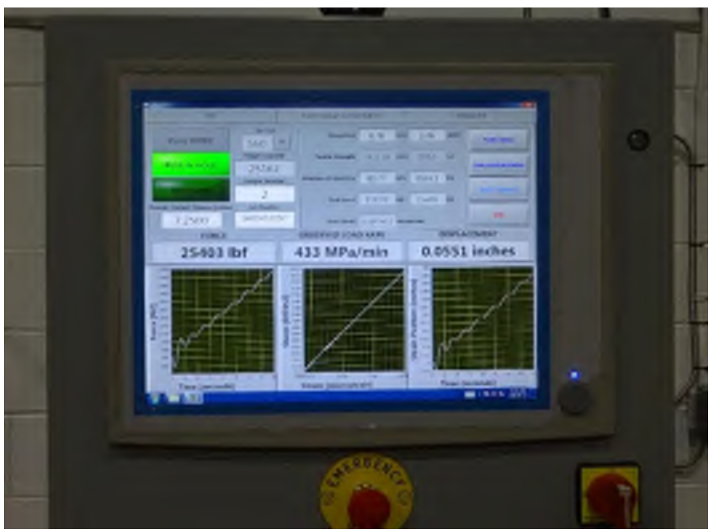
- **Records keeping:**
  - All QC data is kept indefinitely (Lot controlled)
  - QC samples are kept for min. 5 years



TUF-BAR	QUALITY CERTIFICATE			Date			TUF-BAR	
Product Name	TUF-BAR	Material	GFRP	QTY	[illegible]	Lot #	[illegible]	
Size	#5	Plant	FRP-12			Standard	FDOT Specification	
Process	Bend Line							
Mechanical Properties								
		SAMPLE NO.						
Test	FDOT Specification	1	2	3	4	5	GUARANTEED	PASS/FAIL
Tensile Strength (ASTM D7205)	[illegible] ksi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ksi	PASS
Ultimate Elongation (ASTM D7205)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]		PASS
Minimum Tensile Modulus (ASTM D7205)	6500 ksi	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible] ksi	PASS
Transverse Shear Strength (ASTM D7617)	22 ksi							
Physical Properties								
		SAMPLE NO.						
Test	FDOT Specification	1	2	3	4	5	PASS/FAIL	
Dye Penetration (ASTM D5117)								
Fiber Content (ASTM D2584)	≥ 70% (Weight)	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PASS	
Cure ratio (ASTM E2160)	≥ 95%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PASS	
Glass Transition Temperature (ASTM E1356)	≥ 212 F	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PASS	
Water Absorption 24 HR (ASTM D570) / Water Absorption Saturation (ASTM D570)	≤ 0.25% / ≤ 0.75%	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PASS	
Cross-sectional area (ASTM D7205)	[illegible] in.²	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	PASS	
Conclusion								
TEST(S) INCOMPLETE								
QC Technician	[illegible], P. Eng.	Stamp of Quality Inspection	We hereby certify that the material covered by this report will meet the applicable requirements described herein.					
QC Manager	[illegible], P. Eng.							

TENSILE TESTING

- **Dedicated GFRP Rebar pull tester**
  - Capacity 900 kN (200,000 lbs)
- **2 min set-up**
- **Real time Modulus and Elongation Calculation**



TUF-BAR

QUALITY CONTROL and R&D

- Industry is inherently built for continuous improvement and innovation:
  - Producer Quality Control Laboratory
  - Collaboration with Research groups

TUF-BAR

QUALITY CONTROL IMPROVEMENTS

- **Third Party Testing Experience**
  - Training of new labs
  - More opportunity for Quality Assurance

- **Testing Delays:**
  - Concrete casting for bent bars
  - Placement of Steel anchors for tensile specimens

- **Cost of Quality Control**

TUF-BAR

THANK YOU

TUF-BAR Inc.
780-462-8100
1-888-997-3227
info@tuf-bar.com

GFRP Bar Manufacturing Process

Doug Gremel

GFRP Bar Manufacturing Process

Input Materials

Set-up

Machinery

Testing

What matters?

- Measured / Validated Initial Properties

    Tensile & Modulus drive many other parameters

- ✓ Important design properties are all measured
- ✓ Many other properties fall into place

What is the tolerance of the process to meet the end use?

If the process is off, is there a remedy ?

Long-Term Performance

- Inherent with good material selection
- Validated by measured properties
  - ✓ Resin / Glass ratio
  - ✓ Tg
  - ✓ Degree of Cure

Input Materials

- Resin Formulation
  - ✓ Verified by SPI Gel tests
  - ✓ Proper ratios of additives
- Glass fibers
  - ✓ End count
  - ✓ Yield of fiber

Set-up

Aslan FRP

Hughes Brothers

Hughes Brothers, Inc.	Seward, NE	Page 1 of 2
Procedure No. [illegible]	Title: [illegible]	
Revision No. [illegible]	Date: [illegible]	
Prepared By: Quality [illegible]	[illegible]	
Approved By: Quality Manager	[illegible]	
Approved By: [illegible]	[illegible]	

Internal Document Only

Purpose: Set Up guidelines for the Pultrusion of #6 GFRP Vinyl Ester rebar.

Introduction: The following data is to be used for set up only.
[illegible]

GFRP Rebar part number: [illegible] **Nominal Diameter: 0.750 inches (19 mm)**

Set Up Data

Formulation(s):	"[illegible]" Unless otherwise noted "Pressure Pot Overcoat"
End Count:	End Count is determined by the East Stripper Die Size* 95 to 100* ends of 113 yield per line [illegible]
Roving Type:	Owens Corning Type 30-366
Stripper Die Sizes:	1st: 2nd: 100% preferred optional
Guides in Outside Wrap:	No. 8 Guides
Helical Wrap Sets:	40.50 Spacing: 3/4 to 1 inch (19 to 25 mm)
Magnetic Clutch:	Magnetic Clutch Setting: 6 clicks above zero 0 1 2 3 4 5
Line Speed:	30 RPM (m/s)
Oven Temp:	Zone 1 [illegible] during operation. Oven will maintain temp 400 deg. F (162 deg. C). Exit temp shown on the read out on Line 1 at the end of the oven (south line) should be in the 275 to 300 degree F (135 to 150 deg. C) range.
Saw Settings:	[illegible] One number equals one inch (25 mm). [illegible]
Pieces per Shift:	Approx.
Resin Usage:	Approx. every 2.5 - 3 hours.
Lot Traceability:	Each production lot shall have inkjet markings at approximately 78" to identify the Rebar size, Work Order number and month of production. Special identifying markings may be required per customer specifications.

Appendix C Page 29

Aslan FRP

Set-up


Pultrusion Work Order
Work Order Number:
Start Date: 7/10/2017
Due Date: 7/14/2017
Standard Information
INSTALL STEEL STRIPPER DIES
CHARGE WETBATH
FILL PRESSURE POTS


Pultrusion Work Order
Work Order Number:
Start Date: 7/10/2017
Due Date: 7/14/2017
INSTALL SURFACE RESIN BRUSH SYSTEM
SILICA SAND COATING
MONITOR CURING OVEN TEMPERATURE
PRINTING ID AND TRACEABILITY
MONITOR REBAR QUALITY
CUT TO LENGTH AND PACKAGE
CLEAN UP PULTRUSION LINE
Material Information
Blend Materials

Set-up

OWENS CORNING™

Work Order #: 832808

Page: 1

Start Date: 7/18/2017

Due Date: 7/18/2017

IQRF Work Order #:

Item Number	Item Description	Revision	Parts Req
R03-120	#3 GFRP REBAR 120 INCHES IN LENGTH 10MM GFRP REBAR, 305CM IN LENGTH		3,300

Release Date	Release Qty	Order No.	PO No.	Customer	AKA Item Number

1 Cut Part to Print Length and Package

Aslan FRP

Machinery

- Proper set-up of:
  - ✓Proper die
  - ✓Check die wear
  - ✓Line speed
  - ✓Oven/die temps
  - ✓Marking system
  - ✓Surface enhancements

Machinery

HUGHES BROTHERS, INC.

REBAR PULTRUSION REPORT
Straight FRP Rebar

Rebar Size RB4 240 WO No. 627358 Date 3-24-17 Shift 1st

Setup Criteria:
No. of Ends 44 Roving Yield 113
Formulation RBVE 234 Amount added @ Start up 0 #
Oven Temp 443 Line Speed 45
Wrap Setting 75 Wrap Tension 5

Quality Production Checks / Run Verification:

Hour Of Shift	Verify End Count	Verify Line Speed	Verify Oven Temperature	Operator Initials	Comments Or Actions Taken
7:30	44	45	447	JS	
8:45	44	45	446		
3rd	44	45	445		
10:45	44	45	446		300 #
11:57	44	45	441		
12:45	44	45	443		Spool #2
1:30	44	45	445		
2:45	44	45	441		change spool #1, 34

Note: The operator is responsible for hourly checks. All information must be recorded.

Record the Lot Numbers of the Glass Used for this Work Order

579532	

Pcs. Pulled 500 Ft./In. 240

Rejected Pcs. 8 Ft./In. 240

Comments: 124 pc 1st load

||||| |||

368 or cut
need 2 bundle
of 400 pcs

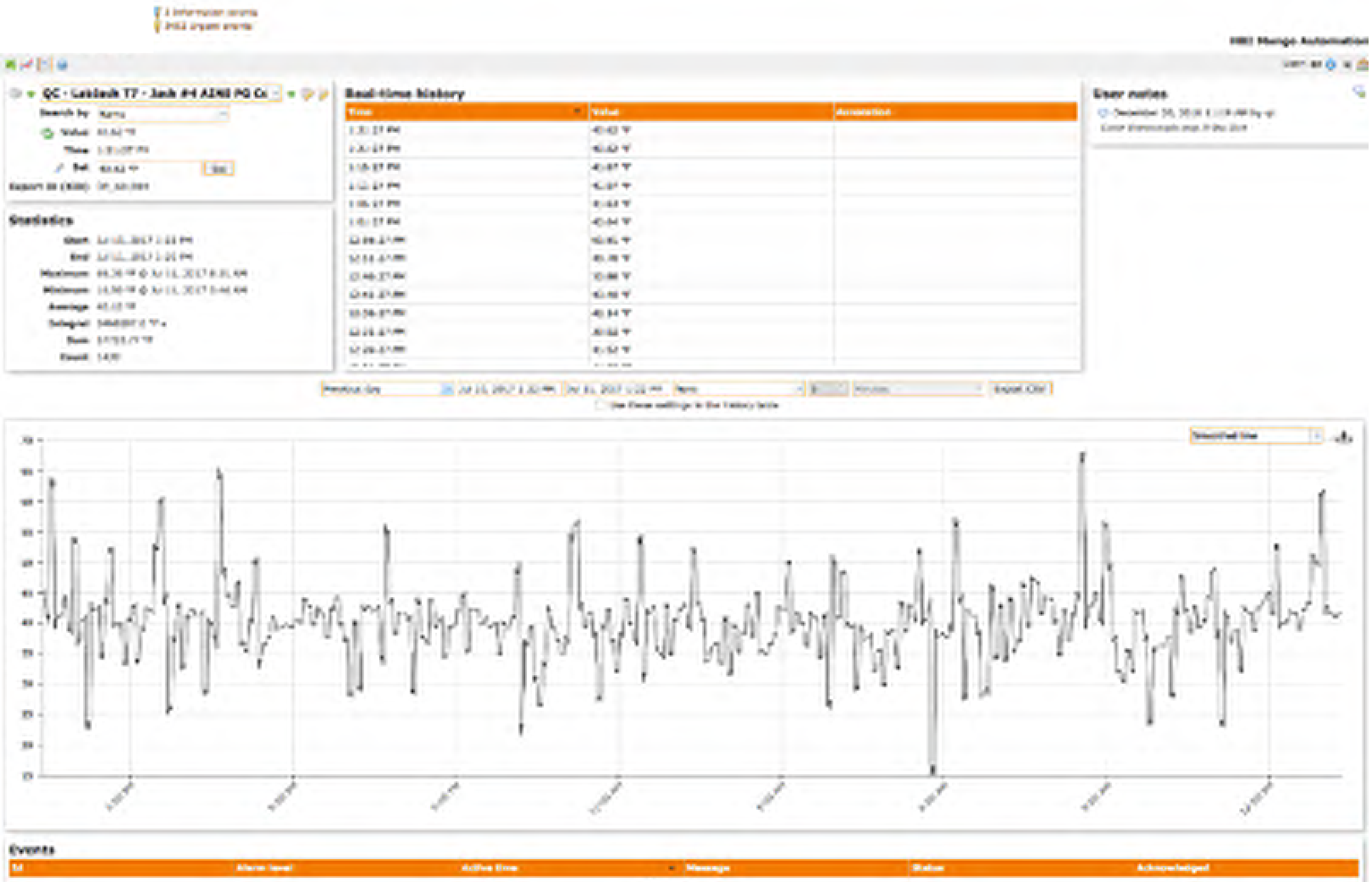
Rev: October 2016

Appendix D Page 31

Aslan FRP

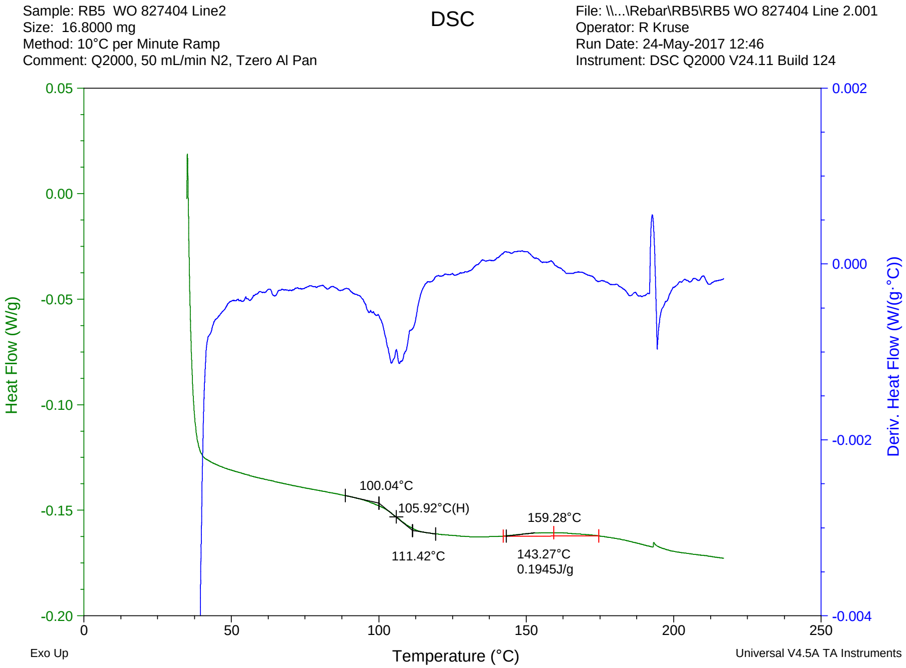
OWENS CORNING

Machinery



Testing

➤ T_g & Degree of Cure



Aslan FRP

Testing

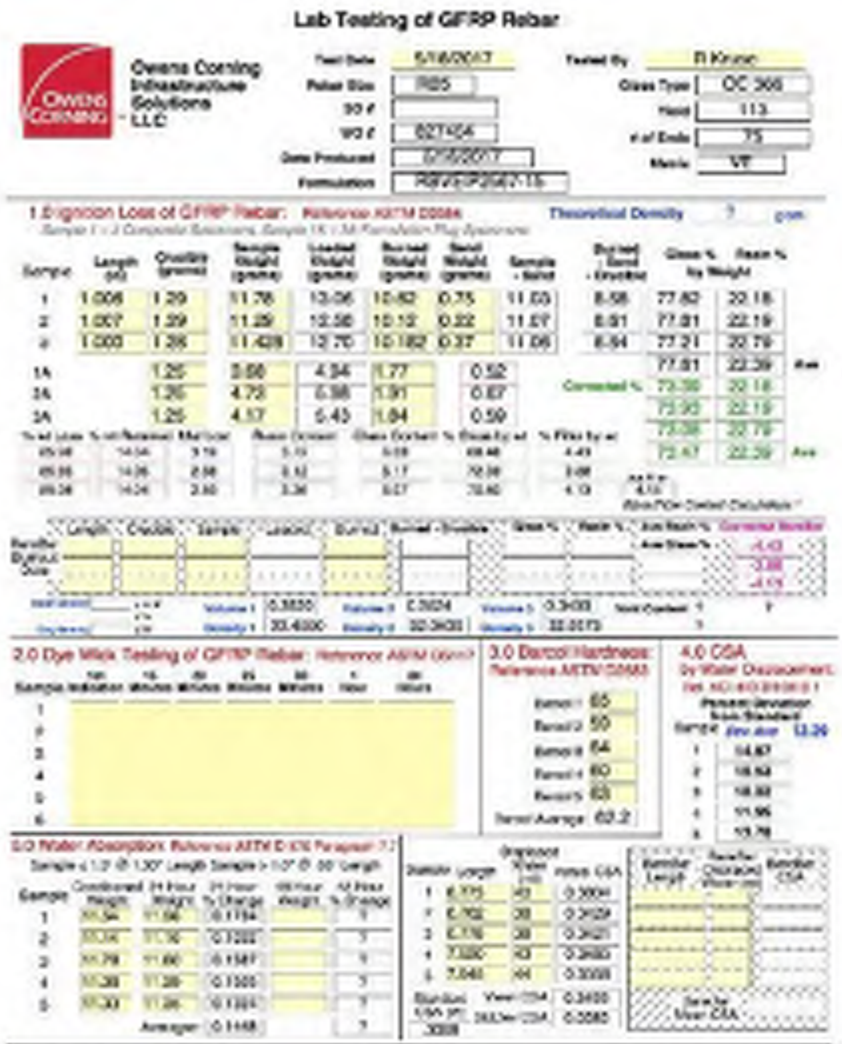
➤ Apparent Shear / Barcol Hardness

Aslan FRP

Long-Term Performance

- Inherent with good material selection
- Validated by measured properties
  - Resin / Glass ratio
  - Tg
  - Degree of Cure

Testing


Lab Testing of GFRP Rebar

Owens Corning Infrastructure Solutions LLC

1.0 Ignition Loss of GFRP Rebar

2.0 Dye Wick Testing of GFRP Rebar

3.0 Barcol Hardness

4.0 CSA

* Provided by Dr. Anand Rau

Aslan FRP

Testing

- Measured Tensile & Modulus Values of finished product indicate:
  - ✓ Glass content is good
    - Transverse shear
    - Bar area
      - ✓ determines good tensile & modulus values

Aslan FRP

Testing

Per ASTM D7205-06 Tensile Testing of GFRP Rebar

Owens Corning Infrastructure Solutions LLC

TEST MACHINE
Baldwin Model 120 CS S/N: 1005
Electromechanical 120,000 lbs Capacity
Tension/Compression
Certification Number 148101216100627
By Instron 12-October-2016
System - MTest Quattro Admet
Grip V Style Per ASTM E4-13

Rebar Size	RB5
Sales Order	
Work Order	827404
Date Produced	5/16/2017
Matrix	VE
Formulation	RBVEIP2567-15
Lot Color Code	
Test Temp	72.2°F
Test R/H	25%
Load Rate	0.50"/min

Lot Type: ◉ Production ○ Experimental ○ Durability

Tested By	R Kruse
Test Date	5/25/2017
Reinforcement	ECR-Glass
Filament Diameter	23 Micron
Sizing	Silane
Yield	113
# of Ends	75
Sample Length	48.00"
Anchor Length	10.00"
Free Length	28.00"
Potting Material	HydroStone

Sample #	Load @ Failure (lbs)	Tensile Strength (psi)	Tensile Strength (MPa)	Ultimate Strain (in/in)	Modulus of Elasticity (psi)	Modulus of Elasticity (GPa)
1	44,293.8	144,373.5	995.5	0.0191	7,552,654	52.1
2	45,712.8	148,998.7	1,027.3	0.0202	7,390,588	51.0
3	43,981.3	143,355.0	988.4	0.0187	7,673,806	52.9
4	42,863.0	139,709.9	963.3	0.0188	7,423,913	51.2
5	42,055.2	137,076.9	945.1	0.0182	7,532,098	51.9
6	44,651.5	145,539.4	1,003.5	0.0191	7,621,297	52.5
7	43,138.2	140,606.9	969.5	0.0187	7,526,440	51.9
			Averages	0.0190	7,531,542	51.9

	PSI	MPa	Strain
Average Tensile	142,808.6	984.7	
Sigma	3,699.9	25.5	0.0006
3 Sigma	11,099.6	76.5	0.0017
Lot Only -3 Sigma	131,709.0	908.1	0.0173

Extensometer Epsilon Model 3543
Certification Number 148101216140227
Calibrated by Instron 12-October-2016
Per ASTM E83-10a

Distance from Anchors	11
LBS of Load at Removal	14,573
Percent of Load at Removal	50%
Span	6.0"

As of 1 Jan 2012: Tensile Strength and Modulus of Elasticity on this sheet are NOT calculated using Actual Cross Sectional Area, but are calculated using a standard Cross Sectional Area.

Sample	Mode of Failure	Line Traceability
1	dc+Failure in Anchor	
2	Failure in Anchor	
3	dc+Failure in Anchor	
4	Failure in Anchor	
5	Failure in Anchor	
6	Failure in Anchor	
7	Failure in Anchor	

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

Measured Ø (in)	Measured CSA A_0 (in)
0.6675	0.3499

Rebar Size	Required Tensile Strength(psi / MPa)	Load Cell Min (lbs / N)	Standard Ø (in / mm)	Standard CSA A_0 (in / mm)
5	105,000	32,214	0.6250	0.3068
16	724.0	143,298	15.88	197.9

Metric Reference

Additional Lab Test Data

Glass to Matrix	77.61 / 22.39	By Weight
Barcol Hardness	62.2	ASTM D2583
Apparent Shear	7,426.2 psi	ASTM D4475
Water Absorption Average 24 Hour	0.1448 %	ASTM D570 P7.7

Traceability

Aslan FRP

Tensile Test outcome

- Variables include:
  - Anchor material
  - Anchor length
  - Grout used
  - Annulus between bar & anchor
  - Where the anchor is gripped in load frame
  - Time between anchor prep & testing
    - Property of compressive strength of grout
- Particular Lab doing the work
- Need Round Robin Testing

Tensile Test outcome

Tolerance of Glass ends to values .. Example #5 (16mm) bar

- Rule of mixtures says 62 ends of 113 yield for 55% fiber volume
  - .. Would give 6.65msi modulus & 39kip bar capacity
- Actually use is 68.5 ends
  - ..with measured modulus of 7.5 msi and 44 kip bar capacity
- Requirement is 6.5 msi and 29 kip bar capacity

- Consists of 274,000 individual glass filaments

Characteristic Properties

Inherent Characteristics
Depend on good choices

- Bond
  - Method of surface treatment
  - consistency
- H_2O Absorption
  - Nothing in process can be done about it
- Strength of Bends
  - Function of bend radius
- Alkaline Resistance
  - Function of cure, Tg and materials choices

Influences & Biases

- Test methods have influences that are not well understood
  - Tensile test highly variable
    - By lab and anchor prep
- Moisture content affected by aspect ratio
  - #2 (6mm) bar vs #8 (25mm) same 1" (25mm) length in tests.. Huge difference in aspect ratio
- Transverse shear results a function of test fixture
- Where to get "independent tests"
- How many labs can do Tg/Cure AND tensile modulus strain
- Few Independent labs or DOT's have any experience

Conclusions

- Once set-up, process is quite stable
- Important design properties are validated by testing of finished product
- Good materials choices yield good product
- Lots of esoteric tests increase cost
- More independent labs are needed
- Round Robin testing should be done

Your Formula for Success
RESINS | GEL COATS | COLORANTS

Best Practices for Providing Consistent Vinyl Ester Resins for the GFRP Rebar Industry

7-18-2017

Overview

Polymer R&D

Resin Manufacturing

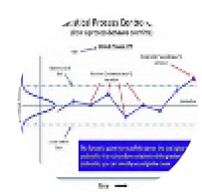
High Quality Rebar

Vinyl Ester for GFRP Rebar

- Critical Applications, such as GFRP Rebar require all input materials to be completely reliable.
- The Resin Industry contributes by making sure every step of their process is as consistent as possible, batch after batch.

R&D → Incoming Raw Materials → Manufacturing → Quality Control → Shipment/Delivery




Research and Development

POLYMER SYNTHESIS

- **Capability to develop exactly the right polymer for optimal application performance.**

- **VEs for rebar are <u>not</u> off the shelf VEs, but designed to meet the needs of the Rebar industry (*Corrosion Resistance, Processing, etc…*)**

- **Synthesis labs and pilot reactors are equipped with the same state of the art control systems as production reactors.**

- **Finished properties and process variables are monitored at each step of scale up from lab glass ware to pilot plant to production reactor.**

CORROSION TESTING

- Designing the polymer to last under the service and environment that it will be exposed.
- Systems that will pass the requirements of CSA S807-10.
- Understanding the chemistry and testing under a variety of the harshest corrosive environments.

Research and Development

ANALYTICAL TESTING

Analytical capabilities including *GPC, GC, MS, AA, DSC, NMR, FTIR* and others help to:

- Confirm the composition of developed polymers and raw materials.
- Confirm consistency of process.
- Provide Problem Solving for customer.

Research and Development

MECHANICAL TESTING

Ability to measure physical properties of cured castings and composites, including:

- Tensile
- Flex
- Elongation
- Compression
- HDT
- Water Absorption
- Short Beam Shear

Research and Development

CONSIDERATIONS FOR REBAR

- Not “off the shelf” VEs
- Designed with Canadian Standards Association - Specifications for fiber-reinforced polymers – S807-10 in mind.
- Polymers designed to be manufactured consistently, batch after batch.

Manufacturing

KEYS TO MANUFACTURING EXCELLENCE

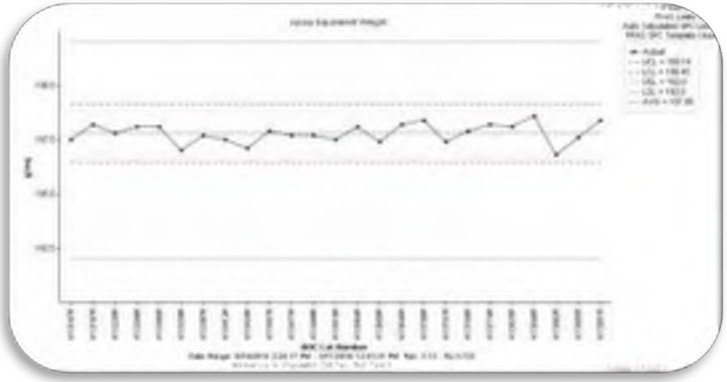
- Automation, Automation, and more Automation.
- Advanced Process Control Technology ensures the exact same polymer batch after batch.
  - Same Composition
  - Same Molecular Weight
  - Same Reactivity
- System for Raw material certification.
- Quality Control Systems

Manufacturing

INCOMING RAW MATERIALS

- All Raw Material Suppliers completely vetted by R&D.
  - Analytical Testing
  - Lab and Pilot plant processing.

- Raw Material sourced from multiple vendors to protect against supply interruption.



- Raw Materials Tested/Statistically Reviewed before accepting at plant.

- Lot Traceability

Raw Material Lot# → *All Batches Containing Lot*

Input   Output

Manufacturing

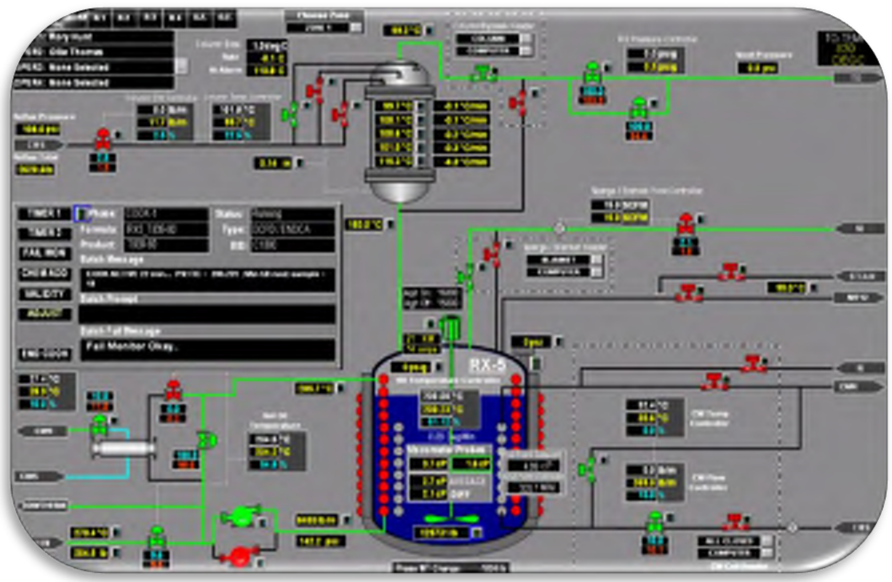
SCHEDULING AND LOGISTICS

- Vessels scheduled to ensure on-time delivery and to avoid any cross contamination.
- Empty tank wagons inspected for cleanliness and correct equipment prior to loading.
- Vessels rinsed to eliminate any chance for cross contamination between products.

Manufacturing Technology

AUTOMATED PROCESS CONTROL

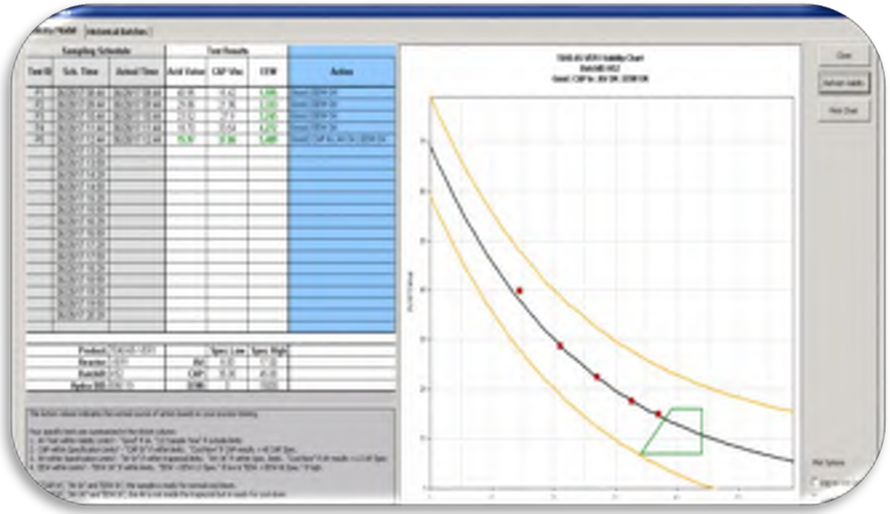
- State of the Art Instrumentation and Automation Provides consistency in ***Composition***, ***MW*** and ***Reactivity***.
- Very Complex Process! No Operator can control as well as Automated Systems.
- Same equipment and processes across all manufacturing sites.
- Redundant Charging Systems.
- Extremely Consistent Temperature Control (+/- 1°C)



Manufacturing Technology

AUTOMATED MONITORING

- Operators monitor and evaluate process variables in real time.

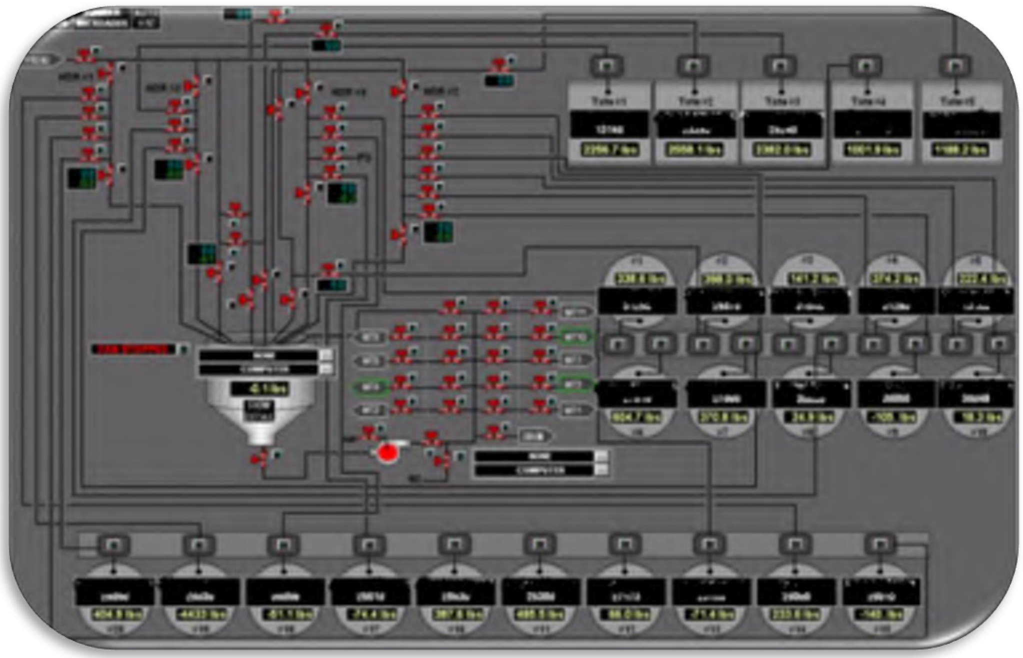


- Engineers monitor process from anywhere.

