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Project Title

Numerical Modeling and Parametric Analysis of Grouted Coupler Connections under Varying Impact Loading Conditions

University

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Research Needs

Grouted coupler connections are a common connection type used in Accelerated Bridge Construction (ABC). ABC refers to a bridge construction type that incorporates innovative techniques, methodologies, and materials to efficiently reduce the construction time, traffic disruption and dynamic performance. According to the Florida International University ABC Project Database, the state of Utah currently has 8 bridges in service constructed using ABC techniques [1]. Evaluation for seismic performance of typical ABC column-footing connections has been undertaken in high earthquake prone states like Utah, California, Nevada, and Idaho [2,3,4]. However, apart from the dynamic load exhibited by earthquake, the deformation and failure behavior of these connections to other dynamic loadings, such as blast and vehicular impact, are also critical and warrant investigation.

A current research project underway at Utah State University is studying the behavior of the Utah Department of Transportation's (UDOT's) current ABC grouted coupler connections (as detailed in the UDOT Structures Design & Detailing Manual) under vehicular impact loading. The preliminary results from this study have shown that variances in the impact loading characteristics (vehicle weight and impact velocity) and pier geometry result in high variances in

the failure modes of these connections. Carrying out extensive experimental work on these combinations is extremely expensive. As such, utilizing the experimental results, validated finite element models can be developed based on experimental results. Such models allow to efficiently evaluate the variations in input characteristics (both geometry and loading conditions) at significantly lower cost. The results of the parametric study will consist of a series of failure envelopes that will capture the full mechanical performance of these grouted connections under the varying performance criteria such as deformation and material strength degradation. This analysis will also aid in the determination of whether the coupler connection performs better when placed in the pier or in the footing under impact loading.

Additionally, the current literature has yet to fully examine the coupler/rebar connections and the component energy transfer under impact loading using numerical and finite element analysis. This is a challenging topic because the connection is a function of four different materials (Portland cement concrete, reinforcing steel, cast iron coupler, and low shrinkage grout). This study will seek to develop a sophisticated finite element model would account for an accurate representation of the coupler/rebar interface, energy transfer from the impacted column location through the coupler into the foundation, and material strength degradation. The model will be validated with existing experimental data collected at the USU SMASH Lab. The experimental data consists of single coupler and full scale column testing. The results of the experiments and modelling will also be compared to normal pier connections to see if any major differences warrant separate damage index calculations.

Research Objectives

This research proposes to accomplish three main objectives:

1) Using experimental data, develop a validated finite element model of the grouted coupler connection and determine an accurate energy transfer model.
2) Use the validated model to parametrically determine the corresponding failure modes of the coupler connection considering variances in the pier geometry, mechanical properties, and impact loading characteristics.
3) Develop a detailed finite element model of the coupler connection and identify the energy transference during impact loading.

Research Methods

The objectives of this research will be attained by separating the project into discrete tasks as outlined below.

Task 1: Literature review. Gather existing information on the finite element modeling of the grouted coupler connections.

Task 2: Finite element model development of singular coupler connections. The development of a single coupler connection including the four different materials (Portland cement concrete, reinforcing steel, cast iron coupler, and low shrinkage grout) will be developed with particular attention paid to the geometry of the coupler and the modelling of the connections between each material. The model will be validated from experimental tests previously conducted.

Task 3: Finite model development of a grouted coupler pier and footing connection. In this task, a complete model of a typical grouted coupler pier and footing connection will be developed using the results from Task 2. The model will be validated from experimental tests previously conducted.

Task 4: Parametric analysis of finite element model under dynamic loading. Using the validated finite element model developed in Task 3, a parametric analysis of the different model input characteristics will be carried out. The parameters to be studied include both column geometry and mechanical properties as well as various combinations of vehicle weight and impact velocity. Additionally, two different coupler locations (in the pier and in the footing) will also be analyzed. Using these results, a failure mode envelope can be constructed and best practices for input design parameters will be developed.

Task 5: Final report. A final report will document the results of Tasks 1 through 4 with an emphasis on reporting practical implications to transportation decision makers.

Expected Outcomes

Discussions with current UDOT bridge officials have suggested that limited testing is carried out on in-service bridge piers that have been subject to vehicular impact especially when the damage appears to be mostly cosmetic. For traditionally constructed piers, research has shown that the use of a damage index can typically be used to assess damage post impact. However, in high seismic areas such as Utah, the grouted connection in ABC piers is necessary for appropriate seismic response. The results of the research will be used to advise UDOT officials as well as transportation officials in other states of survivability of these grouted coupler connections under vehicular impact loading. Depending on the results from this initial study, further study may be warranted to determine a separate damage index protocol. Recommend changes if warranted to the UDOT Structures Design & Detailing Manual will also be recommended.

Relevance to Strategic Goals

This project directly relates to the USDOT strategic goal of Safety. By determining the failure modes of grouted coupler connections in ABC structures, designers will have better information on the geometry and material properties that should be used when designing these types of connections. This will make the structures more resilient to impact loading events thus making them safer.

Educational Benefits

The majority of the research work on this project will be carried out by a dedicated Ph.D. level graduate student with assistance from other students in the PI's research group and under the PI's supervision. Students will gain invaluable experience into carrying out physical experiments and numerical modelling of transportation structures. It is anticipated that the students will also present the results of the research at national conferences.

Technology Transfer

The results of this research will be published in peer-reviewed technical publications as well as presented at conferences. Additionally, the findings will be presented to the UDOT Bridge

Division for any changes that may need to be made to the UDOT Structures Design & Detailing Manual.

Work Plan

The proposed research will be carried out over a 12-month period with time allotted to each task item identified in the Research Methods section of this proposal as follows:

- Task 1: 2 months
- Task 2: 3 months
- Task 3: 3 months
- Task 4: 2 months
- Task 5: 2 months

Project Cost

Total Project Costs:	$150,000
MPC Funds Requested:	$ 75,000
Matching Funds:	$ 75,000
Source of Matching Funds:	Utah Local Technical Assistance Program

References

1. http://utcdb.fiu.edu/, accessed August 2019.
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3. Ebrahimpour, A., Earles, B., Maskey, S., Tangarife, M., & Sorensen, A.D. (2016) *Seismic Performance of Columns with Grouted Couplers in Idaho Accelerated Bridge Construction Applications*, Idaho Transportation Department, RP 246.
4. Haber, Z.B., Saiidi, M.S. & Sanders, D.H. (2013) *Precast Column-Footing Connections for Accelerated Bridge Construction in Seismic Zones*, California Department of Transportation, Report No. CA13-2290, CCEER 13-08.