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GUIDE SPECIFICATIONS for

EXTERNALLY BONDED FRP FABRIC SYSTEMS FOR STRENGTHENING CONCRETE STRUCTURES

SECTION 032500

Prepared by the International Concrete Repair Institute
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Guide Specifications for Externally Bonded FRP Fabric Systems for Strengthening Concrete Structures
Guide No. 330.2-2016
Specification Section 032500

International Concrete Repair Institute
1000 Westgate Drive, Suite 252
Saint Paul, MN 55114 USA
Phone: 651-366-6095 Fax: 651-290-2266
Web: www.icri.org
E-mail: info@icri.org

About ICRI Specifications

The International Concrete Repair Institute (ICRI) was founded to improve the durability of concrete repair and enhance its value for structure owners. The identification, development, and promotion of the most promising methods and materials are primary vehicles for accelerating advances in repair technology. Working through a variety of forums, ICRI members have the opportunity to address these issues and to directly contribute to improving the practice of concrete repair.

A principal component of this effort is to make carefully selected information on important repair subjects readily accessible to decision makers. During the past several decades, much has been reported in the literature on concrete repair methods and materials as they have been developed and refined. Nevertheless, it has been difficult to find critically reviewed information on the state of the art condensed into easy-to-use formats.

To that end, ICRI specifications are prepared by sanctioned task groups and approved by the ICRI Technical Activities Committee. Each guide specification is designed to address a specific area of practice recognized as essential to the achievement of durable repairs. All ICRI specifications are subject to periodic review by the membership and may be revised as approved by the Technical Activities Committee.

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Synopsis
The purpose of this guide specification is to aid the Licensed Design Professional (LDP) in the preparation of technical specifications, for inclusion directly into contracts for construction of repairs involving externally bonded fiber-reinforced polymer (FRP) fabric systems for strengthening concrete structures that are in line with the state-of-the-art materials and methods used in the concrete repair industry. Its primary focus is to provide an outline for developing the three parts of the specification through suggested text, references, and commentary for evaluating alternatives. This guide specification specifically addresses the requirements for the supply and installation of the FRP system. Design of the FRP system is outside the scope of this guide specification. The Licensed Design Professional should design and detail the FRP system using the guidelines presented in ACI 440.2R, *"Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures."*

The guide specification presented herein is based largely on the information contained in ACI 440.2R. The user is encouraged to become familiar with the ACI 440.2R guide. Additional sources of information and other documents commonly referenced in FRP specifications are provided at the end of this document. Some of these documents may not be cited in the guide specification, but are included for the benefit of the user.

Keywords
FRP specification; materials selection; construction methods; testing.

SECTION 032500 – EXTERNALLY BONDED FRP FABRIC SYSTEMS FOR STRENGTHENING CONCRETE STRUCTURES

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Disclaimer

This document is intended as a guide specification for the owner, design professional, and concrete repair contractor. It is not intended to relieve the design professional of any responsibility for the specification of externally bonded FRP materials, installation methods, or practices. While we believe the information contained herein represents the proper means to achieve quality results, the International Concrete Repair Institute must disclaim any liability or responsibility to those who may choose to rely on all or any part of this specification. Portions of the specifications require modification before use. Engineering judgment is required to adapt the standard language to the specific needs of the project governed by the document.

Instructions

This guide specification is intended to be used as a technical specification section in a complete and coordinated project manual that includes Division 01 General Requirements, Division 02 Existing Conditions, technical specifications, and a set of construction drawings with details and requirements specific to the concrete repair and strengthening project. Sections that address substrate and crack repairs, and surface preparation are not included in this guide specification and should be added to the project manual as needed. Revise this specification section by deleting and inserting text to meet project specific requirements.

Black text indicates to the specification user those requirements that are generally accepted as industry standards. Blue text indicates optional requirements, or situations where the specification user must make choices based on the needs of the project. Blue text must either be accepted or modified and changed to black text prior to issuing the document to avoid confusion regarding multiple alternatives or suggestive language.

Red text indicates commentary on the specification and serves to explain and clarify the requirements to the specification user. Within the Word document, the commentary is formatted using a style set to Hidden Text that permits it to be turned on and off in the preferences window when printing and/or viewing.

PART 1 – GENERAL

1.1 SUMMARY

Paragraph 1.1A is intended to allow space for a description of the Work covered by the specification section. In addition to a description of the repair type and scope, it is also advisable to insert references to the general location of the Work and any drawings that indicate the exact location of the Work. Special access issues such as high ceilings, confined spaces or façade access via swing stage can be summarized in this section.

A. Furnish all labor, materials, tools, equipment and supervision to perform all Work necessary for and incidental to install externally bonded fiber-reinforced polymer (FRP) sheet reinforcement to strengthen concrete structures.

Paragraph 1.1B prompts for a list of specification sections related to this section. Sections which describe Work that is to be done in sequence with the Work of this section, or Work that is to be done in the same locations as the Work of this section should be listed here. Detailed specifications for concrete substrate and crack repair, surface preparation, and any coatings to be applied to the installed FRP system, etc. should be included if they are a required part of the FRP installation. General requirements may also be included here.

B. *Related Sections:*

1.2 DEFINITIONS

Article 1.2 is used to indicate definitions of language included in the specification. Additional terms can be referenced through ICRI's online resource, "ICRI Concrete Repair Terminology," at http://www.icri.org/GENERAL/repairterminology.aspx. or ACI's online resource ACI CT-13, "ACI Concrete Terminology" at http://www.concrete.org/Tools/ConcreteTerminology.aspx.

A. Engineer—The Licensed Design Professional responsible for the overall design of the repair project and establishing requirements for the project.

Paragraph 1.2B defines the FRP Engineer. For performance specifications, the FRP Engineer is typically retained by the Contractor to design the FRP system and prepare the calculation and shop drawing submittals. When the Engineer designs and details the FRP, and does not require any engineering submittals this paragraph may be omitted.

B. FRP Engineer—Licensed Design Professional responsible for designing and detailing the specifics of the FRP system to meet the requirements for the project.

C. FRP System—The product comprising reinforcing fabrics and resin components installed using hand or mechanical wet lay-up methods to the surfaces of concrete members to be strengthened.

D. Independent Testing Agency—A testing laboratory experienced in inspecting FRP in the field and testing FRP witness panels.

E. Manufacturer—The supplier of the FRP system including its constituent and component materials.

Only include definition for "Shoring Engineer" if shoring is required as part of the project.

F. *Shoring Engineer—Licensed Design Professional retained by the Contractor to design shoring, bracing, and other temporary support.*

1.3 REFERENCED STANDARDS AND REPORTS

Include the year with the referenced standards used in the specification.

Paragraph 1.3A can be used to define references made in these specifications. The dates of the publications should be kept current but checked to verify that updates have not modified the relevance to these specifications. Standards not otherwise referenced in this specification should be removed from this list.

The following documents are useful and may be referenced in the commentary, but not in the specification. These references are current as OF 2016.

ACI RAP Bulletin 1	Structural Concrete Repair by Epoxy Injection
ACI 117	Specification for Tolerances for Concrete Construction and Materials and Commentary
ACI 224.1R	Causes, Evaluation, and Repair of Cracks in Concrete Structures
ACI 440R	Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures
ACI 440.2R	Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening of Concrete Structures
ACI 440.8	Specification for Carbon and Glass Fiber-Reinforced Polymer Materials Made by Wet Layup for External Strengthening of Concrete and Masonry Structures

ACI 546R	Guide to Concrete Repair
ACI 562	Code Requirements for Evaluation, Repair, and Rehabilitation of Concrete Buildings and Commentary
ASTM C1583	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 D3039	Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials
ASTM D4065	Standard Practice for Plastics: Dynamic Mechanical Properties: Determination and Report of Procedures
ASTM D5687	Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation
ASTM D7522	Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate
ASTM D7565	Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures
ASTM E122	Standard Practice for Calculating Sample Size to Estimate, With Specified Precision, the Average for a Characteristic of a Lot or Process
ICRI 120.1	Guidelines and Recommendations for Safety in the Concrete Repair Industry
ICRI 130.1R	Guide for Methods of Measurement and Contract Types for Concrete Repair Work
ICRI 210.1	Guide for Verifying Field Performance of Epoxy Injection of Concrete Cracks
ICRI 210.3R	Guide for Using In-situ Tensile Pulloff Tests to Evaluate Bond of Concrete Surface Materials
ICRI 310.1R	Guide for Surface Preparation for the Repair of Deteriorated Concrete Resulting from Reinforcing Steel Corrosion
ICRI 310.2R	Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair
ICRI 320.2R	Guide for Selecting and Specifying Materials for Repair of Concrete Surfaces
ICRI 330.1	Guide for the Selection of Strengthening Systems for Concrete Structures

ICC-ES AC125 Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-reinforced Polymer (FRP) Composite Systems

A. ASTM Standards and Reports

Only include ASTM standards for tests that are included in the specification.