Manufacturing Technology

AUTOMATED MONITORING

- Every Process is:
  - Controlled Automatically
  - Made in a Scheduled Sequence
  - Tested continuously for quality control
  - Recorded Electronically

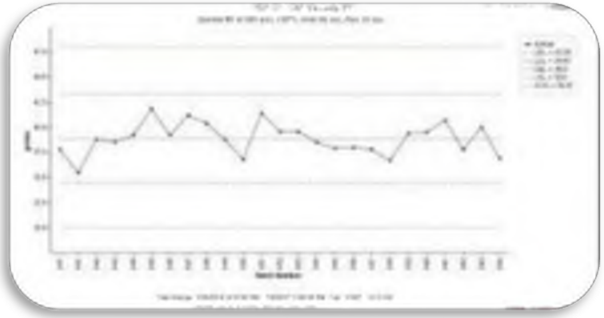


- Everything is measured and recorded – Thousands of data points per batch.

Manufacturing Technology

QUALITY CONTROL

- Testing is a very large part of any Resin Manufacturer's process.
- Automation extends from Process to Lab.
- Real Time Statistical Process Control.
    - Operators and Engineers can identify and respond to variation when it occurs.
    - Provides metrics for continuous improvement.
- Quality control data from laboratories are automatically matched with corresponding process control system data acquired directly from the manufacturing processes, providing superior problem-solving and improvement capabilities.

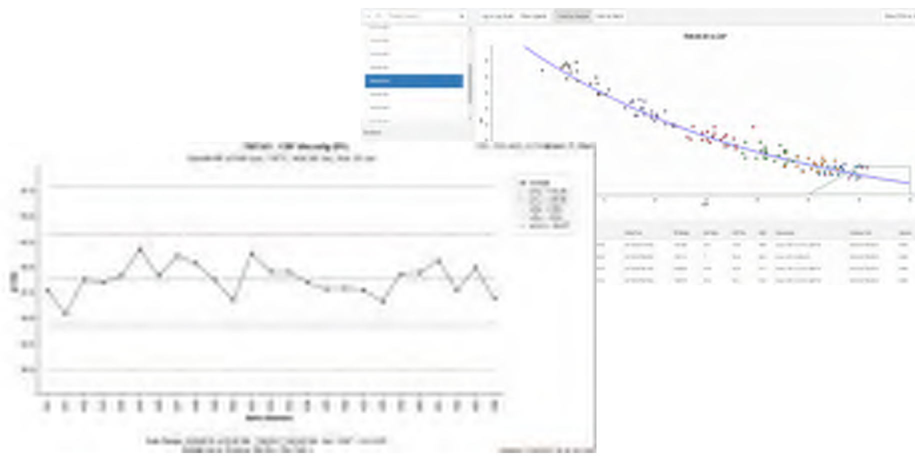


Manufacturing Technology

BATCH CERTIFICATION

- Finished Batch is not certified for shipment in system until all properties are tested to be in spec and have been evaluated statistically.

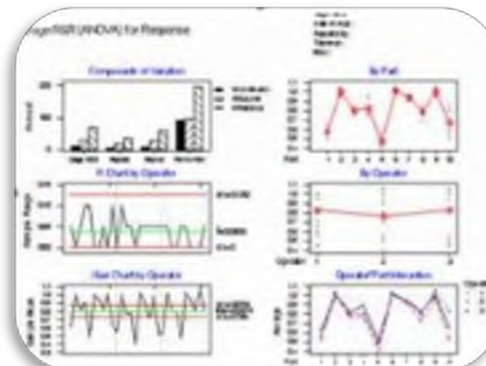
- Certificate of Analysis Generated Automatically when Batch Status is ‘Approved to Ship’



Manufacturing Technology

ADDITIONAL PRIORITIES

- Maintaining ISO Certification.
- Integrated Use of Six Sigma Tools.
- Commitment and Investment in Continuous Improvement.

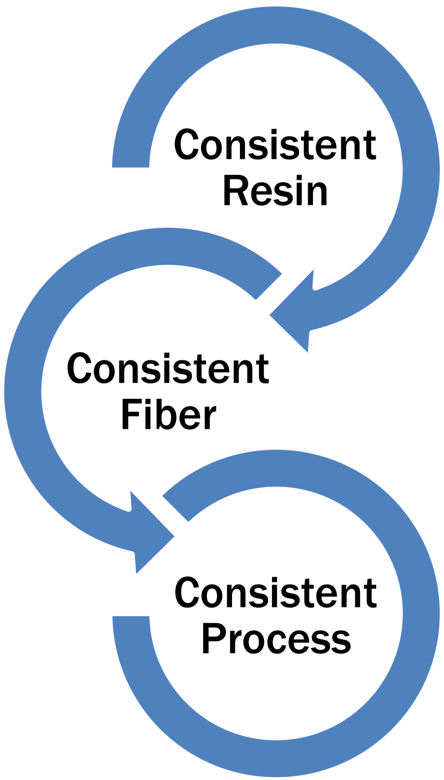


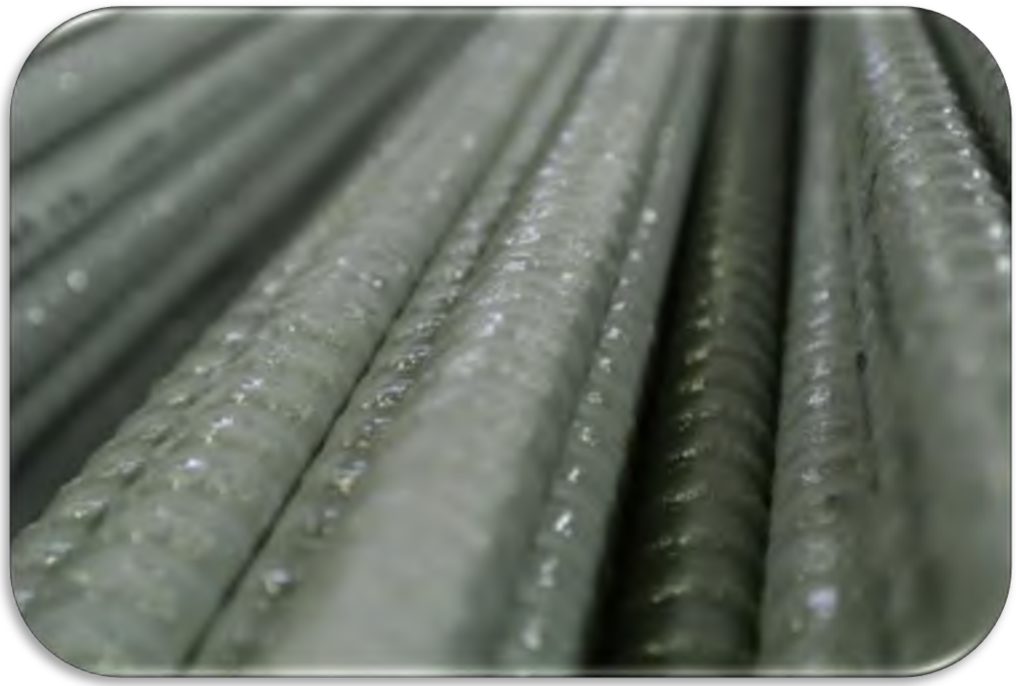
End Use

These processes and investments in Technology are to help make it possible to develop Composites that can replace competitive materials.

For Rebar

- EACH PROCESS AT THE RESIN MANUFACTURER ENSURES THE SAME POLYMER EVERY TIME.
- CONSISTENT MOLECULAR WT., VISCOSITY, REACTIVITY, MONOMER CONTENT.





Rebar with the same:

- Corrosion Properties
- Physical Properties
- % Cure
- Crack Resistance

Thank You

Your Formula for Success

RESINS | GEL COATS | COLORANTS

Driven Field Test of Precast Concrete Piles Reinforced with GFRP Bars in Arthur Drive Bridge

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Professor of Civil Engineering

Canada Research Chair in Advanced Composite Materials for Civil Structures
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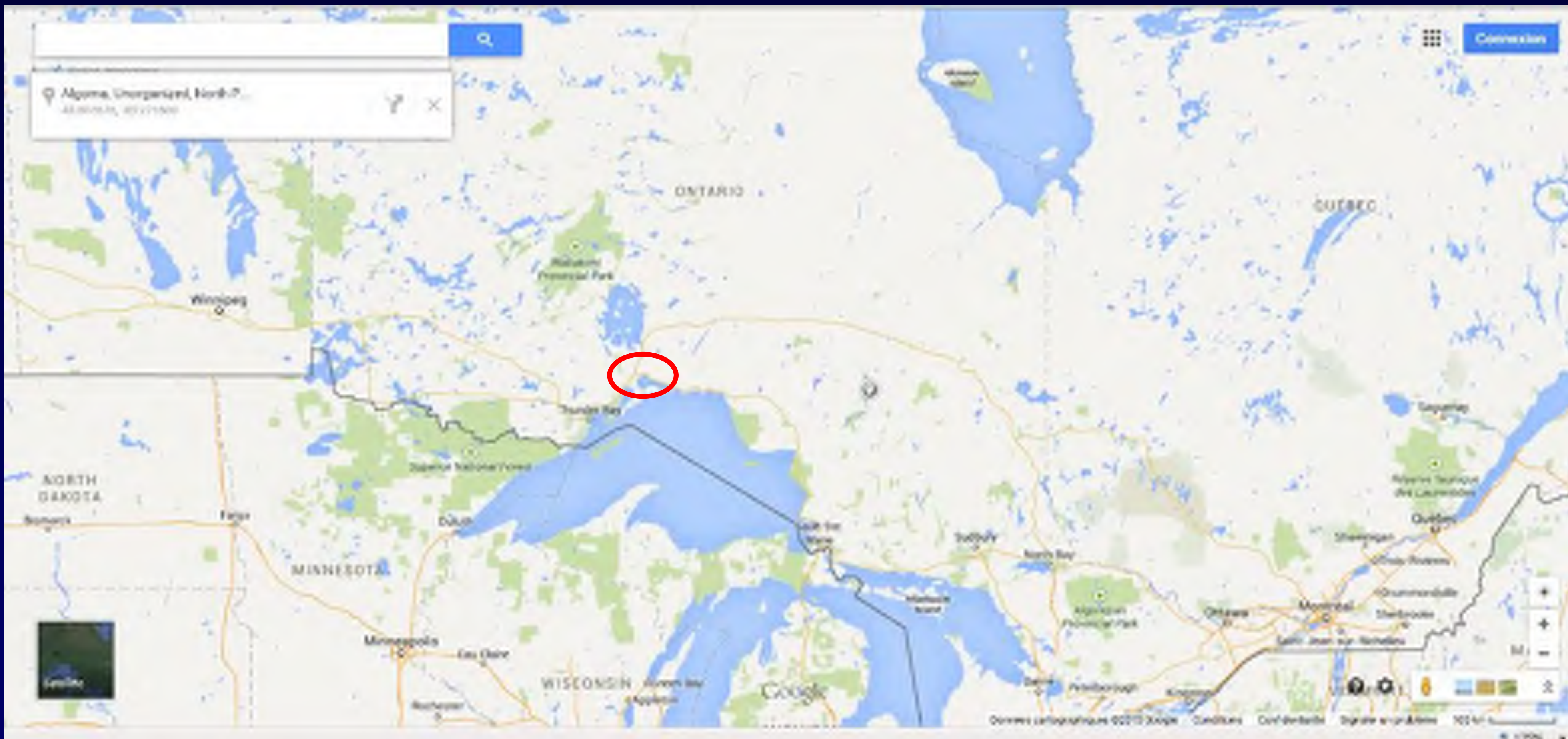
Nipigon River Cable-Stayed Bridge (2012-2017)

The First Deck Slab Reinforced with GFRP Bars in Cable Stayed Bridge: Nipigon River Bridge

Nipigon River Cable-Stayed Bridge (2012-2017)

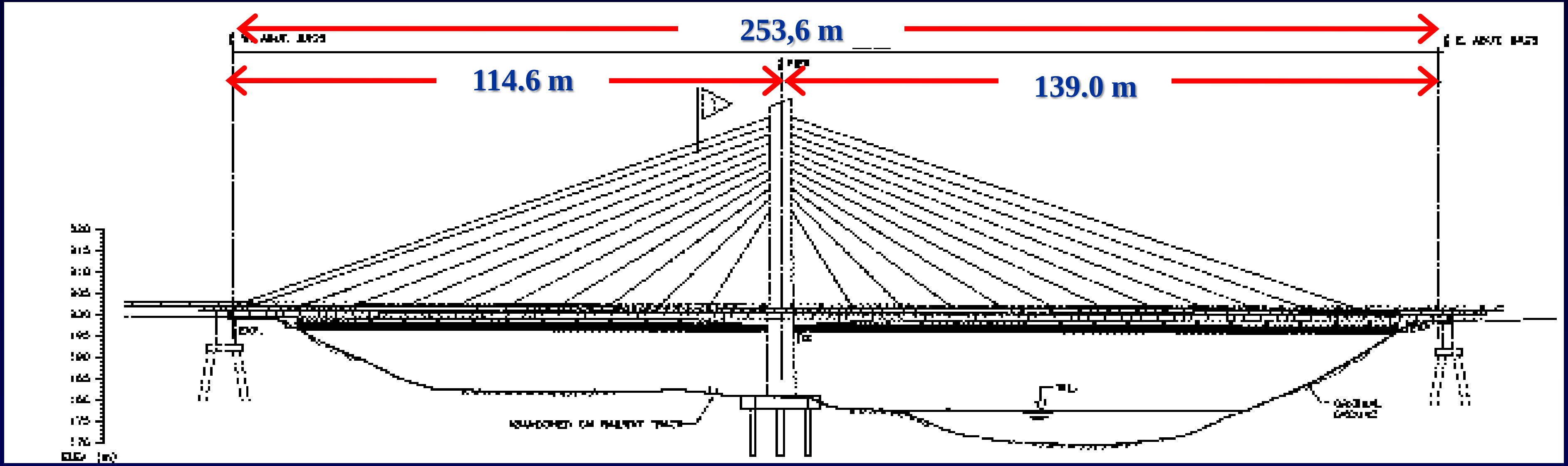


Nipigon River Cable-Stayed Bridge (2012-2017)

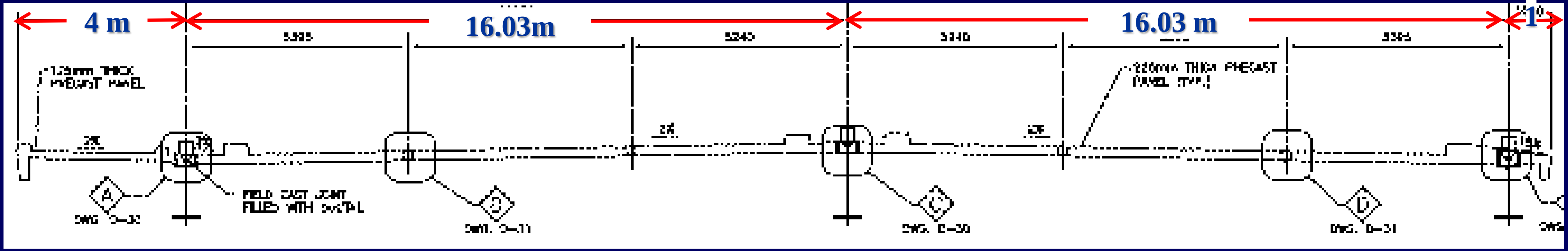
Nipigon River Cable-Stayed Bridge (2012-2017)

- Canada's **first cable-stayed bridge using GFRP bars**
- A two-span, four lanes
- Centre pier structure, **252 m** in total length
- Three-tower center pier of **51m above the bridge deck**
- Built sequentially from the center pier outwards to the east and west abutments by mean of **balanced cantilever technology**

Nipigon River Cable-Stayed Bridge (2012-2017)



Elevation



Deck Slab

Nipigon River Cable-Stayed Bridge (2012-2016)

The MTO decided to use the following structural materials & techniques

1. **Precast Panels**
2. **High Performance concrete**
3. **GFRP rebars (in lieu of stainless steel bars)**
4. **Joint between panels filled with UHPFRC**

In order to achieve service life of 100 years, with no major repair.

Nipigon River Cable-Stayed Bridge (2012-2017)

Partners:

- Ministry of Transportation of Ontario (Northwestern Region-Structural Section)
- McCormick Rankin
- Buckland & Taylor
- Hatch Mott MacDonald
- MCon Manufacturing Facility
- University of Sherbrooke (Prof. Brahim Benmokrane)

Nipigon River Cable-Stayed Bridge (2012-2017)

Material Mechanical Properties

Concrete compressive strength = 70 *MPa*

Primary GFRP Reinforcement

GFRP bar No. 20 of Grade III (CSA-S807)

(A_f= 285 mm^2), E_f= 65000 *MPa*, Guaranteed tensile strength (f_{fu}^*) = 1105 *MPa*

Secondary GFRP Reinforcement

GFRP bar No. 15 of Grade I (CSA-S807)

(A_f= 198 mm^2), E_f= 42500 *MPa*, Guaranteed tensile strength (f_{fu}^*) = 800 *MPa*

Nipigon River Cable-Stayed Bridge (2012-2017)

Materials include:

- 1800 tonnes of structural steel girders,
- 480 pre-cast concrete panels (3 m x 7 m)
- 66 steel cables.
- About 750 000 m of GFRP bars

East

West

Precast Deck Panel Layout

Construction

Construction

Construction

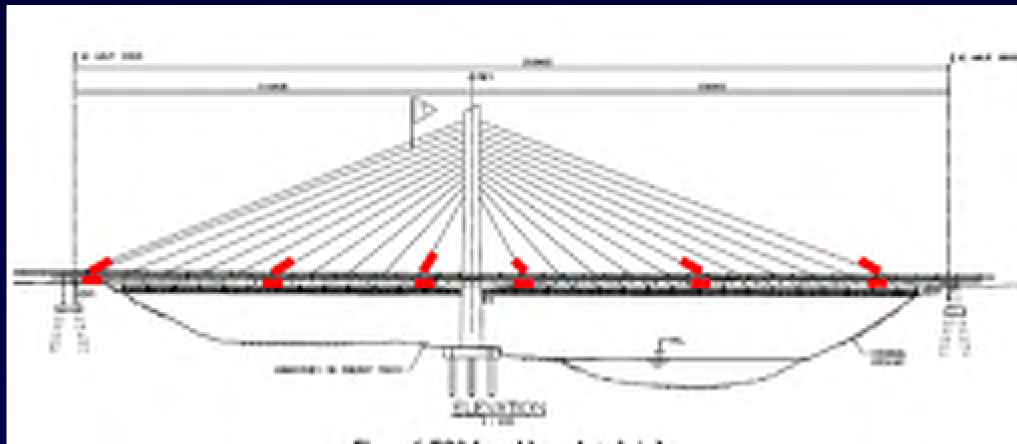
Construction

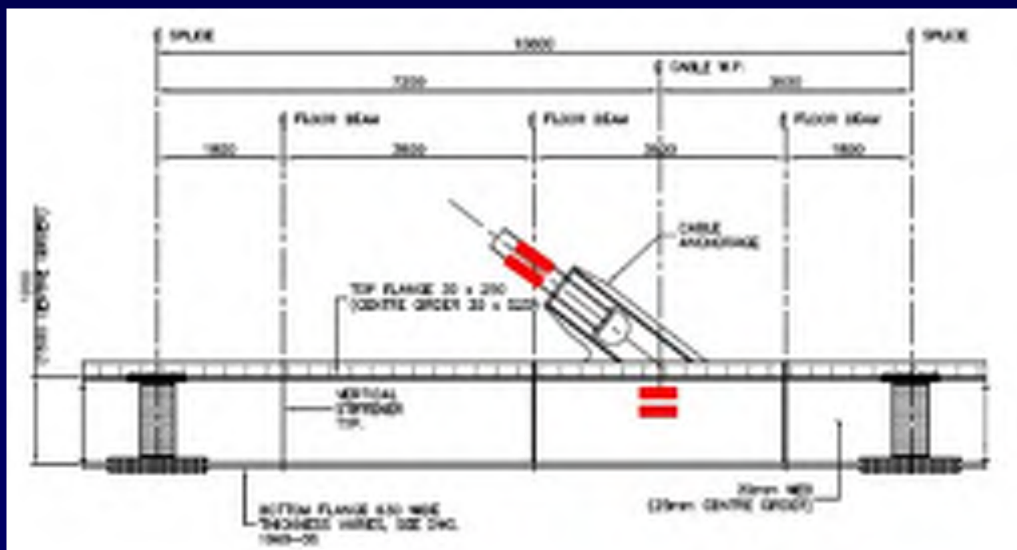
Construction

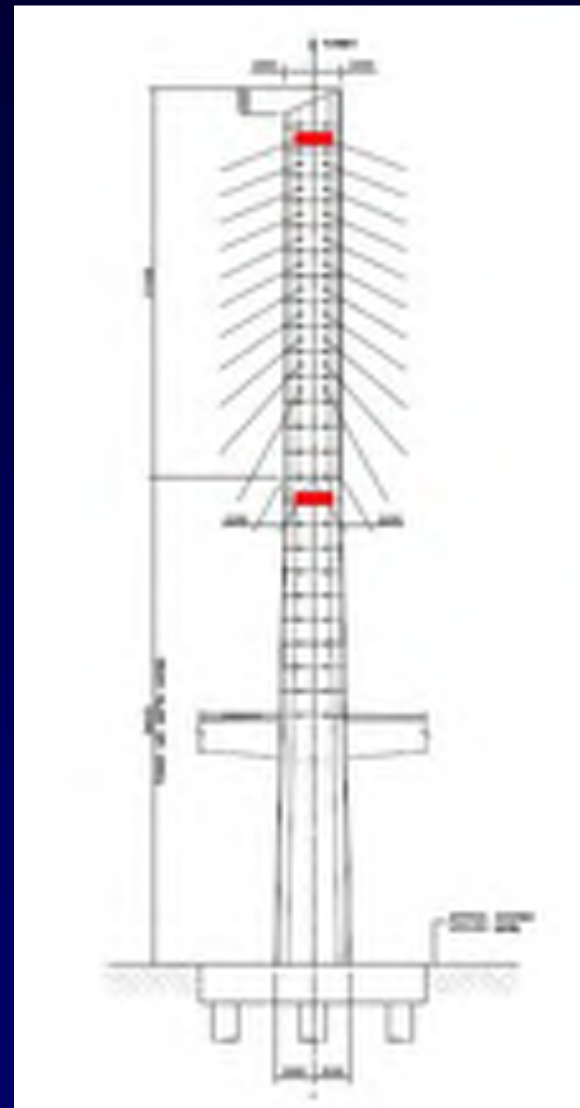
Construction

Construction

Layout and Locations of FOS

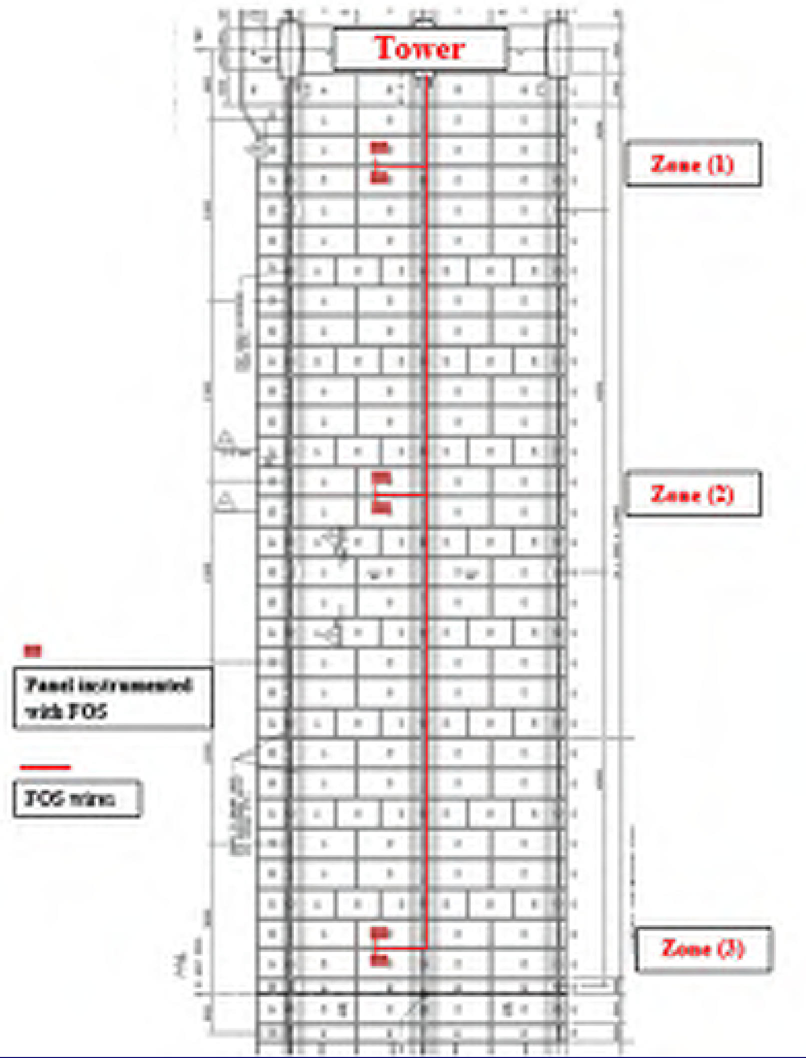






Cables, Steel Girders, and Pylons

Layout and Locations of FOS



Fiber Optic Sensors on the Bottom GFRP Reinforcements

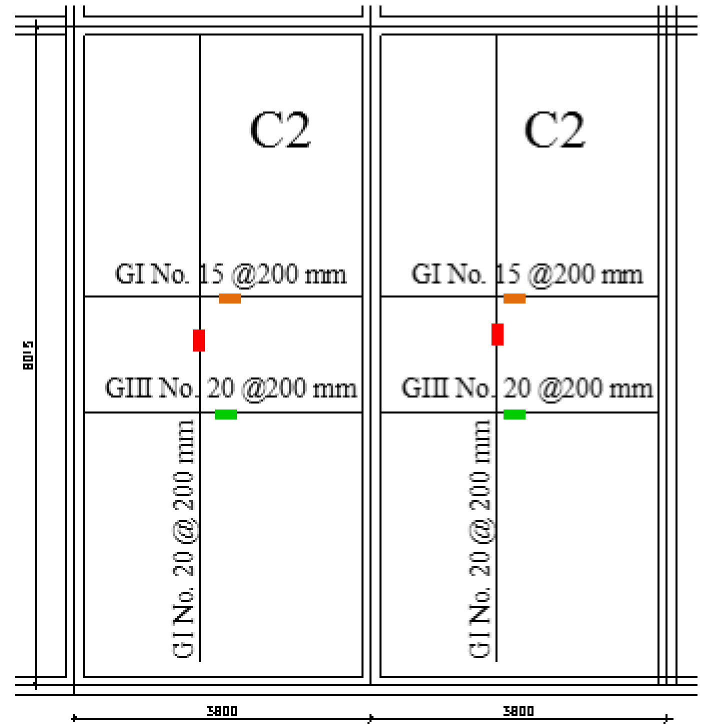


Figure 2. Locations of FOSs on the bottom reinforcements for two adjacent panels

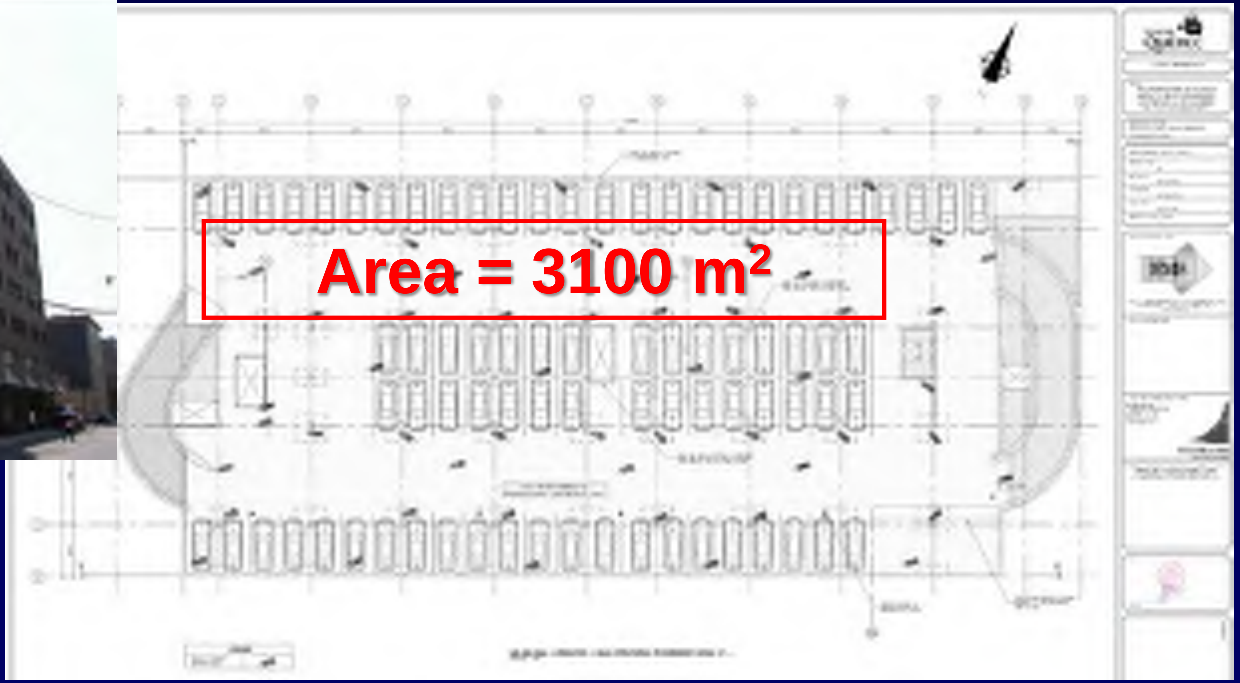
(Typical at Zone 1, 2 and 3)

	2 FOS in the short direction on 2 GFRP Bars No. 15 GI for each panel
	2 FOS in the short direction on 2 GFRP Bars No. 20 GIIII for each panel
	2 FOS in the longitudinal direction on 2 GFRP Bars No. 20 GI for each panel

Bridge Deck Slab

Applications – Parking Garage Structures

- **Two-Way Concrete Structural Slabs - La Chanceliere Parking Garage**

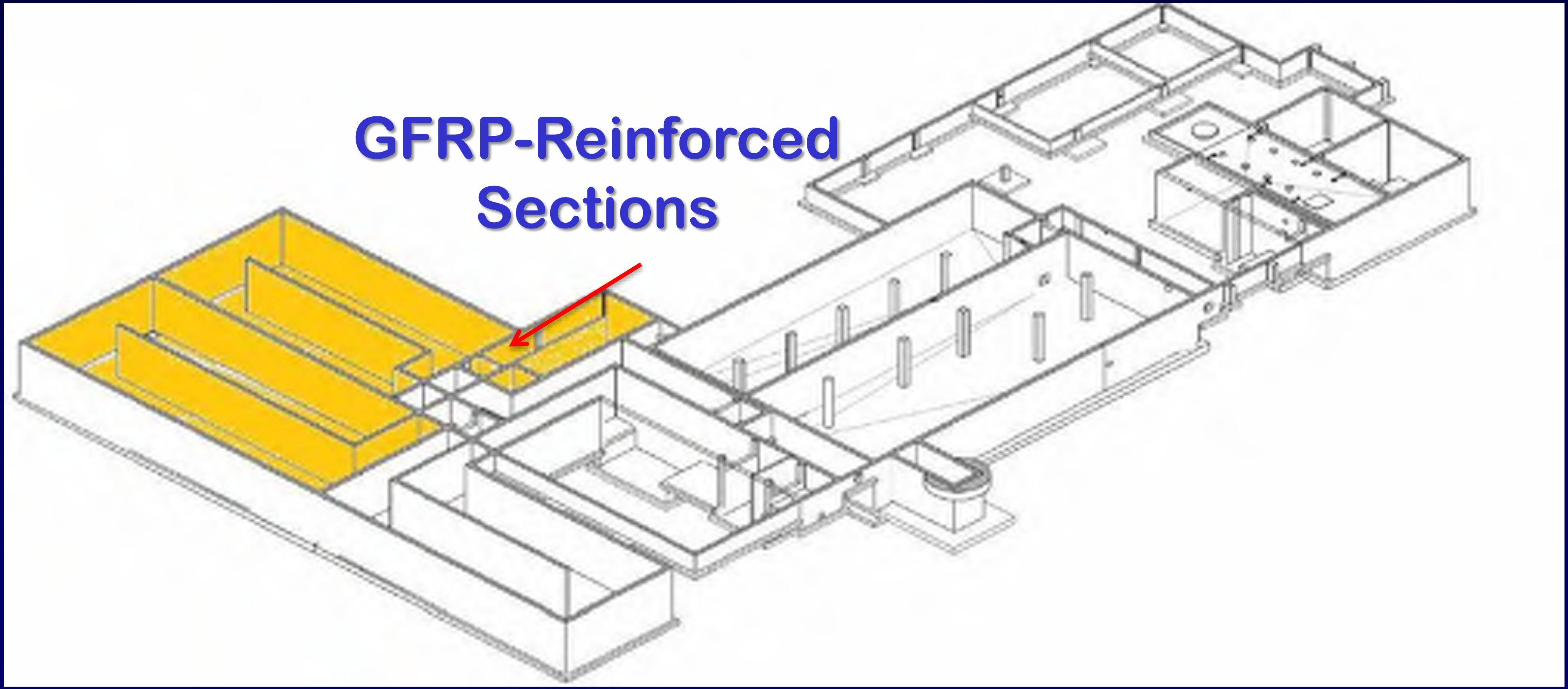


Applications – Parking Garage Structures

Parking in Service

Water Treatment Plant in Thetford Mines, QC

Chlorination RC Tanks



Water Treatment Plant in Thetford Mines, QC

GFRP-Continuously Reinforced Concrete Pavement (CRCP)

