Broadway Bridge Case Study

Bridge Deck Application of Fiber-Reinforced Polymer

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Research into using fiber-reinforced polymer (FRP) for bridge deck applications began in the early 1990s as aerospace companies looked for alternative uses for their advanced products. By the mid-1990s, FRP was gaining acceptance from the bridge community as it was applied to small, low-volume deck demonstration projects. Since that time, FRP decks have been used on increasingly significant projects throughout the United States. Designers have become more familiar with the characteristics that FRP offers and have begun to apply FRP to projects that would most benefit—cases where low weight, corrosion resistance, or rapid installation is critical. FRP decks are often suitable for historic, movable, or high-traffic bridges. One excellent example of an FRP deck application is the Broadway Bridge in downtown Portland, Oregon. This project demanded a new deck that matched the weight of the bridge’s existing steel grating, offered improved skid resistance, and could be installed rapidly.

It is not uncommon to combine the benefits of multiple elements to address increasingly complex construction demands. In ancient times, mud huts were reinforced with straw. Today, contractors build high-rises of steel-reinforced concrete. In both cases, a matrix (mud or concrete) encapsulates and protects load-bearing fibers (straw or steel) (1). A composite material combines two primary constituent elements to accomplish a singular task: carry loads in an efficient, durable manner.

Fiber-reinforced polymer (FRP) materials are a composite solution to today’s complex demands. They combine a polymer matrix of resin, additives, and fillers with a reinforcing agent such as glass or carbon. The marine and aerospace industries have used FRP materials for several decades (1). FRP’s combination of high strength, low weight, and corrosion resistance often positions it as a singular solution to designers’ challenges. Its ability to be customized for part reduction provides designers with a wealth of freedom.

Despite its superb performance, FRP’s growth in civil structural markets has been kept somewhat in check by its high initial cost compared with conventional materials such as steel and concrete. Although this control on growth is a reality, the FRP industry is making strides in those applications where the characteristics of FRP offer distinct advantages over those of conventional materials.

EVOLUTION OF FRP BRIDGE DECKS

FRP bridge decks were originally developed in the 1990s to address the convergence of two increasingly complex paradigms: an aging infrastructure and ever-increasing traffic demands. With bridge decks taking much of the abuse caused by weather and traffic, considerable attention was focused on improving deck lifespan and longevity. FRP’s ability to resist the corrosive effects of weather and deicing salts positioned it as a unique alternative to traditional concrete and steel materials. FRP decks have now been used on more than 90 vehicular bridges in the United States (J. Busel, personal communication, November 29, 2004).

Early forecasters predicted that FRP’s penetration into the bridge market would be in large part due to its ability to translate corrosion resistance into reduced maintenance and life-cycle costs. Although this theory still is valid, other features have brought FRP decks to the forefront in certain bridge applications. Bridge owners and designers seem to be interested primarily in FRP’s low weight. FRP decks have been great replacements for historic bridges and movable bridges because they can reduce deck dead load, increase bridge live load capacity, and possibly even widen certain bridges. Although steel grating was often applied to weight-critical structures in the past, owners are growing weary of grating’s tendency to negatively affect the supporting structure (e.g., by allowing the passage of weather and deicing salts, both of which can contribute to structural deterioration, and by preventing the collection of bridge runoff, which can cause environmental concerns in water below). In addition, grating’s skid resistance tends to decline over its life and raises safety concerns for commuters (including motorcyclists and bicyclists), particularly on wet days. An FRP deck is sometimes the only viable solid-surface alternative for preserving a historic or movable bridge while updating it to modern standards.

Also of significant interest is FRP’s inherent ability to be prefabricated. FRP decks are usually customized into large, lightweight modules that can be set quickly with light-duty equipment. This feature facilitates rapid installation and reduces the impact of construction zones on the traveling public.

Rocks Steel Truss Bridge, constructed in 1934 in Harford County, Maryland, is a historic through-truss bridge that required a lightweight, rapidly installed deck to increase the bridge’s overall live load capacity while minimizing work zone impact on the traveling public (2). A significant movable bridge that used FRP decks is the Schuyler Heim Vertical-Lift Bridge in Long Beach, California (3). Located adjacent to the city’s port, the bridge services significant heavy-truck traffic. The Schuyler Heim Bridge served as a springboard for FRP’s application on other significant structures, the most notable of which is the Broadway Bridge.

BROADWAY BRIDGE

Overview

The Broadway Bridge over the Willamette River in Portland, Oregon, is located in the heart of the city’s harbor and is vital to
its surrounding areas (Figure 1). It carries an average daily volume of 30,000 vehicles in four lanes of traffic. With each of the bascule leaves measuring 140 ft, the Broadway Bridge is also the seventh-longest bascule bridge in the world. Built in 1912, the historic bridge has served Portland’s marine (river) and vehicular traffic quite well for more than 90 years (4).

However, the bridge’s age and frequent use left it with a long list of repair needs. One element that warranted considerable attention was the bascule span’s steel grid deck (5). Years of aggressive traffic loading had worn the grid and lessened its skid resistance. Combined with the bridge’s vertical curve, limited site distance, and traffic signal located near its approach, the low skid resistance caused significant safety concerns. Thus, the grid was selected for replacement.

