An ACI Technical Publication

SYMPOSIUM VOLUME

Field Applications of Non-Conventional Reinforcing and Strengthening Methods for Bridges and Structures

SP-346

Editors:
Yail J. Kim, Steven Nolan, and Antonio Nanni

American Concrete Institute
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Sponsored by
ACI Committee 345

ACI Virtual Concrete Convention
October 25-29, 2020

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First printing, January 2021

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The papers in this volume have been reviewed under Institute publication procedures by individuals expert in the subject areas of the papers.

Printed in the United States of America

Editorial production: Gail L. Tatum

ISBN-13: 978-1-64195-130-2

PREFACE

Field Applications of Non-Conventional Reinforcing and Strengthening Methods for Bridges and Structures

A Sustainable built-environment requires a comprehensive process from material selection through to reliable management. Although traditional materials and methods still dominate the design and construction of our civil infrastructure, non-conventional reinforcing and strengthening methods for concrete bridges and structures can address the functional and economic challenges facing modern society. The use of advanced materials, such as fiber reinforced polymer (FRP) and ultra-high performance concrete (UHPC), alleviates the unfavorable aspects of every-day practices, offers many new opportunities, and promotes strategies that will be cost-effective, durable, and readily maintainable. Field demonstration is imperative to validate the innovative concepts and findings of laboratory research. Furthermore, documented case studies add value to the evaluation of emerging and maturing technologies, identify successful applications or aspects needing refinement, and ultimately inspire future endeavors. This Special Publication (SP) contains nine papers selected from three technical sessions held during the ACI Virtual Concrete Convention in fall 2020. The first and second series of papers discuss retrofit and strengthening of super- and substructure members with a variety of techniques; and the remaining papers address new construction of bridges with internal FRP reinforcing and prestressing in beam, slabs, decks and retaining walls. All manuscripts were reviewed by at least two experts in accordance with the ACI publication policy. The Editors wish to thank all contributing authors and anonymous reviewers for their rigorous efforts. The Editors also gratefully acknowledge Ms. Barbara Coleman at ACI for her knowledgeable guidance.

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Application of UHPC 2.0™ for a Non-Conventional Reinforcing and Strengthening of a Reinforced Concrete Beam for Bridges and Structures

Peter W. Weber and Su Wang

Synopsis: Conventional reinforcing and strengthening methods and material for bridges and structures has several limitations including include the increased weight of structure, the limited service life of the repair, short periods between repairs, uncertain strength of the reinforcement, extended time of repair and typically a heavy carbon footprint based on the materials used. Application of Ultra-High Performance Fiber Reinforced Concrete (UHPFRC) solutions have shown the potential to replace traditional methods over the coming decade because the superior mechanical and durability properties reduce the required thickness of a repairing layer and extend the service life. Based on the overall cost of a given rehabilitation project, UHPFRC based solutions can already compete today but require certain specialized equipment and trained workforce creating real or perceived barriers. In this paper, a new type of nano-engineered UHPFRC based on carbon-nanofibers (CNFs) was introduced, named UHPC 2.0™. The test results show that UHPC 2.0™ possesses ultra-high mechanical properties, improved direct tension performance and durability. In addition, an analytical procedure is provided for case studies to show the performance and economic benefits of usage of UHPC 2.0™ compared to traditional UHPFRC.

Keywords: direct tension; durability; mechanical properties; nano-engineered binder; UHPFRC

FRP Retrofitting and Non-Destructive Evaluation for Corrosion-Deteriorated Bridges in West Virginia

Wael Zatar, Hai Nguyen, and Hien Nghiem

Synopsis: Many aging concrete bridges across the United States have exhibited severe deteriorations and in urgent need of rehabilitation, retrofitting or replacement. The deterioration is caused by a combination of factors including corrosion of reinforcing steel, freeze-thaw damage and chloride/water ingress. Fiber-Reinforced Polymer (FRP) composite fibers, laminates, reinforcing bars and prestressed tendons have been successfully employed in civil infrastructure applications in the past three decades. The State of West Virginia has one of the highest percentages of structurally deficient bridges in the United States and this study covers a few case studies of the use of FRP composites for rehabilitating the State's deficient bridges. Non-destructive ultrasonic pulse-echo testing is employed to map reinforcing rebars and detect delaminations of reinforced concrete slabs. A software, that employs the modified synthetic aperture focusing technique (SAFT) image reconstruction algorithm and signal processing, is developed to effectively visualize the reinforcing rebars and delaminations.

