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Project Title

Behavior of Composite-Strengthened Concrete Bridge Members under Multi-Hazard Loadings

University

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Research Needs

The safety of existing bridge structures is of major interest to transportation agencies. Constructed members are often subjected to multi-hazard distress resulting from a combination of physical and environmental factors (e.g., excessive traffic loadings, deicing chemicals, and elevated temperatures). Upon occurrence of detrimental consequences, the serviceability and load-carrying capacity of the structures degrade (Karbhari et al. 2003; Angst et al. 2012; Alexander and Beushausen 2019); accordingly, technical actions such as rehabilitation are necessary to extend the longevity of the constituting members.

Structural applications of advanced composites are a competitive solution to conventional construction methods (Al-Saadi et al. 2019; Pohoryles et al. 2019). Among several options, carbon and glass fiber reinforced polymer (CFRP and GFRP, respectively) composites gained attention from the bridge engineering community because of their outstanding durability, high strength and modulus, reduced long-term maintenance costs, and easy handling on site (Ray and Rathore 2015; Bedon and Louter 2017; Cabral-Fonsecaa et al. 2018). Numerous projects have been conducted around the world to construct and retrofit bridge girders and decks using CFRP and GFRP materials (Kim 2017).

Notwithstanding the recent endeavors, the behavior of FRP-based bridge members under multi-hazard environments has limitedly been examined. Accordingly, practitioners may not actively utilize such promising FRP technologies. It is, in fact, unclear how FRP-reinforced or -strengthened girders and decks deteriorate under multi-hazard loadings and how their performance would be, from various limit-state standpoints (i.e., serviceability and ultimate limit states).

The majority of existing studies were concerned with a single distress type; consequently, there is a significant knowledge gap in the response of bridge members reinforced or strengthened with FRP composites when subjected to compound load effects (e.g., thermal and mechanical loadings, or corrosion plus heavy trucks). As far as modeling is concerned, most research projects focused on structure-scale examinations, rather than micro- and macro-scales that are necessary to fundamentally understand the initiation and propagation of structural damage.

The proposed research aims to investigate the ramifications of multi-hazard loadings on the performance of FRP-strengthened and -reinforced concrete members. An experimental program will be conducted to study the behavior of CFRP-strengthened concrete girders exposed to thermal and mechanical loadings. A numerical study will also be carried out to comprehend the implications of deicing salts in conjunction with traffic loadings on the behavior of a full-scale bridge, including microscopic corrosion propagation and macroscopic responses.

Research Objectives

The objectives of the research are:

- To elucidate the adverse effects of multi-hazard environments on the performance of FRP-strengthened and -reinforced bridge girders and decks, with a focus on thermomechanical and chloride-mechanical loadings
- To propose practice guidelines for the infrastructure community, which will save rehabilitation expenses for constructed bridge members

Research Methods

The two-fold research program comprises 1) experimental investigations and 2) computational modeling. For the experimental component, reinforced concrete beams will be cast and strengthened with CFRP sheets. The beams will then be exposed to elevated temperatures alongside cyclic mechanical loadings (thermomechanical distress). Regarding the computational study, a full-scale bridge model will be developed using a finite element package. The bridge members will be reinforced or prestressed with FRP bars or tendons. Various corrosion scenarios will be taken into account such as deicing salts and spontaneously spreading chlorides in a marine region. These environmental attributes will be combined with traffic loadings (chloride-mechanical distress).

Expected Outcomes

The research will clarify the complex implications of multi-hazard loadings on the behavior of constructed concrete members reinforced or strengthened with FRP composites. The experimental study combined with computational modeling will provide a multi-directional framework that will be useful to understand the deleterious effects caused by thermomechanical and chloride-mechanical loadings. It is expected that the state of the art in bridge engineering will be enriched, particularly for cost-effective solutions with enhanced longevity. Specifically, the infrastructure community can better preserve the quality of concrete bridges and can ensure their sustainable performance at reduced maintenance costs.

Relevance to Strategic Goals

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*’, which aligns with the goal of the proposed research: understanding the behavior of transportation structures under multi-hazard loadings, which will lead to extending the serviceable life of constructed bridge members at affordable expenses. Significant effort will be expended to address the challenges facing the nation's infrastructure. Furthermore, 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

Highly qualified personnel will be trained with an emphasis on cost-effective sustainable construction and rehabilitation methods. Research findings will add values to Dr. Kim's course titled Structural Rehabilitation (CVEN 5800), which will directly benefit senior undergraduate and graduate students.

Technology Transfer

The professional outreach of the PI will facilitate disseminating research results. The PI is President of the Bridge Engineering Institute, An International Technical Society, and organizes conferences and symposia for research professionals and government engineers in the area of bridge engineering and related fields. The PI is also Chair of American Concrete Institute (ACI) 440I (FRP-prestressed Concrete) and was Chair of ACI 345 (Concrete Bridge Construction and Preservation) from 2012 to 2018. He has actively been involved in writing specifications and design guidelines for various technical committees. Research papers to be published by conference proceedings and journals will broadly transfer the outcomes of the proposed study domestically and internationally.

Work Plan

Task 1: Literature review (Months 1 to 3)
The state of the art of structural behavior under multi-hazard loadings will be understood by collecting and reviewing published papers. Of interest is the influence of synergetic distress consisting of thermomechanical and chloride-mechanical loadings on the degradation mechanism of constructed concrete members with and without FRP composites.

Task 2: Member-level testing (Months 4 to 14)
Laboratory-scale beams will be prepared and strengthened with CFRP sheets. Thermal loading will be applied by electric heat pads, which is a cost-saving experimental technique, at a high moment region; then, sinusoidal mechanical loadings will be associated to exacerbate the structural integrity. Attention will be paid to the formation of a plastic hinge where the failure of the system occurs. Analytical models will be developed to complement test data and to expand the investigation scope based on a parametric study.

Task 3: Structure-level modeling (Months 15 to 21)
Multi-scale bridge models will be developed. The concrete bridge will be reinforced with GFRP bars or prestressed by CFRP tendons, and will be subjected to corrosion damage in tandem with traffic loadings. Regarding microscale investigations, a novel simulation technique called agent-based modeling will be utilized to predict the progression of chlorides into the concrete. On a macroscale study, a finite element model will be developed. Technical results from the microscale models will be linked with the macroscale examinations. As such, fundamental issues

concerning the durability of constructed concrete bridges will be addressed and mitigation strategies will be sought.

Task 4: Development of design recommendations (Months 22 to 23)
Practical design recommendations will be developed for practicing engineers. Because the degradation of existing bridge members cannot be fully explained by current descriptive specifications, performance-based guidelines will be suggested.

Task 5: Final report (Month 24)
A final report will be submitted when the aforementioned tasks are complete.

Project Cost

Total Project Costs:	$80,000
MPC Funds Requested:	$40,000
Matching Funds:	$40,000
Source of Matching Funds:	Faculty time and possible external scholarship/support awarded to participating individuals

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