

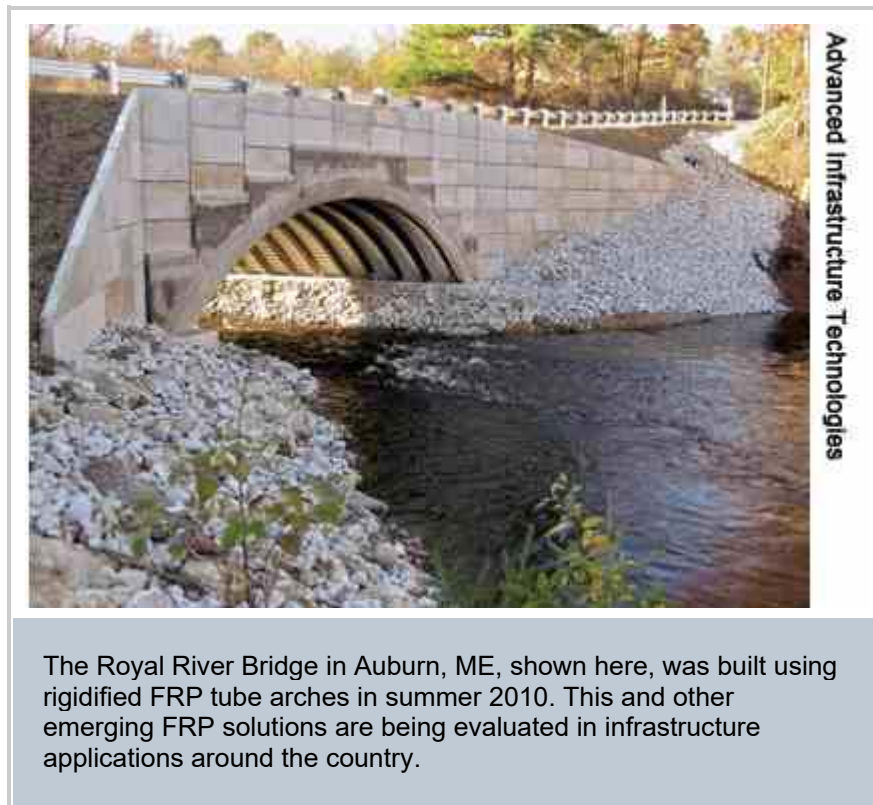
Public Roads, July/August 2011
Vol. 75 · No. 1

Publication Number: FHWA-HRT-11-005

Emerging Bridge Applications

by Louis N. Triandafilou

Researchers and practitioners are applying fiber reinforced polymer composites and reinforced thermoplastics in construction and rehabilitation of highway structures.

