

Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems—Code Requirements and Commentary

Reported by ACI Committee 440

ACI CODE-440.13-24



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**Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems—
Code Requirements and Commentary**

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Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems— Code Requirements and Commentary

An ACI Standard

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ACI CODE-440.13 was developed to provide design professionals a code for the design of strengthening strategies for concrete structures using fiber-reinforced polymer (FRP) systems.

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PREFACE

This Code provides minimum design requirements for strengthening of existing concrete structural systems and members using externally bonded and near-surface-mounted (NSM) fiber-reinforced polymer (FRP) systems. Among the subjects covered are design and detailing for strength, serviceability, and durability; load combinations, load factors, and strength reduction factors; FRP anchorage to concrete; development and splicing of FRP reinforcement; field inspection; and testing. This Code was developed by a consensus process. This Code is written for use by licensed design professionals and authorities having jurisdiction. This Code provides minimum requirements for materials, design and construction, and quality control and assurance requirements for FRP strengthening systems. This Code is written in a format that allows adoption by reference in a repair code or a general building code. Background details or suggestions for carrying out the requirements or intent of this Code provisions are in the Commentary.



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CODE

CHAPTER 1—GENERAL

1.1—Scope

1.1.1 ACI CODE-440.13, “Code Requirements for Strengthening Structural Concrete with Fiber-Reinforced Polymer (FRP) Systems—Code and Commentary,” is hereafter referred to as “this Code.” is presented in a side-by-side column format. These are two separate but coordinated documents, with Code text placed in the left column and the corresponding Commentary text aligned in the right column. Commentary section numbers are preceded by an “R” to further distinguish them from Code section numbers. The two documents are bound together solely for the user’s convenience. Each document carries a separate enforceable and distinct copyright.

1.1.2 This Code shall apply to the strengthening of existing concrete structures using only those unidirectional externally bonded and near-surface-mounted (NSM) fiber-reinforced polymer (FRP) systems permitted in [Chapter 4](#).

1.1.3 This Code provides minimum requirements for the materials, design, and construction of FRP strengthening systems for concrete structures consistent with the requirements of [ACI CODE-562](#).

1.1.4 This Code shall not be applied to the strengthening of masonry structures.

1.1.5 This Code provides minimum requirements for the strength evaluation, testing, and inspection of FRP strengthening systems for concrete structures consistent with the requirements of [ACI CODE-562](#).

1.2—General

1.2.1 The requirements of this Code use strength design provisions for demands and capacities.

1.2.2 FRP strengthening is permitted for the following:

- (a) All members in structures assigned to Seismic Design Category (SDC) A in accordance with [ASCE/SEI 7](#)
- (b) Structural members not designated as part of the seismic-force-resisting system in all SDCs.

1.3—Purpose

1.3.1 The purpose of this Code is to provide for public health and safety by establishing minimum requirements for

COMMENTARY

CHAPTER R1—GENERAL

R1.1—Scope

R1.1.2 Throughout this Code, the term “structure” means an existing building, nonbuilding structure, member, or system.

R1.1.3 This Code focuses on concrete buildings and nonbuilding structures. For buildings or structures similar to buildings, members that are addressed by this Code include concrete portions of composite members, and precast and prestressed concrete members.

The licensed design professional can perform assessment, design, and quality assurance activities that exceed the minimum requirements of this Code. Requirements beyond the minimum stated in this Code, such as those for long-term durability, redundancy, or integrity, can be considered by the licensed design professional.

R1.1.4 Guidance for strengthening of masonry structures is provided in [ACI PRC-440.7](#).

R1.2—General

R1.2.2 Seismic strengthening of members of the seismic-force-resisting systems in structures assigned to SDC B through F is outside the scope of this Code. Other standards, such as [ACI CODE-369.1](#) and [ASCE/SEI 41](#), address repair and strengthening of seismic-force-resisting systems. [ACI PRC-440.2](#) provides guidance for the use of FRP systems for strengthening seismic-force-resisting systems.

R1.3—Purpose



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strength, stability, serviceability, durability, and fire resistance of concrete structures strengthened using FRP systems.

