Case Studies and Failures

Case studies can show the problems and concerns that arise when FRP bridges are used in the national forests. The author and engineering staff from local forests inspected five FRP bridges that have been installed since as early as 1991. The bridges were in the Gifford Pinchot, Medicine Bow-Routt, Mt. Hood, Tahoe and Wallowa-Whitman National Forests. The problems found on each structure fell into three categories:

- Transportation and storage
- Construction
- Environmental

Transportation and Storage Problems

FRP members can be scratched when they are dragged to the site. Scratches damage the protective coating of the fiberglass. Flexural damage may occur when members are bent or stressed during transportation or while they are stored. Care needs to be taken when materials are unloaded from trucks and trailers.

Members of the queen-post bridge (figure 40) on the Mt. Hood National Forest were scratched when they were dragged to the site (figure 41). These scratches can be fixed by sealing them to prevent moisture from wicking into the member.

Figure 40—This deck-truss FRP bridge in the Mt. Hood National Forest has an inverted queen-post configuration.

Figure 41—This truss was damaged when it was dragged or handled improperly.

Construction Problems

Construction problems can occur when members are overstressed or bent excessively during installation. Dropping or impacts can crack FRP. Overtightening bolts may cause members to crack and may affect their strength and structural stability.

The Falls Creek Trail Bridge (figure 42) is a good example of construction problems. Some bolts were overtightened with a pneumatic power wrench, cracking some members at the connections when the bridge was assembled at the Forest Products Laboratory. Figure 43 shows a rectangular tube with an ⅛-inch sidewall, only half the thickness recommended for trail bridges.

Figure 42—A side-truss FRP bridge in the Gifford Pinchot National Forest.

Figure 43—This floor beam tie was damaged when bolts were overtightened.

Cracked connections may have been prevented by just tightening bolts until the lock washers began to flatten out and by being careful not to overtorque the nuts. Sometimes, connections with minor hairline cracks can be sealed with protective coating and monitored. If minor cracks are not sealed, the exposed fibers will wick water into the material. As the water freezes and thaws, the member will deteriorate. If members have major cracks, they should be replaced. Otherwise, the entire structure could fail.

Construction problems also occurred on the Medicine Bow-Routt and Wallowa-Whitman National Forests. The Medicine Bow-Routt bridge is a 20-foot-long by 5-foot-wide side-truss structure (figures 44 and 45), built in 1995. The Wallowa-Whitman National Forest bridge is a

Figure 44—A side-truss FRP bridge in the Medicine Bow-Routt National Forests.

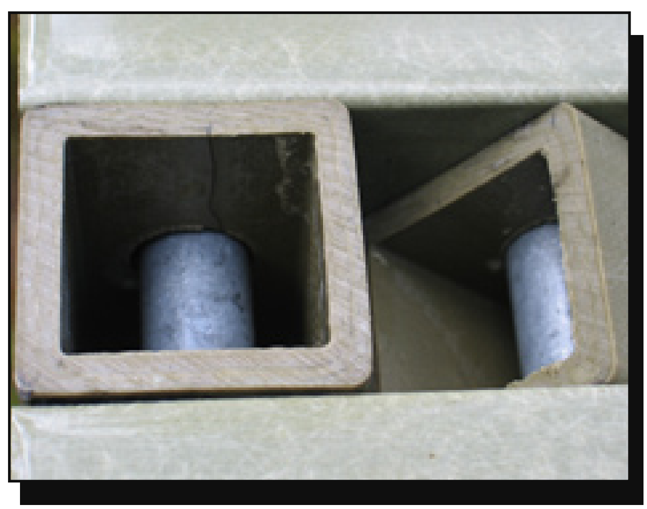

Figure 45—This joint at the top of a vertical post was damaged when bolts were overtightened.

22-foot-long by 6-foot-wide structure (figures 46 and 47), built in 1998. Both bridges had minor cracks at the upper

Figure 46—A side-truss FRP bridge in the Wallowa-Whitman National Forest.

