Make the following Section a part of the Standard Specifications:

"SECTION 577 – FIBER REINFORCED POLYMER SYSTEMS

577.01 Description. The work includes the furnishing of all materials, labor, equipment and services for the supply, installation and finish of all structural strengthening using externally bonded FRP systems.

577.02 Materials. Materials for the FRP systems shall be carbon fiber and conform to ACI 440.2R, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures and the AASHTO 2012 Guide Specifications for Design of Bonded FRP Systems for Repair and Strengthening of Concrete Bridge Elements. In addition, the materials shall conform to the following minimum properties:

(A) Dry Fiber Properties

Tensile Strength – 580,000psi

(a) Tensile Modulus – 33.4 x 10^6 psi

(b) Ultimate Elongation – 1.7%

(B) Composite Gross Laminate Properties of one layer

(1) Tensile Strength – 143,000 psi ASTM D3039

(2) Tensile Modulus – 13.9 x 10^6 psi – ASTM D3039

(3) Elongation Break – 1.0% - ASTM D3039

(4) Nominal Laminate Thickness – 0.08 in. as noted on the plans in accordance with ASTM D1777

Alternatively, provide a system with an equivalent E x A as shown on the plans. Submit calculations by a licensed Hawaii Structural Engineer and supporting documentation for the alternative design to the Engineer for review and approval.

577.03 Construction.

(A) Submittals.

(1) Manufacturer's manual indicating product standards, physical and chemical characteristics, technical specifications, limitations, installation instructions, maintenance instructions and general recommendations regarding each individual material.

(2) A list of surface bonded FRP composite strengthening projects completed by the subcontractor using the selected supplier's FRP system in the last 3 years. The list should include at

a minimum 5 projects proposed FRP system, the dates of work, description and amount of work.

(3) A list of no fewer than 10 successful installations by certified applicator with written consent from manufacturer that the Contractor has been trained. The certified applicator for this project FRP system shall prove a minimum of 5 years of experience in performing retrofits using FRP systems.

(4) Shop drawings detailing the type, locations, dimensions, numbers of layers, and orientation of all FRP materials and coatings to be installed. Design shall follow criteria in ACI 440.2R.

(5) Manufacturer's product data sheets indicating physical, mechanical, and chemical characteristics of all materials used in the FRP system. Data sheets to also include properties of the cured FRP laminates as determined by laboratory testing in accordance with ASTM D7565 and/or ASTM D3039 (ultimate and design tensile modulus, stress and strain). Certification that the durability tests conform to ACI 440R and ACI 440.2R.

(6) Manufacturer's Material Safety Data Sheets (MSDS) for all materials to be used.

(7) Certification by the manufacturer that supplied products comply with local regulations controlling use of volatile organic compounds (VOC's). Products that require the use of respirators do not comply with local regulations controlling use of VOC's and shall not be allowed.

(8) Submit durability test results for physical and mechanical properties as outlined in the AASHTO Guide Specifications for Design of Bonded FRP Systems for Repair, Section C2.2.4.4 with the exception of the Freeze-Thaw testing.

(9) Submit paint manufacturer's paint product data information with proposed paint color and sheen.

(B) Surface Preparation.

(1) "Contact Critical" Applications:

(a) The surface to receive the composite shall be free from fins, sharp edges and protrusions that will cause voids behind the installed casing or that, in the opinion of the Engineer will damage the fibers. Existing uneven surfaces to receive composite shall be filled with the system epoxy filler or other material approved by the Engineer. The contact surfaces shall have no free moisture on them at the time of application. If moisture is present, use the manufacturer suggested wet prime epoxy, if available.

(b) Repair all damaged concrete, spalls, and irregular surfaces to create a flat, or slightly convex, surface. Fill surfaces with thickened epoxy to eliminate air surface voids greater than 0.5 inch diameter.

(c) Round off sharp and chamfered corners to a minimum radius of 0.75 inch or as otherwise noted on the plans by means of grinding or forming with the system's thickened epoxy. Variations in the radius along the vertical edge shall not exceed 0.5 inch for each 12 inch of column height.

