Application of the Advanced FRP Composites to Restore and Improve Bridge Infrastructure

Manoochehr Zoghi[1] and Dean Foster[2]

[1] California State University, Fresno, California, USA
[2] Wright Patterson Air Force Base, Dayton, Ohio, USA

ABSTRACT: Two multi-span prestressed concrete box-beam bridges that had suffered from extensive deterioration symptoms due to excessive use of deicing salts were selected by the Innovative Bridge Research and Construction (IBRC) Program of the Federal Highway Administration (FHWA) for rehabilitation utilizing advanced FRP composite materials. The structural strengthening of both bridges was carried out adopting Sika's StressHead System, first application of its type in the U.S. The unique features of this innovative bridge strengthening technique will be presented in this paper.

KEYWORDS: Innovative Bridge Research and Construction (IBRC), CarboDur CFRP plates, StressHead System

1 INTRODUCTION

As the corrosion decay continues plaguing the bridge infrastructures made of conventional materials, the need for more robust material that will be essentially corrosive resistant and more durable and reliable is evident. According to Whiting et al. (2001), when the structural steel members or reinforcing bars are exposed to the chloride ions from deicing salts or seawater, the passivity of the steel is destroyed, thus, initiating corrosion. Combination of this highly detrimental implication along with other factors such as aging, heavier trucks, improper design, and insufficient maintenance and repair are but a few challenges facing bridge engineers at the onset of the new millennium.

The combined annual spending for bridge improvement by local agencies, states, and Federal Government has been estimated around \$7-\$8 billion (Tang, 2003). Federal Highway Administration (FHWA) advocates the use of high-performance structural materials and quality design as an innovative solution to bridge infrastructure quandary (Hooks and Cooper, 2004; Tang et al., 1998). One of the significant initiatives established through the TEA-21 legislation, has been the Innovative Bridge Research and Construction (IBRC) Program. The IBRC endeavor has been instrumental in providing \$108 million over six year period to advance high-performance materials in bridge applications. It is considered to be one of the largest Federal Government funded initiatives in the world, intended to promote the use of emerging materials and construction techniques for the repair, rehabilitation, replacement, or new and effective construction of bridges and other structures. Nearly half of the 246 proposals funded through the IBRC Program have been constructed with FRP composite materials, scattered throughout the United States to capture their responses under diverse environmental and service conditions.

The Clinton Street and Hopkins Street Bridges, located in Defiance, Ohio, are exemplary IBRC projects. The rehabilitation technique, first of its type in the U.S., entails the use of advanced Carbon Fiber Reinforced Polymer (CFRP) composite laminates, post-tensioned via an innovative anchor system that was developed and patented in Switzerland (Sika, 2002). This innovative technology offers numerous advantages over other conventional methods including excellent long-term durability, high corrosion resistance, expedient installation, tensioning in one operation, and anchorage of the plate in carbon fiber anchor head without adhesive, etc (Sika, 2002 and Meier, et al. 1992). The Special attributes of this endeavor will be presented in this paper.

2 SCOPE OF WORK

The scope of work entailed the combination of initial assessment of existing conditions, analysis and design of the repair/rehabilitation, and subsequent performance evaluation of two six-span prestressed concrete box-beam bridges located in Defiance, Ohio. The construction of these structures involves side-by-side placement of box beams, grouting full-depth shear keys, and then casting the asphalt/concrete deck over the top. The aforementioned simple and expedient construction procedure has made the use of these structures one of the most popular types of bridge construction over the years. The shear keys, however, are known to be susceptible to cracking (Baluch and Sharif, 1996). As a result, the water-saturated with deicing salts have a tendency of eventually penetrating through longitudinal cracks formed along the shear-keys. Additionally, the deck drainage extending the entire length of structures, used to drain the storm water, collect the deleterious materials containing salts and deposit them onto the exposed vertical face of the concrete fascia beams. These deterioration mechanisms yield spalling of concrete and corrosion of reinforcing steel and prestressing strands, compromising the structural integrity and load-carrying capacity of original beams.

In the case of Clinton Street and Hopkins Street Bridges, the root cause of deterioration has been determined to be the improper design of drainage system. The galvanized steel drip strip deflected the brine saturated runoff contaminated with salt onto vertical surfaces of exterior beams, progressively causing deterioration. The drainage detail was, however, considerably improved and implemented later as an integral part of the rehabilitation work to prohibit recurrence of similar situation in the future.

The Scope of service also required a thorough visual inspection of both structures including sounding and documentation of existing conditions and specific deterioration patterns on all affected beams. In addition, the dimensions on construction drawings were verified via precise field measurements, made while conducting the visual inspections. Furthermore, a series of nondestructive live-load tests was performed prior to rehabilitation to establish the baseline rating in relation to the load-carrying capacity of existing structures.

A wide variety of techniques with different types of materials, conventional and otherwise high-performance, were investigated at the onset of this research endeavor to identify the most viable alternative design for strengthening Defiance County Bridges. The post-tensioning Sika CarboDur CFRP plate system, Sika's StressHead System, was singled out to be fitting all the specific requirements of subject bridges. The aforementioned system showcases numerous advantages over traditional methods, as discussed in the ensuing sections of this manuscript.

3 POST-STRENGTHENING DESIGN AND CONSTRUCTION

Following the identification of the extent and exact locations of deteriorations on the affected beams via comprehensive visual inspection and sounding, and nondestructive live-load tests, a systematic repair and rehabilitation plan was devised. The design of rehabilitation was in accordance with the guidelines from the American Association of State Highway and Transportation Officials (AASHTO) Specifications, American Concrete Institute (ACI-440), and Intelligent Sensing for Innovative Structures (ISIS) Canada Design Manuals. The discussion concerning detailed design of strengthening system, however, is beyond the scope of this manuscript. The step-by-step design procedures are outlined and presented in a separate document. The preparatory steps along with distinct attributes of the StressHead System utilized for current post-strengthening application are discussed below.

