MPC-372

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Project Title

A novel methodology for quantifying the performance of constructed bridges in cold regions: development, assessment, and repair.

University

North Dakota State University, Fargo, ND

Principal Investigators

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Research Needs

The American Society of Civil Engineers reported that 27.1% of the 590,750 bridges in the United States were structurally deficient or functionally obsolete. A budget of $9.4 billion will be required to eliminate these deficient bridges (ASCE 2005). Potential economic impact due to deteriorated bridges is significant, provided that structurally deficient bridges should be restricted to selected vehicles or should be closed by posting. This is a particularly important issue for the Midwest region of the US where heavy trucks are required to transport commodities.

Constructed bridge structures experience a number of deterioration mechanisms, over time, induced by traffic volume and environmental conditions. Adequate evaluation of the present state of existing bridges is an important step to establish an effective bridge management program. Roelfstra et al. (2004) developed a condition evaluation approach for existing bridges with emphasis on corrosion damage. An evaluation model was suggested to be used when limited inspection data were available. Jiang and Rens (2010) evaluated the applicability of Bridge Health Index in Pontis Bridge Management System for constructed bridges. A total of 615 bridges in Denver, Colorado were used for this purpose. It was found that the Pontis Bridge Health Index (AASHTO 2003) would need to be improved to generate more realistic evaluation results. Wang et al. (2011) assessed the rating of existing bridges using a system reliability approach. Legal trucks in Georgia were employed for a comparative study between the AASHTO rating methods and refined finite element models. A need for developing refined evaluation criteria was discussed.

Advanced composite materials such as carbon fiber reinforced polymer (CFRP) are a strong candidate for repairing deteriorated bridges. Numerous research projects demonstrated the efficacy of CFRP-repair (Bakis et al. 2002). The application of CFRP for structural rehabilitation in cold regions, however, has been limitedly reported. Kong et al. (2005) studied the response of CFRP-confined concrete cylinders exposed to freezethaw cycles (-18°C) associated with a sustained compression load. Strength reduction due

to freeze-thaw was not noticeable. El-Hacha et al. (2010) studied the effect of harsh environmental conditions on the behavior of CFRP-wrapped concrete cylinders, including freeze-thaw at -18 °C and high temperature exposure at 45°C. CFRPconfinement showed substantial increases in strength and stiffness of concrete cylinders.

Despite the research efforts discussed above, there still remains limited information with regard to the condition evaluation of bridges and corresponding rehabilitation, in particular for cold climate regions. This research project aims at addressing such an identified research gap. Of interest is the behavior of constructed/repaired bridges subjected to non-conforming traffic that is commonly observed in Midwest to transport commodities, and subjected to aggressive environment. Upon successful completion of the proposed research, effective bridge management and planning in Midwest will be accomplished.

Research Objectives

The objectives of the research are:

- To develop a comprehensive evaluation methodology for bridges subject to cold region environment and heavy traffic load, based on National Bridge Inventory (NBI) data
- To examine the efficacy of advanced composites for repairing deteriorated bridge members in aggressive service conditions
- To propose practical guidelines for the evaluation and rehabilitation of existing bridges in cold regions

Research Methods

The research program includes a pioneering effort to achieve the sustainable performance of constructed bridges in cold regions. The project will i) develop a novel assessment methodology for those bridges using over 20 years of actual evaluation data and ii) study the effectiveness of advanced composite materials for repairing deteriorated bridge members in aggressive environment. The concept of *bridge health index* will account for critical attributes influencing bridge deterioration in cold regions. The three-phase research approach is as follows:

- *Development*: a systematic assessment tool for deteriorated bridges due to cold climate conditions will be developed to aid practicing engineers and government official who are involved in bridge evaluation and maintenance
- *Assessment*: applicability of the developed bridge health index will be thoroughly assessed using actual inspection data (i.e., National Bridge Inventory)
- *Repair*: efficacy of structural repair using CFRP composites will be examined for the economic and technical competitiveness of timely rehabilitation action. Sustainable performance of CFRP-repaired structures in aggressive service conditions will be studied.

