



Getting clearance

CFRP U-wrapping shows promise as a repair option

By Adel ElSafty, P.E., P.Eng.
Contributing Author

A significant number of bridges have been struck by tall vehicles, and the occurrence of such accidents keeps rising.

The impact of vehicles with bridge components may result in failure of the bridge system and loss of lives. Despite the persistent and increasing occurrence of bridge collisions, few studies have focused on the assessment of the structural damage, suitable repair material, optimum repair method and repair configuration for impact-damaged girders.

A multitude of procedures have been developed to repair damaged structures. However, as technology advances and new materials are utilized for innovative applications, more desirable procedures for restoration become available. The use of carbon fiber reinforced polymer (CFRP) laminates for restoring or enhancing the performance of reinforced concrete (RC) and prestressed concrete (PSC) bridge girders has become a more commonly acceptable repair method. However, there is still a great need to investigate the effectiveness of using CFRP systems in the repair of PSC girders damaged due to a vehicle collision. Also, many previous research tests experienced debonding of the longitudinal CFRP laminates

attached to the concrete tension surface. The debonding problem associated with FRP laminates hinders the ability to utilize the full tensile strength of the FRP, thereby decreasing the efficiency of the repair. Therefore, there was a demand for researching behavioral aspects of externally bonded CFRP used for repairing laterally damaged bridge girders.

This research investigated the effectiveness of using CFRP laminates in repairing both RC and PSC (full-scale and half-scale) girders damaged primarily by impacts that cut through the steel reinforcement and/or prestressing cables. Included in the investigation is an evaluation of the proper configuration and spacing of CFRP U-wrappings to mitigate the debonding problem.

Other repair-application and design considerations—such as cross section, reinforcement ratio and the level of strengthening (number of CFRP soffit layers)—also were addressed in the experimental program, and the resulting recommendations were ultimately presented. The study investigated the proper CFRP repair configuration (longitudinal layers and U-wrapping) to obtain flexural capacity improvement and desired failure modes for the repaired girders under both static and fatigue loading. The repair systems for eight 40-ft-long AASHTO Type II prestressed concrete girders, 13 half-scale 20-ft-long prestressed concrete



The outcome of this project contributes to saving millions of dollars in repairing damaged prestressed concrete girders.

girders and 34 reinforced concrete beams were designed to restore the original ultimate flexural capacity.

Prestressed concrete members are susceptible to strand fatigue problems under elevated strand stress range. This presents itself as a critical point to investigate, since the lateral damage of concern usually harms some of the prestressing strands. Therefore, in addition to the static load tests, some girders were tested under fatigue loading for 2 million cycles to examine the behavior under simulated traffic conditions, and then static load to failure was conducted.

The objectives of the research project were:

1. To investigate the feasibility and performance of an innovative repair using CFRP laminates to restore the capacity of laterally damaged concrete and prestressed concrete girders;
2. To investigate experimentally and analytically the CFRP laminate performances and their potential debonding;
3. To investigate the effectiveness of using the transverse U-wrappings to anchor and mitigate the longitudinal CFRP debonding problem;
4. To investigate different configurations of both longitudinal and transverse CFRP laminates to constitute a repair;
5. Develop a recommended spacing of the CFRP U-wrappings for repairing laterally damaged prestressed concrete girders; and
6. To investigate the fatigue behavior of CFRP-repaired prestressed concrete girders.

The lateral damage simulation for each girder was achieved by sawing through the concrete of the bottom flange and slicing through one of the prestressing strands. To repair the cut, the surfaces exposed by cutting were first roughened with chisels to improve

bonding quality. These surfaces were then thoroughly cleaned with a water jet and pressurized air, as specified in both NCHRP 514 (NCHRP R-514) and ACI 440.2R-08. The cleaned cut was filled with a high-strength cementitious repair mortar, and a high-pressure epoxy injection procedure was performed after the mortar set. The procedure resulted in a near-perfect repair of the concrete cross section.

The half-scale and full-scale girders had a variety of repair configurations with several numbers of CFRP layers and with different spacing for the U-wraps. The full-scale PSC girders statically tested were arranged in a similar manner to the half-scale specimens. The 40-ft-long PSC girders spanned 38 ft and rested on neoprene pads. The girder loading was applied using a steel spreader beam resting on another set of two pads. Also, load measurements were read by the data acquisition connected to the actuator. The deflection gauges positioned at mid-span were linear variable differential transformer (LVDT) deflection and laser gauges. The LVDT deflection gauges also were placed both above the supported

areas and at quarter points on the girders. Strain gauges were attached to the girders along the cross-section height and on the tension face of the beam along the span of the girder; yet, in the testing of the full-scale girders more of the strain gauges were applied. Each full-scale girder utilized an average of 15 strain gauges, where the half-scale test specimens only had an average of 12 applied.

The girders were tested using the hydraulic actuator mounted to a steel frame at mid-span. The fatigue testing of AASHTO II girders was performed using the 110-kip MTS hydraulic actuator selected based on its large-capacity servo valve, which permitted testing of the girder using a frequency of 2 to 4 Hz. The loading contact area was a 250-mm by 500-mm steel plate specified by AASHTO. Neoprene pads were used at girder supports to simulate field-supporting conditions.

2 million strong

Lessons learned from the fatigue testing of half-scale prestressed concrete girders included the significance of properly covering the damaged section with transverse and longitudinal CFRP strips to restrain the crack opening and propagation in the critical region, thus preventing early debonding and premature failure. In addition, a more refined design approach was utilized to design the CFRP configurations for full-scale girder repair. Also, the fatigue load range indicated in AASHTO LRFD



The half-scale and full-scale girders had a variety of repair configurations with several numbers of CFRP layers and with different spacing for the U-wraps. The full-scale PSC girders statically tested were arranged in a similar manner to the half-scale specimens.

