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REPUBLIC OF THE PHILIPPINES
DEPARTMENT OF PUBLIC WORKS AND HIGHWAYS
OFFICE OF THE SECRETARY
MANILA

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DEPARTMENT ORDER)
)
No. 88)
Series of 2019 08.28.19

SUBJECT : DPWH Standard Specification for Item 416 – Fiber-Reinforced Polymer (FRP) [Amendments to Item 416 - DPWH Standard Specification for Carbon Fiber Sheet and Item 416A - DPWH Standard Specification for Carbon Fiber Plate]

In order to ensure uniformity in the application/ adoption of the Pay Items of Work to be used/ adopted by those who are involved in the preparation of the Design Plans and Quantities, Program of Works (POW) and Approved Budget for the Contract (ABC) for Infrastructure Projects Nationwide, the attached amendments to **DPWH Standard Specification for Carbon Fiber Sheet, Item 416 and Carbon Fiber Plate, Item 416A** (*henceforth unified and renamed as* ***"Item 416 - Fiber Reinforced Polymer (FRP)"***) are hereby prescribed, for the guidance and compliance of all concerned.

This Standard Specification shall henceforth form part of the on-going revision of the DPWH Standard Specifications for Highways, Bridges and Airports, Volume II, 2012 Edition and is now included in the Project and Contract Management Application (PCMA).

This Order supersedes the following issuances and shall take effect immediately:

1. Department Order No. 160, Series of 2016, "DPWH Standard Specification for Item 416 - Carbon Fiber Sheet".
2. Department Order No. 155, Series of 2016, "DPWH Standard Specification for Item 416A – Carbon Fiber Plate".

MARK A. VILLAR
Secretary

EMIL K. SADAIN, CESO I
Undersecretary for UPMO Operations
and Technical Services
Officer-In-Charge

14.1.2 FET/RGT

Department of Public Works and Highways
Office of the Secretary
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DPWH Standard Specification for
ITEM 416 – FIBER-REINFORCED POLYMER (FRP)

416.1 Description

This Item shall consist of furnishing and installation of Fiber-Reinforced Polymer (FRP) system including materials, labor, tools and equipment necessary in undertaking FRP works as shown on the Plans and in accordance with these Specifications.

416.2 Material Requirements

416.2.1 FRP Materials

The FRP System shall consist of high-strength fibers and saturating polymer resin. This combination shall produce a high-strength composite system with the mechanical strength dictated by the fibers and its orientation. The resin matrix holds and bonds the fibers in alignment and provides for tensile load transfer along the fibers. Once cured, it also provides protection to the fibers against exposure. The resin shall have excellent adhesion properties which will allow for the effective load transfer between the primed substrate and composite FRP system.

416.2.2 Different FRP Composite Systems

416.2.2.1 Wet Layup Systems

The fibers are brought to the site dry and are impregnated with the resin. While still wet, the saturated fibers are applied to the primed substrate following the manufacturer's instruction as approved by the Engineer.

416.2.2.2 Pre-cured Systems

The composite laminate is cured in the manufacturing plant and brought to the site in laminated strips or plates. The FRP laminate is installed to the primed substrate by epoxy adhesive following the manufacturer's instruction as approved by the Engineer.

416.2.3 FRP Composite System

The mechanical properties of FRP composite systems are influenced by the environment, as well as the type of loads. Humidity and moisture are particularly detrimental to the integrity of the fibers. Of all the fibers, carbon is least susceptible.

Carbon FRP system can be used in all structural applications except where electrical conductivity is a concern. For this instance, Aramid FRP system is recommended. For bridge deck slabs, application of Carbon FRP systems on the soffit shall be by Grid Arrangement to prevent collection of moisture in the concrete.

Resins shall not be diluted with organic solvents. Only epoxy resins shall be used for the saturating resin of the FRP systems. A protective coating is finally applied to the FRP system to protect it from potentially damaging environmental and mechanical effects. This coating is

typically applied to the exterior surface after the resin of the FRP system has attained the prescribed degree of curing.

416.2.3.1 Carbon Fiber Sheet (CFS) Properties

The CFS shall conform to the computed deficiency of the existing structural member to be strengthened based on design analysis and calculations of the structural/design engineer. For testing requirements, CFS shall conform to the Specifications shown in Table 416.1.

