Alternative Materials for FDOT Sign Structures
Phase I Literature Review

Research Report

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SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
LENGTH				
in	Inches	25.4	millimeters	mm
ft	Feet	0.305	meters	m
yd	Yards	0.914	meters	m

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
AREA				
in^2	Square inches	645.2	square millimeters	mm^2
ft^2	Square feet	0.093	square meters	m^2
yd^2	square yard	0.836	square meters	m^2

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
VOLUME				
ft^3	cubic feet	0.028	cubic meters	m^3
yd^3	cubic yards	0.765	cubic meters	m^3
NOTE: volumes greater than 1000 L shall be shown in m^3				

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
MASS				
oz	ounces	28.35	grams	g
lb	pounds	0.454	kilograms	kg

SYMBOL	WHEN YOU KNOW	MULTIPLY BY	TO FIND	SYMBOL
FORCE and PRESSURE or STRESS				
lbf	Pound force	4.45	Newton	N
lbf/in^2	Pound force per square inch	6.89	kilopascals	kPa

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16. Abstract

Inspections of tubular sign structures by the Florida Department of Transportation (FDOT) have revealed occurrences of premature corrosion on the inside of galvanized steel tubes. As a result, FDOT engineers are seeking alternative materials that may be employed in such structures. Researchers at the University of North Florida (UNF) have conducted a literature review of the state-of-the-practice of employing fiber-reinforced polymer (FRP) composites in such applications. The results of this literature review indicate that FRP composites have promising material characteristics for such applications. FRP composites do not corrode and possess significantly lower densities, which may result in lower construction costs, and extended service life. It is noted however that there will be a short-term premium associated with the implementation of new technology, as compared with the use of traditional construction materials. Further, it is noted that FRP composites tend to fail in a more brittle manner, whereas traditional construction materials are assumed to exhibit greater ductility prior to failure. Consequently, the need for proven design standards, and specifically connection details, will be critical for widespread implementation. Based on this literature review, it is recommended that FDOT engage in a pilot project to test and evaluate the merits of using FRP composites for sign truss structures in Florida. It is proposed that different commercially available products and different design details, specifically connections be evaluated as part of the proposed further study.

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EXECUTIVE SUMMARY

The construction industry has historically made use of four materials: stone, timber, concrete, and steel. In recent years, civil engineers have been seeking alternative materials to steel and concrete that may be less vulnerable to environmental damage. Rising public concern about traffic delays experienced during construction have increasingly influenced civil engineers to seek materials and methods that allow more rapid construction. At the same time, costs must be competitive with traditional materials because of reduced public sector resources to maintain transportation infrastructure. Fiber-reinforced polymer (FRP) composites have emerged as an attractive potential alternative.

Inspections of sign structures by the Florida Department of Transportation (FDOT) have revealed the occurrence of premature corrosion of galvanized steel structural members. As a result, FDOT engineers are also seeking alternative materials that may be employed in these structures.

Researchers at the University of North Florida (UNF) were engaged to conduct a literature review of the state-of-the-practice of employing FRP in such applications. The results of this literature review show that FRP composites have promising material characteristics for such applications. FRP composites are reported to possess significantly lower densities, which may ultimately result in lower construction costs, and extended service life due to lack of corrosion.

It is noted however, that there will be a short-term premium associated with new technology implementation (NTI), as compared with traditional construction materials. Further, it is noted that FRP composites tend to fail in a more brittle manner, when compared with traditional construction materials. Consequently, the need for proven design standards and specifically connection details will be critical to widespread structural implementation.

Based on this Phase I literature review, it is recommended that FDOT engage in a pilot project to test and evaluate the merits of using FRP composites for sign truss structures in Florida. It is proposed that different commercially available materials and different connection details be evaluated as part of this proposed Phase 2 pilot project.

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ALTERNATIVE MATERIALS FOR FDOT SIGN STRUCTURES PHASE I LITERATURE REVIEW

1. INTRODUCTION

The construction industry has historically made use of four traditional materials: stone, timber, concrete, and steel. Until a few hundred years ago, stone and timber were the primary materials used to build structures. In the past two hundred years or so, structural steel and reinforced concrete have emerged as leading construction materials, and most modern urban landscapes are now defined largely by these two materials (Bisby, 2006).

In recent years, civil engineers have been seeking alternative materials to steel and concrete that may be less vulnerable to environmental damage. Rising public concern about traffic delays experienced during construction have also increasingly influenced transportation engineers to seek materials and methods that can be constructed more rapidly. At the same time, costs must be competitive with traditional materials because of limited public sector resources. Fiber-reinforced polymer (FRP) composites have emerged as attractive alternative materials (Alampalli et al., 1999).

As outlined in Figure 1, considerable focus has been devoted to the use of FRP composites in construction since the early 1970s (Hollaway, 2010). The primary driving force is the need to revitalize aging infrastructure with innovative materials and structural systems that last longer and require less maintenance (Mirmiran et al., 2003).

Due to their light weight, high stiffness-to-weight, strength-to-weight ratios, and potentially high resistance to environmental degradation, FRP composites are increasingly being employed for use in the retrofit and rehabilitation of buildings and bridges (Karbhari et al., 2003). The documented success of FRP composites on structural rehabilitation projects has more recently led to the development of promising new lightweight structural all-FRP composite systems (Van Den Einde et al., 2003).

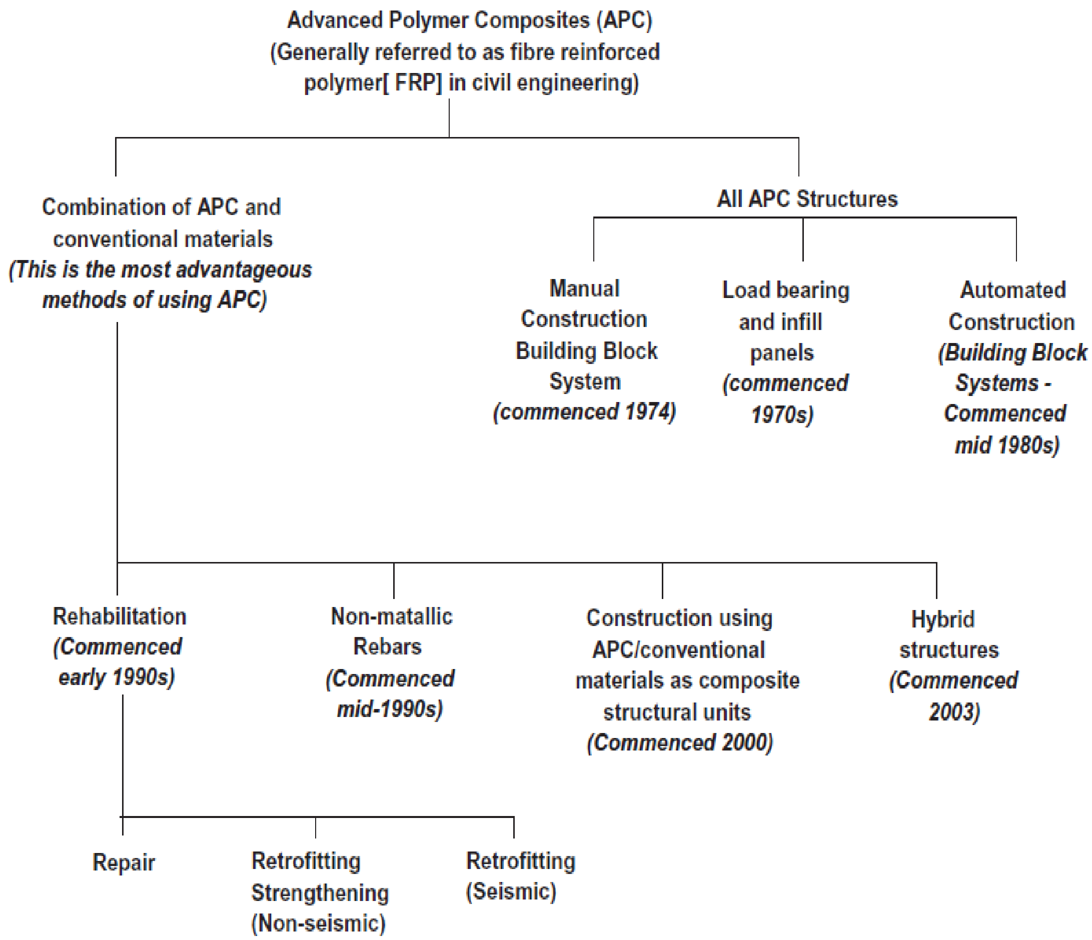

Figure 1 History of FRP Use in Civil Engineering Applications (Hollaway, 2010).

2. OBJECTIVES

Recent inspections of tubular sign and lighting structures by the Florida Department of Transportation (FDOT) have revealed the occurrence of premature corrosion on the inside of galvanized steel signage structure tubes. As a result, FDOT engineers are seeking alternative materials that may be employed in the new construction of such structures. However, prior to engaging in a full-scale testing and evaluation program of alternative materials, an exhaustive literature review is warranted to assist with the identification of the most promising materials and systems currently available. This Phase 1 literature review includes recommendations for more in-depth testing and evaluation, preliminary life-cycle-cost estimates for the employment of the proposed alternative materials, and proposed specification language for future implementation. As noted, the focus of this literature review is on the application of FRP composites technology to overhead sign structures. Existing FRP systems, such as the Composite Support & Solutions, Inc. "Snaplock" system, previously evaluated by Caltrans (Caltrans, 2008), are presented with respect to potential for further evaluation and testing by FDOT.

