U.S.A.'s EXPERIENCE USING
FIBER REINFORCED POLYMER (FRP) COMPOSITE BRIDGE DECKS
TO EXTEND BRIDGE SERVICE LIFE

Jerome S. O'CONNOR[1], and John M. HOOKS[2]

Abstract

Though fiber reinforced polymer (FRP) composites have been used in other industries for years, their use for highway bridge decks is relatively new. Over the past six years, however, approximately 50 bridges have been built or rehabilitated with FRP decks. Since all of these were designed and constructed without the benefit of nationally accepted standards, there are varied lessons to be garnered from these projects. This paper summarizes the experience of state agencies, presents some case studies, and, based on this information, suggests when the use of FRP decks is most appropriate.

BACKGROUND

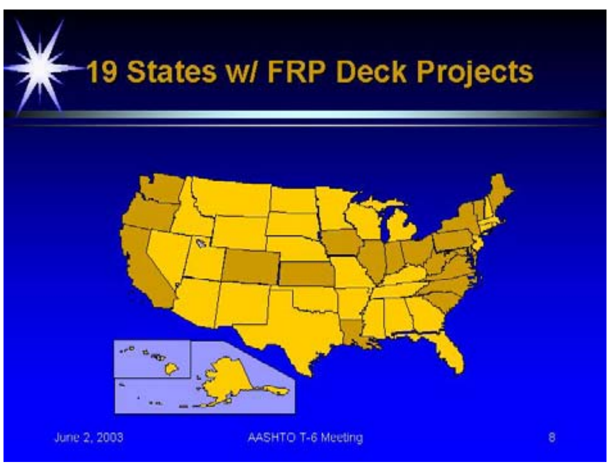

Figure 1. States that have installed FRP decks.

Fiber reinforced polymer composite decks & superstructures have been used in lieu of conventional construction material on approximately 50 bridges in the USA. The purpose of this paper is to summarize experience with these bridge elements and suggest when their use should be considered. Implementation of composite technology has been fostered through a special funding program authorized under the Transportation Equity Act for the 21st Century and administered by the Federal Highway Administration (FHWA). This Innovative Bridge Research and Construction (IBRC) Program is part of a recent emphasis better construction practices and materials that will improve the performance of our nation's bridges.

[1] Multidisciplinary Center for Earthquake Engineering Research, Buffalo, NY ; FHWA's FRP Virtual Team

[2] Federal Highway Administration, McLean, VA; FHWA's FRP Virtual Team

The FHWA has defined a vision for a "bridge of the future" by listing general performance requirements. Composite materials have characteristics that can help meet these objectives. This ideal bridge will have characteristics that will allow the objectives listed below to be met.

- Life cycle cost is a fraction of the current expectation.
- Construction time is a fraction of the current time.
- Material degradation is no longer an issue.
- It is immune to attack from floods and earthquakes.
- A total systems approach is used in their design
- Adaptable to new demands

In addition to advocating moving toward the "bridge of the future", the FHWA is promoting stewardship and management of the existing bridge infrastructure. Some strategies being promoted include: using cost-effective and innovative repair and rehabilitation techniques (in lieu of replacement); use of accelerated construction techniques for rehabilitation of bridges; and use of prefabricated or modular components and systems. Fiber reinforced polymer composite decks & superstructures are ideal systems for use in these strategies and, in some cases, can be effectively used in cases of deteriorated decks, load posted bridges and narrow bridges.

MATERIALS and MANUFACTURE

FRP bridge decks and superstructures are typically made with vinyl ester or polyester resin reinforced with E-glass fiber. They are pre-fabricated in a shop, then assembled and installed at a bridge site where a wearing surface is added. FRP's are engineered materials with their strength dependent on several factors such as fiber type, orientation and percent volume, resin type, manufacturing method, and the bonding materials used in the final assembly.