C581-15	*Standard Practice for Determining Chemical Resistance of Thermosetting Resins Used in Glass-Fiber-Reinforced Structures Intended for Liquid Service*
D1141-98(2013)	*Standard Practice for the Preparation of Substitute Ocean Water*
D2247-15	*Standard Practice for Testing Water Resistance of Coatings in 100% Relative Humidity*
D3045-92(2010)	*Practice for Heat Aging of Plastics Without Load*
D7522/D7522M-15	*Standard Test Method for Pull-Off Strength for FRP Laminate Systems Bonded to Concrete Substrate*
D7565/D7565M-10	*Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures*
E84-16	*Standard Test Method for Surface Burning Characteristics of Building Materials*
E104-02(2012)	*Standard Practice for Maintaining Constant Relative Humidity by Means of Aqueous Solutions*
E1640-13	*Standard Test Method for Assignment of the Glass Transition Temperature by Dynamic Mechanical Analysis*
G153-13	*Standard Practice for Operating Enclosed Carbon Arc Light Apparatus for Exposure of Nonmetallic Materials*

B. ACI Standards and Reports

It is important to note that ACI 440.2R is a guide and not written in mandatory language. However, ACI 440.2R is a good source of information and usually included as a reference in specifications. It should not be referred to in mandatory language.

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

C. ICRI Technical Guidelines

ICRI 310.2R is a guide that makes reference to the ICRI concrete surface profile (CSP) chips used to specify minimum surface profile requirements for FRPs.

ICRI 310.2R-2013 Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair

D. Referenced Standards and Reports may be obtained from the following organizations:

American Concrete Institute (ACI)
38800 Country Club Drive
Farmington Hills, MI 48331 USA
www.concrete.org

ASTM International (ASTM)
100 Barr Harbor Drive
West Conshohocken, PA 19428 USA
www.astm.org

International Concrete Repair Institute (ICRI)
1000 Westgate Drive, Suite 252
Saint Paul, MN 55114 USA
www.icri.org

1.4 SUBMITTALS

Paragraph 1.4A is a requirement that product data be submitted in accordance with procedures to be defined in the Division 01 sections of the specification. The purpose of this paragraph is to define the type and scope of submittals desired, and to define the issue of substitution for specified materials. The submittal should include the items listed, such as limitations and technical specifications, even if it is identical to one of the products named in the specifications, so that all material data may be documented and filed by the Owner. This serves an important purpose for future repair Work which may be performed on the structure with respect to material compatibility, warranties, and anticipated life-cycle considerations.

A. Product Data: Submit product data for all products and constituent materials in accordance with Division 01 General Requirements. Include product standards, physical and chemical characteristics, technical specifications, limitations, maintenance instructions, cleaning and safety information, and general recommendations regarding each material listed. Submit all product data prior to start of Work. *The*

Engineer may reject products that are not listed or do not meet the requirements of this specification. For alternate products, provide documentation that materials submitted are equivalent or superior to those required by this specification. Submit cost and schedule impact for requested alternates when applicable.

B. Shop Drawings:

Subparagraph 1.4B.1 requires submittal of shop drawings showing the details of the FRP installation. For guidance on the type of information required to be included on the shop drawings, see Chapter 14 of ACI 440.2R. Unless the project has been designed and detailed around a single product, it is usually a good idea to require the Contractor to submit shop drawings showing the installation details of the FRP system intended for use.

1. Submit shop drawings that identify the FRP system, the product names of each of the constituent materials, repair areas and locations, dimensions relevant to the detailing and layout of the FRP system, lap splicing details, and installation steps including the necessary preparations of the existing structure and final protective top-coating of the FRP system, if required.

2. *Submit shoring drawings from the Shoring Engineer prior to the start of Work.*

Paragraph 1.4C relates to the submittal of engineering calculations. Any calculation submittals should be sealed by a Licensed Design Professional in the State or Province of the project.

C. Engineering Calculations:

Subparagraph 1.4C.1 relates to the submittal of calculations showing that the FRP system meets the tensile requirements of the specification. Commercially available FRP systems exhibit slight differences in mechanical properties and thickness. It is critical to check the strength/unit width and stiffness/unit width of the proposed system to determine if they meet the specified requirements. Unless the project is designed and detailed around a single product without allowing substitutions, this submittal should always be required.

1. *Submit calculations sealed by an FRP Engineer registered to practice in the State (or Province) of _____ showing that the proposed FRP system meets or exceeds the requirements of this specification.*

Subparagraph 1.4C.2 relates to the submittal of a complete set of calculations for the design and detailing of the FRP system, including the FRP anchor system if one is used. Only include this provision if the project is intended to be a design-build project, where the Contractor is expected to design the entire FRP system. If the project is a design-build project, the Engineer should specify all information on the drawings or in the specifications needed to design the FRP system,

including member sizes, reinforcing steel layout, concrete strengths, unfactored and factored axial and shear forces, and moments, etc. A complete set of existing drawings should also be supplied to the Contractor in the case of design-build projects. The Engineer should allow a minimum of 2 weeks to review and approve the design before the Contractor orders materials. The Engineer is responsible for analyzing the existing structure to define the deficiencies and checking the Contractor's calculations to insure the FRP-strengthened members possess the required strength. Note: FRP anchor systems are not covered in ACI 440.2R and no other industry accepted guidelines for their design or use exist. If FRP anchors are proposed for use on the project, the FRP Engineer should submit design calculations showing how they contribute to the strength and stiffness of the FRP system based on tests of the proposed anchors. The calculations should also list any assumptions made in the design of the anchors.

2. *Submit design calculations sealed by the FRP Engineer registered to practice in the State (or Province) of _____ for all members to be strengthened by the externally bonded FRP system showing the strengthened member meets the required strength. Include calculations for the design and detailing of the FRP anchor system.*

Paragraph 1.4D requires the Contractor to submit their installation procedure for review enabling the Engineer and Owner to address any issues like coordination with occupants, noise, dust, etc. prior to the start of the project. For larger or more complex projects, the Engineer may also wish to require a project schedule to be included with the installation procedure to coordinate inspections and other items.

D. Installation Procedure: Submit installation procedure that addresses all known environmental and substrate conditions that affect the application and curing of the FRP system including a description of any remedial action to ensure the desired performance of the system. *Include a proposed schedule for the installation of the FRP system that shows all critical milestones.*

Paragraph 1.4E is provided in case pipes, conduits, etc. need to be removed or relocated prior to installation of the FRP system. Only include this provision if the FRP Contractor is responsible for removing and relocating the obstructions. This record will enable the Owner to determine if the obstructions were relocated properly.

E. *Record of Obstructions: Submit a drawing or sketch showing the existing layout of any obstructions including pipes, conduits, wiring, junction boxes, etc. that affect the installation of the FRP system.*

Paragraph 1.4F is required for all projects. MSDS should be retained by the Owner and the Contractor should always possess them on site.

F. Material Safety Data Sheets (MSDS): Submit in accordance with the general conditions for all components of the FRP strengthening system including fiber sheets, resins and protective top-coating materials.

Paragraph 1.4G is provided to require the Contractor to submit test reports confirming the FRP system meets the requirements of the specification. This requirement should be included for projects where system prequalification is not possible or feasible, such as for some public bid projects.