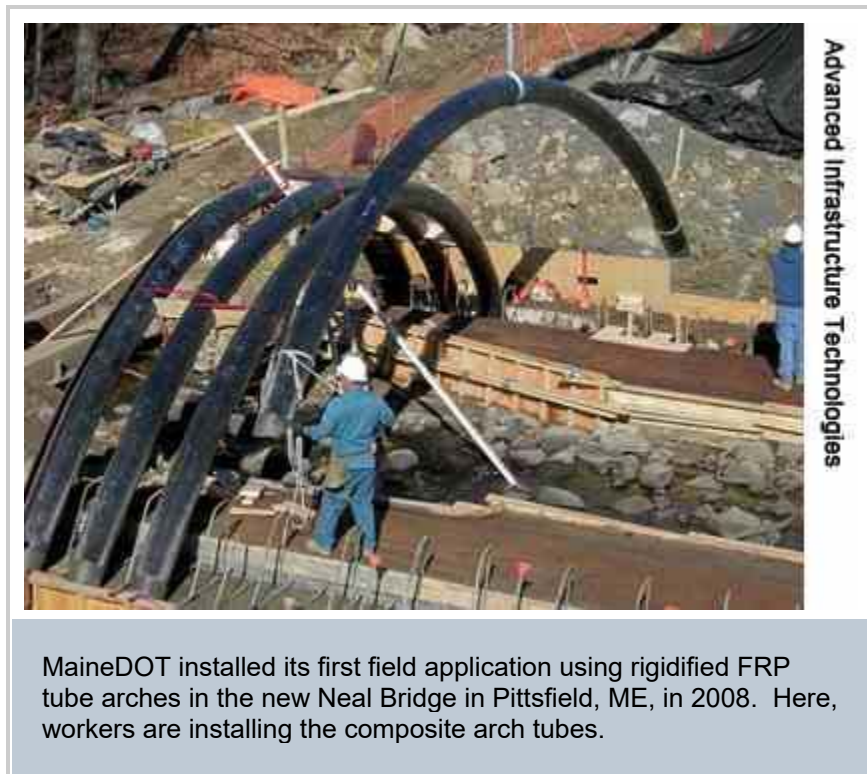


Transportation agencies face ever-increasing challenges minimizing congestion and ensuring the safety of travelers and highway workers while undertaking necessary construction projects. The goal is to offer motorists high-quality, longer lasting highways and bridges while reducing the construction time and traffic congestion that cost the Nation billions of dollars each year in wasted time and fuel.

To meet these challenges, the Federal Highway Administration (FHWA) and State departments of transportation (DOTs) explore and adopt new and innovative construction technologies. For nearly 30 years, FHWA has supported research and development,

technology transfer, deployment, and standardization of fiber reinforced polymer (FRP) composites as a promising solution for bridge construction and rehabilitation.

After a long history of worldwide research, use of FRP composites in seismic retrofits and bonded repairs has become almost commonplace. Also, highway agencies are applying this technology to a growing number of projects involving bridge deck panels and reinforcing bar and prestressing applications. However, despite widespread government and industry support, there has been little self-sustaining, competitive deployment of this technology.



Given the current backlog of structurally deficient and functionally obsolete bridges in the United States — more than 146,000 as of December 2010 according to the National Bridge Inventory — several emerging FRP composite technologies could play an important role in future rehabilitation and replacement. Some promising emerging approaches are focused field applications of rigidified FRP tube arches, hybrid composite beams, and reinforced thermoplastics. Recent deployments in several States highlight field-testing verification of structural properties, initial assessment of potential short- and long-term benefits, implementation challenges, potential agency champions, and patent situations.

Background on FRP

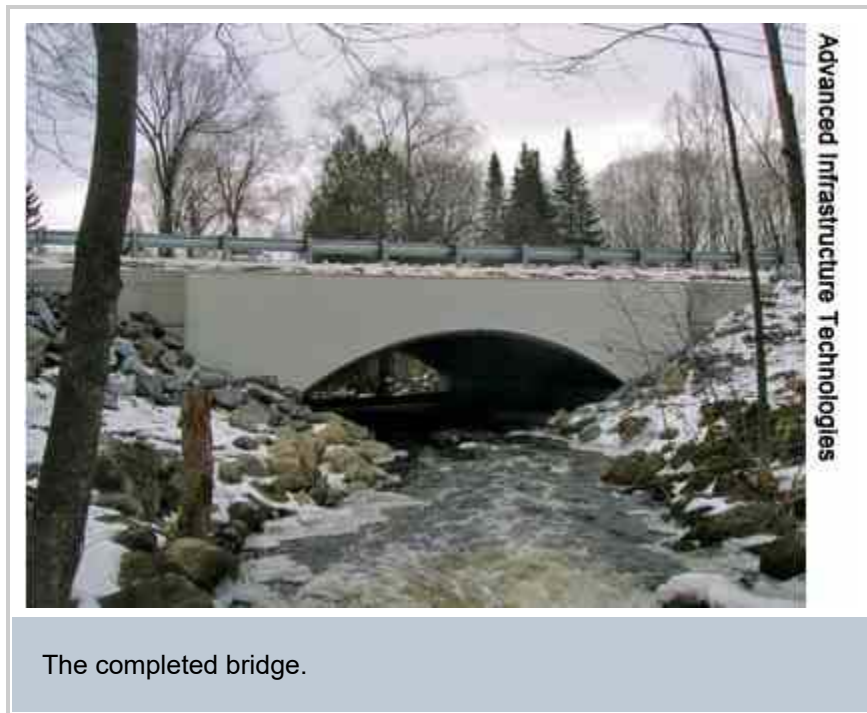
FRP is a general term for polymer-matrix composites reinforced with cloth, matting, strands, or other fibers. FRP composites consist of thermoset resins, which once cured, cannot be returned to an uncured state. Reinforced thermoplastic resin composites, on the other hand, can be softened repeatedly by heating or hardened by cooling. In the softened state, workers can reshape these composites by means of molding or extrusion. FRP and reinforced thermoplastic composites have the potential to create cost-effective, durable, and long-lasting

bridge structures.

