Chapter 2
Reasons to Consider FRP Composites

2-1. General

There are many different reasons to consider using FRP composites in civil engineering applications. The most relevant of these reasons as applied to engineering are discussed below. The main criteria for engineers to use any material to satisfy the requirements of a job are durability, corrosion resistance, cost, weight, material properties, and ease of construction. FRP composites are attractive alternatives to conventional construction materials for these and several other compelling reasons, as follows.

2-2. Structural Considerations

The items presented in this section are a brief presentation of structural considerations. Many of the items are discussed in more detail in the latter sections of Appendix B.

a. Tensile strength. FRP composites provide a number of structural properties that make them an attractive alternative to many conventional engineering materials. Their tensile strength can range from about the strength of mild reinforcing steel to stronger than that of prestressing steels. As such, they offer good incentive for use in situations where high tensile strength is an asset. FRP composites generally exhibit linear tensile stress-strain behavior throughout their load-carrying range and as such do not change their modulus over their loading history. Since FRP composites are materials composed of structural fibers in a plastic matrix, the fibers can be custom-oriented to suit individual needs. A number of good examples of this unique capability are provided in Chapter 5.

b. Fatigue. Research to date indicates that FRP composites exhibit good fatigue resistance in tension-tension cycling (American Concrete Institute, State-of-the-Art Report on Fiber Reinforced Plastic (FRP) for Concrete Structures). Research has yet to document the effects of temperature, moisture, reverse loading, long-term and compression load cycling, and holes on fatigue resistance. Long-fiber composites generally retain a high proportion of their short-term strength after 10^7 cycles. Carbon-fiber composites exhibit the highest fatigue resistance, followed by aramid and then glass (Neale and Labossiere 1991).

c. Low mass. Excessive structural mass is often a reason to consider alternate materials which will provide high load-carrying capacity as well as low density. FRP composites have densities in the range of 1,200 to 2,600 kg/m^3 (75 to 162 lb/ft^3) which make them attractive alternatives to structural materials such as steel with a density around 7,850 kg/m^3 (490 lb/ft^3).

d. Specific strength. The specific strength of materials, defined as the yield strength divided by the density, is often used to make comparisons between materials on the basis of strength and mass. FRP composites, because of their high strength and their very low density, have specific strengths which are up to 60 times that of high strength steels. The high specific strengths associated with FRP composites are very useful in applications such as structural cladding panels, low-density framing materials, and vehicle components. Their low weight makes the assembly and disassembly of temporary structures much easier and less time-consuming than similar structures made of wood or steel. Cost of many of the FRP composites, although higher than conventional construction materials on a pound-per-pound basis, are competitive when the specific strength of the materials is taken into consideration. Final construction costs can even be lower than conventional materials if such factors as more efficient design, transportation costs, and lifting equipment costs are taken into account.

e. Vibration damping. The specific modulus of FRP composites, defined as the modulus of elasticity divided by the density, is also high and provides characteristics such as low vibration in situations where vibration may be a problem (Grace, Bagchi, and Kennedy 1991). Steel has a high density, high modulus, and low damping characteristics whereas composites have low densities, moderate moduli, and high damping characteristics. Use of composites in floors and bearing pads where damping of vibration is of concern can reduce these problems.

f. Repair using composites. Structural repairs of conventional materials using FRP composites can be advantageous from the standpoint of ease of installation and reduced maintenance costs. Conventional techniques for externally strengthening cracked concrete structures call for steel plates or bars to be installed across the crack to carry the structural loads no longer carried by the concrete. FRP plates can be structurally bonded across such cracks to replace the steel repair components. The low mass of these materials makes their handling more convenient, and their noncorrosive nature eliminates the need to protect them from rusting deterioration. Some of these techniques have been used in the European engineering community for over 20 years. Some repair applications using FRP composites are presented in Appendix B.

g. Corrosion resistance.

(1) One of the most convincing reasons to consider the use of FRP composites is their resistance to corrosive elements. The plastic resins that form the matrix of most composites are resistant to deterioration from many chemicals as well as the effects of acidic, salt, and fresh waters. Acidic, salt, and fresh waters are corrosive to ferrous metals. In Corps of Engineers structures, high-maintenance corrosion-susceptible components would be appropriate candidates for the use of FRP composites. The benefits of composites over steel in terms of resistance to corrosion are greatest in the areas of maintenance and life-cycle costs. Components in marine construction such as piling, docks, and submerged construction would be applicable uses. Currently, the Corps, in cooperation with the Navy, is demonstrating the use of these materials by constructing a portion of a pier at Port Hueneme, California. This demonstration pier is constructed of concrete piles prestressed with carbon-fiber-reinforced-plastic (CFRP) tendons, vinyl ester/glass tendons for pile caps, and CFRP tendons in the deck section. The facility has an all-composite deck section as well. Details of this demonstration project are given in Appendix B.

