The Infrastructure Innovators

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Externally Bonded FRP Strengthening System (Fiber Reinforced Polymer Reinforcement

1 PART 1 – GENERAL

1.1 SCOPE OF WORK

This Section specifies materials, design requirements when delegated design is indicated, surface preparation, installation, field quality control, inspection, testing, repair, and protection of externally bonded fiber-reinforced polymer composite strengthening systems.

Systems covered by this Section include field-saturated carbon-fiber-reinforced polymer and glass-fiber-reinforced polymer fabrics externally bonded to concrete and masonry substrates using compatible primers, fillers, saturating resins, adhesives, and protective coatings.

The extent, location, fiber type, fiber orientation, number of plies, dimensions, lap-splice requirements, anchorage, terminations, and protective coatings shall be as shown in the Contract Documents and approved shop drawings.

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1.2 DEFINITIONS

Batch - A quantity of material formed during the same field installation in one continuous process and having identical characteristics throughout.

Bidirectional Laminate - Reinforced polymer laminate with fibers oriented in two different directions in its plane.

Bond-Critical Applications - Applications of FRP systems for strengthening structures that rely on bond to the concrete substrate. Examples are flexural and shear strengthening of beams and slabs.

Catalyst- A substance that initiates a chemical reaction and enables it to proceed under milder conditions than otherwise required that does not, itself, alter or enter into the reaction. See Hardener.

Composite - A combination of two or more materials differing in form or composition on a macro scale. The constituents retain their identities; they do not dissolve or merge completely into one another, although they act in concert. Normally, the components can be physically identified and exhibit an interface between one another. See Composite FRP.

Composite FRP- A polymer matrix, either thermosetting or thermoplastic, reinforced with a fiber or other material with a sufficient aspect ratio (length to thickness) to provide a discernible reinforcing function in one or more directions. See Composite.

Composite Strengthening System - The qualified combination of fibers, resins, primers, fillers, adhesives, anchorage components, and protective coatings installed in the configuration used to establish the system's properties.

Contact-Critical Applications - Applications of FRP systems that rely on intimate contact between concrete substrate and the FRP system to function as intended. An example is the confinement of columns for seismic retrofit. In these specifications are treated in the same way as bond-critical applications. See Bond Critical Applications.

Creep Rupture - Failure of an FRP system resulting from a gradual, time-depended reduction of capacity due to sustained loading.

Cure - The process of causing irreversible changes in the properties of a thermosetting resin by chemical reaction. Cure is typically accomplished by addition of curing agents or initiators, with or without heat and pressure. Full care is the point at which a resin reaches its specified properties. Resin is under cured if its specified properties have not been reached.

Cure Time - The time necessary to cure a thermosetting resin system, thermoset-based composite, or prepreg at a given temperature.

Curing Agent - A catalytic or reactive agent that, when added to resin, causes polymerization. Also called Hardener.

Debonding - A separation at the interface between substrate and the reinforcing layer.

Delamination - Separation of the layers of the FRP laminate from each other.

Developmental Length - The bonded distance required for transfer of stresses from concrete to the FRP to the develop tensile capacity of FRP.

Durability - The ability of a material to resist cracking, oxidation, chemical degradation, delamination, wear, or the effects of foreign object damage for a specified period of time, under the appropriate load conditions and specified environmental conditions.

EOR (Engineer of Record) - The licensed design professional responsible for the structural design of the project and for the acceptance of design-related deviations.

Epoxy - A polymerizable thermosetting polymer containing one or more epoxide groups, cured by reaction with phenols, anhydrides, polyfunctional amines, carboxylic acids, or mercaptans. An important matrix resin in FRP, also used as structural adhesive.

Fabric - Arrangement of fibers held together in two or three dimensions. It may be woven, non-woven, knitted or stitched. Fabric architecture is the specific description of the fibers, their directions and construction.

Fiber - A general term used to refer to filamentary materials. The smallest unit of fibrous material. Often, fiber is used synonymously with filament.

Fiber Content - The amount of fiber present in a composite usually expressed as a volume fraction or a mass fraction of the composite.

Fiber Fly - Short filaments that break off dry fiber tows or yarns during handling and become airborne, classified as nuisance dust.

Fiber -Reinforced Polymer (FRP)_System - Composite material consisting of a polymer matrix reinforced with cloth, mat, strands, or any other fiber form.

FRP Installer – The contractor or applicator trained and authorized to install the specified composite strengthening system.

FRP System Manufacture - The entity responsible for qualification of the complete combination of constituent materials and installation procedures.

Filament - See Fiber.

Filler - A relatively inert substance added to a resin to alter its properties or to lower cost or density. Also used to term particulate additives. Also called extenders.

Fire Retardant - Chemicals used to reduce the tendency of resin to burn. They can be added to the resin or coated on the surface of the FRP.

Flow - The movement of uncured resin under pressure or gravity loads.

Fumed Silica - Powder with high surface area and three-dimensional structure that when mixed with epoxy resin results in viscosity-increasing putty. The powder has a thixotropic type behavior when used as a thickener.

Glass Transition Temperature (Tg) - The approximate midpoint of the temperature range over which a transition in material response from elastic to viscoelastic takes place.

Hardener - Substance added to thermosetting resin to cause polymerization. Usually applies to epoxy resins.

Impregnation - The process of saturating the interstices of a reinforcement or substrate with a resin.

Inhibitor - A substance that retards a chemical reaction, such as ultraviolet degradation. Also used to prolong shelf life of certain resins.

Initiator - Chemicals, most commonly peroxides, used to initiate the curing process for unsaturated polyester and vinyl ester resins. See Catalyst.

