MPC- 415
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Project Title:
Framework of performance-based earthquake design of curved and skewed bridges

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Research Needs:
Earthquakes pose serious threat to society and transportation infrastructure in the United States and around the world. Among all the highway bridges, most of them are straight ones with short and simple spans, which have been extensively studied during the past decades. Comparatively, there are a group of complex bridges which are more vulnerable to earthquake but not yet been sufficiently investigated, such as curved and skewed bridges. It is known that the offset angle of the superstructure of the skewed bridges may present advantages to the transportation layout. However, the dynamic response of this type of bridge has in the past led to failures, particularly due to unseating, under seismic loading. Examples of this kind of failure of skewed reinforced concrete bridges have been observed after the earthquakes in Northridge (1981), Costa Rica (1991), and more recently in Chile (2010) (Moehle & Eberhard, 2000). Curved bridges are also susceptible to the same asymmetrical failure response as that of skewed bridges. An example of where the curved geometry may have contributed to failure was the collapse of the South Connector Overcrossing during the 1971 San Fernando earthquake of magnitude 6.6 M_w. The South Connector Overcrossing (SCO) suffered collapse of two of its deck segments in addition to the column supporting it (Williams and Godden 1979). Despite the significant risk associated with failure and poor performance of those complex bridges, the related studies are still very limited (Bignell et al. 2005; Saadeghvaziri and Yazdani-Motlagh 2000; Maleki 2001; Saiidi and Orie 1992). There are also very little information which can be used for the design of these vulnerable bridges. The PI (along with a co-PI and a graduate student) is currently conducting a study on seismic analysis of Colorado bridges through advanced FEM modeling, which is sponsored by Colorado Department of Transportation. In this study, curved and skewed bridges are of special interests and will be modeled in detail. By taking advantage of the CDOT-funded study, the proposed study is to further develop the performance-based design framework specifically for curved and skewed bridges. It is expected that some useful design guidelines and insights can be found through the proposed study by applying the performance-based concept.

Research Objectives:
This study aims to develop the performance-based design (PBD) framework for curved and skewed bridges. With the PBD framework, people can (1) assess the probability of failure of the critical member and the whole bridge subjected to different earthquake hazard level; and (2) identify optimal design solutions based on the expected performance criteria.

Research Methods:
As introduced earlier, the proposed study will be conducted based on the findings gathered from the ongoing project sponsored by CDOT on vulnerable bridges in Colorado. The bridge models and the dynamic analysis results from the CDOT study will be used in the present study. The 4-stage performance-based engineering procedure will be followed (Moehle 2004).

Expected Outcomes:
It is expected that a performance-based framework to assess the performance of and also design vulnerable curved and skewed bridges will be made. This framework will set a critical basis for any future studies which can expand the horizon of PBD on these vulnerable complex bridges subjected to earthquake and other hazards.

Relevance to Strategic Goals:
This research will directly address several critical issues related to Safety, Economic Competiveness and livable communities such as: *1) Infrastructure longevity; 2) Hazard mitigation; 3) Improved infrastructure design*.

Educational Benefits:
Graduate students and undergraduate will be involved into this project by serving as research assistants.

Work Plan:
Task 1: Literature review
This initial task will consist of a literature review encompassing NCHRP reports, TRB papers, journal papers, state department of transportation reports to determine what existing projects have been completed and what documentation and related details to the project are available. The literature review will cover three major topics: (1) earthquake analysis on bridges; (2) curved and skewed bridge design; and (3) performance-based engineering. Special attention will be given to the related regulations on the "Current Specification" and the "Guide specification". From the existing literature, 2-3 typical designs of curved and skewed bridges will be identified for typical seismic region in the country, including the mountainous region with moderate earthquake risk.

Task 2: Scenario-based hazard and structural analysis
Hazard analysis is conducted by characterizing representative earthquake scenarios covering various intensities, locations, and directions. Appropriate earthquake records will be simulated in the time history. With the typical bridge designs identified in Task 1, the SAP-based 3-D bridge model developed in the CDOT study will be modified to capture all the representative structure design, a comprehensive structural analysis on these bridge models subjected to the selected

earthquake inputs will be conducted (Fig. 1). The scenario-based hazard and structural analysis will provide the key information for the remaining analysis.

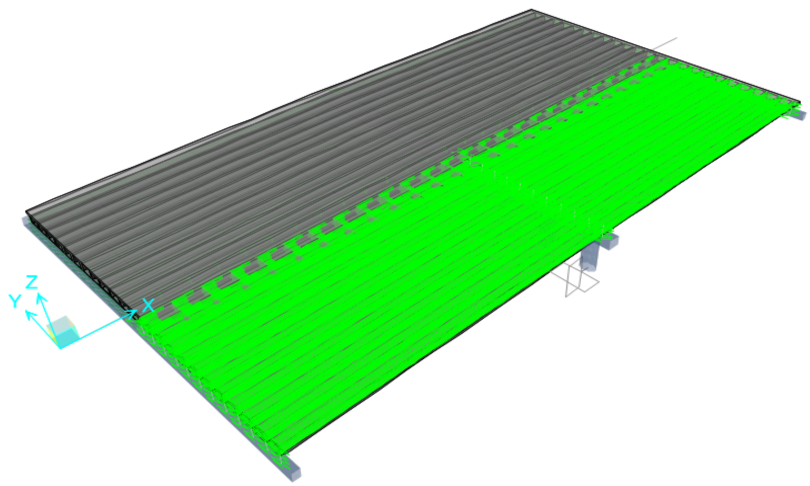

Fig. 1 SAP-based finite element model

Task 3: Damage and loss analysis

Based on the structural analysis results in Task 2, the vulnerability of local member damage, including piers, connections, supports and abutments, will be evaluated. Further, the global vulnerability of the whole structure is also analyzed. With the existing economical model, the loss analysis will be continued. This task involves the characterization of (1) damage costs, i.e. losses for vulnerable bridges as a function of the damage measures (DM) as described in Task 2 to the main assemblies discussed earlier and also (2) service cost related to the accidents, congestions, traffic restrictions or possible closure. A vulnerability function will be developed which relates loss to some measure of ground motion intensity, taking into account some level of structural response uncertainty in the form of a statistical distribution.

Task 4: Decision-making framework

In previous tasks, the performance assessment of vulnerable complex bridges has been investigated within the procedure. Task 3 outlines how the relationship between cost and performance can be statistically characterized. With the addition of the PBE decision and optimization component, a framework of the PBE for LSBs will be developed. The performance of the major categories of assemblies that make up the structural and serviceability performance of a typical bridge typically decreases over the lifetime of the bridge. For an existing bridge, the piers, connections, supports and abutments can be repaired or replaced, if the performance reduces beyond a certain threshold. Similarly, for the new bridge design, if certain load/response models can be put in place and used during the design procedure to satisfy these performance objectives, life safety is maintained and cost can be minimized over time, i.e. life cycle costs.

Time Line:

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Project Cost:
Total Project Costs: $122,000
MPC Funds Requested: $ 61,000
Matching Funds: $ 61,000
Source of Matching Funds: Faculty time and effort, student support. CSU and CDOT project.

TRB Keywords: Bridges, Hazard, Earthquake, Design, Performance-based