Fig. 15—Surface Preparation: Smoothing Surface and Rounding Corners

Fig. 16—Surface Preparation: Epoxy Injection of Cracks

Fig. 17—CFRP Wrap Installation

Fig. 18—CFRP Wrap Installation in First Project Using Longitudinal CFRP Strips for Anchoring

Fig. 19—Pull-off Test

Fig. 20—UV Coating over CFRP Wrap

Fig. 21—Hole for Mechanical Anchor

Fig. 22—Surface Preparation with Holes for Mechanical Anchors

Fig. 23—CFRP Installation over Mechanical Anchor Holes

Fig. 24—Fanning of CFRP Mechanical Anchors

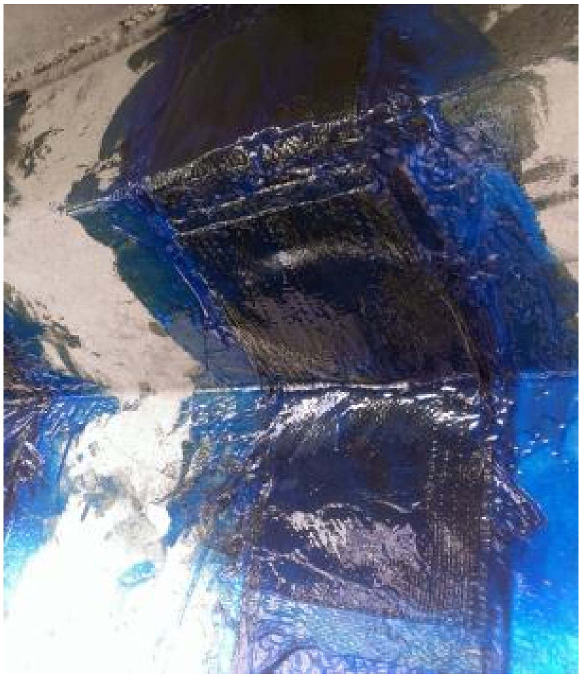

Fig. 25—CFRP Patch over CFRP Mechanical Anchors

Bridge Substructure Repairs with Basalt & Glass FRP Internal Reinforcement

Mohit Soni

Synopsis: Alternative reinforcement such as Glass Fiber Reinforced Polymer (GFRP) and Basalt (BFRP) are gaining popularity due to their corrosion resistant properties in extremely aggressive environments. The Florida Department of Transportation was concerned with the long-term durability of fiber resin systems in wet marine environments and restricted its use in submerged marine locations. This paper demonstrates the implementation of a pilot project after the thorough evaluation of a Fiber Reinforced Polymer resin prior to broader deployment of the alternative reinforcement. The paper focuses on the successful construction implementation to provide an archival reference document for future study and comparison to look at the long-term performance and integrity of the strengthening systems. During the execution of this pilot project, several lessons were learned and are demonstrated in this paper.

Keywords: alternative reinforcement, BFRP, bridge, GFRP, lessons learned, pilot project, shotcrete

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INTRODUCTION

Florida has over 122,000 centerline miles of roadway and over 14,000 bridges (including state and non-state) with over 176 million square feet of bridge area. The coastal areas have the most corrosive environments and Florida is ranked 2nd behind Alaska in the longest coastline in U.S. To efficiently maintain this infrastructure, Florida Department of Transportation (FDOT) constantly looks for new and innovative technology through research and pilot project programs. Studies conducted by FDOT have shown that exposing GFRP to marine environments resulted in some degradation of mechanical properties. Other research on the durability of FRP bars embedded in moist concrete have reported adverse effects on the long-term durability of the FRP bars [1]. Hence, the use of the GFRP was restricted by FDOT within submerged and splash zones. The splash zone is defined by FDOT as 12-ft. above mean high-water elevation, and 4 ft. below mean low-water elevation. Through the constant, proactive collaboration between ACI committee 440, DOT's and the FRP industry to improve the composition of the FRP based on additional research and studies, the manufacturers are providing improved FRP bars. Some of the FDOT sponsored research and studies that contribute to documenting this, include [2-4]*, complemented by more recent work from* [5-8]. This paper includes the FDOT pilot projects associated with the GFRP and BFRP for strengthening and rehabilitation to lift the restrictions on the usage of GFRP, and soon BFRP rebar, in submerged marine environments. This paper address two projects: US 17 over Trout River (Bridge No.720011) and EB SR 312 over Matanzas River (Bridge No.780089) located in Dual County and St. Johns County respectively within the FDOT – District 2 (FDOT D2) jurisdiction. The scope for Bridge No. 720011 incudes the removal of existing jackets from jacketed piles and the design of an impressed current cathodic protection (ICCP) system for previously jacketed piles, field identified prestressed concrete piles, and a detail ICCP system for concrete footers at Pier 9 and Pier 10 utilizing GFRP. The scope for Bridge No. 780089 includes the design of impressed current cathodic protection system utilizing GFRP and BFRP for the columns, struts and footers for piers 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, and 31, repair delaminations for columns 28-1, 28-2, and 29-2, repair undermined seal for piers 24 and 25. Cathodic protection is a process to slow down/stop the corrosion activity. In this process, all anodic areas within the cell are converted into cathodes by applying either direct current (DC) or alternating current (AC) external current flow from an anode into the metal exhibiting the corrosion. There are primarily two types of cathodic protection systems, sacrificial and ICCP. ICCP uses DC, which is generated by various sources such as photovoltaics cells, solar, wind, and generators, as well as regular AC power from utility companies and converted into DC using the rectifier. Additionally, batteries can also be used as a DC power source.