G. Test Reports:

Subparagraph 1.4G.1 requires the Contractor to submit test reports from third party laboratories showing the FRP system meets the material property requirements of the specification. The reports should be reviewed by the Engineer for completeness.

1. *Submit test reports or data from the manufacturer confirming the material properties meet the specified requirements.*

Subparagraph 1.4G.2 should only be included if an FRP anchor system is used on the project. Many anchor systems are available so it is critical that test data be supplied showing the proposed anchor system has been tested for the type of application it is being used.

2. *Submit test reports validating the effectiveness of the FRP anchor system.*

Paragraph 1.4H specifies the items to be addressed by the Contractor's QC plan. On many projects, especially smaller ones, the Contractor is usually responsible for all aspects of quality from verifying the incoming materials meet specifications to performing the field QC tests. It is important the QC plan be reviewed by the Engineer who may informally audit the Contractor during various stages of the project to insure the Contractor is implementing the plan. On larger projects or more complex projects, the Owner may require independent inspections to be performed or code officials may require "special inspections." A comprehensive QC plan enables the Engineer, Contractor, and Independent Testing Agency to understand their roles and responsibilities.

H. *Quality Control Plan: Submit, prior to starting construction, a quality control (QC) plan for approval by the Owner or Engineer addressing all activities and processes required to control the quality of the materials and installation. Include in the QC plan:*

- Procedures for tracking and verifying the quality of all FRP constituent materials;
- Procedures for inspection of all prepared surfaces prior to installation of the FRP;

- Procedures for inspection of installation of FRP system and completed work;
- Number of quality control test samples; and
- Procedures for repair of defective work.

Paragraph 1.4I specifies the submittals required from the Contractor related to the qualifications of the FRP system manufacturer. If approved products and manufacturers are listed in Paragraph 2.1A, then this requirement may be waived. However, if the intent is to enable all qualified products/ manufacturers to supply the project, it is prudent to verify that the products have some track record and the manufacturer is capable of supplying compliant materials.

I. *Qualifications of FRP system manufacturer: Submit the qualifications of FRP systemmanufacturer prior to ordering materials for the project that include the following information:*

1. *Documentation demonstrating the manufacturer meets the requirements of Paragraph 1.5A.*

Subparagraph 1.4I.2 is an optional requirement at the discretion of the Engineer.

2. *___letters of references from ____ projects for which the manufacturer has previously supplied the FRP system.*

J. *Qualifications of Installation Contractor: Submit with the bid the following information:*

1. *Documentation demonstrating the Contractor meets the requirements of Paragraph 1.5B.*

Subparagraph 1.4J.2 requests documentation showing the Contractor has been formally trained by the manufacturer to install the FRP system. This provision should always be included.

2. *Certificate or letter from the manufacturer indicating the Contractor has been trained to install the FRP system.*

Subparagraph 1.4J.3 is an optional requirement at the discretion of the Engineer. Alternately, the Contractor may install the FRP under the supervision of the manufacturer's technical representative.

3. *___letters of references from ____projects the Contractor has previously installed the FRP system. Alternately, the Contractor may install the FRP system under the direct supervision of the manufacturer's technical representative.*

This provision may be waived if the project is small and the Contractor did not deviate from the design drawings. However, on some projects, the Contractor may need to alter the FRP layout to accommodate embedded junction boxes, pipes, conduits, or other items. In some cases, splices may need to be added or FRP sheet widths adjusted. It is recommended that the Contractor submit a marked-up copy of their shop drawing showing the as-built installation.

K. *As-Built Drawings: Submit as-built drawing(s) of the completed FRP installation including locations of any repairs to the FRP and any deviations from the contract drawings.*

Paragraph 1.4L requires the Contractor to submit a mockup report. Mockups generally involve installing a small section of the FRP to the concrete to verify adhesion strength, appearance, and other parameters. Note that mockups are different than witness panels. Witness panels are small panels made on site (not bonded to the concrete) that can later be cut into small coupons and tested to verify mechanical properties.

L. *Mockup Report: The Contractor's FRP field representative will witness the mockup and adhesion testing of the FRP system and submit a report to the Owner or Engineer described in Paragraph 1.5.D.*

Paragraph 1.4M requires the Contractor to submit their daily reports documenting the progress of the project, materials used and QC tests performed. These daily reports would typically be reviewed by the Independent Testing Agency.

M. *Contractor Daily Reports: Submit Contractor's daily reports.*

1.5 QUALITY ASSURANCE

Paragraph 1.5A defines the qualifications of the FRP system manufacturer. This requirement may be waived if the Engineer specifies the approved manufacturers in Paragraph 2.1B.

A. The manufacturer of the FRP system shall meet the following requirements to supply the FRP system for this project:

Subparagraph 1.5A.1 relates to the number of years the manufacturer has been in business.

1. *Been in the business of manufacturing FRP systems for more than ___ consecutive years and can demonstrate experience in supplying the FRP system on projects similar in size and scope.*

Subparagraph 1.5A.2 requires the FRP system be commercially available and all constituent materials be sold under the manufacturers' label. This requirement is intended to prevent Contractors from combining constituent materials procured from different sources.

2. Supplies all constituent materials of the FRP system excluding any top coating materials and verifies that the constituent materials (fiber sheets and resins) have been tested together as a system.

Subparagraph 1.5A.3 requires the manufacturer to formally train the Contractors to install their system. Manufacturers often provide a letter or other documentation to the Contractors stating that they have been formally trained to install their FRP system. If the Contractor plans to use an impregnation machine on site, the manufacturer should have trained them to do so.

3. Maintains a formal, hands-on training program to train Contractors to install their FRP system.

Subparagraph 1.5A.4 is required. Any manufacturer selling FRP products should employ a technical field representative knowledgeable of the design of their FRP systems, how they are installed, and the guidelines presented in ACI 440.2R.

4. Employs a technical field representative knowledgeable of the design of their FRP systems, how they are installed, and the guidelines presented in ACI 440.2R.

B. Contractor shall meet the following requirements to install the FRP system for this project:

Subparagraph 1.5B.1 relates to the number of years the Contractor has been in business and installing FRP systems.

1. *Been in business of installing FRP systems for more than ___ consecutive years and can demonstrate experience in installing the FRP system on projects similar in size and scope.*

Subparagraph 1.5B.2 relates to the experience of the field representative, foreman, crew leader, etc. The Engineer may also require that the individual be the same person from start of project to completion and be located on site.

2. Employs a field representative who will be on site for the duration of the project that has been trained to install the FRP system by the manufacturer.

3. Maintains a documented safety program.

C. Independent Testing Agency shall meet the following requirements to conduct tests of the FRP system for this project:

Subparagraph 1.5C.1 relates to the number of years the Independent Testing Agency has been in business and inspecting FRP systems. Two years is sufficient in most cases.

1. *Been in business of inspecting FRP systems for more than ___ consecutive years and can demonstrate experience with the inspection of installed FRP systems and the testing of witness panels.*

Subparagraph 1.5C.2 relates to the experience of the field technician to be used for the inspection of the FRP system. It is recommended the technician have done similar inspections on a minimum of five previous projects.

2. Employs a field technician knowledgeable of FRP systems who will be on site for field inspections and for monitoring the fabrication and curing conditions of all witness panels. *The technician will have ___ years of experience inspecting FRP systems and performed similar duties on ___ previous projects similar in size and scope.*

Paragraph 1.5D is an optional requirement for a mockup of the FRP installation. If the project is large, complex, or aesthetics are a concern, then a mockup may be beneficial to all parties. Adhesion testing of sections of the mockup can also be used to verify if the substrate is suitable for the FRP.

D. *Demonstrate in a mockup typical installation methods and materials that are used for the project. Mockup shall be representative of the field and environmental conditions to be expected during the project and installed by the same personnel that will do the Work using the same type of equipment as will be used for the Work. Verify the adhesion strength by direct tension pull-off tests in accordance with ASTM D7522.*

E. Any part of the Work that fails to comply with the requirements of the contract documents may be rejected by the Engineer. Repaired Work to be in full compliance with the Contract Documents in accordance with Part 3, Article 3.6. Repair of rejected Work will be at the Contractor's expense.