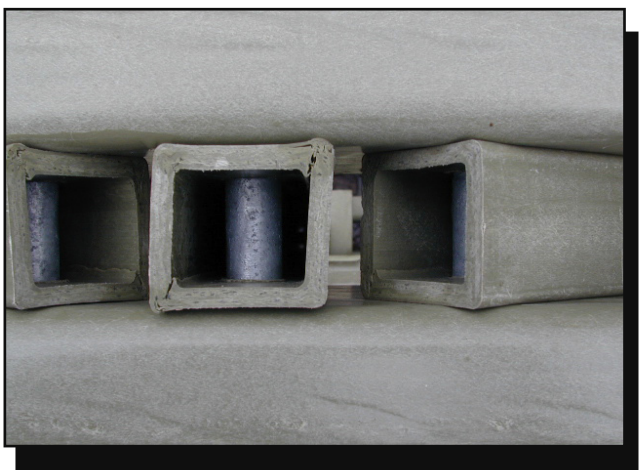

Figure 47— This joint at the top of a vertical post was damaged when bolts were overtightened.

chord joints. The Medicine Bow-Routt Bridge has large cracks in the bottom chord at the bolt connections (see figure 32) that may have been caused by dynamic loads from ATV traffic, by bolts that were overtightened, or by overloading.

Environmental Problems

Environmental problems can be caused by heat, wind abrasion, and sunlight. One of the five bridges inspected no longer had UV protective coating.

The side-truss bridges (figure 48) on the Tahoe National Forest show the problems of UV degradation. The 20-foot-long by 5-foot-wide bridge was built in 1994. The sides of the bridges exposed to full sun have lost their UV protective coating (see figure 30). Wind abrasion from blowing sand and debris can wear away the sealant that provides UV protection. For optimal protection, the members could be recoated with UV protective sealant about every 5 years. If the members are not sealed, the fibers could eventually be exposed, allowing water to wick into the material. As the water freezes and thaws, the member could deteriorate over time.

Figure 48—A side-truss FRP bridge in the Tahoe National Forest.

The two bridges tested at the Forest Products Laboratory had a constant deflection under a sustained load, but the deflection increased dramatically when the temperature rose above 80 degrees Fahrenheit. Consider anticipated maximum temperatures when deciding whether an FRP bridge is the proper choice for large, sustained loads in areas of prolonged extreme heat. For more information, see the test data in appendix D.

FRP Trail Bridge Failures

This section discusses three FRP bridge or catwalk failures and the lessons learned from them. Using a new material with limited knowledge of its long-term behavior can lead to unexpected results. Studying the two trail bridge failures has helped us learn more about FRP material behavior. This information was provided by the National Park Service and by Eric Johansen of E.T. Techtonics, Inc., the supplier of both bridges. Experience has shown that while FRP is not always equivalent to standard materials, sometimes it may be superior.

Redwood National Park

This bridge was the first of two 80-foot-long by 5-foot-wide FRP bridges to be constructed at Redwood National Park. It was designed for pedestrians and stock, but not for pack trains. When a team of mules carrying bags of concrete was 10 to 15 feet onto the bridge, the bridge (see figure 27) began to bounce. The cadence of the mules hit the fundamental frequency of the bridge. The mule train could not back up, so the wrangler started to run the mules across the bridge. When the last mule was halfway across the bridge, one abutment failed and the bridge truss broke. Fortunately, neither the stock nor the packer was injured. The abutment that was well anchored held; the second unanchored abutment did not hold. Crews repaired the abutment and replaced the structure.

This example shows the importance of designing for the correct live loads, determining the fundamental frequency of the bridge, and designing abutments properly. A variety of load conditions and their frequencies should be analyzed and considered in the design. The mule train produced different load patterns and different resonances than those produced by a single horse or mule. The bridge had the same horizontal and vertical fundamental frequencies, so when the fundamental frequency was obtained, the horizontal and vertical vibrations accentuated each other. Proper abutment design and an understanding of abutment conditions can help ensure that the bridge-to-abutment connections will provide the needed strength and support.

The proposed *Guide Specifications for Design of FRP Pedestrian Bridges* (appendix B) recommends that bridges be designed with different vertical and horizontal natural frequencies to minimize any potential amplification of stresses when the two frequencies are combined.