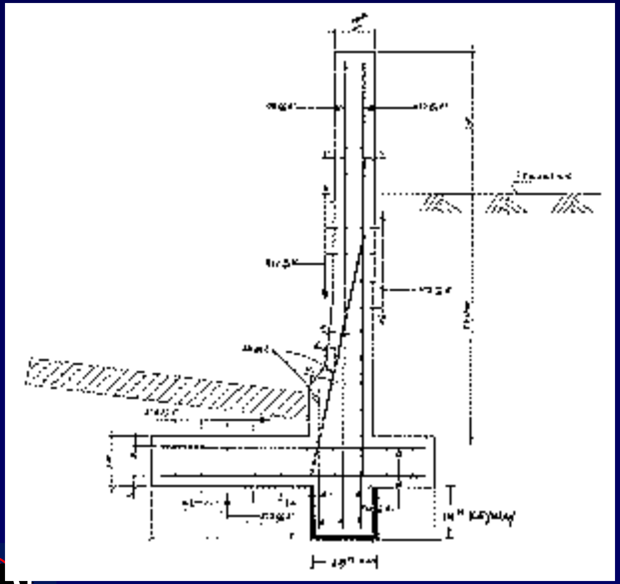
BFRP- RC Box Break Waves - Project Tanger Med II

(Tanger, Morocco)

Jetty

95 RC Boxes : 235 000 m3 of concrete)

Retaining BFRP-RC Walls - Port of Miami Tunnel Project (Miami, FL, USA)

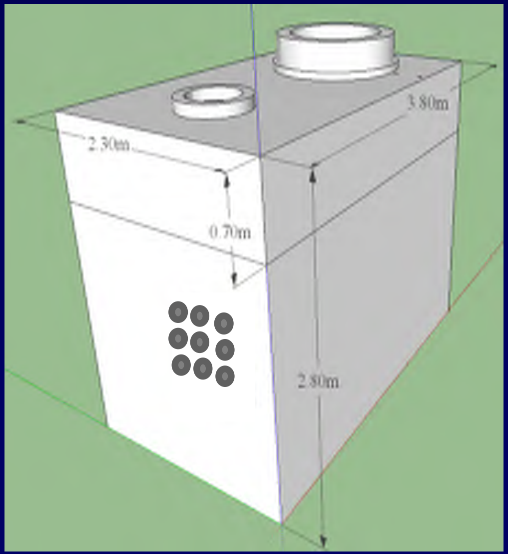


Tunnels (Toronto Subway) – Soft Eyes

RC Soft-Eyes TC Subway North Tunnels - Toronto, ON

Precast GFRP-RC Chambers

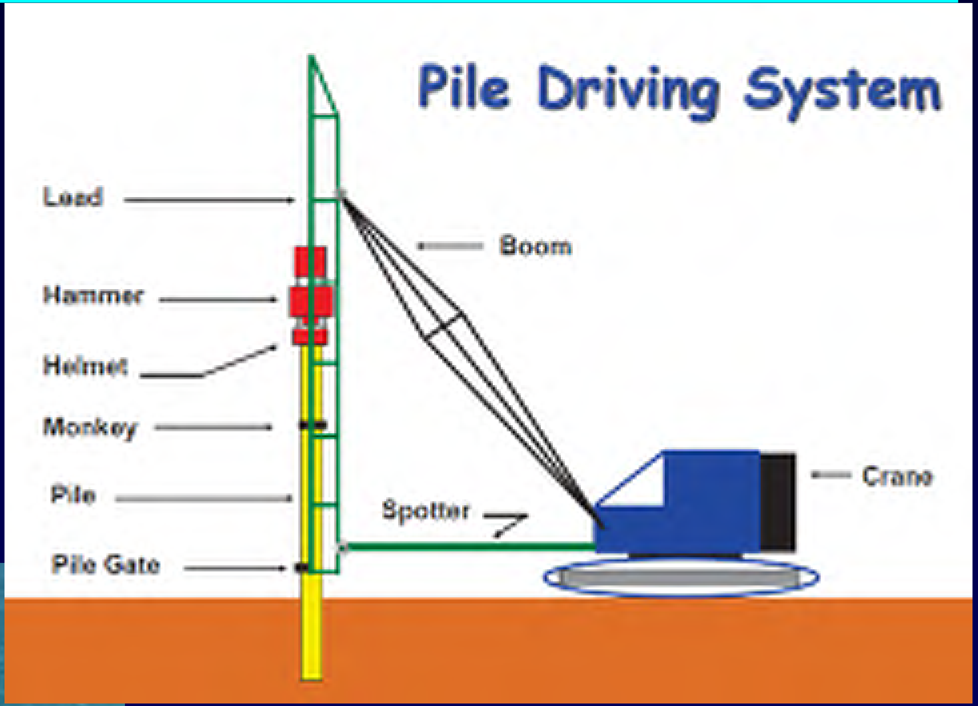




Prestressed GFRP Concrete Sleepers-Railways Applications

Prestressed GFRP Concrete Sleepers-Railways Applications

Precast GFRP-RC Piles



Precast GFRP-RC Piles

Precast GFRP-RC Piles

Partners

- Ministry of Economy, Science, and Innovation of Quebec
- Florida Department of Transportation (Tallahassee, FL)
- Gate Precast Company (Jacksonville, FL)
- F & W Construction Company, Inc. (Ozark, AL)
- GRL Engineers, Inc. (Orlando, FL)
- Smart Structures (West Palm Beach, FL)
- Ministry of Transportation of Quebec
- Hydro-Quebec (Montreal, Quebec)
- Pultrall Inc. (Thetford Mines, QC)

Precast GFRP-RC Piles/Objectives

1. Determine the structural performance (Axial, Flexural, and Shear capacity) of RC Piles reinforced with **GFRP bars, ties and Spirals.**

2. Determine the bearing capacity and the **technical viability** of the use of precast GFRP RC piles in harsh environments and the possibility of installing them following the **procedures normally employed for steel** conventional precast prestressed/noprestressed concrete piles.

3. Establish recommendations for design, testing and installation of such these **piles for bridge and marine applications.**

FRP Reinforcement

V-ROD GFRP

V-ROD CFRP

Type	D_b (mm)	Tensile Strength F_{fu} (MPa)	E_f (GPa)	Strain ε_{fu} (%)
GFRP	13	1125	52	2,2
	20	1590	65	2,5
CFRP	15	1680	140	1,2

Laboratory Experimental Tests

Flexural

GFRP circular cages

Casting process

Specimens after casting

Circular specimens

Laboratory Experimental Tests

Laboratory Experimental Tests

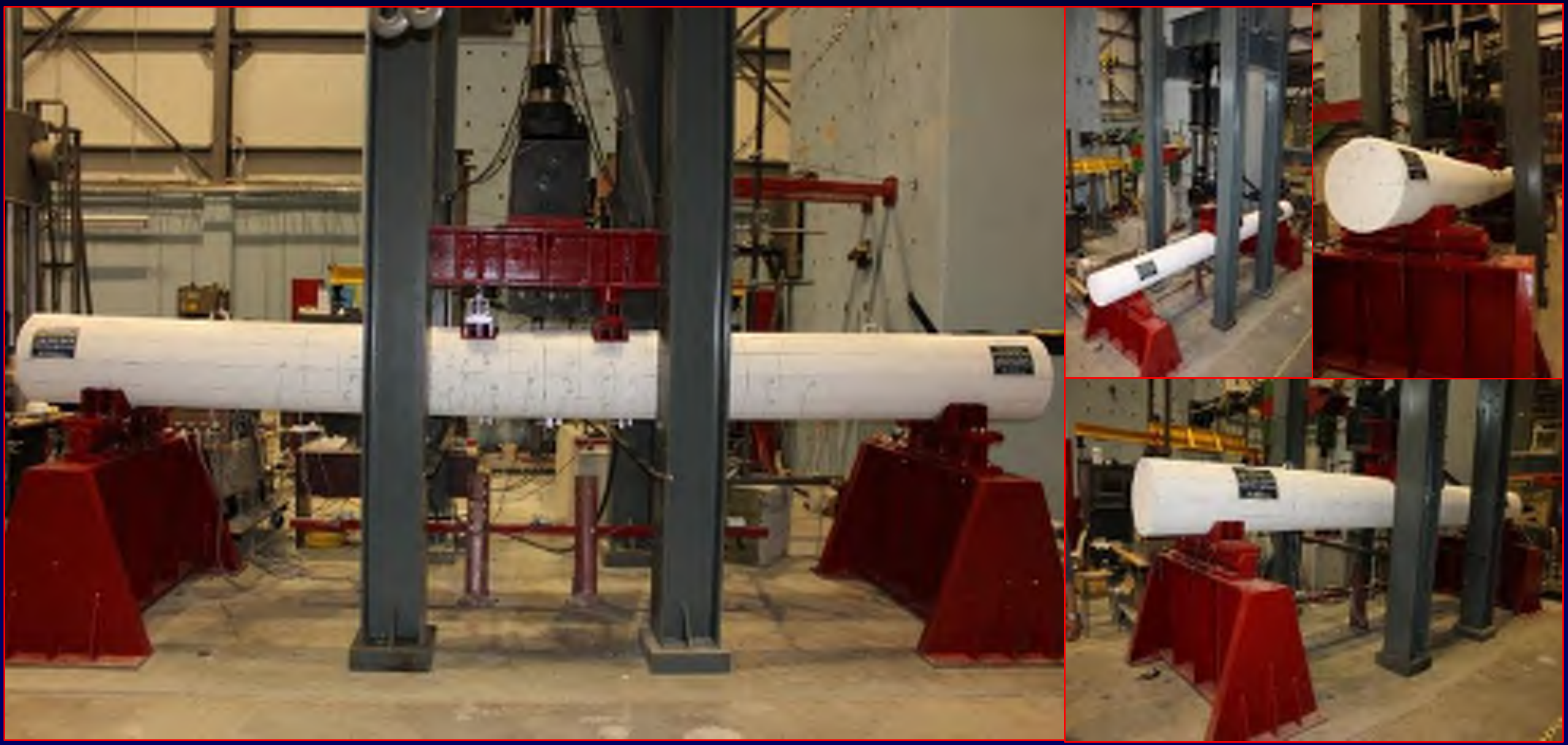
Square cages

Casting process

Specimens after casting

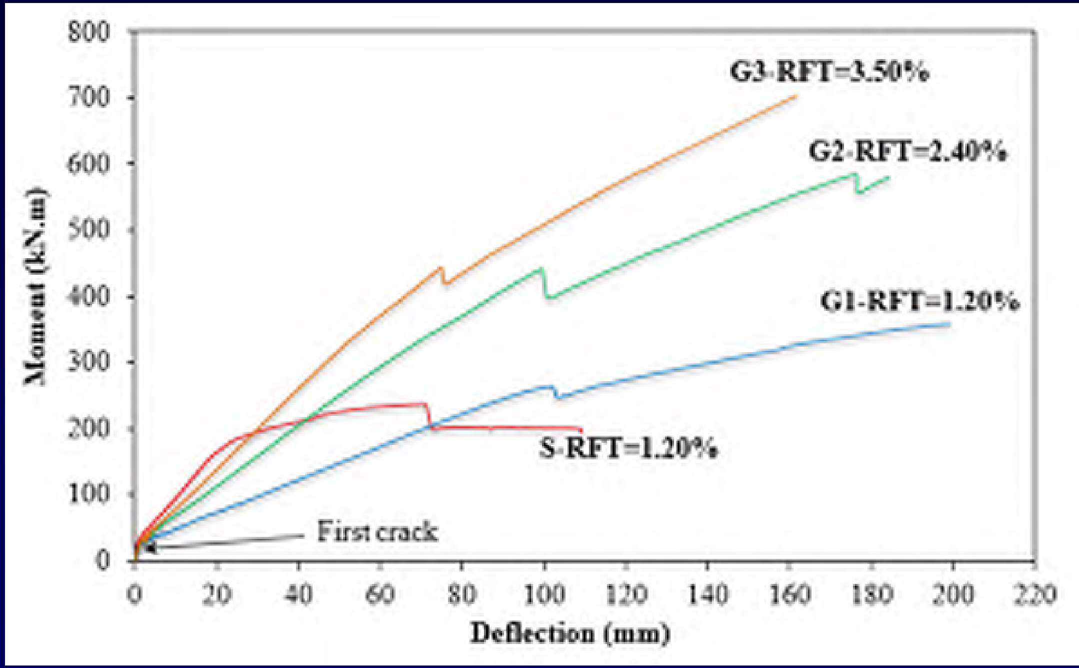
Square specimens

Laboratory Experimental Tests



Test setup for circular specimens

Laboratory Experimental Tests



G1

G1 G2 G3 S

S

Laboratory Experimental Tests

Failure Modes of Square Steel, CFRP, and GFRP RC Piles

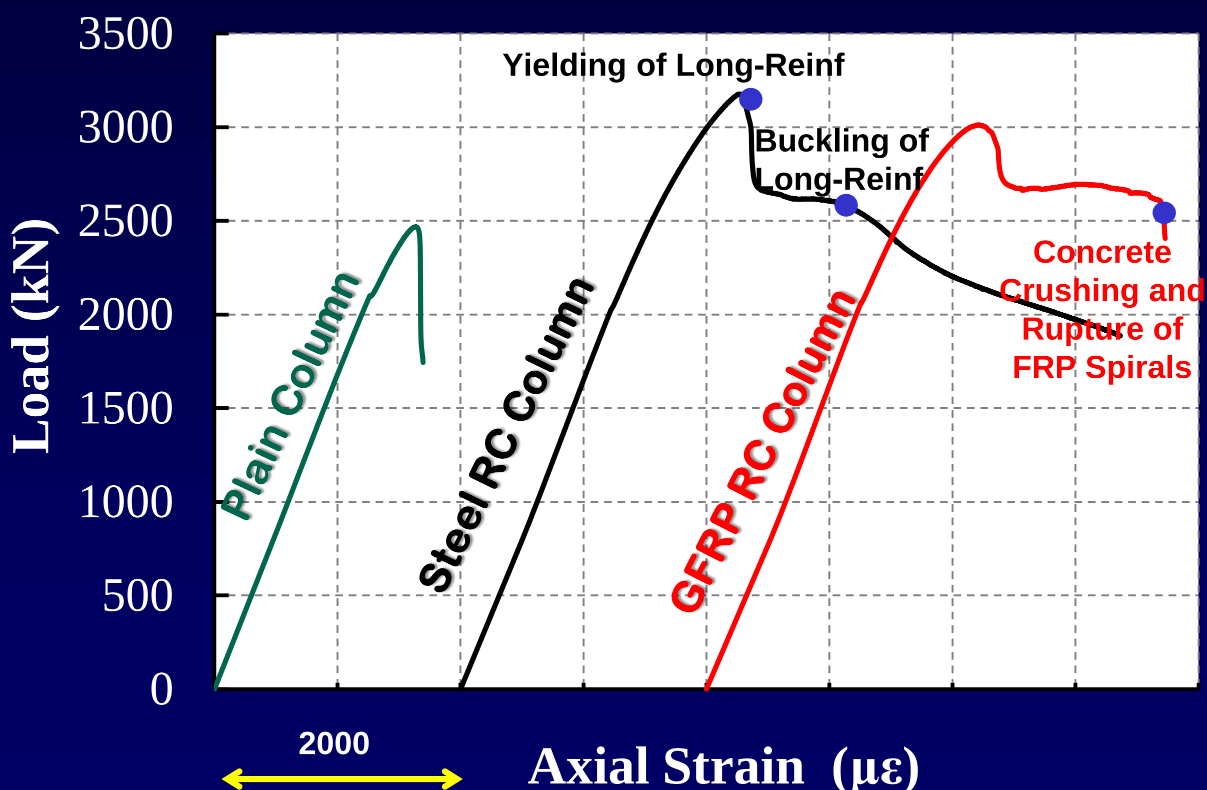
Laboratory Experimental Tests

Failure Modes of Circular Steel and GFRP RC Piles

Laboratory Experimental Tests

Axial Loading

Effect of Type of Reinforcement (GFRP versus steel)



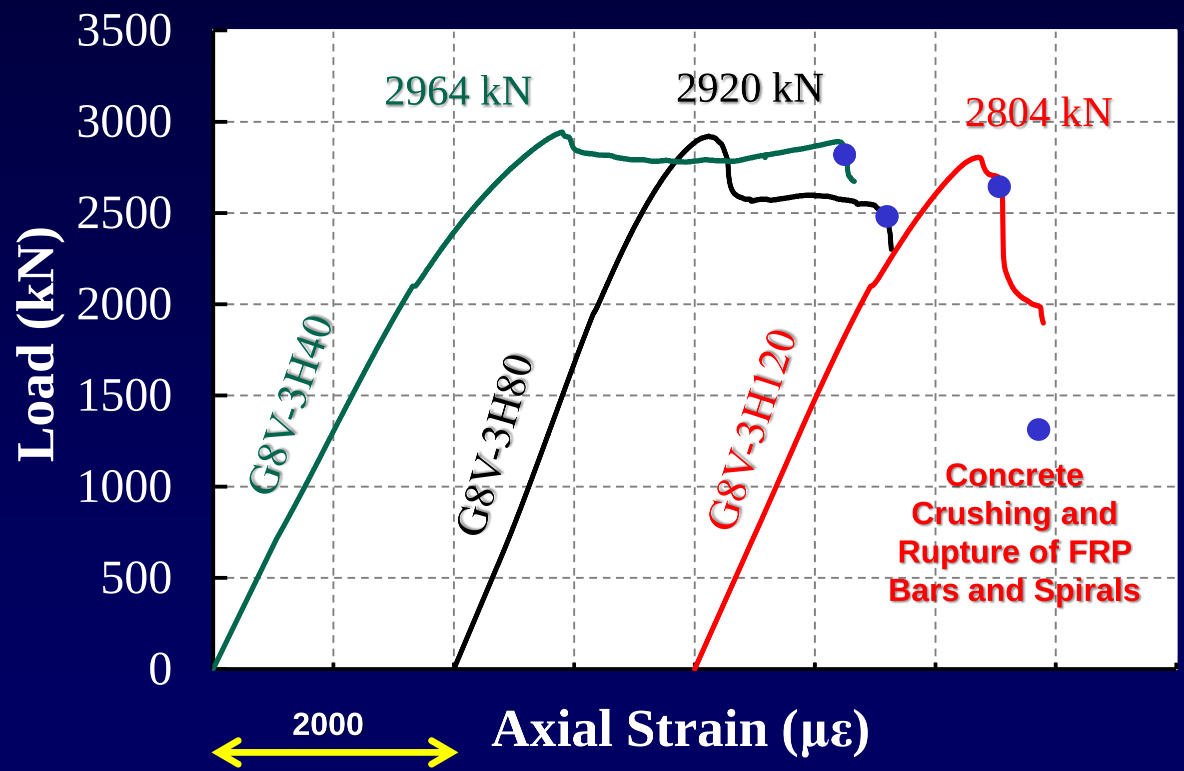
Plain Steel GFRP

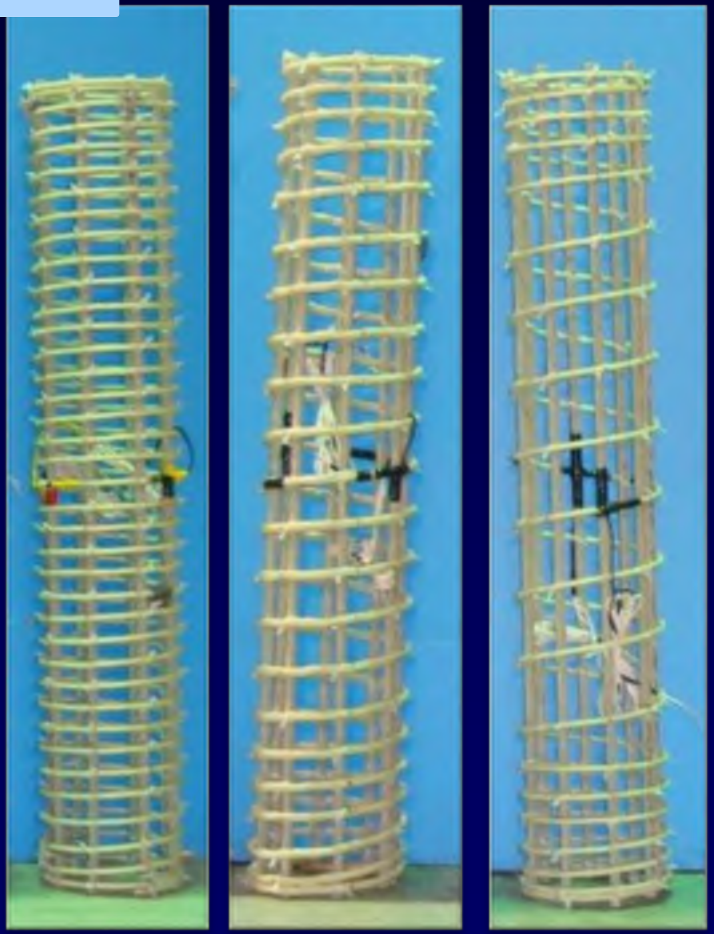
Reinforcement ratio is the same for all 2.2%

Laboratory Experimental Tests

Axial Loading

Effect of Spiral Spacing

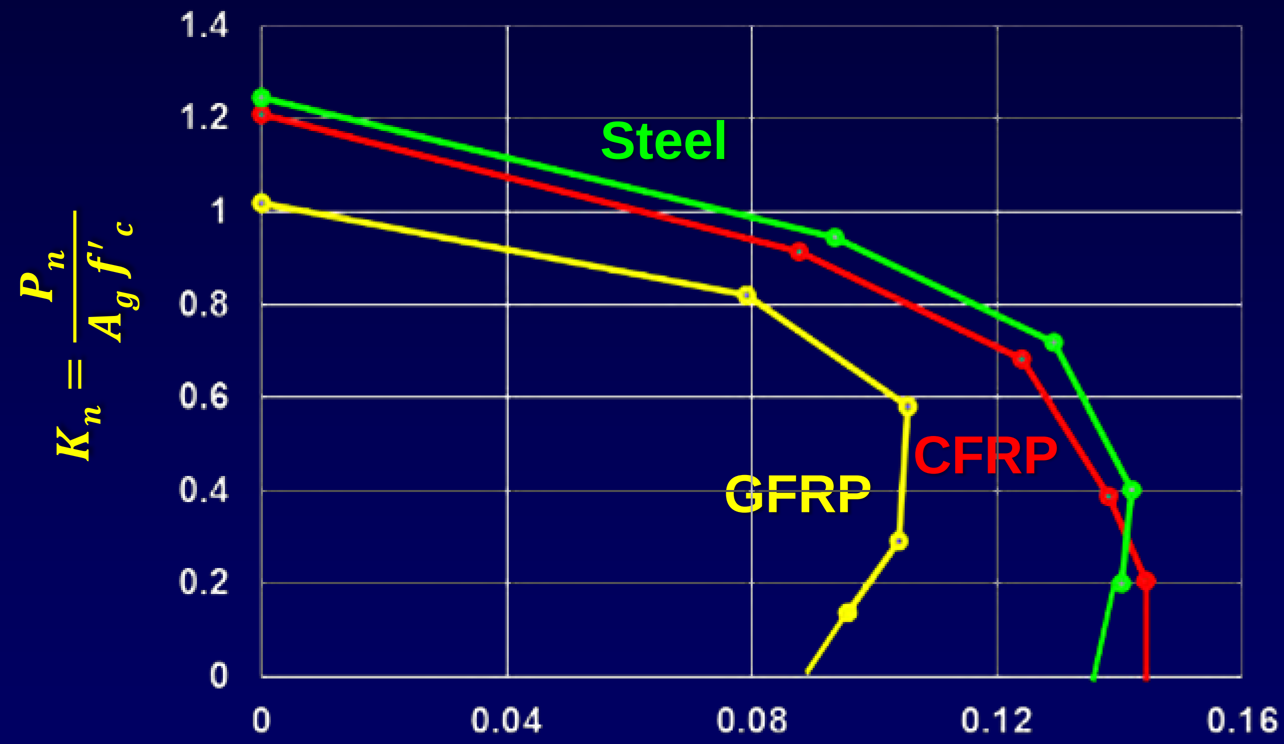




40 mm 80 mm 120 mm

Laboratory Experimental Tests

Axial-Flexural



$$R_n = \frac{M_n}{A_g f'_c D} = \frac{P_n(e+x)}{A_g f'_c D}$$

Normalized *P-M* diagram:

Steel

CFRP

GFRP

Reinforcement ratio is the same for all 2.2%

Pile Driving Field Test

Handling and Pile Installation

Concrete and FRP Reinforcement-Pile Field Tests

CONCRETE: 8500 ksi (60 MPa)

GFRP Bar

D_b (mm)	Tensile strength F_{fu} (MPa)	Elastic Modulus E_f (GPa)	Ultimate Strain ε_{fu}(%)
15	1365	54	2,5
25	1330	68	2,6

Prestressing CFCC Carbone Strand

D_b (mm)	Tensile strength F_{fu} (MPa)	Elastic Modulus E_f (GPa)	Ultimate Strain ε_{fu}(%)
15	2350 270 kn	155	1,6

Pile Driving Test-Design

Design of Prestressed and Non Prestressed Piles

- Design for Flexure
- Design for Shear
- Design for Axial
- Design for Combined Axial-Flexure

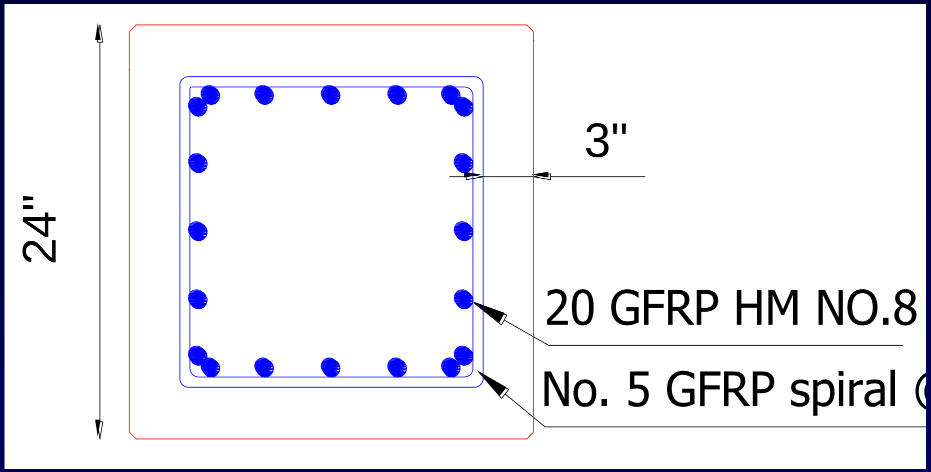
Wave Tensile Stress Analysis

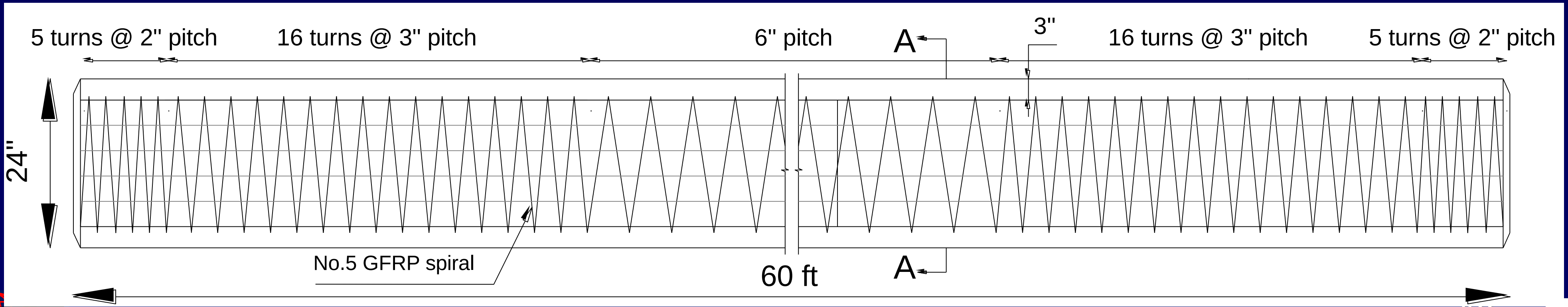
- Manual Calculations Using Goble's Equations
- Using IHCWAVE Software Program
- Validation with previous Project
- Predication of tensile stresses

Pile Driving Test-Design

Pile No. 1

- 20 GFRP bars No. 8 (25 mm)
- GFRP Spirals No. 5 (16 mm)
- Reinforcement Ratio = 2.7%
- Spliced GFRP bars were used
- Concrete 8500 ksi

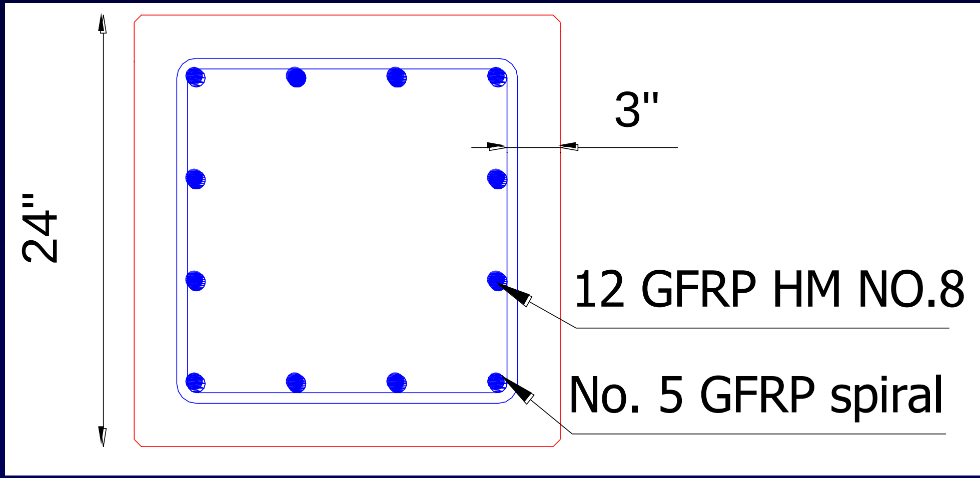


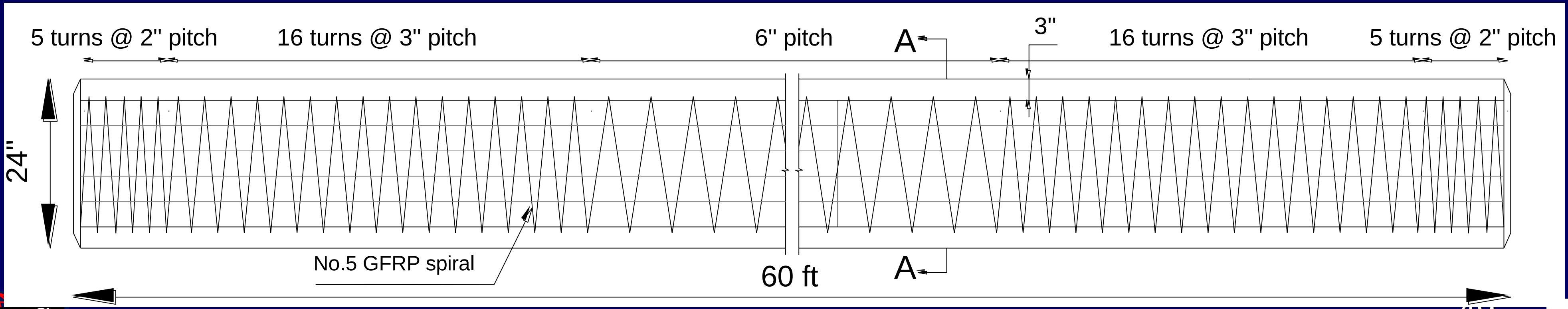


Pile Driving Test-Design

Pile No. 2

- 12 GFRP bars No. 8 (25 mm)
- GFRP Spirals No. 5 (16 mm)
- Reinforcement Ratio = 1.6%
- Spliced GFRP bars were used
- Concrete :8500 ksi



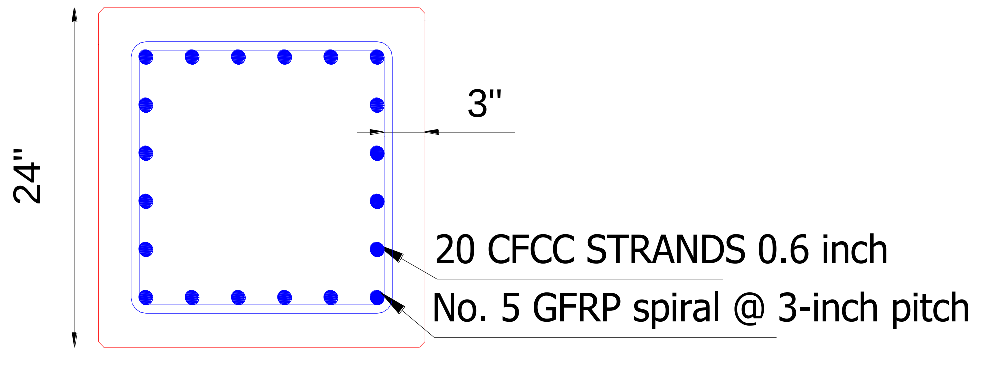


Pile Driving Test-Design

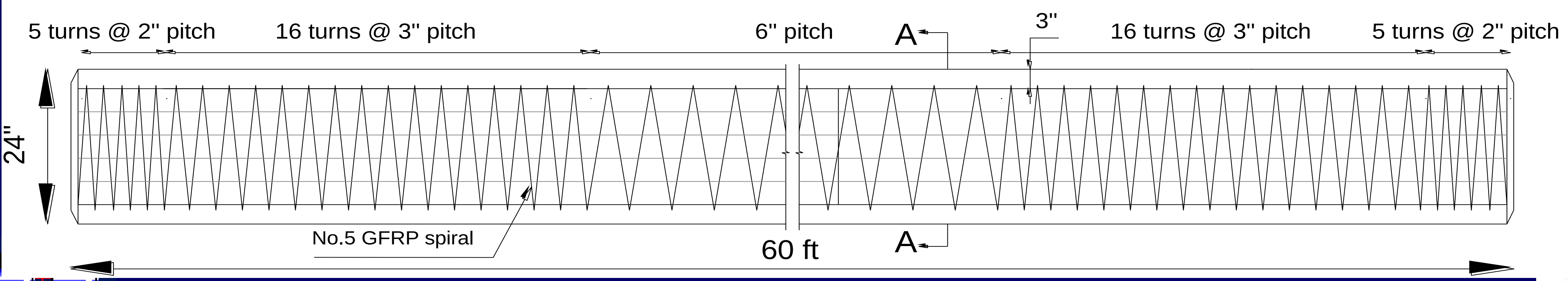
Pile No. 3

The prestressing strand pattern was based on FDOT's standard details for **a 24–in. square pile** with **20 0.6–in.** diameter (15.2–mm) strands The 20–strand option was chosen because of GATE's casting bed strand template.

