

Introduction



Figure 1—A fiber-reinforced polymer trail bridge in the Santa Fe National Forest.

Trail bridges (figure 1) not only provide convenient access to the national forests for hikers or packstock, they can protect fragile riparian ecosystems. Trail bridges can be difficult—in some cases, dangerous—to build. The bridges may be miles from a trailhead. Hauling the bridge materials on packstock through steep, rugged country and relying only on human power for assembly and installation makes the work challenging. Helicopters can't be used in wilderness areas without permission of the forest supervisor, and they may be too expensive for some projects even where they can be used.

Historically, trail bridges were built from native logs cut on the site. Most areas do not have logs that are strong enough to span longer crossings. In addition, trail bridges made from native logs may have a life expectancy of no more than 5 to 15 years. At some sites, repeated replacement of bridges made from native logs has left small clear cuts around the bridge site. Increasing recreational

Highlights...

- Fiber-reinforced polymer trail bridges are lighter and easier to assemble than traditional bridges built from wood or steel.
- At some remote sites, the advantages of light weight and ease of assembly may make fiber-reinforced polymer trail bridges a better alternative than wood or steel bridges.
- Wood for bridges made from native materials may be in short supply at some remote sites.
- Fiber-reinforced polymer materials are easy to damage when they are being transported to the bridge site and when they are being assembled.
- This report includes the results of controlled tests and case studies of field installations of fiber-reinforced polymer bridges.

Introduction

use and tightened budgets also contribute to the need for lightweight, low-maintenance bridges that are easy to construct.

Fiber-reinforced polymer (FRP) bridges, commonly called *fiberglass bridges*, offer a potential solution. FRP trail bridge members are fabricated from reinforcing resins (commonly referred to as polymers or plastics) and strands of materials (usually fiberglass) with tensile and bending strengths comparable to those of steel or concrete.

FRP materials are lightweight and durable. Common shapes match those of the rolled steel materials used for trail bridge components, such as tubes, channels, W shapes, and angles. The lightweight FRP structural members are easier to transport to remote locations than common bridge materials, such as steel or timber. In addition, their light weight makes them simpler and safer to assemble.

During the 1990s, several national forests and national parks installed FRP trail bridges, but very little was known about their design or long-term durability. An evaluation was needed to verify that FRP trail bridges were acceptable, safe, and economical.

In 1997, the Fiber-Reinforced Polymer Trail Bridge Project at the Missoula Technology and Development Center (MTDC) began evaluating the feasibility of FRP materials for trail bridges used by the U.S. Department of Agriculture (USDA) Forest Service and the U.S. Department of the Interior National Park Service. One of the project's first accomplishments was to arrange a partner-

ship with the U.S. Department of Transportation's Federal Highway Administration (FHWA), Eastern Federal Lands Highway Division, Bridge Design Group to jointly design, fund, test, and install prototype trail bridges.

A 44-foot bridge was funded and designed by the FHWA. A 22-foot bridge was purchased by the Forest Service as an "off-the-shelf" bridge designed by E.T. Techtonics, Inc., a major supplier of FRP trail bridges.

A second partnership with FHWA's Recreational Trails Program helped to fund this project and disseminate the results.

The plan for these prototype bridges was to:

- 1—Have an experienced bridge-design group review the available design information and develop a design and drawings.
- 2—Install the bridges at a test facility and monitor bridge behavior under design loading and severe environmental conditions.
- 3—Install the bridges at field locations to determine installation strategies and techniques.
- 4—Monitor the field installations to determine unique maintenance requirements.
- 5—Publish a guide explaining FRP technology and presenting design methodologies, performance-based specifications for purchasing materials, and recommendations for installation and maintenance.

Background on FRP Trail Bridges

The first FRP pedestrian bridge was constructed in Israel in 1975. Since then, FRP pedestrian bridges have been constructed in Asia, Europe, and North America. A list of FRP pedestrian bridges constructed in the United States is included in appendix E. Composites may form all or part of a bridge, such as the deck or tower columns of a bridge that uses other standard materials, such as timber or steel. FRP technology is being used in both trail and road bridges. FRP bridge superstructures typically are made with vinyl ester or polyester resin reinforced with E-glass fiber. They are engineered and prefabricated before being assembled and installed at a bridge site.