Laminate - One or more layers or plies of fiber, bonded together in a cured resin matrix.

Lay Up - The process of placing the FRP reinforcing material in position for installation.

Licensed Design Professional - A professional engineer legally authorized to practice in the project jurisdiction and responsible for the application design or evaluation.

Lot - A quantity of material manufactured during the same plant production in one continuous process and having identical characteristics throughout. In these specifications, batch is used interchangeably. See Batch.

Mat - A fibrous material for reinforced polymer consisting of randomly oriented chopped filaments, short fibers (with or without a carrier fabric), or long random filaments loosely held together with a binder.

Matrix - The essentially homogenous resin or polymer material in which the fiber system of a composite is embedded.

Micro-Cracking - Cracks formed in composites when stresses locally exceed the strength of the matrix.

Pin Holes - A small cavity, typically less than 0.06 in. in diameter, that penetrates the surface of a cured composite part.

Pitch - Petroleum or coal tar precursor base used to make carbon fiber.

Polyester - A thermosetting polymer synthesized by the condensation reaction of certain acids with alcohols and subsequently cured by additional polymerization initiated by free radical generation. Polyesters are used as binders for resin mortars and concretes, fiber laminates, and adhesives. Commonly referred to as “unsaturated polyester”.

Polymer - A compound formed by the reaction of simple molecules that permit their combination to proceed to high molecular weights under suitable conditions.

Polyurethane - A thermosetting resin prepared by the reaction of diisocyanates with polyols, polyamides, alkyd polymers, and polyether polymers.

Post cure - Additional elevated-temperature cure to increase the level of polymer cross linking; final properties of the laminate or polymer are enhanced.

Pot Life - Time interval, after mixing of thermosetting resin and initiators, during which the mixture can be applied without degrading the final performance of the resulting polymer composite beyond specified limits.

Prepreg - A fiber or fiber sheet material containing resin whose reaction has progressed to the stage where consistency is tacky. Multiple plies of prepreg are typically cured with applied heat and pressure. Also pre-impregnated fiber or sheet.

Pultrusion - A continuous process that combines pulling and extrusion for manufacturing composites that typically have a constant cross-sectional shape. The process consists of pulling a fiber material through a resin bath and then through a heated shaping die, where the resin is cured.

Putty - A Viscous epoxy resin typically used for bonding of FRP materials more often on walls and overhead. Thickened epoxy or a tack-coat act as the primary putties in the FRP systems. Putty can also be used to fill bug holes and voids up to .5”

Resin - A component of a polymeric system that requires a catalyst or hardener to polymerize or cure for use in composites. Resin often refers to the mixed polymer component or matrix of the FRP.

Resin Content - The amount of resin in a laminate expressed as a percentage of either total mass or total volume.

Roving - A number of yarns, strands, tows, or ends of fibers collected into a parallel bundle with little or no twist.

SDS – Safety Data Sheet

Shelf Life - The length of time a material, substance, product, or reagent can be stored under specified environmental conditions and continue to meet all applicable specifications or remain suitable for its intended function. Also called storage life.

Structural Adhesive - A resinous bonding agent used for transferring required loads between adherents.

Substrate - The original concrete and any cementitious repair materials used to repair or replace the original concrete. It can consist entirely of original concrete, entirely of repair materials, or of a combination of the two. The FRP is installed on the surface of the substrate.

Tack Coat - A manufactured thickened epoxy used as a putty in FRP applications.

Thermoset - A cross-linked polymer that cannot be softened and reformed by an increase in temperature. Cross linking is an irreversible process; thermosets cannot be returned to a molten state. Examples are epoxy, phenolic, and vinyl ester.

Thickened Epoxy - Is epoxy resin mixed with fumed silica to create a more viscous product. Thickened epoxy is typically used as a putty in the FRP systems. See Putty

Tow - An untwisted bundle of continuous fibers.

Unidirectional Laminate - A reinforced polymer laminate in which substantially all of the fibers are oriented in the same direction.

Vinyl Ester - A polymerizable thermosetting resin containing vinyl and ester components, cured by additional polymerization initiated by free-radical generation. Vinyl esters are used as binders for fiber laminates and adhesives.

Viscosity - The property of resistance to flow exhibited within the body of a material, expressed in centipoises. A higher viscosity has higher resistance to flow.

Volatiles - Materials such as water and solvents in a resin formulation that are capable of being driven off as vapor.

Wet Lay-Up - A method of making a laminate system by applying the resin system as a liquid, when the fabric or mat is put in place.

Wet-Out - The process of coating or impregnating roving, yarn, or fabric in which all voids between the strands and filaments are filled with resin. It is also the condition at which this state is achieved.

Witness Panel - A small FRP panel, manufactured on site under conditions similar to the actual construction. The panel may be later tested to determine mechanical and physical properties to confirm the expected properties for the full FRP structure.

1.3 REFERENCES

1.3.1 ACI—American Concrete Institute

1. 116R-00: Cement and Concrete Terminology.
2. 117-90: Specifications for Tolerances for Concrete Construction and Materials, and Commentary.
3. 224.1R-07: Causes, Evaluation, and Repair of Cracks in Concrete Structures.
4. 224R-01: Control of Cracking in Concrete Structures.
5. 440R-07: State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures.
6. 440.2R-23: Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening of Concrete Structures.
7. 440.11-22: Building Code Requirements for Structural Concrete Reinforced with Glass Fiber-Reinforced Polymer (GFRP) Bars.
8. 503R-93: Use of Epoxy Compounds with Concrete.
9. 503.4-92: Standard Specifications for Repairing Concrete with Epoxy Mortars.
10. 503.5R-92: Guide for the Use of Polymer Adhesives in Concrete.
11. 503.6R-97: Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concretes
12. 546R-04: Concrete Repair Guide.

