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GFRP Poles for Traffic Signs and Signal Poles: A Case Study in Saudi Arabia

Waseem Ahmad Khatri[1], Muhammed Al Mehthel[1], Mirza M. Baig[1], Tariq Al Baker[2]

[1]Consulting Services Department, Saudi Arabian Oil Company, Dhahran, Kingdom of Saudi Arabia
[2]Transportation & Equipment Services Department, Saudi Arabian Oil Company, Dhahran, Kingdom of Saudi Arabia
Email: waseem.khatri@aramco.com

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Abstract

GFRP poles have been widely used as lighting poles but their use as traffic signs and signal poles is still under development. This paper highlights the literature review and case study of using GFRP poles for traffic signs and signal poles in the Eastern Province of Saudi Arabia. The case study details the design of poles, construction, maintenance and their performance. Traffic sign poles were manufactured using filament winding and signal poles using pultrusion process. AASHTO Standard "Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals" and ANSI 136.2. were used as materials specification and design for the pole. There is a need to develop dedicated design and construction guidelines to standardize the construction process. Further study about the crash resistance of GFRP poles at different speeds needs to be explored. In addition, the paper presents a high level comparison between the different materials like weight, safety, environmental degradation, strength, service life, durability in an aggressive environment, carbon footprint and economics.

Keywords

Glass Fiber Reinforced Plastics (GFRP), Poles, Foundations, Filament Winding, Pultrusion

1. Introduction

Historically, manufacturers and end users have relied on wood, metal and concrete for all types of poles and post applications due to a perceived conventional material knowledge of strength in addition to other properties. In the past decade or so, significant amount of progress has been made in the field of nonmetallic materials like Glass fiber Reinforced Polymer (GFRP). GFRP material has demonstrated to have many benefits and advantages, such as being lightweight, corrosion resistant, high reliability, excellent dielectric strength, and long service life. GFRP poles offer better safety in comparison to steel as it snaps when impacted due to lower shear strength. In comparison, steel with higher impact resistance increases chances of injuries to occupants of the vehicle.

Applications of Glass Fiber Reinforced Polymers (GFRP) products have grown steadily during the past few years, as they became extremely popular in different areas of the aerospace, automotive, marine, O&G (oil and gas) and the built environment [1].

The development of GFRP for commercial use started in the 1940s, particularly in the naval industry. Afterward, with the global production increase, the GFRP pole use has increased in the late 1960S. When the combination of low material and production costs along with advances in fabrication developed, GFRP production became more economical and attractive in other fields.

GFRP offers very flexible design solutions, due to its extraordinary fabrication adaptability, high durability and structural efficiency (strength-to-weight ratio) and its usage also benefits from increasingly low production and erection costs.

Traditional materials such as wood, steel and concrete are commonly used to construct electrical transmission and distribution poles. Due to the shortage of wooden poles, their short life expectancy, and various environmental concerns have promoted utility companies to search for a cost-effective alternative. Wooden poles are continuously exposed to weather, fungi, woodpeckers, etc., which results in a very significant deterioration of their load-bearing capacity with time. The estimated service life of wooden poles is the region of is between 5 - 10 years or more subject to environmental exposure any extension of this service life requires continuous inspection and follow-up care. In a number of European countries, concrete poles are used. The main disadvantage of concrete poles is their weight, which drastically increases transportation and erection costs. Another challenge is the environmental impact in the form of CO_2 emission resulting from the increased energy required for manufacturing of the cement. Chlorides and carbonation impact on the steel reinforcement due to environmental impact can also affect their long-term performance. Concrete poles due to corrosion of the steel reinforcement result in further strength deterioration and expensive maintenance. Steel is the most common material for the construction of transmission poles in North America. These poles are expensive. Corrosion protection is of primary concern in steel poles which must be painted or galvanized, a process which does not always guarantee long-term protection.

There has been limited application of the GFRP poles for traffic signals and traffic signs and for other utility applications. The traditional steel poles have been used for decades, however they pose corrosion issues as highlighted earlier. In addition, the steel poles similar to concrete have a high impact on collision and yield which can injure the passengers and the drivers in a crash. Unlike steel poles, GFRP poles have lower impact resistance compared to steel and can shear off when subjected to high impact forces, this can reduce the impact on the vehicle occupants [2].

