



Project Summary Report O-4138-5

Project O-4138: Full-Scale Crash Tests of  
FRP Bar Reinforced Bridge Rails

Author: C. Eugene Butth, P.E.

## Crash Tests Evaluate Performance of GFRP Reinforced Bridge Rail

Corrosion of reinforcing steel in structural concrete has been and continues to be a problem in many reinforced concrete structures such as highway bridges. Ways of addressing the problem have been pursued with varying degrees of success. Recently, non-metallic reinforcing bars have been offered and are being studied as a solution for eliminating corrosion.

The purpose of this project was to investigate the structural performance of a bridge rail constructed with glass fiber reinforced polymer (GFRP) reinforcement and subjected to collision loads from full-scale crash tests. The project involved the design of GFRP reinforcement for a modified T202 bridge rail and deck overhang. A prototype bridge rail (with deck overhang) was constructed and subjected to two full-scale crash tests.



*GFRP bars in place immediately before placement of concrete. GFRP bars are tied with nylon cable tie.*

### What We Did ...

Texas Transportation Institute (TTI) researchers and Texas Department of Transportation (TxDOT) engineers designed glass fiber reinforced polymer reinforcement for a modified T202 bridge rail and deck overhang. Two design assumptions were used:

- Significant properties of fiber reinforced polymer (FRP)

bars, such as tensile strength, creep rupture, and fatigue endurance, are reduced by long-term exposure to the environment.

- Another significant property of FRP bars is the brittle behavior exhibited when loaded to rupture. This has been cause for concern on the part of those investigating the use of FRP bars in reinforced concrete.

The approach being adopted is to over-reinforce members so that the concrete portion reaches its load limit before the FRP bars do because the concrete portion is the more ductile of the two materials. This approach will provide members with more ductility than those designed to fail by rupture of the GFRP reinforcement.

One design allowed for deterioration in strength and stiffness of the reinforcement that is expected to result from





Vehicle during collision with 30-inch version of bridge rail.



After-test photo of bridge rail showing marks from vehicle. Note that tire contacted post.

exposure to the environment. This design resulted in an increased amount of reinforcement and was “overdesigned” immediately after construction. The other design did not allow for deterioration and had the appropriate strength and stiffness level immediately after construction.

A prototype test rail with deck overhang was constructed using the

two reinforcing levels. One half of the length used one level and the other half used the other level. Two full-scale crash tests following the test 3-11 requirements for Test Level 3 of National Cooperative Highway Research Program (NCHRP) Report 350 were performed.

## What We Found ...

The first crash test was performed on the portion of railing with increased reinforcement. The railing demonstrated adequate structural capacity by containing and redirecting the vehicle with no structural distress. However, the vehicle rolled onto its side and did not pass the performance requirements of NCHRP Report 350.

TxDOT and TTI engineers decided to test the weaker portion of the railing with a structural steel tube added to the top to increase total height to 30 inches. The vehicle did not roll over in this test. The bridge rail demonstrated adequate structural capacity and met the performance requirements of NCHRP Report 350. A brief summary evaluation for each bridge rail is provided in [Table 1](#).

## The Researchers Recommend ...

Research to date indicates that GFRP reinforcing bars perform acceptably in bridge rails subjected to vehicle collision loads. Properties and behavior of GFRP bars have been reasonably well defined through other research and the American Concrete Institute has published guidelines for designing concrete structures with GFRP reinforcing bars.

The researchers recommend continued investigation and limited field use of GFRP in bridge rail/deck structures.



Table 1. Performance Evaluation Summary for GFRP Reinforced Bridge Rail.