Expected Outcomes

The research will provide an object-oriented evaluation methodology associated with rehabilitation techniques for constructed bridges in cold regions. Government officials (including DOT staff), practicing engineers, and research professionals will benefit from research findings, specifically those who are in Midwest. The following outcomes will be

expected:

• Relationships between the long-term performance of existing bridges and cold region's attributes will be mathematically modeled using multiple regression techniques so that the level of future deterioration will be adequately prognosticated

• The comprehensive assessment method based on the concept of bridge health index will help technical personnel in conducting the inspection and condition evaluation of bridges

• Behavior of CFRP-repaired bridge members in aggressive service environment will be understood, including deterioration mechanisms.

• Preliminary design guidelines for CFRP rehabilitation in cold regions will be proposed to enhance the sustainability of in-site bridges

Relevance to Strategic Goals

The research activities are relevant to the theme of the regional University Transportation Center at NDSU in terms of the transportation infrastructure and the movement of passengers and freight, particularly rural and intermodal transportation in cold regions. Foci of the research are aligned with the Secretary of Transportation's Strategic Goals (i.e., *State of Good Repair* and *Environmental Sustainability*), given that the research will address the sustainability of constructed bridges subject to aggressive environmental conditions and the efficacy of CFRP-repair in such circumstances.

Educational Benefits

Educational benefits from this research are two-fold. First, highly qualified personnel will be trained in the area of civil infrastructure: two graduate students will participate in the research project. Second, the project will impact an existing bridge course at NDSU: the PI teaches CE425/625 (Bridge Evaluation and Rehabilitation) in every Spring semester. Technical findings from the research tasks will be incorporated into course contents. Students taking CE425/625 will better understand technical issues related to constructed bridges.

Work Plan

Task 1: The research team will collect published papers relevant to the research and evaluate existing assessment methods to identify their pros and cons, including various physical and environmental attributes. (Month 1-3)

Task 2: The National Bridge Inventory (NBI) of the constructed bridges in North Dakota (representing bridges in cold regions) will be analyzed using a statistical approach to determine their degradation trend with time. The PI has already secured 20 years of database of these bridges and developed a statistical model (Kim and Yoon 2010) so that synergies are expected. (Month 4-9)

Task 3: A new assessment method based on the results of Task 2 will be developed for existing bridges subjected to cold region environment, especially for those situated in upper Midwest. The concept of Bridge Health Index (BHI) will be utilized. (Month 10-18)

Task 4: The developed assessment method will be appraised by random sampling of the NBI database. Prediction errors will be quantified and probabilistic distributions will be constructed for reliability studies. (Month 16-21)

Task 5: Representative bridge elements (laboratory-scale) will be designed and constructed. Two groups of test specimens will be prepared: unrepaired and repaired using CFRP. Aggressive environmental conditions will be applied to these specimens as per ASTM standards (e.g., ASTM C666: Standard test method for resistance of concrete to rapid freezing and thawing). Damage propagation will be regularly measured using ASTM C215 (Fundamental transverse longitudinal and torsional resonant frequencies of concrete specimens). (Month 1-12)

Task 6: The conditioned specimens will be monotonically tested to examine their behavior and load-carrying capacity. Efficacy of CFRP-repair in aggressive environment will be quantified. Empirical models will be developed. (Month 13-21)

Task 7: A technical report will be provided, including preliminary design guidelines for CFRP-repair in cold regions. A presentation will be made through LTAP at NDSU to broadly disseminate research findings. Regional engineers will be trained. (Month 19-24)

Project Cost
Amount funds requested: $100,000
Matching funds (in-kind: 100,000): graduate student tuition ($70,276), faculty research during academic year ($4,954/PI x 3 PIs/yr x 2 yr = $29724)

TRB Keywords: bridge, evaluation, rehabilitation, fiber reinforced polymer, cold region

References (details are available upon request)
AASHTO (2003); Bakis et al. (2002) JCC 6(2) 73-87; El-Hacha et al. (2010) JCC 14(1) 83-63; Jiang and Rens (2010) JPRC 24(6), 580-587; Kim and Yoon (2010) JBE 15(5), 542-552; Kong et al. (2005) ACI-SP230, 705-722; Roelfstra et al (2004) JBE 9(3), 268-277; Wang et al. (2011) JBE 16(6), 854-862.