The Glass Fiber-Reinforced Plastic (GFRP) poles are lighter and offer corrosion resistance compared to steel poles. Although the initial cost of GFRP poles may be slightly higher than traditional poles, this can be compensated with the improvement in the construction schedule, transportation, and the long-term benefits it offers. A number of companies are already involved in the production of such poles. Research in this area, however, is limited. This case study provides the design, construction details and high-level comparison and additional research to be conducted in relation to developing specific standards, high level comparison, construction details and crash resistance of the GFRP poles.

2. Design of GFRP Traffic Signs and Signals Poles

AASHTO Standard "Specifications for Structural Supports for Highway Signs, Luminaires and Traffic Signals" is a primary standard for the materials specification and the design of GFRP poles. There is National Cooperative Highway Research program (NCHRP) Report 494—"Structural Supports for Highway Signs, Luminaires, and traffic signals" which provide details for design and also supports the AASHTO standard. In addition, for materials specifications ANSI 136.2—"For roadway and Area lighting equipment Fiber Reinforced Composite (FRC) lighting pole" can be followed. The poles can be pultruded or filament winded with advanced UV protection in a matrix that offers superior toughness and strength. In addition, the poles shall exhibit excellent corrosion, moisture and fire resistance properties. Table 1 shows typical physical strength associated with different process.

Table 1. Different process of manufacturing and typical physical properties [3].

Process	Percent of glass fiber by weight	Tensile strength (ksi)	Tensile modulus (10^3 ksi)	Flexural Modulus (ksi)	Compressive strength (ksi)
Filament winding (glass-polymer)	40 - 75	35 - 50	2500 - 3600	30 - 50	30 - 45
Pultrusion (glass-matt polymer)	40 - 80	60 - 150	4000 - 6000	100 - 150	30 - 70
Pultrusion (glass mat and roving polymer)	30 - 55	7 - 35	800 - 2500	10 - 30	15 - 40
Centrifugal casting	40 - 45	30 - 40	2200 - 2500	30 - 40	25 - 35
Hand lay up	40 - 75	30 - 40	800 - 2500	10 - 30	15 - 40

2.1. Design Loads

Horizontal supports of sign structures (cantilevered or bridge type) and traffic signal structures shall be designed forwind loads applied normal to the support at the centroids of the respective areas. The vertical supports for luminaire structures, traffic signal structures (excluding pole-top mounted traffic signals and pole-top luminaire structures), and sign support structures shall be designed for the effects of wind from any direction. These wind load cases are consistent with ASCE/SEI 7 - 10 Article 27.4.

2.2. Deflection Limits

The lateral deflections limits proposed by the performance specification as per AASHTO are as following:

- Under Service load combination, the deflection at the top of vertical supports with transverse load applications shall be limited to 2.5 percent of the structure height;
- Under Service I II load combination, the slope at the top of vertical supports with moment load applications shall be limited to 0.35 in./ft.

The stiffness requirement is intended to ensure that the pole does not deflect excessively when maintenance workers use ladders to access attachments located at the top of the pole.

2.3. Bending Test

The provisions for the performance evaluation of FRP poles in bending are based on ASTM D4923. The safety factor as per AASHTO against failure in bending is 2.0, which accounts for the variability of materials and performance often found in FRP products from different manufacturers and different production methods. When testing FRP poles with hand holes, the hand hole should be placed on the compression side of the pole and the hand hole cover should be removed during testing.

2.4. Weathering Performance

The weathering performance evaluation of FRP poles require that the surface of the pole be exposed to a minimum of 2500 hours of accelerated weathering according to ASTM G154. The proposed specification requires the use of UV-B lamps with 313-nmwavelength and a testing cycle of 4 hours of UV exposure at 60 degrees Celsius and 4 hours of condensation at 50 degrees Celsius. UV-B 313 lamps produce the shortest wavelengths found in sunlight in the surface of the earth. This particular type of sunlight is known to be responsible for considerable polymer damage capable of affecting the mechanical performance of FRP poles. After testing, the finished surface shall not exhibit fading, fiber exposure, chalking, cracking, or crazing.

2.5. Flame Resistance

FRP poles should be flame resistant in order to avoid propagation of fires induced by short circuits or fuel spills. The proposed performance specification for FRP poles requires that specimens tested for flame resistance according to ASTMD635 be manufactured with the same materials and identical manufacturing process as the actual poles. The specimens are considered flame resistant if they cease to burn before the gauge mark of 3.94 inches (100 mm) is reached.