1.3.2 ASTM- American Society for Testing and Materials

1. D7565 / D7565M: Standard Test Method for Determining Tensile Properties of Fiber-Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures
2. D3039: Test Method for Tensile Properties of Polymer Matrix Composite Materials.
3. D3418: Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry.
4. D4541: Test Method for Pull-Off Strength of Coatings Using Portable Adhesion Tester.
5. D7522 / D7522M: Standard Test Method for Pull-Off Strength for FRP Bonded to Concrete Substrate
6. D5687: Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation.

1.3.3 AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements.

1.3.4 ICBO- International Conference of Building Officials
1. AC125: Acceptance Criteria for Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) Composite Systems.
2. AC178: Acceptance Criteria for inspection and Verification of Concrete and Reinforced and Unreinforced Masonry Strengthening Using Fiber-Reinforced Polymer (FRP) Composite Systems.

1.3.5 ICRI- International Concrete Repair Institute
1. ICRI 310.2R:Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, Polymer Overlays, and Concrete Repair.
2. ICRI320.2: Guide Specifications for Externally Bonded FRP Fabric Systems for Strengthening Concrete Structures
3. ICRI320.2R: Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces.

1.3.6 NCHRP- National Cooperative Highway Research Program
1. Report 514: Bonded Repair and Retrofit of Concrete Structures Using FRP Composites (Recommended Construction Specifications and Process Control Manual).

1.4 PRE-QUALIFICATION OF FRP INSTALLER/CONTRACTOR

The Contractor/applicator must be prequalified by the owner or its representative for each FRP system after providing the following necessary information:

1. A minimum of 5 years of documented experience or 10 documented similar field applications with acceptable reference letters from respective owners.
2. A certificate of completed training from the manufacturer/supplier for at least two field representative who will be present onsite throughout the project.

1.5 SUBMITTALS

1.5.1 Action Submittals

1.5.1.1 Product Data Sheet (PDS)- Submit current product data for each fabric, resin, primer, filler, adhesive, coatings, and accessory

1.5.1.2 Shop Drawings- Show repair limits, member dimensions, fiber type, fiber orientation, number of plies, laminate dimensions, laps, splices, terminations, anchorage, penetrations, transitions, and protective coatings

1.5.1.3 Installation Work Plan- Describe access, substrate preparation, environmental controls, material conditioning, resin mixing, saturation, placement, curing, protection, inspection, testing, repair, and sequencing.

1.5.1.4 Delegated-Design Submittal- Where required, submit sealed calculations and drawings prepared by the responsible licensed design professional.

1.5.1.5 Quality Control Plan- Submit the project-specific plan required by this section.

1.5.1.6 Qualification Information- Submit manufacturer, Installer, onsite supervisor, testing-agency, and inspector qualifications

1.5.1.7 Safety Data Sheets- Submit current SDS for each chemical component

1.5.2 Submit a list of completed surface bonded FRP composite strengthening projects completed with the manufacturer's FRP systems in the past 5 years. The list should include projects with proposed FRP system, the dates of work, type, description and amount of work performed.

1.5.3 Submit certifications of applicator with written consent from the FRP manufacturer that the contractor has been trained in proper application of manufacturer’s systems.

1.5.4 Alternative materials submit Installation procedures and general recommendations regarding each material to be used. Must receive approval by EOR.

1.5.5 Alternative materials submit FRP manufacturer’s Safety Data Sheets (SDS) for all materials to be used. Must receive approval by EOR.

1.5.6 Alternate materials must submit an evaluation service number from IAPMO or ICC according to AC125.

1.5.7 Alternative materials submit FRP manufacturer’s product data sheet indicating physical, mechanical, structural, and chemical characteristics of all materials used in the FRP system. Include expected Modulus of Elasticity of strengthened composite system and expected yield strain. Must receive approval by EOR.

2 PART 2 – PRODUCTS

2.1 ACCEPTABLE MANUFACTURERS & COMPOSITE STRENGTHENING SYSTEM

Subject to compliance with requirements, available manufacturers offering products that may be incorporated into the Work include, but are not limited to, the following:

QuakeWrap System
QuakeWrap, Inc
6840 S. Tucson Blvd
Tucson, AZ 85756
Phone: (866) QuakeWrap
Fax: (520) 791-0600
www.QuakeWrap.com

These will be the only systems permitted, used in accordance with the manufacturer's recommendations, subject to the requirements of the plans and this specification.

Quality Control-Testing and Certification: Manufacturer shall certify that every batch or lot of material conforms to this specification and shall submit test results for every batch or lot of materials.

Labeling, packaging and storage shall include any health hazard warnings, precautions for handling and recommended first aid procedures in case of contact.

All materials used shall conform to this specification and other specifications referenced within and subject to the approval of the Engineer.

2.2 SYSTEM QUALIFICATION

2.2.1 The composite strengthening system shall be qualified as a complete system consisting of the specific combination of fibers, resins, primers, fillers, adhesives, coatings, anchors, and installation procedures proposed for the Work

2.2.2 Qualification shall be supported by testing applicable to the proposed fiber type, fabric architecture, resin system, number of plies, substrate, exposure conditions, and structural application.

2.2.3 Wet-layup carbon- and glass-FRP systems shall comply with the applicable requirements of ACI 440.8 and the approved system qualification or evaluation report.