With the passage of national highway legislation in the 1980s and 1990s, FHWA's early research evolved into an implementation program that has advanced the application of FRP composites in highway structures. Along with traditional programs that have been carried over from one transportation authorization bill to the next, such as the Highway Bridge Program, more recent legislation including 1998's Transportation Equity Act for the 21st Century and 2005's Safe, Accountable, Flexible, Efficient Transportation Equity Act: A Legacy for Users contained new programs from which States could draw to deploy FRP technologies. A few examples are the Innovative Bridge Research and Construction Program, and its successor, the Innovative Bridge Research and Deployment Program, and the Highways for LIFE Program (an effort to advance longer-lasting highway infrastructure using innovations to accomplish the fast construction of efficient and safe highways and bridges).

In addition to providing funding, FHWA has demonstrated a leadership role in forging partnerships with State DOTs, industry, and academia in use of these emerging materials.





Rigidified FRP Tube Arches

Erecting bridges in environmentally sensitive areas presents a number of challenges, not the least of which is getting the requisite heavy machinery into the area. Seeking a low-cost, low-impact bridge solution for these types of environments, researchers with the University of Maine's Advanced Structures and Composites Center set about developing a bridge kit that could be delivered to a jobsite in the bed of a pickup truck and installed in a matter of days using only light-duty equipment. Funding from FHWA's Innovative Bridge Research and Construction Program helped support research and development of the bridge kit.



Workers are pouring concrete into FRP tube arches for the Royal River Bridge, constructed in Auburn, ME.

The kit consists of three main components: carbon- and glass-FRP composite tube arches, a self-consolidating concrete mix design, and corrugated fiberglass panels. Once onsite, workers inflate the 12- to 15-inch (30.5- to 38-centimeter) diameter tubes and bend them around arch forms. The crew then uses a vacuum-assisted transfer molding process to infuse the tubes with resin. The tubes, which cure in a matter of hours, function as stay-in-place forms for the self-consolidating concrete, eliminating the need for temporary formwork. They provide structural reinforcement for the concrete in the longitudinal direction, in shear, and as confinement, eliminating the need to install rebar. Over the longer term, the tubes will help protect the enclosed concrete from deterioration.

The self-consolidating concrete mix design uses high-range water reducers to achieve enhanced flowability and viscosity-modifying admixtures to achieve stability, eliminating aggregate segregation. The mix also includes set retarders (for stabilizing hydration), shrinkage reducing admixtures, and 0.375-inch (9.5-millimeter) pea stone aggregate.

The rigidified FRP tube arch technology underwent nearly 5 years of development and testing by principal investigator Habib Dagher, Ph.D., director of the University of Maine's Advanced Structures and Composites Center and professor of structural engineering. Dagher and his team subjected specimens of varied diameter and shell properties to static and fatigue tests to validate finite element modeling tools. The model predicted the nonlinear load-deflection response and capacity that resulted from laboratory four-point bending tests of concrete-filled FRP tubular beams.

They also subjected the arches to two-stage static load tests. The first test was to determine the initial tensile rupture at the crown, at a load corresponding to the ultimate strength of the arch. At the crown, the arch maintained stability along with a significant portion of its initial strength. Then the researchers investigated post-damage behavior until tensile rupture at the shoulders, signifying complete instability and failure of the arch. Actual behavior of the arch

was tested to within 3 percent of the finite element modeling predictions, documenting the high degree of accuracy of the analytical tool.

Rigidified FRP Tube Arches in the Field

The first field installation occurred in 2008, when the Maine Department of Transportation (MaineDOT) replaced the 70-year-old Neal Bridge in Pittsfield. Workers installed 23 arches at 2-foot (0.6-meter) spacing to create a 34-foot (10.7-meter) span. Construction was completed in less than 2 weeks at a cost of about \$581,000, which was comparable to the cost of a steel or precast concrete bridge.

In 2009, MaineDOT built a second rigidified FRP tube arch structure, the McGee Bridge, in North Anson. This 28-foot (8.5-meter)-long bridge, also constructed in less than 2 weeks, cost about \$89,350, which was the lowest bid alternative submitted. MaineDOT awarded a third bridge in April 2010 and advertised another two in fall 2010, and three more are in design. All these structures are being funded through an initiative sponsored by the Maine Governor that aims to incorporate composite technologies into bridge construction and maintenance. The University of Maine is working with Advanced Infrastructure Technologies, a company headquartered in Orono, ME, to market this technology. The Massachusetts Department of Transportation expects to have a project underway later this year.

