

Externally Bonded Fiber Reinforced Polymer (FRP) Strengthening System

General 2010 Specification

1 GENERAL

1.1 DESCRIPTION OF WORK

- .1 This specification is intended to define the minimum requirements of structural strengthening using externally bonded fiber reinforced polymer (FRP) composite systems.
- .2 The work includes the furnishing of all materials, labor, equipment and services for the supply, installation and finish of all structural strengthening using externally bonded FRP composite system.
- .3 The general contractor or subcontractor shall furnish all materials, tools, equipment, transportation, necessary storage, access, labor and supervision required for the proper installation of the externally bonded FRP composite system.

1.2 WORK INCLUDED

- .1 This Section of the Specification is not necessarily complete in itself. Read in conjunction with the Contract Document.

1.3 REFERENCE STANDARDS

General

The publications listed below form a part of this specification to the extent referenced. Where a date is given for referenced standards, the edition of that date shall be used. Where no date is given for reference standards, the latest edition available on the date of the Notice of Invitation to Bid shall be used.

International Code Council (ICC)

- .1 ICC AC125, Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber Reinforced Polymer (FRP) Composite Systems.
- .2 ICC AC178, Interim Criteria for Inspection and Verification of Concrete and Reinforced and Unreinforced Masonry Strengthening Using Externally Bonded Fiber Reinforced (FRP) Composite Systems.

American Standard for Testing and Materials (ASTM)

- .3 ASTM D7565/D7565M, Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures.
- .4 ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.
- .5 ASTM D7522/D7522M, Standard Test Method for Pull-Off Strength for FRP Bonded to Concrete Substrate.
- .6 ASTM D4541, Standard Test Method for Pull-off Strength of Coating Using Portable Adhesive-Testers.

American Concrete Institute (ACI)

- .7 ACI 440.2R-08, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.

International Concrete Repair Institute (ICRI)

- .8 ICRI Technical Guideline No. 310.2-1997 (formerly No. 03732), Guideline for Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays.

1.4 MATERIAL QUALIFICATIONS

- .1 Materials for the FRP system have been pre-qualified and shall be supplied by the following manufacturers:
 - A. Fyfe Co. LLC (8380 Miralani Drive, Suite A, San Diego, CA 92126. Tel: 858-642-0694, Fax: 858-444-2982, Email: info@fyfeco.com)
 - B. Approved alternate FRP manufacturer. Alternate FRP systems must provide all items listed in Section 1.5 of this specification with their bid; otherwise, they shall be considered non-compliant.

1.5 SUBMITTALS

Quality Control and Quality Assurance:

- .1 Submit product data indicating product standards, physical and chemical characteristics, technical specifications, limitations, installation instructions, maintenance instructions and general recommendations regarding each individual material.

- .2 Only epoxy resins will be accepted for construction of FRP systems referenced in this specification. Other resins, such as polyesters/vinyl esters, are not allowed as substitutes. The manufacturer shall clearly define the epoxy resin working time. Any batch that exceeds the batch life shall not be used.
- .3 The proposed FRP Systems shall be compliant with ICC AC125 and provide a current ICC Evaluation Service Report, compliant with the 2006 International Building Code (IBC).
- .4 Submit a list of completed surface bonded FRP composite strengthening projects completed with the manufacturer's FRP composite system in the past 3 years. The list should include at a minimum 25 projects with proposed FRP system, the dates of work, type, description and amount of work performed.
- .5 Surface bonded FRP composite system shall be installed by certified applicator with written consent from manufacturer that the contractor has been trained. Certified applicator shall have a minimum of 3 years experience in performing FRP composite retrofits.
- .6 The Engineer may suspend the work if the Contractor substitutes an unapproved fiber reinforced composite system or unapproved personnel during construction.

Design and working drawings:

- .7 Stamped and signed structural calculations and drawings by a professional Civil or Structural Engineer. Design shall be based on the clearly written performance criteria defined on the structural drawings.
- .8 Working drawings shall detail the type, locations, dimensions, numbers of layers, and orientation of all FRP materials and coatings to be installed.
- .9 A list of two different manufacturer approved testing laboratories that can perform the required ASTM D7565/D7565M and/or ASTM D3039 tests as per Section 3.3 of this specification.

Product Information:

- .10 Provide an ICC Evaluation Service Report, compliant with the 2006 IBC, for the proposed products.
- .11 Provide approved UL rated assembly data for any required fire-resistant finishes (e.g. 2-hour/4-hour rated assembly per ASTM E119, Class 1 Flame & Smoke per ASTM E84).

