FDOT TRANSPORTATION SYMPOSIUM

Prestressed Concrete Beam Design: HSSS vs. CFRP Strands

Vickie Young and Steve Nolan

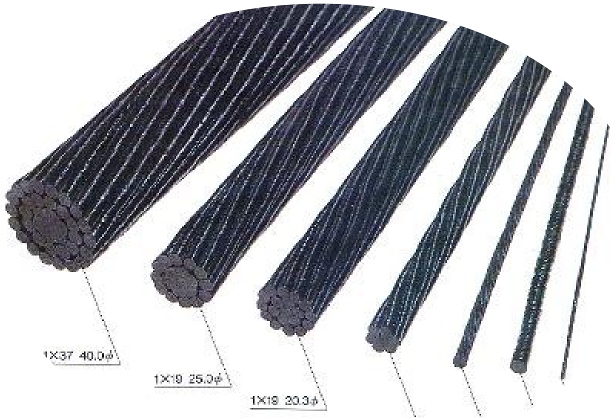
AGENDA

- INTRODUCTION: Corrosion Resistant Materials in Prestressed Concrete
- PART 1: High Strength Stainless Steel (HSSS) Strands
- PART 2: Carbon Fiber Reinforced Polymer (CFRP) Strands

INTRODUCTION:
What Corrosion Resistant Materials (CRM) are available ?

Stainless Steel

CRM



Fiber Reinforced Polymers (FRP)

Glass (GFRP)

Carbon (CFRP)

Introduction - Using CRM in Prestressed Concrete Components

- Benefits
  - Lower life cycle costs including reduced Maintenance Costs
  - Reduced concrete cover (FRP)
  - Longer structure life

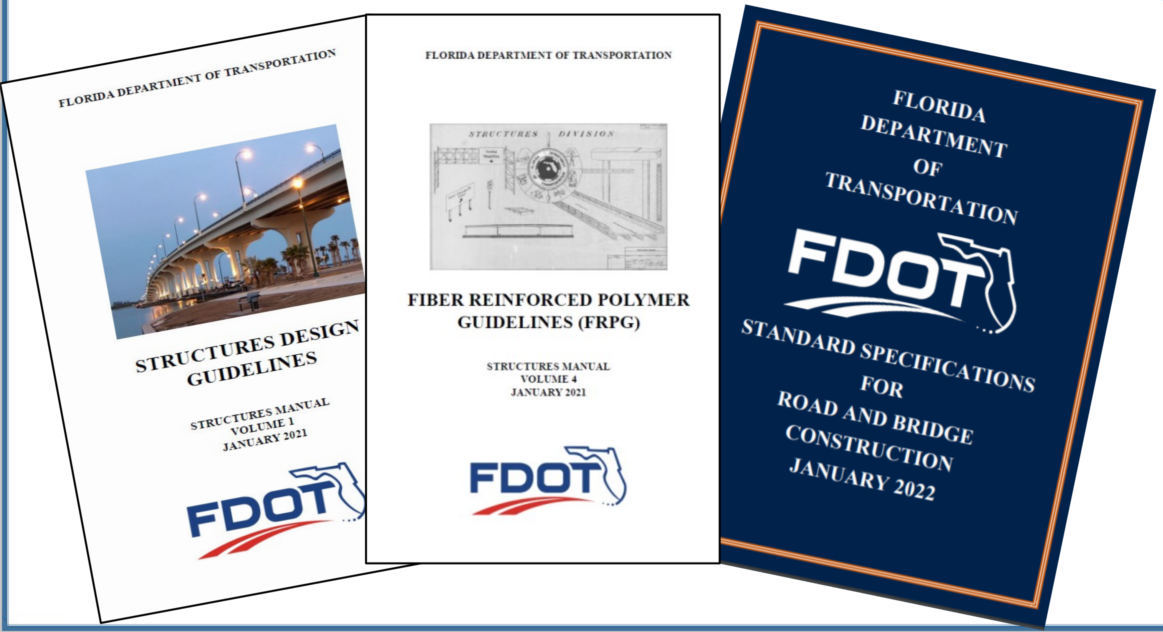
- Disadvantages
  - Higher Initial Cost (Both HSSS & FRP)
  - Availability & Time (Both HSSS & FRP)
  - Dissimilar metals
  - FRP bars cannot be Field Bent

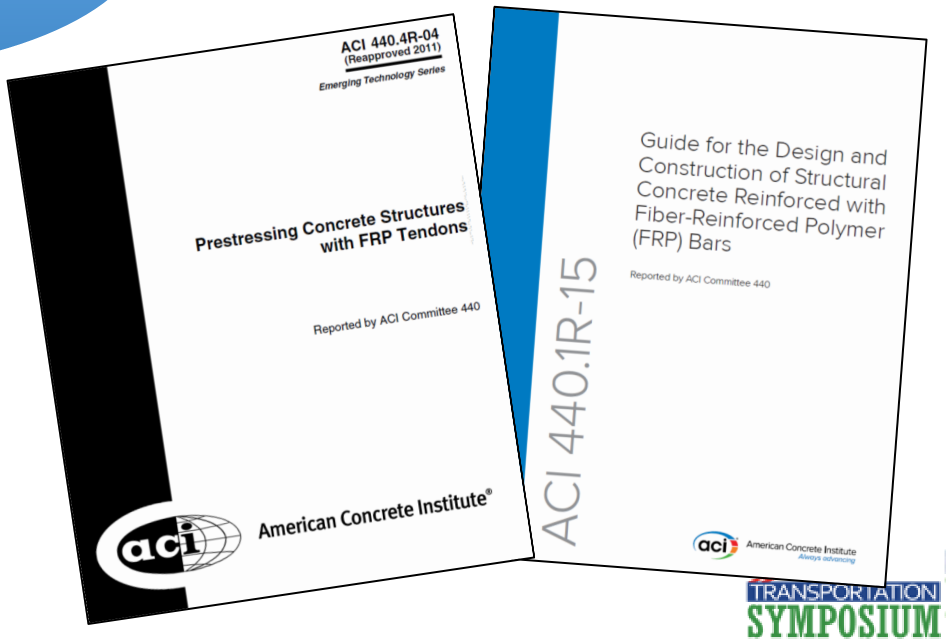
FDOT TRANSPORTATION SYMPOSIUM

Strand Types:

1. *Carbon Steel Strands*
2. ***Stainless Steel Strands***
3. ***Carbon Fiber Reinforced Polymer Strands (CFRP)***

References & Guides





TRANSPORTATION RESEARCH BOARD TRB

NCHRP NATIONAL COOPERATIVE HIGHWAY RESEARCH PROGRAM

National Research

U.S. Department of Transportation Federal Highway Administration

AASHTO

NCHRP 12-120 [Active]

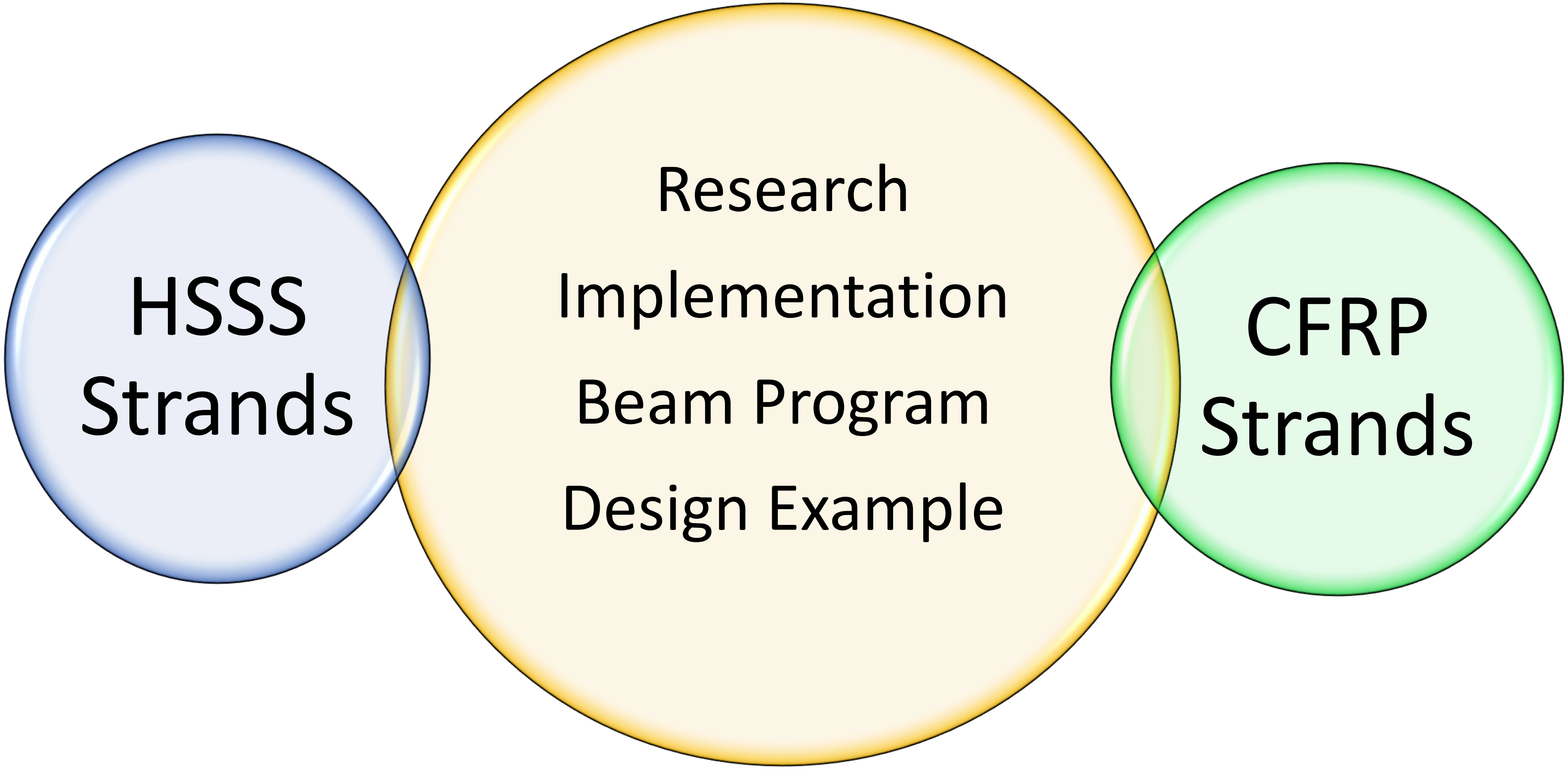
Stainless Steel Strands for Prestressed Concrete Bridge Elements

Project Data	
Funds:	$600,000
Staff Responsibility:	Dr. Waseem Dekelbab
Research Agency:	University of Houston
Principal Investigator:	Dr. Abdeldjelil Belarbi
Effective Date:	7/1/2020
Completion Date:	3/1/2023

NCHRP 12-121 [Active]

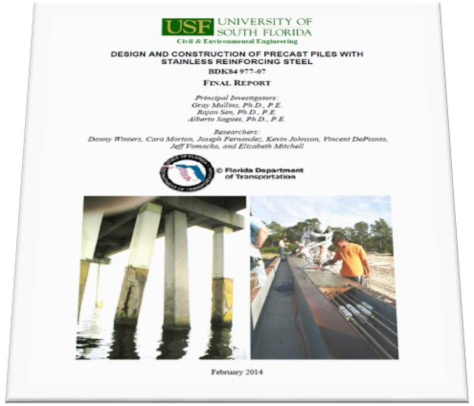
Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement

Project Data	
Funds:	$540,000
Staff Responsibility:	Dr. Waseem Dekelbab
Research Agency:	University of Houston
Principal Investigator:	Dr. Belarbi, Abdeldjelil
Effective Date:	4/19/2021
Completion Date:	4/19/2024


HSSS Strands
Research
Implementation
Beam Program
Design Example
CFRP Strands

PART 1:

HSSS
Strands


USF UNIVERSITY OF SOUTH FLORIDA
Civil & Environmental Engineering
DESIGN AND CONSTRUCTION OF PRECAST PILES WITH STAINLESS REINFORCING STEEL
BDK84 977-07
FINAL REPORT
Principal Investigators:
Gray Mullins, Ph.D., P.E.
Rajan Sen, Ph.D., P.E.
Alberto Sagüés, Ph.D., P.E.
Researchers:
Danny Winters, Cora Morton, Joseph Fernandez, Kevin Johnson, Vincent DePiante, Jeff Vomacka, and Elizabeth Mitchell
Florida Department of Transportation
February 2014

Completed Research


Stainless Steel Strands and Lightweight Concrete for Pretensioned Concrete Girders
FDOT Contract No. BDV30-977-22
FSU Project No. 041063
FDOT
FAMU-FSU College of Engineering
December 2020
Final Report A – Stainless Steel Strands

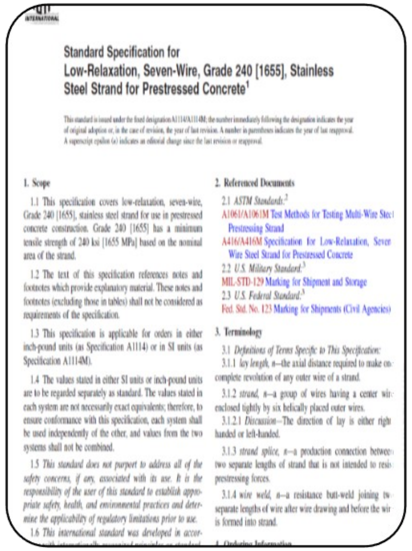
Design and Construction of Precast Piles with Stainless Steel Reinforcing

- ❑ Done USF in 2014, Additional Follow Up Testing done by FDOT SRC 2017 – 2018
- ❑ Research Project Objective:
  - ❑ Evaluate 3 Different Stainless Steel Materials to identify a suitable Stainless Steel Strand
  - ❑ Grade 316 SS, XM-29 & Duplex 2205
- ❑ Testing & Evaluation Included:
  - ❑ Structural Capacity
  - ❑ Long-term Relaxation
  - ❑ Corrosion Resistance
  - ❑ Field Fabrication
  - ❑ Cost Comparison
- ❑ Final Conclusions & Recommendations:
  - ❑ Use Duplex 2205

Stainless Steel Strands for Prestressed Concrete Girders

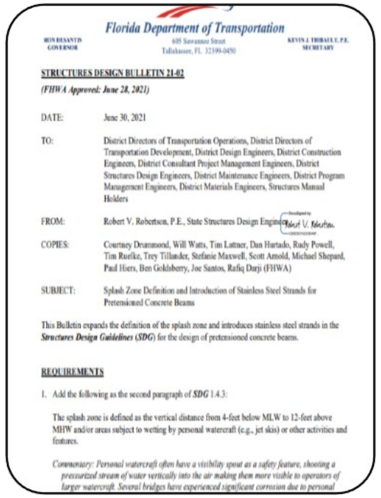
- ❑ Done FSU, Completed in 2020
- ❑ Research Project Objective:
  - ❑ Strength, Ductility & Deformability using HSSS strand PS Girders
  - ❑ Evaluate Shear Using CRM Bars
- ❑ Testing & Evaluation Included:
  - ❑ Structural Capacity: Flexure & Shear Testing of 13 AASHTO Type II girders
  - ❑ Material Testing of 0.62” Dia. Strand
  - ❑ Transfer length
- ❑ Final Conclusions & Recommendations:
  - ❑ Means & Methods same as CS Strands
  - ❑ Phi for flexure = 0.75, stress-strain curve was developed
  - ❑ Min. Reinforcing Limits

Implementation



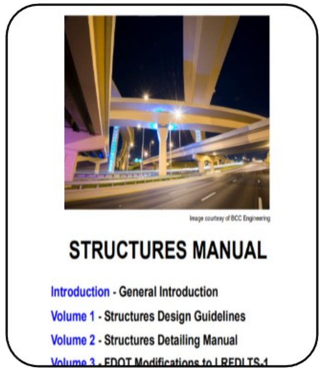
ASTM → Spring 2020

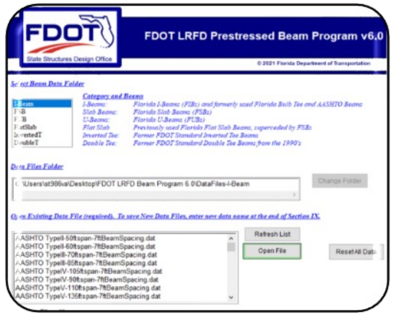
FDOT Specs → Updated for Jan. 2022 Book



SDB → June 2021

SDM → January 2022





FDOT Beam Program → Fall 2021

FDOT Standard Plans → Future

2. For pretensioned concrete beams located within the splash zone, evaluate the use of CFRP and stainless steel prestressing strands. See ***SDG*** 1.4 for definition of splash zone. Coordinate with the District Structures Design Engineer and the State Materials Office for guidance.

4. For stainless steel strands, use the following design requirements and guidance:

   a. Use ASTM A1114, Grade 240, low-relaxation, stainless steel prestressing strands for the design of pretensioned beams. Use only straight strand configurations.

   b. Use materials for mild reinforcing and other embedded items that are compatible with stainless steel. Do not used mild reinforcing or other embedded items made of CFRP or carbon steel.

   Commentary: Grade 75 stainless steel reinforcing is the preferred compatible material for design efficiency and simplicity in construction. Glass & basalt FRP reinforcing are also compatible with stainless steel. CFRP and carbon steel reinforcing are not compatible and will experience accelerated corrosion due to electrical contact with stainless steel.

   c. Use the following design values:

      i. Resistance factor φ of 0.75 for flexure. Include this value on the Load Rating Summary Sheet.

      ii. Maximum steel stress immediately prior to transfer (f_{pbt}) of $0.65f_{pu}$.

iii. The prestressing strand failure (rupture) is defined to occur when the strain in the extreme strand layer reaches the ultimate tensile strain (ε_{pu}) of 0.014.

SDB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Structures Design Bulletin 21-02

Florida Department of Transportation

605 Suwannee Street
Tallahassee, FL 32399-0450

RON DESANTIS
GOVERNOR

KEVIN J. THIBAULT, P.E.
SECRETARY

STRUCTURES DESIGN BULLETIN 21-02

(FHWA Approved: June 28, 2021)

DATE:	June 30, 2021
TO:	District Directors of Transportation Operations, District Directors of Transportation Development, District Design Engineers, District Construction Engineers, District Consultant Project Management Engineers, District Structures Design Engineers, District Maintenance Engineers, District Program Management Engineers, District Materials Engineers, Structures Manual Holders
FROM:	Robert V. Robertson, P.E., State Structures Design Engineer
COPIES:	Courtney Drummond, Will Watts, Tim Lattner, Dan Hurtado, Rudy Powell, Tim Ruelke, Trey Tillander, Stefanie Maxwell, Scott Arnold, Michael Shepard, Paul Hiers, Ben Goldsberry, Joe Santos, Rafiq Darji (FHWA)
SUBJECT:	Splash Zone Definition and Introduction of Stainless Steel Strands for Pretensioned Concrete Beams

This Bulletin expands the definition of the splash zone and introduces stainless steel strands in the ***Structures Design Guidelines*** (***SDG***) for the design of pretensioned concrete beams.

REQUIREMENTS

1. Add the following as the second paragraph of ***SDG*** 1.4.3:

The splash zone is defined as the vertical distance from 4-feet below MLW to 12-feet above MHW and/or areas subject to wetting by personal watercraft (e.g., jet skis) or other activities and features.

