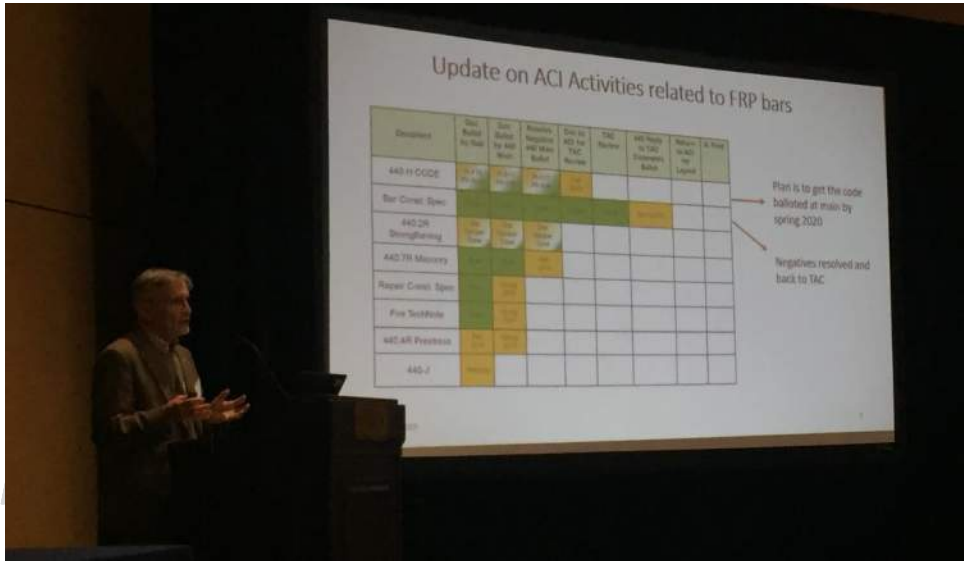
Second International Workshop on GFRP Bars for Concrete Structures

January 18-19, 2019
Orlando, Florida

Day 1

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

(1:15 - 3:00pm)



Presentations (2 @ 10 mins)

1.1 US perspective

a. (Antonio Nanni – ACI)

b. (Steven Nolan – AASHTO/FDOT)

1.2 Canadian perspective *(Brahim Benmo*

Discussion 1.3 (30 mins)

Presentations (2 @ 10 mins)

1.4 Australian perspective and experience on GFRP bars in concrete structures *(Allan Manalo, USQ)*

1.5 European perspective *(Emmanuel Ferrier)*

Discussion 1.6 (30 mins)

Update on ACI Activities related to FRP bars

Document	Doc Ballot by Sub	Doc Ballot by 440 Main	Resolve Negative 440 Main Ballot	Doc to ACI for TAC Review	TAC Review	440 Reply to TAC Comments Ballot	Return to ACI for Layout	In Print
440-H CODE	PI-F15 PII-Su16	PI-S17 PII-S18	PI-S17 PII-S18	Fall 2019				
Bar Const. Spec	Done	Done	Done	Done	Done	Spring 2018		
440.2R Strengthening	One Section Done	One Section Done	One Section Done					
440.7R Masonry	Done	Done	Fall 2018					
Repair Const. Spec	Done	Spring 2018						
Fire TechNote	Done	Spring 2018						
440.4R Prestress	Fall 2018	Spring 2019						
440-J	Pending							

Plan is to get the code balloted at main by spring 2020

Negatives resolved and back to TAC

440-H – FRP Reinforced Concrete Code

Chapter completed Ballot at Main

Chapter 1 (General)

Chapter 4 (Structural System Requirements)

Chapter 5 (Loads)

Chapter 21 (Strength Reduction Factors)

Chapter 26 (Construction Documents and Inspection)

Chapters under ballot at Main

Chapter 22 (Sectional Strength)

Chapter 25 (Reinforcement Details)

Chapter Balloted at Sub

Chapter 7 (One-Way Slabs): Will require 2nd ballot at sub

Chapter 9 (Beams): Will require 2nd ballot at sub

Chapter 20 (GFRP Reinforcement Properties): Ready to ballot at main

Chapter 24 (Serviceability Requirements): Ready to ballot at main

440-H – FRP Reinforced Concrete Code

Rough Drafts Ready for Small Group Review

Chapter 10 (Columns): Author –Nanni; Reviewers - Harries & Shield
Chapter 11 (Walls): Authors – Sadeghian & Tomlinson; Reviewers - Harries & Shield
Chapter 13 (Foundations): Author – Nanni; Reviewers – Bischoff
Chapter 15 (Joints) & Chapter 16 (Connections): Author – El Salakawy; Reviewers – Galati, Polak, Masetti

Rough Drafts Requiring Revision by Authors

Chapter 8 (Two-Way Slabs): Authors – Benmokrane, El Salakawy & Masmoudi Brown indicated that there is need of volunteers to do this effort, new Associate and associated members are strongly encouraged to step up and help with this task.
Chapter 16 (Connections between members): Authors – El-Salakaway

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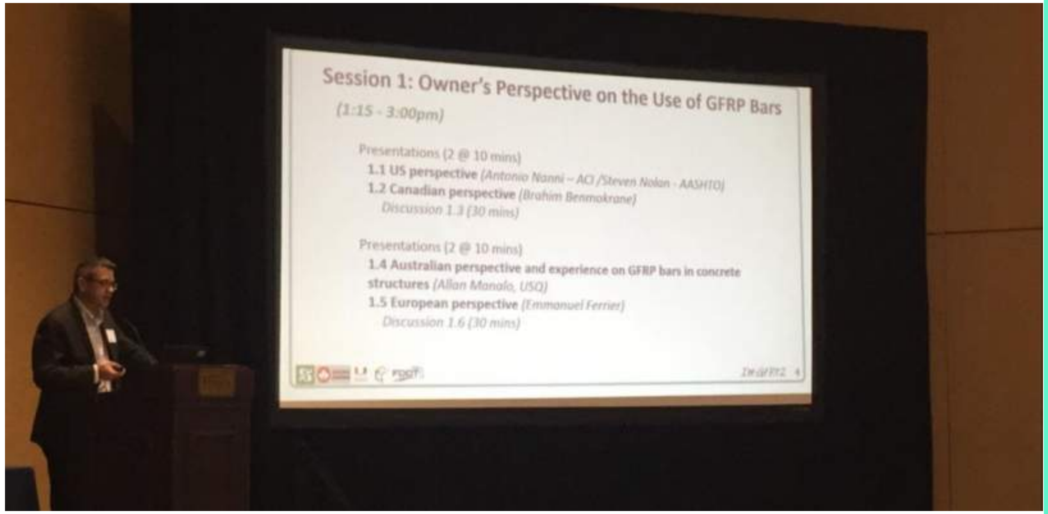

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Recent and Future FDOT Activities

1. STIC Incentive Project: *BFRP-RC Standardization*
2. NCHRP-IDEA-2017: *MildGlass*
3. 2018 FRP-RC Project Updates
   - Bakers Haulover Cut
   - Halls River Bridge
   - Sunshine Skyway Seawall Rehab
   - SR A1A Secant Pile Seawall
4. 2019 FRP-RC/PC Projects Scheduled:
   - NE 23rd Ave/Ibis Waterway – *2/27/19 letting*
   - US 41 over North Creek – *2/27/19 letting*
   - US 41 over Morning Star & Sunset Canal – *2/27/19 letting*
   - US 1 over Cow Key channel, 6 Span Replacement – *10/21/19 letting*
   - Pensacola Beach Pedestrian Tunnels (3) – *Design 100% (city project)*

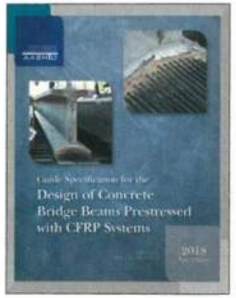
AASHTO Guide Specifications

**** Research Project Statement NCHRP 20-07/Task 428:**
Update of the 2012 AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements.

BRIDGES & STRUCTURES

Fiber-Reinforced Polymer

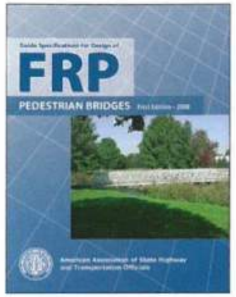
NEW!



GUIDE SPECIFICATIONS FOR THE DESIGN OF CONCRETE BRIDGE BEAMS PRESTRESSSED WITH CFRP SYSTEMS, 1ST EDITION

These guide specifications apply to the design of prestressed concrete beams constructed of normal weight concrete and prestressed by carbon fiber-reinforced polymer (CFRP) prestressing systems. 2018. 70 pp.

PDF Download Code: CFRP-1-UL | List Price: 51 | Member Price: $38



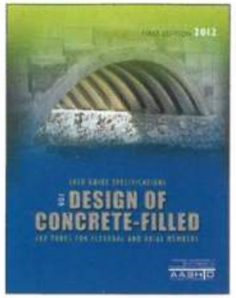
GUIDE SPECIFICATIONS FOR DESIGN OF FRP PEDESTRIAN BRIDGES, 1ST EDITION

These guide specifications apply to fiber-reinforced polymer (FRP) composite bridges intended to carry, primarily, pedestrian and bicycle traffic. 2008. 20 pp.

PDF Download Code: GSDFPB-1-UL | List Price: $27 | Member Price: $20

LOOSELEAF Code: GSDFPB-1 | List Price: $34 | Member Price: $25

LOOSELEAF & PDF Combo Code: GSDFPB-1-PUL | List Price: $47 | Member Price: $35



AASHTO LRFD GUIDE SPECIFICATIONS FOR DESIGN OF CONCRETE-FILLED FRP TUBES, 1ST EDITION

These guide specifications present provisions for the analysis and design of concrete-filled fiber-reinforced polymer (FRP) tubes (CFFT) for use as structural components in bridges. Design methodology allows CFFTs to be designed as flexural members, axial compression members, or members subjected to combined flexural and axial compression, in addition to shear. CFFT bridge components may include beams, arches, columns, and piles. 2012. 48 pp.

PDF Download Code: LRFDFRP-1-UL | List Price: $32 | Member Price: $24

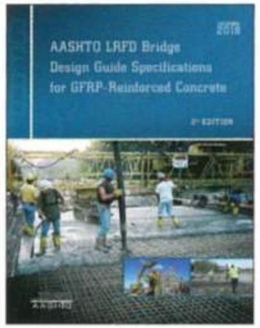
LOOSELEAF Code: LRFDFRP-1| List Price: $41 | Member Price: $30

LOOSELEAF & PDF Combo Code: LRFDFRP-1-PUL | List Price: $57 | Member Price: $42

GUIDE SPECIFICATIONS FOR DESIGN OF BONDED FRP SYSTEMS FOR REPAIR AND STRENGTHENING OF CONCRETE BRIDGE ELEMENTS, 1ST EDITION **

These guide specifications are intended for the repair and strengthening of reinforced and prestressed highway bridge structures using externally bonded fiber-reinforced polymer (FRP) composite systems. 2012. 52 pp.

NEW!



AASHTO LRFD BRIDGE DESIGN GUIDE SPECIFICATIONS FOR GFRP-REINFORCED CONCRETE, 2ND EDITION

These guide specifications offer a description of the unique material properties of glass fiber-reinforced polymer (GFRP) composite materials, as well as provisions for the design and construction of concrete bridge decks and railings reinforced with GFRP reinforcing bars. This revised edition includes information on the advancements in material specifications, and new knowledge and field experiences beyond bridge decks and traffic railings.

Some of the major updates in this new edition include a title change from the 2009 first edition, AASHTO LRFD Bridge Design Guide Specification for GFRP-Reinforced Concrete Bridge Decks and Traffic Railings, to acknowledge the inclusion of information beyond bridge decks and traffic railings; greater consistency with the AASHTO LRFD Bridge Design Specifications, 8th Edition; Consideration of flexural members, such as girders and bent caps, not included in first edition; consideration of substructure and foundation elements along with compression members; differentiation between the fatigue and creep limit states; and revised shear design methodology. 2018. 122 pp.

PDF Download Code: GFRP-2-UL | List Price: $135 | Member Price: $100

FDOT FRP Research Efforts

1992	Feasibility of Fiberglass Pretensioned Piles in a Marine Environment	Sen, R.	USF
1995	Active Deformation Control of Bridges with AFRP Cables	Arockiasamy, M.	FAU
1995	Durability of CFRP Pretensioned Piles in a Marine Environment – Phase II	Sen, R.	USF
1997	Mechanical and Microscopy Analysis of CFRP Matrix Composite Materials	Garmestani, H.	FAMU/ FSU
1997	FRP Composite Column and Pile Jacket Splicing	Mirmiran, A.	UCF
1997	An Analytical and Experimental Investigation of Concrete Filled FRP Tubes	Mirmiran, A.	UCF
1997	Flexural Reliability of RC Bridge Girders Strengthened with CFRP Laminates	Okeil, A.	UCF
1998	Studies of CFRP Prestressed Concrete Bridge Columns and Piles in Marine Environment	Arockiasamy, M.	FAU
1999	LRFD Flexural Provisions for PSC Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF
2000	Investigation of Fender Systems for Vessel Impact	Yazdani, N.	FAMU/ FSU
2001	Design of Concrete Bridge Girders Strengthened with CFRP Laminates	El-Tawil, S.	UCF
2003	Hybrid FRP-Concrete Column	Mirmiran, A.	NC State
2004	CFRP Repair of Impact Damaged Bridge Girders	Hamilton, T	UF
2009	Thermo-Mechanical Durability of CFRP Strengthened RC Beams	Mackie, K	UCF
2011	Testing of Trelleborg Structural Plastics	Wagner, D.	FDOT

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FDOT FRP Research Efforts *(cont.)*

2012	The Repair of Damaged Bridge Girders with CFRP Laminates	El-Safty, A.	UNF
2014	Investigation of CFCC in Prestressed Concrete Piles	Roddenberry, M.	FAMU/ FSU
2015	Repair of Impact Damaged Utility Poles with FRP, Phase II	Mackie, K.	UCF
2015	Use of CFRP Cable for Post-Tensioning Applications	Mirmiran, A.	FIU
2017	Durability Evaluation of Florida's FRP Composite Reinforcement for Concrete Structures	Hamilton, T.	UF
2018	Bridge Girder Alternatives for Extremely Aggressive Environments	Brown, J.	ERAU
2018	Degradation Mechanisms and Service Life Estimation of FRP Concrete Reinforcements	El-Safty, A.	UNF
2018	Testing, Evaluation, and Specification for Polymeric Materials used for Transportation Structures	El-Safty, A.	UNF
2018	Performance Evaluation of GFRP Reinforcing Bars Embedded in Concrete Under Aggressive Environments	Kampmann, R.	FAMU/ FSU
2019	Inspection and Monitoring of Fabrication and Construction for the West Halls River Road Bridge Replacement	Roddenberry, M.	FAMU/ FSU
2021	Evaluation of GFRP Spirals in Corrosion Resistant Concrete Piles	Jung, S.	FAMU/ FSU
2021	Development of GFRP Reinforced Single Slope Bridge Rail	Consolazio, G.	UF
2019	Performance Evaluation, Material and Specifications for Basalt FRP Reinforcing Bars Embedded in Concrete (STIC)	Kampmann, R. Roddenberry, M.	FAMU/ FSU