2.6. Fabrication Details

The manufacturing process can influence the structural properties of the material. Other factors that affect the properties of the FRP laminate are the orientation of the glass fibers and the fiber content. Aligning fibers in a single direction provides high stiffness and strength parallel to the fibers, but properties in the perpendicular direction approach those of the plastic matrix. Typically, in pole structures, the glass reinforcement is primarily oriented in the longitudinal direction with minimum reinforcement in the transverse direction. The glass-to-resin ratio (by weight) is usually used as a measure of the fiber content. The strength and stiffness properties of FRP generally increase with increasing the glass-to-resin ratio. Table 1 shows typical ranges for mechanical properties for FRP laminates with different manufacturing processes.

2.7. Quality Control and Acceptance Criteria

The performance specification contains a set of provisions on quality control and acceptance criteria for FRP materials. Those provisions specify that the manufacturer must submit detailed technical information about the proposed product for approval prior to production. The submitted technical information should include samples of the manufactured proposed product, stating clearly the kind and quality of the fibers and resin used in the composite. This is required because the structural properties of FRP members are highly dependent on the type and quality of glass fibers and resins used, as well as the manufacturing process. The new provisions on quality control also include requirements for storage and shipping of finished FRP products to prevent damage prior to installation. Mechanical properties of FRP composites depend on the proportion of fibers and matrix materials, manufacturing methods mechanical characteristics for constituent materials, and orientation of fibers through matrix. Fibers could be designed as "Continuous Form" (aligned and continued fibers are in general straight and long as well as paralleled to each other) or as "Woven Form" (fibers produced in a cloth form and providing strength multi-directionally) or in "Chopped Form" (fibers are in general irregularly and discontinuously arranged and known as fiberglass.

3. High Level Comparison between Different Construction Materials

Table 2 below highlights a high-level comparison of the GFRP with traditional materials like wood, steel, and aluminum which are used for traffic sign and

Table 2. High level comparison table with different construction materials [4].

Properties	GFRP	Wood	Steel	Aluminum
Corrosion	No	No	High	No
Weight (lightweight)	✓	X	X	✓
Safety (with limited avail data)	High	Low	Low	Medium
Painting	Can be pigmented impregnated within the manufacturing. color can last for service life	Can peel off subject to environment and requires regular maintained	Can peel off subject to environment and requires regular maintained	Normally its galvanized
Environmental degradation	Low	High	Very high	Low
Strength	Tailor made	Subject to age	Subject to age	Low
Service life (years)	More than 20 years based on historical data	10 - 20	10 - 20	20
Performance in aggressive environment	Excellent	Poor	Poor	Good subject to age
Ease of transportation	✓	X	X	✓
Construction efficiency	✓	X	X	✓
Asset maintenance liability	Low	High	High	High
CO_2 emissions	Lower	High	High	High
Cost	Slightly higher but better Life cycle costs	Higher due to scarcity and low quality	Higher	Higher

signal pole construction. GFRP offers light weight to high strength properties. The environmental degradation for the wood and steel is high when exposed to corrosive and wet environment whereas the GFRP poles can easily withstand these exposures. Service life offered by the GFRP is in excess of 20 years-based ion historical data. GFRP pole colors can be pigmented within the composition (within resin) and this does not require regular painting maintenance.

4. Manufacturing Process of Poles

Pultrusion is a continuous manufacturing process utilized to make GFRP profiles with constant cross-sections whereby fiberglass reinforcements, in the form of roving and mats, are saturated with resin and channeled into a heated die. The profile exits the die in a solid state and in the form of the desired cross-section. Figure 1 & Figure 2 demonstrate the manufacturing process as shown below.

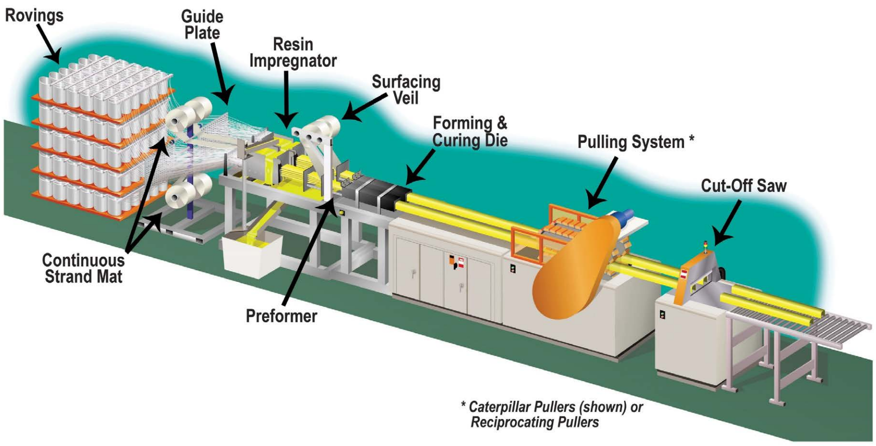

Figure 1. Pultrusion process [5].