1.3.2 This Code does not address all design considerations.

1.3.3 Construction means and methods are not addressed in this Code.

1.4—Interpretation

1.4.1 The official version of this Code is the English language version using inch-pound units published by the American Concrete Institute.

1.4.2 In case of conflict between the official version of this Code and other versions of this Code, the official version governs.

1.4.3 Modifications to this Code that are adopted by a particular jurisdiction are part of the laws of that jurisdiction but are not a part of this Code.

1.4.4 If provisions in this Code conflict with the regulations governing existing structures of the authority having jurisdiction, or those of a code adopting this Code, the regulations of the authority having jurisdiction or the adopting code shall govern.

1.4.5 If provisions in this Code conflict with requirements of standards referenced within this Code, this Code shall govern.

1.4.6 This Code shall be interpreted in a manner that avoids conflict between or among its provisions. Specific provisions shall govern over general provisions.

1.4.7 The Commentary consists of a preface, commentary text, tables, figures, and cited publications. The Commentary is intended to provide contextual information, but is not part of this Code, does not provide binding requirements, and shall not be used to create a conflict with or ambiguity in this Code.

1.4.8 This Code shall be interpreted and applied in accordance with the plain meaning of the words and terms used. Specific definitions of words and terms in this Code shall be used where provided and applicable, regardless of whether other materials, standards, or resources outside of this Code provide a different definition.

1.4.9 The following words and terms in this Code shall be interpreted in accordance with (a) through (e):

(a) The word “shall” is always mandatory.

R1.3.2 The minimum requirements in this Code do not replace sound professional judgment or the licensed design professional’s knowledge of the specific factors surrounding a project, its design, the project site, and other specific or unusual circumstances to the project.

CODE

- (b) Provisions of this Code are mandatory even if the word “shall” is not used.
- (c) Words used in the present tense shall include the future.
- (d) The word “and” indicates that all of the connected items, conditions, requirements, or events shall apply.
- (e) The word “or” indicates that the connected items, conditions, requirements, or events are alternatives, at least one of which shall be satisfied.

1.4.10 In any case in which one or more provisions of this Code are declared by a court or tribunal to be invalid, that ruling shall not affect the validity of the remaining provisions of this Code, which are severable. The ruling of a court or tribunal shall be effective only in that court’s jurisdiction and shall not affect the content or interpretation of this Code in other jurisdictions.

1.5—Authority having jurisdiction

1.5.1 All references in this Code to the authority having jurisdiction shall be understood to refer to the persons who administer and enforce this Code.

1.6—Licensed design professional

1.6.1 All references in this Code to the licensed design professional shall be understood to refer to the persons who possess the knowledge, judgment, and skills to interpret and properly use this Code and are licensed in the jurisdiction where this Code is being used. The licensed design professional is responsible for, and in charge of, the design of the strengthening measures using FRP systems.

1.7—Inspector

1.7.1 All references in this Code to the inspector shall be understood to refer to the persons employed or retained by an approved agency and approved by the authority having jurisdiction as having the competence necessary to observe, test, or otherwise evaluate field installations of FRP systems for compliance with the construction documents.

1.8—Design and construction documents

1.8.1 Documentation of FRP system design shall satisfy 1.8.1.1 or 1.8.1.2.

1.8.1.1 The required performance of the FRP strengthened structural system shall be specified in the construction documents.

1.8.1.2 Complete details of the FRP system shall be depicted on the construction documents.

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R1.6—Licensed design professional

R1.6.1 The design of FRP systems is often delegated to a licensed design professional with expertise in this work, commonly known as a specialty engineer. Others, for example the engineer of record for a rehabilitation project, are often responsible for the condition assessment that identifies the need for strengthening, the strengthening requirements, and for determining whether an FRP strengthening system is an appropriate option for the application.

R1.8—Design and construction documents

R1.8.1 Both methods are described in [ACI SPEC-440.12](#) and are applicable to all FRP strengthening systems.

R1.8.1.1 This method requires the FRP system performance to be specified by the licensed design professional and design calculation to be submitted as a deferred submittal demonstrating that the required performance is achieved. Information pertaining to required performance typically includes existing material strength, existing and required strengthened capacity, dimensions, and considerations for environmental exposure and fire.