1.6 DELIVERY, STORAGE, HANDLING AND DISPOSAL

A. Deliver materials to Project site in manufacturer's original, factory-sealed, unopened containers, with label intact identifying the manufacturer, brand name, system component name and identification number and production date.

B. Comply with manufacturer's written instructions for minimum and maximum temperature requirements and other conditions for storage.

C. Store all materials off of the ground, under cover, and in a dry location. Protect from dust, direct sunlight, physical damage, rain, water, freezing and excessive heat, foreign matter or other detrimental conditions until ready for use.

Paragraph 1.6D addresses how the materials to be used on the project are to be handled. In general, the Contractor should comply with the written instructions provided by the manufacturer. Note that in addition to the materials comprising the FRP system, other materials like cleaning solvents or concrete repair materials may also be present on the job site.

D. Comply with manufacturer's written instructions for handling of all constituent materials comprising the FRP system, cleaning solvents, and any other materials required to complete the project.

Fiber sheets, particularly unidirectional fiber sheets must be handled gently.

1. Handle fiber sheets with care. Avoid separating fibers, folding, or wrinkling fiber sheets to prevent damage to the sheets and breakage of fibers.
2. Stack cut fiber sheets flat or on a roll with a radius in compliance with the manufacturer's written recommendations. Do not fold sheets.
3. Address safety hazards, including but not limited to skin irritation and sensitization, and breathing vapors and dusts, when handling the materials.
4. Monitor resins during and after mixing to avoid fuming, flammable vapors, fire, or boiling.

Paragraph 1.6E states the Contractor is responsible for complying with all laws and regulations as it relates to the materials used on site. The Engineer should amend this paragraph to include any requirements unique to the project.

E. Ensure that all components of the FRP system at all stages of Work conform to the local, state (or province), and federal environmental and worker's safety laws and regulations.

1. *Comply with local, state (or province), federal regulations and as specified in the contract documents for maximum acceptable levels of volatile organic compounds (VOCs), hazardous air pollutants (HAPs), and toxicology of the FRP constituent materials.*

2. Make the MSDS for all constituent materials of the FRP system available and accessible to all personnel at the project site.

3. *Inform all personnel of the dangers of inhaling fumes of resins, and take necessary precautions, including personnel protection against injury. Ventilate the resin mixing area to the outside.*

F. Clean up the site of any hazardous materials used during the installation of the FRP system on a daily basis.

G. Dispose of any component of the FRP system that has exceeded its shelf life or pot life, or has not been properly mixed or stored, and any unused or excess material that is deemed waste in compliance with applicable regulations.

1.7 WARRANTY

Insert warranty requirements in this location or include the phrase "Refer to the project manual, specifications, and drawings for minimum warranty requirements."

A. *Provide warranty…*

1.8 PAYMENT BASIS

The pay basis for FRP projects is usually lump sum which includes all materials, equipment, and labor to supply and install the FRP system. Substrate repairs, like spall repairs or crack injection is excluded since that Work is covered in other sections. Sometimes, a unit price basis is required, which should be based on the square foot (or square meter) of coverage area (including all plies) as opposed to square foot (or square meter) of FRP fabric. The unit price basis generally includes surface preparation, and all materials, equipment, and labor to supply and install the first ply and all subsequent plies of FRP.

A. Payment for strengthening concrete structures with externally bonded FRP fabric reinforcement will be *lump sum (or unit price basis with the unit of measurement square foot [or square meter] of coverage area)* in accordance with the recommendations of ICRI 130.1R.

1.9 SAFETY

A. Perform all Work in accordance with the applicable provincial, local, state and federal requirements for safety, and the recommendations of ICRI 120.1.

PART 2 – PRODUCTS

2.1 MANUFACTURERS

A. Subject to compliance with requirements, provide products from one of the following manufacturers:

List manufacturers and corresponding products.

1. *Approved Manufacturers and Products*

Paragraph 2.1B allows the Contractor to submit an alternate FRP system for approval. There are several suppliers of high quality FRP systems, so a provision for allowing alternates is reasonable.

B. Alternate FRP strengthening systems may be substituted provided they meet the requirements of this specification. Submit all substitutions to the Engineer for approval.

2.2 FRP STRENGTHENING SYSTEMS

Paragraph 2.2A specifies that the manufacturer supply all the constituent materials and that they be tested together as a system. This provision prevents the use of untested combinations of fiber sheets and resins that are incompatible.

A. All constituent materials comprising the FRP system shall be supplied by a single manufacturer, tested together as a system, and cured in the same manner as the expected field conditions. The manufacturer's name shall appear on the labels of the constituent materials.

Paragraph 2.2B describes acceptable fiber sheets. In this paragraph, the Engineer should specify either carbon or E-glass fibers, but not both due to differences in properties. The Engineers should consult Section 9.3 of ACI 440.2R for guidance on the selection of various FRP systems.

B. Dry Fiber Reinforcement Sheet: Continuous *carbon or E-glass* fibers woven or assembled into a dry fabric. Fiber reinforcement sheets may be unidirectional, bi-directional, or multi-directional and be capable of being fully wetted out by the saturating resin.

C. Saturating Resin: Compatible with the fiber reinforcement sheets and other constituent materials comprising the FRP strengthening system. The saturating resin shall have sufficiently low viscosity to ensure full impregnation of the fiber sheets prior to the resin curing.

Paragraph 2.2D provides the general requirements for the primer resin. Note that not all FRP systems have a primer resin. The primer is typically a very low viscosity resin that is applied directly to the prepared concrete substrate and is intended to enhance the bond of the FRP system to the concrete. For "contact-critical" applications where the FRP system is completely wrapped around the concrete member like a column wrap, a primer is less important. This paragraph should remain in the specification and is only applicable to manufacturers that supply a primer with their system. Bond-critical and contact-critical applications are explained further in the commentary prior to Article 3.3.

D. Primer, if required by the manufacturer: Compatible with the other constituent materials comprising the FRP strengthening system.

Paragraph 2.2E provides the general requirements of the putty resin. Most FRP projects require a putty resin of some type to fill bug holes, level uneven surfaces, or in some cases to provide a thick, sticky material to bond the heavier FRP sheets. Some FRP manufacturers include a putty resin in their FRP system, while others supply a paste adhesive from their traditional concrete repair product line. Regardless of how the putty is supplied, it should be compatible with the FRP system.

E. Putty, if required by the manufacturer: An adhesive of paste consistency and compatible with the other constituent materials comprising the FRP strengthening system. The manufacturer of the FRP system shall supply the putty as part of their system or as a product guaranteed to be compatible with the FRP system.

Paragraph 2.2F relates to the FRP anchoring systems. This paragraph can be excluded for most projects. However, for projects where FRP anchors are desirable, include this provision, and the Engineer should approve the anchor system based on the anchor submittals. Note that many FRP anchor systems are proprietary and may even be covered by patents limiting competitive bidding. Where competitive bidding is important to the Owner, the Engineer should not allow proprietary or patented anchoring systems.

F. *Anchors: FRP anchoring systems, if required, will be approved by the Engineer based on test reports, and other information including detailing, limitations and design parameters of the FRP anchoring system.*

Paragraph 2.2G requires compatibility between the FRP system and the top coating system. If a top coat is required for aesthetics (e.g. paint) or protection (e.g. fire retardant paint), a stand-alone specification covering the surface preparation and application of the top coating should be added to the project documents.

G. *Top Coating Materials: Top coating materials used for protection or aesthetics shall be compatible with the FRP system; requirements for top coating materials are contained in Article ___ of these Specifications.*

The mechanical property requirements of the FRP system are defined in Paragraph 2.2H. The Engineer should only include tables representing the desired material (carbon or E-glass). Note that FRP systems are available in various thicknesses (fabric weights) and may also comprise fibers ranging in strength and modulus depending on the supplier. As such, the best way to specify FRP mechanical properties is using the "unit strength" and "unit stiffness" approach. This approach is most easily defined as the strength (kips or kN) per unit width of a single layer. Rather than specifying the modulus, the stiffness per unit width of a single layer should be specified.

