FLORIDA DEPARTMENT OF TRANSPORTATION

FIBER REINFORCED POLYMER GUIDELINES (FRPG)

STRUCTURES MANUAL
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1 GENERAL REQUIREMENTS

1.1 GENERAL

A. This volume implements basic design guidelines for Fiber Reinforced Polymer (FRP) Composites used for the specific applications listed herein. As is the case with all other structural materials, the engineer must practice the appropriate standard of care when designing components using FRP Composites.

B. The FRP Composites industry is growing rapidly and utilizes a wide and expanding range of material combinations and fabrication methods. The industry is becoming more aware of the need for standardization of fabrication methods and specifications for materials, design and construction. Some segments of the industry have developed nationally recognized industry standards for specific components using FRP Composites. If they are available, these standards are referenced within this volume.

C. FRP structural components and systems are sensitive to the effects of moisture, temperature, ultraviolet light, chemical attack and other environmental effects that may lead to deterioration in structural strength and stiffness during the service life of the structure. Ultraviolet light embrittles the matrix and may cause loss of tensile strength in glass fibers. Ultraviolet light is best dealt with by using surface coatings (veils) with UV inhibitors which reduce the long-term effects of ultraviolet light and can enhance the aesthetics of the system. Acids and alkalis may have a deleterious effect on the matrix. The effects of alkalinity on FRP composites depend on the chemical characteristics of the exposure and the material system.

D. The EOR must give these issues careful attention during the structural design and determine the appropriate measures of protection such as the use of protective coatings in order to ensure the required service life is obtained. Protective coatings are a design decision and are highly dependent upon the usage application. Any requirements for protective coatings must be specified in the plans and any associated Technical Special Provisions must be developed and included in the Specifications Package.

1.2 DESIGN REVIEW

Unless otherwise stated herein, the use of FRP Composites requires the prior approval of the State Structures Design Engineer (SSDE). Obtain concept approval before proceeding with any design efforts. Make this submittal early in the project development process to ensure the design approach/application is acceptable and to streamline design efforts. After the concept is approved, submit all designs using FRP Composites to the SSDE for review and possible approval. Allow a minimum of two weeks for review time.

Modification for Non-Conventional Projects:
Delete ***FRPG*** 1.2 and insert the following: The use of FRP Composites must be submitted for approval through the Alternative Technical Concept process unless their use is specifically addressed in the RFP.

1.3 APPROVAL OF USE

A. Project specific approval is at the sole discretion of the SSDE due to the complex and variable nature of FRP Composites for design, fabrication and durability.

B. Components subject to vehicular impact, e.g. single and multiple column sign supports, light poles, traffic railing/noise wall combinations, etc., may be considered only if applicable crashworthiness evaluations have been completed and proof of FHWA acceptance is provided. Additional information and requirements can be seen at the FHWA website Roadside Hardware Policy and Guidance.

C. The Florida DOT ***Materials Manual*** Chapter 12 contains the requirements for the Quality Control Program and Quality Assurance for FRP products that are to be used for Department contracts. The FRP Production Facility Listing is available on the State Materials Office website at:

http://www.fdot.gov/materials/quality/programs/qualitycontrol/materialslistings/postjuly2002.shtm

2 BASALT AND GLASS FIBER REINFORCED POLYMER (BFRP, GFRP) AND CARBON FIBER REINFORCED POLYMER (CFRP) REINFORCING BARS

2.1 PERMITTED USE (Rev. 01/23)

A. BFRP, GFRP and/or CFRP reinforcing bars may be used in the following concrete components:

- Approach Slabs
- Bridge Decks and Bridge Deck overlays
- Cast-in-Place Flat Slab Superstructures
- Pile Bent Caps (Only specify GFRP and/or CFRP for submerged locations)
- Pier Columns and Caps (Only specify GFRP and/or CFRP for submerged locations)
- Retaining Walls, Noise Walls, Perimeter Walls
- Pedestrian/Bicycle Railings
- Bulkheads and Bulkhead Copings with or without Traffic or Pedestrian/Bicycle Railings
- MSE Wall Panels and Copings
- Drainage Structures
- Dowel bars for expansion joints in junction slabs when paired with a keyed joint.

B. Other components that may be considered but require SSDE approval before use, include:

- Traffic Railings
- Bulkhead Copings with Traffic Railings

C. The use of BFRP, GFRP and/or CFRP reinforcing bars in other locations will be considered on a case-by-case basis.

D. Do not use BFRP reinforcing bars in concrete components permanently submerged in water.

2.2 DESIGN CRITERIA

A. Design all concrete members containing GFRP reinforcing bars in accordance with the ***AASHTO LRFD Bridge Design Guide Specifications for GFRP Reinforced Concrete***. For BFRP use the same design criteria as GFRP.