3. ECONOMICS

3.1 Initial Cost of FRP

When researching initial cost, FRP composites were separated into two categories: 1) carbon FRP (CFRP) and 2) glass FRP (GFRP). As presented in Table 1 (Basham, 1999), bulk prices for FRP rebar range from $3.00 to $4.00 per pound. Steel rebar costs range from $0.50 to $1.60 per pound. Based on this data, and assuming proportional costs for structural shapes, the initial cost of GFRP is estimated to be about three (3) times greater than that of steel.

According to the news release, Carbon fiber cars could put the U.S. on highway to efficiency, from the Oak Ridge National Laboratory, "…today the cost to purchase commercial-grade carbon fiber is between eight and ten dollars per pound…" (Oak Ridge National Laboratory, 2006). Based on this information, the initial cost of CFRP is estimated to be on the order of 2 to 3 times greater than that of GFRP, as much as 8 times more than that of steel. Consequently, GFRP composites have been much more widely employed in the production of structural shapes than CFRP. It is noted that CFRP has been widely used in the repair of damaged infrastructure.

Table 1 Comparison of Corrosion-Resistant Rebar (Basham, 1999).

Table 1 Comparison of corrosion-resistant rebar

Type of rebar	Times more corrosion resistant than black rebar	Scratch and chip resistance	Bending	Cutting	Welding	Chloride threshold	Cost, $/lb[1]
Epoxy-coated ■ Damage level 0.5% ■ Damage level 0.004%	150 to 1,175 69 to 1,762	Easily damaged, requiring field repairs	Allowed but can damage epoxy coating	Allowed; coating of cut end required	Allowed; coating of weld required	Same as black rebar Very high	0.32
Galvanized (zinc-coated)	38	Very tough; hard to damage	Allowed but may weaken coating	Allowed; coating of cut end required	Allowed; coating of weld required	4 to 10 times higher than black steel	0.50
GFRP	Won't corrode	Fairly tough; difficult to damage	Field bends not allowed	Allowed; sealing of cut end may be required	Nonweldable	Immune to chloride attack	3.00 to 4.00[2]
Solid stainless steel	800 to 1,500	Not an issue	Allowed	Allowed	Allowed; special welding procedures apply	15 to 24 times higher than black rebar	1.60
Stainless-steel-clad	Same as solid stainless-steel rebar	Very tough; nearly impossible to damage	Allowed	Allowed; coating of cut end may be required	Allowed; special welding procedures apply	Same as solid stainless-steel rebar[3]	0.60

[1]Costs shown are based on Reference 5 and information from industry experts. They are material costs only and may vary in different parts of the country.

[2]GFRP density is considerably less than steel and values cannot be directly compared to steel rebar.

[3]Values assumed the same as solid stainless steel.

3.2 Life Cycle Cost Examples

The Office of Applied Economics at the National Institute of Standards and Technology (NIST) conducted a Life Cycle Cost Analysis (LCCA) on various FRP composite bridge deck systems as compared with a traditional reinforced concrete bridge deck (Ehlen and Marshall, 1996). This example LCCA included consideration of agency costs, user costs, and third-party costs. The agency costs were further evaluated with respect to initial construction costs (operation, maintenance and repair costs), and disposal costs. The detailed components of this example LCCA are reproduced here in Figure 2.

The alternative material/design systems compared in the example are reproduced here in Figure 3. As reported by Ehlen and Marshall, the three different FRP composite alternatives considered included:

1. SCRIMP (Seeman Composite Resin Infusion Molding Process): This is one form of vacuum-assisted resin transfer molding. E-glass fabric is laid in its final design configuration using a foam core and an external mold. Resin is then pulled through the cavities using vacuum pressure. Once the resin sets, the mold is removed. The foam remains as a permanent but nonstructural part of the deck.
2. Wood-Core Sandwich: Vertical Asian structural bamboo sections are assembled into a rigid “sandwich” core. The top, bottom, and sides are then covered with layers of fiberglass, and resin applied.
3. Pultruded Plank: Lineal planks are pultruded from resin-wetted fiberglass fabric and fiberglass strand. Once individual planks have set, three sections are then joined at their sides with key strips to form a wider cross-section.

Further, as reported by Ehlen and Marshall the following assumptions were common to all four material/design combinations:

1. The intended service life of the bridge is 40 years (specified by the North Carolina Department of Transportation (NCDOT)), so the LCC study period is set at 40 years.
2. The real discount rate for computing the present value of all future costs is 3.0% (this is based on OMB Circular No. A-94, Appendix C Revised February 1996).
3. Length of highway affected by bridge construction, maintenance, and disposal: 1 mile each for NC130 and US17 (estimated from project drawings).
4. Average Daily Traffic (ADT) figures: based on NCDOT forecasts recorded on project drawings.
5. Normal driving speeds for NC130 and US17: 45 mph and 55 mph (NCDOT)

6. Average driving speed on NC130 and US17 during bridge work: 35 mph (NCDOT).
7. Normal accident rate (per million-vehicle-miles): 1.9 (California Department of Transportation (Caltrans).
8. Accident rate in road work areas (per million-vehicle-miles): 2.2 (Caltrans).
9. Hourly value to drivers of delay: $10.73/hr (Caltrans, 1995).
10. Hourly vehicle operating cost: $8.88/hr (Caltrans, 1995).
11. Average cost per accident: $103,781 (Caltrans, 1995).

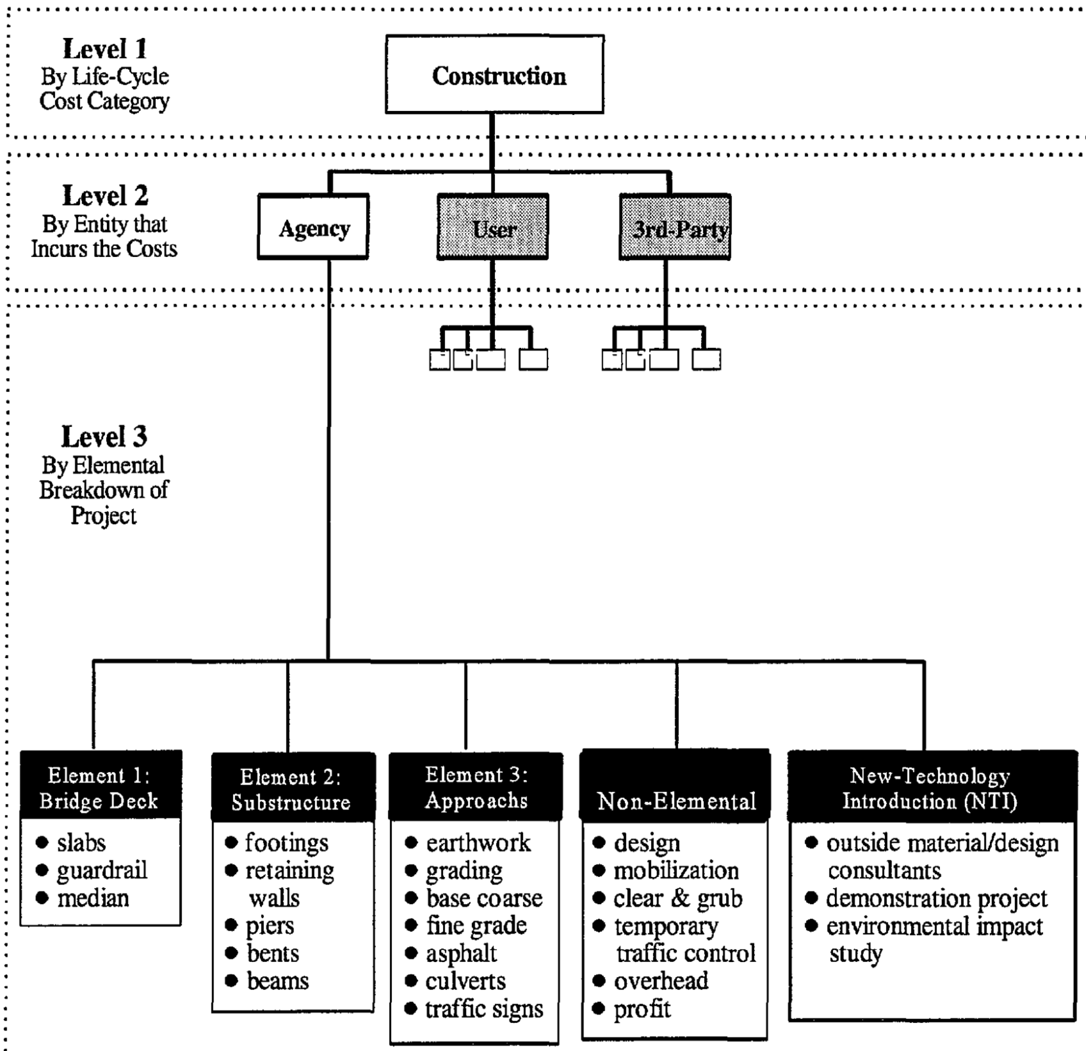

Figure 2 Detailed Components of Example LCCA (Ehlen and Marshall, 1996).