Table 416.1 Specifications of Carbon Fiber Sheet

Property	Test Method	Unit	Requirement				
Type	-	-	Uni-directional, high strength cloth				
Fiber Areal Weight	-	g/m^2	200	300	400	450	600
Design thickness	-	mm	0.111	0.167	0.222	0.25	0.333
Density	ASTM D3039	g/cm^3	1.8				
Tensile Strength	ASTM D3039	N/mm^2	3400 (Min.)				
Young's Modulus of Elasticity	ASTM D3039	kN/mm^2	230 (Min.)				
Pull-off Bond Strength to Concrete	ASTM D7234						
• Dry		N/mm^2	1.5(Min.) CF				
• Wet		N/mm^2	1.5(Min.) CF				

** ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*
** ASTM D7234, Standard Test Method for Pull-Off Adhesion Strength of Coatings on Concrete Using Portable Pull-Off Adhesion Testers*

The epoxy adhesive for bonding CFS shall conform to the Specifications shown in the Table 416.2.

Table 416.2 Specifications of Epoxy Adhesive for bonding CFS

Property	Test Method	Unit	Requirement		
			Primer	Epoxy Putty	Penetrating Epoxy Resin/Impregnation
Viscosity	ASTM D2393	mPa.s	≤1000	Paste - like	5000 (Min.)
Tensile Strength	ASTM D638M	N/mm^2	≥15	≥20	≥30
Flexural Strength	ASTM D790M	N/mm^2	≥20	≥40	≥40
Compressive Strength	ASTM D695M	N/mm^2	≥40	≥50	≥50

Tensile Shear Bond to Steel	ASTM D1002	N/mm^2	≥10
Pull-off Bond Strength • Dry • Wet	ASTM D7234	 N/mm^2 N/mm^2	 ≥1.5 CF ≥1.5 CF

**CF- Concrete Failure*
** ASTM D2393, Standard Test Method for Viscosity of Epoxy Resins and Related Components*
** ASTM D638M, Standard Test Method for Tensile Properties of Plastics (Metric)*
** ASTM D790M, Standard Test Method for Flexural Properties of Unreinforced and Reinforced Plastics and Electrical Insulating Materials (Metric)*
** ASTM D695M, Standard Test Method for Compressive Properties of Rigid Plastics (Metric)*
** ASTM D1002, Standard Test Method for Apparent Shear Strength of Single-Lap-Joint Adhesively Bonded Metal Specimens by Tension Loading (Metal-to-Metal)*

416.2.3.2 Carbon Fiber Plate (CFP) Properties

The CFP shall conform to the computed deficiency of the existing structural member to be strengthened based on design analysis and calculations of the structural/design engineer. For testing requirements, CFP shall conform to the Specifications shown in Table 416.3.

Table 416.3 Specifications of Carbon Fiber Plate

Property	Test Method	Unit	Requirement			
Carbon Fiber Type	-	-	High Strength			High Modulus
Design Thickness	-	mm	1.0 (±0.1)	1.5 (±0.1)	2.0 (±0.1)	2.0 (±0.1)
Width	-	mm	50 (+2/-0)			
Density	ASTM D3039	g/cm^3	1.6 (Min.)			
Tensile Strength	ASTM D3039	N/mm^2	2400 (Min.)			1500 (Min.)
Modulus of Young's Elasticity	ASTM D3039	kN/mm^2	167 (Min.)			285 (Min.)
Carbon Fiber Weight / Unit Length	-	g/m^2	60	90	120	
Carbon Fiber Weight / Unit Area	-	g/m^2	1200	1800	2400	
Pull-Off Bond Strength to Concrete: • Dry • Wet	ASTM D7234	 N/mm^2 N/mm^2	 1.5(Min.) CF 1.5(Min.) CF			

The epoxy adhesive for bonding CFP shall conform to the Specifications shown in Table 416.4.

Table 416.4 Specifications of Epoxy Adhesive for Bonding CFP

Property	Test Method	Unit	Requirement
Specific Gravity	ASTM D792	-	1.7±0.20
Flexural Strength	ASTM D790M	N/mm^2	45 (Min.)
Compressive Strength	ASTM D695M	N/mm^2	70 (Min.)
Modulus of Elasticity	ASTM D695M	N/mm^2	4000 (Min.)
Tensile Strength	ASTM D638M	N/mm^2	25 (Min.)
Tensile Shear Bond	ASTM D1002	N/mm^2	15 (Min.)
Bond Strength to: • Carbon Fiber Plate and Concrete • Carbon Fiber Plate and Steel	ASTM D7234	 N/mm^2 N/mm^2	 1.5 (Min.) CF 3.5 (Min.)