(2) "Bond-Critical" Applications:

(a) Surface preparation shall be in accordance with recommendations of ACI 546R and ICRI 03730.

(b) Prepare surface to receive composite to a concrete surface profile (CSP) 3 in accordance with the ICRI examples.

(c) Pressure inject any cracks larger than 0.010 inch wide with epoxy.

(d) All substrates shall be clean, sound, and free of surface moisture. Remove dust, laitance, grease, curing compounds, waxes, impregnations, foreign particles, and other bond inhibiting materials from the surface by blast cleaning or other mechanical means. All contact surfaces shall then be cleaned by hand or compressed air within 24 hours prior to receiving FRP repair.

(3) Contractor shall prepare a sample area of each type of application for acceptance by the Engineer prior to commencing with application work.

(C) Installation. Construction of the FRP system shall conform to ACI 440.2R-08. A representative of the FRP system manufacturer shall initially and periodically observe and monitor all aspects of preparation mixing, and application of materials.

(1) Prepare the epoxy matrix by combining components at a weight (or volume) ratio specified by the manufacturer. The components of epoxy resin shall be mixed with a mechanical mixer until uniformly mixed, typically 5 minutes at 400-600 revolutions per minute.

(2) Saturation of the carbon fiber fabric shall be performed and monitored according to the manufacturer's specified fiber-epoxy resin ratio. Fabric shall be completely saturated prior to application to contact surface in order to ensure complete impregnation. Saturation shall be supervised and checked

by the certified installer. Both the epoxy resin and fabric shall be measured accurately, combined, and applied uniformly at the rates shown on the approved working drawings and per manufacturer's recommendations.

(3) After preparing surfaces, use a roller or trowel to apply one prime coat of epoxy resin to the substrate (2 mil min.). Allow primer to become tacky to the touch.

(4) Fill any uneven surfaces or recesses with thickened epoxy.

(5) Apply saturated fabric to substrate surface by hand lay-up, using methods that produce a uniform, constant tensile force that is distributed across the entire width of the fabric, and ensure proper orientation of the fabric. Under certain application conditions, the system may be placed entirely by hand methods assuring a uniform, even final appearance. Gaps between composite bands may not exceed 0.5 inch width in the fabric's transverse joint unless otherwise noted on project drawings. A lap length of at least 6 inches per ply is required at all necessary overlaps in the primary fiber direction of the fabric.

(6) Orient fabric as designated by the designer. Fabric alignment shall not exceed 3 degrees misalignment form planned alignment.

(7) Apply subsequent layers, continuously or spliced, until designed number of layers is achieved, per shop drawings.

(8) Use a roller or hand pressure to release or roll out entrapped air, and ensure that each individual layer is firmly embedded and adhered to the preceding layer or substrate.

(9) Detail all fabric edges, including termination points and edges, with thickened epoxy.

(10) Feather all edges and seams. Finish, as specified below, between 24 and 72 hours after final application of epoxy. If finish is provided beyond 72 hours of the application of the epoxy, the surface must be roughened by hand sanding or brush blasting, prior to finishing. The finish shall be thickened epoxy with coarse to medium broadcast clean, dry silica sand or two coats of acrylic paint, furnished by the FRP system manufacturer, with an approximate dry film thickness of 4 mils. Color will be determined by Engineer.

(11) Protect the FRP system from environment contamination, disturbance and damage during application and curing of the system

(12) Ambient and substrate temperature shall be between 40° F to 100° F during installation.

(D) Inspection and Testing

(1) Monitor and record the mixing of all epoxy components for proper ratio and adherence to manufacturer's recommendations, batch numbers for fabric and epoxy used each day, and note locations of installation. Measure square footage of fabric and volume of epoxy used each day. Submit report to the Engineer.

(2) Direct tension adhesion testing shall be conducted using the method described by ASTM D7522 and/or ASTM D4541. A minimum of two tests shall be performed for each day's work area or for every 500 square feet of surface area to be covered by the FRP application, whichever is smaller. Pull-off tests shall be performed on a representative adjacent area to the area being strengthened whenever possible. Tests shall be performed on each type of substrate or for each surface preparation technique used.

