# FRP Reinforced Concrete in Texas Transportation—Past, Present, Future

by T. E. Bradberry and S. Wallace

**Synopsis:** Fiber reinforced polymer (FRP) materials can be used in concrete infrastructure elements to achieve short-term and long-term construction and performance goals that cannot be met with traditional steel reinforcement. Like other states, Texas is faced with materials-based transportation infrastructure challenges including: deterioration of concrete due to the corrosion of steel reinforcement, bridge girders damaged by vehicle impacts, concrete bridges that have no visual signs of distress but are load-posted or otherwise deficient in load rating, girders and bent caps that have inadequate shear reinforcement by current standards or that exhibit service cracking, and even a need to provide reinforcement that does not interfere with vehicle imaging loops requiring magnetic/electrical isolation near turnpike toll plazas. This paper reports on Texas transportation infrastructure construction and maintenance projects where FRP materials have been implemented as a means to meet each of these challenges. Included herein are descriptions of selected Texas Department of Transportation (TxDOT) construction and maintenance projects involving concrete internally and externally reinforced by FRP materials. These projects are either completed or will soon go to contract. Most of these projects have been carried out on a trial or experimental basis but they serve to provide a brief glimpse into the probable future of FRP reinforcement in Texas transportation projects.

Keywords: corrosion-induced concrete deterioration; fiber reinforced polymer composites; FRP repair; FRP strengthening; impact damage; infrastructure; rehabilitation; structural concrete; transportation

**Timothy E. Bradberry, P.E.,** an engineer-manager in the Bridge Division of the Texas Department of Transportation, Austin, Texas, received his BSCE from Auburn University and his MSCE from the University of Texas at Austin. He is a member of ACI Committee 440, Fiber Reinforced Polymer Reinforcement. His interests include design of structural concrete, shear behavior and time dependant behavior of structural concrete and design and analysis of bridges.

**Scott L. Wallace, P.E.,** a senior bridge engineer at Carter & Burgess, Inc, in Austin, Texas, received his BSCE from South Dakota State University. He formerly worked for the Federal Highway Administration, developing a design procedure for FRP pedestrian bridges. His research interests include fiber-reinforced-polymer-reinforced concrete bridges and fiber-reinforced-polymer pedestrian bridges.

## INTRODUCTION

With the recent publication of design guidelines for the application of FRP internal and external reinforcements to reinforced concrete, design engineers now have tools with which to meet challenges, which steel reinforcement has not satisfactorily met in the past. Not the least of these challenges has been that presented by the aging and deterioration transportation infrastructure of the United States. To a significant degree these same challenges face engineers at the Texas Department of Transportation (TxDOT). Fiber-reinforced-polymer (FRP) reinforcement has been used in Texas to meet such challenges on a number of projects in recent years. Some applications, such as using FRP as internal reinforcement for the purpose of eliminating electrochemical corrosion of reinforcement and subsequent corrosion product induced deterioration of surrounding concrete, have limited application in Texas. This is because, other than in marine environments, concentrations of chlorides in concrete exceeding corrosion threshold levels are not as prevalent in Texas as they are in jurisdictions to the north. Other applications, such as externally bonded FRP strengthening of bridge elements, whose original design strength is now substandard making otherwise healthy looking concrete bridges load rate below acceptable levels for widening or other rehabilitation, are likely to be more widely employed. Externally bonded FRP fabrics used in the repair of impact damaged bridge girders are fast becoming an accepted practice by TxDOT bridge maintenance engineers and thus shows promise for more widespread use in Texas. Yet another emerging application for FRP internal reinforcement exploits the non-magnetic property of GFRP reinforcement to provide reinforced concrete that does not interfere with vehicle imaging loops requiring magnetic/electrical isolation near turnpike toll plazas. Examples of these projects plus an application where FRP reinforcement is used to correct a design flaw are presented in this paper. Finally, the future of FRP reinforcement in Texas transportation infrastructure is briefly considered.

