ACCEPTANCE CRITERIA FOR INSPECTION AND VERIFICATION OF CONCRETE AND REINFORCED AND UNREINFORCED MASONRY STRENGTHENING USING FIBER-REINFORCED POLYMER (FRP) COMPOSITE SYSTEMS

AC178

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PREFACE

Evaluation reports issued by ICC Evaluation Service, Inc. (ICC-ES), are based upon performance features of the International family of codes and other widely adopted code families, including the Uniform Codes, the BOCA National Codes, and the SBCCI Standard Codes. Section 104.11 of the *International Building Code*® reads as follows:

> The provisions of this code are not intended to prevent the installation of any materials or to prohibit any design or method of construction not specifically prescribed by this code, provided that any such alternative has been approved. An alternative material, design or method of construction shall be approved where the building official finds that the proposed design is satisfactory and complies with the intent of the provisions of this code, and that the material, method or work offered is, for the purpose intended, at least the equivalent of that prescribed in this code in quality, strength, effectiveness, fire resistance, durability and safety.

Similar provisions are contained in the Uniform Codes, the National Codes, and the Standard Codes.

This acceptance criteria has been issued to provide all interested parties with guidelines for demonstrating compliance with performance features of the applicable code(s) referenced in the acceptance criteria. The criteria was developed and adopted following public hearings conducted by the ICC-ES Evaluation Committee, and is effective on the date shown above. All reports issued or reissued on or after the effective date must comply with this criteria, while reports issued prior to this date may be in compliance with this criteria or with the previous edition. If the criteria is an updated version from the previous edition, a solid vertical line (**I**) in the margin within the criteria indicates a technical change, addition, or deletion from the previous edition. A deletion indicator (➜) is provided in the margin where a paragraph has been deleted if the deletion involved a technical change. This criteria may be further revised as the need dictates.

ICC-ES may consider alternate criteria, provided the report applicant submits valid data demonstrating that the alternate criteria are at least equivalent to the criteria set forth in this document, and otherwise demonstrate compliance with the performance features of the codes. Notwithstanding that a product, material, or type or method of construction meets the requirements of the criteria set forth in this document, or that it can be demonstrated that valid alternate criteria are equivalent to the criteria in this document and otherwise demonstrate compliance with the performance features of the codes, ICC-ES retains the right to refuse to issue or renew an evaluation report, if the product, material, or type or method of construction is such that either unusual care with its installation or use must be exercised for satisfactory performance, or if malfunctioning is apt to cause unreasonable property damage or personal injury or sickness relative to the benefits to be achieved by the use of the product, material, or type or method of construction.

Acceptance criteria are developed for use solely by ICC-ES for purposes of issuing ICC-ES evaluation reports.

ACCEPTANCE CRITERIA FOR INSPECTION AND VERIFICATION OF CONCRETE AND REINFORCED AND UNREINFORCED MASONRY STRENGTHENING USING FIBER-REINFORCED POLYMER (FRP) COMPOSITE SYSTEMS (AC178)

1.0 INTRODUCTION

1.1 Scope: This criteria establishes minimum requirements for the inspection of both prefabricated and field-applied fiber-reinforced polymer (FRP) composite systems recognized under the ICC-ES Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems (AC125) in ICC-ES evaluation reports under the 2006 *International Building Code*® (IBC) and 1997 *Uniform Building Code*™ (UBC).

The reason for the development of this criteria is to provide minimum requirements for the inspection of both prefabricated and field-applied fiber-reinforced polymer (FRP) composite systems , since the codes do not provide requirements.

1.2 References:

1.2.1 2006 *International Building Code*® (IBC), International Code Council.

1.2.2 1997 *Uniform Building Code*™ (UBC), International Conference of Building Officials.

