

**INTERNATIONAL ASSOCIATION OF PLUMBING AND MECHANICAL OFFICIALS
UNIFORM EVALUATION SERVICES****EVALUATION CRITERIA FOR
DIAPHRAGM STRENGTHENING USING FIBER REINFORCED POLYMERS****EC 038-2019
(Adopted September 13, 2019)****1.0 INTRODUCTION**

- 1.1 Purpose:** This Evaluation Criteria establishes the requirements for fiber reinforced polymer (FRP) to be recognized in an evaluation report independently reviewed and issued by an evaluation service agency under the International Building Code® (IBC), the International Residential Code® (IRC), and the California Building Code® (CBC). Basis of recognition is IBC Section 104.11, IRC Section R104.11, and CBC Section 104.11.

This Evaluation Criteria provides requirements for the evaluation of fiber reinforced polymers to supplement the requirements provided in the IBC, the IRC, the CBC, or other associated standards for these products. The reason this criteria was developed is to provide guidelines for diaphragm strengthening using FRP since the IBC, IRC, and CBC do not provide requirements for testing and determining the structural capacities, reliability, and serviceability of these products for this purpose.

The information generated in accordance with this criteria may be used by design professionals to design diaphragm strengthening using FRP that complies with the prequalification testing requirements of Section 4.0 of this criteria. In order to demonstrate compliance with Section 4.0 of this criteria, a manufacturer shall acquire an evaluation report for the FRP product in accordance with Section 7.0 of this criteria.

- 1.2 Scope:** The scope of this criteria is for using externally bonded fiber reinforced polymers (FRP) to strengthen reinforced concrete diaphragms resisting seismic motions and loadings. This criteria is applicable to wet layup FRP systems composed of high-strength fiber reinforced sheets, or fabrics, combined with a polymer resin. This criteria does not include prefabricated systems such as FRP plates, rods or near-surface-mounted systems. Other requirements for strengthening concrete with FRP shall be in accordance with the IBC, ACI 318, ACI 440.2R, and AC125.

The criteria provides guidelines to calculate, test and evaluate diaphragm shear, chord and collector enhancement using externally bonded FRP. This criteria shall apply to the following diaphragm systems with existing conventional or prestressed (post-tensioned) reinforcement:

1. Monolithic cast-in-place concrete diaphragms.
2. Cast-in-place, composite concrete topping slab diaphragms on precast floors or roofs at least two inches (51 mm) thick, provided the cast-in-place topping slab is reinforced and the surface of the previously hardened concrete on which the topping slab is placed is clean, free of laitance, and intentionally roughened.
3. Cast-in-place, non-composite concrete topping slab diaphragms at least 2½ inches (63 mm) thick, provided the cast-in-place topping slab is detailed for continuous seismic load path to vertical lateral-force-resisting elements.

1.2.1 Limitations and Additional Considerations:

1. Measures shall be taken to mitigate thermal stresses that may develop from FRP reinforcement exposure to direct sunlight. For example, at roof diaphragm applications, shade or emissive coating may need to be provided to minimize potential for temperature elongation or shrinkage.
2. Detailed considerations for the shear transfer mechanism and related diaphragm shear strength are required for untopped precast concrete diaphragms. The failure mechanism in untopped concrete diaphragms is generally not expected to follow the same assumed truss action as occurs in conventional concrete, and special consideration is required at shear transfer between adjacent precast elements and into the supporting vertical elements. Some other considerations for untopped precast concrete diaphragms may include decreased composite action due to axial shortening from shrinkage cracking at interfaces between cast-in-place concrete and precast elements as well as axial elongation in the seismic lateral-force-resisting system beams. Although there are detailing considerations provided in Section 5.0 of this criteria, this criteria does not provide comprehensive design recommendations for untopped precast diaphragms.
3. Only the topped concrete portion of non-prismatic diaphragm systems shall be considered effective for seismic shear strength, such as in concrete over metal deck or waffle slab applications, unless specific component testing is provided to justify alternative values.
4. The compressive strength of the existing diaphragm elements, f'_c , shall be a minimum of 2,500 psi (17.2 MPa).
5. Care shall be taken to avoid damage to (prestressed) post-tensioned reinforcement, where present in diaphragms, by post-installed FRP anchorage.

1.3 Definitions: For terms not defined in this section, applicable codes, or referenced standards shall have the ordinary accepted definition for the context for which they are intended.

1.3.1 Additives: Substances added to the polymer resin to aid in processing of the FRP material.

1.3.2 Carbon fiber reinforced polymer (CFRP): A composite material comprising a polymer matrix reinforced with a carbon fiber fabric.