The number of turns and pitches for the **GFRP spirals** was designed to provide confinement to the concrete core and to avoid premature failure at the ends due to prestress release and impact load during driving.

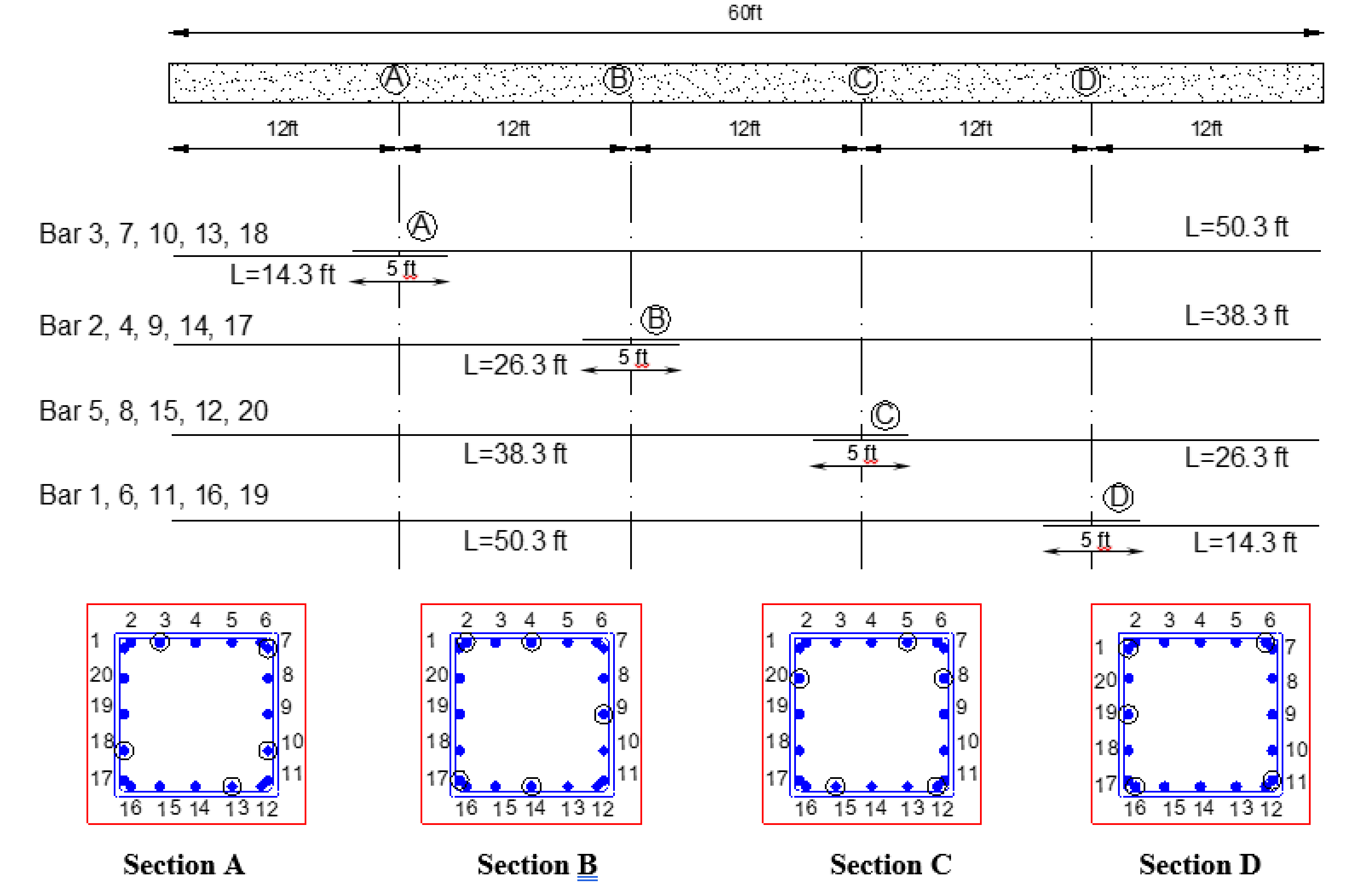


Concrete : 8500 ksi



Pile Driving Test-Design

Pile No. 1 - Splice Length Details



Pile Driving Test-Fabrication

GFRP bars and Spirals for Pile No. 1 and 2




Pile Driving Test-Fabrication

Cages fabrication for Pile No. 1 and 2

Pile Driving Test-Fabrication

Cages fabrication for Pile No. 1 and 2


Pile No. 1

Pile No. 2


Pile Driving Test-Fabrication

Fabrication of Pile No. 1 and 2




Pile Driving Test-Fabrication

EDC Instrumentation -Pile No. 1 and 2

Pile Driving Test-Fabrication

Coupler and Prestressing-Pile No. 3




Pile Driving Test-Fabrication

Casting-Pile No. 1 and 2

Pile Driving Test-Fabrication

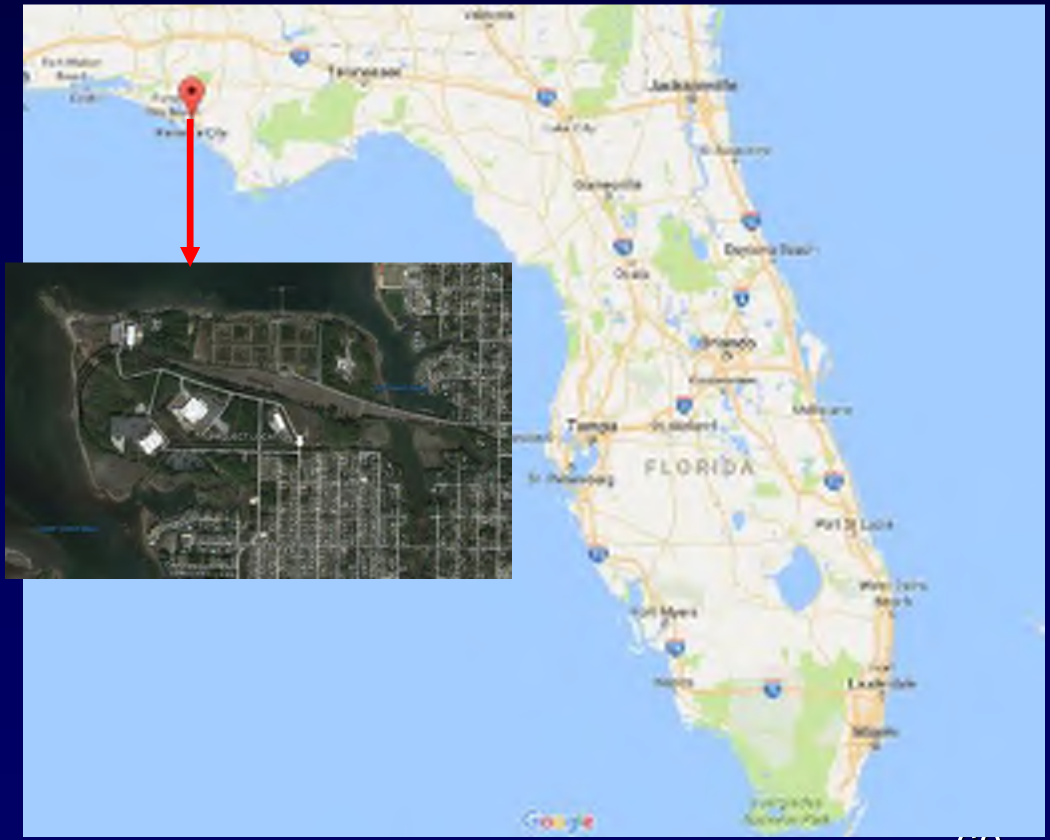
Unmolding




Pile Driving Field Test

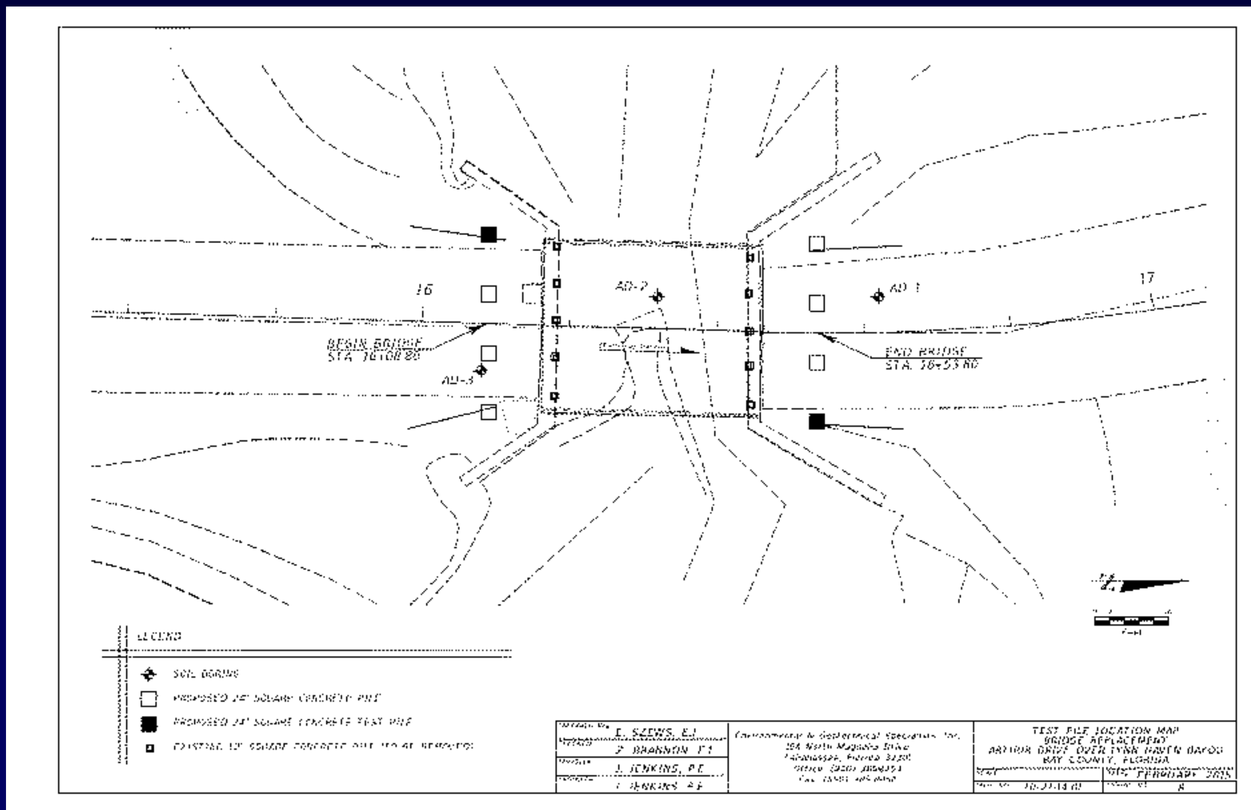
Dynamic Load Test

On March 2nd at the FDOT Arthur Drive project site in Lynn Haven, Florida, the three piles were tested

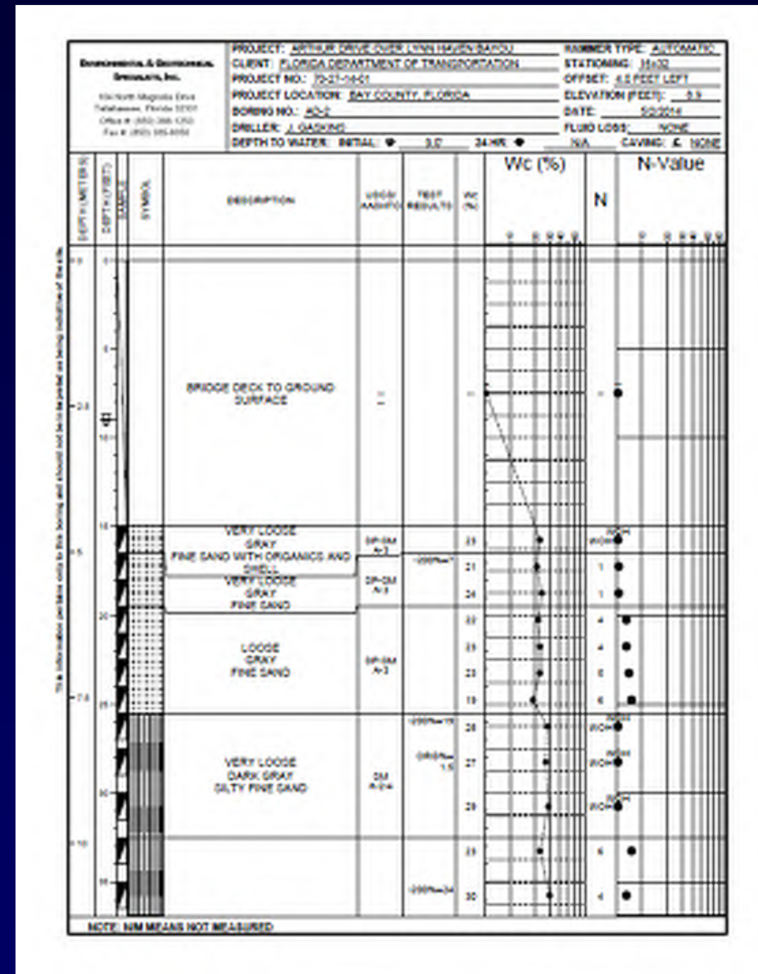


Pile Driving Field Test

Arthur Drive Bridge, Lynn Haven, Florida



Bridge Layout



Soil Boring

Pile Driving Field Test

The three piles at the Bridge Site

Pile Driving Field Test

Test requirements and the information desired from the testing work:

1. Normal Pile installation according to the requirements FDOT
2. Performing dynamic load test after the driving process to obtain its geotechnical load capacity according to ASTM D4945-12.
3. Monitoring pile driving using PDA
4. Measuring the stresses and energy during piles installation by PDA :

- Top compression stress;
- Toe compression stress;
- Tensile stress;
- Maximum energy transmitted to the pile
- Measuring the force and velocity during blow of the dynamic test
- Total soil resistance to pile driving (static and dynamic)
- Counting the blow numbers per measured m of penetration

Pile Driving Field Test

Hammer Type

Pile driving and testing were performed with a Vulcan 512 single-acting air hammer (12 kips ram weight, fitted with mechanism that allowed for reportedly 3 and 5 feet stroke heights).

Pile Driving Field Test

The three piles before driving test

Pile Driving Field Test

PDA (Pile Driving Analyzer)

PDA Computer

Accelerometer (left) and strain transducer (right)

- The main PDA testing objectives are the **monitoring of pile driving stresses and structural integrity**. The data is also utilized to monitor hammer performance and estimate soil resistance.
- A Pile Driving Analyzer®(PDA) system is utilized for field testing and data processing, and **the CAPWAP® program** is used for selected data analysis.

Pile Driving Field Test

PDA (Pile Driving Analyzer)

Pile Driving Field Test

Start of Driving and Dynamic Load Test

Pile Driving Field Test

Driving and Dynamic Load Test

Pile Driving Field Test Results

Visual observations

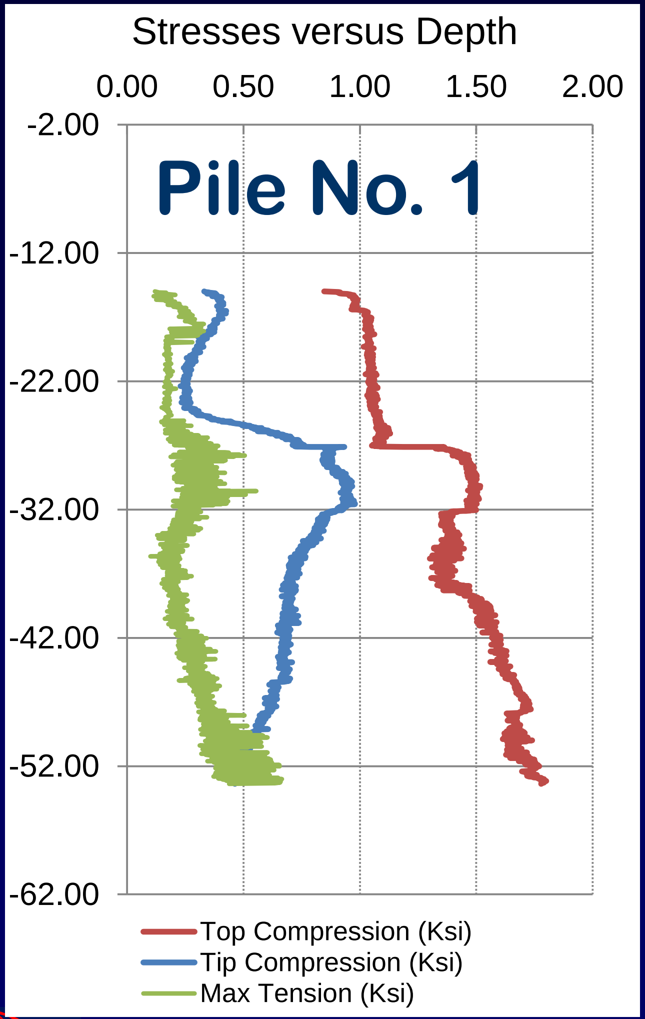
- Normal pile driving behavior
- No cover spalling
- No cracking
- No damage
- Average Pile capacity 333 ksi

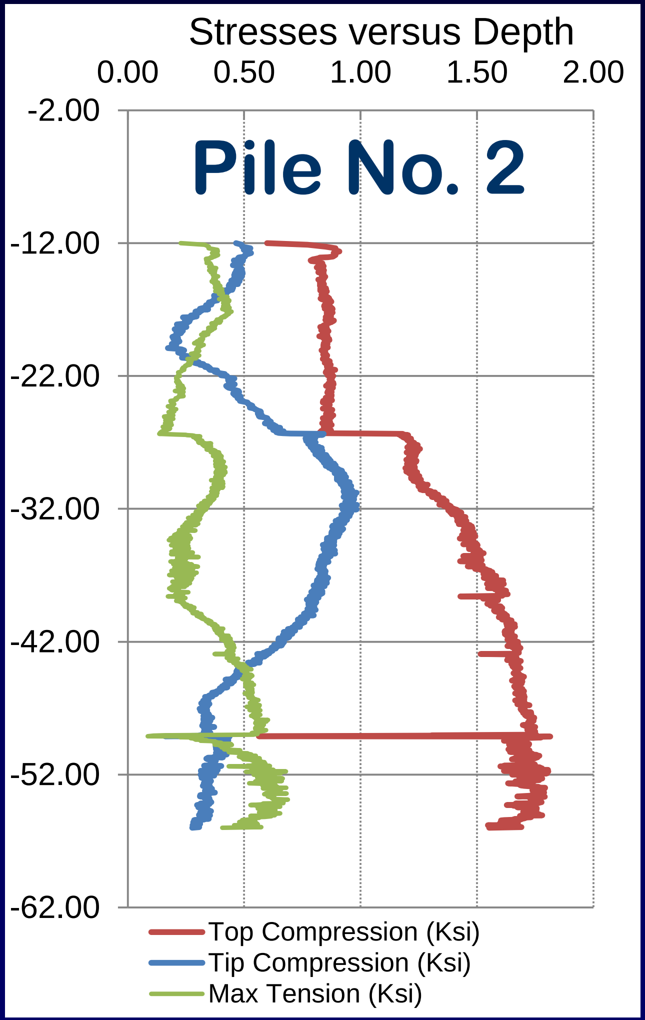
Instrumentation

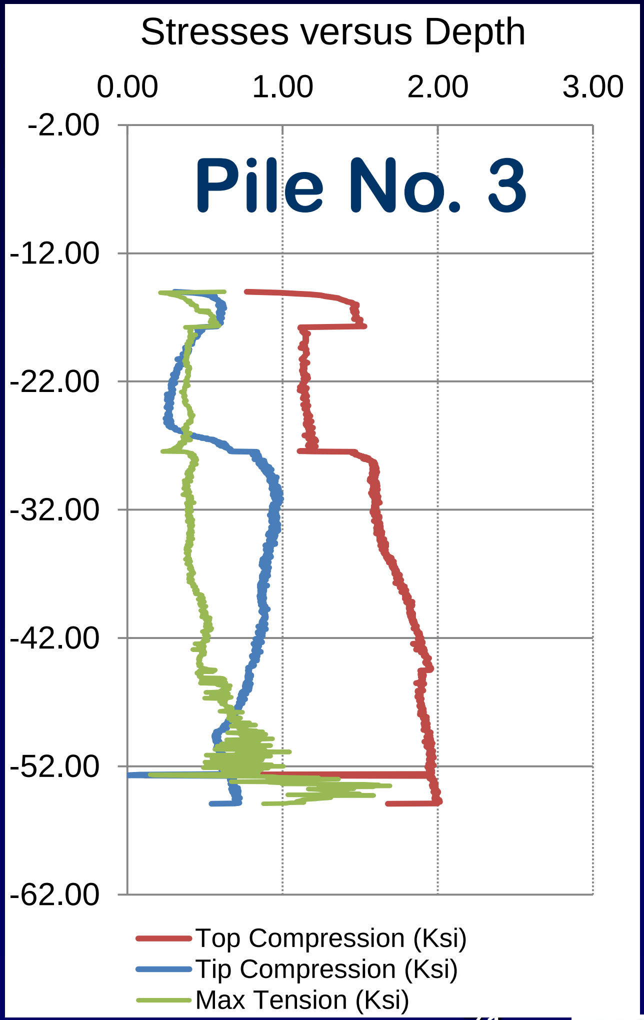
- PDA
- EDC

Pile Driving Field Test Results

Measured Stress versus Depth







Pile Costs Estimation

Concrete Pile Size – 24”

Cost/F US$	GFRP NonPrestressed	Steel Prestressed	CFCC Prestressed
Fabrication and shipment	50	80	120
Reinforcement	20	30	80
Driving	25	25	25
Total	**95**	**135**	**225**

Conclusions

This research project on GFRP RC piles have shown very positive results and suggest the technical viability of the use of precast GFRP reinforced concrete piles in harsh environments and the possibility of installing them following the procedure normally employed for precast concrete piles reinforced with steel bars.

Additional tests are planed next year.

Acknowledgment

Halls River Bridge

Prof. **Antonio Nanni**
University of Miami (USA)
Università di Napoli Federico II (Italy)

International Workshop on
Glass Fiber Reinforced Polymer Bar
18 July 2017, Delta Hotel, Sherbrooke, QC, CANADA

Outline

Halls River Bridge

- Bridge Overview
- Update on bridge construction
  - Images from 01/11/2017 to 07/10/2017 compliments of:

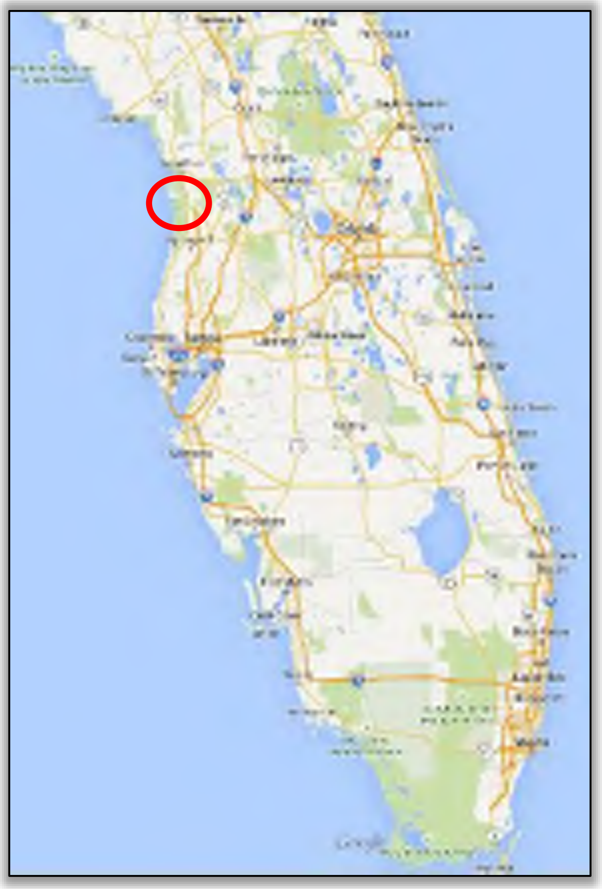
ASTALDI CONSTRUCTION Corp.

- Bridge elements directly related to SEACON
  - Intro to SEACON; Bulkhead caps; Retaining walls and Traffic railings

Halls River Bridge

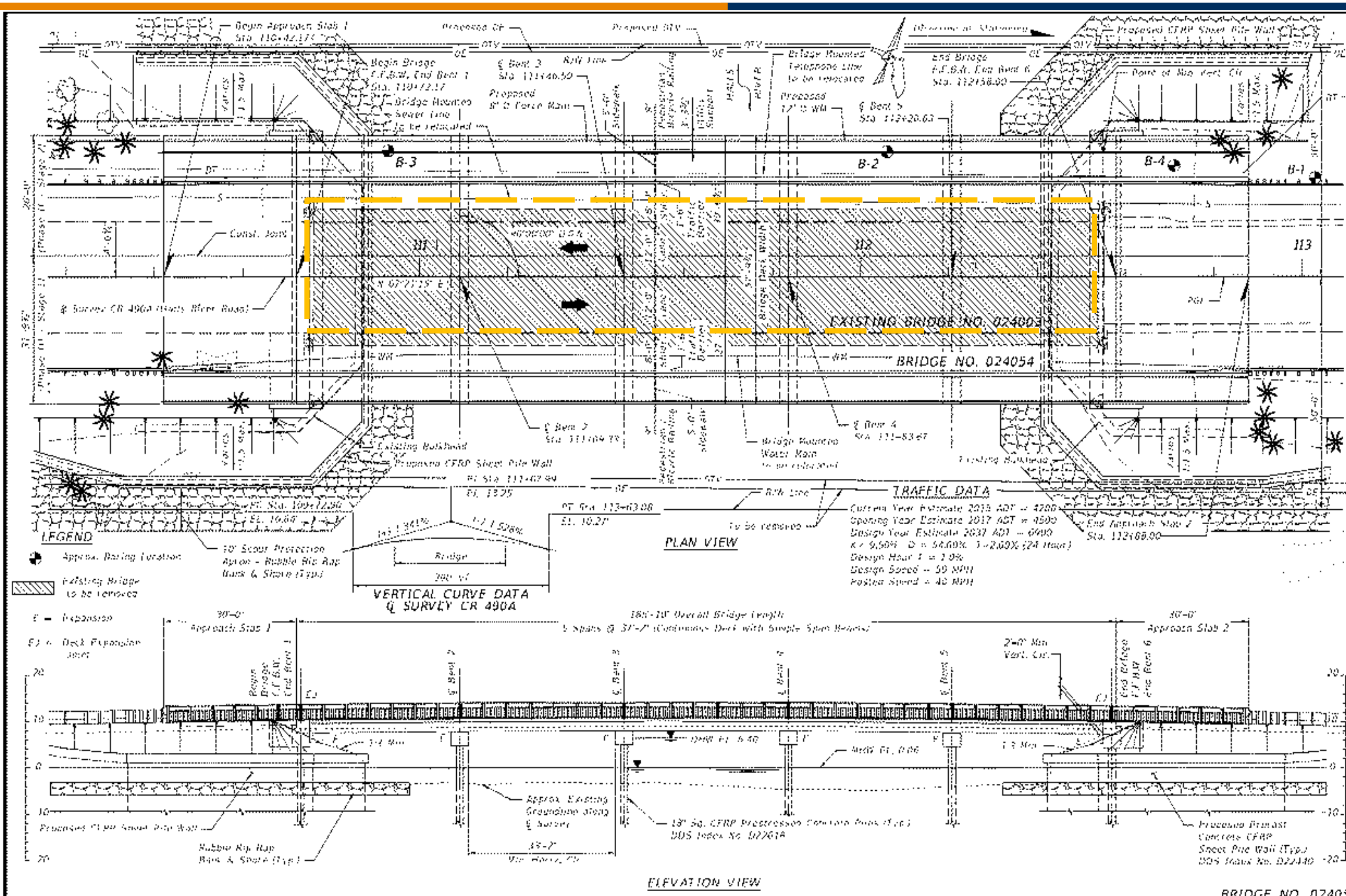
Infravation
An Infrastructure Innovation Programme

- FDOT design and construction supervision
- Astaldi general contractor
- Components with GFRP reinforcement:
  - Deck and railings
  - Pile caps
  - Bulkhead cap
  - Sheet piles (stirrups only)
  - Retaining walls



Project Overview –
Halls River Bridge Replacement

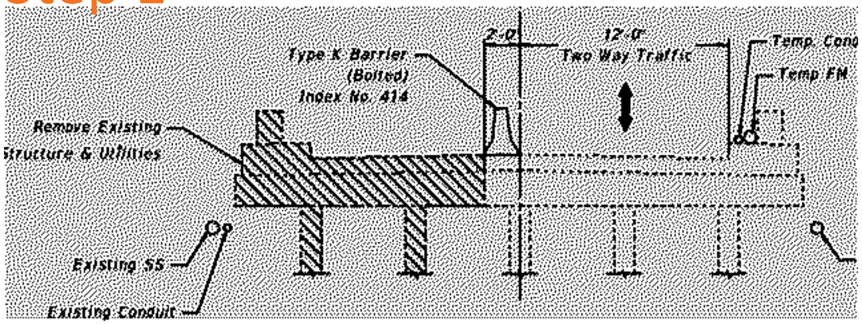
Infravation
An Infrastructure Innovation Programme



