

Carbon Fibers in Civil Structures: Rehabilitation and New Construction

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STRENGTHENING WITH COMPOSITES

Background

In the case of reinforced (RC) or prestressed concrete (PC) structures, a promising new repair technology involves the use of externally bonded FRP laminates. Similar to steel plate bonding, FRP laminate bonding involves adhering a thin, flexible fiber sheet to the concrete surface with a thermoset resin. This technique, known as manual lay-up, may be used to increase the shear and flexural capacity of beams and slabs and to increase confinement in columns. In addition, the system does not add significant dead load to the structure, suffers little from corrosion, and may be installed in a relatively short period of time. Figure 1 shows (a) the fiber sheet and (b) its installation.



Figure 1. Externally Bonded CFRP Laminates

The use of near surface mounted (NSM) FRP rods is another promising technology for increasing flexural and shear strength of deficient RC and PC members (De Lorenzis 2000). Advantages of using NSM FRP rods, with respect to externally bonded FRP laminates, are the possibility of anchoring the rods into adjacent members and minimal installation time. Furthermore, this technique becomes particularly attractive for flexural strengthening in the negative moment regions of slabs and decks, where external reinforcement would be subjected to mechanical and environmental damage and would require protective cover which could interfere with the presence of floor finishes. The rods are installed by cutting a groove into the concrete surface and

embedding them into the groove with a resin-based paste. Figure 2 shows the installation of NSM FRP rods on (a) a concrete beam (shear strengthening), (b) a concrete slab (flexural strengthening), (c) a concrete column end (flexural strengthening), and (d) a masonry wall (in-plane strengthening).

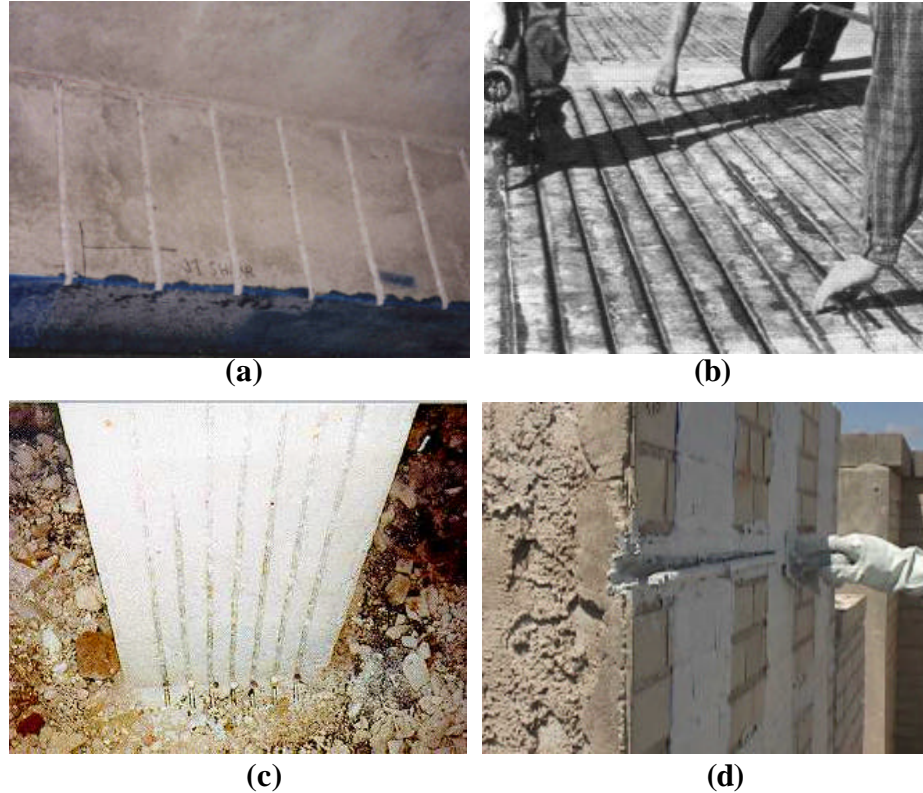


Figure 2. Example Applications of NSM FRP Rods

Deficient bridges

National growth and economical prosperity are closely related to the adequacy of the transportation infrastructure. Bridges, in particular, are considered one of its critical components. Many US bridges are made of reinforced concrete and were designed in accordance with older codes to accommodate traffic loads smaller than currently permitted. Moreover, most of these structures were designed for gravity loads only, with no consideration to seismic vulnerability.

