



## FIBER-REINFORCED POLYMER COMPOSITES FOR STRENGTHENING BRIDGES IN OREGON

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The historic Horsetail Falls Bridge is located in the Columbia River Gorge, 30 miles east of Portland, Oregon (see Figure 1). Built in 1914 at a cost of \$1,817.70, this 60-foot by 24-foot reinforced concrete bridge consists of three 20-foot spans. This bridge and many others are an important part of the state's cultural heritage. They were built in the early 20th century as the advent of the automobile created a need for highway routes through Oregon's rugged mountains and coastal terrain.

### Problem

The Horsetail Falls Bridge was not designed to carry the traffic loads that are common today. In a recent rating of the bridge, the beams were found to be severely deficient in both shear and flexural strength. Visual evaluation revealed that the bottom of the deck and the beams had many hairline cracks, a few larger cracks, and some exposed corroded reinforcing steel. If these problems were not addressed through structural reinforcement, the bridge would have to be posted with load restrictions. Conventional reinforcement, however, would have significantly altered the bridge's appearance, seriously impacting its aesthetic appeal and its value as a historic structure.

### Solution

The Oregon Department of Transportation (ODOT), in collaboration with Oregon State University and



FIGURE 1 Historic Horsetail Falls Bridge, circa 1914.

Blue Road Research, a private organization, has been studying fiber-reinforced polymer (FRP) materials for structural reinforcement of bridges and fiber-optic sensors for monitoring of structural behavior. Synthesis reports on both subjects have been completed, and further research is continuing.

On the basis of work completed to date, it was determined that FRP materials could be used as a cost-effective, structurally sound methodology for upgrading bridges. Four commercially available FRP composite systems were considered for structural reinforcement of the Horsetail Falls Bridge. To identify suitable FRP systems for the bridge, the project investigators reviewed the published material properties of

each system and the known properties of the structure. They then developed alternative designs using each system. Analysis of the alternative designs indicated that glass FRP laminate would be most suitable for shear strengthening, while carbon FRP laminate would be best for flexural enhancement.

Another objective was to develop a means for monitoring the performance of the FRP composites used on the bridge. Performance evaluation and long-term durability testing would require that sensors be embedded in the structural elements of the bridge for the life of the structure. Because of their durability, versatility, and sensitivity, fiber-optic, Bragg grating, strain sensors were selected. The design required installation of 14 pairs of sensors. For each sensor installed in grooves cut in the con-

crete, a second sensor was required on the cured FRP composites over the concrete.

Concurrently, ODOT contracted with OSU to build four full-size beams as similar as possible to the actual bridge beams. Under load testing, the control beam failed at 107 kilo-pounds (kips). Beams strengthened with composites for shear only and flexure only failed at 150 and 155 kips, respectively. The beam strengthened for shear plus flexure, the same configuration as the fully strengthened beams on the bridge, did not fail at 162 kips, the capacity of the loading system. These test results revealed a significant increase in strength and provided validation of the concept of structural reinforcement with FRP composites.

## Application

All delaminated and unsound concrete was removed from the Horsetail Falls Bridge. Epoxy resin was injected into the cracks and used to fill any delaminated areas. The surfaces of all the beams were prepared by repeated filling, grinding, and needle gun scaling. Fiber-optic sensors were installed in precut slots in the concrete to measure shear and flexural strain. Carbon FRP sheets impregnated with resin were then adhered to the bottom and lower portion of the sides of all transverse beams on the structure for flexural strengthening (see Figure 2). Impregnated glass FRP sheets were placed around the transverse and longitudinal beams to enhance their shear capacity. Once the composite installation was complete, the second set of sensors was installed in the new materials. Since this bridge is a historic structure, a special cosmetic coat of paint was placed over



FIGURE 2 Installation of carbon-epoxy sheets on bridge beams.

the FRP composite and sensors to match the appearance of the original concrete.

Upon completion of the construction, the bridge was test loaded using a vehicle with known axle weights. Results of load tests on the full-size, fully strengthened beams indicated that no posting of load restrictions was necessary for the Horsetail Falls

Bridge. Similar load testing is scheduled during the next 2 years. Results of laboratory tests will be used in conjunction with data obtained from the bridge to verify finite-element models of the original and composite-strengthened beams at Oregon State University.

## Benefits

This work with use of FRP composites for bridge strengthening has yielded a number of benefits:

- ◆ Test results validated the concept of bridge strengthening with FRP composites.
- ◆ The historic Horsetail Falls Bridge exceeds the current required load-carrying capacity; thus no posting of load restrictions is necessary.
- ◆ The appearance of the structure was not significantly altered; the bridge's historic value was thereby preserved.
- ◆ The cost of strengthening the bridge using FRP composites was \$32,000, whereas the engineering estimate for a conventional repair was \$69,000. Thus savings of \$37,000 were realized on the cost of rehabilitating the bridge.
- ◆ The objective of obtaining sensitive and durable strain sensors was met with the fiber-optic Bragg grating sensor and state-of-the-art demodulation equipment.
- ◆ ODOT expects that three to four bridges per year will be candidates for this type of reinforcement. As some of these bridges are larger than the Horsetail Falls Bridge, the potential exists for significant savings.

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