MPC-446
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Project Title:
A Modified Approach for Predicting Fracture of Steel Components under Combined Large Inelastic Axial and Shear Strain Cycles

University:
Colorado State University

Principal Investigators:
Hussam Mahmoud
Assistant Professor
hussam.mahmoud@ colostate.edu
970-491-6605

Research Needs:

Steel bridges are considered to have a superior performance under earthquakes when compared to their reinforced concrete counterpart. Such reputation stems from the fact that few steel bridges have been subjected to strong ground motion in the last decade in North America. In addition to the lack of seismic exposure of the bridges, research on the seismic performance of steel bridges' superstructure is limited to few studies. Under very large inelastic strain cycles, the bridge components could fail and threaten the integrity of the bridge. Materials undergoing very large strain can only withstand a small number of reverse loading cycles, which is termed ultra-low cycle fatigue (ULCF). The stress range in High Cycle Fatigue (HCF) characterizes the behavior when the material is subjected to stress level below the yield stress. Under the HSF mechanism, small strain increment will result in relatively larger change in stress and therefore, it is appropriate to describe the behavior using the Stress-Number of cycles approach. Conventional Low Cycle Fatigue (LCF) is used to characterizes the response when the stress range close to or slightly beyond the yield point; therefore the Strain - Number of cycles curve might more applicable in this case. The Manson-Coffin equation describing the LCF behavior is currently the most popular and acceptable among different model.

Conventional low cycle fatigue models, such as the Coffin-Manson relationship, have shown to overestimate the ULCF life. During large amplitude cyclic strain loading, large variation in stress triaxiality usually occurs, which could lead to competition among several potential dominant failure modes. Therefore, the available phenomena based cyclic void growth model (CVGM) developed from material with no hardening and only high stress triaxiality, may not be applicable for materials under complex stress state. In addition existing ULCF models only account for axial cyclic loading while disregarding the potential for pure or combined shear loading.

Research Objectives:
The objectives of this project are as follows

1) Collect experimental data on identifying mathematical models for predicting low-cycle fatigue (LCF) and ultra-low cycle (ULC) fatigue behavior in metallic structures.
2) Generate data from experimental testing to be used for predicting LCF and ULCF response of bridge girders.
3) Develop a framework for fracture predictions.

Research Methods:
In this study, a modified approach will be proposed to simulate ULCF failure initiation and crack propagation up to fracture in components subjected to pure axial loading, pure shear loading, or the combination of such. The approach will be developed by extending the ductile failure criteria of monotonic loading, the modified Gurson model, such that failure modes in the whole stress triaxiality range can be captured. Numerical simulation will be performed using the finite element package, ABAQUS. and will be calibrated and correlated to small-scale cyclic experimental results. Comparative study between the proposed approach and available ULCF models will be highlighted, and the fracture propagation will also studied to capture the fracture modes transition after the crack initiation. The results of this study can be used by bridge design engineers for predicting the ULCF failure in steel structures under high reverse cycles of elastic strain.

Expected Outcomes:
Experimental data will be produced and added to the existing set of data on ULCF under axial loading. In addition, new experimental data will be generated under cyclic shear loading, which currently does not exist in the literature. In addition, a theoretically derived analytical model, calibrated to experimental results, will be developed, which can be used to predict the onset of failure. Moreover, a framework will be developed to integrate numerical finite element models with the analytical model in a closed-loop framework for ULCF predictions.

Relevance to Strategic Goals:
This project will maintain infrastructure integrity by increasing the reliability of lifecycle performance predictions used in infrastructure design, construction, and management. Specifically, the developed ULCF framework can be used to assess vulnerabilities of the transportation system to seismic activities and extreme events and develop repair methods for such vulnerabilities.

Educational Benefits:
A graduate student will be assigned to lead all tasks of the project. 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 is being taught by the PI.

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 general mathematical models for predicting LCF and ULCF. A comparative study between both models will be included and their shortcomings highlighted. In addition, experimental data for small

specimens under cyclic loading will be collected and stored to be partially used for calibrating the mathematical model to be developed in Task 3.

Task 2 - Construction of Specimens

The results of the literature review will be used to identify the geometry of the small-scale specimen to be tested under cyclic axial and shear loading and the parameters to be varied. Approximately 30 - 40 small-scale specimens will be fabricated (with length of approximately of 5 inches) to be tested. The specimens will be constructed to represent different levels of stress triaxiality as influenced by the geometry. In addition, the nature of loading (axial versus shear) will be taken into account when fabricating the specimens.

Task 3 - Testing of Specimens

The testing protocol will include fatigue loading of the specimens under large axial and shear inelastic strain cycles and different loading frequency. The data will be collected and plotted to evaluate the influence of the varied parameters on the ULCF life.

Task 4 - Development and Calibration of the Mathematical Model

A mathematical model will be developed to account for the application of cyclic axial, shear, or a combination of such. The generated experimental data will be used to calibrate the mathematical model and assess it is limitations. The developed model will be integrated with finite element models, using ABAQUS, and MATLAB in Task 5

Task 5 – Development of a Framework to be used for Fracture Prediction

The Mathematical model used in Task 4 will be integrated in a framework with ABAQUS numerical finite element models using MATLAB for the prediction of ULCF life of components. An iterative method will be used in the developed framework such that the onset of fracture can be predicted. The Framework will account for the actual material properties using an externally written user-subroutine

Task 6 - Reporting and Dissemination

A final report will be produced describing the results of the research and will include the experimental data, the mathematical model, and the finite element models. 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: $116,850
MPC Funds Requested: $ 57,000
Matching Funds: $ 59,850
Source of Matching Funds: Student's scholarship and PI salary

TRB Keywords: Seismic, Fatigue Cracks, Steel