

## Section 03 01 30.72 Strengthening of Concrete with FRP (Fiber Reinforced Polymer) Reinforcement

### PART 1 - GENERAL

#### 1.1 Related Documents

- A. The Conditions of the Contract for Construction and the General Requirements of Division 1 of these Specifications apply to the Work in this Section.

#### 1.2 Work Included

- A. The Work of this Section shall include furnishing all labor, materials, equipment, and supervision to prepare the surface of the structural concrete members and to install the FRP Reinforcement as indicated on the Drawings.

#### 1.3 Related Work

- A. The following work is related to this Section:
- |                    |  |
|--------------------|--|
| 1. Concrete Repair | Section 03 01 30.71 (cast-in-place concrete)<br>Section 03 01 40.71 (precast concrete) |
| 2. Epoxy Injection | Section 03 64 23   |

#### 1.4 Reference Standards

- A. Comply with the following reference standards, except where more stringent requirements are indicated on the Drawings or specified herein:
- American Concrete Institute (ACI)
    - ACI 440.2R-08, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures
    - ACI 440R-07, Report on Fiber-Reinforced Polymer (FRP) Reinforcement for Concrete Structures
    - ACI 440 R-96, State-of-the-Art Report on Fiber Reinforced Plastic (FRP) Reinforcement for Concrete Structures.
    - ACI 503 R, Pull-off test to determine FRP adhesion to concrete substrate.
  - International Concrete Repair Institute (ICRI)
    - ICRI Guideline No. 03742, Guide for the Selection of Strengthening Systems for Concrete Structures



- b. ICRI Guideline No. 03739, Guide to Using In-Situ Tensile Pull-Off Tests to Evaluate Bond of Concrete Surface Materials
3. Sika CarboDur Composite Strengthening Systems – Engineering Guidelines for Design and Application.
4. American Society of Testing and Materials (ASTM) as cited herein.

## 1.5 Quality Control

- A. Quality Control procedures performed by the Manufacturer shall include, but not be limited to the following:
  1. Manufacturer shall have a nationally recognized program of contractor training, certification and technical support.
  2. The Manufacturer shall have minimum ten years experience in FRP Reinforcement confirmed by actual field tests of minimum 100 successful installations.
  3. The Manufacturer shall be able to supply testing data to demonstrate system properties and durability of the actual FRP Reinforcement to be used.
- B. Quality Control procedures performed by the Contractor shall include, but not be limited to the following:
  1. The Contractor shall be trained by the Manufacturer and shall have completed a program of instruction in the use of FRP Reinforcement.
  2. The Contractor shall have a minimum of two years experience in FRP Reinforcement confirmed by actual field tests of at least 5 successful installations.
  3. The Contractor shall inspect all materials prior to application to assure that they meet specifications and have arrived to the job-site undamaged.
  4. The FRP Reinforcement shall be completely inspected by the contractor during and immediately following application of the composite materials. Conformance with the design drawings, proper alignment of fibers and quality workmanship shall be assured. Entrapped air shall be released or rolled out before the epoxy sets. Defects shall be noted in the Daily Construction Log.
  5. After FRP Reinforcement has cured, the contractor shall inspect the all work to check for voids and or debonding. Repairs shall be made as per Par. 3.7 Repair of Defects, and noted in the Daily Construction Log.

## 1.6 Submittals

- A. Submit for record Material Safety Data Sheets (MSDS) of each product, used on site.