B. Design all concrete members containing CFRP prestressing bars, strands and tendons in accordance with the **AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems.**

C. Refer to the ***AASHTO LRFD Bridge Design Specifications*** and ***ACI CODE-318*** for requirements and criteria that are not specifically addressed in the above listed publications.

D. Where factored loads are referenced in the above listed ***ACI*** publications, use load factors prescribed by ***AASHTO LRFD Bridge Design Specifications***.

2.3 ADDITIONAL GUIDANCE

A. Do not use CFRP reinforcing bars in contact with steel reinforcing, metal lifting devices or other embedded metal items.

B. Use the nominal diameters, nominal cross-sectional areas, and the mechanical properties of FRP reinforcing bars in accordance with ***Specifications*** Section 932-3 for the design of structural concrete.

C. Calculate the development length of CFRP bars (l_e) per ***ACI PRC-440.1***.

D. Show all Permissible locations, types, and dimensions of splices, including staggers, for CFRP reinforcing bars in the Plans. Calculate the lengths of tension lap splices per ***ACI PRC-440.1***. Splicing of FRP reinforcement by mechanical connections is not permitted.

E. Use the following minimum concrete covers:

FRP Reinforced Component (Precast and Cast-in-Place)	Environment		
	S[1]	M[1]	E[1]
	Concrete Cover (inches)		
Superstructure Components			
Cast-in-Place Beams	2		
Top deck surfaces of Short Bridges[2]	1.5		
Top deck surfaces of Long Bridges[2]	2[3]		
Front and back surfaces of Pedestrian/Bicycle Railings constructed using the slip form method	2.5		
Wall copings and all other bridge superstructure surfaces and components not listed above	1.5		
Noise Wall Posts	2		
Precast Concrete Perimeter Wall Posts	1.75		
Precast Noise and Perimeter Wall Panels	1.5		
Substructure Components			
External surfaces cast against earth	3		
Exterior formed surfaces, columns, and tops of footings	2		
Exterior formed surfaces of Approach Slabs other than the bottom surface	2		
Beam/Girder Pedestals No. 5 bars and smaller	1.5		
Beam/Girder Pedestals No 6 bar thru no. 10 bars	2		
Prestressed Piles	3[4]		
Cast-in-Place Cantilever Retaining Walls and Gravity Walls	2		
MSE Walls No. 5 bars and smaller	1.5		
MSE Walls No 6 bar thru. no. 10 bars	2		
Box and Three-sided Culverts	2		
Bulkheads and Sheet Pile Wall Caps	2		
Sheet Piles	Front and Back Faces - 3[5] Sides - 2		

1. S = Slightly Aggressive; M = Moderately Aggressive; E = Extremely Aggressive
2. See Short & Long Bridge Definitions and exempted bridge types in ***SDG*** Chapter 4.
3. Cover dimension includes a 0.5-inch allowance for planing; See ***SDG*** 4.2.2.
4. The 3" cover facilitates the use of existing formwork and strand configurations as shown on the ***Standard Plans*** for concrete piles pretensioned with steel strands. A 2" cover is permitted for non-standard pile designs which utilize CFRP strands for pretensioning.
5. The 3" cover facilitates the use of existing formwork and strand configurations as shown on the ***Standard Plans*** for concrete sheet piles pretensioned with steel strands. A 2" cover is permitted for non-standard sheet pile designs which utilize CFRP strands for pretensioning.

F. In the plans, specify the concrete class in accordance with ***SDG*** 1.4.3 except do not specify the use of highly reactive pozzolans or calcium nitrite for corrosion protection.

Commentary: Until the Department completes further research on the requirements for minimum cover and concrete admixtures for use with FRP reinforcing bars, the use of existing requirements for a given concrete class without the listed admixtures for corrosion protection is a conservative approach which will enable FRP reinforcing bars to be used where it benefits the Department.

G. Use ***Standard Plans*** 415-010 FRP Bar Bending Details. Include this standard in the plans using the Developmental Standard Plans Usage Process in ***FDM*** 115.

