

Strengthening of an Impact-Damaged PC Girder

By Antonio Nanni, PhD, PE

Repair of impacted prestressed and reinforced concrete (PC and RC, respectively) structures using traditional and emerging technologies has been the subject of several studies. Fiber-reinforced polymer (FRP) systems composed of fibers embedded in a polymeric matrix exhibit properties that make them suitable for their use as structural reinforcing elements. FRP composites are characterized by excellent tensile strength in the direction of the fibers and by negligible strength in the direction transverse to the fibers. FRP composites are corrosion resistant and are expected to perform better than other construction materials in terms of weathering behavior. Several types of fibers have been developed for use in FRP composites. For this project, carbon fibers, which are recognized to be the stiffest and most durable, were used.

Scope

The objective of this project was to restore the original ultimate flexural capacity of an accidentally impact-damaged PC girder of Bridge A5657 located on Route 28 over the Gasconade River, south of Dixon, Missouri. Two prestressing tendons in the central girder of the north span of the bridge were fractured due to the impact.

Similar projects involving the strengthening of damaged bridge girders have been conducted (Nanni 1997), including two in the State of Missouri (Nanni, Huang, and Tumialan 2001; Schiebel, Parretti, and Nanni 2001). In these projects, carbon

FRP (CFRP) laminates were proposed for installation by manual lay-up to restore the original ultimate capacity of the impacted girder.

Material Properties and Girder Geometry

The damaged girder is prestressed by 38 low-relaxation steel strands with a tensile strength of 270 ksi (1862 MPa). It was assumed that a portion of the bridge deck with dimensions of 8 x 106 in. (20 x 270 cm) provided composite action with the girder. The cross section of the damaged girder is shown in Fig. 1. Material properties used in the analysis are shown in Table 1.

A commercially available FRP strengthening system was selected for its high strength and excellent performance under sustained and cyclic loading. The system includes primer, putty, fiber sheets, and impregnating resin (that is, saturant) for installation by manual lay-up. Material properties of the FRP reinforcement reported by the manufacturer, such as the ultimate tensile strength, do not account for long-term exposure to environmental conditions and were considered as initial properties. FRP properties to be used in all design equations are given as follows according to ACI 440 guidelines (ACI 440 2002)

$$f_{fu} = C_E f_{fu}^* \quad (1)$$
$$\epsilon_{fu} = C_E \epsilon_{fu}^*$$



Bridge A5657 on Route 28 over the Gasconade River south of Dixon, Missouri



Impact-damaged PC girder of Bridge A5657

Table 3: Factored flexural capacity

Girder	d_p , in. (cm)	ϕM_n , ft-k (kN-m)
Virgin	65.9 (167)	8040.5 (10,901)
Impacted	65.7 (166)	7617.3 (10,328)
Repaired	65.7 (166)	8061.0 (10,929)

around the bulb of the girder over the previous installation (refer to Fig. 3(b)). The purpose of the U-wrap is to prevent delamination of the FRP plies applied to the bottom surface of the girder.

Length of FRP Reinforcement

FRP reinforcement was no longer needed at the cross section where the damaged strands again become fully effective. For the damaged strands, it is reasonable to assume a linear transition between the point of zero stress and full prestress transfer over their development length. The development length l_d is expressed as follows (refer to Fig. 4 and ACI 318-99)

$$l_d = (f_{ps} - \frac{2}{3}f_{se})d_b \quad (4)$$

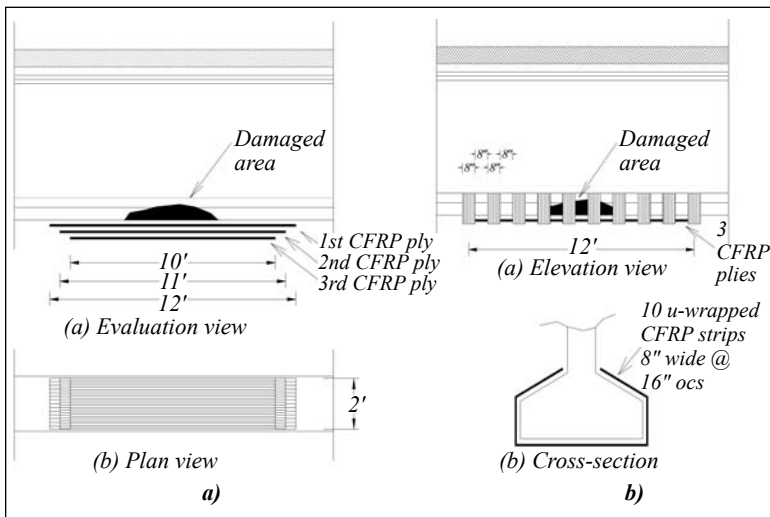


Fig. 3: CFRP flexural strengthening (1 in. = 2.54 cm)