- B. Submit product data indicating product standards, physical and chemical characteristics, environmental durability, technical specifications, limitations, installation instructions, and general recommendations regarding each material.
- C. Submit for record, a qualification statement by the Contractor listing their completed FRP Reinforcement projects, including size, location, owner, engineer/architect and contact numbers.
- D. Submit for record a complete description of the FRP Reinforcing system materials, surface preparation, application procedures, application rates, and cure times.
- E. Submit for record copies of purchase order and packaging slips showing quantities and dates of primer and resin purchased.
- F. Submit for review and approval shop drawings including, the following:
  - 1. Limits of FRP Reinforcing.
  - 2. Details of epoxy injection crack repair and epoxy resin patching.
  - 3. Complete system details including, but not limited to, FRP Reinforcement, primer, resin, and protective coating.
- G. Submit for record test results of the Pull-off test to determine FRP adhesion to concrete substrate.
- H. Submit for record Daily Construction Logs kept by the Contractor. These logs shall include the following information: Weather and temperature at application times; Amount of product used and square footage/linear footage of substrate covered; Batch numbers of all products used; Names of all crew members; Any bond-strength tests, noting location, quantity and who performed these tests.
- I. Submit an approved ICC Evaluation Report in the name of the proposed FRP system to be used on this project.
- J. Submit independent test report verifying the environmental durability of the proposed system to be used on this project. Such reports shall include as a minimum:
  - 1. 10,000 hr. resistance to salt water
  - 2. 10,000 hr. resistance to high temperature (38C) and high humidity (100%)
  - 3. 10,000 hr. resistance to alkali solution (pH 9.5)
  - 4. 3,000 hr. resistance to dry heat (60C)
  - 5. resistance to 20 freeze/thaw cycles
  - 6. resistance to UV/condensation @ 100 cycles
  - 7. resistance to diesel fuel (4 hr. exposure)

## 1.7 Job-Site Conditions

- A. Do not apply FRP Reinforcement materials if raining, snowing, or dew condensation is expected or existing concrete surface is wet or if the ambient or surface temperature are below 40° F (4°C).



- B. The ambient temperature and temperature of the epoxy components shall be between 50° F (10°C) and 80° F (27°C) at the time of mixing. See appropriate technical data sheets for more specific instructions.
- C. Precautions should be taken to avoid damage to any surface near the work zone due to mixing and handling of the specified material.
- D. The Contractor is solely responsible for fume control and shall take necessary precautions against injury to Installer personnel or adjacent building occupants during application of primer and resin, etc. Contractor personnel shall use protective equipment and area shall be well vented to the outside. As a minimum, Installer must take the following precautions:
  - 1. Contractor to locate and protect building air intake during application.
  - 2. Contractor to follow all state, federal, and local safety regulations.
  - 3. Contractor to follow all Manufacturers' safety requirements as indicated on appropriate MSDS sheets.

## **1.8 Delivery, Storage, and Handling**

- A. Deliver primer, saturant and protective coating in original, unopened containers with the Manufacturer's name, labels, product identification, and batch numbers.
- B. FRP Reinforcement shall be stored in a cool dry area away from direct sunlight, flame, moisture, or other hazards.
- C. Store primer, saturant and protective coating under conditions as recommended by the Manufacturer in a cool dry place out of direct sunlight. Products that have exceeded their shelf life shall not be used.
- D. Contractor is required to confirm that all materials used in accordance with this Section conform to local, state, and federal environmental and worker's safety laws and regulations.
- E. During operations Contractor shall maintain barricades.
- F. The Contractor shall properly dispose of empty containers in accordance with local regulations.

## **PART 2 - PRODUCTS**

### **2.1 FRP Reinforcement Fabric and/or Laminate**

- A. FRP Reinforcement fabric shall be high strength, high modulus, fiber fabric that may be unidirectional or woven (in various fiber architectures) to suit specific repair needs.
  - 1. FRP Reinforcement fabric shall be of the type, size, layer and location as indicated on the Drawings.
  - 2. FRP Reinforcement fabric shall meet the following minimum requirements:



