FY 16/17 Research Initial Scope of Work

I. Project Title:

Development of Guideline for Generation, Selection, and Adjustment of Ground Motions in Hazard Assessment of Performance Based Earthquake Engineering

II. Project Problem Statement:

For seismic design/analysis of bridge structures, selection and adjustment of ground motions to a seismic hazard level of interest is a first fundamental step in the concept of Performance Based Earthquake Engineering (PBEE). Standard procedures for this step have not been established in Caltrans design practice. A research team led by Professor Armen Der Kiureghian at University of California at Berkeley proposed a probabilistic methodology for generating synthetic ground motions given key site and seismic parameters. Recently, this methodology has been extended to produce two components in principal directions. The evaluation of this methodology was limited to few seismic scenarios and non-pulse cases. Since it appears that ground motions generated by this methodology have intensities that match current design hazard levels with minimal effort, it is worthy of further evaluation with various seismic scenarios. Ultimately, a standard guideline for ground motion selection and adjustment is expected as the main deliverable of this project. The guideline may be adopted to MTD 20-17 and SDC Section 6.1.

III. Problem Statement Background/Context:

In Performance Based Earthquake Engineering (PBEE), a hazard assessment is a first stage in which designers identify seismic and geological characteristics and evaluate the seismic hazards at a bridge site. The seismic hazards evaluated in this stage are used in the form of ground motion acceleration time histories for nonlinear time history structural analysis as the next stage of PBEE.

The key in the hazard analysis is to produce and select number of ground motion time histories whose intensity, perhaps measured in spectral accelerations, match a design hazard level at the site (For Caltrans practice, the required hazard level is considered design acceleration response spectrum (ARS) with 5% probability of seismic occurrence in 50 years. The design ARS is generated by ARS online). One technique has been to select actual or synthetic records and adjust them to the desired hazard level. Either linear scaling or spectral matching (time or frequency domain) technique is adopted for the adjustment.

Several design guidelines such as ASCE/SEI 7 & 43 and FEMA 65 attempt to address this key element (selection and adjustment of the ground motions) but they have three common limitations as follows:

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1. Some of information (i.e. direction of principal direction in near fault case) in the guidelines may not be valid any more according to the latest research efforts
2. The guidelines don't clearly address how to match ground motion with velocity pulse due to near-fault effects (forward directivity) which is discussed later in this problem statement.
3. Lastly, there exist no standards for matching (adjustment) of two orthogonal components of motions to geometric-mean-based target response spectrum.

National Institute of Standards and Technology (NIST) funded a project to investigate this subject. The project team performed an extensive review of the existing design guidelines including the ones noted above and made comprehensive study encompassing various aspects in order to come up with further recommendation, however, the study is more inclined toward the building design/analysis rather than the bridge structures. Also, its conclusion for Item 2 above still remain in question.

Due to the above limitations of current design guideline, Caltrans need to develop standard procedures and guidelines for motion generation and selection for analysis of ordinary bridges. Ground motions can be obtained in two different ways: by using database of existing records (i.e. PEER NGA data base or COSMOS) or by using synthetic motion realization model. The problem with use of existing records is that the database may not be able to provide enough number of records at a given seismic scenario. To overcome this problem, Professor Armen Der Kiureghian (ADK) and his colleagues at UC Berkeley proposed a site-based stochastic model to generate any number of synthetic motions based on site seismic and geological characteristics (Ref 2). The model features forward directivity which is the most important among near-fault effects. The forward directivity combines a velocity pulse with ground motion records and these records are commonly named pulse-like motions. Lately, the model has been enhanced to generate two orthogonal components of ground motion time histories in principal directions. Major Principal Direction is defined as the direction where arias intensity and velocity pulse are maximum for non-pulse and pulse-like motions, respectively.

In their latest study for two components of near fault motions, a comparison was made between the response spectra of synthetically generated motions and the ones using Next Generation Attenuation (NGA) – Ground Motion Prediction Equations (GMPEs). The comparison showed that both methodologies provide the response spectra in reasonable agreement (Ref 2)

Recent in-house study reveals that an average of displacement demands of SDOF subject to multiple nonpulse-like motions generated using the ADK model is compatible with the one from the design ARS (Ref 3).

The studies mentioned above were made based on few seismic scenarios and the effort was not extended to more varying cases, especially pulse like motions, to ensure overall behavior is consistent. Since it appears that the ADK model is capable of producing any number of ground motions whose intensity match current design hazard level with minimal effort and time, it is worthy of further evaluation with various seismic scenarios and of establishing a standard guideline for its use.

IV. Research Objective:

Develop recommended standard procedure to guide designers to better plan for generation, selection, and adjustment of ground motions in a consistent manner making use of the most advanced and practical tools.

V. Support California Bridges & Structure Strategic Direction:
(http://onramp.dot.ca.gov/hq/des/spi/docs/Final_California_Bridges_Structures_Strategic_Direction_9-11-14.pdf)

The proposed research work will improve the first step of performance based earthquake engineering which is well line with California Bridges and Structures Strategic Direction 2014 - Objectives 3, 8, 12 and associated Strategies 3.1, 8.1, 8.3, & 12.2.