1.2.3 ACI 546R, 2004, Concrete Repair Guide, American Concrete Institute.

1.2.4 ACI 503R, 1993, Use of Epoxy Compounds with Concrete (reapproved 2008), American Concrete Institute.

1.2.5 ASTM D 33039D/3039M-2007, Standard Test Method for Properties of Polymer Matrix Composite Materials, ASTM International.

1.2.6 ASTM D 3418-2003, Standard Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry, ASTM International.

1.2.7 ASTM D 4541-2002 Standard Test Method for Pull-off Strength of Coatings Using Portable Adhesion Testers, ASTM International.

1.2.8 ISO/IEC Standard 17025, 1999, General Requirements for the Competence of Testing and Calibration Laboratories, International Organization for Standardization.

1.2.9 ICC-ES Acceptance Criteria for Test Reports (AC85).

1.2.10 ISO/IEC 17020, 1998, General Criteria for the Operation of Various Types of Bodies Performing Inspection, International Organization for Standardization.

1.2.11 ISO/IEC Guide 58, 1993, Calibration and Testing Laboratory Accreditation Systems - General Requirements for Operation and Recognition, International Organization for Standardization.

1.2.12 ICC-ES Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-reinforced Composite Systems (AC125).

1.2.13 ICRI Guideline No. 03730, 1995, Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion, International Concrete Repair Institute.

1.2.14 ICRI Guideline No. 03732, 1997, Guide for Selecting and Specifying Surface Preparation for Sealers, Coatings and Membranes, International Concrete Repair Institute.

1.3 Definitions:

1.3.1 Fiber-reinforced Polymer (FRP) Composite System: For purposes of this criteria, the definition shall conform to the definition in ICC-ES AC125.

1.3.2 Composite Material: A combination of high-strength fibers and polymer matrix material. This composite may be applied either during manufacture of the structural element or after construction. The FRP composite can be either precured or preimpregnated (prepreg) off-site by the manufacturer under controlled conditions, or can be composed at the site using wet lay-up method or any other approved method.

1.3.2.1 Precured: These composites consist of a fiber or fiber sheet material containing resin applied off-site, and are cured off-site with the application of heat, pressure, water or other substances. The resulting materials are in the form of sheets, grids or shells.

1.3.2.2 Preimpregnated (prepreg): These composites consist of a fiber or fiber sheet material containing resin applied off-site, that is advanced to a tacky consistency. Multiple plies of prepreg are typically cured in the field with the application of heat, pressure, water or other substances.

1.3.2.3 Wet lay-up: A method of preparing a laminate product at the jobsite by applying the resin system as a liquid when the fabric or mat is put in place.

1.3.3 Engineer: For purposes of this criteria, the "engineer" must be approved by owner for the specific project. When "engineer" is used in combination with "licensed," "registered" or "professional," the terms are to be considered interchangeable.

1.3.4 Testing Laboratories: Testing laboratories shall comply with Section 2.0 of the ICC-ES Acceptance Criteria for Test Reports (AC85) and Section 4.2 of the ICC-ES Rules of Procedure for Evaluation Reports.

1.3.5 Inspector: Must be employed by an inspection agency accredited by the International Accreditation Service (IAS), and approved by the code official.

2.0 REQUIRED INFORMATION

Inspector must receive from the contractor:

2.1 Project drawings from engineer.

2.2 Project specifications from engineer.

2.3 Installation instructions approved by the engineer. These shall include the following items:

1. Description of how the product or system will be used, installed, cured, and protected at the site.

2. Procedures establishing quality control in field installation.

3. Requirements for product handling, storage and disposal.

4. Anchor or joining details (including composite and noncomposite details, e.g., wall footing, beam-to-column) installation into structural elements.

