MPC-412
January 1, 2013- December 31, 2013

Project Title:
Fatigue Strength of CFRP-repaired Reinforced Concrete Bridge Girders under Service Temperature

University:
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Research Needs:
Fatigue cracking is known to be a common problem in steel and concrete bridge girders due to the frequent passage of axle loads. In reinforced concrete bridges, elements such as slabs, girders, and piers, are subjected to a high number of stress cycles that can lead to the development of cracking in the concrete or the reinforcing steel. Fatigue crack development in the reinforcement is a frequent issue, which have been previously studied by various researchers. One promising solution for mitigating such cracks is the use of CFRP patches or plates for the repair of the cracked elements. The application of CFRP patches result in an overall increase in member stiffness and strength, thereby reducing the stress range applied and slowing down or arresting crack propagation.

Owing to its light weight, durability, and ease of handling; numerous studies have been carried out to investigate the use of FRP for the rehabilitation of the increasingly aging and deteriorated civil structures and infrastructures systems in the US. The studies focused primarily on quantifying the increase in flexure and shear strength to structural elements when reinforced with FRP. The use of FRPs for retrofitting of concrete structures has been proven successful. It has traditionally been used in the form of sheets or plates attached to the concrete surface or as wrappings for columns. The past and potential use of FRP in strengthening and retrofitting concrete structures has been documented in various publications (Meier and Betti 1997; Taljsten 1997; Maruyama 1997; Neale and Labossiere 1997; Thomas 1998; Benmokrane and Rahman 1998; Triantafillou 1998; Miramiran et al. 2004; among many others).

One of the hurdles associated with fully utilizing CFRP for the repair of bridge elements is the rapid loss of bond strength when the epoxy temperature increases beyond 60^{o}C (Gamage et al. 2005). It is however important to note that there is a significant lack of data in the literature pertaining to the variation of the mechanical properties of CFRP/epoxy as a function of temperature. Moreover, there is a large discrepancy between the available test results and bond strength data under elevated temperatures (Gamage et al. 2005). As anticipated, the expected loss of bond strength with temperature will have an impact on the effectiveness of the CFRP in reducing the applied stress range on the structural elements. Consequently, the propagation rate of a cracked reinforced beam will also vary as a function of the applied temperature. *To the knowledge of the PI, there are no studies that have addressed the effect of temperature on crack propagation in the concrete or steel reinforcement in a CFRP-retrofitted girder under cyclic loading. In addition, no studies have considered the propagation of cracks under temperature cycles, superimposed onto the applied cycles from the axle loads.*

Research Objectives:
The objectives of this project are as follows

1) Collect experimental data on the fatigue response of CFRP-repaired RC girders under various service temperatures.
2) Develop finite element models for fatigue life predictions of the girders.
3) Recommend best repair practice for increasing the fatigue life of the repaired girders.

Research Methods:
The project will begin with an extensive literature review on available experimental data and numerical models related to assessing fatigue crack growth in the reinforcements and the concrete in RC girders as influenced by temperature and axle loads. The literature review will help in identifying the most critical parameters that need to be addressed in the subsequent experimental task.
Following the literature review, an experimental program will be developed with the aim of assessing the effectiveness of CFRP repair on slowing down the propagation rate of the cracked girders as a function of the applied axle load and temperature load. The program will be designed to include control specimens that can be used for comparison purposes. Detailed instrumentation plans will be developed to capture the localized behavior and the global performance. In addition to experimental testing, finite element models will be developed and used in a parametric study and in predictions of fatigue life.
This project will be conducted in cooperation with another MPC project at CSU: Predicting Fatigue Service Life Extension of RC Bridges with Externally Bonded CFRP Repairs, PI: Dr. Rebecca Atadero, in order to explore several aspects of the research question.

Expected Outcomes:
Experimental data will be produced and added to the existing set of data on CFRP repair of reinforced concrete beams. Numerical models will be developed and calibrated to experimental results. Guidelines will be provided, which can be used by engineers for retrofitting bridge girders using CFRP.

Relevance to Strategic Goals:
This project will advance the knowledge on the effectiveness of CFRP for the fatigue repair of reinforced concrete beams under service cyclic loading (temperature and axle loading). Modifications to the existing repair strategies using CFRP will be recommended. The project is also expected to allow the transportation agencies to apply effective measures to mitigate and retrofit the questionable bridge elements. The project will enhance the existing federal effort in achieving a **state of good repair** in the deteriorated bridges in the US.

Educational Benefits:
A graduate student will be assigned to lead all tasks of the project as a research assistant. Moreover, the results of the study will be used as a case study in a graduate level course CIVE 664 (Mechanics of Fatigue and Fracture). This is a newly developed course that will be taught by the PI starting Spring 2013. The course has already been approved by the university.

Work Plan:
Achieving the overarching goal of this project requires the completion of six different tasks.

Task 1 - Literature Review
The research team at CSU will conduct a comprehensive literature review to identify common practice for retrofitting reinforced concrete bridge girders with CFRP at various deteriorations levels of the girders. Current data on the response characteristics of CFRP-repaired RC girders under static and fatigue loading will be collected and categorized. In addition, studies on the effect of service temperature on CFRP debonding and on the performance of the girders when the girders are loaded under static load will be reviewed. The review will be an essential step in identifying the most important parameters to be investigated when evaluating the fatigue response of the repaired RC girders under service temperature.

Task 2 - Construction of Specimens
The results of the literature review will be used to identify the geometry of the RC beams that need to be tested and the parameters to be varied. Approximately 15 to 20 girders with length approximately of 16.4 ft (5 m) will be constructed to be tested. The girders will be constructed to represent different levels of damage state including undamaged girders. The damage will be introduced by pre-cracking of the reinforcing steel and the concrete. The specimens will be retrofitted with CFRP and tested under varying service temperatures.

Task 3 - Testing of Specimens
The testing protocol will include fatigue loading of the girders under stress range and loading frequency that is representative of a typical traffic loading in CO. The data will be collected and plotted on an S-N curve to evaluate the fatigue life. The temperature will be applied using ceramic plate heaters, which are controlled using 480 volt control panel with direct feed from thermocouples. The temperature load will represent service temperature and will be applied in the form of thermal cycles. The cycle profile will obtained from existing data available in the literature for states that have similar weather conditions as those of CO (e.g. Barr et al. 2005).

Task 4 - Development and Calibration of Finite Element Models
Finite element models will be developed and calibrated to experimental results. The models will be used to conduct a paramedic study and in estimating fatigue life in Task 5.

Task 5 – Parametric Study and Fatigue Life Predictions
The experimental data and the calibrated numerical models will be used to conduct a parametric study to evaluate the effect of temperature on the fatigue life of repaired RC girders. The results of the FEM will be used with linear elastic fracture mechanics to predict the number of cycles per incremental crack extension along the crack surface.

Task 6 - Reporting and Dissemination

A final report will be produced describing the results of the research and will include the retrofit and design recommendations. The results will be presented at national conferences and disseminated in the form of scholarly papers which will be published in reputable journals.

	Months								
Task	1-2	3-4	5-6	7-8	9-10	11-12	13-14	15-16	17-18
1	■	■							
2		■	■						
3				■	■	■			
4					■	■	■		
5							■	■	
6									■

Project Cost:
Total Project Costs: $130,000
MPC Funds Requested: $ 65,000
Matching Funds: $ 65,000
Source of Matching Funds: PI time and effort

TRB Keywords: Reinforced Concrete Bridges, Fatigue, Cracks, CFRP Repair, Service Temperature.

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