FRP as Internal Reinforcement to Concrete Structures

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June 14, 2022
Minnesota Concrete Council

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Overall Table of Contents

Selection of slides from:

Table of Contents

Part I

Some fundamentals on FRP

- Bar Types and Shapes
- Mechanical Properties
- Special Considerations

GFRP Rebars

Fiber reinforced polymer (FRP) bars as alternative reinforcement for concrete

A composite material system made of:
Fibers + Resin

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FRP Bar Types

Several commercially available GFRP solid round bars with different external surface (not standardized) deformations:

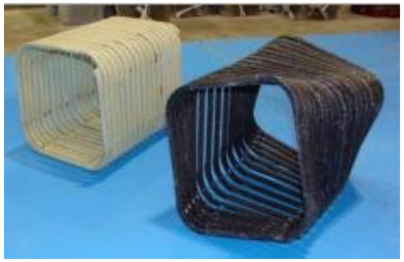
- (A & F) Sand coated + helical wrap
- (B) Helically wrapped
- (C) Ribbed
- (D) Sand coated
- (E) Helically grooved

FRP Bar Shapes

- Straight bars

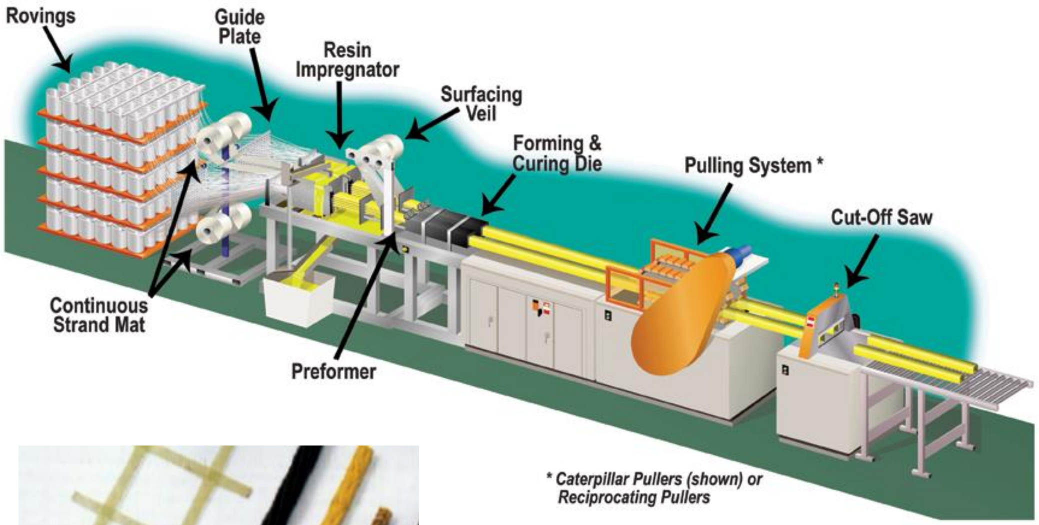
- Bent bars

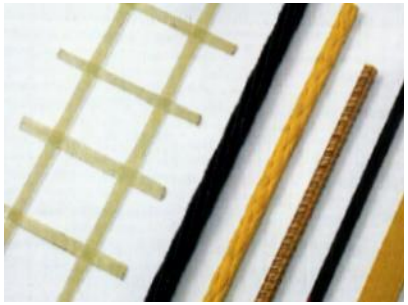
- Spirals

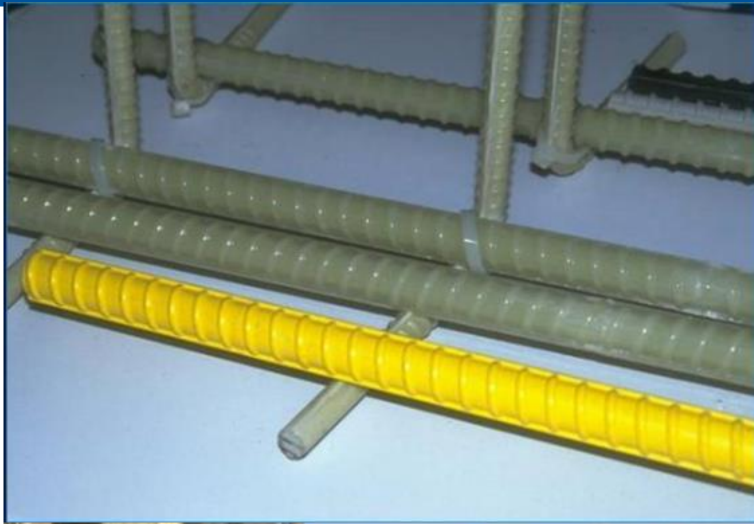


- Twisted strands (PC use)

FRP Bars and Grids





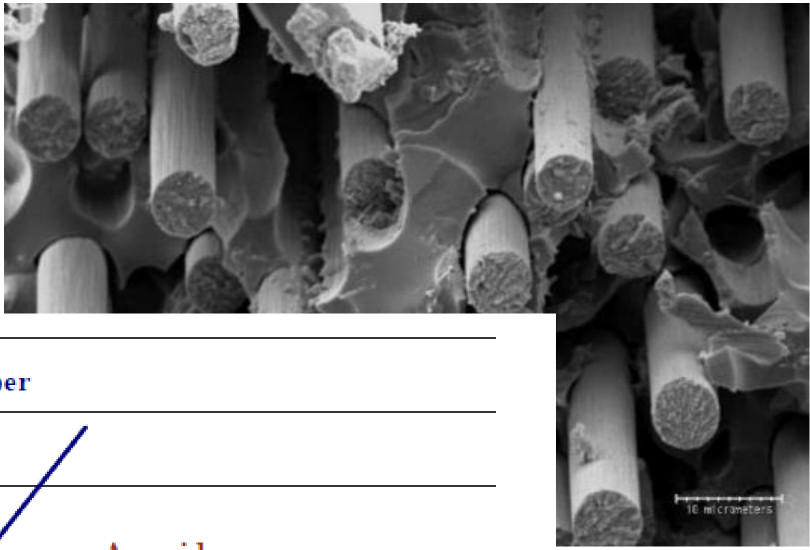


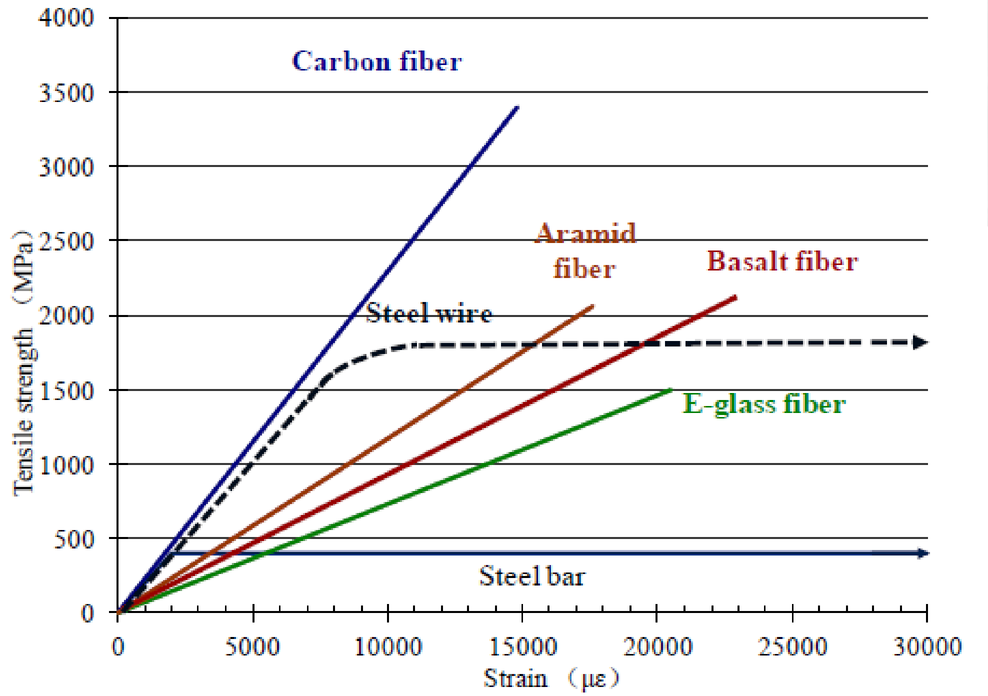
Typically produced by the Pultrusion process but some filament winding for close stirrups

