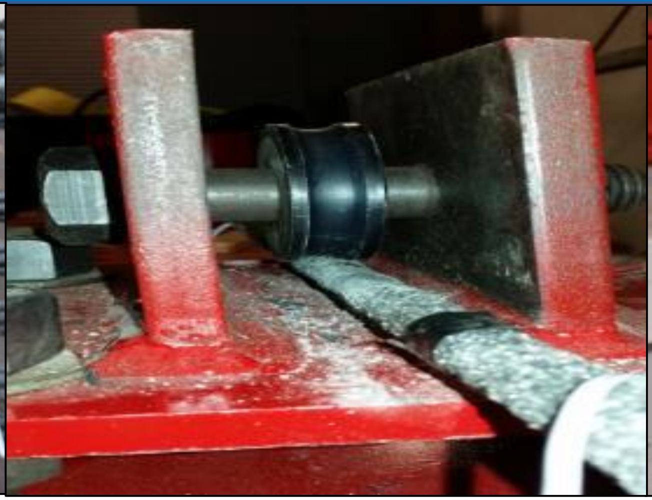
# AASHTO CFRP-Prestressed Concrete Design Training Course




FDOT
Florida Department of
TRANSPORTATION

UNIVERSITY of HOUSTON
CULLEN COLLEGE of ENGINEERING
Department of Civil & Environmental Engineering

# Design of Pretensioned Concrete Bridge Beams with Carbon Fiber-Reinforced Polymer (CFRP) Systems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# COURSE DESCRIPTION

Corrosion of mild steel reinforcement or prestressing strands results in deterioration of concrete structures and is one of the major challenges facing bridge structures. Researchers found CFRP reduces the maintenance and rehabilitation costs for bridges by eliminating the potential for corrosion of the reinforcement. Recently, NCHRP Project 12-97 led by Dr. Belarbi and his team developed AASHTO design guide specifications for bridge beams prestressed with CFRP system.

**This presentation covers the design of pretensioned concrete bridge elements with CFRP Systems, including the properties of prestressing CFRP, flexural design, shear design, and design of prestressed concrete piles. In addition, the presentation covers design examples of Florida-I-Beam, Florida-Slab-Beam, prestressed concrete pile, and sheet pile for retaining wall.**

# COURSE CONTENT AREAS

1. Introduction & References
2. Prestressing CFRP
3. Flexural Design
4. Shear Design
5. Prestressed Piles
6. Design Examples

# COURSE OVERVIEW & EXPECTATIONS


**Concepts**

- Introduction of concepts
- Understanding of methods
- Use of available resources

**Questions & Examples**

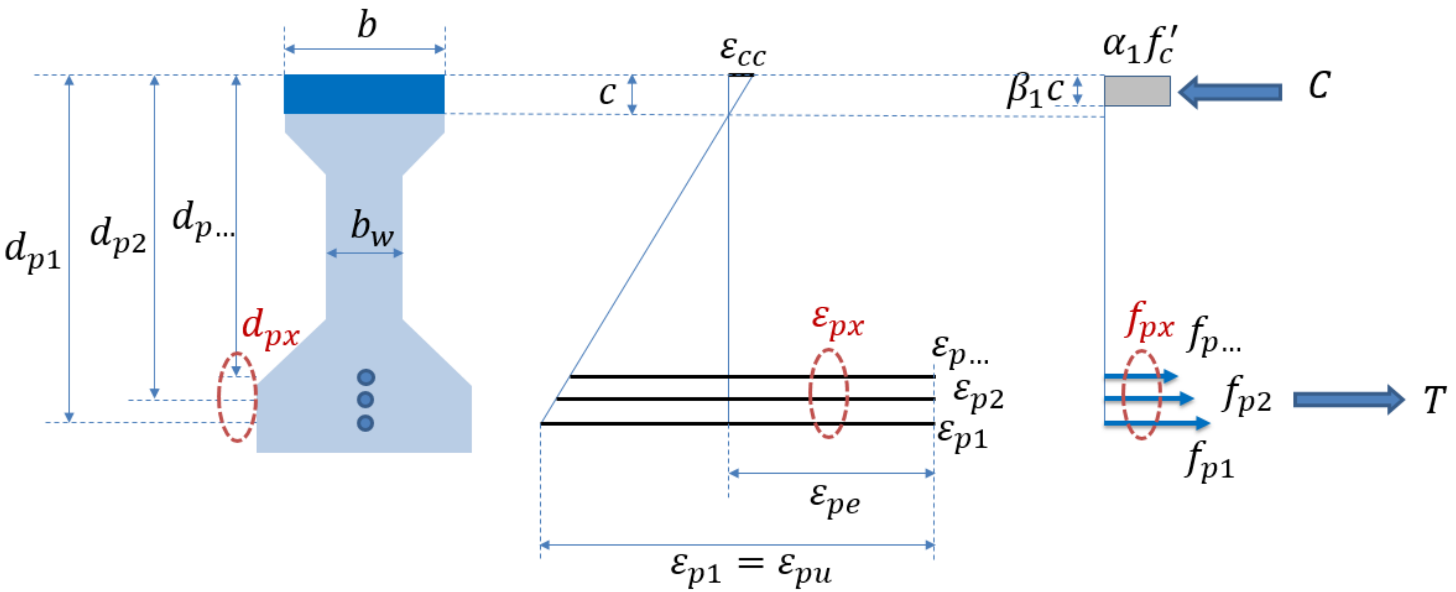
- Review questions
- Reinforce methods
- Apply concepts

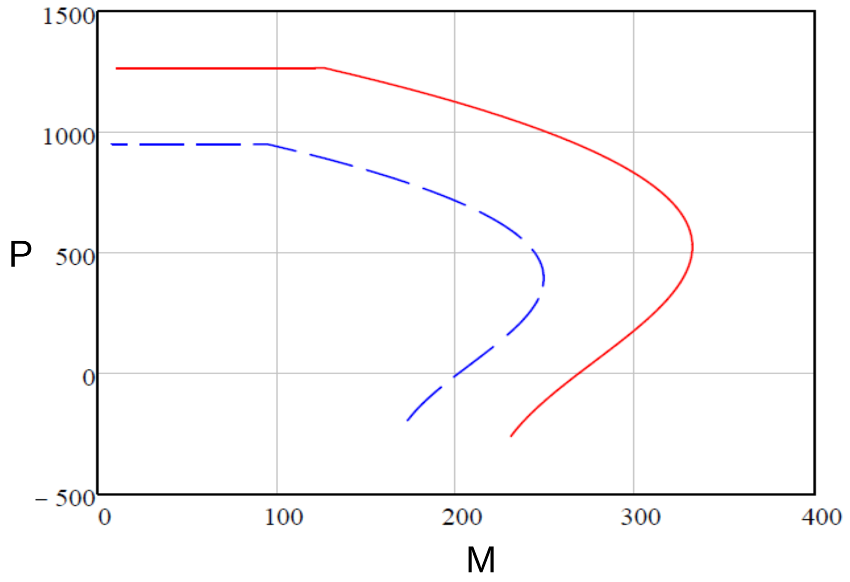
**Participation**

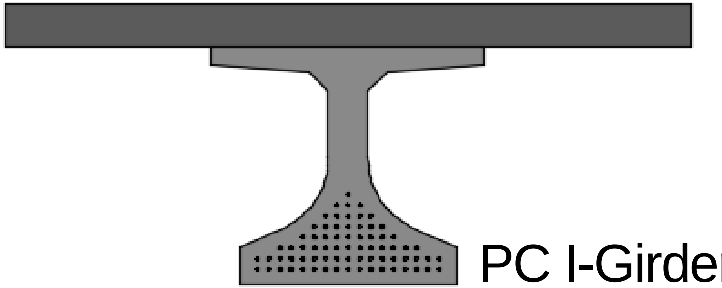
- Active participation needed
- Ask questions
- Opportunity for discussions