VI. Description of Work:

There are four main items (tasks) to be addressed in form of guidelines:

1. Adjustment of pairs (each pair has two orthogonal components) of ground motions to geometric mean based design response spectrum:

   Current Caltrans design response spectrum is based on NGA model using geometric mean of spectral accelerations from fault normal (FN) and parallel (FP) directions. There is no guideline about how to adjust the generated two components to the design ARS.

   Somerville proposed a way to split the geometric mean ARS into FN and FP by applying empirical ratios of spectral acceleration in FN and FP to geometric mean (Ref 4). This methodology has been used to spectrally match two FN and FP components of existing records to design response spectrum for Doyle Drive Project (Ref 5). Similarly, Huang et al proposed ratio of maximum rotated component to geometric mean (Ref 6). These methodologies may be evaluated and may serve as a basis to establish the adjustment guideline through this research.

2. Procedure to obtain input parameters for synthetic ground motion simulation.

a. The ADK model requires the distance between the epicenter or hypocenter and the bridge site as one of input parameters, however the distance is unknown in most of cases. This study is expected to identify how to estimate the distances in practical and reasonable way.
b. Typically, bridge sites are surrounded by multiple faults. However, The ADK model produces motions for a given scenario. In cases where multiple faults exist, guidance is needed on how to set up and how many seismic scenarios to consider for motion generation.

3. Evaluation of adjustment method for pulse like motions: Linear scaling or spectral matching

   If adjustment is needed, a question remains: which method is more appropriate under what circumstances. Two issues should be evaluated with emphasis on preservation of the effect of velocity pulse in pulse-like seed motions after adjustment.

   a. Since spectral matching may not be able to preserve the pulse characteristics of seed motions, the velocity pulse may be extracted from seed motions and added back into the ground motion following spectral matching.

   b. The current design ARS increases by 20% in case the bridge site is close to active faults to account for near fault effect. The research also needs to investigate the 20% increase is appropriate to account for forward directivity.

4. Number of ground motions in selection

   Two aspects shall be considered to establish the criteria in this part:

   a. The criteria shall provide requirements about how many motions are to be selected for structural analysis in response to different damage assessment criteria. For example, MTD 20-17 requires seven motions to determine average displacement demand of seven different time history analyses.

   b. Since the latest ADK model adopted probability of pulse-like motion occurrence proposed by Baker (Ref 7), the criteria shall include requirement of minimum number of ground motion in order to properly incorporate Baker's model in selection process. For example, if the possibility is 30%, selecting only two motions may not guarantee that the pulse-like motions are properly chosen.

<u>Due to the size and complexity of the four tasks above, it is recommended that Tasks 1 & 2 are to be studied through this proposed research first. Tasks 3 & 4</u>

will be addressed in a separate research project followed by this proposed research.

For the displacement demand estimation of the structure in this research, a realistic bridge is to be modeled using softwares (i.e. OpenSEES, CSiBridge, or Midas CIVIL) enabling nonlinear time history analysis. Ideal candidates would be two to three span box girder bridges with CIDH pile foundations situated in competent soil with short seat abutments sitting on sloping embankment. The bridge columns are to have adequate ductility by forming plastic hinges. The Caltrans Office of Earthquake Engineering will assist the researcher in providing the design plans for the bridges upon request.

VII. Related Research: (*Results of literature review)*

1. NIST, 2011. Selecting and Scaling Earthquake Ground Motions for Performing Response History Analysis, *NIST/GCR 11-917-15*, prepared by the NEHRP Consultants Joint Venture for the National Institute of Standards and Technology, Gaithersburg, Maryland.
2. Dabaghi, M. and Kiureghian, A. D., 2014, Stochastic Modeling and Simulation of Near-Field Ground Motions for Performance-Based Earthquake Engineering, *Pacific Earthquake Engineering Research Center Research Report No PEER 2014/20*, University of California, Berkeley.
3. Tom Shantz, 2015, Near-Fault Record Selection: Status and Issues, *In-house presentation*.
4. Somerville, P.G., Smith, N.F., Graves, R.W., and Abrahamson, N.A., 1997, Modification of Empirical Strong Motion Attenuation Relations to Include the Amplitude and Duration Effects of Rupture Directivity: *Seismological Research Letters*, v.68, No. 1, pp. 199-222, Jan/Feb.
5. AMEC Geomarix, 2010, Seismic Hazard Assessment and Site Response Analysis – Part 1: Seismic Hazard Assessment and Ground Motion Development for Doyle Drive Replacement Project, San Francisco, California.
6. Huang, Y.-N., Whittaker, A.S., and Luco, N., 2008, Maximum Spectral Demands in the Near-Fault Region, *Earthquake Spectra* 24:1, 319-341.
7. Shahi, S., and Baker, J. W., 2011, An empirically calibrated framework for including the effects of near-fault directivity in probabilistic seismic hazard analysis, *Bulletin of the Seismological Society of America*, 101(2), 742-755

VIII. Deliverables/Deployment Potential:

High – The proposed work will [1] improve methods discussed in MTD 20-17 and SDC Section 6.1 by introducing a consistent guideline of selecting and adjusting ground motion time histories for nonlinear dynamic structural

analysis, and [2] benefit designers by providing a ground motion generation and adjustment tool in simple and efficient manner.

IX. Sponsor: Office of Earthquake Engineering
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