



Project Summary Report 9-1520-S

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Project 9-1520: FRP Reinforcing Bars in Bridge Decks

Authors: David Trejo, Francisco Aguiñiga, Gene Buth, Robert L. Yuan,
Ray W. James, and Peter B. Keating

Fiber-Reinforced Polymer Bars for Reinforcement in Bridge Decks

Conventional steel reinforcement tends to corrode in aggressive environments. The resulting corrosion products take up more volume than the original base steel. As the steel reinforcement continues to corrode, the corrosion products continue to expand and place tensile forces on the concrete surrounding the reinforcement. Because concrete exhibits low tensile capacity, the corrosion products cause the concrete to crack and spall.

Cracking and spalling of concrete bridge decks result in reduced service life and unsafe driving conditions. Fiber-reinforced polymer (FRP) composite materials do not exhibit the typical expansion associated with steel corrosion and could thus, if engineered properly, be an effective reinforcement material to extend the service life of the nation's bridge decks (and possibly other bridge components).

Glass FRP (GFRP) reinforcement is now

commercially available for use in concrete structures as shown in Figure 1. This project investigated the applicability of using three commercially available GFRP bars for reinforcement in a bridge deck. Although results indicate that there is potential for the use of GFRP bars in bridge decks, the researchers identified some characteristics of the bars that may need to be modified so that these bars can be used more extensively in bridges.

What We Did...

Researchers at the Texas Transportation Institute and engineers at the Texas Department of Transportation developed a work plan to evaluate the performance of three commercially available GFRP bars for possible use in bridge decks. This plan included field impact tests of full-scale deck-rail samples constructed with GFRP reinforcement and epoxy-coated reinforcement, laboratory evaluations of the three GFRP reinforcing bars and GFRP-reinforced prisms,

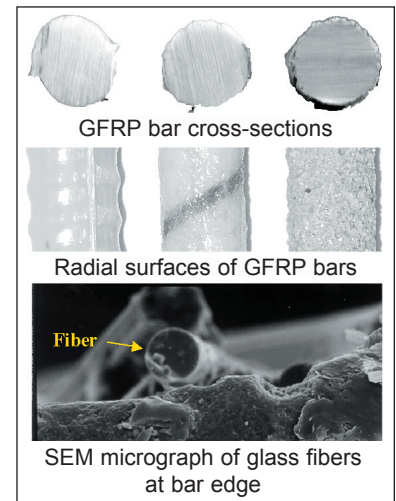


Figure 1. GFRP bars.

and the evaluation of a bridge deck constructed with GFRP bars.

A major challenge associated with the use of GFRP bars in bridge decks is how to safely connect the bridge rails to the bridge deck. Because GFRP reinforcement cannot be bent in the field and because these bar types typically exhibit significant reductions in strength when pre-bent, concerns were raised as to whether a system could be developed to ensure a safe rail system. To evaluate performance, the research team designed and evaluated



GFRP-reinforced and epoxy-coated-steel-reinforced systems for full-scale short sections for pendulum impact testing. In addition, a full-scale deck-rail system was constructed to evaluate the performance under actual vehicle impact.

The laboratory test plan included the evaluation of GFRP bars for tensile strength as a function of exposure type and time, moisture absorption, direct shear, and creep. GFRP-reinforced concrete prisms were evaluated for cracking, bond strength, performance under cyclic loading, and the propensity to crack under thermal loads. During the laboratory investigation a bridge was constructed with sections of GFRP reinforcement. This bridge, the Sierrita de la Cruz Bridge in Amarillo, Texas, was evaluated for crack spacings and widths after approximately two years in service. Comparisons were made between the steel-reinforced and GFRP-reinforced deck sections.

What We Found...

The full-scale impact testing concluded that a deck-rail section using a combination of GFRP and epoxy-coated-steel reinforcement performed similarly to a section made entirely with epoxy-coated reinforcement. Although the sections containing GFRP reinforcement exhibited slightly more damage, the researchers and engineers concluded that the performance of the GFRP-reinforced and epoxy-coated-reinforced samples was sufficient to perform full-scale crash testing. Full-scale crash testing conducted in this study and in companion



Figure 2. Impact of vehicle on Texas T202 rail reinforced with GFRP and epoxy-coated reinforcement.

0-4138 determined that a modified version of the Texas T202 deck-rail system (now designated T203) constructed from both GFRP and epoxy-coated reinforcement exhibited minimal damage when tested according to National Cooperative Highway Research Program (NCHRP) Report 350 test designation 3-11. Figure 2 shows the impact on the deck-rail system during the crash testing.

