SECTION ### Concrete Girder Strengthening with Fiber Reinforced Polymers

###-1 Description:

The work under this section shall consist of furnishing all labor, materials, and equipment necessary to strengthen or repair existing concrete girders through the installation of fiber reinforced polymer (FRP) as an externally bonded system for girder surface, in accordance with the requirements of these specifications and as shown on plans. Externally bonded system consists of continuous fiber "ply" sheets saturated with a resin or pre-cured FRP laminates that are adhered to girder surface.

###-1.01 Design Requirements:

The design of the FRP composite system shall conform to ACI 440.2R and shall provide structural strengthening or repair for concrete girders as shown on the plans and per the manufacturer's requirements and these special provisions. The contractor shall submit design calculations of the FRP composite system for approval to the Engineer. The design calculations shall be signed and sealed by a registered Professional Civil Engineer in the State of Arizona and conforming to requirements set forth in the ICC ES AC125. FRP design values must be lower than the calculated mean determined from the test results of the ASTM D 7565 and/or ASTM D 3039 field test specimens.

###-1.02 Submittal Requirements:

The contractor shall submit shop drawing, design calculations and all supplemental data in accordance with the requirements of subsection 105.03 of the standard specifications to the Engineer for review. The submittal shall be complete and shall include the items listed below:

(A) Materials that are used shall include the following:

(1) Names of materials' suppliers.

(2) Technical data and safety data sheets.

(3) Commercial designation/name of the materials.

(4) Materials properties for dry fiber shall include the following:

(a) Tensile strength.

(b) Tensile modulus.

(c) Density.

(d) Effective dry fiber thickness.

(5) Material properties for resin, including primers and coatings shall include the following:

(a) Mechanical properties of resin.

(b) Mix ratio by weight and volume.

(c) Pot life and shelf life.

(d) Resin gel time, mixing, and application temperature range.

(e) Cure time

(f) Application rate.

(6) Material properties for each FRP composite system shall include the following:

(a) Number of layers.

(b) Ultimate tensile strength.

(c) Elongation at break.

(d) Tensile modulus.

(e) Effective composite thickness.

(f) Percent fiber volume fraction.

(g) Direction and orientation of the primary fiber.

(B) Contractor shall submit data sheets for all materials to be used at the job site in accordance with OSHA 29 CFR 1910.1200.

(C) Details of ends of fiber and splices including overlaps and staggered construction.

(D) Details of transition in composite thickness.

(E) The Manufacturer's Process Specification Manual for the selected system, including:

(1) Installation procedures.

(2) Surface temperature and moisture limitations.

(3) Application time limits between successive layers.

(4) Plans for curing.

(5) Methods for fabricating and field/laboratory testing.

(6) Methods to replace and repair delaminated or defective sections of FRP composites.

(7) Name of the independent testing facility to be used to test samples.

(8) Storage and handling of materials.

(F) Supplemental data shall include test data provided by the manufacturer of the FRP composite system showing the performance of the system in similar applications, with a description of the method of installation. The results of the testing shall indicate resistance to the anticipated environment, including moisture, temperature extremes and chemicals normally associated with exposed steel. Untested systems shall not be used.

(G) Measures for protecting workers and the public from hazardous materials that may be generated during construction.

(H) Measures to permit application and curing of the composites during inclement weather.

(I) Measures for preventing materials, equipment, and debris from falling from the overhead structure.

A Certificate of Compliance for the FRP composite system and the components thereof shall be furnished to the Engineer in conformance with the requirements of subsection 106.05(B) of the standard specifications.

Upon submission, the Department will review all drawings and supplemental data in 30 calendar working days. If a second submittal is required, the contractor's schedule shall allow for an additional 10 days for review.

###-1.03 Quality Assurance:

(A) General:

The contractor shall inform workers having access to the work area of the contents of the applicable material safety data sheets (MSDS) and of potential health and safety hazards and protective controls associated with materials used on the project. The contractor shall train workers in the safe handling and application of FRP materials and the exposure limit for each material that the worker will use or otherwise be exposed to during the course of the project. The contractor shall instruct personnel that have the potential to need respirators and masks in the use and maintenance of such equipment.

(B) Contractor:

The contractor shall have completed a minimum of five FRP composite strengthening projects on overhead surfaces and a minimum of one of those projects using the manufacturer's composite system. The contractor shall submit to the Engineer at the preconstruction meeting the dates of work, type, description, and amount of work performed, the type of FRP system installed for each project,

and the name and telephone number of a contact person or owner for which the work was completed.

(C) Field representative

A field representative of the contractor shall be present onsite during the installation of the FRP system. The contractor shall submit the name and qualifications for its field representative who will perform the actual work supervision, the date certification course completed, and a list of a minimum of five completed FRP composite strengthening projects of similar applications, one using the manufacturer's composite system. The contractor shall submit to the Engineer at the preconstruction meeting the dates of work, type, description, and amount of work performed, and the name and telephone number of a contact person or owner for which the work was completed.

(D) Applicators:

(1) Training:

The contractor shall submit certification that the FRP composite applicators have completed, as a minimum, a certification course provided by the FRP manufacturer, which includes hands-on application of FRP systems to concrete substrates.

(2) Experience:

Only qualified applicators meeting the requirements of section ###-1.03 (B) and those having prior experience in the specified surface preparation and coating applications shall be assigned to perform the work described herein. The contractor shall submit a syllabus of the certification course, as well as listing of past application projects completed by the applicators. The contractor shall include the dates of work, type, description, and amount of work performed, and the name and telephone number of a contact person or owner for which the work was completed.