Commentary: Personal watercraft often have a visibility spout as a safety feature, shooting a pressurized stream of water vertically into the air making them more visible to operators of larger watercraft. Several bridges have experienced significant corrosion due to personal watercraft spraying chloride water onto the underside of the bridge.

iv. Meet the following minimum reinforcement limit for designs controlled by strand rupture:

$$\frac{c}{d} \geq \left(\frac{9.2f'_c + 0.48f_{pe} - 3.9}{1000}\right)$$

where:

c = distance from the extreme compression fiber to the neutral axis (in)

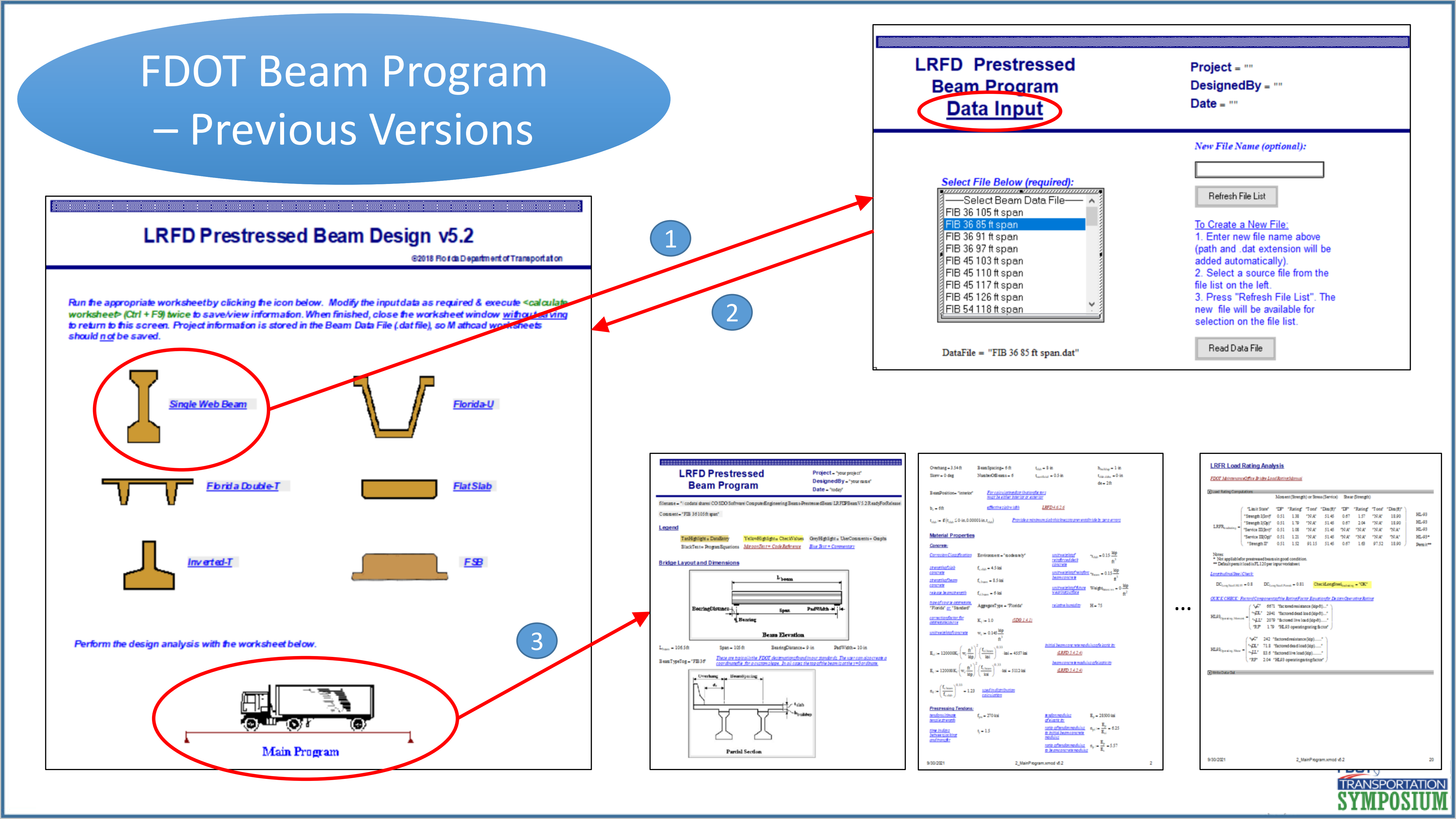
d = distance from the extreme compression fiber to the bottom layer of strands (in)

f'_c = compressive design strength of deck concrete (ksi)

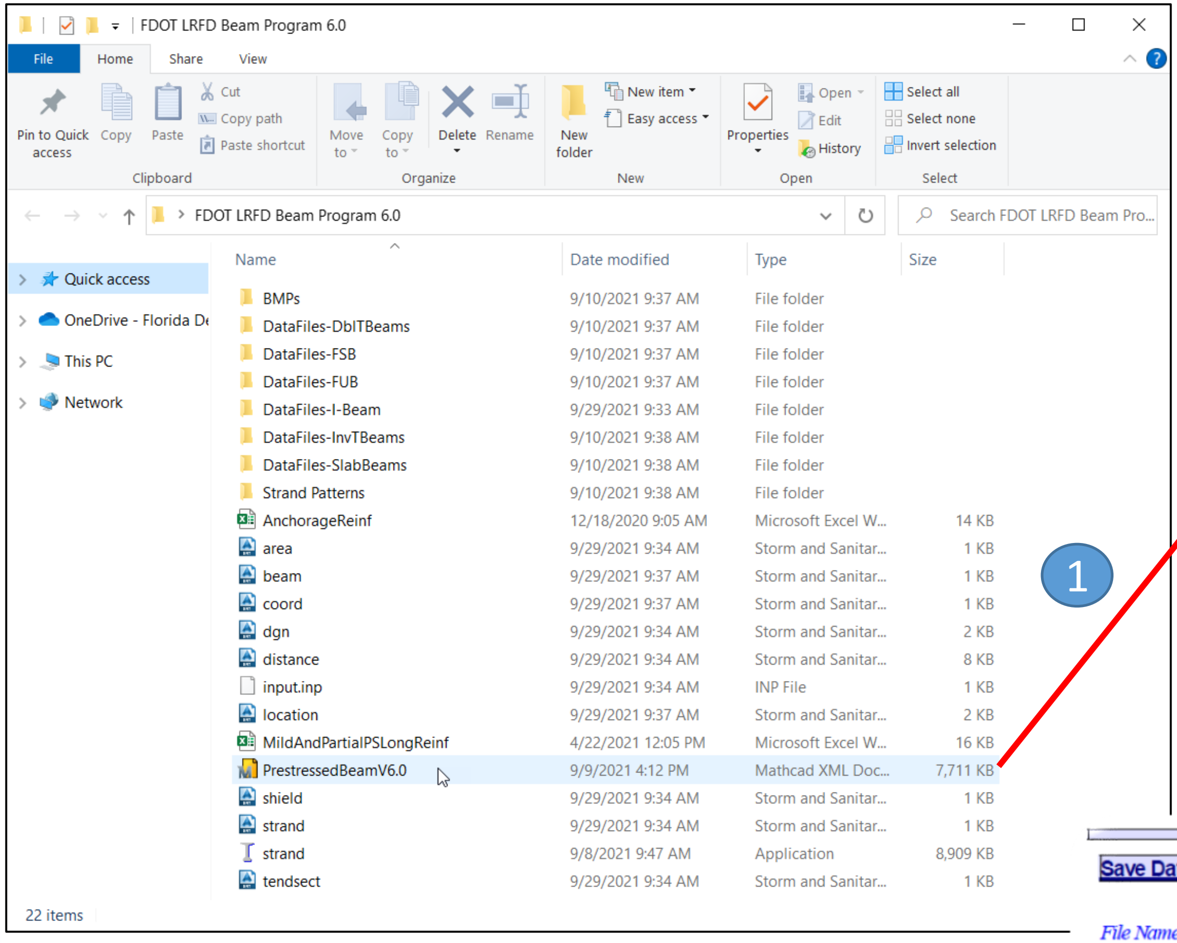
f_{pe} = effective stress in prestressing steel after losses (ksi)

Commentary: The design requirements for stainless steel strands are based on results from research report FDOT BDV30-977-22.

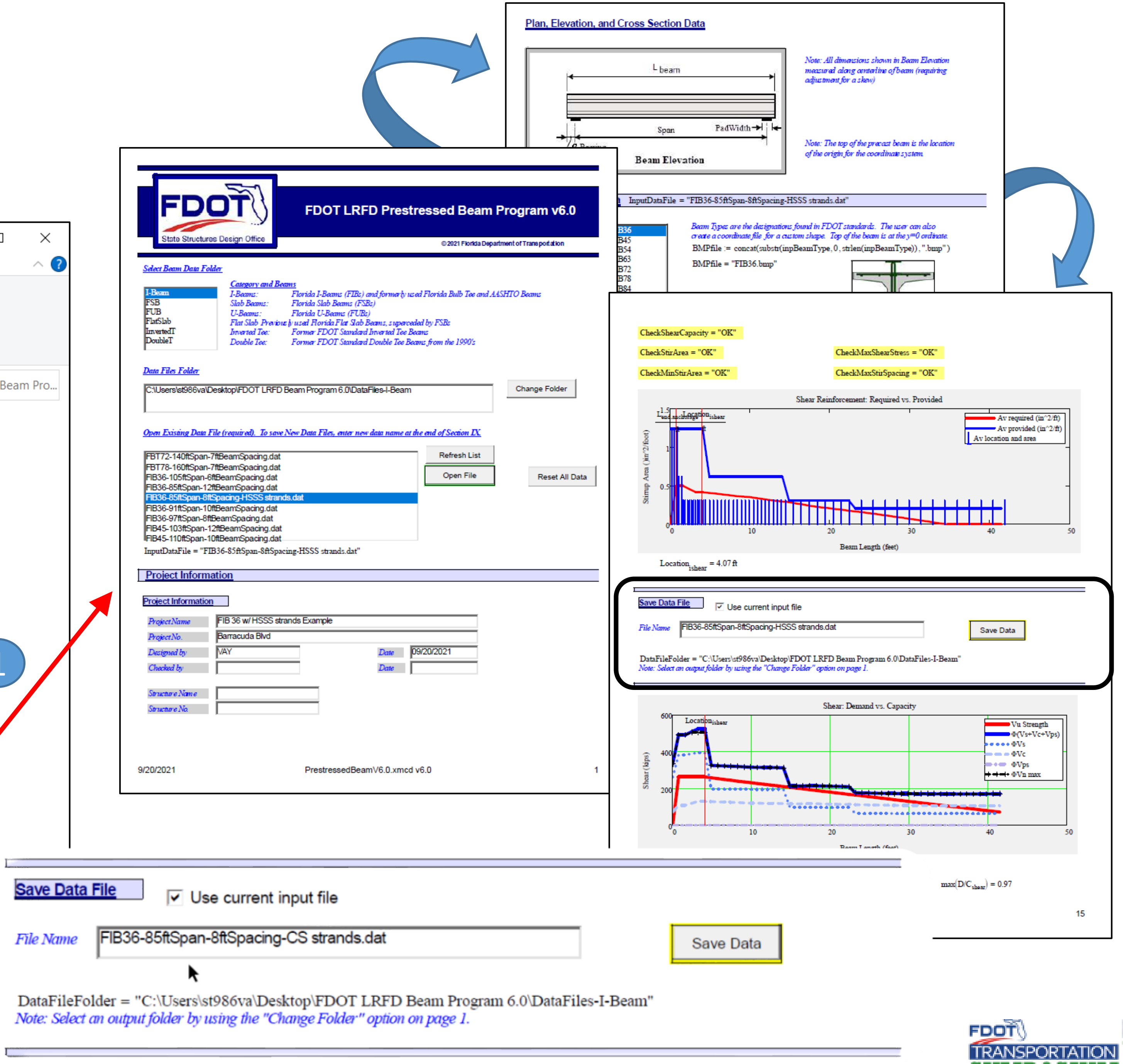
FDOT TRANSPORTATION SYMPOSIUM


FDOT Beam Program
– Previous Versions
LRFD Prestressed Beam Design v5.2
©2018 Florida Department of Transportation
Run the appropriate worksheet by clicking the icon below. Modify the input data as required & execute <calculate worksheet> (Ctrl + F9) twice to save/view information. When finished, close the worksheet window without saving to return to this screen. Project information is stored in the Beam Data File (.dat file), so Mathcad worksheets should not be saved.
Single Web Beam
Florida-U
Florida Double-T
Flat Slab
Inverted-T
FSB
Perform the design analysis with the worksheet below.
Main Program
1
2
3
LRFD Prestressed
Beam Program
Data Input
Project = ""
DesignedBy = ""
Date = ""
New File Name (optional):
Select File Below (required):
——Select Beam Data File——
FIB 36 105 ft span
FIB 36 85 ft span
FIB 36 91 ft span
FIB 36 97 ft span
FIB 45 103 ft span
FIB 45 110 ft span
FIB 45 117 ft span
FIB 45 126 ft span
FIB 54 118 ft span
Refresh File List
To Create a New File:
1. Enter new file name above (path and .dat extension will be added automatically).
2. Select a source file from the file list on the left.
3. Press "Refresh File List". The new file will be available for selection on the file list.
Read Data File
DataFile = "FIB 36 85 ft span.dat"
LRFD Prestressed
Beam Program
Legend
Bridge Layout and Dimensions
Beam Elevation
Partial Section
Material Properties
LRFR Load Rating Analysis
...
TRANSPORTATION
SYMPOSIUM

FDOT Beam Program v. 6.0

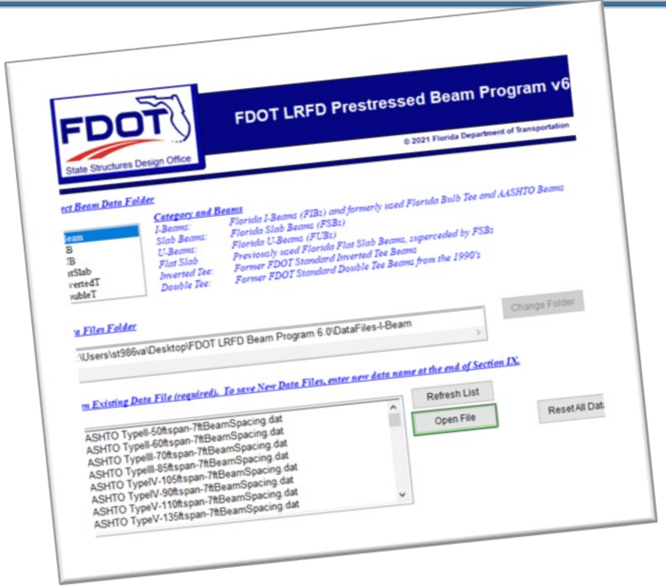


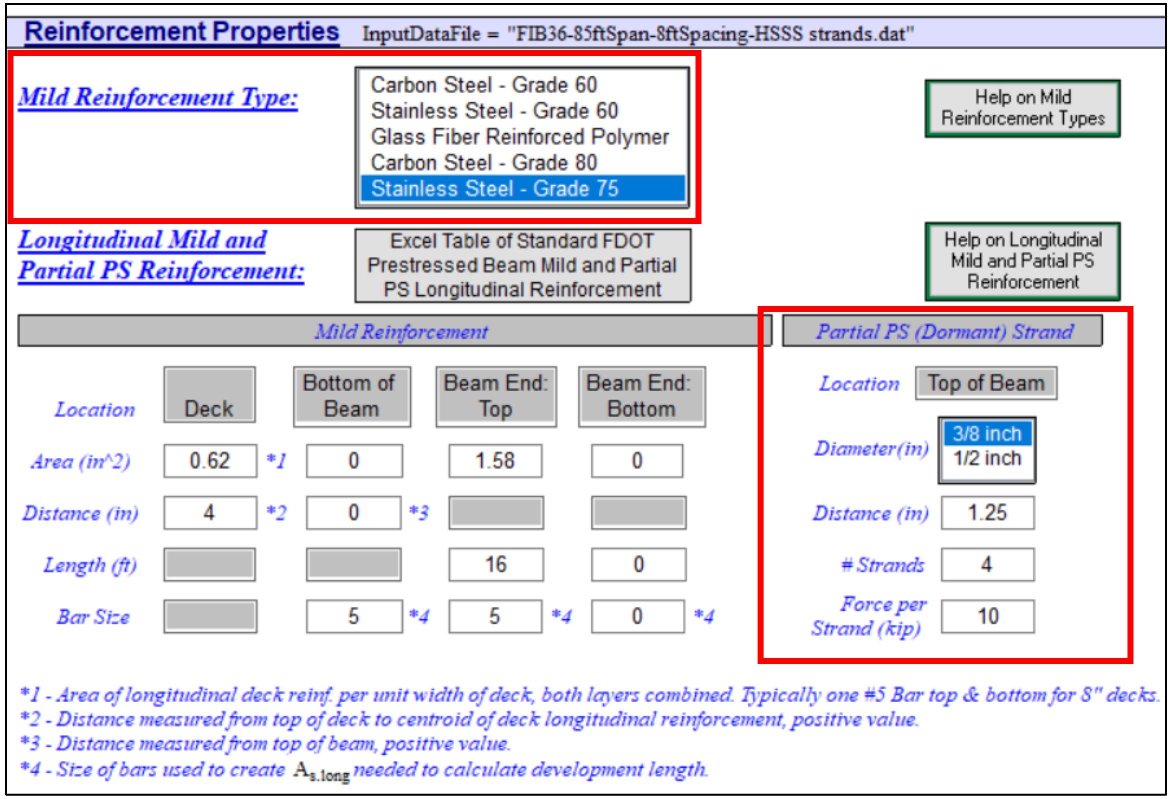
1

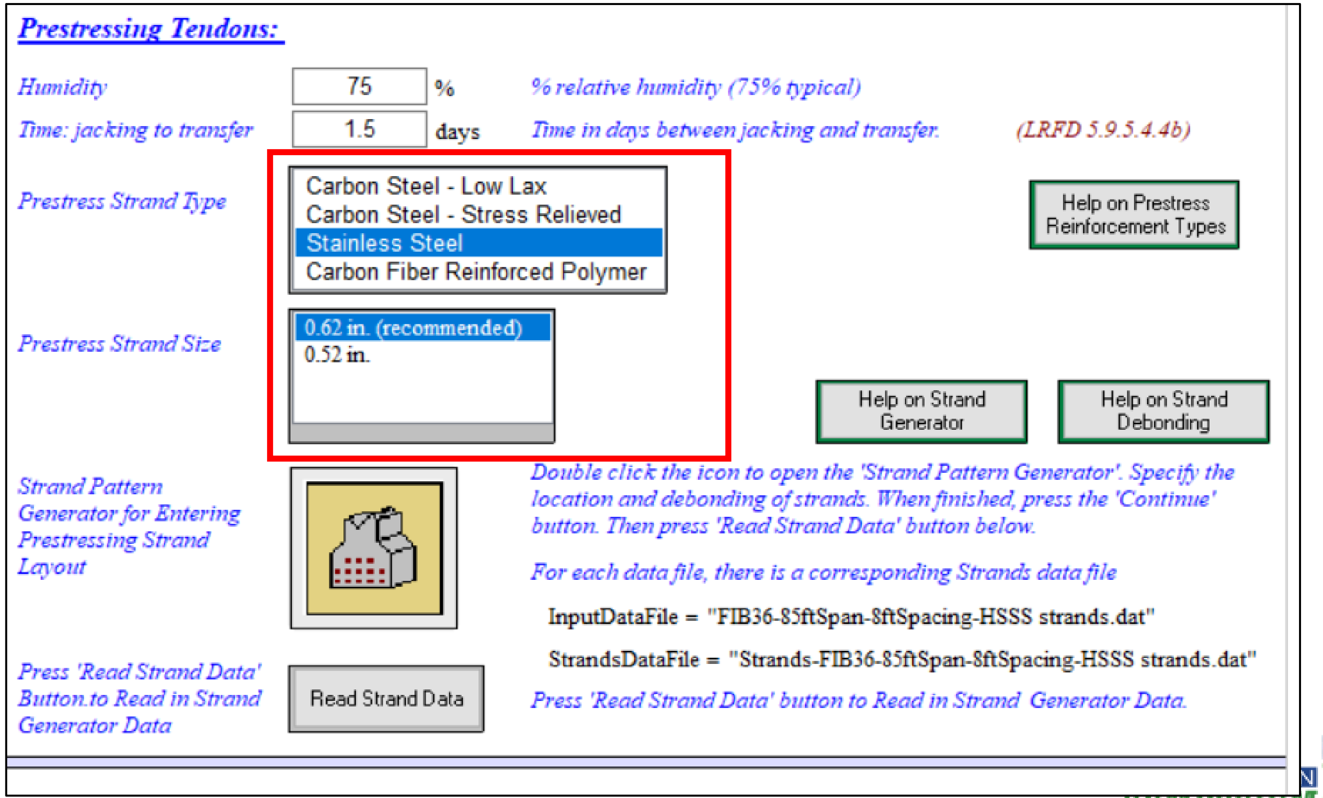


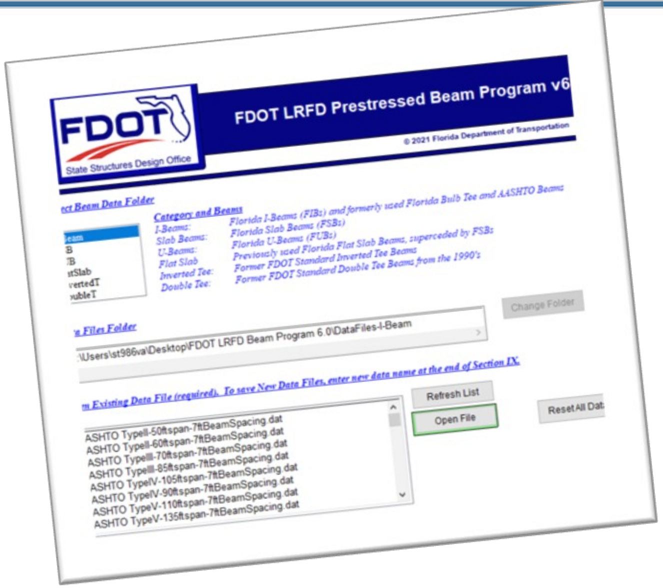
Only 1 MathCAD file

FDOT Beam Program v. 6.0



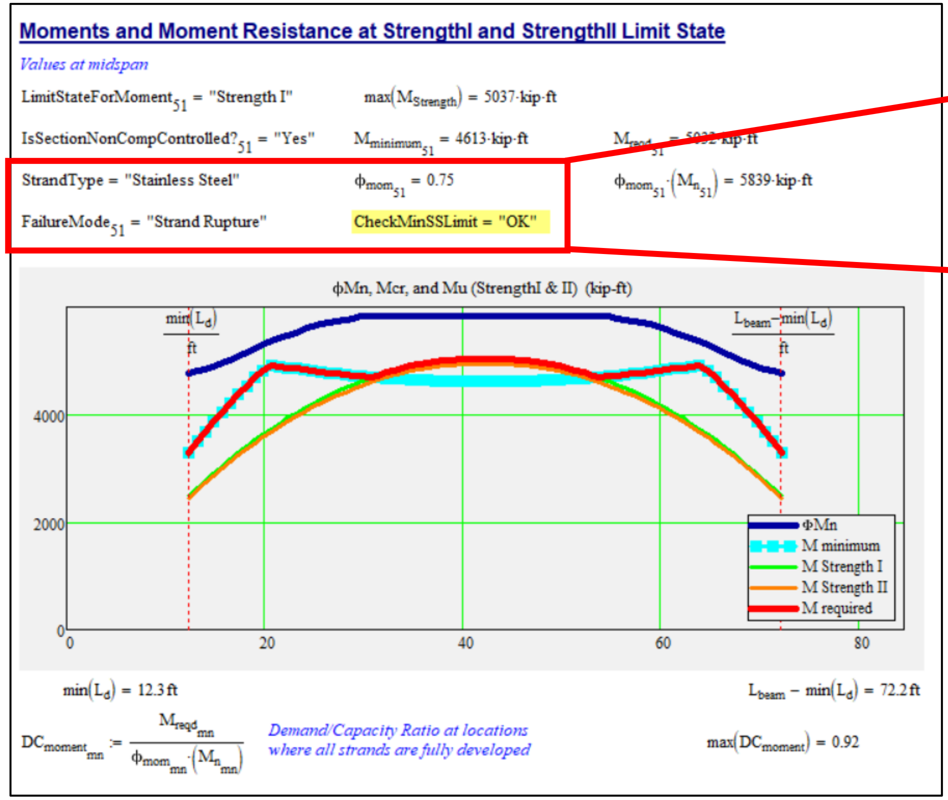






FDOT Beam Program v. 6.0

Release Date is Still Pending but Working Version Available Upon Request



StrandType = "Stainless Steel" $\phi_{mom_{51}} = 0.75$

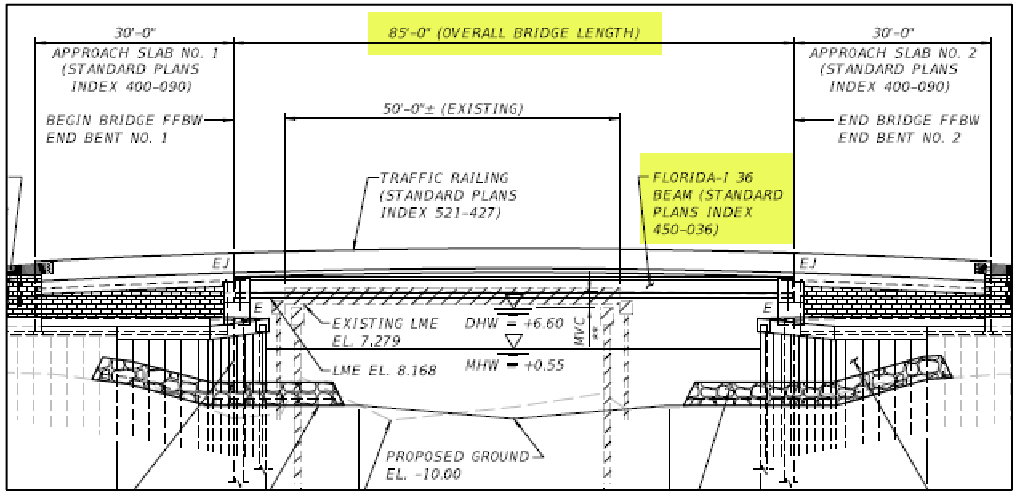
$FailureMode_{51}$ = "Strand Rupture" CheckMinSSLimit = "OK"