H. Mechanical Property Requirements: FRP system shall meet or exceed the following mechanical property requirements:

Subparagraph 2.2H.1 defines how the material properties are to be reported. Note that the tensile strength properties should be reported in the "unit strength" format and elongations as a percent. Data sheets supplied by the manufacturer should include a statement attesting to how their design properties are reported.

1. Minimum guaranteed properties for tensile strength and elongation shall be calculated by subtracting 3 standard deviations from the average values obtained from 20 or more tensile tests.

Subparagraph 2.2H.2 defines how stiffness should be calculated.

2. Average values for tensile stiffness shall be calculated by dividing the guaranteed tensile strength by guaranteed tensile elongation.

The table in Subparagraph 2.2H.3 specifies the required mechanical properties for the FRP system. Strength and stiffness should be specified in units of kips/inch/ply (kN/m/ply) which is consistent with ASTM D7565. The Engineer should populate this table with the minimum values used in the design of the FRP. Note that FRP strengthening systems are not standardized. They are available in many fabric weights and made with many different grades of fibers. For this reason, the Engineer should populate the table with values associated with the more common FRP systems on the market and avoid unique systems. In addition, it is usually a better idea to specify values corresponding to lighter weight fabrics since the Contractor can always propose to use fewer, thicker plies. The Engineer should also verify that multiple manufacturers can meet these requirements by checking the properties reported on their technical data sheets. Unit strength and stiffness can be calculated by taking the product of the ply thickness and the tensile strength and modulus, respectively. ACI 440.8 specifies minimum performance requirements for wet layup FRP systems and may be

referenced in this specification. Mechanical properties should be specified in units of kips/inch/ply (kN/m/ply).

3. Unidirectional *Carbon or E-Glass* Fiber FRP System:

Property	*Requirement*	*Test Method*
Ultimate Tensile Strength in longitudinal direction of fibers	*X.XX kips/in./ply (kN/m/ply)*	*ASTM D7565*
Chord Tensile Stiffness	*XXX kips/in./ply (kN/m/ply)*	*ASTM D7565*
Ultimate Tensile Rupture Strain	*X.XX%*	*ASTM D7565*

Paragraph 2.2I relates to the glass transition temperature (T_g) requirements for the FRP system. Most FRP systems are cured under ambient temperatures and have glass transition temperatures (the temperature when the resin starts to soften and become less effective at transferring load) ranging between 140 °F (60 °C) and 180 °F (82 °C). Note that this requirement is not intended to satisfy fire endurance requirements. For a complete discussion on the design of FRP systems for fire rated members, see Sections 9.1 and 9.2 in ACI 440.2R.

I. Physical Property Requirements: FRP system shall meet or exceed the following physical property requirements:

The Engineer should include Subparagraph 2.2I.1 on all projects and select a temperature that is safely above the maximum service temperature the FRP system is expected to experience. Be careful not to specify too high of a temperature requirement as it could make it difficult to meet the specification requirements with an ambient temperature cure FRP system. For dry environments, the glass transition temperature of the FRP system should be at least 27 °F (15 °C) greater than the expected service temperature.

1. Glass Transition Temperature: Average glass transition temperature (ASTM E1640) of the cured FRP system shall be based on a minimum of 5 or more tests. The reported glass transition temperature of the cured FRP strengthening system shall exceed 140 °F (60 °C) *or the maximum expected service temperature the FRP system is expected to experience plus 27 °F (15 °C), whichever is greater*.

Paragraph 2.2J alerts the Contractor to any smoke/flame spread requirements for the project. Most FRP systems can meet the most rigorous requirements, but may require a flame resistant top coat, like an intumescent. In addition, the Engineer should mention if the smoke and flame spread requirements apply to exterior applications as it will affect the choice of flame resistant coating.

J. *Smoke and Flame Spread Requirements: FRP system shall meet a Class A smoke and flame spread rating in accordance with ASTM E84.*

Paragraph 2.2K defines the durability requirements, specifically the types of environmental exposure tests required.

K. Durability Requirements: FRP system shall meet or exceed the following durability requirements:

Subparagraph 2.2K.1 indicates how the retention strengths are to be presented.

1. Retained tensile strengths and elongations of the FRP system after exposure to the environments listed below shall be reported as a percentage of the room temperature, dry test values.

Subparagraph 2.2K.2 indicates sample size and how to calculate the retention strengths. Most testing shows little to no degradation of stiffness, only strength.

2. The percentage of the tensile strength retained shall be calculated by dividing the average of 5 or more tests made at the applicable environmental exposure condition by the average of 5 or more tests made at room temperature, dry conditions. All tests shall be performed on FRP made from the same lots of fiber reinforcing sheets and polymer resins. The FRP test sample shall not be coated with a protective topcoat.

Subparagraph 2.2K.3 provides a table of test environments that most FRP suppliers have used to test the durability of their FRP systems. The Engineer should exercise caution when listing the required test environments as some or most may not be applicable to the project. For instance, an FRP system used to strengthen a member in a conditioned, interior space would not be subject to any durability issues and hence it could be argued that no durability testing should be required. However, to insure that low quality FRP materials are not used on the project, it is usually a good idea to require at least 3000 hours of exposure to water. If the project is located in an unusual environment, it may be wise to consult with several manufacturers and add applicable test environments. Note that Table 9.1 of ACI 440.2R provides a list of environmental reduction factors to be considered in the design of the FRP system.

If freeze-thaw is a concern, the user may use the test method documented in ICC-ES AC125 described below:

Condition samples in a 100% relative humidity chamber at 100°F (38°C) for three weeks. Cycle the conditioned samples at 0°F (-18°C) for 4 hours, minimum followed by 12 hours, minimum, in a 100% relative humidity chamber at 100°F (38°C).

3. Exposure Environments:

Environment	*Exposure Time*	*Applicable Tests*
Water	*3000 hours*	*ASTM D2247* *ASTM E104*
Saltwater	*3000 hours*	*ASTM D1141* *ASTM C581*
Alkali (pH 9.5)	*3000 hours*	*ASTM C581*
Dry Heat	*3000 hours*	*ASTM D 3045*
Freeze-Thaw	*20 cycles*	Use ICC-ES Method
Cyclic Exterior Exposure	*2000 hours*	*ASTM G153*

Subparagraph 2.2K.4 provides the retention strengths for durability based on Table 9.1 of ACI 440.2R. Carbon FRP strengthening systems should retain 85% of their strength, and E-glass FRP systems should retain 50% of their strength for aggressive exposure conditions or 65% of their strength for normal exterior exposure. The Engineer should select the appropriate requirement based on the type of FRP system.

4. Carbon FRP strengthening systems shall retain 85% of their strength. *E-glass FRP systems shall retain 50% (for aggressive exposure conditions) or 65% (for normal exterior exposure) of their strength*.

PART 3 – EXECUTION

3.1 EXAMINATION

A. Verify dimensions of concrete members to be strengthened with externally bonded FRP reinforcement.

Paragraph 3.1B requires the Contractor to assess the condition of members to be strengthened prior to starting so that areas not already known or shown on repair drawings can be brought to the Engineer's attention. In addition, pipes, conduit, embedded junction boxes, etc. should also be brought to the Engineer's attention. In general, this provision should always be included in the specification.

B. Visually assess the member to be strengthened and all surfaces to receive the FRP system for conditions that may affect the installation. Report all areas exhibiting evidence of deterioration or distress to the Engineer prior to the initiation of surface preparation or FRP installation.

Paragraph 3.1C is not used on most projects as the condition evaluation and design are done prior to the construction. However, if the concrete strength of some members could not be verified during the inspection phase of the project, this provision may be included. Compression tests of cores or adhesion tests may be used to assess the strength of the concrete substrate. Note that if concrete strengths are found to be much less than assumed in design, Work should be stopped until the Engineer evaluates the design.

C. *Conduct exploratory and/or non-destructive tests to verify the integrity or strength of the concrete to which the FRP will be adhered.*

Paragraph 3.1D makes the Contractor responsible for providing the necessary pathways, scaffoldings and other means of access to the repair areas for personnel, equipment and materials. The Engineer should include any other special requirements in this specification or in the project documents.