Laboratory tests of the three commercially available GFRP bars determined the following:

- The mean tensile strength of GFRP bars exposed to simulated concrete pore solution degraded 1 percent at 26 weeks and 7 percent at 50 weeks of exposure.
- Over the duration of this project the modulus of elasticity of the GFRP bars studied tended to increase with exposure time.
- The results from this research indicate that the environmental strength

reduction factors included in the American Concrete Institute (ACI) 440 design guidelines may not be sufficiently conservative.

- Results from this research indicate that the direct shear strength of GFRP bars could be reduced as much as 9 percent when exposed to simulated concrete pore solutions for a period of 68 weeks. Results also indicate that the shear stiffness could be reduced as much as 15 percent for some bars after 48 weeks of exposure to simulated concrete pore solutions.
- Results from this research indicate that GFRP bars can creep between 2 and 6 percent over six months when stressed at 23 percent of the ultimate strength of the bar.
- The method provided by the ACI 440 design guidelines to compute long-term deflections of FRP-reinforced concrete elements may not produce



conservative predictions based on the findings of this work, but further work is needed to verify this.

- Tests on GFRP-reinforced concrete slabs led to the validation of Equation 8.9c in ACI 440 that predicts the maximum crack width.
- Cyclic loading tests on GFRP-reinforced concrete beams show that deflections can be increased between 78 and 680 percent when the beams are loaded for 2 million cycles and the GFRP bar stress range is 18.9 ksi. This research made evident the importance of deflections of GFRP-reinforced concrete elements induced by cyclic loading. Thus, deflections due to cyclic loading should be considered in the design of GFRP-reinforced concrete flexural elements.
- Bond tests performed in this project on GFRP bars embedded in concrete showed reduced bond strength values after 16 months when exposed to a moist, elevated-temperature environment.

- Tests on GFRP-reinforced concrete slabs subjected to heat indicate that a typical 8-inch-thick concrete deck reinforced with 0.75-inch diameter bars and a concrete compressive strength of 5880 psi and concrete covers of 1, 2, and 3 inches could stand a temperature increase of approximately 54 °F without cracking.

The evaluation of the bridge deck on the Sierrita de la Cruz Bridge after approximately two years of service found that the GFRP-reinforced (upper mat) and epoxy-coated-reinforced (lower mat) spans (spans 6 and 7) exhibited approximately 50 percent more transverse cracking than did the epoxy-coated-only reinforced section. In addition, the GFRP- and epoxy-coated-steel-reinforced section exhibited crack widths approximately three times as wide as the cracks on the epoxy-coated-steel-reinforced decks. Figure 3 shows the bridge after approximately two years in service. Figure 4 shows the cracking of the GFRP- and epoxy-coated-reinforced section.

The Researchers Recommend...

GFRP bars exhibit good characteristics for use as reinforcing bars for concrete structures. Although the low modulus of elasticity presents design challenges, national and international organizations have nearly overcome these challenges. As with any new product, test procedures are still being developed and data are still being collected to better evaluate the long-term performance of these products. It is anticipated that further research will identify key parameters that influence the long-term performance and manufacturers will modify their products to enhance the performance when used in concrete.

Because the Texas Department of Transportation typically uses precast, prestressed panels to construct bridge decks, GFRP bars could likely be used under these conditions. However, the use of GFRP bars in full-depth, cast-in-place concrete decks should proceed only if the key performance parameters can be enhanced.



Figure 3. New Sierrita de la Cruz Bridge.



Figure 4. Crack on GFRP-epoxy-coated-reinforced section (crack has been marked).



For More Details...

The research results and recommendations are documented in Report 9-1520-3, *Characterization of Design Parameters for Fiber Reinforced Polymer Composite Reinforced Concrete Systems*.

Research Supervisor: David Trejo, TTI, trejo@civil.tamu.edu, (979) 845-2416

Key Researcher: Francisco Aguiniga, Texas A&M University—Kingsville, francisco.aguiniga@tamuk.edu, (361) 593-3967

TxDOT Project Director: Tim Bradberry, Bridge Division, TBRADBER@dot.state.tx.us, (512) 416-2179

TxDOT Research Engineer: Tom Yarbrough, Research and Technology Implementation Office, tyarbro@dot.state.tx.us, (512) 465-7403

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