2.2.4 Provide an ICC-ES, IAPMO UES, or other evaluation report acceptable to the Engineer when required by the Contract Documents or governing authority

2.2.5 Untested combinations of fibers and resins shall not be used.

2.2.6 Mechanical properties used for design shall not exceed the statistically based or guaranteed properties established by the applicable qualification standard and approved system documentation.

2.2.7 Clearly identify whether reported properties are based on:

1. Net fiber area.

2. Gross laminate area.
3. Nominal cured ply thickness.
4. Guaranteed or characteristic values.
5. Average test values.
6. Environmental reduction or design values.

2.2.8 Do not interchange properties reported using different area or thickness conventions.

2.3 CARBON FABRIC

2.3.1 Fabric shall be composed of high strength, high modulus carbon fibers. The fibers shall be primarily oriented in the longitudinal (0°) direction or in the 0° and 90° direction for biaxial fabrics. The fabric shall be black in color and impregnated using two component high strength epoxy resin. The fabric total weight shall be no less than 18 oz/yd^2.

2.3.2 Carbon fabrics shall be supplied in rolls no less than 24" in width.

2.3.3 Carbon fabric shall conform to the following physical properties

Carbon Fabric and Laminate Properties:

	QuakeWrap U20C	**QuakeWrap U27C**	**QuakeWrap U41C**	**QuakeWrap B20C**
Dry Fiber Properties:				
Tensile	725 ksi	550 ksi	725 ksi	711 ksi
Tensile	39,160 ksi	33,500 ksi	39,160 ksi	33,400 ksi
Ultimate Elongation	1.9%	1.64%	1.9%	2.1%
Density	0.065 lb./in^3	0.065 lb./in^3	0.065 lb./in^3	0.065 lb./in^3
Aerial Weight	20 oz/yd^2	27.8 oz/yd^2	41 oz/yd^2	20.0 oz/yd^2
Laminate Properties:				
Tensile Strength	146.9 ksi	179.0 ksi	146.9 ksi	145.1 ksi
Tensile Modulus	13,800 ksi	14,000 ksi	14,530 ksi	6,440 ksi
Ultimate Elongation	0.94%	0.92%	0.99%	1.00%
Breaking Force	5,730 lb./in.	8,400 lb./in.	10,240 lb/in.	2,250 lb./in.
Ply Thickness	0.040 in.	0.0470 in.	0.067 in.	0.0499 in.

2.4 GLASS FABRIC

2.4.1 Glass fabric shall be high-strength unidirectional or biaxial, white in color, weighing at least 20 oz/yd^3 and impregnated using two component high strength epoxy resin.

2.4.2 Glass fabric shall be supplied in rolls with a minimum width of 24".

2.4.3 Glass fabric shall conform to the following physical properties:

Glass Fabric and Laminated Properties:

	QuakeWrap U27G	**QuakeWrap B26G**	**QuakeWrap B2408G**
Dry Fiber Properties:			
Tensile Strength	470 ksi	470 ksi	470 ksi
Tensile Modulus	10,500 ksi	10,500 ksi	10,500 ksi
Ultimate Elongation	4.50%	4.50%	4.50%
Density	0.092 lb./in^3	0.092 lb./in^3	0.092 lb./in^3
Aerial Weight Fabric Only	27 oz/yd^2	26 oz/yd^2	32 oz/yd^2
Longitudinal (0°) Direction:			
Tensile Strength	70.9 ksi	68.3 ksi	25.7 ksi
Tensile Modulus	3,630 ksi	4,090 ksi	1,744 ksi
Ultimate Elongation	1.80%	1.44%	<2%
Breaking Force	3,190 lb./in.	1,420 lb./in.	1,430lb./in.
Transverse (90°) Direction:			
Tensile Strength	N/A	68.3 ksi	24.3 ksi
Tensile Modulus	N/A	4,300 ksi	1,702 ksi
Ultimate Elongation	N/A	1.42%	<2%
Breaking Force	N/A	1500 lb./in.	1,360 lb.ft.
Ply Thickness	.040in	0.022 in.	0.056in

2.5 EPOXY RESIN – POLYMER

2.5.1 Fabric shall be impregnated with two components, high strength, and low viscosity structural epoxy. The resin shall have low viscosity and long pot life, with a fast cure time designed for high volume saturation of heavy reinforcement fabrics using an impregnator machine or hand tools as per project requirements to thoroughly and uniformly saturate the fabric.

2.5.2 Saturating resins shall be 100% solids formulation with low toxicity and low odor conforming to the following physical properties:

Epoxy Resin Properties

	QuakeBond 300SR
Viscosity Mixed at 77° F (25° C)	1,250cps
Pot Life at 77° F (25° C)	67 minutes)
Full Cure time	24 hours
Density at 68° (20° C)	Part A: 9.67lbs./gal (1.16 kg/L) Part B: 8.27lbs./gal (1.00 kg/L)
Tensile Strength (ASTM 638) Tensile Modulus (ASTM 695)	10,000psi (65.4 MPa) 244,200psi (3,250 MPa)
Flexural Strength (ASTM D-790) Flexural Modulus (ASTM D790)	15,100psi (76.8 MPa) 501,000psi (1,740 MPa)
Water Absorption (% gain) in 24 hours	< .5%
Expansion Coefficient [-37.4° – 40.1° C] Expansion Coefficient [120° – 222° C	78*10-6 m/m 0C 151.8*10-6 m/m 0C

2.5.3 Adhesive resins shall be 100% solids formulation with low toxicity and low odor conforming to the following physical properties.