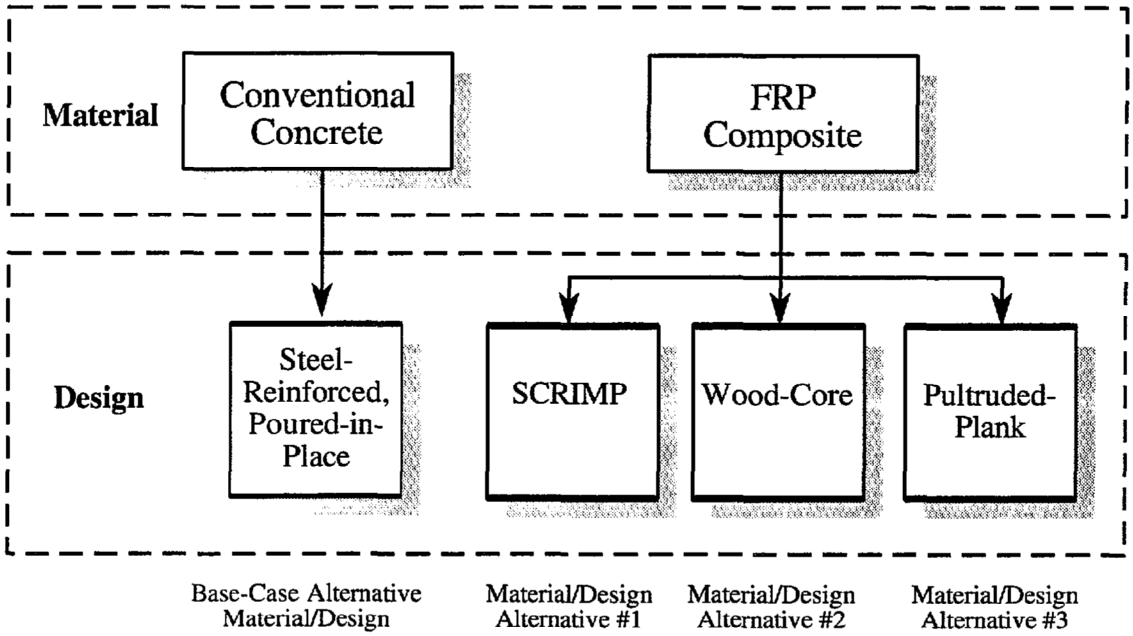

Figure 3 **Alternatives Compared in Example LCCA (Ehlen and Marshall, 1996).**

Table 2 **LCCA Summary, with and without New Technology Implementation Costs (Ehlen and Marshall, 1996).**

Material	LCC with NTI Costs	LCC without NTI Costs
Reinforced Concrete	**$345,374**	$345,374
SCRIMP FRP	$634,548	$548,174
Wood-Core FRP	$401,163	**$314,789**
Pultruded-Plank FRP	$673,195	$586,821

The summary results of this example LCCA are also reproduced here in Table 2. This study concluded that FRP composites come at a premium (on the order of two (2) times the cost of traditional construction materials) when considering new technology implementation (NTI) costs. However, without the expense for NTI, the LCC for some FRP systems can even be lower than that of traditional materials when considering user and third-party costs in the analysis. These researchers further noted that it is appropriate to eliminate the NTI costs in such comparisons, as this premium will diminish as the use of the new technology gains popularity and experience is gained by local engineers and contractors.

Another example economic analysis was conducted on FRP composites used in the repair of concrete bridge columns by researchers in Virginia and California (El-Mikawi and Mosallam, 1996). As summarized in Table 3, these researchers identified significant benefits in service life, reduced maintenance costs, and reduced construction time when compared with traditional repair methods. It is also noted that for this repair example, the premium on the initial cost of FRP composites was found to be only 30% higher, whereas the expected life of the FRP composite repair was estimated to be almost two times that of steel. It is noted that this cite example is specific to the repair of damaged structures, as opposed to the previously cited new construction example.

3.3 Estimated FRP Sign Structure Costs

The current furnish and install construction costs for galvanized steel FDOT sign truss structures range from about $30,000 for cantilever structures less than 30 feet in length to about $150,000 for full-span structures (see Appendix A). For budgeting purposes, it is estimated that similar truss structures, manufactured from FRP composites could be furnished and installed in Florida at an initial cost of about 3 times that of galvanized steel, or less than $100,000 for small cantilever structures, and up to $500,000 for large, full-span truss structures. Again, this estimated cost for FRP sign structures includes a premium for NTI costs. As local engineers and contractors gain experience with FRP design and installation, it is envisioned that the initial cost will be significantly reduced.

In summary, the initial cost of using FRP composites for infrastructure applications has been found to be significantly higher than that of traditional construction materials. However, researchers have documented that FRP composites may be employed in specific applications at a lower LCC than that of traditional construction materials. As the demand for and supply of newer FRP composite materials grows, the economics of their use in construction is expected to improve.

Table 3 Economic Analysis Parameters for the Repair of Concrete Bridge Columns (El-Mikawi and Mosallam, 1996).

Economic parameters	Steel	Composites
Expected life of repair (years)	12	20
Initial cost (ratio)	1	1.3
Maintenance costs (ratio)	1	0.25
Construction duration (months)	6	3[a]

[a] Two months for the design and fabrication of the composite material; the actual installation of the composites takes one or two days per column

4. MATERIALS

4.1 Fibers

Three general fiber types are commonly employed in FRP composites, including: glass, carbon, and aramid. Each of these general fiber types may also be divided into subclasses. For glass fibers, the two prevailing types are: e-glass and s-glass; for carbon fibers, the two prevailing types are: high strength and high modulus; and for aramid fibers, the two prevailing types are: Kevlar 29 and Kevlar 49 (Potyrała, 2011). As can be seen in Table 4, carbon fibers tend to rank highest with respect to engineering properties. This has resulted in significant use of carbon fibers (CFRP) in FRP applications in recent years. Glass fibers (GFRP) are also frequently used due to availability. Aramid fibers have predominantly been used in nonstructural applications such as body armor due to their relatively high cost.

4.2 Polymers

Polymers bind the fibers together and protect the fibers from environmental degradation. The polymer matrix has a relatively low density and keeps the composite lightweight, but still strong. The forces between the individual fibers are transferred to the matrix through shear stresses. There are two main categories of resins that this matrix can be made of, including: thermoplastics and thermosetting resins. These resins are composed of long-chain molecules that are held together by relatively weak forces but have very strong bonds within individual molecules. Thermosetting resins are commonly used in structural engineering applications. These polymers generally have good thermal stability, good chemical resistance, and low creep and relaxation properties. The three main thermosetting resins include: polyesters, vinylesters, and epoxies. FRP bridge structures have typically been manufactured out of pultruded, vinylester polymer and E-glass fiber (Bank, 2006). It is noted however, that the durability of FRP composites depends intrinsically on the components of the composite, but in particular on the polymer and is a function of the environments into which it is placed (Hollaway, 2010).

4.3 Manufactured Shapes

The three basic manufacturing techniques include layup, filament winding, and pultrusion. Pultrusion was developed in the U.S. in the 1950's, and is the most common manufacturing method for structural engineering shapes. Composite Technology, Inc. (CTI) provides pultruded FRP composite shapes for primary load-bearing structural components. These pultruded sections were designed specifically for composite materials to compete with and replace conventional structural materials. These sections were made competitive by tailoring the geometry, advantageously placing fibers, and controlling the load path to overcome stiffness and engineering limitations, and erection costs (Green et al., 1994).

Table 4 Typical Fiber Properties (Potyrała, 2011).

Typical properties	Fibres					
	glass		aramid		carbon	
	E-Glass	S-Glass	Kevlar 29	Kevlar 49	HS (High Strength)	HM (High Modulus)
Density ρ [g/cm^3]	2,60	2,50	1,44	1,44	1,80	,190
Young´s Modulus E [GPa]	72	87	100	124	230	370
Tensile strength R_m [MPa]	1,72	2,53	2,27	2,27	2,48	1,79
Extension [%]	2,40	2,90	2,80	1,80	11,00	0,50

As shown in Figures 4 and 5, there are now a variety of structural GFRP and CFRP shapes available. Circular and rectangular tubes, wide flange, and L sections are typically the preferred shapes for bridge truss structures. There are virtually no dimensional limits when it comes to manufacturing these shapes. In the U.S., prominent companies producing pultruded profiles include: Strongwell, Creative Pultrusions and Bedford Reinforced Plastic (Potyrała, 2011). Charts listing the common shapes and sizes produced by these manufacturers are reproduced here in Appendix A.

4.4 Mechanical Properties

The mechanical properties of FRP composites can be highly variable, even when the specimens are prepared and tested under identical conditions (Abdallah et al., 1996). Table 5 presents the mechanical properties of various FRP composites as compared with traditional steel and aluminum alloys. As seen in Table 5, the specific strength (strength-to-weight ratio) and specific Young's modulus (stiffness-to-weight ratio) of FRP composites is generally greater than that of traditional metals. This translates into more efficient sections, which further translates into ease of handling and assembly, lighter erection equipment, and lower transportation costs (Potyrała, 2011). Ultimately, lower material densities can substantially reduce a project's construction costs.

4.5 Durability

As previously noted, FRP composites are increasingly being used in civil engineering applications due to their specific strength advantages. Thus, the study of their long-term durability is crucial (Robert and Benmokrane, 2010). As previously noted, the durability of FRP composites depends intrinsically on the components of the composite, but in particular on the polymer, and is a function of the environments into which it is placed (Hollaway, 2010). The lack of a comprehensive, validated, and easily accessible database for their durability as related to civil infrastructure applications has been identified as a critical barrier to widespread acceptance of these materials by structural designers and civil engineers. This concern is even more critical since the structures of interest are primarily load-bearing and are expected to remain in service over extended periods of time and in some cases, without significant inspection or maintenance (Karbhari et al., 2003).