(E) Regulatory Requirements:

The Contractor shall ensure that the composite system used does not release volatile organic compounds (VOC) into the air in excess of the most restrictive of National Institute for Occupational Safety and Health (NIOSH) Recommended Exposure Limits (RELs), Occupational Safety and Health Administration (OSHA) Permissible Exposure Limits (PELs) or American Conference of Governmental Industrial Hygienists (ACGIH®) Threshold Limit Values (TLVs®) for worker or occupant exposure during installation and/or over the useful life of the structure. If VOCs exceed any of the aforementioned exposure limits during installation or use, the contractor shall provide additional ventilation for the duration of the excess

outgassing. The Contractor shall ensure that at no time will they exceed Short-Term Exposure Limits (STEL), even if additional ventilation or air supply is provided.

The contractor shall provide the necessary equipment to comply with these requirements. Once cured, the contractor shall ensure the FRP composite system does not exhibit any detectable odor at a distance of one foot from the FRP surface.

The contractor shall submit certification that resins proposed for use meet Federal VOC regulations and those of the local Air Pollution Control Districts having jurisdiction over the geographical area in which the project is located.

(F) Pre-installation Meetings:

Prior to commencement of any work, the contractor shall arrange and conduct a meeting between the Engineer, contractor, and the independent special inspector to discuss the project requirements. The meeting shall consist of a review of all the requirements of the specification and overall project a review and discussion of all aspects of the project including containment, environmental control, surface preparation, strengthening system application, quality assurance, schedule requirements, and safety.

The contractor shall request clarification of any ambiguities and advise the Engineer of any potential conflicts. The contractor shall request clarification from the Engineer regarding any technical requirements that appear improper or inappropriate.

###-1.04 Delivery, Storage, and Handling:

(A) Labeling:

The contractor shall deliver the polymer resin materials in original factory-sealed containers with the manufacturer's labels intact and legible with verification of product nomenclature, manufacturer's name, product identification and batch number, date of manufacture, shelf life, and expiration date. The contractor shall not use the polymer resin materials that have exceeded the shelf life or expiration date.

(B) Storage:

The contractor shall store materials in a covered, well-ventilated area protected from exposure to any detrimental conditions including airborne contaminants, dirt, dust, sunlight, temperatures lower than 40 degrees F or greater than 100 degrees F, rainfall, sparks, or flame and shall be stored in accordance with the

manufacturer's requirements. The Contractor shall store polymer resins separate from their hardeners.

###-1.05 Site Conditions:

(A) Environmental Requirements:

(1) Application Temperature:

The primers, saturating resins, and adhesives shall not be applied to cold or frozen surfaces. When the surface temperature of the concrete surface falls, below a minimum level or above a maximum level, as specified by the FRP system manufacturer, the work will cease until both the air and concrete temperature is within the range of the manufacturers' specified application temperature. Supplemental sources of heat shall not be used to raise the air or concrete surface temperature unless approved by the FRP composite system manufacturer.

(2) Wet or Damp Surfaces:

The contractor shall not apply resins and adhesives to damp or wet surfaces unless they have been formulated for such applications.

(3) Breathable Surfaces:

Concrete surfaces shall not be completely covered with FRP composite systems. The Engineer and contractor shall ensure that the FRP composite system is designed to allow air and vapor transmission in accordance with the manufacturer's recommendations.

(B) Existing Conditions:

The contractor should field verify all the existing conditions and review the as built drawings. Work Coordination

(C) Work Coordination:

The contractor shall coordinate work to minimize exposure of personnel present near the bridge, other contractor personnel, and visitors, to dust, mist, and odors from FRP system's preparation, application, and clean-up operations.

###-1.06 Warranty

The Contractor shall furnish a warranty (either by the manufacturer or FRP Installation Contractor) for the FRP composite system installation. The contractor shall ensure that the warranty covers the FRP composite system design, installation, bond to the substrate and interlaminar bond, as well as, mechanical

property retention, and fabric-resin compatibility. The warranty shall run directly to the Department and shall cover a period of not less than 5 years from the date of the Department’s acceptance.

###-2 Material Requirements:

###-2.01 FRP Composite System

(A) General:

The FRP composite system shall consist of fibers and resins, including primers, developed through certified material characterization and certified structural testing. The tensile modulus and strength shall be based on the cured FRP composite system. The cured FRP composite system shall conform to the requirements in Table 1:

Table 1

Properties at 72±2°F	Wet lay-up Carbon		Test method(1)
	Dry fiber	Composite	
Ultimate tensile strength, in primary fiber direction, ksi, min	500	130	ASTM D 3039
Ultimate elongation, %, min	1.35	0.9	
Composite tensile modulus of primary fiber, ksi, min	28,800	9,400	
Fiber volume, %, min	40		ASTM D 2584 or ASTM D 3171
Glass transition temperature, min	140		ASTM D 3418 or ASTM D 4065
Interlaminar shear, ksi, min	6.2		ASTM D 2344
Dry fiber thickness per layer, in.	0.0065		
Properties at 72±2°F	Wet lay-up E-Glass		Test method(1)
	Dry fiber	Composite	
Ultimate tensile strength, in primary fiber direction, ksi, min	470	75	ASTM D 3039
Ultimate elongation, %, min	4.5	1.7	
Composite tensile modulus of primary fiber, ksi, min	10,500	3,000	
Fiber volume, %, min	40		ASTM D 2584 or ASTM D 3171
Glass transition temperature, min	140		ASTM D 3418 or ASTM D 4065
Interlaminar shear, ksi, min	5.5		ASTM D 2344
Dry fiber thickness per layer, in.	0.0065		

Notes:
(1) Subject to approval of the Engineer, other test methods, such as those published by Suppliers of Advanced Composite Materials Association or manufacturer's published Quality Control Procedures may be used when equivalency and suitability have been documented.

