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**INSPECTION AND EVALUATION OF A BRIDGE DECK REINFORCED
WITH CARBON FIBER REINFORCED POLYMER (CFRP) BARS**



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INSPECTION AND EVALUATION OF A BRIDGE DECK REINFORCED WITH CARBON FIBER REINFORCED POLYMER (CFRP) BARS

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| 16. Abstract Cracking in reinforced concrete decks is inevitable. It leads to the corrosion and eventual deterioration of the deck system. The use of non-corrosive reinforcement is one alternative to steel in reinforced concrete construction. This report deals with the field evaluation and performance of a concrete bridge deck reinforced with carbon fiber reinforced polymer (CFRP) bars. The bridge is identified as the Elkin Station Road Bridge on route CR1210 over the Two-Mile Creek in Clark County, KY. The CFRP bars were placed in the top and bottom mats of the bridge deck in both the transverse and longitudinal directions. The results of the laboratory tensile tests of the CFRP bars used in the deck are presented in this report. The bridge was opened to traffic in May 2002. Monitoring of crack formation and location, and maximum crack width and length in the deck initiated in June 2002 and continued until September 2005. The cracks in the deck were not measurable since the maximum observed crack width was less than the smallest unit (1/100 inch) on the crack comparator. This indicates that the cracks are well below the maximum allowed crack width of 0.013 inch per AASHTO Standard Specification for exterior exposure. | | | |
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EXECUTIVE SUMMARY

This report details the evaluation and performance of a concrete bridge deck reinforced with carbon fiber reinforced polymer (CFRP) bars. It is well-known that concrete elements such as bridge decks have a tendency to crack. Studies have also shown that cracking may begin as soon as the concrete is cast. Cracking of conventional concrete leads to exposure and corrosion of steel reinforcement, and eventual deterioration in terms of strength and serviceability of the deck system.

In this study, the bridge deck of the Elkin Station Road Bridge on route CR1210 over the Two-Mile Creek in Clark County, KY, was reinforced with CFRP bars. CFRP bars were employed as transverse and longitudinal reinforcement in the top and bottom reinforcing mats. Prior to the field implementation, tensile tests on the CFRP bars were carried out to determine their mechanical properties. The results of the laboratory testing are presented in this report.

The bridge was opened to traffic in May 2002. Monitoring of crack formation and location, and maximum crack width and length in the deck initiated in June 2002 and continued until September 2005. The cracks in the deck were not measurable since the maximum observed crack width was less than the smallest measure of 1/100 inch on the crack comparator. This indicates that the cracks are well below the maximum allowed crack width of 0.013 inch per AASHTO Standard Specification for exterior exposure.

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1.0 INTRODUCTION

1.1 Background

Most concrete girder bridges incorporate cast-in-place concrete elements (e.g. curbs, sidewalks, barriers, decks, etc.) in their design. As is typical of any concrete component, these elements have a tendency to crack. Cracking of load carrying elements such as concrete bridge decks can be caused by a variety of factors.

Cracking of concrete decks on older bridges is a common occurrence. This may be due to increasing demands on the existing structures where the higher loads were not specified or considered in the original design. Additionally, repetition of these increased loads not only causes fatigue, but also increases the frequency of cracking. Cracking of concrete bridge decks leads to deterioration; typically in terms of strength and eventual loss of serviceability (Allen 1991). When loss of serviceability occurs, the superstructure generally requires replacement. Hence, it is not inconceivable that billions of dollars have been spent nationwide replacing concrete bridge decks deteriorated by the effects of cracking.