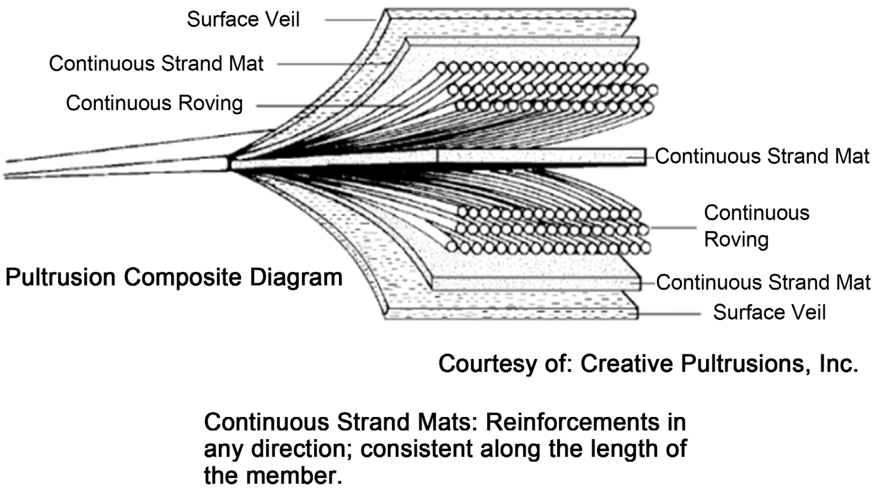

Figure 2. Pultrusion process [5].

The one-piece pultruded pole is constructed by the pultrusion process using a polymer binder containing a minimum 65% "E-CR" or "E" fiberglass by weight. All GFRP poles are manufactured with electrical grade E-glass reinforcements in the form of unidirectional roving, Continuous Filament Mat (CFM) and stitched fabric mats. The fiberglass materials are continuously applied in uni-directional and angular orientations of 0˚, ±45˚, and 90˚ to the longitudinal pole neutral axis with uniform tension by the pultrusion process.

The GFRP poles is pultruded with a high-performance Vinyl Ester (VE) resin that is based on a bisphenol-A epoxy matrix. The VE resin is utilized for its superior toughness and fatigue attributes. The VE resin provides fire retardant properties that permit the pole to "self-extinguish" in the event of a fire. GFRP poles contain UV protection with the addition of UV Light Absorbers which are mixed into the thermoset resin, prior to production and function as long term light stability promoter [5].

As shown in **Figure 3**, filament winding is the process of winding resin

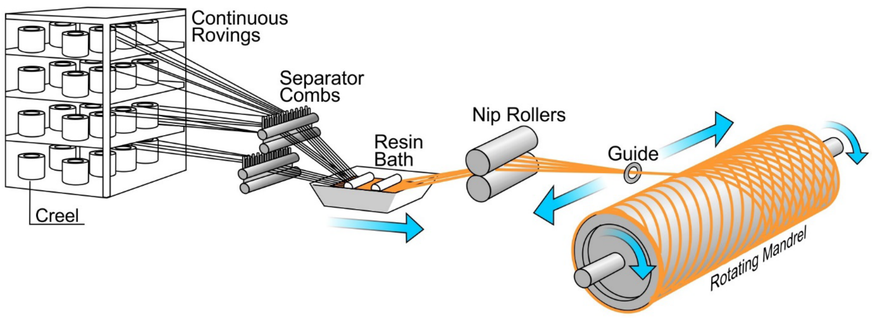

Figure 3. Filament winding [7].

impregnated glass or advanced fiber around a rotating mandrel, to create a composite structure. By using different fibers and resins and incorporating various winding techniques, filament winding creates high fiber loading with directional strength characteristics. Composites products produced through the filament winding process exhibit excellent strength. This process can produce sail boat masts, large diameter tanks, pressure vessels, cement mixers, pipes, natural gas cylinders and many other products [6].