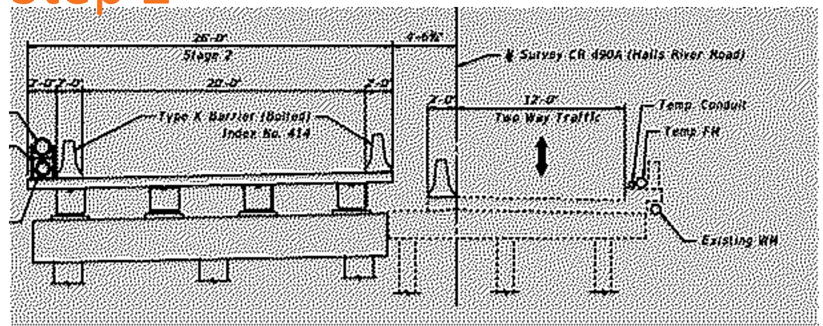
Existing (orange) and New Layout

Construction Steps

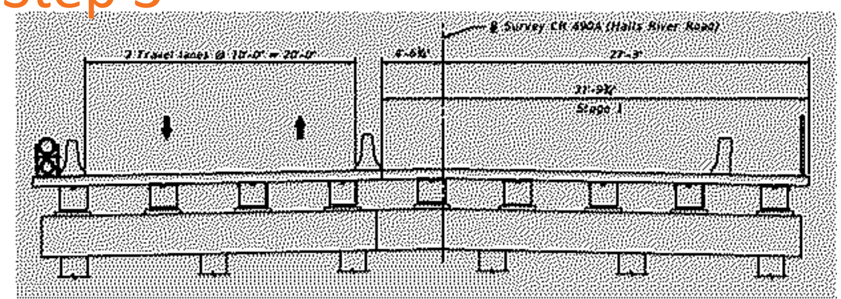
Step 1



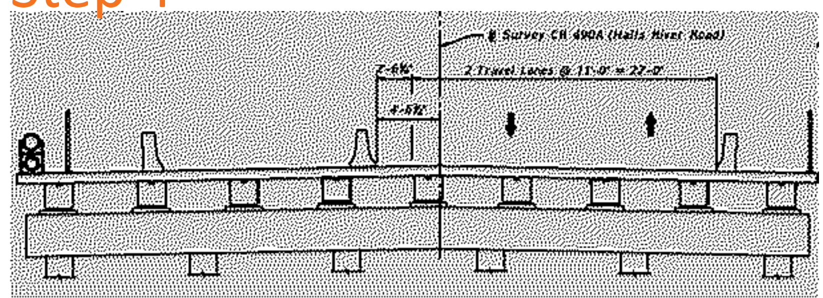
Step 2



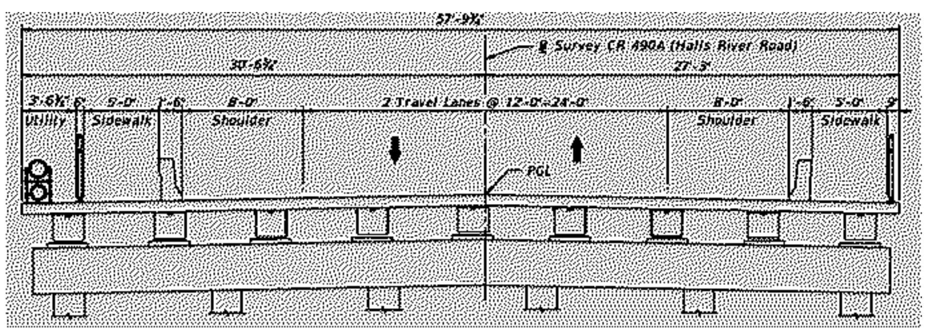
Step 3



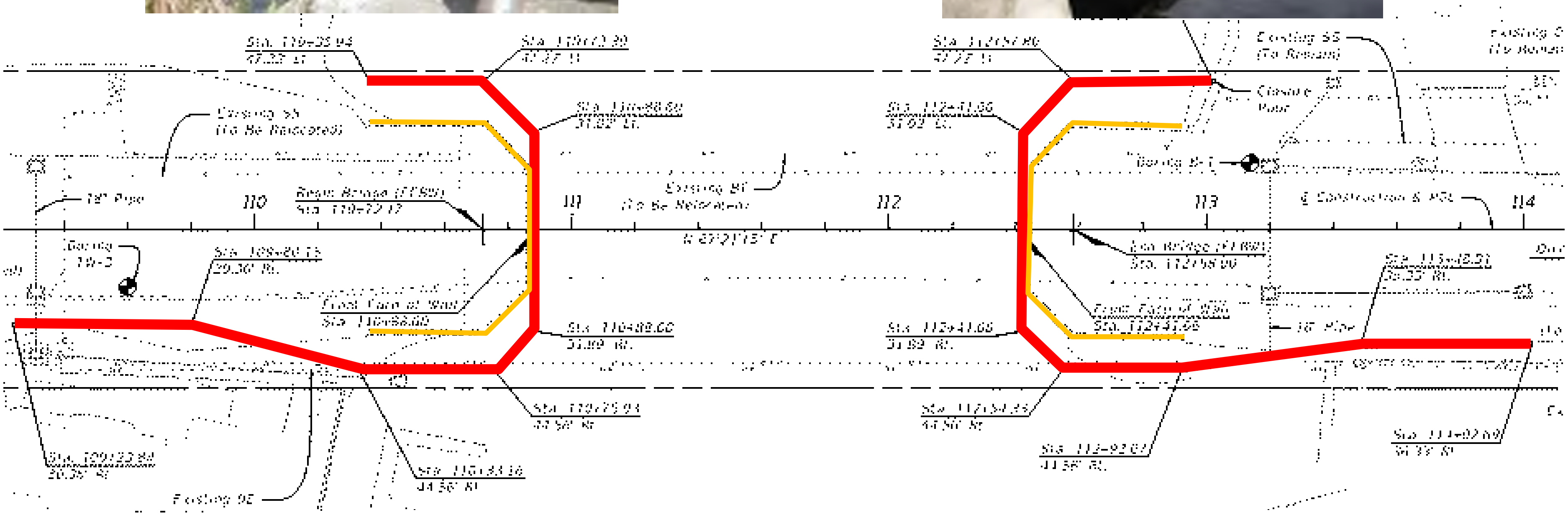
Step 4



Final Step



Project Overview – Halls River Bridge Replacement



Existing (orange) and New Bulkhead (red) Layout

Work progress: 1/11/2017 - day one

Existing bridge view

Work progress: 1/11/2017 - day one

Work on approach road with temporary paving

Work progress: 1/31/2017

Barriers set in place: 12 ft. width temporary two-way traffic lane on existing bridge (South side)

Work progress: 2/06/2017

Demolition of existing bent caps and piles

Work progress: 2/17/2017

Driving of 18 in. square CFRP prestressed concrete (PC) piles at pier #3

Work progress: 2/24/2017

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Piles driven at piers #3 and #5; temporary sheet-pile installation at West side

Work progress: 3/09/2017

Trial installation of the CFRP-PC sheet-pile by impact hammer

Work progress: 3/21/2017

Delivery of GFRP reinforcement

Work progress: 3/21/2017

Piles driven at piers #4 and #6

Work progress: 4/03/2017

Formwork installation for bent caps at piers #3, #4 and #5

Work progress: 4/04/2017

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View of formwork and temporary sheet-pile installation on the East side

Work progress: 4/12/2017

Excavation at East side for permanent CFRP-PC sheet-pile wall

Work progress: 4/12/2017

6 man-power complete bent cap cage in 4.5 hours

Work progress: 4/13/2017

Placing of GFRP reinforcement cage at bent caps #4 and #5

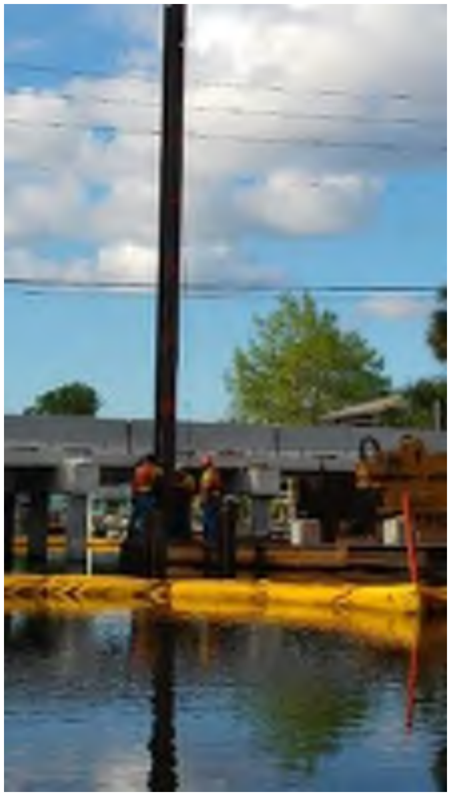
Work progress: 4/18/2017




Concrete placement at bent caps #4 and #5

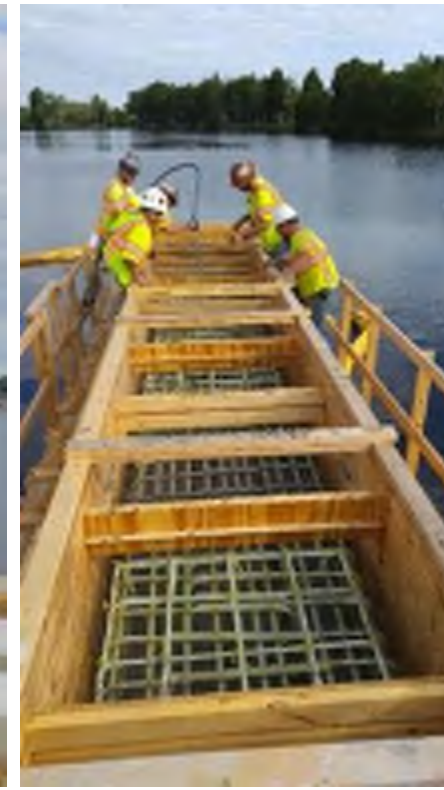
Work progress: 4/25/2017

Infravation
An Infrastructure Innovation Programme



Exploratory steel H-shape driven 150 feet at pier #2
(determine splice length of permanent piles at pier #2)

Work progress: 4/26/2017



Demolding completed at bent caps #4 and #5.
Concrete placement at bent cap #3

Work progress: 5/16/2017

Combined action of excavator and auger drill to install CFRP-PC sheet piles

Work progress: 5/30/2017

Hybrid Composite Beams set in span 4

Work progress: 6/13/2017

Extra temporary sheet piles driven to sustain and protect excavation of East seawall

Work progress: 6/21/2017

32-in.-deep holes drilled on installed piles in bent 2 for splicing. Temporary jig set-up

Work progress: 6/27/2017

Infravation
An Infrastructure Innovation Programme

Epoxying pile splices male-female sides

Work progress: 6/28/2017

First set of the 42-ft pile splices driven in bent 2

Work progress: 6/29/2017

Infravation
An Infrastructure Innovation Programme

Second set of 42-ft pile splices joined on top of first set of pile splices. 7 gallons of epoxy per splice

Outline

Halls River Bridge

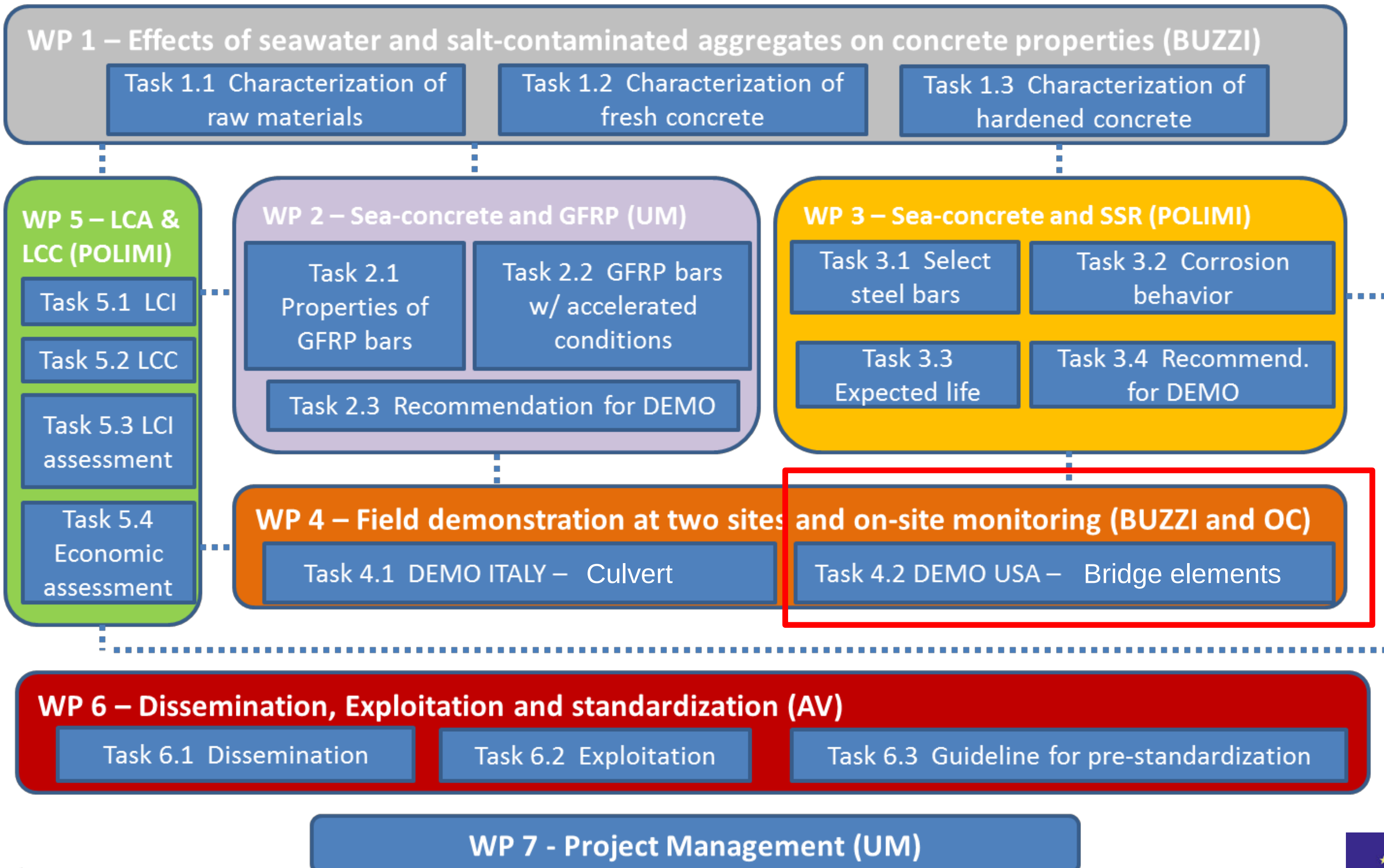
- Bridge Overview
- Update on bridge construction
  - Images from 01/11/2017 to 07/10/2017
- Bridge elements directly related to SEACON
  - Intro to SEACON
  - Bulkhead caps and test blocks
  - Retaining walls
  - Traffic railings

SEACON - Scope & Participants

Scope: Safe utilization of seawater and salt-contaminated aggregates (natural or recycled) for a sustainable concrete production when combined with non-corrosive reinforcement

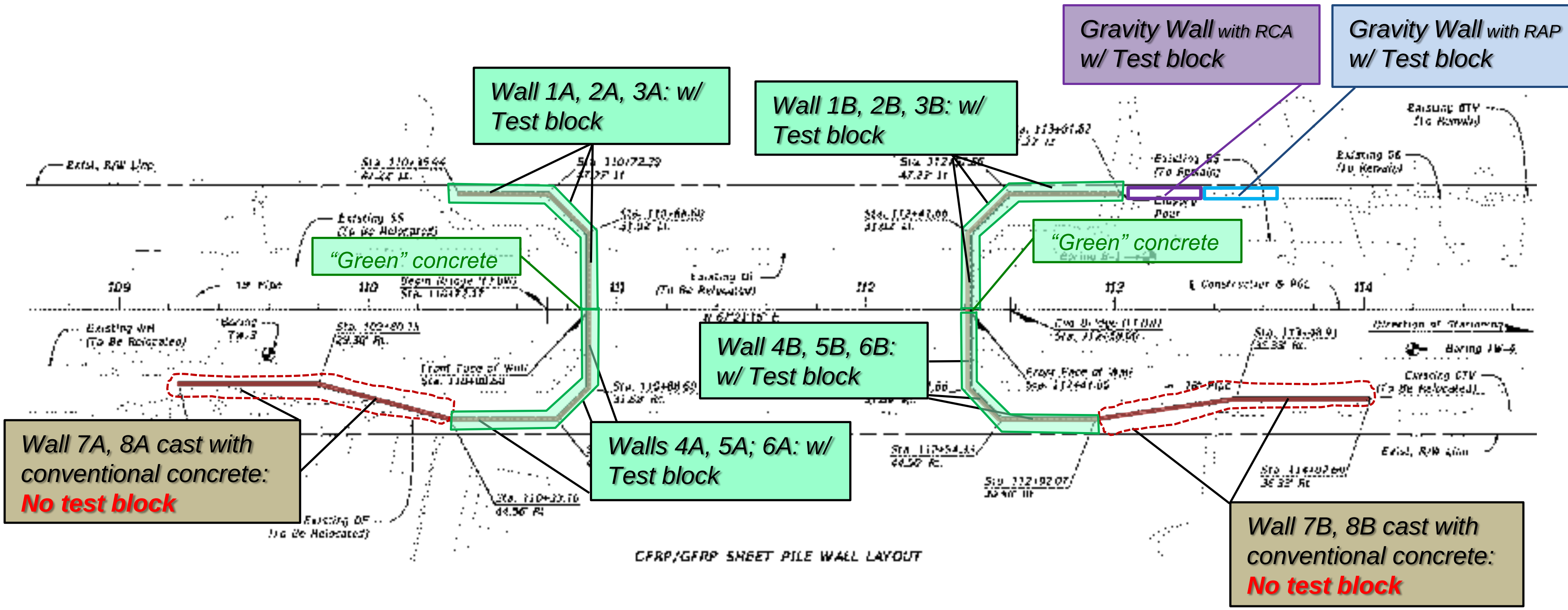
Nine among Partners & Collaborators

WPs, Tasks and Their Relationships



Bulkhead Cap for Sheet Pile Walls

"Green" concrete uses seawater for mixing



Total wall cap length: 575 LF

Total test block length: 395 LF

Bulkhead cap test blocks

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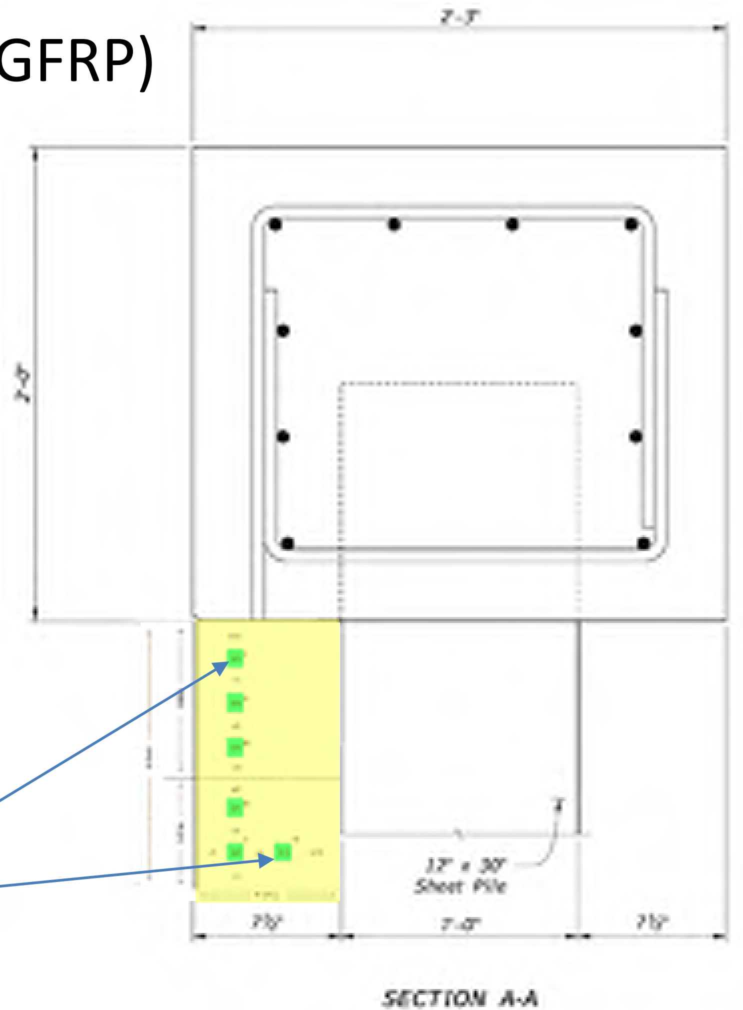
(with BFRP/CFRP/GFRP)

Bulkhead cap and test block are to be cast monolithically with same concrete mix



Six FRP bars for lab testing

Legend: Test block to be removed at different ages

Gravity Walls (with GFRP & RAP or RCA)

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An Infrastructure Innovation Programme

Mix Design Criteria:

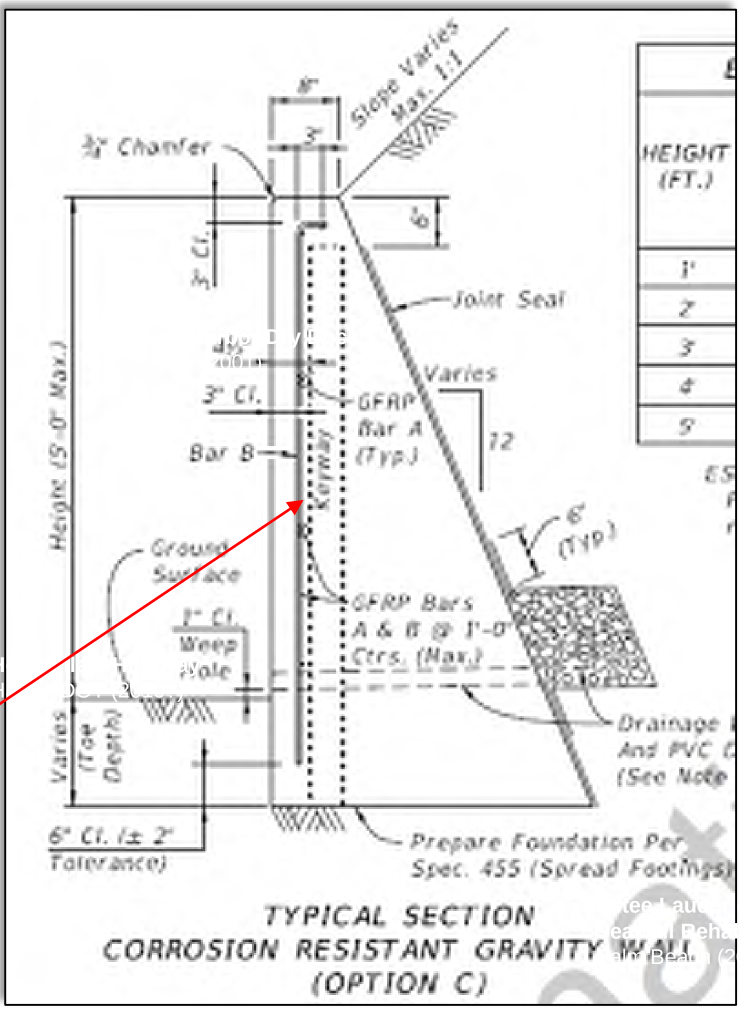
FDOT Material Specifications ***–347*** (RAP)

Dev347 (RCA – *project specific*)

Challenges:

i. Consistent aggregate gradation envelope for alternate source substitution

ii. Relevant performance based specifications



GFRP bar

Traffic Railings

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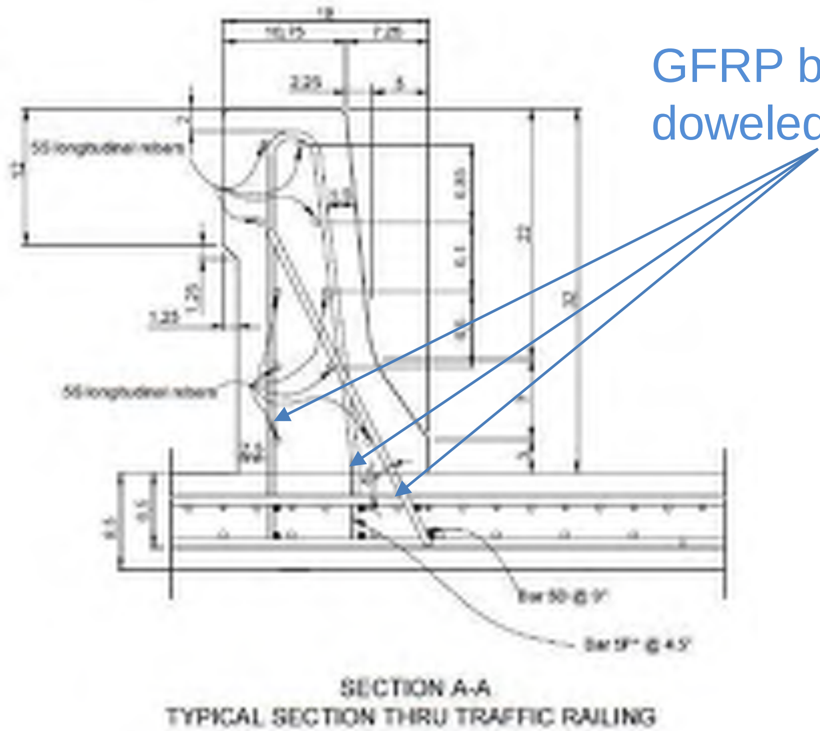
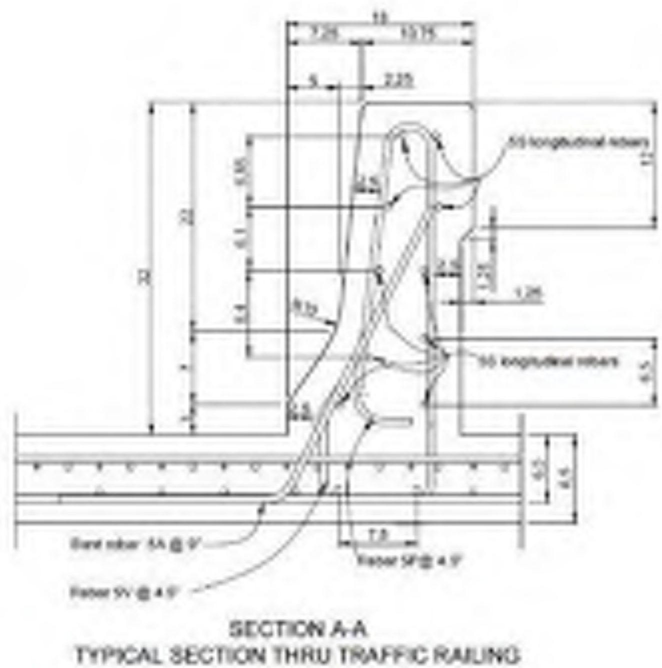
North Side – constructed on existing deck

South Side – constructed with deck





Concrete mixtures with: a) white cement; and, b) blend of slag and fly ash

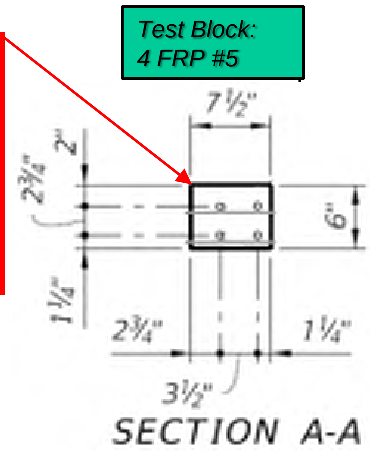
SEACON Test Matrix

Infravation
An Infrastructure Innovation Programme

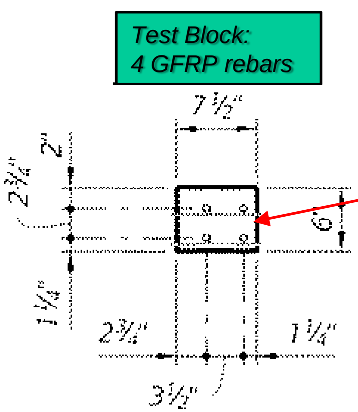
- RCA & RAP Gravity Walls

<u>24 test blocks of each RCA and RAP concrete mixes</u>

4 GFRP #5 rebar (half the blocks cast with conventional RCA and RAP mixes & half with green RCA and green RAP mixes)



- White Cement & Slag Blend Traffic Parapets



<u>12 test blocks of each WHITE CEMENT and SLAG BLEND concrete mixes</u>

Test blocks with 4 GFRP rebar

(All blocks cast separately not attached to walls or parapets)

Summary

- **Demonstration Project with Innovative Materials –** First in Florida
  - Superstructure: Hybrid Composite Beams; GFRP Bars: Deck, Barriers & Approach Slabs
  - Substructure: CFRP PC Piles; Bent Caps: GFRP Bars
  - Sheet Pile Walls: CFRP/GFRP Sheet Piles; Wall Cap: GFRP Bars
- **Estimated Project Cost - $6.1M (Structures = $3.7M)**
  - **B**ridge Cost = **$221 / sq. ft.**
    (Conventional Construction = **$166 / sq. ft.**)
- **Accelerated Construction**
  - Lighter Materials – Beams and Rebar
  - Faster Transportation and Delivery – reduced construction time

Any Question?

Thank you!