	QuakeBond 220
Viscosity Mixed at 77° F (25° C)	Non-Sag Paste
Pot Life at 77° F (25° C)	2 – 3 hrs. (thin film set time)
Full Cure time	24 hours
Tensile Strength (ASTM 638)	4,360 psi (38.6 MPa)
Flexural Strength (ASTM D-790) Shear Strength (ASTM D-1002)	9,000 psi (62.1 MPa) 2,300 psi (15.1 MPa)
Water Absorption (% gain) in 24 hours	< 1%
Tensile Elongation	3%
Adhesion to Concrete Adhesion to Steel	Substrate Failure 1,200 psi

2.6 OTHER MATERIALS

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 PART 3 – EXECUTION

3.1 GENERAL PROCEDURES

The FRP Contractor or an Engineer retained by the FRP Contractor shall design the FRP reinforcement to meet the structural performance requirements indicated in Contract Documents. The design of the FRP reinforcement shall conform to the design provisions given in the ACI 440.8 and ACI 440.2R-23.

3.2 SURFACE PREPARATION

All necessary repair and restoration of a concrete section shall be approved by the Engineer prior to surface preparation. In these specifications, contact-critical applications are treated in the same way as bond-critical applications. An adhesive bond with adequate strength shall always be provided between FRP and concrete. Surface preparation shall also promote continuous intimate contact between FRP and concrete by providing a clean, smooth, and flat or convex surface. Surface preparation for FRP shell systems where grout is pumped into the gap between the shell and the existing column surface is specified in Section 3.2.5. All surface preparations shall be approved by the Engineer before installing the FRP system. A minimum substrate concrete strength of 2,500 psi unless otherwise approved by the Engineer.

3.2.1 Surface Grinding:

All irregularities, unevenness, and sharp protrusions in the surface profile shall be ground away to a smooth surface with less than 1/32 in. deviation. Disk grinders or other similar devices shall be used to remove stain, paint, or any other surface substance that may affect the bond. Voids or depressions with diameters larger than 1 ½ in. or depths greater than 1/8 in., when measured from a 12-in. straight edge placed on the surface, shall be filled according to Section 3.2.4.

3.2.2 Chamfering Corners:

All inside and outside corners and sharp edges shall be rounded or chamfered to a minimum radius of .5 in. Ridges, form lines, and sharp or roughened edges greater than ¼ in. shall need to be ground down or filled with putty, as specified in Section 3.2.4. Obstructions and embedded objects shall be removed before installing the FRP system if required by the Engineer.

3.2.3 Crack Injection:

All interior cracks in the surface of concrete or the substrate that are wider than 0.010 in. and all exterior cracks wider than 0.006 in. shall be filled using pressure injection of epoxy according to ACI 224R-01 and 224.1R-07. The FRP system shall be installed no earlier than 24 hours after crack injection. Any surface roughness caused by injection shall be removed as per Section 3.2.1. The Limit of crack injection shall be as indicated on the plans.

3.2.4 Surface Profiling:

After surface grinding, any remaining unevenness in the surface greater than that specified in Section 3.2.1, including out-of-plane variations, fins, protrusions, bug holes, depression voids, and roughened corners, shall be filled and smoothed over by using putty made of epoxy resin mortar or polymer cement mortar with strength equal to or greater than the strength of the original concrete.

3.2.5 Surface Cleaning:

Substrate concrete and finished surface of concrete shall be cleaned to the approval of the Engineer. Cleaning shall remove any dust, laitance, grease, oil, curing compounds, wax, impregnations, stains, paint coatings, surface lubricants, foreign particles, weathered layers, or any other bond-inhibiting material. If power wash is used, the surface shall be allowed to dry thoroughly before installing the FRP system. The cleaned surface shall be protected against redeposit of any bond-inhibiting materials. Newly repaired or patched surfaces that have not cured a minimum of 7 days shall be coated with a water-based epoxy paint or other approved sealers.

3.2.6 Debris and Dust Containment:

Proper care shall be taken to contain and remove dust and debris. Such containment and extraction shall be dictated by the specific requirements of the site. Consideration should be made for enclosed areas, areas where falling debris is possible, and areas where dust and debris may inhibit the function of adjacent equipment, processes, and/or daily practices. All areas are to be properly ventilated. Walkways and paths of ingress and egress shall be kept free of dust and debris.

3.3 STORAGE, HANDLING, AND DISPOSAL

3.3.1 Storage Requirements:

All components of the FRP system must be delivered and stored in the original factory-sealed, unopened packaging or in containers with proper labels identifying the manufacturer, brand name, system identification number, and date. Catalysts and initiators should be stored separately. All components must be protected from dust, moisture, chemicals, direct sunlight, physical damage, fire, and temperatures outside the range specified in the system data sheets. Any component that has been stored in a condition different from that stated above must be disposed of, as specified in Section 3.3.7.

3.3.2 Shelf Life:

All components of the FRP system, especially resins and adhesives, that have been stored longer than the shelf life specified on the system data sheet shall not be used and must be disposed of, as specified in Section 3.3.7.

3.3.3 Handling:

All components of the FRP system, especially fiber sheets, must be handled with care according to the manufacturer recommendations to protect them from damage and to avoid misalignment or breakage of the fibers by pulling, separating, or wrinkling them or by folding the sheets. After cutting, sheets shall be either stacked dry with separators or at a radius no tighter than 12 in. or as recommended by the manufacturer.

3.3.4 Safety Hazards:

All components of the FRP system, especially resins and adhesives, must be handled with care to avoid safety hazards, including but not limited to skin irritation and sensitization and breathing vapors and dusts. Mixing resins shall be monitored to avoid firming and inflammable vapors, fire hazards, or violent boiling. The Contractor is responsible for ensuring that all components of the FRP system at all stages of work conform to the local, state, and federal environmental and worker's safety laws and regulations. The Contractor is advised that a forced ventilator system may be required inside enclosed sections and that provision for ventilation, if any, shall be included in the cost of the work.