Fiber Reinforced Polymer (FRP) Bars

- **Fiber** – Structural element
  - E-CR Glass
  - Basalt
  - Carbon

- **Matrix** – Binder
  - Vinyl Ester
  - Epoxy





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Some fundamentals on FRP

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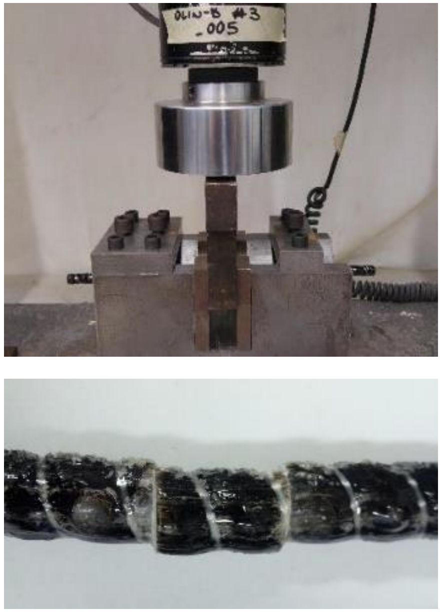
Testing Methods (Selected)

ASTM D7205 Tensile

ASTM D7913 Bond Strength to Concrete

ASTM D7914 Bent Bar

ASTM D7617 Trans. Shear Behavior



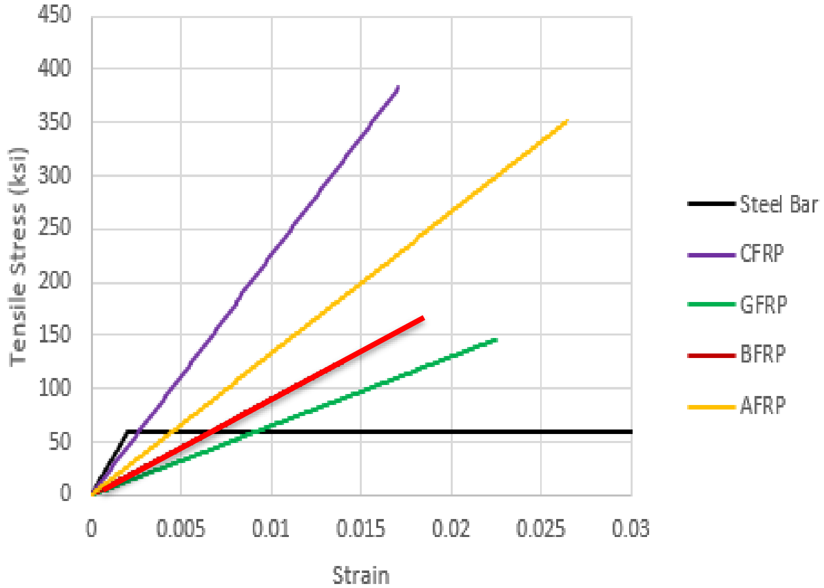
ASTM E2160 Enthalpy of Polymerization

ASTM E2160 Glass Transition Temp.

FRP Mechanical Properties

- **Higher tensile strength, but less stiff than steel**
  - ✓ Provides less confinement to concrete and RC members have more deflection than steel-RC
- **Anisotropic behavior**
  - ✓ High strength in the fiber direction
  - ✓ Low shear strength and dowel action (resin dominated)
- **Elastic up to failure - no ductility**
  - ✓ Cannot be used in seismic areas, no plastic hinges formed in RC members

Tensile Stress-Strain Characteristics



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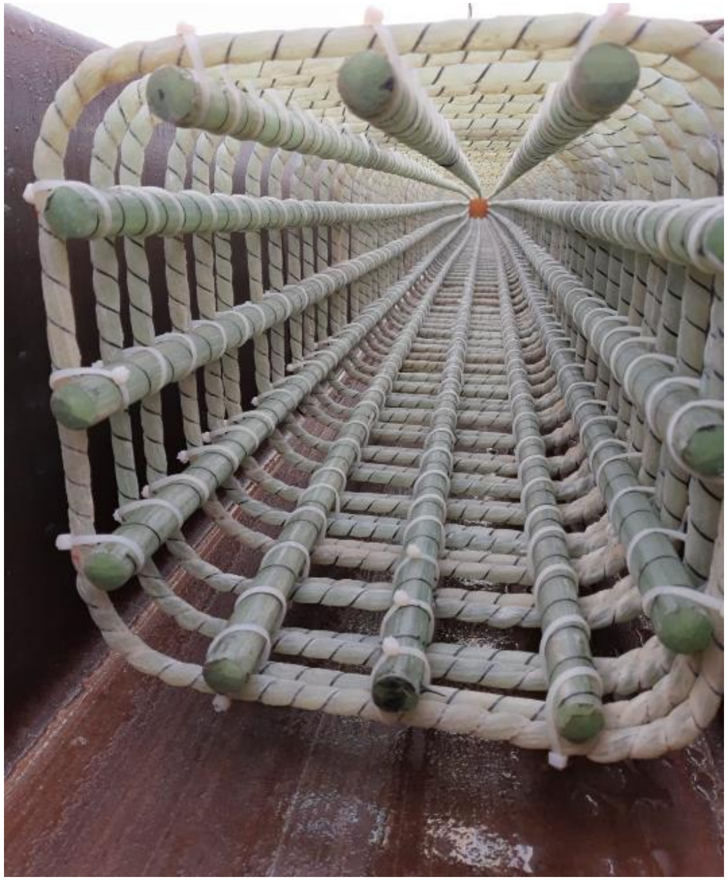
Some fundamentals on FRP

- Bar Types and Shapes
- Mechanical Properties
- Special Considerations

FRP BENDS

- Field bending or straightening of GFRP bars **not possible** when using a thermoset resin binder

- All stirrups are **pre-bent**



FRP BAR CUTTING

- Cutting FRP rebar will NOT compromise bar durability. NO treatment or sealing of ends is necessary
- Softer material results in easier and faster cutting
- No metal means less sparking and heat generation during

To cut, use:

- Fine toothed saw on field
- Diamond tipped blade in a chop saw used in factory

Do NOT use:

- Shear
- Bend and Break
- Torch

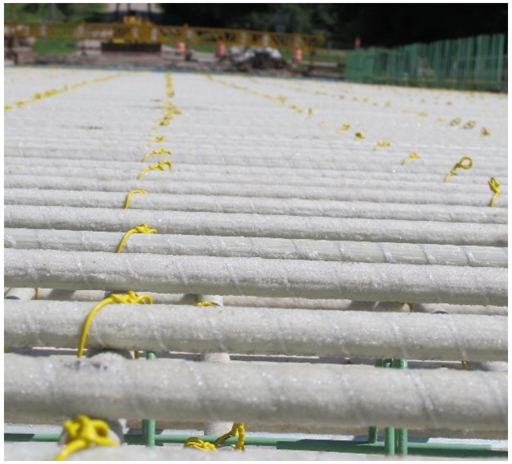
FRP BAR HANDLING

- FRP Bars similar to steel, but significantly lighter: #5 GFRP = 0.287 lb/ft; #5 Steel = 1.000 lb/ft
- Workers carry more bars per trip, or use less workers to carry similar quantities
- Placement easier due to ease of handling
- Creating bent shapes on site not possible, field forming of straight bars to match a profile acceptable
- Recommended to wear gloves, as well as any other project/site specific safety gear
- Material will not get as HOT as steel in direct sunlight