It is acceptable that when bridge decks become damaged, deteriorated, or approach the intended design or service life, replacement or repair is warranted. However, studies have shown that concrete bridge decks may be cracking and deteriorating shortly after the concrete is cast. The study of the cause and control of cracking in concrete bridge decks is a subject that continues to gather enormous interest as researchers and scientists are in search of ways to minimize this deficiency. Issa (1999) and others (Kochanski et al. 1990; Krauss and Rogalla 1996; Carden and Ramey 1999; Schmitt and Darwin 1999; and Saadeghvaziri and Hadidi 2002) have concluded that cracking in concrete bridge decks during the early phases of a given service life may be attributed to a combination of factors such as high evaporation rate; high magnitude of shrinkage; the use of high slump concrete; excessive water in the concrete during mixing or placement; insufficient top reinforcement cover; insufficient vibration of the concrete; inadequate reinforcing details at joints; and weight and deflection of the forms. Researchers have also concluded that early cracking in concrete bridge decks can accelerate deterioration of the struc-

tures, thereby increasing the maintenance cost, and potentially, shortening the service life of the affected structural system.

Current AASHTO (2002) design practice for concrete bridge decks requires considerations for crack control (AASHTO Section 8.16.8.4) and shrinkage and temperature reinforcement (AASHTO Section 8.20). However, cracking of concrete decks may occur due to the volume change of a restrained mass of concrete, and furthermore, construction techniques that inevitably lead to cracking are currently unavoidable (Saadeghvaziri and Hadidi 2002). One might suggest that providing an adequate depth of concrete cover can minimize or *eliminate* concrete cracking. Adequate concrete cover for steel reinforcement prevents underlying steel bars from being exposed to atmospheric conditions, and is widely thought to be a means to prevent the onset of corrosion or deterioration. However, one study (Meyers 1982) has shown that even concrete decks with covers of 76 mm (3 in) or more seem to be more susceptible to cracking.

Ultimately, the use of non-corrosive materials in concrete construction may be the only alternative to overcoming concrete cracking and any accompanying corrosion problems; which in combination, lead to the deterioration of concrete bridge decks. Alternative forms of reinforcement that are non-corrosive, and possess comparable strength and stiffness [such as micro-composite multistructural formable steel (MMFX), stainless steel (SS), stainless steel clad (SSC), fiber reinforced polymer (FRP) composites, etc.], have emerged as possible substitutes for steel in certain applications. The use of alternative reinforcement in concrete bridge decks thus far is proved a success (Yost and Schmeckpeper 2001; Harik et al. 2004).

1.2 Objective and Scope

The research presented in this study evaluates the performance of concrete bridge deck panels reinforced with carbon fiber reinforced polymer (CFRP) bars. Of particular interest is the crack formation in the concrete bridge decks. The task is ongoing and is being carried out by: (1) identifying the location of crack formation under loaded and unloaded conditions, (2) measuring the length and width of cracks in concrete bridge decks, (3) comparing the cracks to the limits set forth by AASHTO specification (i.e. 0.013 in for exterior exposure).

2.0 THE CR1210 BRIDGE OVER TWO MILE CREEK

2.1 Bridge Description

The subject of this study is located on Elkin Station Road on route CR1210 over the Two Mile creek in Clark County, KY. The two-traffic lane concrete bridge is 31 ft (9.5 m) wide and 61 ft (18.6 m) long as depicted in Fig. 2.1. The bridge is designed for HS25 truck loads.