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1.8.2 The construction documents for strengthening using FRP systems shall convey the location, nature, and extent of the work, and the necessary information to perform the work in conformance with the requirements of this Code and the authority having jurisdiction.

1.8.3 Construction documents shall require that materials used for the work conform to this Code and governing regulatory requirements in effect at the time an application for construction of the project is submitted to the authority having jurisdiction.

1.8.4 Calculations pertinent to design shall be submitted with the construction documents if required by the authority having jurisdiction.

1.9—Testing and inspection

1.9.1 Testing and inspection of concrete structures strengthened with FRP systems shall be conducted in accordance with **Chapter 11**.

1.9.2 Testing and inspection of FRP systems and constituent materials shall be conducted in accordance with Chapter 11 to ensure compliance with **Chapter 4**.

1.9.3 Testing and inspection of concrete substrates prior to the application of FRP systems shall be conducted in accordance with Chapter 11 to ensure compliance with **Chapter 5**.

1.10—Approval of special systems of design, construction, or alternative construction materials

1.10.1 Alternate FRP strengthening systems not within the scope of this Code shall be permitted to be used if equivalent strength, serviceability, and durability are demonstrated by testing and analysis, to satisfaction of the authority having jurisdiction.

1.10.2 FRP systems that are approved by the authority having jurisdiction through alternative means and methods clauses in the design basis code shall be permitted.

R1.10—Approval of special systems of design, construction, or alternative construction materials

R1.10.1 Results from load tests, large- or full-scale model tests loaded to failure, and other types of physical testing can be used to supplement analytical procedures in the evaluation or design of FRP systems or their use in strengthening existing structures.

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COMMENTARY

CHAPTER 2—NOTATION AND DEFINITIONS

CHAPTER R2—NOTATION AND DEFINITIONS

2.1—Code notation

A_{anc}	= gross laminate area of the fiber anchor, in. ²
A_e	= cross-sectional area of effectively confined concrete section, in. ²
A_f	= nominal area of FRP reinforcement, in. ²
$A_{fanchor}$	= area of transverse FRP U-wrap for anchorage of flexural FRP reinforcement, in. ²
A_{fv}	= area of FRP shear reinforcement with spacing s_f , in. ²
A_g	= gross area of concrete section, in. ²
A_{st}	= total area of nonprestressed longitudinal steel reinforcement excluding prestressing reinforcement, in. ²
a_b	= smaller cross-sectional dimension for rectangular FRP, in.
b_b	= larger cross-sectional dimension for rectangular FRP, in.
b_c	= short side dimension of compression member of prismatic cross section, in.
b_w	= web width or diameter of circular section, in.
C_E	= environmental reduction factor
c	= distance from extreme compression fiber to the neutral axis, in.
D_c	= diameter of circular cross section, in.
d	= distance from extreme compression fiber to centroid of tension reinforcement, in.
d_b	= diameter of round NSM bar, in.
d_{fv}	= effective depth of FRP shear reinforcement, in.
E_2	= slope of linear portion of stress-strain model for FRP-confined concrete, psi
E_c	= modulus of elasticity of concrete, psi
E_f	= design chord tensile modulus of elasticity of FRP, psi
E_f^*	= chord tensile modulus of elasticity of FRP, psi
E_s	= modulus of elasticity of steel, psi
f_c	= compressive stress in concrete, psi
f_c'	= specified compressive strength of concrete, psi
f_{cc}'	= compressive strength of confined concrete, psi
$f_{c,s}$	= compressive stress in concrete at service condition, psi
f_{fd}	= design stress of externally bonded FRP reinforcement, psi

R2.1—Commentary notation

A_p	= area of prestressed reinforcement in tension zone, in. ²
A_s	= area of nonprestressed longitudinal steel tension reinforcement, in. ²
b	= width of compression face of member, in.
C_c	= resultant force of concrete stress block, lb
d_f	= effective depth of FRP flexural reinforcement, in.
d_p	= distance from extreme compression fiber to centroid of prestressed reinforcement, in.
e	= eccentricity of prestressing steel with respect to centroidal axis of member at support, in.