Olympic National Park

During the construction of the Staircase Rapids Trail Bridge in Olympic National Park, the bridge was installed with some out-of-plane bowing of the top chord (compression) in one side truss (see figure 28). Heavy snows 5 years later collapsed four steel bridges and this FRP bridge. Although snow loads far above design snow loads were the catalyst, failure probably was caused by a creep-buckling failure of the initially bowed side truss. Even in its failed state with 3 feet of deflection, this trail bridge was used by pedestrians for several months.

This bridge was only specified for a 35-pound-per-square-foot snow load, not the 85 pound-per-square-foot minimum live load recommended by AASHTO and the Forest Service. The time-dependent properties of FRP materials will tend to slowly increase any buckling caused by construction problems, overloads, or impacts.

During assembly, make sure that all members are in alignment. The design should ensure that all bays have outriggers to help alleviate compression effects in the top chord. Snow loads greater than 150 pounds per square foot require specialized design by experienced designers.

Aquarium of the Americas

A catwalk collapsed in New Orleans, LA, on August 7, 2002, at the Aquarium of the Americas. Ten aquarium members on a special tour fell into a tank of sharks. Sharks and visitors survived the collapse.

A team of experts determined that the catwalk collapsed when an angle bracket connected to a diagonal brace failed. The failed angle bracket was used inappropriately. The live load was about 82 percent of the design live load called for in the plans. This failure highlights the importance of connection design and the consequences of poor designs. This catwalk does not represent a design typically used in trail bridges.

Recommendations

More FRP trail bridges are being constructed on national forest lands. The pros and cons of FRP bridges need to be considered when deciding the type of bridge that best suits the needs.

Selection Considerations

When deciding whether to use FRP materials for a trail bridge, consider:

- How does the overall durability of the material compare to concrete, steel, or timber?
- How does the cost of the FRP structure compare to a similar structure of concrete, steel, or timber?
- How difficult is site access and construction?
- Will the temperatures be above 100 degrees Fahrenheit during peak load periods? If so, FRP bridges should be avoided because they lose strength and become more flexible at high temperatures.
- What is the likelihood of impacts from flood debris or collisions?
- How would a collision compromise the structure?
- Could the structure be repaired easily?
- How much would repairs cost and how would the repairs affect the overall strength of the member?
- Does the appearance of FRP trail bridges concern wilderness land managers?

Materials, Testing, Specifications, and Standardization

Researchers and developers in the bridge-building industry seem to be focusing on material testing. Because of the unfamiliarity of FRP composites in this industry, a great deal of materials testing needs to be done and standards need to be established. Methods need to be developed so material properties can be predicted over the long term. Analytical methods that can predict structural behavior also are needed.

A database needs to be developed recording the long-term performance of existing bridges. The performance data can be used to develop much needed material specifications, leading to new and improved design methods and procedures.

Other barriers to the widespread use of FRP materials include:

- The high initial cost of FRP materials compared to timber
- The lack of design codes, standards, and guidelines
- The lack of proven inspection methods for FRP composites
- The lack of proven inservice durability data

Establishing guidelines and minimum performance requirements is essential before FRP can become a common material for Forest Service trail bridges.

In some ways, manufacturers make it more difficult to overcome these barriers. FRP composites are engineered materials, meaning that the composition of the material is adjusted to produce particular performance characteristics. Each manufacturer sells different products. These products are proprietary and manufacturers have been unwilling to make their specific fiber architecture (precise material proportions and fiber orientation) available. This makes it difficult to produce standard tests, general design procedures, and specifications. The proprietary nature of the materials also makes it difficult to assure quality control during their manufacture. The industry may have to loosen its hold on information about the materials if it wishes to develop a broad market in the bridge industry.

The results of the initial testing suggest that the methods used to model the load-carrying capacity of the 44-foot bridge tested at the Forest Products Laboratory were very accurate. When the actual performance of the tested bridges is considered as well, the design procedures described in appendix H appear to provide a good basis for a thorough, reliable design of an FRP composite truss bridge. However, these procedures represent only a beginning and will need to be adapted as materials and our understanding of their behavior advance.

FRP composite bridges are not yet a practical solution for bridges designed to meet AASHTO and similar codes. Further study and testing are needed to better understand the material and its uses. However, FRP materials have the potential to meet an important need for lightweight, strong, low-maintenance, attractive trail bridges in remote locations.

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