"Rigidified inflatable FRP tube arches could serve as an alternative to other proprietary [and conventional] arch bridge systems for use in a number of ordinary applications for spans of 20-100 feet [6.1-30.5 meters]," says the University of Maine's Dagher. "Advantages include speed of construction and ease of access to environmentally sensitive areas and other locations where it is not feasible to bring in heavy equipment. This type of bridge structure has...proven to be cost competitive based on alternate bidding with conventional materials. Further, it has the potential to last longer in severe exposure environments, resulting in lower life-cycle and maintenance costs."



Hybrid composite beams are a critical component in the new Knickerbocker Bridge in Boothbay, ME. This view of the bridge under construction shows the erected beams with their wing extensions.

Hybrid Composite Beam Technology

A second emerging approach for bridge construction is hybrid composite beams, which combine the properties of concrete, steel, and FRP composites together in beam fabrication. This combination results in stronger and lighter weight bridge members that can be placed using lighter and smaller pieces of construction equipment. Hybrid composite beams offer the possibility of cost-effective spans and corrosion resistance. These beams also offer a lower overall carbon footprint than concrete because they use 70-80 percent less cement. (Cement production accounts for 3.4 percent of carbon emissions worldwide.)

A hybrid composite beam is made up of a compression arch consisting of 6,000 pounds per square inch, psi (41,370 kilopascals, kPa) of self-consolidating concrete that is pumped into an internal arch-shaped conduit. The arch is composed of a polyisocyanate foam similar to roofing insulation. The modulus of elasticity of the self-consolidating concrete is 4.4 million psi (30.34 million kPa). The tension reinforcement consists of either 270,000-psi (1,862-megapascal) galvanized prestressing strand or fiberglass cloth placed in the bottom of the beam. The tension and compression reinforcement are placed within a rectangular fiberglass shell of quad-weave fabric with fibers that are oriented in four directions. This variable orientation gives the shell consistent strength and performance characteristics in all directions, simplifying the design and providing for an efficient use of composites to resist various internal stresses.

Hybrid Composite Beams in the Field

These beams underwent a 14-year research and development program led by John Hillman, who created the HC Bridge Company, LLC, to market this technology. "While working at Jean Muller International, I was exposed to the vacuum-assisted resin transfer molding process," Hillman says. "Combining some knowledge of FRP composites with my experience on a steel arch bridge and numerous posttensioned concrete bridges, I was intrigued with the idea of combining several different materials to create an optimized composite beam. At first it was sort of an academic curiosity, but it rapidly evolved into an obsession to validate the concept."

The first installation of a bridge using hybrid composite beams was on a railroad test track in Pueblo, CO, in 2007. It was a 30-foot (9.1-meter) span designed for Class 1 railroad loads of 320,000 pounds (145,150 kilograms). Researchers erected the structure at the Transportation Technology Center, operated by a subsidiary of the Association of American Railroads. The bridge was subjected to more than 2 years of heavy axle loading — approximately 237 million gross tons or 1.5 million cycles of fatigue. Laboratory and in situ measurements of live load deflections agreed well with analytical predictions, attesting to the accuracy of the predictions.

The first highway installation was on the High Road Bridge in Lockport, IL, in 2008, funded under the FHWA Innovative Bridge Research and Deployment Program. Workers delivered all six of the 57-foot (17.4-meter)-long girders to the site on one tractor-trailer, a clear efficiency benefit compared to the one girder per trailer that would have been necessary for shipping prestressed concrete box beams. Workers erected the six 42-inch (107-centimeter)-deep

girders in less than 3 hours, compared to the 12 hours the contractor said it typically would take to install this number of box beams.

In a side-by-side comparison of a MaineDOT project, a 33-inch (84-centimeter)-deep by 48-inch (122-centimeter)-wide precast concrete box beam weighed about 784 pounds per linear foot (1,167 kilograms per linear meter), while the same depth and width of hybrid composite beam weighed in at 250 pounds per linear foot (372 kilograms per linear meter) with concrete placed in the arch section.