D. Provide necessary pathways, scaffoldings and other means of access to the repair areas for personnel (including Owner and Engineer representatives), equipment and materials.

Paragraph 3.1E relates to any obstructions that may have to be temporarily removed or relocated to enable the FRP system to be installed, including items that prohibit adequate access to the repair area. Include this section for all projects. The Engineer should exclude any items the Owner will address.

E. Make a record drawing, sketch, or photo of all obstructions including pipes, conduits, wiring, junction boxes, and other items that affect the installation of the FRP system to enable them to be removed, relocated and subsequently reinstalled (*responsibility to be specified*). Engineer shall approve any removal or relocation of obstructions.

Paragraph 3.1F relates to the items that affect access to the project and should be included in the specification for all projects. The Engineer should exclude any items the Owner will address.

F. Remove, replace, and *dispose* of any plants, fences and other obstructions that prevent access to the repair areas (*responsibility to be specified*). Engineer shall approve replacement and *disposal* of any plants, fencing or other obstructions removed to gain access to the repair areas.

Paragraph 3.1G relates to the condition of the equipment the Contractor uses on the project. Unless this provision is addressed in another specification, it should be retained in this specification.

G. Provide all necessary equipment in clean and operating condition and in sufficient quantities to ensure continuous and uninterrupted FRP installation.

Article 3.2 provides general requirements for repairs to the concrete that may be required prior to installing the FRP system. Typical repairs may address spalls, exposed or corroded reinforcing steel and cracks. The intent of this guide specification is to generally outline how these repairs should be handled as they relate to the FRP system but not to provide detailed requirements for making the repairs. The Engineer should include separate specification sections for making each of the various substrate repairs anticipated for the project elsewhere in the project documents. For example, this guide specification requires that cracks wider than 0.01 inch (0.25 mm) be injected with epoxy prior to installing the FRP system, but does not present detailed requirements for executing the crack injection repairs. The materials, equipment, and construction requirements for the crack injection repairs should be covered in a separate specification section. This specification section should be identified in Paragraph 1.1B of this specification.

3.2 SUBSTRATE REPAIR

A. Make all substrate concrete repairs in accordance with applicable specifications prior to installation of the FRP system. Before application of FRP system, consult with Engineer and manufacturer to determine the appropriate degree of curing and drying of repairs to which the FRP system will be bonded.

Paragraph 3.2B cautions against applying FRP systems to substrates suspected of containing corroded reinforcement. Ongoing corrosion can lead to spalling of the substrate which may cause the FRP system to delaminate in the case of bond-critical applications, or overstress the FRP system in the case of contact-critical applications. Bond-critical and contact-critical applications are explained further in the commentary prior to Article 3.3.

B. Do not apply FRP systems to concrete suspected of containing corroded reinforcement or reinforcement which is likely to corrode and concrete exhibiting alkali aggregate reaction (AAR), unless approved by the Engineer.

Paragraph 3.2C relates to the repair of cracks in the concrete member. The Engineer should specify detailed requirements for the pressure injection of cracks in a separate specification which should be based largely on the guidelines of ACI 224.1R and ACI RAP Bulletin 1 (RAP-1), and verified according to ICRI 210.1. FRP systems should not be applied across moving cracks.

C. Inject all cracks in the surface of concrete or the substrate wider than *0.01 in. (0.25 mm)* with epoxy resin under pressure in accordance with applicable specifications prior to installation of the FRP system.

Surface preparation is critical to the success of an FRP strengthening project and the intent of this guide specification is to define the requirements. FRP applications can be categorized as being either “bond-critical” which rely on bond to the substrate, or “contact-critical” which rely on

intimate contact to the substrate to function properly. Flexural strengthening of a slab or beam, or 3-sided U-wraps used to provide additional shear strength to a beam, are examples of bond-critical applications. Retrofitting a column for seismic forces by completely wrapping with FRP is an example of a contact-critical application. Surface preparation requirements vary slightly depending on the application type. Section 6.4.2 of ACI 440.2R provides guidance on surface preparation for FRP systems.

3.3 SURFACE PREPARATION

Paragraph 3.3A relates to the Work performed prior to surface preparation and the optional language requiring approval.

A. Make all necessary substrate and crack repairs *and secure approval from the Engineer* prior to initiating surface preparation.

Paragraph 3.3B should be modified by the Engineer to be consistent with the size of the project and the project schedule. In many cases, it is not practical to inspect all surfaces prior to application. The responsibility for inspection of surface preparation should be defined in this section. The Engineer should specify who inspects and approves the surfaces. Inspection and approval can be by the Engineer, Independent Testing Agency, or Contractor's FRP representative.

B. ___ *shall approve preparation of all surfaces to receive the FRP system prior to application of the FRP system.*

Paragraph 3.3C defines the surface profile requirements for bond-critical applications which can be safely used for contact-critical applications. If the project is large and consists of all contact-critical applications, the Engineer may want to ease the requirements for complete removal of substances that could affect the bond. Grit blasting, grinding, pressure washing, or any other technique capable of producing a minimum surface profile of CSP 3, as defined by ICRI 310.2R, is generally used. Specific techniques may be prescribed to address project conditions. Dust collection guidelines should be included in the specification or in the contract documents to address project requirements.

C. Surface Profile: Remove localized out-of-plane variations like form lines that exceed 1/32 in. (0.8 mm) or to the tolerances recommended by the FRP System manufacturer. Prepare concrete surface to a surface profile not less than CSP 3, as defined by ICRI 310.2R, or to the tolerances recommended by the FRP system manufacturer.

Paragraph 3.3D defines how the corners of members are to be detailed prior to installing the FRP. In general, inserting the FRP into an inside corner of a member (e.g. inside corner of a beam and bottom of slab) should be avoided. Include the statement, "Construct a circular fillet to a minimum

radius of 0.5 in. (13 mm) at all inside corners where the FRP is installed," when this detail is unavoidable.

D. Rounding Corners: Round all outside corners and sharp edges to where the FRP is wrapped around the member to a minimum radius of 0.5 in. (13 mm). *Construct a circular fillet to a minimum radius of 0.5 in. (13 mm), or per the manufacturer, at all inside corners where the FRP is installed*.

Paragraph 3.3E requires the Contractor to clean the surfaces. The Engineer should include language for securing approval if that is the intent.

E. Surface Cleaning: Clean concrete surfaces using methods recommended by the FRP System Manufacturer to remove any dust, laitance, grease, oil, curing compounds, wax, impregnations, stains, paint coatings, surface lubricants, foreign particles, weathered layers and any other bond-inhibiting material. *Secure the approval of the Engineer and manufacturer prior to installing the FRP system*.

3.4 INSTALLATION OF FRP SYSTEM

A. Environmental Conditions for Installation:

1. *Document the temperature and weather conditions before and during installation of the FRP system. Comply with the contract documents and manufacturer's written recommendations.*

2. Do not apply the FRP system or any of its constituent materials to frozen or wet surfaces. Do not apply FRP materials if rain, snow, or dew point condensation is expected.

FRP installations must be done within the temperature ranges specified by the manufacturer. When cold temperatures are expected, it is important to raise and maintain the temperature of the work area and substrate by including the optional language. Clean heat sources are required since they are unlikely to affect the bond of the FRP to the substrate.

3. Ensure ambient and concrete surface temperatures are within the range specified by the manufacturer for FRP installation. *If necessary, enclose the workspace and use propane, electric, or other clean heat sources to raise and maintain the ambient and concrete surface temperatures to the ranges recommended by the manufacturer. Do not use kerosene heaters.*

Moisture restrictions may be waived for resins that have been formulated for wet applications and meet all specified adhesion criteria. If restrictions are waived, adhesion testing should verify bond strength in bond-critical applications.

4. *Ensure moisture levels on concrete substrate and moisture vapor transmission rates comply with manufacturer's written recommendations.*

Subparagraph 3.4A.5 alerts the Contractor to the potential for moisture vapor transmission which can affect the quality of the installation and effectiveness of the FRP.