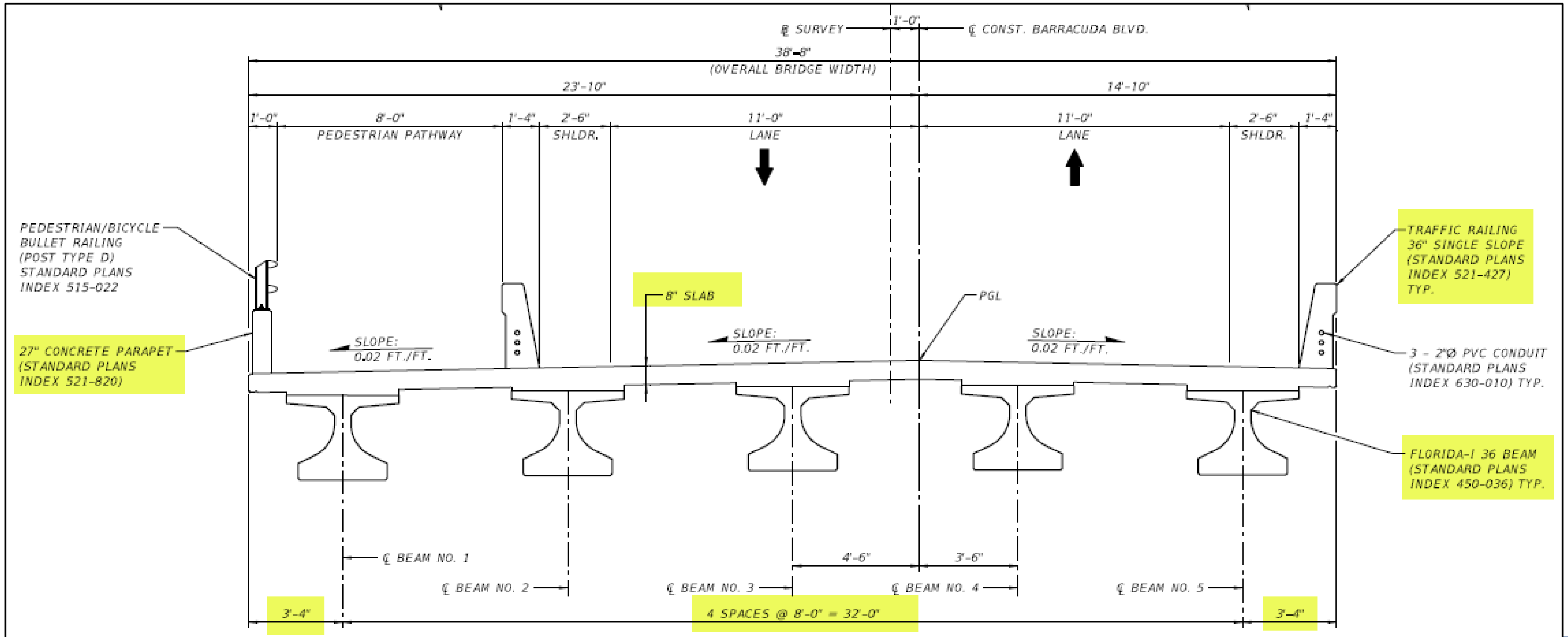
From SDB (2021) & SDG (2022 Release)

iv. Meet the following minimum reinforcement limit for designs controlled by strand rupture:

$$\frac{c}{d} \geq \left(\frac{9.2f'_c + 0.48f_{pe} - 3.9}{1000}\right)$$

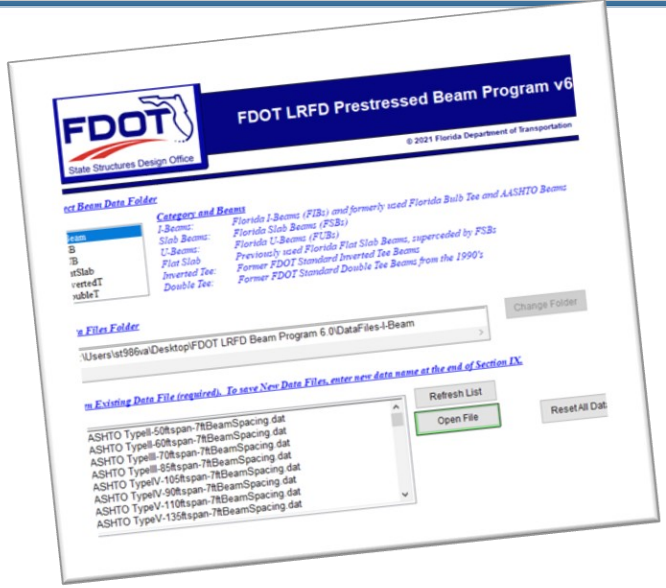
Design Example: HSSS strands



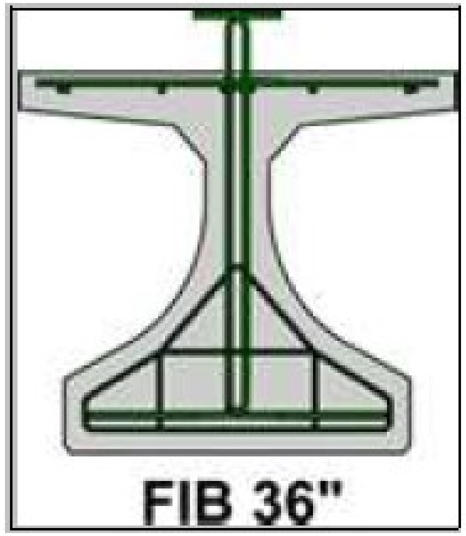


TYPICAL SECTION

TRANSPORTATION SYMPOSIUM



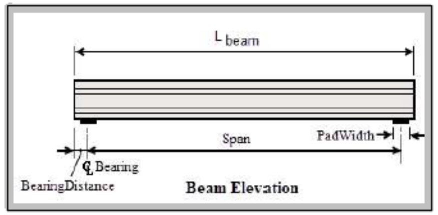
Design Example: HSSS strands



- Beam Type: **FIB36** (See Standard Plans & Instructions of Index 450-036)
- Beam Spacing: **8'-0"**, Number of Beams: **5**
- Span Length: **85'-0"**
- **Extremely** Aggressive Environment
- Using **0.62" Dia HSSS strands w/ Grade 75 SS mild reinforcing**
- Run FDOT Beam Program Version **6.0**

Design Example: HSSS Strands

Plan, Elevation, and Cross Section Data



Note: All dimensions shown in Beam Elevation measured along centerline of beam (requiring adjustment for a skew)

Note: The top of the precast beam is the location of the origin for the coordinate system

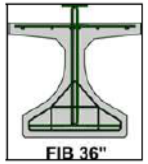
Superstructure Data
InputDataFile = "FIB36-85ftSpan-8ftSpacing-HSSS strands.dat"

Beam Type — FIB36 / FIB45 / FIB54 / FIB63 / FIB72 / FIB78 / FIB84 / FIB96 / TypeII (selected: FIB36)

Beam Types are the designations found in FDOT standards. The user can also create a coordinate file for a custom shape. Top of the beam is at the y=0 ordinate.

BMPfile := concat(substr(inpBeamType, 0, strlen(inpBeamType)), ".bmp")

BMPfile = "FIB36.bmp"



L_{beam}	84.5625	ft	See Beam Elevation above.
Bearing Distance	9	in	See Beam Elevation above.
Pad Width	10	in	Width of the bearing pad, see Beam Elevation above.
Beam Spacing	8	ft	Measured from beam centerline to centerline.
Overhang	3.333	ft	Measured from centerline of exterior beam.
Deck Thickness	8	in	Not including sacrificial thickness.
$t_{sacrificial}$	0	in	Sacrificial thickness cast with the deck (used for DL only, not section properties). (0" for BridgeLengths ≤ 100 ft, SDG 4.2.2)
d_e	2	ft	Front face of barrier to centerline of exterior beam (3 ft max). (LRFD 4.6.2.2.1)
Beam Position	Interior / Exterior (selected: Interior)		Use either "interior" or "exterior".
$Weight_{future.ws}$	0.015	kip/ft^2	Future wearing surface. (0.015ksf for BridgeLengths ≤ 100 ft, SDG Table 2.1)
$Weight_{barrier}$	0.365	kip/ft	Weight of single barrier. (0.43 klf for 36" single slope barrier, SDG Table 2-2.1)
Number of Barriers	3		Number of barriers in x-section (multiplies single barrier weight).
Number of Beams	5		Number of beams in the span cross section. (LRFD 4.6.2.2.1)
Skew	0	deg	measured from the perpendicular to the longitudinal axis in bridge plan view.

9/20/2021 PrestressedBeamV6.0.xmcd v6.0 2

Dimensions Specific to Certain Beam Categories

I-Beams, U-Beams and Inverted-T Beams

$h_{buildup}$	1	in	Buildup or haunch is the concrete between the bottom of deck and top of beam.

Slab-Beams (Florida Slab Beams, Flat Slab Beams)

Slab Beam Width		in	Width of the slab unit (not including Gap width)
$Slab\ Beam_{Thickness}$		in	Thickness of the slab unit.
$t_{deck.delta}$		in	maximum additional deck thickness over support to accommodate camber, used for additional DL only.
Gap		in	Gap distance between slab beams. (Beam Spacing - Slab Beam Width)

Double Tee Beams

Width Double-T		ft	Width of the Double-T unit.
$Depth_{flange}$		in	Depth of the flange of the Double-T unit. See Beam Cross Section above.

Concrete Material Properties

FDOT Environmental Classification	Slightly / Moderately / Extremely (selected: Extremely)		Environmental Classification determines the Allowable Tension Stress
f'c of deck or WS	5.5	ksi	Strength of deck or wearing surface concrete.
f'c of beam or slab	8.5	ksi	28 day concrete strength of beam or slab.
f'ci of beam or slab	6.8	ksi	Release concrete strength of beam or slab.

Help - Conc. Strength

Additional Dead Load Data:

Uniform Dead Loads

Additional Uniform Noncomposite DL: 0.222 kip/ft

Additional Uniform Composite DL: 0 kip/ft

$W_{deck} = 0.85 \cdot \frac{kip}{ft}$ $W_{beam} = 0.84 \cdot \frac{kip}{ft}$ $W_{forms} = 0.08 \cdot \frac{kip}{ft}$

$W_{future.ws} = 0.12 \cdot \frac{kip}{ft}$ $W_{barrier} = 0.22 \cdot \frac{kip}{ft}$

Reinforcement Properties
InputDataFile = "FIB36-85ftSpan-8ftSpacing-HSSS strands.dat"

Mild Reinforcement Type: Carbon Steel - Grade 60 / Stainless Steel - Grade 60 / Glass Fiber Reinforced Polymer / Carbon Steel - Grade 80 / Stainless Steel - Grade 75 (selected: Stainless Steel - Grade 60)

Help on Mild Reinforcement Types

Longitudinal Mild and Partial PS Reinforcement: Excel Table of Standard FDOT Prestressed Beam Mild and Partial PS Longitudinal Reinforcement

Help on Longitudinal Mild and Partial PS Reinf

Mild Reinforcement

Location	Deck		Bottom of Beam		Beam End: Top		Beam End: Bottom	
Area (in^2)	0.62	*1	0		1.58		0	
Distance (in)	4	*2	0	*3				
Length (ft)					16		0	
Bar Size			5	*4	5	*4	0	*4

Partial PS (Dormant) Strand

Location	Top of Beam
Diameter (in)	3/8 inch / 1/2 inch (selected: 3/8 inch)
Distance (in)	1.25
# Strands	4
Force per Strand (kip)	10

*1 - Area of longitudinal deck reinf. per unit width of deck, both layers combined. Typically one #5 Bar top & bottom for 8" decks.
*2 - Distance measured from top of deck to centroid of deck longitudinal reinforcement, positive value.
*3 - Distance measured from top of beam, positive value.
*4 - Size of bars used to create $A_{s.long}$ needed to calculate development length.

Prestressing Tendons:

Humidity: 75 % — % relative humidity (75% typical)

Time: jacking to transfer: 1.5 days — Time in days between jacking and transfer. (LRFD 5.9.5.4.4b)

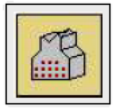
Prestress Strand Type: Carbon Steel - Low Lax / Carbon Steel - Stress Relieved / Stainless Steel / Carbon Fiber Reinforced Polymer (selected: Stainless Steel)

Help on Prestress Reinforcement Typ

Prestress Strand Size: 0.62 in. (recommended) / 0.52 in. (selected: 0.62 in. (recommended))

Help on Strand Generator | Help on Strand Debonding

Strand Pattern Generator for Entering Prestressing Strand Layout



Double click the icon to open the 'Strand Pattern Generator'. Specify the location and debonding of strands. When finished, press the 'Continue' button. Then press 'Read Strand Data' button below.

For each data file, there is a corresponding Strands data file

InputDataFile = "FIB36-85ftSpan-8ftSpacing-HSSS strands.dat"

StrandsDataFile = "Strands-FIB36-85ftSpan-8ftSpacing-HSSS strands.dat"

Press 'Read Strand Data' Button to Read in Strand Generator Data

Read Strand Data

Press 'Read Strand Data' button to Read in Strand Generator Data.

9/20/2021 PrestressedBeamV6.0.xmcd v6.0 7

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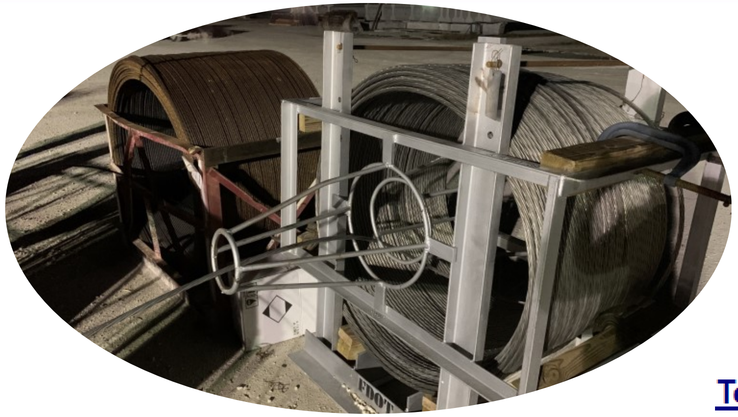
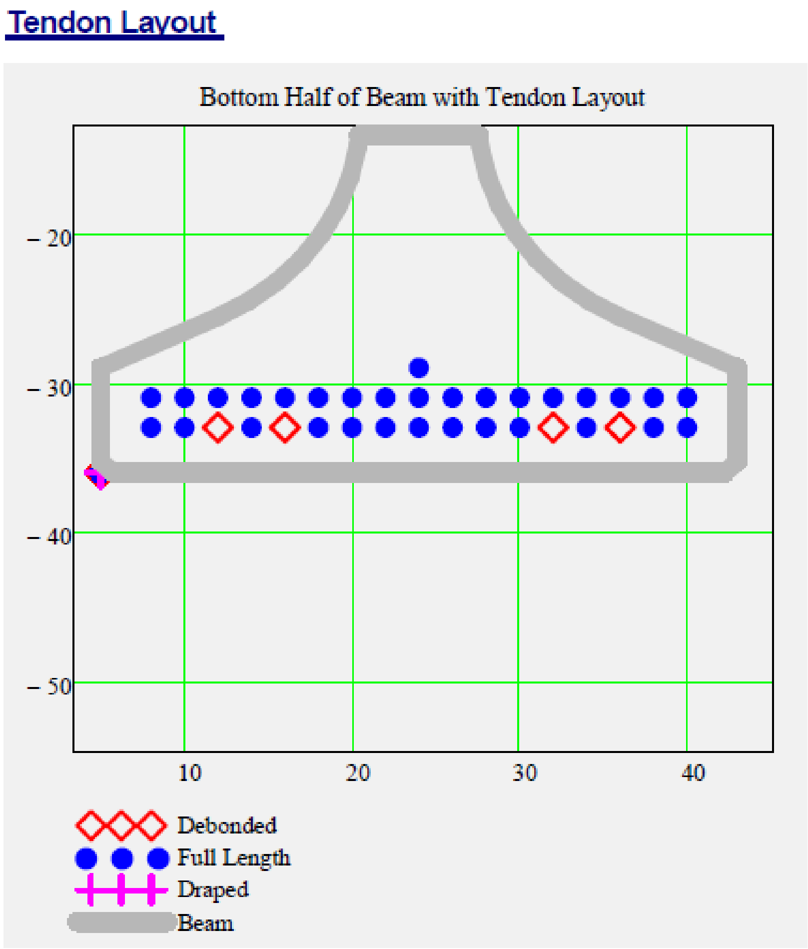
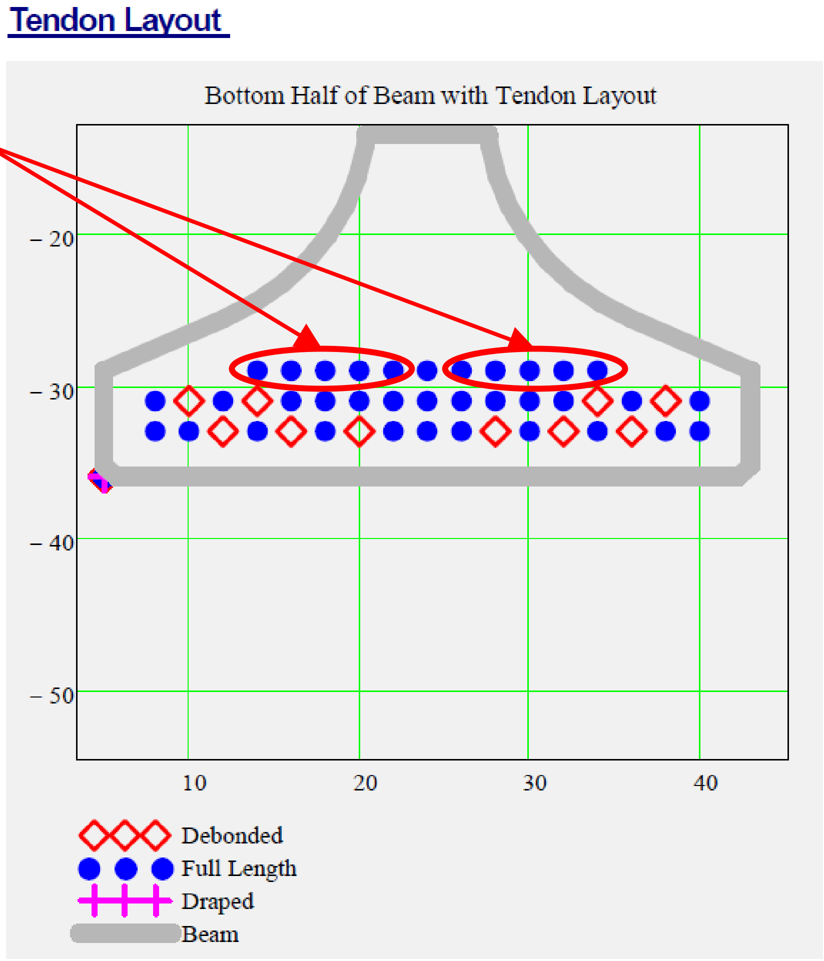
Carbon Steel
Strands = 35



HSSS
Strands = 45



Required 10
Additional strands

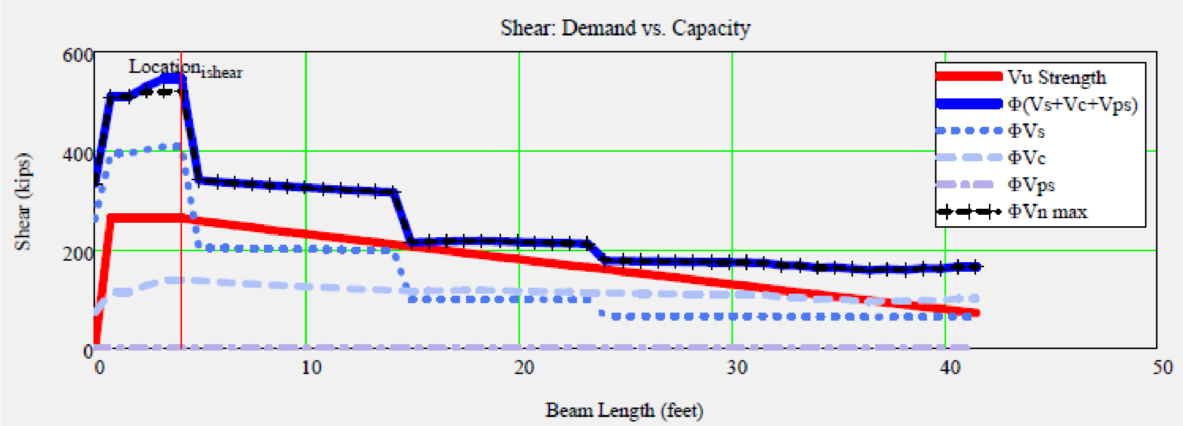


TRANSPORTATION SYMPOSIUM

What about SHEAR design?