1.3.3 Composite: Engineering materials (for example, concrete and FRP) made from two or more constituent materials that remain distinct but combine to form materials with properties not possessed by any of the constituent materials individually; the constituent materials are generally characterized as matrix and reinforcement.

1.3.4 Embedded Fiber Anchor: A post-installed FRP anchor placed into pre-drilled holes saturated with polymer resin.

1.3.5 Evaluation Service Agency: Organization evaluating building products or finished construction for conformance to applicable codes and standards and publishing report or listing documents summarizing conclusions. The agency shall be accredited for the applicable product scope in accordance with ISO/IEC Standard 17065. The agency's accreditation shall be issued by an accreditation body conforming to ISO/IEC 17011 and that is a signatory of the International Laboratory Accreditation Cooperation (ILAC) Mutual Recognition Arrangement (MRA) or another approved agency.

1.3.6 Fabric: A two-dimensional network of woven, nonwoven, knitted or stitched fibers, rovings or tows.

1.3.7 Fabric, Reinforcing: Continuous carbon, glass and aramid fibers are common reinforcements used in reinforcing fabrics. The reinforcing fabric provides strength and stiffness to the FRP system. The reinforcing fabric architecture may vary and may provide either uniaxial or multiaxial strength to the system. Most structural reinforcement applications will consist of a unidirectional laminate architecture.

1.3.8 Fiber-reinforced polymer (FRP): A general term for a composite material comprising a polymer matrix reinforced with fibers in the form of a fabric. Reference is made to **Composite**.

- 1.3.9 Filler:** A finely divided, relatively inert material, such as silica fume, added to resin to improve workability, reduce cost or reduce density.
- 1.3.10 Fiber Splice Anchor:** An FRP anchor used for developing tension forces either between separate FRP sheets or between an FRP sheet and concrete, usually used to transition through an existing intersecting concrete component.
- 1.3.11 Force-Controlled Action:** An action that is not allowed to exceed the nominal strength of the element being evaluated. Force-controlled actions and their acceptance criteria are prescribed in Chapter 7.5 of ASCE/SEI 41 when this criteria is used in conjunction with ASCE/SEI 41. Force-controlled actions are classified as seismic load effects including Overstrength Factor when this criteria is used in conjunction with ASCE/SEI 7.
- 1.3.12 Fully Anchored:** Mechanical anchorage that is capable of developing the ultimate and maximum strength of the bonded FRP laminate.
- 1.3.13 Glass fiber reinforced polymer (GFRP):** A composite material comprising a polymer matrix reinforced with glass fiber fabric.
- 1.3.14 Laminate:** A single or multiple plies of reinforced fabric and resin molded together.
- 1.3.15 Lay-up, dry:** The process of saturation of reinforcing fabric with resin after the fabric has already been placed onto the host structure.
- 1.3.16 Lay-up, wet:** The process of on-site saturation of the reinforcement fabric with resin followed by application of the saturated fabric to the host structure to cure in-place.
- 1.3.17 Polymer:** The product of polymerization; more commonly a rubber or resin consisting of large molecules formed by polymerization.
- 1.3.18 Quasi-static:** Loading that mimics dynamic loads but is slow enough that the inertial and strain-rate effects on the test specimen are negligible.
- 1.3.19 Resin:** Generally, a thermosetting polymer used as the matrix and binder in FRP composites.
- 1.3.20 Resin, epoxy:** A class of organic chemical bonding systems used in the preparation of special coatings or adhesives for concrete or as binders in epoxy-resin mortars, concretes and FRP composites.
- 1.3.21 Tow:** An untwisted bundle of continuous filaments.
- 1.3.22 Unit Fiber Weight:** The measured dry carbon or glass fiber weight per unit length of reinforcing fabric or fiber anchor.

1.4 Notation

A_{cv} = gross area of concrete section, not to exceed the thickness times the width of the diaphragm, in.² (mm²)

A_{Eqv} = equivalent laminate area of an anchor, in.² (mm²)

A_{fv} = area of FRP shear reinforcement with spacing s , in.² (mm²)

b_w = unit width of diaphragm analyzed for strengthening, in. (mm)

b_f = effective fiber design width for fiber contribution to collector element, in. (mm)