Prior to installation of the prestressed Sika CarboDur CFRP plates, the entire damaged regions of concrete were completely removed to original sound concrete. Subsequently, the surface areas were thoroughly cleaned. The manufacturer's procedures were then followed to repair the prepared areas with appropriate patching materials. In addition, all cracks were sealed by injecting an adhesive resins.

Since the mounting of anchorages necessitated drilling holes into the concrete at the diaphragm locations, it was imperative to identify the exact locations of diaphragms and existing reinforcements. Ground penetrating radar (GPR) appeared to be the most valuable nondestructive tool for this application. In addition, a bi-directional CFRP fabric was installed at each anchor location extending 2 feet beyond the centerline of the anchor dowel to provide supplemental reinforcement in the anchor zone of each strengthened beam. The main components of the StressHead System are a fixed anchor, a live or stressing anchor, and a deviator plate (Berset, 2002). The factory-mounted CFRP fixed anchor head consists of an elliptical cross-section with 60 mm (minor diameter) by 80 mm (major diameter) by 110 mm (length) dimensions. The anchor head is secured in place via a flat transverse beam that is positioned over the CFRP laminate and two threaded bolts to the anchorage shoe (Figures 1). The stressing or live anchor includes a slotted steel plate that is placed in front of the CFRP anchor head. Threaded rods, protruding through the steel plate, enables the application of post-tensioning force via a hydraulic jack (Berset, 2002). Both, the fixed and movable anchorages are bolted and bonded onto the 114 mm diameter by 190 mm deep cored holes within the concrete at designated diaphragm locations. Furthermore, a 184 mm by 102 mm stainless steel deviator plate is secured in place via a 16 mm diameter by 76 mm long concrete anchor bolt. The deviator plates are utilized to address the existing beam camber (see Figure 2).

The post-tensioned CFRP laminates were bonded to the clean patched concrete surface, analogous to the non-prestressed CFRP laminates, using an epoxy adhesive. The bonding was deemed necessary to prohibit the intrusion of moisture and debris onto the interface of concrete surface and CFRP laminates. The post-tensioning operation of CFRP strips was achieved via a hydraulic jack, while the force and deflection were controlled, during the pot-life of the adhesive (Figure 3).

A prototype installation of a StressHead System is exhibited in Figure 4. The relatively miniaturized dimensions (99 mm long by 72 mm wide by 56 mm high) along with durability characteristics (made entirely from CFRP, identical to the laminates) and expedient installation are but a few attributes of this innovative technology.

Figure 1. Tension Anchor.

Figure 2. Deviator Plate.

Figure 3. Hydraulic Jack Applying the Post-Tensioning Force.

Figure 4. Installed Prototype StressHead System and Laminate.

4 CONCLUSIONS

The root cause of deterioration concerning the Clinton Street and Hopkins Street Bridges, located in Defiance, Ohio was concluded to be due to corrosion of reinforcing steel and prestressing strands, inflicted by the deicing salts as a result of the improper design of drainage system. The application of CFRP laminates in conjunction with the innovative StressHead System and post-tensioning operation proved to be highly successful for rehabilitation of prestressed concrete box-beam bridges. In fact, the International Repair Institute bestowed an Award of Excellence in Transportation category in 2004 for the project's uniqueness, use of the state-of-the-art techniques and materials, along with functionality and value engineering.

5 REFERENCES

American Association of State Highway and Transportation Officials, "Standard Specifications for Highway Bridges," 16th Edition, Washington, D.C., 1996.

Berset, T., "Development of a Post-Tensioning System using Unbonded CFRP Tendons," Proceedings of the 4th Ph.D. Symposium in Civil Engineering, September 2002, Munich, Germany.

Baluch, M.H., and Sharif, A., "External FRP Plates to Strengthen Reinforced Concrete Beams," First International Conference on Composites in Infratsructure, National Science Foundation, Tucson, AZ, January 15-17, 1996, pp. 814-828.

Hooks, J.M. and Cooper, J., "Federal Sponsorship of Innovative Bridge Programs," http://www.nabro.unl.edu/articles/20002012/download/Hooks.pdf, Accessed, 5-20-2004.

Meier, U., Deuring, M., Meier, H., and Schwegler, G., "Strengthening of Structures with CFRP Lamniates: Research and Applications in Switzerland," Advanced Composite Materials in Bridges and Structures, CSCE, Sherbrooke, Canada, 1992, 00. 243-251.

Sika Services AG, "Sika StressHead – Prestressed CarboDur CFRP Plate System," Zurich, Switzerland, April 2002.

Tang, B.M., "FRP Composites Technology Brings Advantages to the American Bridge Industry," Proceedings Published in the 2nd International Workshop on Structural Composites for Infrastructure Applications, Cairo, Egypt, December 16-18, 2003.

Tang, B.M., Podolny, Jr., W., "A Successful Beginning for Fiber Reinforced Polymer (FRP) Composite Materials in Bridge Applications," FHWA Proceedings, International Conference on Corrosion and Rehabilitation of reinforced Concrete Structures, Orlando, Florida, December 7-11, 1998.

Whiting, D.A., Corely, W.G., Tabatabai, H., "Deterioration and Repair of Prestressed Concrete Bridge Members," APWA International Public Works Congress, NRCC/CPWA Seminar Series: Innovations in Urban Infrastructure, Philadelphia, PA, September 2001.