Repair of Damaged Prestressed Concrete Bridges Using CFRP

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ABSTRACT

Every year many prestressed concrete (P/C) girder bridges in Iowa are damaged by overheight vehicles. Traditional P/C girder repair strategies include welded steel jackets, internal strand splices, and external post-tensioning. Unfortunately, these types of repairs are both labor intensive and vulnerable to future corrosion. One possible alternative to these traditional repair techniques is to repair/strengthen impact damaged P/C girders with carbon fiber reinforced polymers (CFRP). These types of materials have the advantage of large strength/weight ratios, excellent corrosion/fatigue properties, and are relatively simple to install. This paper will present experimental results from one of the three damaged P/C girder bridges that were repaired using CFRP.

The results from testing this bridge before and after being repaired with CFRP will be presented. Data from these tests verified that CFRP is an effective method for repairing/strengthening damaged P/C girder bridges.

Key words: carbon fiber reinforced polymers—damaged prestressed concrete bridges—field testing repair—strengthening

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Proceedings of the 2003 Mid-Continent Transportation Research Symposium, Ames, Iowa, August 2003.

INTRODUCTION

Each year numerous highway bridges in Iowa are damaged by impacts due to over height vehicles, which result in costly repairs and traffic disruptions. Iowa State University, in conjunction with the Iowa Department of Transportation (Iowa DOT) is investigating the use of externally bonded carbon fiber reinforced polymers (CFRP) to repair and strengthen damaged prestressed concrete (P/C) girders. Though different types of repair methods, materials, and elements are being considered, the objective of this research is to investigate the effectiveness of CFRP as a material to repair damaged P/C bridge girders.

The repair and strengthening of reinforced concrete (R/C) structures with CFRP is a generally accepted practice. However, there has been minimal research on the use of CFRP to strengthen and repair impact damaged P/C bridge girders. Current accepted methods to repair P/C girders include the use of steel jackets, tendon splices, exterior prestressing or the replacement of the damaged girders. Drawbacks of these methods include relatively high costs, corrosion, poor fatigue performance, and long periods of traffic disruption. The advantages of using CFRP include reduced installation time, corrosion resistance, and ease of application. To determine the effectiveness of CFRP as a repair method for P/C bridge girders, laboratory as well as field tests are being undertaken.

Review of Previous Work

An extensive literature search has been conducted to investigate the use of CFRP in concrete repairs. Included in this search was the investigation of methods for repairing vehicle impacted P/C bridges.

A comprehensive survey was developed and sent to state and Canadian highway officials to determine what policies and procedures are being followed in the case of impact damaged P/C bridges. The questionnaire also addressed whether CFRP had been used as a repair material or was being considered for use. Of the agencies that replied, seven indicated using CFRP to repair various highway structures and only one agency noted it would not consider using CFRP as a repair material.

In HR-397, "Field/Laboratory Testing of Damaged Prestressed Concrete Girder Bridges" *(1)*, a damaged P/C girder bridge (one exterior and one interior P/C beams were seriously damaged) was tested in the damaged state and after the two damaged beams had been replaced. The two P/C girders that were removed were also tested – one in the damaged condition and the other after being repaired with CFRP. Results of this investigation verified the effectiveness of CFRP in repairs. Additional details of this investigation may be found in Ref. 2 as well as in the final report to HR-397*(1)*.

In TR-428, "Effective Structural Concrete Repairs" *(3,4)* research on the P/C bridge girders is continuing. In this Iowa DOT sponsored investigation, which is still in progress, several procedures for structurally repairing damaged reinforced or prestressed concrete elements are being investigated. Only the portion of this study related to the use of CFRP on P/C girders is presented in this paper. Although this portion of the study involved both laboratory and field testing, only a portion of the field work will be presented in this paper.