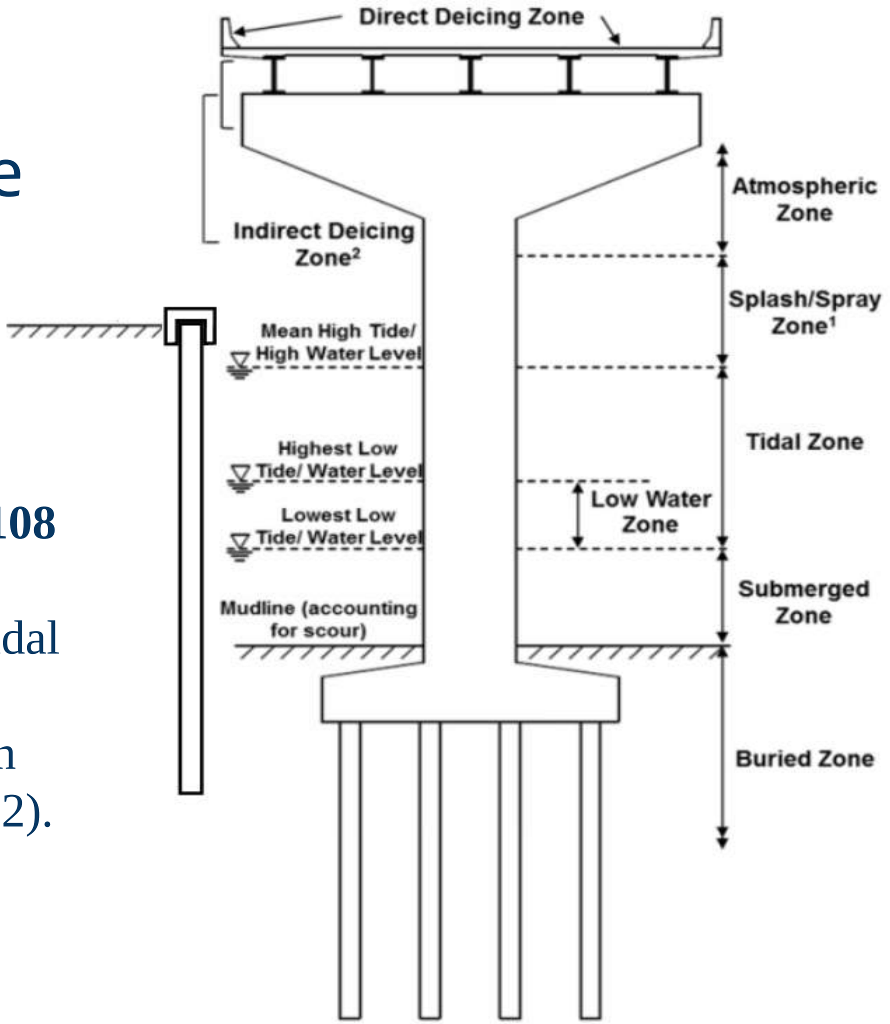
AASHTO Initiatives of Interest

- NCHRP 12-108 – Design Guide for Service Life Design

Micro-Exposure Zones proposed under NCHRP Project 12-108 and SHRP2-19B.

[1] For unprotected locations, the 20 feet area above the tidal zone (UFGS, 2012; Caltrans, 2014). For locations protected by seawalls or otherwise sheltered from open ocean waves, 6-feet area above tidal zone (UFGS, 2012).

[2] If subject to splash/spray/runoff due to joint failure.



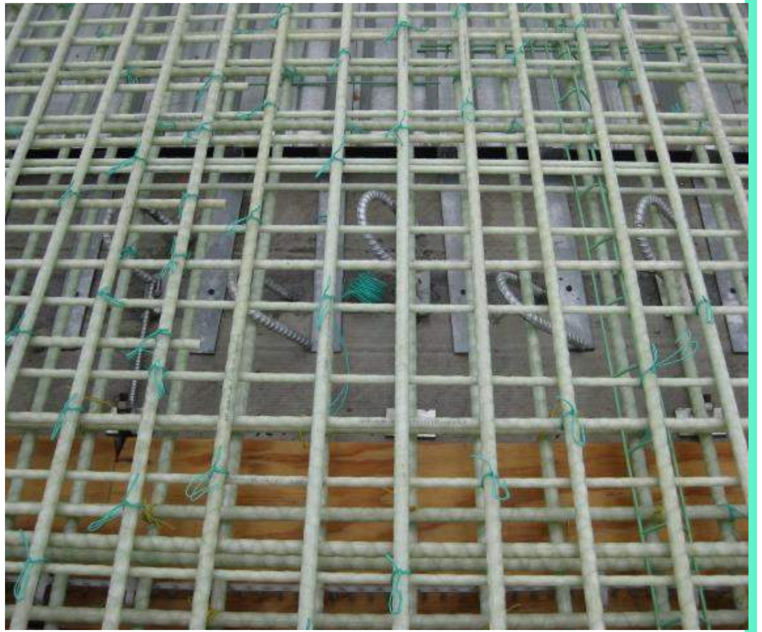
FDOT FRP-RC/PC Projects

Current Project Status for 2018

- Halls River Bridge Replacement- *Mar/Apr 2019 completion?*
- Bakers Haulover Cut – *Seawalls completed 2018*
- Sunshine Skyway Seawall Rehab - *2020 completion?*
- US 17/Trout River & SR 312/Matanzas River Bridge Substructure (Rehab) - *completed*
- SR A1A Secant Pile Seawall -*11/6/18 contractor awarded*

Halls River Bridge

Halls River Bridge



Halls River Bridge

Prestressed Sheet Pile System (rebuilt 1970's): Extensive corrosion damage in splash zone

Light-weight for easy handling

Divers placing GFRP rebar mat in forms

Bulkhead wall cap GFRP reinforcement in place

Completed view of North Wall

Bakers Haulover Cut Bridge Rehab.

Skyway Rest Area Seawall (Cap Rehab.)

US 17 & SR 312 Bridge Substructure (Rehab)

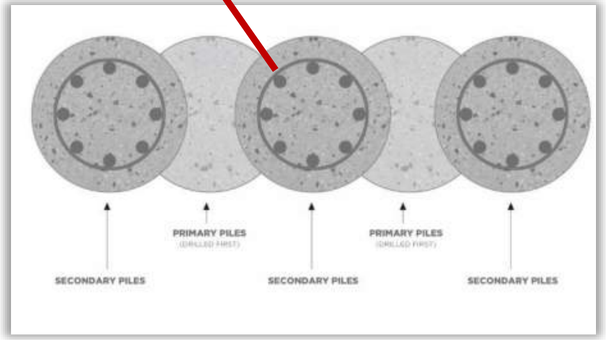
Looking Forward to Construction – Feb. 2019

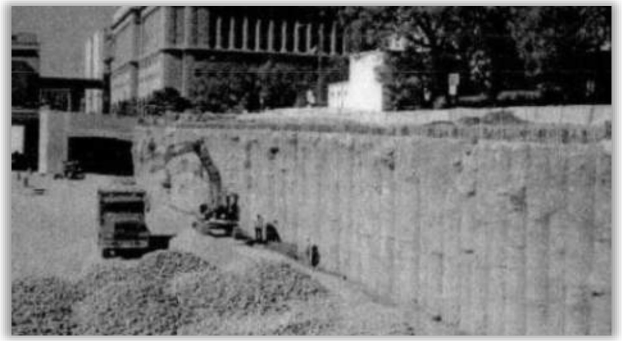
- SR A1A Secant-Pile Seawall – *11/6/18 contractor awarded*

Proposed Secant Wall Concept Rendering

SR A1A damage after Hurricane Matthew (2016)

GFRP-RC Secant Piles





Looking Forward… New Projects in 2019

- NE 23rd Ave/Ibis Waterway – *2/27/19 letting*
- US 41 over Morning Star & Sunset Canal – *2/27/19 letting*
- US 41 over North Creek – *7/31/19 letting*
- US 1 over Cow Key channel, 6 Span Replacement – *10/21/19 letting*
- Pensacola Beach Pedestrian Tunnels (3) – *Design 100% (city project)*

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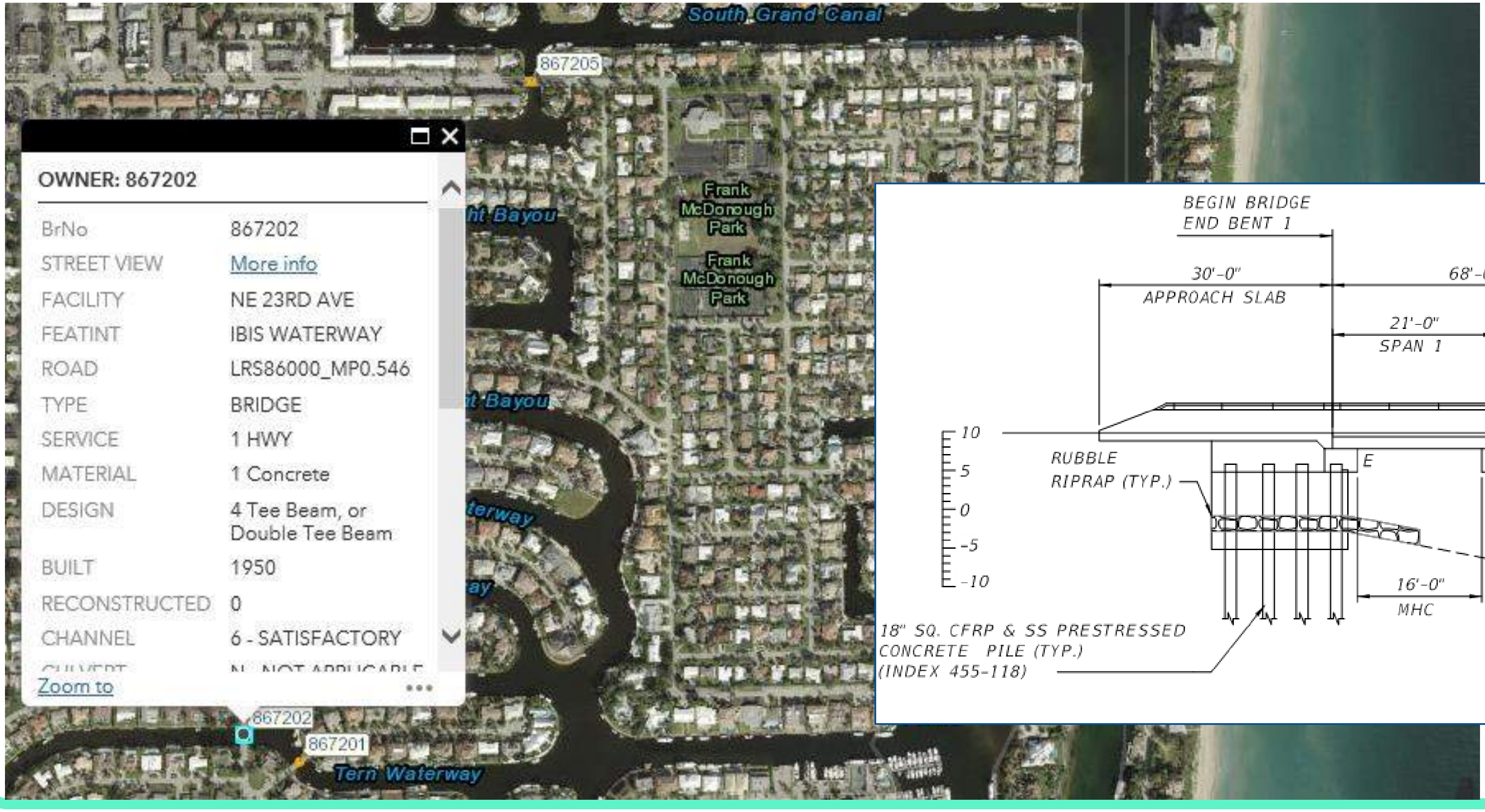
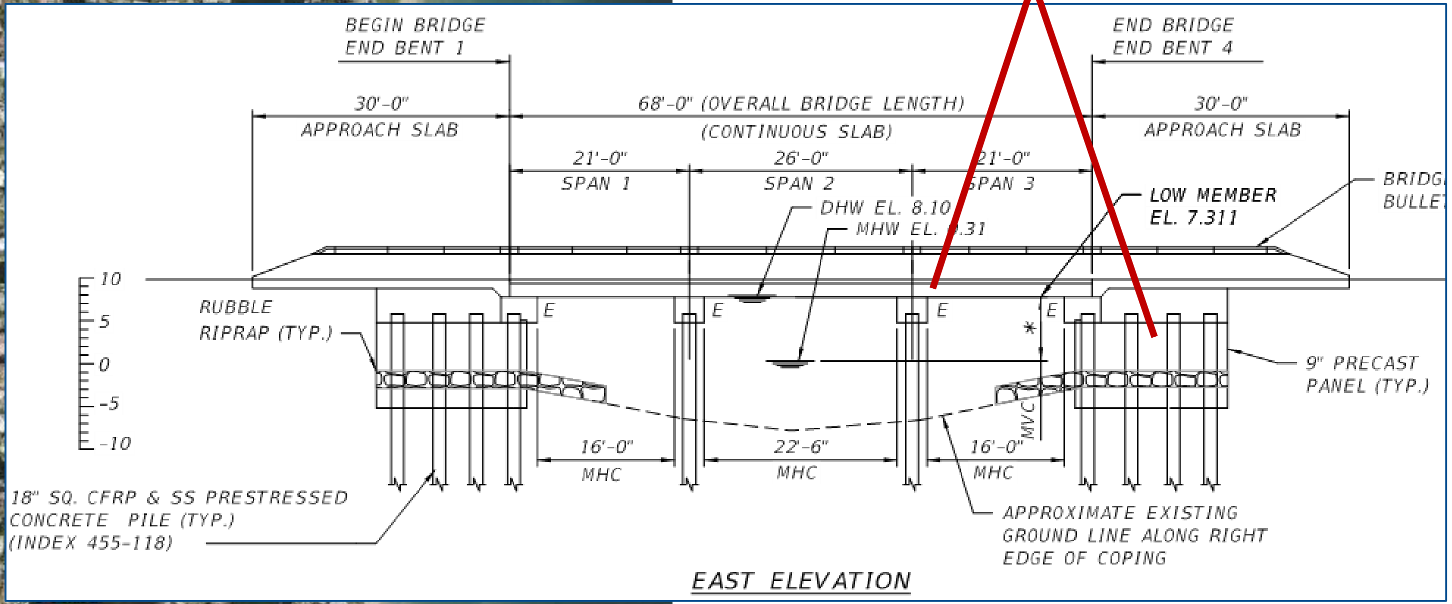
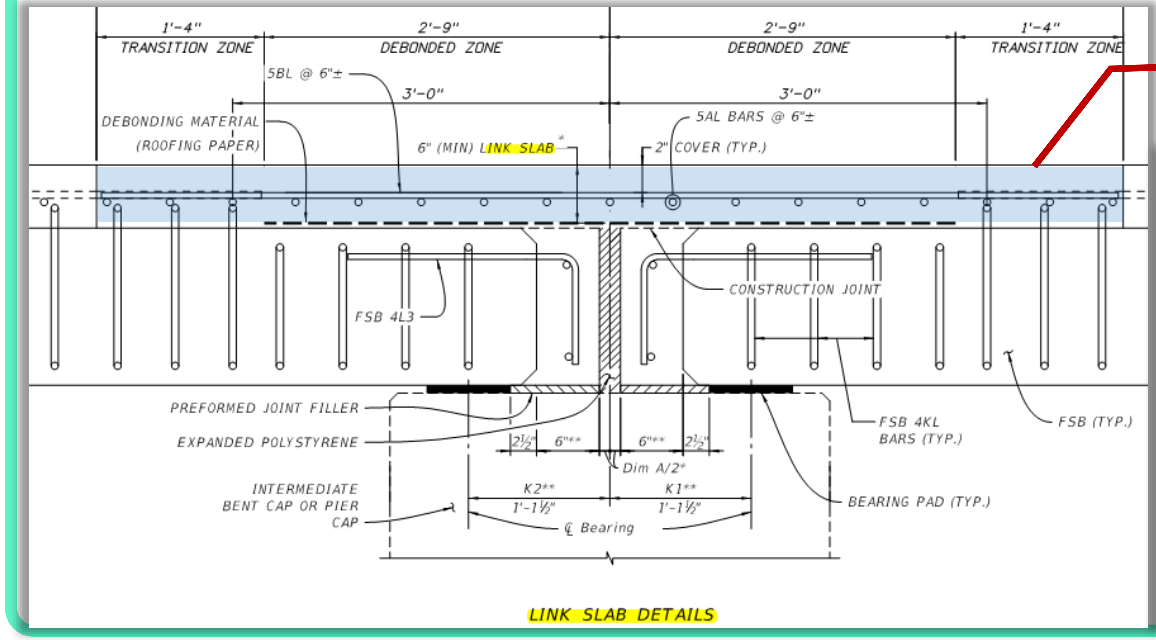


