Rehabilitation of Sewers Using Fiber Reinforced Polymers

PERFORMANCE SPECIFICATION GUIDELINE (PSG)

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nassco.org

Disclaimer

EFFECTIVE SPECIFICATIONS

Effective specifications should encourage the most innovative, efficient and experienced contractor to provide the level of quality required by the Owner at the best and lowest competitive price

The specification should not strive to encourage the contractor to seek the cheapest approach and product delivery available to provide the lowest price.

Effective specifications are critical for project success, which includes:

1. Product selection for the best solution.
2. Definition of project goals and requirements, both short and long term.
3. Construction means and methods as defined, in writing, by the contractor.
4. Product provided and installed as specified by the product manufacturer.
5. Product quality and quantity confirmed through inspection and testing.
6. Product design and service life verified through warranty inspection.

Index

PERFORMANCE SPECIFICATIONS

NASSCO recommends performance specifications that require the contractor to use superior skill, experience and innovative means available to deliver a specified product at a defined level of quality at a competitive price. This requires that the contractor, not the engineer, define the means and methods by submitting a detailed Performance Work Statement (PWS) before the project begins.

1 PART 1 – GENERAL

1.1 SCOPE OF WORK

1.1.1 This specification is intended to provide guidelines and performance requirements for the rehabilitation of gravity sewers using internally bonded fiber reinforced polymer (FRP) composite systems. The pipe rehabilitation system described herein shall include a carbon fiber reinforced polymer (CFRP) and/or glass fiber reinforced polymer (GFRP) as the main reinforcement system. The FRP can also include layers of other materials to increase stiffness of the lining system in a cost-effective manner. The latter may be proprietary to the Manufacturer. Any materials used for the FRP system shall be subject to the approval of the engineer of record (EOR).

1.1.2 The work includes furnishing of all materials, labor, equipment and services for the supply, installation and finish of structural strengthening using a FRP system.

1.1.3 The FRP Contractor shall include all engineering, labor, materials, tools, equipment, appliances and services required to engineer, design, deliver, furnish all items necessary for the proper execution and completion of the work as shown in the Contract Documents, as specified herein and/or as required by job conditions. Detailed design of the FRP system for the specific site conditions is included with the installation of the system by the installer selected by the Owner or General Contractor. All items not shown or specified, but which are necessary for the proper execution and completion of the Work, shall be provided by the Contractor.

1.1.4 The extent of the FRP lining system covered shall be as defined herein and as shown on the plans.

1.1.5 The FRP Contractor shall cooperate and coordinate with all other trades in executing the work described in the contract documents**.**

1.2 REFERENCES

1.2.1 ACI—American Concrete Institute

1. 117-90: Specifications for Tolerances for Concrete Construction and Materials, and Commentary.
2. 224.1R-07: Causes, Evaluation, and Repair of Cracks in Concrete Structures.
3. 224R-01: Control of Cracking in Concrete Structures.
4. 440R-07: State-of-the-Art Report on Fiber Reinforced Plastic Reinforcement for Concrete Structures.
5. 503R-93: Use of Epoxy Compounds with Concrete.
6. 503.4-R92: Standard Specifications for Repairing Concrete with Epoxy Mortars.

7. 503.6R-97: Guide for the Application of Epoxy and Latex Adhesives for Bonding Freshly Mixed and Hardened Concretes
8. 546R-04: Concrete Repair Guide.

1.2.2 ASTM- American Society for Testing and Materials

1. D3039: Test Method for Tensile Properties of Polymer Matrix Composite Materials
2. D3418: Test Method for Transition Temperatures of Polymers by Differential Scanning Calorimetry.
3. D5687: Guide for Preparation of Flat Composite Panels with Processing Guidelines for Specimen Preparation.
4. D7565: Standard Test Method for Determining Tensile Properties of Fiber Reinforced Polymer Matrix Composites Used for Strengthening of Civil Structures.
5. D7290: Standard Practice for Evaluating Material Property Characteristic Values for Polymeric Composites for Civil Engineering Structural Applications.
6. D638: Standard Test Method for Tensile Properties of Plastics.
7. D695: Standard Test Method for Compressive Properties of Rigid Plastics.
8. D790: Standard Test Methods for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials.
9. D543: Standard Practices for Evaluating the Resistance of Plastics to Chemical Reagents.
10. D150: Standard Test Methods for AC Loss Characteristics and Permittivity (Dielectric Constant) of Solid Electrical Insulation