## RESEARCH SIGNIFICANCE

This paper demonstrates the increasing use of FRP reinforcement by TxDOT transportation engineers in the construction and repair of transportation infrastructure for the state of Texas. All the projects presented have been designed by TxDOT transportation engineers or TxDOT consultants who, presented with a structural or material problem, solved the problem by using FRP reinforcement. These projects indicate that FRP reinforced concrete is considered by TxDOT engineers to be a viable option to traditional steel reinforced concrete in environments and situations where steel reinforced concrete has not performed well or cannot be effectively used.

## FRP REINFORCEMENT

Although FRP is a new material for reinforcing concrete in the transportation infrastructure industry, it has been a primary material in the aerospace, automotive, and recreational equipment industries for years. Because of its reduced weight, superior corrosion resistance, and magnetic transparency, FRP reinforcement in concrete elements may offer longer life and more versatile application than traditional steel reinforcement, particularly for transportation infrastructure. In Canada, where reinforced concrete bridge decks deteriorate due to corrosion of steel reinforcement and are replaced approximately every twenty years, the Ontario Ministry of Transportation is using FRP composite reinforcement for extending bridge deck service life to 75 years *(1)*. In the United States FRP reinforcement is also being used in transportation infrastructure, with the first application of internal reinforcement being the fully GFRP bar reinforced concrete deck of a bridge in McKinleyville, West Virginia, built in 1996 *(2)*.

Transportation design engineers in the United States have been reluctant to employ FRP reinforcement largely because of their perception that design and construction standards or guidelines are not available and because of the challenges to reinforced concrete design philosophy presented by FRP reinforced concrete. In fact, domestic state governments and engineering associations worldwide are cooperating to standardize workable national and international design parameters and specifications. In addition, the composites industry is forging critical associations with the civil engineering community and organizations such as the American Concrete Institute (ACI) and the Civil Engineering Research Foundation (CERF) *(3)*. CERF alone has funded approximately $4,000,000 of research in this effort as of 2002. In May of 2001, ACI Committee 440, "Fiber Reinforced Polymer Reinforcement", published an emerging technology series document offering guidance to engineers in the design and construction of concrete reinforced with FRP bars *(4)*. In October of 2002, ACI Committee 440 published a second emerging technology series document, one that includes recommendations on the engineering and construction of concrete strengthened with externally bonded FRP systems *(5)*. FRP strengthening systems use FRP composite materials such as laminates and fabrics as supplemental externally bonded reinforcement. Development of these and similar design and construction documents backed by good research data and demonstrated field experience are essential to overcoming the individual and corporate reluctance of infrastructure designers to employ FRP reinforcement in transportation projects.

## USE OF FRP REINFORCEMENT IN TEXAS

The Texas Department of Transportation (TxDOT) supports the use of FRP reinforcement and is increasingly employing it to meet challenges such as the following:

- Concrete deterioration caused by steel reinforcement corrosion.
- Rapid repair of overheight vehicle or payload impact damage to bridge superstructure elements such as prestressed concrete bridge girders.
- Rehabilitation of bridges whose current load rating is inadequate because they were built before implementation of the HS-20 design live-loading.
- Strengthening or repair of girders and bent caps that have inadequate shear reinforcement by current standards or exhibit service cracking that is aesthetically undesirable and may be of structural concern, such as the cracking that often occurs at the reentrant corners of inverted tee bent caps.
- Reinforcement that will not interfere with vehicle imaging loops requiring magnetic or electrical isolation near the planned toll plazas of the Texas Turnpike Authority's central Texas (Austin District) toll roads.

### Repair and Strengthening Using Externally Bonded FRP Fabrics and Laminates

Three completed projects are reported to illustrate the use of externally bonded FRP fabrics and laminates in the repair and strengthening of Texas transportation infrastructure projects:

- The repair of an impact-damaged bridge superstructure using a carbon FRP (CFRP) system.
- The strengthening of a pan girder bridge using CFRP systems to increase its load rating.
- The repair and strengthening of the ends of inverted-tee bent caps having cracked reentrant corners, using a CFRP system.

### Solution for Corrosion-Induced Concrete Deterioration

In the Texas panhandle, frequent use of chloride-containing deicing agents has pushed the chloride concentration at the level of reinforcement in many concrete bridges past the steel corrosion threshold, resulting in corrosion-induced deterioration of the reinforcement and deleterious cracking of the surrounding concrete. One completed Texas project illustrates use of glass FRP (GFRP) internal bar reinforcement as an alternative to epoxy-coated steel reinforcement for preventing corrosion-induced concrete deterioration in a bridge deck.