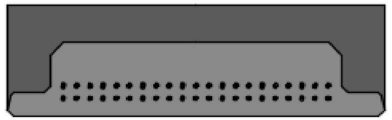
# OBJECTIVES OF THIS COURSE

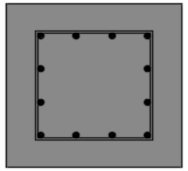
## Behavior & Design & Examples

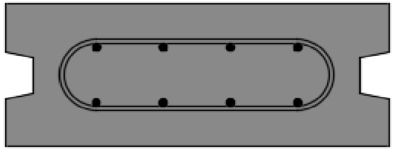




PC I-Girders


PC Slab-Beams


PC Piles


PC Sheet Piles

# LEARNING OBJECTIVES

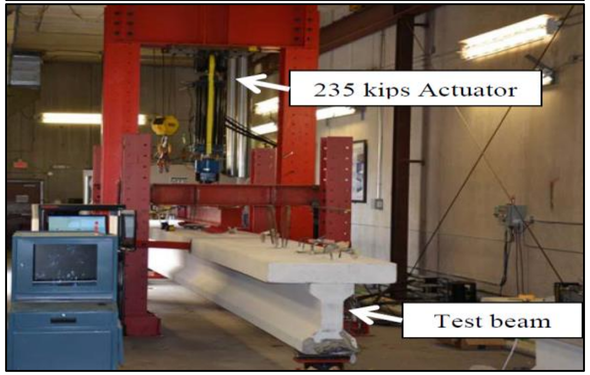
- Identify material properties and stress limitations of prestressing CFRP, as well as short-term and long-term prestress losses

- Explain design procedures of flexural design for pretensioned concrete beams with prestressing CFRP strands/tendons

- Discuss shear design procedures of pretensioned concrete beams with prestressing CFRP

- Describe procedures to construct P-M diagram for prestressed concrete piles with prestressing CFRP

- Illustration design examples of Florida-I-Beam, Florida-Slab-Beam, prestressed concrete pile, and sheet pile for retaining wall.



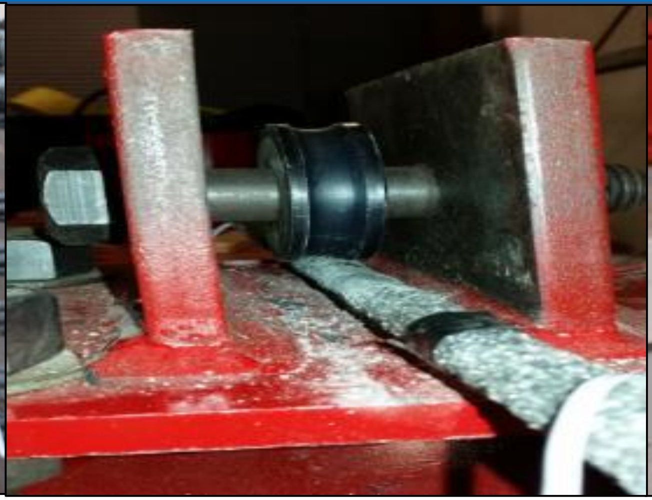
# Abdeldjelil Belarbi, PhD, PE, FACI, FASCE, FSEI

Dr. Abdeldjelil (DJ) Belarbi is a Distinguished Professor of Civil Engineering at the University of Houston. During his career, he taught more than 14 different undergraduate and graduate courses on subjects related to civil and structural engineering. His primary research contributions focus on the constitutive modelling, analytical, and experimental investigations of reinforced and prestressed concrete structures. He is a Fellow of ACI, and a Fellow of the American Society of Civil Engineers (ASCE), and the Structural Engineering Institute (SEI). In addition to his involvement in ACI 440, he is currently the co-Chair of ACI-440-E (professional development). He is the current Chair of ACI-ASCE 445 (Shear and Torsion), member of ACI 341 (Earthquake-Resistant Concrete Bridges) and member of ACI 318-E (Section and Member Strength). Dr. Belarbi is the recipient of numerous awards and honors including the 1995 Outstanding Paper Award of the Earthquake Engineering Research Institute (Earthquake Spectra Journal) and the Honorable Mention for Outstanding paper from The Masonry Society.

# COURSE OUTLINE

1. Introduction & References
2. Prestressing CFRP
3. Flexural Design
4. Shear Design
5. Prestressed Piles
6. Design Examples

# 1. INTRODUCTION & DESIGN CODES, MANUALS AND REFERENCES

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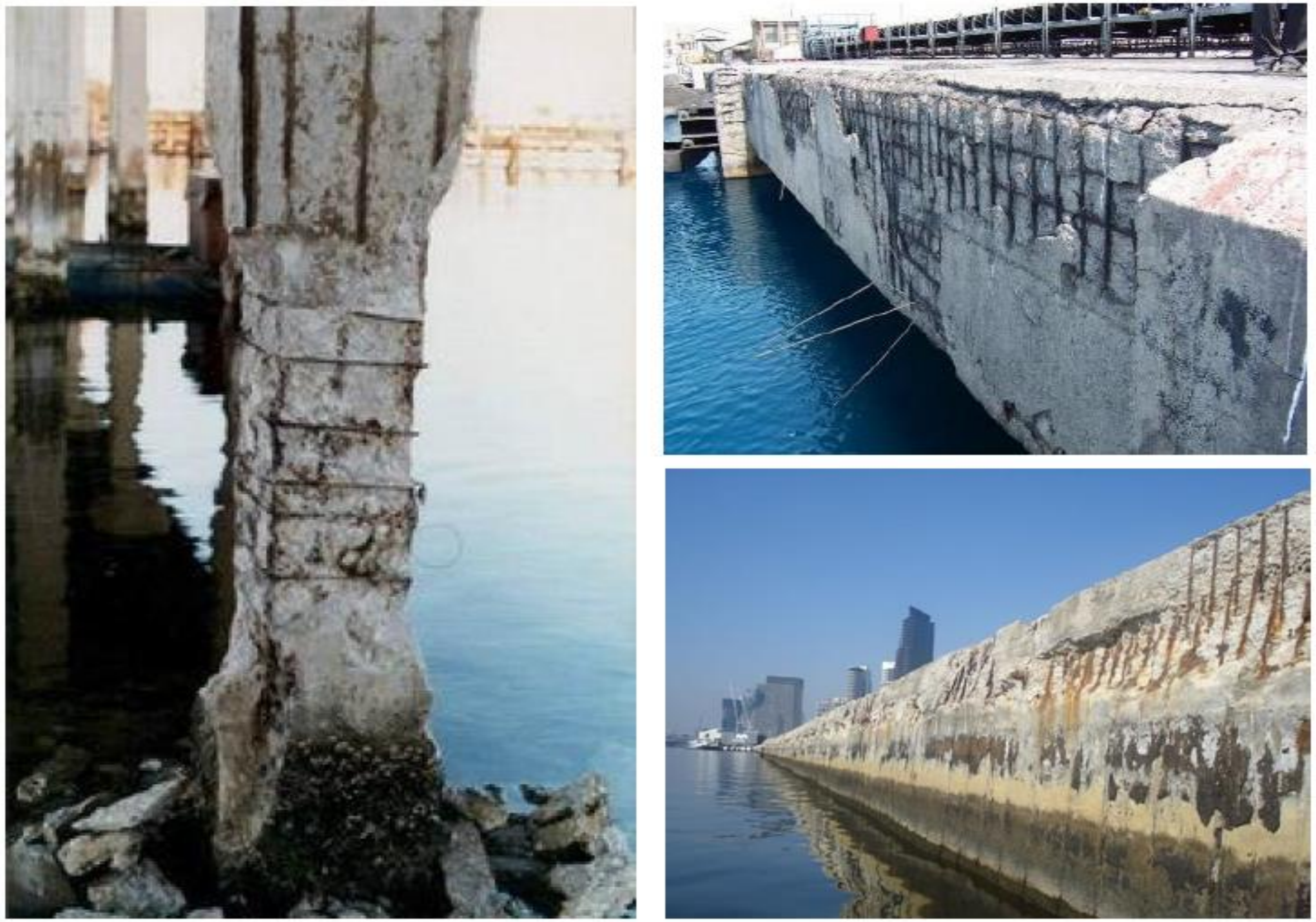
# INTRODUCTION

## Problem Statement

- Failure mechanism for structures exposed to aggressive environments is often caused by corrosion of steel reinforcement