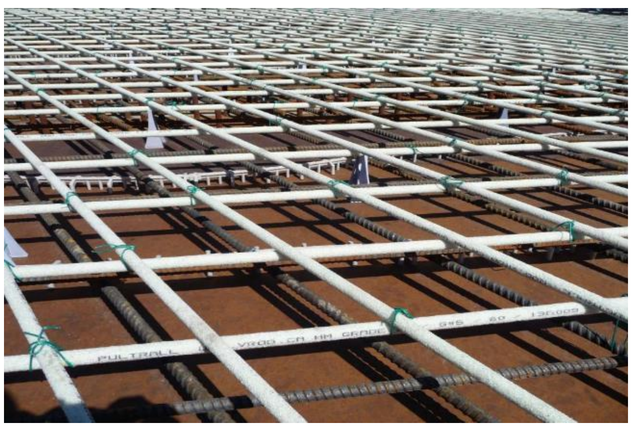
FRP BAR TYING

- Plastic clips
- Zip ties
- PVC coated wire
- Epoxy coated wire
- Standard steel wire
- Tie guns
- Recommended that chairs be placed more frequently for stability

2/3 of normal chair Spacing may be scoped on project



DISADVANTAGES OF FRP BAR



- No ductility
- Lower elastic modulus than steel
- No ability to bend at site
- High CTE perpendicular to fibers
- Lack of familiarity among engineers, contractors and owners

ADVANTAGES OF FRP BAR

- Corrosion resistant
- High strength-to-weight ratio
- Ease of application & installation
- Lightweight (¼ the weight of steel)
- Transparent to magnetic fields and radar frequencies
- Electrically & thermally non-conductive

FIRST COST COMPARABLE WITH EXPOXY-COATED STEEL

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Part II

Guides & Standards

- ASTM Material Spec
- Documents for Buildings
- Documents for Bridges

Some Notions on Analysis & Design

- Tensile Strength

Material Specifications

ASTM D7957 spec sets minimum QUALIFICATION & QC requirements for **Glass FRP bars (round and solid)**

INTERNATIONAL

Designation: D7957/D7957M – 17

Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement[1]

This standard is issued under the fixed designation D7957/D7957M; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This specification covers glass fiber reinforced polymer (GFRP) bars, provided in cut lengths and bent shapes and having an external surface enhancement for concrete reinforcement. Bars covered by this specification shall meet the requirements for geometric, material, mechanical, and physical properties described herein.

1.2 Bars produced according to this standard are qualified using the test methods and must meet the requirements given by Table 1. Quality control and certification of production lots of bars are completed using the test methods and must meet the requirements given in Table 2.

1.3 The text of this specification references notes and footnotes which provide explanatory material. These notes and footnotes (excluding those in tables) shall not be considered as requirements of the specification.

1.4 The following FRP materials are not covered by this specification:

1.4.1 Bars made of more than one load-bearing fiber type (that is, hybrid FRP).

1.4.2 Bars having no external surface enhancement (that is, plain or smooth bars, or dowels).

1.4.3 Bars with geometries other than solid, round cross sections.

1.4.4 Pre-manufactured grids and gratings made with FRP materials.

1.5 This specification is applicable for either SI (as Specification D7957M) or inch-pound units (as Specification D7957).

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

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

1.8 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

A615/A615M Specification for Deformed and Plain Carbon-Steel Bars for Concrete Reinforcement
C904 Terminology Relating to Chemical-Resistant Nonmetallic Materials
D570 Test Method for Water Absorption of Plastics
D792 Test Methods for Density and Specific Gravity (Relative Density) of Plastics by Displacement
D2584 Test Method for Ignition Loss of Cured Reinforced Resins
D3171 Test Methods for Constituent Content of Composite Materials
D3878 Terminology for Composite Materials
D7205/D7205M Test Method for Tensile Properties of Fiber Reinforced Polymer Matrix Composite Bars
D7617/D7617M Test Method for Transverse Shear Strength of Fiber-reinforced Polymer Matrix Composite Bars
D7705/D7705M Test Method for Alkali Resistance of Fiber Reinforced Polymer (FRP) Matrix Composite Bars used in Concrete Construction
D7913/D7913M Test Method for Bond Strength of Fiber-Reinforced Polymer Matrix Composite Bars to Concrete by Pullout Testing
D7914/D7914M Test Method for Strength of Fiber Reinforced Polymer (FRP) Bent Bars in Bend Locations

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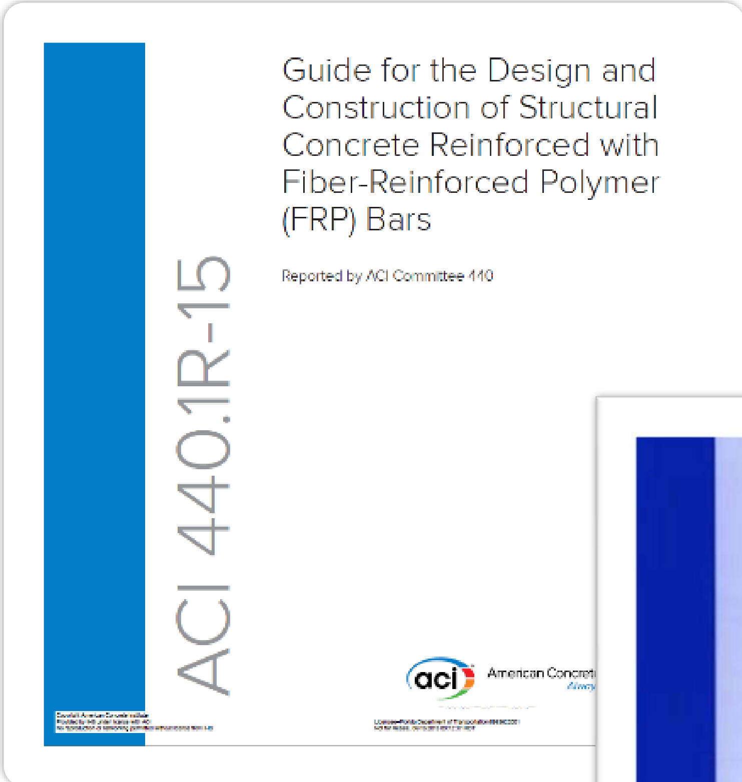
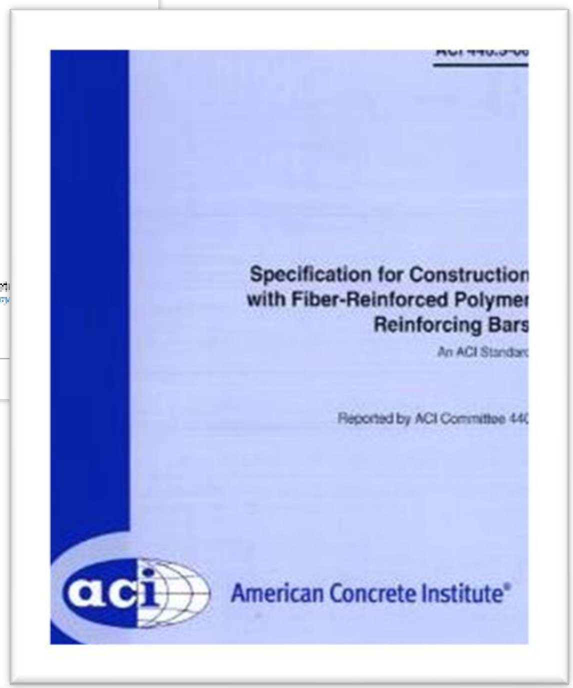
How to Specify/Design Building Structures


Guide for the Design and Construction of Structural Concrete Reinforced with Fiber-Reinforced Polymer (FRP) Bars

Reported by ACI Committee 440

ACI 440.1R-15

ACI 440-22 Building Code (2022 completed public comment) is 318-19 dependent


Specification for Construction with Fiber-Reinforced Polymer Reinforcing Bars

An ACI Standard

Reported by ACI Committee 440

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ES ICC EVALUATION SERVICE

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

AC454

Approved December 2020

Masonry Building Code TMS 402 (2021 completed public comment) includes GFRP reinforcement as Appendix D

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How to Specify/Design Transp. Structures

AASHTO Design Guide Spec

- Currently available
- References ASTM D7957

Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.