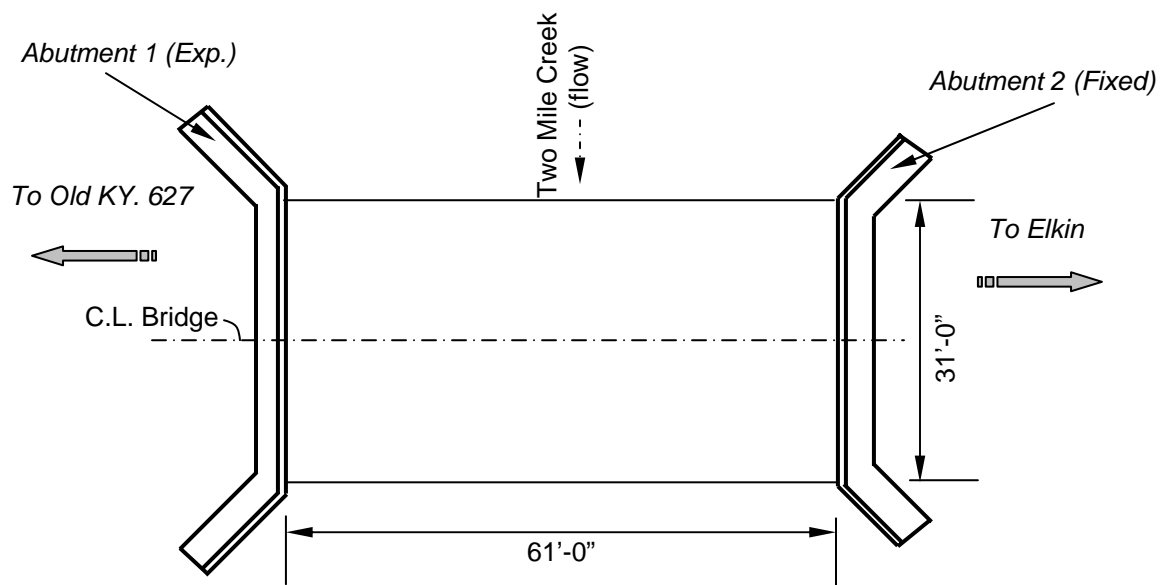
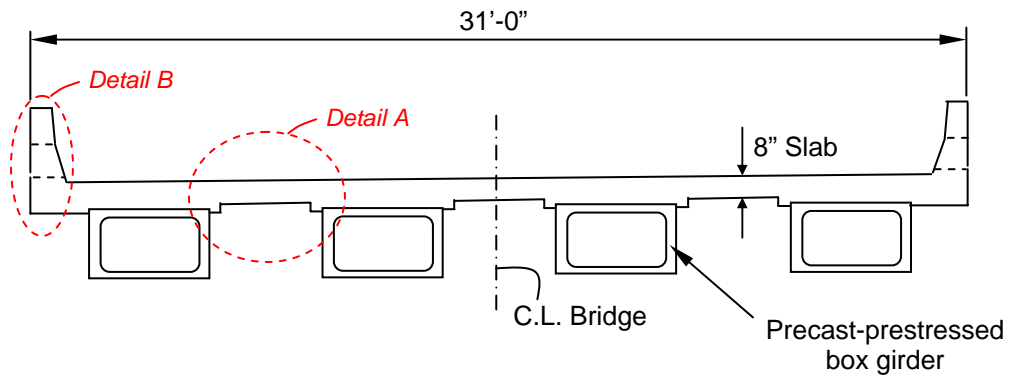
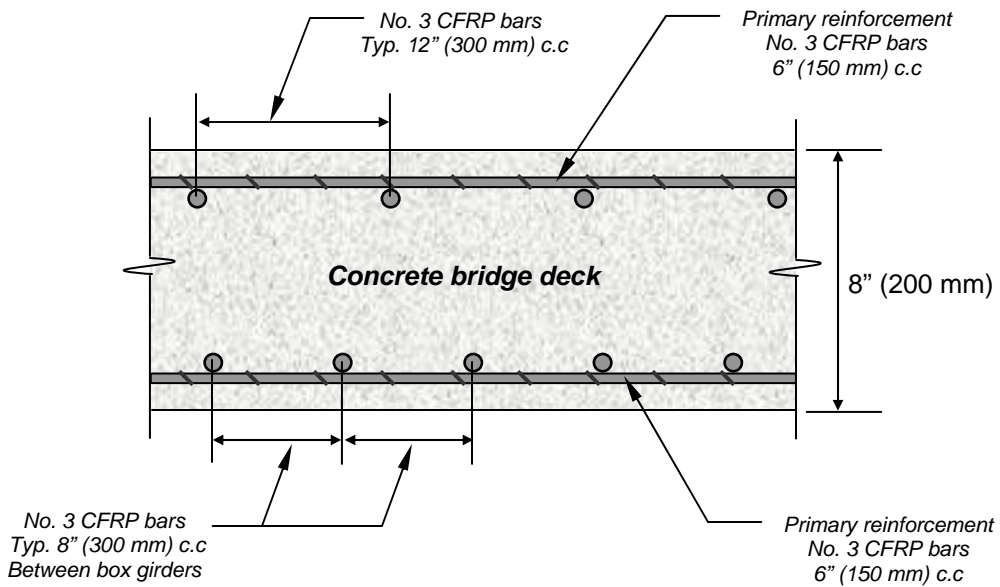