Fire Resistance of Concrete Slabs Reinforced with GFRP Bars

Mark F. Green and Hamzeh Hajiloo
Queen’s University, Kingston, Canada

First International Workshop on
GFRP Bars for Concrete Structures (IWGFRP-1)
Sherbrooke, Quebec 18 July 2017

Buildings need to be designed for fire safety

- FRP reinforced concrete buildings need design procedures for fire

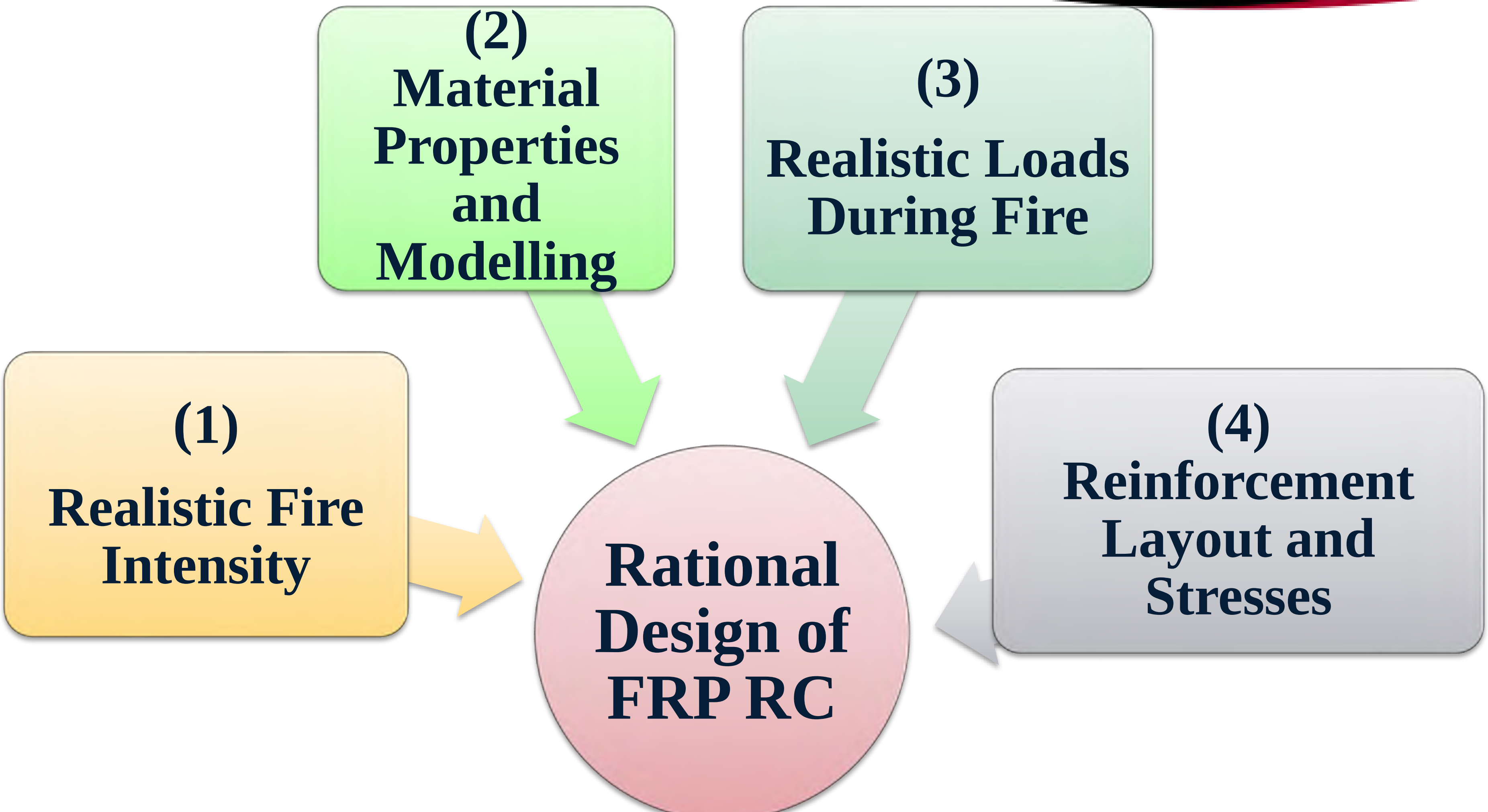
US Bridges (1980 to 2012)

- 30 failures due to fire
- 20 failures due to earthquake

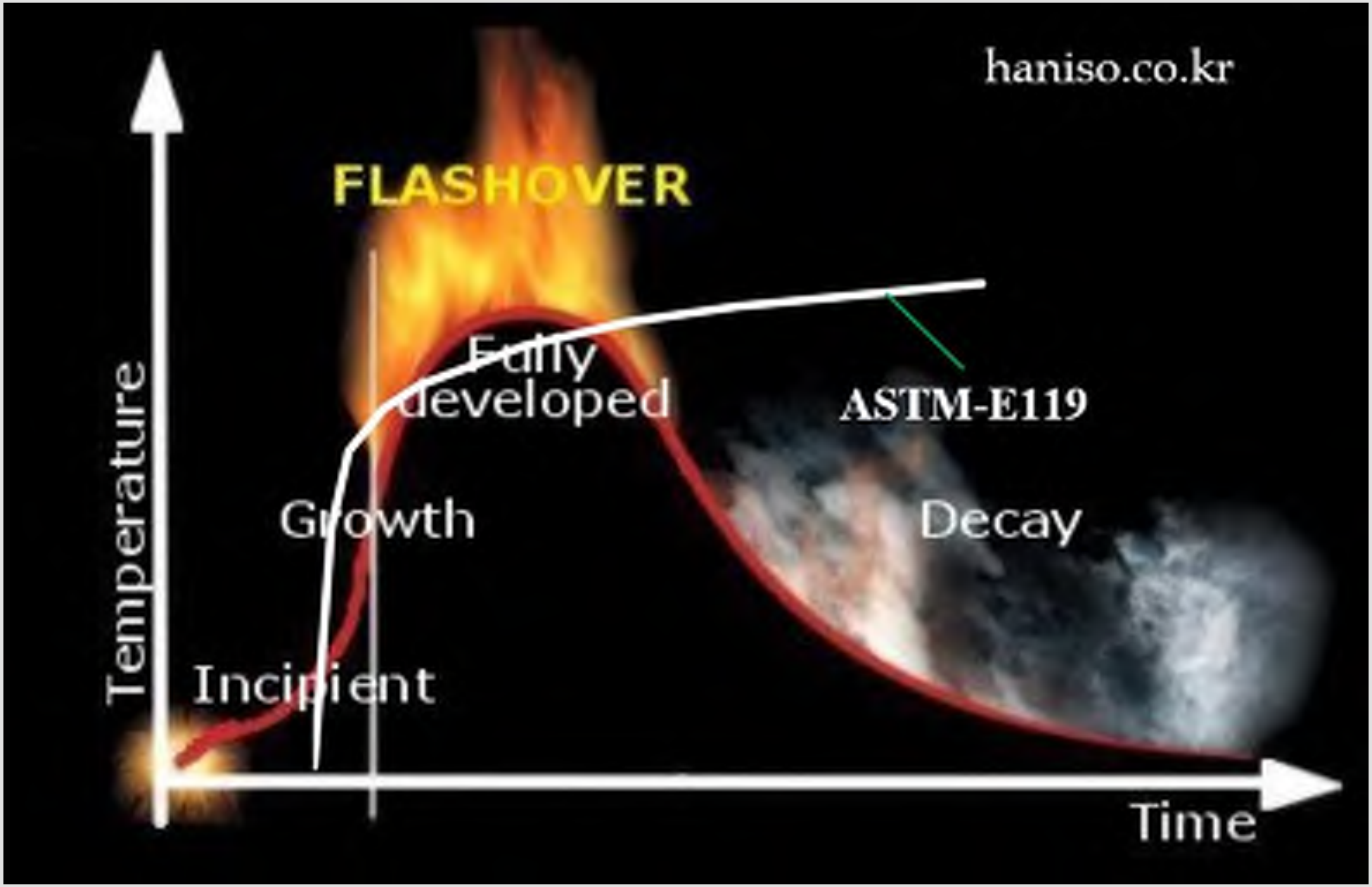
(Lee et. al. A study of US bridge failures)

Credit: Associated Press

An aerial view of the collapsed freeway overpass near downtown Oakland


(2) Material Properties and Modelling
(3) Realistic Loads During Fire
(1) Realistic Fire Intensity
Rational Design of FRP RC
(4) Reinforcement Layout and Stresses

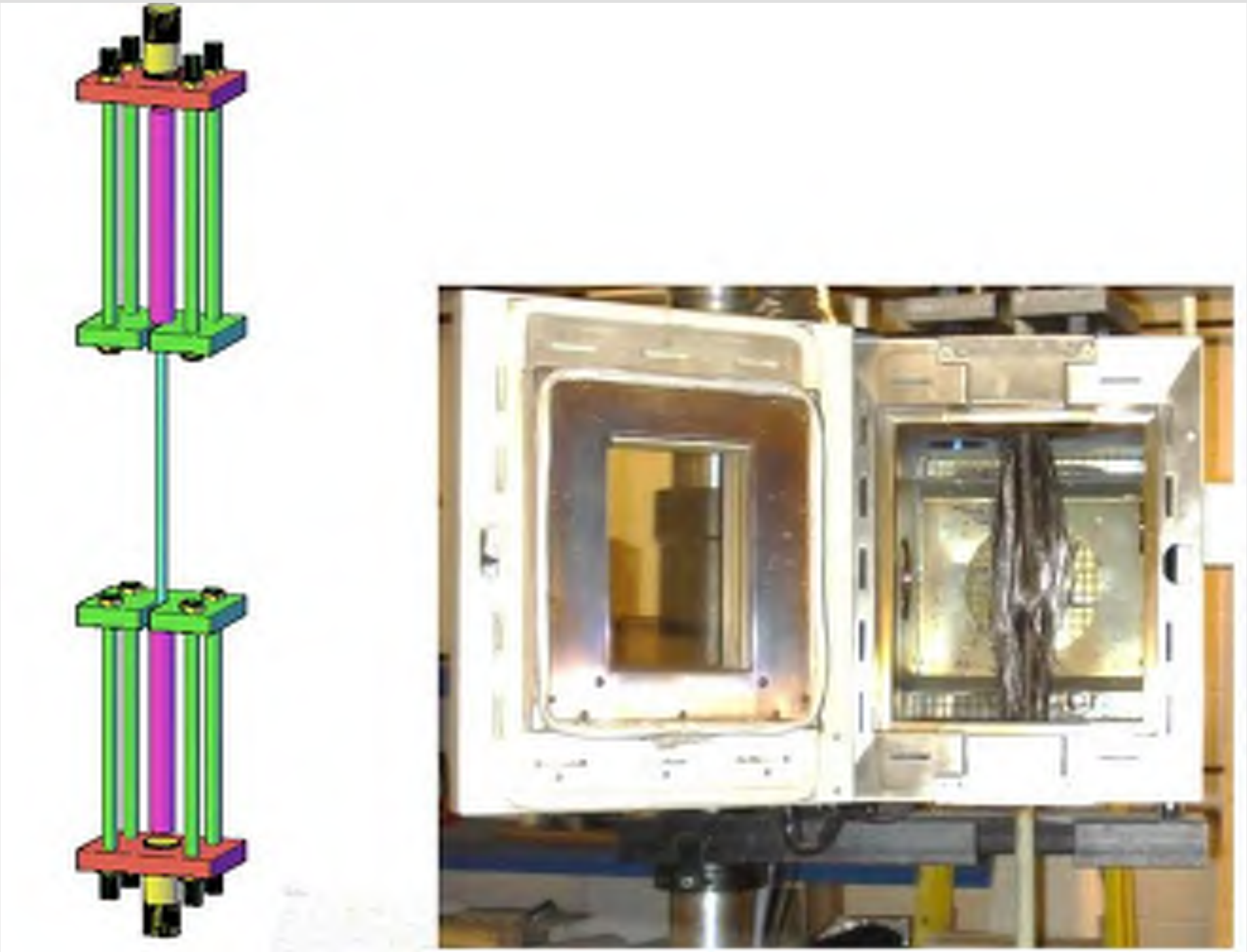
(1) Realistic Fire Intensity



After haniso.co.kr and Bisby and Stratford (2013)

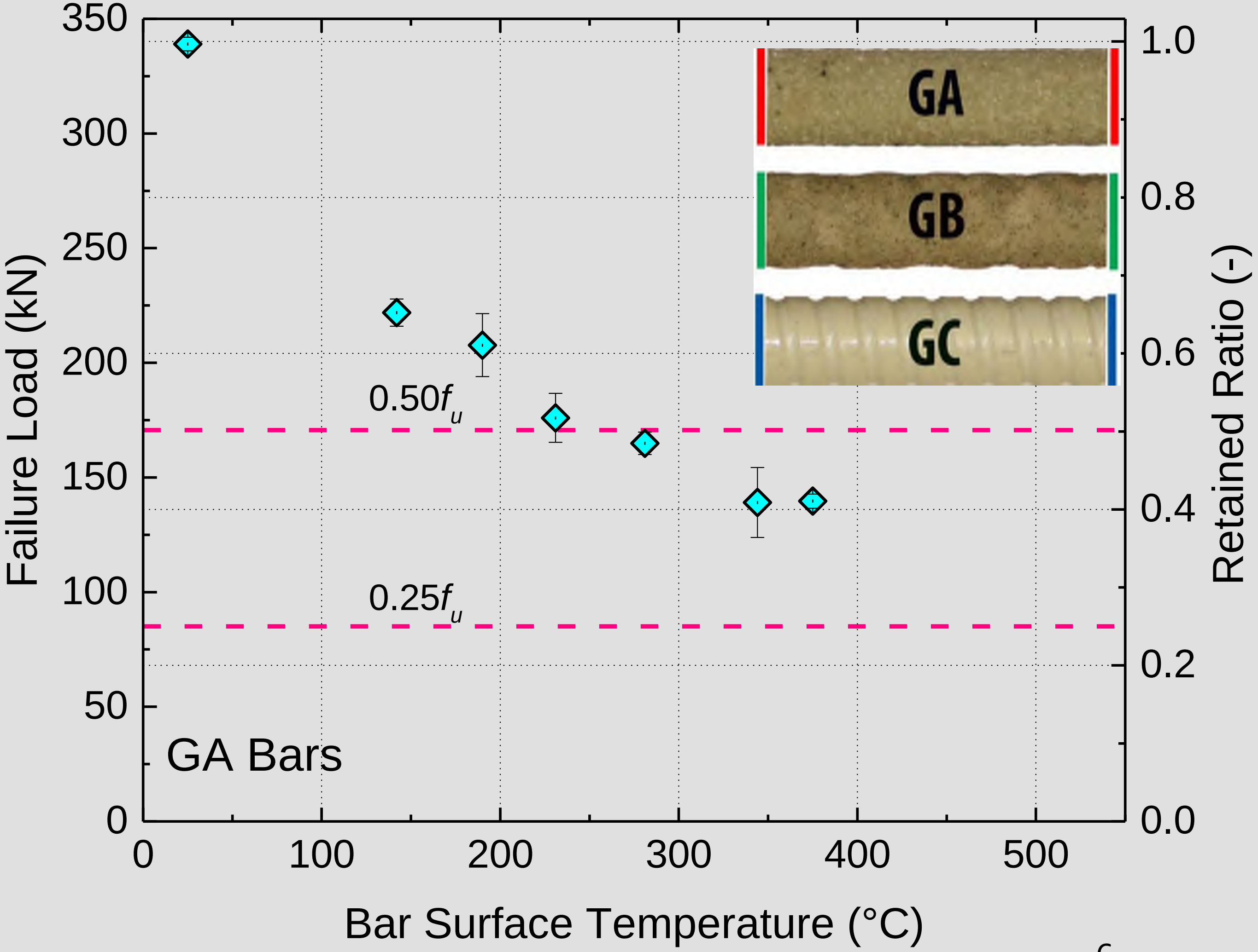
(2) Material Properties and Modelling

Tension Tests



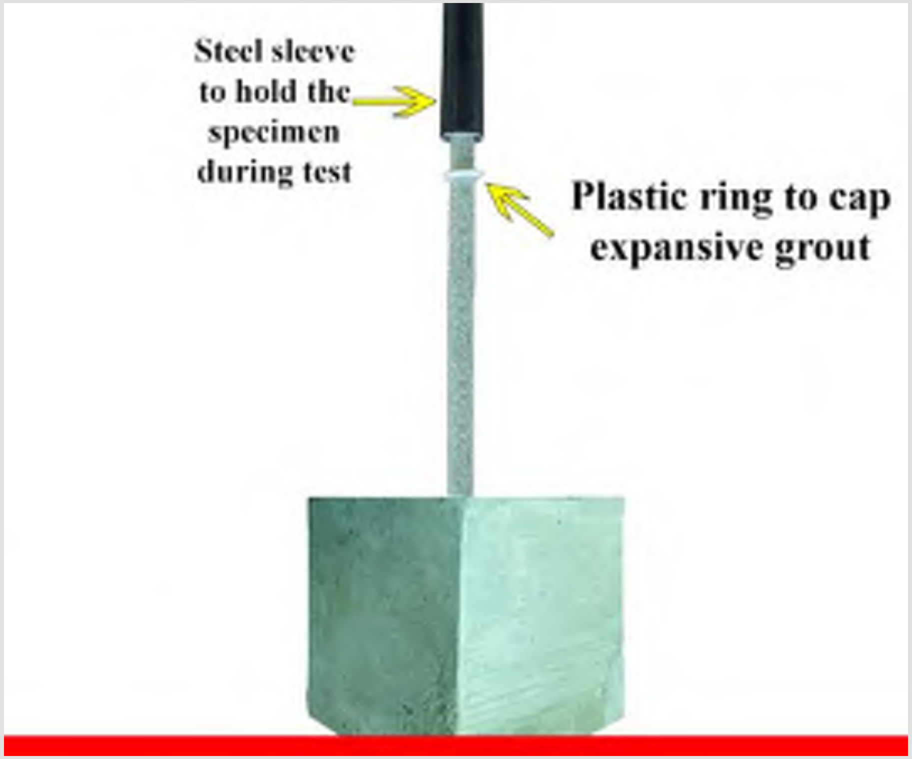
(2) Material Properties and Modelling

GA bars in tension



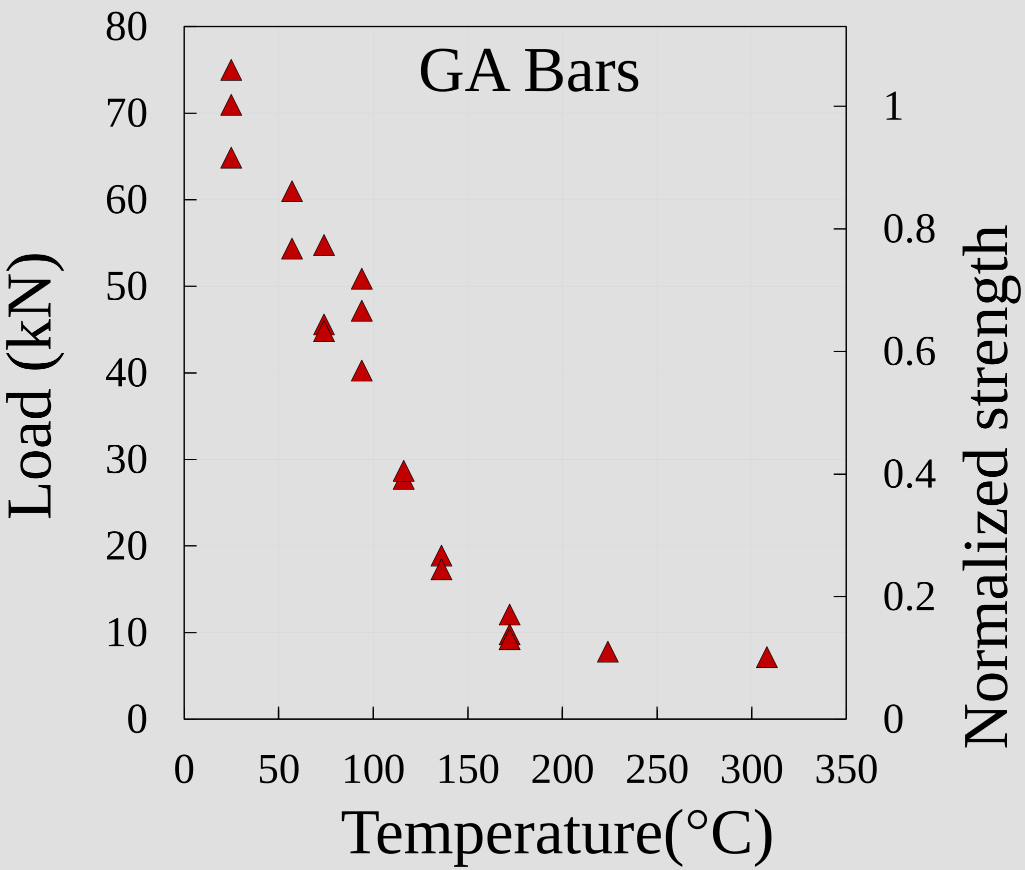
(2) Material Properties and Modelling

Material tests conducted on bond strength of FRP reinforcement at elevated temperatures

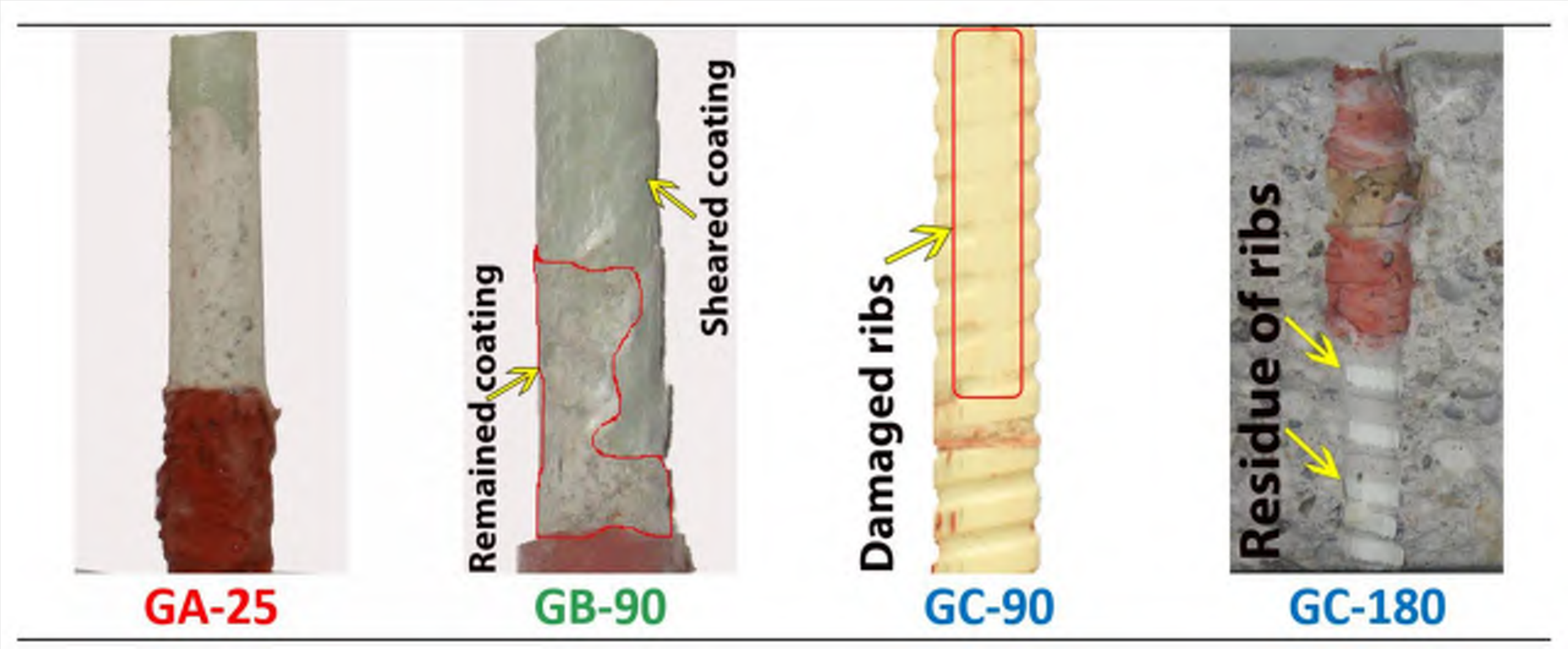


(2) Material Properties and Modelling

Some pullout test results:



(2) Material Properties and Modelling

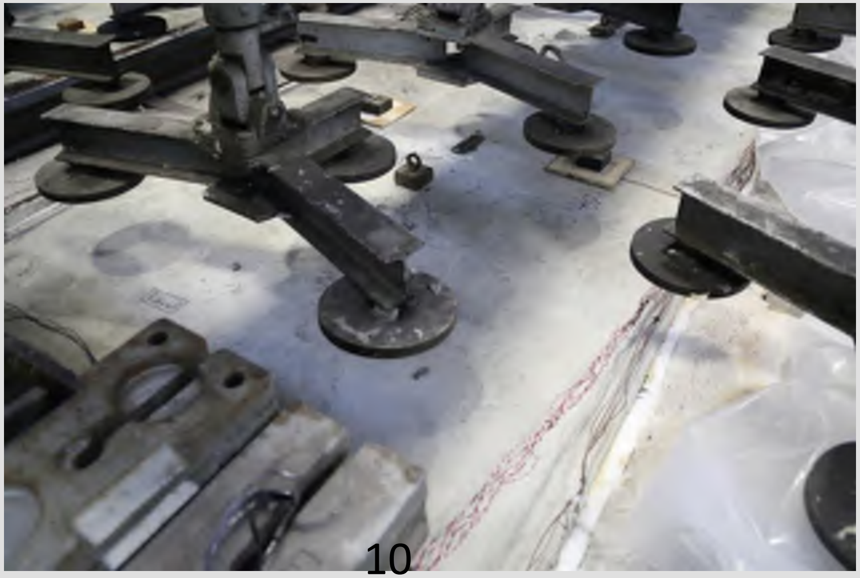


Various types of failure in steady-state temperature tests

Fire tests

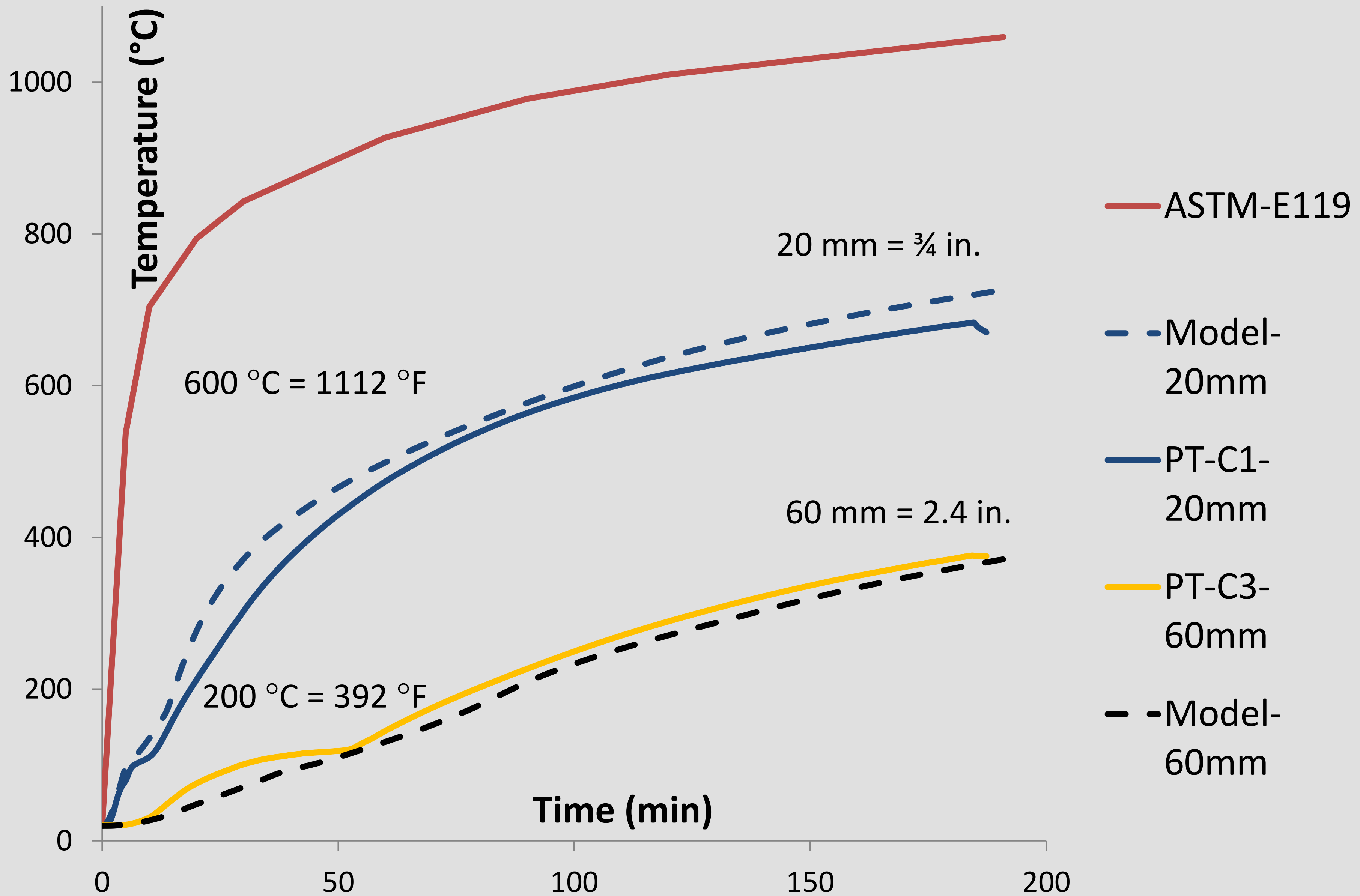
Slabs on the furnace

Slab fabrication



Uniform loading on the slabs

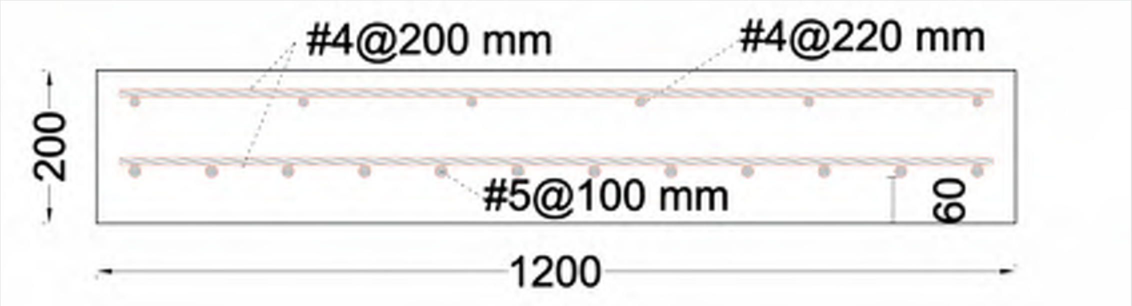
(2) Material Properties and Modelling



(3) Realistic Loads During Fire

The significance of realistic loads are discussed using the results of the latest fire tests on FRP RC slabs at NRC, Ottawa.

Full-scale slabs with 60 mm clear concrete cover:



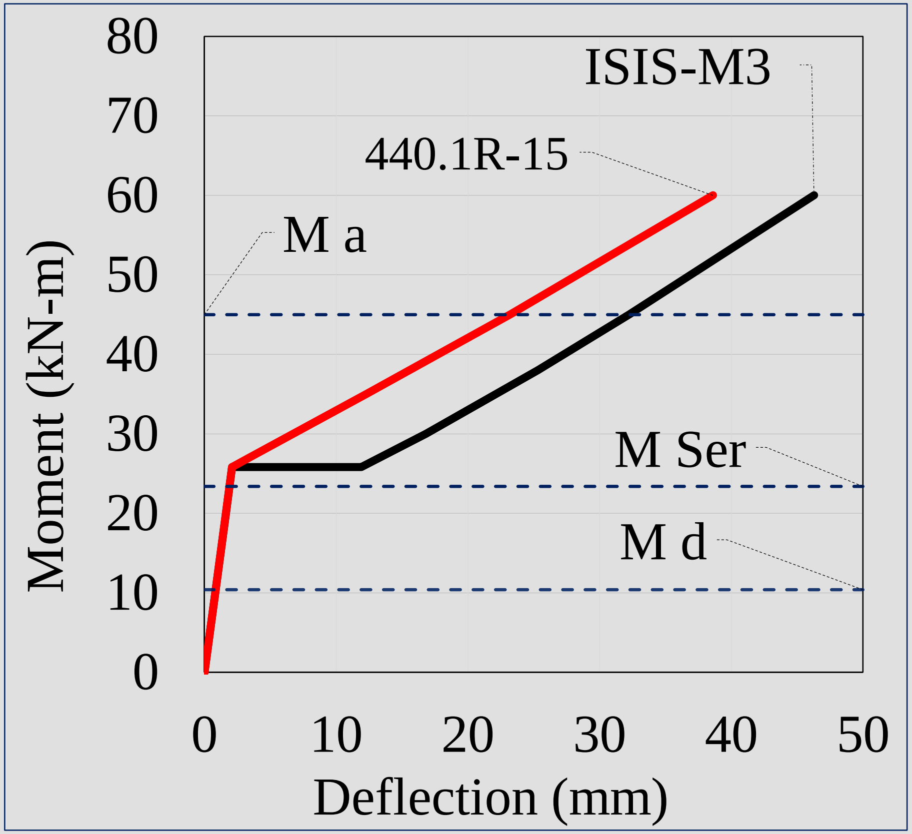
Width	Thickness	Clear Cover	Span	M_f	M_{Ser}	M_{cr}	M_r
mm	mm	mm	m	kN-m	kN-m	kN-m	kN-m
1200	200	60	3.8	32.5	23.4	25.8	84

The moment in fire was 45 kN.m (33 kip.ft)

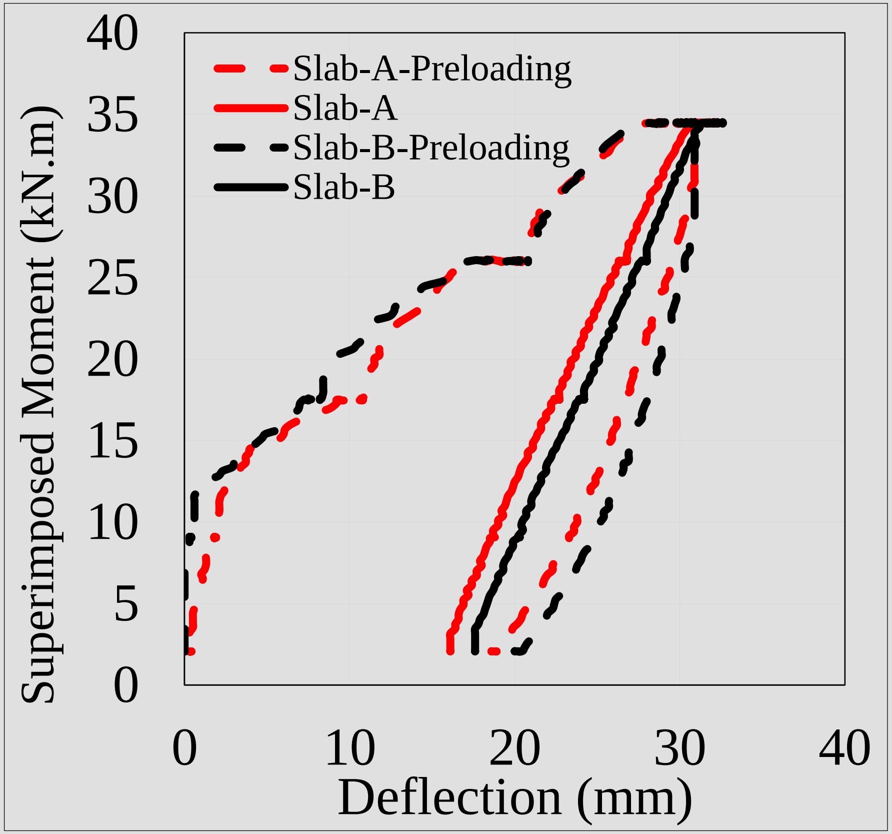
Overloaded by 90% with respect to service moment.

(3) Calculated (design) and measured deflections

Live load deflection limit l_n/360 = 10.5 mm (0.4 in.)



