MPC-373

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Proposals Title: Damage Assessment, Characterization, and Modeling for Enhanced Design of Concrete Bridge Decks in Cold Regions

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A. Research Needs

Concrete Decks play an integral and significant role in the durability and structural integrity of bridge structures. Decks provide not only a platform or a surface for vehicle traffic, but also provide lateral and torsional rigidity to the overall structure of a bridge. Because of the important role bridge decks play, engineers have always been concerned with their maintenance and upkeep. During the last decade, the Federal Highway Administration (FHWA) identified an inventory of 600,000 bridges, each of which being greater than 20 feet in length (Tang 2003). Together with the states and local agencies, the government had spent about $7 to $8 billion per year for the upkeep of the bridges. Of these huge expenditures, concrete bridge decks had received a lion's share of the retrofit dollars. Among the inventory of bridges, some thirty percent were classified as “structurally deficient” or “obsolete” requiring substantial retrofitting efforts. The percentage was higher in states where the deicing agents caused corrosion on non-coated deck reinforcement.

Concrete decks sustain damage due to a variety of stresses arising from exposure to heavy loads, fatigue, dynamic loads; environment effects such as extreme temperatures and variations; and exposure to manmade products such as deicing agents which could cause corrosion. Since damage in concrete materials alters the stiffness properties, it is then critical to thoroughly understand and examine the damage development, progression, and characterization to facilitate a reliable design and effective maintenance of bridge systems. In this research proposal, damage from heavy loads, fatigue, and temperature effects will be considered as they constitute important factors in the strength and reliability of bridge decks especially in the Upper Great Plain states.

Although significant efforts have been spent in the understanding of concrete materials, the characterization of induced multiaxial damage and the modeling efforts have lagged disproportionately in the bridge engineering community. For one, the majority of testing and engineering models have been done under uniaxial stress state (Petryna and Stangenberg, 2004). The use of uniaxial testing and the 1-D modeling is understandable given the simplicity and of using 1-D approaches; however, in the majority of cases, concrete decks experience biaxial stress state, and the and the overreliance on unidirectional design concepts and methodology can seriously undermine the safety and reliability of bridge structures specially under complex loading regimes (Olsson and Pettersson, 2010)

This proposal outlines an approach that will be based on the first principles of mechanics whereby families of general biaxial strength envelopes are developed for concrete decks that are a function of applied stresses and also temperature. A novel approach is then proposed in which for fatigue loadings these surfaces are allowed to collapse or contract inwards thereby predicting the fatigue life of the material. This novel approach is in complete agreement with experimental data that fatigue loading reduces the life of materials. Such design methodology would allow the study of freeze-thaw cycles, such as present in Upper Midwestern states, in a more routine and comprehensive fashion and can indeed be considered as a special low-cycle fatigue issue with tensile stresses or strains present.

B. Research Objectives

The objectives of the research are:

- To develop ~~a~~ comprehensive mathematical formulation and design equations for the biaxial strength of concrete decks under a variety of extreme levels of low temperatures present in the Upper Midwestern States.
- To develop a fatigue-based formulation due to vehicle loading from the biaxial strength of concrete stated above so that design engineers could safely predict the life cycle of the bridge deck component.
- To extend the above mentioned formulations for characterizing the freeze-thaw cycle damage as a parameter on the overall design in cold regions.

C. Research Methods

The proposed approach will utilize advanced theories of *Damage Mechanics* to provide rigorous mathematical foundation based on the first principles of mechanics. With this approach, standard curve fitting will not be required as deign parameters will be identified and obtained based on simple and standard material tests. Since damage in concrete causes anisotropy in the material, the formulation will be set up to capture such an important and realistic behavior characterization and will be reflected in the design questions that will follow. Biaxial strength curves will be developed based on the stresses in different directions, temperature, and damage parameters. A family of curves will be developed to reflect the effect of extreme low temperature on the strength of concrete materials.

With the development of these design strength curves, a novel approach will be utilized whereby the biaxial curves (shown in Figure 1 as LS) will be allowed to contract inward (shown in Figure 1 as RS) to reflect the fact that under fatigue loading, engineering materials tend to lose strength and hence exhibit reduced life. At failure, the loading frequency, n, becomes the fatigue life designated as "N" in Figure 1. The manner in which the design strength curves (LS and RS) contract inwards as the number of cycles (n) increases will be specified for use by design engineers. A family of LS curves will be developed based on various temperatures. The realistic range of extreme cold temperatures experienced in Upper Midwestern states range from -5 to -35 degrees Fahrenheit and will be considered in this work.