Carbon fiber for the FRP composite system shall consist of unidirectional or a bi-directional polyacrylonitrile (PAN) based continuous carbon fiber filament sheet. Carbon fiber for end anchorage shall consist of 0°/90° woven continuous pan-based fiber filament with a minimum density of 8.8 oz/yd^2 (0.3 kg/m^2).

E-Glass fiber for FRP composite system shall consist of unidirectional or a bi-directional continuous glass fiber filament with calcium alumina borosilicate composition and a maximum alkali content of 2.0 percent. The minimum density of the Glass fiber fabric shall be 24 oz/yd^2 (0.8 kg/m^2)

Resins for the FRP composite system shall be system compatible epoxy. Epoxy resins for all FRP composite systems shall conform to the provisions in section 1015 of the standard specifications, except that no State Specification Number will be required. Carbon and E-Glass fibers shall be properly sized to be compatible with resin used. The final resin protective coat must be formulated to resist cracking and chipping. All components of epoxy resin must be within their shelf life and expiration date at the time of the FRP composite system installation.

(B) Wet Lay-up System:

A wet lay-up FRP system consists of E-Glass or carbon fiber in an epoxy resin.

(C) Pre-cured System:

A pre-cured FRP system consists of E-Glass or carbon fiber, fabricated as strips in a solid laminate configuration with a resin matrix of epoxy applied to the surface of the concrete girder using an epoxy structural adhesive.

###-2.02 Primer:

The primer shall be a low viscosity epoxy used to fill any surface microcracks of the concrete surface and enhance the bond between the FRP system and the concrete substrate.

###-2.03 Finish and Coating

The contractor shall perform a final finish and apply coatings per these special provisions and the plans.

###-2.04 Accessories:

(A) Anchors:

The contractor shall install anchors for the FRP system per the recommendation of the FRP system manufacturer and as shown on the Plans.

(B) Miscellaneous:

The contractor shall provide other materials as needed for the proper installation of the complete composite system as specified within these special provisions.

###-2.05 Mixes:

The resin components shall be mixed in accordance with the FRP composite system manufacturer's recommended procedure. The contractor shall ensure that all resin components are at a proper temperature and are mixed in the correct ratio until there is a complete mixing of components and a uniform color is achieved. The contractor shall identify and mix resin in quantities sufficiently small to ensure that all mixed resin can be used within the resin pot life. The contractor shall not use mixed resin that exceeds its pot life as defined by the FRP composite system manufacturer.

###-2.06 Fire Protection:

The FRP system shall meet requirements for Class 1 fire rating in accordance with ASTM E 84 and the flame spread index shall not be greater than 50 when tested in accordance with ASTM E 84 and meet the requirements of the ACI440-2R-17 Section 9.2.1.

###-3 Construction Requirements:

###-3.01 Preparation:

(A) Materials Testing:

The contractor and special inspector shall ensure that delivered FRP materials to the project meet the specified requirements prior to starting the project and FRP composite system installation. This may require laboratory testing. The Engineer will reject all materials that do not meet the minimum requirements, as specified in Table 1 (Section ###-2.01(A)) of these special provisions.

(B) Substrate Repair:

Before working on the concrete surfaces, the contractor shall check for unsound concrete at areas where the FRP composite system will be installed. Unsound concrete is defined as concrete that emits a dead or hollow sound when chained or tapped with a metal tool. The Engineer shall determine the soundness of concrete and the contractor shall inform the Engineer of additional unsound concrete areas discovered prior to the FRP composite system installation. The contractor shall remove and patch unsound concrete in accordance with Section ###-3.01(B)(1).

Cracks on the concrete surface to receive the FRP composite system shall be assessed and inspected by the Engineer prior to any repair work. The Engineer shall specify the crack repair work necessary based on the plans, the FRP composite system manufacturer's recommendations, and in accordance with the crack repair provisions of ACI PRC-224.1 and Section ###-3.01(B)(2).

(1) Unsound Concrete Repair:

The concrete patching material shall be a high early strength pre-mixed structural concrete patch containing cementitious materials with a minimum 28-day compressive strength (f'c) of 4,000 psi. The patch material shall be listed on the ~~ADOT~~ Department's Approved Product List.

The work shall include removal and disposal of spalling concrete and cleaning corroded reinforcing. The objective of this repair is to provide adequate bonding of the FRP, provide protection to the existing reinforcement, restore the original shape of the concrete, and prevent future water penetration.

The locations on the concrete substrate that require repair shall be field identified and marked by the Engineer and confirmed by the contractor. After all the concrete repair locations are marked, the contractor shall remove only loose and spalling concrete as directed by the Engineer and in accordance with ACI 546R-14 and ICRI No. 03730.

Remove loose or delaminated concrete around reinforcement on existing concrete in accordance with ACI 546R-14 and ICRI No. 03730. After removal of concrete, undercut all exposed corroded reinforcement with a minimum 3/4-inch clearance between exposed reinforcement and surrounding concrete or 1/4-inch larger than the largest aggregate in repair patching material, whichever is greater. If non-corroded reinforcing steel is exposed during the undercut process, care shall be taken not to damage the reinforcement's bond to the surrounding concrete. If the bond between the reinforcement and the concrete is broken, undercutting of the reinforcement shall be required. Any reinforcement which is loose shall be secured in place by tying to other secure bars or by other approved methods. Where existing reinforcement is exposed, Engineer shall visually observe reinforcement before new concrete cover is installed. The contractor shall repair concrete to its original dimensions.