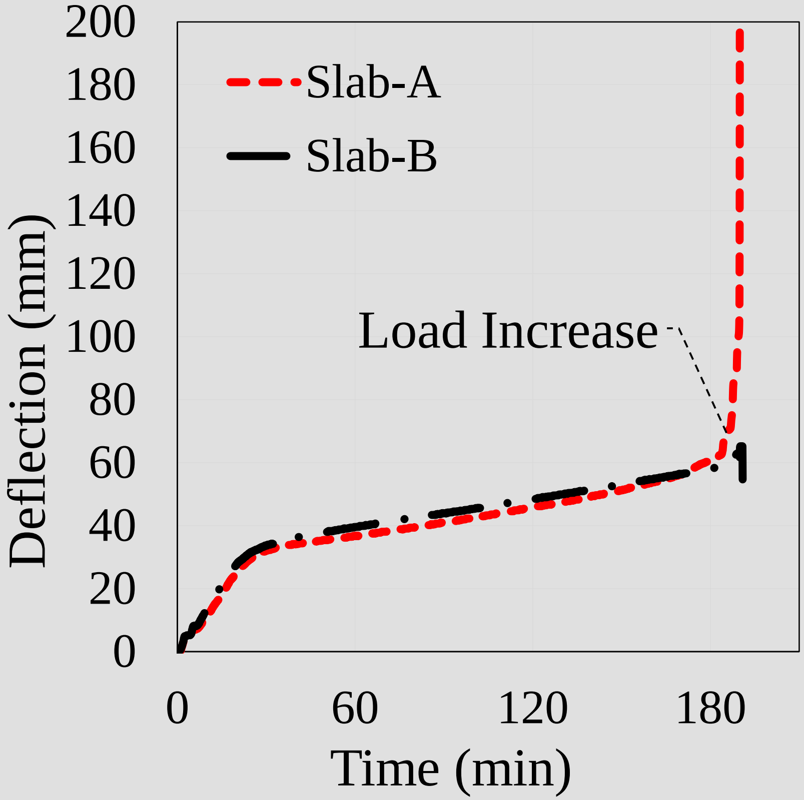
Calculated Deflections



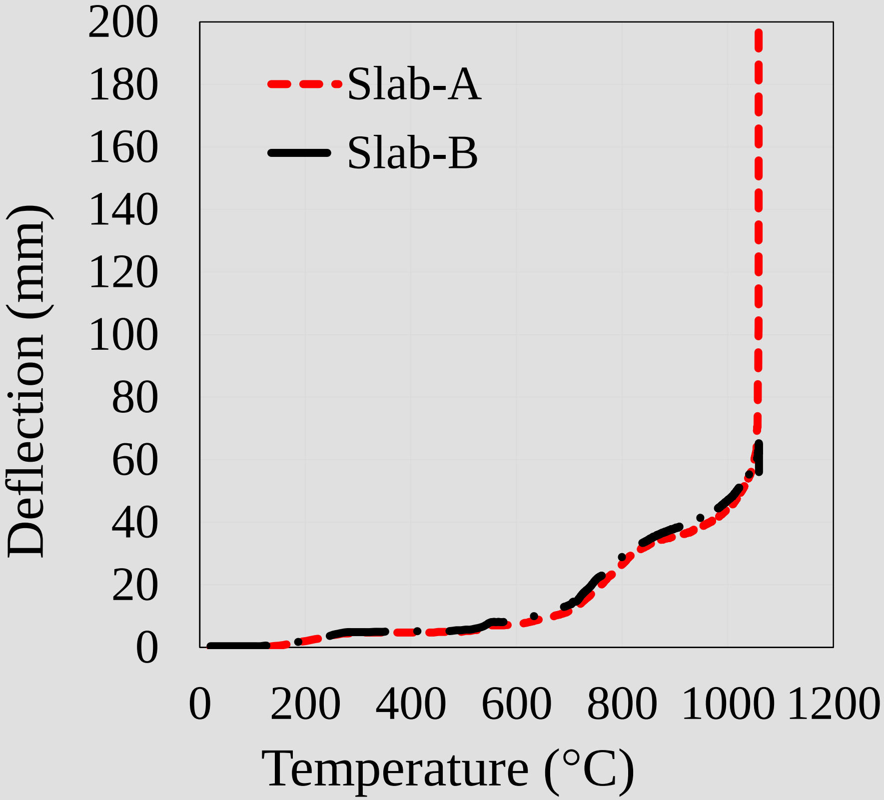
Measured Deflections

(3) Realistic Loads During Fire

Full-scale slabs with 60 mm clear concrete cover:



Deflection vs time during fire test

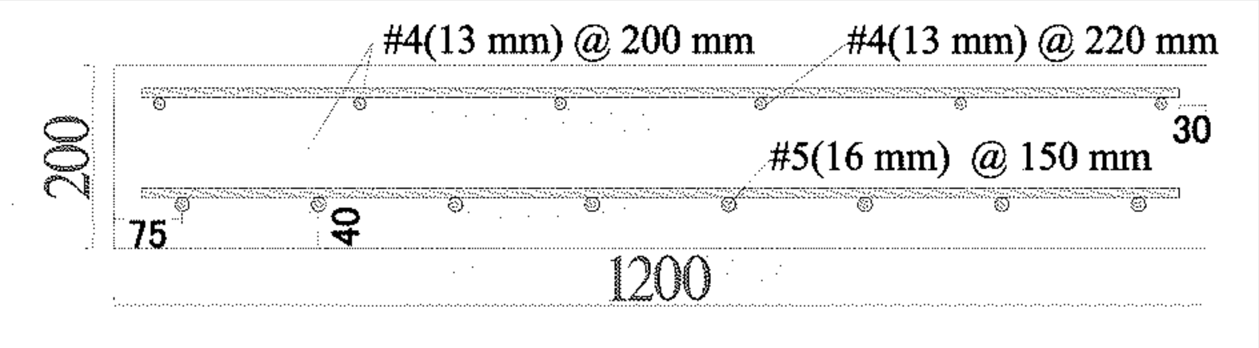


Deflection vs furnace temperature

NOTE: Deflections in the above curves are due to only fire plus the effect of load increase at the end of test.

(3) Realistic Loads During Fire

Full-scale slabs with 40 mm clear concrete cover:



Design of a FRP reinforced concrete slab

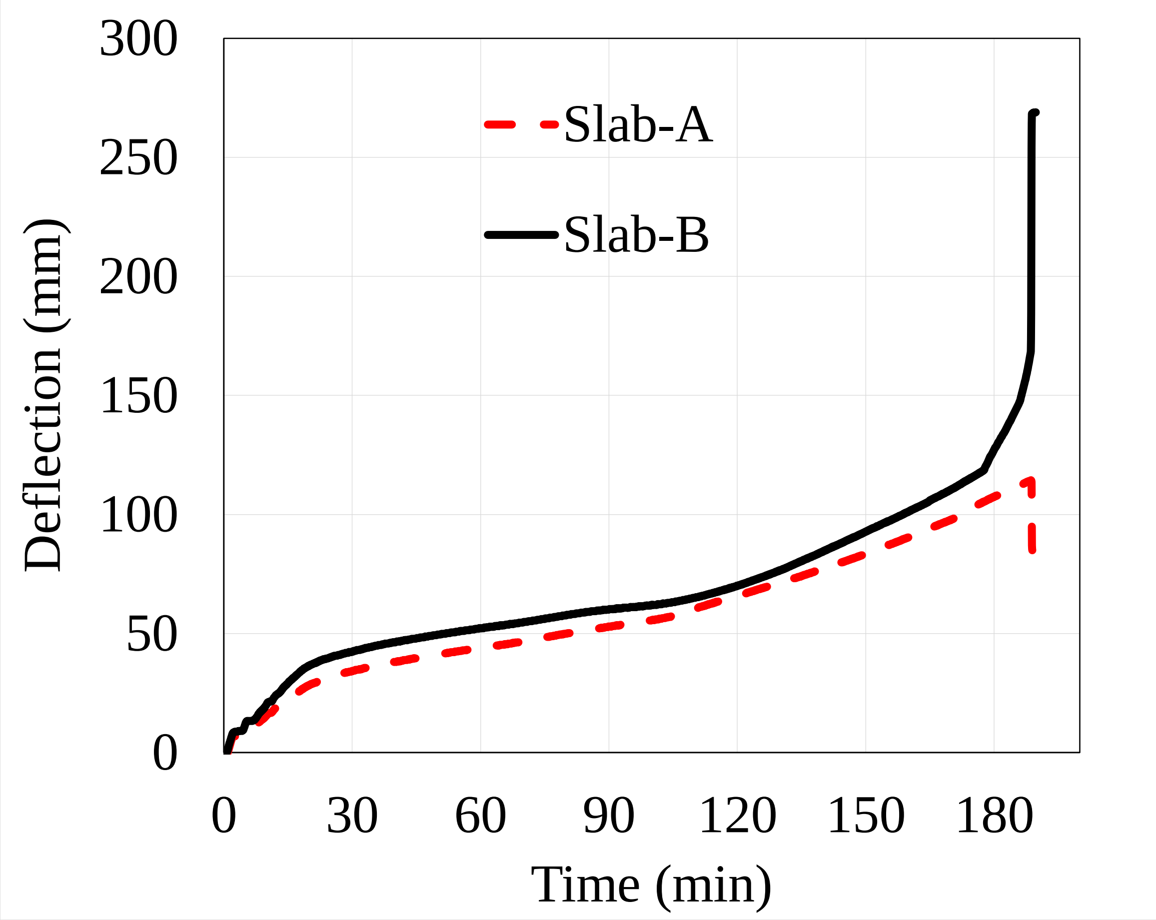
Width	Thickness	Clear Cover	Span	M_f	M_{Ser}	M_{cr}	M_r
mm	mm	mm	m	kN-m	kN-m	kN-m	kN-m
1200	200	40	3.8	32.5	23.4	26.3	92

The moment in fire was 45 kN.m.

Overloaded by 90% with respect to service moment.

(3) Realistic Loads During Fire

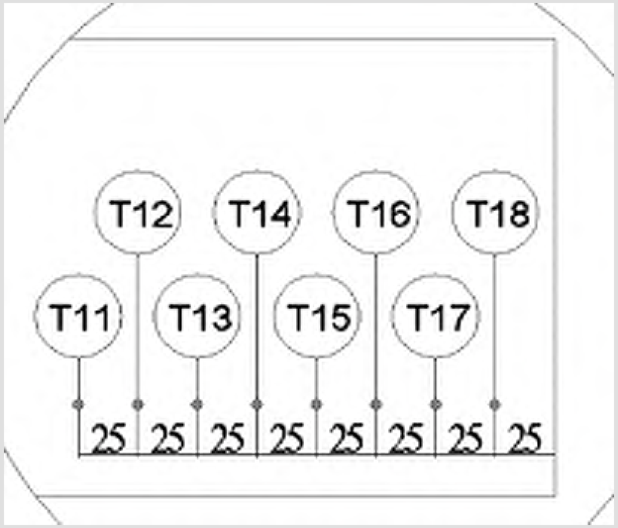
Full-scale slabs with 40 mm clear concrete cover:



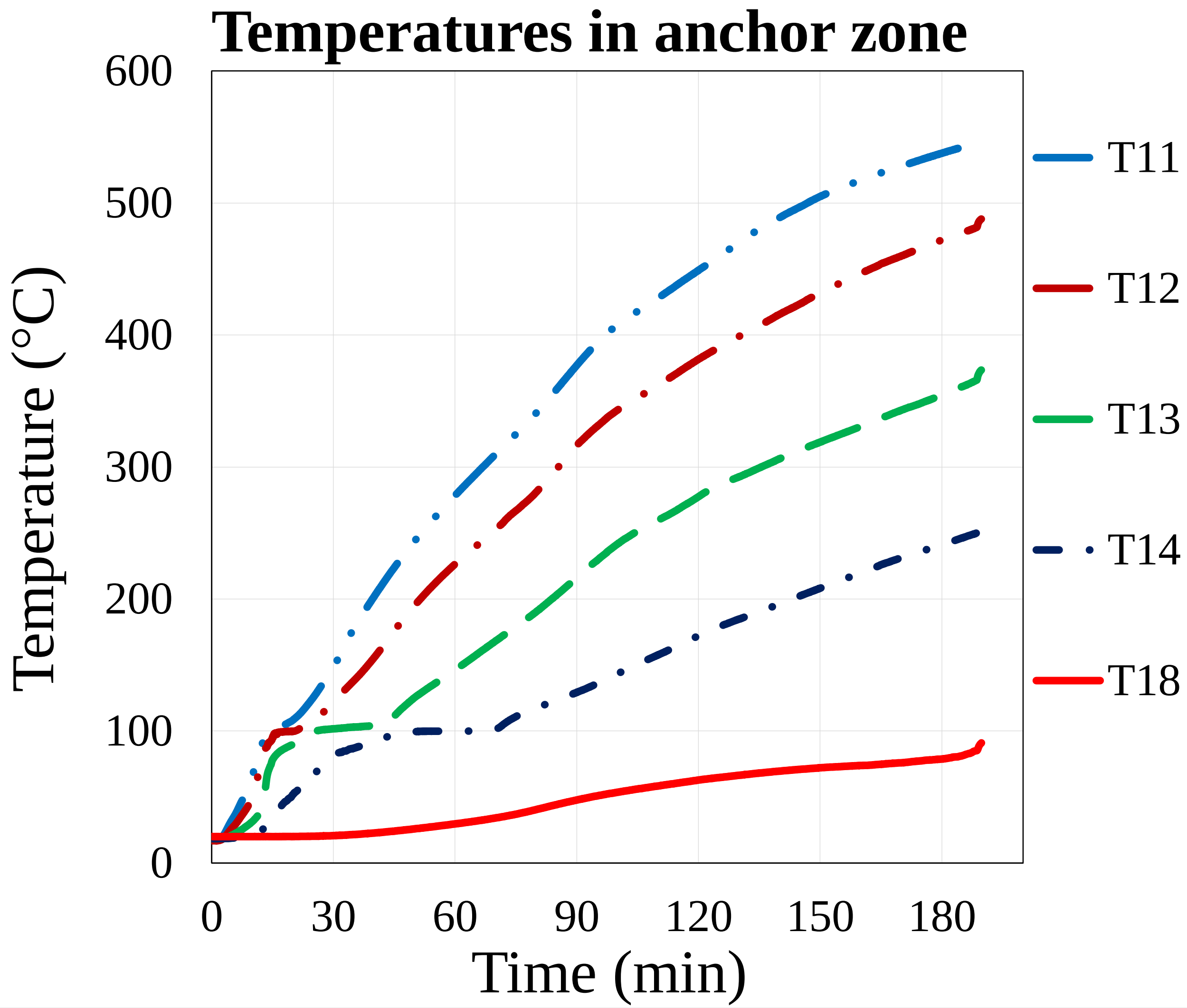
Deflection vs time during fire test

(4) Reinforcement Layout

Temperatures reduce towards the end of slab



Closely placed thermocouples in anchor zone (200 mm)



(4) Reinforcement Layout

Failure of one of the slabs

Pullout of FRP bars in the unexposed zone

(4) Reinforcement stresses

- All bars embedded in support
- First test 160 MPa (23 ksi) and 2600 $\mu\varepsilon$
- Second test 200 MPa (30 ksi) and 3300 $\mu\varepsilon$
- ACI 440 stress limits (GFRP)
  - ❑ 0.2 f_{fu} = 200 to 340 MPa (30 to 50 ksi)
- CSA S806/S6 strain limits for crack control
  - ❑ 2000 $\mu\varepsilon$

CONCLUSIONS AND FUTURE DIRECTIONS

- Realistic fires include cooling phase
- Material properties and modelling
  - ❑ GFRP performs well in tension
  - ❑ Bond is critical (anchor into cool zones)
- Fire tests and realistic
  - ❑ Strength does not govern design
  - ❑ 3 hours of fire resistance with 40 mm cover
- Anchorage and stress levels
  - ❑ *How to design appropriate anchorage?*

Acknowledgments

- Natural Sciences and Engineering Research Council of Canada (NSERC)
- J. Gales, M. Noel
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- University of Sherbrooke
  - B. Benmokrane, H. Mohamed
- MITACS Canada
- Ministry of Transportation of Ontario (MTO)
- Pultrall Inc. and BP Composites Ltd.

Thank you for your attention

First International Workshop on
Glass Fiber Reinforced Polymer (GFRP) Bar
for Concrete Structures (IWGFRP-1)

Are GFRP Rebars Sustainable?

Lawrence C. Bank, PhD, PE
Dist.M.ASCE, F.ACI, F.IIFC
Professor of Civil Engineering

The City College of New York

CUNY
The City University of New York

Objective

If GFRP rebars are durable does that mean that they are sustainable?

Outline

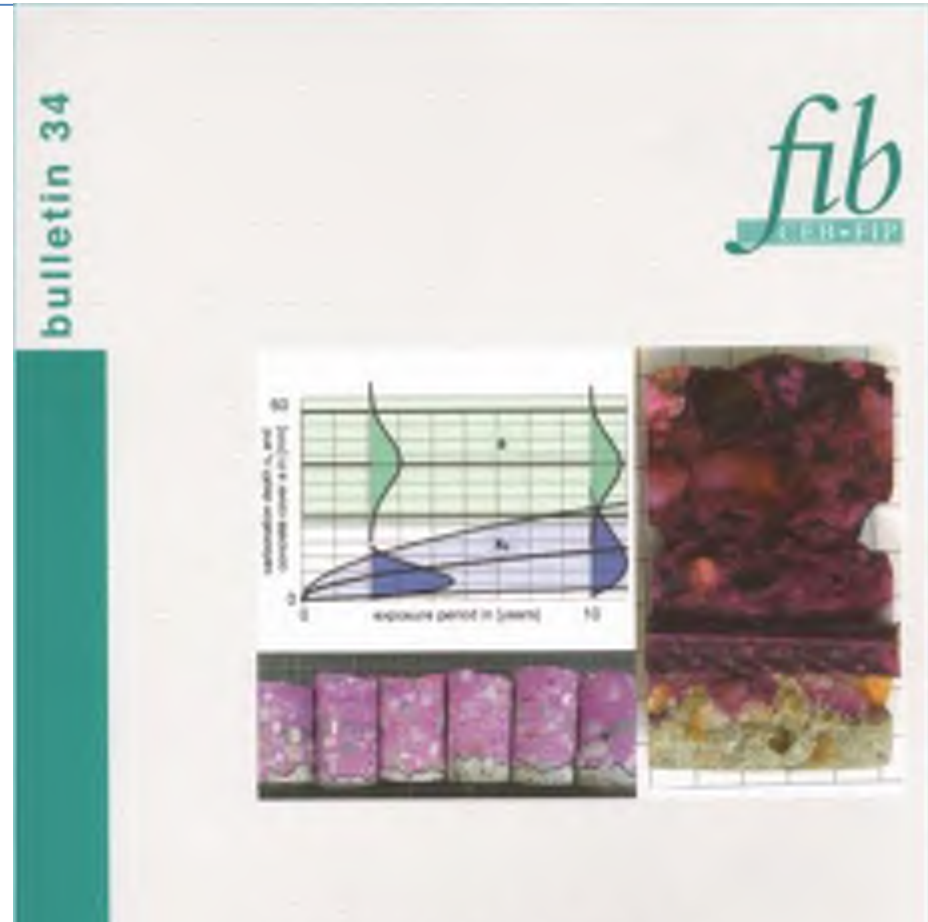
1. Design for Durability
2. Design for Sustainability
3. Are GFRP rebars durable?
4. Are GFRP rebars sustainable?

Design for Durability

INTERNATIONAL STANDARD

ISO 13823

General principles on the design of structures for durability



3.9

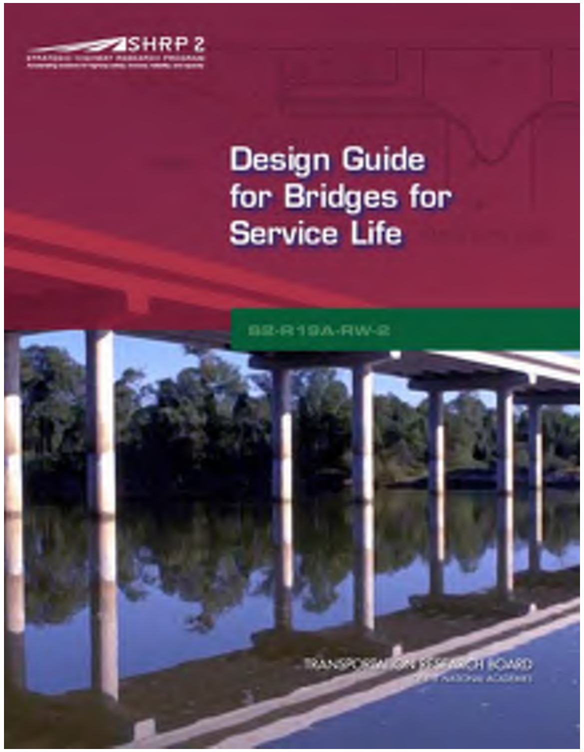
design life

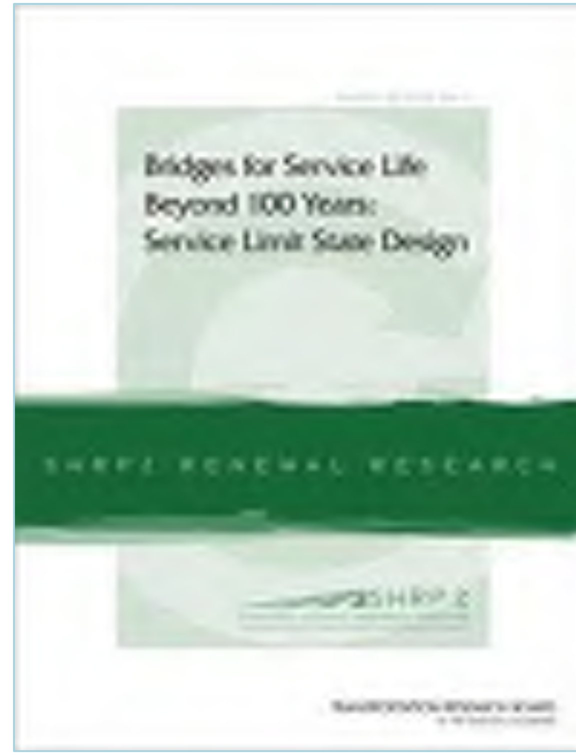
specified period of time for which a structure or a component is to be used for its intended purpose without major repair being necessary

3.10

durability

capability of a structure or any component to satisfy, with planned maintenance, the design performance requirements over a specified period of time under the influence of the environmental actions, or as a result of a self-ageing process





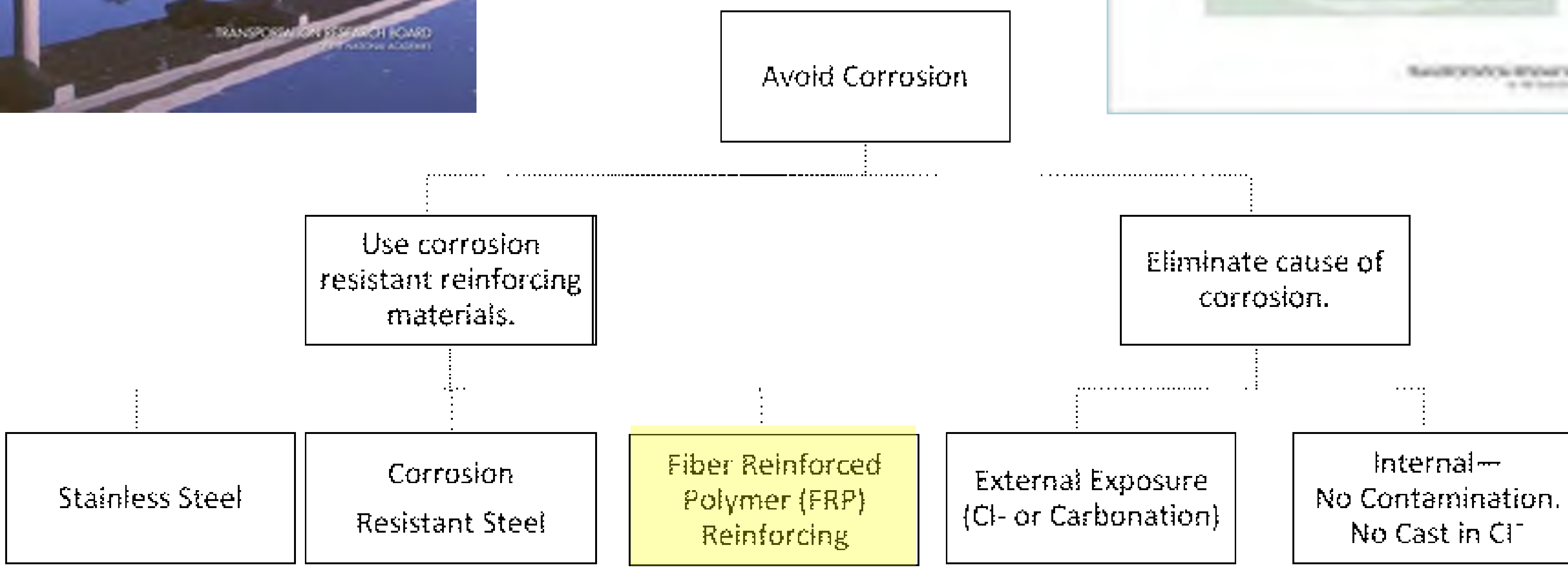
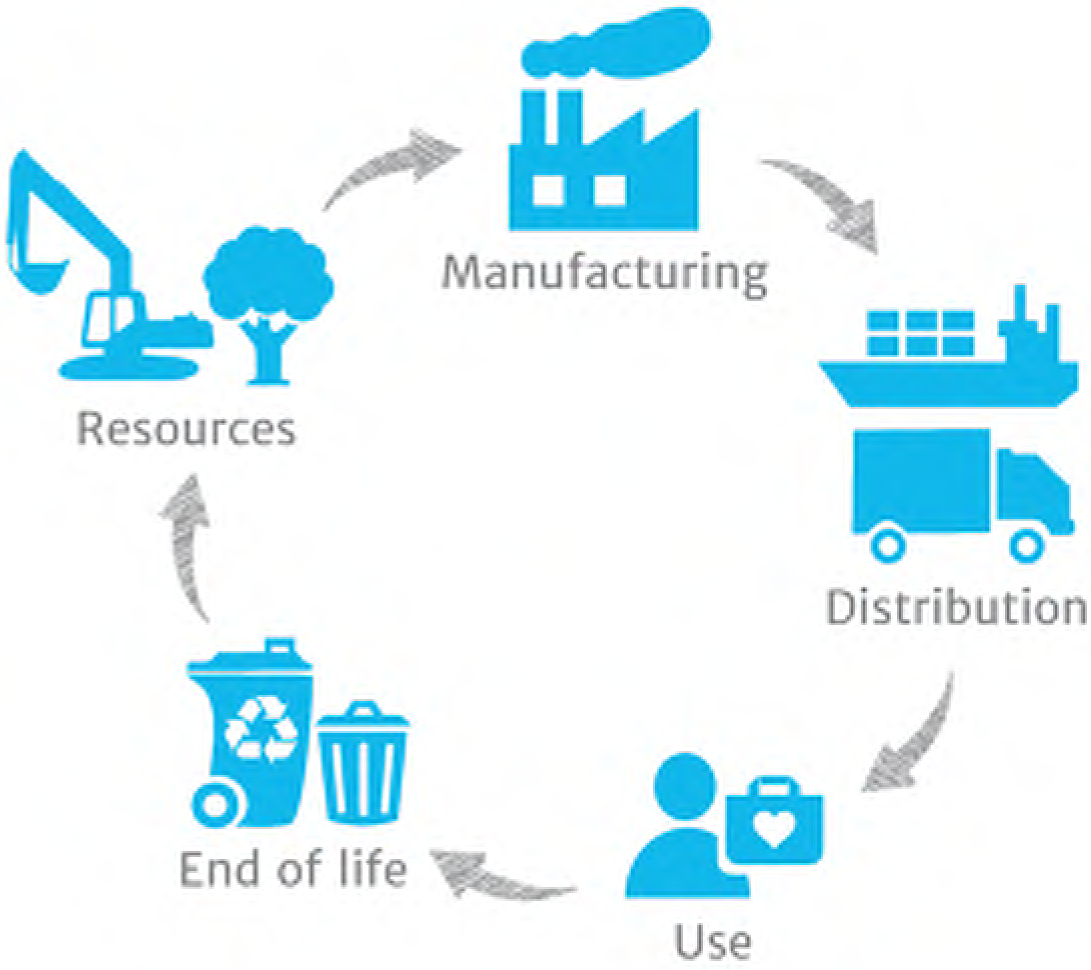


Figure 5.9. Options for avoiding corrosion.

Design for Sustainability

Sustainability

Life Cycle Stages

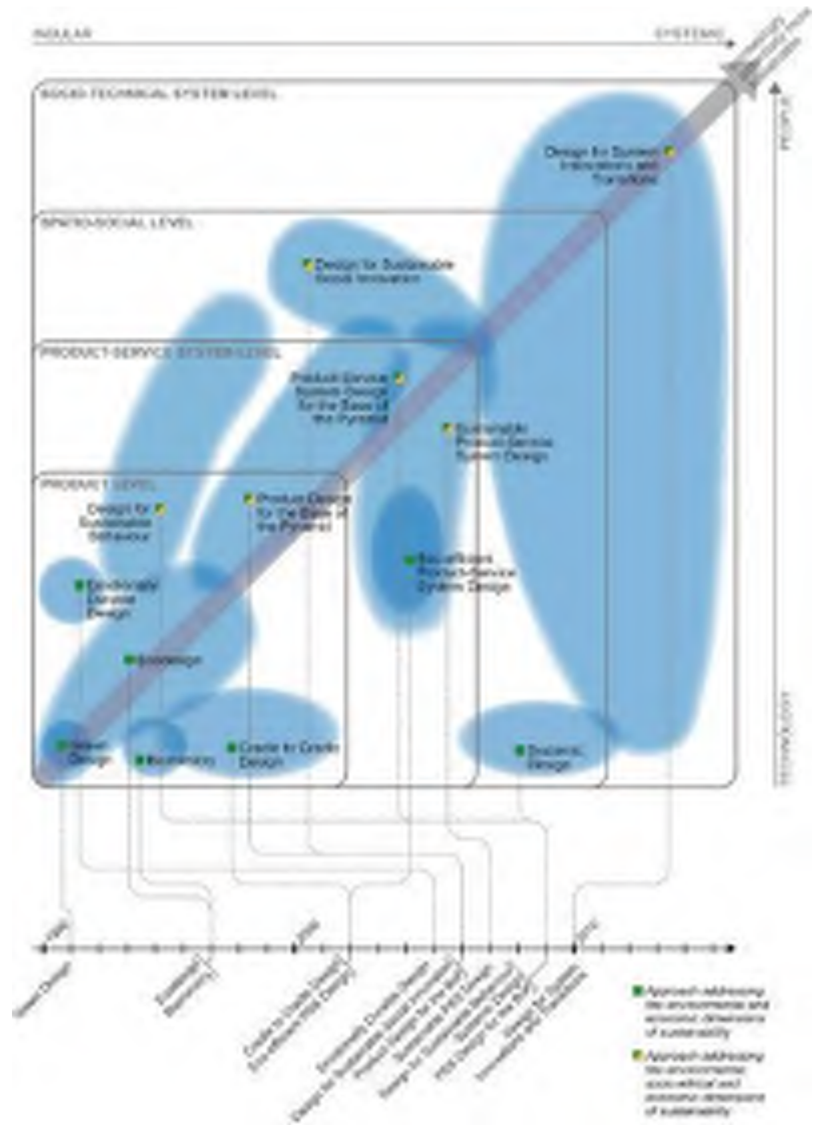


eeq
Éco Entreprises Québec

Design for Sustainability

Four innovation levels:

- Product
- Product-Service System
- Spatio-Social
- Socio-Technical System



F. Ceschin, I. Gaziulusoy, (2016), **Evolution of design for sustainability: From product design to design for system innovations and transitions**, Design Studies, 47, 118-163.

What is the design Target?

Sustainability Target Value (STV) design based on
global natural ecosystem carrying capacities

Table 1
STV targets and rationale.

Environmental indicator	Life cycle target	Base data (US DOE, 2009)
Global Warming Potential	2.29×10^3 kg CO_2e/m^2	1.33×10^2 kg CO_2e/m^2-yr
Primary Energy	5.42×10^4 MJ/m^2	2.35×10^3 MJ/m^2-yr
Potable Water	9.88×10^4 L/m^2	2.63×10^3 L/m^2-yr
Ozone Depletion Potential	0.00 kgCFC11e	NA

Sustainable target value design: integrating life cycle assessment and target value design to improve building energy and environmental performance Russell-Smith, S.V., Lepech, M.D., Fruchter,R., Meyer, Y.B. JOURNAL OF CLEANER PRODUCTION 2015; 88: 43-51

Are GFRP rebars Durable?

Report on Studies of Concrete Reinforced with GFRP Specimens from Field Demonstration Structures

Research Team:

Dr. A. Mufti, ISIS Canada Research Network & UM

Dr. M. Onofrei, ISIS Canada Research Network & UM

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Dr. M. Boulfiza, University of Saskatchewan

Dr. B. Bakht, ISIS Canada Research Network

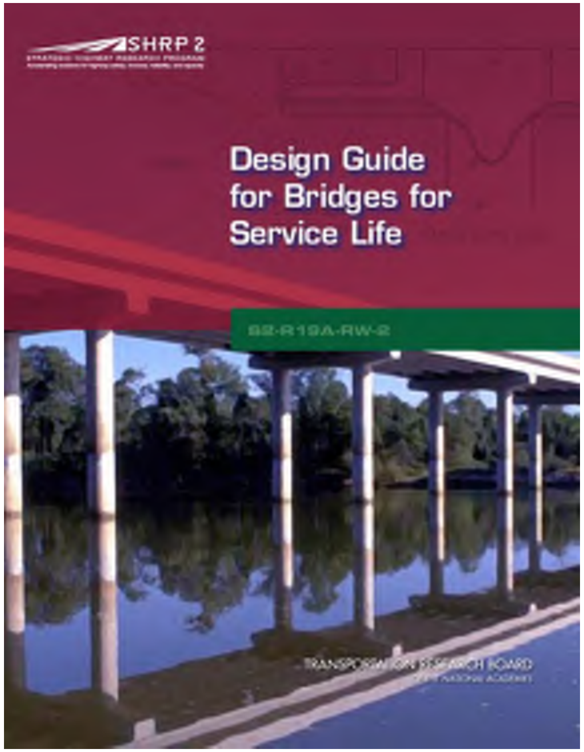
Dr. G. Tadros, ISIS Canada Research Network

Dr. J. Newhook, Dalhousie University

Mr. P. Brett, K.R.M. Consulting Ltd.