(3) The epoxy bonded to the prepared surface shall be allowed to cure as per manufacturer's requirements before execution of the direct tension pull-off test. The locations of the pull-off tests shall be representative and on flat surfaces. If no adjacent areas exist, the tests shall be conducted on areas of the installed FRP system subjected to relatively low stress during service.

(4) The minimum acceptable value for any pull-off test is 175 pounds per square inch. The average of the tests shall not be less than 200 pounds per square inch. Additional tests may be performed to qualify the work at each identified area. Each pull-off test is to exhibit a failure mode in the substrate and not the epoxy-to-substrate bond plane.

(5) ASTM D7522-D4541 testing is only required for "Bond-Critical" applications of the FRP system (i.e. bond of FRP-to-concrete is critical to strengthening performance of the system)

(6) Prepare a minimum of one "sample batch" daily consisting of two 12 inch by 12 inch samples of cured composite. Each sample of the "sample batch" will be taken at appropriate times during the day as to ensure the maximum material deviance in the components of the FRP composite.

(7) Prepare sample on a smooth, flat, level, surface covered with polyethylene sheeting, or 16 mil plastic film, prime with epoxy resin. Then place one layer of saturated fabric and

apply additional topping of epoxy. Cover with plastic film and squeegee out all bubbles. Samples shall be stored in a sample box and not moved for a minimum 48 hours after casting. The prepared, identified samples shall be given to a pre-approved and experienced independent testing laboratory approved by the Engineer. The laboratory shall then precondition samples for 48 hours at 140° F before testing.

(8) A minimum of fifteen-percent of all 12-inch-by-12-inch sample panels shall be tested by the laboratory approved by the Engineer. Testing specimens shall be cut from samples and tested for ultimate tensile strength, tensile modulus and percentage elongation as per ASTM D7565 and/or ASTM D3039 in the longitudinal fiber direction. Tensile and all other material properties must meet or exceed FRP composite system properties as required by structural calculations. If one coupon does not achieve the design properties, additional coupons from the same sample shall be tested. If these coupons fail (on average), coupons from the other 12-inch-by-12-inch sample, from the same batch for that day, shall be tested. If all tested samples of the sample batch do not meet the conditions of acceptance, 25 percent of all samples shall be tested. Testing results shall be submitted to the Engineer not later than three weeks after testing.

(9) FRP design values must be lower than the calculated mean determined from the test results received from the ASTM D7565 and/or ASTM D3039 field test specimens. Acceptable minimum values for ultimate tensile strength, tensile modulus, and elongation shall not be below the submitted design values unless calculations are performed using the tested values that exhibit an acceptable capacity as per the original design demands and concept. Small voids and bubbles on the order of 3 inch diameter and voids and delaminations on the order of 6 inches in diameter or an area of 5 inch x 5 inch shall require remediation prior to acceptance by the Engineer.

(E) Repair of Defective Concrete. Contractor shall submit a repair plan which gives the locations and types of defective work. The plan shall propose repair procedures and materials for each type of work. The plan will be accepted by the Engineer prior to commencing with repair works. Repairs shall meet accepted industry standards for each type of defect and equal or exceed the values of the designed strengthening.

(F) Painting. Finished FRP surface shall be painted with an acrylic, polyurethane, or high solids epoxy paint as recommended by FRP manufacturer. Prior to painting, FRP shall be cleaned and prepared according to manufacturer's recommendations. Color of paint shall be

similar to that of the portland-cement concrete in the adjacent components and shall be approved by the Engineer.

Complete a paint test section of a minimum 6 square feet for acceptance by the Engineer. Redo test section until accepted by Engineer. Production finish shall closely match test section.

577.04 Measurement. The Engineer will pay the fiber reinforced polymer (FRP) systems per square foot. FRP systems quantity is calculated based on the area of FRP required, multiplied by the number of layers required.

577.05 Payment. The Engineer will pay for the accepted FRP systems at the contract unit price per square foot, complete in place. Payment will be full compensation for work prescribed in this section and the contract documents.

The Engineer will pay for the following pay item when included in the proposal schedule:

Pay Item	**Pay Unit**
Fiber Reinforced Polymer (FRP) Systems	Square Feet”

END OF SECTION 577