Existing reinforcement shall be thoroughly cleaned to remove all rust, corrosion, and scaling as needed to promote maximum bonding of the replacement material. All dirt, grease, and other deleterious materials shall be removed from the repair areas and an approved bonding agent shall be applied to repair areas prior to placement of concrete according to the manufacture's recommendations. Tools used for concrete removal shall be approved by the Engineer prior to the start of any concrete repair work. Equipment and tools shall not be used to remove spalling concrete, which in the opinion of the Engineer, can cause the removal of excess

quantities of sound concrete along with spalling concrete. After patch material has properly cured concrete shall receive a penetrating crack sealer. Penetrating crack sealer shall cover all exposed concrete surfaces as specified by the engineer and plans.

Concrete patch repair work to bring concrete to original dimensions shall not take place until epoxy crack injection work is completed in accordance with the provisions in Section ###-3.01(B)(2).

(2) Crack Repair:

Crack repairs consisting of epoxy injection into the existing cracks in concrete substrate shall conform as specified herein. Crack locations will be identified and approved by the Engineer. Any cracks requiring epoxy injection in concrete surfaces not receiving FRP composite system shall be identified and approved by the Engineer.

The epoxy resin product shall conform to the physical requirements of ASTM C 881. The product shall be on the current ADOT Approved Products List and shall conform to the requirements of Section 1015. The equipment used to meter and mix the two injection adhesive components and inject the mixed adhesive shall be portable, positive displacement type pumps with interlock to provide positive ratio control of exact proportions of the two components at the nozzle. The injection equipment shall have automatic pressure control capable of discharging the mixed adhesive at any preset pressure up to 160 +/- 5 psi. The equipment shall have the capability of maintaining the volume ratio for the injection of the adhesive prescribed by the manufacturer of the adhesive within a tolerance of +/-5 percent by volume at any discharge pressure up to 160 psi. The injection equipment shall be equipped with sensors on both the component A and B reservoirs that will automatically stop the machine when only one component is being pumped to the mixer head. Before work is begun, the equipment shall be ratio and pressure checked. These checks may be done in the field or in the contractor's office before the equipment is brought to the field. If the equipment is tested in the office, a letter documenting the test results shall be supplied to the Engineer.

(a) Surface Preparation:

Prior to injection of the epoxy resin adhesive, the surface adjacent to the cracks or other areas of application shall be prepared so as to expose clean, sound concrete. The surface shall be cleaned of dirt, grease, oil, efflorescence, or other foreign matter which would be detrimental to the bond of the epoxy adhesive to the concrete. Use of acid or corrosives shall not be permitted for cleaning. The determination of the exact procedure to be used shall be the responsibility of the contractor.

(b) Ports:

The determination of the type, location and spacing of ports shall be the responsibility of the contractor.

(c) Surface Seal:

Surface seal material shall be applied to the face of the crack between and around the entry ports. For through cracks, the surface seal shall be applied to both faces. The surface seal shall have sufficient strength to withstand injection pressures of 250 psi. The surface seal material shall have sufficient time to reach adequate strength before the contractor proceeds with the injection.

(d) Injection:

The freshly catalyzed resin shall be dispensed into the ports at sufficient pressure and for adequate duration to fill crack completely. Before moving to the next port, the resin exiting an adjacent port shall be clear and free from impurities.

The contractor shall determine the order of injection at the various ports. The operation shall be conducted in such a manner as to minimize trapped air voids in the crack and to ensure a good bond between the epoxy and the concrete.

(e) Remove Surface Seal:

Upon completion of the injection operation, the contractor shall remove the surface seal flush with the existing surface where FRP is to be installed, the surface shall be prepared in accordance with Section ###-3.01(B)(2).

(C) Surface Preparation:

Where shown on the plans, the girder surface shall be smoothed to a Class 1 surface finish shall be achieved in conformance with the provisions in Section 601 of the specifications. If a filler material, is required to prepare the concrete surface an FRP composite system compatible resin shall be used.

The surface to receive the FRP composite system shall be prepared by abrasive blasting or grinding. The concrete surface shall be prepared to a minimum Concrete Surface Profile (CSP) 3 as defined by the International Concrete Repair Institute's (ICRI) Surface-Profile-Chip. Laitance, dust, dirt, oil, curing compound, existing coatings and other materials that may interfere with the bond of the FRP composite system shall be removed. Surfaces to receive the FRP composite system shall be free from fins, sharp edges and protrusions that can cause voids or depressions behind the installed FRP composite system or that, in the opinion of the Engineer, will damage the fibers. Voids or depressions are defined as volumes greater than 1/2- inch in diameter by 1/8-inch depth. Existing uneven surfaces to receive FRP composite system, including voids or depressions, shall

be filled with epoxy or epoxy-based filler compatible to or consisting of the FRP manufacturer's product. The contractor shall furnish the Engineer with the latest edition of the ICRI Guideline No. 03732 "Selecting and Specifying Concrete Surface Preparation of Sealers, Coatings, and Polymer Overlays" prior to preparing the concrete surface.

The contractor and special Inspector shall test the concrete moisture using ASTM D 4263 prior to the installation of the FRP composite system to ensure the concrete moisture levels are within the FRP manufacturer's product tolerances and project requirements.

###-3.02 Installation of FRP:

(A) General:

At the time of installation:

(1) No moisture shall be present on the concrete surface or any contact surfaces.