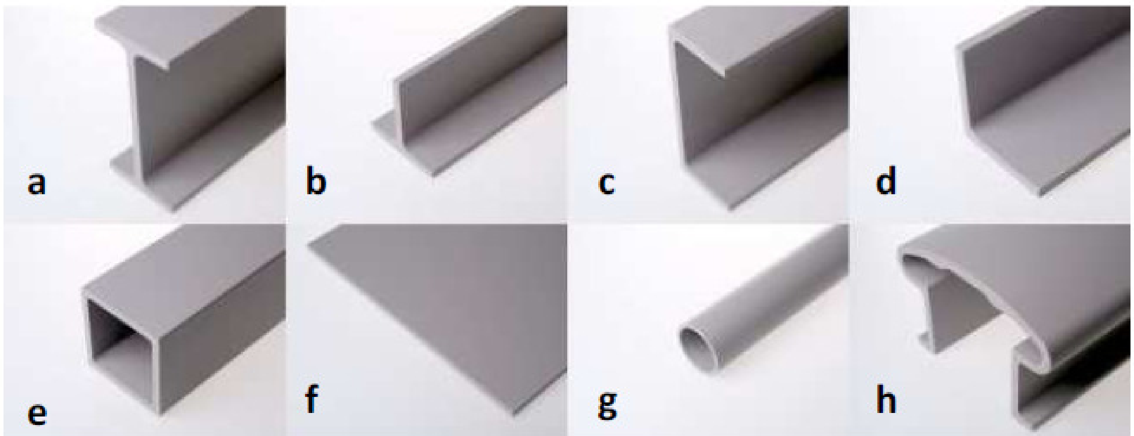

Figure 4 Typical GFRP Profiles Available, as Produced by Fibreline Composites: a) Steel I-beam, b) T-Bar, c) Channel Section, d) Square, e), Square Tube, f) Plate, g) Circular Tube, h) Handrail (Potyrała, 2011).

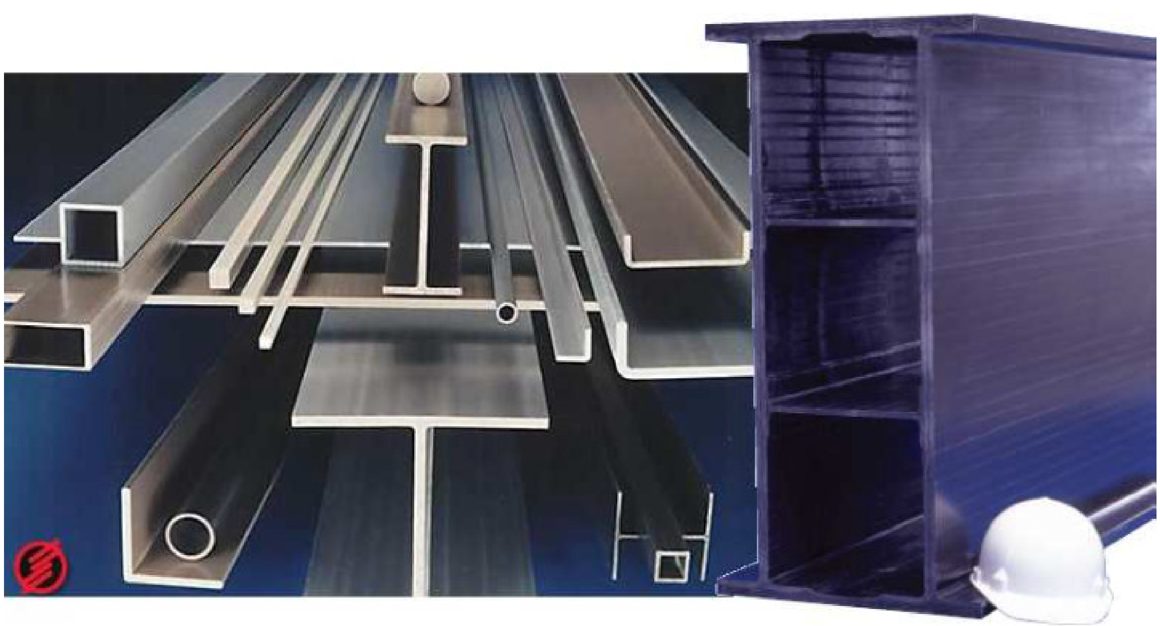

Figure 5 The Range of Composite Profiles Reinforced with Glass and Carbon Fibers, as Produced by Strongwell (Potyrała, 2011).

Table 5 Typical GFRP, CFRP, vs. Metal Properties (Potyrała, 2011).

Typical properties	Material					
	Duraluminum	Titan TiA 16Va4	Steel St52	GFRP	CFRP quasiisotr. vol. Fraction 60%	CFRP orthotropic vol. Fraction 80%
Density ρ [g/cm^3]	2,80	4,50	7,80	2,10	1,50	1,70
Tensile strength R_m [MPa]	350	800	510	720	900	3400
Specific strength R_m/ρ [MPa× cm^3/g]	125	178	65	340	600	2000
Young´s Modulus E [GPa]	75	11	210	30	88	235
Specific Young´s Modulus E/ρ [GPa× cm^3/g]	27	2	27	14	59	138

4.5.1 Fatigue Loading

There is now a significant body of literature that provides a fairly detailed account of the types of damage that commonly develop during the tensile and compressive fatigue loading of high modulus fibrous composite laminates. Although this body of information is by no means complete, many detailed descriptions of microevents that accompany such loadings are available, and models have been developed, including successful attempts to represent and predict the stiffness changes that accompany certain types of damage (Reifsnider et al., 1983).

4.5.2 Moisture Susceptibility

Researchers at Virginia Tech studied the effects of short-term cyclic moisture aging on the strength and fatigue performance of a glass/vinyl ester pultruded composite system. In particular, this work addresses the change in quasi-static properties and tension–fatigue behavior of a commercial glass/vinyl ester system in fresh and salt water. The quasi-static tensile strength was observed to reduce by 24% at a moisture concentration of 1% by weight. This reduction in strength was not recoverable even when the material was dried, suggesting that the exposure to moisture caused permanent damage in the material system. The cyclic moisture absorption–desorption experiments altered the fatigue performance of the composite system tested. These results were consistent with previous researchers conclusions that fatigue failure in glass-fiber-reinforced polymeric composites is a fiber-dominated mechanism with a characteristic slope of 10% UTS/decade (McBagonluri et al., 2000).

4.5.3 Buckling

Post-failure examination of pultruded carbon fiber-epoxy cylindrical rods tested in compression reveals that failure of the fibers is microbuckling-induced. This is a bending failure as a consequence of buckling. Other events, such as fiber-matrix debonding (splitting) and matrix yielding, do not by themselves cause the final failure, but they facilitate fiber buckling by reducing the lateral support for the fibers (Soutis, 2000).

4.5.4 UV Degradation and Creep

The effect of ultraviolet (UV) radiation on the creep rate of nine different polymers was also evaluated under load. A reversible increase in creep rate was detected. This effect was attributable to radiation damage resulting in the breakage of bonds in the stressed polymer. The outcomes reveal a close relationship between the processes of polymer fracture and deformation (Regel et al., 1967).

UV radiation may also cleave the covalent bonds in organic polymers, causing yellowing and embrittlement. Transportation engineers should seek advice from the manufacturer of the specific materials regarding UV resistance (Hollaway, 2010).

In summary, the results of accelerated laboratory testing of the overall durability of various FRP composites revealed the following general conclusions (Hollaway, 2010):

1. Carbon fibres and FRP rods had good durability characteristics.
2. Aramid fibres and FRP rods had good durability properties except under static fatigue, UV radiation and acidic environment.
3. Glass fibres had poor durability characteristics as far as their alkaline resistance is concerned, although they had satisfactory characteristics in an acidic and freeze thaw environment. FRP materials in general showed poor performance at high temperatures and therefore their use should be avoided when fire resistance is required.
4. There is a need to limit the tensile load depending on the duration of the load in cases where the FRP are used as internal reinforcement.

5. DESIGN GUIDANCE

As previously noted, FRP composite materials have been used in the rehabilitation and replacement of older degrading traditional structures and for new construction since the early 1970s. However, the lack of design standards for civil infrastructure limits their structural applications. The majority of the existing applications have been designed based on research and guidelines provided by manufacturers or simply based on experience. As a result, the final structure is often over-designed (Awad et al., 2012). The need for formal design guidance has been identified by numerous authors (NCHRP, 2003; Chambers, 1997; and others).

5.1 Available Guide Specifications

Three key documents are recommended for specific guidance in the implementation of FRP composites for sign structures in Florida. NCHRP Report 494, "*Structural Supports for Highway Signs, Luminaires, and Traffic Signals*," published in 2003, provides useful specifications regarding the performance of FRP materials and structural elements (NCHRP, 2003).

The FDOT Structures Office publication, "*FDOT Modifications to Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*," published in 2012 also provides specific design input for such structures in Florida (FDOT, 2012).

Another useful specification for FRP composite materials for use in civil engineering structural systems, "*A Model Specification for FRP Composites for Civil Engineering Structures*", was developed by researchers at the University of Wisconsin. This model specification provides a classification system for FRP materials, describes admissible constituent materials and limits on selected constituent volumes, describes tests for specified mechanical and physical properties, specifies limiting values of selected properties in the as-received condition and in a saturated state, and provides a protocol for predicting long-term property values subjected to accelerated aging (Bank et al., 2003).

5.2 Connections

Connections are a particularly critical design detail for FRP composite structures. A well designed connection can reduce installation time, properly transfer loads, and resist degradation over the lifespan of a structure. Three different types of FRP connections are discussed herein, including: Snap-Fit, Mechanical, and Chemically Bonded Connections.

5.2.1 Snap-Fit Connections

A snap-fit connection is a 'built-in' or integral latching mechanism. Snap-fit connections differ from mechanical or chemical connections in that they require minimal additional pieces, materials or tools during installation. Figure 6 provides a schematic illustration of an example FRP Snap-fit connection (Caltrans, 2008).

