

FRP REINFORCEMENT FOR BRIDGE STRUCTURES

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INTRODUCTION

Current studies indicate that the use of advanced composites for structural application is expected to increase exponentially in the next decade (1). The market growth will mainly stem from the increased need for repair/strengthening of deficient structures and for new infrastructure systems that last longer and cost less to maintain. FRP composites can be manufactured in many shapes and forms. Applications of FRP composites in civil/infrastructure engineering are diverse and may include internal reinforcement, structural elements, and externally bonded reinforcement. For concrete reinforcement, the most popular forms of FRP are smooth and deformed bars, prestressing tendons, and pre-cured and cured-in place laminates/shells (2). FRP bars and tendons are currently produced with sizes and deformation patterns similar to those of steel bars and strands. FRP composites are light in weight, which means they are easier to transport and install. They are corrosion-resistant and therefore perform well in terms of long-term durability and maintenance cost. FRP pre-cured and cured-in-place laminates/shells and sheets are used for external concrete reinforcement (3) and FRP shells have been used as jackets for columns (4). FRP strengthening is currently being marketed in the form of systems.

Two techniques for surface reinforcement for concrete structural members are addressed in this paper, namely: externally bonded laminates and near surface mounted (NSM) rods. A project involving the full-scale strengthening and testing to failure of a highway bridge is used to illustrate the field application and construction process of the two strengthening techniques. Internal FRP reinforcement for new concrete members is also addressed in the paper. A project consisting of the construction of a concrete box culvert bridge is described to illustrate the use of internal FRP reinforcement.

FRP AS EXTERNAL REINFORCEMENT FOR CONCRETE MEMBERS

Installation of Externally Bonded Laminates

Surface bonded FRP includes two possibilities: pre-cured and cured-in-place laminates (manual lay-up). For the latter, a surface primer is applied first to the concrete prepared surface to fill micro-cavities. After the primer is cured, a layer of putty is applied to level uneven spots and fill surface cavities. The recommended resin is then mixed and applied to the concrete surface in a thin uniform layer using a roller. A fiber sheet (pre-impregnated or dry) is cut to the desired length and width and pressed to the concrete using a "bubble roller". This act eliminates the entrapped air between the fibers and resin and ensures the impregnation of the FRP sheet with

resin. After the ply is installed, a second layer of impregnating resin is applied. In the case of multiple plies, the process is repeated.

Installation of Near Surface Mounted Rods

The use of near surface mounted (NSM) FRP rods is an attractive method for increasing flexural or shear strength of deficient concrete members. This strengthening technique is practical since the anchorage of the mounted rods into adjacent members is feasible. In addition, application of NSM FRP rods does not require surface preparation work and is advantageous when the end anchorage of the FRP reinforcement is an essential design requirement or when the installation of laminates involves extensive surface preparation work.

Installation of the NSM rod is achieved by grooving the surface of the concrete. Traditionally, surface mounted reinforcement is placed parallel to the existing reinforcement. The grooves may have a square cross section with dimensions exceeding the diameter of the FRP rod to allow for embedment. Concrete can be grooved by making two parallel saw cuts on the concrete surface using conventional tools and technology. The two cuts have predetermined depth and are spaced at a distance equal the required width of the groove. The concrete in between the two cuts is then chipped off, thus creating the groove. After the groove is cleaned, it is initially filled half way with a high viscosity binder (e.g., epoxy paste) compatible with the FRP rod. The high viscosity binder ensures easier field execution, especially for the case of over-head application. An FRP rod is then placed into the groove and lightly pressed in place. This action forces the paste to flow around the rod and cover the sides of the groove. The rod can be held in place using wedges at an appropriate spacing. The groove is then filled with the same binder and the surface is leveled.

Demonstration Bridge

Prior to its demolition, a reinforced concrete bridge was strengthened and tested to failure. The bridge was built in 1932 and consisted of three simply supported decks made of 18 in (460 mm) thick solid reinforced concrete slabs with an original roadway width of 25 ft (7.6 m). Each simply supported deck spanned 26 ft (7.9 m). The bridge deck was supported by two abutments and two bents. Each bent consisted of two piers connected at the top by a RC cap beam. The piers had a 2 by 2 ft (0.6 × 0.6 m) square cross-section and were supported by 4 by 4 by 2.5 ft (1.2 × 1.2 × 0.75 m) square spread footings. In general, the condition of the bridge was good. Two of the three bridge decks were strengthened with externally bonded reinforcement. The first was strengthened using externally bonded carbon FRP sheets and the second using near surface mounted carbon FRP rods (see Fig. 1). The decks were tested to failure under static load. The piers, originally designed for gravity loads, were seismically upgraded using NSM carbon FRP rods, as well as jackets made of unidirectional carbon or glass FRP sheets. All strengthening work was carried out on the bridge while in service. Bridge upgrading was rapid with no interruption of traffic flow.