**\*\*Typical Minimum Requirement Chart- Spec Writer to customize per product\*\***

	SikaWrap Hex 100G	SikaWrap Hex 103C	
<b>Property*</b> Prior to testing, laminate samples shall be cured at least 7 days at 70°F then post-cured at 140°F for 48 hours	<b>Requirement</b>	<b>Requirement</b>	<b>ASTM Test Method</b>
<b>Laminate Tensile Strength</b> , In primary fiber direction – 1 layer, per inch width	3,000 lbs./layer (13.3 kN/layer)	3,775 lbs./layer (16.8 kN/layer)	D3039
<b>Laminate Tensile Modulus</b> , In primary fiber direction	3.4x10 <sup>6</sup> psi (23,400 MPa)	9.0x10 <sup>6</sup> psi (62,000 MPa)	D3039
<b>Laminate Elongation</b> at break	2.00%	0.91%	D3039
<b>Dry Fabric Weight</b> , Minimum, per square yard	27 oz./yd <sup>2</sup> (913 g/m <sup>2</sup> )	18 oz./yd <sup>2</sup> (618 g/m <sup>2</sup> )	
<b>Percent Laminate Tensile Strength</b> Retained after:			
7 days, 100% humidity, 100°F (38°C)	90%	90%	
3,000 hrs exposure to alkali	90%	90%	
3,000 hrs exposure to salt water	90%	90%	
3,000 hrs exposure at 140°F (60°C)	90%	90%	
<b>Visual Defects</b>	✓	✓	D2563

3. Approved products are:
  - a. SikaWrap Hex Fabrics (100G, 106G, 107G, 320G, 430G, 103C, 113C, 117C, 230C), Sika Corp, Lyndhurst, NJ.
  - b. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.

B. FRP Precured Strip shall be high strength, high modulus, unidirectional carbon fiber reinforced polymer (CFRP).

1. FRP Precured Strip shall be of the type, size, layer and location as indicated on the Drawings.
2. FRP Precured Strip, shall meet the following minimum requirements:

**\*\*Typical Minimum Requirement Chart- Spec Writer to customize per product\*\***

	Sika CarboDur Strip	
<b>Property</b>	<b>Requirement</b>	<b>ASTM Test Method</b>
<b>Laminate Tensile Strength</b> , In primary fiber direction	406,000 psi (2,800 MPa)	D3039
<b>Laminate Tensile Modulus</b> , In primary fiber direction	23.2x10 <sup>6</sup> psi (160,000 MPa)	D3039
<b>Laminate Elongation</b> at break	1.69 %	D3039
<b>Laminate Thickness</b>	0.047 in. (1.2mm)	
<b>Fiber Volume</b> , minimum	68%	D2563

3. Approved products are:
  - a. Sika CarboDur, Sika Corp., Lyndhurst, NJ.
  - b. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.



## 2.2 Concrete Surface Primer

- A. Surface Primer shall be a two component, 100% solids, moisture/tolerant, high modulus, high strength epoxy.
- B. Surface Primer shall meet the following minimum requirements:

*\*\*Typical Minimum Requirement Chart- Spec Writer to customize per product\*\**

	Sikadur 300	Sikadur 330	
Property	Requirement	Requirement	ASTM Test Method
Tensile Strength	8,000 psi	4,900 psi	D638
Tensile Modulus	250,000 psi	---	D638
Elongation at Break	3.0%	1.2%	D638
Flexural Strength	11,500 psi	---	D790
Flexural Modulus	500,000 psi	506,000 psi	D790
Heat Deflection Temp. (HDT)	117F (47C)	120F (48C)	D648

- C. Approved products are:
1. Sikadur 300, Sika Corp., Lyndhurst, NJ.
  2. Sikadur 330, Sika Corp., Lyndhurst, NJ.
  3. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.

## 2.3 Fabric Saturant

- A. Saturant resin shall be two component, 100% solids, moisture tolerant, high strength, high modulus epoxy.
- B. Saturants shall meet the following minimum requirements:

*\*\*Typical Minimum Requirement Chart- Spec Writer to customize per product\*\**

	Sikadur 300	Sikadur 330 (Dry Lay-up)	
Property	Requirement	Requirement	ASTM Test Method
Tensile Strength	8,000 psi	4,900 psi	D638
Tensile Modulus	250,000 psi	---	D638
Elongation at Break	3.0%	1.2%	D638
Flexural Strength	11,500 psi	---	D790
Flexural Modulus	500,000 psi	506,000 psi	D790
Heat Deflection Temp. (HDT)	120 F	120F (48C)	D648

- C. Approved products are:
1. Sikadur 300, Sika Corp, Lyndhurst, NJ.
  2. Sikadur 330 (Dry Lay-up), Sika Corp, Lyndhurst, NJ.



3. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.

## 2.4 Epoxy Repair Mortar

- A. Repair mortar shall be 100% solids, non-sag paste epoxy.
- B. Approved products are:
  1. Sikadur 30, Sika Corp., Lyndhurst, NJ.
  2. Sikadur 31, Sika Corp., Lyndhurst, NJ
  3. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.

## 2.5 Protective Coating

- A. Protective coating shall be polymer or acrylic based and shall be UV resistant.
- B. Approved products are:
  1. Sikagard 550W, Sika Corp., Lyndhurst, NJ.
  2. Sikagard 670W, Sika Corp., Lyndhurst, NJ.
  3. Alternate products must be submitted **and** approved by the Engineer a minimum of two weeks prior to the bid date.

## PART 3 - EXECUTION

### 3.1 General

- A. Inspect surfaces to receive the work and report immediately in writing to the Engineer as required in the General Conditions and deficiencies in the surface that render it unsuitable for proper execution of this work.
- B. Protect vehicles, concrete, and other items surrounding work area from dust or damage due to Work of this Section.

### 3.2 Surface Preparation

- A. All concrete surfaces shall be dry and free of surface moisture and frost, and tested by the Contractor to evaluate moisture transmission in accordance with ASTM D4263 "Indicating Moisture in Concrete by the Plastic Sheet Method."
- B. All concrete surfaces shall be sound. Remove deteriorated concrete, dust, laitance, grease, paint, curing compounds, waxes, impregnations, foreign particles, and other bond inhibiting materials from the surface by blast cleaning or equivalent mechanical means.
- C. All concrete surfaces shall be air blasted and vacuumed clean to a dust free condition.



- D. Concrete surface irregularities less than one inch shall be ground and smoothed and/or filled with an approved repair mortar (e.g., Sikadur 30) with the addition of 1 part oven dried sand to make an epoxy mortar. Surface irregularities shall be limited to less than 0.04 inches (1 mm). Surface irregularities greater than one inch shall be repaired using an approved cementitious repair mortar (e.g. SikaTop 123).
- E. External concrete corners shall be rounded to at least a 1/2" radius when perpendicular to fiber orientation and internal corners shall be smoothed by trowelling epoxy mortar into the corners.
- F. The adhesive strength of the concrete shall be verified after preparation by random pull-off testing (ACI 503R) at the direction of the Engineer. Minimum tensile strength is 200 psi with concrete substrate failure, or as approved by the Engineer.

### **3.3 Mixing Primer and Saturant**

- A. Mix components in accordance with Manufacturer's recommendations.
- B. Diluting is not permitted. Pre-condition materials as indicated on technical data sheet.
- C. Mix only that quantity which can be used within its pot life.
- D. Do not batch delivered units into smaller quantities. Mix only full units.

### **3.4 Primer Application**

- A. Apply primer in accordance with Manufacturer's recommendations.
- B. Primer may be applied with a brush or roller. Apply second coat as necessary after first coat has penetrated into concrete.
- C. Surface depressions shall be filled with epoxy filler per manufacturers' instructions.
- D. Primer must be covered with fiber within 24 hours of application, depending on temperature conditions. If 24-hour window is exceeded, the primed surfaces must be solvent wiped with a fast flashing solvent (e.g. MEK) or roughened with sandpaper to break the amine blush.

### **3.5 FRP Reinforcement Application**

#### **Method 1: Wet Lay-Up**

- A. Apply FRP Reinforcement in accordance with Manufacturer's recommendations.
- B. When using saturator equipment, follow Manufacturer's procedures for proper machine set-up and calibration. Rollers shall be calibrated to saturate the fabric with the proper resin-to-fabric ratio. The roller gap shall be checked daily by a qualified





technician for accuracy. The resin-to-fabric ratio shall also be verified by resin usage and documented on the daily project logs.