ASTM INTERNATIONAL

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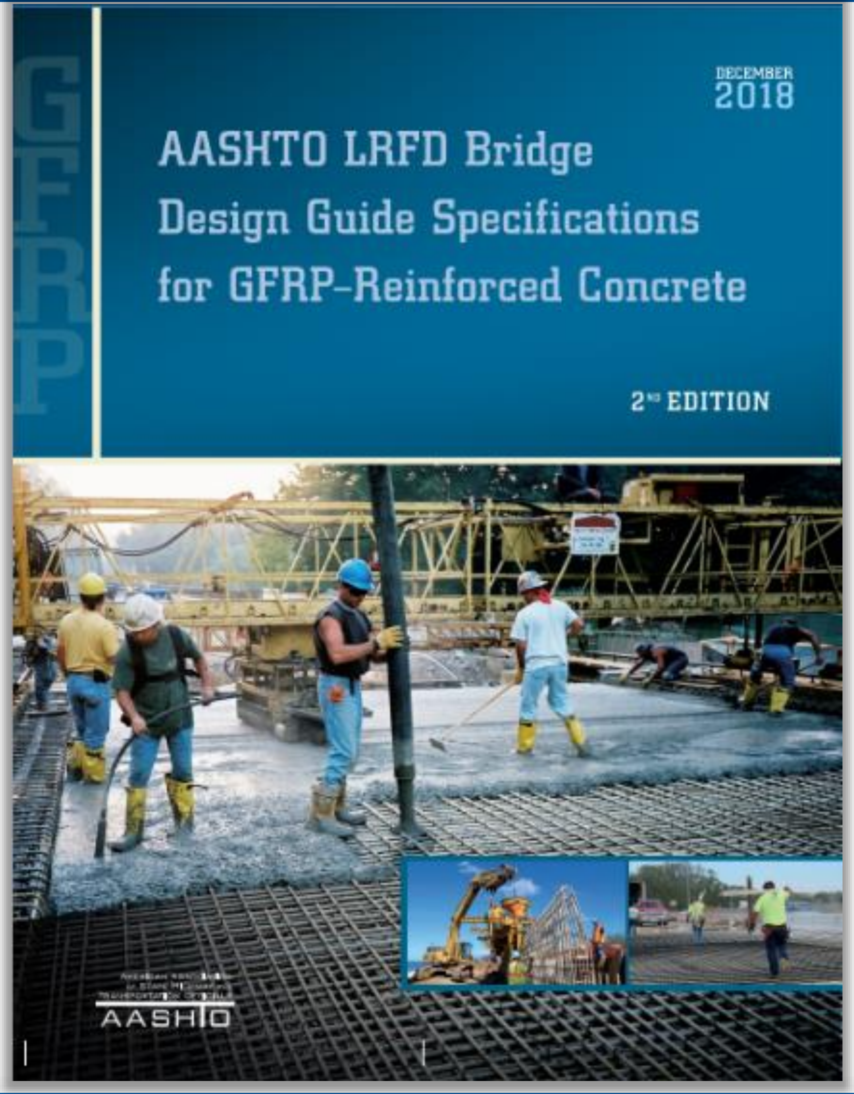


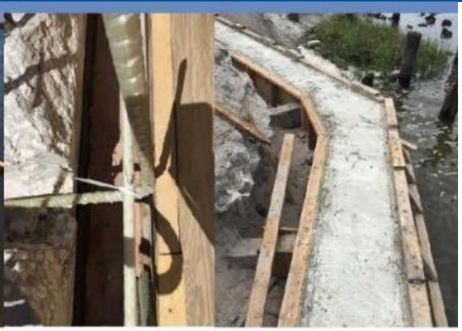
www.fdot.gov/structures/innovation


Fast Facts:

Glass Fiber Reinforced Polymer

Project Location:	FDOT District Two Duval County Jacksonville, Florida
Agency:	Florida Department of Transportation
URL:	http://www.fdot.gov/structures/innovation/FRP.shtm
Project Name:	US-17 (SR-5) Over Trout River Bridge No. 720011 FPID: 426169-1
Project Description:	Bridge Substructure Rehabilitation
Project Purpose & Need:	Bridge Inspection Reports identified concrete deterioration in the substructure. Work activities included removal of existing Pile Jackets and installation of new Pile Jackets and Pier Footing Jackets with Impressed Current Cathodic Protection (ICCP). Glass Fiber Reinforced Polymer (GFRP) dowels and reinforcement were used in select locations.

FDOT

Fast Facts:

Glass Fiber Reinforced Polymer

Project Location:	FDOT District Two Levy County Cedar Key, Florida
Agency:	Florida Department of Transportation
URL:	http://www.fdot.gov/structures/innovation/FRP.shtm
Project Name:	SR 24 over Number Three Channel Bridge No. 340003 FPID: 426169-1
Project Description:	Rehabilitation of three bridges in Cedar Key
Project Purpose & Need:	Bridge Inspection Reports identified deterioration, including evidence of corroded steel reinforcement in the bulkhead cap on bridge 340003. Work activities included removal of the existing bulkhead cap and installation of a new bulkhead cap with GFRP reinforcement.

FDOT

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Design Tensile Strength

- Design tensile strength and strain are:

$$f_{fd} = C_E f_{fu}$$

AASHTO GFRP 2.4.2.1-1

$$\varepsilon_{fd} = C_E \varepsilon_{fu}$$

Where C_E is the environmental reduction factor ***AASHTO* Table** 2.4.2.1-1

Fiber	Concrete not exposed to earth or weather	Concrete exposed to earth or weather
Glass	0.8	0.70