- ➤Stirrups & Interface Shear → Can swap One for One with CS
- ➤FDOT Standard Beam End Reinforcement → No Change

Mild Reinforcement Type:	Carbon Steel - Grade 60 (selected) Stainless Steel - Grade 60 Glass Fiber Reinforced Polymer Carbon Steel - Grade 80 Stainless Steel - Grade 75



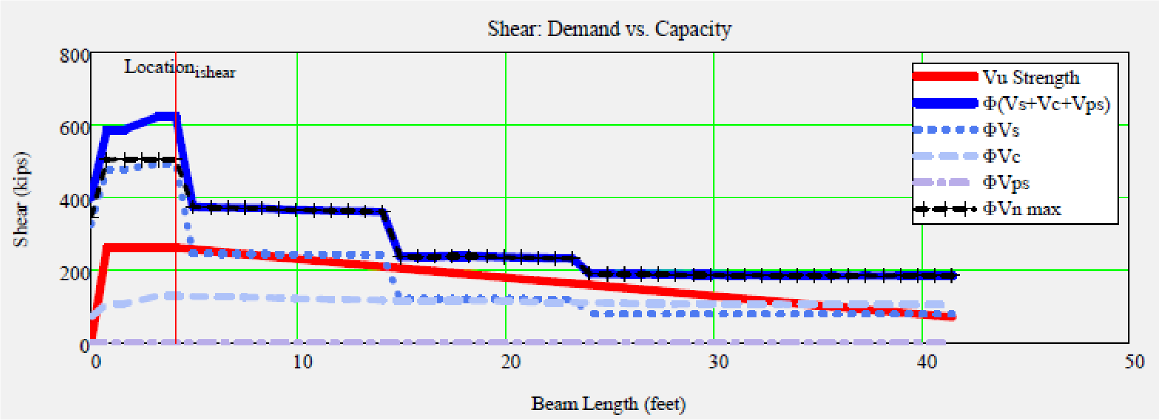
fCheckD/CShear =

"CheckType"	"Location(ft)"	"Vu (kip)"	"Vr (kip)"
"Shear"	14.87	206.40	215.12

$\max(D/C_{shear}) = 0.96$

≈

Mild Reinforcement Type:	Carbon Steel - Grade 60 Stainless Steel - Grade 60 Glass Fiber Reinforced Polymer Carbon Steel - Grade 80 Stainless Steel - Grade 75 (selected)



fCheckD/CShear =

"CheckType"	"Location(ft)"	"Vu (kip)"	"Vr (kip)"
"Shear"	14.87	206.40	237.37

$\max(D/C_{shear}) = 0.87$

Design Example: HSSS strands

	Carbon Steel Strands	HSSS Strands	CFRP Strands
Diameter, d_b	0.6 inch	0.62 inch	
Area, A_{ps}	0.217 sq. inch	0.231 sq. inch	
Modulus of elasticity, E_p	28,500 ksi	24,000 ksi	
Ultimate tensile stress, f_{pu}	270 ksi	240 ksi	
Yield strength, f_{py}	243 ksi (90% f_{pu})	216 ksi (90% f_{pu})	
Jacking stress, f_{pj}	202.5 ksi (75% f_{pu})	156 ksi (**65%** f_{pu})	
Effective stress after losses, f_{pe}	181 ksi (67% f_{pu})	134 ksi (56% f_{pu})	
Effective prestressing force per strand	39 kips	31 kips	
Total number of strands	35	45	
Service III Stress D/C Ratio	0.97	0.99	
Strength LS Flexural D/C Ratio	0.85	0.92	
Nominal flexural capacity, M_n	6222 k-ft	7785 k-ft	
Factored flexural capacity, ϕM_n	6222 k-ft (ϕ =1.00)	5839 k-ft (ϕ =0.75)	

TRANSPORTATION SYMPOSIUM

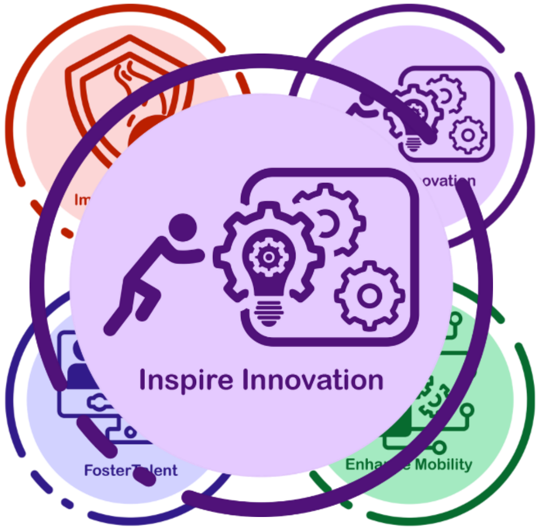
PART 2:

CFRP
Strands

FDOT TRANSPORTATION SYMPOSIUM

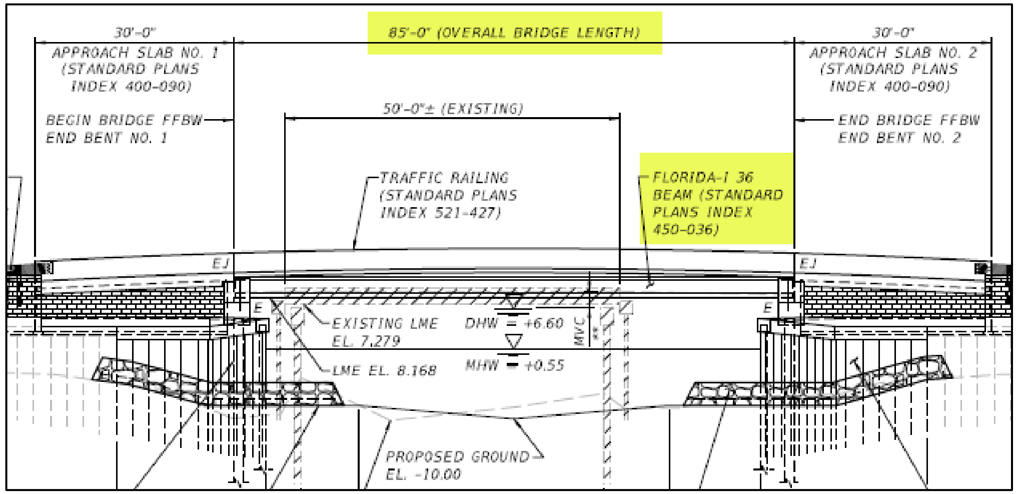
Outline

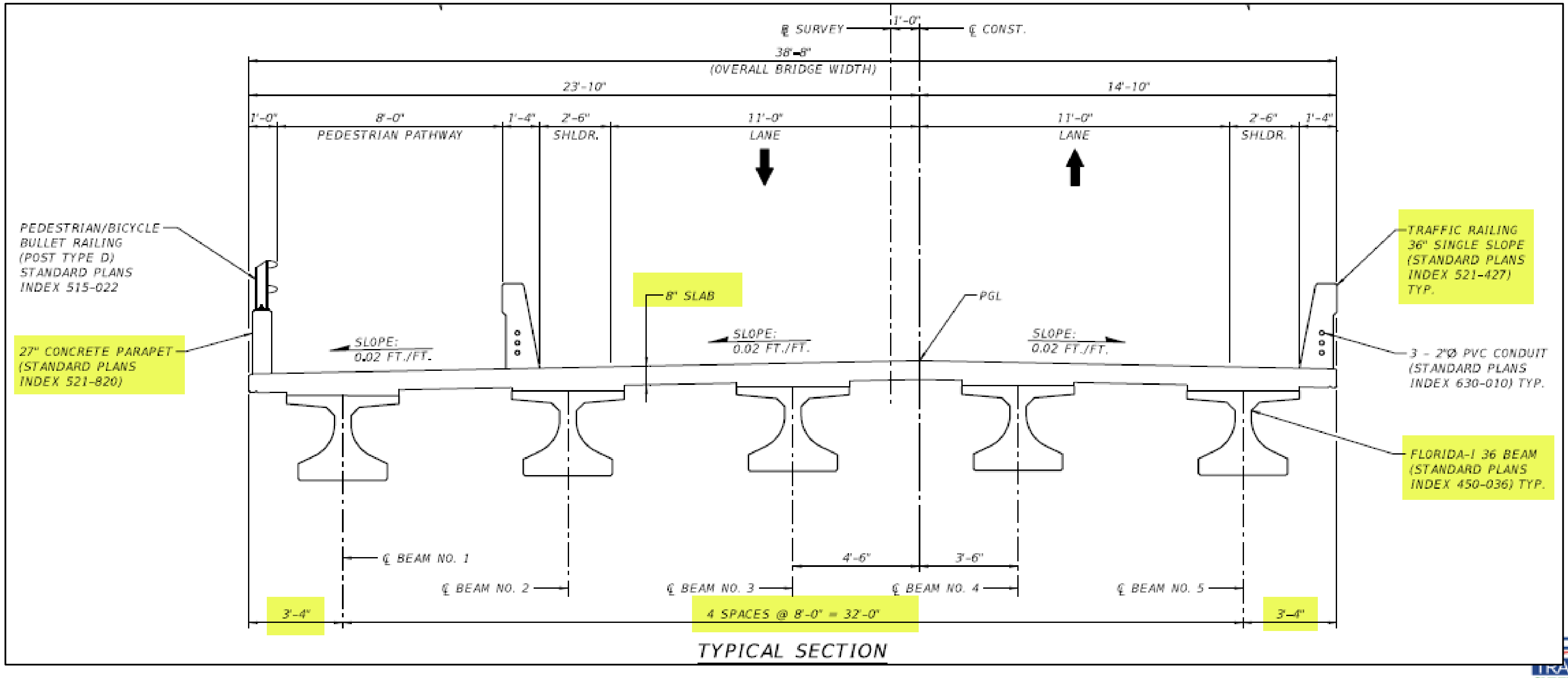
- Design Example Comparison
- Designer Guidance and Tools
- Review Background & Research



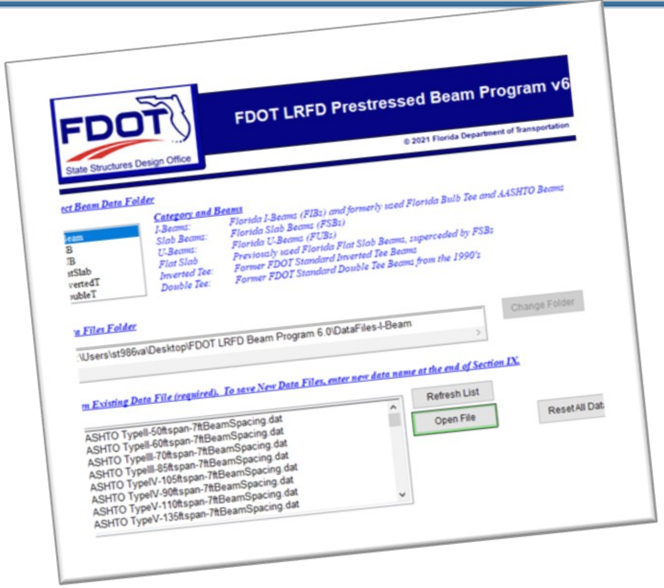
#3 FDOT Vital Few

Design Example Comparison (continued)

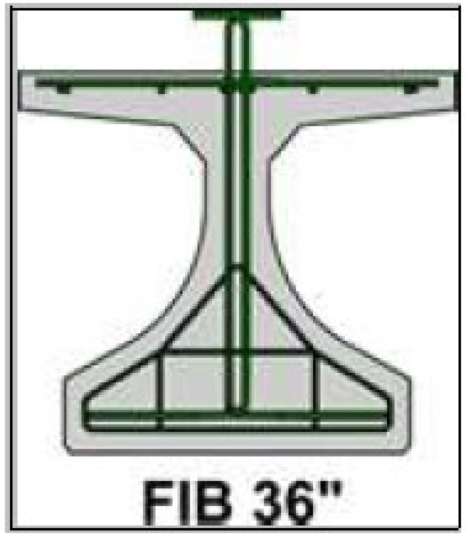




PART 2 – CFRP Strands



Design Example Comparison (continued)



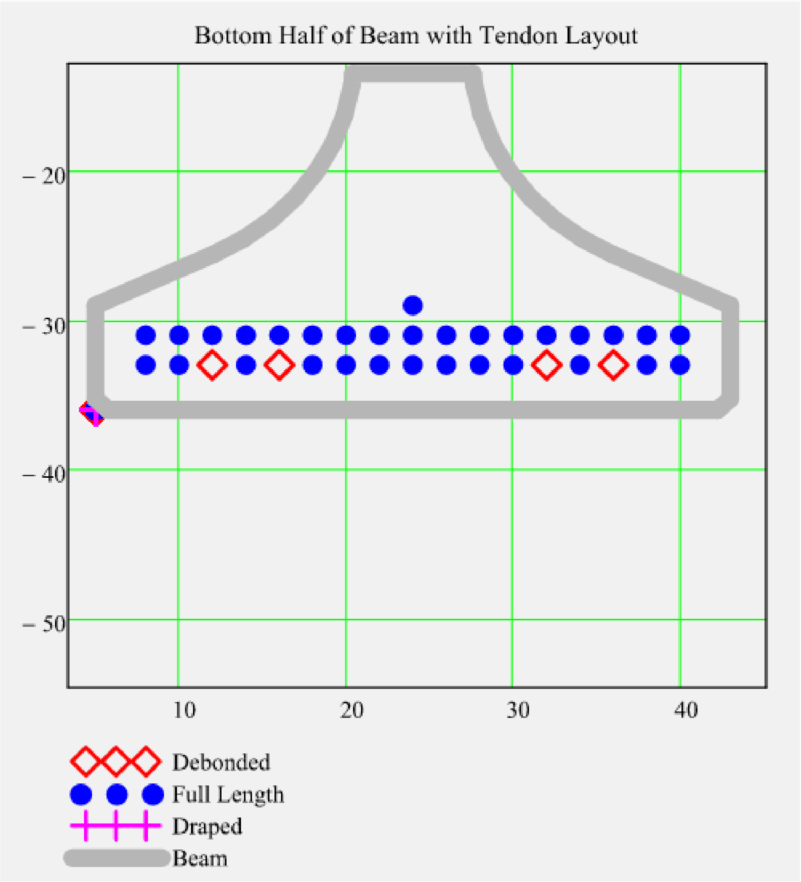
- Beam Type: **<u>FIB36</u>** (See Standard Plans & Instructions of Index 450-036)
- Beam Spacing: **<u>8’-0”</u>**, Number of Beams: **<u>5</u>**
- Span Length: **<u>85’-0”</u>**
- **<u>Extremely</u>** Aggressive Environment
- Using **<u>0.60” Dia. CFRP strands with GFRP shear reinforcing</u>**
- Run FDOT Beam Program Version **<u>6.0</u>**

Carbon Steel Strands = 35

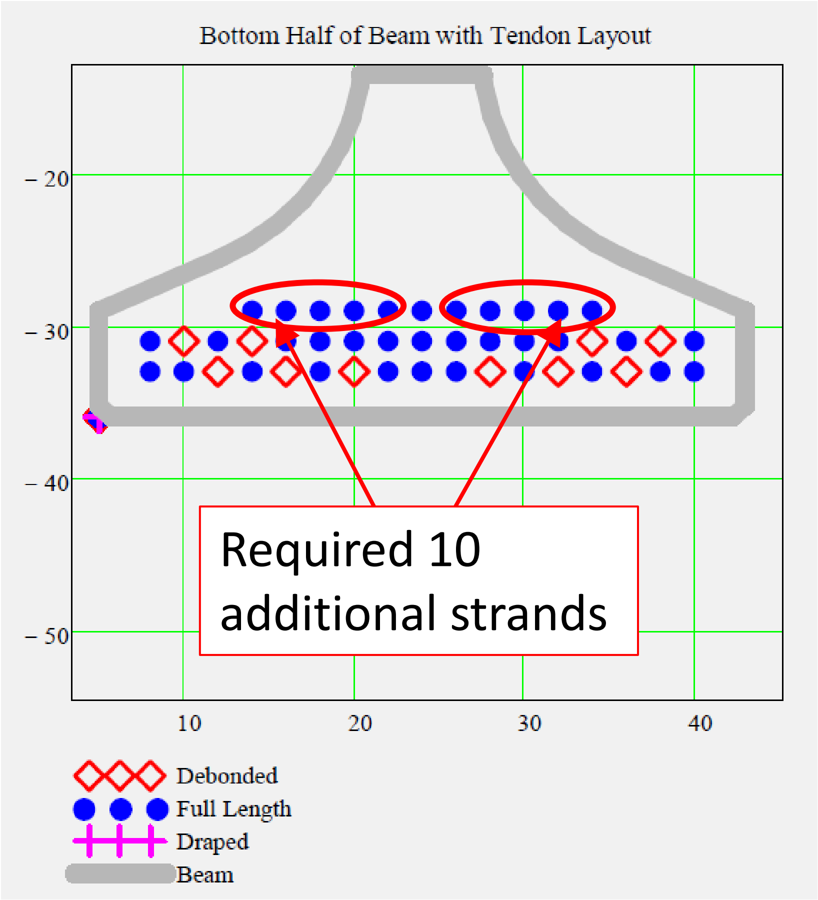
HSSS Strands = 45

CFRP Strands = 35

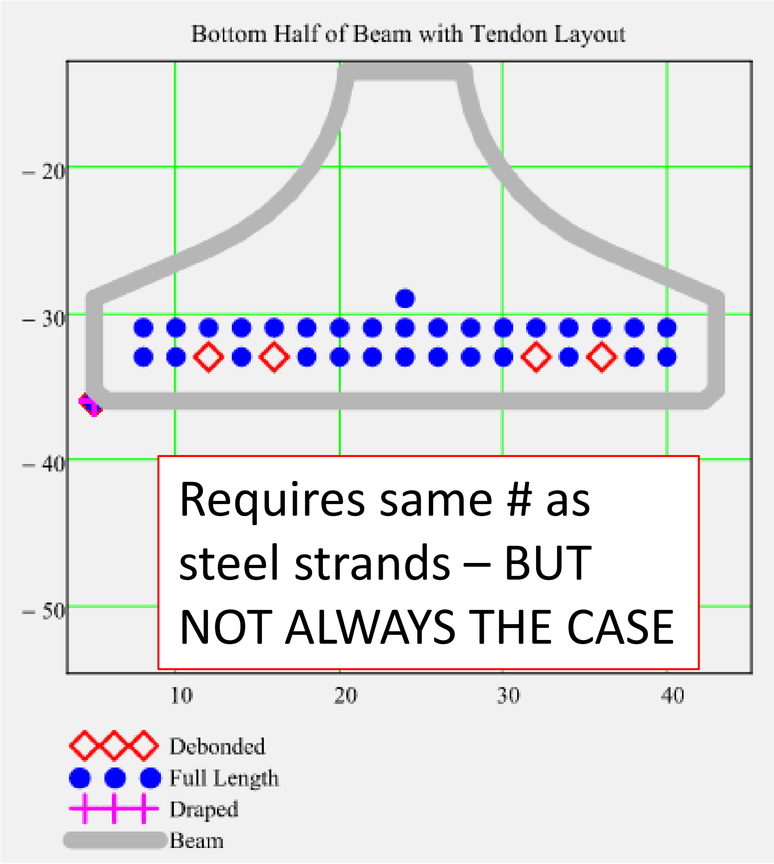
Tendon Layout



Tendon Layout



Tendon Layout



Design Example Comparison (cont.)

* Up to 70% f_{pu} permitted

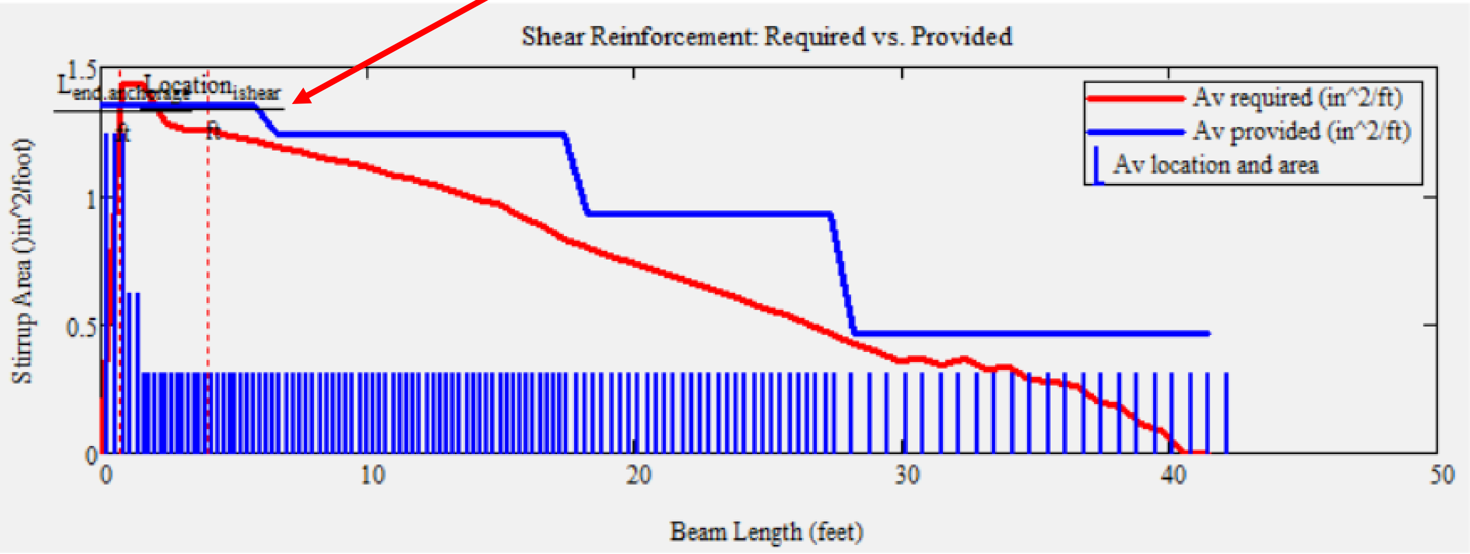
	Carbon Steel Strands	HSSS Strands	CFRP Strands
Diameter, d_b	0.6 inch	0.62 inch	0.6 inch (15.2mm CFCC)
Area, A_{ps}	0.217 sq. inch	0.231 sq. inch	0.179 sq. inch
Modulus of elasticity, E_p	28,500 ksi	24,000 ksi	22,400 ksi
Min. Strain at Rupture, ε_{pu}	$\geq$ 3.5%	$\geq$ 1.4%	$\geq$ 1.6 %
Ultimate tensile stress, f_{pu}	270 ksi	240 ksi	369 ksi
Yield strength, f_{py}	243 ksi (90% f_{pu})	216 ksi (90% f_{pu})	n/a
Jacking stress, f_{pj} *[Force-kips]*	202.5 ksi (**75%** f_{pu}) *[44]*	156 ksi (**65%** f_{pu}) *[36]*	246 ksi (**66.6%** f_{pu}) * *[44]*
Effective stress after losses, f_{pe}	181 ksi (67% f_{pu})	134 ksi (56% f_{pu})	216 ksi (59% f_{pu})
Effective prestressing force per strand	39.3 kips	31.0 kips (1085 kips)	38.7 kips
Total number of strands	35	45	35
Service III Stress D/C Ratio (3√f'c.psi)	0.97	0.99	0.99 (~0.50 if using 6√f'c) *GOVERNS*
Strength I & II Flexural D/C Ratio *@ midspan* *Along span (approx. 20-ft from ends)*	0.81 0.85	0.86 0.92	0.92 0.92
Nominal flexural capacity, M_n	6222 k-ft	7785 k-ft	7293 k-ft
Factored flexural capacity, ϕM_n *@ midspan*	6222 k-ft (ϕ =1.00)	5839 k-ft (ϕ =0.75)	5470 k-ft (ϕ =0.75)

TRANSPORTATION SYMPOSIUM

Design Example Comparison (cont.)