It may be economically unfeasible to replace every outdated bridge across the country due to many reasons including cost, time of construction, and traffic disturbance. A potential solution is the use of new technologies that allow for the upgrading of deficient structures at low cost and with minimal users' inconvenience. To this extent, strengthening systems that utilize FRP systems in the form of "external" reinforcement may be of great interest to the civil engineering community (Nanni 1997). Reinforcement can be in the form of FRP laminates to be adhered to the concrete surface or FRP rods to be embedded in slots grooved on the concrete surface. Some repair examples are discussed.

Bridge J857, located on Route 72 in Phelps County, MO, was strengthened in August of 1998 while in service (Alkhrdaji et al.1999) (Figure 3-a). The three-span structure had a roadway width of 25 ft., with each deck spanning 26 ft. One of the three solid RC decks was strengthened using NSM FRP rods. The NSM reinforcement consisted of sandblasted CFRP rods with 7/16-in. diameter. Strengthening to approximately 130% of the existing nominal moment capacity was desirable in order to upgrade the bridge decks for HS20-modified truck loading. The design called for 20 NSM CFRP rods spaced at 15 in. on-center. The rods were embedded in 20-ft. long, 3/4-in. deep, and 9/16-in. wide grooves cut into the soffit of the bridge deck parallel to its longitudinal axis. Strain gages and fiber optic sensors were applied to the concrete and to the steel and FRP reinforcement to monitor strain during testing. Once the bridge was decommissioned, each of the three decks was tested to failure by applying quasi-static load cycles. For the deck with NSM rods, failure was initiated by the rupture of some CFRP rods at the location of the widest crack. This deck exhibited the highest failure load, corresponding to an increase in moment capacity of 27% over the unstrengthened deck. Two columns were also strengthened with NSM CFRP rods to increase their flexural capacity (Figure 2-c). The rods were mounted on two opposite faces of the columns and anchored 15 in. into the footings.

Similarly to Bridge J857, another bridge was selected for demonstration of the CFRP strengthening technology. This is Bridge G270 located on Route 32 in Iron County, MO (Mayo et al. 1999). It is a 20-ft. long solid reinforced concrete slab built in 1922 with an original roadway width of about 18 ft. The bridge currently carries a traffic volume of 1600 vehicles per day. Around 1990 the original baluster handrails were removed and replaced with a three-beam guardrail, which expanded the roadway width to approximately 20 ft. The bridge has a load restriction posting of 19 tons for H20 trucks and a 34-ton weight limit for all others. Due to the restrictive load posting and its location near a lead mine, a generator of heavy truck traffic, the Missouri Department of Transportation (MoDOT) selected this bridge for demonstration of this strengthening technique (Figure 3-b).



Figure 3. Bridges J857 and G270

Masonry and concrete buildings

Current trends in construction toward repair and rehabilitation have emphasized the need to provide additional strength to existing structures. Structures that experience a

change in use, a degradation problem, or a design/construction defect typically require some degree of strengthening. Some examples are discussed.

A strengthening project was carried out to upgrade the structural floor of Myriad Convention Center, Oklahoma City, OK in 1997 and 1998 (Hogue et al. 1999) (Figure 4-a). A combination of externally bonded steel plates, Carbon FRP (CFRP) sheets and NSM CFRP rods was utilized.

NSM CFRP rods were used for strengthening of six RC silos in Boston, MA, in 1998 (Figure 4-b). Longitudinal and transverse grooves 1/2-in. wide and 1/2-in. deep were cut on the surface of the structures and sandblasted CFRP rods with a nominal diameter of 5/16 in. were embedded in the epoxy-filled grooves.