Composites at a Glance

The most common and readily available FRP material is referred to simply as fiberglass. Fiberglass is a composite with a polymer resin matrix that surrounds, coats, and is reinforced by glass fibers (figure 2). Although resin alone

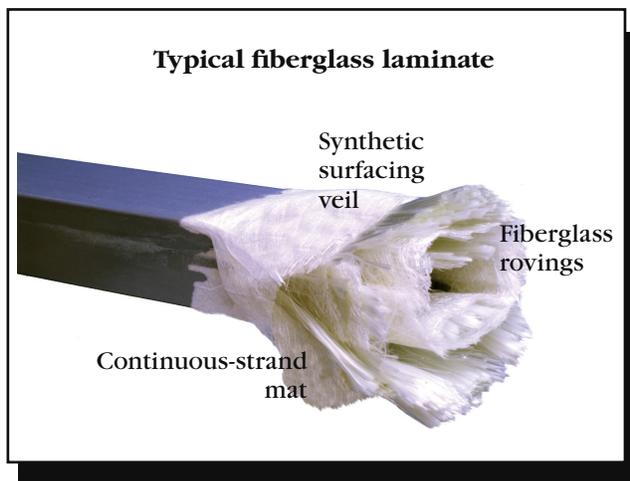


Figure 2—The composition of FRP materials.—*Courtesy of Strongwell*

would be strong enough for some applications, bridges require reinforcing fibers. While many fibers could reinforce resins, the low cost of glass fiber makes it the

primary reinforcement used in FRP bridge components. The E-glass fibers are good electrical insulators and have low susceptibility to moisture damage and high mechanical strength. The amount of fiber in composites used for structural applications ranges from 45 to 75 percent. The type of resin determines corrosion resistance, resistance to flame, and maximum operating temperature, while contributing significantly to other characteristics, including resistance to impacts and fatigue.

The strength of FRP materials, including fiberglass, is determined by the type, orientation, quantity, and location of the reinforcing fibers. Reinforcing fibers are primarily longitudinal, creating members having very high tensile strength. The resin binds the reinforcing fibers in a matrix and provides some rigidity. Fiberglass weighs between one-fourth and one-fifth as much as steel, but has similar strength. The modulus of elasticity of fiberglass is similar to concrete and about one-eighth that of steel.

Fiberglass members have a surface layer of polyester fabric and resin (a surface veil) to protect against corrosion, water intrusion, and degradation by ultraviolet light. The glass fibers carry the loads imposed on the composite (impact strength, stiffness, and tension), while the resin matrix serves as a binder to distribute the load across all the fibers in the structure.

Many FRP bridges are composed of closed-section shapes (tubes). These shapes provide better buckling and torsional characteristics than do open shapes such as *W* shapes or channels. (figure 3). Sometimes, open sections are used for bridges, but closed sections should be used whenever possible.

The two main manufacturing processes for composites are pultrusion and extrusion. FRP composite products usually are produced by pultrusion, while some other composite products, such as wood-plastic decking and siding, typically are produced by extrusion. Pultrusion

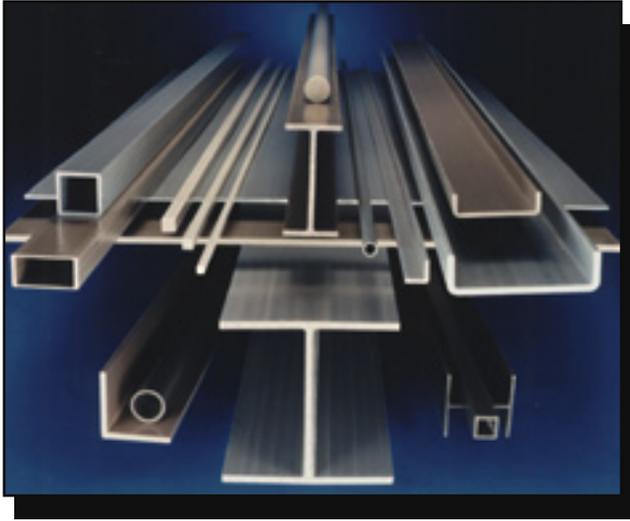


Figure 3—Some different shapes (open and closed) for FRP members. —Courtesy of Strongwell

is a manufacturing process (figure 4) for producing continuous lengths of FRP structural shapes with constant crosssections, such as rods, beams, channels, and plates.

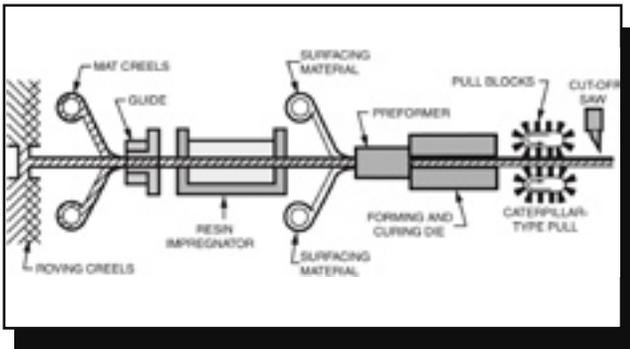


Figure 4—The pultrusion process for manufacturing FRP.—Courtesy of Strongwell

Pultrusion

The raw materials used to manufacture FRP members are a liquid resin mixture (containing resin, fillers, and special additives) and flexible textile reinforcing fibers. Pultrusion involves using a continuous pulling device to

pull these raw materials through a heated steel-forming die. The reinforcing fibers are in continuous forms, such as rolls of fiberglass mats, called *doffs*. The reinforcing fibers are pulled through a resin bath that saturates (wets out) the fibers with a solution containing the resin, fillers, pigment, catalyst, and any other additives.