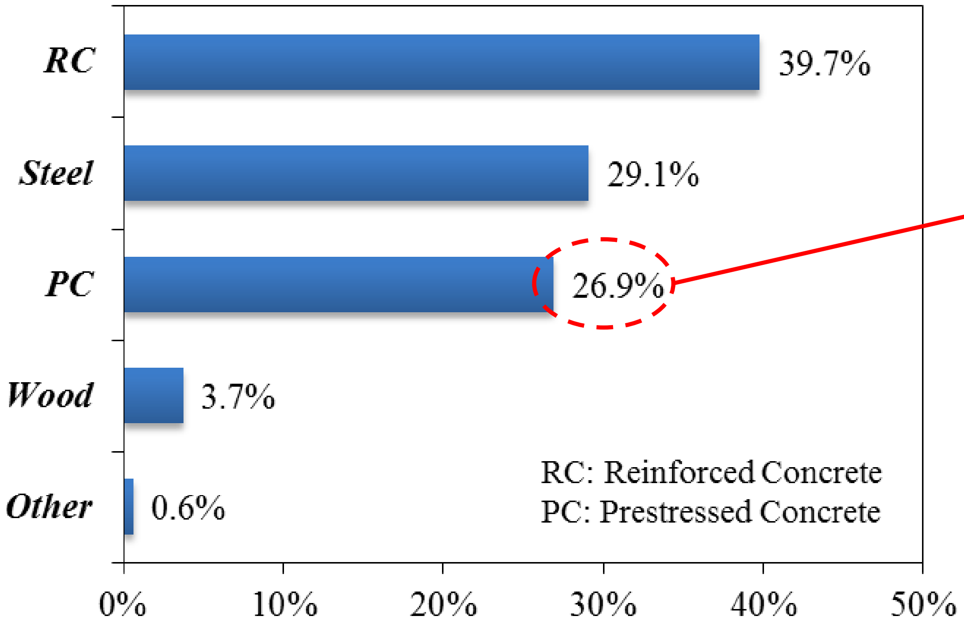
- Traditional corrosion mitigation efforts:

  □Admixtures
  □Increase Concrete Cover
  □Alter Concrete Mix
  □Membranes & Overlays
  □Epoxy-Coated, Galvanized or Stainless Steel Rebar & Strands



**SERVICE LIFE OF STRUCTURES GREATLY REDUCED BY CORROSION**

# INTRODUCTION




http://www.lafargeprecastedmonton.com/anthony-henday-ring-road/img_0983/
www.fhwa.gov
https://www.alibaba.com/product-detail/post-tension-concrete-prestressing-steel-pc_60677672453.html

# INTRODUCTION

## Different Types of Prestressing Strands


(a) Carbon steel


(b) Epoxy coated

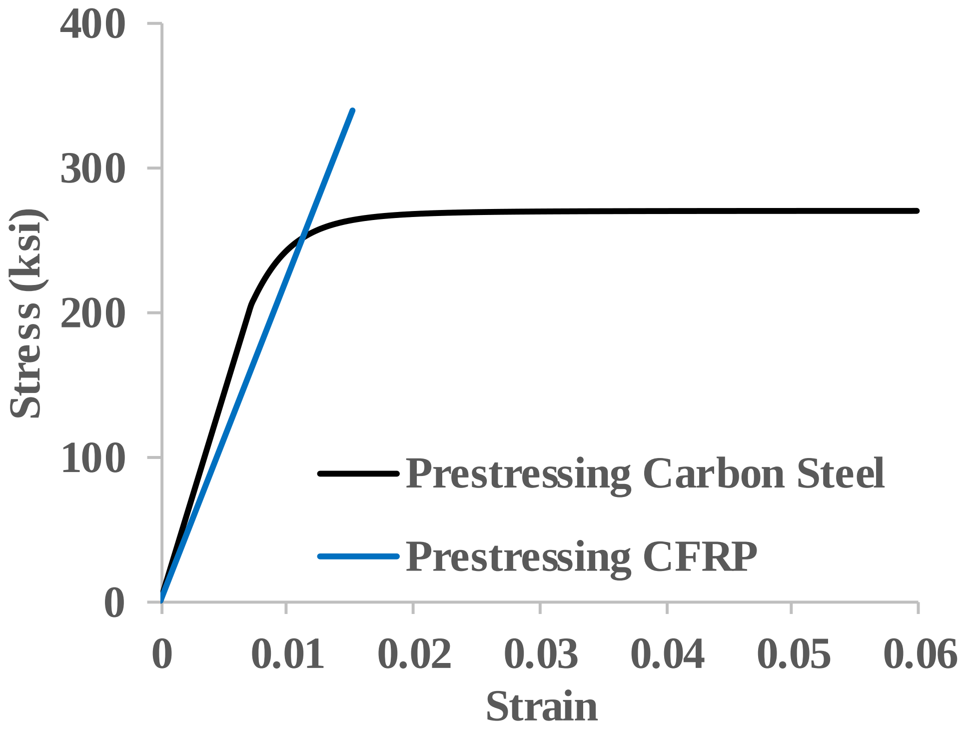

(c) Galvanized


(d) Stainless steel


(e) FRP

# INTRODUCTION

## Carbon Fiber Reinforced Polymers (CFRP)



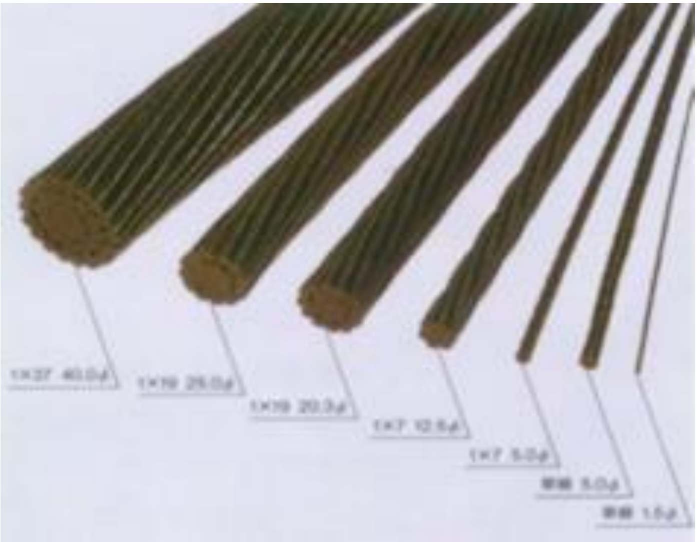

High Strength

Corrosion Resistant

Light weight

# INTRODUCTION

## Commercially Available CFRP Types



CFRP Cable — CFRP Bar — CFRP sheets

CFRP Cable and CFRP Bar: *Internal (reinforcing) and external (strengthening) application*

CFRP sheets: *external (strengthening) application*

Tokyo rope product sheet
www.google.com/images

# INTRODUCTION

## Advantages of CFRP Prestressing

20 years

*Steel prestressed bridge*

*(In a marine environment)*

20 years

*CFRP prestressed bridge*

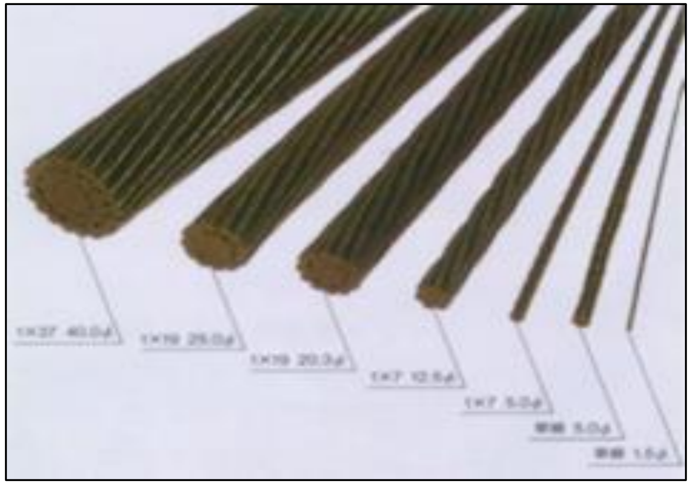
(Enomoto et. al., 2011)

