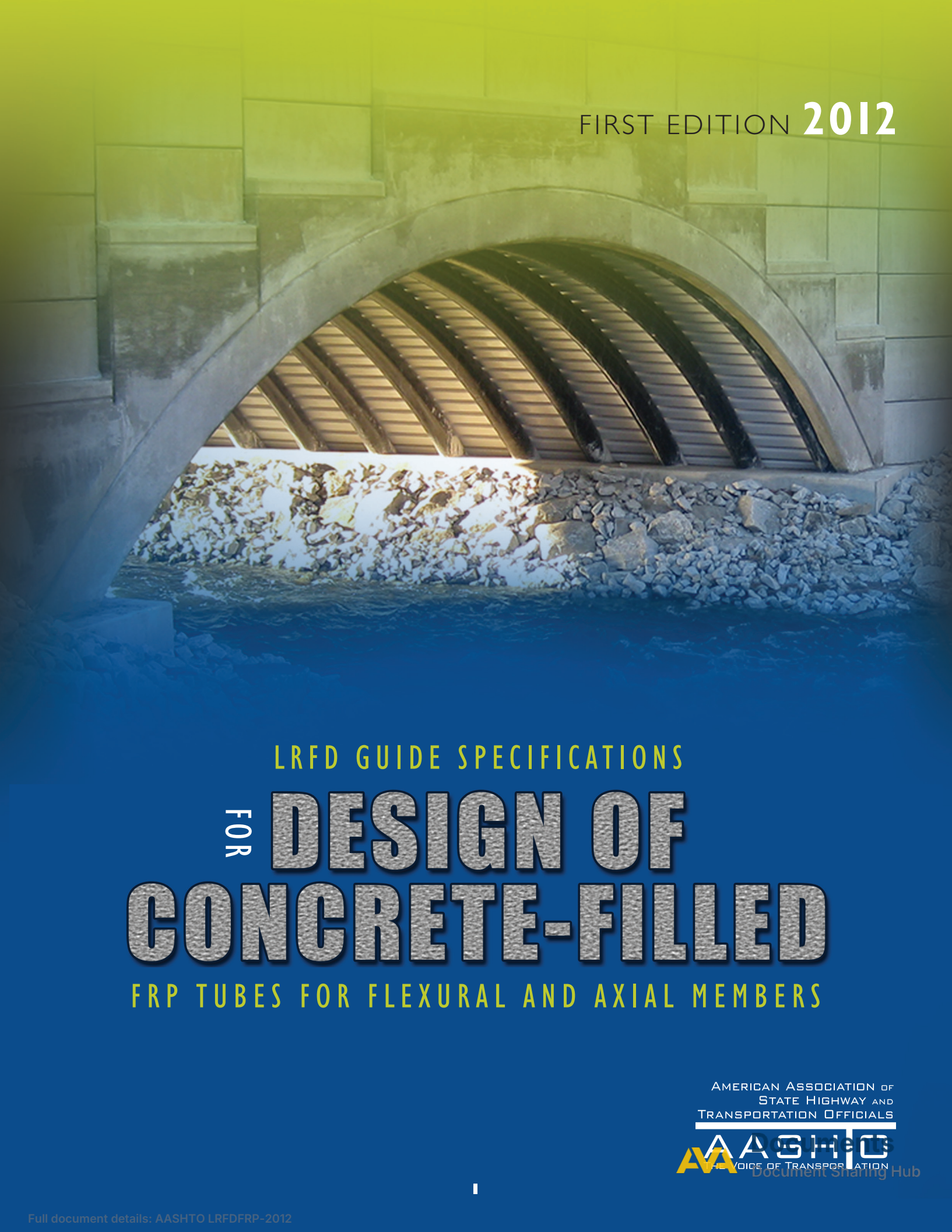


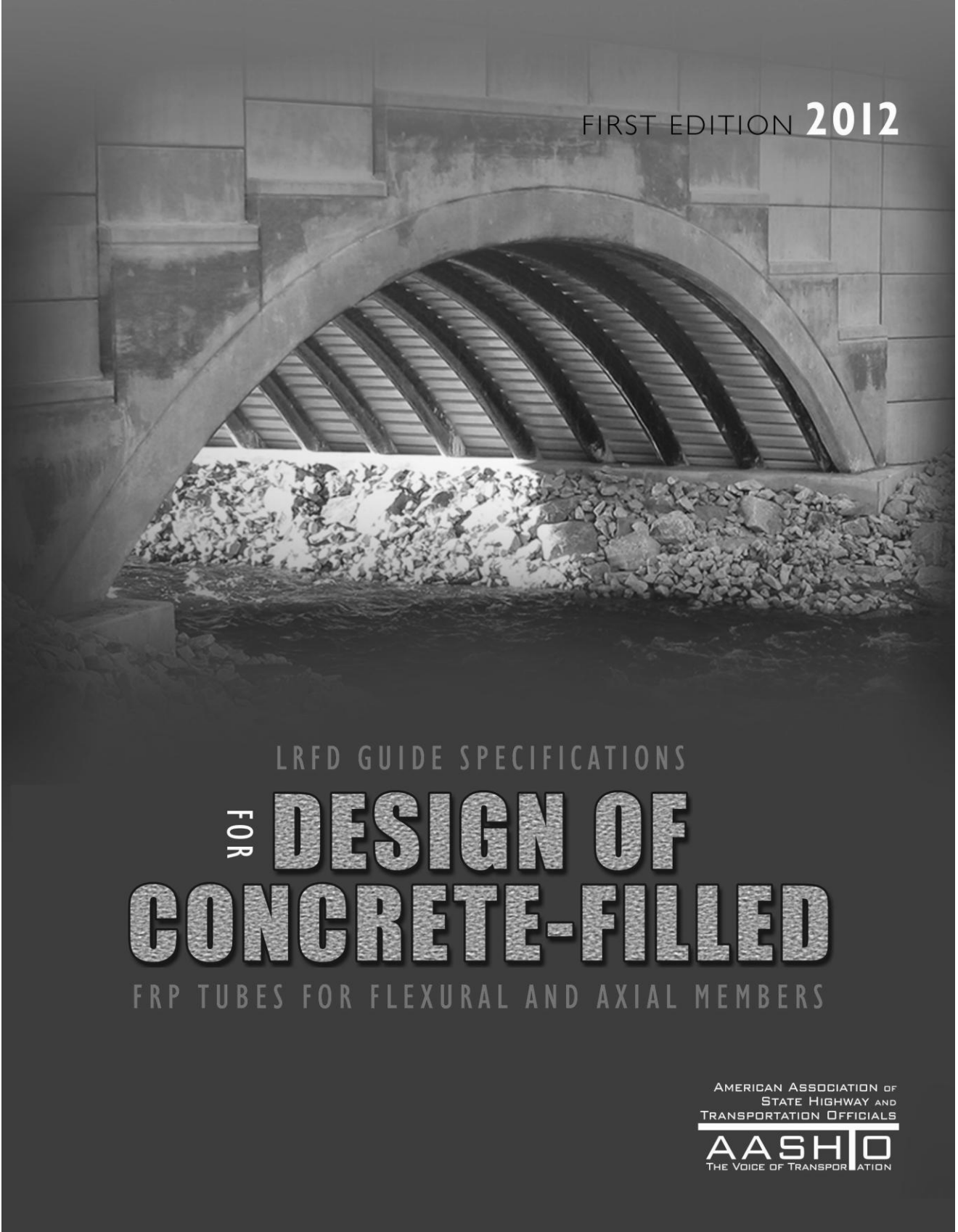


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FRP TUBES FOR FLEXURAL AND AXIAL MEMBERS

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## FOREWORD

*LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members*, First Edition (2012) was developed as a collaborative effort between Dr. Amir Fam of Queen's University, Ontario, the University of Maine, and Advanced Infrastructure Technologies with review and approval by the AASHTO T-6 Technical Subcommittee for Fiber-Reinforced Polymer Composites.

The basis of this document was derived from a large body of research published over the past 15 years by a variety of research institutions. These resources can be found in the references sections of this document.

AASHTO Subcommittee on Bridges and Structures

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- Dr. Amir Fam, Ph.D., P.E., Professor and Canada Research Chair in Innovative and Retrofitted Structures

### **University of Maine, Orono, ME**

- Dr. William Davids, Ph.D., P.E., John C. Bridge Professor of Civil Engineering and Department Chair
- Dr. Habib Dagher, Ph.D., P.E., Director, AEWAC Advanced Structures and Composites Center and Professor of Civil/Structural Engineering

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- Daniel Bannon, Bridge Design Engineer
- Jonathan Kenerson, Manufacturing Manager

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- Jeffrey L. Robert, Maryland Department of Transportation
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- Sam Fallaha, Florida Department of Transportation
- Matthew Chynoweth, Michigan Department of Transportation
- Timothy J. Keller, Ohio Department of Transportation
- Michael Keever, California Department of Transportation
- Lou Triandafilou, U.S. Department of Transportation

## PREFACE

This new AASHTO publication, *LRFD Guide Specifications for Design of Concrete-Filled FRP Tubes for Flexural and Axial Members*, First Edition (2012), comprises three sections:

Section 1—Introduction

Section 2—Concrete-Filled FRP Tubes (CFFTs)

Section 3—Material Specifications

A list of references is included at the end of each section.

