MPC-581
October 19, 2018

Title
Structural Fiber Reinforcement to Reduce Deck Reinforcement and Improve Long-Term Performance

University
Utah State University

Principal Investigators
Marc Maguire, PhD.
Assistant Professor
Utah State University
Phone: (435) 797-1139
Email: m.maguire@usu.edu
ORCID: 0000-0002-7897-0344

Research Needs
Repair of reinforced concrete bridge decks represents a large portion of bridge manager's budgets. A survey of 52 transportation agencies identified more than 100,000 bridges across the United States that have exhibited early age bridge deck cracking (Krauss and Rogalla 1996). Reducing the amount of cracking on bridge decks would likely lead to better infrastructure resilience and lower long term costs. While various reinforcing materials are available to reduce or eliminate corrosion, they are often considered near cost prohibitive (e.g., stainless steel) or difficult to procure (carbon fiber rebar) or come with significant design challenges (e.g., glass fiber rebar). Epoxy coated mild reinforcement is the steel corrosion protection of choice among many Departments of Transportation, however its performance is highly dependent on the initial condition of the coating which is historically easy to damage during the manufacture, transport and construction (Frosch et al. 2014). Other coating options like galvanized reinforcement or stainless clad reinforcement are often seen as not worth the cost as evidenced by their relative lack of use.

Bridge deck cracking is often attributed as one of the main factors contributing to early age repairs on bridge decks by allowing a path for moisture and chlorides to initiate corrosion cells (Frosch et al. 2010) sooner than diffusion based corrosion. Early age cracks are caused by a variety of factors including concrete shrinkage and thermal loading.

Fiber reinforced concrete (FRC) is known to reduce crack sizes (Zollo 1997), but is not commonly used for bridge deck primary reinforcement. There have been some research on bridge decks using FRC as crack control reinforcing (Gopalaratnam et al 2016), but such decks have not used FRC capable of carrying significant tensile stresses. Bridge decks are typically designed using two methods: the strip method and empirical deck design, in neither method is FRC easily adaptable because the AASHTO LRFD specifications do not incorporate any FRC design methodology. In the US, there is no distinction between structural FRC (SFRC) a non-structural FRC, where as in the Japanese and European codes, a distinction is made and design methodologies are codified. However, there are two known SFRC fibers in the US market: Helix steel fibers and Cem-fil glass fiber reinforced polymer (GFRP) fibers. SFRC made with these fibers have the potential to achieve and maintain over 1200psi tensile strength while exhibiting excellent ductility and strain hardening. These strength numbers are comparable to Ultra High Performance Concrete, which is lauded for its tensile strength, but are overall more economical and anecdotally easier to work with. GRFP SFRC is likely the best option for bridge decks since it will not cause visually unappealing surface corrosion like steel fibers are known for.

By combining SFRC with various types of reinforcement (black steel, stainless steel, GFRP rebar), the total amount of steel can be reduced, limiting the total amount of damaged caused to a bridge deck. Potentially, the entire top mat of reinforcement could be eliminated or even all discrete reinforcement and the SFRC will provide additional crack control.

Research Objectives

This project aims to investigate SFRC hybrid bridge deck structural performance regarding punching shear, flexural strength and flexural fatigue will be used to develop design criteria for SFRC bridge decks.

The PI will test several prototype bridge decks using a combination of SFRC, black reinforcement, stainless steel reinforcement and GFRP reinforcement. Using the information gained from this study, design recommendations will be made regarding the use of SFRC hybrid bridge decks.

Research Methods

This project will be separated into discrete tasks as outlined below.

Task 1: Literature review, prototype bridge deck design and specimen design. Information regarding FRC design and traditional design will be synthesized in order to create a rational design for a prototype deck. This prototype bridge deck will be further modified into a set of flexural and punching shear specimens. The specimens to be investigated will be a control bridge deck using black steel, a SFRC and black steel bridge deck, an SFRC and GFRP bridge deck, an SFRC and stainless bridge deck and an all SFRC bridge deck. Fibers and GFRP bars have been requested and approved from Cem-fil (a division of Owens Corning).