(2) Concrete surface or any contact surfaces shall be free of efflorescence, oils, loose materials, dust, and laitance.

(3) Concrete surface shall have an International Concrete Repair Institute (ICRI) surface profile of CSP 3 prepared by abrasive or blasting techniques for bond critical application per 440-2R-17 Section 6.4.2.1. or as specified in the Plans and these special provisions.

(4) Ambient temperature shall be in the range of 40 degrees F to 100 degrees F and the temperature of the epoxy resin components shall be within the range of 45 degrees F to 90 degrees F for FRP composite systems installation. If the manufacturers recommended range is different than specified, the contractor shall use the least temperature range.

(5) Relative humidity shall be less than 90 percent. If the manufacturer's recommended value is different than specified, the contractor shall use the least value.

(6) Surface to receive the FRP composite system shall be at least 5 degrees F above the dew point temperature.

(B) Primer:

The primer components shall be mixed according to the FRP composite system manufacturer's mixing instructions. The contractor shall ensure resin components are at a proper temperature and mixed in the FRP composite system manufacturer's prescribed mix ratio for its prescribed mixing time to achieve a uniform mix.

The primer shall be applied to areas on the concrete surface where the FRP system is to be placed. The contractor shall apply primer uniformly on the prepared surface at the FRP system manufacturer's specified rate of coverage. The primer shall be allowed to cure to the degree specified by the FRP composite system manufacturer before applying subsequent materials.

(C) Putty/Filler:

The contractor shall ensure putty/filler used is compatible with the FRP composite system and complies with the FRP system manufacturer's requirements. The contractor shall use putty or another epoxy-based paste with adequate bonding properties to concrete only to fill voids and smooth surface discontinuities prior to application of other materials. The putty shall be allowed to cure to the degree specified by the FRP system manufacturer before applying subsequent materials. The contractor shall grind rough edges or trowel lines of cured putty smooth prior to continuing the installation.

(D) Wet Lay-up Systems:

The contractor shall install the FRP composite system in accordance with the FRP composite system manufacturer's recommendations and the plans. The contractor shall apply sufficient saturating resin to achieve full saturation of the fibers in accordance with the manufacturer's requirements and Plans. The contractor shall release or roll out entrapped air between layers before the resin sets and place successive layers of saturating resin and fiber materials before complete cure of the previous layer of resin. The contractor shall handle FRP composite system sheet and fabric materials in a manner to maintain the fiber straightness and orientation. The contractor shall remove and repair fabric kinks, folds, or other forms of severe waviness and complete each FRP composite system section with the specified number of layers within the manufactured recommended epoxy cure timeline.

(E) Pre-cured Systems:

The contractor shall install the FRP composite system in strict accordance with the FRP composite system manufacturer's recommendations and uniformly apply adhesives to the prepared surfaces where pre-cured systems are to be placed.

The contractor shall apply adhesives at a rate recommended by the FRP composite system manufacturer to ensure full bonding of successive layers.

The contractor shall release or roll out entrapped air between layers before the adhesive sets and complete each FRP composite system section with the specified number of layers within the manufactured recommended epoxy cure timeline.

(F) Lap Splices and Overlaps:

The contractor shall stagger lap splices a minimum of 3 feet unless noted otherwise in the plans, shop drawings, or by the Engineer.

Overlap lengths shall be the maximum of the lengths either as recommended by the FRP composite system manufacturer or the plans but shall not be less than 18-inches. Overlapping shall be required for splices in the fiber direction of individual layers.

(G) Curing of Resins:

The contractor and special inspector shall inspect the primer and FRP composite system resin during the mixing process and after the FRP composite system has been installed to ensure proper cure according to the manufacturer's recommendation. Field modification of the FRP composite system resin chemistry is not permitted.

(H) Surface Finish:

The contractor shall apply paints and coatings prior to final FRP composite system resin cure for best results. If applying the paints and coatings after the FRP composite system resin has cured, the coating can be applied by performing an 80-grit abrasive blasting to break the gloss finish in preparation of a finish coating. Dust and residue shall be removed from all surfaces by flushing with clean water before applying the coating. The contractor shall ensure all surfaces are dry before applying the surface finish coating.

The contractor shall use coatings compatible with the FRP strengthening system in accordance with provisions of ASTM D 3359, Method A, with a minimum rating of 4A and applied in accordance with the manufacturer's recommendations. The contractor shall apply two finish layers of coating according to the coating manufacturer's instructions prior to full cure of the FRP system.

(I) Installation Procedure Modification:

Installation procedures may be modified to achieve maximum results, subject to approval by the Engineer. Procedural modifications approved by the Engineer prior to implementation are allowed.

(J) System Placement Tolerances:

The contractor shall follow the FRP composite system ply orientation and ply stacking sequence in accordance with the plans. The contractor shall ensure variations in angle from the intended direction of fiber alignment prescribed in the plans are less than 5 degrees.

###-3.03 Feature Compatibility:

(A) Weep Holes:

The contractor shall maintain all weep holes and ensure that no resin enters existing weep holes. Existing weep holes shall not be covered with the FRP composite system.

(B) Construction and Expansion Joints:

The contractor shall maintain all control and expansion joints and ensure that the FRP composite system does not bridge existing control and expansion joints.