** ASTM D792, Standard Test Method for Density and Specific Gravity (Relative Density) of Plastics by Displacement*

416.2.3.3 Aramid Fiber Sheet (AFS) Properties

The AFS shall conform to the computed deficiency of the existing structural member to be strengthened based on design analysis and calculations of the structural/design engineer. For testing requirements, AFS shall conform to the Specifications shown in Table 416.5.

Table 416.5 Specifications of Aramid Fiber Sheet

Property	Test Method	Unit	Requirement			
Type of Fiber Orientation	-	-	Uni-directional			
Fiber Areal Weight	ASTM D3039	g/m^2	280	415	623	830
Design Thickness		mm	0.193 (Min.)	0.286 (Min.)	0.430 (Min.)	0.572 (Min.)
Tensile Strength	ASTM D3039	N/mm^2	2060 (Min.)			
Young's Modulus of Elasticity	ASTM D3039	kN/mm^2	118 (Min.)			
Tensile Capacity	-	kN/m	392 (Min.)	588 (Min.)	882 (Min.)	1176 (Min.)
Pull-off Bond Strength to Concrete • Dry • Wet	ASTM D7234	 N/mm^2 N/mm^2	 1.5(Min.) CF 1.5(Min.) CF			

The epoxy adhesive for bonding AFS shall conform to the Specifications shown in Table 416.2 of Section 416.2.3.1.

416.2.3.4 Protective Coating

The protective coating must provide resistance to weather and ultraviolet rays, as the epoxy resin used as part of the FRP system is particularly susceptible to degradation from ultraviolet rays when exposed over extended periods of time. The protective coating shall likewise be tough and durable, to protect the system against vandalism, and general wear due to abrasion. When near bodies of water, the protective coating must likewise provide moderate protection against chemical attacks.

Protection systems come in variety of forms such as polymer coatings (polyurethanes), acrylic coatings, cementitious coatings, and intumescent coatings. The commonly used is acrylic urethane-based coatings which are effective against carbon dioxide, ultraviolet rays and moderate chemical attacks. It is not susceptible to moisture. It exhibits excellent bond to epoxy substrates and it cures to a durable and hardened layer. A minimum of two (2) adhesion/bond tests shall be conducted to the fully cured protective coating to confirm its adhesion to the substrate and compatibility to the FRP system by using direct pull-off tests, at locations determined by the Engineer. Bond tests must have a minimum tensile stress value of 1.5 N/mm^2, failure to reach the value will be a cause of rejection of the material.

416.3 Construction Requirements

416.3.1 Materials Handling

The FRP components shall be delivered in original, unopened (except carbon fabric or strips) containers clearly marked with the manufacturer's name, product identification, and batch numbers. Storage and handling of the various products shall be in conformity with the manufacturer's recommendations, instructions and requirement of ACI 440.2R-17, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures.

416.3.2 Surface Preparation

All concrete surfaces on which the FRP composite is to be wrapped shall be clean, sound, and free from fins, sharp edges, protrusions, and surface moisture. If water leaks through cracks on concrete surface to be covered with FRP, surface preparation and application of FRP shall be in accordance with the approved manufacturer's application. Disc grinder or abrasive sandblasting is used to clean the concrete and to ensure that concrete surface is even and smooth. An element exhibiting distress (structural or corrosion related) shall be restored to its structural integrity and cross-sectional profile prior to composite wrapping. All concrete spalls, honey combed areas, structural cracks and steel reinforcement corrosion shall be remedied using appropriate techniques and repair materials approved by the Engineer. Both the Contractor and the manufacturer's technical representative must verify the suitability of any changes to the application methods proposed by the Engineer.

416.3.3 Crack Sealing

Crack sealing shall conform to the applicable requirements of Item 740, Structural Concrete Injection and Crack Repair. Cracks larger than 0.3 mm shall be injected with epoxy using a system/method approved by the Engineer.

416.3.4 Waterproofing

Waterproofing shall conform to the applicable requirements of Item 407, Concrete Structures, No. 6 of Subsection 407.2 Waterproofing and Damp proofing.