5. Do not install the FRP system when environmental conditions support moisture vapor transmission from the concrete substrate.

6. Commencement of FRP installation will constitute acceptance of substrate conditions by Contractor.

B. Mixing of Resin Constituent Materials: Mix all resin constituent materials in accordance with manufacturer's instructions. Follow manufacturer's instructions regarding mix ratio, temperature range, paddle type, mix duration, etc. Do not dilute any resin constituent materials with any organic solvents or thinners. Discard any mixed resin that exceeds its pot life or shows signs of increased viscosity.

Paragraph 3.4C relates to the application of the primer and putty. Note that some FRP systems do not use a primer to enhance the bond to the substrate and some projects, particularly contact-critical applications, may not require a primer. Putty will almost always be required to fill bug holes and other minor voids, to smooth uneven surfaces, or to provide a tacky surface that can hold the weight of the FRP sheets. In general, the putty and subsequent resin coats should be applied to a tacky, uncured coat. If the primer or putty becomes tack-free, their surfaces may need to be lightly sanded and cleaned before applying the next constituent material of the FRP system to ensure good bond between the various constituent materials and between plies. The specification suggests using sandpaper and acetone to accomplish the surface preparation, but each manufacturer may have their preferred approach.

C. Application of Primer and Putty: If required by the FRP system manufacturer, coat the concrete surface to receive the FRP system with a primer resin *using a medium nap paint roller or other tools recommended by the manufacturer***.** Apply primer at a coverage rate such that it penetrates the pores of the concrete substrate but does not drip or run. Fill any bug holes or small voids and level any uneven surfaces with the putty resin *using a trowel or putty knife or other tools recommended by the manufacturer to apply the putty***.** Do not apply the putty until the primer is tack-free, unless approved by the manufacturer. Fillers or other thickening agents may be

added to the putty in accordance with the manufacturer's instructions. Do not apply putty to a previously applied primer or putty coat if that coat has fully cured, unless first prepared per the manufacturer's instructions.

Paragraph 3.4D provides the Contractor with the preferred methods of impregnating and applying the FRP sheets to the substrate. The objective of impregnating the FRP sheet is to achieve full wet-out of the fibers and complete encapsulation of all fibers by the saturating resin. Medium nap rollers used to apply the resin to the substrate or to the FRP sheet, and fin rollers (also known as rib rollers) used to Work the resin into the sheets, have been shown to wet out the fibers on thin fiber sheets. Mechanical saturators may also be used to wet-out the fiber sheets and are common on large projects requiring high production rates. If a mechanical saturator is used, the Contractor should include step-by-step procedures for its use in the submitted installation manual. Unfortunately, there are no practical, quantitative methods to measure how well the FRP sheet has been wet-out. Mil gages may be used to determine an approximate volume of saturant applied to the substrate but not how well the fiber sheet has been wet-out. Testing witness panels and performing pull-off tests should provide confidence in the quality of the installation.

D. Impregnating with Saturating Resin and Applying Fiber Sheet: Follow manufacturer's recommended procedures for impregnating fiber sheets with saturating resin. Apply saturating resin using a medium nap roller or mechanical saturator. Do not apply saturating resin or impregnated fiber sheet to a previously applied resin coat if that coat has fully cured, unless prepared per the manufacturer's instructions. Place fiber sheet onto substrate. Roll fiber sheets in the direction of the fibers *using a fin roller* to remove any air entrapped between the fiber sheets and concrete surface and to fully impregnate the fiber sheets with saturating resin. Achieve full contact with the concrete substrate during rolling. Do not roll unidirectional fiber sheets in the direction transverse to the fibers to avoid damaging the fibers.

E. Alignment of FRP Materials: Install FRP sheets with the fibers aligned in the direction indicated on the drawings *or other contract documents*. Report any deviation in the alignment of the fibers of more than 5° (approximately 1 in/ft [90 mm/m]) to Engineer for acceptance/rejection.

Paragraph 3.4F provides the requirements for installing more than one fiber sheet. The main consideration when multiple sheets are required is the ability of the FRP system to support its own weight without sliding or sloughing.

F. Multiple Fiber Sheet Plies: Follow the manufacturer's recommended procedures for installing multiple fiber sheet plies and the contract documents for the orientation of the fibers, ply stacking sequence, and length. Limit the number of plies applied in a

single day to that which can be supported by the previously applied system without sloughing or sliding. Consult with the manufacturer to determine the maximum number of plies that can be applied in a single day considering temperature and other variables. Do not apply additional fiber sheet plies to previously cured plies unless first prepared per the manufacturer's instructions. Apply an additional coat of saturating resin, if required by the manufacturer.

Paragraph 3.4G relates to lap splices. The Engineer should indicate on the drawings or in sketches, the locations where lap splices are acceptable. In general, lap splices should always be staggered to avoid a large build-up of thickness. The manufacturer should also be consulted to determine the appropriate lap length which varies by product.

G. Lap Splicing of Fiber Plies: Provide lap splices equal to or exceeding the length recommended by the manufacturer such that the full tensile strength of the fiber sheet is achieved. *Install lap splices in acceptable regions (low moment or low shear) as indicated on the drawings or sketches*. Stagger lap splices for multiple plies or side-by-side installations *unless noted otherwise on the drawings or sketches*. Document the location of lap splices on an as-built drawing or sketch.

Paragraph 3.4H should only be included in the specification if an FRP anchoring system is used.

H. *Anchoring of FRP Sheets: Secure approval of the FRP anchoring system prior to the start of construction. Install FRP anchoring system in accordance with drawings and manufacturer's written recommendations.*

Include Paragraph 3.4I if embedded metal items, like junction boxes, anchor hardware, etc. are suspected to occur on the project.

I. *Metal Contact with Carbon FRP Systems: Do not allow bare metal to come into direct contact with the carbon FRP system. Protect metal hardware from galvanic corrosion by providing an insulating barrier of additional resin or E-glass FRP between the carbon FRP and the metal.*

Paragraph 3.4J should be retained, in case the Contractor is required to drill or core through the FRP system after installation.

J. Penetrations of FRP Sheets: Secure approval from the Engineer for all penetrations through the FRP system.

Article 3.5 addresses field quality control of the FRP installation which is accomplished by a combination of visual inspections and tests. The International Building Code (IBC) requires that special inspectors be retained by the Owner or licensed design professional. Although FRP is not

addressed within IBC, a similar approach may be implemented. For many projects, the Contractor's QC representative samples materials, visually inspects the FRP installation, and performs on-site QC tests.

3.5 FIELD QUALITY CONTROL

Paragraph 3.5A is provided to assign responsibility for the QC inspections. If the Owner elects to retain an independent third party testing agency, then the text specifying the "Contractor's QC representative…" should be omitted. Conversely, if the Contractor is to be responsible for the QC tests, omit the text related to the Owner hiring an independent third party testing agency.

A. Independent Testing Agency *or Contractor's QC representative*: Field inspections and tests defined in Paragraphs 3.5D thru 3.5H shall be performed by a QC inspector retained by the *Contractor or Owner*. The QC Inspector shall be trained in the installation and testing of FRP systems.

B. Inspection of Materials: Inspect all manufacturers' certifications for the delivered and stored FRP constituent materials for conformity to the contract documents prior to starting the project.

Paragraph 3.5C requires the Contractor to prepare written daily inspection reports. If an independent third party testing agency is retained by the Owner, these reports would be reviewed by the independent third party testing agency.

C. Daily reports: Prepare daily reports documenting the date and time of installation, environmental conditions including general weather, ambient and surface temperatures, relative humidity, and if applicable, the type of auxiliary heat source used. Include the fiber lot numbers used that day and the members strengthened with those lots and any inspections performed, type and location of defects found, how the defects were dealt with, results of adhesion tests, and any repairs made to the FRP system.

Paragraph 3.5D requires that all corners be inspected prior to installing the FRP to verify they meet the minimum radius requirements of Paragraph 3.3D. This paragraph may be omitted if the project does not have any corners. Once FRP is applied, it is not possible to inspect the corners.