Fig. 2.1 – Plan view of the Elkin Station Road Bridge on route CR1210 over the Two Mile creek, Clark County, KY.

The bridge deck is cast-in-place concrete supported by four precast-prestressed concrete box girders (Fig. 2.2). The main (primary) reinforcements are of No. 3 carbon fiber reinforced polymer (CFRP) bars spaced 6 inches (150 mm) center-to-center at the top and bottom of the concrete deck. The No. 3 CFRP temperature and shrinkage (in the bridge direction) bars at the top of the concrete deck are spaced 12 inches (300 mm) center-to-center, and No. 3 CFRP temperature and shrinkage bars at the bottom of the concrete deck are placed between the box girders and are spaced 8 inches (200 mm) center-to-center.



Typical section



Detail A

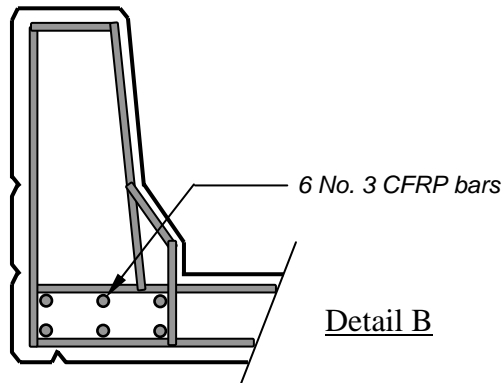


Fig. 2.2 – Details of the concrete bridge deck reinforced with CFRP bars.

2.2 Carbon Fiber Reinforced Polymer (CFRP) Bars

Before deploying the CFRP bars, the tests to determine mechanical properties such as tensile strength and stiffness of the bars were conducted. Details of the experiments can be found in Hill et al. (2003). Fig. 2.3 summaries the tensile stress/strain relation of the CFRP bars.