2.4 Quality control manual for specified FRP composite system.

2.5 Proof of installer's certification for FRP composite system, as per Annex A.

3.0 REQUIRED INSPECTION

Inspector shall be at the jobsite during the composite system application for the following purposes:

3.1 To document that all materials conform to the ICC-ES evaluation report, engineering drawings and specifications.

3.2 To verify completed surface preparation as per Section 5.0.

3.3 To verify at least two batch mixes of resin, primer and adhesives per day, as per Section 6.2. For precured or preimpregnated laminates, the mixing of resin used to saturate the composite fibers shall be monitored in the manufacturing plant, and the verification requirements shall be addressed in the manufacturer's quality control manual. [For precured or preimpregnated laminates that require field application of adhesives (having more than one constituent) for bonding to the substrate or field application of resins (having more than one constituent) for bonding of two laminates together, the field verification of such adhesive or resin batch mixes shall comply with this Section and Section 6.2.]

3.4 To verify proper application of resin to fibers for wet lay-up systems, and the proper application of adhesives for precured or preimpregnated laminates as per Section 6.0. For precured or preimpregnated laminates, the application of the resin to the composite fibers shall be monitored in the manufacturing plant, and the verification requirements shall be addressed in the manufacturer's quality control manual.

3.5 To spot-check at least five areas per day, to verify fiber alignment, number of layers, and the direction of fibers of each layer (as per Sections 6.6–6.9).

3.6 To verify proper curing of composite system, as per Section 7.0.

3.7 To examine each segment of entire project upon completion of installation, through at least visual inspection and sounding.

3.8 To verify correct preparation and curing of test samples as per, Section 9.0.

3.9 To verify that all required testing is performed by an accredited testing laboratory and to witness all field testing, as per Section 9.0.

3.10 To identify and map any defects or substandard areas, as per Section 8.1.

3.11 To inspect the repair of all defects and verify that they meet engineer's recommendations (as per Section 8.2).

3.12 To inspect composite for galvanic corrosion. There should be no direct contact between any FRP composite carbon-based system and any metallic parts, including newly installed details required for the strengthening system (such as steel angles, plates, bolts and any other existing metallic part). If such conditions exist, the engineer shall be notified immediately.

4.0 INSPECTION OF MATERIALS

4.1 Inspector must verify that the specified FRP composite system is being applied. This includes verifying the following:

4.1.1 Fabric certificate of compliance in accordance with ICC-ES evaluation report, plans and specifications.

4.1.2 Polymer matrix certificate of analysis in accordance with ICC-ES evaluation report, plans and specifications. Polymer resins shall be verified to be within shelf life specifications.

4.1.3 Coating system certification in accordance with ICC-ES evaluation report, plans and specifications, if required.

4.2 Inspector must verify that all materials are stored as per manufacturer's recommendations.

5.0 SURFACE PREPARATION

5.1 Surface must be properly prepared as per manufacturer's recommendations. Surface preparation requirements are based upon intended application of composite material and the type of substrate. Applications of FRP composite systems are divided into two categories: contact-critical and bond-critical. For example, columns wrapped for confinement are a contact-critical application, and one-sided wall applications are a bond-critical.

5.1.1 Contact-critical applications require complete contact between the FRP composite system and the structural member. At a minimum, the surface to receive composite shall be free from fins, sharp edges and protrusions that may cause voids behind the installed casing or that may damage the fibers. One of the most important steps is removing any unsound concrete or masonry and repairing these areas using a compatible bonding agent and epoxy mortar according to ACI 546R and ICRI Guidelines No. 03730. Uneven existing surfaces may be filled with resin filler or other material approved by the engineer. Well-adhered paint may not require removal, as long as it is compatible with the specified FRP composite system and is approved by the engineer. Sharp and chamfered corners must be rounded as per the ICC-ES evaluation report, plans and specifications, when they are perpendicular to the direction of major reinforcement.