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Part III

Field Applications

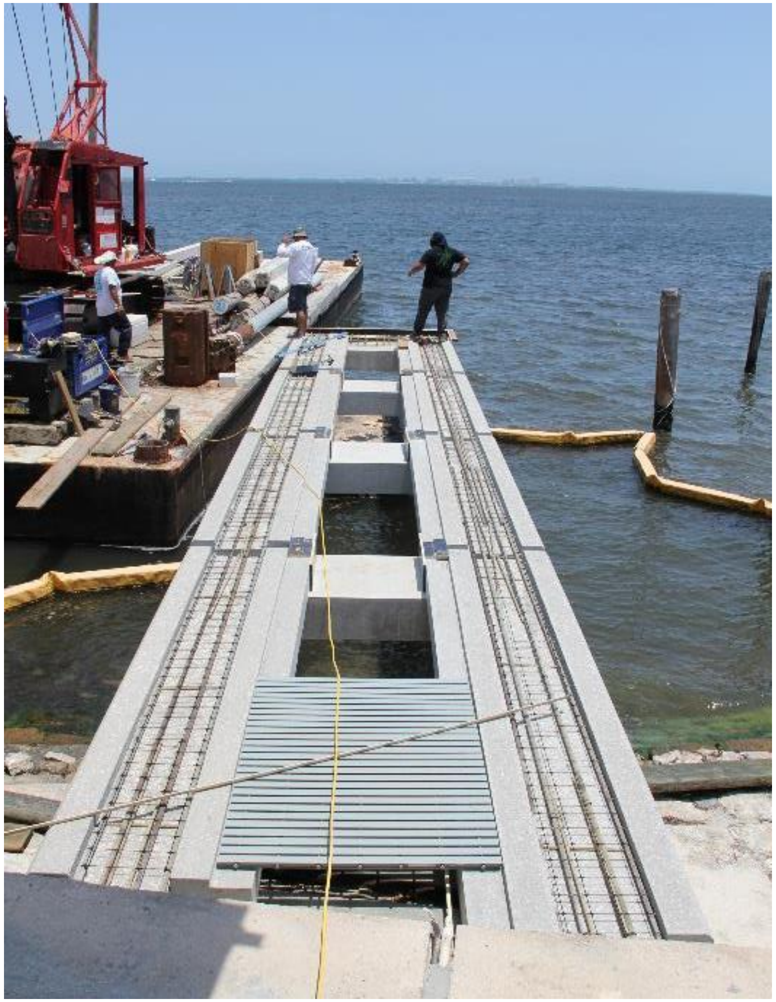
- iDock (Marine Dock) in Miami, FL
- NE 23rd Avenue Bridge over Ibis Waterway, Broward County, FL
- SR-A1A Flagler Beach (Segment 3), FL
- Flood Mitigation Canal, Jazan Saudi Arabia

Where Should FRP Be Used?

- **Concrete structures susceptible to corrosion**
  - Steel corrosion by chlorides
  - Environments that lower concrete pH
  - Structures with minimum concrete cover
- **Concrete structures requiring non-ferrous reinforcement due to**
  - Electro-magnetic considerations
  - Thermal non-conductivity
- **Where machinery will "consume" the reinforced concrete member** (i.e., mining and tunneling)

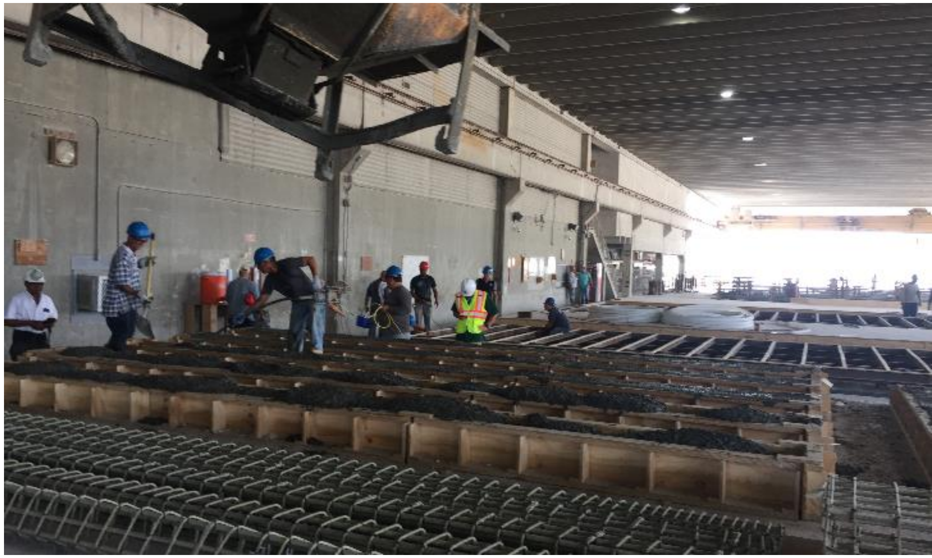
iDock Construction Intent - Miami, Florida

- Replacement of hurricane Irma-damaged dock with GFRP-RC precast concrete components, CIP BFRP-RC continuity pour and GFRP gratings
- Demo prototype for precast-concrete dock modular-system, that exhibits extended durability and resilience to extreme events



Benzecry, V., M. Rossini, C. Morales, S. Nolan and A. Nanni, "Design of Marine Dock Using Concrete Mixed with Seawater and FRP Bars," J. Compos. Constr., 2021, 25(1): 05020006, DOI: 10.1061/(ASCE)CC.1943-5614.0001100, 13 pp.

Precast Construction



Precast Construction

Traditional vs. Innovative Approach

- **Traditional:** precast steel-PC piles and cast in-place RC caps with timber decking
- **Innovative:** precast modular-units with rapid assembly time with GFRP & BFRP reinforcement to eliminate corrosion-related maintenance and provide higher resistance

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iDock Precast Element Installation

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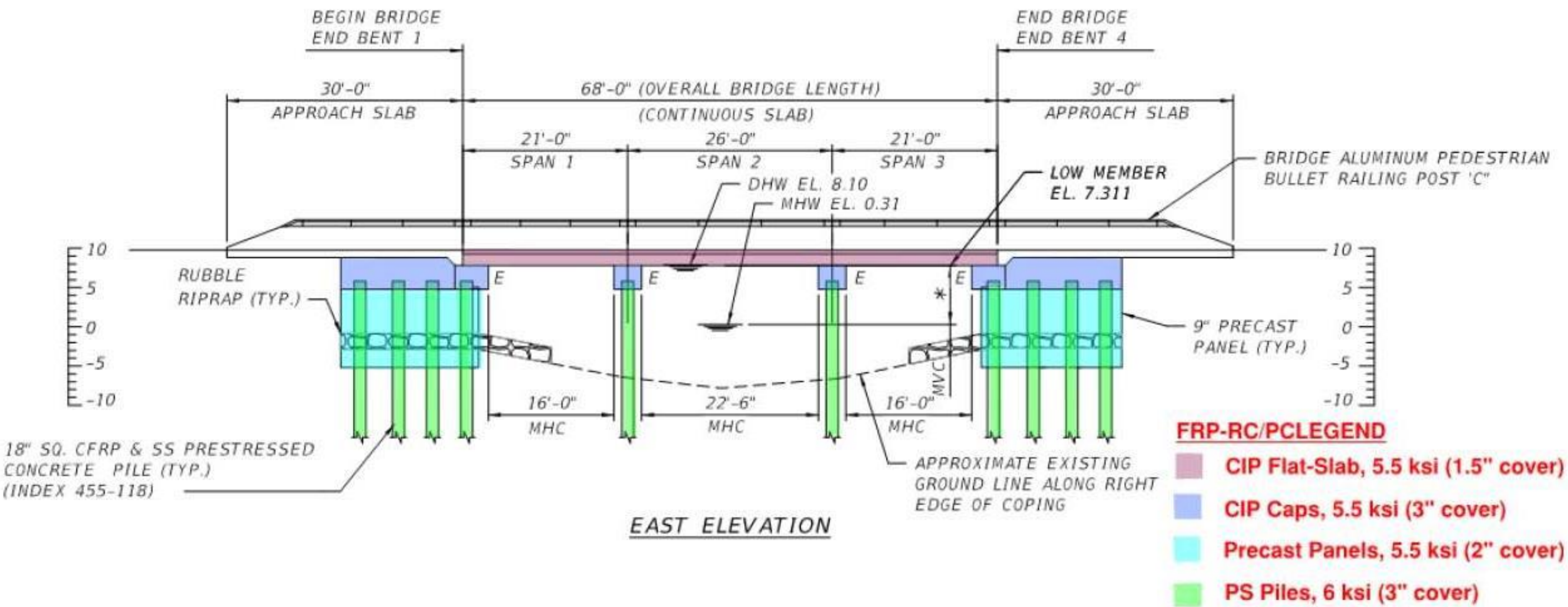
IBIS Waterway Bridge Layout