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f_{fe} = effective stress in the FRP; stress attained at section failure, psi
 $f_{f,s}$ = stress in FRP caused by a moment within elastic range of member, psi
 f_{fu} = design ultimate tensile strength of FRP, psi
 $\bar{f}_{fu}$ = mean tensile strength of a sample of at least 20 FRP test specimens
 f_{fu}^* = ultimate tensile strength of the FRP material, psi
 f_t = maximum confining pressure due to FRP jacket, psi

$f_{ps,s}$ = stress in prestressed reinforcement at service load, psi
 f_{pu} = specified tensile strength of prestressing reinforcement, psi
 f_{py} = specified yield strength of prestressing reinforcement, psi
 $f_{s,s}$ = stress in nonprestressed steel reinforcement at service loads, psi
 f_y = specified yield strength of nonprestressed steel reinforcement, psi
 h = overall thickness, height, or depth of member
 h_{anc} = minimum embedment depth of fiber anchor in concrete, in.
 h_c = long side cross-sectional dimension of rectangular compression member, in.

k_1 = modification factor applied to κ_v to account for concrete strength
 k_2 = modification factor applied to κ_v to account for wrapping scheme
 L_a = total length of unbonded tendon between anchorages, in.
 L_e = active bond length of FRP laminate, in.
 ℓ_{df} = development length of FRP system, in.
 M_{cr} = cracking moment, in.-lb
 M_n = nominal flexural strength at section, in.-lb

M_u = factored moment at a section, in.-lb
 N = number of plies of FRP reinforcement

P_n = nominal axial compressive strength of a concrete section, lb
 P_u = factored axial force; to be taken as positive for compression and negative for tension, lb

f_{ps} = stress in prestressed reinforcement at nominal strength, psi

f_s = stress in nonprestressed steel reinforcement, psi

I_{cr} = moment of inertia of cracked section transformed to concrete, in.⁴

I_g = moment of inertia of gross section about centroidal axis, in.⁴

k = ratio of depth of neutral axis to reinforcement depth measured from extreme compression fiber

M_s = service moment at section, in.-lb

M_{snet} = service moment at section beyond decompression, in.-lb

P_e = effective force in prestressing reinforcement (after allowance for all prestress losses), lb

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R_A = ratio of area of fiber in fiber anchor to area of fiber in one leg of shear U-wrap

r_{anc} = length of fiber anchor splay, in.

r_c = radius of edges or corners of a prismatic cross section confined with FRP, in.

s_{anc} = center-to-center spacing of fiber anchors, in.

s_f = center-to-center spacing of FRP strips, in.

T_g = glass transition temperature, °F

t_f = nominal thickness of one ply of FRP reinforcement, in.

V_c = nominal shear strength provided by concrete, lb

V_f = nominal shear strength provided by FRP stirrups, lb

V_n = nominal shear strength, lb

V_s = nominal shear strength provided by steel shear reinforcement, lb

V_u = factored shear force at section, lb

w_f = width of FRP reinforcing plies, in.

α = angle of application of primary FRP reinforcement direction relative to longitudinal axis of member, degrees

α_{anc} = angle over which fiber anchor is splayed over externally bonded FRP, degrees

β_{anc} = embedment angle of fiber anchor, degrees

ϵ_{bi} = strain in concrete substrate at time of FRP installation (tension is positive), in./in.

ϵ_c = strain in concrete, in./in.

ϵ_c' = compressive strain of unconfined concrete corresponding to f_c' , in./in.

ϵ_{ccu} = ultimate axial compressive strain of confined concrete corresponding to $0.85f_{cc}'$ in a lightly confined member (member confined to restore its concrete design compressive strength), or ultimate axial compressive strain of confined concrete corresponding to failure in a heavily confined member, in./in.

ϵ_{ct} = concrete tensile strain at level of tensile force resultant in post-tensioned flexural members, in./in.

r = radius of gyration of cross section, in.