1.2.3 NACE International

1. SSPC-SP12 / NACE 5 Surface Preparation and Cleaning of Steel and Other Hard **Materials by High- and Ultra High- Pressure Water Jetting Prior to Recoating.**
2. SSPC-SP13 / NACE 6 Surface Preparation of Concrete.

1.2.4 ICRI- International Concrete Repair Institute

1. No. 03732: Selecting and Specifying Concrete Surface Preparation for Sealers, Coatings, and Polymer Overlays.
2. No. 03733: Guide for Selecting and Specifying Materials for Repairs of Concrete Surfaces.

1.3 PRE-QUALIFICATION OF FRP SYSTEM INSTALLER/CONTRACTOR

The Contractor must be trained and certified by the Manufacturer and approved by the Owner for installation of the FRP system.

1.4 PERFORMANCE WORK STATEMENT (PWS)

A performance work statement (PWS) shall be submitted by the Contractor for the approval of Owner and EOR. The PWS shall include the following:

1.4.1 Certifications of applicator with written consent from the FRP manufacturer that the Contractor has been trained in proper application of manufacturer's systems.

1.4.2 Physical and mechanical properties of each proposed FRP material and other components, including test results conducted per the ASTM standards as applicable to the project. Physical properties shall, at the minimum include: Density, hardness (ASTM D2240), corrosion resistance (ASTM D543) glass transition temperature (ASTM E1640), fabric ply thickness, resin cure times, and FRP fabric roll dimensions range. Mechanical properties shall, at the minimum include: Compressive strength (of the resin per ASTM D695), tensile and flexural strengths of the laminate (per ASTM D3039 and D790, respectively), and ring stiffness of the system per ASTM (D2412) parallel plate load test.

1.4.3 FRP manufacturer's Safety Data Sheets (SDS) for all materials to be used.

1.4.4 Product data sheets (PDS) for the components of the FRP system.

1.4.5 Safety plan in compliance with local, state and federal requirements.

1.4.6 Detailed installation plan describing all work items.

1.4.7 Manufacturers' qualifications and pertinent test data.

1.4.8 FRP system designer's qualifications and the criteria used for the design.

1.4.9 Installers' qualifications including their experience in similar projects.

1.4.10 Product installation procedure

1.4.11 QA/QC plan including field sampling and testing.

1.4.12 Design drawings and specifications.

2 PART 2 – PRODUCTS

2.1 ACCEPTABLE MANUFACTURERS & COMPOSITE STRENGTHENING SYSTEM

2.1.1 General

Materials for the FRP system must be suitably qualified, compliant with industry standards and properties provided herein, and supplied by a reputable manufacturer approved by the Owner. Before the materials are ordered or work is performed, Contractor must identify which materials are proposed to be utilized and from which manufacturer(s) Contractor proposes to obtain the materials.

Quality Control Testing and Certification: Manufacturer shall certify that every batch or lot of material conforms to the project 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 the project specification and other specifications referenced within and subject to the approval of the EOR.

2.1.2 Design Loads

The FRP system shall be designed for the following loads as they apply for the specific site conditions:

- Earth load (a long-term loading)
- External pressure from ground water calculated at pipe invert (a long-term loading)
- Live load (a short-term loading, usually will not occur simultaneously with other short-term loads)
- Internal working pressure (a long-term loading, where applicable)
- Water weight (a long-term loading)
- Host pipe weight (a long-term loading)

2.2 GLASS FABRIC

2.2.1 Glass fabric layers may be used with or without carbon fiber, where loading conditions allow.

2.2.2 A glass fabric layer shall be used to create a dielectric barrier if the host pipe is conducive to electricity (steel, iron, etc.). The minimum dielectric constant (κ) shall be 4 (ASTM D150) for the dielectric barrier.