According to Jack Waxweiler, commissioner of the Lockport Township Highway Department, the project was extremely efficient. "It took approximately 90 minutes to set six beams," he says. "For traditional steel beams, this erection process would have taken a lot longer and required the use of heavier equipment. Instead, the hybrid composite beams arrived in one truck, which is much more time efficient and economical. This project finished 2 months ahead of schedule, and I credit the new beam technology for the unusually early completion of a bridge of this magnitude. I am confident that hybrid composite technology will reduce the necessary maintenance and repairs I see with other bridges. My goal is to maintain the best and safest bridges and roads for Lockport Township residents, and I believe the hybrid composite technology helps accomplish this goal. Lockport Township residents are driving on a new state-of-the-art bridge structure."

In June 2009, the New Jersey Department of Transportation installed hybrid composite beams in its replacement of the Route 23 Peckman's Brook Bridge in Cedar Grove, NJ, also funded under the FHWA Innovative Bridge Research and Deployment Program. The 31-foot (9.5-meter) side-by-side girders each weighed only 2,200 pounds (998 kilograms), approximately one-tenth of the weight of each equivalent concrete beam. Workers used a methyl methacrylate material, which has high shear strength, to connect the beams.

MaineDOT also is constructing a hybrid composite beam project: the 8-span, 540-foot (165-meter)-long Knickerbocker Bridge in Boothbay, ME. The design for the beams is a modification of the one used for the Illinois and New Jersey structures, with wings projecting from the upper edges of each beam until they touch each other. This design provides continuous permanent formwork for the cast-in-place deck. Prototype beams have undergone more than 2 million fatigue cycles of successful load testing, failing at 60 percent beyond minimum design code requirements.

According to Nate Benoit, project manager for the MaineDOT Bridge Program, the department chose hybrid composite beams for the Knickerbocker Bridge for a number of reasons. "First, the bridge is in a saltwater environment with limited freeboard," he says, "and we wanted to take advantage of the high corrosion resistance that the hybrid composite beam shell provides. Second, the lightweight superstructure required only one crane and one barge to erect the bridge. Third, the lightweight superstructure reduced the dead load applied to the pile bents and allowed for a more economical substructure." All beams have been erected, and the project is on schedule for a June 15, 2012, completion.

Other State DOTs have plans to use the hybrid composite beams. For example, the Virginia Department of Transportation (VDOT) intends to use the technology on a bridge at Route 729 over Battle Run in Rappahannock County. VDOT is working with the Virginia Center for Transportation Innovation and Research and Virginia Tech's Cooperative Center for Bridge Engineering to research and deploy this and other FRP technologies and applications.

Reinforced Thermoplastics Technology

A third emerging technology for bridge applications is reinforced thermoplastics, which consist of 65 percent high-density polyethylenes blended with 35 percent polystyrene or polypropylene glass fibers. The resulting materials have a high resistance to corrosion, rotting, and insect infestation, making them excellent candidates for replacing deteriorated railroad ties. Reinforced thermoplastics also possess favorable durability and toughness characteristics without chemical additives.

Thermoplastics are lightweight, at 55 pounds per cubic foot, lb/ft³ (881 kilograms per cubic meter, kg/m³), compared to 60 lb/ft³ (961 kg/m³) for wood, 150 lb/ft³ (2,403 kg/m³) for reinforced concrete, and 490 lb/ft³ (7,849 kg/m³) for structural steel. Favorable engineering properties such as flexural, compressive, and shear stress make these materials a viable alternative for highway bridge applications.

In laboratory testing at Rutgers, The State University of New Jersey, Dr. Thomas Nosker also found that thermoplastics are virtually impervious to moisture, retaining their properties in humid and wet environments. Thermoplastics also are chemically resistant to most acids and salts, and resist abrasion by the salt and sand typical of marine environments. In addition, Nosker developed fire inhibitors that can be added to the formulation of reinforced thermoplastics and has requested fire resistance testing in accordance with ASTM International standards.

When deployed in bridge applications, reinforced thermoplastics represent a potentially long-lasting alternative to wood structures. According to Nosker, each year millions of tons of plastics are dumped in landfills worldwide. Diverting some of these materials to bridge applications represents an environmentally preferable solution for reusing a waste product in the context of replacing deficient low-speed, low-volume bridge structures. In addition, with the application of concrete or asphaltic concrete to the deck, reinforced thermoplastics could be an option for an even greater range of applications.

