MAINTENANCE AND REHABILITATION OF CONCRETE HIGHWAY BRIDGES WITH CFRP COMPOSITES

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ABSTRACT

Corrosion of steel reinforcing bars (rebars) in concrete highway bridges is considered the primary limit state, in severe environments. Corrosion of rebars results in reduction of steel section, loss of bond between rebars and concrete, as well as spalling of concrete cover in the vicinity of the corroded rebars. The cost of maintenance of deteriorated concrete bridges in the USA mounts in billions of dollars. Carbon Fiber Reinforced Polymer (CFRP) composites have proven to be the material of choice for repair and strengthening of existing concrete structures. However, their use in maintenance of existing bridges has not been efficiently explored. Smart detailing of CFRP composites allows for reduced construction cost and time. In addition, a successful retrofit and protection system for a deteriorated concrete bridge in severe environments must incorporate corrosion protection system, e.g. sacrificial anodes, corrosion inhibiting paints, etc. This paper presents the various types of structural retrofit systems for corroded concrete bridges. These systems include but not limited to the use of CFRP composites for both; cost-effective maintenance and repair of deteriorated bridges, along with corrosion protection systems. Examples of CFRP retrofitted concrete bridges with CFRP composites are presented.

1 INTRODUCTION

Environmental deterioration issues are the main focus of considerable concern in the construction market. Increasing numbers of structures are experiencing significant amounts of deterioration prior to reaching their full design service life. This premature deterioration considered a problem in terms of the structural integrity and public safety. In addition, deterioration of a structure has a considerable magnitude of associated costs [1].

In many cases, the root of a deterioration problem is caused by corrosion of steel reinforcement in concrete structures. Concrete normally acts to provide a high degree of protection against corrosion of the embedded reinforcement. The concrete inherently provides a highly alkaline environment to the steel. This protects or passivates the steel against corrosion. However, corrosion will result in those cases that typically experience poor concrete quality, inadequate design or construction, and harsh environmental conditions.
Carbon fiber reinforced polymer (CFRP) composites have proven to be the material of choice for repair and strengthening of existing concrete structures. However, the CFRP composite is not a corrosion protection system. A successful retrofit and protection system for a deteriorated concrete bridge in severe environments must incorporate corrosion protection system, e.g. sacrificial anodes, corrosion inhibiting paints, etc.

Several researchers have investigated the effects of CFRP composites on behavior of strengthened reinforced concrete beams. Arduini & Nanni, and Blaschko et al. [2,3] presented the modes of failure of CFRP strengthening reinforced concrete beams. The most common failure mode was premature debonding between concrete surfaces and CFRP composites. This failure mode causes wasteful application of CFRP composite materials due to undevelopment of their full capacities. To prevent this premature brittle failure, several different anchoring systems were investigated by Ritchie et al., Sharif & Baluch, and Spadea & Bencardino [4,5,6]. However, it is still necessary to develop a simple and more effective anchorage system, e.g. diagonal CFRP anchors.

2 ENVIRONMENTAL DETERIORATION OF CONCRETE BRIDGES

Corrosion of steel bars results in loss of steel section, spalling of the concrete cover, and loos of bond between the steel bars and the surrounding concrete. In the field, concrete structures are also subject to carbonation, freeze-thaw, and other deterioration mechanisms depending on their surrounding environments. In heavily reinforced concrete structures, e.g. bridge piers, corrosion of steel bars results in delamination of the concrete cover over a large surface area. Figure 1 shows examples of environmentally deteriorated concrete bridges.

![Environmentally Deteriorated Concrete Bridge Piers](image)

Environmental deterioration of a concrete bridge decreases its service life. In addition, it may also lead to a more critical condition; structural deficiency. Figure 2 shows corrosion of a concrete bridge cap beam, where the corrosion of the main steel bars has led to a structural flexural deficiency. Similarly, corrosion of transverse reinforcing bars may also lead to premature shear failure.