Field Demonstration Projects

To date, three field demonstration projects have been completed. CFRP was used to strengthen all three of these bridges based upon the results and installation procedures established in the laboratory. As previously noted, only one of the damaged P/C girder bridges, which was repaired using CFRP, will be presented in this paper.

The bridge that was damaged was on the south bound portion of the IA Highway 65 bridge that crosses IA Highway 6 in the vicinity of Altoona, Iowa. This four span bridge consists of two 96.5 ft main spans and two approach spans – the north one 36 ft long and the south one 46 ft long. A cross-section of this bridge is presented in Fig. 1. All six of the LXD P/C girders in one of the main spans were damaged by an overheight vehicle traveling east on IA Highway 6. Although, as illustrated in Fig. 2, all 6 girders were damaged approximately 30 ft from the center pier, most of the damage was to the first two girders. Damage to Beam 1 consisted of spalling of concrete from the bottom flange and the severing of one strand. Damage to Beam 2 (shown in Fig. 3) was the most severe in that significantly more concrete spalled from the bottom flange exposing five strands two of which were severed.

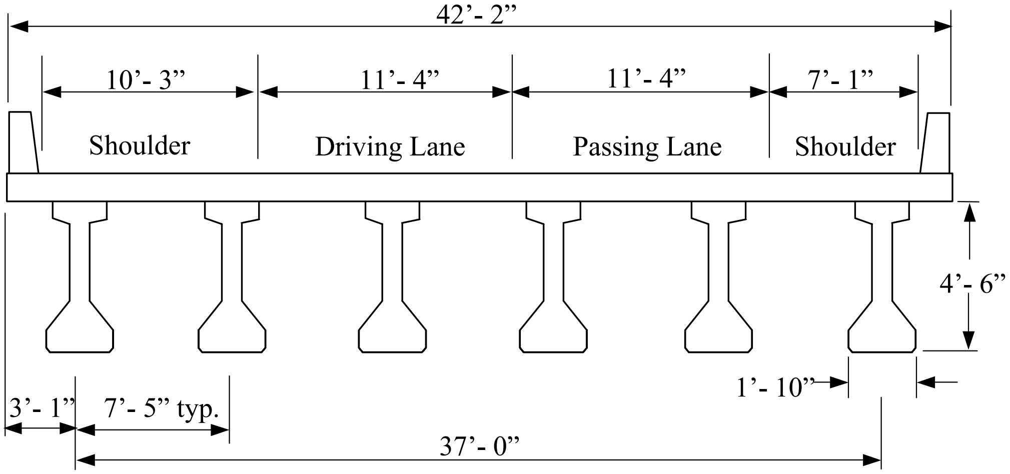

FIGURE 1. Cross section of Altoona Bridge

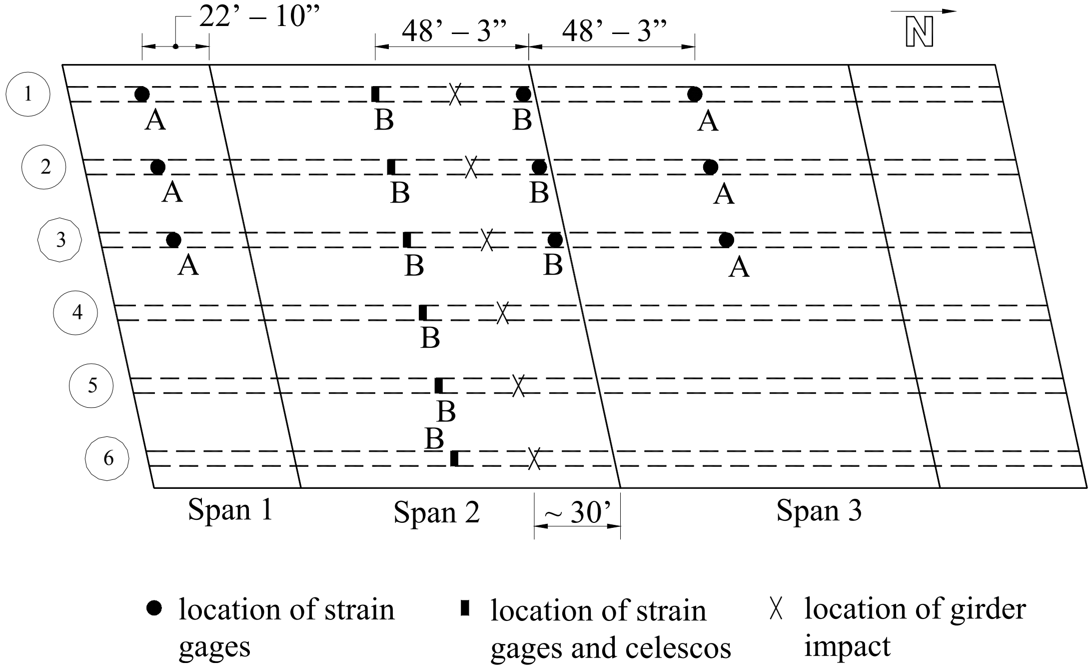

FIGURE 2. Location of Damage, Strain Gages, and Deflection Transducers on the Altoona Bridge