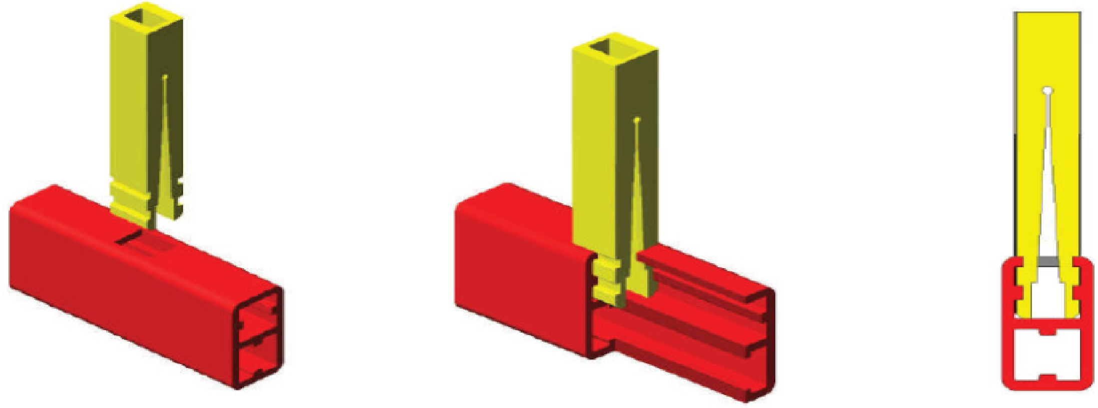

Figure 6 Composite Support & Solutions, Inc. "Snaplock" Connection, (Caltrans, 2008).

These "Snap" joints are based on an original fiber-architecture design that was obtained by paying special attention to interlaminar requirements for load introduction. The snaplock joint has already been successfully used for an all-composite transmission tower and for a heavily loaded truss structure (Goldsworthy and Hiel, 1998).

The California Department of Transportation (Caltrans) conducted a research program to investigate the use of composite materials for overhead sign structures, as well as the assembly of these structures without fasteners. A composite overhead sign structure was designed and analyzed. A two-post sign truss with a clear span of 90 feet was selected as a benchmark. The layout of a fastenerless composite sign truss with two-posts revealed significant weight savings. A newly developed composite "snap joint", which is pultrudable, is the heart of this lightweight sign structure. Performance tests revealed that this joint has a static load capacity of more than 22,000 lb (Caltrans, 2008).

However, as can be seen in Table 6, there are many limiting requirements for snap-fit connections, including minimizing degrees of freedom, long grip length for cantilever applications, and perceivable feedback of the snap-fit connection upon proper engagement, complex snap sequences, and smoothened edges throughout a snap-fit connection. These are just a few of the guidelines described in the *First Snap-Fit Handbook, 2nd Ed.* (Bonenberger, 2005).

As also outlined in Tables 7 through 9, there are many aspects of a snap-fit connection to consider when deciding if it is an appropriate connection type. One of the most important of these considerations is the ability to validate the effectiveness of the internal portion of the connection. If there happens to be any misalignment in the two mating surfaces, the effectiveness of the connection will be compromised. Furthermore, it will be difficult, if not impossible, to diagnose such misalignment and other major problems with the internal portion of the snap-fit connection after fabrication. For snap-fit connections exposed to high or sustained forces, the connection may also experience plastic creep. In addition, snap-fit connections subject to a high frequency of service are prone to fatigue and damage. FRP snap-fit connections may also be vulnerable to UV degradation, therefore protective coatings must be applied to all exposed portions of the connection. Snap-fit connections are also more expensive than typical mechanical connections, therefore high-volume production is needed in order to recoup the cost differential between traditional mechanical or chemically bonded connections and snap-fit connections.

Table 6 Minimum Requirements for Snap-Fit Applications (Bonenberger, 2005).

Suggested minimum requirement statements	Comments
The snap-fit interface should provide proper **constraint** between the mating parts in all degrees of motion (DOM).	Minimize the DOM removed by lock features. Maximize the DOM removed by locators. Lock features should only provide constraint in the separation direction.
Snap-fit interface features must be **compatible** with assembly motions and the part shapes.	Assembly (and separation) motions must not create un-intended deflections or high strains on the interface features.
The lock and locator features must provide **strength** against assembly damage and failure or unintended release under applied forces.	Verify with feature level analysis or end-use testing.
Assembly guides must be provided to direct locking features to the mating features during assembly.	For ease of assembly and prevention of feature damage, the first features to make contact should be guides. Use selected locators as guides when possible.
Clearance must be designed into all constraint pairs and all potential interference corners must have relief (radii or bevels).	For ease of assembly.
All features must be manufacturing **process-friendly**.	Follow common rules of good mold design.
The attachment must provide **feedback** to the assembly operator of proper engagement.	Feedback may be tactile (preferred), audible or visual.

Other things to watch for. These are desirable attributes for a snap-fit and should be included in proposals as appropriate.

All interface features must have a **radius** called out at all strain sites. No sharp internal corners are permitted.	Follow common injection molding guidelines for determining minimum allowable radii.
Where feasible, the tip, slide, twist and pivot **assembly motions** are preferred over a push motion.	The push motion is least preferred because it maximizes degrees of motion that must be removed by the lock features.
Cantilever hook style locking features should be used in **low-demand** applications only. Consider other lock styles for applications that are moderate or high demand.	The cantilever hook style has the lowest strength capability and robustness of the available beam-based locking features.
Cantilever hook style locking features should not be used in **short grip length** applications.	As a general rule of thumb, the minimum grip length for a cantilever hook lock must be greater than 5× the beam thickness. 7× to 10× is preferred.
Interface feature **mold tolerances** should be loose or normal. Fine and close tolerances should not be necessary.	Fine and close tolerances may indicate a lack of robustness in the design. Proper lock and locator selection and constraint management will enable loose or normal tolerances.

Table 7 Is a Snap-Fit Connection Appropriate? (Bonenberger, 2005).

Application	Response*		Why
Do you have design responsibility for both the mating part and base part?	Yes	No	It is much easier if you "own" both parts.
Does your organization have design responsibility for both parts?	Yes	No	Communication is important.
Are manufacturing volumes high?	Yes	No	Must recover higher initial costs.
Does a validation procedure exist for the application and will it test the snap-fit?	Yes	No	End-use testing is important.
Are performance requirements available for the application?	Yes	No	Snap-fit must meet them too.
Is the application spring-loaded? Can it fly apart during assembly or service?	Yes	No	May cause injury, a "booby-trap".
Is sealing required in the application? Will gaskets be used?	Yes	No	Sealing may require clamp load.
Is clamp load required in the application?	Yes	No	Plastic snap-fits can't give clamp load.
Will high or sustained forces be applied to the attachment?	Yes	No	Increases possibility of plastic creep.
Will the application experience shock or impact loading?	Yes	No	Careful analysis and strong locks needed.
Is the application subject to mass loading only?	Yes	No	Preferred to functional or structural loads.
Is the application subject to a high frequency of service?	Yes	No	Damage or fatigue of locks is possible.
If service is required, is disassembly obvious or is instructional information available?	Yes	No	Reduce chances of damage.
Is the application used in a high temperature environment?	Yes	No	Short-term plastic performance changes and long-term degradation.
Is the application used in an extreme low temperature environment?	Yes	No	Causes brittle behavior in plastics.
Do federal safety, health or other standards regulate the application?	Yes	No	If it is, thorough documentation required.

* The response indicated in dark font is generally more favorable to use of a snap-fit.

Table 8 Is a Snap-Fit Connection Appropriate? (Continued) (Bonenberger, 2005).

Components/Materials	Response*		Why
Is the mating part high mass?	Yes	No	Stronger locks required.
Is there adequate space on the parts for snap-fit features?	Yes	No	Space for lock deflection and protrusions.
Is one or both of the parts to be made of plastic?	Yes	No	Easier to do a snap-fit in plastic.
Is the mating part a: Trim, Bezel, Panel, Control module Cover, Switch, Access door	Yes	No	These applications are usually easy.
Is either of the parts expensive?	Yes	No	Consider a back-up attachment.
Do the joined materials differ significantly in rate of thermal expansion?	Yes	No	Care needed in developing constraint.
Are the parts made of "engineering" polymers?	Yes	No	More predictable and higher performance.
Is the application exposed to ultra-violet light?	Yes	No	Performance degradation is possible.
Is the plastic exposed to chemicals in the environment?	Yes	No	Performance degradation is possible.
Is high dimensional variation likely?	Yes	No	Care needed in developing constraint.
Are you a polymers expert or do you have access to an expert?	Yes	No	Materials data interpretation.

* The response indicated in dark font is generally more favorable to use of a snap-fit.

Table 9 Is a Snap-Fit Connection Appropriate? (Continued) (Bonenberger, 2005)

Information/Data	*Response**	*Why*
Will accurate load information be available for analysis?	Yes No	For critical applications, a necessity.
Is accurate material property data available for both of the parts to be joined?	Yes No	Needed for accurate analysis.
Will accurate dimensional data be available?	Yes No	For determining position and compliance.
Is part/base packaging known or predictable?	Yes No	Access for assembly motions & service.
Do you know the possibility of misuse or unexpected loads on the attachment?	Yes No	For complete analysis of reliability.
Organizational	*Response**	*Why*
Is the application a new design rather than a carry-over?	Yes No	Sometimes it is easier to start fresh.
Is there enough lead-time to accommodate possible longer design time?	Yes No	Generally a longer development time.
Does the organization understand the trade-off between a piece-cost penalty and assembly savings?	Yes No	Support for the effort.
Does the part supplier have experience with molding snap-fit applications?	Yes No	Better understanding of manufacturing requirements and issues.
Does the purchasing/bidding process allow the final supplier to be the prototype supplier?	Yes No	They will learn from prototype development.
Does the purchasing/bidding process allow the supplier to participate in design meetings?	Yes No	Can give advice during development.