3.3.5 Safety Data Sheets:

The SDS for all components of the FRP system shall be accessible to all at the project site. Specific handling hazards and disposal instructions shall be specified in the SDS *3.2.3. Personnel and Workplace Protection.* The Contractor is responsible for providing the proper means of protection for safety of the personnel and the workplace. The Contractor shall inform the personnel of the dangers of inhaling fumes of primer, putty, or resin and shall take all necessary precautions against injury to personnel. The resin mixing area shall be well vented to the outside.

3.3.6 Clean-Up:

The Contractor is responsible for the cleanup of the equipment and the project site from hazardous and aesthetically undesirable FRP components using appropriate solvents, as recommended in the system data sheet.

3.3.7 Disposal:

Any component of the FRP system that has exceeded its shelf life or pot life or has not been properly stored, as specified in Section 3.3.1, and any unused or excess material that is deemed waste shall be disposed of in a manner amiable to the protection of the environment and consistent with the SDS.

3.4 WET LAY-UP INSTALLATION

This section specifies general installation procedures for the wet lay-up of CFRP and GFRP systems.

3.4.1 Contractor Qualifications:

3.4.2 Environmental Conditions:

Environmental conditions for installation shall be examined before and during installation of the FRP system to ensure conformity with the contract documents and manufacturer's recommendations. Do not apply primers, putty, saturating resins, or adhesives on cold, frozen, damp, or wet surfaces. Ambient and concrete surface temperatures shall be within manufactures specified temperatures according product data sheets. Moisture level on all contact surfaces shall be less than 10 percent at the time of installation of the FRP system, as evaluated according to ACI 503R-93. Moisture restrictions may be waived for resins that have been formulated for wet applications.

3.4.3 Moisture Vapor Transmission:

Application of bonded FRP systems shall not proceed if any moisture vapor transmission is present. Concrete dryness is necessary when using elevated temperature cure. Any bubble that

develops from moisture vapor transmission can effectively be injected with the same adhesive material used for the FRP system following the procedure specified in Section 3.7.2.

3.4.4 Dew Point

Maintain the substrate temperature at least 5°F above the dew point during application and cure unless otherwise permitted by the manufacturer.

3.4.5 Applications for Inclement Weather:

When inclement weather does not allow installation of the FRP system, as specified in Section 3.4.1, auxiliary measures may be employed to correct the conditions. An auxiliary heat source may be used in cold weather to raise the ambient and concrete surface temperatures to acceptable levels, as recommended by the manufacturer, but not higher than the glass transition temperature (Tg). Pressurized air may be used to dry the surface dampness.

3.4.6 Equipment:

The Contractor shall provide all necessary equipment in sufficient quantities and in clean operating conditions for continuous uninterrupted FRP installation.

3.4.7 Mixing of Resin Components:

All resin components, including the main agent and hardener, shall be mixed at the proper temperature using the appropriate weight ratio and for a duration specified by the manufacturer until thorough mixing with uniform color and consistency is achieved. Resins shall not be diluted with any organic solvents such as thinner. Manual stirring and small electrically powered mixing blades are allowed. Resin shall be mixed in quantities sufficiently small to ensure that it can be used within its pot life. Any mixed resin that exceeds its pot life or begins to generate heat or shows signs of increased viscosity shall not be used and shall be disposed of according to SDS. Mixing of some resins may be accompanied by noxious fumes. Precautions must be taken regarding the resin's impact on the environment, including emission of volatile organic compounds and toxicology.

3.4.8 Primer and Putty:

When necessary, apply one or two coats of primer on the concrete surface to penetrate its open pores. Ambient and concrete surface temperatures must be within the range specified in Section 3.4.1. The putty shall be applied as soon as the primer becomes tack free or is not sticky to the fingers. The putty shall be applied within 7 days after primer application; otherwise, the primer-coated surface shall be roughened with sandpaper or a similar tool. The resulting surface shall be cleaned according to Section 3.2.5 before applying the putty. Apply 40-mil thick coat of putty in one layer, and smooth over the surface to fill in any small voids, cracks, or uneven areas. Any swelling on the surface after applying the putty shall be corrected to meet surface profile as specified in Section 3.2.4. The surfaces of primer and putty shall be protected from dust, moisture, and any other contaminants before applying the FRP.

3.4.9 Saturant:

The saturant shall have sufficiently low viscosity to ensure full impregnation of the fiber sheets prior to curing. To maintain proper viscosity of the saturant, the ambient and concrete surface temperatures must be within the range specified in Section 3.4.1. Any mixed saturant that exceeds its pot life shall be disposed of according to Section 3.3.6.

3.4.10 Applying Fiber Sheet and Saturant:

The fabric will be uniformly saturated with the saturant using the Saturating Machine. The fabric will be cut to the length specified in the contract documents and shall be installed in place and gently pressed onto the wet putty. Any entrapped air between the fiber sheet and the concrete surface shall be released or rolled across the sheet in the direction parallel to the fibers while allowing the resin to impregnate the fibers and achieve intimate contact with the substrate. Rolling perpendicular to the fiber direction is not allowed. In bi-directional fabrics, rolling shall be initially in the fill direction end to end and then in the warp direction. Subsequent layers of fabric (if called for in the design) shall be properly saturated with saturant and applied on top of the first sheet of fabric with no interruption.