Keywords: concrete bridges; concrete imaging; deterioration; FRP composites; non-destructive testing and evaluation; structural rehabilitation; ultrasonic pulse-echo

Impact Damage Retrofit of RC Bridge Girder Previously Retrofitted with CFRP Fabric

Abheetha Peiris and Issam Harik

Synopsis: Following an over-height truck impact, Carbon Fiber Reinforced Polymer (CFRP) fabric was used to retrofit the exterior girder in a four-span Reinforced Concrete Deck on Girder (RCDG) Bridge on route KY 562 that passes over Interstate 71 in Gallatin County, Kentucky. The impacted span (Span 3) traverses the two northbound lanes of Interstate 71. While the initial retrofit was completed in May 2015, a second impact in September 2018 damaged all four girders in Span 3. The previously retrofitted exterior girder (Girder 4) suffered the brunt of the impact, with all steel rebars in the bottom layer being severed. Damage to Girders 1, 2, and 3 was minor and none of the bars were damaged. A two-stage approach for the containment and repair of the damaged girders following an over-height truck impact was implemented when retrofitting the bridge. The repair and strengthening of all the girders using CFRP fabric was the economical option compared to the alternative option of replacing the RCDG bridge. The initial CFRP retrofit was found to have failed in local debonding around the impact location. The CFRP retrofit material that was not immediately near the impact location was found to be well bonded to the concrete. The removal of this material and subsequent surface preparation for the new retrofit was time consuming and challenging due to traffic constraints. In Girder 4 all but one of the main rebars were replaced by removing the damaged sections and installing straight rebars connected to the existing rebars with couplers. One of the rebars could not be replaced. A heavy CFRP unidirectional fabric, having a capacity of 534 kN (120,000 lbs.) per 305 mm (1 ft.) width of fabric, was selected for the flexural strengthening and deployed to replace the loss in load carrying capacity. A lighter unidirectional CFRP fabric was selected for anchoring and shear strengthening of all the girders, and to serve as containment of crushed concrete in the event of future over-height impacts. The retrofit with spliced steel rebars and CFRP fabric proved to be an economical alternative to bridge replacement.

Keywords: bridge; CFRP; heavy fabric; impact damage; reinforced concrete; retrofit

Shear Strengthening of Beams on the Sunshine Skyway Bridge Trestle Spans with CFRP

Atiq H. Alvi

Synopsis: The Sunshine Skyway Bridge is recognized as the State of Florida's "flagship bridge." The goal of the Florida Department of Transportation (FDOT) and specifically its entity that maintains the Skyway Bridge, the District 1 & 7 Structures Maintenance Office (DSMO), is to extend the life of this bridge to 100 years. Beam cracking on the trestle spans have been noted since the 1990s. In 2005 the DSMO initiated an in-depth study to determine the cause of cracking and to recommend a repair procedure. Upon completion, a committee of FDOT staff from various key offices in the State, along with consultant experts, determined criteria to address these cracks. The repairs included epoxy crack injection, penetrant sealer, and carbon fiber reinforced polymer (CFRP) wrap installation. FDOT addressed the repairs in three phases. The first repair project was in 2009, the second in 2013, and the third and final began in 2019.

Keywords: AASHTO Type IV girders, carbon fiber reinforced polymer (CFRP), cracking, debonding, strengthening

Bridge Substructure Repairs with Basalt & Glass FRP Internal Reinforcement

Mohit Soni

Synopsis: Alternative reinforcement such as Glass Fiber Reinforced Polymer (GFRP) and Basalt (BFRP) are gaining popularity due to their corrosion resistant properties in extremely aggressive environments. The Florida Department of Transportation was concerned with the long-term durability of fiber resin systems in wet marine environments and restricted its use in submerged marine locations. This paper demonstrates the implementation of a pilot project after the thorough evaluation of a Fiber Reinforced Polymer resin prior to broader deployment of the alternative reinforcement. The paper focuses on the successful construction implementation to provide an archival reference document for future study and comparison to look at the long-term performance and integrity of the strengthening systems. During the execution of this pilot project, several lessons were learned and are demonstrated in this paper.

Keywords: alternative reinforcement, BFRP, bridge, GFRP, lessons learned, pilot project, shotcrete

Effect of CFRP Strengthening on the Behavior of Older and Newer Bent Caps in a Widened Concrete Bridge

Yazan Almomani, Nur Yazdani, and Eyosias Beneberu

Abstract: A reinforced concrete bridge built in 1940 and located in Dallas, Texas, exhibited moderate to severe corrosion-related deterioration in the concrete bent caps. The damaged bent caps were repaired with epoxy mortar and externally strengthened with carbon fiber reinforced polymer (CFRP) laminates. Three-dimensional numerical models of the bent caps were created to better understand the cap behavior in bending and during various stages of the repair. The models were calibrated using data obtained from full-scale live load bridge testing. . The models were loaded until failure (rapid crack opening or CFRP debonding) to show the crack patterns, strain distributions and the bent cap capacities. The bent cap moment capacity increased by about 30% after repair/strengthening, because the original bent caps had extensive damage at the flexure-critical areas. The dowel-connected newer bent caps from the 1970 widened bridge contributed to the load sharing with the older bent caps.