## Solution for Magnetic Transparency Needs of Vehicle Imaging Loop Detectors

A recent realized transportation application of FRP reinforcement is its use in central Texas as reinforcement for pavement and bridge deck sections on area toll roads. Loop detectors embedded in concrete riding surfaces generate magnetic fields that enable them to detect characteristics of vehicles as they pass through toll plazas. For the system to function properly, magnetic fields must not be allowed to generate electrical current that could result in cross-talk between adjacent and remote loop detectors. GFRP reinforcement's unique, non-magnetic, non-conductive properties meet this challenge. One Texas project currently awaiting construction illustrates this unique application.

## Past Project: GFRP Reinforcement in a New Concrete Bridge Deck

**Background**–Corrosion of metallic reinforcement accelerated by the use of chloride containing deicing agents is a primary cause of concrete bridge deck deterioration. A potential innovative solution to this problem is to eliminate this corrosion by using electrochemically inert FRP bars in lieu of steel reinforcement. However, because FRP bars are linearly elastic to failure TxDOT engineers have been hesitant to use them. Nonetheless, TxDOT engineers requested funds through the TEA-21, Innovative Bridge Research and Construction Program (IBRCP) for a proposal to use FRP bars as reinforcement in a concrete bridge deck. The IBRCP required TxDOT to use the FRP bars as an innovative material before performing companion research. This is due to a requirement that the innovative material be incorporated into a construction project which encumbered the funds in the same fiscal year in which they were awarded; a time frame within which the contracting and completion of a companion research program was not possible. The IBRCP facilitated the design and construction of a TxDOT bridge that incorporated FRP bars in its concrete deck by providing funds for field monitoring, comprehensive laboratory companion testing, and the estimated increased cost of the FRP bar reinforced deck over what a conventionally designed and constructed bridge deck would cost. An important factor contributing to the success of the project in light of the restrictions the program placed on obtaining and using the findings of companion research was the transfer, during the project design phase, of preliminary consensus design guidelines to the design engineer by members of ACI Committee 440. This sharing of design technology occurred prior to the publication of ACI 440.1R-01 *(4)*.

**Project Overview**–In the year 2000, TxDOT used GFRP bars as top mat reinforcement in the concrete deck of the Sierrita de la Cruz Creek Bridge constructed near Amarillo, Texas. Placed in service in January 2001, the phase-constructed bridge carries an estimated 1,650 vehicles per day (including approximately 300 trucks, many of which are fully loaded gravel trucks) along a portion of Ranch-to-Market Road 1061 (RM 1061) situated in Potter County, Texas. The bridge is the first Texas transportation application of internal FRP reinforcement.

The project bridge design engineer performed the complete bridge design, including the GFRP-bar reinforced concrete deck *(6)*, consulting extensively with various members of ACI Committee 440 because the Committee's ACI 440.1R-01 *(4)* document had not yet been published. The bridge design engineer assumed the Westergaard theory of slab behavior to determine the distribution of wheel load effects to the design forces to the deck *(7)*. In current Texas practice, concrete bridge decks are typically supported on prestressed concrete beams having no end or interior diaphragms (see Figure 1); therefore, arch slab behavior relying on the development of compressive membrane forces and restraint of beam top flange movements cannot be fully achieved—thus internal reinforcement of the bridge decks is required. The resulting design was governed by serviceability considerations with the estimated crack width being the controlling parameter. For a detailed treatment of the design procedure see Reference 6.

The bridge deck design accommodated the properties of all the GFRP bars that were available in North America in 1999, the year the project was designed. The design team developed special specifications for the GFRP bar reinforced concrete slab and the contractor selected the product which met the special specification. The contractor, who was awarded the contract through the competitive bid process, chose GFRP bars produced by Hughes Brothers, Inc. of Seward, Nebraska.