Glass fabric shall have the minimum physical and mechanical properties as agreed upon by the EOR and Manufacturer A sample material properties table is provided below.

Longitudinal (0°) Direction:			
Weight (Fabric Only)	20 oz/yd^2 (670 g/m^2)	27 oz/yd^2 (904 g/m^2)	26 oz/yd^2 (871 g/m^2)
Fiber Orientation	Uniaxial	Uniaxial	Biaxial
Tensile Strength	63.7 ksi (439 MPa)	85.2 ksi (587 MPa)	54.2 ksi (374 MPa)
Tensile Modulus	2,940 ksi (20,270 MPa)	3,980 ksi (27,440 MPa)	3,217 ksi (22,180 MPa)
Ultimate Elongation	2.20%	2.30%	2.10%
Breaking Force	2,365 lb/in. (4,140 N/cm)	3,490 lb/in. (6,110 N/cm)	2,170 lb/in. (3,800 N/cm)
Transverse (90°) Direction:			
Tensile Strength	N/A	N/A	52.0 ksi (358 MPa)
Tensile Modulus	N/A	N/A	2,700 ksi (18,615 MPa)
Ultimate Elongation	N/A	N/A	1.90%
Breaking Force	N/A	N/A	1,560 lb/in. (138 N/cm)
Ply Thickness	.037in	N/A	0.040 in. (1.0 mm)

2.3 CARBON FABRIC

2.3.1 The carbon fabric shall be composed of high strength, high modulus carbon fibers. The fabric shall be black in color and impregnated using two component high strength epoxy or other approved resin.

2.3.2 Fiber sizing and coupling agent shall be compatible with the resin system used to impregnate the fibers. To avoid galvanic corrosion of steel in proximity to carbon fibers, a dielectric barrier such as glass fiber fabric may be used to isolate the steel from the FRP laminate.

2.3.3 Carbon fabric shall conform to the minimum physical and mechanical properties as agreed upon by the EOR and Manufacturer. A sample material properties table is provided below.

Carbon Fabric and Laminate Properties	
Dry Fiber Properties	
Tensile Strength	400 ksi (2,760 MPa)
Tensile Modulus	25,000 ksi (172,400 MPa)
Ultimate Elongation	1.5%
Density	0.065 lb/in^3 (1.8 g/cm^3)
Aerial Weight	27.8 oz/yd^2 (931 kg/m^2)
Laminate Properties	
Tensile Strength	135 ksi (930 MPa)
Tensile Modulus	9,000 ksi (62,000 MPa)
Ultimate Elongation	0.98%
Breaking Force	2,500 lb/in (4,380 N/cm)
Ply Thickness	0.0490 in (1.2 mm)

2.3.4 Alternative fabrics can be used for improved ring stiffness at reduced costs. Such materials can be proprietary and are subject to the approval of EOR. Although revealing the chemical composition of alternative systems is at the discretion of the manufacturer, the physical and mechanical properties of such materials and the overall system are subject to the review of the EOR**.**

2.4 SATURATING RESIN – POLYMER

2.4.1 Fabrics shall be impregnated with a two component, high strength, and low viscosity structural epoxy or other resin system as listed in Section 2.5. 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.

- The resin system shall be resistant to service environment conditions, including but not limited to moisture, elevated temperature, and chemicals in the fluid flowing inside host pipe.
- The resin system shall not be diluted with any organic solvents such as a thinner.
- The resin system shall not be used outside of the manufacturer's specified pot life.
- The resin system shall not be applied on cold or frozen surfaces.
- Only moisture tolerant resins shall be allowed to be applied on wet surfaces.
- Temperature and moisture range for application shall be within the manufacturer's specified values.

2.4.2 Primer:
For systems requiring a primer, the primer shall have sufficiently low viscosity to penetrate the concrete substrate and provide an adhesive bond for the thickened resin applied.