3.4.11 Multiple-Fiber Plies:

In multiple-ply installations, subsequent layers of fabric (if called for in the design) shall be properly saturated with saturant and applied on top of the first sheet of fabric with no interruption. The amount of resin overcoat for intermediate ply is approximately 15-20 percent greater than a single-ply installation because the saturant serves as overcoat for the applied ply and undercoat for the next ply. Follow the contract documents for the fiber orientation and ply stacking sequence. Each ply shall be applied before the onset of complete gelation of the previous layer. The number of plies that can be applied in a single day shall be based on the manufacturer's recommendation and the approval of the Engineer. Multiple plies can also be applied in several days. When previous layers are cured, interlayer surface preparation, such as light sanding and filling with putty, may be required, as specified in Section 3.4.6.

3.4.12 Overlapping:

A lap joint shall be constructed when an interruption occurs in the direction of the fibers. The length of the lap splice shall be as specified by the contract documents, but must be at least 12 in. Staggering of lap splices on multiple plies and adjacent strips shall be required unless permitted by contract documents. No lap joint is necessary in the transverse direction unless specified in the contract documents.

3.4.13 Alignment of FRP Materials:

The fiber plies shall be aligned on the structural member according to the contract documents. Any deviation in the alignment more than 5 degrees (approximately 1 in./ft) is not acceptable. Once installed, the fibers shall be free of kinks, folds, and waviness.

3.4.14 Curing:

The FRP system shall be allowed to cure for the time and at the temperature required by the approved product data.before full loads are applied. Field modification of resin chemistry for rapid curing is not allowed. Elevated cure temperature may be used, as specified in Section 3.4.3, if rapid curing is necessary. Cure of installed plies shall be monitored before placing subsequent plies. In case of any curing irregularity, installation of subsequent plies shall be halted. Unless otherwise noted in the contract documents and approved by the Engineer, the full load shall not be applied until curing is complete. Protect the FRP system while curing, as specified in Section 3.4.14.

3.4.15 Protective Coating and Finishing

The protective coating system shall be applied only to the FRP repair material installed on the exterior surface of the webs. When required, the coating shall be a non-vapor-barrier, flexible, waterproof, UV-resistant and compatible with the FRP system. The coating may be a polymer-modified Portland cement coating or polymer-based latex coating. The mortar finish shall be made with silicate sand between sieves No. 40 (1/64 in.) and No. 6 (1/8 in.) and spread over the FRP system before the resin hardens. Appropriate methods should be used for vertical or overhead work. The thickness of the coating shall be specified per the coating manufacturer's instructions. Final appearance shall closely match the color and texture of the adjacent concrete. For each protective coating system submitted by the Contractor, the contractor shall supply three (3) samples of the FRP material finished as it will be installed in the field and coated with the recommended coating system for acceptance by the Engineer. The samples shall be approved by the Engineer prior to the start of repairs.

3.4.16 Protective Coating Field Application:

Surface preparation shall be as recommended by the manufacturer. Solvent wipes shall not be used to clean the FRP surface unless approved by the FRP manufacturer. If abrasive cleaning is necessary, air pressure shall be limited to avoid any damage to fibers. Ambient and surface temperatures shall be within the range specified in Section 3.4.1, prior to applying the protective coating. Do not apply the coating when surface moisture is present or when rainfall or condensation is anticipated.

3.4.17 Temporary Protection:

Temporary protection shall be installed on the exterior web surface to protect the installed FRP system against rain, dust, dirt, excessive sunlight, extreme temperatures and high humidity until the resin has fully cured, as approved by the Engineer

3.5 INSPECTION & QUALITY ASSURANCE

A specific QA plan shall be developed from the tests identified in this section. All inspections and tests in this section will be performed by a trained inspector acting on behalf of the Department for QA of the project in the presence of the Contractor and the Engineer. The Contractor may have its own inspector for QC.

3.5.1 Inspection of Materials:

The manufacturer's certifications for all delivered and stored FRP components will be inspected for conformity to the contract documents before starting the project. Materials testing will be conducted on samples of pre-cured FRP or witness panels of wet lay-ups, if specified in the contract documents. Any material that does not meet the requirements of the contract documents will be rejected. Additional witness panels may be taken during the installation process if specified in the contract documents.

3.5.2 Daily Inspection:

Daily inspection will include date and time of repair; ambient and concrete surface temperatures; relative humidity; general weather conditions; surface dryness per ACI 503.4-92; surface preparation and surface profile using ICRI surface profile chips; qualitative description of surface cleanliness; type of auxiliary heat source, if any; widths of cracks not injected with epoxy; fiber

or procured laminate batch numbers and their locations in the structure; batch numbers, mixture ratios, mixing times, and qualitative descriptions of the appearance of all mixed resins, primers, putties, saturants, adhesives, and coatings; observations of the progress of the cure of resins; conformance with installation procedures; adhesion test results of bond strength, failure mode, and location; FRP properties from tests of field sample panels or witness panels, if required; location and size of any delamination's or air voids; and the general progress of work.

3.5.3 Inspection for Fiber Orientation:

Fiber or ply orientation, fiber kinks, and waviness will be examined by visual inspection for conformity to the contract documents. Tolerances will follow Installation of CFRP System (Section 3.4.11). Nonconforming FRP area will be removed and required as per Repair of Defective Work (Section 3.7.4).