- .12 Properties of the composite materials as determined by independent laboratory testing in accordance with ASTM D7565/D7565M and/or ASTM D3039 (tensile modulus, stress and strain).
- .13 Large-scale structural testing results of the proposed composite system from independent laboratories on similar structural sections.
- .14 Installation procedures, maintenance instructions, and general recommendations regarding each material to be used.
- .15 Manufacturer's Material Safety Data Sheets (MSDS) for all materials to be used.
- .16 Manufacturer's product data sheet indicating physical, mechanical and chemical characteristics of all materials used in the FRP system.
- .17 Written verification from the manufacturer that their applicator has received the required certifications and training.
- .18 Certification by the manufacturer that supplied products comply with local regulations controlling use of volatile organic compounds (VOC's).
- .19 Products that require the use of respirators do not comply with local regulations controlling use of VOC's and shall not be allowed.

1.6 PERFORMANCE

- .1 Design the composite system to achieve the structural performance shown on the structural drawings. Design calculations for the composite system shall be submitted for approval by the engineer of record, and shall be stamped by a registered Civil or Structural Engineer. The composite system must meet the stiffness requirement ($E \times A$), or the clearly-written performance criteria as indicated at all identified locations in the structural drawings. The modulus (E) and

associated area (A) of the FRP system shall be based on published design values consistent with long term durability exposure testing.

- .2 Calculations shall conform to the requirements set forth in the bid documents and be based on the design modulus and associated area of the composite to be installed. FRP design values must be lower than the calculated mean determined from the test results received from the ASTM D7565/D7565M and/or ASTM D3039 field test specimens (See Section 3.3 of this specification).

1.7 PRODUCT DELIVERY, HANDLING AND STORAGE

- .1 Deliver epoxy materials in factory-sealed containers with the manufacturer's labels intact and legible with verification of date of manufacture and shelf life.
- .2 Store materials in a protected area at a temperature between 40°F and 100°F.
- .3 Products shall be stored according to the manufacturer's requirements and shall avoid contact with soil and moisture. Products shall be stored to avoid UV exposure.

1.8 COORDINATE WITH OTHER TRADES

- .1 Prior to construction, the trades shall be briefed on any new or unusual construction procedures to ensure that they are aware of special conditions (e.g. new penetrations, construction anomalies).

2 PRODUCTS

2.1 ACCEPTABLE MANUFACTURERS & COMPOSITE STRENGTHENING SYSTEM

- .1 Approved Tyfo® Fibrwrap® System(s) to be supplied by Fyfe Co. LLC (8380 Miralani Drive, Suite A, San Diego, CA 92126. Tel: 858-642-0694, Fax: 858-444-2982, Email: info@fyfeco.com). Products include:

Composite fabric: SCH fiber – primary carbon fiber, unidirectional.
SEH fiber – primary glass fiber, unidirectional.

Epoxy saturant/primer: Tyfo® S epoxy is used as a primer and is also combined with the fiber to form the Tyfo® Fibrwrap® System.

Epoxy saturant/primer for underwater application: Tyfo® SW-1 epoxy is used as a primer and is also combined with the fiber to form the Tyfo® Fibrwrap® System.

Primer/Filler: Thickened Tyfo[®] S, WS, WP or TC thickened epoxy for protective seal coat, filling voids and primer where needed.

Finishes: Tyfo[®] A, Tyfo[®] U, Tyfo[®] HS for protection from ultraviolet and to provide long-term environmental durability. Alternate finishes must be approved by the owner.

Fire Resistant Finishes: Tyfo[®] RR, Tyfo[®] FC/F, Tyfo[®] 4HFL, Tyfo[®] AFP for any applicable fire resistant finish. Alternate finishes must be approved by the owner.

Field thickened epoxy matrix, which is compatible with composite system's resin matrix, may be used to patch "bugholes" up to 1.5" in depth and to fill voids.

Epoxies other than the pre-qualified materials above can be evaluated prior to the tender closing; materials meeting the requirements will be allowed by written addendum.

- .2 The manufacturer shall provide specific information on physical, mechanical and chemical properties of fiber, epoxy resin and FRP composite.

2.2 CERTIFIED APPLICATORS

- .1 Installations of the Tyfo[®] Fibrwrap[®] Systems shall be performed by certified applicators only. Certified applicators shall have the minimum experience and written consent as recommended by the FRP manufacturer (See Sections 1.5.5 & 1.5.17 of this specification).
2. Installer must provide a five (5) year bonded warranty by an "A" VIII rated surety (as defined by *A.M. Best Co.*) and licensed and admitted to provide surety bonds in the State of [xxx] for 10% of the contract amount.

2.3 OTHER MATERIALS

- .1 Contractor to provide compatible primer, filler and other materials recommended by the manufacturer as needed for the proper installation of the complete surface bonded FRP composite system.