* The response indicated in dark font is generally more favorable to use of a snap-fit.

5.2.2 Mechanical and Chemically Bonded Connections

Figures 7 and 8 present the various mechanical and chemically bonded connection configurations. Connections with metals are characterized by continuity, homogeneity, and isotropy, while FRP composite connections are heterogeneous, anisotropic, and brittle. Therefore, every discontinuity of the fibers in FRP composite elements (i.e., holes for bolts in pultruded elements) reduces the load-bearing capacity of the element (Potyrała, 2011). The intrusive nature of mechanical fasteners reduces the load-bearing capacity of connection itself. The advantages and disadvantages of mechanical and chemically bonded connections are listed in Table 10. The noted advantages of chemically bonded connections over mechanical connections are also summarized as follows:

1. Since the load is distributed over an area of adhesive bonding, this results in a more uniform distribution of stresses and higher resistance to flexural, fatigue, and vibrational stresses;
2. Glued joints between profiles are typically more rigid than traditional bolted joints;
3. They are more applicable to join irregular surfaces;
4. They are less expensive, lighter and faster to apply;
5. Some types of glue are extremely strong, making it possible to limit the extent of contact areas;
6. It is possible to accommodate differences in thermal expansion of the joined materials;
7. They provide integrity;
8. Chemically bonded joints perform well under dynamic loading.

The noted disadvantages of bonded joints are summarized as follows:

1. Chemically bonded connections are still in the research phase, therefore design of such connections is difficult;
2. Load-bearing capacity of a bonded joint is not proportional to the area which is glued. The load-bearing capacity of a specific joint only increases with the glued area to a certain point, after which it remains constant for the glued area. This condition is due to the fact that fracture is connected with certain tensions in the adhesive layer, typically in the transition from one profile to the other;
3. Failure in bonded joints takes place suddenly in contrast to bolted joints;
4. A number of adhesive agents have properties that depend on time and are influenced by environmental factors such as humidity and the chemical composition of the air, thus it is difficult to determine the durability of the connection;
5. Inspection is difficult after bonding is complete;
6. Connections are impossible to demount, which significantly limits the possible replacement parts.

Chemically bonded connections can fail in three different ways (modes): adhesive failure, cohesive failure, and a combination of both adhesive and cohesive failures. Mechanical connections can fail in four different ways (modes). As shown in Figure 9, moving from left to right, these mechanical modes of failure are: shear, tension,

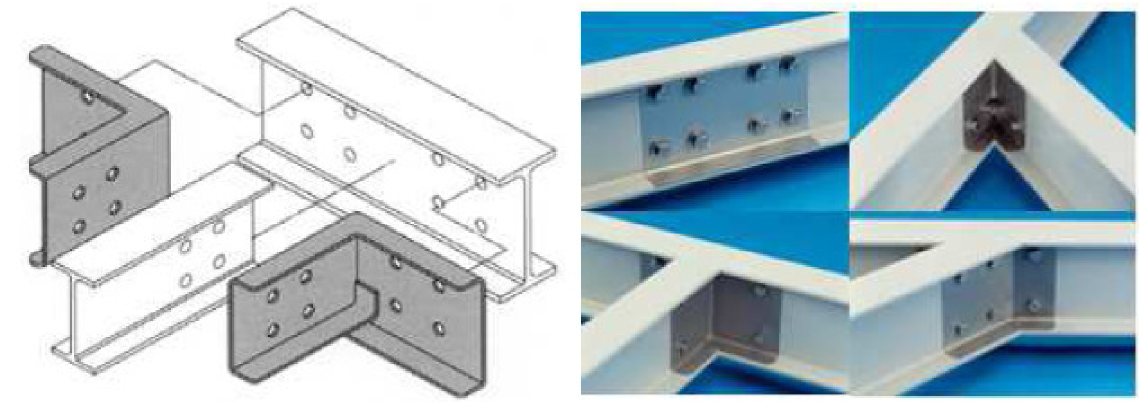

Figure 7 Mechanical Connections for Structural FRP Shapes (Potyrała, 2011).

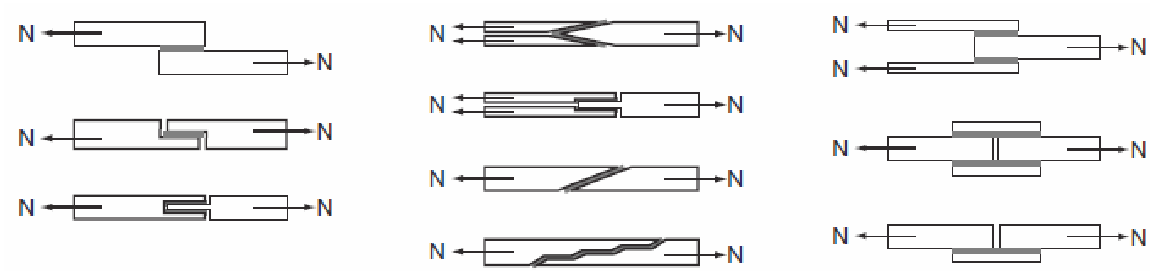

Figure 8 Various Bonded FRP Connection Configurations (Potyrała, 2011).

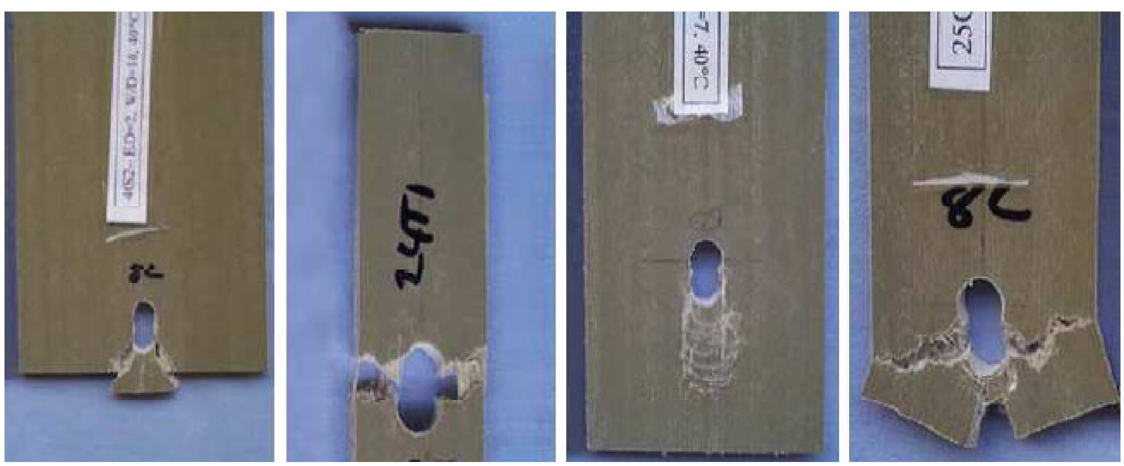

Figure 9 Typical Failure Modes of Mechanical Connections (Potyrała, 2011).

Table 10 Advantages and Disadvantages of Different FRP Connections (Potyrała, 2011).

Mechanical connections	
Advantages	**Disadvantages**
- requires no special surface preparation - can be disassembled - ease of inspection - quasi-ductile behaviour	- low strength to stress concentrations - special practices required in assembly - fluid and weather tightness normally requires special gaskets or sealants - corrosion of metallic fasteners
Bonded connections	
Advantages	**Disadvantages**
- high joint strength can be achieved - low part count - fluid and weather tightness - potential corrosion problems are minimized - smooth external surfaces - stiffness	- cannot be disassembled - requires special surface preparation - difficulty of inspection - temperature and high humidity can affect joint strength - brittle
Combined connections	
Advantages	**Disadvantages**
- bolts provide support and pressure during assembly and curing - growth of bondline defects is hindered by bolts	- structurally bolts act as backup elements – in an intact joint, bolts carry no load

compression, and splitting. The failure mode for a typical mechanical connection in an FRP structure is dependent on the location of the fastener hole relative to the edge of the member. The failure mode for a chemically bonded connection in an FRP structure is dependent on the effectiveness of the adhesive and manufacturing process for the fibers. Failure in a bonded joint occurs suddenly and without warning, therefore connections in load-bearing structures are typically accompanied by mechanical fasteners as opposed to adhesives (Potyrała, 2011).

There are numerous metrics that one can use to evaluate the feasibility of the type of connection to be used in an overhead sign structure. Some of these metrics are displayed in Table 11. In the area of construction speed, bonded connections require little to no expenditure of time for their construction in the field, whereas mechanical connections require extensive tooling and organization in the field that leads to extended construction times. One of the major downsides to bonded connections is their lack of warning or visibility when they are under distress. Mechanical connections, on the other hand, clearly display any signs of fatigue and abnormal stress. In the area of environmental resistance, bonded joints are much more resistant than their metallic counterparts.

As presented in Table 11, one possible connection configuration would be to strategically combine the two in order to utilize both of their advantageous aspects and minimize the overall disadvantages of such a system. For example, bonded connections are sensitive to peeling stresses, but when combined with metallic fasteners, the entire connection becomes resistant to peel loading. In addition, the tooling costs for bonded connections are high, but when combined with metallic fasteners, the entire connection's tooling costs are reduced.

Table 11 Characteristics of Different Connections (Potyrała, 2011).