416.3.5 Prime Coat

Contact surface shall be dry before coating with primer. The primer should be formulated and compatible with the carbon fiber material and not to be applied during rains, storms or when the air is misty or when conditions are unsatisfactory. Application rate shall be such as to ensure complete saturation of the contact surface. Primer should be cured between 2 to 3 hours before proceeding to the next step.

416.3.6 Putty Application

For the adjustment and correction of surface irregularity and unevenness, epoxy putty should be applied, after the primer is tack-free. Any concave, pores, or gap on the concrete surface must be smoothened with epoxy putty. After the putty becomes tack-free, it is required to roughen the surface with sandpaper, then cleaned.

416.3.7 Application of Epoxy Resin (Penetrating/Impregnation Epoxy Resin)

Prior to undercoating epoxy resin adhesive, ambient temperature at the work site shall be checked to confirm the curing conditions before applying the resin. The Contractor shall check and confirm that the primer and putty have become tack-free and there is no clay and dust on the concrete surface prior to the Engineer's inspection. If there is a time interval of longer than 3 days after the primer and putty application, the primer and putty coated surface should be roughened with sandpaper, and the surface cleaned before the adhesive application.

The contact surface condition shall be tack-free and application shall not be done during rains or storms or when the air is misty or conditions that are unsatisfactory to carry out the work.

Application rate of the penetrating epoxy resin shall be in accordance with Table 416.7.

Table 416.7 Application Rate of the Penetrating Epoxy Resin

Carbon Fiber Sheet Areal Weight (g/m^2)	Standard Usage Weight of Penetrating/Impregnation of Epoxy Resin (kg/m^2)		
	Undercoating	Over-coating	Total
200	0.3 ~ 0.4	0.4 ~ 0.2	0.5 ~ 0.7
300	0.4 ~ 0.5	0.4 ~ 0.3	0.7 ~ 0.9
400	0.5 ~ 0.6	0.5 ~ 0.4	0.9 ~ 1.1
450	0.55 ~ 0.65	0.5 ~ 0.4	1.0 ~ 1.15
600	0.6 ~ 0.65	0.5 ~ 0.65	1.1 ~ 1.3

Aramid Fiber Sheet Areal Weight (g/m²)	Standard Usage Weight of Penetrating/Impregnation of Epoxy Resin (kg/m²)		
	Undercoating	Over-coating	Total
280	0.3 ~ 0.4	0.3 ~ 0.4	0.6 ~ 0.8
415	0.4 ~ 0.5	0.4 ~ 0.5	0.8 ~ 1.0
623	0.5 ~ 0.6	0.5 ~ 0.6	1.0 ~ 1.2
830	0.6 ~ 0.7	0.6 ~ 0.7	1.2 ~ 1.4

416.3.8 FRP Application

1. For Wet layup system, the saturated fabric (FRP composite) shall be applied onto the prepared surface entirely by hand, using methods that produce a uniform constant tensile force along the primary fiber direction to ensure removal of all entrapped air voids and proper orientation and straightness of the main fiber.

2. Lap splice should be done by overlapping the fibers along their length ensuring continuity in one direction. A lap length of not less than 20 cm shall be provided and should be staggered unless noted on the Plans.

3. Roller pressure shall be used to ensure that each layer is firmly embedded and adhered to the preceding layer or substrate. Press the FRP using a roller starting from the center towards the edge to squeeze out entrapped air before the epoxy resin sets.

4. For pre-cured systems, epoxy adhesive shall be applied onto the surface where the FRP pre-cured laminate will be applied at the rate recommended by the manufacturer. Generally, the epoxy adhesive shall be applied on the surface at the rate of 0.2 to 0.3 kg/lm. The adhesive layer shall be applied to the plates in a curved profile measuring 3 mm in the center and 1 mm on the edges, in order to reduce formation of voids. Before the adhesive sets, a roller must be used with uniform pressure to release entrapped air and to expel excess adhesive and produce even edges.

5. The specified normal curing time is only for reference purposes. The actual curing periods should be determined considering the ambient temperature and manufacturer's recommendation in the work site, subject to the Engineer's approval. The cured composite shall be of uniform thickness and density and shall be bonded between layers and show no sign of porosity.