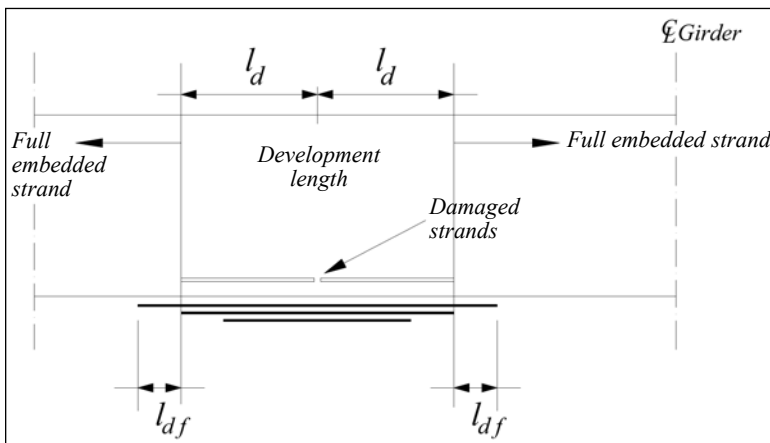


Fig. 4: Strand and FRP development length

where d_b is the strand diameter (in inches), f_{ps} is the stress in the prestressed reinforcement at nominal strength of member (in ksi), and f_{se} represents the effective stress in the prestressed steel after losses (in ksi). In turn, f_{ps} and f_{se} computed according to ACI 318-99 become equal to $f_{ps} = 253$ ksi (1744 MPa). From Eq. (4), the development length for the strand can be calculated equal to 5.5 ft (1.70 m).

The length of the first and longest FRP ply was then set equal to 12 ft (3.65 m), which corresponds to 11 ft (3.35 m) necessary to account for the tendons' development length plus 1 ft (0.3 m), corresponding to 6 in. (15 cm) at each end, deemed necessary for the FRP development length suggested by ACI 440.2R-02. The remaining two plies were set to have lengths of 11 and 10 ft (3.35 and 3.0 m).

Installation

Before carrying out the CFRP laminate installation, the damaged area of the girder was restored with a rapid-setting, no-shrinkage, cementitious mortar. The sequential installation procedure was as follows:

- **Surface preparation:** The bottom edges of the girder are rounded for proper wrapping and the concrete surface is sandblasted until the aggregate is exposed and the surface of the concrete is free of loose and unsound materials;
- **Application of primer:** A layer of epoxy-based primer is applied to the prepared concrete surface using a short nap roller to penetrate the concrete pores and to provide an improved substrate for the saturant;
- **Application of putty:** After the primer becomes tack-free, a thin layer of putty is applied using a trowel to level the concrete surface and to patch small holes;
- **Application of first layer of saturant:** The first layer of saturant is rolled on the putty using a medium nap roller. The functions of the saturant are: to impregnate the dry fibers, to maintain the fibers in their intended orientation, to distribute stress to the fibers, and to protect the fibers from abrasion and environmental effects;
- **Application of fiber sheet:** After the fiber sheet is measured and pre-cut, it is placed on the concrete surface and gently pressed into the saturant. Prior to removing the backing paper, a trowel is used to remove any air void. After the backing paper is removed, a ribbed roller is rolled in the fiber direction to facilitate impregnation by separating the fibers; and
- **Application of second layer of saturant:** A second layer of saturant is applied and worked into the fibers with a ribbed roller. After this, the second and third fiber sheet can be installed by repeating the described procedure.

After fiber installation and curing, a layer of protective coat was applied to ensure UV protection



Application of primer



Application of first fiber sheet



Patching



Application of second fiber sheet



Surface preparation



Application of U-wraps

of the FRP and to warrant durability performance of the system.

Inspection, Maintenance, and Validation

Based on current experience, FRP strengthening of impacted girders is a long-term reliable repair procedure, and no special maintenance should be

necessary. However, the continuing long-term evaluation of the applied strengthening system is recommended. For this purpose, on the same girder and close to the abutment to facilitate operations, one FRP strip was installed in the same fashion and number of plies of that adopted during the strengthening system installation. The area for inspection is 20 in. (50 cm) wide and 2 ft (60 cm) long. An engineer should tap this area when



Virgin girders



Strength girders

inspecting the bridge and if any doubt arises, perform a bond test. The bond test (that is, bond pull-off or torsion tests) can be used to evaluate the quality of bond over time.

The strengthening approach was validated by means of laboratory tests on full-size PC members that validated the performance of the FRP system.

Externally bonded FRP laminates provide a solid solution for flexural strengthening of an impacted precast PC girder. The strengthening methodology described is particularly indicated in all those cases where the deficiency is located on the tension side of the concrete cross section, leading to the best and economical use of emerging materials such as composites. The appeal of advanced materials in the repair and rehabilitation stems from the ease of installation and relative minimization of downtime. A two-man crew with a cherry-picker was able to complete the repair over a period of 3 half-days. The alternative would have been an onerous, expensive, and time-consuming solution.

References

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