AASHTO Publications Staff  
December 2012

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## INTRODUCTION

## 1.1—SCOPE

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

These Specifications are not intended to supplant proper training or the exercise of judgment by the Design Professional, and state only the minimum requirements necessary to provide public safety. The Owner or the Design Professional may require the sophistication of the design or the quality of materials and construction, or both, to be higher than the minimum requirements.

The Design Professional shall be familiar with the provisions of the *AASHTO LRFD Bridge Design Specifications*, 6<sup>th</sup> Edition (AASHTO, 2012), hereafter referred to as “AASHTO LRFD,” and the latest interim revisions, as well as with the design of conventional reinforced concrete structures and structures exposed to earth loading.

The commentary directs attention to other documents that provide suggestions for carrying out the requirements and intent of these Specifications. However, those documents and this commentary are not intended to be a part of these Specifications.

## 1.2—DEFINITIONS

**Composite Action**—A condition in which two or more elements or components are made to act together by eliminating relative movements at their interface.

**Design Professional**—The architect, engineer, architectural firm, or engineering firm responsible for the design of the bridge and issuing Contract Documents or administering the Work under Contract Documents, or both.

**Fiber**—Any fine thread-like natural or synthetic object of mineral or organic origin. Note: This term is generally used for materials whose length is at least 100 times its diameter.

**Fiber, Aramid**—Highly oriented organic fiber derived from polyamide incorporating an aromatic ring structure.

**Fiber, Carbon**—Fiber produced by heating organic precursor materials containing a substantial amount of carbon, such as rayon, polyacrylonitrile (PAN), or pitch in an inert environment.

## C1.1

FRP materials have emerged as an alternative material to steel reinforcement for concrete structures. They offer advantages over steel reinforcement due to their noncorrosive nature and nonconductive behavior. FRP is also a versatile material that can be produced in many forms such as reinforcing bars, grids, rigid plates, flexible sheets, and several structural shapes, including tubes. This specification is focused on one application of FRP in the form of tubes used as structural stay-in-place forms filled with concrete [Fardis and Khalili (1981), Nanni and Bradford (1995), Mirmiran and Shahawy (1996), Davol (1998), Burgueño (1999), Fam (2000), Fam and Rizkalla (2001), Fam and Rizkalla (2002)]. Due to differences in the physical and mechanical behavior of FRP materials as opposed to steel, particularly when used as stay-in-place structural forms, unique guidance on the engineering and construction of bridge components using this technology is needed.

*Fiber, Glass*—Fiber drawn from an inorganic product of fusion that has cooled without crystallizing.

### 1.3—LIMITATIONS

Composite action between the concrete core and FRP tube is required for a CFFT member to develop its stiffness and strength as defined in these Specifications. CFFTs that do not have sufficient bond between the concrete core and FRP tube to ensure composite action are not addressed in these Specifications. Composite action shall be verified in accordance with Article 2.5. The assumed failure mechanism of CFFTs used as flexural members shall not be based on the formation of plastic hinges. CFFTs shall not be used as ductile earthquake resisting elements.

### 1.4—DESIGN PHILOSOPHY

These Specifications are based on limit state design principles where structural components shall be proportioned to satisfy the requirements at all appropriate service, fatigue and creep rupture, strength, and extreme event limit states. In many instances, serviceability or fatigue and creep rupture limits may control the design.

Provisions related to limit states analyses, general design and location features, loads and load factors, and structural analysis and evaluation shall be in compliance with AASHTO LRFD.

### 1.5—REFERENCES

AASHTO. 2012. *AASHTO LRFD Bridge Design Specifications, 6th Edition with Interims*, American Association of State Highway and Transportation Officials, Washington DC.

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Fam, A. 2000. "Concrete-Filled Fibre-Reinforced Polymer Tubes for Axial and Flexural Structural Members." Doctoral dissertation, Univeristy of Manitoba. Winnipeg, Manitoba, Canada.