NCHRP Report 350 Test 3-11 Evaluation Criteria		Results from 27 inch High Railing with Extra Reinforcement	Results from 30 inch High Railing with Standard Reinforcement
<b>Structural Adequacy</b>			
A.	Test article should contain and redirect the vehicle; the vehicle should not penetrate, underide, or override the installation although controlled lateral deflection of the test article is acceptable.	<b>Pass:</b> The TxDOT T202(M) with GFRP reinforcement contained and redirected the 4498 lb (2042 kg) pickup truck. The vehicle did not penetrate, underide, or override the bridge rail. No measurable deflection was noted.	<b>Pass:</b> The TxDOT T202(MOD) with GFRP reinforcement and metal rail on top contained and redirected the 4502 lb (2044 kg) pickup truck. The vehicle did not penetrate, underide, or override the bridge rail. No measurable deflection was noted.
<b>Occupant Risk</b>			
D.	Detached elements, fragments, or other debris from the test article should not penetrate or show potential for penetrating the occupant compartment, or present an undue hazard to other traffic, pedestrians, or personnel in a work zone. Deformations of, or intrusions into, the occupant compartment that could cause serious injuries should not be permitted.	<b>Pass:</b> No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 5.0 inches (128 mm) in the floor pan to instrument panel on the left side near the driver's feet.	<b>Pass:</b> No detached elements, fragments, or other debris were present to penetrate or to show potential for penetrating the occupant compartment, or to present undue hazard to others in the area. Maximum occupant compartment deformation was 5.6 inches (143 mm) in the kickpanel area on the passenger's side.
F.	The vehicle should remain upright during and after collision although moderate roll, pitching, and yawing are acceptable.	<b>Fail:</b> The 4498 lb (2042 kg) pickup truck rolled onto its left side after exiting the installation.	<b>Pass:</b> The 4502 lb (2044 kg) pickup truck remained upright during and after exiting the installation.
<b>Vehicle Trajectory</b>			
K.	After collision it is preferable that the vehicle's trajectory not intrude into adjacent traffic lanes.	<b>Fail*:</b> The vehicle came to rest on its left side, 172.6 ft (52.6 m) downstream of impact and 31.2 ft (9.5 m) forward of the traffic face of the rail.	<b>Fail*:</b> The vehicle came to rest upright, 187.7 ft (57.2 m) downstream of impact and 15.7 ft (4.8 m) forward of the traffic face of the rail.
L.	The occupant impact velocity in the longitudinal direction should not exceed 12 m/s, and the occupant ridedown acceleration in the longitudinal direction should not exceed 20 g's.	<b>Pass:</b> Longitudinal occupant impact velocity was 20.3 ft/s (6.2 m/s), and longitudinal occupant ridedown acceleration was -5.3 g's.	<b>Pass:</b> Longitudinal occupant impact velocity was 21.3 ft/s (6.5 m/s), and longitudinal occupant ridedown acceleration was -4.6 g's.
M.	The exit angle from the test article preferably should be less than 60 percent of test impact angle, measured at time of vehicle loss of contact with test device.	<b>Fail*:</b> Exit angle at loss of contact was 18.9 degrees, which was 72 percent of the impact angle.	<b>Pass*:</b> Exit angle at loss of contact was 14.2 degrees, which was 57 percent of the impact angle.

\*Criterion K and M are preferable, not required.



## For More Details . . .

This project is documented in the following reports:

Report 4138-1: *NCHRP Report 350 Test 3-11 of the TxDOT T202(M) Bridge Rail with GFRP Reinforcement*

Report 4138-2: *NCHRP Report 350 Test 3-11 of the TxDOT T202(MOD) Bridge Rail with GFRP Reinforcement and Metal Rail*

Report 4138-3: *Performance of the TxDOT Modified T202 Bridge Rail Reinforced with Fiber Reinforced Polymer Bars*

Related Research:

Report 1520-1: *Pendulum Impact Tests of Bridge Deck Sections*

Report 1520-2: *FRP Reinforcing Bars in Bridge Decks: State of Art Review*

Research Supervisor: C. Eugene Buth, TTI, [g-buth@tamu.edu](mailto:g-buth@tamu.edu), (979) 845-6159.

Researchers:

Roger P. Bligh, TTI, [rbligh@tamu.edu](mailto:rbligh@tamu.edu), (979) 458-3874

William F. Williams, TTI, [w-williams@tamu.edu](mailto:w-williams@tamu.edu), (979) 862-2297

Wanda L. Menges, TTI, [w-menges@tamu.edu](mailto:w-menges@tamu.edu), (979) 845-6157

Rebecca R. Haug, TTI, [r-haug@tamu.edu](mailto:r-haug@tamu.edu), (979) 845-8971

TxDOT Project Director: Timothy Bradberry, [tbradber@dot.state.tx.us](mailto:tbradber@dot.state.tx.us), (512) 416-2179.

**To obtain copies of reports, contact Dolores Hott, Texas Transportation Institute, TTI Communications, (979) 845-4853, or e-mail [d-hott@tamu.edu](mailto:d-hott@tamu.edu). See our online catalog at <http://tti.tamu.edu>.**

## TxDOT Implementation Status July 2003

For TxDOT, the most likely application of the results of this project is use of glass fiber reinforced polymer reinforcement for connection of the bridge rail to the bridge deck. This might be useful in areas of the state where severe corrosion potential exists, such as northern districts where deicing salts are commonly used or in coastal environments. At this time, however, there are no plans to develop statewide standards for this application.

Wholesale use of GFRP as reinforcement for concrete bridge rails is unlikely to occur until long term performance issues (strength degradation over time) have been resolved and the cost of GFRP approaches that of epoxy-coated reinforcing steel.

**YOUR INVOLVEMENT IS WELCOME!**

## Disclaimer

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data, and the opinions, findings, and conclusions presented herein. The contents do not necessarily reflect the official view or policies of the Texas Department of Transportation (TxDOT), Federal Highway Administration (FHWA), the Texas A&M University System, or the Texas Transportation Institute. This report does not constitute a standard, specification, or regulation, its contents are not intended for construction, bidding, or permit purposes. In addition, the above listed agencies assume no liability for its contents or use thereof. The names of specific products or manufacturers listed herein do not imply endorsement of those products or manufacturers.

This research project was conducted under a cooperative program between the Texas Transportation Institute, the Texas Department of Transportation, and the U.S. Department of Transportation, Federal Highway Administration. The authors acknowledge and appreciate the guidance of the Program Chairman, David Hohmann; the Project Director, Timothy Bradberry; and the TxDOT Project Monitoring Committee: Robert Sarcinella, Kevin Pruski, Peter Chang, Mark Bloschok, and Brian Mosser.