Longer service life
Lower life cycle costs

# INTRODUCTION

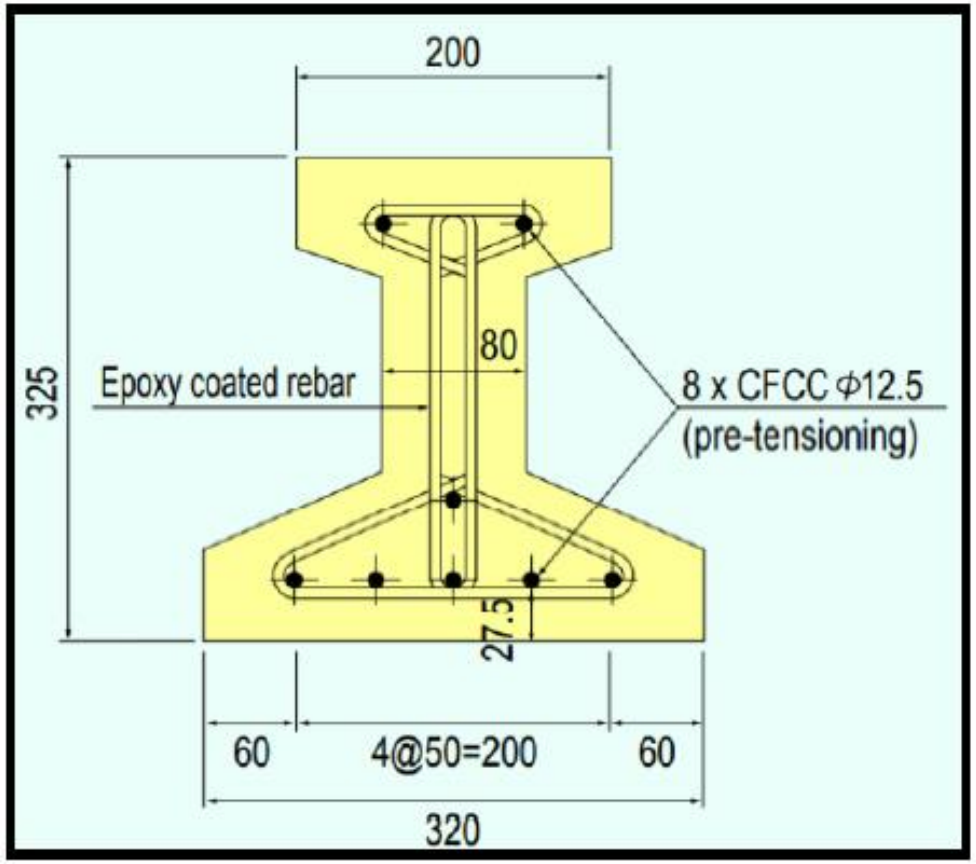
## Key Benefits

- Corrosion resistant
- High strength to weight ratio
- Lightweight
- Transparent to magnetic fields and radar frequencies
- Thermally non conductive



# INTRODUCTION

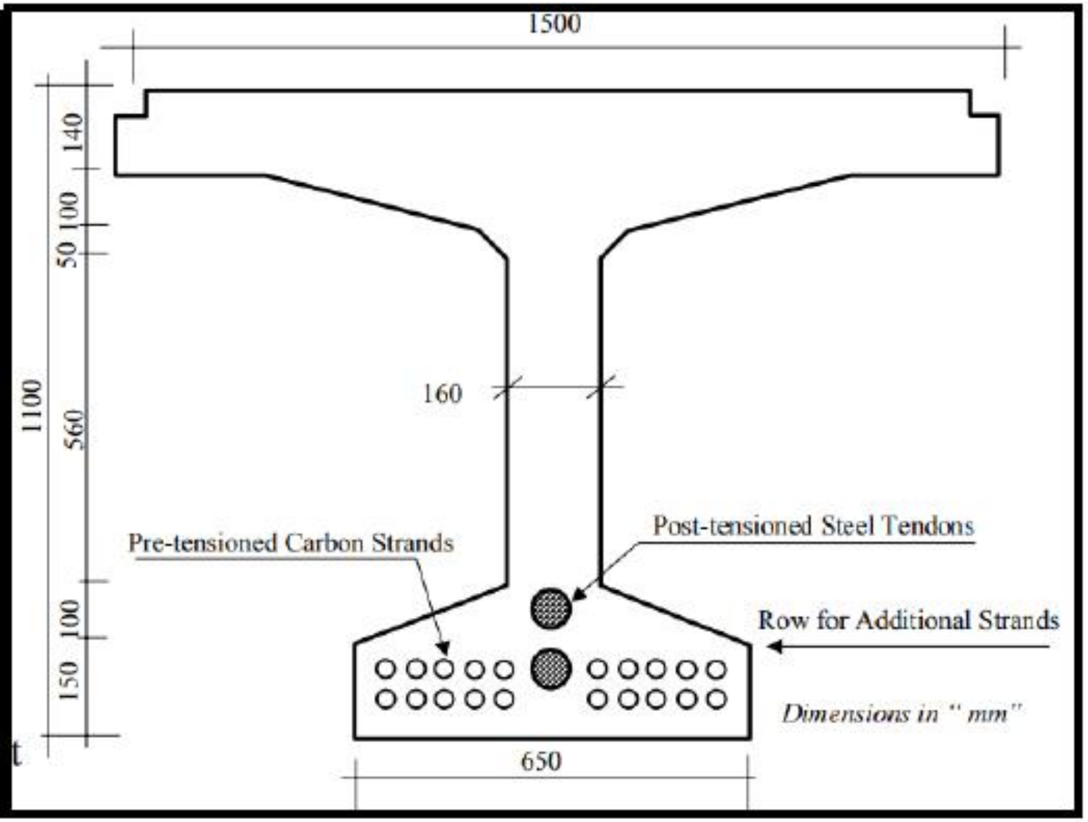
**PROJECT**: The Shinmiya Bridge (Japan, 1988)




[NCHRP Report 907]

# INTRODUCTION

**PROJECT**: The Beddington Trail Bridge (Canada, 1993)



# INTRODUCTION

**PROJECT**: Taylor Bridge (Canada, 1997)

[NCHRP Report 907]

# INTRODUCTION

**PROJECT**: The Bridge Street Bridge (Michigan DOT, 2001)

# INTRODUCTION

**PROJECT**: Halls River Bridge (Florida) - CFRP Prestressed Piles & Sheet Piles




# DESIGN CODES, MANUALS & REFERENCES

NCHRP Report-907: Design of Concrete Bridge Beams Prestressed with CFRP Systems


NCHRP
NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM
RESEARCH REPORT 907
Design of Concrete Bridge Beams Prestressed with CFRP Systems
The National Academies of
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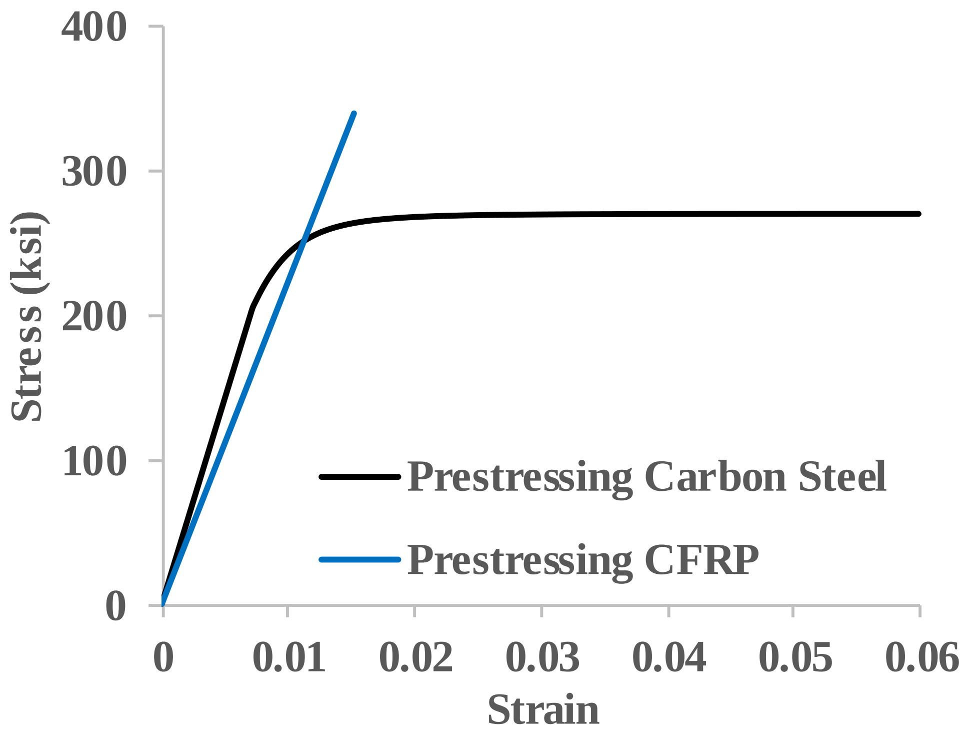
# Material Properties: Prestressing CFRP vs. Carbon Steel



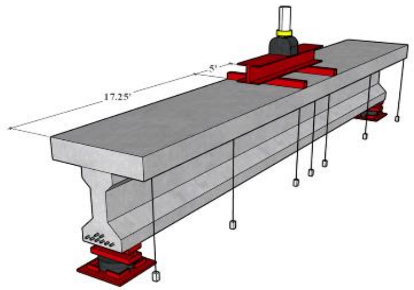

| Material specification | AASHTO M203 | AASHTO CFRP |
|---|---|---|
| Steel/CFRP type | 1080 carbon steel | CFRP |
| Grade | 250 and 270 | 340-360 |
| Modulus of elasticity (ksi) | ≅ 28,500 | 18,000-22,500 |
| Total elongation (%) | ≥ 3.5 | ≅ 1.6 |
| Relaxation: (1000 hours @ 80% GUTS) | ≤ 3.5% | ≤ 5.0% |