2.4 PREPARATION OF SPECIFICATIONS PACKAGE

Specifications Sections 400, 410, 415, 932 and 933 are available and include minimum material requirements for FRP reinforcing bars and their use in concrete components. The use of additional specifications and/or Modified Special Provisions for materials, fabrication and construction techniques may be necessary based on project specific requirements. It is the responsibility of the EOR to ensure all specifications required for the Contractor to successfully complete the project are included in the project Specification Package.

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. Contact the SDO for guidance when using CFRP strands with pretensioned beams.

3.2 DESIGN CRITERIA

A. Design concrete members using CFRP strands in accordance with ***the AASHTO Guide Specification for the Design of Concrete Bridge Beams Prestressed with CFRP Systems***.

B. Refer to ***ACI PRC-440.4 Prestressing Concrete Structures with FRP Tendons*** for requirements and criteria that are not specifically addressed in the above listed publication.

3.3 ADDITIONAL GUIDANCE

A. In the plan notes, specify the values assumed in the design for the following mechanical properties:
   - Minimum Ultimate tensile strength of CFRP strand, f_{pu} (ksi) per ***Specifications*** Section 933
   - Ultimate strain in CFRP strand, ε_{pu} as defined in ***ACI PRC-440.1*** and ***ACI PRC-440.4***
   - Minimum Modulus of Elasticity of CFRP strand, E_f (ksi) per ***Specifications*** Section 933, but assuming 22,400 ksi for CFRP cable-strand and 18,000ksi for single bar-strand.
   - CFRP stressing force. Limit the stressing force to that allowed for the same size of 270 ksi carbon steel strand.

Commentary: The CFRP strands cannot be jacked directly and must be coupled to carbon steel strand tails. To keep stresses at safe levels, the maximum jacking force must consider the carbon steel strand tails. For example, the maximum jacking force is 44 kips for 0.6-inch diameter CFRP strand.

   - Maximum concrete tensile stress in prestressed components with bonded prestressing for the Service Limit State is $0.19\sqrt{f'c}$ (ksi)

B. Place a note in the plans directing the Contractor to either obtain products using strands meeting these criteria, or submit shop drawings and calculations for a revised reinforcement scheme using the properties obtained from the manufacturer.

C. In the plans, specify the concrete class in accordance with ***SDG*** 1.4.3 except do not specify the use of highly reactive pozzolans or calcium nitrite for corrosion protection.

Commentary: Until the Department completes further research on the requirements for minimum cover and concrete admixtures for use with CFRP strands, the use of existing requirements for a given concrete class without the listed admixtures for corrosion protection is a conservative approach which will enable CFRP strands to be used where it benefits the Department.

D. Do not use CFRP strands in combination with or in contact with steel reinforcing, proprietary pile splices or other embedded steel items. For confinement reinforcing, use only BFRP or GFRP or CFRP spiral ties.

E. The use of preplanned proprietary pile splices is not permitted.

3.4 PREPARATION OF SPECIFICATIONS PACKAGE

Specifications Sections 400, 415, 450, 932 and 933 include construction requirements for concrete piles and minimum material requirements for FRP reinforcing bars and CFRP prestressing strands. The use of additional specifications and/or Modified Special Provisions for materials, fabrication and construction techniques may be necessary based on project specific requirements. It is the responsibility of the EOR to ensure all specifications required for the Contractor to successfully complete the project are included in the project Specification Package.

4 CARBON FIBER REINFORCED POLYMER (CFRP) STRUCTURAL STRENGTHENING

4.1 PERMITTED USE

Externally bonded CFRP composite systems may be used for strengthening and repairs as part of a design project when approved by the SSDE, and as part of a maintenance project when approved by the State and/or District Structures Maintenance Engineer(s).The use of externally bonded systems for piers subjected to vehicular impact loads is prohibited.

4.2 DESIGN CRITERIA

A. FRP composite systems used in repair or strengthening shall have CFRP as the primary reinforcement. If either a pre-cured laminate or wet layup system is used, the resin and adhesive must be a thermoset epoxy formulation specifically designed to be compatible with the fibers or pre-cured shapes. In wet layup systems, shear and flexural reinforcement shall have no more than three layers except as required for anchorages.

B. Design all FRP repair systems for concrete members in accordance with ***ACI PRC-440.2-17 Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*** except as noted herein. Obtain loads using the ***AASHTO LRFD Bridge Design Specifications (LRFD)***.

C. Modify Section 9.2 as follows:

When strengthening a single girder in a span containing at least four similar girders, the following limit shall control:

$$(\phi \mathbf{R_n})_{\mathbf{Existing}} \geq (\mathbf{1.1S_{DL}} + \mathbf{0.75S_{LL}})$$

Where:

$(\mathbf{\Phi R_n})_{\mathbf{Existing}}$ = the capacity of the existing member considering ONLY the existing reinforcement

$\mathbf{S_{DL}}$ and $\mathbf{S_{LL}}$ = the unfactored dead load and live load effects, respectively, that occur after the member has been strengthened.