5.1.2 Bond-critical applications require a complete bond between the FRP system and the structural member. The surface to receive composite shall be free from fins, sharp edges and protrusions that will cause voids behind the installed casing or that will damage the fibers. Existing uneven surfaces may be filled with resin filler or other material approved by the engineer. As for contact-critical applications, the most important step is removing any unsound concrete or masonry and repairing these areas

using a compatible bonding agent and epoxy mortar according to ACI 546R and ICRI Guidelines No. 03730. Surface preparation should be in accordance with the recommendations of ACI 546R and ICRI Guideline No. 03730. The concrete surface should be prepared to a minimum amplitude as per plans and specifications. Sharp and chamfered corners must be rounded as per the ICC-ES evaluation report, plans and specifications, when the corners are perpendicular to the direction of major reinforcement.

5.2 A system-compatible primer should be applied to the surface to receive composite. The primer should be placed uniformly on prepared surface as per manufacturer's specifications.

6.0 INSTALLATION OF FRP COMPOSITE SYSTEM

6.1 Verify ambient and concrete temperatures and surface dryness.

Conditions of Acceptance: No work shall proceed if the temperature of the air or the concrete surface being repaired or strengthened is outside the range of the manufacturer's recommendations. The humidity and dew point are to be considered as per manufacturer's recommendations. All surfaces shall meet moisture content recommendations of the FRP composite system manufacturer.

6.2 Verify resin and/or adhesive mixes.

Conditions of Acceptance: Prepare the resin or adhesive mix by combining components by the weight or volume ratio specified by the manufacturer. The components of the resin or adhesive shall be mixed through use of a mechanical mixer. Complete combination of all components shall be verified as per manufacturer's specs. No modifications of the resin or adhesive system are allowed, excluding manufacturer prefabricated additives approved by the registered design professional and the code official.

(For precured or preimpregnated laminates requiring application of resin to the composite fibers in the manufacturing plant, the requirements for verification of resin mixes are as noted in Section 3.3)

6.3 Verify proper saturation for wet lay-up systems.

Conditions of Acceptance: Wetting of the fabric shall be performed according to manufacturer's specified fiber-resin ratio approved by the engineer. Full saturation of the fibers must be achieved. A calibrated saturation machine may be used to ensure proper fiber-resin ratio. If hand saturation or any other method is being used, a field test must be performed to verify that the correct amount of resin is being applied as per manufacturer's recommendations.

(For precured or preimpregnated laminates requiring application of resin to the composite fibers in the manufacturing plant, the requirements for verifying proper saturation are as noted in Section 3.4.)

6.4 Verify precured systems.

Conditions of Acceptance: The precured laminates or panels shall be adhered to the wet adhesive in a manner recommended by the manufacturer.

6.5 Verify proper application.

Conditions of Acceptance: Pockets of air between layers should be released or rolled out before the resin sets.

6.6 Verify fiber orientation.

Conditions of Acceptance: Fiber orientation shall comply with project plans and specifications. A misalignment of more than 1 inch per foot (8 centimeters per meter) shall be reported to the engineer. Also, any fabric kinks, folds or severe waviness shall be reported by the inspector to the engineer.

6.7 Verify splice and overlap.

Conditions of Acceptance: All splices and overlaps shall comply with project plans and specifications.

6.8 Verify number of layers.

Conditions of Acceptance: Completed application must have the specified number of layers per the engineering drawings.

6.9 Verify application of special coatings.

Conditions of Acceptance: Where required, all special coatings shall be applied per manufacturer's recommendations described in the project specifications. Also, verify that the coating being applied is compatible with the FRP composite system.

7.0 EVALUATION OF CURING

Conditions of Acceptance: Cure temperature ranges and corresponding curing times shall be determined by the manufacturer. For preimpregnated systems that require field application of heat, pressure, water or other means of curing, the inspector shall perform evaluations per the manufacturer's recommendations. The inspector can evaluate relative cure of the resin by visual observation of resin tackiness and the hardness of retained resin samples relative of the surrounding temperature. Samples shall be handled with care so as to not affect the cure. For precured or preimpregnated systems, adhesive hardness evaluation should follow manufacturer's recommendation. The composite system shall be protected from weather and other damaging conditions as per manufacturer's recommendations, until cured.