# DESIGN CODES, MANUALS & REFERENCES

## Load-Deflection Behavior: CFRP vs. Steel Pretensioned Beam

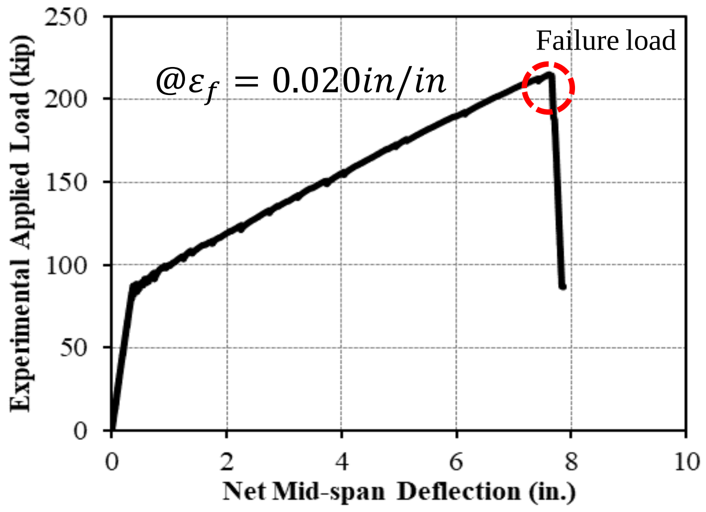
### CFRP pretensioned beams

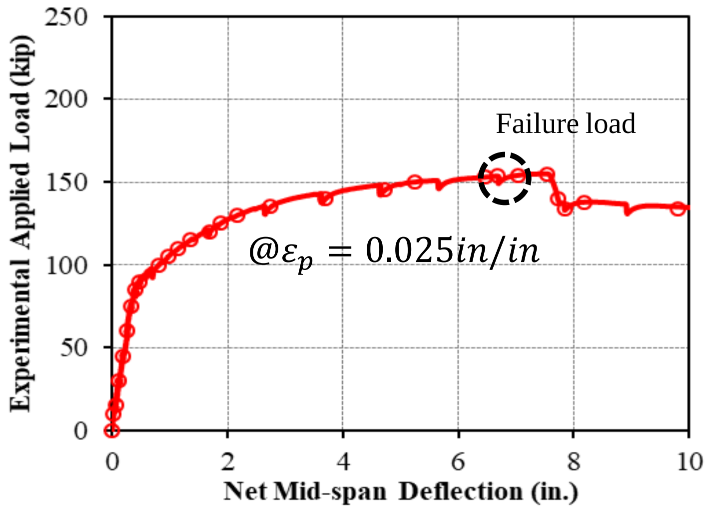
8 CFRP strands
($\emptyset$ = 0.6 in)
$A_{pf}f_{fpu}$=625 kips



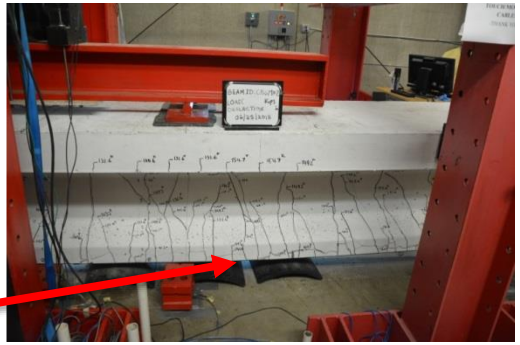

### Steel pretensioned beams

8 steel strands
($\emptyset$ = 0.6 in)
$A_sf_{pu}$=470 kips




*CFRP Rupture*



*Concrete Crushing*

# DESIGN CODES, MANUALS & REFERENCES

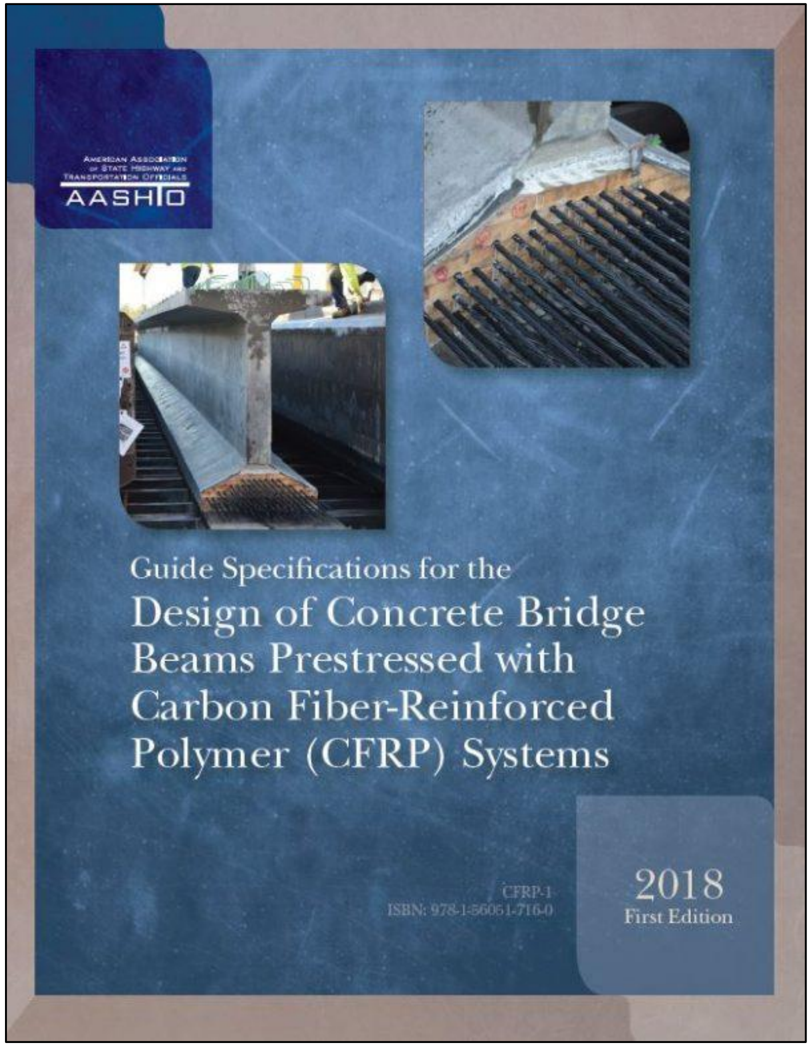
Guide Specifications for the Design of Concrete Bridge Beams Prestressed with Carbon Fiber-Reinforced Polymer (CFRP) Systems, 1st Edition, 2018

**SECTION 1:**

**GUIDE SPECIFICATIONS FOR THE DESIGN OF CONCRETE BRIDGE BEAMS PRESTRESSED WITH CARBON FIBER-REINFORCED POLYMER (CFRP) SYSTEMS**

**SECTION 2:**

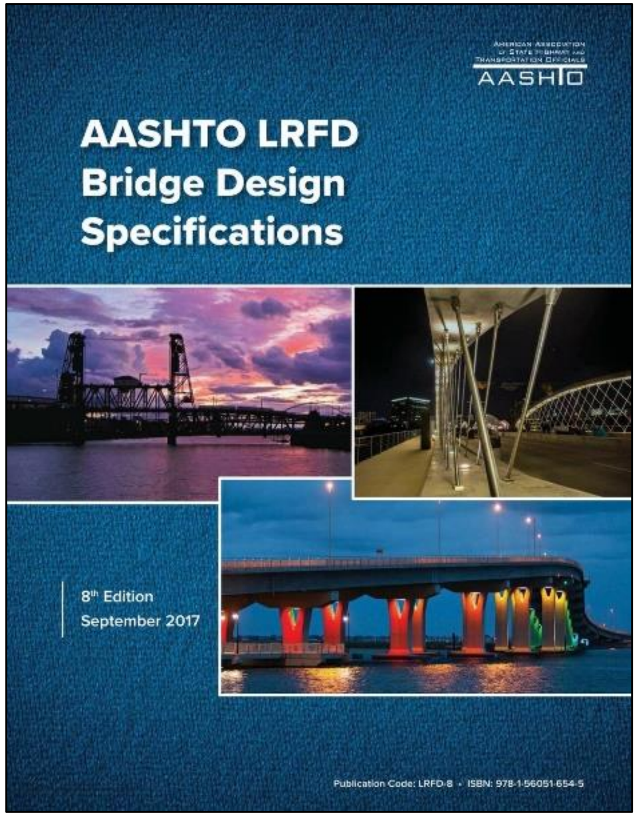
**MATERIAL SPECIFICATIONS FOR CARBON FIBER-REINFORCED POLYMER PRESTRESSING CABLES AND BARS**