When multiple girders in a single span are strengthened then the following limit shall control:

$$(\phi \mathbf{R_n})_{\mathbf{Existing}} \geq (\mathbf{1.1S_{DL}} + \mathbf{1.0S_{LL}})$$

If the existing reinforcement is insufficient to satisfy this equation, then implement alternative means of strengthening or replacement of the structure. Use load factors and capacity reduction factors from the ***LRFD*** for this check.

D. Modify Section 9.4 as follows:

For environmental considerations, use an environment reduction factor C_E = 0.85 for all bridge applications.

E. Modify Section 10.2.8 and 10.3.1.4 as follows:

Check stresses in existing reinforcement (using Equations 10.2.8a or 10.3.1.4a/b) using Service I Load Combination from ***LRFD***.

F. Modify Section 10.2.9 and 10.3.1.5 as follows:

Use the standard fatigue truck from ***LRFD*** to check fatigue stresses in CFRP composites. Check allowable fatigue stresses in prestressing or mild steel using Chapter 5 of the ***LRFD***.

G. Modify Chapter 11 as follows:.

Shear strengthening using FRP is restricted to complete wrapping or 3-sided U-wrapping as illustrated in Figure 4.2-1. If U-wrapping is used, the termination of the wrap must be anchored to prevent debonding. Design U-wrap systems using an anchorage that has been previously tested to ensure the system will behave in a similar manner to a completely wrapped system.

H. Modify Chapter 14 as follows:

In addition to the requirements in Section 14.1.2, place transverse CFRP reinforcement at the termination points of each ply of CFRP flexural reinforcement, and along the length of the member from end to end of the CFRP reinforcement at a maximum spacing of **d**. Alternatively, place 0-90 degree fabric, which when wrapped the full depth of the web can provide simultaneous transverse and longitudinal strengthening. The width of the transverse reinforcement at the termination shall measure at least **¾d** along the member axis and shall have at least 30% of the capacity of the flexural reinforcement. Intermediate transverse reinforcement shall have a minimum length of **d/4**.

4.3 PREPARATION OF SPECIFICATIONS PACKAGE

The Engineer of Record shall develop Technical Special Provisions for construction and quality control that conform to the specifications given in Attachment A of ***National Cooperative Highway Research Program (NCHRP) Report 609*** "Recommended Construction Specifications and Process Control Manual for Repair and Retrofit of Concrete Structures Using Bonded FRP Composites", except as noted herein.

Technical Special Provisions should be non-proprietary, multi-vendor solutions (2 minimum), reviewed and approved by the State Specifications and Estimates Office and the State Structures Design Office, or District Structures Maintenance Office as applicable per ***FRPG*** Section 4.1.

5 THERMOSET PULTRUDED STRUCTURAL SHAPES

5.1 USAGE CONSIDERATIONS

A. The use of thermoset pultruded structural shapes is permitted for the following applications without prior approval by the SSDE:

1. Bridge fender systems per ***SDG*** 3.14
2. Stay-in-place formwork for bridge decks per ***SDG*** 4.2 and where permitted by ***Specifications*** Section 400

B. The Department will consider the use of thermoset pultruded structural shapes in the following applications for structural members:

1. Pedestrian bridges (structural members and bridge decking)
2. Structural shapes for miscellaneous structures (e.g. access/inspection platforms)
3. Single sign support posts (see also ***FRPG*** 1.3)
4. Light poles (see also ***FRPG*** 1.3)
5. Sheet Piles
6. Tubes used as arch beams for bridge culverts (concrete-filled only)
7. Tubes used for concrete filled bearing piles.

5.2 DESIGN CRITERIA

A. Design bridges using concrete-filled thermoset pultruded tubes in accordance with the ***AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members***.

B. Design all other thermoset pultruded structural shapes in accordance with the ***ASCE Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures***.

C. In addition to the requirements of Paragraph B, design pedestrian bridges using thermoset pultruded structural shapes in accordance with the ***AASHTO Guide Specifications for Design of FRP Pedestrian Bridges***.

5.3 ADDITIONAL GUIDANCE

A. In the plan notes, specify the design criteria and the values assumed in the design.

B. Place a note in the plans directing the Contractor to either obtain products meeting these criteria, or submit shop drawings and calculations for revised structural shapes using the properties obtained from a producer shown on the list of Producers with Accepted Quality Control (QC) Programs.