416.3.9 Protective Coating Application

The protective coating shall be compatible with the FRP strengthening system and applied in accordance with the manufacturer's recommended procedure as approved by the Engineer. Typically the use of solvents to clean the FRP surface before applying coatings is not recommended due to the deleterious effects that solvents can have on the polymer resins. The coatings shall be periodically inspected and maintenance shall be provided to ensure the effectiveness of the coatings.

416.3.10 Quality Control and Inspection

1. Inspection of all materials shall be done to ensure conformity with contract requirements, and that all materials are new and undamaged.

2. Inspection of all surface preparation is carried out prior to FRP system application.

3. Inspection of all work completed including sounding of all repairs to check for any debonding, voids, and correction of any defective work.

416.3.11 Sampling and Testing

After allowing at least 24 hours for the initial resin saturate to cure, the Contractor shall perform a visual and acoustic tap test inspection of the layered surface. All voids, bubbles and delamination shall be repaired in accordance with the manufacturer's recommendation approved by the Engineer. The Contractor shall conduct adhesion testing of the fully cured CFS installation using direct pull-off tests, at locations determined by the Engineer. Failure at the bond line at tensile stress below 1.50 N/mm^2 will be cause for rejection of the repair. A minimum of two (2) pull-off tests per system (span) shall be performed. The test shall be completed prior to the application of the protective top coat on the FRP.

The product subjected to sampling shall meet ACI 440.2R-17, Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures and ASTM D3039, Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials.

416.4 Method of Measurement

FRP Wet layup System such as Carbon Fiber-Reinforced Polymer Sheet and Aramid Fiber-Reinforced Polymer Sheet installed in accordance with the Plans and Specifications will be measured in square meters. The quantity to be paid for shall be the square meters of FRP composite used and accepted by the Engineer. No measurement will be made for epoxy injection of cracks.

FRP Pre-cured System such as Carbon Fiber-Reinforced Polymer Plate installed in accordance with the Plans and Specifications will be measured in square meters. The quantity to be paid for shall be the square meter of FRP composite laminate/plate used and accepted by the Engineer. No measurement will be made for epoxy injection of cracks.

Protective coating shall not be measured and paid for separately, but the cost thereof shall be considered as included in the contract unit price of the items where called for.

416.5 Basis of Payment

The quantity measured as prescribed in Section 416.4, Method of Measurement shall be paid for at the Contract Unit Price or lump sum price bid for the pay item listed below that is included in the Bill of Quantities.This unit price shall cover full compensation for all materials, labor, tools, equipment, supervision and related services necessary to complete this Item.

Payment shall be made under:

Pay Item Number	Description	Unit of Measurement
416 (1) a	Carbon Fiber, Sheet, 1 layer	Square Meter
416 (1) b	Carbon Fiber, Sheet, 2 layers	Square Meter
416 (1) c	Carbon Fiber, Sheet, 3 layers	Square Meter
416 (1) d	Carbon Fiber, Sheet, 4 layers	Square Meter
416 (2)	Carbon Fiber, Plate	Square Meter
416 (3) a	Aramid Fiber, Sheet, 1 layer	Square Meter
416 (3) b	Aramid Fiber, Sheet, 2 layers	Square Meter
416 (3) c	Aramid Fiber, Sheet, 3 layers	Square Meter
416 (3) d	Aramid Fiber, Sheet, 4 layers	Square Meter

References:

1) *American Society for Testing and Materials (ASTM) D3039/ D3039 M – Standard Test Method for Tensile Properties of Polymer Matrix Composite Materials*
2) *American Concrete Institute (ACI) 440.2R-17 – Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures*
3) *Memorandum of Undersecretary Emil K. Sadain re: DPWH Standard Specification for Item 1048 – Fiber Reinforced Polymer (FRP)*
4) *Department Order No. 160 – DPWH Standard Specification for Item 416 – Carbon Fiber Sheet*
5) *Department Order No. 155 – DPWH Standard Specification for Item 416A – Carbon Fiber Plate*
6) *Bridge Repair Manual 2nd Edition (Improvement of Quality Management for Highway and Bridge Construction and Maintenance, Phase II), Department of Public Works and Highways (DPWH) and Japan International Cooperation Agency (JICA)*
7) *Alpha Kogyo KK, Alphatec Chemical Corporation and Alphatec FRP Systems*
8) *Sika Wrap Fabric System and Sika Fibre Mesh*