T_f = resultant force of FRP system, lb

T_s = resultant force of internal reinforcing steel, lb

T_y = resultant force of internal reinforcing steel assuming yield of steel, lb

y_b = distance from centroidal axis of gross section, neglecting reinforcement, to extreme bottom fiber, in./in.

α_1 = multiplier on f_c' to determine intensity of an equivalent rectangular stress distribution for concrete

β_1 = ratio of depth of equivalent rectangular stress block to depth of the neutral axis

ϵ_{cu} = ultimate axial strain of unconfined concrete corresponding to $0.85f_c'$ or maximum usable strain of unconfined concrete, in./in.

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occur at $f_c = 0.85f'_c$ or $\epsilon_c = 0.003$, depending on the obtained stress-strain curve

ϵ_{fd} = debonding strain of externally bonded FRP reinforcement, in./in.
 ϵ_{fe} = effective strain in FRP reinforcement attained at failure, in./in.
 ϵ_{fu} = design rupture strain of FRP reinforcement, in./in.
 ϵ_{fu}^* = rupture strain of FRP reinforcement, in./in.
 ϵ_{pe} = effective strain in prestressing steel after losses, in./in.

ϵ_{ps} = strain in prestressed reinforcement at nominal strength, in./in.

ϵ_{sy} = strain corresponding to yield strength of nonprestressed steel reinforcement, in./in.
 ϵ_t = net tensile strain in extreme tension steel reinforcement at nominal strength, in./in.
 ϵ_t' = transition strain in stress-strain curve of FRP-confined concrete, in./in.
 η = parameter that combines the effects of member continuity and applied load pattern for producing maximum factored moment at the critical section under consideration
 ϕ = strength reduction factor
 κ_a = shape factor for FRP reinforcement in determination of f'_{cc} (based on geometry of cross section)
 κ_b = shape factor for FRP reinforcement in determination of ϵ_{ccu} (based on geometry of cross section)
 κ_v = bond-dependent coefficient for shear
 ρ_g = ratio of area of longitudinal steel reinforcement to cross-sectional area of a compression member (A_s/bh)
 σ = standard deviation
 τ_b = average bond strength for near-surface-mounted FRP bars, psi
 ψ_f = FRP strength reduction factor

ϵ_{pi} = initial strain in prestressed steel reinforcement, in./in.
 ϵ_{pnet} = net strain in flexural prestressing steel at limit state after prestress force is discounted (excluding strains due to effective prestress force after losses), in./in.
 $\epsilon_{pnet,s}$ = net strain in prestressing steel beyond decompression at service, in./in.

$\epsilon_{ps,s}$ = strain in prestressing steel at service load, in./in.
 ϵ_s = strain in nonprestressed steel reinforcement, in./in.

2.2—Definitions

R2.2—Definitions

For consistent application of this Code, it is necessary that terms be defined where they have particular meaning in this Code. The definitions given are for use in application of this Code only and do not always correspond to ordinary usage. A glossary of most-used terms in concrete manufacturing, concrete design and construction,

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bond critical—application of strengthening system that relies on load transfer from the substrate to the system material achieved through bond stresses at the interface.

carbon fiber—fiber produced by heating organic precursor materials containing a substantial amount of carbon, such as rayon, polyacrylonitrile, or pitch in an inert environment.

carbon fiber-reinforced polymer—composite material comprising a polymer matrix reinforced with carbon fiber fabric, mat, or strands.

construction documents—written and graphic documents and specifications prepared or assembled that describe the location, design, materials, and physical characteristics of the elements of a project necessary for obtaining a building permit and construction of the project.

contact critical—application of strengthening system that relies on load transfer from the substrate to the system material achieved through contact or bearing at the interface.

creep rupture—breakage of a material under sustained loading at stresses less than the tensile strength.

cure—process by which the components of a thermosetting resin react to produce specified properties.

design basis code—legally adopted code requirements under which the assessment and strengthening measures are designed and constructed.

externally bonded FRP system—wet layup or precured FRP strengthening system applied to the surface of a concrete member.

fabric—two-dimensional network of woven, nonwoven, knitted, or stitched fibers; yarns; or tows.