D. *Inspect all rounded outside corners and all fillets of inside corners prior to application of FRP. Rework all corners not meeting the minimum requirements of this specification.*

Paragraph 3.5E describes the requirements for fabricating and testing witness panels. Witness panels, like concrete cylinders, are used to verify the strength of the installed material. Witness panels will increase the cost of a project so their use should be limited where possible. For some strengthening projects where the design strains are small (e.g. shear strengthening), witness panels are not as important as verifying the bond with pull-off tests.

E. *FRP System Tensile Testing: Use witness panels, fabricated on site to verify the cured FRP system meets the strength requirements of the project. The following criteria apply to the fabrication and testing of witness panels:*

Subparagraph 1 may be altered to specify a different frequency depending on the size of the project. The witness panels may be made of 1 or 2 plies, but this should be left up to the Contractor and manufacturer.

1. *Make witness panels from the same fiber, saturating resins, equipment, and methods used in the installation of the FRP system. Make panels with one or two plies and large enough to extract a minimum of 10 tensile test coupons. Fabricate a panel for every 5,000 ft^2 (500 m^2) of material installed or in accordance with the contract documents.*

Subparagraph 2 requires the panels to be cured at the same conditions as the FRP system.

2. *Store witness panels in a dry location on site and allow the panels to cure under the same environmental conditions as the installed FRP system.*

Subparagraph 3 provides acceptance criteria for the FRP system based on the testing of witness panels. Note that tensile testing of FRP materials is challenging and only the most experienced laboratories are able to generate reliable test results. Expect variation in the test results.

3. *Send panels to a third party laboratory experienced with the tensile testing of FRP materials and test 5 samples in accordance with ASTM D7565. Report the average tensile strength and elongation to failure and the number of plies of the cured samples. The FRP system shall be accepted if average tensile strength exceeds << >> kips/inch/ply (kN/m/ply). Otherwise test the remaining 5 samples and combine the results with the original five samples. The FRP system shall be accepted if the average tensile strength of the combined tests exceeds << >> kips/inch/ply. Otherwise it shall be rejected.*

F. Inspection for Fiber Orientation: Prior to top coating visually inspect the installed FRP system for fiber kinks, waviness and fiber orientation. Report unusual waviness and all kinks to the Engineer for acceptance/rejection. Report any deviation in

the alignment of the fibers of more than 5° (approximately 1 in/ft or 90 mm/m) to Engineer for acceptance/rejection. Remove and repair rejected areas.

Delaminations are probably the most common defect found in an FRP installation. Paragraph G provides the inspection requirements and acceptance criteria which is based on ACI 440.2R. Small delaminations, provided they are concentrated are acceptable. Larger delaminations or many small delaminations may be repaired by injecting with resin or selectively removed and replaced. The Engineer may wish to modify these acceptance criteria if the FRP sheet is narrow where a small delamination could affect a large percentage of the width of the sheet. For instance, a 1 in. x 2 in. (25 mm x 51 mm) delamination having an area of 2 in^2 (1290 mm^2) and occurring within a 4 in. (102 mm) wide sheet, could affect 50% of the width of the sheet and could be an issue.

G. Inspection for Delaminations: After waiting a minimum of 24 hours for the FRP system to initially cure and before the application of any top coatings, visually inspect the installed FRP system for delamination defects including bubbles, air pockets, voids, and areas of debonding. Lightly tap the cured FRP system with a hammer or other object to verify the location and size of defects by noting a "dead" sound. Conduct acoustic tap testing at a frequency of one tap per 0.5 ft^2 (0.05 m^2). Small delaminations less than 2 in^2 (1290 mm^2) each are permissible as long as the delaminated area is less than 5% of the total laminate area and there are not more than 10 such delaminations per 10 ft^2 (1 m^2). Note the size and location of all delamination defects and report to the Engineer for acceptance/rejection. Repair or remove and repair rejected areas in accordance with Article 3.6.

Paragraph 3.5H provides subjective criteria for evaluating the cure of the resin. This provision is intended to alert the Contractor to making small resin cup samples that can be checked as needed. Problems with the cure of the resin will be observed within 1-2 days in most cases.

H. Inspection for Relative Cure of Resin: Obtain resin-cup samples for each batch of mixed resin used. Cure resin-cup samples at the temperature as the installed FRP system. Verify the relative cure of the resins comprising the FRP system by regularly examining the resin-cup samples. For questionable samples, consult with the manufacturer for acceptance criteria. Remove and repair the FRP system in all areas where the resin is found to have not properly cured.

Requirements for conducting bond pull-off tests should be specified in Paragraph 3.5I. Criteria for sampling are presented in ASTM D7522 and should take into account the job size, number of crews, number of days of installation, number of methods for preparing surfaces, etc. In general, unless daily production is very limited, a minimum frequency of 3 specimens per day, 1 specimen per 1,000 sq ft (93 sq m), or 5 specimens per test condition, whichever is greater, is recommended.

For narrow width plies where a tensile bond test would damage a large portion of the strip, the test may need to be performed on a separate ply installed just for the test.

I. Inspection for Adhesion to Substrate: Inspect the bond between the cured FRP system and the concrete substrate by conducting direct tension pull-off tests in accordance with ASTM D7522. Conduct adhesion testing at a frequency of three tests per day of installation or one test per 1000 ft^2 (93 m^2) of substrate contact area whichever results in more tests being performed. Acceptance criteria is as follows:

Subparagraph 3.5H.1 defines the acceptance criteria which includes the provision for reporting unusual failure modes to the Engineer for further evaluation.

1. Pull-off strength shall exceed 200 psi (1.4 MPa) and failure shall occur in the concrete substrate. Failures occurring between plies or between the concrete substrate and the FRP system, regardless of the strength, shall be reported to the Engineer for evaluation.

2. If one or more of the pull-off tests is found unacceptable, perform two additional tests adjacent to the area where the unacceptable pull-off test results were located. If one of the additional pull-off tests is found unacceptable the Work shall be rejected.

3.6 REPAIR OF DEFECTIVE WORK AND QC TEST SITES

A. Submit all proposed repair procedures to the FRP system to the Engineer for approval prior to making the repairs.

B. Repair locations in the FRP system where the bond tests were performed by lapping additional plies in accordance with the manufacturer's written recommendations.

C. Repair all unacceptable defects found in the cured FRP system following the manufacturer's written recommendations for making repairs to the FRP system. All repairs shall be subject to the same application, curing, and quality control specifications as the original Work.

D. Repair large delaminations greater than 25 in^2 (16,130 mm^2) by selectively cutting away the affected FRP sheet and applying an overlapping FRP sheet patch of equivalent plies.

Paragraph 3.6E alerts the Contractor to the potential for growing the delamination by pressure injecting resin.

E. Repair delaminations less than 25 in^2 (16,130 mm^2) by injecting with saturating resin or by selectively cutting away the affected FRP sheet and applying an overlapping FRP sheet patch of equivalent plies. Engineer, in consultation with the manufacturer, shall approve the injection repair procedure. If any delamination growth is suspected between the FRP plies due to injection, the procedure shall be halted and reported to the Engineer.

Modify Paragraph 3.6F with lap lengths that are appropriate for the FRP system.

F. Localized Replacement of FRP System: For larger defects or where deemed necessary by the Engineer, remove the entire thickness of the defect to a minimum of 1 in. (25 mm) past the damage limit on all sides. Prepare the substrate and apply the FRP system in accordance with the manufacturer's written recommendations. Extend the additional FRP layers a minimum of 6 inches (153 mm) on all sides of the defect repair or greater as recommended by the manufacturer or specified elsewhere in contract documents. Do not apply additional fiber sheet plies to previously cured plies unless first prepared per the manufacturer's instructions.

3.7 CLEANING

A. Remove excess epoxy resin prior to curing of the FRP strengthening.

B. Do not use solvents to remove or clean already cured epoxy resin.

END OF SECTION 032500

INTERNATIONAL
CONCRETE REPAIR
INSTITUTE

1000 Westgate Drive, Suite 252
St. Paul, MN 55114
Phone: 651-366-6095 Fax: 651-290-2266
www.icri.org