2.4.3 Thickened Resin:
A thickened resin system, which consists of the saturating resin and fumed silica (or similar) supplied by the manufacturer as premixed, or mixed at the site according to the manufacturer's recommended procedure, shall be used to provide a smooth surface for the application of the FRP laminate. The thickened resin system shall be used to fill in surface voids and even out the concrete substrate. It is permissible to use a thin coat of thickened epoxy between laminae to enhance adhesion.

2.4.4 Saturating resins shall be 100% solids formulation with low odor conforming to the minimum physical and mechanical properties agreed upon by the EOR and Manufacturer. A sample epoxy resin properties table is provided below.

Epoxy Resin Properties

Color – Part "A" is pigmented syrup, Part "B" is amber liquid

Viscosity Mixed at 770 F (250 C)	1,500 – 1,600 cps
Pot Life at 770 F (250 C)	3 – 4 h (thin film set time)
Cure time (>55 °F)	24 h
Density at 392 ºF (200 ºC)	Part A: 70.5 lb/ft^3 (1.13 kg/L) Part B: 62.4 lb/ ft^3 (1.00 kg/L)
Tensile Strength (ASTM 638) Tensile Modulus (ASTM 695)	7,150 psi (49 MPa) 289,000 psi (1,992 MPa)

Flexural Strength (ASTM D-790) Flexural Modulus (ASTM D790)	11,140 psi (77 MPa) 252,400 psi (1,740 MPa)
Compressive Strength (ASTM D695) Compressive Modulus (ASTM D695)	13,000 psi (90 MPa) 350,000 psi (240 MPa)
Water Absorption (% gain) in 24 hours	< 1%
Expansion Coefficient [-37.40 – 40.10 ºC] Expansion Coefficient [1,200 – 2,220 ºC]	78 $\times 10^{-6}$ m/m ºC 151.8 $\times 10^{-6}$ m/m ºC

2.5 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 system. Vinyl ester resins can be used to saturate the FRP fabrics as an alternative to epoxy. The vinyl ester (or epoxy vinyl ester) resins shall have the minimum physical and mechanical properties agreed upon by the EOR and Manufacturer. A sample epoxy vinyl ester resin properties table is provided below. It should be noted that use of vinyl ester resins will require additional safety measures when applied in confined space due to styrene or other monomer emissions. Cure times of vinyl ester resins vary in a wide range, and if the project requires faster cure times than those provided by the Manufacturer in ambient temperature, then heating of resin during application should be considered commensurate with the Manufacturer's curing schedule.

Viscosity (ISO 2555)	200 – 250 cps
Gel Time	30 min
Density	62.4 lb/ ft^3 (1.00 kg/L)
Tensile Strength (ASTM 638) Tensile Modulus (ASTM 695)	12,800 psi (88 MPa) 460,000 psi (3.2 GPa)
Flexural Strength (ASTM D-790) Flexural Modulus (ASTM D790)	22,000 psi (153 MPa) 500,000 psi (3.5 GPa)
Compressive Strength (ASTM D695	17,600 psi (121 MPa)
Water Absorption (% gain) in 24 hours	< 1%
Expansion Coefficient [-37.40 – 40.10 ºC] Expansion Coefficient [1,200 – 2,220 ºC]	78 ×10-6 m/m ºC 151.8 ×10-6 m/m ºC

3 PART 3 – EXECUTION

3.1 GENERAL PROCEDURES

The design of the FRP reinforcement shall conform to the design provisions given for the particular project and applicable standards.

3.2 INSTALLATION BY THE WET LAYUP METHOD

Contractor can propose alternative installation techniques and design improvements to meet the project goals and design requirements outlined in the drawings and technical specifications. Such proposed changes will be submitted as a part of the Performance Work Statement (PWS) 30 days before the start of construction, and is subject to the approval of Owner and EOR.

3.2.1 Surface Preparation

3.2.1.1 The Contractor shall expose and inspect the interior of the pipe to be rehabilitated with the FRP system. Inspection shall check the location and inspect cracks and existing conditions of the concrete.

