MPC-554

December 11, 2017

Project Title:
Composite-based Rehabilitation of Constructed Bridge Girders with Grooved Geometrics

University:
University of Colorado Denver

Principal Investigators:
Yail Jimmy Kim
Professor
University of Colorado Denver
Phone: (303) 352-3653
Email: jimmy.kim@ucdenver.edu
ORCID: 0000-0002-4286-1461

Research Needs:
According to a recent survey (ASCE 2017), the infrastructure of the United States is graded D+, which requires over $123 billion to improve the condition of constructed bridges (approximately 40% and 10% of the nation's bridges are older than 50 years and are diagnosed structurally deficient, respectively). Technical concerns arise because 188 million trips are made every day across a structurally deficient bridge (ASCE 2017). Accordingly, the bridge engineering community has been seeking solutions to address this critical problem at affordable costs. Among many available methods that can enhance the functionality of constructed bridge members, advanced composite materials such as carbon fiber reinforced polymer (CFRP) are considered a promising alternative to conventional repair/strengthening materials and are broadly used across the nation. The reason is that composite-based rehabilitation offers a number of benefits, namely, high strength and modulus, light weight, easy implementation, low labor, durability, and favorable life cycle costs.

Bakis et al. (2002) provided a comprehensive review of advanced composites for construction. A wide variety of technical topics were covered: structural shapes, highway bridge decks, internal reinforcements, externally bonded reinforcements, and codes/standards. Karbhari et al. (2003) identified detrimental factors degrading the durability of composite-based structural members. Premature debonding failure of bonded composites from the substrate and its implications were expounded. Hollaway (2010) reported the state-of-the-art of composite applications in civil infrastructure with emphasis placed on serviceability. The importance of composite-substrate interface was elaborated since its disintegration directly affects the efficacy of rehabilitation. Kalfat and Al-Mahaidi (2016) discussed a method that mitigated the onset of premature failure in bonded composite sheets using spike anchors.

The concise literature review provided above indicates that the integrity of the composite-substrate interface (specifically, CFRP-concrete interface) is a critical component controlling the performance of repair/strengthening systems. Although the several proposed approaches appear to be applicable, there still is a dearth of research to fundamentally reframe the interfacial characteristics of CFRP composites bonded to a concrete substrate, so that the occurrence of premature debonding can be alleviated. This research explores a novel bonding scheme by creating grooves along the substrate and filled by an epoxy adhesive, which are expected to reduce interfacial shear stresses between the CFRP and concrete. The feasibility of the proposed idea will be experimentally verified and its performance will be comparatively assessed against existing debonding mitigation methods. A theoretical study will be conducted to complement experimental findings, including reliability-based modeling, fuzzy logic, and statistical characterization.

Research Objectives:

1. Development of an effective rehabilitation method
2. Theoretical characterization of the rehabilitation method
3. Proposal of design recommendations for practical implementation

To develop an effective method that preserves the integrity of the CFRP-concrete interface by creating grooves along the concrete substrate, followed by adhesive-filling

To characterize the behavior of the newly-developed interfacial configuration based on reliability, fuzzy logic, and advanced statistics

To suggest design recommendations for the implementation of the novel composite-based rehabilitation technique that will extend the longevity of constructed bridge girders

Research Methods:

The proposed research includes a systematic endeavor to develop a novel CFRP-strengthening method for bridge structures, which will alleviate the onset of premature debonding failure. The aim of the research is twofold: i) scientific investigations to fundamentally understand the debonding-mitigation mechanisms of the CFRP-concrete interface in conjunction with grooved geometrics and ii) a practical implementation plan to assist practitioners who are involved in bridge rehabilitation projects. A three-phase research approach is summarized with the following:

- Debonding mitigation mechanisms associated with grooved geometrics: extensive interface testing will be conducted to evaluate the failure characteristics of CFRP-concrete interface subjected to mechanical loading. Test parameters will encompass the size and number of grooves that will play a crucial role in reducing the stress singularity resulting from an exponentially increasing shear stress profile along the substrate.
- Theoretical study to complement experimental findings: experimental data will be collected, analyzed, and characterized by factorial analysis. The analysis of variance (ANOVA) will be employed at a 5% confidence level in order to statistically appraise differences between the groove configurations, if any. Reliability-based vulnerability will be established to quantify the level of uncertainty, depending upon the groove characteristics. Multiple-regression will generate mathematical equations that represent the capacity of the interface, followed by parametric investigations.

- Practice recommendations: the aforementioned technical phases will provide a foundation for developing practice guidelines. The quantified uncertainty and reliability will be useful when proposing performance-based design recommendations. It is anticipated that four performance levels will be categorized, which will overcome the limitations of currently used prescriptive design provisions in most specifications such as ACI440.2R-08 and AASHTO Guide Specifications.

Expected Outcomes:
The research findings will be used to develop a new repair/strengthening method that will advance the state-of-the-art of infrastructure rehabilitation. The following will be elucidated: progressive failure of the CFRP-concrete interface associated with multiple groove configurations, interaction between the grooves in terms of stress transfer, degree of uncertainty in interface mechanics, statistically quantified differences in the load-carrying capacity of the interface, and performance-based design provisions. All these efforts will fulfill the needs of the bridge rehabilitation community. Upon completion of the above-described research, i) composite-based rehabilitation will gain additional confidence; ii) practicing engineers will better enjoy the benefit of CFRP composite materials, iii) bridge owners will save expenses; and iv) sustainable built-environment will be accomplished. The research will also impact other disciplines such as interface physics, adhesive and adhesion, multi-material interaction, and measure-theory in mathematics.