In the U.S. there are more than six competitive suppliers of these systems. Each uses one of three basic manufacturing methods:

- *pultrusion* (e.g. Martin Marietta Composites),
- *vacuum-assisted-resin-transfer-molding* (VARTM) (e.g. Hardcore Composites)
- *open mold hand lay-up* (e.g. Kansas Structural Composites)

Figure 2. X-section of a VARTM deck.

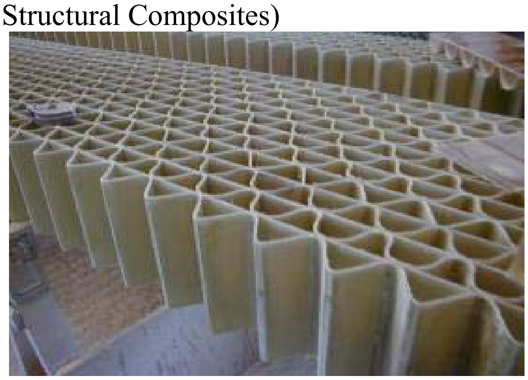

Figure 3. Core of an open mold deck.

Figures 2 and 3 illustrate two “sandwich” systems where a core is bonded between a top and bottom face sheet. Table 1 is offered as a qualitative comparison of the manufacturing methods. Each method has its own merits.

Figures 4 and 5 illustrate the pultrusion manufacturing process. A complex array of glass fiber is pulled through a resin bath and heated as it passes through a die to produce sections that are bonded together to form deck panels.

Manufacturing method	**Ability to customize**	**Adherence to dimensional tolerance**	**Attractive cost**	**Ability to incorporate special features (e.g. scuppers)**	**Overall quality**
1. Pultrusion	L	H	L	L	H
2. VARTM	H	L	H	H	M
3. Open mold	H	M	H	M	M

Table 1. Qualitative comparison of manufacturing methods.
Relative benefit: H = high, M = Medium, L = Low

Figure 4. Pultrusion of glass fiber and resin.

Figure 5. Panels made up of pultruded sections.

A list of known suppliers and completed projects can be found at the following internet web site: http://www.fhwa.dot.gov/bridge/frp/frppract.htm

BENEFITS

Currently, bridge decks made of composite materials cost more than conventional concrete decks. However, comparing costs on a unit area basis does not always give a true indication of value. The unique properties that FRP materials give certain advantages that can still make FRP a prudent choice for bridge decks and superstructures.

One important benefit is derived from the *prefabricated* nature of FRP decks. These benefits are shared with pre-cast concrete construction and are well known for their ability to *speed construction* and *minimize traffic delays*. An environmentally controlled factory environment also lends itself to an improvement in *quality*. The Federal Highway Administration is encouraging modular construction as a means of meeting tax payers' demands for *less environmental and economic impact* resulting from construction projects (e.g. less delay, wasted fuel, noise, and pollution). Additionally, because of the short time needed to fabricate a bridge and the possibility of stockpiling standard sizes, a project's initiation and planning phase can be dramatically decreased. This can be a big benefit in emergency situations. Establishing standard bridges for mass production could also simplify the purchase of these modular units to allow installation by smaller agencies with small work forces and light equipment.

Figure 6. Prefabricated FRP deck being installed on prefabricated prestressed concrete beams. Bettendorf, Iowa.

Another spectrum of benefits stems from the *light-weight* nature of FRP. Weight savings over concrete can allow the conversion of dead load to live load carrying capacity. Instead of 581 kg/m^2 (120 psf) for a typical concrete deck, a bridge can be designed for 122 kg/m^2 (25 psf) or less. On a rehabilitation project, the weight savings can result in an improvement in load ratings, possible removal of weight restrictions and restoration of full service even after factoring in the reduced capacity of a steel superstructure due to section loss. Use of a light deck can also allow widening to accommodate an additional lane or shoulder without requiring major improvements to the substructure.