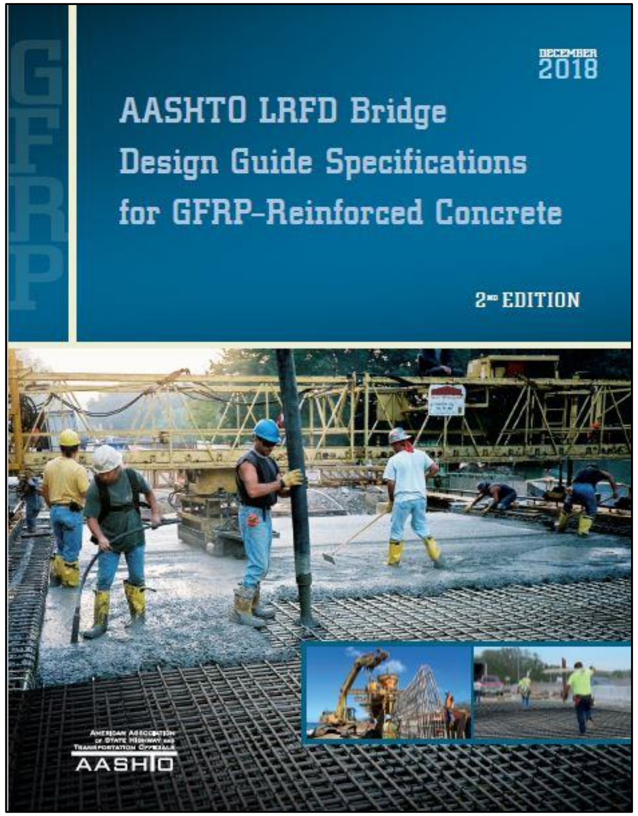


# DESIGN CODES, MANUALS & REFERENCES

- **AASHTO** LRFD Bridge Design Specifications, 8th Edition, 2017

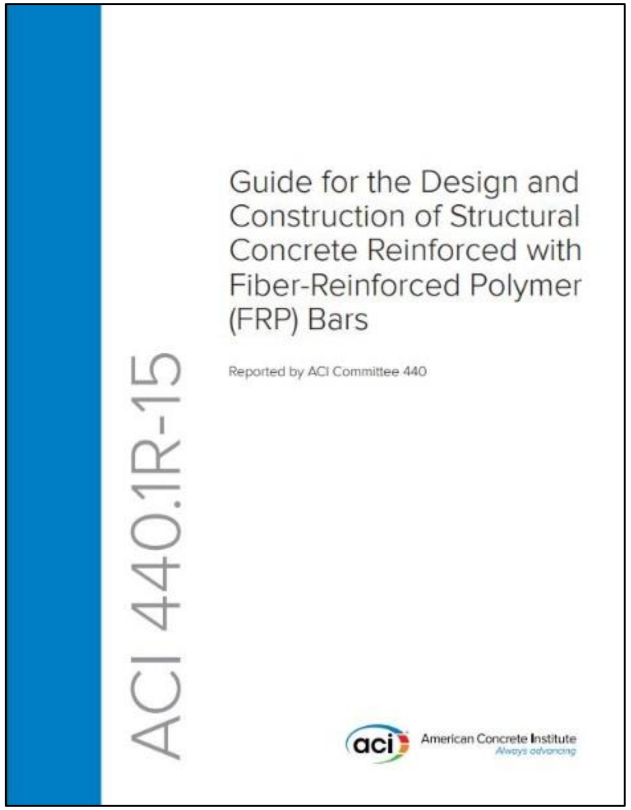
- **AASHTO** LRFD Bridge Design Guide Specifications for **GFRP**-Reinforced Concrete, 2nd Edition, 2018

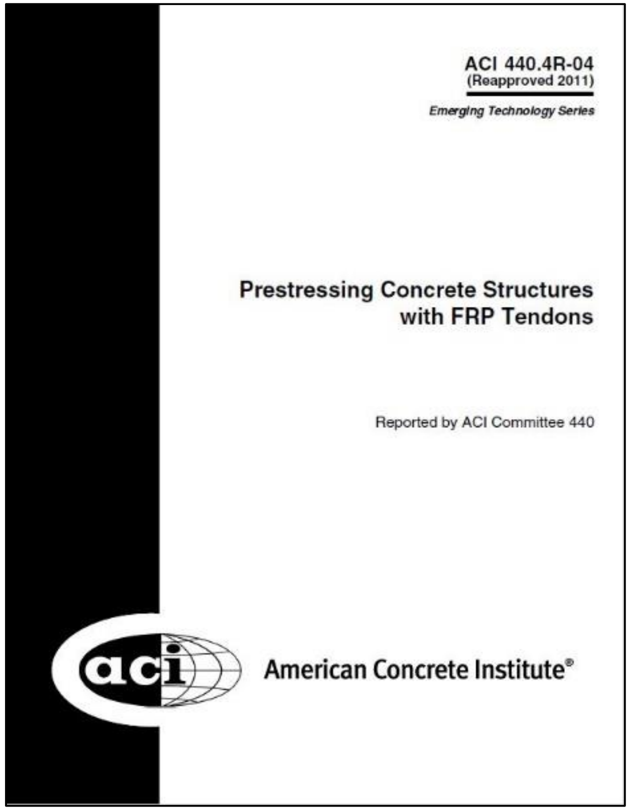


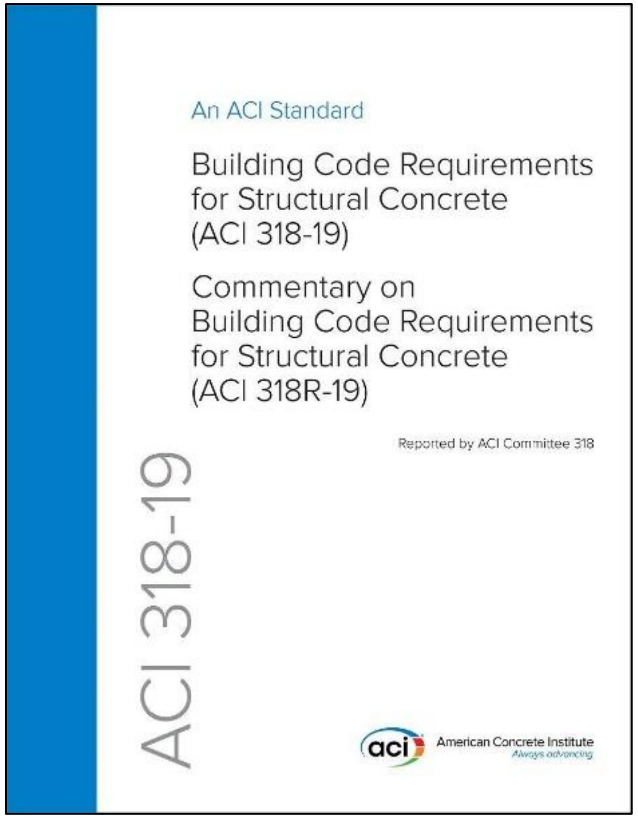



# DESIGN CODES, MANUALS & REFERENCES

- **ACI 440.1R-15** Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars, 2015
- **ACI 440.4R-04** Prestressing Concrete Structures with FRP Tendons, 2011
- **ACI 318-19** Building Code Requirements for Structural Concrete and Commentary, 2019



# DESIGN CODES, MANUALS & REFERENCES

- **FDOT Structures Manual**, January 2020

FIBER REINFORCED POLYMER GUIDELINES (FRPG)

STRUCTURES MANUAL
VOLUME 4
JANUARY 2020



Topic No. 625-020-018 January 2020

FLORIDA DEPARTMENT OF TRANSPORTATION

Image courtesy of WSP USA

STRUCTURES MANUAL



FDOT

# DESIGN CODES, MANUALS & REFERENCES

- **FDOT Materials Manual**

## CHAPTER 12: Fiber Reinforced Polymer Composites

| | | | |
|---|---|---|---|
| Section 12.1 | Fiber Reinforced Polymer Composites | N/A | V2-Section 12.1 |

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## Materials Manual Section 12.1, Volume II

### FIBER REINFORCED POLYMER COMPOSITES

Section 12.1, Volume II

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## Materials Manual

The Materials Manual contains the instructions needed to complete Quality Assurance and Materials Acceptance for Florida Department of Transportation contracts. This web page, which displays only the most recent versions of the files, has been divided into Volumes I and II as shown below. **Volume I (V1)** includes Department Personnel Responsibilities and **Volume II (V2)** includes Non-Department Personnel Responsibilities. For questions or comments regarding this page, please contact Allen Hughes at (352) 955-6651. To receive notification of updates to the Materials Manual, please join our mailing list.