GFRP-RC Flat Slab, Traffic Railing, Bent Caps, & Wall Panels

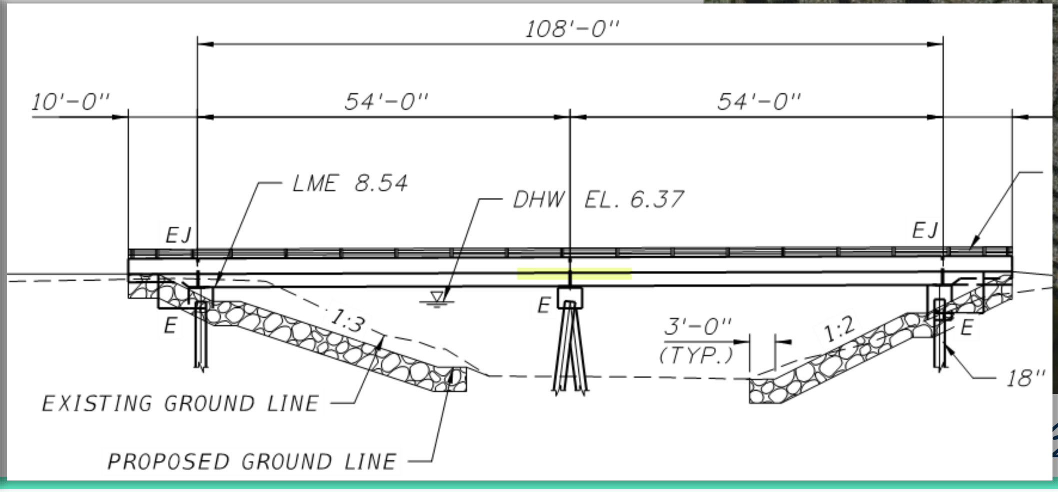


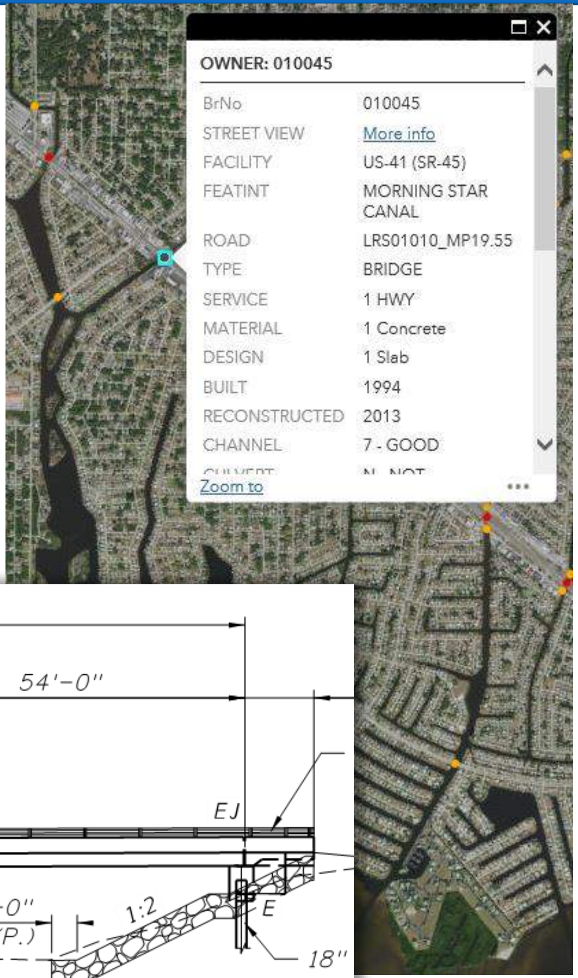
Looking Forward… New Projects in 2019

- US 41 over Morning Star & Sunset Canal – *2/27/19 letting*
  - *GFRP-RC link-slab (shown)*
  - *GFRP-UHPC link-slab (similar)*



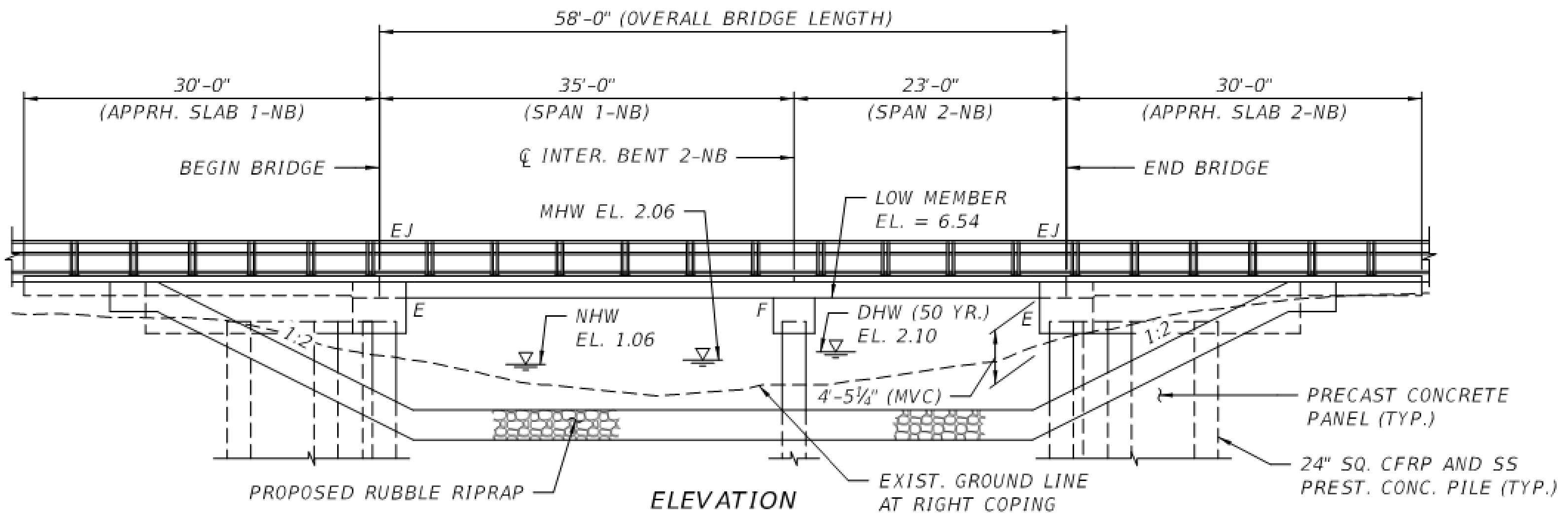
GFRP-RC Link-Slab

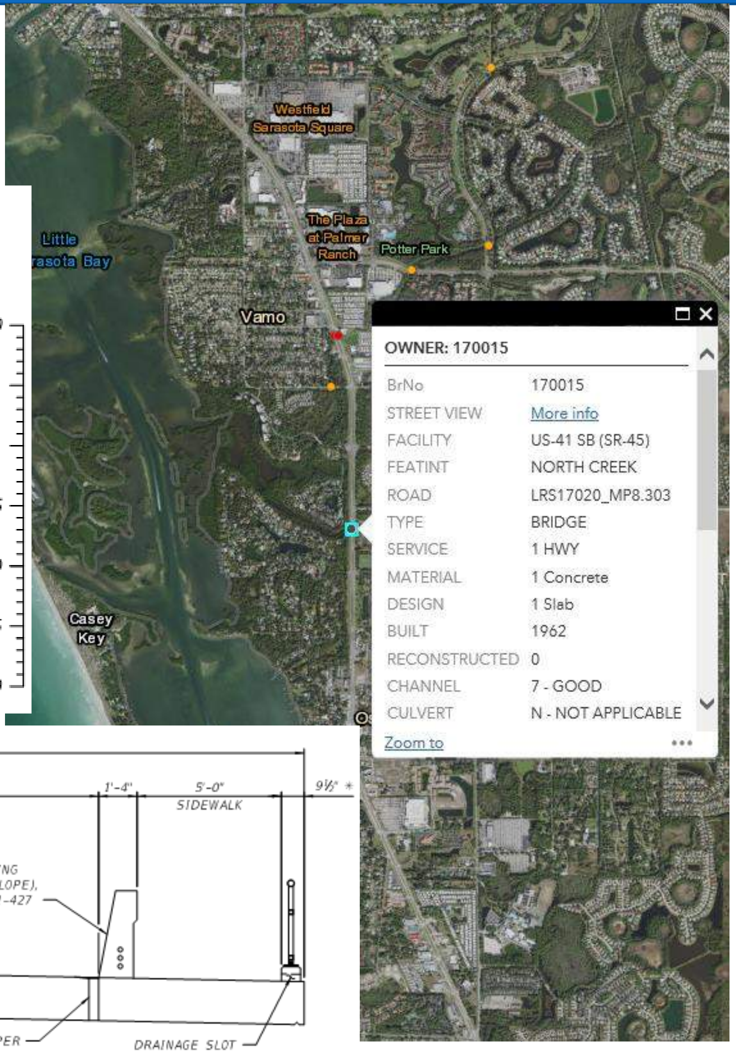




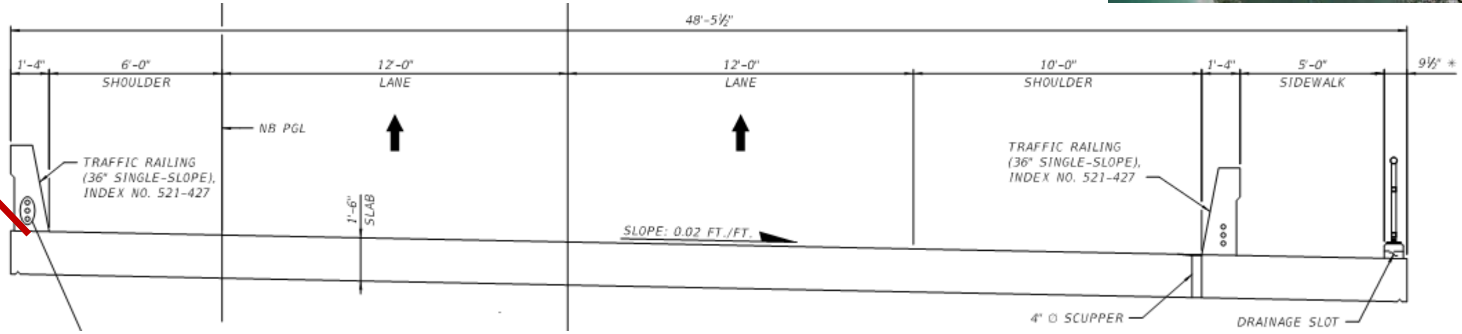
Looking Forward… New Projects in 2019

- US 41 over North Creek – *7/31/19 letting*





GFRP-RC Flat Slab and Traffic Railing



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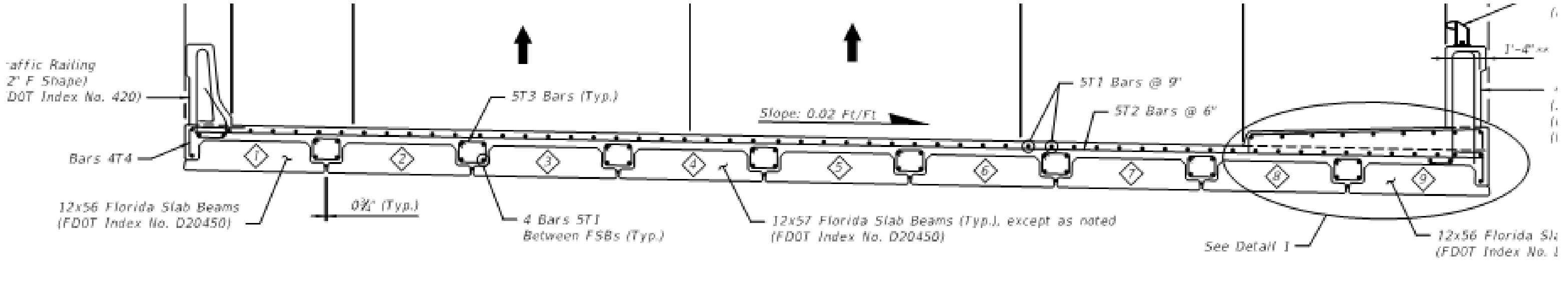
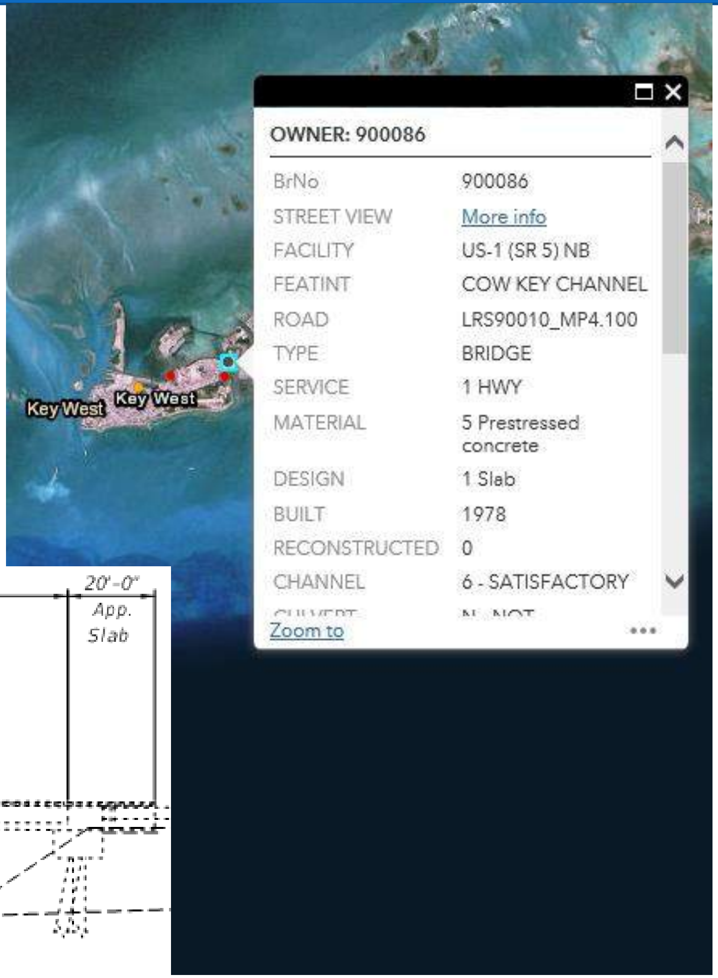
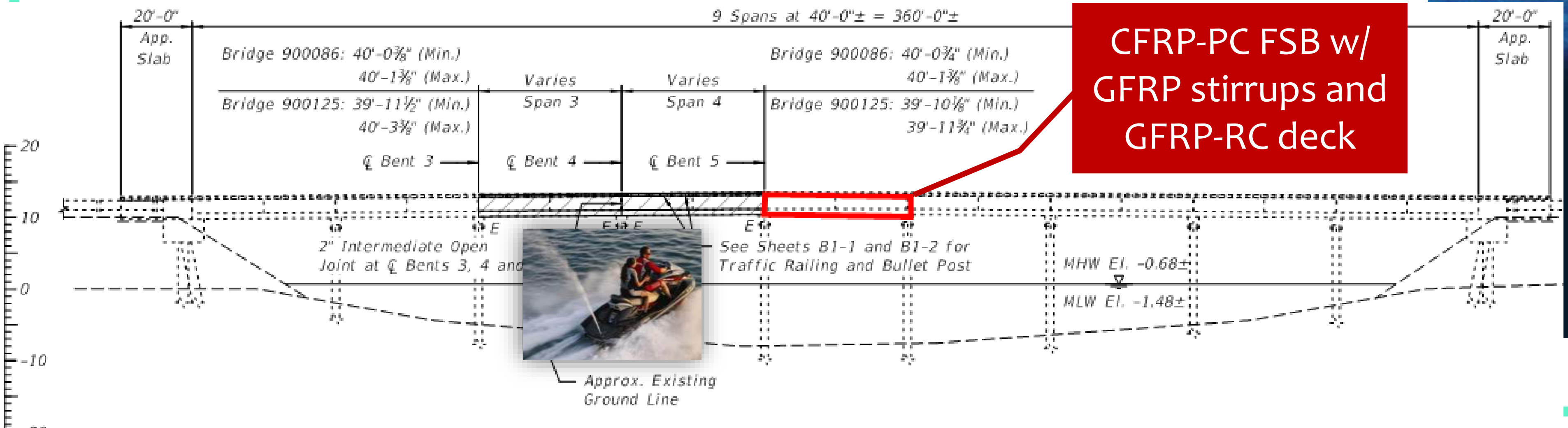
Looking Forward… New Projects in 2019