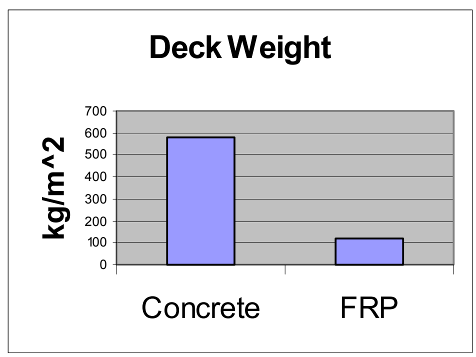

Figure 7. Weight per Unit Area

On new construction, the weight savings might *lower foundation requirements* (e.g. fewer or smaller piles). The reduced mass also provides a substantial *reduction in earthquake induced displacements*. This is particularly helpful on elevated structures or those in proximity to a fault.

Composite decks also offer the potential for *long service life*. Though they have yet to undergo the test of time, the fact that they do not crack like concrete nor corrode like steel suggest that they will last for many years with little maintenance. Concrete decks are typically predicted to last 25 years before requiring replacement. Today, design life of FRP decks is comfortably set at 75 years (i.e. the life of the bridge). De-icing salt is not a problem for a properly detailed FRP system. Noticeably, over half of FRP deck projects in the USA have been in the states of West Virginia, Ohio, and New York where the use of de-icing salts has led to the premature deterioration of many existing concrete bridge decks and steel bridge superstructures.

The properties of composite bridge elements can be *tailored to meet the requirements* of the job by changing the fiber architecture. By varying the fiber type, density within the matrix, number of layers, and orientation, the strength of a deck can be customized in each direction. By engineering the material, most efficient use can be made of each constituent, thereby optimizing the overall system and improving cost effectiveness. Although this may not be worthwhile on a project by project basis, a manufacturer's deck design can easily be tailored to certain classes of bridges to match required load and deflection criteria.

The benefits of prefabrication, weight and *corrosion resistance* make composite materials a good material for certain types of bridges.

Project cost savings can be realized when FRP materials are prudently utilized. For instance, if it is possible to rehabilitate an old steel truss bridge using composite material, a complete bridge replacement can be avoided, resulting in substantial savings. This "fixes the problem" and frees up funds for use on other deficient bridges.

Certain bridge types are well suited to FRP decks. *Historic bridges* particularly benefit from light-weight decks. These older structures were often designed to accommodate a light (e.g. timber) decking material and need a product of similar weight when rehabilitated. Using a high tech material like FRP offers advantages unavailable when replacing in-kind. The FRP system is most often *water-tight* and provides protection to the flooring system below. In contrast, timber decking is prone to leakage that can lead to premature corrosion of lightly designed steel members. The composite system also can accept a thin, light, skid resistant wearing surface that can further improve live load capacity.

Movable bridges are a particularly good application for FRP decks. Whether for rehabilitation or new construction, the lower weight can decrease *lift requirements*, resulting in lower capital, operating and maintenance expenses while at the same time reducing the potential for excessive displacements during earthquake induced ground motion.

Figure 8. Schuyler Heim lift bridge Long Beach, CA

CASE STUDIES

Case Study #1

Location: Route 367 over Bentley Creek, Chemung County, New York State

A 126' truss, built in 1941, was posted with a 14 Ton weight restriction due to section loss in the steel superstructure and flooring system. There was also excessive dead load from numerous courses of asphalt wearing that had been added over the years. Using VARTM-FRP technology, the service life of the bridge was extended from 60 years to 90 or more.

Figure 9. NY 367 over Bentley Creek, a typical truss application.

Relieving the bridge of 265 Tons of dead load allowed it to be restored to full service, thereby avoiding a complete bridge replacement. Replacing the deck in-kind with concrete would not have alleviated the posting problem.