###-3.04 Quality Control:

The contractor shall maintain quality assurance and quality control (QA/QC) programs and criteria for the project. The contractor and special inspector shall provide continuous inspection of the surface preparation and FRP composite system application to ensure full compliance with the specified requirements. The contractor shall submit a quality assurance plan for installation and curing of all FRP composite system materials to include personnel safety issues, installer certification, application, and inspection of the FRP composite system, location, and placement of splices, curing provisions, means to ensure dry surfaces, quality assurance samples and cleanup. The plan shall indicate the testing that will be performed and identify the party or parties responsible for this testing.

The department shall hire and provide a qualified special inspector approved by the Engineer with experience and expertise in testing, evaluation, and installation of FRP composite systems. The special inspector shall not be an employee of the contractor or be financially associated with the contractor beyond the FRP composite system special inspection contract. The special inspector shall perform inspections in accordance with this specification and ICC ES AC178.

A continuous full-time inspection shall be provided by a qualified FRP special inspector approved by the Engineer to observe all aspects of the FRP composite system application as outlined in Section ###-3.08. The FRP composite system installation shall be inspected by the FRP special inspector during and immediately following the application of the FRP composite system.

The testing laboratory shall be one approved by the Engineer and the testing laboratory shall have experience and capabilities to properly test FRP materials. The testing laboratory shall submit the testing results to the Engineer for review and to verify compliance with the plans and project specifications.

###-3.05 Qualifications of Special Inspector

Prior to the start of construction, the special inspection agency shall provide written documentation to the Engineer demonstrating the competence and relevant experience or training of the FRP special inspectors who will perform the FRP special inspections and tests during FRP installation. Experience or training shall be considered relevant only where all the following documentation has been provided:

(A) Individual holding a master's or Ph.D. civil engineering degree with a structural emphasis from an ABET accredited university showing coursework and research associated with FRP.

(B) Experience pertaining to the testing, evaluation, and prior installation of FRP wet layup or NSM applications.

(C) Registered design professional in responsible charge licensed in State of Arizona or design professional under the approved special inspection agency.

###-3.06 Laboratory Testing:

(A) Witness Panels:

(1) Wet Lay-up:

The contractor shall fabricate witness panels onsite using installation procedures identical to the method used to install the FRP composite system to the steel surfaces. Two witness panels shall be fabricated each day of production or one for each 500 square feet of installation, whichever is greater. The contractor shall saturate a 12-inch ✕ by 12-inch piece of fabric confirming to the fiber-resin ratio specified for the project by the manufacturer. Below are the steps for witness panel fabrication:

(a) On a smooth, flat, and level surface covered with a polyethylene sheeting or 16-mil plastic film.

(b) The contractor shall prepare the witness panel by placing two layers of saturated fiber fabric oriented in the same direction on the sheeting or film.

(c) An additional topping of polymer resin shall be applied as necessary to achieve complete impregnation of fibers with polymer resin.

(d) The contractor shall remove excess resin using a roller and the completed sample shall be covered with plastic film.

(e) The contractor shall squeegee out all air bubbles. Store samples at the work site to experience the similar environmental conditions of the actual FRP composite system installation.

(f) Do not move them for a minimum 48 hours after casting. Mark the panels with the date of fabrication, location of application, number of plies and primary fiber direction.

(g) The contractor shall send the samples within one week of fabrication to the pre-approved testing laboratory for testing and evaluation.

(2) Pre-cured FRP laminate:

Witness panel samples for pre-cured sheet and strip material shall be the width of the procured sheet and a length sufficient to achieve 144-square inches in total surface area taken randomly from the material received at the job site.

(B) Witness Panel Testing:

The testing laboratory shall determine tension strength, and elastic modulus of the FRP materials. The testing laboratory shall test at least two - coupons from each witness panel in the testing laboratory in accordance with ASTM D 7565 and ASTM D 3039. If one coupon from a witness panel fails to meet the minimum strength specified in Table 1, test five - additional coupons from the witness panel corresponding to the failed coupon. If a second one fails, test five - coupons from all panels for that day of production. Take appropriate remedial measures per Section ###-3.09 to ensure integrity and design requirements are met for the applied area of the FRP composite system associated with the failed witness panels. In addition, test a minimum of five - coupons from each witness panel for the remainder of the job or until ten successive witness panels are tested with no coupon failures. Then two - coupon tests per witness panel may be resumed. The Engineer may waive or alter the frequency of testing.

(C) Report:

The laboratory shall report the mechanical properties of the witness panels in accordance with ASTM D 7565 and ASTM D 3039 and submit a copy of the report to the Engineer and special inspector for review.

###-3.07 Field Testing:

(A) Mixed Resin Hardness:

(1) Description:

The contractor shall prepare two samples of each mixed resin, primers, binders, saturants, and adhesives, per day from two separate and non-consecutive batches of each. The resin samples should be a minimum of 1/8-inch thick and 2-inches in diameter. The mixed resin samples shall be retained for testing to evaluate curing progress.

(2) Testing:

The contractor shall evaluate relative curing progress of the resin on the job site by measuring the hardness of the resin sample at 24-hours and 48-hours of cure in accordance with provisions of ASTM D 2240.

The contractor shall ensure the polymer resin exceeds the Shore-D hardness reported by the FRP composite system manufacturer evaluated at the lowest air temperature for the curing time period. Measurements shall be taken at a minimum of three different points distributed over the resin specimen's surface at least 1/4-inch apart from each other.

(3) Remedial Measures:

In the event that measured hardness is less than the FRP composite system manufacturer's reported hardness, the contractor shall take remedial measures as specified in Section ###-3.09.