Figure 2 shows concrete being placed on the GFRP-bar mat, which is chaired off the precast, prestressed concrete subdeck. These panels are reinforced with conventional active steel prestressing strands in the span direction (perpendicular to the beams) and passive steel bars in the orthogonal direction. The panels provide the critical positive-moment reinforcement for all bays (the region of slab between adjacent beams) except the bay where the two phases of construction meet. For that bay, epoxy-coated steel bars provide positive-moment bottom reinforcement.

The specific gravity of GFRP bars is about one fourth that of steel reinforcement. Although the savings in mass (weight) of the finished bridge deck is minimal, the transportation cost for the reinforcement is less and the placement cost, as measured by the ease with which the "iron workers" are able the place the bars in the formwork, is also less for GFRP bars as compared with epoxy-coated steel bars. This was the experience of the contractor for this project.

The new structure replaced a functionally obsolete reinforced concrete pan-girder structure that had exhibited significant loss of concrete cover due to corrosion-induced deterioration of the reinforcement. The all new 13.8-m (45.28-ft) overall-width bridge consists of seven 24.0-m (78.74-ft) prestressed concrete girder spans, two of which have top mat GFRP-bar reinforced concrete decks. The remaining five spans have top mat epoxy-coated-steel reinforced concrete decks for performance comparison with the GFRP-bar reinforced concrete decks.

**Research and Technology Transfer**–Two related research studies are associated with the Sierrita de la Cruz Creek Bridge.

The federally funded (IBRCP) TxDOT Research Project No. 9-1520, "FRP Reinforcing Bars in Bridge Decks", conducted by a consortium of three research agencies—Texas Transportation Institute (TTI) at Texas A&M University, The University of Texas at

Arlington (UTA), and Texas Tech University (TTU)—serves as the bridge deck monitoring and companion test research program. The scope of this project includes evaluation and documentation of the performance of FRP bars used as internal top mat reinforcement in bridge decks and the development of AASHTO type design recommendations for their application. The study involves a literature search to document the state-of-the-art, laboratory companion tests to establish material and structural behavior, full-scale prototype crash testing, and field monitoring of the prototype FRP reinforced concrete bridge deck system during construction and early service life. This project is still underway, having been extended ten months to complete the last of the required testing. Two interim research reports have been published *(8, 9)*.

The Texas funded TxDOT Research Project No. 0-4138, "Full-Scale Crash Tests of FRP Bar Reinforced Bridge Rails," conducted by TTI grew directly out of the IBRCP funded project in order to investigate the crash worthiness of fully FRP reinforced concrete bridge rails. This project addresses the behavior of such concrete bridge rails on concrete deck slab structures where both rail and slab are reinforced with GFRP bars when the rail/slab system is subjected to full-scale vehicle crash tests in accordance with the requirements of NCHRP 350, Test 3-11. This project has been completed and the final and summary reports approved for publication *(10, 11)*.

TxDOT has also sponsored UTA's participation in the bond test portion of the "ConFibreCrete" European research network, Federation of Concrete (FIB) Task Group 9.3, and ISIS Canada jointly organized "Round Robin Tests for FRP Reinforcement" *(12, 13)*.

To demonstrate and generate interest in the IBRCP project, the Federal Highway Administration (FHWA) sponsored a half-day innovation showcase on July 25, 2000, in conjunction with the July 26, 2000 placing of the concrete for the first phase of the bridge deck. Also, the bridge design engineer has received and filled requests for technical information about this project. The requests came from several interested state DOTs who were considering, planning or designing their own FRP bars in bridge deck projects as well from Dr. Brahim Benmokrane was designing such a project to be build in Canada.

## Past Project: Externally Bonded CFRP System for Repair of an Impact Damaged Bridge Girder

**Background**–Occasionally in Texas an overheight truck, or its payload, hits a bridge superstructure and causes enough damage that a structural repair is warranted. For prestressed concrete beam superstructures, depending on the degree of severity of the impact damage, three classes of repair procedures and materials are employed in compliance with TxDOT Special Specification Item 4421, "Repair of Impact Damaged Prestressed Concrete Bridge Beams" *(Appendix "A")*, with Category I repair being that class of repair required for the most severely damaged beams. Since the development of this special specification TxDOT research has provided guidance on damage assessment and repair protocols *(14)*. More recently, it has become common practice for the Bridge Division bridge construction and maintenance engineer charged with the design of such repairs to use externally bonded FRP fabric as a little "extra insurance" or, in a recent case not reported herein, as a fully designed and explicit load carrying element.