Reinforced Thermoplastics In the Field

Most of the initial bridge applications using reinforced thermoplastics have been on U.S. Army base installations, including at Fort Bragg, NC, Fort Eustis, VA, and Fort Leonard Wood, MO. The Army's interest in the technology was prompted by the need for corrosion-resistant, high-strength bridges with low life-cycle costs and a high return on investment. And, Army officials were aware of Nosker's work in the late 1980s on recycled plastic lumber.

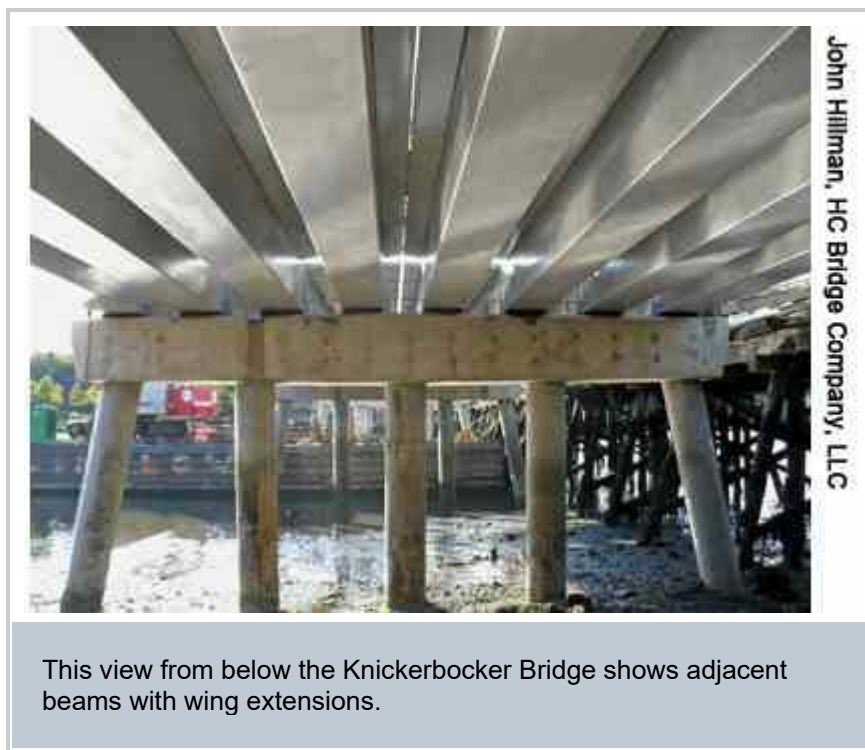
The Army subjected the bridges to load testing involving jeeps and tanks. The Fort Leonard Wood structure, installed in 1998, involved a 24-foot (7.3-meter)-long by 26-foot (7.9-meter)-wide deck replacement on existing abutments. The bridge was designed for a maximum load of 25,000 pounds (11,340 kilograms), which would accommodate the base's military vehicle traffic. The structure at Fort Bragg is an all-thermoplastic bridge — pilings, pile caps, and deck — that was completed in 2009 and successfully load tested with a 70-ton (63.5-metric ton) M1 Abrams tank.

At Fort Eustis, in 2010, the Army completed two railroad bridges with most components consisting of recycled structural plastic materials. The four-span, 36.5-foot (11.1-meter) and eight-span, 84-foot (25.6-meter) structures were designed for appropriate American Railway Engineering and Maintenance-of-Way Association design loads and deflection criteria.

Aside from retaining the existing timber abutments, the Army decided to use reinforced thermoplastic materials in all remaining elements and components, including the railroad ties,

curbs, girders, shear blocks, pier caps, piling, and transverse connectors. Researchers measured deflections during locomotive load testing to be approximately 0.25 inch (6.35 millimeters) on each bridge, which was within 0.03 inch (0.762 millimeter) of estimated deflections and met the railway association's criteria.

The New Jersey Department of Environmental Protection (NJDEP) funded construction of the first known reinforced thermoplastic bridge for automobiles in Wharton State Forest in 2002. The 56-foot (17-meter)-long structure was designed for standard highway bridge loadings and included reinforced thermoplastic bents and I-beams. "NJDEP already had funding available and was interested in a lightweight, low-maintenance structure," Nosker says. "It was aware of our work at Rutgers and asked us to build the bridge. It took four of us 11 days to complete the bridge, using 30,000 pounds of material. We would have needed 90,000 pounds of conventional timber to complete the job. After nearly 10 years in service, the bridge is still performing very well."