	Mechanical	Bonded	Combined
Stress concentration at joint	high	medium	medium
Strength/weight ratio	low	medium	medium
Seal (water tightness)	no	yes	yes
Thermal insulation	no	yes	no
Electrical insulation	no	yes	no
Aesthetics (smooth joints)	bad	good	bad
Fatigue endurance	bad	good	good
Sensitive to peel loading	no	yes	no
Disassembly	possible	impossible	impossible
Inspection	easy	difficult	difficult
Heat or pressure required	no	yes/no	yes/no
Tooling costs	low	high	low
Time to develop full strength	immediate	long	long

6. CONCLUSIONS

In summary, based on the results of this literature review it appears that FRP composites have promising material characteristics, such as high specific strength and stiffness. FRP composites can be produced with substantially lower densities than traditional structural materials, and may result in faster and easier construction, and potentially reduce construction costs. In addition, FRP composites do not corrode, potentially extending service life with minimal maintenance (Potyrała, 2011).

Other researchers have documented that FRP composites tend to fail in a more brittle manner than traditional structural materials. Thus, proven design standards, specifically connection details, will be critical to implementation. Without such guidance, designers will be forced to over-design members and connections in order to offset uncertainty. This would ultimately result in less efficient and even more costly designs.

Due in part to this lack of familiarity with FRP design and construction methods, the initial cost for implementation is expected to be on the order of three (3) times that of traditional materials. However, as the industry adapts better to their use in structural applications, this cost differential is expected to decrease over time.

7. RECOMMENDATIONS

Based on the findings of this Phase I literature review, it is recommended that FDOT engage in a pilot project to test and evaluate the merits of using FRP composites for sign truss structures in Florida. It is proposed that different commercially available structural elements and connection details be evaluated as part of this study.

Four guide specification documents are recommended in support of this proposed pilot study. These include:

1. NCHRP Report 494, "*Structural Supports for Highway Signs, Luminaires, and Traffic Signals*," (NCHRP, 2003);
2. "*FDOT Modifications to Standard Specifications for Structural Supports for Highway Signs, Luminaires, and Traffic Signals*," (FDOT, 2012);
3. "*A Model Specification for FRP Composites for Civil Engineering Structures*." (Bank et al., 2003); and
4. The "*First Snap-Fit Handbook, 2nd Ed.*" (Bonenberger, 2005).

Again, for budgeting purposes, it is estimated that FRP composite truss structures could be furnished and installed in Florida at an initial cost of about three (3) times that of the currently used galvanized steel, or for less than $100,000 for small cantilever structures and up to $500,000 for large, full-span truss structures.

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APPENDIX A

TYPICAL FRP STRUCTURAL SHAPE AND SIZE AVAILABILITY CHARTS

PULTRUDED STRUCTURAL FIBERGLASS SHAPE AVAILABILITY

SIZE (mm)	ST	FR	VE	WT. kg/m
ANGLE				
25.4 X 3.2	•	•	•	0.28
38.1 X 4.8	•	•		0.66
38.1 X 6.4	•	•	•	0.80
50.8 X 6.4	•	•	•	1.10
76.2 X 6.4	•	•	•	1.67
76.2 X 9.5	•	•	•	2.44
76.2 X 12.7				3.11
101.6 X 6.4	•	•	•	2.25
101.6 X 9.5	•	•	•	3.29
101.6 X 12.7	•	•	•	4.35
152.4 X 101.6 X 12.7	•	•		5.44
152.4 X 9.5	•	•	•	4.98
152.4 X12.7	•	•	•	6.60
ROD				
3.2 White	•			0.02
4.8 White	•			0.03
6.4 White	•			0.06
8 White	•			0.10
9.5 White/Gray	•		•	0.15
12.7 White/Gray	•		•	0.24
15.9 White/Gray	•		•	0.39
19.1 White/Gray	•		•	0.57
25.4 White/Gray	•		•	1.00
31.8 White	•			1.48
38.1 White/Gray	•	•		2.25
SPECIAL SHAPES				
146.5 X 66.7 X 4.8 White	•			2.43
139.7 X 6.4				1.59
152.4 X 76.2 X 3.2 X 4.8 Gray	•			2.00
203.2 X 76.2 X 3.2 X 4.8 Gray	•			2.20
25.4 X 38.1 X 6.4 Gray			•	1.42
38.1 X 38.1 X 6.4 Gray			•	1.58
50.8 X 38.1 X 6.4 Gray			•	1.70
WIDE FLANGE BEAM				
76.2 X 76.2 X 6.4	•	•	•	2.55
101.6 X 101.6 X 6.4	•	•	•	3.52
152.4 X 152.4 X 6.4	•	•	•	5.18
152.4 X 152.4 X 9.5	•	•	•	7.75
203.2 X 203.2 X 9.5		•	•	10.10
203.2X203.2X12.7 (6.1m& 7.6m)		•	•	13.08
254 X 254 X 9.5				12.77
254X254X12.7 (6.1m & 7.6m)		•	•	16.41
304.8X304.8X12.7 (6.1m &7.6m)		•	•	20.39
SQUARE TUBE				
25.4 X 3.2	•	•	•	0.51
31.8 X 6.4				1.10
38.1 X 3.2	•	•	•	0.82
38.1 X 6.4 STD- White	•		•	1.46
44.5 X 3.2				0.91
44.5 X 6.4		•		1.88
50.8 X 3.2	•	•	•	1.04
50.8 X 6.4	•	•	•	2.06
57.2 X 3.2				1.30
57.2 X 6.4				2.49
63.5 X 6.4	•	•		2.64
76.2 X 3.2				1.62
76.2 X 6.4	•	•	•	3.17
76.2 X 9.5				4.50
88.9 X 6.4	•	•		3.86
101.6 X 6.4	•	•	•	4.42
101.6 X 9.5	•	•		6.38
152.4 X 9.5	•	•		9.65
ROUND TUBE				
25.4 X 3.2	•	•		0.42
31.8 X 6.4				0.89
38.1 X 3.2	•	•		0.58
38.1 X 6.4		•		1.24
44.5 X 3.2				0.80
44.5 X 6.4				1.39
50.8 X 6.4	•	•	•	1.58
76.2 X 2.5				1.04
76.2 X 6.4				2.56
76.2 X 12.7	•			4.57
124.2 X 3.2				2.70
124.2 X 4.8				4.42
SQUARE BAR				
25.4 X 25.4 White	•			1.21
31.8 X 31.8 Yellow	•			1.74
38.1 X 38.1 Yellow	•			2.83
FLAT SHEET				
3.2 X 1219.2 X 2438.4	•	•	•	1.94
3.2 X 1219.2 X 3657.6	•			1.94
4.8 X 1219.2 X 2438.4	•	•	•	2.73
4.8 X 1219.2 X 3657.6	•			2.73
6.4 X 1219.2 X 2438.4	•	•	•	3.61
6.4 X 1219.2 X 3657.6	•			3.61
9.5 X 1219.2 X 2438.4	•	•	•	5.11
12.7 X 1219.2 X 2438.4	•	•	•	7.22
15.9 X 1219.2 X 2438.4				8.73
19.1 X 1219.2 X 2438.4				10.16
25.4 X 1219.2 X 2438.4		•		13.03

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Figure A-1 Bedford Reinforced Plastics Structural Shape and Size Availability Chart.

Special Pultruded Shapes

(Not EXTREN® Composite Design)

	PE	PE/FR	VE/FR
Channel			
3-1/2 x 2 x 7/32	N	N	N
1.875 x .125 x 1.125 x .188"	N		
3.29 x .128 x 1.180 x .190"	N		
3.31 x .135 x 1.187 x .210"	N		
4.0 x .125 x 1.750 x .187"	N		
Corner Post			
3-1/4 x 1/4	N	N	N
Curb Angle***			
1 x 1-1/2 *(Black Gray)*	S	S	S
1-1/2 x 1-1/2 *(Black Gray)*	S	S	S
2 x 1-1/2 *(Black Gray)*	S	S	S
4 x 2-1/4 x 1/4 *(Black Slate Gray)*	S	S	S
F-Section			
5-1/2 x 1 x 1/4	N	N	N
6 x 1-1/2 x 1/4	N	N	N
Flat Strips			
2 x 3/16	N	S	S
2 x 1/4	N	N	N
3 x 3/16	N	N	N
3 x 1/4	N	S	N
3 x 3/8	N	N	N
3 x 1/2	N	S	N
4 x 1/2	N	N	N
6 x 1/4	N	N	N
Flight Channel			
5-1/4 x 1/8 x 2-1/2 x 3/16	N		
7-1/8 x 1/8 x 2-1/2 x 3/16	N		

* *Standard color - orange*

	PE	PE/FR	VE/FR
Fluted Tube			
1-1/4			S
Rectangular Tubes			
13 x 8-1/2 x 3/8	N	N	N
15 x 6 x 3/8	N	N	N
16 x 8-1/2 x 3/8	N	N	N
18 x 6 x 3/8	N	N	N
20-5/8 x 6 x 1/4	N	N	N
22-5/8 x 6 x 3/8	N	N	N
Slide Guide			
2-1/2 x 2-1/4 x 1/4 *(Black White)*	N		
Square Tube w/Rd. Hole			
1" sq. with 3/4" rd. hole	N	N	N
Stair Riser			
8 x 1-1/2 x 18	N	N	N
Strut			
1-5/8 x 1-5/8 x 5/32 *(Black Gray)*	N	N	N
Top Rail			
2 x 1/4 modified rd. tube	N	N	N
Unequal Leg Angles			
1-3/4 x 1-1/4 x 1/4	N	N	N
Z-Section			
1-1/4 x 2-1/2 x 1/8	N	N	N

Custom Pultrusions

Strongwell produces custom pultrusions in many shapes and materials for hundreds of customers. The special pultruded shapes listed on this page are only a partial listing of dies owned by Strongwell.

NOTES: Unless otherwise noted, all dimensions are in inches.

All EXTREN® Series 500 products can be produced to meet NSF potable water standards in minimum mill run quantities. Only products bearing the NSF logo are certified.