5. Poles Materials Specifications and Performance

GFRP poles are engineered to meet American National Standard Institute (ANSI) and National Electric Safety Code (NESC) code requirements. The poles shall be pultruded with advanced UV protection in a matrix that offers superior toughness and strength. In addition, the poles shall exhibit excellent corrosion, moisture and fire resistance properties. The specification applicable for the material requirements, the manufacture and performance of lightweight non-taper, self-supporting and/or guyed, direct buried GFRP poles shall be in accordance to ANSI C136.20-2012 American National Standard For "Roadway and Area Lighting Equipment—Fiber-Reinforced Composite (FRC) Lighting Poles".

GFRP poles shall fulfill the requirements of section 10 of ANSI C136.20-2012 American National Standard for "Roadway and Area Lighting Equipment—Fiber-Reinforced Composite (FRC) Lighting Poles" Additionally, poles shall be classified as "self-extinguishing" per UL94 with a V0 rating. The flame spread shall be class I per ASTM E-84 with a Flame Spread Index (FSI) of 25 or less [8].

6. Case Study in Saudi Aramco Completed Project—Traffic Signs and Signals

1) Loading: The main loading considered for the design of the traffic signs was 140 km/hour which is an average wind speed in the Eastern province of Saudi Arabia.

The poles were designed as per the Load Resistance factor design (LRFD) method was used and the GFRP materials properties as shown in **Table 3** shows materials properties **Figure 4** below shows associated load diagrams for shear,

Table 3. Design values.

Materials Properties	Value
Flexural Strength	665 Mpa
Flexural Modulus	2.18 × 104 Mpa
Tensile Strength	690 Mpa
Tensile Modulus	3.96 × 104 Mpa
Impact Ductility	499 Kj/M2
Compression Strength	427 Mpa
Post (Diameter × Thickness):	(75 × 5) mm

bending and axial force.

The design section was 75 mm diameter by 5 mm thick wall GFRP pole. The pole was supported by the concrete foundation of 500 mm square by 600 mm deep. Figure 5 shows the general arrangement of the traffic sign pole. Section A shows the details of sign plate and pole construction arrangement. Photo 1 shows the completed manufactured sign with pole. Photo 2 & Photo 3 shows the completed signs erected on site for arrow sign (to keep left or right) for a side road and 80 KPH speed limit sign.

2) Traffic signal design: For traffic signal pole design, similar approach to traffic sign was taken to ensure in the design of signal pole can withstand the wind loading and associated signal head loadings. Figure 6 below shows the design adopted to produce signal pole.

The GFRP poles and the GFRP box were produced separately. The purpose of the box was to secure the pole and the connect the whole structure to the concrete foundation. A flange on top of the box was produced as shown in Figure 6 to secure the pole with bolts. Four M16 bolts with 80 mm length were used to secure the pole to the box foundation. The box was secured to the concrete foundations with 4 bolts of M16 bolts.

Photo 4 shows signal pole constructed at an intersection.

7. Construction Process

The GFRP pole based on their indented use are designed for static and dynamic loads. The static loads include self-weight and other weights of sign, lantern etc. creating a bending moment. Under dynamic loads most significant is the wind load. Based on the requirements for specific heights these can be design for higher wind load of more than 160 km/hr & 1.3 gust factor. GFRP poles are electrically nonconductive and corrosion resistant to salts & seawater. Based on the specific project requirements other than standard requirement GFRP poles can be evaluated and tested for seawater and salts impact by short term testing.

GFRP poles do not require special breakaway connections as shown in Figure 7 and can be installed directly buried as per Figure 8 in concrete foundation.