3.5.4 Inspection for Debonding:

After at least 24 hours for the initial curing of the resin, a visual inspection of the surface will be performed for any swelling, bubbles, voids, or delamination. If an air pocket is suspected, an acoustic tap test will be carried out with a hard object to identify delaminated areas by sound, with at least one strike per 1 ft^2. Defects smaller than 2 in^2 will require no corrective action, unless as specified in Section 3.7.2. Defects larger than 2 in^2 but smaller than 25 in^2 will be repaired as per Section 3.7.2. Defects larger than 2 in^2 but smaller than 25 in^2, and with a frequency of less than 5 per any unit surface area of 10-ft length or width, will be repaired as per Section 3.7.3. Larger defects will be repaired as per Section 3.7.4.

3.5.5 Inspection for Cure of Resin:

If specified in the contract documents, the relative cure of resin in FRP systems will be examined by visual inspection or by laboratory testing of witness panels or resin-cup samples using ASTM D3418. Follow recommendations of the resin manufacturer for acceptance criteria. If the cure of resin is found unacceptable, the entire area will be marked and repaired as per Section 3.7.4.

3.5.6 Inspection for Adhesion:

After at least 24 hours for the initial cure of the resin and before applying the protective coating, a direct pull-off test will be performed following ASTM D7522 to verify tensile bond between the FRP system and the concrete. Test locations and sampling frequency are as specified in the contract documents or as recommended by the Contractor and approved by the Engineer. At a minimum, three pull-off tests with at least one test per span or one test per 1,000 ft2 of the FRP system, and one test per substrate concrete type, will be performed. Inspect the failure surface of the core specimen to ensure that the failure surface is by cohesive failure within concrete. Unless otherwise indicated in the Contract Documents, a result below 200 psi shall trigger evaluation by the Engineer of Record and shall not automatically constitute rejection of the FRP installation. The evaluation shall consider whether failure occurred cohesively within the concrete substrate, at the FRP-to-substrate interface, within the FRP laminate, between FRP plies, or within the test-fixture adhesive.If one or more of the pull-off tests is found unacceptable, the work will be rejected, and repair will follow Section 3.7.4. Repair cored areas as per Section 3.7.3.

3.5.7 Tests:

Tests on witness panels will be carried out. The most common is the tensile test following ASTM D7565 on at least five witness panels for each type of FRP system to measure strength, elastic modulus, and ultimate strain. The measured thickness of the FRP laminate will also be recorded. The FRP system will be unacceptable if the average tensile strength and the lowest tensile strength are more than 5% and 10% below that specified in the contract documents, respectively.

3.6 REPAIR OF DEFECTS

This section specifies the conditions and types of defects that require repair and the acceptable methods of repair. Defects are of different types and may be generally classified as aesthetic, short-term critical, or long-term critical. Repair procedure depends on the type, size, and extent of defects. Repair procedures for any conditions not addressed in these specifications or in the contract documents shall be submitted by the Contractor and approved by the Engineer prior to proceeding with the work.

3.6.1 Repair of Protective Coating:

Defects in protective coating can be of three types: small hairline cracks, blistering, and peeling. In all cases, moisture content of the substrate should be below 0.05% before applying a new coating. Prior to any repair of protective coating, the FRP system shall be examined visually or otherwise to ensure that no defect exists within or on the surface of the FRP. Defects in FRP, if found, shall be repaired as per Section 3.7.3 & 3.7.4. If protective coating appears to show small areas with cracks, the local surface shall be lightly sanded. Then, a new coating with appropriate primer shall be applied according to the manufacturer's recommendations. At the minimum, the coating shall be applied over an area extending 1 in. on either side of the defect. If the protective coating shows signs of blistering, the entire area of blisters as well as the surrounding area to a distance of at least 12 in. shall be carefully scraped clean. In no case should a blistered surface be recoated without complete removal of the existing coating. The area shall be wiped clean and dried thoroughly. Once dry, the area can be recoated after application of the primer coat if required by the manufacturer. If the surface shows signs of excessive peeling, the entire coating shall be scraped off and the surface lightly sanded, wiped clean, and thoroughly dried before applying a new coat according to the manufacturer's recommendations.

3.6.2 Epoxy Injection of Small Defects:

Small entrapped voids or surface discontinuities no larger than 2 in^2shall not be considered defects and require no corrective action unless they occur next to edges or when there are more than five such defects in an area of 10 ft^2. Small defects of size between 2 and 25 in^2 in diameter shall be repaired using low-pressure epoxy injection as long as the defect is local and does not extend through the complete thickness of the laminate in case of multiple-ply FRP systems. If any delamination's growth is suspected between the FRP plies due to injection, the procedure shall be halted, and repair shall follow Section 3.7.3.

3.6.3 Patching of Minor Damage:

Minor defects are those with areabetween 2 and 25 in^2 and a frequency of less than five per any unit surface area of 10-ft length or width. The area surrounding the defects to an extent of at least 1 in. on all sides shall be carefully removed. The area shall be wiped clean and thoroughly dried. The area shall then be patched by adding an FRP patch of the same type as original laminate and extending at least 1 in. on all sides of the removed area. Repair can also be conducted using the procedure in Section 3.7.4.

3.6.4 Replacement of Large Defects:

Defects larger than 25 in^2 in shall be carefully marked and scarfed out extending to a minimum of 1 in. on all sides. Scarfing shall be progressing through the layers in the case of multiple-ply FRP systems until past the defective area. In case the defect extends to the first FRP ply adjacent to the concrete, the entire thickness of the FRP and primer shall be removed. The substrate shall be appropriately prepared, and primer reapplied after ensuring that the surface and FRP are clean

and dry. Application of a new FRP system within the scarfed area shall follow procedures for the original FRP system, except that an additional layer extending a minimum of 6 in. on all sides of the scarfed area shall be added as a patch. Once cured, the protective coating shall be applied over the entire area.

END OF SECTION