South Carolina
Department of Transportation

Flexural Retrofit of Bridges Using CFRP Systems – Volume I: Bridge Girders

SUMMARY REPORT

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With the need for structural rehabilitation of the nation's bridges clearly evident, the use of alternative composite structural materials such as Fiber Reinforced Polymer (FRP) materials has gained attention for repair, rehabilitation, and/or strengthening of these structures.

The majority of experimental work to date has been conducted on beam specimens having a soffit-mounted FRP application similar to steel plate bonding, referred to in this study as conventional adhesive applied (CAA), leading to the determination that the performance of these beams is controlled by the quality of the bond between the FRP and concrete substrate and its ability to transfer stress from the steel to the FRP. Since this body of research points to bond issues, methods of improving and maintaining the bond quality in such applications is of primary importance.

With the goal of addressing this issue, a form of FRP application referred to as Near-Surface Mounted (NSM) in this work, has recently been the subject of investigation. Because the FRP strips are embedded in adhesive within the substrate concrete in NSM applications, substantially better bond characteristics can result.

Another application of FRP use on beams for flexural strengthening examines a different bonding technique altogether. This method of application, referred to as powder actuated fastener-applied (PAF) in this work, uses a powder-actuated nail gun to install mechanical fasteners through predrilled holes in the FRP into the concrete substrate, "nailing" the FRP in place. This application is recent and little experimental verification has been completed. The system is proprietary.

The research presented here is a comparative study of the static and fatigue performance of reinforced concrete beams retrofit with three different commercially available methods of flexural strengthening using Carbon Fiber Reinforced Polymer (CFRP) materials, i.e.,: Conventional Adhesive Applied (CAA), Near Surface Mounted (NSM), and Powder Actuated Fastened (PAF). Both small-scale and full-scale beam were investigated. The small-scale beams spanned 4,572 mm (180 in.) and measured 254 mm (10 in.) deep and 152 mm (6 in.) wide. Ten small-scale beams were investigated. Nine of the beams were strengthened with carbon fiber reinforced polymer (CFRP) composites and the remaining specimen was used as a control specimen. Of the ten specimens, six strengthened specimens were tested under cyclic loading conditions. Four specimens, three retrofit and one control, were tested monotonically to failure.

Results from the small-scale experimental study indicated that all three of the methods of FRP application investigated resulted in significant strength increases over the control specimen under monotonic conditions. Concrete crushing was the primary failure mode for all of the monotonic specimens, with the exception of the CAA specimen which failed through midspan debonding. Additionally, the test findings point to the fact that the CAA method was outperformed by the other methods under cyclic conditions. Results and observations from this study also indicated that the NSM and PAF applications exacerbate a potentially weak splitting plane around the level of the internal reinforcement due to the termination of the fasteners (PAF) and the FRP (NSM) at this location. Further discussion pertaining to the practicality, performance, and cost is presented for each of the methods of retrofit examined within this study.

Eight full-scale reinforced concrete bridge girders having three different carbon FRP (CFRP) retrofit systems were tested under both monotonic and fatigue loads. Analytical models for predicting debonding failure were evaluated for their ability to capture experimentally observed behavior and were used to develop an understanding of the parameters affecting the midspan debonding mechanism and how such debonding failures can be mitigated. Additionally, a finite element (FE) model was used in a parametric study intended to investigate the state of stress at the crack tip as a midspan debonding crack propagates along the FRP-concrete interface. Through this investigation it was intended to provide analytical verification of the assumed interface crack behavior and to attempt to correlate this behavior with a practical benchtop debonding test.

Results of this study indicate that all three CFRP flexural strengthening measures employed were sufficient to allow the girders to carry the current HS25 design load with little nonlinear deformation. Under cyclic loads, the durability of the bond was observed to degrade. Midspan debonding failure can be predicted using the intermediate crack induced debonding models provided they account for the ratio of FRP plate to substrate width and loading and specimen geometry. Finally, the state of stress at an interface crack tip in a reinforced beam under flexural testing is dominated by shear stresses. This is contrary to the behavior obtained in using the modified double cantilever beam (MDCB) test method, where a mixed mode behavior dominated by peel stresses has been observed. Therefore, to be able to use such tests to study the bond behavior in a real structure would require a change in the set up so that the shear stresses become dominant.

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