Claude Napier, VDOT

The U.S. Army built this railroad bridge at Fort Eustis in Newport News, VA, using recycled structural plastic materials, also known as reinforced thermoplastics.

Axion International, Inc., a company based in New Providence, NJ, is producing and marketing the reinforced thermoplastic materials. Counties in Maine and Ohio are in the process of designing highway structures using reinforced thermoplastics. The North Carolina and Virginia DOTs also have expressed interest in the material. In addition, reinforced thermoplastics are finding their way into other infrastructure applications such as marinas, fenders, boardwalks, culverts, and temporary, reusable bridges.

AASHTO Implementation

The American Association of State Highway and Transportation Officials' (AASHTO) Technology Implementation Group has evaluated the two highlighted FRP technologies and reinforced thermoplastics. Specifically, AASHTO's assessments addressed the following factors: (a) adequacy of field testing, (b) potential for substantial benefits, (c) potential for widespread application, (d) necessity of technology promotion, (e) primary implementation challenges, (f) potential for champion agencies, (g) existence of patent situations, and (h) marketing level needed.

Based on these assessment factors, members of the AASHTO Subcommittee on Bridges and Structures' Technical Committee T-6 Fiber Reinforced Polymer Composites ranked the three technologies as focus areas for the near future. The committee determined a high level of desirability for advancing the rigidified FRP tube arches and hybrid composite beams, and a moderate level of desirability for the reinforced thermoplastics. MaineDOT has volunteered to be the lead State, taking on the next step in the implementation process, which will include conducting a market analysis and developing a marketing plan for technology implementation. Other State DOTs represented on the team include Massachusetts, Michigan, Missouri, and New York, along with the Maine Composites Alliance and the University of Maine.

Benefits of FRP Technologies

Based on the experiences gained from the field deployments and assessments performed by the participating agencies, these emerging bridge technologies can yield a number of benefits. First, these materials offer a reduced carbon footprint and have the potential to achieve a minimum 100-year service life using 80 percent less cement than concrete. FRPs are lightweight — on the order of 10-20 percent (based on calculated unit weights of the materials) of the weight of concrete — and are corrosion resistant. In addition, they consistently exceed the bridge design code requirements for strength specified by AASHTO's Load and Resistance Factor Design guidelines.

Finally, FRPs support FHWA's Every Day Counts initiative, which aims to identify and deploy innovations to shorten project delivery, enhance safety, and protect the environment. Toward that end, FRPs offer solutions for project delivery and congestion relief by accelerating bridge construction with prefabricated elements and systems.

Challenges With Implementation

Despite the success of completed field installations and backing from FHWA and AASHTO, these technologies continue to face impediments to widespread deployment. One challenge is the sole source nature of the emerging products, which would require the need for alternate bid designs.

Manufacturing capacity currently is limited to one supplier. Also common to each is the lack of AASHTO-approved vehicular design standards, which is where the Technology Implementation Group comes in with its evaluations. For the reinforced thermoplastics technology, the current lack of capability to attach a crash-tested bridge railing that meets AASHTO design standards limits the number of applications with vehicular traffic. Also, researchers have not yet investigated the application of a proven deck overlay material. Other challenges include the need for education in the use of these new FRP technologies and for developing procedures for load rating and conducting safety inspections of these types of bridges.

Toward Commercialization

The emergence of these technologies is one measure of the success of FHWA's Applied Highway Infrastructure Research Program on Composite Materials, which was implemented in the 1990s. That program identified two interdependent measures: field implementation and private sector involvement. Each of these three technologies has involved private sector companies with manufacturing know-how, marketing expertise, and regional or national sales organizations. Engineers who have an understanding of composite structural design have provided the engineering design. Together, with public sector leadership, these private sector innovators are pursuing the promise of an improved driving experience for the American public.

Building on this successful track record, highway agencies, industry, and academia are continuing to move forward in developing and deploying FRP composites and reinforced thermoplastic technologies in infrastructure applications. With the backing of AASHTO and recent naming of a lead State (Maine) to spearhead ongoing evaluations, researchers will continue to advance these technologies through field testing and monitoring, verification of structural properties, and assessment of short- and long-term structural performance. With all partners working together, these technologies are on track to finding greater acceptance and

adoption across the country.



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