Keywords: bridge bent caps; widened bridges, CFRP strengthening; numerical modeling; finite element analysis; load testing

Recent Canadian Developments Related to Unconventional Reinforcing for Concrete Structures, Design Codes, and Applications in Buildings and Bridges

Brahim Benmokrane, Hamdy M. Mohamed, Khaled Mohamed, and Salaheldin Mousa

Synopsis: The design principle of fiber-reinforced polymer (FRP) reinforcing composite bars for concrete structures has been well established through extensive research and field practices. Provisions governing certification testing and evaluation as well as quality control/assessment and FRP design provisions, are now in place to regulate materials specifications and design aspects and guide FRP manufacturers and end-users. The Canadian Standards Association (CSA) group addressing the state-of-the-art FRP material specifications and design requirement recently issued two updated provisions. The new edition of CSA S807 includes several additions and modifications in terms of quality and qualification requirements, material properties, testing procedures, and material mechanical and durability limitations. Additionally, the updated Section 16 of CSA S6 for the design of fiber-reinforced structures and highway bridges aimed at providing more rational design algorithms and allowing practitioners to take full advantage of the efficiency and economic appeal of FRP bars. This paper presents a summary of these recent modifications in Canadian codes and standards, introducing the underlying rationale. Additionally, the paper highlights the recent field applications of FRP bars in different types of concrete civil-engineering infrastructure.

Keywords: fiber-reinforced polymer bars; concrete; standards; field applications.

US 41 over North Creek; FRP Reinforced Concrete Two-Span Flat Slab Bridge and CFRP-Prestressed Concrete/GFRP Reinforced Substructure and Bulkhead Wall System

Joseph Losaria, Steven Nolan, Andra Diggs II, and David Hartman

Synopsis: This case study highlights the use of Fiber Reinforced Polymer (FRP) materials on the US 41 Highway Bridge over North Creek in Sarasota County near the Florida Gulf Coast. Design and construction involved the use of Glass-FRP (GFRP) reinforcement on the cast-in-place (CIP) concrete flat slab superstructure, Carbon-FRP (CFRP) prestressing strands on the concrete piles, and GFRP reinforced precast panels for the substructure combining a bridge bearing abutment and retaining wall system. The application of FRP prestressing and reinforcing is promoted by the Florida Department of Transportation (FDOT) under their Transportation Innovation Challenge initiative. Soldier-pile retaining walls are a commonly used system in southeastern US coastal states, but the incorporation of innovative materials such as CFRP-prestressing for piles and GFRP-reinforcing for concrete panels is not yet widespread. Comparison of lateral stability results of this wall system during construction and in the final condition is discussed. In addition, to describing the preferred FRP-PC/RC solution adopted for this project, a comparison is provided to a recently completed adjacent bridge that utilized a conventional carbon-steel PC soldier-pile and RC precast panel wall system. A further comparison is presented for the design and cost of the wall system based on the project design criteria (ACI 440.1R, ACI 440.4R, and 2009 AASHTO LRFD Bridge Design Guide Specifications for GFRP-Reinforced Concrete, 1st Edition) with the refinements and savings possible under the newer editions. Finally, the life-cycle cost, durability and environmental benefits from the use of the innovative CFRP and GFRP reinforcing systems in this type of traditional wall system, are identified for typical urban coastal areas with extremely aggressive conditions, congested access, and challenging environmental constraints.

Keywords: bulkhead wall; CFRP; composite bridges; GFRP; soldier pile

6-Span CFRP-PC/GFRP-RC Bridge over Placido Bayou

Christopher Gamache, Ananda Bergeron, and Pooya Farahbakhsh

Synopsis: The intent of this paper is to provide an illustrative example of a municipal bridge replacement design project utilizing fiber reinforced polymer materials approved for use by the Florida Department of Transportation. Specifically this paper describes the design of the Nathaniel J. Upham (40^{th} Avenue NE) Bridge replacement project and illustrates the application of carbon fiber reinforced polymer (CFRP) prestressing tendons and glass fiber reinforced polymer (GFRP) reinforcing bars in both precast and cast-in-place concrete elements. Due to the structure's high level of exposure in the extremely aggressive environment, the design for the replacement bridge focused on concrete elements that were durable and resilient to the effects of corrosion in those conditions. Prestressed and cast-in-place concrete elements with GFRP and CFRP reinforcement and prestressing tendons were utilized for the primary structural elements with direct exposure to salt water. In addition, link slabs with GFRP reinforcing were utilized at each intermediate bent to improve the bridge's performance. The design of the bridge elements followed the Florida Department of Transportation's design guidelines and requirements. The bridge replacement project is currently at the completion of the design phase and is scheduled to be advertised in the early summer of 2020 with the start of construction anticipated in the fall of 2020.

Keywords: CFRP-PC; corrosion resilient; Florida slab beam; GFRP-RC; link slab