All necessary repair and restoration of a concrete section shall be approved by the EOR prior to surface preparation.

The Contractor shall examine the existing conditions to identify potential obstructions and constraints; shall verify dimensions, geometry and access locations; and shall map all visible voids and cracks in the host pipe.

An adhesive bond with adequate strength shall always be provided between the first layer of the FRP system and substrate. Surface preparation shall also promote continuous intimate contact between the FRP system and substrate by providing a clean, and smooth surface.

3.2.1.2 Surface Grinding/Blasting:

All irregularities, unevenness, and sharp protrusions in the surface profile shall be ground away to a smooth surface with CSP 3/CSP 2 surface profile for concrete substrate. 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 3.2.1.4.

3.2.1.3 Crack Injection:

In case of host pipe having deep cracks and fractures to an extent that it imposes a risk of failure of the substrate during FRP application, these cracks and fractures will be filled and the host pipe shall be pre-strengthened by crack injection. Where crack injection is necessary, internal or external cracks wider than 0.010 in. shall be filled using pressure injection of epoxy. The FRP system shall be installed no earlier than 12 hours after crack injection. Any surface roughness caused by injection shall be removed as per Section 3.2.1.2. The limit of crack injection shall be as indicated on the plans.

3.2.1.4 Surface Profiling:

After surface grinding, any remaining unevenness in the surface greater than that specified in Section 3.2.1.2, fins, protrusions, bug holes, eroded surfaces shall be filled and smoothened over by using putty made of epoxy resin mortar or polymer cement mortar.

3.2.1.5 Surface Cleaning:

Substrate concrete and finished surface of concrete shall be cleaned prior to application of the FRP system. Cleaning shall remove any dust, laitance, grease, oil, curing compounds, wax, stains, coatings (as necessary), 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.

3.2.1.6 Surface Preparation for Metal Pipes:

Surface of steel and any other metallic pipes or pipe joint rings shall be prepared to achieve adequate bond strength between the FRP system and the metal substrate. The surface preparation procedure for the steel substrate shall be a minimum of SSPC SP-10 / NACE No. 2 near white metal surface. Sand blasting or another suitable method shall be used to ensure the required surface profile is achieved. The prepared steel surface shall be free of materials including epoxy mortar, concrete, dust, dirt, and oil at the time of the FRP system installation. The cleaned metal substrate shall be primed with epoxy prior to the installation of the initial layer of glass fiber lamina for the system's dielectric barrier.

3.2.2 Installation

This section specifies general installation procedures for the wet lay-up of the FRP system composed of FRP laminae. Contractor shall submit a site specific installation procedure in the PWS, which shall, at the minimum include the following measures.

3.2.2.1 Environmental Conditions:

Environmental conditions for installation shall be examined before and during installation of the FRP system to ensure conformity to the contract documents and manufacturer’s recommendations. Primers, putty, saturating resins, or adhesives shall not be applied on cold, frozen, damp, or wet surfaces, unless the resin is moisture tolerant. Ambient and concrete surface temperatures shall be within 45-95 °F (7-35 °C). 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.

The work area is usually a confined space that will require an entry permit in accordance with OSHA regulations. The Contractor is responsible for the training of all personnel, air testing, safety equipment and complying with the requirements of OSHA. A detailed safety plan shall be submitted by the Contractor as part of the PWS and is subject to approval of the Owner.

3.2.2.2 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 3.2.1.3.

3.2.2.3 Applications in Inclement Weather:
When inclement weather does not allow installation of the FRP system, as specified in Section 3.2.2.1, 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) of the primer or saturating resin. Pressurized air may be used to dry the surface dampness.

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

3.2.2.5 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 a thinner. Electrically powered mixing blades shall be used for mixing. 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 the 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. If flammable resins are used, explosion proof electrical motors or air driven motors should be used for mixing.

3.2.2.6 Primer and Putty:
When necessary, apply one or two coats of primer on the substrate surface to penetrate its open pores. 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 3.2.1.5 before applying the putty. Apply 40-mil (1 mm) 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 3.2.1.4. The surfaces of primer and putty shall be protected from dust, moisture, and any other contaminants before applying the FRP system.