- US 1 over Cow Key channel, 6~span replacement – *10/21/19 letting*



SUPERSTRUCTURE CROSS SECTION



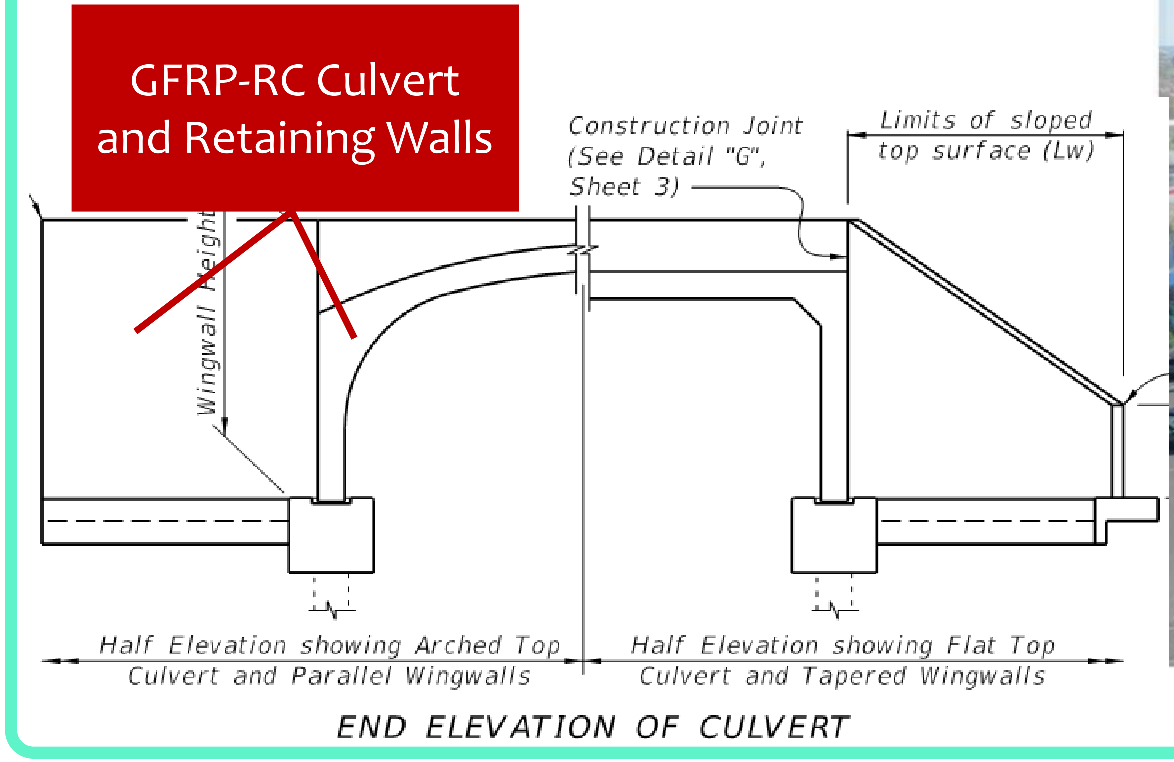


ELEVATION

CFRP-PC FSB w/ GFRP stirrups and GFRP-RC deck

Looking Forward… New Projects in 2019

- Pensacola Beach Pedestrian Tunnels (3) – *Design 100% (city project)*



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structures *(Allan Manalo, USC*

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Second International Workshop on GFRP Bars for Concrete Structures

Orlando, FL, January 18-19, 2019

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

Canadian Perspective

Brahim Benmokrane, PEng., Ph.D.

Professor and Tier-1 Canada Research Chair, and NSERC/Industry Research Chair

Department of Civil Engineering, University of Sherbrooke, Sherbrooke, QC, CANADA

Outline of presentation

- CAN/CSA Codes and Standards
- New Development of GFRP Bars
- Current use of GFRP rebar in Canada
- MTO & MTQ’s Policies and Practices for Use of GFRP Rebar
- Design and Research Issues
- Construction Issues and Visual Inspection
- Conclusions

CAN/CSA Codes and Standards

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 in 2010, 3rd Edition in 2000, 4th Edition in 2019 (Approved)*
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, 2nd Edition in 2019 (Approved)*

CAN/CSA Codes and Standards

New Development of GFRP Bars in Canada

- GFRP Bars
- GFRP Stirrups
- GFRP Spirals & Hoops
- GFRP Bent Bars
- GFRP Headed Bars
- GFRP Dowels
- GFRP Adhesive Anchors

Canadian GFRP Bar Manufacturers

At least six Canadian GFRP bar manufacturers qualified their products in accordance with CAN/CSA S807 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)
6. PULTRON INC. (MATEEN)

New Development of GFRP Bars in Canada

Glass FRP Bars (High Modulus and High Strength)

1. *Guaranteed Tensile strength up to 1200 MPa (175 ksi)*
2. *Modulus of elasticity up to 60 GPa (9 Msi)*

New Development of GFRP Bars in Canada

GFRP Grades (CAN CSA S807)

Table 2
Grades of FRP bars and grids corresponding to their minimum modulus of elasticity, GPa
(See Clause 8.3 and Table 3)

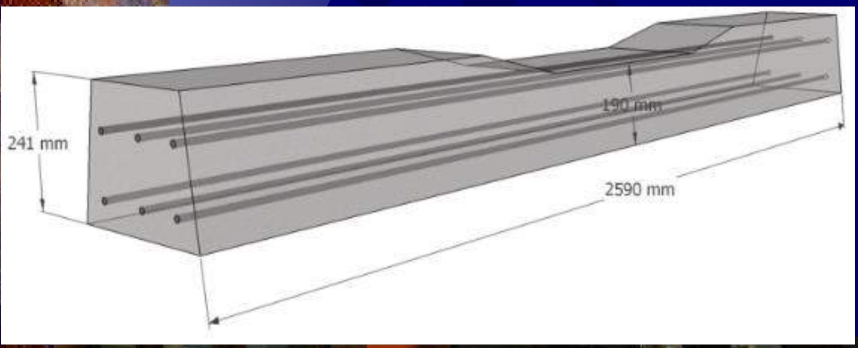
Designation	Grade I Individual bars	Grade I Bars in a grid	Grade II Individual bars	Grade II Bars in a grid	Grade III Individual bars	Grade III Bars in a grid
AFRP	50	40	70	60	90	80
CFRP	80	70	110	100	140	130
GFRP	40	30	50	40	60	50

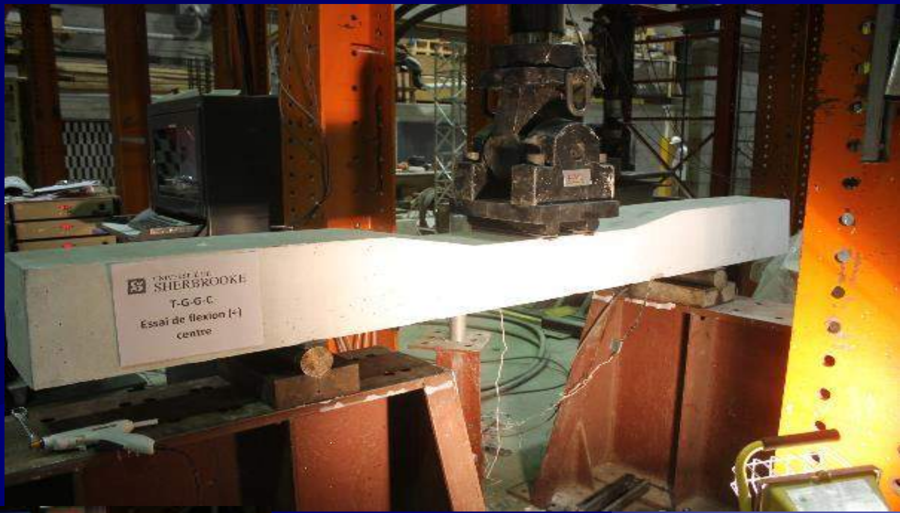
New Development of GFRP Bars in Canada

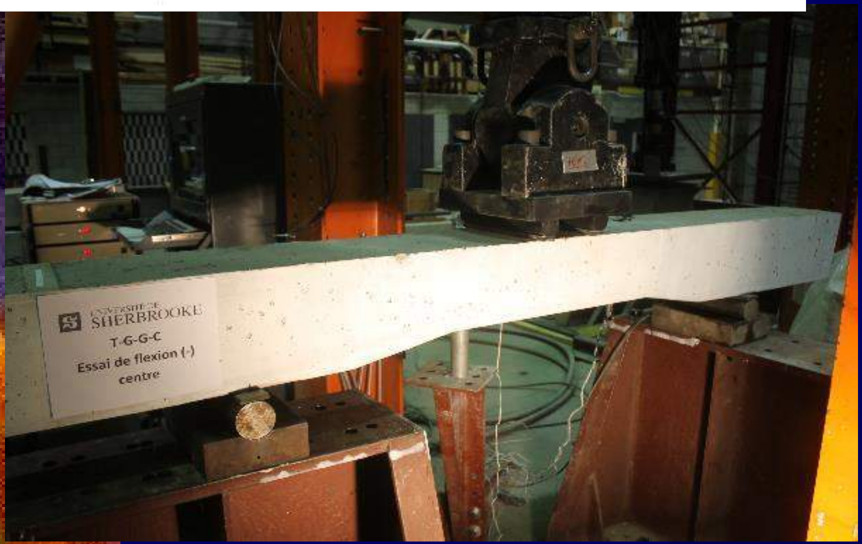
Prestressed GFRP Concrete Sleepers for Railways Applications

New Development of GFRP Bars in Canada

Prestressed GFRP Concrete Sleepers for Railways Applications

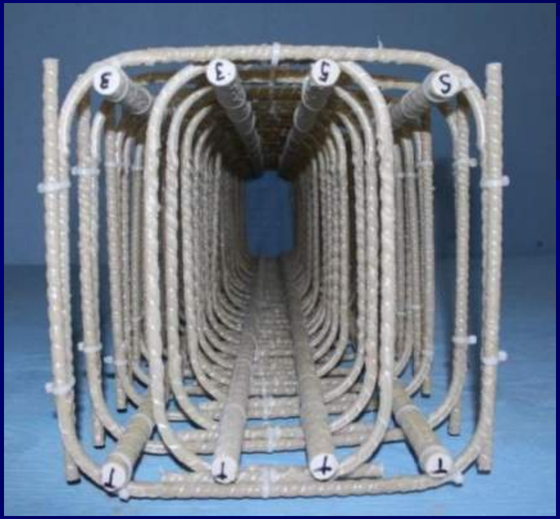






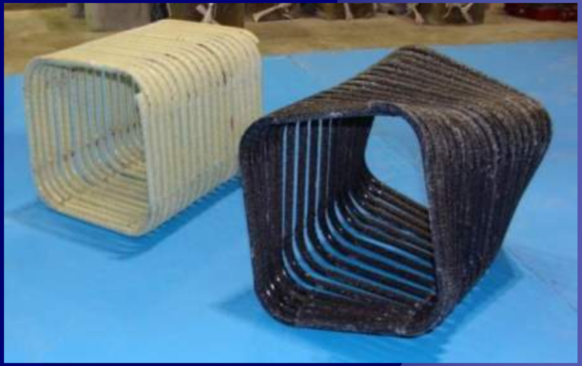
New Development of GFRP Bars in Canada

GFRP Ties



New Development of GFRP Bars in Canada

GFRP Spirals and Hoops



Precast Driven Piles (USA)- Arthur Drive Bridge, Lynn Haven, Florida

Cages fabrication for GFRP RC Precast Piles

Pile Driving Field Test

The three piles at the Bridge Site

Pile Driving Field Test

Test Results/Visual observations

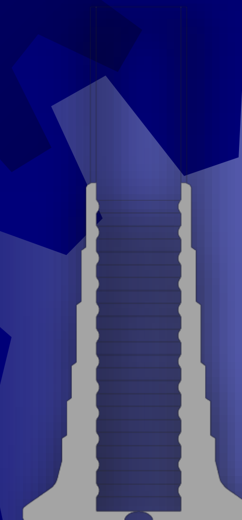
- Normal pile driving behavior
- No cover spalling
- No cracking
- No damage
- Average Pile capacity 333 ksi

New Development of GFRP Bars in Canada

GFRP Bent Bars

New Development of GFRP Bars in Canada

Glass FRP Headed bars



New Development of GFRP Bars in Canada

Glass FRP Headed bars

Minimum pullout capacity of anchor headed bars (CSA S807)

Fibre	Diameter, mm	Minimum pullout capacity, kN		Slip at loaded end limits
Glass	15	100		At 100 kN no more than 0.5 mm
	20	120		At 100 kN no more than 0.5 mm

Current Use of GFRP Bars in Canada

FRP Rebar Use in Concrete Bridges in Canada

202 Bridges – 5 provinces

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

Source:
ACMA, 2016

Current Use of GFRP Rebar

Field Applications – Bridge Deck Slabs

Current Use of GFRP Rebar

Field Applications – Bridge Deck Slabs

- Val-Alain Bridge, Val-Alain, QC, 2004

Current Use of GFRP Rebar

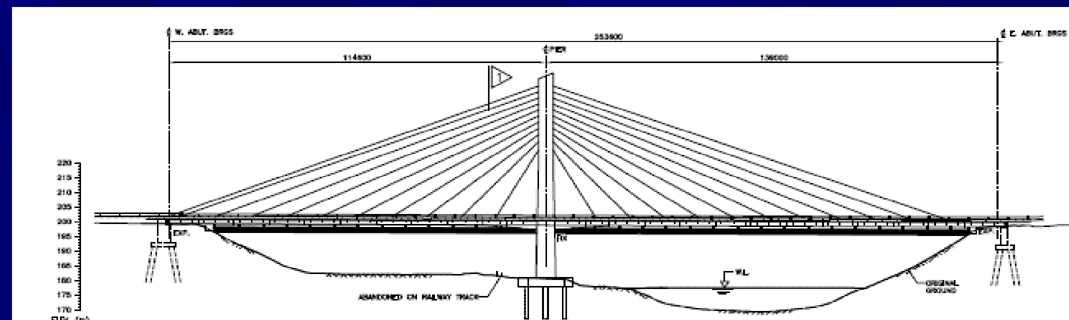
Field Applications – Bridge Barrier Walls

