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TO: District Design Engineers, District Structures and Facilities Engineers,
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SUBJECT: Temporary Design Bulletin C06-03
Carbon Fiber Reinforced Polymer - CFRP

This design bulletin provides design procedures and recommended construction specifications for the use of bonded fiber-reinforced polymer (FRP) composites to strengthen or repair bridge elements.

REQUIREMENTS

Add the following as **Section 7.8 - Repair or Strengthening using Carbon Fiber Reinforced Polymers**, to Volume I of the January 2006 Structures Manual (Structures Design Guidelines).

7.8.1 System Selection

FRP composite systems used in repair or strengthening shall have carbon as the primary reinforcement (CFRP). Whether a precured laminate or wet layup system is used, the resin and adhesive shall be a thermoset epoxy formulation specifically designed to be compatible with the fibers or precured shapes.

7.8.2 Design

The design of CFRP systems is considered a Category 2 structure and the plans and specifications shall be reviewed and approved by the Structures Design Office for this repair portion of the project. Design shall conform to ACI Committee 440.2R-02 ("Guide for the Design and Construction of Externally Bonded FRP Systems for Strengthening Concrete Structures" American Concrete Institute, ACI 440.2R-02, 2002, 45 pp.) except as noted herein. Loads shall be obtained using LRFD Bridge Design Specification.

*A.V. Pavlov
for W.N.*

- a) *Replace* “PART 3 – RECOMMENDED CONSTRUCTION REQUIREMENTS” *with the following:*

Section II of National Cooperative Highway Research Program Report (NCHRP) 514 (Mirmiran, A., Shahawy, M., Nanni, A., Karbhari, V., (2004) “Bonded Repair and Retrofit of Concrete Structures Using FRP Composites, Recommended Construction Specifications,” Transportation Research Board, 102 pp.)

- b) *Modify Section 8.2 as follows:*

When a single girder in a span containing at least four similar girders is strengthened then the following limit shall control:

$$(\phi R_n)^{Existing} \geq (1.2S_{DL} + 0.85S_{LL})$$

where $(\phi R_n)^{Existing}$ is the capacity of the existing member considering ONLY the existing reinforcement, S_{DL} and S_{LL} are the unfactored dead load and live load effects, respectively, that occur after the member has been strengthened. When multiple girders in a single span are strengthened then the following limit shall control:

$$(\phi R_n)^{Existing} \geq (1.2S_{DL} + 1.0S_{LL})$$

If the existing reinforcement is insufficient to satisfy this equation, then alternative means of strengthening or replacement of the structure shall be implemented. This check shall be conducted using load factors and capacity reduction factors from the LRFD Bridge Design Specification.

- c) *Modify Section 8.3.1 as follows:*

An environmental reduction factor $C_E = 0.85$ shall be used for all bridge applications.

- d) *Replace equation 9-5 with.*

$$\phi = 0.9 \text{ when } \frac{c}{d_t} < 0.375$$

$$\phi = 0.7 + 0.2 \left[\frac{1}{c/d_t} - \frac{5}{3} \right] \text{ when } 0.600 \leq \frac{c}{d_t} \leq 0.375$$

$$\phi = 0.7 \text{ when } \frac{c}{d_t} > 0.600$$

where c is the distance from extreme compression fiber to neutral axis when the section is at capacity and d_t is the distance from extreme compression fiber to centroid of extreme layer of longitudinal tension steel.

e) Modify Section 9.4 as follows:

Stresses in existing reinforcement (using equation 9-6) shall be checked using Service I Load Combination from LRFD Bridge Design Specifications.

f) Modify Section 9.5 as follows:

Use the standard fatigue truck from LRFD Bridge Design Specifications to check fatigue stresses in CFRP composites. Allowable fatigue stresses in prestressing or mild steel shall be checked using Chapter 5 of the LRFD Bridge Design Specifications.

g) Modify Section 9.6 as follows:

Strength of nonprestressed concrete sections repaired with CFRP composites shall be calculated using the equations given in Section 9.6. Strength of prestressed sections repaired with CFRP composites shall be calculated using equilibrium and strain compatibility. Regardless of method, the strain in the CFRP composites at ultimate capacity shall not exceed the bond critical limit given in equation 9-3.

h) Modify Chapter 10 as follows:

Shear strengthening shall be restricted to one of the following methods. The first is with a completely wrapped element as illustrated in Fig. 10.1 of the ACI 440.2R-02. U-wraps may also be used only if the termination of the wrap is anchored to prevent debonding. The anchorage system shall have been tested to ensure the system will behave similar to the fully wrapped system.

i) Modify Chapter 12 as follows:

In addition to the requirements in section 12.1.12, transverse CFRP reinforcement shall be provided at the termination points of each ply of CFRP flexural reinforcement. In addition, transverse reinforcement shall be provided at a maximum spacing of d along the length of the member from end to end of the CFRP reinforcement. Alternatively, 0-90 degree fabric shall be permitted, which when wrapped up into the web can provide simultaneous transverse and longitudinal strengthening. The width of the transverse reinforcement at the termination shall measure at least $\frac{3}{4}d$ along the member axis and shall have at least 30% of the capacity as that of the flexural reinforcement. Intermediate transverse reinforcement shall have a minimum length of $d/4$.

7.8.3 Construction

The Engineer or Record shall develop Technical Special Provisions for Construction and quality control that conform to the specifications given in Section II of National Cooperative Highway Research Program Report (NCHRP) 514 (Mirmiran, A., Shahawy, M., Nanni, A., Karbhari, V., (2004) "Bonded Repair and Retrofit of Concrete Structures Using FRP Composites, Recommended Construction Specifications," Transportation Research Board, 102 pp.) except as noted herein.

In wet layup systems, shear and flexural reinforcement shall have no more than three layers. This does not include anchorage requirements listed in 7.8.2 i).

Technical Special Provisions shall be non-proprietary, multi-vendor solutions (2 minimum), reviewed and approved by the State Specifications Offices and the State Structures Design Office.

APPLICABILITY

This design bulletin is intended for use on simple span deck and girder concrete bridges containing mild steel or pretensioned reinforcement or both. It is assumed that the prestressed reinforcement is ASTM A416 (AASHTO M203) Grade 240 or 270 seven-wire strand and that the mild steel reinforcement is ASTM A615 (AASHTO M31) Grade 60.

BACKGROUND

The draft of this policy was initially presented at the FDOT Load Rating Summit in December 2005. Composites are used to repair and strengthen concrete structural elements in a number of ways. Although not suitable for every application, carbon fiber reinforced polymer (CFRP) composites can provide an economical and rapid tool in some instances. Potential uses include:

- Repair impact damaged reinforced or prestressed concrete girders
- Repair corrosion-damaged reinforced or prestressed concrete girders
- Wrap corroded piles to slow the progress of corrosion and delay more extensive repairs or replacement.
- Increasing the flexural or shear strength, or both, of existing reinforced or prestressed elements.

The use of CFRP composites to reinforce concrete structures is a relatively new technology and the long-term performance regarding infrastructure applications is being monitored. Therefore, the increase in load capacity provided by the CFRP reinforcement should be limited to avoid catastrophic collapse should the repair fail. This is accomplished by requiring that the element must, at a minimum, support service level loads without the contribution of the CFRP composite. Environmental reduction factors from ACI 440.2R-02 shall be used as recommended in that document. Surface bonded CFRP composites should be inspected every two years for delamination and degradation of the epoxy matrix and adhesive.

IMPLEMENTATION

All past projects utilizing this repair material have been designed and load tested on a case-by-case basis making each location a unique repair. The purpose of this policy is to formalize the design methods and thereby provide consistent repairs.

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