(2) Storage structures for corrosive liquids are suited to FRP composite materials. Fiberglass tanks have been used for storage of chemicals for many years. One documentable example is a fuel storage tank, built in the late 1960's, using E-glass fiber in a vinyl ester matrix. The fibers were wound over a steel skeleton, resin was applied and allowed to cure, and the process repeated a second time. The tank has been in service for over 20 years and has developed no leaks in that time. Building components that are exposed to industrial chemicals either in the air, immersed, or through spray contact will not deteriorate as would steel, concrete, or wood components. Applications where FRP composites would be appropriate would include storage tanks, cover plates, walkways, pipes and culverts, and any other metallic component exposed to corrosive chemicals.

2-3. Production Options

a. Fabrication. The variety of fabrication techniques that are available with FRP's provide for many custom properties. Multiple types of fibers can be combined to produce materials with the advantages of each component; fibers can be oriented in specified directions to better suit specialized loading conditions; and material properties such as strength and stiffness can be controlled to meet the user need. Special molding techniques allow complicated pieces to be fabricated as one unit, eliminating joint conditions which can be a source of weakness. One method of producing FRP composites is by a technique known as pultrusion, a process much like extrusion. In the pultrusion process, the FRP materials are pulled through dies while the matrix is being cured and is in a moldable condition. These dies can be in the form of an I-beam, a channel section, or any custom cross section. Examples of some of the cross sections currently produced are shown in Figure 2-1. Other processes that are commonly used include filament winding, autoclave molding, and scrimp and are described in more detail in section 4-4. Another good example of the custom fabrication capabilities of these materials is demonstrated in custom fabricated sandwich panels. In these panels, load-bearing, FRP, honeycomb core structures are sandwiched between FRP skin plates producing a very strong, lightweight structural component.

b. Custom geometry. The length and geometry of a given pultruded cross section can be custom designed as well. The pultrusion process lends itself to custom fabrications. The length of the fabricated shape does not have to be a predetermined length. The designer can work with the fabricator to produce products in lengths and shapes needed for specific applications.

c. Color and coating. Since the matrix of FRP composites consists of resins that begin in the liquid state, many architectural treatments can be added before they harden. For example, custom coloring can be added to the resins in the manufacturing process, thereby eliminating the need for and cost of painting or other color application after the fact. Since the color is integrally mixed in the matrix, it cannot be scraped off or abraded during its lifetime. It is also possible to embed sand or other nonslip surface treatments as a secondary operation, and the treatment will become part of the component. Nonslip gratings and walkways are an example of this type of application.

2-4. Economic Considerations

a. Life-cycle costs. While the initial cost of composite materials is usually higher than alternative construction materials, there are a number of economic considerations which make their use feasible and economic. Corrosion protection was mentioned as an area where composites are beneficial to the cost of maintenance. Many life-cycle costs could be eliminated or drastically reduced with the use of FRP composites. The costs associated with periodically repainting steel to protect it against corrosion are maintenance costs that would

Figure 2-1. Cross sections of pultruded FRP components

be eliminated if materials that did not require such coatings were used. The costs of rehabilitating structures damaged by corrosion, such as blast cleaning of steel to remove corrosion products, would be eliminated with noncorrosive composite materials. In general, periodic maintenance of structures would be reduced and replacement costs would be delayed through greater use of FRP composites. Some FRPs could require coating protection for aesthetic reasons or for exceptionally harsh environments.

b. Construction and transportation costs. Construction and transportation costs can be reduced with use of the low density composites. Since many charges for freight are based on weight, the low densities of FRP composite components reduce shipping costs and require less need for heavy construction handling equipment at sites. Fabrication costs will be reduced in two areas. Through increased ease of handling of components, smaller crews can be utilized to handle components assembled in the field. Further, preassembly of some components can reduce field assembly costs. In addition to reduced costs, faster construction times can be realized through the improved handling capabilities.

2-5. Environmental Considerations

a. Reduced environmental toxicity. Many of the building materials that we presently use are harmful to our environment in some way or another. Examples of such materials are lead-based paints, creosote and other petroleum products used in piling to kill or ward off marine borers and shipworms. The components of FRP materials are, for the most part, inert and will not leach into the environment. The use of conventional maintenance coatings on structures can be toxic to the environment. The use of FRP's eliminates some of these hazardous chemicals. Piling made from FRP materials do not rot nor are they attacked by marine organisms so there is no need to treat pilings with harmful chemicals such as creosote.

b. Recycling. Many of the plastic materials that we use as food containers and composite components of automobiles can be recycled when no longer needed. These recycled plastics and glass fibers can be reused to make FRP composite components, thereby reducing the volume of waste we put in our landfills. Marine piles are currently being produced from recycled materials (Taylor 1994). High density polyethylene plastics that are recycled from milk jugs, juice containers, and detergent bottles are being combined with fiberglass pultruded reinforcing elements to produce these piles. As many as 15,000 containers can be recycled into one 18-m (59-ft) pile. FRP composites themselves can be recycled when their useful life is through. These components can be reprocessed to recover most of their original materials and the materials reused.