C. The thermoset pultruded structural shape must meet the requirements of ***Specifications*** Section 973.

5.4 PREPARATION OF SPECIFICATIONS PACKAGE

For applications other than bridge fender systems, create and include a Technical Special Provision for construction requirements in the project Specifications Package based on the ***ANSI Code of Standard Practice, Industry Guidelines for Fabrication and Installation of Pultruded FRP Structures***.

6 VACUUM INFUSION PROCESS (VIP) STRUCTURAL SHAPES

6.1 USAGE CONSIDERATIONS

A. The use of Vacuum Infusion Process (VIP) structural shapes is permitted for bridge fender systems per ***SDG*** 3.14 without prior approval by the SSDE.

B. The Department will consider the use of VIP structural shapes in the following applications for structural members:
   1. Decks for pedestrian bridges
   2. Single sign support posts (see also ***FRPG*** 1.3)
   3. Light poles (see also ***FRPG*** 1.3)
   4. Sheet Piles
   5. Stay-in-place formwork where permitted by ***Specifications*** Section 400
   6. Tubes used as arch beams for bridge culverts (concrete-filled only)

6.2 DESIGN CRITERIA

A. Design bridges using concrete-filled VIP tubes in accordance with the ***AASHTO LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members***.

B. For all other usages of VIP structural shapes, use environmental reduction factors in accordance with the ***ASCE Pre-Standard for Load & Resistance Factor Design (LRFD) of Pultruded Fiber Reinforced Polymer (FRP) Structures*** to account for material degradation and loss of ductility over the design service life of the structure or component.

C. In addition to the requirements of Paragraph B, design pedestrian bridge decks manufactured from VIP structural shapes in accordance with the ***AASHTO Guide Specifications for Design of FRP Pedestrian Bridges***.

6.3 ADDITIONAL GUIDANCE

A. In the plan notes, specify the design criteria and the values assumed in the design.

B. There are currently no established industry-wide design, fabrication and construction specifications for VIP; therefore, full scale testing may be required at the discretion of the SSDE. Provide a report from an independent laboratory certifying any required testing.

C. The VIP structural shape must meet the requirements of ***Specifications*** Section 973.

6.4 PREPARATION OF SPECIFICATIONS PACKAGE

For applications other than bridge fender systems, create and include a Technical Special Provision for construction requirements in the project Specifications Package based on the use of VIP structural shapes that are obtained from a producer shown on the list of Producers with Accepted Quality Control (QC) Programs.

7 THERMOPLASTIC STRUCTURAL SHAPES

7.1 USAGE CONSIDERATIONS

A. The use of thermoplastic structural shapes for bridge fender systems per ***SDG*** 3.14 is permitted without prior approval by the SSDE.

B. The Department will consider the use of thermoplastic structural shapes in the following applications for structural members:

1. Landscaping retaining walls
2. Sheet pile walls
3. Boardwalk structures

7.2 DESIGN CRITERIA

Design thermoplastic structural shapes containing FRP reinforcing bars meeting the requirements of ***Specifications*** Section 932 and using the applicable criteria from ***ACI PRC-440.1, Guide for the Design and Construction of Structural Concrete Reinforced with FRP Bars***.

7.3 ADDITIONAL GUIDANCE

A. In the plan notes, specify the design criteria and the values assumed in the design.

B. The design of thermoplastic structural shapes containing FRP reinforcing must only consider the structural properties of the FRP reinforcing contained within its thermoplastic matrix, except fender system wales may substitute macro-fiber reinforcing for FRP reinforcing bar.

C. The thermoplastic matrix must meet the requirements of ***Specifications*** Section 973.

D. In the plans, provide details of each member's cross section and the location, size and grade of any FRP reinforcing bars.

E. There are currently no established industry-wide design, fabrication and construction specifications for thermoplastic structural shapes; therefore, full scale testing may be required at the discretion of the SSDE. Provide a report from an independent laboratory certifying any required testing.

7.4 PREPARATION OF SPECIFICATIONS PACKAGE

For applications other than bridge fender systems, create and include a Technical Special Provision for construction requirements in the project Specifications Package based on the use of thermoplastic structural shapes that are obtained from a producer shown on the list of Producers with Accepted Quality Control (QC) Programs.

VOLUME 4 - REVISION HISTORY

2.1 ..... Usage of BFRP reinforcing bars updated based on research.