8.0 IDENTIFICATION AND REPAIR OF DEFECTS

8.1 All installed areas shall be visually inspected for defects. The installed composite shall be completely adhered to the substrate. Any suspect areas should be sounded with a ball peen hammer. A light tapping will indicate the presence of any voids behind the installed composite. Caution should be used so as not to damage the installed composite system during inspection. Inspector shall map all defects and the corresponding repairs after approval by the engineer.

Conditions of Acceptance:

a. Small entrapped air pockets and voids [on the order of $^1/_{16}$ inch (1.6 mm) - $^1/_8$ inch (3.2 mm) diameter] naturally occur in mixed resin systems and do not require repair or treatment.

b. Except at the edges or boundaries, delaminations of less than 2 square inches (13 square centimeters) are permissible. No more than 10 delaminations of this size shall be allowed per 10 square feet (approximately 1 meter

squared) of the laminated area. Delaminations larger than 2 square inches (13 square centimeters) shall be repaired by any method approved by the engineer.

c. Any delaminations spanning more that 5 percent of the surface area shall be repaired by any method approved by the engineer.

8.2 Inspector shall supervise repair of all defects.

Conditions of Acceptance: Repairs can be performed by backfilling delaminations with resin or replacing the damaged section. Repairs shall be made in accordance with project specifications and the engineer's recommendations.

8.3 Precured system.

Conditions of Acceptance: Each defect shall be evaluated and repaired according to the manufacturer's procedures approved by the engineer.

9.0 TESTING REQUIREMENTS

9.1 Testing of FRP Composite Wet Lay-up Systems: A minimum of two sample sets measuring 12 inches by 12 inches (30 cm by 30 cm), made of two composite layers, with the major reinforcement in the same direction for both layers, should be fabricated for testing each day the wet lay-up system is applied. Samples shall be tested by accredited laboratories per ASTM D 3039. Test reports shall comply with ICC-ES AC85. Each sample shall be coded and dated, and shall be accompanied with the site environmental information such as temperature and relative humidity. These samples shall be cured at the site under the same environmental conditions. The engineer shall determine the required percentage of coupons requiring testing. It is recommended that a minimum of 15 percent of all sample sets be tested. If the tested samples do not meet the conditions of acceptance, it is recommended that 25 percent of all sample sets be tested.

Conditions of Acceptance: Tensile properties must meet or exceed FRP composite system properties as defined in project specifications. If one coupon does not achieve the design properties, additional coupons from the same sample shall be tested. If these coupons fail (on average), coupons from the other 12-inch-by-12-inch sample, from the same batch for that day, shall be tested.

9.2 Testing of Precured Systems: Four sets of samples shall be tested per job. Samples shall be tested by accredited laboratories per ASTM D 3039. Test reports shall comply with ICC-ES AC85.

Conditions of Acceptance: Tensile properties must meet or exceed FRP composite system properties as defined in project specifications. If one coupon does not achieve the design properties, additional coupons from the same sample shall be tested. If these coupons fail (on average), coupons from the other 12-inch-by-12-inch sample, from the same batch for that day, shall be tested.

9.3 Field-testing: Inspector shall be present to supervise all field-testing. The following tests may be performed at the request of the owner, engineer or inspector, but are not required:

9.3.1 Pull-off Test: Testing shall be conducted in accordance with ASTM D 4541 or ACI 503R.

9.3.2 Resin Test: Test shall comply with ASTM D 3418. If resin does not meet project specifications, the engineer must be notified, and the affected area of the FRP must be removed and replaced.

9.3.3 Cured Thickness Test: Small core samples may be taken to ascertain the laminate thickness and/or number of plies. After sampling, hole should be filled as per manufacturer's recommendations. Taking samples from high-stress or splice areas should be avoided.

Conditions of Acceptance: All results must meet project specifications. If material fails to meet specifications, repairs must be made according to engineer-approved methods.