**Project Overview**–An over-height vehicle struck the Farm-to-Market 1927 (FM 1927) bridge over eastbound IH 20 in Ward County in the Odessa District on January 17, 2002, severely damaging an external beam. The four-span precast prestressed concrete beam bridge was built in 1964. The simply supported superstructure consists of two 13.72-m (45-ft) end spans and two 18.29-m (60-ft) interior spans with four beams at 2,438 mm (8-ft) center to center in each span. The damaged beam is a Type C beam in the 18.29-m (60-ft) span over eastbound IH 20, and it required closing of a lane of IH 20 during the inspection and repair. The beam's web and the bottom flange near the middle of the span between two diaphragms were fractured into several pieces as shown in Figures 3 and 4. However, based on visual inspection and "sounding" of the forty-four 13-mm (3/8-in) diameter prestressing strands, all but one were in good condition and seemed to have retain the "lion's share" of their pre-impact tension, in spite of the loss of surrounding concrete. The one exception was a strand which had been severed in a previous impact. The concrete deck, the top flange, and the rest of the beam were in good shape.

After careful evaluation, TxDOT engineers concluded that the damaged beam was repairable. Because a large area of concrete in the web of the beam was severely fractured, the Bridge Division bridge maintenance engineer proposed one layer of CFRP composite in addition to the normal repair method to restore the shear strength and the integrity of the beam. The CFRP composite wrap was not rationally designed to carry a particular level of stress but rather was assumed desirable for enhancing the integrity of the repair. The damage assessment described above and the subsequent repair procedures described below were informed by TxDOT sponsored research *(14)*.

TxDOT engineers provided details and specifications for the repair work. Repairs to the prestressed concrete beam were in accordance with Special Specification Item 4421, "Repair of Impact Damaged Prestressed Concrete Bridge Beams," Category I repair *(Appendix "A")*. Category I repairs are targeted at damaged prestressed concrete beams with significant spalling, section loss, and cracking. The special specifications give the engineer authority to require that a loaded 9.17-cu m (12 yard) dump truck or other loaded vehicle, as approved by the engineer, be placed on the bridge over the damaged beam to keep the beam loaded while the repair material cures. The benefits of this preloading prior to repair are numerous and include 1) restoration of beam profile and precompression, 2) facilitation of the removal of damaged concrete, 3) improved penetration of injected epoxy into cracks opened by preloading, 4) restoration of a portion of the effective prestress of the strands, and 5) precompression of the patching material providing a hedge against subsequent cracking under service loads *(14)*. TxDOT engineers recommended that the loaded trucks stay on the span until the patched concrete cured for at least 24 hours and reached 27.58 MPa (4,000 psi) using high early strength concrete. After completing the concrete repair, including the injection of epoxy to seal cracks and the removal of the loaded truck from the deck, the contractor wrapped the repaired area between two adjacent diaphragms with a single layer of CFRP composite fabric. TxDOT engineers specified that the CFRP installation be performed by a subcontractor who specialized in the work following the manufacturer's instruction and with approval of the Engineer. The direction of the longitudinal fiber was perpendicular to the longitudinal beam axis (vertical on the web) because the CFRP was intended for shear strengthening.

The Bridge Division construction engineer estimated the costs of two alternative repairs as follows:

- *Estimated Cost to Repair the Beam*—$26,445 (including the use of the CFRP) plus the cost of mobilization and traffic-handling during an estimated seven days of construction time.
- *Estimated Cost to Replace the Beam*—$54,866 plus the cost of mobilization and traffic-handling during at least 20 days of construction time and 10 days of fabrication and delivery time for the new Type C Beam.

The work included concrete repair using rapid-set non-shrink multipurpose grout and rapid set non-shrink concrete mix with a gravel size of 9.52-mm (3/8-in), epoxy injection, and installation of a CFRP-composite wrap made by Sika, consisting of a unidirectional carbon-fiber fabric and a compatible epoxy adhesive.