### Additional Information

**Introduction** [PDF-40KB] **Registration** [PDF-7KB] **Suggestions/Comments**
**Preface** [PDF-37KB] **Revision History**

### CHAPTER 1: Mineral Aggregates

| | | | |
|---|---|---|---|
| Section 1.1 | Construction Aggregates | V1-Section 1.1 [PDF-225KB] | N/A |
| Section 1.2 | Mitigation of Point-of-Use Aggregate Problems | V1-Section 1.2 [PDF-141KB] | N/A |

### CHAPTER 2: Soils Materials and Foundations

| | | | |
|---|---|---|---|
| Section 2.1 | Structural Layer Coefficients for Flexible Pavement Base Materials | V1-Section 2.1 [PDF-71KB] | N/A |
| Section 2.2 | Soils and Foundations | V1-Section 2.2 [PDF-208KB] | N/A |
| Section 2.3 | Earthwork Operations | V1-Section 2.3 [PDF-254KB] | N/A |
| Section 2.4 | Polymer Slurry | N/A | V2-Section 2.4 |

### CHAPTER 3: Bituminous Materials

| | | | |
|---|---|---|---|
| Section 3.1 | District Materials Activities for Asphalt Pavement Construction | V1-Section 3.1 [PDF-190KB] | N/A |
| Section 3.2 | Flexible Pavement Coring and Evaluation | V1-Section 3.2 [PDF-37KB] | N/A |
| Section 3.3 | Superpave Mix Design Procedure | N/A | N/A |
| Section 3.4 | Asphalt Emulsion | N/A | V2-Section 3.4 |
| Section 3.5 | Asphalt Binder | N/A | V2-Section 3.5 |

# DESIGN CODES, MANUALS & REFERENCES

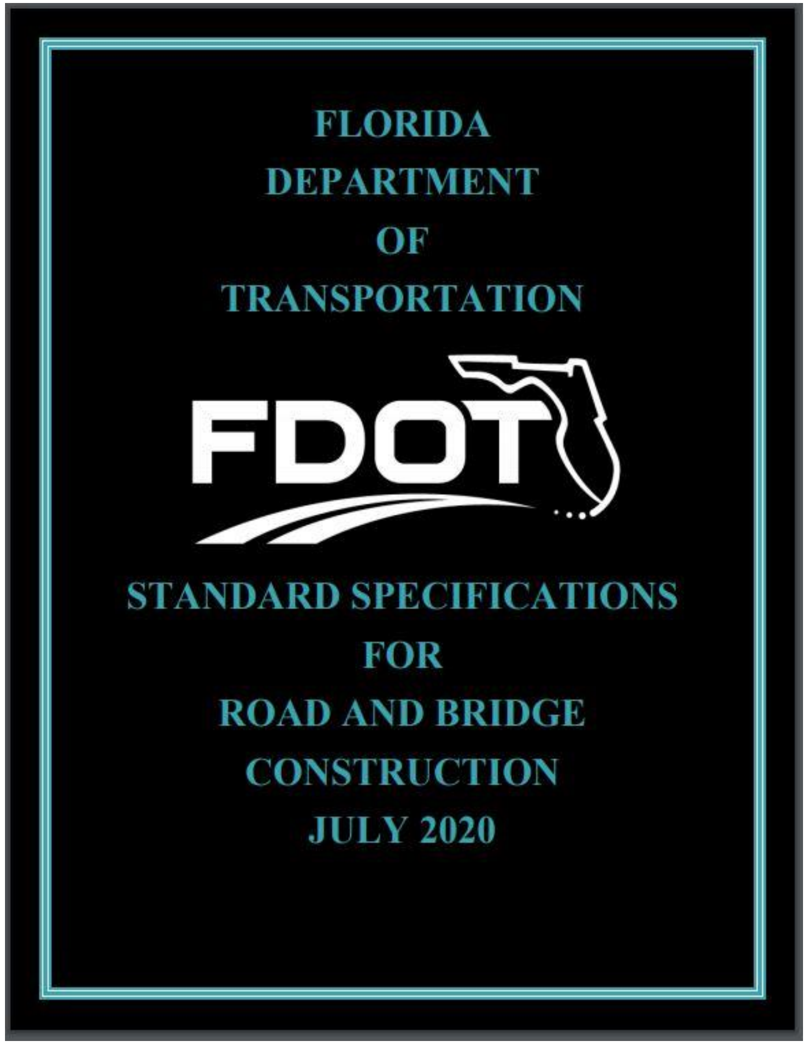
- **FDOT Standard Specifications for Road and Bridge Construction**, July 2020

**SECTION 933**
**PRESTRESSING STRAND AND BAR**

Table 1-2
Typical Sizes and Loads of CFRP Prestressing Strands and Bars

| Type | Nominal Diameter (in) | Nominal Cross Sectional Area ($in^2$) | Nominal Ultimate Load ($P_u$) (kips) | Nominal Ultimate Tensile Stress (ksi) |
|---|---|---|---|---|
| Single Strand - 5.0mm Ø | 0.20 | 0.025 | 9.1 | 364 |
| 7-strand - 7.9mm Ø | 0.31 | 0.048 | 17.8 | 370 |
| 7-strand - 10.8mm Ø | 0.43 | 0.090 | 33.1 | 367 |
| Single Strand - 9.5mm Ø | 0.38 | 0.110 | 35.0 | 318 |
| 7-strand - 12.5mm Ø | 0.49 | 0.117 | 43.3 | 370 |
| Single Strand - 12.7mm Ø | 0.50 | 0.196 | 59.0 | 301 |
| 7-strand - 15.2mm Ø | 0.60 | 0.179 | 66.2 | 369 |
| 7-strand - 17.2mm Ø | 0.68 | 0.234 | 86.6 | 338 |

**will be corrected as 370 ksi in January 2021 Edition*



# DESIGN CODES, MANUALS & REFERENCES

- **FDOT Standard Plans - FY 2020-21**

| | | | |
|---|---|---|---|
| 455-101 | | Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes | 22600 |
| 455-102 | | Square CFRP and SS Prestressed Concrete Pile Splices | 22601 |
| 455-112 | | 12" Square CFRP and SS Prestressed Concrete Pile | 22612 |
| 455-114 | | 14" Square CFRP and SS Prestressed Concrete Pile | 22614 |
| 455-118 | | 18" Square CFRP and SS Prestressed Concrete Pile | 22618 |
| 455-124 | | 24" Square CFRP and SS Prestressed Concrete Pile | 22624 |
| 455-130 | | 30" Square CFRP and SS Prestressed Concrete Pile | 22630 |
| 455-154 | | 54" Precast/Post-Tensioned CFRP and SS Concrete Cylinder Pile | 22654 |
| 455-160 | | 60" Prestressed CFRP and SS Concrete Cylinder Pile | 22660 |


| | | | |
|---|---|---|---|
| 455-101 | | Square CFRP and SS Prestressed Concrete Piles - Typical Details and Notes | 22600 |
| 455-102 | | Square CFRP and SS Prestressed Concrete Pile Splices | 22601 |




Office of Design

Office of Design / Standard Plans / Standard Plans FY 2020-21

**Standard Plans - FY 2020-21**

FDOT Standard Plans

See the FDOT Design Manual (FDM), Chapter 115, for additional information on the use of **Standard Plans** within FDOT Contract Plans. Subscribe to our FDOT Contact Management Subscription Service to receive the most current notices, bulletins, memoranda, and other important information.