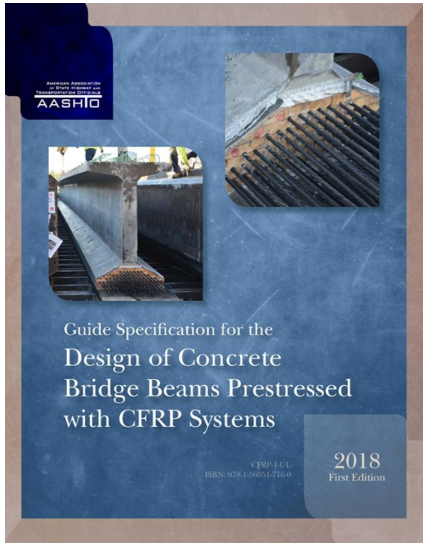
	Carbon Steel Strands	HSSS Strands	CFRP Strands
Total number of strands	35	45	35
Beam Camber at release	1.5 inches	1.35 inches	1.5 inches
Final Net Camber at 120 days	1.0 inches	0.8 inches	1.1 inches
Shear Stirrups (@ critical section)	#5's @ 9" sp. (Gr.60)	#5's @ 10" sp. (Gr.75)	#5's @ 2.75" sp. (GFRP - FDOT 932-3)
Factored Maximum, ϕV_c	138 kips (ϕ =0.90)	133 kips (ϕ =0.90)	115 kips (ϕ =0.75)

Shear Resistance may limit some designs using GFRP reinforcement

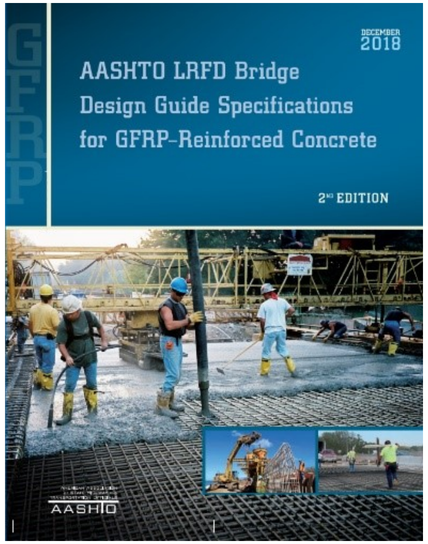


Design guidance

- ***AASHTO*** Guide Specifications, *published in 2018*
  - *Design of Concrete Bridge Beams Prestressed with CFRP Systems*
    - ***FDOT Spec 933-1.3*** for CFRP strand
  - *Design Guide Specifications for GFRP-Reinforced Concrete*
    - ***FDOT Spec 932-3/ASTM D7957*** for GFRP Rebar, *published in 2017*



AASHTO CFRP-1
Only addresses CFRP prestressing strands in design



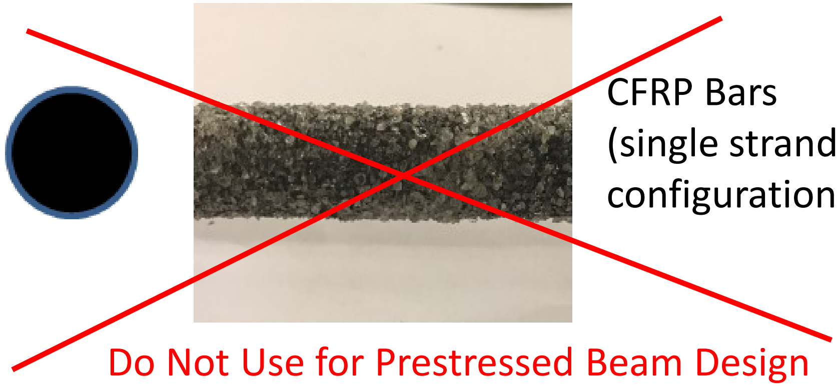
AASHTO GFRP-2:
FDOT is using this design criteria for Auxiliary Reinforcing

Design guidance and tools – Flexural Design

- **Flexural Design Highlights**
  - Use only 0.60” dia. CFRP 7-strand (CFCC)
  - Limit jacking force to 44 kips *[**FRPG** 2022]*
  - Use Strain compatibility
  - Resistance Factor 0.75 for both compression-controlled and tension-controlled design
  - Tension limit at Service III is 0.19 √f’c (ksi)
  - Strength Limit State will often govern.

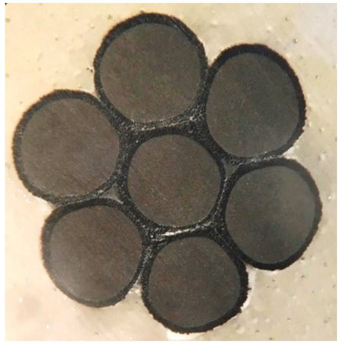
Table 933-1
Typical Sizes and Loads of CFRP Prestressing Strands and Bars

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 (Bar) - 9.5mm Ø	0.38	0.110	35.0	318
7-strand - 12.5mm Ø	0.49	0.117	43.3	370
Single Strand (Bar) - 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	370
7-strand - 19.3mm Ø	0.76	0.289	106.9	370

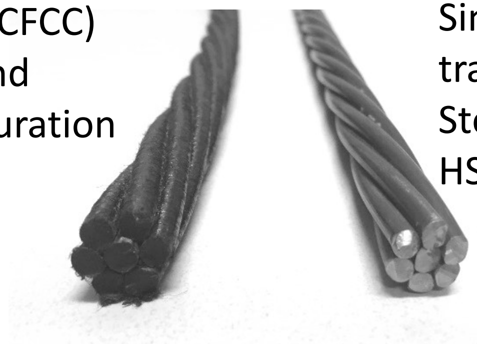


CFRP Bars (single strand) configuration

Do Not Use for Prestressed Beam Design



CFRP (CFCC) 7-strand configuration

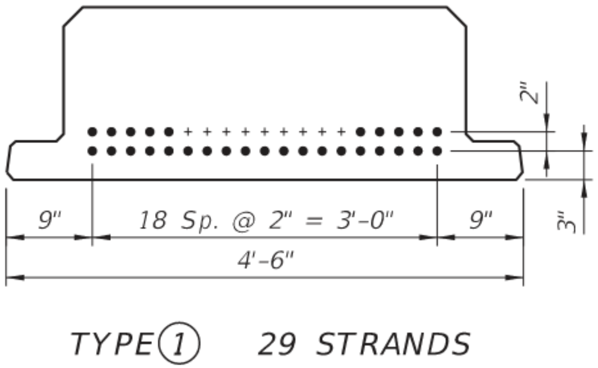


Similar to traditional Steel and new HSSS strand

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Flexural Design

- **Flexural Design Highlights**
  - Use 0.60" dia. CFRP 7-strand
  - Limit jacking force to 44 kips *[**FRPG** 2022]*
    - **AASHTO CFRP-1** *allows up to 70% f_{pu}, but with new 369 ksi nominal strength for CFCC the max. value (46.2 kips) is great than that allowed for 0.6" dia. steel strand (ASTM A416, 270 ksi) which are used for coupling, stressing, and anchoring.*
    - *This is 66.5% f_{pu} jacking stress, but it is recommended to **just show the force (in kips).***



STRAND DESCRIPTION:

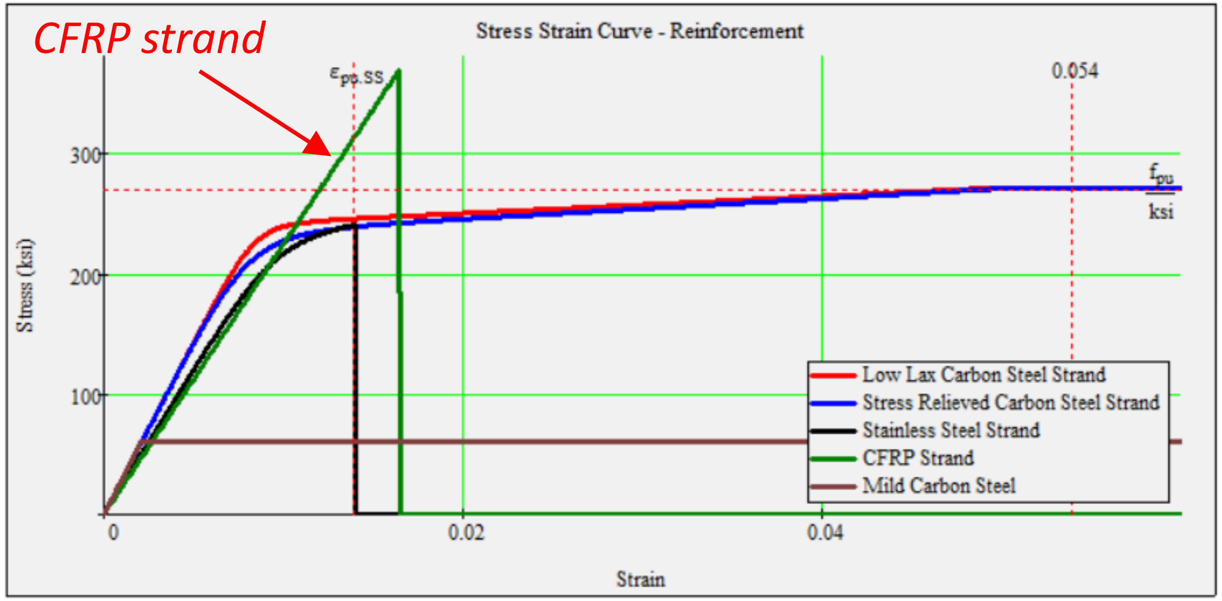
Use 0.60" Diameter, 369 ksi Guaranteed Ultimate Tensile Strength (GUTS), Strands stressed at ~~65% GUTS~~ 44 kips each. Nominal area per strand equals 0.179 sq. in.

STRAND DEBONDING LEGEND

• – fully bonded strands.

Design guidance and tools – Flexural Design

- **Flexural Design Highlights**
  - Use 0.60” dia. CFRP 7-strand
  - Limit jacking force to 44 kips
  - Strain compatibility



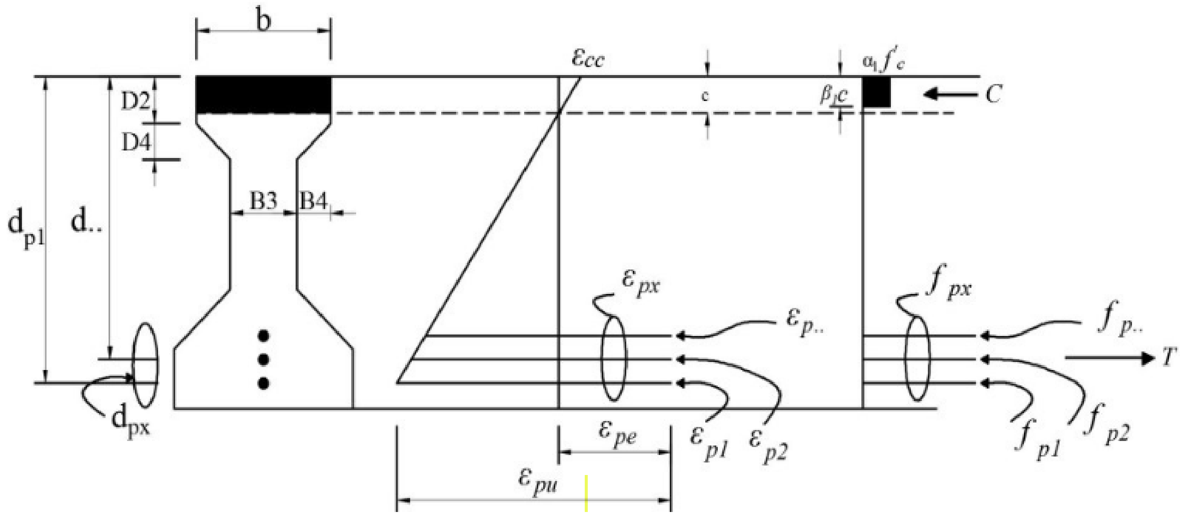


Figure C1.7.3.1-1—Tension-controlled Section

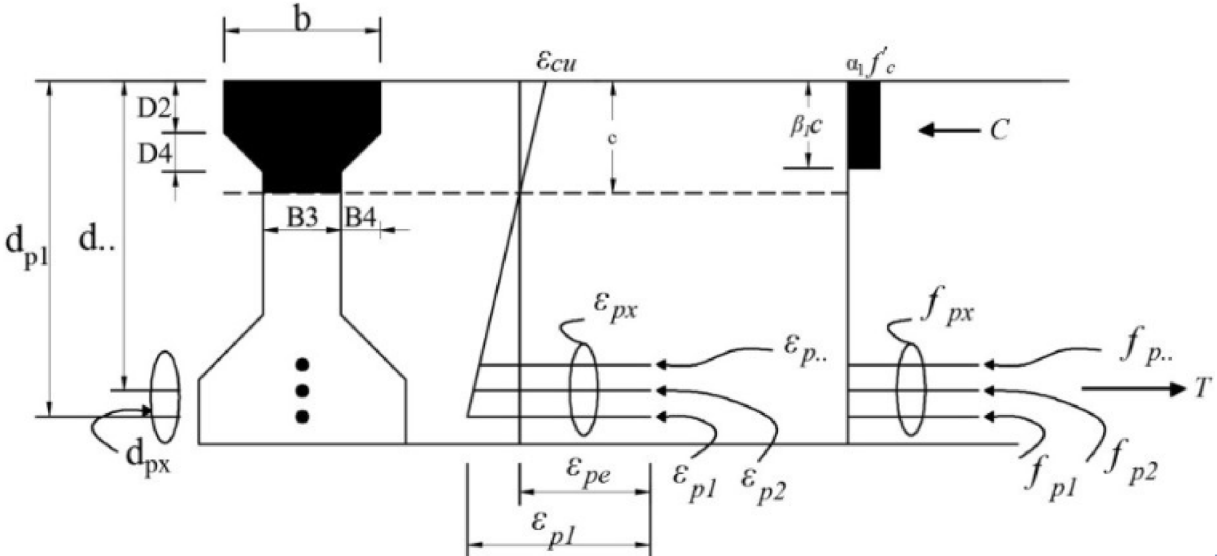
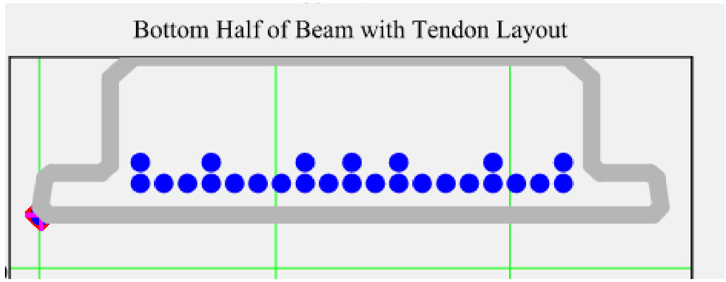


Figure C1.7.3.1-2—Compression-controlled Section

SYMPOSIUM

Design guidance and tools – Flexural Design

- **Flexural Design Highlights**

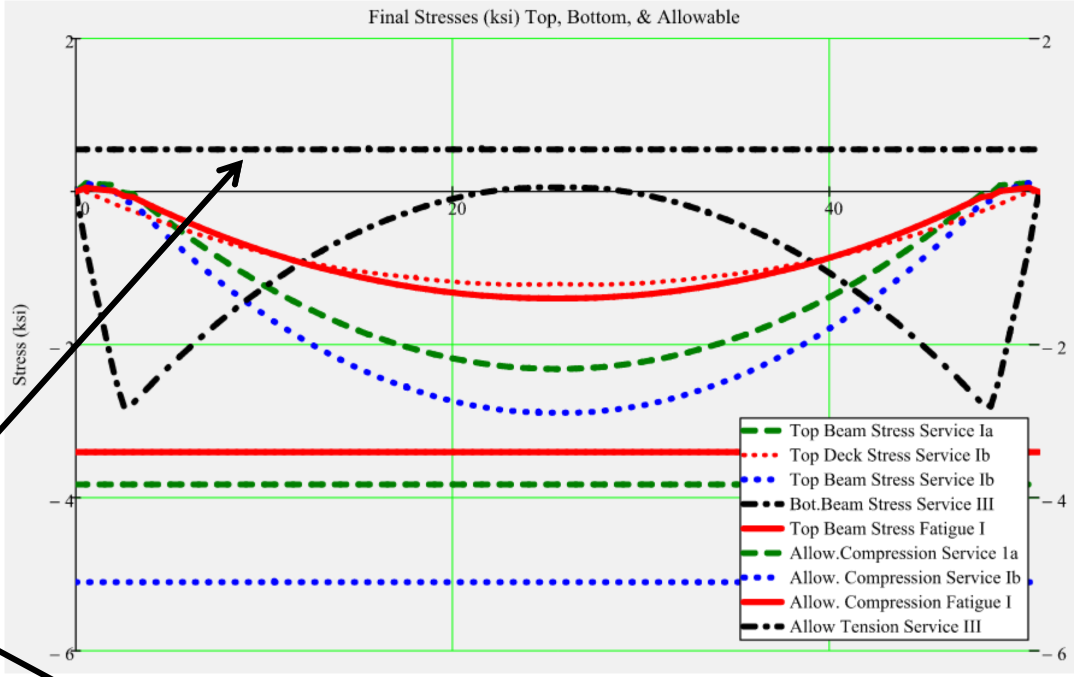


BeamType = "FSB15"

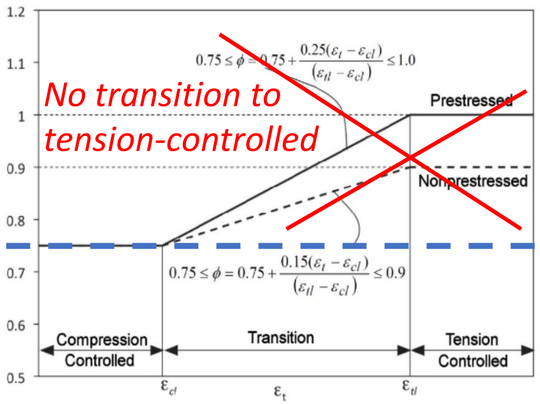
$h_{beam} = 15 \cdot in$

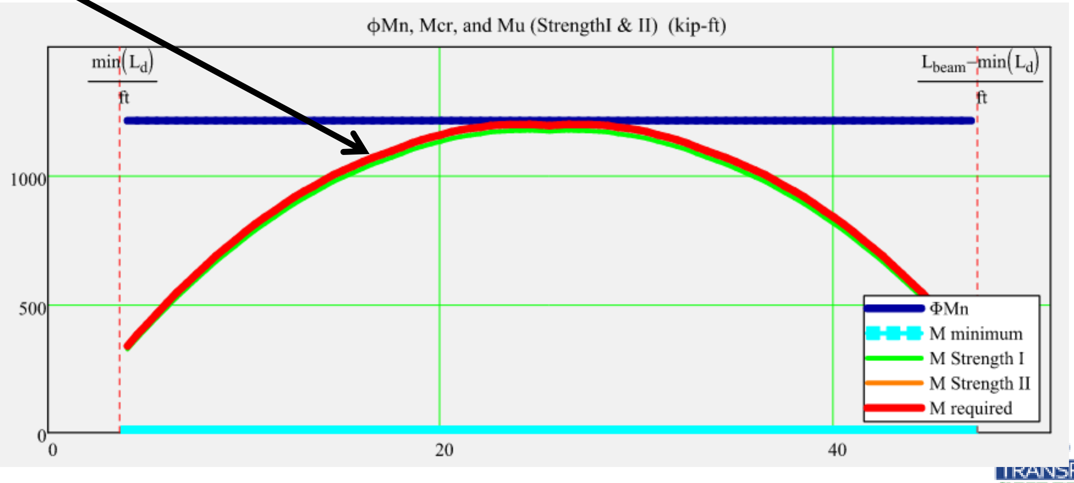
$A_{strand} = 0.179 \cdot in^2$

#Strands = 26



- Tension limit at Service III is 0.19 √f'c (ksi)
- Strength Limit State will often govern.
- Resistance Factor $\phi = 0.75$, for both compression-controlled and tension-controlled designs





TRANSPORTATION SYMPOSIUM

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - ***AASHTO CFRP-1*** does not address FRP shear stirrups, so modifications need to be applied to the provisions based on ***AASHTO GFRP-2***

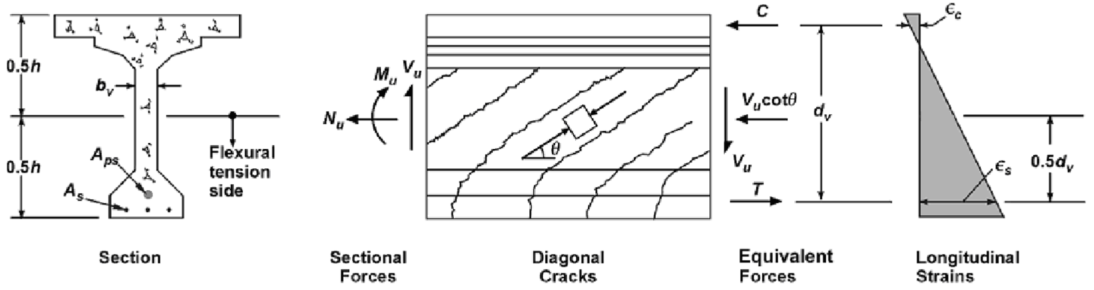


Figure 5.7.3.4.2-1—Illustration of Shear Parameters for Section Containing at Least the Minimum Amount of Transverse Reinforcement, V_p = 0

1.8.2.1—General

The factored shear resistance, V_r, shall be taken as:

$$V_r = \phi V_n \quad (1.8.2.1\text{-}1)$$

where:

ϕ = resistance factor for shear as specified in Article 5.5.4.2 of *AASHTO LRFD Bridge Design Specifications*

V_n = nominal shear resistance as specified in Article 1.8.3 (kip)

1.8.3.1—Nominal Shear Resistance

The nominal shear resistance, V_n, shall be determined as specified in Article 5.7.3.3 of the *AASHTO LRFD Bridge Design Specifications*.