Some of the design parameters related to material behavior will be obtained by performing experimental tests at NDSU. NDSU Civil Engineering has an environmental temperature chamber allowing materials to be subjected to low temperatures as suggested. Also, several freeze-thaw cycle tests will be conducted to calibrate and to obtain design parameters used in the model.

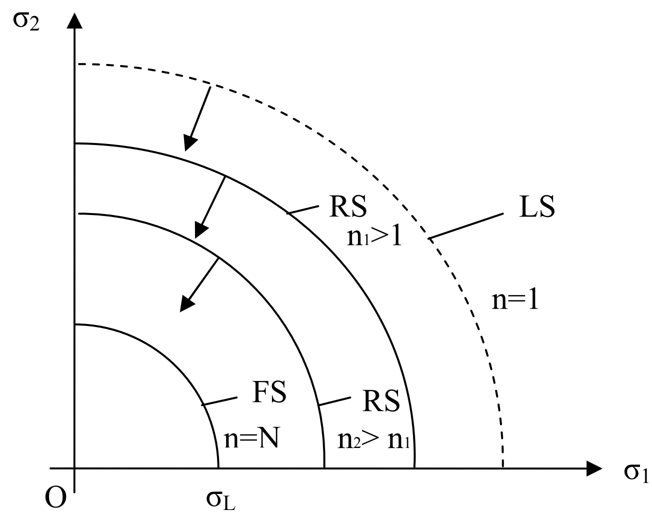

Figure 1. Schematic representation of Strength surfaces in two-dimensions.

D. Expected Outcomes

This research project aims in developing a better and more realistic design of concrete bridge decks under biaxial, fatigue, and low temperature conditions. It presents a novel approach that such complex loading regimes can be addressed and analyzed systematically and based on established principles of engineering mechanics. It will provide engineers with a better and more realistic approach to the design of concrete decks and will enable them to successfully include the effects of structural damage in the reliability analysis of their design. The following outcomes are expected:

- A family of biaxial strength curves will be developed representing various stress combinations and cold temperatures
- Fatigue design curves will be developed for various stress levels, load frequency, and cold temperatures
- Freeze-thaw damage will be identified representing climatic conditions in Upper Midwestern States
- The effect of various damages on the stiffness degradation of concrete decks will be characterized for implementation in design equations.

E. Relevance to Strategic Goals

Sound and reliable engineering of bridge decks is required for sustainable and economical design of bridge structures. As such, this present proposal is well within the current theme of the MPC and the Transportation Strategic Goal of "State of Good Repairs and Safety." A thorough understanding of parameters and sound engineering as proposed in this research would lead to safe and reliable design of bridge decks.

F. Educational Benefits

One full-time graduate student is expected to help the PIs on the conduct of this research. He will be trained to develop necessary analytical skills, to design, control, and perform experimental investigations, and to help write technical articles on research findings. Research findings will also be presented in weekly Civil Engineering seminars as well as presentation by the Co-authors in CE425/625 courses (Bridge Evaluation and Rehabilitation).

G. Work Plan

Task 1: Collect current state of the art design methodologies and published work on the design of concrete bridge decks subjected to fatigue and low temperatures. (Months 1-3)

Task 2: Formulate biaxial design envelopes and curves as a function of applied stresses, fatigue load cycles, and temperature. (Months 1-8)

Task 3: Identify various damage functions and their variations with temperature. Perform laboratory tests to determine temperature effects on basic properties and design parameters. (Months 9-15)

Task 4: develop new design curves for concrete decks under fatigue and low temperatures based on Tasks 2 and 3. (Months 16-21)

Task 5: Refine models based on interim reports, prepare and finalize the report for submission and publication. (Months 23-24)

H. Project Cost

Amount funds requested: $100,000

Matching funds (in-kind: 100,000): graduate student tuition ($35,138), faculty research during academic year ($10,810.3/PI x 3 PIs/yr x 2 yrs. = $64,862)

TRB Keywords: bridge Deck, Damage, Fatigue, Temperature, Freeze-thaw

References (details are available upon request)

Tang (2003), Petryna and Stangenberg (2004), Olsson and Pettersson (2010).