Skip to Standard Plans for Bridge Construction

*(Last updated: 06/24/2020)*

**Standard Plans for Road Construction**

| Standard Plans Index | Interim Revision, Errata, or Developmental (Dev) | Index Title | Design Standards Index | Standard Plans Instructions | Design Tools |
|---|---|---|---|---|---|
| **Support Detail** | | | | | |
| eBook | | Standard Plans for Road Construction - Complete eBook | | | |
| Cover | | Cover Sheet | | | |
| Abbrev | | Abbreviations Sheet | | | |
| TOC Road | | Table of Contents - Road Construction | | | |
| Crosswalk | | Crosswalk of Design Standards Index to Standard Plans | | | |
| Revisions | | Revision History Log | | SPI | |
| **Miscellaneous** | | | | | |
| 000-510 | | Superelevation Transitions - High Speed Roadways | 510 | | |
| 000-511 | | Superelevation Transitions - Low Speed Roadways | 511 | | |
| 000-525 | | Ramp Terminals | 525 | | |
| **General Construction Operations-Roadway** | | | | | |
| | | **Maintenance of Traffic** | | | |
| 102-100 | | Temporary Barrier | 415 | SPI | XLS |
| 102-110 | | Type K Temporary Concrete Barrier System | 414 | | |
| 102-120 | | Low Profile Barrier | 412 | | |
| IR102-600 | Interim | General Information for Traffic Control Through Work Zones | 600 | | |

# Questions?

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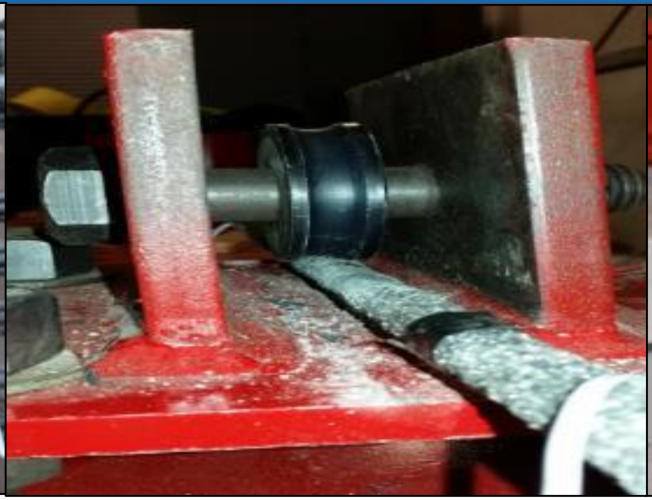
# 1. INTRODUCTION & DESIGN CODES, MANUALS AND REFERENCES

## *1.1 Review Questions: Fundamentals*

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# REVIEW QUESTIONS

## 1.1.1) Where could FRP reinforcement for concrete be most suitable?

a. Any concrete member susceptible to steel corrosion by chlorides

b. Any concrete member requiring non-ferrous reinforcement due to electro-magnetic considerations

c. As an alternative to epoxy, galvanized, or stainless steel reinforcements

d. Applications requiring thermal non-conductivity

e. All the above

# REVIEW QUESTIONS

## Where Should FRP Be Used?

- Concrete structures susceptible to corrosion
  - -Steel corrosion by chlorides
  - -Aggressive agents that lower concrete pH
  - -Structures with minimum cover concrete
- Concrete structures requiring non-ferrous reinforcement due to
  - -Electro-magnetic considerations
  - -Thermal non-conductivity

# REVIEW QUESTIONS

## 1.1.1) Where could FRP reinforcement for concrete be most suitable?

a. Any concrete member susceptible to steel corrosion by chlorides

b. Any concrete member requiring non-ferrous reinforcement due to electro-magnetic considerations

c. As an alternative to epoxy, galvanized, or stainless steel reinforcements

d. Applications requiring thermal non-conductivity

**e. <u>All the above</u>**

# REVIEW QUESTIONS

## 1.1.2) Which of the following is NOT applicable to FRP rebar/strands?

a. Corrosion resistant

b. Ductility

c. Low thermal conductivity

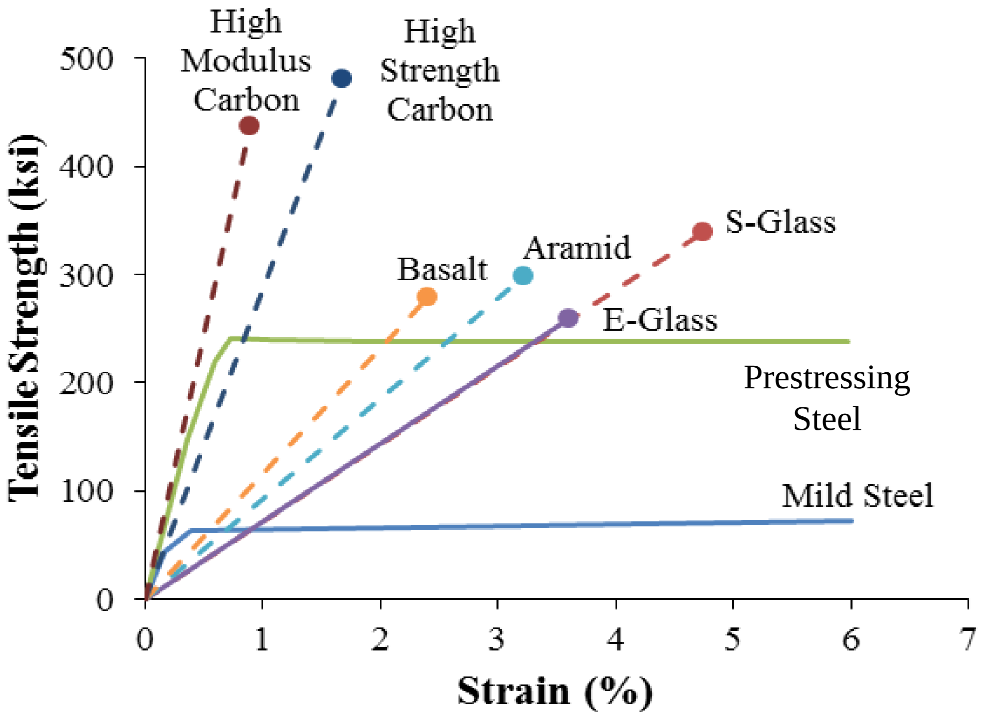
d. Light weight

e. High strength to weight ratio

# REVIEW QUESTIONS

## 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



# REVIEW QUESTIONS

## 1.1.2) Which of the following is NOT applicable to FRP rebar/strands?

a. Corrosion resistant

**b. <u>Ductility</u>**

c. Low thermal conductivity

d. Light weight

e. High strength to weight ratio

# REVIEW QUESTIONS

## 1.1.3) The density of CFRP is about _________?

a. About 5 times lighter than steel

b. Similar to that of steel

c. About 5 times heavier than steel

a. Half that of steel

# REVIEW QUESTIONS

## FRP Density

- CFRP density: ~0.055 $lb/in^3$
- Steel density:  ~0.284 $lb/in^3$

# REVIEW QUESTIONS

## 1.1.3) The density of CFRP is about _________?

a. **<u>About 5 times lighter than steel</u>**

b. Similar to that of steel

c. About 5 times heavier than steel

a. Half that of steel

# REVIEW QUESTIONS

## 1.1.4) FRP has higher strength in the direction _______ to the fibers?

a. Transverse

b. Parallel

# REVIEW QUESTIONS

## FRP Strength

Parallel (Tension) >> Transverse (Shear)

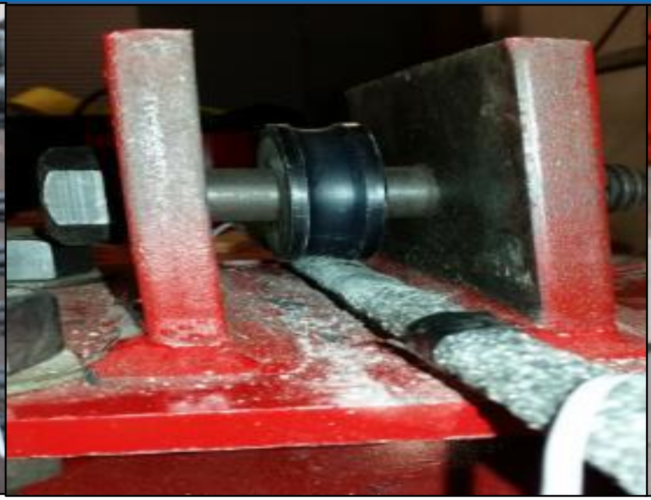
# REVIEW QUESTIONS

## 1.1.4) FRP has higher strength in the direction _______ to the fibers?

a. Transverse

**b. <u>Parallel</u>**

# AASHTO CFRP-Prestressed Concrete Design Training Course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