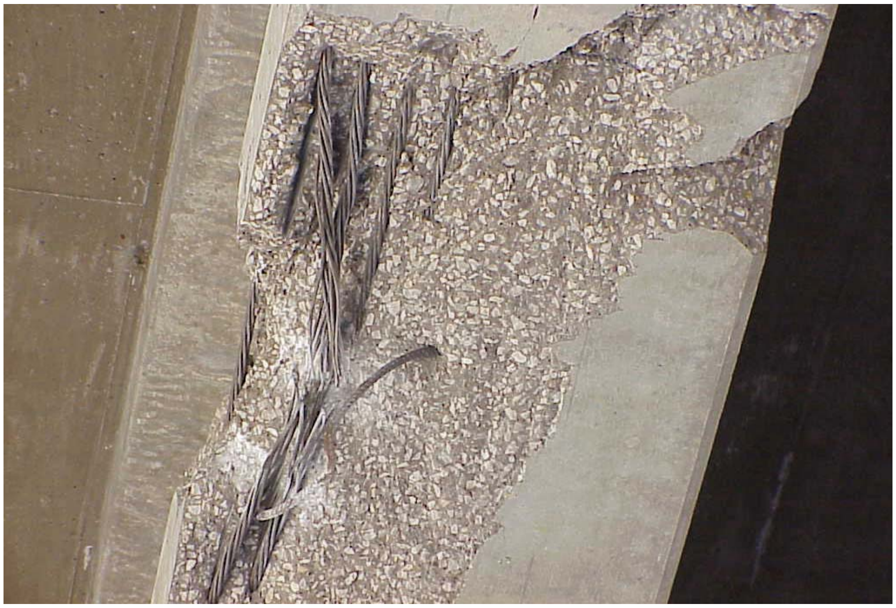

FIGURE 3. Photograph of the Damage to Beam 2 in the Altoona Bridge

FIELD TESTING

As previously stated, this bridge was tested before and after the CFRP was installed so that the effectiveness of the strengthening system could be determined. Instrumentation consisted of strain gages and deflection transducers located as shown in Fig. 2. A total of 24 gages were used on the bridge – one on the side of the bottom flange at Section A in Fig. 2 and two at Section B in Fig. 2 - one on the side of the top and one on the side of the bottom flanges. Deflections were measured at the centerline of all six beams in Span 2. Two Iowa DOT trucks (rear tandem) were used in the testing of the bridge. The two trucks (rear tandem) used in the testing prior to the repairs had an average weight of 51,100 lbs, while the average weight of the two trucks used in the final tests after repairs was 46,700 lbs. Static as well as dynamic load tests were performed on the bridge. Thirty-two different load tests, with the trucks positioned to produce the largest positive and negative moments in the various girders were completed in the static portion of the test. Dynamic data were obtained with one of the trucks traveling at three different speeds: 3-8 mph, 30-35 mph and 65-70 mph. For additional details on the position of the truck(s) in the various tests, the reader is referred to Ref 4.