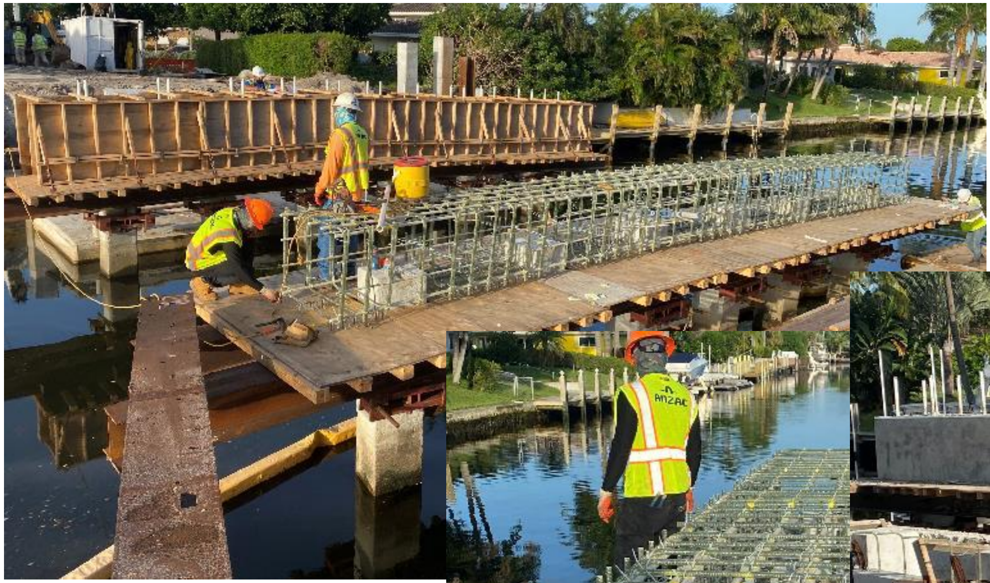


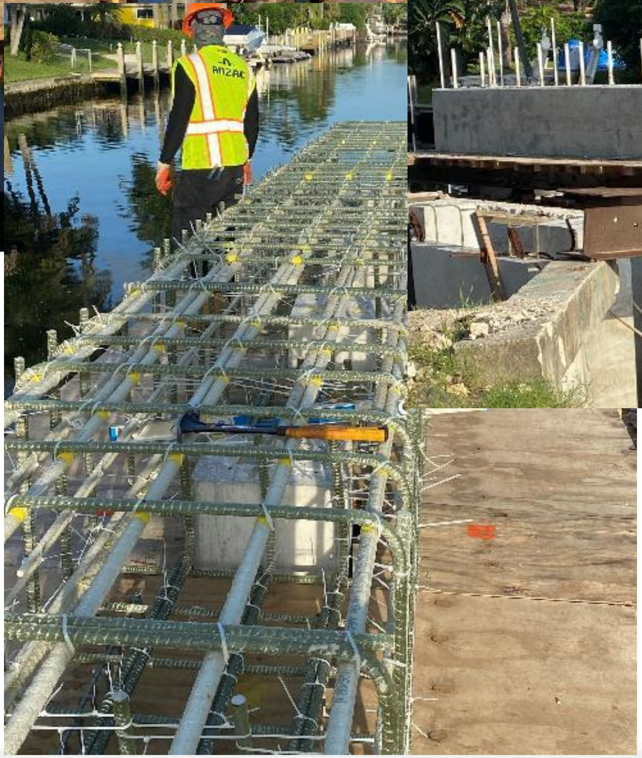
Three-span IBIS-Waterway bridge with CIP flat-slab, CIP caps, precast PC panels and piles

GFRP-RC Intermediate Bent Cap Beams

GFRP cage assemblies with spliced-bars at intermediate pile locations. GFRP bars inspected and lab-tested for Q/A

GFRP-RC Intermediate Bent Cap Beams



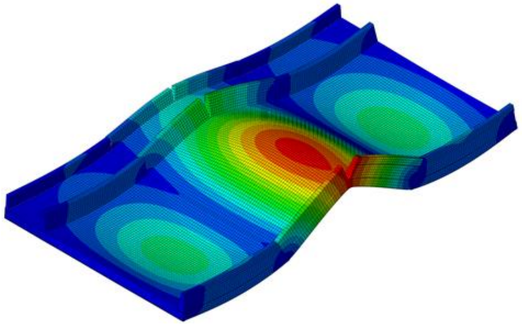


Completing assembly and forming

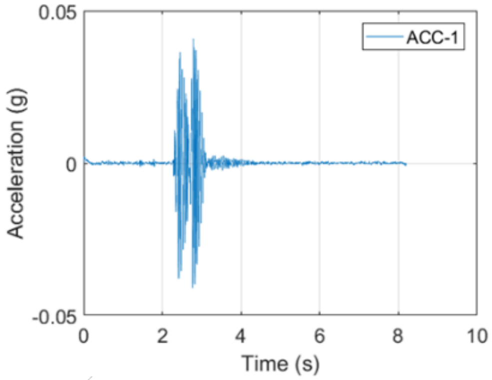
Casting completed and forms stripped

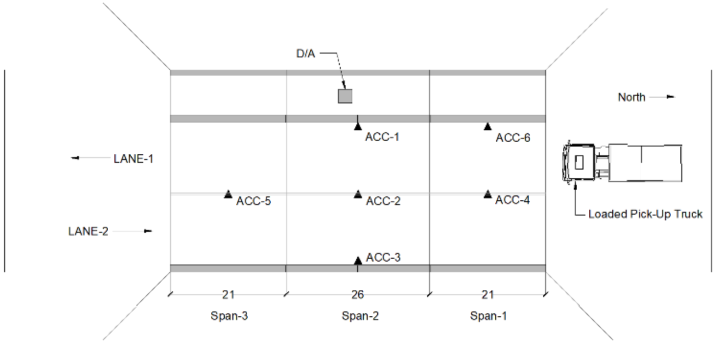
LOAD TESTING

May 1, 2021. Load test as benchmark for possible stiffens degradation over time by frequency evaluation



Mode I





Bridge average natural frequency 17.5 Hz (Mode 1)