Patching of the concrete and the epoxy injection took four days; CFRP composite installation took one day. The total cost was $47,000, which included $22,000 for concrete repair and $25,000 for CFRP composite installation. The area of CFRP installation was about 13.94-sq m (150-sq ft). This small area of CFRP and the cost of mobilization may be the primary reasons this job was so costly on a unit basis. After completion of all repair work, all lanes under the bridge were opened to traffic in April of 2002 (see Figure 5).

## Past Project: Externally Bonded CFRP Systems for Increasing the Load Rating of a Bridge

**Background**–Brena, et al *(15, 16)* conducted TxDOT sponsored research to investigate the feasibility of using externally bonded FRP composite material to increase the load rating of bridges in order to make them eligible for widening[1]. The research testing program involved two phases—first, static and dynamic tests on a total of thirty

[1]A bridge widening project requires that the portion of the bridge to remain have a load capacity high enough to justify widening over replacement. This capacity is quantified through various load ratings that are normally based on the original bridge plans and material specifications but sometimes include such items as mill test reports to get a better idea on the "real" material properties. However, assessment of this load rating involves other information on the bridge along with engineering judgment. As a rule of thumb, a proposed bridge widening will not be approved unless the load rating of the remaining portion of the bridge after widening is at least H-20 (operating level) and no less than about HS-17 (inventory level). The number shown for the H rating is the allowable weight of the vehicle in tons, and the number shown for the HS rating is the rating factor multiplied by 20. Thus, a rating factor of 1.0 would result in a rating of HS 20, a rating factor of 1.25 would result in an inventory rating of HS 25, and a rating factor of 0.75 would result in an inventory rating of HS 15.

(30) beams, and subsequently, tests on four (4) full-scale strengthened bridge specimens. The thirty (30) beam tests identified the failure mechanisms and were instrumental in the determination of the appropriate size and spacing of transverse straps used to delay the onset of debonding of the FRP fabrics and/or pultruded plates from the concrete surface. The full-scale bridge specimens included both reinforced concrete tee-girders (for the Texas pan-girder type bridge) and flat-slabs (for the Texas FS-slab type bridge—curbs removed after slab strengthening). The pan-girder specimen was selected and dimensioned to reproduce key features of the expected behavior of a portion of the prototype pan-girder bridge. The full-scale bridge specimen is a reproduction of an interior section of the prototype bridge and was used to demonstrate that the strengthening system would provide the desired load capacity with the requisite level of ductility. The CFRP composites selected for the pan-girder test specimens were designed to increase the inventory rating for the bridge specimen from HS-10 to HS-20. Shown in Figures 6 through 8 are the pan-girder bridge specimens during testing and after debonding failure of the external CFRP laminate system.

**Overview of the TxDOT Research Implementation Program**–TxDOT has a policy encouraging the implementing of all “field ready” results from its research programs as well as from that of other agencies or even private entities such as transportation product manufacturers. In this policy, implementation is defined as the adoption of a product for use, including technology transfer activities that promote adoption, such as the following:

- **Information Dissemination**–includes the development, packaging and distribution of brochures, manuals, articles, reports, videos, and other materials which provide product descriptions and instructions to enable and promote use.
- **Training**—includes training course development and conduct necessary to enable and promote use.
- **Demonstration**—the placing of a product into TxDOT’s operational environment to demonstrate its use, which includes the following:
  - **Deployment**—the initial procurement and dissemination of a product to users, and
  - **Implementation Field Testing**—the demonstration and/or verification of product performance in TxDOT’s operational environment, including District/Division/Office (D/D/O) or National Experimental and Evaluation Program (NEEP) projects.

**Overview of the Implementation Project**–A demonstration type project was approved for implementation of the research results of Brena, et al *(15, 16)*. The research results were implemented in the widening of a bridge carrying Farm-to-Market Road 1632 (FM 1362) traffic over Sue Creek in Burleson County. The original bridge is a two-span reinforced concrete pan-girder structure—a very common bridge type in Texas that was issued as a standard for various pre HS-20 design loading bridges built between 1948 and 1964. The two simply supported spans are each 9.14-m (30-ft) long, and the overall width of the bridge is 6,553-mm (21.5-ft), with proposed widening out to 9,754-mm (32-ft).