FIELD REPAIRS

Prior to installation of the CFRP, the manufacturer's recommended patching material and procedures were used to repair the spalled concrete on the various beams, CFRP plates were attached to the most heavily damaged beam – Beam 2 after the patch material had cured. Four 4-in. wide by 75 ft long protruded CFRP laminates (shown in Fig. 4) were installed on the bottom flange of Beam 2 using an epoxy-resin which was applied to both the laminate and the P/C girder. A rubber roller was used to enhance the bond. The tensile design strength of the CFRP laminates was 406 ksi. After installation of the four laminates, a CFRP wrap was installed in the vicinity of the patch (80 in. of the girder was wrapped) to confine the patch and to prevent any plate debonding. Five CFRP strips (approximately 6 ft long which was sufficient length to cover the bottom flange and all but approximately the top 1 in. of the web) were installed. Similar CFRP sheets were installed at the location of the patches in the other beams to assist in confining the patches.

FIGURE 4. Photograph of CFRP on Beam 2 of Altoona Bridge

TEST RESULTS

The Altoona Bridge was tested before (Fall, 2000) and after (Spring, 2001) the bridge was repaired with CFRP. Although both strain and deflection data were recorded during the two tests, since the strains and deflections describe the same change in behavior, only the deflection data are presented in this paper. Deflections at the midspan of Span 2 for two load cases (LC1 and LC2) are presented in Figs. 5 and 6, respectively. In LC1, two trucks – one in Lane 1 (see Fig. 7) and the other in Lane 2 – were positioned at the midspan of Span 2. A photograph of the trucks in this position is shown in Fig. 8. In LC2, two trucks are end-to-end in Lane 1 centered at the midspan of Span 2. The combined weight of the two trucks in LC1 was 102,200 lbs and 93,400 lbs in LC2. Data presented in Figs. 5 and 6 have been normalized to the larger weight (102,200 lbs) so that a comparison of results from LC1 and LC2 can be made. Of the numerous different load cases, LC1 and LC2 are presented because they produce the largest deflections and strains in Beams 1 and 2.