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Field Applications

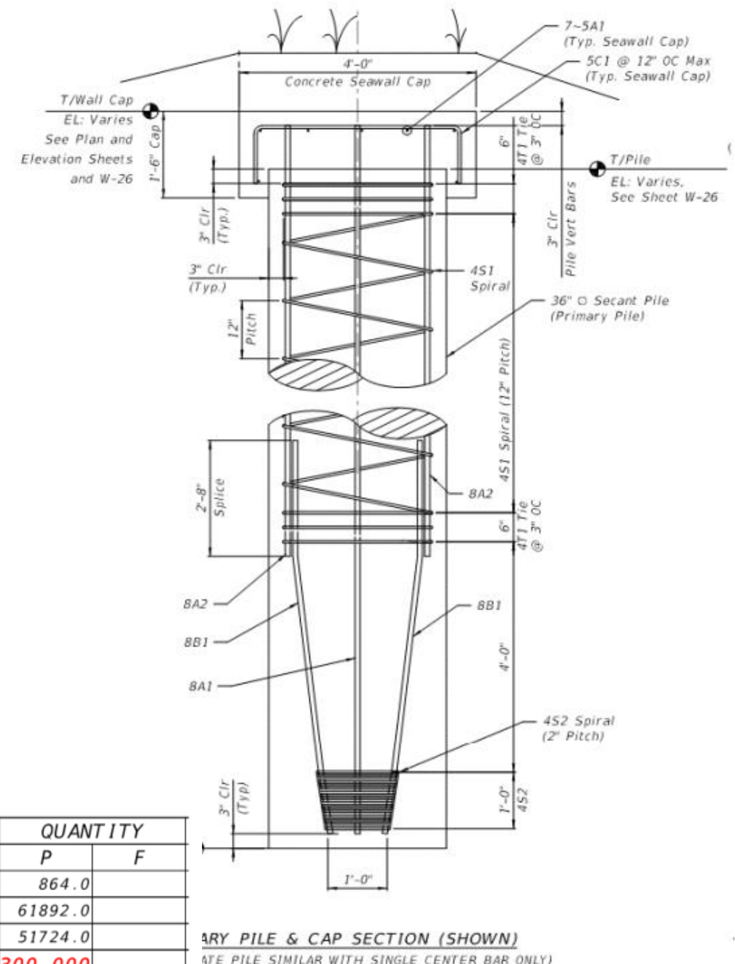
A1A Seawall, Flagler Beach, Florida

Steputat, C., S. Nolan, L. Denty, P.A. Kaminskiand A. Nanni,
"A Seawall Constructed with GFRP Bars as Structural Reinforcing,"
Concrete International, V. 41, No. 9, Sept. 2019, pp. 26-30.

Flagler Beach, FL (SR-A1A) Damage & Recovery

GFRP Design for Secant-Pile Seawall

- 4920-ft. long secant pile seawall
- First FDOT project with about 1.5 million linear feet of GFRP bars
- Secant piles in high chloride content sand, high water table and periodically exposed to salt spray



WALL NO.	PAY ITEM NO.	PAY ITEM DESCRIPTION	LOCATION STA. TO STA.	SIDE	UNIT	QUANTITY P	QUANTITY F
W1 Thru W11	0400-4-11	Class IV Concrete (Retaining Wall Cap)		Rt	CY	864.0	
	415-10-5	Fiber Reinforced Polymor Bars, #5			LF	61892.0	
	455-112-6	Pile Auger Grouted, 36" Diameter			LF	51724.0	
		#5 GFRP Reinforcing Bars	approx.		FT	300,000	
		#8 GFRP Reinforcing Bars	approx.		FT	960,000	

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GFRP Bar Site Delivery and Storage

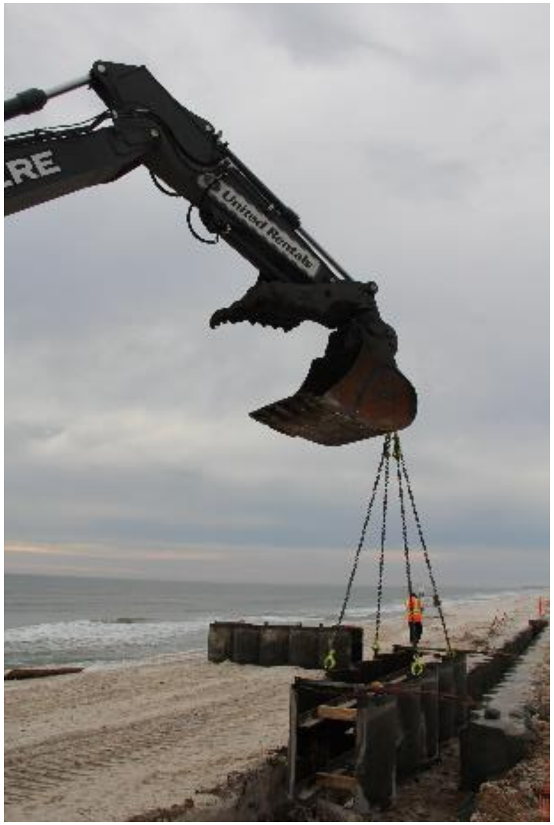
- Straight bars, bent bars, hoops and toe bent bars
- Site storage and protective measures from elements

GFRP Bars - Cage Assembly

GFRP Bars - Cage Assembly

- Cages constructed with 25 #8 GFRP bars, spiral ties and “toe-end”
- GFRP cages were 38-ft. in length

Guide Wall for GFRP Secant-Piles



Guide wall trench boxes installed to assure pile alignment

Secant-piles installed via guide wall form

Removal of steel formwork prior to drilling secant-piles

Concrete Grouting of GFRP Secant-Piles

Concrete grouting of Secant-piles

Secant-pile cages delivered to pile-drilling area and ready for installation

1,847 Secant-piles installed. 5,000 linear feet of pile-cap

Flagler Beach - GFRP Pile Cage Installation

GFRP cage installation

Auger-cast primary piles 36 in. in diameter and 36 ft. long
Secondary piles18 ft. long

Continuous Pile-cap and Dune Restoration

Pile-cap placement and dune restoration/re-establishment

Project completed in 4½ months

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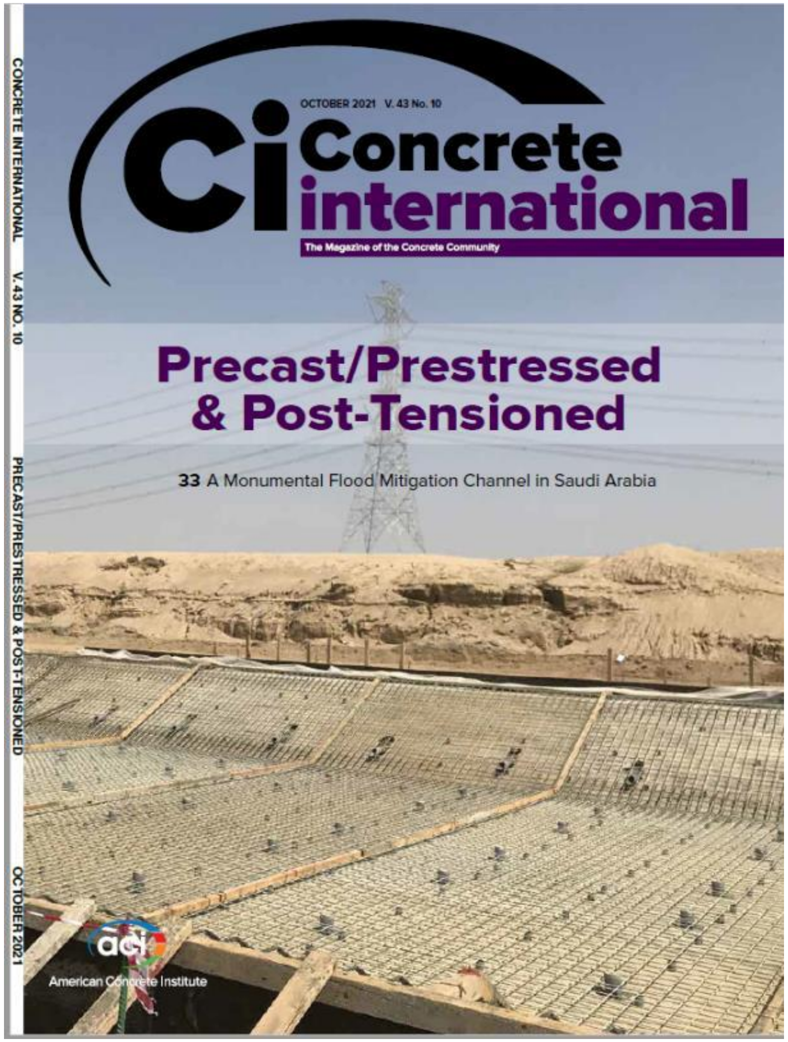
Flood Mitigation Canal, Jazan, Saudi Arabia