Relevance to Strategic Goals:
- State of Good Repair
- Economic Competitiveness

The theme of the regional University Transportation Center at North Dakota State University (Mountain-Plains Consortium) is 'Transportation Infrastructure and Operations to Support Sustainable Energy Development and the Safe Movement of People and Goods' that aligns with the goal of the proposed research: developing a sustainable rehabilitation method to preserve the condition of constructed concrete bridge members at reduced long-term maintenance expenses. Significant effort will be expended to address the challenges confronting the nation's infrastructure. In addition, the primary interest of the current investigation meets the Secretary of Transportation's Strategic Goals (i.e., State of Good Repair and Economic Competitiveness).

Educational Benefits:
Educational components of this project are as important as research findings, because new generation engineers are responsible for our constructed transportation infrastructure. The PI will train highly qualified personnel (two graduate students are expected to participate in this project) and will integrate technical outcomes with structural engineering courses at the University of Colorado Denver. A number of undergraduate and graduate students will, therefore, benefit from the current MPC project. The PI will encourage his graduate students to take part in conference activities and national technical committees, so that they can share their findings and communicate with colleagues and potential employers. The PI will devote himself to maximizing the educational benefit of the MPC-sponsored project.

Tech Transfer:
As stated in this proposal, the proposed research has two important aspects: scientific investigations and practical implementation. The ideas and outcomes of the novel composite-based rehabilitation method will be disseminated through professional meetings, such as American Concrete Institute conventions and internationally renowned composite conference series. In so doing, other researchers and practicing engineers can learn this new rehabilitation technology, which may lead to further development and field applications. Journal papers will be submitted whenever sufficient technical data are available, so that the technology is shared by the national and international communities.

Work Plan:

1. Literature review
2. Composite-substrate interface test
3. Reinforced beam test with the proposed rehabilitation scheme
4. Development of performance-based design provisions

Task 1: An extensive literature review will be conducted to understand the current state of research and practice in the area of composite-based rehabilitation for bridge structures, particularly the behavior of CFRP-concrete interface. Of interest are interfacial integrity, bond development and failure mechanisms, existing debonding mitigation techniques, uncertainty quantification, and criteria to establish performance-based design. (Month 1-3)

Task 2: Concrete blocks will be cast and CFRP sheets will be bonded with variable groove configurations. After curing, the specimens will be monotonically loaded to failure. For comparison, additional CFRP-bonded blocks (without grooves) will be prepared in conjunction with conventional U-wraps and an emerging adhesive called silyl modified polymer (SMP), and will be tested. The behavior of the CFRP-concrete interface will be measured by an extensometer, strain gages, and a load-cell. The analysis of variance (ANOVA) will statistically characterize experimental data. Multiple-regression will follow to generate mathematical expressions. (Month 4-10)

Task 3: Based on the test results of Task 2, groove configurations will be optimized for structural application. Laboratory-scale reinforced concrete beams (grooved) will be prepared and strengthened with CFRP sheets. Experimental parametric investigations will be conducted by adjusting the optimized geometrics developed at the interface level in order to meet structure-level requirements. Fuzzy logic theory will be employed to address the radical uncertainties associated with the grooved interface that is different from the conventional flat-bond-lined interface. Furthermore, reliability analysis will be carried out to complement the fuzzy logic approach. (Month 10-20)

Task 4: All technical data acquired from Tasks 2 and 3 will be integrated to develop performance-based design provisions. The current task is important from a practice point of view, which will overcome the limitations of traditional prescriptive design provisions for composite-based rehabilitation. (Month 21-24)

Project Cost:

Total Project Costs:	$80,000
MPC Funds Requested:	$40,000
Matching Funds:	$40,000
Source of Matching Funds:	faculty time and external scholarship/support for students

References:

ASCE. 2017. Infrastructure report card, American Society of Civil Engineers, Reston, VA

Bakis, C.E., Bank, L.C., Brown, V.L., Cosenza, E., Davalos, J.F., Lesko, J.J., Machida, A., Rizkalla, S.H., and Triantafillou, T.C. 2002. Fiber-reinforced polymer composites for construction: state-of-the-art review, Journal of Composites for Construction, 6(2), 73-87.

Karbhari, V.M., Chin, J.W., Hunston, D., Benmokrane, B., Juska, T., Morgan, R., Lesko, J.J., Sorathia, U., and Reynaud, D. 2003. Durability gap analysis for fiber-reinforced polymer composites in civil infrastructure, Journal of Composites for Construction, 7(3), 238-247.

Hollaway, L.C. 2010. A review of the present and future utilization of FRP composites in the civil infrastructure with reference to their important in-service properties, Construction and Building Materials, 24, 2419-2445.

Kalfat and Al-Mahaidi, R. 2016. Mitigation of premature failure of FRP bonded to concrete using mechanical substrate strengthening and FRP spike anchors, Composites Part B, 94, 209-217.