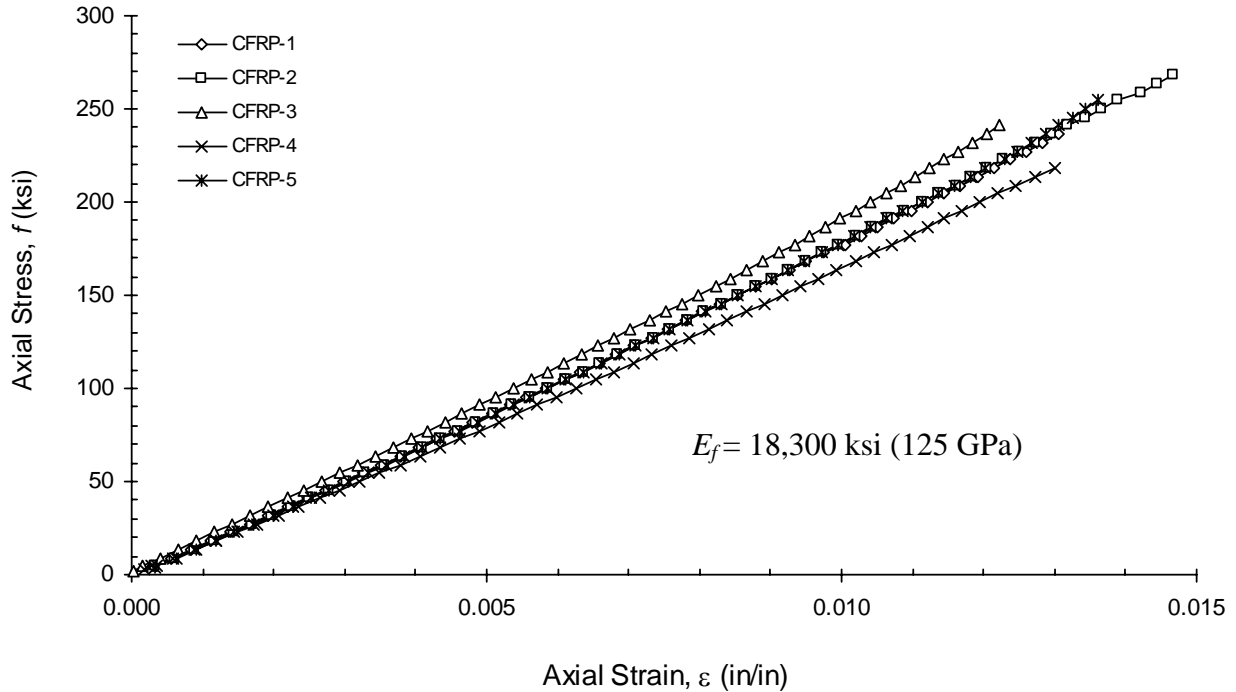


Fig. 2.3 – Tensile stress/strain relation of CFRP bars (Hill et al. 2003).

The ultimate tensile strength of the CFRP bars [$f_u = 270 \text{ ksi (1,875 MPa)}$] is many times greater than the conventional grade-60 steel [$f_u = 80 \text{ ksi (550 MPa)}$]. The tensile modulus of elasticity of this particular type of CFRP bar [$E_f = 18,300 \text{ ksi (125 GPa)}$] is approximately 65% that of steel [$E_s = 29,000 \text{ ksi (200 GPa)}$].

In addition to bar testing, slab panels reinforced with CFRP bars were also tested experimentally. It has been shown both analytically and experimentally that the moment capacities of slab panels reinforced with CFRP bars well exceed the AASHTO factored design moment. Details on the experiments and results can be found in Hill et al. (2003).

3.0 FIELD INSPECTION AND EVALUATION

3.1 Bridge Deck Construction

The construction of concrete bridge decks reinforced with CFRP bars follows the same procedure used in concrete bridge decks reinforced with conventional steel. However, the handling of CFRP bars in the field required fewer workers because of the light-weight nature of the material (Fig. 3.1). Fig. 3.2 shows the CFRP bars for the bridge deck before the placement of concrete. It should be noted that since CFRP bars are more flexible than steel bars when construction workers are stepping on them to pour the concrete for the deck, the regular spacing of chairs used for steel bars was reduced in half for CFRP bars. Additional recommendations when dealing with FRP bars can be found in Deitz et al. 1999.



Fig. 3.1 – Light-weight CFRP bars.



(a) Placement of CFRP bars



(b) Close-up view of CFRP bars

Fig. 3.2 – Construction of concrete bridge deck reinforced with CFRP bars.

3.2 Field Inspection and Evaluation

After construction of the bridge, the concrete deck has been continuously monitored for cracks over a predefined area. The monitoring of crack formation and location, and maximum crack width and length in the deck was initiated in June 2002. A typical crack inspection form is shown in Fig. 3.3.

Date: _____
Time: _____
Temperature: _____
Humidity: _____

↑
To Elkin
↑

| | | | | | | | | | | |
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| 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | |
| | | | | | | | | | | A |
| | | | | | | | | | | B |
| | | | | | | | | | | C |
| | | | | | | | | | | D |
| | | | | | | | | | | E |
| | | | | | | | | | | F |
| | | | | | | | | | | G |
| | | | | | | | | | | H |
| | | | | | | | | | | I |
| | | | | | | | | | | J |

↓
To Old KY 627
↓

1' ←
↑ 1'

Fig. 3.3 – Typical crack inspection form.