- d = distance from extreme compression fiber to centroid of longitudinal tension reinforcement, in. (mm)
- d_{fv} = effective depth of FRP shear reinforcement, in. (mm)
- E_f = tensile modulus of elasticity of FRP, psi (MPa)
- f'_c = specified compressive strength of concrete, psi (MPa)
- f_{fe} = effective stress in the FRP reinforcement; stress attained at nominal strength, psi (MPa)
- 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
- κ_v = bond-dependent coefficient for shear
- l_d = development length
- L_e = active bond length of FRP reinforcement, in. (mm)
- n = number of layers of FRP reinforcement
- t_f = nominal thickness of one ply of FRP reinforcement, in. (mm)
- V_c = nominal shear strength supplied by concrete with steel tension reinforcement, lb (N)
- V_f = nominal shear strength provided by FRP reinforcement, lb (N)
- V_n = nominal shear strength, lb (N)
- V_s = nominal shear strength supplied by steel shear reinforcement, such as stirrups, lb (N)
- ϵ_{fe} = effective strain in FRP reinforcement at nominal strength, in./in. (mm/mm)
- ϵ_{fu} = design rupture strain of FRP reinforcement, in./in. (mm/mm)
- λ_A = dry fiber weight per unit length of an anchor, oz./in.
- $\gamma_{s,Exp}$ = dry fiber weight per square surface area of a laminate, oz./in.²
- ϕ = strength reduction factor
- ψ_f = FRP strength reduction factor
- θ = orientation angle of fiber – primary fiber direction

2.0 REFERENCED STANDARDS AND DOCUMENTS

Standards shall be applied consistent with the specific edition of the code(s) for which the Evaluation Report is prepared unless otherwise approved by UES.

2.1 American Concrete Institute

- American Concrete Institute, ACI 318-14 Building Code Requirements for Structural Concrete and Commentary.

- American Concrete Institute, ACI 355.4-11 Qualification of Post-Installed Adhesive Anchors in Concrete and Commentary.
- American Concrete Institute, ACI 369.1-17 Standard Requirements for Seismic Evaluation and Retrofit of Existing Concrete Buildings (369.1) and Commentary.
- American Concrete Institute, ACI 374.2R-13 Guide for Testing Reinforced Concrete Structural Elements under Slowly Applied Simulated Seismic Loads.
- American Concrete Institute, ACI 440.8-13, Specification for Carbon and Glass Fiber-Reinforced Polymer Materials Made by Wet Layup for External Strengthening.
- American Concrete Institute, ACI 440.2R-17, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.

2.2 American Society of Civil Engineers

- ASCE/SEI 41, Seismic Evaluation and Retrofit of Existing Buildings.
- ASCE/SEI 7, Minimum Design Loads and Associated Criteria for Buildings and Other Structures.

2.3 ASTM International

- ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials, ASTM International.
- ASTM D4541, Standard Test Method for Pull-off Strength of Coating Using Portable Adhesive-Testers, ASTM International.
- ASTM D7522/D7522M, Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate, ASTM International.
- ASTM D7565, Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures, ASTM International.
- ASTM E575, Standard Practice for Reporting Data from Structural Tests of Building Constructions, Elements, Connections, and Assemblies.

2.4 Center for Transportation Research

- CTR Technical Report 0-6306-1, Shear Strengthening of Large Reinforced and Prestressed Concrete Elements Using Carbon Fiber Reinforced Polymer (CFRP) Sheets and CFRP Anchors, Rev February 2012.
- CTR Technical Report 0-6783-1, Use of Carbon Fiber Reinforced Polymer (CFRP) with CFRP Anchors for Shear-Strengthening and Design Recommendations/Quality Control Procedures for CFRP Anchors, March 2017.

2.5 Federal Emergency Management Agency

- FEMA 461, Interim Testing Protocols for Determining the Seismic Performance Characteristics of Structural and Nonstructural Components, June 2007.

2.6 International Code Council

- International Building Code (IBC) 2018, 2015, 2012.
- International Residential Code (IRC) 2018, 2015, 2012.
- California Building Code (CBC) 2019, 2016, 2013.
- ICC-ES AC125, Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber-Reinforced Polymer (FRP) Composite Systems.
- ICC-ES AC178, Acceptance Criteria for Inspection and Verification of Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) Composite Systems.

2.7 International Organization for Standardization

- ISO/IEC 17011:2004, Conformity Assessment, General Requirements for Accreditation Bodies Accrediting Conformity Assessment Bodies.
- ISO/IEC 17020:2012 Conformity Assessment, Requirements for the Operation of Various Types of Bodies Performing Inspection.
- ISO/IEC 17025:2005, General requirements for the Competence of Testing and Calibration Laboratories, International Organization for Standardization.
- ISO/IEC 17065:2012, Conformity assessment – Requirements for Bodies Certifying Products, Processes and Services, International Organization for Standardization.