2-6. Material Property Considerations

a. Magnetic properties. FRP composites possess some properties that are not available from more conventional materials. Because their components are plastic resins coupled with glass, carbon, and aramid fibers, they are immune to magnetic forces. FRP materials are used in several of the designs for vehicles and guideways of magnetically levitated transportation systems to eliminate any adverse forces that would be induced through proximity to the magnets used for levitation and locomotion. Components of vehicles where magnetic compasses are employed often use composites in the vicinity of the compasses to eliminate any magnetic influence in the guidance systems. Special facilities that employ electromagnetic technology often are built entirely using composites. A dramatic architectural use of FRP composites is seen in the structure used to hide radio antennae on top of the Sun Bank Building in Orlando, Florida (Figure 2-2). Glass fiber structural shapes and cladding panels were used to construct four, three-story-high housings to contain the antennae. The structures were designed to resist hurricane force winds.

b. Conductivity. Electrical conductivity is a hazard in many construction environments. High voltages, passing through metallic construction materials acting as conductors, can cause injury or even death. Most FRP composites (including glass and aramid fiber composites) are electrically nonconductive. This makes them good candidates for construction materials where the threat of electrocution is a consideration. For many years stepladders have been made from fiberglass composites for their non-conducting properties. Electric cable trays, walkways in the vicinity of exposed electric conductors (such as at power plants), and booms of bucket trucks are all examples of FRP composites used to eliminate electrocution hazards and other electrical problems.

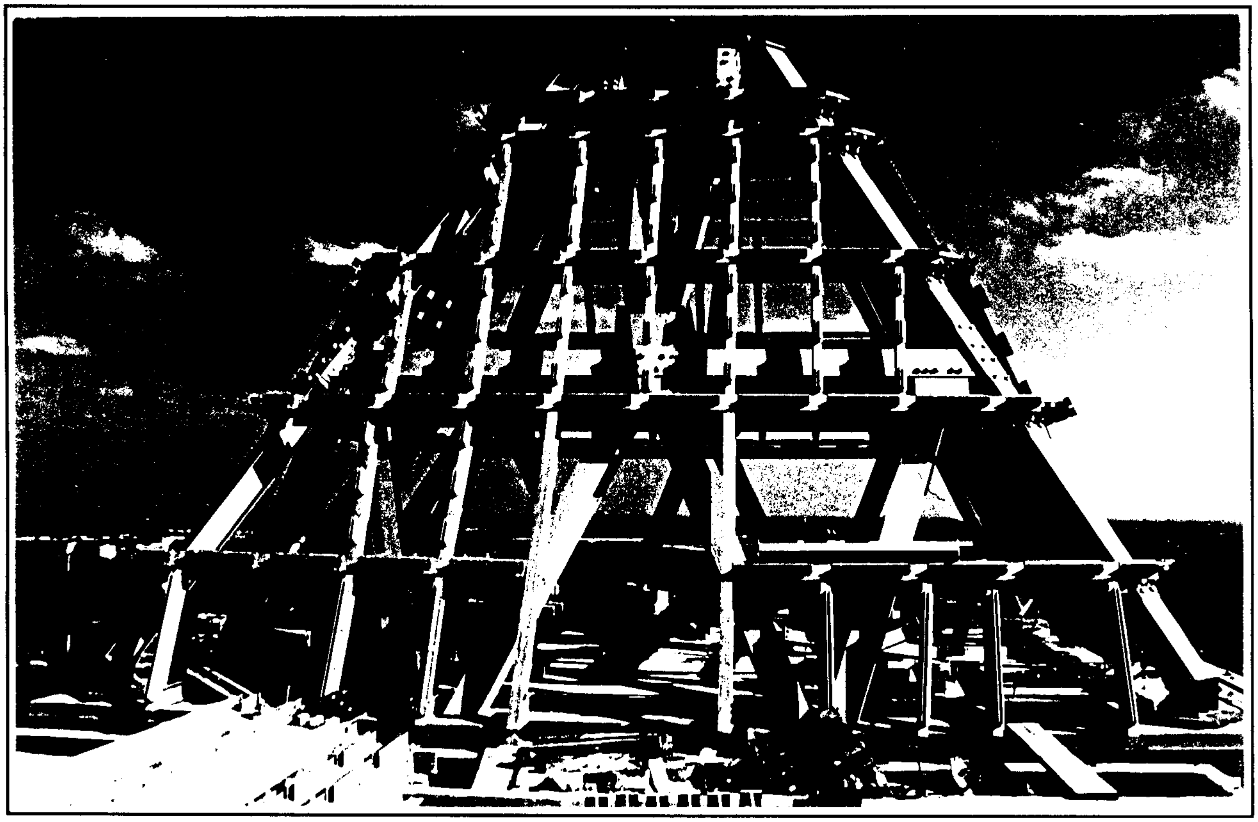

Figure 2-2. FRP materials used as electromagnetically transparent housings