A preformer squeezes away excess resin and gently shapes the materials before they enter the die. In the die, the reaction that sets the resin is activated by heat and the composite is cured (hardened). The cured shape (profile) is pulled through a saw that cuts it to length. The hot material needs to be cooled before it is gripped by the pull block (made of durable urethane foam) to prevent the pull blocks from cracking or deforming the FRP materials. For more indepth information on composites, see the *Introduction to Composites* by the Composites Institute of the Society of the Plastics Industry, Inc. (1998).

Advantages of FRP Materials

The advantages of composites in trail bridge applications include their light weight (figure 5), high strength, resistance to corrosion, and fast, easy installation. These properties make them competitive with standard bridge materials in situations where access and construction present difficulties. Composite materials can be designed to provide a wide range of tensile, flexural, impact, and compressive strengths. They can be formed into any shape and colorants can be added to allow the structures to blend with most landscapes. The use of composites prevents large trees from being over harvested near bridge sites and eliminates any potential environmental impacts of treated wood or galvanized steel used in riparian environments. Composites cost less than stainless or high-carbon alloy steel components that might be used in highly corrosive environments.

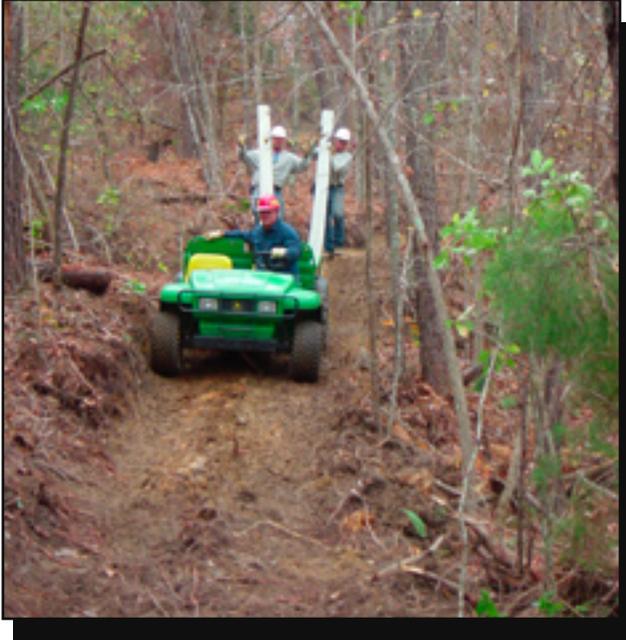


Figure 5—FRP members are lightweight and can be lifted by hand.

Disadvantages of FRP Materials

One disadvantage of FRP materials is their relatively high cost compared to wood or unpainted low-carbon steel. Other disadvantages include:

- The need for different saw blades and drill bits than those used with wood or steel.
- Bridge designs controlled by the amount of deflection rather than the strength needed to keep the bridge from failing (because of the flexibility of FRP materials).
- Proprietary bridge designs (rather than designs based on standard specifications).

- Limitations on enviromechanical performance.
 - At high temperatures the material’s strength decreases and deflection increases.
 - These materials continue deflecting under heavy, sustained loads (creep).
 - Impact loading during collisions can damage these materials.
- Limited experience with FRP materials in the construction design industry.
- Lack of design standards and codes.
- Lack of performance history.

Cost

FRP trail bridges cost about as much as equivalent steel bridges and almost twice as much as timber bridges. Costs for remote trail bridges are very difficult to compare because installation costs can be as high as 50 to 70 percent of the bridge’s total cost. Maintenance costs for FRP composite bridges can be less than the maintenance costs for wood or timber bridges. In addition, fiberglass components are easy to transport and install, which can represent potential cost savings compared to transporting and installing timber or steel components.

The materials for a 30-foot-long by 3-foot-wide fiberglass side truss bridge (with a design loading of 125 pounds per square foot) might cost \$117 per square foot. The materials for a comparable glue-laminated beam type of bridge could cost just \$65 per square foot. The heaviest piece of fiberglass would weigh 80 pounds, while the glue-laminated beams for a comparable timber bridge would weigh 1,200 pounds.