RESEARCH SIGNIFICANCE

The most common type of deterioration on Florida marine bridges is corrosion induced damage to substructure components, such as prestressed concrete piles and concrete footings. By using preservation techniques, marine bridge owners can save millions in costly replacement and extend the service life of the existing structure. FDOT's conventional approach on preservation includes both cathodic protection and concrete rehabilitation using conventional carbon-steel. These pilot projects utilized the alternative innovative reinforcement, including GFRP and BFRP, in lieu of conventional carbon steel. Having the non-metallic reinforcing in the substructure and foundation is advantageous and facilitates the installation and improves the constructability. The non-metallic reinforcing is relatively light in weight for handling, has higher strength, and is corrosion-free. Studies [2] conducted by FDOT to investigate characterization of newly developed sand-coated BFRP bars and evaluate their bond-dependent coefficient (k_b) confirms that the developed basalt FRP (BFRP) bars meet the requirements of [9] and [10] concerning their physical/mechanical properties as shown in Fig 1. Additionally, the k_b value for the tested BFRP bars were consistent with [11] for sand-coated FRP bars and the predicted crack widths were within the range of experimentally measured ones. However, investigating the long-term performance of these bars in different environments and under different exposure conditions required the implementation of pilot projects and additional monitoring. As a result, this and other pilot projects were implemented by FDOT. However, work on further research and studies of these FRP bars will continue in order to more accurately defining the durability model for BFRP internal reinforcing under studies [4,12] building on earlier work.

PROCEDURE

The substructure component needs to be cleaned and free of marine growth before the rehabilitation process can begin (Fig. 2). The process includes the removal of any loose concrete and verifying that all reinforcement within the component is robust and continuous. As a part of the planned bridge substructure repair and cathodic protection installation on the US 17 Trout River and SR 312 over Matanzas River bridges, an iterative sensitivity analysis of the piles was performed. The purpose of the sensitivity analysis was to evaluate the degree of risk associated with the removal of concrete and reinforcement from active piles and footers. Removal of concrete and reinforcing steel may significantly affect the stability of the bridges during rehabilitation. The analysis helps to determine the maximum amount of concrete and reinforcing material that can be removed from each pile without the requirement of temporary shoring or bracing. Results of these analyses are tabulated and reported herein and were provided on the plans to alert the contractor to the amount of concrete that can be safely removed.

PILOT PROJECTS

US 17 over Trout River details

The existing bridge is comprised of 27 spans totaling 1,458ft. The superstructure is comprised of AASHTO Type III prestressed beams. The substructure is comprised of a combination of 20-in. square prestressed pile bents and pile footings. The overall bridge width is 69.75-ft. and carries two lanes in each direction. The No. 4 GFRP bars were embedded into existing pier footings 9 and 10 to attach the new footing jacket to the existing pier footer. The pier 10 footing jacket also included No. 6 GFRP bars. Pneumatically applied concrete (shotcrete) was used to apply concrete to pier 9 and pier 10 footings to form the pier jacket.