FACT FINDER

Overall, test results confirmed that CFRP systems can be designed to restore lost flexural capacity, possibly enhance the original capacity and maintain desired failure mode.

specifications that simulated service load conditions was applied for the full-scale girders. This repair configuration restored and increased the load-carrying capacity of the girders. Evenly spaced transverse U-wrappings provided an efficient configuration to mitigate debonding. The damaged full-scale AASHTO prestressed concrete bridge girders repaired using the CFRP laminates withstood more than 2 million cycles of fatigue loading with little degradation. Then, the girders were tested in flexure until failure under a four-point loading arrangement.

The CFRP repair restored the lost flexural capacity of the damaged girder due to lateral impact that severed several prestressing strands. The flexural capacity loss due to induced lateral damage was 10% for full-scale and 18% for half-scale girders. The CFRP repair not only restored the lost flexural capacity of the

damaged girders but also enhanced the flexural capacity for the repaired girders by up to 28% and 69% compared with that of the control-damaged full-scale PS and half-scale PSC girders, respectively.

Moreover, the enhanced flexural strength capacity of the CFRP-repaired girders exceeded the capacity for undamaged control girder by about 16% and 38% for full-scale PSC and half-scale PS girders, respectively. Damaged prestressed bridge girders repaired using nonprestressed fabric CFRP laminates suffered little degradation even after more than 2 million cycles of fatigue loading. Without consideration for shear enhancements, the optimum spacing for transverse anchoring is recommended to be between a distance of one-half to two-thirds the height of the AASHTO girder (or one-half the height of the entire composite cross section).

Basically, the repair system composed of longitudinal CFRP laminate applied to the girder soffit along with U-wrapping anchored with a longitudinal CFRP strip at the top ends of U-wraps proved to be an excellent repair option for damaged girders. The study recommended the proper CFRP repair and the optimum repair configuration, including the spacing of U-wrapping for the repaired girders.

Details for optimum application also were described. Test results showed that with proper CFRP configuration and detailing, CFRP systems can be designed to restore the flexural capacity and maintain the desired failure mode. Test results indicated that the capacity of the repaired girder was restored and even exceeded the capacity of the control undamaged girder in both strength and ultimate displacement.

The study also suggested the optimum configuration of CFRP repair systems (longitudinal strips and U-wrapping). The longitudinal CFRP

CIMLINE

DURA PATCHER

ROUGH ROAD AHEAD? WE CAN SMOOTH IT OUT.

Build a pavement preservation strategy around Cimline Cracksealers and DuraPatcher pothole patchers and save! We stretch your budget without adding excessive maintenance costs. Proven by hundreds of satisfied public works departments.

NEW Gen IV MAGMA for 2013



CIMLINE

CIMLINE
800-328-3874

PAVEMENT MAINTENANCE GROUP
www.cpmg.info

DURA PATCHER
866-607-2824

laminates applied to the girder soffit along with U-wrapping anchored with a longitudinal CFRP strip at the top ends of U-wrappings proved to be an excellent repair alternative for damaged girders. Evenly spaced transverse U-wrappings provide very efficient configuration for CFRP flexural enhancement repairs to mitigate debonding. When repairing laterally damaged girders having a loss of concrete and ruptured prestressing strands, it is necessary to cover the damaged section with transverse and longitudinal strips to restrain the crack opening and propagation in the critical region, which initiates early debonding.

Wrapping up

Based on their results, the researchers formulated a system for assessing the degree of damage to bridge girders after collisions and then correlated this with repair options. The scope and level of detail considered by the researchers resulted in a comprehensive guide for the application of CFRP laminates to collision-damaged bridge girders. The researchers indicated that proper CFRP repair design, in terms of the number of CFRP longitudinal layers and U-wrapping spacing, could result in obtaining significant enhancement for the capacity and desired failure modes for the repaired girders. Favorable failure modes of the repaired girders can be maintained using an efficient CFRP repair configuration utilizing evenly spaced transverse U-wrappings to prevent undesirable modes of failure such as debonding of the longitudinal CFRP strips from the girder concrete soffit.

Overall, test results confirmed that CFRP systems can be designed to restore lost flexural capacity, possibly enhance the original capacity and maintain desired failure mode. The capacity of repaired girders often exceeded the capacity of controls in both strength and ultimate displacement. The increase in load-carrying capacity for the CFRP-repaired girders was associated with a reduction in girder ductility. Experimental results were examined analytically using standard models.

The research also presented the flexural behavior of the repaired girders including load-deflection characteristics,



The girders were tested using the hydraulic actuator mounted to a steel frame at mid-span. The fatigue testing of AASHTO II girders was performed using the 110-kip MTS hydraulic actuator selected based on its large-capacity servo valve.



The lateral damage simulation for each girder was achieved by sawing through the concrete of the bottom flange and slicing through one of the prestressing strands.

strain development and modes of failure. Similarly, an analytical design model was established and proposed to more effectively design CFRP repairs for laterally damaged prestressed and reinforced concrete bridge girders.

The outcome of this project contributes to saving millions of dollars in repairing damaged prestressed concrete girders and increasing their flexural capacity to sustain increasing traffic loads. The conducted research resulted in the ability to restore and possibly enhance the original capacity of a collision-damaged bridge girder using

nonprestressed fabric CFRP repair applications. The CFRP laminate withstood more than 2 million cycles of fatigue loading with little degradation. The DOTs will be able to use the optimum configuration of longitudinal CFRP and U-wrapping to repair the damaged prestressed concrete bridge girders. **R&B**

ElSafty is an associate professor, School of Engineering, at the University of North Florida, Jacksonville, Fla.

For more information about this topic, check out the Bridges Channel at www.roadbridges.com.