Villen Salan, E.A., M.K. Rahman, S. Al-Ghamdi, J. Sakr, M. Al-Zahrani and A. Nanni,
“A Monumental Flood Mitigation Channel in Saudi Arabia,”
Concrete International, Oct. 2021, Vol. 43, No. 10, pp. 53-61

Credits:

- Saudi Aramco Jazan Complex Projects Department (JCPD): owner rep
- AECOM: hydraulic and structural designs
- Al-Yamama Company for Trading and Contracting (AYC): construction.
- Saudi Aramco Consulting Services Department (CSD): design supervision
- King Fahd University of Petroleum and Minerals (KFUPM): research and monitoring

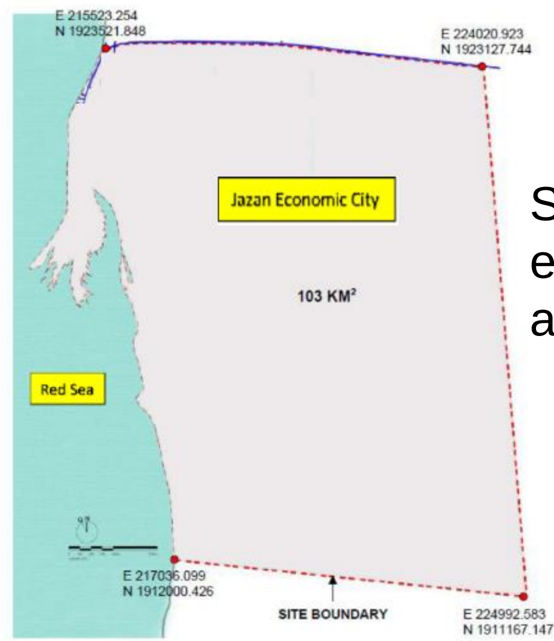
Flood Mitigation Canal, Jazan, Saudi Arabia

World's largest concrete structure reinforced with glass fiber-reinforced polymer (GFRP) bars completed in Saudi Arabia in 2021.

The 21.3 km long, flood mitigation channel (FMC) has been constructed on the southwest of Saudi Arabia on the outskirts of the new Jazan Economic City (JEC)

Project location:

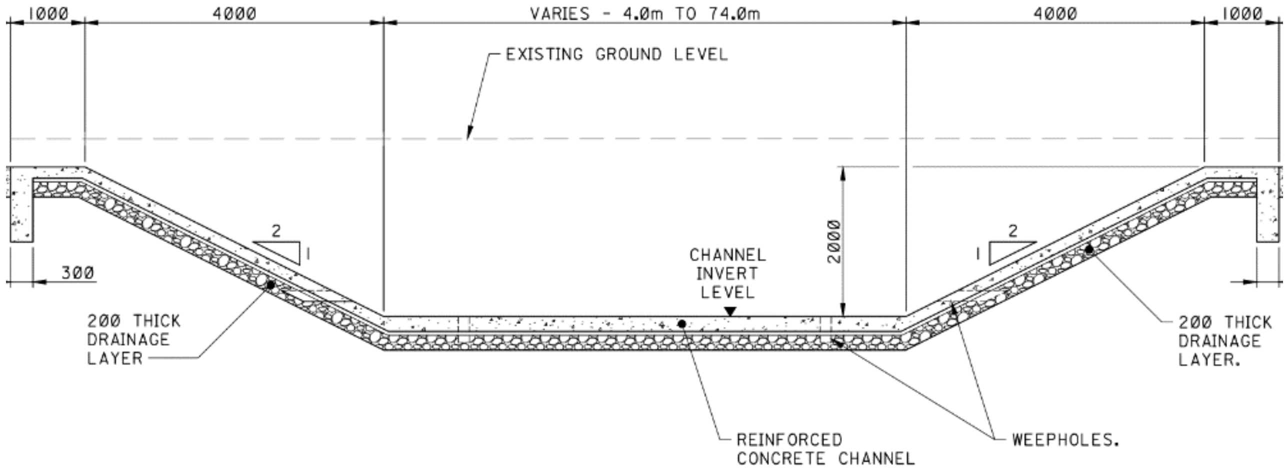
Jazan on southwest coast of Red Sea



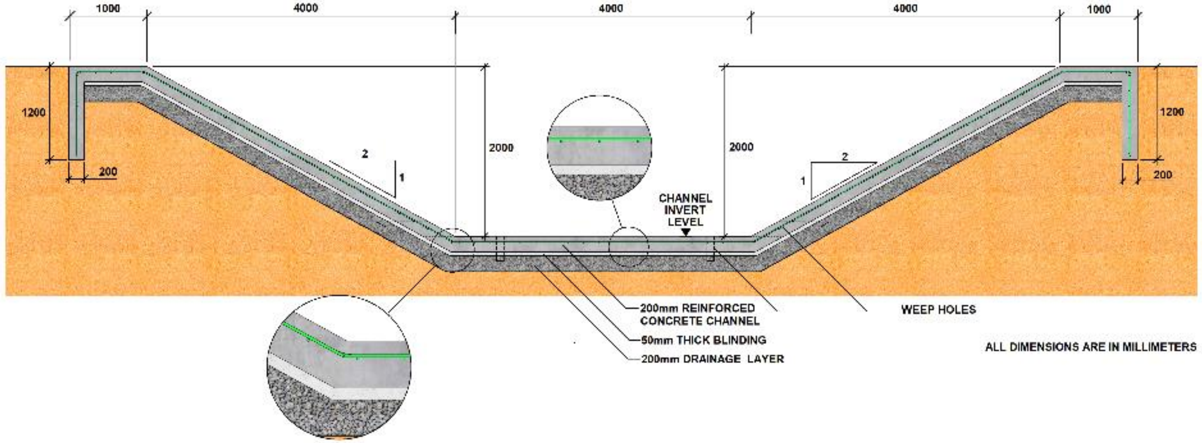
Site boundary encloses an area of 103 km^2

Flood Mitigation Canal, Jazan, Saudi Arabia

Cross section showing original design with ECS bars



Cross section at the upstream end, showing revised design with GFRP bars



Flood Mitigation Canal, Jazan, Saudi Arabia

Base slab reinforced with grids of GFRP bars:

(a) delivery of bars

(b) storage of bars on blinding layer of interior panel of base slab (openings for later installation of weep hole pipes)

(c) grid assembly

Flood Mitigation Canal, Jazan, Saudi Arabia

Sloped sides of canal tied to base slab using bespoke splice bars:

(a) worker carries bundle of splice bars

(b) view of upstream section of canal showing grids, weep holes, and channel edge formwork

(c) detail of lap slice at base-slope intersection

Flood Mitigation Canal, Jazan, Saudi Arabia

Concrete placement of a panel and sloped side at night to avoid day heat

Flood Mitigation Canal, Jazan, Saudi Arabia

Cost comparison for ECS and GFRP options based on a 30 x 30 x 0.2 m slab panel

Cost item	ECS bars, $	GFRP bars, $	GFRP cost/ ECS cost, %
Reinforcing bars	9,235	8,222	89
Concrete	17,514	15,840	90
Bar supports	486	608	125
Bar ties	2,856	1,659	58
Labor	3,852	1,284	33
Crane	1,068	0	0
Safety gloves	9.60	15	156
Total	35,021	27,628	79

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CONCLUSIONS

Due to compelling sustainability and resilience reasons, FRP reinforcement could be a suitable replacement for conventional steel in RC structures exposed to aggressive environments

<u>This technology would allow to</u>:

- Save fresh water and other natural resources
- Eliminate corrosion and reduce maintenance costs
- Increase the service life of concrete structures
- Improve constructability by lowering transportation and installation costs


Thank you!
Questions?