10.0 REQUIRED DOCUMENTATION PROVIDED BY INSPECTOR

Daily inspection reports shall include:

10.1 Date and time of installation.

10.2 Ambient temperature and general atmospheric observations.

10.3 Surface temperature of structural member to be strengthened.

10.4 Surface dryness.

10.5 Surface preparation methods and the resulting profile.

10.6 Surface cleanliness.

10.7 Widths of cracks not injected with epoxy.

10.8 Fiber or prefabricated-cured laminate batch number(s) and approximate location in structure.

10.9 Batch numbers, mix ratios, mixing times, and mixed color of all resins, including primers, saturants, adhesives and coatings mixed for the day.

10.10 Observations on progress of cure of resins.

10.11 Conformance with installation procedures.

10.12 FRP system properties from panel test (if required).

10.13 Results from field tests (if required).

10.14 Location and size of any delaminations or air voids.

10.15 General progress of work.

Note: A sample copy of the FRP system inspection checklist is provided in Appendix A.■

ANNEX A

Fiber-reinforced Polymer (FRP) Composite System Installer's Certification

Name of fiber-reinforced polymer (FRP) composite system:

_____

_____

_____

_____

Fiber-reinforced polymer (FRP) composite system manufacturing company name and address:

_____

_____

_____

Telephone number: _____

	INSTALLATION	**CONFORMS**
A.	Designer's requirements, details and instructions	_____
B.	Manufacturer's details and requirements	_____

The information entered above is offered in testimony that the fiber-reinforced polymer (FRP) composite system installation conforms to the FRP composite system manufacturer's installation methods and procedures.

Fiber-reinforced polymer (FRP) composite system installer company name and address:

_____

_____

_____

Signature of responsible officer for certification: _____

Typed name and title of officer: _____

Telephone number: (_____) _____

ANNEX A

Fiber-reinforced Polymer (FRP) Composite System Inspection Checklist

Project Name: _____

Location: _____

Required Information for Project to Proceed:

- Project drawings
- Project specifications
- Installation instructions
- Quality control manual
- Installer's certification (See Annex A)
- ICC-ES evaluation report

_____

Date: _____ Time In: _____ Time Out: _____

Temperature: Relative Humidity:

General Weather: _____

Surface Temperature of Element to Receive FRP Composite: _____

1. What is the specified FRP composite system being used?
2. Has the installer's certification been verified?
3. Are materials being stored as per manufacturer's recommendations?
4. Are environmental conditions within the manufacturer's recommendations for application?
5. Has surface prep been completed per project or manufacturer's specification?
6. What is the resulting surface profile?
7. Is surface free of dust, debris, oil or other contaminants?
8. Record lot numbers for all fiber or prefabricated-cured laminates to be used today.
9. Record all lot and batch numbers for resins, primers, saturants, etc.
10. Have two random batches of resins been checked to assure proper mix ratio?
11. Have resins been mixed per manufacturer's specification?
12. For wet lay-up systems, are fibers being saturated using the manufacturer's recommended procedure?
13. Is the proper fiber-resin ratio being achieved?
14. Have composites been installed per project plans and manufacturer's specifications, including proper orientation, alignment, required number of layers, and required splices and overlaps?
15. Has any entrapped air been released from between layers?
16. Record location(s) of installation in structure.
17. Have resins been checked to ensure proper progress of curing?
18. Have all edges and seams been protected with system compatible resin?
19. Have all test samples been made and environmental information been included?
20. Record name of accredited laboratory to be used for testing.
21. Record results from any field tests.
22. Have repairs been made if field testing does not meet project specifications?
23. Record (map) the location of delaminations or voids.
24. Have delaminations or voids been repaired per manufacturer's specification?
25. Have required coatings, including fireproofing, been blended and applied per manufacturer's specification?
26. Upon completion, has entire project been visually inspected, including sounding?
27. Has final certification been issued by inspector that the installed system meets all specified requirements?

Inspector Signature _____

Date _____

Owner Signature _____

Date _____