3.2.2.7 Saturant:
Saturant is the term for the engineered resin used to impregnate FRP fabrics and turn them into laminae upon cure. The saturant used in a FRP system 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 substrate surface temperatures must be within the range specified in Section 3.2.2.1. Any mixed saturant that exceeds its pot life shall be disposed of according to Section 3.5.

3.2.2.8 Applying Fiber Sheet and Saturant:

The fabric will be uniformly saturated with the saturant using the saturating machine or hand saturated, where site conditions are not favorable for using the 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 (transverse) direction end to end and then in the warp (longitudinal) 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.

3.2.2.9 Multiple-Fiber Plies:

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 plies shall factor in overcoat for the applied ply and undercoat for the next ply. Follow the PWS for the fiber orientation and ply stacking sequence. Each ply and core fabric 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 EOR. When previous layers are cured, interlayer surface preparation, such as light sanding and filling with putty, may be required, as specified in Section 3.2.2.6.

3.2.2.10 Overlapping:

Lap joints shall be constructed over a minimum of one CFRP or GFRP laminate. The lap joint layer shall not be the top laminate. The length of the lap splice shall be as specified by the contract documents, but must be at least 6 in. (152 mm) long. Staggering of lap splices on multiple plies and adjacent strips shall be required unless permitted by contract documents.

3.2.2.11 Alignment of FRP Materials:

The fiber plies shall be aligned on the host pipe 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.

3.2.2.12 Termination Points

The termination points of the FRP system shall be designed such that water is not allowed to seep in between the host pipe and the FRP system. The FRP system shall be sealed properly at the termination points by applying epoxy sealant. Where flow velocities are high or in pressurized conduits, elastomeric internal joint seals with compressed steel bands shall be used at the termination points, at the discretion of EOR, with the appropriate details included in the drawing set.

3.2.2.13 Curing:

The FRP system shall be allowed to cure for the minimum amount of time specified per the manufacturer's recommendations. Field modification of resin chemistry for rapid curing shall not be allowed. Elevated cure temperature may be used, if rapid curing is necessary. Alternatively, ultraviolet light (UV) cure can be applied to systems without carbon fiber laminates. The actual cure time shall be as per the PWS for each project, and cure times vary depending on the type of resin. Cure of installed plies shall be monitored before placing subsequent plies. In case of any curing irregularity, installation of subsequent plies shall be halted. Protect the FRP system while curing.

3.2.2.14 Protective Coating and Finishing:

It is permissible to use a top coat for abrasion resistance and improved flow conditions. The top coat shall be either thickened epoxy, with or without a pigment added to facilitate inspection, or another resin as agreed between the Purchaser and Contractor. The top coat shall be compatible with exposure conditions including moisture, abrasive chemicals in sewage, salt water, and physical abrasion due to debris and silt in sewers. Applicability of the top coat to the FRP system in abrasive environments shall be verified by testing (ASTM D4060) as required by the EOR.

3.2.2.15 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 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 3.2.2.1, prior to applying the protective coating.

3.3 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 Owner for QA of the project in the presence of the Contractor and EOR. The Contractor may have its own inspector for QC. The project specific QA/QC plan shall be included in the PWS submittal.

3.3.1 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 as detailed in the PWS. Any material that does not meet the requirements of the contract documents or PWS will be rejected. Additional inspection measures may be taken during the installation process if specified in the contract documents or PWS

3.3.2 Daily Inspection:

Daily inspection will include date and time of repair; 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 delaminations or air voids; and the general progress of work.

3.3.3 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 Sections 3.2 and 3.3. Any nonconforming FRP repair area will be removed and required as per Repair of Defective Work (Section 3.4).