STRONGWELL

ISO-9001:2008 Quality Certified and ISO-14001:2004 Environmentally Certified Manufacturing Plants

BRISTOL DIVISION*
400 Commonwealth Ave., P. O. Box 580, Bristol, VA 24203-0580 USA
(276) 645-8000 Fax (276) 645-8132
* *EXTREN® manufacturing location*

CHATFIELD DIVISION
1610 Highway 52 South, Chatfield, MN 55923-9799 USA
(507) 867-3479 Fax (507) 867-4031

www.strongwell.com

STC112

Figure A-2 Strongwell Structural Shape and Size Availability Chart.

Pultex® Fiberglass Standard Structural Profiles and Superstud!™/Nuts!

Product Availability List

All items are available upon request in standard resin series:

Series 1500 = Isophthalic Polyester (I) - Olive Green
Series 1525 = Isophthalic Fire Retardant (IFR) - Slate Grey (Dark Grey)
Series 1625 = Vinyl Ester Fire Retardant (VFR) - Beige
x = Stocked Items (All items stocked in 20' lengths unless otherwise noted.) ♦ = SuperStructural Items

Delivery:

Stocked Items: 1-3 days
Items Out of Stock: 2 weeks
Non-Stocked Items: 2-4 weeks

Equal Leg Angle

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
1 x 1/8	x	x		3,000	0.17
1 x 1/4				2,500	0.31
1-1/2 x 1/8				2,700	0.25
1-1/2 x 3/16				2,200	0.38
1-1/2 x 1/4	x	x	x	2,000	0.51
2 x 1/8				2,500	0.35
2 x 3/16				2,000	0.56
2 x 1/4	x	x	x	1,800	0.68
3 x 1/8		x		2,000	0.53
3 x 3/16				1,500	0.78
3 x 1/4	x	x	x	1,500	1.08
3 x 3/8	x*	x	x	1,200	1.74
4 x 1/4♦		x	x	1,300	1.59
4 x 3/8♦		x	x	900	2.28
4 x 1/2♦	x	x		1,300	3.01
6 x 1/4♦				900	2.29
6 x 3/8♦		x		800	3.57
6 x 1/2♦		x	x	700	4.68

*Stocked in NSF Olive Green Only.

Unequal Leg Angle

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
1 x 1-1/2 x 1/8				2,500	0.21
1 x 2 x 1/8				2,500	0.27
1 x 2 x 3/16				2,000	0.46
1 x 2 x 1/4				2,000	0.50
1 x 3 x 1/8				2,000	0.35
1-1/4 x 3/4 x 1/8				3,000	0.16
1-1/4 x 2 x 1/4				1,500	0.55
1-1/2 x 2 x 1/8				2,500	0.37
1-1/2 x 2 x 1/4				1,500	0.55
1-1/2 x 3 x 1/8				2,000	0.39
1-1/2 x 3 x 3/16				1,500	0.57
1-1/2 x 3 x 1/4				1,500	0.79
1-5/8 x 2-5/8 x 1/8				2,500	0.38
2 x 3 x 3/16				1,000	0.66
2 x 3 x 1/4				1,500	0.91
2 x 3 x 3/8				1,500	1.28
2 x 4 x 1/4				1,500	1.07
2 x 4 x 3/8				1,000	1.99
3 x 4 x 1/4				1,200	1.25
3 x 4 x 3/8				1,000	1.85
3-1/2 x 5 x 1/2				1,000	2.98
3-1/2 x 11 x 1/8				1,000	1.14
4 x 6 x 1/4				1,000	1.62
4 x 6 x 3/8				700	2.93
4 x 6 x 1/2				700	3.79

Channel

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
1-1/2 x 1 x 3/16				2,200	0.48
2 x 9/16 x 1/8		x		2,800	0.27
2-3/4 x 1 x 1/8				5,000	0.42
3 x 7/8 x 1/4	x***	x		1,700	0.78
3 x 1 x 3/16				1,800	0.63
3 x 1-1/2 x 1/4			x	1,300	0.98
4 x 1-1/16 x 1/8				1,900	0.54
4 x 1-1/8 x 1-3/4 x 3/16		x		1,500	0.87
4 x 1-1/8 x 1/4		x	x	1,200	1.02
5 x 1-3/8 x 1/4				1,300	1.37
6 x 1-5/8 x 1/4	x	x	x	1,200	1.67
6 x 1-11/16 x 3/8	x**	x	x	1,000	2.51
7 x 2 x 1/4				1,200	2.08
8 x 2-3/16 x 1/4		x#**	x#**	1,000	2.22
8 x 2-3/16 x 3/8	x***	x	x	800	3.28
10 x 2-3/4 x 1/8				1,500	1.44
10 x 2-3/4 x 1/2		x		600	5.77
11-1/2 x 2-3/4 x 1/2♦				600	6.46
24 x 3 x 1/4				500	10.44
14" x 6" x 1/2" ♦				600	5.61
24 x 4 x 1/2				500	11.21

*Stocked in 20'1", 30'1" and 40'1" lengths only.
**Stocked in 20'1", 25'1" and 30'1" lengths only.
***Stocked in 20'1" lengths only.
#**Stocked in 1525 Light Grey and 1625 Beige Only: 25' lengths. Call for availability.
♦Also available in SUPURTUF™ Polyurethane Resin. Consult factory.

I-Beam

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
3 x 1-1/2 x 1/4♦				1,400	1.01
4 x 2 x 1/4♦		x		1,300	1.63
6 x 3 x 1/4♦	x	x		800	2.39
6 x 3 x 3/8♦		x		800	3.78
8 x 4 x 3/8♦		x	x	600	4.74
8 x 4 x 1/2♦		x		700	6.45
10 x 5 x 3/8♦				700	6.06
10 x 5 x 1/2♦		x*		600	7.93
12 x 6 x 1/2♦				400	9.63

*Stocked in 25' lengths only.

Wide Flange Beam

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
3 x 1/4♦	x	x		1,000	1.84
4 x 1/4♦	x	x*	x	800	2.44
6 x 1/4♦		x*		700	3.64
6 x 3/8♦		x	x	600	5.53
8 x 3/8♦		x		400	7.28
8 x 1/2♦		x*		400	9.99
10 x 3/8♦				400	9.07
10 x 1/2♦		x*		400	12.03
12 x 1/2♦		x**		300	14.92

*Stocked in 20' and 25' lengths only.
**Stocked in 25' lengths only.

Round Tube

Size (inches)	I	IFR	VFR	Min. Mill Run	Wt. Ft.
3/4 x 3/32				2,000	0.17
1 x 1/8	x	x		2,000	0.28
1-1/4 x 3/32				1,900	0.27
1-1/4 x 1/8				1,900	0.34
1-1/2 x 1/8	x	x		1,900	0.42
1-1/2 x 1/4	x			1,500	0.77
1-3/4 x 1/8				1,800	0.50
1-3/4 x 1/4			x	1,500	0.91
2 x 1/8				1,500	0.64
2 x 1/4		x**		1,400	1.08
2-1/2 x 1/8				1,500	0.82
2-1/2 x 1/4				1,000	1.32
3 x 1/4				800	1.68

*Stocked in Dark Grey and Yellow Only.

CREATIVE PULTRUSIONS, INC.
214 Industrial Lane ■ Alum Bank, PA 15521
Phone: 814-839-4186 ■ Toll Free: (888) CPI-PULL
www.creativepultrusions.com ■ E-mail: cpul@pultrude.com

Product Availability List
Imperial Version

CPSALI-0111.1C
DLR: 03/21/11

Figure A-3 Creative Pultrusions, Inc. Structural Shape and Size Availability Chart.

APPENDIX B

2011 FDOT OVERHEAD SIGN STRUCTURE COST DATA (FDOT, 2011)

The average furnish and install construction costs for galvanized steel FDOT sign truss structures in 2011 ranged from about $30,000. for cantilever structures less than 30 feet in length (FDOT Index Number 11310) to about $150,000. for full-span truss structures up to 150 feet in length (FDOT Index Number 11320). The cited data is summarized on the following pages in Tables B-1 and B-2, and Figures B-1 and B-2.

Table B-1 Cantilever Sign Structure, FDOT INDEX NO: 11310.

FDOT Pay Item Number	Description	Average Cost (2011)
0700 23112	(Furnish & Install) Truss & Sign Truss Span Length: 30 ft or Less Sign Panel Size: 101 ft^2 to 200 ft^2	$38,401.22
0700 23113	(Furnish & Install) Truss & Sign Truss Span Length: 30 ft or Less Sign Panel Size: 201 ft^2 to 300 ft^2	$46,237.00
0700 23114	(Furnish & Install) Truss & Sign Truss Span Length: 31 ft – 40 ft Sign Panel Size: Greater than 300 ft^2	$59,000.00

Figure B-1 Typical FDOT Cantilever Sign Structure, FDOT INDEX NO: 11310.

Table B-2 Span Truss Sign Structure, FDOT INDEX NO: 11320.

FDOT Pay Item Number	Description	Average Cost (2011)
0700 22123	(Furnish & Install) Span Truss & Sign Truss Span Length: 51 ft to 100 ft Sign Panel Size: 501 ft^2 to 700 ft^2	$87,650.00
0700 22124	(Furnish & Install) Span Truss Span Length: 51 ft to 100 ft Sign Panel Size: Greater than 700 ft^2	$126,907.00
0700 22132	(Furnish & Install) Span Truss Span Length: 101 ft to 150 ft Sign Panel Size: 301 ft^2 to 500 ft^2	$122,008.22
0700 22134	(Furnish & Install) Span Truss Span Length: 101 ft to 150 ft Sign Panel Size: Greater than 700 ft^2	$133,271.67

Figure B-2 Typical FDOT Span Sign Structure, FDOT INDEX NO: 11320.

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