Current Use of GFRP Rebar

Precast Deck Slabs

Current Use of GFRP Rebar

Field Applications – Precast Deck Slabs



Nipigon River Cable-Stayed Bridge

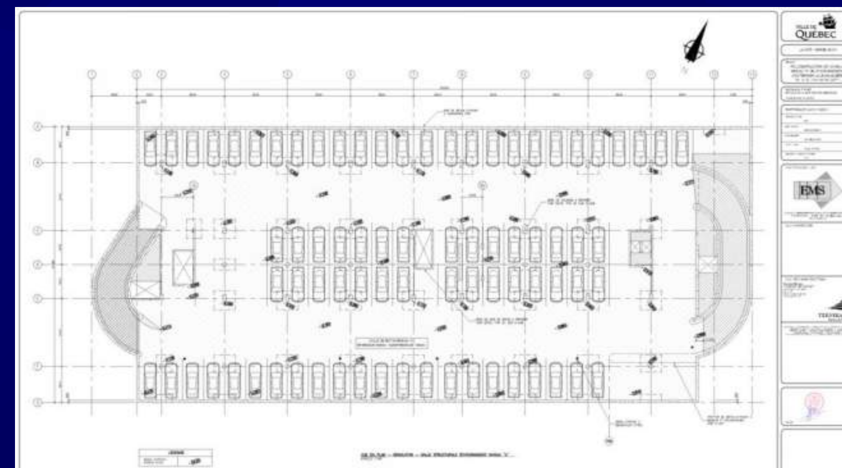
The First Deck Slab Reinforced with GFRP Bars in Cable Stayed Bridge

Nipigon River Cable-Stayed Bridge

- 2012-2017 (106 M$)
- ~827 ft. (252m) in length
- two-span, four lanes
- 480 precast concrete panels (10 ft. x 23 ft.)
- High Performance concrete
- Panel joint filled with UHPFRC
- Many partners

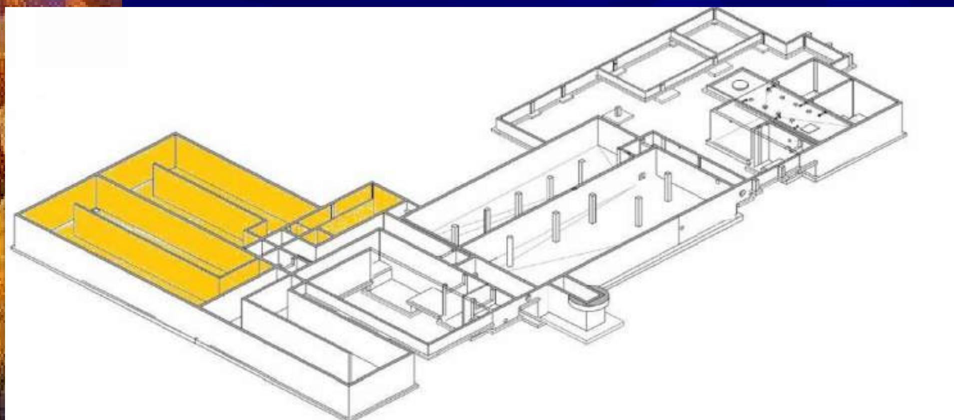
Current Use of GFRP Rebar

Field Applications – Parking Garages



Current Use of GFRP Rebar

Field Applications – Water Treatment Plants



Current Use of GFRP Rebar

Tunnels & RC Soft Eyes

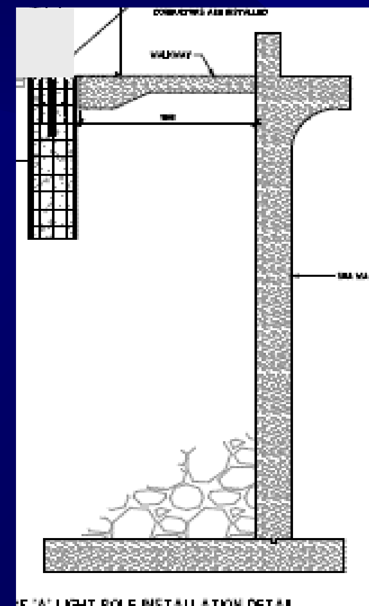



Current Use of GFRP Rebar

Field Applications – Concrete Pavements

Current Use of GFRP Rebar

Retaining Walls



Current Use of GFRP Rebar

Field Applications – Precast Utilities

MTO & MTQ’s Policies and Practices for Use of GFRP Rebar

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

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.

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, Tembar and Vrod, Standard Drawing has been issued..
- All other manufacturers will have to go through similar crash test in order to have their product/design qualified for PL3 /TL5 barrier.

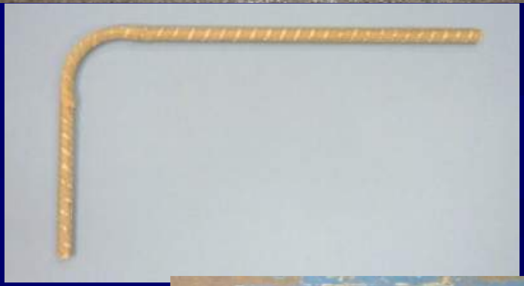
PL3/TL5 Barrier Wall

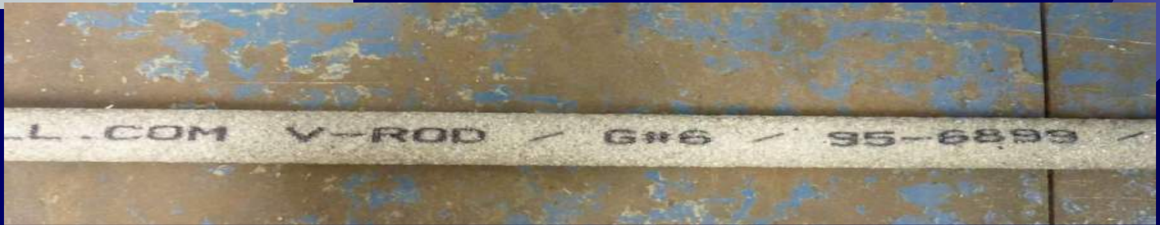
Crash Test with GFRP PL-3 barriers TTI, TEXAS

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.

MTO has recently implemented Guidelines for Inspection and Acceptance of Glass Fibre Reinforced Polymer (GFRP) Reinforcing Bars





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:

  - research at Ryerson University funded by MTO to evaluate GFRP dowels in epoxy grout and long term effects to be completed soon

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 Mark Green at Queens University on Fire Resilience of GFRP reinforced components is completed and has shown very positive 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

Conclusions

1. Application of GFRP bar in different structures in Canada has been proved to be very successful to date

2. The concrete structures reinforced with GFRP bars have a first cost almost the same as concrete structures reinforced with epoxy coated or galvanized steel bars. Stainless steel bars are 2 to 4 times more expensive than GFRP bars.

Conclusions

Current Applications in Bridges & Buildings

Status

- Very good structural behavior
- Excellent short-term durability (≈ 20 years)

Conclusions

Main Concerns

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

Thank you for your attention

brahim.benmokrane@usherbrooke.ca

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

(1:15 - 3:00pm)

Presentations (2 @ 10 mins)

1.1 US perspective *(Antonio Nanni – AC*

1.2 Canadian perspective *(Brahim Benn*

Discussion 1.3 (30 mins)

Presentations (2 @ 10 mins)

1.4 Australian perspective and experience on GFRP bars in concrete structures *(Allan Manalo, USQ)*

1.5 European perspective *(Emmanuel Ferrier)*

Discussion 1.6 (30 mins)

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AUSTRALIA

Australian perspective and experience on GFRP bars

Dr Allan C Manalo
Associate Professor in Civil Engineering
Theme leader – Civil Composites RPT
Centre for Future Materials / School of Civil Engineering and Surveying
University of Southern Queensland, Toowoomba, Qld 4350, Australia

2nd International Workshop on GFRP Bars for Concrete Structures

NSERC CRSNG
MIAMI
FDOT

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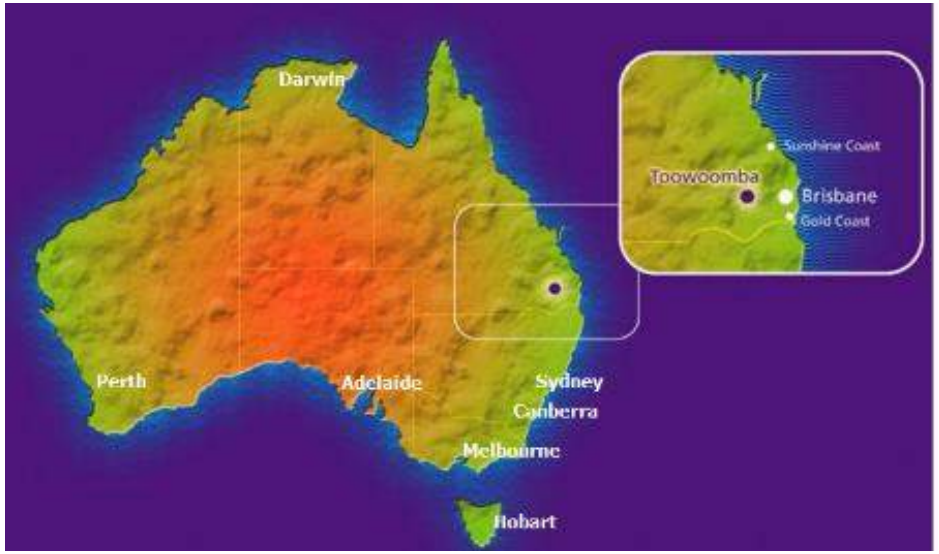
USQ
AUSTRALIA

University of Southern Queensland

- Established in 1967
- Approximately 27,000 students
  - (800 international students on-shore)
- Queensland’s No. 1 provider of online studies

-The Department of Education, 2014

- 3 campuses in Australia (Queensland):
  - Toowoomba, Springfield, Ipswich
- 2 Faculties
  - Faculty of Business, Education, Law & Arts
  - Faculty of Health, Engineering & Sciences
- 3 Research Institutes and 9 Research Centres
  - Centre for Future Materials



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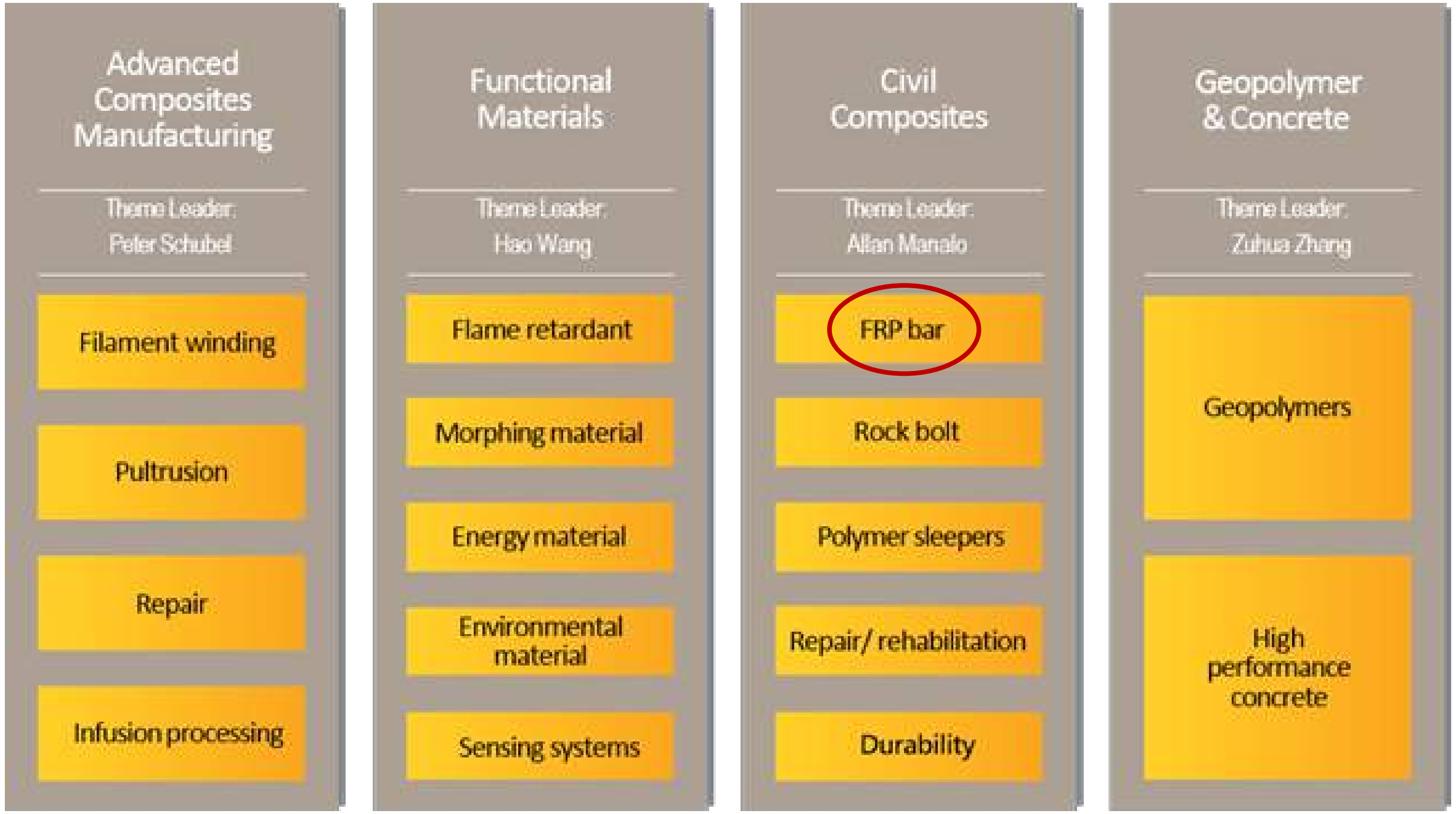
Centre for Future Materials

Established in 1995

One of the leading research centres in Australia for engineered fibre composites

Delivering R&D to Reality

- USQ does industry lead research – not academic interpretation of what industry may want.
- Working closely with industry partners
- Development of advanced/sustainable materials & manufacturing
- From research laboratory to real-life applications
- Providing education and training, and playing a major role in the development of materials and design standards



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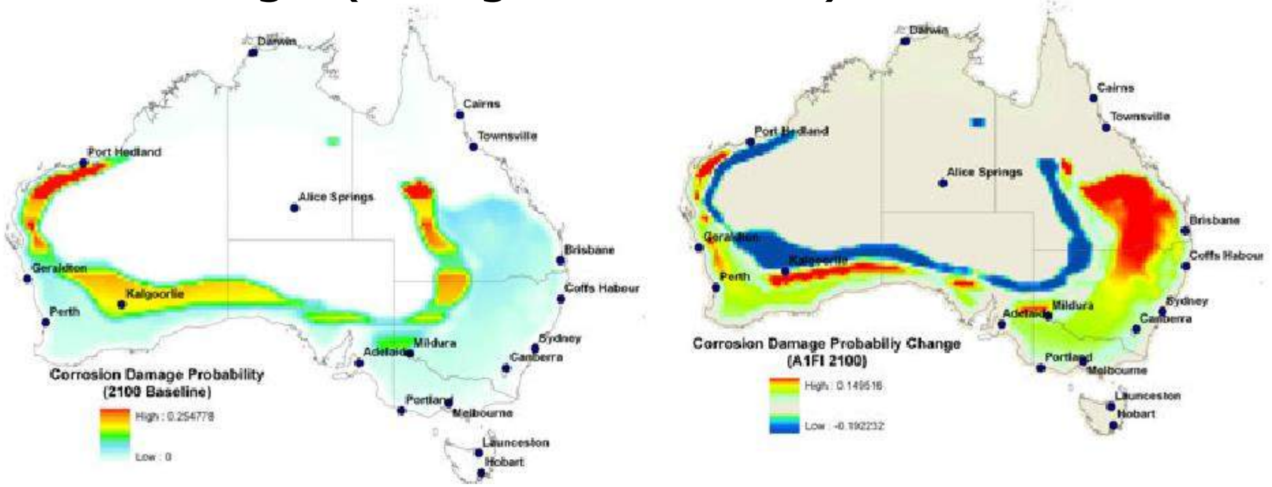
The need for FRP bars

Corrosion of steel reinforcement

- Most concrete bridge infrastructure start to deteriorate only after 30 years of service (Austroads, 2016).
- Repair or replacement costs associated with steel corrosion in Australia are estimated at **AU$13 billion per year**.
- The risk of corrosion is likely to increase significantly due to climate change (Wang et al. 2012).