Because so many bridges are in need of replacement, competition for funds and a place on the capital program would have meant making the public wait five years or more for a solution. The rehabilitation with FRP was started immediately upon discovery of the problem instead of waiting. By custom designing the composite material and using a depth of 14", the deck could be designed to span from transverse floor beam to floor beam. This meant that deteriorated longitudinal steel stringers would become non-supporting and could be left in place without repair. Computed load ratings for the bridge were verified through load testing and were shown to be even higher than the bridge's original design. The total project cost was $1 million less than the next most feasible alternative.

Case Study #2

Location: MD Route 24 over Deer Creek, Harford County, Maryland

This was also a truss rehabilitation, but the structure is on a severe skew (34^o). The state DOT formed a committee of state and federal engineers, a university professor and contractors to assist with selection of the decking supplier. Since costs on the proposals received contained approximately the same unit price, the primary consideration was constructability. The group chose to use pultruded panels placed transversely and secured to the steel stringers with grouted pockets encasing stud shear connectors. It was supported along the skewed edge with a concrete diaphragm. The project successfully demonstrated how quickly an FRP deck system could be installed.

The bridge, originally built in 1934, was redecked in just weeks. Upon completion, and prior to opening to traffic, a load test was conducted to demonstrate that the conditions of the deck specification were met, and to establish a baseline for future testing. The testing also verified that the chosen connection detail provided composite action between the deck and steel. Continuous monitoring is being performed with network of strain gages and a wireless communication system.

Figure 10. MD Route 24 over Deer Creek Note the high skew angle.

Case Study #3

Location: NY Route 248 over Bennetts Creek, Steuben County, New York State

In this case, a severely deteriorated concrete slab bridge, which was posted at 10 Tons, was removed and replaced with an all composite superstructure. The project was easily accomplished by a bridge maintenance crew which was not accustomed to doing this type of work. The installation of the superstructure took just a few hours. The replacement bridge arrived at the site on a truck in two pieces, then was placed on reconstructed abutments. The final wearing surface came pre-installed, as did composite stay-in-place forms for a concrete barrier.

Figure 11. Original concrete slab built in 1926.

Figure 12. FRP slab bridge built in 1998.

The objective of the project was to replace a deteriorated 1926 bridge with a FRP superstructure and do it on a compressed time schedule using in-house DOT maintenance forces. The 24 inch deep FRP superstructure consists of two skewed panels. The panels are joined along the centerline of the road with a shear key and adhesive grout providing load transfer between them. A crown was provided by sloping the bridge seat. The bridge railing is a cast-in-place concrete parapet with double steel box beam tubing mounted on the face. The parapet is anchored to the superstructure by epoxy coated rebar cast into the FRP deck at the time of fabrication. A 3/8-inch epoxy/basalt polymer concrete wearing surface (Transpo T-48) was applied in the shop. The project was opened to traffic in October 1998, nine months ahead of schedule.

Case Study #4

Location: County Route 46 over East Branch Salmon River, Lewis County, New York

Figure 13. CR46 over East Branch Salmon River

The goal of this project was to replace the existing open steel grating at an economical cost. Five deck panels, each 5-inches thick, were installed transversely on the existing supporting steel. The panels were all placed within two and a half hours. The panels were of high quality and the fit of the panels was precise. Initial load test confirmed that the structure meets HS20 Loading.

SUMMARY

There are about 50 bridges in the United States that are carrying public traffic on fiber reinforced polymer composite decks. Experience with this technology has been generally favorable and further deployment of the technology is anticipated. This section summarizes the benefits of FRP, some of the limitations, issues that need to be studied further, and facets that affect the economics of their use. Observation of the installed decks while in service will provide a great deal of additional insight.