3.3.4 Inspection for Debonding:

After at least 24 hours from initial installation 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 one ft^2 ($0.1\ m^2$). Defects smaller than .5 in. (12 mm) in diameter will require no corrective action, unless as specified in Section 3.5. Defects larger than .5 in. (12 mm) but smaller than 2 in. (50 mm) in diameter will be repaired as per Section 3.4.2. Defects larger than 2 in. (50 mm) but smaller than 6 in. (150 mm) in diameter, and with a frequency of less than 5 per 10 ft^2 ($1\ m^2$) of surface area, will be repaired as per Section 3.4.3. Larger defects will be repaired as per Section 3.4.4.

3.3.5 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 third party laboratory testing of 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 3.4.

3.3.6 Tests:

Specimens from the installed FRP system or samples representative thereof, shall be tested for tensile, compressive, and adhesive strengths.

Adhesion test — Refer to ASTM D7234 for adhesion to concrete and ASTM D4541 for adhesion to metal (e.g., steel). In order to validate the adequacy of the surface preparation and the adhesion strength of the carbon fiber strengthening system, the Contractor shall perform random adhesion tests on the prepared concrete and steel substrate of pipe segments adjacent to repair pipes as directed by the Engineer and witnessed by the Owner's inspector. The Owner's inspector should designate the areas for trial adhesion tests prior to the surface preparation activities. These areas shall be cleaned, prepared, and covered with two-ply FRP system test patches with minimum dimensions of 2 ft x 2 ft (60 cm x 60 cm) for adhesion test to concrete substrate and minimum dimensions of 4 in. x 4 in. (10 cm x 10 cm) for adhesion to steel substrate. The patch shall consist of two orthogonal plies of FRP laminae, with a layer of GFRP first applied on any steel substrate. Three adhesion tests shall be performed on each test patch. The remaining adhesion test patches shall be finish coated and remain in place for future testing purposes as needed. The Contractor shall log the location of the adhesion test and report the test results to the Owner.

Tensile strength test (ASTMD3039) Depending on the composition of the FRP system used for a particular application, test panels shall be field fabricated using the carbon/glass fiber fabric, any core (3D) fabric, resins and saturation equipment used in the application. Tensile test panels shall be approximately 12 in. by 24 in. The test panel shall be prepared on a smooth flat surface overlaid with plastic (polyethylene or vinyl) sheeting. Saturating resin shall be used to prime the surface, followed by the saturated system, and finally topped with more saturating resin. A cover of plastic sheeting shall be placed over the panel and the panel squeegeed to remove any bubbles and other surface irregularities to ensure a smooth flat surface. The panel shall be labeled with time, date, and sample panel number, fabric lot numbers, and resin batch numbers, and stored in an environment representative of the pipeline inside condition to cure until collected for lab testing.

The test lab will perform a minimum of ten tensile tests with the fibers oriented in the strong direction for each tensile test panel in accordance with ASTM D3039, and report certified tests results for tensile strength, tensile modulus, related specimen dimensions, and percent elongation. For projects where multiple test panels with the same fabric batch are prepared, it is permissible to perform 5 tension tests per panel instead of 10 tests per panel, subject to review and approval by the Engineer.

The FRP system will be unacceptable if the average tensile strength is below that specified in the contract documents.

Compressive strength test (ASTM D695)

The resin used for the FRP system shall have the minimum compressive strength as required by the EOR. This shall be verified by taking resin samples from the job site. A minimum of five samples shall be prepared for compressive strength testing per ASTM D695.

The standard test specimen, except as indicated shall be in the form of a right cylinder or prism whose length is twice its principal width or diameter. Preferred specimen sizes are 12.7 by 12.7 by 25.4 mm (0.50 by 0.50 by 1 in.) (prism), or 12.7 mm in diameter by 25.4 mm (cylinder).

Results of the compressive strength test shall be reviewed and approved by the Engineer. If the average compressive (yield) strength of the samples is less than the value as indicated in the design, then that resin batch shall be rejected. Two or more individual samples having a yield strength less than the value indicated in the design shall also result in rejection of the resin batch regardless of the average value.

3.4 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 indicated below are exemplary, and the actual procedure specific to each project shall be submitted as a part of the PWS.