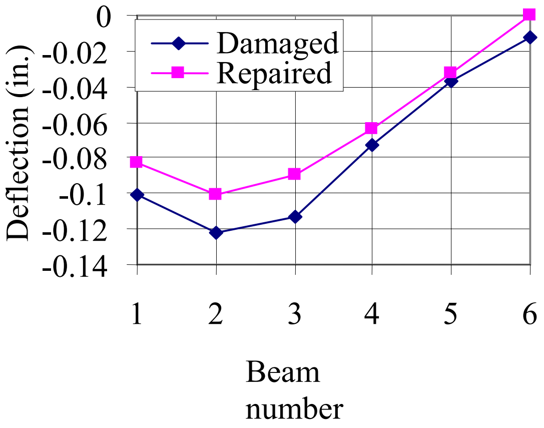

FIGURE 5. Comparison of LC1 deflections in Altoona Bridge

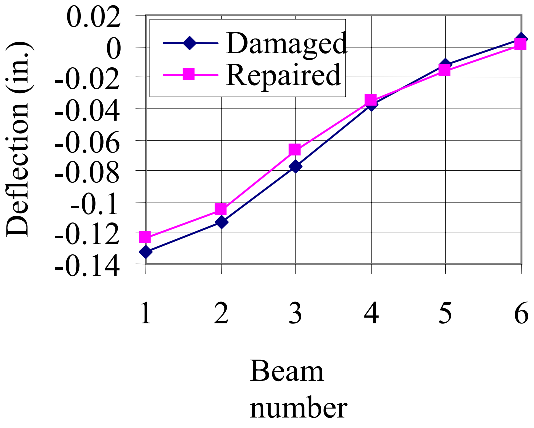

FIGURE 6. Comparison of LC2 deflections in Altoona Bridge

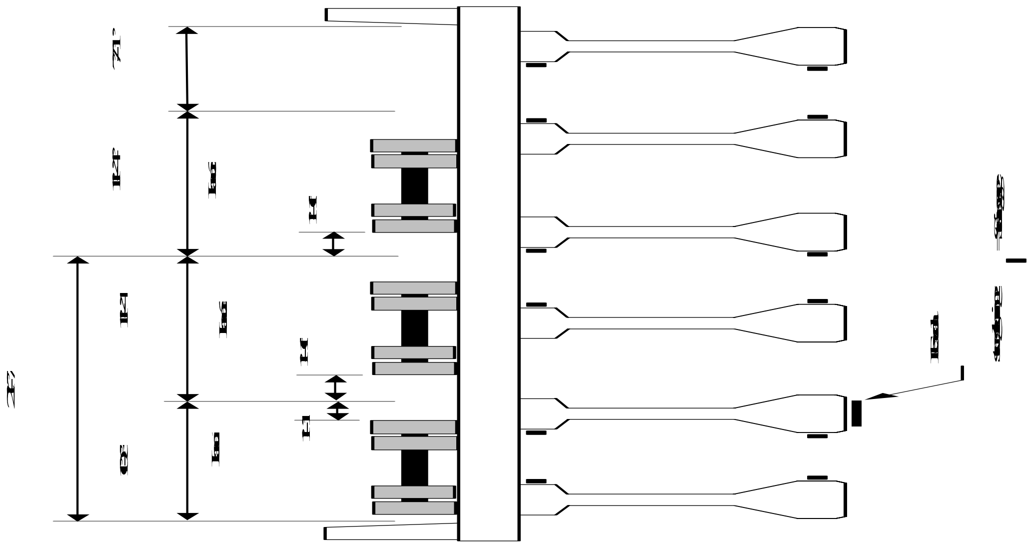

FIGURE 7. Truck lanes used in the Altoona Bridge tests

FIGURE 8. Photograph of Trucks in LC1 Tests

The effect of the CFRP strengthening system is apparent in both Figs. 5 and 6. After the CFRP was installed (which increased the moment of inertia of Beam 2 by approximately 5 percent), deflections at the midspan of Span 2 decreased for both LC1 and LC2. Strains in Beam 2 due to the slight increase Beam 2 stiffness increased a small amount but were still in the 50-60 MII range.

SUMMARY AND CONCLUSIONS

Although only one of the field tests completed in this study has been presented in this paper, based on this field test and other laboratory and field tests, the authors are confident in the CFRP strengthening system. Repair procedures using CFRP were developed to restore the moment capacity to P/C girders that have severed strand(s). CFRP also has the functional capacity of confining patches so that if some of the patch material becomes loose, it does not fall on passing vehicles.

Based upon this study:

- Flexural strengthening of impact damaged P/C girders is feasible when approximately 15 percent of the strands are severed.
- CFRP sheets restore a portion of the flexural strength lost when P/C girders are damaged.
- Transverse CFRP sheets assist in the development of the longitudinal CFRP plates and prevent debonding. Such jackets also confine patch material.
- CFRP reduced beam deflections in some cases by as much as 20%. Actual deflections measured, however, were very small.

ACKNOWLEDGEMENTS

The study presented in this paper was conducted by the Bridge Engineering Center at Iowa State University through funding provided by the Iowa DOT and the Iowa Highway Research Board. The authors wish to acknowledge the assistance of numerous Iowa DOT maintenance personnel and Doug Wood, ISU Structures Laboratory Manager, for their help with the field testing. The opinions, findings, and conclusions expressed in this paper are those of the authors and not necessarily those of the Iowa DOT.

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