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Project Title

Reliability of ABC Grouted Coupler Connected Bridge Piers Subject to Vehicular Impact

University

Utah State University

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Research Needs

Accelerated Bridge Construction (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 behavior of these connections to other dynamic loadings, such as blast and vehicular impact, are also critical and warrant investigation. This is especially true when the frequency of occurrence of vehicular impact to bridge structures, which far surpasses that of earthquake, is considered. One of the issues with vehicular impact is that while the damage resulting from the impact may appear to only be cosmetic, the residual capacity of the pier can be drastically reduced. This makes it even more susceptible to failure under subsequent extreme dynamic loading such as seismic.

The behavior of traditionally constructed bridge piers subject to vehicular research has been researched previously, however the grouted connections used in ABC (such as those described in the UDOT Structures Design & Detailing Manual, Section 20.4.6.3) have yet to be considered. Application of the results from traditionally constructed piers to ABC coupler connected bridges is not feasible because of the different base connection which introduces new potential failure modes including base shear, grout fracture and de-bonding, and coupler failure. Of particular concern is the grout in the coupler. If the grout in the coupled connection is fractured under impact, the bond between the coupler and the reinforcing steel is lost, allowing the reinforcing steel to pull out from the coupler under dynamic loading resulting in excessive drift.

The residual capacity of the impacted bridge piers is especially important in high seismic areas where it is highly possible that the piers will be subsequently exposed to a dynamic earthquake load. In the case of most typical multi-hazard analysis, the fault tree analysis assumes that the events happen simultaneously. As such the probability of failure for each is considered for a completely "healthy" component. By understanding the residual capacity of the bridge piers, a sequential multi-hazard analysis can be carried out that more accurately predicts failure probability. Sequential loading for vehicular impact and blast loading has already been investigated in terms of performance by the PI and others [5], but research on the sequential loading for impact and earthquake has yet to be carried out.

This project proposes to look at the behavior of UDOT's current ABC grouted coupler connections (as detailed in the UDOT Structures Design & Detailing Manual) under vehicular impact loading. The research will be carried out at the Utah State University SMASH Lab where a one story impact pendulum is currently under construction. At completion, the pendulum will be capable of replicating impact loads on structures on the same magnitude as a sedan traveling at 55 m.p.h. Typical connections will first undergo impact testing to determine the resulting damage indices. These indices will be compared to results of traditionally constructed piers. The impacted coupler piers will also be evaluated to determine failure modes and inspected for de-bonding between the pier and support base. Some of the impacted piers will then be carefully cut open to inspect the grout within the coupler for evaluation. Finally, the remaining impacted piers will be subjected to simple pushover analysis to determine loss of ductility.

Research Objectives

This research proposes to accomplish two main objectives:

1) Evaluate the current UDOT grouted splice sleeve connection configuration for response of the bridge pier subject to vehicular impact.

2) Evaluate the residual seismic capacity of post impacted, grouted splice sleeve connections as well as carrying out sequential multi-hazard analysis for these connections under impact and earthquake loading.

Research Methods

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

Task 1: Literature review and prototype pier identification. Information regarding vehicular impact of bridge piers as well as dynamic loading of ABC grouted coupler pier connections will be synthesized. Using the UDOT Structures Design & Detailing Manual, as well as resources from other published literature, a prototype pier will be selected for testing.

Task 2: Flexural and impact testing of singular coupler connections. Prior to carrying out full scale testing on pier, the mechanical response of singular coupler connections under both quasi-static flexural loading and impact loading will be evaluated to determine the response as well as soundness of the grouted connection. Single coupler connections will be cast and tested in flexure with a point load applied at a distance of 3 meters from the connection. Similar specimens will then be constructed and subjected to a drop weight loading also at a distance of 3

meters from the base connection. The purpose of this task is determine the amount of energy that is transferred to the grout within the couple as well as evaluate the damage level.

Task 3: Impact testing of full scale grouted coupler piers. Five full scale grouted coupler connected prototype piers will be constructed. One of the five will act as the control pier and will have no impact applied. The remaining four will be impacted at two different energy levels (two piers for each energy level). Damage levels will be noted and compared to predicted values for deflection.

Task 4: Destructive evaluation of impacted piers. Following impact, two of the piers (one for each energy level) will carefully be de-constructed to determine the level of damage to the pier and to the grouted connection.

Task 5: Push over analysis. The control pier as well as the two remaining impacted piers will be subjected to push over analysis as previously used to determine drift capabilities and pier ductility. The results of the three piers will be used to identify decrease in capacity as well as system reliability.

Task 6: Final Report. A final report will document the results of Tasks 1 through 5 with an emphasis on reporting practical implications to transportation decision makers.

Expected Outcomes

Discussions with current UDOT bridge officials has 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 with a secondary emphasis in State of Good Repair. By evaluating the damage to grouted coupler connected bridge piers, the safety of these connections under subsequent loading and against deterioration can be determined. Additionally, this project will help decision makers determine the level of repair that must be done subsequent to an impact event.

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 on transportation infrastructure. It is anticipated that the students will also present the results of the research at regional and national conferences. The PI also participates in the USU College of

Engineering's annual summer program for high school juniors, Engineering State. The PI is currently developing an impact related module to be presented during this program.

Technology Transfer

The results of this research will be published in peer-reviewed technical publications as well as presented as 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 an 18 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: 4 months

Task 5: 4 months

Task 6: 2 months

Project Cost

Total Project Costs:	$127,000.12
MPC Funds Requested:	$ 63,500.06
Matching Funds:	$ 63,500.06
Source of Matching Funds:	Utah LTAP

References

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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.
5. Thomas, R.J., Steel, K. & Sorensen, A.D. (2018) "Reliability Analysis of Circular Reinforced Concrete Columns Subject to Sequential Vehicular Impact and Blast Loading", *Engineering Structures*, Vol.168, pp. 838-851.