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor ϕ = 0.75 (not 0.90) for GFRP stirrups
  - Use General Procedure (MCFT)
  - Limit maximum stirrup spacing to 0.5d (not $0.8d_v$)

Shear Analysis

ShearMethod := General Procedure

ShearMethod = 1

Toggles the shear methodology desired by the user:

- *"General Procedure" is the default shear design method per LRFD 5.7.3.4.2,*
- *"Simplified Procedure" corresponds to the "Simplified Procedure for Prestressed and Nonprestressed Sections" per LRFD 7th Ed. Section 5.8.3.4.3. This procedure was removed from the 8th Ed.*
- *"Appendix B5" corresponds to the "General Procedure for Shear Design with Tables".*

MildReinfType = "Glass Fiber Reinforced Polymer"

ϕ_{shr} := if(MildReinfType = "Glass Fiber Reinforced Polymer", 0.75, 0.90) = 0.75

AASHTO CFRP-1 [1.8.2.1] → AASHTO BDS [5.5.4.2]

$\phi = 0.90$ for shear and torsion in monolithic prestressed concrete sections having <u>bonded</u> strands or tendons (Steel)

but AASHTO GFRP-2 Spec [2.5.2.2]

$\phi = 0.75$ Use this value - Conservative for now until ***NCHRP 12-121*** completed

$$V_r = \phi V_n$$

Factored Shear Resistance

Resistance factor

Nominal Shear Resistance

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor 0.75 (not 0.9) for GFRP stirrups
  - Use General Procedure (MCFT)

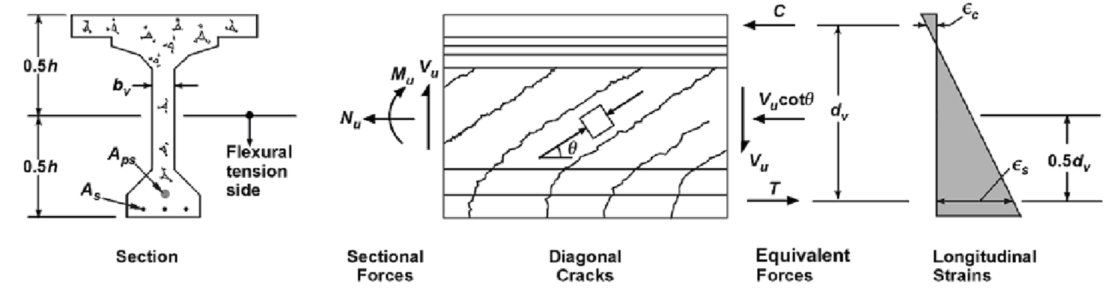


Figure 5.7.3.4.2-1—Illustration of Shear Parameters for Section Containing at Least the Minimum Amount of Transverse Reinforcement, $V_p = 0$

Nominal Shear Resistance

Contribution by concrete $V_c = 0.316\beta\lambda\sqrt{f_c'}b_v d_v$

Contribution by transverse reinforcement

$$V_f = \frac{f_{fv} A_v d_v cot\theta}{s}$$

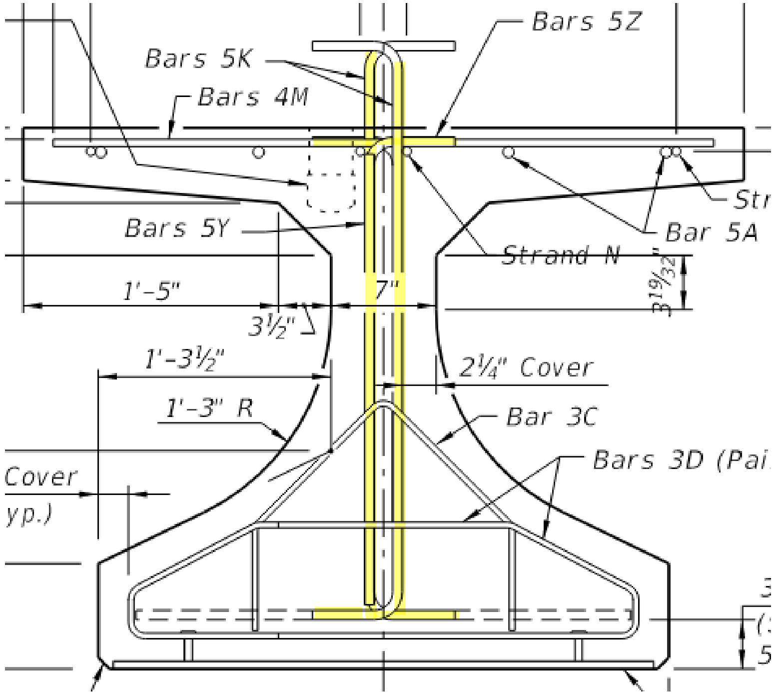
Contribution by prestressing force in the direction of the shear force ($V_p = 0$ for straight strands)

Avoids crushing in the web prior to reaching strength limit for stirrups

$$V_n = \text{min.} \begin{cases} V_n = V_c + V_f + V_p \\ V_n = 0.25 f_c' b_v d_v + V_p \end{cases}$$

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor 0.75 (not 0.9) for GFRP stirrups
  - Use General Procedure (MCFT)
  - 0.8d_v)



Note:
For I-Beams (FIB & AASHTO Type II), designer may need to pair Bars K to meet the shear resistance with GFRP stirrups since approx. 1/3rd the factored contribution of steel stirrups.

Contribution by GFRP transverse reinforcement

$$V_f = \frac{f_{fv} A_v d_v \cot\theta}{s}$$

$$f_{fv} = \min\left(0.004E_f, f_{fb}\right)$$

$$0.004E_f = 26\ ksi$$

(Typically Governs!)

$$f_{fb} = \phi_{bend} f_{fd}$$

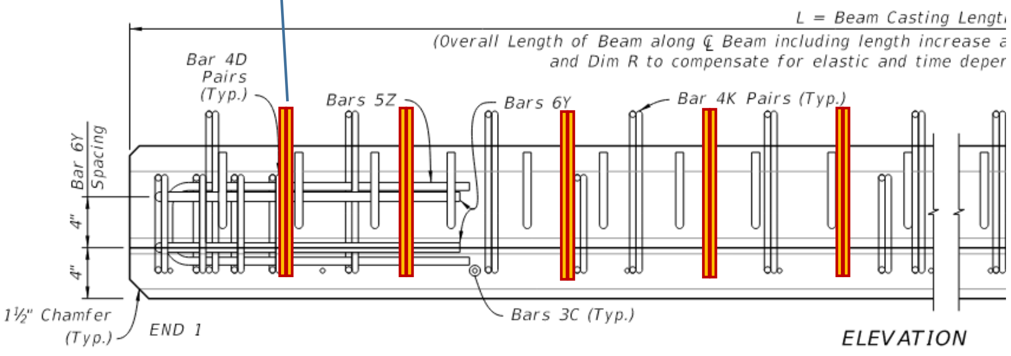
$$\phi_{bend} = \left(0.3 + 0.05\frac{r_b}{d_b}\right) \text{ or } 0.60$$

for *FDOT per Spec. 932-3*

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor 0.75 (not 0.9) for GFRP stirrups
  - Use General Procedure (MCFT)
  - Limit maximum stirrup spacing to 0.5d (not 0.8d_v)

FSB: Additional stirrups (shown in orange) will be required for GFRP compared to steel.



Additional GFRP stirrups will be required compared to steel stirrups

Steel Stirrups: $s_{max} = min(0.8d_v, 24")$ for $v_u < 0.125 f'_c$ *AASHTO BDS [5.7.2.6]*

GFRP Stirrups: $s_{max} = min(0.5d, 12")$ *AASHTO GFRP-2 [2.7.2.6]*

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Shear Design

- **Interface Shear Design Highlights**
  - ***AASHTO CFRP-1*** does not address, but interface shear resistance section, but generally refers back to ***BDS***.
  - Recommend using ***GFRP-2*** *[2.7.4]* provisions with Shear resistance factor $\phi = 0.75$ (not 0.90)
  - Note that f_{fd} should include the reduction factor for bent bars.

2.7.4—Interface Shear Reinforcement—Shear Friction

For interface steel reinforcement, the provisions of Article 5.7.4 of the *AASHTO LRFD Bridge Design Specifications* shall apply.

For interface GFRP reinforcement, the design shall comply with the applicable provisions of Article 5.7.4 of the *AASHTO LRFD Bridge Design Specifications*.

The interface shear resistance shall be calculated based on the design tensile strength of the GFRP reinforcement considering reductions for service environment, f_{fd}, as specified in Article 2.4.2.1, and the applicable cohesion, c, and friction, μ, factors as specified in Article 5.7.4.4 of the *AASHTO LRFD Bridge Design Specifications*.

$$V_{ri} = \phi V_{ni}$$

$$V_{ni} = cA_{cv} + \mu(A_{cf} f_{fd} + P_c)$$

area of reinforcement crossing the shear plane

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Shear Design

- **Interface Shear Design Highlights**

Includes reduction factor due to bends

<u>**Interface Shear Reinforcement**</u>

Design strength of interface shear reinforcing

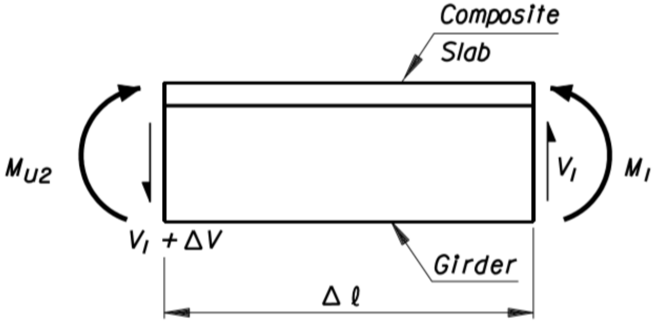
MildReinfType = "Glass Fiber Reinforced Polymer"

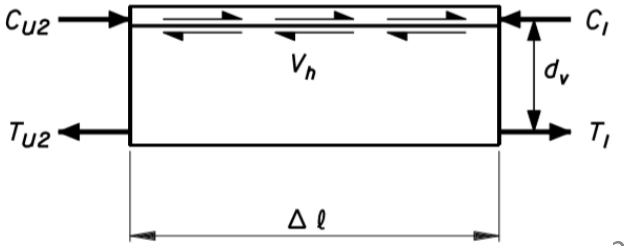
$f_{y.d.stirrup} := \text{if}[(\text{MildReinfType} = \text{"Glass Fiber Reinforced Polymer"}), f_{fb}, f_y] = 31.54 \cdot ksi$

$f_{y.d.stirrup} := \text{if}(f_{y.d.stirrup} > 60 \cdot ksi, 60 \cdot ksi, f_{y.d.stirrup})$

$\text{if}(f_{y.d.stirrup} > 60 \cdot ksi, 60 \cdot ksi, f_{y.d.stirrup})$

assumed a roughened surface $c := 0.28 \cdot ksi$ $\mu := 1.00$ $K_1 := 0.3$ $K_2 := \text{if}\left(\gamma_{beam} \le 0.135 \cdot \frac{kip}{ft^3}, 1.3 \cdot ksi, 1.8 \cdot ksi\right)$





TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing**
  - **CFRP-1** defaults back to **BDS**
  - Due to lower stiffness of GFRP stirrups we may need to increase size or reduce spacing to control crack size – **Contact SDO for Guidance!**

1.9.3—Details for Pretensioning

1.9.3.1—General

Unless otherwise specified, applicable provisions of Article 5.9.4 of the *AASHTO LRFD Bridge Design Specifications* shall apply.

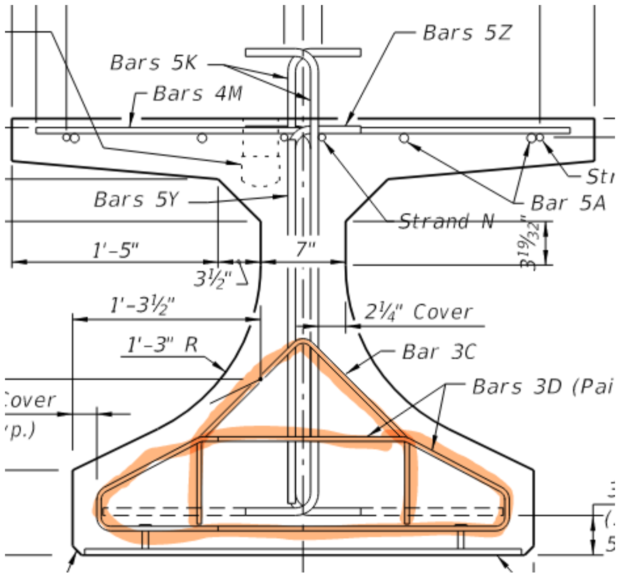
✓ For the distance of 1.5d from the end of the beams other than box beams, reinforcement shall be placed to confine the prestressing ~~steel~~ **[CFRP]** in the bottom flange. The reinforcement shall not be less than No. 3 deformed bars, with spacing not exceeding 6.0 inch and shaped to enclose the strands

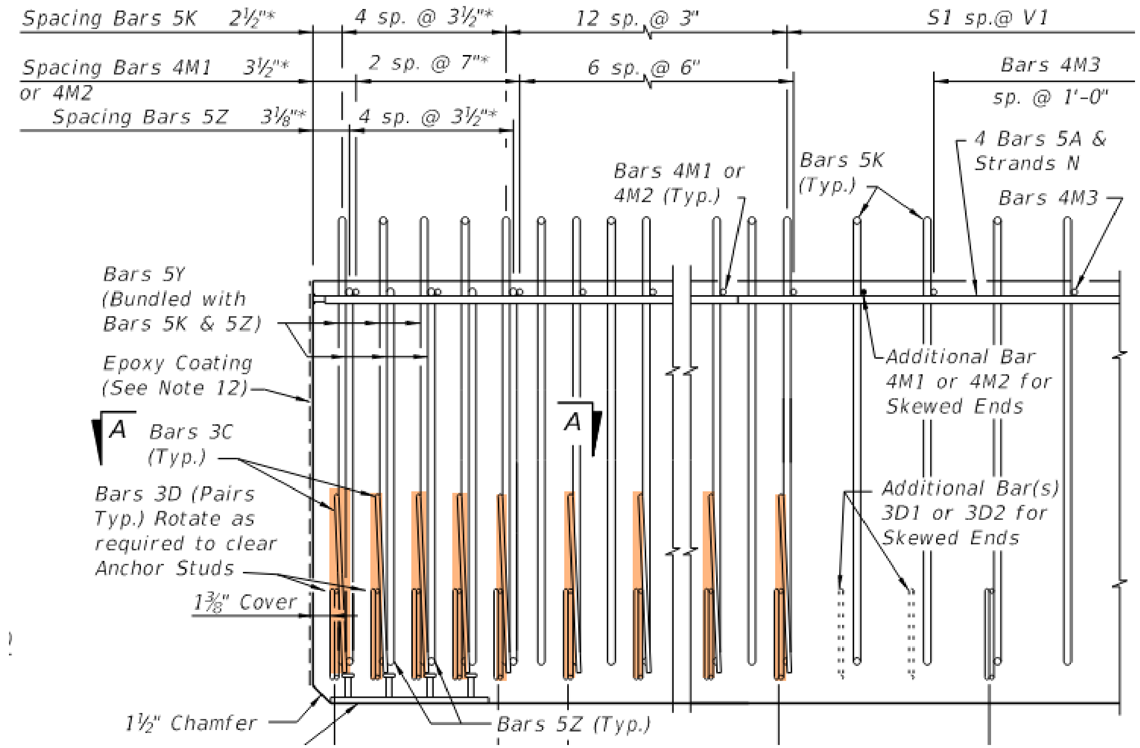
✓ For box beams, transverse reinforcement shall be provided and anchored by extending the leg of stirrup into the web of the girder

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing**
  - **CFRP-1** defaults back to **BDS**
  - Due to lower stiffness of GFRP stirrups we may need to increase size or reduce spacing to control crack size – **Contact SDO for Guidance!**

FIB-36 (Index 450-036) Example:





FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Splitting Reinforcing**
  - ***CFRP-1*** defaults back to ***BDS***, but ***SDG 4.3.1*** requires a more conservative approach for single-web beams.

Pretensioned Anchorage Zone

- Splitting Resistance

$$P_r = f_f A_f \geq 0.04 \cdot P_i$$

Total prestressing force at transfer
$P_i = n_p f_{pi} A_{pf}$

Splitting Resistance

Stress in FRP bar ≤ 20 ksi

Note: In ***LRFD***, f_s for steel is limited to 20 ksi for crack control. However, for FRP, it may depend on the "effective" stiffness of the anchorage reinforcing

LRFD:
- 4% P_i from the end of the beam to $h/4$

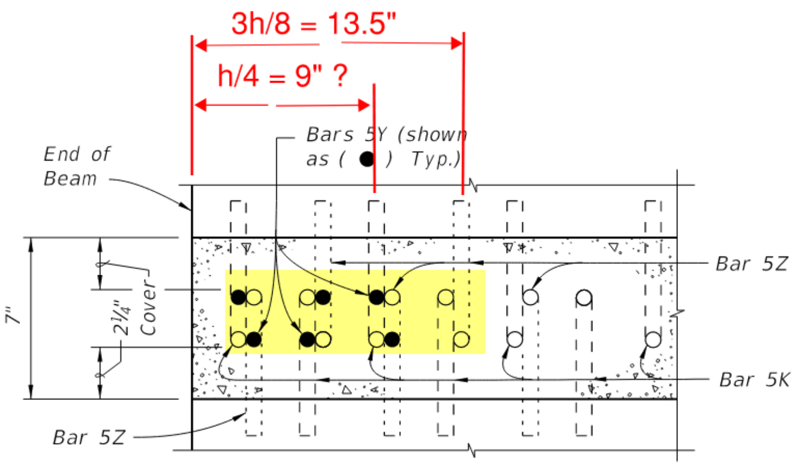
FDOT ***SDG*** 4.3.1.D *(more restrictive)*
- 3% P_j from the end of the beam to $h/8$, but $\geq 10''$
- 5% P_j from the end of the beam to $h/4$, but $\geq 10''$
- 6% P_j from the end of the beam to $3h/8$, but $\geq 10''$

For pretensioned I-girder or bulb tees, A_f is the total area of the vertical reinforcement located with a distance of $h/4$ from the end of the member

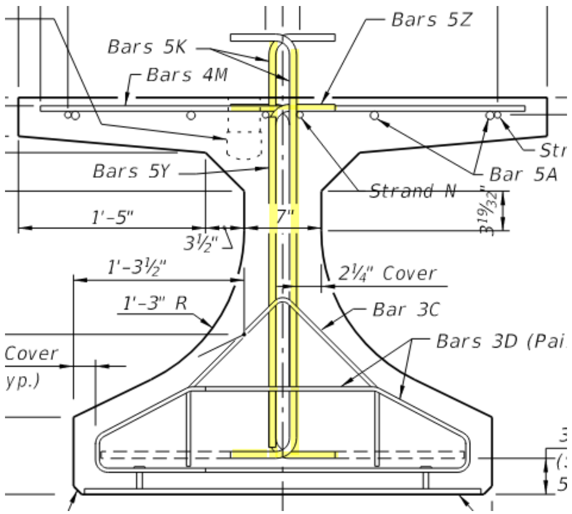
Design guidance and tools – Beam End Zone

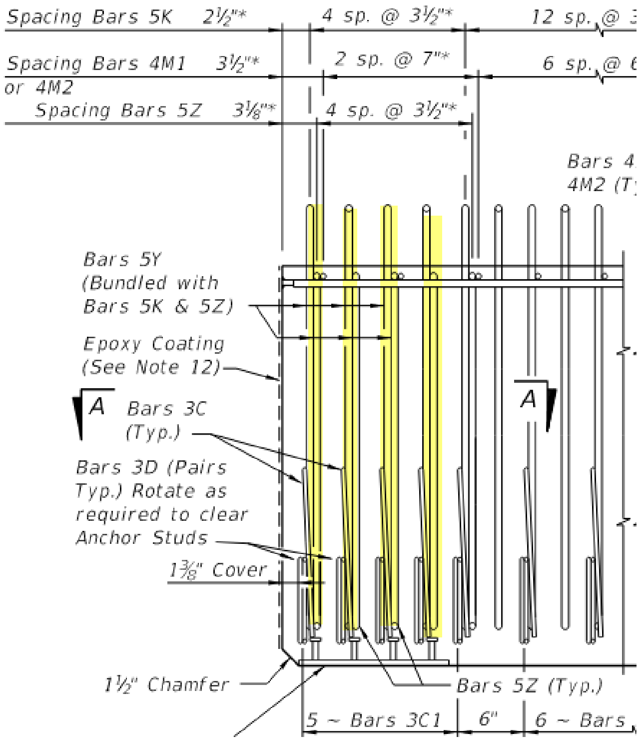
- **Splitting Reinforcing**
  - ***CFRP-1*** defaults back to ***BDS***
  - Due to lower stiffness of GFRP stirrups we may need to increase size or reduce spacing to control crack size – **Contact SDO for Guidance!**

FIB-36 (Index 450-036) Example:



SECTION A-A FOR CONVENTIONAL REINFORCING
(Showing Bars 5K, 5Y & 5Z Only)





FDOT TRANSPORTATION SYMPOSIUM

More Design guidance

- Design Guidance

FLORIDA DEPARTMENT OF TRANSPORTATION

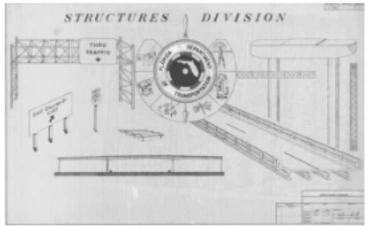
Image courtesy of WSP USA

STRUCTURES MANUAL

Volume 1 - Structures Design Guidelines
Volume 2 - Structures Detailing Manual
Volume 3 - FDOT Modifications to LRFDLTS-1
Volume 4 - Fiber Reinforced Polymer Guidelines

Frequently Asked Questions
2018 Revision History
Archived Structures Manuals
Additional Links

FLORIDA DEPARTMENT OF TRANSPORTATION



FIBER REINFORCED POLYMER GUIDELINES (FRPG)

STRUCTURES MANUAL
VOLUME 4
JANUARY 2022

FDOT

Fiber Reinforced Polymer Guidelines DRAFT Topic No. 625-020-018
3 - Carbon Fiber Reinforced Polymer (CFRP) Strands January 2022

3 CARBON FIBER REINFORCED POLYMER (CFRP) STRANDS

3.1 PERMITTED USE

Standard Plans for sheet piles, and square and round bearing piles with CFRP strands are available. See ***SDG*** Table 3.5.1-1 for additional requirements. CFRP strands may be used with the pretensioned beam shapes shown in the ***Standard Plans*** without prior approval of the SSDE.