Existing conditions—Existing pier footings as well as piles were severely deteriorated due to spalls and delamination. Reinforcements were exposed with a section loss of 25% or more. The majority of damage occurred within the splash zone on the piles as well as footings. The existing conditions are depicted in Fig. 3.

Construction method—The concrete was applied using shotcreting techniques (Fig. 4) for pier 9 and due to the problems with concrete quality issues on pier 10 (Fig. 5), the shotcrete was removed from the footing and the process of conventional forming of the jacket and placing concrete was used. This provided an opportunity to explore the removal of concrete from FRP bars. Use of GFRP with shotcrete has been used in other applications elsewhere in the past; however, its use on the substructure/foundations within the splash zone in marine environment was permitted for the first time in Florida by FDOT after industry development of improved GFRP bars using ECR glass fiber and vinyl-ester (VE) resins, that were further studied and tested [2] by FDOT. Below is the list of pilot applications incorporated on US 17/Trout River project:

- GFRP (ECR-VE) bars used in conjunction with shotcrete
- GFRP (ECR-VE) bars used in the splash zone
- GFRP (ECR-VE) bars used with conventional cast-in-place construction methods

Innovations—The conventional approach includes installation of grade 60 carbon-steel rebar in conjunction with cast-in-place concrete. The innovative (non-conventional) approach includes the utilization of GFRP bars in a variety of settings, including in conjunction with shotcrete as well as with conventional cast-in-place construction methods in the splash zone, and the removal of concrete from GFRP bars. The utilization of GFRP bars within the splash zone/marine environment on these successful pilot projects will support the outcome of the studies [2] for lifting the restrictions on use of GFRP bars within the submerged and splash zone of marine environments. The restriction was in place due to concerns regarding long-term degradation of GFRP fiber/resin systems in the presence of seawater.

SR 312 over Matanzas River

The existing bridge is comprised of 37 spans totaling 3,575ft. The superstructure is comprised of AASHTO Type IV prestressed beams for approach spans and steel plate girders for the 3-span channel unit. The substructure is comprised two-column piers supported by waterline footings and 20-in. square prestressed piles as well as steel H-pile buried footings. The overall bridge width is 42.75-ft. for both eastbound and westbound bridges and carries two lanes in each direction (see Fig. 6). Work activities included the removal of existing multi-column pier jackets and installation of new jackets on the multi-column pier. New jackets were installed at the selected multi-column piers. Pier footing Jackets with ICCP were installed. Ribbon anodes were installed between the piles on the pier footing. GFRP dowels and BFRP mesh were used in select locations. Pier 15, pier 19, pier 20, pier 21, pier 22, pier 23, pier 26, pier 29, pier 30, and pier 31 were rehabilitated as follows:

- Columns: No. 4 L-shape GFRP dowel bars were embedded into the columns to attach the 6-in. x 6-in. x 5/32-in. (150mm x 150mm x 4mm) BFRP mesh for crack control to protect the titanium anode mesh.
- Footing Struts: No. 4 L-shape GFRP dowel bars were embedded into the strut to attach the No. 4 GFRP bars in longitudinal and No. 3 GFRP bars in transverse direction to protect the titanium anode mesh. Dowel spacing was 6-in. and GFRP bars were spaced at 1-ft. in both directions alongside of the strut.
- Footing: This is among the first FDOT projects to implement ribbon anodes.

Existing Conditions—Existing pier footings were severely deteriorated due to spalls and delamination. Reinforcement was exposed with section loss of 25% or more. The majority of damage occurred within the splash zone on the footings and on the strut as well as columns. The existing conditions are depicted in Fig. 7.

Construction Method—Shotcrete was used in the column and strut to form the jacket. However, due to problems with concrete quality, the shotcrete was removed and re-applied to the piers with concrete quality issues. This has provided another opportunity to explore removal of concrete from the BFRP mesh and GFRP bars and for its reuse. The footing concrete was placed using conventional cast-in-place methods. Below is the list of innovations unique to this project (see Figs. 8 & 9).

- Use of GFRP (ECR-VE) bar in conjunction with shotcrete
- GFRP (ECR-VE) bar use in the marine environment
- Use of BFRP (Basalt-Epoxy) mesh in conjunction with GFRP (ECR-VE) bar
- Use of ribbon anodes in footings for cathodic protection of remaining carbon-steel reinforcing

The GFRP dowel bar was embedded 2.5-in. into the concrete by drilling and injecting and FDOT approved Type HV adhesive. The leg of the dowel bar was oriented horizontally to facilitate the vertical installation (hanging) of BFRP mesh. Once the BFRP mesh was installed it was secured in place using the non-metallic ties to GFRP dowel bars. Minimum concrete cover of 1-in. was maintained over the FRP bars.