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



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

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Research on FRP bars

Institution	Materials	Bond	Bending	Shear	Slab	Impact	Columns	Durability
USQ	√	√	√	√	√		√	√
Monash		√						√
UoW	√					√	√	
UWA							√	
UniSA			√					

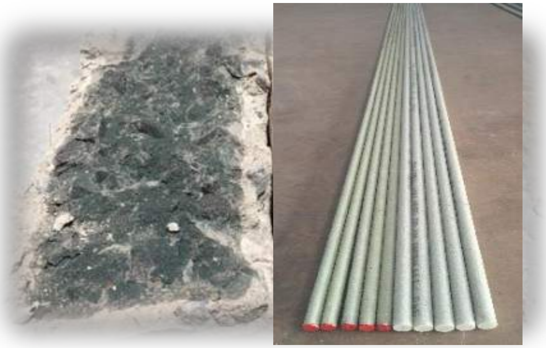
USQ – University of Southern Queensland

Monash – Monash University

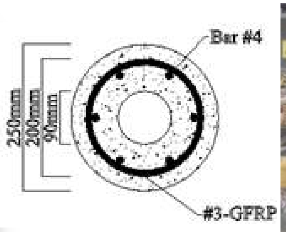
UoW – University of Wollongong

UWA – University of Western Australia

UniSA – University of South Australia



Geopolymer concrete reinforced with GFRP bars



Hollow concrete members reinforced with GFRP bars

Comparative durability of cement-embedded and bare GFRP bars

Current Australian market

- There are two main suppliers/ distributors of GFRP bars in Australia, with basalt FRP bars are now being introduced.
- Between 2012 and 2017, there were more than ***1.5 million meters*** of GFRP bars installed in actual construction projects.
- Market for GFRP bars increases by ***13% per year***, and with an estimated market value of around AU$5.0 million in 2017.

V-Rod (Inconmat Australia)

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

ROCKBAR® (Galen Australia)

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

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Current applications

- GFRP bars are used in Australia mainly as reinforcement in concrete structures exposed to harsh environmental conditions.
- 20% of market are for electrical and magnetic non-conductive applications including rail signal loops, hospital MRI's and nuclear science buildings
- Market penetration targets are **marine infrastructure**, **precast concrete** and **electrical** applications.

Anthon Jetty Wyndham, WA

Seawall replacement, Sylvania Waters Sydney

Annex extension, Toowoomba City Hall refurbishment project

Detector loop at Goldcoast Light Rail project

Recent applications

Pinkenba Wharf at Wagners' Pinkenba cement facility in Brisbane

- 252m long, 16m wide wharf comprising of **191 precast geopolymer concrete deck reinforced with GFRP bars**.
- Largest use of GFRP bars in Australia in a single job, i.e. 305 km (**152 tonnes**) of 16 mm, 19 mm, and 22 mm diameter bars.
- Designed following the **CSA S806-12** with reference to relevant AS standards, i.e. AS3600 and loading codes.

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Recent applications

Molecular Horizons Building, University of Wollongong

- Specified for electromagnetic neutrality and sensitive electrical research equipment. Tested and certified for fire performance.
- Designed following the **CSA S806-12** with reference to relevant AS standards, i.e. AS3600 and loading codes.
- Uses over **50 tonnes** of GFRP bars in 14 mm deep piles, pile caps, ground slabs, columns and walls through to the 2nd story and first floor suspended slab.

Lifting and installation of pile cage

Pile cage in position

Pile cage in bored pier hole

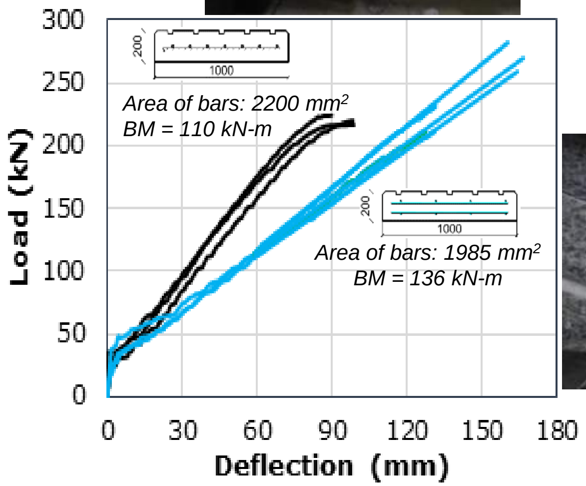
Pilecap

Recent applications

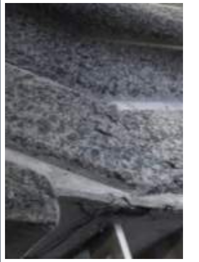
Precast boat ramp planks

- Optimal design of precast concrete ramp planks reinforced with GFRP bars.
- Eliminated the use of expensive silica fume in concrete mix, making the planks at a cost similar to that of galvanised steel reinforced.

Test set-up for boat ramp planks



Load and deflection behaviour



Mesh fabrication and mesh installation of GFRP reinforced is **30% faster** than GS reinforced (121.36 vs 173.82 worker minutes per 30 planks):

Installation of planks at Parkyn Parade boat ramp in Mooloolaba, Sunshine Cost.

Standard drawings approved by TMR:

SD4003 - Precast planks for boat ramp - Type RG4000 FRP (PDF, 459 KB)

Published at:

https://www.tmr.qld.gov.au/business-industry/Technical-standards-publications

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New opportunities

FRP-reinforced precast concrete in tunnels and railways

http://www.railone.com/products-solutions/long-distance-and-freight-transport/ballastless-track-systems/rheda-2000r/

Challenges:

- Significant outlay for government
- Severe atmospheric condition, *i.e. sulphur dioxide fumes from diesel powered engines*
- Stray current corrosion in electrified railway systems
- High moisture and seepage
- Costly maintenance

Advantages:

- Significant outlay for government
- Severe atmospheric condition, *i.e. sulphur dioxide fumes from diesel powered engines*

Ballastless track reinforced with FRP bars

Continuously FRP reinforced concrete track slabs

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Design codes/specifications

BD-108 Fibre-Reinforced Polymer (FRP) Bars

new Australian Standard for 'Design of concrete structures using Fibre-Reinforced Polymer (FRP) bars'
(proposal under consideration by Standards Australia)

Nominating Organisations :

- **University of Southern Queensland**
- Australian Institute of Building
- AUSTROADS
- Cement Concrete & Aggregates Australia
- Composites Australia Inc
- National Precast Concrete Association Australia
- Concrete Institute of Australia
- Consult Australia
- University of Melbourne

Education and Training

CIV8803 – Mechanics and Technology of Fibre Composites

Online course offered by USQ

Technology workshops:

to provide practising Australian engineers and civil engineering firms, as well as engineering students, with the knowledge necessary to ***design concrete structures with GFRP reinforcing bars***.

Technology transfer:

Practical design and application of GFRP bars in construction including handing, installation and assembly.

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Perspective

- **Current market and use of GFRP bars in Australia is increasing.**
- **Precast concrete members for marine/boating and rail infrastructure are identified as new and emerging markets for GFRP bars.**

- deflection and "catastrophic" failure is not a major issue as the structure is continuously supported by ground or water.

- **Current limitation for rapid acceptance is, still no Australian Codes in both design and manufacturing.** *Material standards, CSA vs ASTM and design standards, ACI vs ASTM? Can we develop a harmonised standard, i.e. ISO?*
- **Continuous education and training to risk adverse engineers to increase knowledge and confidence in the design and use of the materials.**
- **Minimise the use of bent bars.** *Need for new developments on cost-effective bent bars.*

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Thank you.

Find out more:

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07 4631 2547

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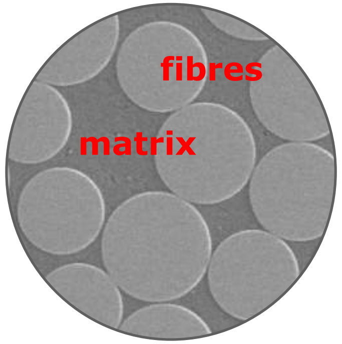
The solution



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

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Discussion 1.6 (30 mins)

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

Emmanuel FERRIER

LMC² - Université LYON 1

2nd International Workshop on GFRP bars for Concrete Structures

NSERC CRSNG

MIAMI

FDOT

Laboratoire des Matériaux
Composites pour la Construction
EA 7427

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Outline

- Primary drivers for DOT’s & other owners to fully implement GFRP rebar?
- Projects where GFRP were not specified in the past ?
- Accelerated Construction advantages with FRP ?
- Conclusions

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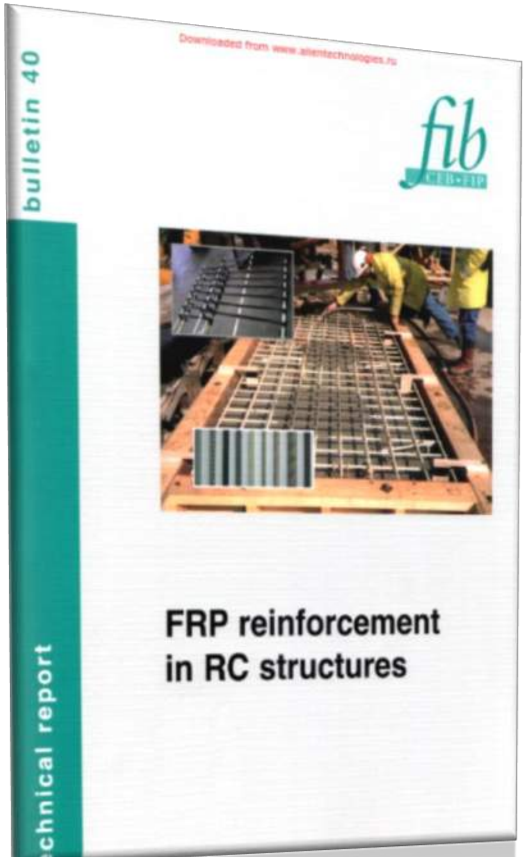
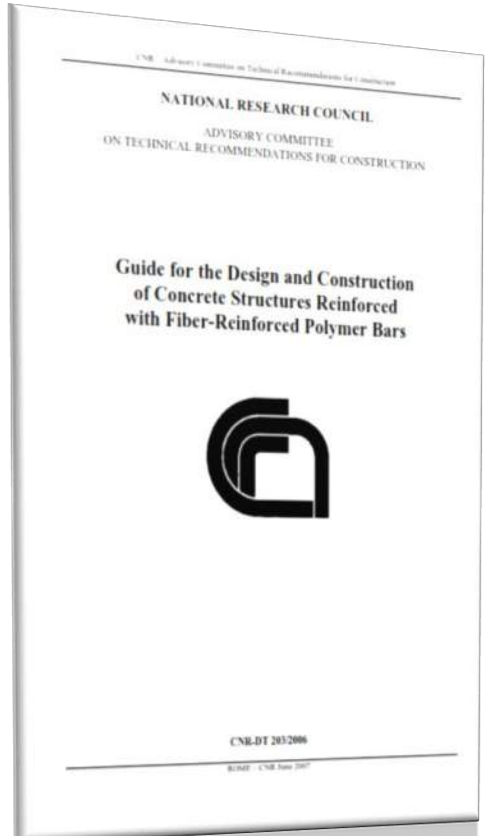
Codes and specification in Europe





French AFGC working group 2018-2021

AFGC

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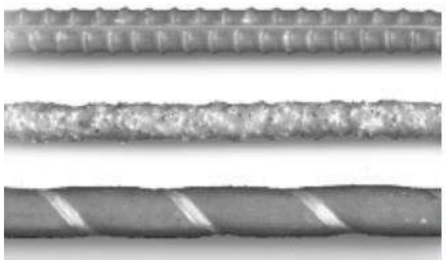
Materials design value



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

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.

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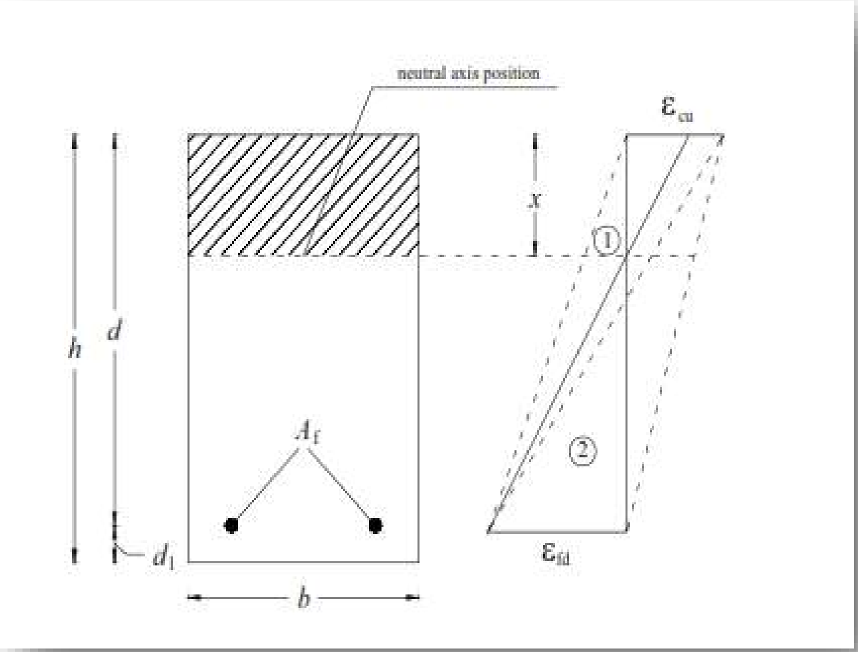
ULS calculation hypothesis



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

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

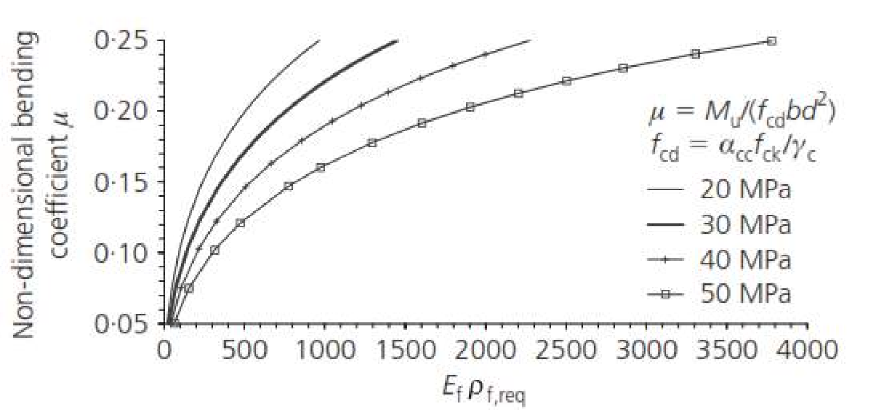


Figure 4. Design chart for flexural capacity of constant-width FRP RC elements

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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 shc 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.