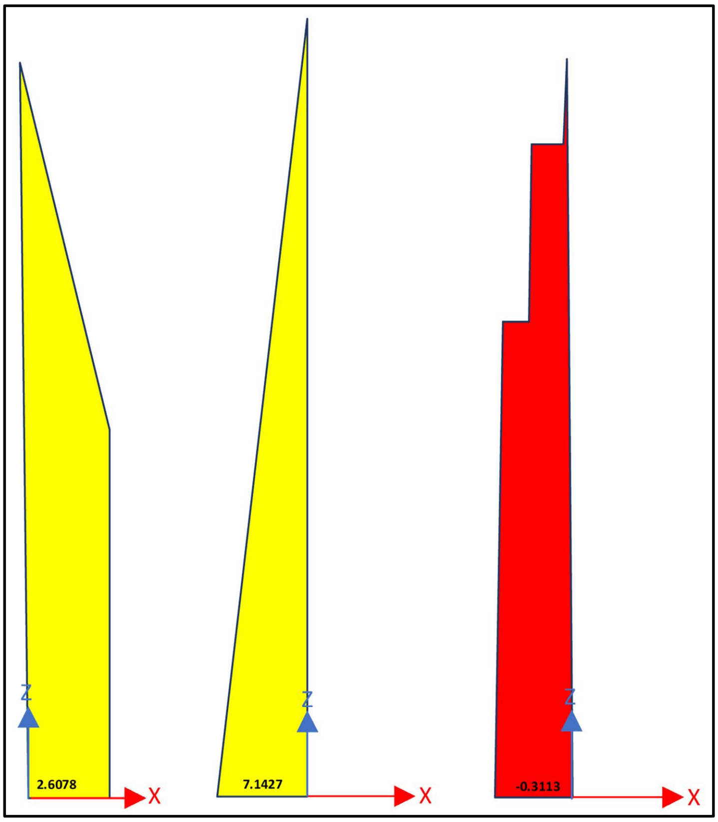

Figure 4. Shear force diagram, bending moment, axial force diagram.

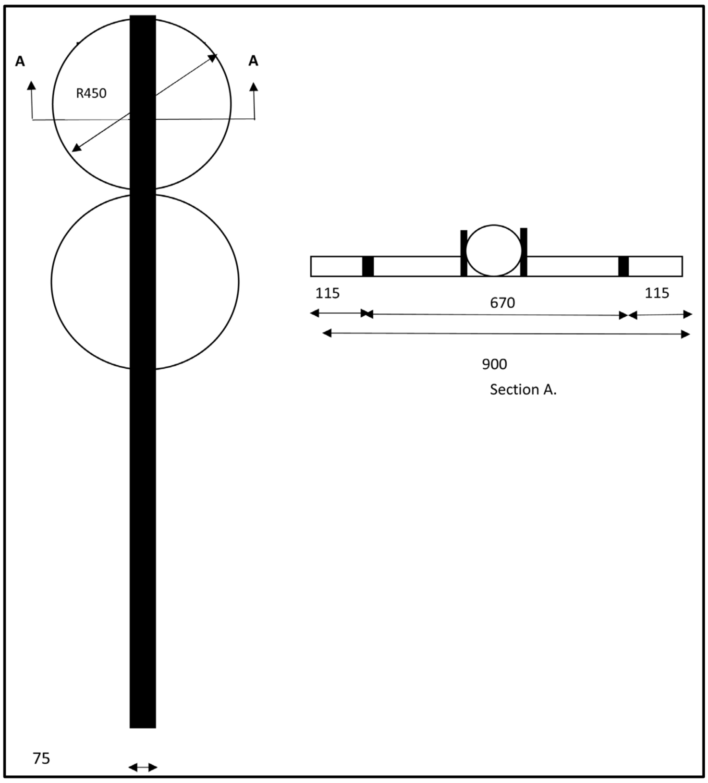

Figure 5. Traffic sign details [9].

Photo 1. GFRP signs.

Photos 2. Completed GFRP traffic signs [9].

Photos 3. Completed GFRP traffic signs [9].

Photo 4. Traffic signal construction details with sections [10].