fiber anchor—bundle of fibers having a specified length and fiber content and impregnated with resin; a portion of the anchor is embedded into the concrete substrate and the remaining portion is splayed over externally bonded fabric.

fiber content—amount of fiber present in a composite, expressed as a percentage volume fraction or mass fraction of the composite.

fiber volume fraction—ratio of the volume of fibers to the volume of the composite containing the fibers.

glass fiber—filament drawn from an inorganic fusion typically comprising silica-based material that has cooled without crystallizing.

glass fiber-reinforced polymer—composite material comprising a polymer matrix reinforced with glass fiber fabric, mat, or strands.

glass transition temperature—representative temperature of the temperature range over which an amorphous material (such as glass or a polymer) changes from (or to) a brittle, vitreous state to (or from) a plastic state.

impregnate—to saturate fibers with resin or binder.

and research in concrete is contained in “ACI Concrete Terminology,” available on the ACI website. Additional definitions relevant to FRP strengthening systems can be found in [ACI PRC-440.2](#).

FRP systems are conventionally supplied as systems to ensure the compatibility of all constituent components.

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intumescent coating—covering that swells, increasing volume and decreasing density, when exposed to fire imparting a degree of passive fire protection.

jacket—FRP system that fully encloses a concrete column member cross section and has a lap splice adequate to develop the capacity of the FRP.

laminated—multiple plies or layers of fiber reinforcement molded together.

near-surface-mounted FRP system—precured FRP strengthening system installed into grooves cut into concrete surface.

precured FRP system—collective term for all components of an FRP strengthening application that may include surface primer, adhesive, precured FRP, and protective overcoats, as applicable.

putty—thickened polymer-based resin used to prepare the concrete substrate.

saturating resins—polymer-based resin used to impregnate the reinforcing fibers, bond them in place, and transfer load between fibers.

vinyl ester resin—thermosetting reaction product of epoxy resin with a polymerizable unsaturated acid (usually methacrylic acid) that is then diluted with a reactive monomer (usually styrene).

wet layup—manufacturing process where dry fabric reinforcement is impregnated on site with a saturating resin matrix and then cured in place.

wet layup fiber-reinforced polymer system—collective term for all components of an FRP strengthening application that may include surface primer, putty, saturant, fiber fabric, mat or strands, and protective overcoats, as applicable.

witness panel—small mockup manufactured under conditions representative of field application, to confirm that prescribed procedures and materials will yield specified mechanical and physical properties.

FRP systems are conventionally supplied as systems to ensure the compatibility of all constituent components.

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CODE

COMMENTARY

CHAPTER 3—REFERENCED STANDARDS

3.1—American Concrete Institute

ACI CODE-216.1-14—Code Requirements for Determining Fire Resistance of Concrete and Masonry Construction Assemblies

ACI CODE-318-19(22)—Building Code Requirements for Structural Concrete and Commentary

ACI SPEC-440.6-08(22)—Specification for Carbon Fiber-Reinforced Polymer Bar Material for Concrete Reinforcement

ACI SPEC-440.8-13(23)—Specification for Carbon and Glass Fiber-Reinforced Polymer Materials Made by Wet Layup for External Strengthening

ACI SPEC-440.12-22—Specification for Strengthening of Concrete Structures with Externally Bonded Fiber-Reinforced Polymer (FRP) Materials using the Wet Layup Method

ACI CODE-562-21—Assessment, Repair, and Rehabilitation of Existing Concrete Structures—Code and Commentary

3.2—American Society of Civil Engineers

ASCE/SEI 7-22—Minimum Design Loads and Associated Criteria for Buildings and Other Structures

3.3—ASTM International

ASTM C882/C882M-20—Standard Test Method for Bond Strength of Epoxy-Resin Systems Used With Concrete By Slant Shear

ASTM C1583/C1583M-13—Standard Test Method for Tensile Strength of Concrete Surfaces and the Bond Strength or Tensile Strength of Concrete Repair and Overlay Materials by Direct Tension (Pull-off Method)