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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

Outline

- Primary drivers for DOT's & other owners to fully implement GFRP rebar?
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Pavement on seaside

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

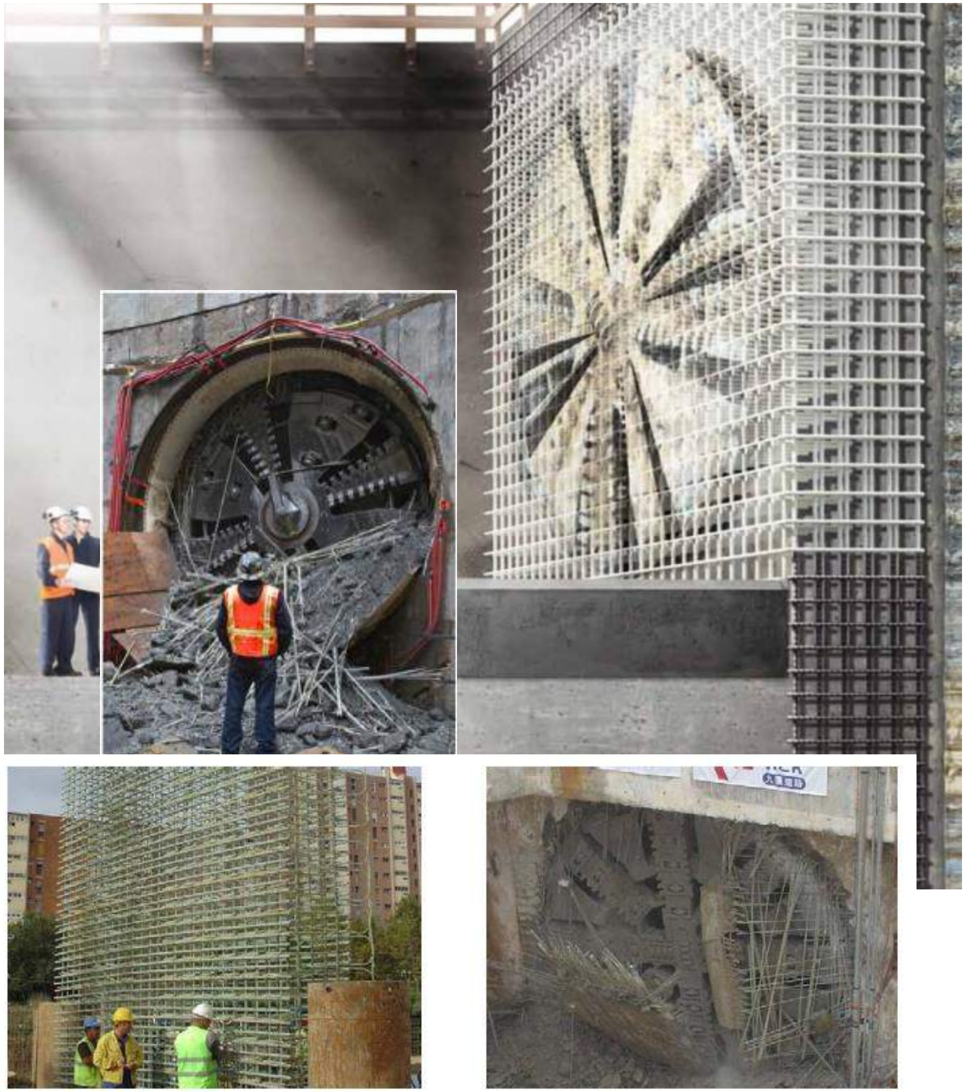

Figure 1-3: Soft eye FRP reinforcement

- 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

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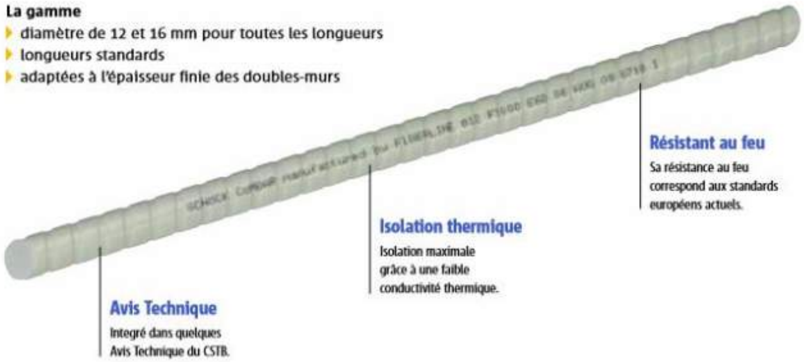
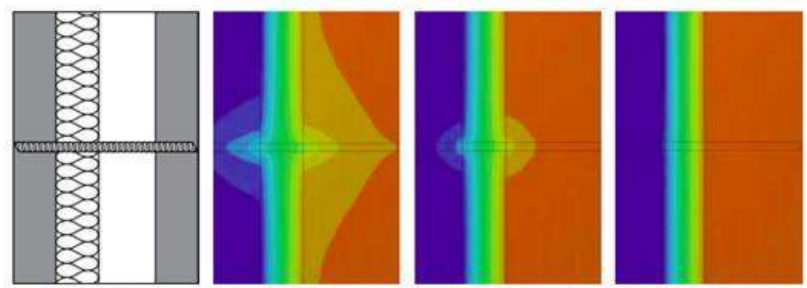
Soft Precast wall bolt



Schöck
Solutions constructives innovantes



Coupe sur prémur isolé | Acier haute adhérence $\lambda = 60$ W/(m·K) | Acier haute adhérence inoxydable $\lambda = 15 - 17$ W/(m·K) | Connecteur thermique Schöck Thermoanker $\lambda = 0{,}5$ W/(m·K)

Soft Precast wall bolt

Schöck
Solutions constructives innovantes

Soft Precast wall bolt

FFB FEDERATION FRANÇAISE DU BATIMENT

Le Bâtiment, une richesse pour la France

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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 œuvre 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. Préfabriqué 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 12 m, pour une largeur de panneaux allant jusqu'à 3,80 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 m^2 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!

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Soft Precast wall bolt

Avis Technique 3/15-817

Annule et remplace l'Avis Technique 3/10-645 et son Modificatif 3/10-645*01Mod.

Composants structuraux
Stuctural components
Strukturelle Bauteile

Goujons SCHÖCK

Titulaire : SCHÖCK BAUTEILE GmbH
Industriegebiet Steinbach
Vimbucher Strasse 2
D-76534 Baden-Baden

Tél. (France) : 03 88 20 92 28
Fax (France) : 03 88 20 51 76
Internet : www.schoeck.fr
E-mail : export@schoeck.com

Vu pour enregistrement le : 02 FEV. 2016
Charles BALOCHE

Commission chargée de formuler des Avis Techniques
(arrêté du 21 mars 2012)

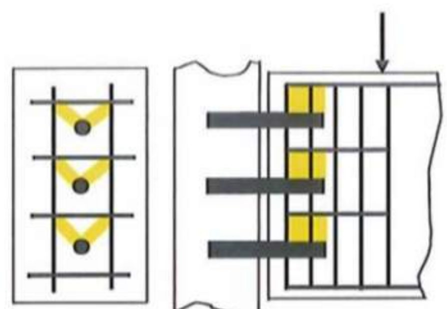
Groupe Spécialisé n° 3
Structures, planchers et autres composants structuraux

Vu pour enregistrement le

CSTB

Logements Bellerive

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



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Outline

- Primary drivers for DOT's & other owners to fully implement GFRP rebar?
- Projects where GFRP were not specified in the past ?
- Accelerated Construction advantages with FRP ?
- Conclusions

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Composite structures using FRP bars

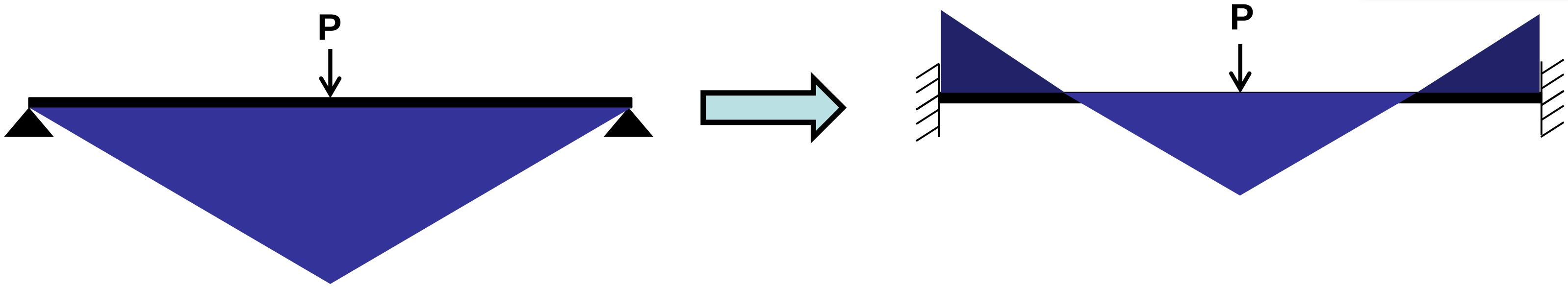
-Used of full system effect on mechanical behaviour

- mixing material with FRP bars

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.

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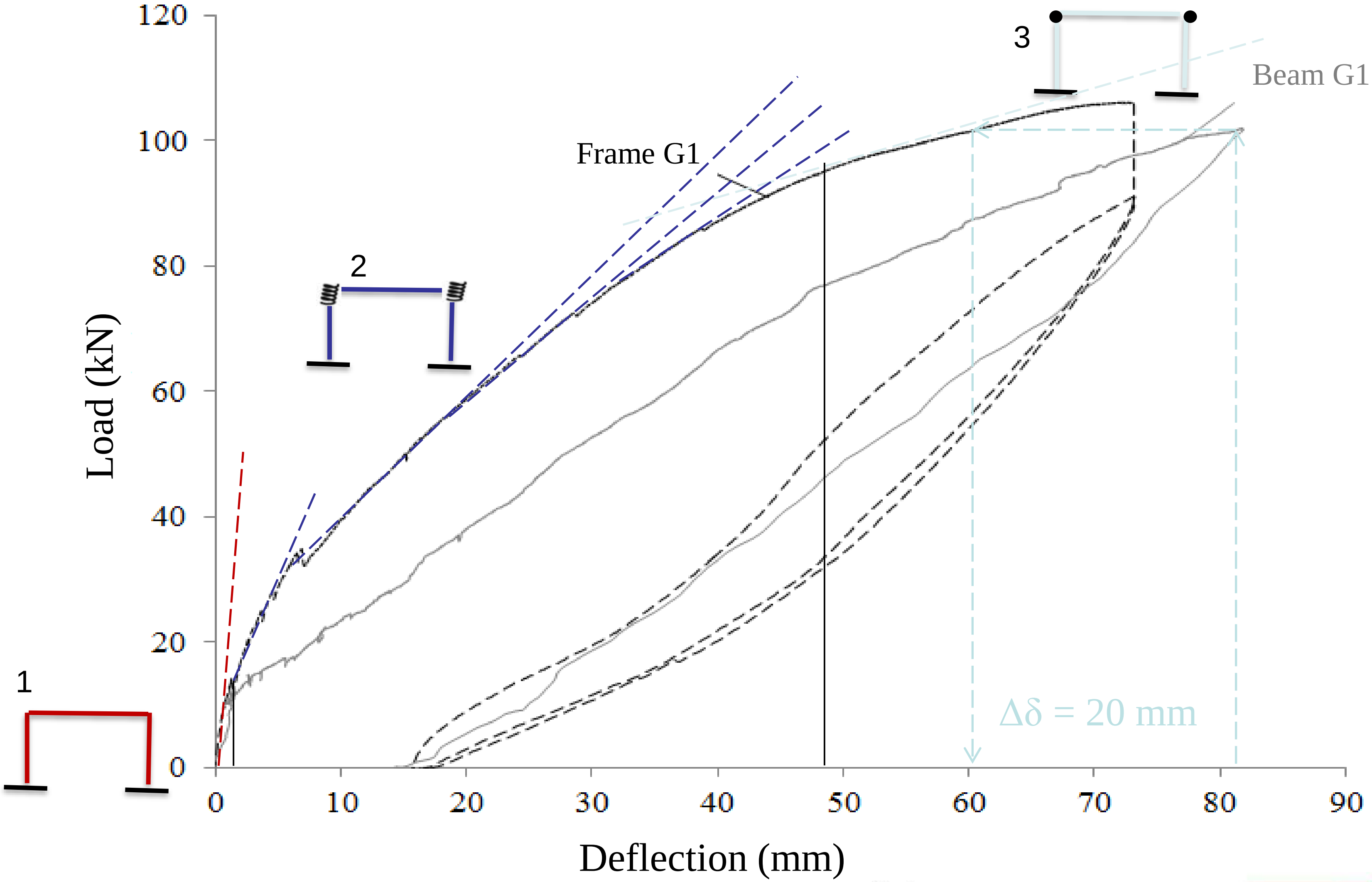
Experimental setup