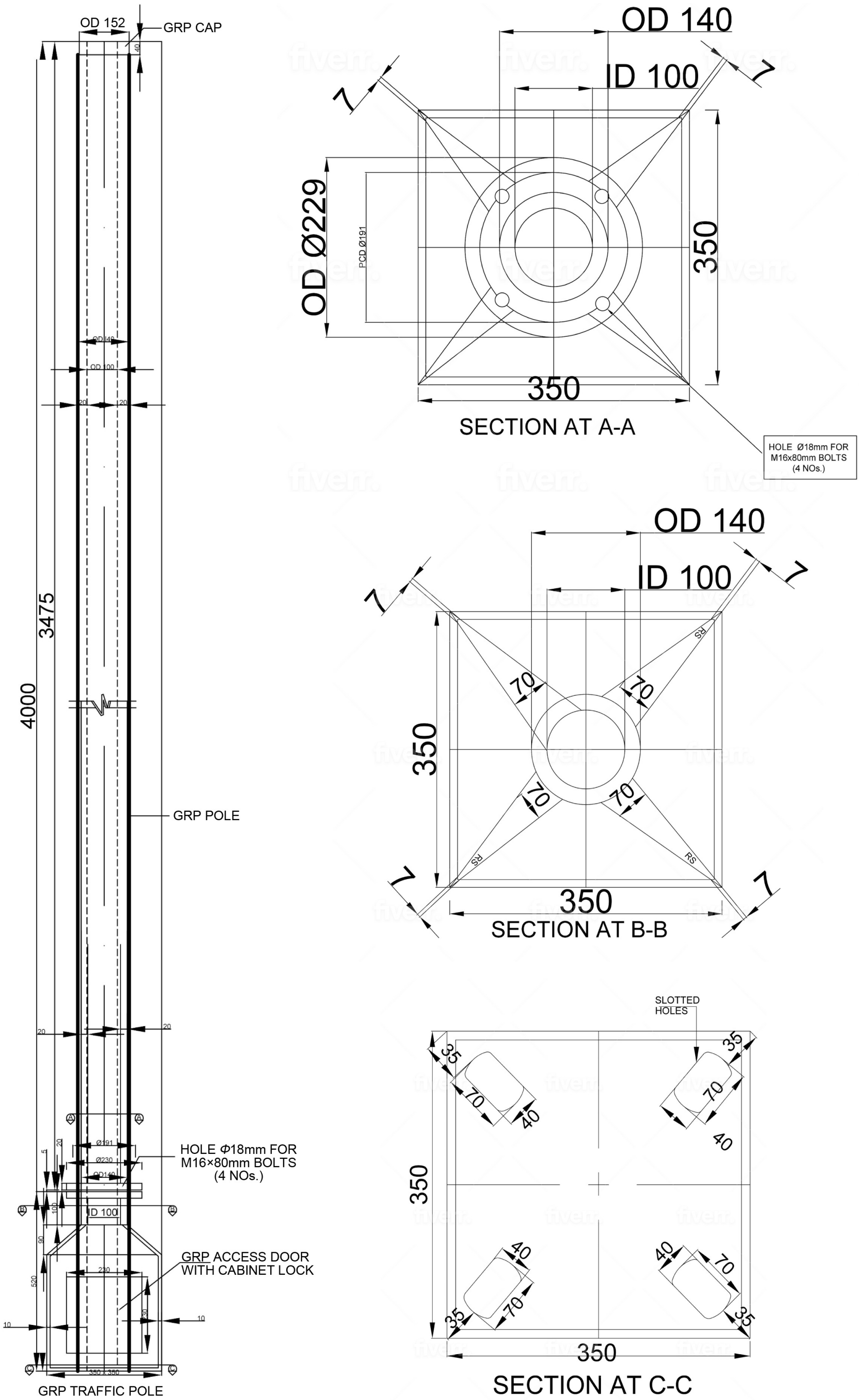

Figure 6. Traffic signal construction details with sections [10].

With excellent shock absorption capability, break away pattern and light weight GFRP poles are safe for car & driver in case of direct impact as the steel can produce higher impact and can create more injuries to the passengers compared to GFRP which can snap upon impact.

GFRP poles are recommended to have a minimum embed depth of 10% of

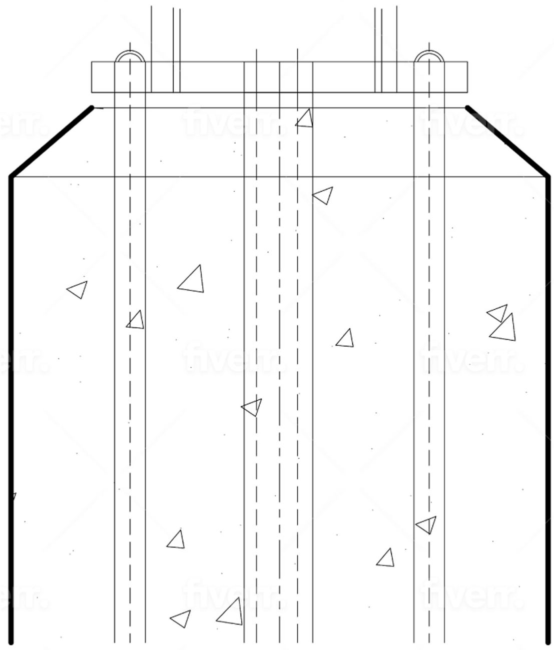

Figure 7. Breakaway plate and bolts installation for metallic poles pole.