(B) In-Place FRP Hardness:

(1) Testing:

The contractor shall evaluate relative curing progress of the in-place FRP resin at 24-hours and at 48-hours using the Shore-D Durometer Hardness test for both neat resin and for FRP laminate on concrete substrate as described in ASTM D 2240. A minimum of five tests shall be performed on each 100 square feet of surface or portion thereof with FRP composite system applied to it. The contractor shall ensure the Shore-D Hardness exceeds the FRP composite system manufacturer's values for the time period measured and the lowest air temperature during that time period. Minimum Shore-D hardness values for fully cured resin and fully cured FRP laminate on concrete substrate shall be submitted to the engineer.

(2) Report:

The contractor shall report both the individual and mean hardness values obtained, the locations where each hardness test was performed, the FRP composite system application date, test date and time, air temperature when the FRP composite system was applied, air temperature when testing was performed, and the type and serial number of the durometer used.

(3) Remedial Measures:

In the event that hardness is less than the manufacturer's reported hardness for the temperature range, the contractor shall take remedial measures as specified in Section ###-3.09. For any structural member where testing indicates that the installed FRP composite system does not meet the minimum specified hardness values, the FRP composite system installation and the Engineer shall be notified.

The contractor shall remove the effected, installed FRP composite system at no cost to the Department and shall be replaced with a new FRP composite system that is installed and tested with results that meet or exceed the minimum hardness values.

(C) Adhesion Strength:

(1) Testing:

Using the method described by ACI 440.3R or ASTM D 4541, the contractor and special inspector shall conduct adhesion testing of installed samples. The contractor and special inspector shall perform at least one test for each day of production or for each 1,000-square feet of FRP application, whichever is more. The samples should be a minimum of 1/2-inch in diameter up to a maximum of 2 inches in diameter. The contractor shall perform pull-off tests on each area of fiber sheet installed on a single day. Perform tests on each type of concrete substrate or for each surface preparation technique used.

The contractor shall allow the FRP system at test site to cure a minimum of 24-hours before execution of the direct tension pull-off test. The locations of the pull-off tests shall be representative and on flat surfaces. If possible, conduct the tests on areas of the FRP composite system subjected to relatively low stress during service. The minimum acceptable value for any single tension test is 175 psi. The average adhesion strength of the three tests at each location shall not be less than 200 psi. The tension adhesion tests shall exhibit failure of the concrete substrate indicated by a layer of concrete on at least 80 percent of the underside of the test puck following the test.

(2) Report:

The contractor shall report to the department the adhesive strength values as recorded by the special inspector for each test and the average strength for each day's production. The contractor shall report to the department the type of failure for each test as recorded by the special inspector. The report shall include the mode of failure to identify, either the adhesive failure between test puck and the FRP, the adhesive failure between the FRP and concrete substrate, or the cohesive failure in the concrete substrate.

(3) Remedial Measures:

In the event that the adhesive strength does not meet the minimum allowable strength, FRP composite system installation shall be halted and notify the Engineer about failure.

The contractor shall remove affected, installed FRP composite system at no cost to the Department. Clean the substrate surface and apply FRP composite system that meets or exceeds the minimum specified values.

(4) Test Repair:

After testing, the contractor shall fill the hole in the FRP composite system with putty and smooth it. The contractor shall apply a 4-inch (100 mm) or more overlapping sheet patch of equivalent FRP composite system plies over the location where the sample was taken.

(D) Laminate Thickness and Number of Piles:

The contractor shall measure the cured laminate thickness and count the number of plies. The contractor shall avoid taking samples from high stress areas or splice areas. Where laminate is too thin or not having sufficient plies, add additional plies shall be added to meet design specifications.

###-3.08 QA/QC Inspection:

(A) FRP Special Inspector Duties:

The FRP special inspector shall inspect the FRP composite system during and immediately following FRP composite system installation to ensure the FRP system installation was performed per the plans and special provisions. The FRP special inspector shall inspect the FRP composite systems, and all associated work as required by the applicable codes and as described in Section ###-3.04 of these special provisions. The FRP special inspector shall observe all aspects of onsite preparation and material application including surface preparation, resin component mixing, application of primer, application of resin, fiber sheet, curing of FRP composite system, and the application of protective coatings.

(B) Daily Inspection Records:

The FRP special inspector shall include the following information in daily inspection records:

(1) Date and time of installation.

(2) Ambient temperature, relative humidity, and general weather observations.

(3) Surface temperature of the concrete receiving the FRP composite system.

(4) Surface dryness of the concrete receiving the FRP composite system.

(5) Surface preparation methods of the concrete receiving the FRP composite system.

(6) Surface cleanliness of the concrete receiving the FRP composite system.

(7) Type of auxiliary heat source, if applicable.

(8) Fiber or pre-cured laminate batch number(s), manufacturer, and location in structure.

(9) Batch numbers, expiration dates, mix ratios, mixing times, and mixed color of all resins, including primers, putties, saturants, adhesives, and coatings mixed for the day.

(10) Observations of progress of cure of resins.

(11) Conformance with installation procedures.

(12) Pull-off test results: bond strength, failure mode, and location.

(13) FRP composite system properties and test results from witness panel tests, if required.

(14) Location and size of any delaminations or air voids.

(15) General progress of work.

The FRP special inspector shall submit daily inspection and progress reports to the Engineer and contractor.

(C) Void Detection:

After allowing at least 24-hours for initial resin cure to occur, the FRP special inspector shall perform a visual and acoustic tap test inspection of the layered FRP composite system surface. Other methods for detecting voids can be employed if approved by the engineer. The FRP special inspector shall mark voids requiring corrective action in accordance with the specified FRP composite system maintenance and repair procedures per FRP system manufacturer and per Section ###-3.09.