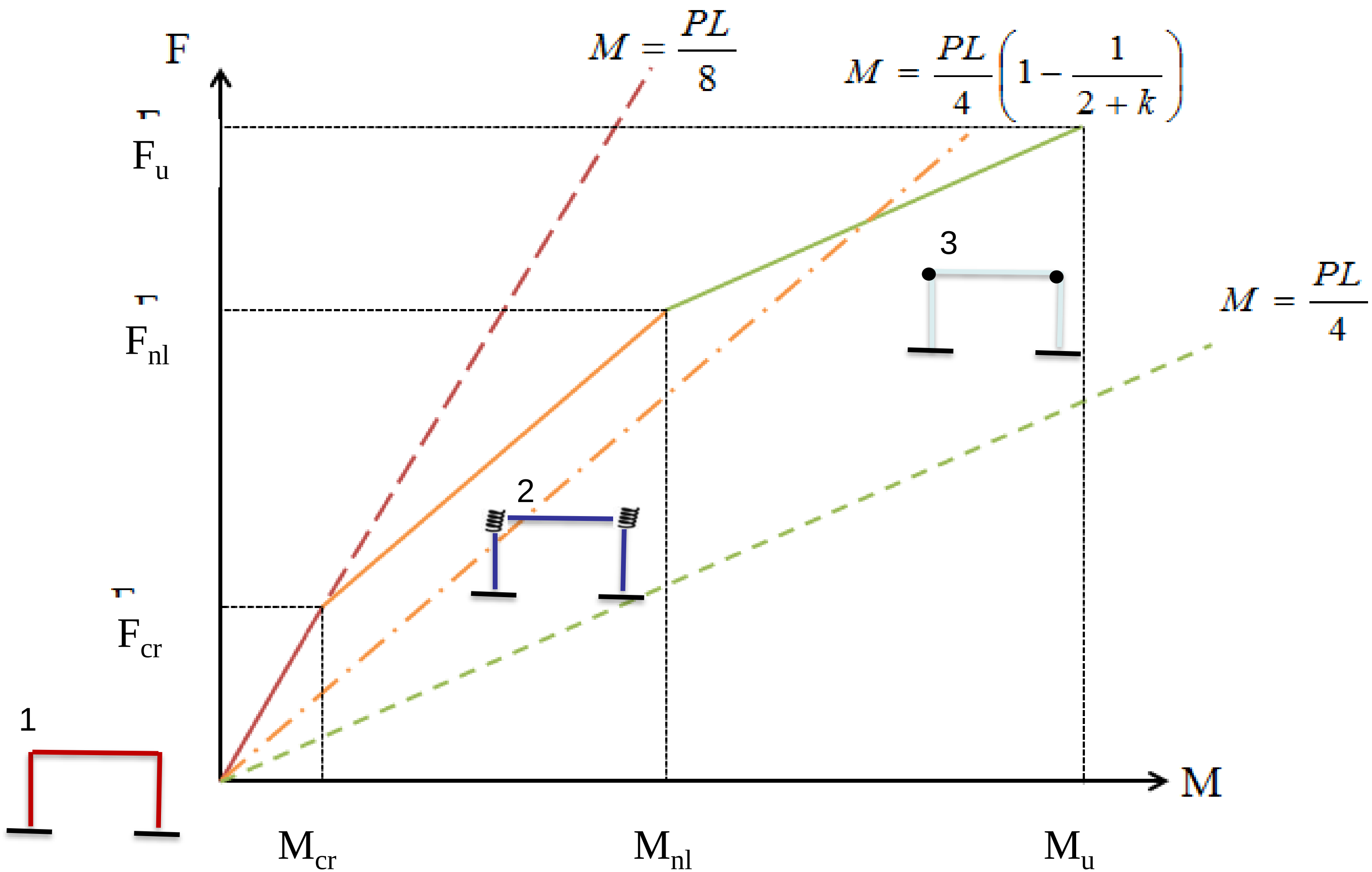
- 3-points bending test

Experimental results

Difference of deflection between isostatic and hyperstatic system



Force deduced from calculated features moments



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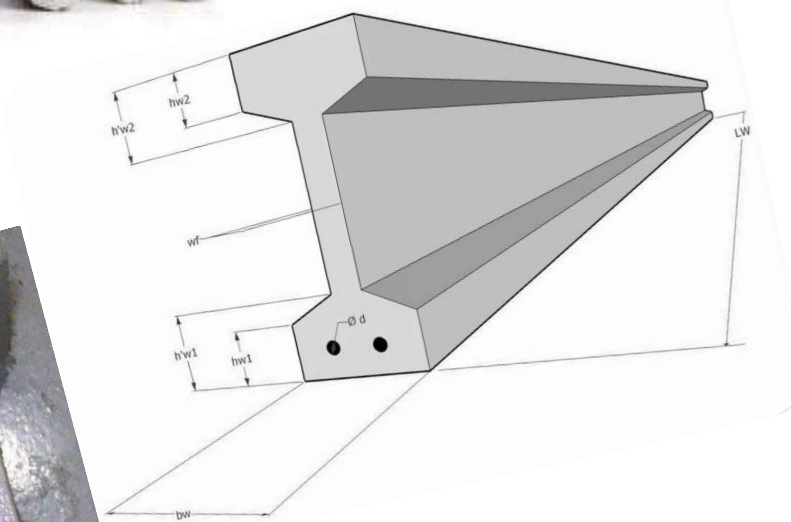
« …get the best of each material for new product… »

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: 200 MPa in compression
15 MPa in tension

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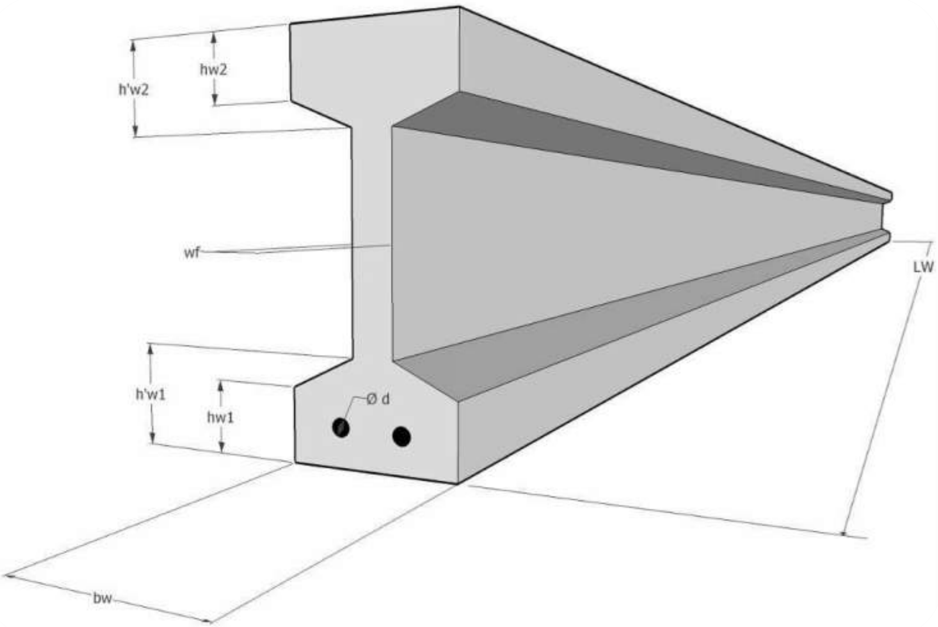
« …UHPC and FRP… »



	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.]	[mm^2]
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

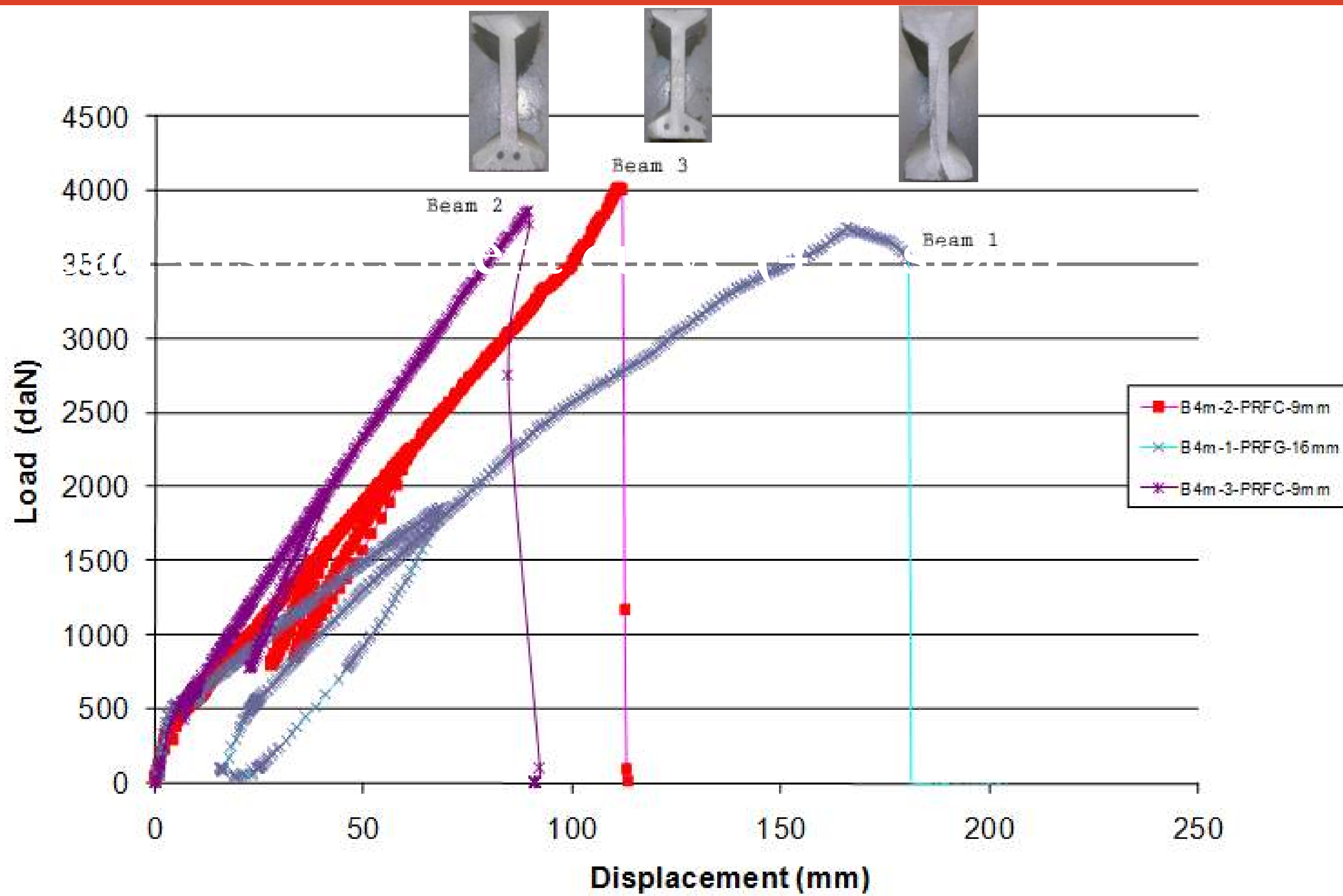

Beam 2


Beam 3


Beam 4

Beams section after testing

Load deflection curve



Choice of the sections

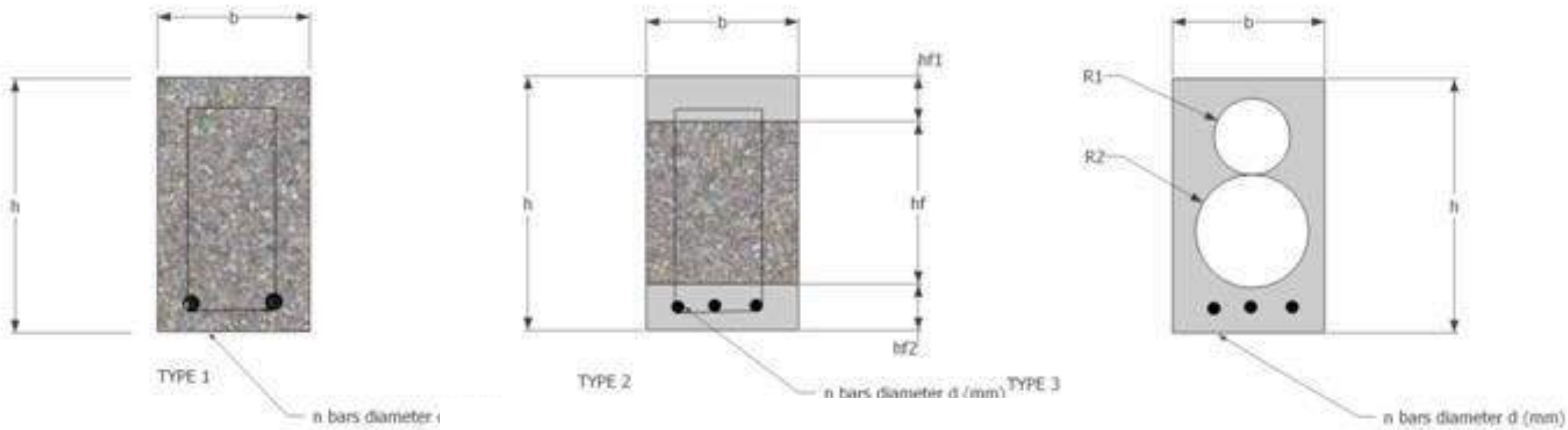


Fig. 1 - Geometrical parameters of beams

Normal strength concrete
UHPC

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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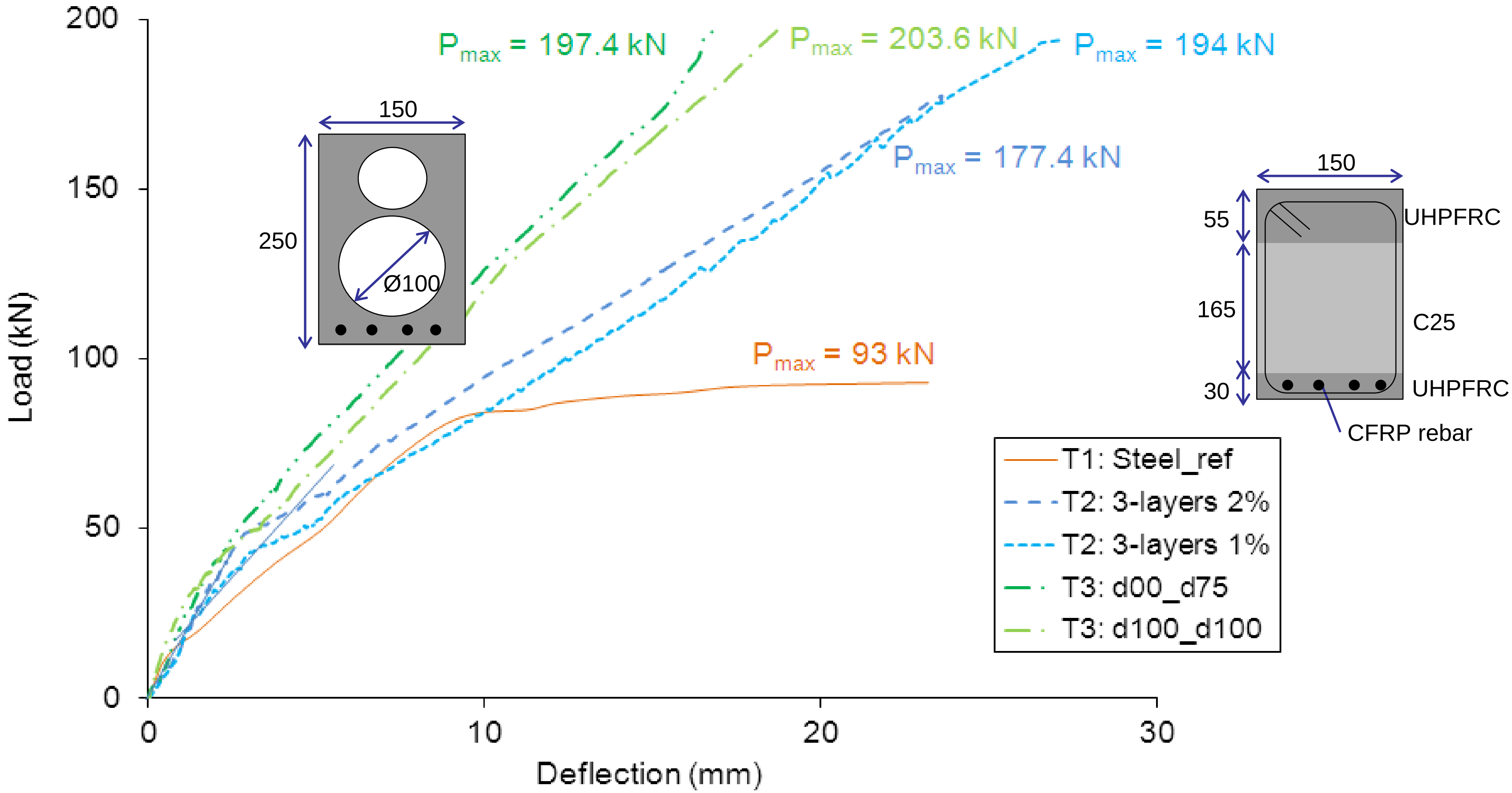
Experimental results

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



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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

Thanks

Any questions?

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