Value Added

Economic value

Since these decks cost more than conventional materials when compared on a unit area basis, applications need to be selected on some criterion other than first cost. Situations where their value might be recognized include when:

1) Life cycle cost is considered in the economic analysis. The expected service life of the composite deck exceeds 75 years with little or no maintenance. This is about three times the expected life of a concrete bridge deck.
2) Their light weight provides a direct benefit by allowing the load capacity ratings of

a bridge to be increased or maintained, such as when:

   a) A bridge was originally designed for a light weight deck. FRP will allows the bridge to carry the same live loads without continuing problems associated with open grate decks.
   b) Additional dead load has been added over the years. The dead load from the original deck and overlays can be "traded in" for live load capacity.
   c) There is reduced capacity in the steel superstructure due to section loss. Using a light deck can allow the same loads to be carried without having to strengthen members weakened by loss of cross section.
   d) Weight savings can lead to decreased operating expense, e.g. movable bridges.
   e) Switching from a heavy deck to a light weight deck can increase load capacity to compensate for loading that was not anticipated during design.

3) The deck can be used to protect the flooring system from water and salt
4) Speedy construction results in
   a) Shorter need for maintenance and protection of traffic schemes
   b) Decreased user cost (e.g. fuel costs, value of time)

Less tangible benefits

Additional value can be obtained with the use of FRP decks, although they are not so easily identified and quantified by an economic analysis. Further reasons to consider their use are:

   a) FRP can make the salvage and restoration of a historic structure possible.
   b) Quick and easy installation means less disruption to the environment (e.g. air and noise pollution).
   c) Speedy construction results in decreased inconvenience to the user.
   d) There is less maintenance required due to resistance to chemical attack.
   e) Alternative procurement methods become available because of their pre-manufactured nature. A bridge deck can be purchased and installed instead of built on site. This type of product delivery can result in less administrative cost while accelerating implementation of a solution to the problem at hand.
   f) They can lessen a structure's vulnerability to dynamic loads such as earthquakes.
   g) Several manufacturers are willing to provide a product warranty which is not typical for the construction industry. A department of transportation (DOT) agency frequently discovers defects in construction projects within a few years of completion, but since it is well beyond formal project acceptance, they are forced to accept the consequences. Using warranteed manufactured projects can eliminate some of the problems intrinsic to with field construction.

At his point in time, the technology is most suitable for trusses, historic structures, bridges originally designed for light loads, bridges to be widened, bridges where the superstructure is in good condition but the deck is poor, bridges that can be rehabilitated with a complete FRP superstructure and the abutments are salvageable, bridges where a low dead load is desirable, movable bridges, emergency bridges and temporary, rapidly deployed bridges.

Disadvantages

There are certain disadvantages associated with using FRP at the present time. Initial cost is probably the largest barrier to widespread use of these materials. Even when there is a valid case for their use, it is not always obvious that FRP provides a cheaper alternative. For instance, consideration of user costs and life cycle costs is not always a practice of a transportation agency that is trying to allocate resources based on a limited amount of construction funding. A careful assessment of the circumstances is necessary to assure a prudent use of limited resources; extra time and money can be consumed convincing key decision makers that the risk of using an unfamiliar material is reasonable and acceptable.

Also, FRP has a low modulus of elasticity when compared to steel and concrete (~3,000 ksi vs. 29,000 ksi). This has a direct affect on the stiffness of an FRP structure or deck panel. In order to meet serviceability requirements for deflection, FRP systems are inevitably over designed from a strength perspective. New shapes, manufacturing methods, and hybridization with other materials may lead to a more optimal design, but for now we accept a high factor of safety that is counter to economy of cost. Similarly, uncertainty over material properties gives rise to conservatism and subsequently higher cost. Until manufacturing methods become adopted that assure consistency in material properties that are verifiable with standard testing methods, specification writers will necessarily need to write a tight specification to insure the finished product will be safe and reliable.

Also, manufacturers have not demonstrated a desire to produce a shared standard design. Because of their complexity, a new deck design typically requires a finite element analysis. Furthermore, engineers have ethical responsibilities that prevent them from accepting a "black box" design without fully understanding its behabior. Manufacturers' proprietary interests inhibit acceptance by the practicing engineer and create unnecessary difficulty and confusion. Most bridge designers are not experts in composite materials and prefer to stay with well understood materials rather than venture into the world of new materials and fiber architecture. Since they also need to be considerate of the cost of their services to the bridge owner, it is reasonable for them to take this approach. This also protects them from a perceived increased liability stemming from the use of a non-standard, relatively unknown commodity.