3.3 Field Inspection Results

The bridge was opened to traffic in May 2002. As mentioned earlier the monitoring was initiated in June 2002, and continued until September 2005. The cracks in the deck were not measurable since the maximum observed crack width was less than the smallest measure of 1/100 inch on the crack comparator. A typical crack comparator used in this task is presented in Fig. 3.4.

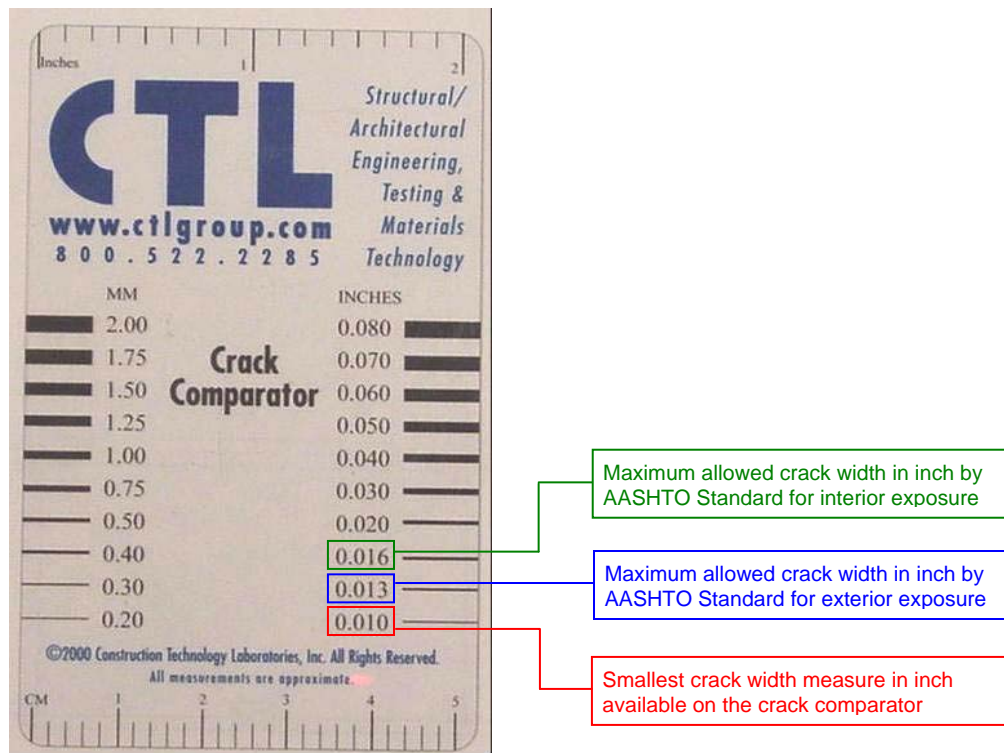


Fig. 3.4 – Crack comparator.

4.0 SUMMARY AND CONCLUSION

Cracking of concrete elements is inevitable. Therefore, the solution to corrosion problem may be the use of non-corrosive reinforcements such as fiber reinforced polymer (FRP) bar. The report presents the field evaluation and performance of a concrete bridge deck reinforced with carbon fiber reinforced polymer (CFRP) bars.

The subject of this investigation is the Elkin Station Road Bridge on route CR1210 over the Two-Mile Creek in Clark County, KY. In the bridge deck, CFRP bars were used as the primary, and also temperature and shrinkage reinforcements, at the top and bottom of the 8-inch concrete deck. The CFRP bars were tested for their mechanical properties prior to their implementation.

The bridge was completed in May 2002, and immediately, monitoring of the bridge deck was initiated in June 2002. The monitoring of performance included field inspection and evaluation of crack location and formation, and crack length and width. As of September of 2005, the cracks in the deck were not measurable since the maximum observed crack width was less than the smallest measure of 1/100 inch on the crack comparator. This indicates that the cracks are well below the maximum allowed crack width of 0.013 inch per AASHTO Standard Specification for exterior exposure.

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