Innovations—The conventional approach includes the installation of grade 60 carbon-steel in conjunction with cast-in-place concrete. The innovative (non-conventional) approach includes the utilization of GFRP rebar and BFRP reinforcing mesh in conjunction with both shotcrete and conventional cast-in-place construction methods in a marine environment, and provided an opportunity to explore the removal of poorly cast concrete from BFRP mesh (see Fig. 10). The utilization of GFRP bars within the splash zone of a marine environment on these successful pilot projects were consistent with the outcome and recommendations of the studies [2] sponsored by FDOT on improved FRP, providing further opportunities for future monitoring and support for lifting the restrictions on use of GFRP bars within the splash zone of marine environments.

TESTING

A very robust technical special provision (TSP) was prepared for the shotcrete, performance which included the testing requirements including creating the test panels (see Fig. 11). The surface for the shotcrete test panels were prepared identical to the actual application to facilitate adequate bonding as defined by ACI 548.11R-12 [13]. The surface preparation included removal of all spalled, severely cracked, deteriorated, loose, and unsound concrete from the existing concrete surface by chipping, scarifying, sandblasting, and water blasting. Any concrete that was contaminated by chemicals or oils were removed. A substrate profile in accordance with the International Concrete Repair Institute standard (ICRI Guideline 03732 as updated) CSP 5, with an angular surface profile of 1/8 in. to ¼ in. was prepared. Once surface preparation was completed, all repair areas were thoroughly cleaned by sandblasting and hydro-milling, to remove any traces of dirt, grease, fractured concrete, oil, or other substances that may interfere with the bond of the newly placed shotcrete. Particular care was taken to remove debris around reinforcements. The surface of GFRP bars were provided with sand coating that promotes bond adhesion of the bar to shotcrete (see Fig. 12). A 28-day compressive strength of 5,000 psi for shotcrete was proposed. Shotcrete was to be uniform and dense, free from deficiencies that would indicate delamination, voids, sand pockets, or poorly consolidated material. The procedures for preparing shotcrete test panels and the testing specimens cored from panels were performed in accordance with ASTM C 1140 [14]. The minimum panels size was 18-in. square and not less than 6-in. thick. For each compressive strength test, three cores were tested in compression. Since none of the specimens showed apparent evidence of improper sampling, coring, or testing, the test result was taken to be the average of the strengths of the three specimens. Prior to the application of shotcrete, testing of the existing substrate concrete for pull off strength was done in accordance with ASTM C 1583 [15]. Surface preparation was found to be adequate for bonding as defined by ACI 548.11R-12 [13] for SR 312 over Matanzas River Testing (see Fig. 13).

LESSONS LEARNED

Several challenges were overcome during the design as well as construction of both US 17 over Trout River and SR 312 over Matanzas River and are listed below:

- Longer lead times than typically expected for steel rebar was required for the procurement of GFRP due to the production shop availability for bending/fabrication GFRP bars as well as both GFRP and BFRP producers were not available locally.
- For pilot projects take into account the availability of experienced workers on similar technology as the technology was implemented for the first time in the state.
- GFRP/BFRP material storage guidelines and specifications including the temperature were not available in the FDOT specifications.
- Limitations on the field modifications associated with the reinforcing due to the shop bending/fabrication of the bars.
- Location of the site in relation to the concrete plant provided tight time intervals to place the concrete, possibly contributing to the poor placement of the shotcrete.
- Very little to no damage was observed after removal of concrete from BFRP mesh and GFRP bars and this reinforcing was then successfully reused.
- Shotcreting techniques require very strict quality control in mix design, temperatures as well as nozzle man skill and qualification for its success.

CONCLUSION

US 17 over Trout River Bridge and EB SR 312 over Matanzas River Bridge incorporated numerous innovations as pilot projects. In the end, both projects were successfully constructed and are being monitored long-term by the FDOT State Materials Office. The technologies and innovations implemented in both projects are performing well and as a result partially contributed to FDOT lifting the restrictions on the usage of GFRP bars in the marine environment and implemented this innovative technology in several recent projects.

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