Decks - The mode of failure of each deck was dependent on the strengthening scheme and occurred after the yielding of the original steel reinforcement. For the deck with NSM rods, failure was initiated by the rupture of some CFRP rods at the location of the widest crack. The

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failure mode of the deck strengthened with CFRP laminates was a combination of rupture and peeling of the laminates. As for the reference deck, the classical mode of failure of yielding of steel reinforcement followed by the crushing of concrete at ultimate was attained. The deck strengthened with CFRP laminates had a capacity of 134.1 k-ft (181.8 kN-m). The deck strengthened with NSM rods showed the highest capacity of 147.1 k-ft (200 kN-m). The capacity of the unstrengthened deck was 114.6 k-ft (155.4 kN-m).

Piers - The piers were tested to failure by applying cyclic lateral loads to the cap beams. To achieve this, the central portion of the cap beam was removed and a hydraulic jack was inserted in the gap while a second jack was attached to a reaction frame confining the piers cap beam, as shown in Figure 2. The two jacks were used alternately to create a cyclic loading condition. A 10-in (254-mm) strip of each deck was saw-cut along the longitudinal axis of the bridge to allow for the relative displacement of the piers. In order to reduce the superstructure/substructure interaction, the bridge decks supported on piers 3 and 4 were jacked up and lubricated steel plates were inserted between the deck and the cap beam. Failure loads of bridge piers exceeded in magnitude the predicted loads. For pier #1 (unstrengthened), the applied lateral load at failure was 79 kips (351 kN) with maximum lateral displacement at the top of the pier was 0.61 in (15.5 mm). For pier #2, the failure was initiated by a crack, which occurred at the column flare where NSM rods were terminated, followed directly by the yielding of steel reinforcement. The applied lateral load at failure was 81 kips (360 kN) and the lateral displacement at the top of the pier varied from 0.058 in (1.5 mm) just before cracking to 0.116 in (2.9 mm) at test termination. For pier #3, cracks occurred simultaneously at the top and the base of the pier at about 65 kips (289 kN). Failure was initiated by rupture of the mounted FRP rods at the base of the column at 86 kips (382 kN) with a maximum lateral displacement at the top of 0.86 in (21.8 mm). As for pier #4, the pier started to rotate as a rigid body at 50 kips (222 kN). The test was terminated when the lateral displacement exceeded 1.5 in (38.1 mm).



Fig. 1: NSM FRP rods on deck soffit



Fig. 2: Cyclic loading for bridge piers

INTERNAL FRP REINFORCEMENT FOR CONCRETE MEMBERS

A culvert bridge was constructed using precast concrete boxes reinforced entirely with glass FRP rods. The new bridge replaced a deteriorated steel pipes culvert bridge on Walker Ave. in the City of Rolla, Phelps County, Missouri (Figure 3).

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The 36 ft (10.97 m) wide bridge consisted of 18 precast concrete boxes arranged in two rows, nine boxes per row. A crew from the city public work department installed the boxes and the bridge was opened to traffic on October 13, 1999. Each box segment is 5 ft (1.52 m) wide and 5 ft (1.52 m) deep with a wall thickness of 6 in (152 mm) and is reinforced with a mesh of #2 GFRP rods (Figure 4). The precast units were manufactured by Scurlock Industries of Springfield, Missouri using a dry cast process.

In addition to field construction, the project included the laboratory verification through testing to failure of two of these boxes. Long-term monitoring of the new culvert bridge will also be performed over the course of three years using fiber optic sensors that were attached to the FRP rebars at different locations prior to casting.



Fig. 3: Installing of concrete box units



Fig. 4: GFRP reinforcement cage

CONCLUSIONS

The objective of this paper is to demonstrate the use of FRP reinforcement in bridge applications. Two strengthening techniques (i.e., externally bonded FRP laminates and NSM FRP rods) and new construction (i.e., internal FRP bars) were discussed. Test results indicate that all techniques are effective in increasing the flexural capacity of concrete sections.

Application of FRP reinforcement may not be suited for every case but does provide practitioners with an additional effective tool to upgrade or build new reinforced concrete structures.

Research and development is continuing to refine the design methods, installation procedures, and quality control tests to provide the construction industry with science-based procedures. In the interim, a judicious use of composites can provide substantial benefits.

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