A strengthening and load-testing program at the decommissioned Malcolm Bliss Hospital in St. Louis, MO was conducted in 1999 (Tumialan et al. 1999) (Figure 4-c and d). In the building, a five-story RC-frame addition built in 1964, static load tests up to failure were carried out in order to validate strengthening of masonry walls and RC joists using externally bonded FRP laminates and NSM FRP rods. The program on masonry walls strengthened with FRP composites included testing of unreinforced masonry walls subjected to out-of-plane loading and reinforced masonry walls under in-plane loading.



(a)



(b)



(c)



(d)

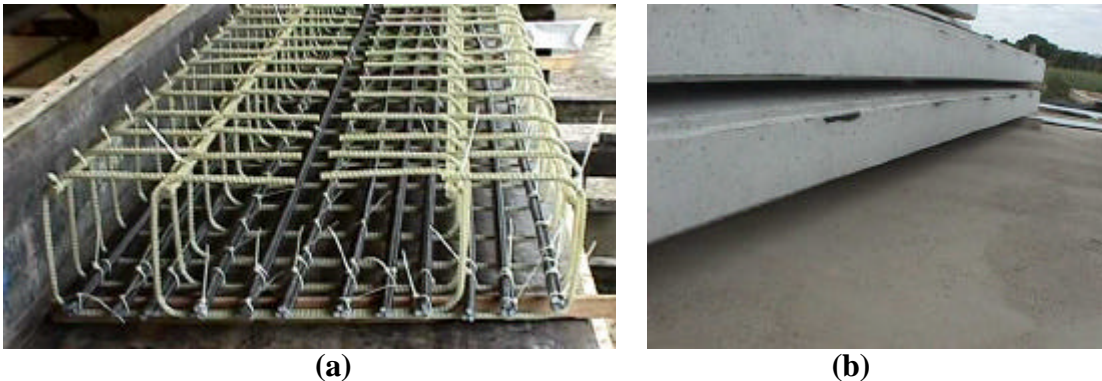
Figure 4. Examples of Strengthening

NEW CONSTRUCTION

Background

Although several projects in North America have successfully implemented this technology (i.e., internal FRP reinforcement for concrete structures), there is still not a large experience base for design and construction professionals to draw from. Furthermore, codes and standards do not yet exist for this technology. .

One current example of the use of FRP in new construction involves the installation of an FRP-reinforced concrete bridge in St. James, MO. Work is in progress to replace a traditional RC slab bridge with a multi-panel concrete bridge reinforced with FRP rods for both shear and flexure. Figure 5 illustrates (a) the cage of reinforcing bars used in the panels and (b) the completed panels. The precast panels are 12 in. deep and 34 in. wide. The bridge will consist of 9 panels, for an overall width of 25 ft.-8 in., and will have a length of 24 ft. Both carbon and glass FRP bars were used for the reinforcement.



(a) (b)
Figure 5. Prefabricated Bridge Panels

PROGRESS IN BUILDING CODES AND STANDARDS

The American Concrete Institute is in the process of publishing two documents that are expected to have a significant impact on the use of FRP composites as reinforcement to concrete. The two documents are titled:

Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures

Guide for the Design and Construction of Concrete Reinforced with FRP Bars

The US and international civil engineering communities will finally have in their hands the tools that are required for owner's and public official's acceptance and the FRP manufacturing industries will have guidance for the fabrication and quality control of suitable products.

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BIO-SKETCH

Antonio Nanni, FACI, FASCE, is the V&M Jones Professor of Civil Engineering and Director of the Center for Infrastructure Engineering Studies (CIES) at the University of Missouri-Rolla. Dr. Nanni is a registered PE in the states of FL, PA and MO. He is an active member in the technical committees of ACI, ASCE, ASTM and TMS. He is interested in construction materials, their structural performance, and field application. Since 1989, Dr. Nanni has been involved in R&D on the use of composites for infrastructure. He has conducted design and load testing of numerous structures strengthened with FRP in the USA and overseas.