How Long do Fiberglass Boats Last?

The same feature that helped launch the fiberglass boat industry in the 1960s may be hurting new boat sails now. According to a Boat/US Magazine, Jan, 2006 article, "In 2004, 71% of boats changing hands were pre-owned, as compared to 63% in 1997, according to a recently released study by the National Marine Manufacturers Association (NMMA). The durability of fiberglass boats forces the industry to innovate each year with new product features and styling to attract buyers.



?

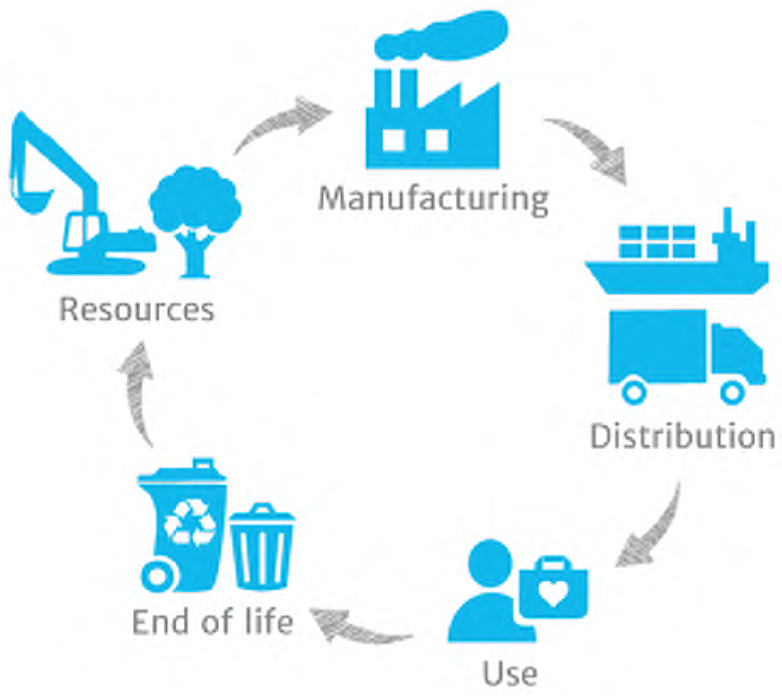
Table 3.10. Technology Table for Corrosion of Reinforcement.

Service Life Issue	Solutions	Advantage	Disadvantage
Corrosion of reinforcement	Electrochemical chloride extraction	Extract chlorides from the concrete, or use in new structures to increase corrosion threshold	Extraction depends on the depth and location, risk of embrittlement (prestressed), difficult to predict service life
	Cathodic protection	Prevent corrosion from initiating, advantage as a repair method	High cost involved in maintaining the power source and sacrificial mesh anode. Embrittlement of strand and softening of concrete (prestressed structures)
	Sealers	Prevent solutions from penetrating the concrete, easy to apply either during or after construction	Difficult to ensure adequate coverage. Varying performance and cost. Short service life. Abrasion, sunlight and environment affect the sealer's efficiency
	Membrane	Prevent moisture infiltration	Varying performance. Difficult to install on curved or rough decks and to maintain quality and thickness during field installation.
Corrosion of reinforcement	Stay in place metal form for marines structures	Prevent infiltration of aggressive solutions	Cost
	Stainless steel	High resistance to corrosion	Initial cost
	FRP	High resistance to corrosion	FRP prone to degradation from environmental factors
	Z bars (galvanizing over epoxy coating)	High resistance to corrosion	
	Epoxy coated steel	Create protective layer over the steel and increase the electrical resistance	Epoxy coating can be damaged during handling, shipping and storage corrosion can initiate under the coating
	Low carbon chromium steel	High resistance to corrosion	High strength, no yield point
	Drainage design	Minimize saturation	Continuous maintenance
	Post Tension	Puts the concrete in compression minimizing cracks that facilitate the penetration of chlorides	Post tensioning ducts and grout are concerns in resisting corrosion

Are GFRP rebars Sustainable?

Life Cycle Assessment (LCA)

"Life Cycle Assessment (LCA) is a tool for the **systematic evaluation of the environmental aspects of a product or service system through all stages of its life cycle**." UNEP - UN Environment Program

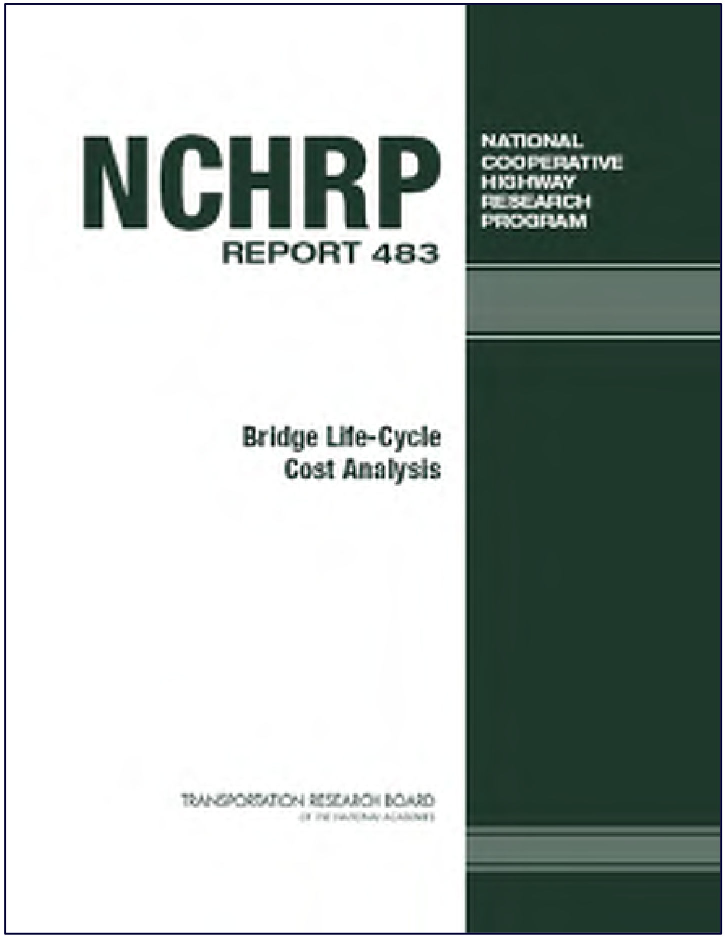


How long is life?

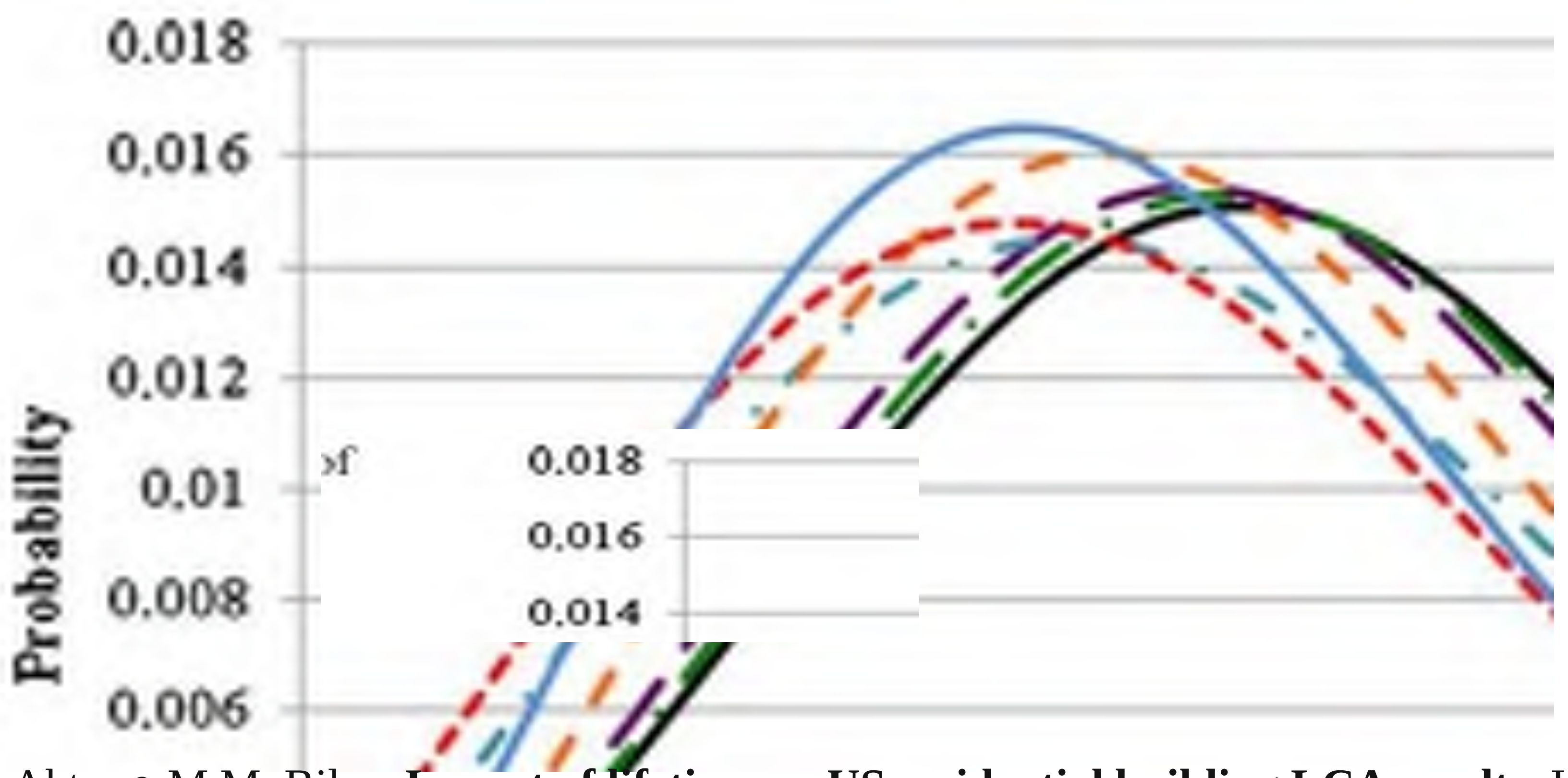
Life Cycle Cost Analysis (LCCA)

"Life-cycle cost analysis is a **process for evaluating the total economic worth of a usable project** segment by analyzing initial costs and discounted future costs, such as maintenance, user, reconstruction, rehabilitation, restoring, and resurfacing costs, over the life of the project segment."

Source: Transportation Equity Act for the 21st Century

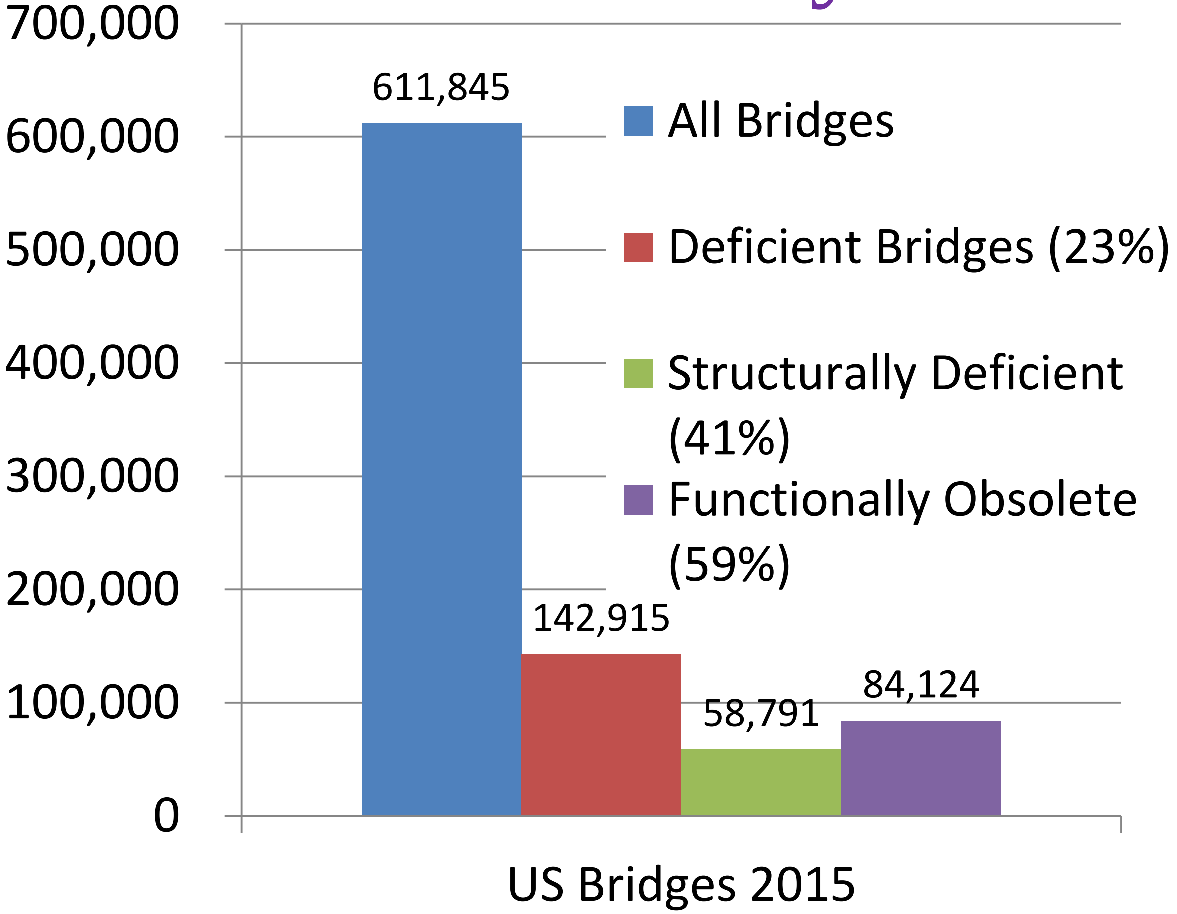


Residential buildings are demolished after 61 yrs when they become obsolete but are still physically sound



C.B. Aktas & M.M. Bilec, **Impact of lifetime on US residential building LCA results**, Int J Life Cycle Assess (2012) 17:337–349.

Functionally obsolete bridges are more difficult to "repair" than structural deficiency



Construction Industry

- Profit

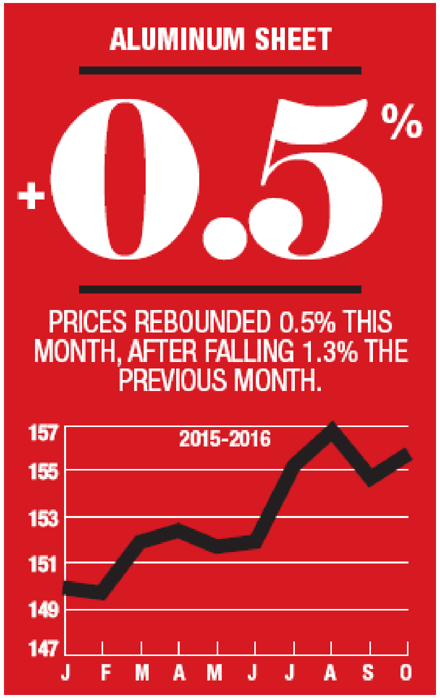
  - bidding, labor, first cost
- Risk

  - material supply, skills, bonding
- Jobs

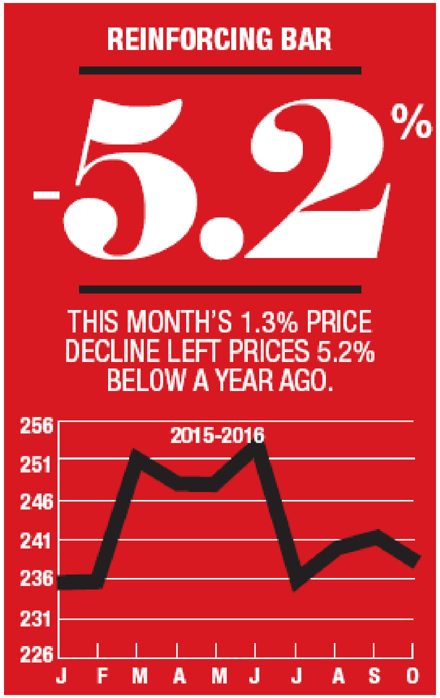
  - inspection, maintenance (615,000 US bridges inspected every 2 yrs)

Commodity or Specialty Product?

ENR's Materials Prices For October 2016



1992=100



1992=100

20-CITY AVERAGE

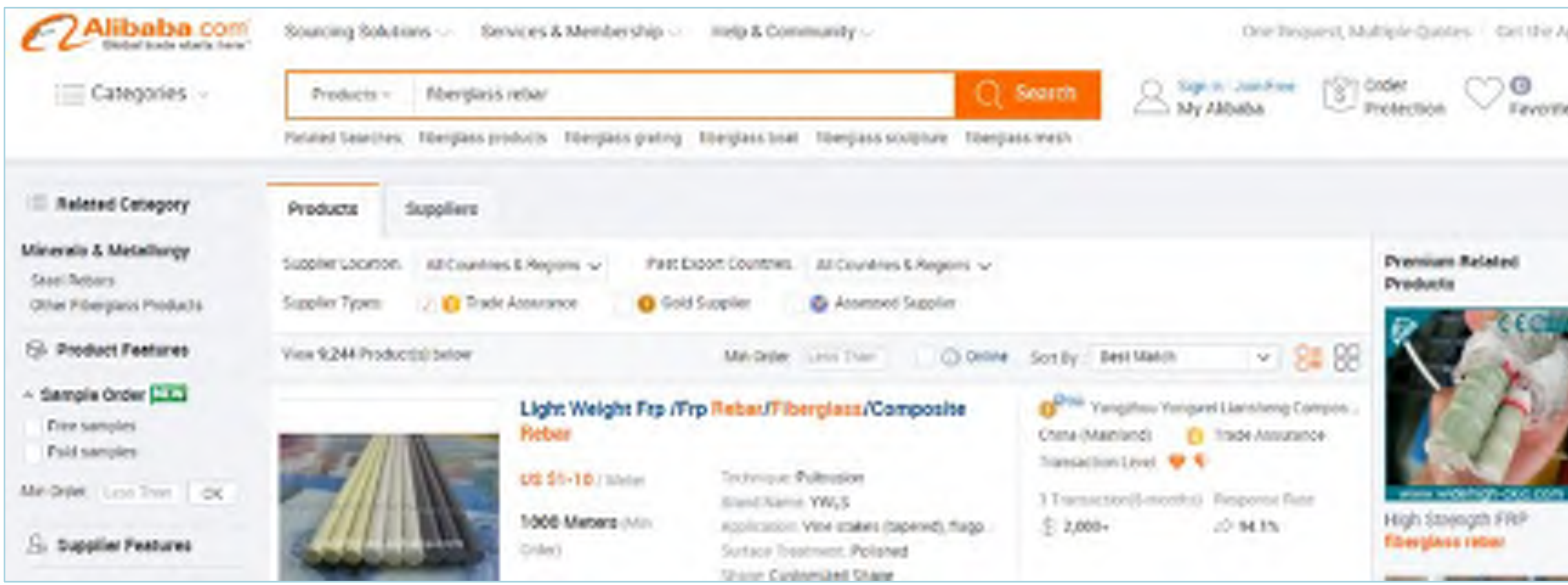
ITEM	UNIT	$PRICE	%MONTH	%YEAR
STANDARD STRUCTURAL SHAPES				
Average	CWT	49.96	+0.1	+0.8
Channel beams, 6" Deep, 8.2 LB/LF	CWT	49.78	–0.1	+0.9
I-beams, 6" Deep, 12.5 LB/LF	CWT	51.56	+0.1	+0.3
Wide-flange, 8" Deep, 31 LB/LF	CWT	48.53	+0.2	**+1.2**
REINFORCING BARS				
Grade 60, No. 4	CWT	44.55	-1.3	**–5.2**
HOT-ROLLED CARBON-STEEL PLATE				
12 gauge, 48" x 10'	CWT	47.44	+0.1	+2.4
ALUMINUM SHEET				
3003H14, 36" x 96"	CWT	197.25	**+0.5**	+5.2

Where do I find the spot price of #4 FRP bar?

(For EA parity needs to be same $/lb – since weight ratio =1/5 but modulus ratio = 5)

GFRP rebars are ubiquitous

0.72 $/ft = 3.78 $/lb



COMPOSITE GROUP
CHELYABINSK

Beneficiary address: 2nd Paveletskaya str. 36, 454000 Chelyabinsk, Russia

LLC «COMPOSITE GROUP CHELYABINSK»

Beneficiary acc. No: 40702840138180000018

Beneficiary bank : AO «ALFA-BANK»
Beneficiary bank address: Kalanchevskaya str. 27, 107078 Moscow, Russia

SWIFT: ALFARUMM

No. 14: 0.24 $/ft = 1.26 $/lb

We offer you Composite Fiberglass Rebar for the following prices:

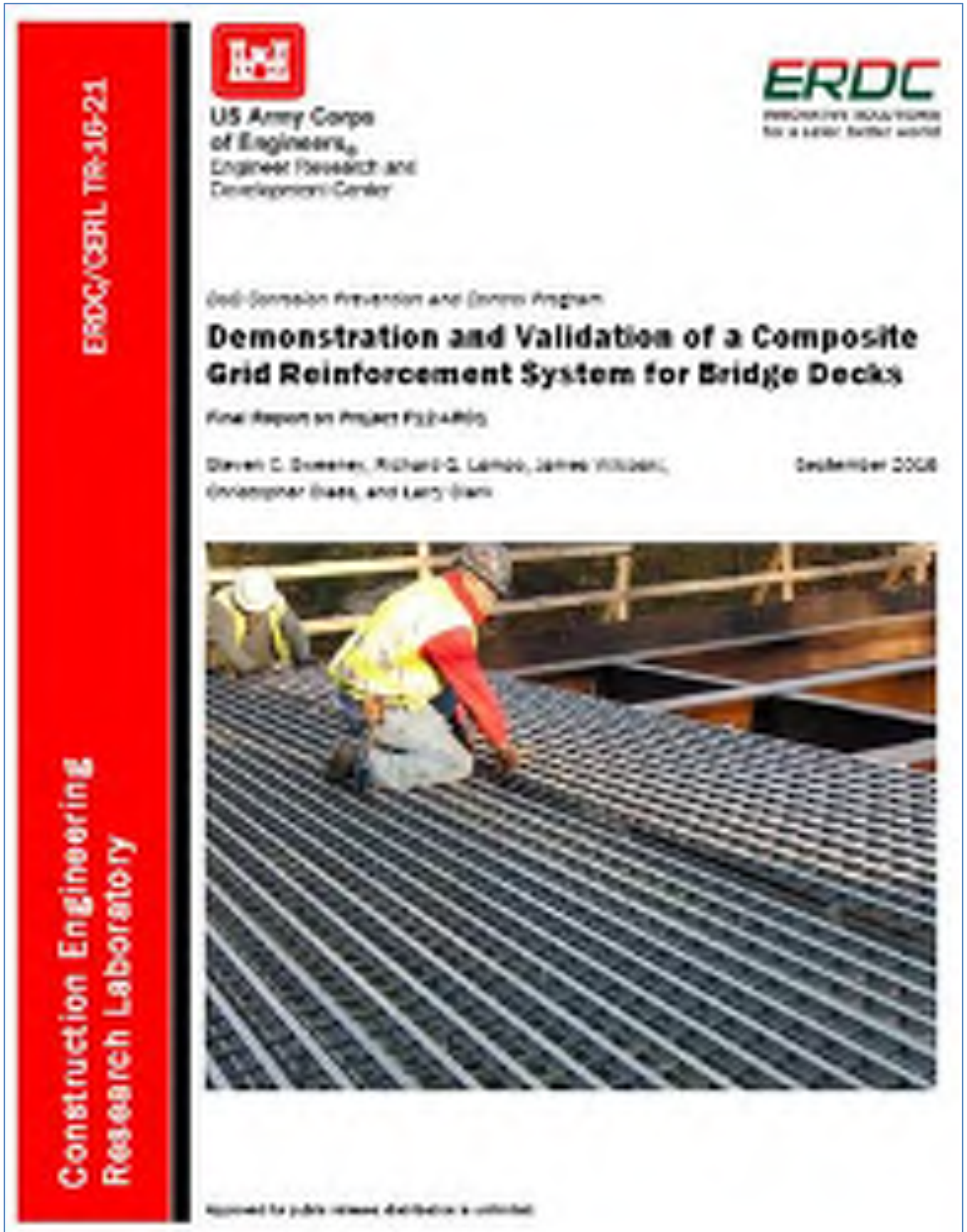
Outer diameter of reinforcing bars, mm	Price per 1 meter (USD) 100,000 meters and more	Meters in 1 ton of the product	Theoretic weight in 1 meter (kg)
4	0,11	50 000	0.02
6	0,15	20 000	0.05
8	0,25	12 500	0.08
10	0,37	8 350	0.12
12	0,53	5 000	0.2
14	0,79	3 850	0.26
16	1,07	2 860	0.35
18	Contracted prices	-	-
20		-	-

Any manufactured lengths upon request
The products are available in hanks (from Ø4 mm to Ø10 mm only) or rods.
Larger diameters are available upon request.

After more than 10 years of being in service, the innovative feature of FRP stay-in-place forms and FRP deck reinforcement **shows no noteworthy degradation** that wouldn't be expected at a bridge of its age.

Cracking observed in the bridge surface cannot be conclusively attributed to the use of or, conversely, the lack of FRP reinforcement. In fact, **similar crack patterns are seen on traditionally constructed bridges of the same configuration**

With respect to the deck construction, there is **likely cost savings by using the stay-in-place FRP forms and no steel** within the deck. That said, specific attention should be paid to deck crack growth going forward



As estimated by the Bridge No. 4 contractor, these benefits **reduced the construction time for the deck by approximately 80%, with a pursuant total 75% reduction in labor costs** as compared to work performed on the adjacent steel-reinforced concrete deck that is documented in ERDC/CERL TR-16-22 (Sweeney et al. 2016).

The construction cost for an FRP composite bridge deck, adjusted to 2008 constant dollars, is $61.55/sf. Using a construction time reduced by two-thirds as compared to reinforced concrete construction, **the traffic delay costs for FRP is $8.00/sf**.

What happens to GFRP reinforced concrete at its End-of-Life ?

Long-term business sustainability

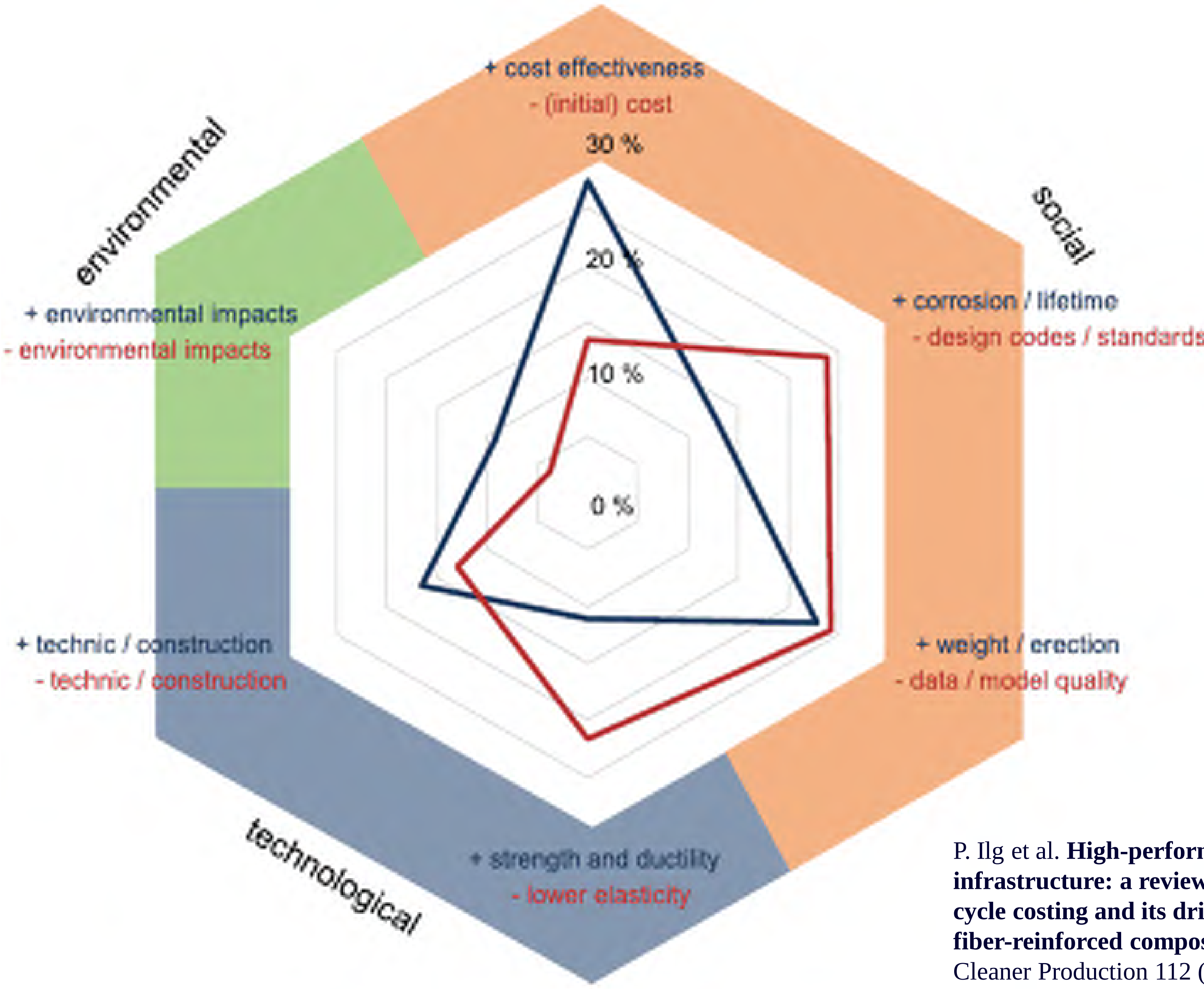

CW
CompositesWorld
Blog Zones Magazine Sourcebook Podcast Products News Events

How have composite bridges measured up?

The latest US highway bill includes a provision to assess performance of composite bridges built years ago, bridges that CW wrote about.

Blog Post: 1/8/2016
SARA BLACK

Can one even purchase an off-the-shelf FRP deck these days?



P. Ilg et al. **High-performance materials in infrastructure: a review of applied life cycle costing and its drivers - the case of fiber-reinforced composites**, Journal of Cleaner Production 112 (2016) 926-945

Conclusions

- Are GFRP rebars durable?

YES

- Are GFRP rebars sustainable?

DON'T KNOW

Extra Slides

Sustainable Development

Our **Common** Future (1987), Brundtland Report, UN.

I. The Concept of Sustainable Development

1. Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs. <u>It contains within it two key concepts</u>:

- **the concept of 'needs', in particular the essential needs of the world's poor, to which overriding priority should be given**; and
- **the idea of limitations imposed by the state of technology and social organization on the environment's ability to meet present and future needs**.

Gro Harlem Brundtland – former Prime Minister of Norway and Director-General of the World Health Organization. Chaired the Brundtland Commission.

Sustainability Today – Brown Agenda

UN Sustainable Development Goals (2015)

- **No Poverty**
- **Zero Hunger**
- **Good Health and Well-being**
- **Quality Education**
- **Gender Equality**
- **Clean Water and Sanitation**
- **Affordable and Clean Energy**
- **Decent Work and Economic Growth**
- **Industry, Innovation and Infrastructure** - Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- **Reduced Inequalities**
- **Sustainable Cities and Communities** - Make cities and human settlements inclusive, safe, resilient and sustainable
- **Responsible Consumption and Production**
- **Climate Action**
- **Life Below Water**
- **Life on Land**
- **Peace, Justice and Strong Institutions**
- **Partnerships for the Goals**

Sustainability Today – Green Agenda

UN Intergovernmental Panel on Climate Change (IPCC)

Fifth Assessment Reports (2013/4)

The Fifth Assessment Report (AR5) is **the most comprehensive assessment of scientific knowledge on climate change since 2007** when the Fourth Assessment Report (AR4) was released.

Windows	Life Expectancy in Years
Aluminum/Aluminum-Clad	15 to 20
Double-Pane	8 to 20
Skylights	10 to 20
Vinyl/Fiberglass Windows	20 to 40
Window Glazing	10+
Wood	30+