3.4.1 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. Defects in FRP, if found, shall be repaired as described below. 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. (25 mm) 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. (30 cm) 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.

3.4.2 Epoxy Injection of Small Defects:

Small entrapped voids or surface discontinuities no larger than 0.5 in. (12 mm) in diameter shall 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 (1 m^2). Small defects of size between 0.5 and 2 in. (12 and 50 mm) 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 FRP system.

3.4.3 Patching of Minor Damage:

Minor defects are those with diameters between 2 and 6 in. (50 and 150 mm) and a frequency of less than five per any unit surface area of 10 ft^2 (1 m^2) length or width. The area surrounding the defects to an extent of at least 1 in. (25 mm) 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 extending at least 1 in. (25 mm) on all sides of the removed area.

3.4.4 Replacement of Large Defects:

Defects larger than 6 in. (150 mm) in diameter shall be carefully marked and scarfed out extending to a minimum of 1 in. (25 mm) on all sides. Scarfing shall be progressing through the layers of the FRP system until past the defective area. The substrate shall be appropriately prepared and primer reapplied after ensuring that the surface is clean and dry. Application of an FRP patch system shall extend a minimum of 6 in. (150 mm) on all sides of the scarfed area. Once cured, the protective coating shall be applied over the entire area.

3.5 STORAGE, HANDLING, AND DISPOSAL

3.5.1 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 3.5.7.

3.5.2 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 3.5.7.

3.5.3 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. (30 cm) or as recommended by the manufacturer.

3.5.4 Safety Hazards:

All components of the CFRP 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 fuming 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. Refer to the Safety Plan for details.

3.5.5 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 section entitled *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. Refer to the Safety Plan for details.

3.5.6 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.

3.5.7 Disposal:

Any component of the FRP system that has exceeded its shelf life or pot life or has not been properly stored, 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.

3.6 PROJECT CLOSE-OUT AND MAINTENANCE

3.6.1 Documentation of the work:

The Owner may provide specification language requiring documentation of the work be prepared and submitted by the Contractor on completion of the work. The documentation shall include the following:

- Information on the products and installation method used
- Pre- and post-inspection results
- Test results
- Any changes or deviations from the contract documents and possible corrective work

Owner's Inspector may also prepare documentation of the project and include the following:

- Purchaser's Inspector's tests and reports
- Material test reports
- Field test reports
- As-built drawings of the renewed or strengthened segments

3.6.2 Verification/Basis for Rejection:

Materials not complying with the requirements of this specification shall be rejected. Repairs, replacements, and retesting shall be accomplished in accordance with the contract documents.

3.6.3 Affidavit of Compliance:

The Owner may require an affidavit from the Manufacturer or Contractor, as applicable, that the material provided or the installation performed complies with the applicable requirements of the specifications provided herein.

4 PART 4 - WARRANTY

The Contractor shall provide a minimum 2-year warranty on the material and labor used for installation of the FRP system. Any defects affecting structural and hydraulic performance of the FRP system shall be repaired by the Contractor at no cost to the Owner. The methods to repair such defects include, but are not limited to those outlined in Section 3.4 or a submittal in PWS. Cosmetic defects such as discoloration and minor undulations do not need to be repaired or included in the warranty. Any damage caused by direct impact or loads that are substantially higher than the normal operation is not covered by the warranty. The Owner will provide all required access to the area to be repaired.

5 PART 5 - TYPICAL BID ITEMS

Bid items vary in a FRP project depending on the scope. The following list includes the basic items to be included in a sewer pipe rehabilitation project. This list can be revised per the specific work items of each project.

1. FRP Materials: Carbon and glass fiber, resins, top coat, and any proprietary materials as approved by the EOR.
2. Mobilization: Cost of shipping the materials, travel (crew), and site setup.
3. Pipe inspection (CCTV or man entry) – pre and post installation.
4. Flow bypass.
5. Auxiliary structures (for access and bypass, as necessary).
6. Pipe cleaning.
7. Scaffolding.
8. FRP Installation.
9. QA testing.
10. Surface restoration (as necessary).
11. Demobilization.