Further Research

Further evaluation of installed decks and laboratory specimens will result in a better understanding of the performance of materials and systems. This will aid the development of better specifications. Some issues needing further investigation are listed in Table 2.

1. Thermal properties (both global and local) 2. Composite behavior 3. Connections to the superstructure 4. Design optimization 5. Deflection control 6. Selection, grading and durability of resins and adhesives 7. Local deformation under wheel loads 8. Wearing surface selection and installation 9. Field joints between prefabricated panels 10. Bridge railing and attachment to the deck 11. Fatigue and long term performance 12. Methods of inspecting and monitoring 13. Repair, strengthening, and stiffening 14. Creep and the potential for sudden failure due to rupture 15. Changes in a bridge's global response to dynamic loading after relieving dead load 16. Ability to reuse or recycle materials

Table 2. Further investigation needed.

Lessons learned

1. Since FRP material is not commonly understood by engineers designing infrastructure projects, FRP suppliers should be held to a performance based specification. Using performance standards also has additional benefits of encouraging innovation and allowing the refinement of new technology.
2. Anticipated strains should be kept under 20% of minimum guaranteed ultimate strength to avoid the risk of creep rupture.
3. Imposed deflection limits should be given careful consideration because of the effect on the cost of the system. The limit selected is a function of rider comfort, but also the ability of the wearing surface to endure local flexure.
4. Consideration should be given to the fact that composite material properties may deteriorate with time. Manufacturers' certified values for material properties may need to be "knocked down" to account for this.
5. An owner should insure that a manufacturer can credibly certify consistency of quality and then should provide its own quality assurance checks. Because most agencies do not have in house expertise in composite materials (and the manufacturer will often be in another state), it will not be feasible to deploy full time plant inspectors to oversee fabrication of FRP decks. Bridge owners will need to rely on a third party certification procedure (e.g. ISO 9001 certification).
6. DOT agencies should ask for a manufacturer's product warranty. Though not offering as much safeguard as a performance bond, it provides a certain level of protection to offset increased risk.

In addition to technical hurdles, increased use of advanced materials for bridge decks will depend on such factors as

a) Training among engineers who are currently practicing and those passing through the academic institutions now.
b) Standard specifications for design, construction and materials testing.
c) Comfort level and understanding. It's new and unfamiliar to the industry. In contrast, properties of reinforced concrete are well known.
d) Risk and fear of the unknown.
e) FRP industry's lack of understanding of standard construction practices and the importance of project schedules. DOT's have a very direct interaction with their client, the tax-paying, traveling public and manufacturers may not be sensitive to the associated responsibilities.

Conclusion

Currently, FHWA encourages the use of innovative construction materials and techniques by providing earmarked funding. The Innovative Bridge Research and Construction Program has provided engineers with the opportunity to exploit the unique properties of these materials even though they might not otherwise be competitive. While the program successfully created an incubation period for engineers to try out the materials, the true measure of success will come when FRP decks are able to compete on their own without supplemental financial support. The above case studies and discussion should offer some insight as to when they can be cost effectively used today.

Acknowledgments

Funding for many of the projects studied was provided by the U.S. DOT Federal Highway Administration (FHWA) under its Innovative Bridge Research and Construction (IBRC) program. The authors thank all contributors of project photographs and Martin Marietta Composites for providing photographs of the manufacturing process.

Disclaimer

Content is the sole responsibility of the authors and does not necessarily reflect policy of Federal Highway Administration, MCEER, or any other agencies cited. Mention of any material, manufacturer, or supplier does not constitute endorsement by the authors or agencies involved.