ASTM D570-22—Standard Test Method for Water Absorption of Plastics

ASTM D638-22—Standard Test Method for Tensile Properties of Plastics

ASTM D695-15—Standard Test Method for Compressive Properties of Rigid Plastics

ASTM D3039/3039M-17—Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials

ASTM D3418/D3418M-03—Standard Test Method for Transition Temperatures and Enthalpies of Fusion and Crystallization of Polymers by Differential Scanning Calorimetry

ASTM D4258-05(2017)—Standard Practice for Surface Cleaning Concrete for Coating

ASTM D4259-18—Standard Practice for Preparation of Concrete by Abrasion Prior to Coating Application

ASTM D7565/D7565M-10(2017)—Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures

ASTM D7682-17—Standard Test Method for Replication and Measurement of Concrete Surface Profiles Using Replica Putty

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ASTM D7957/D7957M-22—Standard Specification for Solid Round Glass Fiber Reinforced Polymer Bars for Concrete Reinforcement

ASTM E119-22—Standard Test Methods for Fire Tests of Building Construction and Materials

3.4—Underwriters Laboratories

ANSI/UL 263-11—Fire Tests of Building Construction and Materials

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CHAPTER 4—FRP SYSTEM REQUIREMENTS

CHAPTER R4—FRP SYSTEM REQUIREMENTS

4.1—General

4.1.1 FRP systems shall conform to the requirements of 4.2, 4.3, or 4.4 and be reported based on gross laminate area or nominal bar area.

4.1.2 Gross laminate area shall be taken to be equal to laminate thickness t_f multiplied by the laminate width.

4.2—Wet layup FRP systems

4.2.1 Wet layup FRP systems shall conform to the requirements of **ACI SPEC-440.8**.

4.3—Precured carbon FRP systems

4.3.1 For precured carbon FRP plates, ultimate tensile strength and mean chord tensile modulus shall be determined in accordance with ASTM D7565/D7565M or ASTM D3039/D3039M.

4.3.2 The ultimate tensile strength of precured carbon FRP, determined as the mean tensile strength of a sample of at least 20 specimens minus three times the standard deviation ($f_{fu}^* = \bar{f}_{fu} - 3\sigma$), shall not be less than 170 ksi.

R4.1—General

R4.1.1 **ACI PRC-440.2** defines the ultimate tensile strength of an FRP strengthening system (f_{fu}^*) as the mean tensile strength of a sample of at least 20 specimens minus three times the standard deviation ($f_{fu}^* = \bar{f}_{fu} - 3\sigma$). The chord tensile modulus (E_f^*) is defined as the mean chord tensile modulus of a sample of at least 20 test specimens. From these, rupture strain is determined: $\epsilon_{fu}^* = f_{fu}^*/E_f^*$.

R4.2—Wet layup FRP systems

R4.2.1 ACI SPEC-440.8 is applicable to carbon and glass fiber systems applied using the wet layup method with an epoxy resin. ACI SPEC-440.8 reports mechanical properties determined in accordance with **ASTM D7565/D7565M** in terms of tensile force and chord tensile modulus per unit width of material. To obtain the required strength and modulus in terms of gross laminate area, the reported tensile force and chord tensile modulus per unit width values are divided by the nominal laminate thickness. ASTM D7565/D7565 prescribes tensile testing in accordance with **ASTM D3039/D3039M**. Results from ASTM D3039/D3039M testing, which uses gross laminate area, can be reported directly.

Based on the requirements of ACI SPEC-440.8, minimum ultimate tensile strength and mean chord tensile modulus requirements for wet layup FRP systems are 55 ksi and 2500 ksi, respectively.

R4.3—Precured carbon FRP systems

R4.3.1 Precured carbon FRP plates are used for externally bonded and, when cut into strips, near-surface-mounted (NSM) applications. Mechanical properties determined in accordance with ASTM D7565/D7565M are reported in terms of tensile force and chord tensile modulus per unit width of material. To obtain the required strength and modulus in terms of gross laminate area, the reported tensile force and chord tensile modulus per unit width values are divided by the nominal FRP laminate thickness. ASTM D7565/D7565 prescribes tensile testing in accordance with ASTM D3039/D3039M. Results from ASTM D3039/D3039M testing, which uses gross laminate area, can be reported directly.