3 APPLICATION

3.1 SURFACE PREPARATION

Columns:

- .1 The surface to receive the composite shall be free from fins, sharp edges and protrusions that will cause voids behind the installed casing or that, in the opinion of the Engineer, will damage the fibers. Existing uneven surfaces to receive

composite shall be filled with the system epoxy filler or other material approved by the Engineer. Filling of large voids in surfaces to receive composite shall be paid as an extra to the contract work of installing the composite system (small pinholes or micro-bubbles in the concrete surface or resin do not require special detailing). The contact surfaces shall have no free moisture on them at the time of application. If moisture is present, use the manufacturer suggested wet prime epoxy, if available.

- .2 Repair all damaged concrete, spalls, and irregular surfaces to create a flat, or slightly convex, surface. Fill surfaces with thickened epoxy to eliminate air surface voids greater than 0.5" diameter. Well-adhered paint and concrete do not require removal.
- .3 Round off sharp and chamfered corners to a minimum radius of 0.75" by means of grinding or forming with the system's thickened epoxy. Variations in the radius along the vertical edge shall not exceed 0.5" for each 12" of column height.

Beams/Slabs/Walls:

- .4 Surfaces shall be prepared for bonding by means of abrasive blasting or grinding to remove existing laitance and expose aggregate [minimum ICRI CSP-2 concrete surface profile]. All contact surfaces shall then be cleaned by hand or compressed air. One prime coat of the manufacturer's epoxy shall be applied and allowed to cure for a minimum of one hour. Prior to the application of the saturated composite fabric, fill any uneven surfaces with the manufacturer's thickened epoxy. Provide anchorage as detailed on construction drawings, if required.
- .5 Round off sharp and chamfered corners (to be wrapped around) to a minimum radius of 0.75" by means of grinding or forming with the system's thickened epoxy. Variations in the radius along the edge shall not exceed 0.5" for each 12" of length.

3.2 INSTALLATION

- .1 Preparation work for project: Visit site to ensure that all patch work is complete and cured. Review project specifications in detail.
- .2 Verify ambient and concrete temperatures. No work shall proceed if the temperature of the concrete surface is less than 40°F or greater than 100°F or as specified on the epoxy component labels. The ambient temperature and temperature of the components shall be between 40°F and 100°F, unless provisions

have been made to ensure components' temperature is maintained within this range or the range specified by the manufacturer.

- .3 Prepare the epoxy matrix by combining components at a weight (or volume) ratio specified by the manufacturer. The components of epoxy resin shall be mixed with a mechanical mixer until uniformly mixed, typically 5 minutes at 400-600 rpm.
- .4 Components that have exceeded their shelf life shall not be used.
- .5 Saturation of the fabric shall be performed and monitored according to the manufacturer's specified fiber-epoxy resin ratio. Fabric shall be completely saturated prior to application to contact surface in order to ensure complete impregnation. Saturation shall be supervised and checked by the certified installer. Both the epoxy resin and fabric shall be measured accurately, combined, and applied uniformly at the rates shown on the approved working drawings and per manufacturer's recommendations.
- .6 All cutting of fabrics, mixing of epoxy and combination thereof shall take place in a protected area away from critical structure functions and any electrical equipment.
- .7 Prepare surfaces as required, including corner preparation.
- .8 Remove dust and debris by hand or with compressed air as per specification.
- .9 Clean up and protect area adjacent to element where FRP composite is being applied.
- .10 Using a roller or trowel, apply one prime coat of epoxy resin to the substrate (2 mil min.). Allow primer to become tacky to the touch.
- .11 Fill any uneven surfaces or recesses with thickened epoxy.
- .12 Apply saturated fabric to substrate surface by hand lay-up, using methods that produce a uniform, constant tensile force that is distributed across the entire width of the fabric, and ensure proper orientation of the fabric. Under certain application conditions, the system may be placed entirely by hand methods assuring a uniform, even final appearance. Gaps between composite bands may not exceed 0.5" width in the fabric's transverse joint unless otherwise noted on project drawings. A lap length of at least 6" is required at all necessary overlaps in the primary fiber direction of the fabric.
- .13 Apply subsequent layers, continuously or spliced, until designed number of layers is achieved, per project drawings.

- .14 Using a roller or hand pressure, release or roll out entrapped air, and ensure that each individual layer is firmly embedded and adhered to the preceding layer or substrate.
- .15 Detail all fabric edges, including termination points and edges, with thickened epoxy.
- .16 Finish: All edges and seams must be feathered. Use system as directed by the manufacturer. Finish as specified between 24 and 72 hours after final application of epoxy. If after 72 hours the epoxy is cured, the surface must be roughened by hand sanding or brush blasting, prior to finishing.
- .17 System may incorporate structural fasteners but limitations and detailing must be verified with composite system manufacturer.