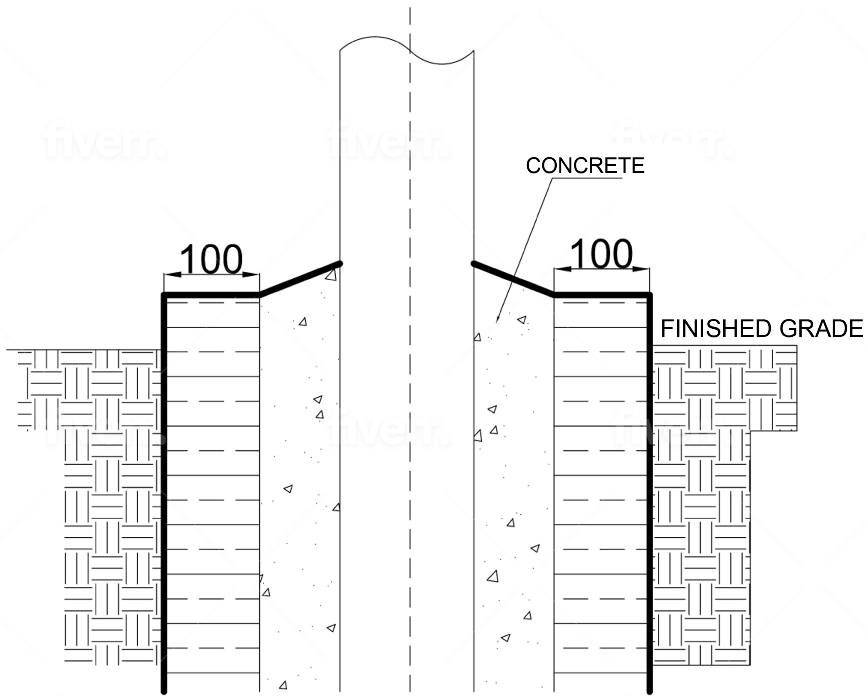

Figure 8. Direct buried installation of GFRP.

mounting height plus 2 ft in (609 mm) or as determined by loading and soil conditions. The designer should be aware of unusual or poor soil conditions and higher than normal loadings that may require greater burial depths.

If required by the end user, GFRP poles designed to be mechanically fastened to a foundation shall be provided with an anchor base plate. The total system shall be capable of withstanding the combined forces described in the relevant standard.

With regard to the UV resistance, the finished surface of the pole shall resist degradation from the environment in which the pole is installed. The pole shall be tested per ASTM G154 for a minimum of 5000 hours using a QUV "A" lamp with four hours on and four hours off cycle 5.

GFRP poles, with specified luminaire, arms, and other attachments installed, shall have a minimum bending strength of at least 1.5 times the maximum bending moment induced by maximum wind loading conditions as calculated per AASHTO LTS. When a hand hole is specified, the pole shall attain this load with the hand hole in compression and the cover removed 5.

The GFRP pole shall have no more than 1% permanent deflection for the loading value as calculated in ANSI C136.20. This loading shall be applied for 5 minutes at 77˚F (25˚C) ± 4˚F (1.5˚C), with measurement being taken 5 minutes after unloading [11].

8. Further Research

The use of GFRP as traffic signs has not been fully adopted worldwide like steel. As such there is a need to standardization of the design to meet proponent expectation for ease of manufacturing and maintenance. There is also a need for the assessment of the crash test at higher speed like 140 KPH and above to see how they perform and any implication to vehicle occupant safety.

9. Conclusions

GFRP poles offer an attractive alternative to traditional materials like wood, steel and aluminum. They offer better resistance to environmental factors like corrosion, and ease of erection due to light weight and offer better life cycle costs (LCC) compared to traditional materials and reduce maintenance liability. The use of GFRP poles offers a sustainable option, improves the productivity and helps to reduce the carbon footprint in comparison to other traditional materials.

GFRP poles as traffic signs and signal poles are fairly new concepts and not common, and hence the initial capital cost can be slightly higher. But GFRP poles offer better performance, durability and resistance to corrosion and outperform other traditional materials. The average life of steel, wood and aluminum can be circa 10 years but GFRP can offer 20 years plus life with minimum maintenance. There is a need to increase the awareness to use GFRP poles in road infrastructure among transport agencies and other stakeholders. To expedite and promote the use of GFRP traffic signs and signal poles, efforts are required in standardizing the design and development of specific standards for manufacturer to adopt to reduce the overall cost of manufacturing.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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