(D) Delaminations:

(1) Description:

The FRP special inspector shall evaluate the cured FRP composite system for delaminations or air voids between multiple plies or between the FRP composite system and concrete interface. Inspection methods that are used shall be capable of detecting delaminations of 1-square inch or greater. The special inspector shall submit all delaminations or other anomalies to the Engineer for evaluation and an appropriate remedial measure per the provisions in Section ###-3.09 shall be taken.

(2) Wet Lay-up Systems:

Small delaminations or air voids less than 1-square inch each shall be considered permissible, so long as the delaminated area is less than 5-percent of the total laminate area and there are no more than ten such delaminations or air voids per 10-square feet. The special inspector shall submit all delaminations or other anomalies to the Engineer for evaluation and an appropriate remedial measure per the provisions in Section ###-3.09 shall be taken.

The contractor shall repair large delaminations or air voids, greater than 25 square inches by selectively cutting away the affected sheet and applying a sheet patch of equivalent plies overlapping the undisturbed FRP composite system by a minimum of 4-inches on all sides. The contractor may use anchors in reticent corners where overlapping is not possible as approved by the Engineer. The number and locations of the anchors shall require approval by the Engineer.

Delaminations or air voids greater than 1 square inch and less than 25 square inches may be repaired by resin injection or ply of FRP composite system replacement, depending upon the size and number of delaminations and their locations. A minimum of 4 inch lap on all sides of the delaiminations or air voids shall be provided where a new ply of FRP composite system is used. The contractor shall notify the Engineer which repair method will be used.

(3) Pre-cured Systems:

For pre-cured FRP systems, the FRP special inspector shall evaluate each delamination or air void and any repair shall be in accordance with the Engineer's direction.

(E) Fiber Orientation:

The FRP special inspector shall evaluate fiber or pre-cured laminate orientation by visual inspection. The FRP special inspector shall evaluate fiber waviness which is defined as a localized appearance of fibers that deviate from the general straight-fiber line in the form of kinks or waves. The FRP special inspector shall report fiber or pre-cured laminate misalignment of more than 5 degrees from that specified on the Plans (approximately 1 in/ft) to the Engineer for evaluation and acceptance.

(F) Record Retention:

The FRP Special Inspector shall retain the records of the inspections and witness panels test results throughout the warranty period.

The FRP Special Inspector shall retain samples of mixed resin and maintain a record of the placement of each batch throughout the warranty period.

Upon completion of repairs, the FRP Special Inspector shall re-inspect the FRP composite system to verify that the repair was properly installed.

The FRP Special Inspector shall evaluate the FRP composite systems and accept or reject it based on conformance or nonconformance respectively with the plans and special provisions. The FRP Special Inspector shall include FRP composite system material properties, as-built fiber orientation, presence of delaminations, cure of resins, and adhesion to substrate in the evaluation.

The contractor shall submit procedures to properly maintain the installed FRP composite system, as well as written manufacturer recommended repair procedures for future possible damage to the in-place FRP composite system.

###-3.09 Repairs:

(A) Application Defects:

The contractor shall repair all defects spanning more than 5-percent of the surface area according to the FRP composite system maintenance and repair procedure. There are two types of repairs: resin injection or removal and reapplication of the FRP system.

The contractor shall repair large delaminations or air voids, greater than 25 square inches by selectively cutting away the affected sheet and applying an FRP system by a minimum of 4-inches on all sides.

Delaminations or air voids greater than 1-square inch and less than 25-square inches may be repaired by resin injection or ply of FRP composite system replacement, depending upon the size and number of delaminations and their locations. The Contractor shall notify the Engineer which repair method will be used.

(B) Tears in Reinforcing Fibers:

The Contractor shall repair tears in the reinforcing fibers that cross fiber tows greater than 2-inches in length by adding additional plies of the FRP composite system material with a minimum of 8in lap on either side of the tear.

(C) Remedial Measures for Defects:

In locations where the FRP composite system adhesion does not meet the minimum adhesion requirements, the contractor shall remove the FRP composite system from the surface and shall apply new FRP composite system after properly preparing the surface in accordance with Section ###-3.

###-3.10 Work Area Clean Up:

Upon completion of the work, the contractor shall remove staging, scaffolding, and containers from the work site. The contractor shall remove any FRP composite system, resin, and other deposits on adjacent surfaces and leave the entire jobsite cleaned to equal or better condition to that prior to the start of the job. The contractor shall place cloths, cotton waste and other debris, that might constitute a fire hazard, in closed metal containers removed at the end of each day and, dispose of all resins and adhesives properly as indicated on the Safety Data Sheet. The contractor shall store and transport all resins and adhesives as indicated in the Safety Data Sheet.

The contractor shall follow the directions of the Safety Data Sheet to contain and dispose of spent abrasive blast media properly as required by local authorities and shall contain all material to be discarded at the site until properly disposed of.

###-4 Method of Measurement:

The FRP composite system used for concrete girder strengthening, or repairs will be measured by the square foot of a single layer of the FRP composite system. The quantity to be paid for will be the total area receiving the FRP composite system as shown on the plans.

###-5 Basis of Payment:

The accepted quantities of FRP composite system used for concrete girder strengthening, measured as provided above, will be paid for at the contract unit price per square foot, complete in place, including removal of fins, sharp edges and protrusions and filling of voids or depressions in surfaces to receive the FRP composite system, rounding corners, job control testing, and cleaning and painting, the girder strengthened or repaired with the FRP composite system, as shown on the plans, as specified in the Standard Specifications and these special provisions, and as directed by the Engineer.