Note: Additional clarification is needed on how to design for FRP shear stirrups & end zones

https://www.fdot.gov/structures/structuresmanual/currentrelease/structuresmanual.shtm

Design guidance and tools

- Materials & Construction


Materials Acceptance and Certification System

elect Report to View

Production Facility

Aggregate Production Facility Listing	Lists all Aggregate Production Facilities
All Producers (Excel)	Lists all non-expired Production Facilities in an Excel file
Approved Aggregate Products For Friction Course	Lists all Aggregate Friction Course Products by Geological
Approved Aggregate Products From Mines or Terminals Listing	Lists Approved Aggregate Products for Mines or Terminals
Approved Products at Expired Mines or Terminals	A summary report to identify Approved Products at Expired Terminals Expired at Mine
Asphalt Production Facility Listing	Lists all Asphalt Production Facilities
Asphalt Recycled Products	Approved Asphalt Recycled Products Report by Plant
Asphalt Targets	A listing of the asphalt gradation and gravity (Gsb) data for
Cementitious Materials Production Facility Listing	Lists Cementitious Materials Production Facilities
Coatings Production Facility Listing	Lists all Coatings Production Facilities
Fiber Reinforced Polymer Production Facility Listing	Lists all Fiber Reinforced Polymer Production Facilities

https://mac.fdot.gov/smoreports

Sections 415, 450, 932-3 & 933

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

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools

- FDOT Design Software

FDOT | OFFICES | MAPS & DATA | CONTACT | ABOUT | PROJECTS | RESOURCES | NEWSROOM

Structures Design

Programs Library

By downloading any programs, you are agreeing to the following disclaimer:

No warranty, expressed or implied, is made by the Florida Department of Transportation as to the accuracy and functioning of any prog
results they produc
Transportation in a

The Structures De:

For Mathcad probl

Prestressed Beam v6.0	10/01/2021	Exe (Zip) (Mathcad 15)	Used with FDOT Standard Plan Index 450-010 to 450-299 (formerly Index 20010 to 20299) to design simple span prestressed beams (Florida-I, AASHTO, Florida Bulb-T, Florida-U, Florida Double-T, Flat Slab, Inverted-T, FSB) in accordance with the AASHTO LRFD Bridge Design Specification.

V6.0 includes selections for:

a) HSSS or CFRP prestressing strands

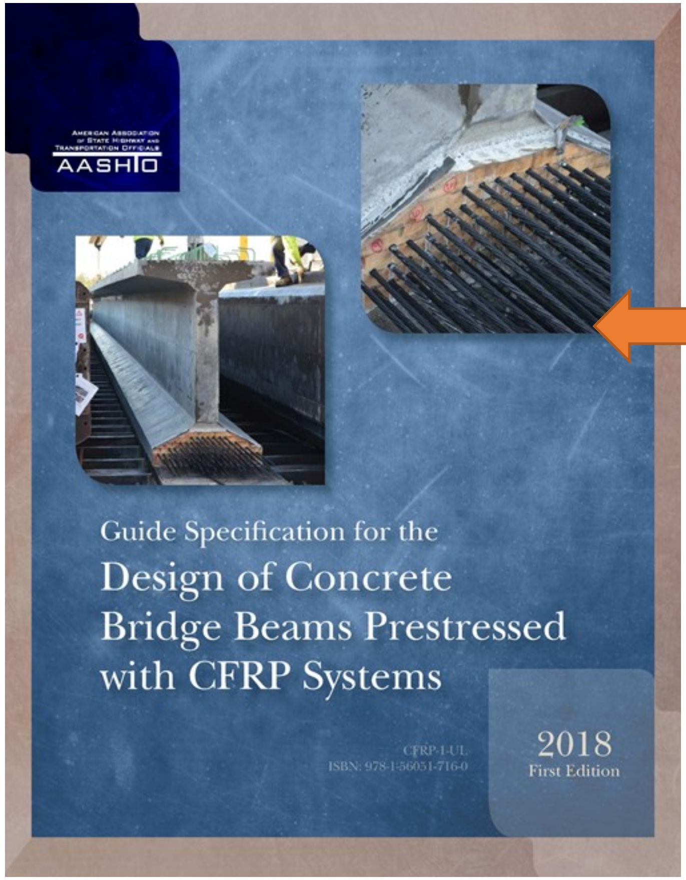
b) SS or GFRP shear reinforcing

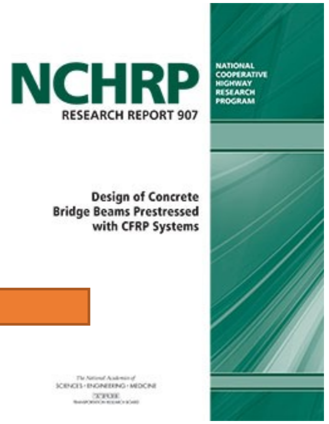
https://www.fdot.gov/structures/proglib.shtm

FDOT TRANSPORTATION SYMPOSIUM

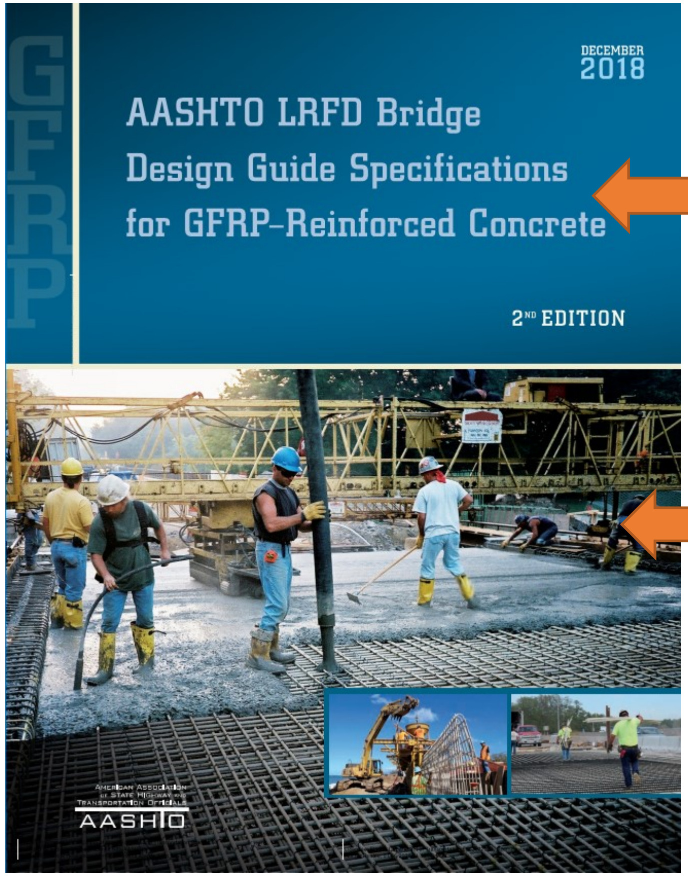
Review Background & Research

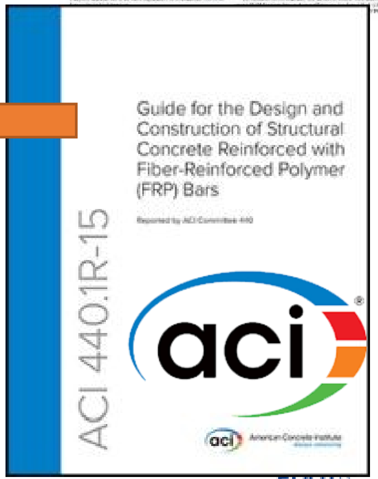
- AASHTO Design Guide Specification for CFRP-PC Beams





- AASHTO Design Guide Specifications for GFRP-RC





Shear Design

PART 2 – CFRP Strands

Review Background & Research

- Ongoing Research
  - **NCHRP 12-121 Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement**

NCHRP 12-121 [Active]

Guidelines for the Design of Prestressed Concrete Bridge Girders Using FRP Auxiliary Reinforcement

Project Data	
Funds:	$540,000
Staff Responsibility:	Dr. Waseem Dekelbab
Research Agency:	University of Houston
Principal Investigator:	Dr. Belarbi, Abdeldjelil
Effective Date:	4/19/2021
Completion Date:	4/19/2024

Where to find more CFRP-PC info & training

FDOT Transportation Innovation Challenge

The Department invites you to share your thoughts on ways we can challenge ourselves to be innovative, efficient and exceptional at our **Invitation to Innovation website**

We also invite you to review our Design Office Innovations listed in the links below. Additional innovations will be added as they are identified and developed. If you have any questions, details and contact information are included within the information for each innovation web site.

Structures Design Office

- Curved Precast Spliced U-Girder Bridges
- Fiber Reinforced Polymer Reinforcing
- FRP Members and Structures
- Geosynthetic Reinforced Soil Integrated Bridge System
- Geosynthetic Reinforced Soil Wall
- Prefabricated Bridge Elements and Systems
- Segmental Block Walls
- Ultra-High Performance Concrete (UHPC)

- FRP-Design Innovation

FDOT Florida Department of TRANSPORTATION

Improve Safety, Enhance Mobility, Inspire Innovation

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Structures Design

Structures Design / Design Innovation

Fiber Reinforced Polymer Reinforcing

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

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

Overview

The deterioration of reinforcing and prestressing steel within concrete is one of the prime causes of failure of concrete structures. In addition to being exposed to weather, concrete transportation structures in Florida are also commonly located in aggressive environments such as marine locations and inland water crossings where the water is acidic. Cracks in concrete create paths for the agents of the aggressive environments to reach the reinforcing and/or prestressing steel and begin the corrosive oxidation process. An innovative approach to combat this major issue is to replace traditional steel bar and strand reinforcement with Fiber Reinforced Polymer (FRP) reinforcing bars and strands. FRP reinforcing bars and strands are made from filaments or fibers held in a polymeric resin matrix binder. FRP reinforcing can be made from various types of fibers such as glass (GFRP), basalt (BFRP) or carbon (CFRP). A surface treatment is typically provided that facilitates a bond between the reinforcing and the concrete.

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

Where to find more CFRP-PC training

Structures Design

Structures Design / Design Innovation

Fiber Reinforced Polymer Reinforcing

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

Overview
Usage Restrictions / Parameters
Design Criteria
Specifications
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Producer Quality Control Program
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Contact

Overview

The deterioration of reinforcing and prestressing stee... structures. In addition to being exposed to weather, conc... aggressive environments such as marine locations and inla... create paths for the agents of the aggressive environments corrosive oxidation process. An innovative approach to com... reinforcement with Fiber Reinforced Polymer (FRP) reinforc... from filaments or fibers held in a polymeric resin matrix bind... glass (GFRP), basalt (BFRP) or carbon (CFRP). A surface t... reinforcing and the concrete.

2020
- TRB 2020 Workshop 1063 (Jan 12, 2020):
  - Externally Bonded Wraps
  - FRP Design Tools, CBB Implementation & Pedestrian Bridges
- FDOT Executive Workshop (January 15, 2020)
- FTS2020 "FRP Reinforced and Prestressed Concrete Designer Training Int...
- FDOT/FRP Industry 4th RC/PC Workshop (August 4, 2020)
- FDOT GFRP-RC Designer Training for Bridges & Structures (August 10, 2020)
- FDOT CFRP-PC Designer Training for Bridges & Structures (September 9, 2020)
- CAMX 2020 - Infrastructure Education Presentation: Advancements in composite infrastr...

Structures Design Office / FDOT 2020 CFRP-PC Design Training Course

FDOT 2020 CFRP-PC Design Training Course

Training Information

Dates
September 9, 2020

Location
FDOT - Hosted Online via GoTo Webinar

FDOT Florida Department of TRANSPORTATION — UNIVERSITY of HOUSTON CULLEN COLLEGE of ENGINEERING Department of Civil & Environmental Engineering

Design of Pretensioned Concrete Bridge Elements with Carbon Fiber-Reinforced Polymer (CFRP) Systems

Abdeldjelil Belarbi, PhD, PE, FACI, FASCE, FSEI
Distinguished Professor
University of Houston
belarbi@uh.edu

September 9, 2020

Video Recording - Design of Pretensioned Concrete Bridge Elements with CFRP Systems (GoTo Stage)

Presentation Slides:
- Introduction
- Prestressing CFRP
- Flexural Design
- Shear Design
- Axial Design - Prestressed Piles

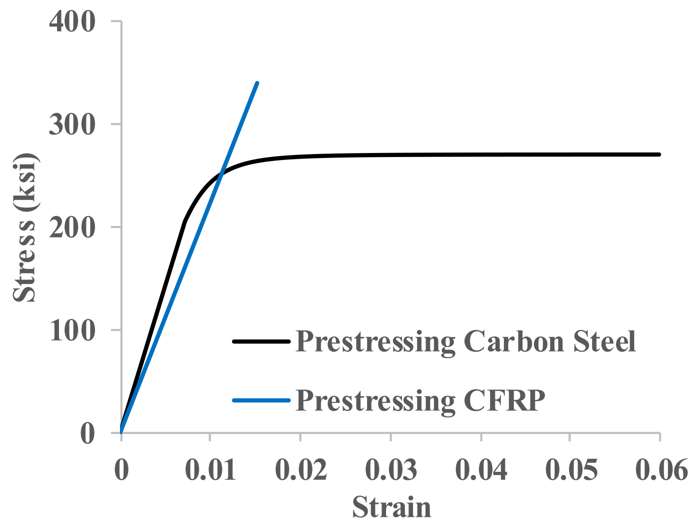
Support Documents:
- Matchcad Design Example - FIB36 Girder
- Matchcad Design Example - FSB12x57" Slab-Beam
- Matchcad Design Example - Bearing Pile 18"x18"
- Matchcad Design Example - Sheet Pile 12"x30"

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

2020 Training on CFRP-Prestressed Concrete Design for Beams and Piles

6-Hour Recorded Webinar Course

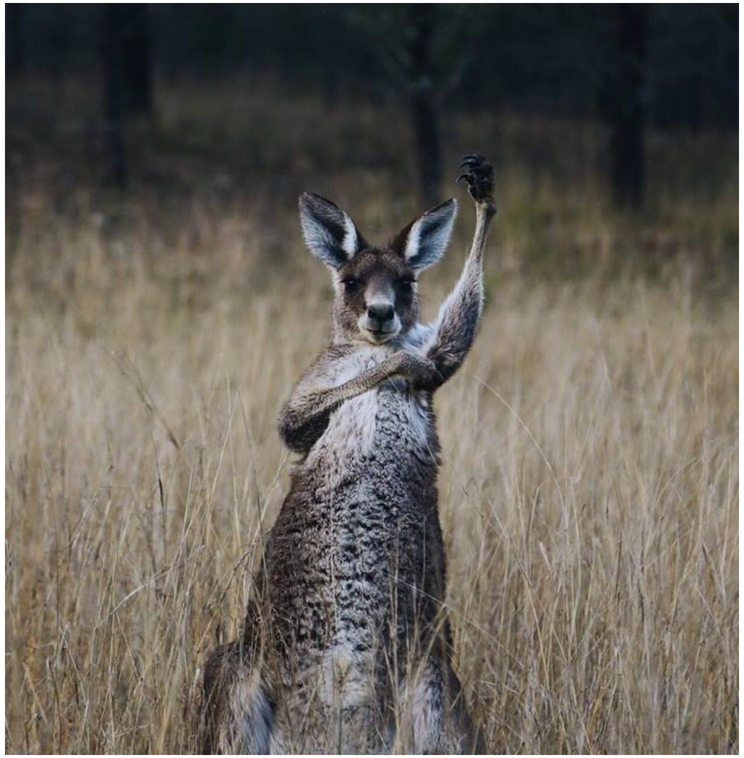
Design of Pretensioned Concrete Bridge Elements with Carbon Fiber-Reinforced Polymer (CFRP) Systems



Abdeldjelil Belarbi, PhD, PE, FACI, FASCE, FSEI
Distinguished Professor
University of Houston
belarbi@uh.edu

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

Questions



NO text.
NO call.
NOTHING
is worth losing a life over.

PUT IT DOWN
IT'S THE LAW

Contact Information

Steven Nolan, P.E.
FDOT State Structures Design Office,
605 Suwannee St, Tallahassee, FL. 32399
Steven.Nolan@dot.state.fl.us

Vickie Young, P.E.
FDOT State Structures Design Office,
605 Suwannee St, Tallahassee, FL. 32399
Vickie.Young@dot.state.fl.us

FDOT Implementation - FRP-RC/PC Projects

FRP-PC Piles & RC projects:

Arthur Drive over Lynn Haven Bayou **
Bakers Haulover Cut Bulkhead Replacement **
Cedar Key Bulkhead Rehab **
Halls River Bridge **
NE 23rd Ave over Ibis Waterway
PortMiami Tunnel Retaining Walls **
South Maydell Dr over Palm River
SR-A1A Flagler Beach Seawall (Segment 3) **
SR-5 (US-17) over Trout River **
SR-5 (US 41) over Morning Star and Sunset Waterways
SR-5 (US 41) over North Creek
SR-30 over St Joe Inlet
SR-312 over Matanzas River **
SR-520 over Indian River Bulkhead Rehab
Sunshine Skyway Seawall Rehabilitation **
UM Innovation Bridge **
UM Fate Bridge **
UM i-Dock **

*** completed*

FSB FRP-PC projects:

Construction completed:

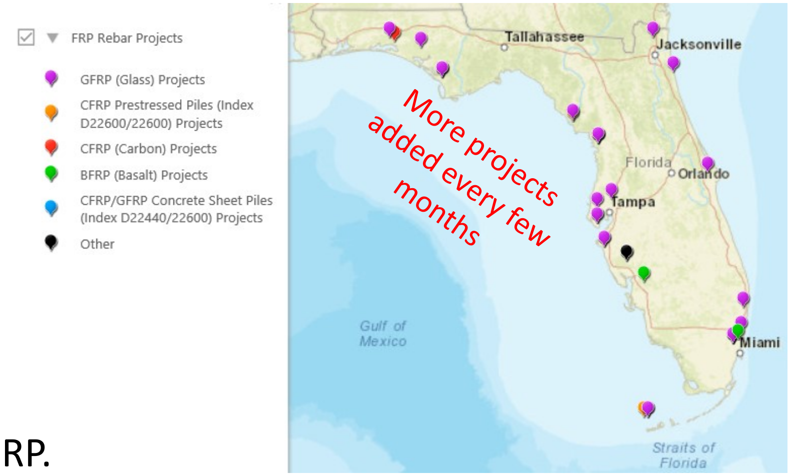
- US-1 over Cow Key Channel **

Under construction:

- 40th Ave NE over Placido Bayou
- Observation Platform under US-1/ Loxahatchee River (Jupiter Inlet) - SS or FRP.

In design:

- Observation Platform under SR-A1A North Beach Causeway (St Lucie) - SS or FRP.
- SR 5/US 1 Over Earman River Canal
- CR30A over Western Lake



Sample Projects - Current & Completed in Florida

Design guidance and tools – Beam End Zone

- **ADDITIONAL SLIDES for Confinement and Splitting Reinforcing Details**

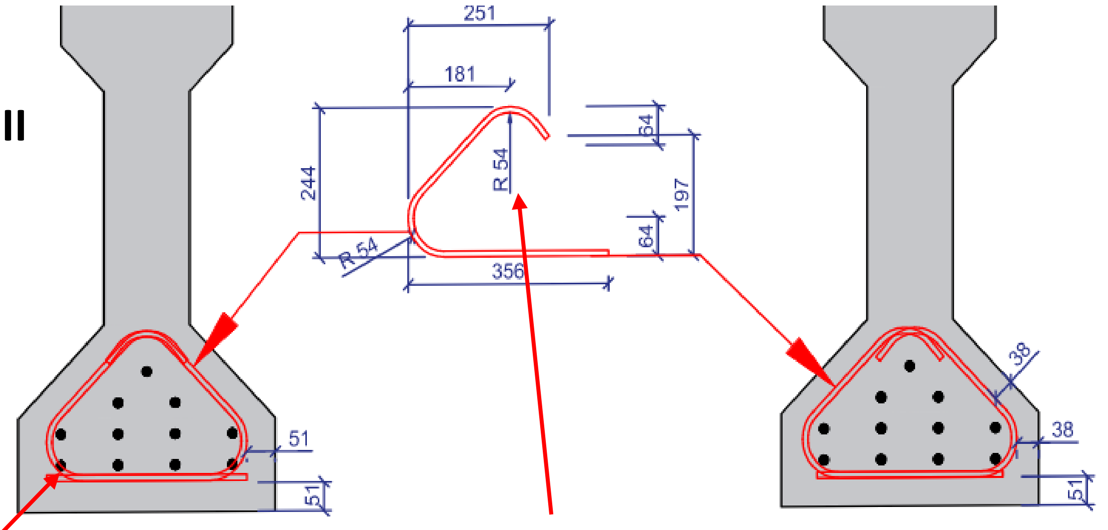
(Detailing issues)

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing – AASHTO Type II:** GFRP Modification for concrete cover
  - Using typical #3 Bars D.
  - Note GFRP Bars require larger radius (See Index 415-010) than steel (Index 415-001)

AASHTO Type II Example



CONFLICT with 2" cover

#3 GFRP ~ 2 1/4" dia. bend (as drawn)

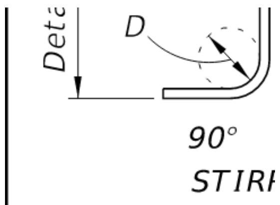
GFRP confinement reinforcement configuration

Modified GFRP confinement reinforcement configuration

GFRP Stirrup Bends

BAR SIZE	D
#3	2¼"
#4	3"
#5	3¾"
#6	4½"
#7	5¼"
#8	6"