3.3 INSPECTION AND TESTING

.1 Field Inspection

- .1 The contractor shall monitor the mixing of all epoxy components for proper ratio and adherence to manufacturer's recommendations. Record batch numbers for fabric and epoxy used each day, and note locations of installation. Measure square footage of fabric and volume of epoxy used each day. Complete report and submit to Owner, engineer-of-record and FRP composite system manufacturer.
- .2 A Certified Special Inspector shall periodically observe all aspects of preparation, mixing, and application. All FRP composite applied areas shall be inspected, in accordance with the manufacturer's specifications for voids, bubbles, and delaminations. All defective areas shall be repaired as specified in Section 3.4 "Required Remediation".
- .3 The contractor shall provide a report signed by a registered professional engineer certifying that the installation is acceptable, complete with the testing reports and photographs.

.2 In-situ Testing

ASTM D7522/D7522M and/or ASTM D4541 – Adhesion Tests (if required by engineer-of-record)

- .1 Direct tension adhesion testing of cored samples shall be conducted using the method described by ASTM D7522/D7522M and/or ASTM D4541. A minimum of three tests shall be performed for each day of production or for

each 500 ft² (45m²) of FRP application, whichever is less. Pull-off tests shall be performed on a representative adjacent area to the area being strengthened whenever possible. Tests shall be performed on each type of substrate or for each surface preparation technique used.

- .2 The prepared surface of the bonded FRP system shall be allowed to cure a minimum of 72 hours before execution of the direct tension pull-off test. The locations of the pull-off tests shall be representative and on flat surfaces. If no adjacent areas exist, the tests shall be conducted on areas of the FRP system subjected to relatively low stress during service. The minimum acceptable value for any single tension test is 175 psi. The average of the tests at each location shall not be less than 200 psi. Additional tests may be performed to qualify the work.
- .3 Test locations shall be filled with thickened epoxy after the values have been recorded and verified by the special instructor and the test dollies have been removed.

.3 Laboratory Testing

Sampling

- .1 Record lot number of fabric and epoxy resin used, and location of installation. Measure square footage of fabric and volume of epoxy used each day. Label each sample from each day's production.
- .2 A "sample batch" shall consist of two 12" by 12" samples of cured composite. A minimum of two "sample batches" shall be made daily. The two "sample batches" will be taken at appropriate times during the day as to ensure the maximum material deviance in the components of the FRP composite.

.4 Preparation of Samples

- .1 Prepare sample on a smooth, flat, level surface covered with polyethylene sheeting, or 16 mil plastic film, prime with epoxy resin. Then place **one** layer of saturated fabric and apply additional topping of epoxy. Cover with plastic film and squeegee out all bubbles.
- .2 Samples shall be stored in a sample box and not moved for a minimum 48 hours after casting. The prepared, identified samples shall be given to a pre-approved and experienced testing laboratory. The laboratory shall then precondition samples for 48 hours at 140°F before testing.

- .5 ASTM D7565/D7565M and/or ASTM D3039 – Tension Tests
- .1 Testing specimens shall be cut from samples and tested for ultimate tensile strength, tensile modulus and percentage elongation as per ASTM D7565/D7565M and/or ASTM D3039 in the longitudinal fiber direction.
 - .2 Test a minimum of 15% of all samples as per ICC AC178. If one coupon fails, specimens from the same 12” x 12” sample will be tested. If these specimens also fail, the other 12” x 12” sample from the same “sample batch” will be tested. In the extreme case that this sample also fails, the remaining “sample batch” for that day will be tested and appropriate remediation shall be taken to ensure integrity of the system at locations from the failed “sample batch”. In addition, 25% of the remaining samples shall be tested by the same criteria as per ICC AC178.
 - .3 Testing results shall be made available within 3 weeks of sample submission.
- .6 Acceptance Criteria
- .1 FRP design values must be lower than the calculated mean determined from the test results received from the ASTM D7565/D7565M and/or ASTM D3039 field test specimens. Acceptable minimum values for ultimate tensile strength, tensile modulus, and elongation shall not be below the submitted design values.
 - .2 Any values below the submitted design values are considered a failure and require remediation.

3.4 REQUIRED REMEDIATION

- .1 Small voids and bubbles [on the order of 3” diameter] shall be injected or back filled with epoxy.
- .2 Voids and delaminations on the order of 6” in diameter or an area of 5” x 5” shall be reported to the engineer of record and remediation shall be submitted by the contractor for approval.
- .3 In the event that laboratory testing determines a “sample batch” to possess insufficient material properties, remedial measures shall be taken. Any structural member where the installed FRP composite system has material properties determined to be below the minimum specified values, additional layers shall be installed until the composite thickness is increased by the same percentage as the deficiency of the material’s tensile modulus. Or any other remediation directed by the engineer.

3.5 MAKE GOOD

- .1 Make good at no cost to the Owner, any damage to the new or existing structures, property or services caused by the installation and testing of the FRP composite.

3.6 CLEAN UP

- .1 Remove all surplus material, equipment and debris from the site on completion of the work. Leave the site clean.

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