Delayed maintenance of highway bridges has led to extensive deterioration of many concrete bridges. The safety level of many of the deteriorated bridge has reached to a critical level. Immediate attention to the structural integrity and safety is required. However, any rehabilitation project must start with thorough assessment and evaluation to produce a cost-effective strengthening system.
In order to protect and strengthen a deteriorated concrete bridge, the cause of the deterioration should be investigated. In case of corrosion of steel bars, a corrosion protection system should be adopted. As corrosion of steel bars results in loss of steel section, new form of external reinforcement are used to restore the strength of deteriorated bridges. In recent two decades, the carbon fiber reinforced polymer (CFRP) composite has the material of choice due to its corrosion resistance, light weight, and ease of application. Due to their high tensile strength, CFRP composites used in structural rehabilitation are added as external tensile reinforcement. CFRP composites increase strength, and when well detailed, they enhance ductility of deteriorated concrete bridges. CFRP composites are not corrosion protection system, therefore, a corrosion protect system should be employed along with CFRP composites to prevent further corrosion of steel bars in strengthened concrete bridge, e.g. sacrificial anodes.

3.1 Ductility of CFRP strengthened Flexural Members

Kim and Aboutaha [7] conducted a series of tests on CFRP strengthened rectangular reinforced concrete beams with various amount of internal steel reinforcement ratios. The beams consisted of four rectangular strengthened beams, which had the same amount of the CFRP sheets, but different amount of internal tensile steel reinforcement: 2#4, 2#5, 2#7, and 2#8 rebars for Beams B4, B5, B7, and B8, respectively. Figure 3 shows the details of the beams.

Figure 3 Response of CFRP Strengthened Beams with variable steel reinforcement ratios [7]
The primary goal of this test was to investigate the effect of the amount of internal tensile steel reinforcement on the behavior of CFRP strengthened reinforced concrete beams. The results of this investigation suggest that reinforced concrete members with higher steel reinforcement ratios have higher ductility, as shown in Figure 4. This is a very important finding for CFRP strengthened deteriorated bridge elements, as corrosion reduces the size of the steel bars, which results in higher forces being carried by the CFRP sheets, which may lead to premature debonding of the CFRP sheets.

Aboutaha [1] conducted an experimental investigation on CFRP repaired AASHTO Type II highway girder. The girder was first tested to its full ultimate flexural strength, followed by a second test to investigate the stiffness and strength of the girder in its damaged condition, and then followed by testing the girder after being strengthened with CFRP sheets. Figure 5 shows the details of the girder. The results of this investigation suggest that CFRP sheets installed on the tension side of a damaged AASHTO Type II girder can improve both the stiffness and strength, as shown in Figure 6.

3.2 CFRP Strengthening of Deteriorated Concrete Bridge Columns

Efficiency of CFRP system for strengthening concrete bridge columns depends on the details of the column. For circular columns, CFRP system could increase the axial strength, flexural ductility, and shear strength. On the other hand, for rectangular columns, CFRP system could
increase shear strength, however, their effectiveness in increasing the flexural ductility and axial strength is very limited.

![Figure 6 Response of the original, damaged, and repaired AASHTO Type II girder [1]](image)

Strengthening of concrete column depends on the level of deterioration. For severely deteriorated column, where the steel bars have lost large percentage of their cross-sectional area, along with major loss of bond between the steel bars and the surrounding concrete, the addition of new steel bars is required, followed by strengthening with a CFRP composite system. Figure 7 shows the details of a severely deteriorated circular reinforced concrete column. It is important to ensure the continuity of the load path through the steel reinforcing bars. The new steel bars should be spliced or welded to the existing bars. In addition, every section should have adequate flexural strength. Strengthening of circular deteriorated concrete column with CFRP systems is done by transverse wrapping of the column. This is true regardless of the purpose of the strengthening system: increasing axial and/or shear strength, improving flexural ductility, or enhancing confinement.

![Figure 7 Structural rehabilitation of severely deteriorated circular concrete column. -Major loss of steel bars [1]](image)
8 CONCLUSIONS

Based on this investigation, the following conclusions could be drawn:

a) Corrosion of steel bars is the primary limit state for concrete bridges in severe environments.

b) Thorough evaluation and assessment of deteriorated bridges is required to design a cost-effective strengthening system.

c) CFRP composites do not corrode; however, they are corrosion protection system. Therefore, in order to prevent further corrosion, a corrosion protection system should be adopted along with any strengthening system.

d) As corrosion reduces the size of steel reinforcing bars, CFRP sheet will have to carry higher forces, which results in premature debonding of the CFRP sheet, and lower ductility.

e) Continuity of the load-path and forces in the CFRP system is essential for its successful application. Structural engineers should pay attention to detailing as much as design of the amount of the CFRP system.

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