Steel Stirrup Bends



STIRRUP

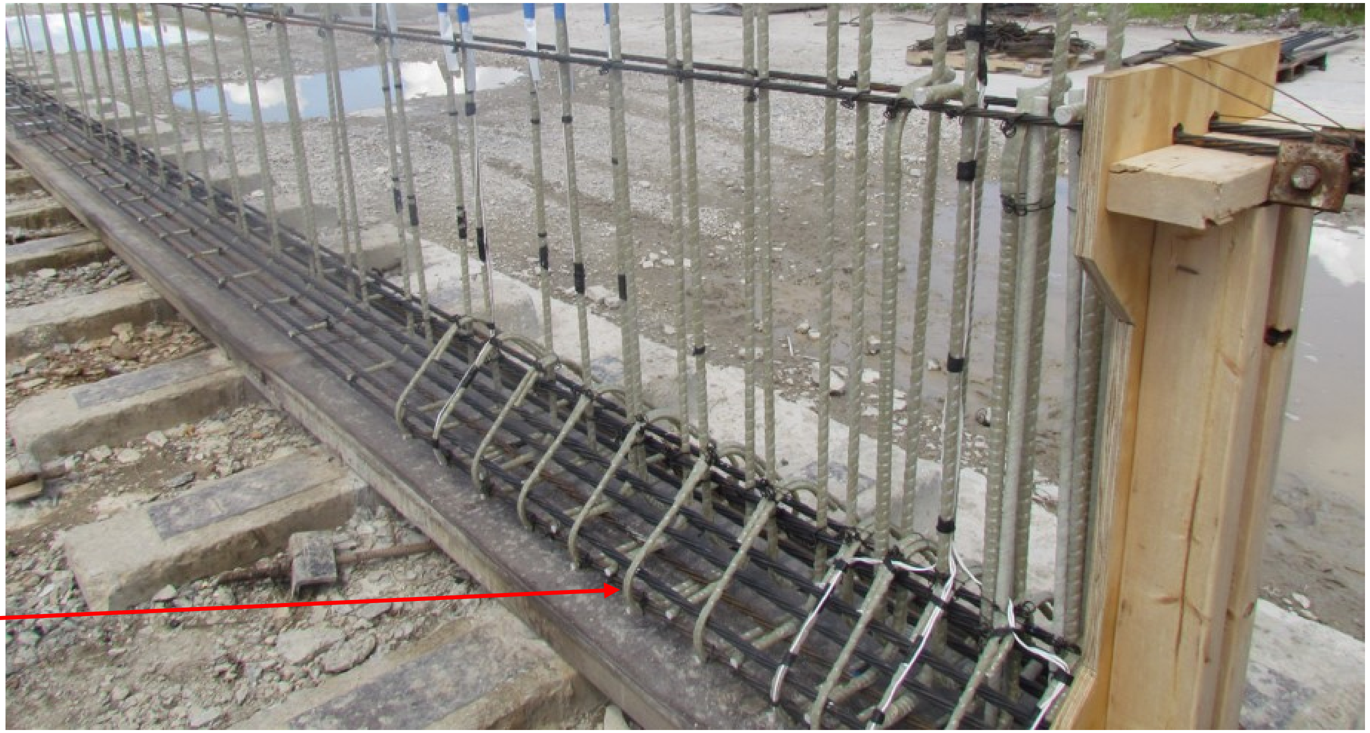
BAR SIZE	D
#3	1½"
#4	2"
#5	2½"
#6	4½"
#7	5¼"
#8	6"

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing – Type II** GFRP Modification concrete cover
  - Using #3 Bars D.
  - Also, using 3” spacing is possible for increased confinement stiffness, but may not be necessary with limited strands (13) as shown in ***BVD30 977-22.***

AASHTO Type II Example



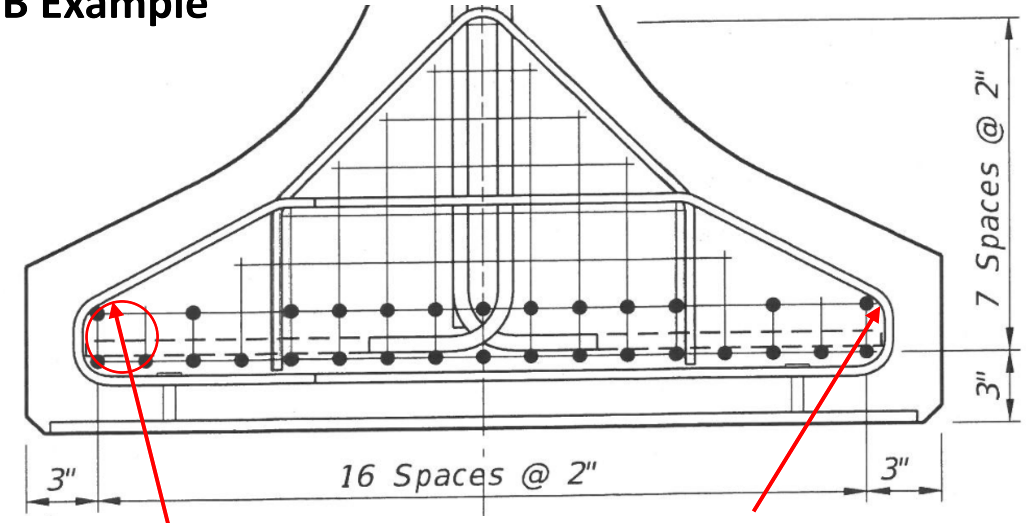
#3 GFRP Bars D
at standard spacing.

FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing –** GFRP Modification (FIB Option) to increase stiffness
  - Upsize Bars C & D from #3’s to #4’s.
  - Note GFRP Bars require larger radius (See Index 415-010) than steel (Index 415-001)
  - Spacing closer than 3½” not a realistic option for FIB Beams.

FIB Example



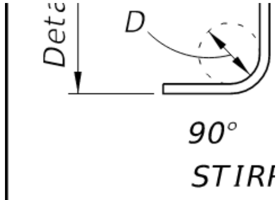
#4 GFRP = 3” dia. bend → STRAND CONFLICT unless cover is reduced

#3 GFRP = 2 ¼” dia. bend (as drawn)

GFRP Stirrup Bends

BAR SIZE	D
#3	2¼"
#4	3"
#5	3¾"
#6	4½"
#7	5¼"
#8	6"

Steel Stirrup Bends



STIRRUP

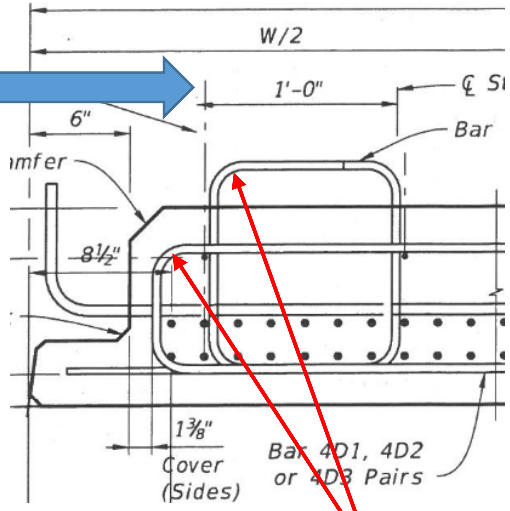
BAR SIZE	D
#3	1½"
#4	2"
#5	2½"
#6	4½"
#7	5¼"
#8	6"

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing –** GFRP Modification (FSB Option 1) stiffness
  - Could upsize Bars D & K from #4's to #5's, but conflicts with bottom corner strands for several FSB widths W = 49", 53", & 57" **– Not Recommended.**
  - Will need to Shift Strands N location due to conflict with Bars D.

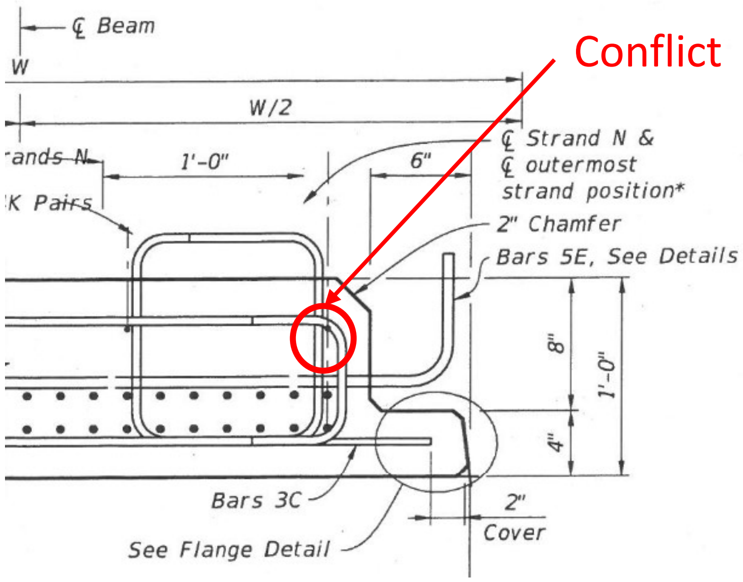
FSB12 Example

Align, Strands N with 2nd outermost strands



Modified Strand N position for GFRP

#4 GFRP = 3" dia. bend

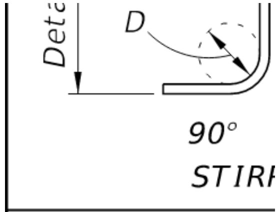


Current Standard Index Strand N position

GFRP Stirrup Bends

BAR SIZE	D
#3	2¼"
#4	3"
#5	3¾"
#6	4½"
#7	5¼"
#8	6"

Steel Stirrup Bends



STIRRUP

BAR SIZE	D
#3	1½"
#4	2"
#5	2½"
#6	4½"
#7	5¼"
#8	6"

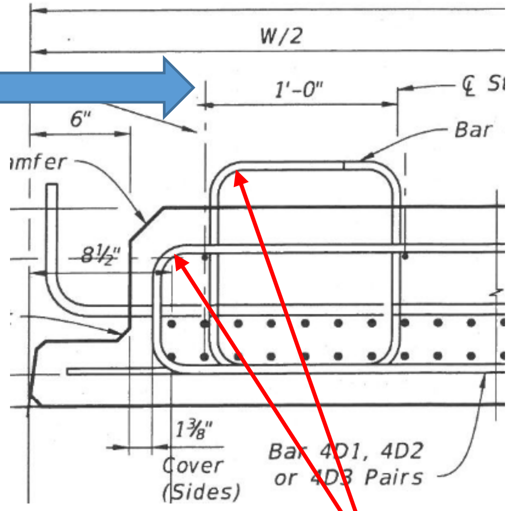
FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing –** GFRP Modification (FSB Option 2) stiffness
  - Keep Bars D & K as #4's, but add 2 additional rows of Bars K (closer spacing) as a better option for FSBs
  - Will need to Shift Strands N location due to conflict with Bars D.

FSB12 Example

Align, Strands N with 2nd outermost strands

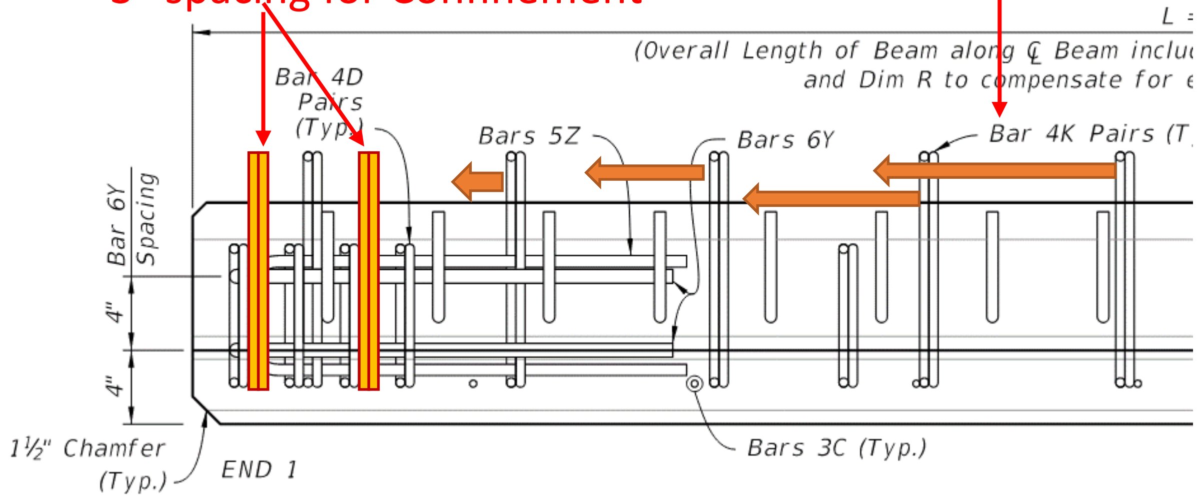


Modified Strand N position for GFRP

#4 GFRP = 3" dia. bend

Add 2 more rows of Bars K at end ~ 3" spacing for Confinement

Remainder of Bars K usually tighter spacing to meet max. shear spacing



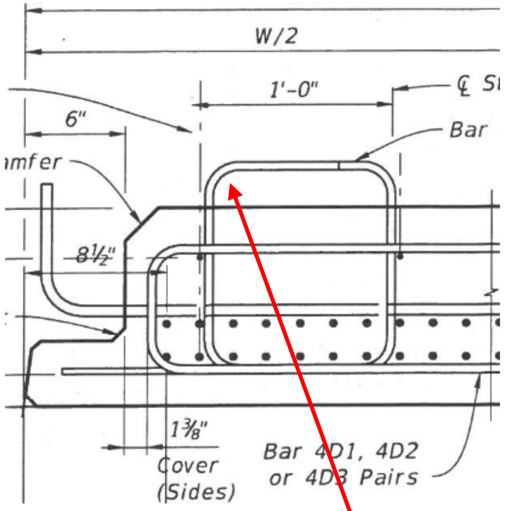
ELEVATION VIEW - Modified End Spacing for Bars K

Preferred Solution

Design guidance and tools – Beam End Zone

- **Confinement Reinforcing –** GFRP Modification (FSB Option 2) continued:
  - Keep Bars D & K as #4's, but add 2 additional rows of Bars K (closer spacing).
  - Will need to Shift Strands N location due to conflic

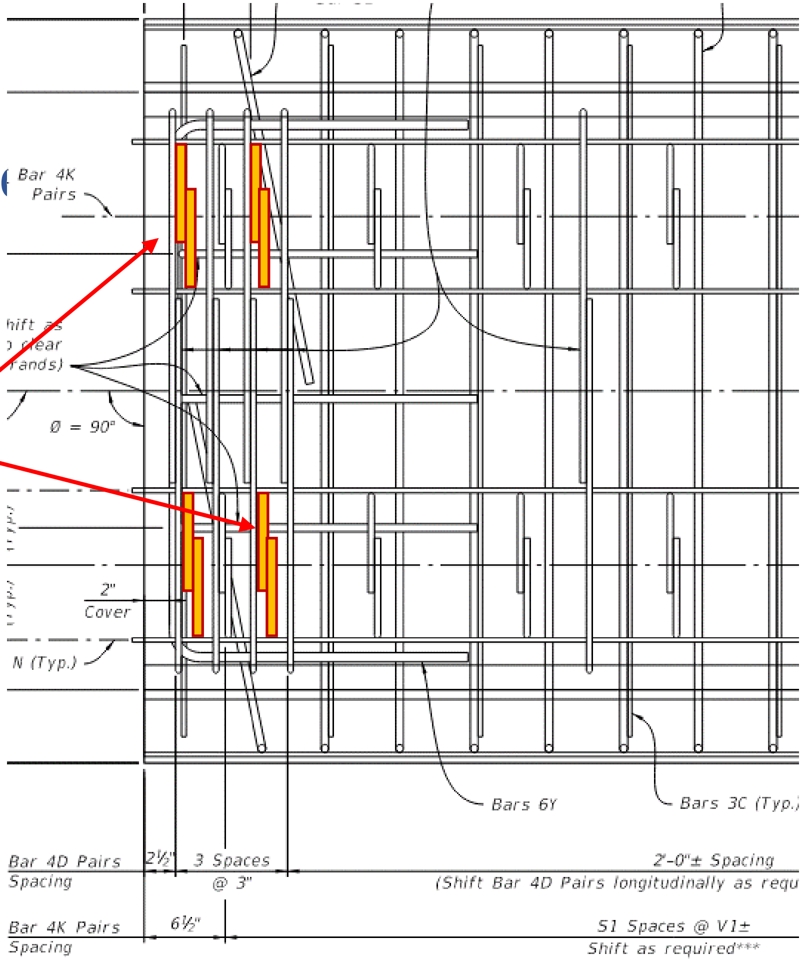
FSB12 Example



PARTIAL SECTION VIEW

Add 2 more rows of Bars K

Preferred Solution



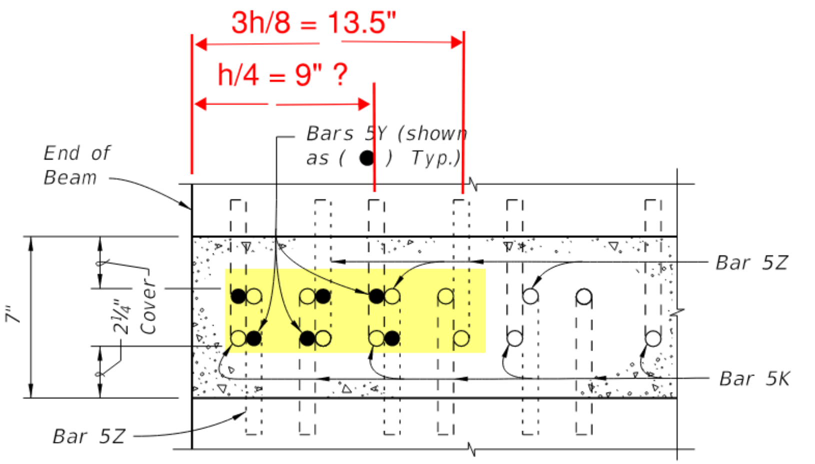
TOP VIEW - Modified End Spacing for Bars K

FDOT TRANSPORTATION SYMPOSIUM

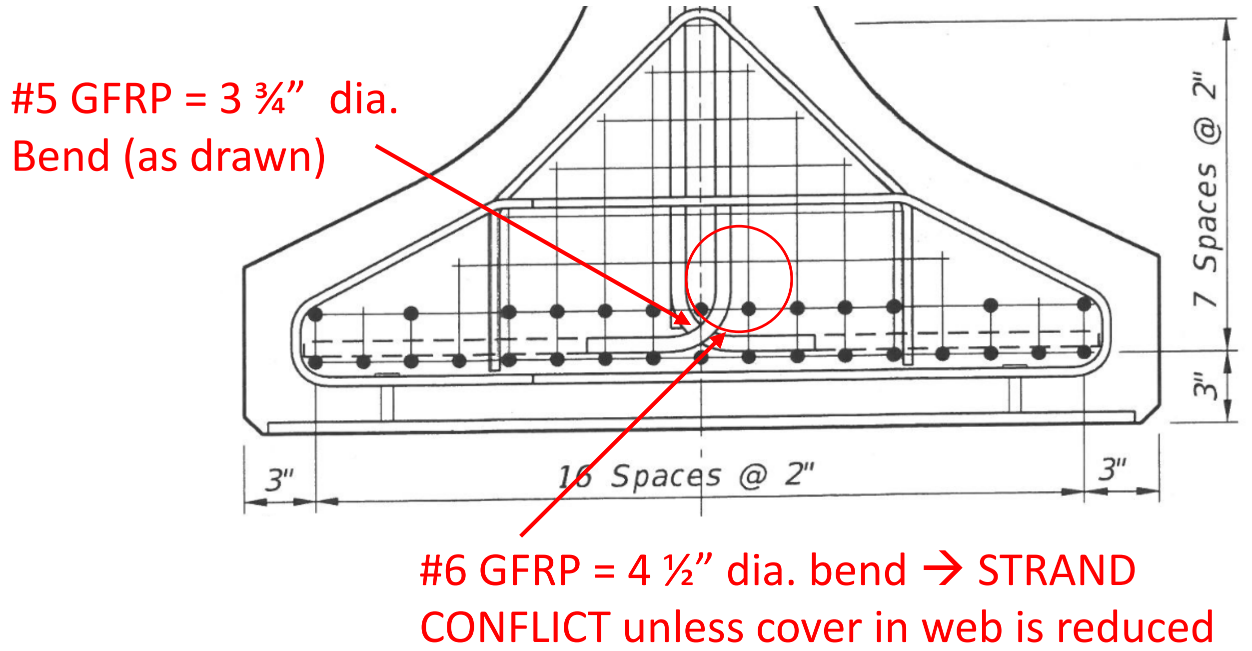
Design guidance and tools – Beam End Zone

- **Splitting Reinforcing –** GFRP Modification Option if needed
  - Could upsize Bars D & K from #5's to #6's, but conflicts with center strand in second row unless web concrete cover is slightly reduced

FIB-36 (Index 450-036) Example:



SECTION A-A FOR CONVENTIONAL REINFORCING
(Showing Bars 5K, 5Y & 5Z Only)



FDOT TRANSPORTATION SYMPOSIUM

Design guidance and tools – Beam End Zone

- **ADDITIONAL SLIDES Shear Design**

(Maximum & Minimum Shear Reinforcing)

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor 0.75 (not 0.9) for GFRP stirrups
  - Use General Procedure (MCFT)
  - Provide at least the Minimum Transverse Shear Reinforcing
  - Limit maximum stirrup spacing to 0.5d (not $0.8d_v$)

$$0.004E_f = 26\ ksi$$

(Typically Governs!)

$$f_{fv} = \min(0.004E_f, f_{fb})$$

$$A_{v,min} = 0.05\frac{b_v s}{f_{fv}}$$

AASHTO GFRP-2 [2.7.2.4]

$$A_{v,min} = 0.0316\lambda\sqrt{f'_c}\frac{b_v s}{\cancel{f_y} f_{fv}}$$

AASHTO BDS [5.7.2.5]
alternate modification
Possible in future

$A_{vmin} :=$ | $\left(0.0316\cdot\lambda\cdot\sqrt{f_{c.beam}\cdot ksi}\cdot\frac{b_v}{f_y}\right)$ if [(MildReinfType = "Carbon Steel
| $\left(0.05\cdot\frac{b_v}{f_{fv}}\cdot ksi\right)$ otherwise

Design guidance and tools – Shear Design

- **Transverse Shear Design Highlights**
  - Use Shear resistance factor 0.75 (not 0.9) for GFRP stirrups
  - Use General Procedure (MCFT) – However, ***GFRP-2*** [2.7.2.5] has a more conservative limit for V_f maximum contribution.
  - Provide at least the Minimum Transverse Shear Reinforcing

Maximum Contribution by transverse reinforcement

$$V_{f.max} = 0.25\sqrt{f_c'}\, b_v d_v$$

FDOT Beam Program v6.0, includes this limit:

$$V_{s.prov.shr_{hs}} := \begin{cases} \left(A_{v.prov.shr_{hs}} \cdot f_y \cdot d_{v_{hs}} \cdot \cot(\theta_{hs})\right) & \text{if } [(\text{MildReinfType} = \text{"Carbon Steel"}) + \\ \min\left(A_{v.prov.shr_{hs}} \cdot f_{fv} \cdot d_{v_{hs}} \cdot \cot(\theta_{hs}), 0.25 \cdot \sqrt{f_{c.beam} \cdot ksi} \cdot b_v \cdot d_{v_{hs}}\right) & \text{otherwise} \end{cases}$$

2.7.2.5—Maximum Transverse Reinforcement

The nominal shear resistance provided by the transverse reinforcement, V_f, as specified in Article 2.7.3.5 shall satisfy:

$$V_f \leq 0.25\sqrt{f_c'}\, b_v d_v \qquad (2.7.2.5\text{-}1)$$

where:

May be too restrictive for web crushing limit

C2.7.2.5

The upper limit of V_f, given by Eq. 2.7.2.5-1, is intended to ensure that the concrete in the web of the beam will not crush prior to rupture of the transverse reinforcement.