Task 2: Flexural Testing and Punching Shear Testing. Flexural and punching shear testing will be performed by monotonic loading on each of the simple span bridge deck designs. Preliminarily, flexural shear specimens will be between 10ft and 16ft long by 4ft wide and 8in. deep. Preliminarily, punching shear specimens will be 16ft by 16ft and 8in. deep. Material testing of the individual components will be performed.

Task 3: Fatigue Testing. Flexural fatigue will be investigated to ensure behavior of fibers through a large range of loading. Number of fatigue cycles will be determined through discussion with the local DOT.

Task 4: Data and Cost Analysis. Following testing, the data will be analyzed to determine if the bridge decks tested can provide a safe alternative to traditional bridge decks. A design methodology will be proposed that can describe the behavior of the various types of decks.

Task 5: Final Report. A final report will document Task 1 through Task 5 with a focus on making the results practice-ready.

Expected Outcomes

A preliminary cost analysis has suggested that SFRC bridge decks can allow reduction of black steel reinforcement and will be cost neutral with an epoxy coated bridge deck, the traditionally cheapest corrosion resistant bridge deck option. A similar or even more pronounced cost reduction is expected for stainless steel because of its higher strength and much greater cost, although would likely still be more expensive than a black steel option. The likelihood of adoption dramatically increases if the improvement is at or near cost neutral for initial costs. Furthermore, by removing the potential for corrosion of reinforcement from a bridge deck, there will be a decrease in long term maintenance costs.

This project will provide proof that hybrid SFRC can provide the strength of a traditional bridge deck. Research will focus on the flexural, punching and long term strength (fatigue) to ensure a safe design. A design methodology will be outlined for potential inclusion into the AASHTO LRFD to allow SFRC to be incorporated into routine design.

Relevance to Strategic Goals

This project relates to all of United States Department of Transpiration strategic goals, however it is primarily related to *State of Good Repair* and *Economic Competitiveness*. A description of how the outcomes are related to the strategic goals is below.

- *State of Good Repair:* SFRC hybrid decks will reduce corrosion induced damage to bridge decks by removing easily corroded black steel bars from the bridge deck and controlling cracks so that less water and chlorides can infiltrate to create corrosion cells.
- *Economic Competitiveness:* Ideally, SFRC hybrid decks will enable a cost neutral bridge deck reinforcing option when compared to common epoxy coated systems, but will result in lower long terms costs due to its resistance to corrosion induced damage.

Educational Benefits

One graduate student and one undergraduate researcher will be funded by this project. These students will be trained in contemporary analysis methods and design codes, making them highly sought after graduates. The results of this research will provide new applications for new materials that can be incorporated into Utah State University design courses.

Technology Transfer

Results will be disseminated through the report and presentations at national meetings and conferences. At least one journal article will come from this work. All data from this research will be stored in a repository such that the information will be easily retrievable. Research will be incorporated into a wide variety of education and training activities through the Utah Local Technical Assistance Program centered at Utah State University.

Work Plan

The proposed research will be carried out over an 18 month period under the following schedule:

Task 1: Three Months

Task 2: Four Months

Task 3: Five Months

Task 4: Four Months

Task 5: Two Months

Project Cost

Total Project Costs:	$133,000
MPC Funds Requested:	$66,500
Matching Funds:	$66,500
Source of Matching Funds:	LTAP

References

Frosch, R., Labi, S., Sim, C. (2014) "Increasing Bridge Deck Service Life: Volume 1 – Technical Evaluation" FHWA/IN/JTRP-2014/16. Indianapolis, IN.

Frosch R., Gutierrez, S., Hoffman, J., (2010) "Control and Repair of Bridge Deck Cracking" FHWA/IN/JTRP-2010/4. Indianapolis, IN.

Gopalaratnam, V., Meyer, J., Young, K., Belarbi, A., Wang, H., (2006) "Steel-Free Hybridg Reinforcement System for Concrete Bridge Decks" RI02-002. Jefferson City, MO.

Krauss, P., Rogalla, E. (1996) "Transverse Cracking in Newly Constructed Bridge Decks" *NCHRP Report No. 380, Transportation Research Board, National Report Council*, Washington, DC.

Zollo, R. (1997) "Fiber-reinforced concrete: an overview after 30 years of development" Cement and Concrete Composites, 19(2), 107-122.