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Mirmiran, A. and M. Shahawy. 1996. "A New Concrete-Filled Hollow FRP Composite Column," *Composites Part B: Engineering*, Special Issue on Infrastructure, Elsevier Science Ltd., 27B (3–4), pp. 263–268. Elsevier, Amsterdam, The Netherlands.

Nanni, A. and N. Bradford. 1995. "FRP Jacketed Concrete under Uniaxial Compression," *Construction and Building Materials*, 9(2), pp. 115–124. Elsevier, Amsterdam, The Netherlands.

### C1.3

Bond may be achieved by shear interlock mechanism, such as a roughened inner surface of the FRP tube or friction, or both, that can be further enhanced by the use of low-shrinkage or expansive concrete. FRP materials demonstrate a linear-elastic behavior up to failure and do not demonstrate yielding, which is the basis for plastic hinge formation and moment redistribution.

### C1.4

The limit states specified herein are intended to provide for a buildable, serviceable bridge, capable of safely carrying design loads for a specified lifetime.

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## SECTION 2

# CONCRETE-FILLED FRP TUBES (CFFT)

### 2.1—SCOPE

This Section contains the provisions for the design of concrete-filled FRP tubes (CFFT) for use as components of a bridge structure.

### 2.2—DEFINITIONS

*Component*—A constituent part of a structure.

*Composite Action*—A condition in which two or more elements or components are made to act together by eliminating relative movements at their interface.

*Creep*—Time-dependent plastic strain in a material subjected to sustained stress.

*Creep Rupture*—The gradual, time-dependent reduction of tensile strength due to permanent loading that leads to a premature failure of the section.

*Dynamic Load Allowance*—An increase in the applied static force effects to account for the dynamic interaction between the bridge and moving vehicles.

*Specified Strength of Concrete*—The nominal compressive strength of concrete specified for the work and assumed for design and analysis of new structures.

*Stay-in-Place Form*—A permanent form for the concrete that remains in place after construction is finished.

### 2.3—NOTATION

|               |   |                                                                                                                                      |
|---------------|---|--------------------------------------------------------------------------------------------------------------------------------------|
| $A_c$         | = | effective concrete area (in. <sup>2</sup> ) (2.12.2)                                                                                 |
| $c$           | = | distance from the extreme compression fiber to the neutral axis (in.) (2.11.3.2)                                                     |
| $C_E$         | = | environmental reduction factor (2.6.1.2)                                                                                             |
| $d_v$         | = | effective shear depth (in.) (2.12.2)                                                                                                 |
| $D$           | = | average diameter of circular FRP tube (in.) (2.7.3.2) (2.10.3) (2.11.3.2)                                                            |
| $D_i$         | = | inner diameter of circular FRP tube (in.) (2.10.3)                                                                                   |
| $D_o$         | = | outer diameter of circular FRP tube (in.) (2.9.5.2)                                                                                  |
| $e$           | = | eccentricity where $e$ is the ratio of applied moment $M_n$ to the compression load $P_u$ (2.11.1)                                   |
| $E_c$         | = | elastic modulus of concrete (ksi) (2.7.3.2) (2.10.3) (2.11.3.2)                                                                      |
| $\epsilon'_c$ | = | the longitudinal compressive strain in the concrete that corresponds to compressive strength $f'_c$ (2.7.3.2) (2.10.3)               |
| $E_{ft}$      | = | elastic modulus of the tube laminate in the hoop direction (ksi) (2.6.1.3) (2.10.3) (2.12.2)                                         |
| $E_{fl}$      | = | elastic modulus of the tube laminate in the longitudinal direction (ksi) (2.6.1.3) (2.10.3)                                          |
| $E_s$         | = | elastic modulus of steel (ksi) (2.11.4)                                                                                              |
| $EI$          | = | flexural stiffness of concrete-filled FRP tube (kip-in. <sup>2</sup> ) (2.11.4)                                                      |
| $f'_c$        | = | unconfined concrete design compressive strength (ksi) (2.7.3.2) (2.9.5.2) (2.12.2)                                                   |
| $f'_{cc}$     | = | confined concrete design compressive strength (ksi) (2.10.3)                                                                         |
| $f_{fcu}$     | = | design compressive strength of FRP laminate in longitudinal direction considering reductions for service environment (ksi) (2.7.3.2) |