The grid replacement was no easy task. To minimize costly, complicated rework of the bascule span’s mechanical drive system, designers needed to match the weight of the existing steel grid as closely as possible. Although direct replacement with a new grid was an option, the owner preferred an alternative solid surface to improve the skid resistance of the deck’s wearing surface. Another significant rehabilitation challenge involved construction time: The new deck installation had to be quick. River and vehicular commuters alike required as much access to the bridge as could be allowed. Because of the bridge’s critical importance to commerce and the traveling public, its owner applied strict limitations to the project’s construction schedule, limiting the bridge’s closure to vehicular traffic to a defined 60-day period in summer 2004. During this period, the contractor executed key portions of the extensive structural rehabilitation, including steel repair, lead paint abatement, and the grid deck replacement. Although closed to vehicular traffic, the bridge was available to river traffic at regular intervals: The bascule span was available for opening every 4th day within the aggressive 60-day schedule. This requirement meant that the new deck not only had to be installed quickly but also had to be modular and securable if a bascule opening were required during construction. Significant liquidated damages awaited the contractor if these requirements were not met.

With these requirements in mind, the bridge owner selected a DuraSpan FRP bridge deck system (manufactured by Martin Marietta Composites) to replace the worn steel grid on the bascule span. The deck, composed primarily of glass fibers and polyester resin, was a nominal 5 in. thick and weighed approximately 15 psi. Key desirable features included low weight, prefabricated construction, and solid-surface design. Other deck properties provided ancillary benefits, including resistance to corrosion, fatigue, and creep. The FRP deck also could be customized to accommodate certain key features of the existing bridge.

Details

Many of the FRP deck details were designed to mimic those of conventional materials, particularly the precast concrete panels. As such, the deck-to-beam connections look quite familiar to those who have experience with conventional deck design (Figure 2). Broadway Bridge used conventional shear studs and grout-filled cavities to connect the new deck to the bridge’s longitudinal beams. Grout was poured through the deck into a cavity formed by stay-in-place metal angles (Figure 3), providing a variable haunch along each longitudinal beam. This attachment method had a proven track record in static testing, fatigue testing, and in-place performance. All work was performed from above.

Similar connections have allowed FRP decks and steel beams to perform together in composite action (6). Research also provides guidance for calculating the FRP deck’s effective compression flange width when composite behavior is assumed (7). Because of this connection’s inherent ability to transfer shear, Broadway Bridge’s beam–deck system likely exhibits some level of composite behavior. However, the beams were sized to carry loads without consideration of composite behavior.

The prefabricated FRP panels arrived at the job site in 8- × 46-ft modules, ready for installation on the beam’s variable haunches. The length of each panel (46 ft) matched the width of the bridge deck, because the FRP panels span perpendicular to the bridge’s longitudinal beams. Shop workers had predrilled all holes to accommodate the connections to the bridge’s longitudinal beams. At the heel of each bascule leaf, the FRP deck interfaced with a concrete transi-
tion deck, which was designed to accommodate dynamic vehicular forces. At the bridge’s center open joint (2 in.), the deck interfaced with heavy steel angles to accommodate dynamic forces. At the side edges, workers bonded an FRP curb to the deck along its full length.

Deck designers were able to incorporate a key feature of the existing bridge’s geometry: its cross section (Figure 4). Via their own weight, the pultruded panels matched the parabolic crown (2.25 in.) on the bridge’s approach spans. Cambering was analyzed in the shop, and panels arrived at the job site in their “curved” state. Another key geometric feature of the existing bridge was its vertical alignment. In the portions of the bridge where the longitudinal stringers were vertically curved, each panel was placed on the stringers and conformed to the existing profile with a “chord” effect. Each panel was straight, whereas the field joints accommodated incremental, extremely slight rotations before adhesive curing. Both accommodations facilitated the use of FRP on the unique structure and are expected to have minimal negative effects on the integrity of the deck system.

With no AASHTO design criteria yet established for FRP decks, the supplier took full responsibility for the design and performance of its proprietary system. To address the inherent gap between manufacturer and specifier, the manufacturer provided sealed contract drawings and shop drawings with its deck system.

**Installation**

The project’s construction sequence (when incorporating the extensive painting portion and other issues) forced the contractor to establish deck staging areas several hundred feet from the bascule leaves but still within Broadway Bridge’s truss. Two forklifts walked each panel from its staging area to its eventual resting place while maintaining extremely tight clearances on either side (Figures 5 and 6). These dual forklifts started at the heel of each span and worked toward the center of the bridge, walking over previously set panels. Each panel’s low weight (typically less than 6,000 lb) allowed the contractor to use light-duty, high-performance equipment.

All of the bascule span’s 32 deck panels (more than 250 linear feet and nearly 12,000 ft²) and half of the shear studs were in place after two shifts (Figure 7). Miscellaneous tasks (including FRP splice strips at field joints and the remainder of the shear studs) were completed on the 3rd day. Panels were correspondingly secured to the beams with temporary attachments and ready for a bascule opening on the 4th day.

On subsequent 3-day construction cycles, workers completed the installation by placing the grout, curb, and a thin-polymer-concrete wearing surface. In early September 2004, Multnomah County reopened the Broadway Bridge to vehicular traffic while the extensive painting project continued.
A testing plan is in place to monitor the performance of the new FRP deck system. In accord with FHWA and the Oregon Department of Transportation, the bridge’s owner (Multnomah County) has scheduled a series of load tests to occur at intervals throughout the life of the system (C. R. Maggio, personal communication, Jan. 31, 2005).

CONCLUSIONS

Although the FRP market is still growing, FRP decks are quite viable in certain circumstances. FRP composites offer a singular solution to a complex set of demands that simply has not been available to owners and designers previously. The aggressive demands of the Broadway Bridge will prove to be an excellent case study as FRP decks are applied to more and more projects that require the unique benefits that FRP provides.

REFERENCES


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