- C. Once the fabric is saturated, it may then either be spooled for easy handling, or cut to specified lengths and booked for handling. Care must be taken not to damage the fibers.
- D. The fabric may then be applied to the surface with no delay. Work from one end to the other, taking care to orient the fibers as specified. Remove any air entrapped in the fabric with a ribbed roller or squeegee.
- E. Sheets shall be lapped in the longitudinal direction 6 inches minimum or as indicated on the Drawings. Note: no lapping is required of the sheets parallel to the direction of fiber orientation.

### **Method 2: Dry Lay-Up**

- A. Apply FRP Reinforcement in accordance with Manufacturer's recommendations.
- B. FRP Reinforcement sheets shall be cut beforehand into prescribed lengths. Sheets shall be lapped in the longitudinal direction 6 inches minimum or as indicated on the Drawings. Note: no lapping is required of the sheets parallel to the direction of fiber orientation.
- C. Follow Manufacturer's recommendations regarding primer open times.
- D. Apply a primary saturant coat uniformly by roller brush.
- E. Apply FRP Reinforcement sheets fiber side down to the concrete over the fresh saturant using a ribbed roller to remove any air bubbles.
- E. FRP Reinforcement sheets shall be left alone for about 30 minutes allowing for the primary saturant to soak through the fabric. Correct any dislocation on lifting.
- G. Apply secondary saturant coat with roller over installed sheets in order to impregnate and replenish primary saturant.
- H. If succeeding FRP Reinforcement sheets are specified on the Drawings repeat application procedures.

### **Method 3: Precured Strip Application**

- A. Apply FRP Precured Strip in accordance with Manufacturer's recommendations.
- B. Care shall be taken not to damage the fibers in handling and unpacking the Strips.
- C. Strips may be either delivered to project site in factory pre-cut lengths, or cut on site. Care must be taken not to fray or otherwise damage the fibers when field cutting. Follow Manufacturer's recommendations for field cutting of strips.



- D. Strips shall be cleaned with a fast flashing solvent (e.g. MEK) to remove any bond inhibiting materials. A clean white cotton rag shall be used for this purpose. Continue cleaning the Strip in this manner until no black residue shows on the rag. Cleaning shall be performed the same day the strips are to be used.

### **3.6 Curing**

- A. Protect finished installation of FRP Reinforcement from rain, sand, dust, etc. using protective sheeting or other barriers. Do not allow protective sheeting to come in contact with finished application.
- B. Curing of finished application shall be a minimum of 24 hours and in order to achieve full strength curing shall be extended for a period of two weeks at an average ambient temperature of 68°F.

### **3.7 Repair of Defects**

- A. Upon completion of the curing process, the installed system shall be checked for areas where saturant has not penetrated or where saturant has not completely cured. Such areas shall be epoxy injected to re-establish bond subject to the approval of the Project Engineer.
- B. Repair procedures shall be performed in accordance with guidelines established by ACI 440.2R-08 (paragraph 7.2.3) and approved by the Project Engineer. All repairs shall be subject to the same application, curing and quality control specifications as the original work.
  - 1. Small delaminations and voids less than 2 in<sup>2</sup> each are permissible as long as the delaminated area is less than 5% of the total laminate area and there are no more than 10 such delaminations per 10 ft<sup>2</sup>.
  - 2. Medium sized delaminations and voids greater than 2 in<sup>2</sup> but less than 25 in<sup>2</sup> may be repaired by epoxy resin injection or ply replacement, depending on the size and number of delaminations and their location. The repair procedure should be determined by the Project Engineer.
  - 3. Larger size delaminations and voids greater than 25 in<sup>2</sup> should be repaired by selectively cutting away the affected sheet and applying an overlapping sheet patch of equivalent plies. The overlap should extend a minimum of 6 in. in all directions.

### **3.8 Protective Coating**

- A. Apply protective coating in accordance with Manufacturer's recommendations.

### **3.9 Cleaning**

- A. Uncured saturants may be cleaned from tools with an approved solvent and properly disposed.
- B. Cured saturants shall be removed by mechanical means and properly disposed.



## END OF SECTION

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