Research Problem Statement

ODOT Research Section
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I. TITLE

17-011 A Design Guideline for Bridge Pile Foundations subjected to Liquefaction-Induced Lateral Spreading in Oregon

II. PROBLEM

The latest estimates predict that a magnitude 9.0 earthquake by the Cascadia subduction zone will cause over 1 billion USD in damages to highway bridges in Oregon (ODOT 2009). Past earthquakes indicate that liquefaction-induced landslides are a major cause of collapse of bridges. Liquefaction is a phenomenon where saturated granular soils temporarily lose strength during earthquakes. Design codes require that bridge foundations be designed to sustain both lateral spreading loads (kinematic) and superstructure loads during shaking (inertia). Previously, it was believed that these two loads act independently and, subsequently, foundations were designed to resist each of these loads separately. However, results of a series of centrifuge tests at UC Davis and full-scale shake-table tests in Japan showed that these two loads can occur concurrently. As a result, Caltrans published a design guideline in 2012 that combines 100% of lateral spreading load with 50% of inertial load. The Caltrans (2012) guideline was later adopted by ODOT Geotechnical Design Manual (2014) with some modifications. However, the centrifuge tests used to develop the Caltrans (2012) guideline were performed using elastic piles. Bridge foundations are more often designed for inelastic, rather than elastic, responses. The results of a follow-up study showed that the combination of lateral spreading and inertia could be exacerbated when piles enter inelastic region (Khosravifar et al. 2014). Furthermore, there is a lack of knowledge on how the combination of lateral spreading and inertia is affected by Cascadia subduction earthquakes, which are known to have long-duration characteristics in contrast to shallow crustal earthquakes common to California. Our preliminary data show that long-duration earthquakes amplify the combination of lateral spreading and inertia. Accordingly, there is an *urgent need* to update ODOT GDM (2014) guideline to address the above two issues. The *overall objective* of this research is to develop a simple guideline for inelastic design of bridge pile foundations under combined effects of liquefaction-induced lateral spreading and superstructure inertia, during Cascadia subduction earthquakes.

III. PROPOSED RESEARCH, DEVELOPMENT, OR TECHNICAL TRANSFER ACTIVITY

Our *central hypothesis* is that Cascadia subduction earthquakes adversely affect inelastic demands on bridge foundations subjected to lateral spreading and inertia, and that this effect cannot be captured using Caltrans (2012) guideline. The following tasks are proposed to achieve the overall objective of this application:

1) ***Nonlinear dynamic analysis (NDA)***

   Nonlinear dynamic analysis (NDA) will be used to develop a database of inelastic performance of bridge foundations subjected to liquefaction-induced lateral spreading during Cascadia subduction earthquakes. The rationale is that the inelastic demands obtained from these dynamic analyses can be used to evaluate the accuracy of simplified static procedures in estimating pile demands (described in following tasks). 2D finite-element models will be made and calibrated against existing centrifuge tests and full scale tests on RC bridge columns. Subduction motions will be selected based on seismotectonic settings of Oregon and will be spectrally matched to design spectra developed by USGS for two representative locations: (a) coastal region with high seismicity, and (b) central regions with moderate seismicity. The parametric study will cover a range of applicable pile geometries and will specifically address the type of potentially liquefiable soils encountered in Oregon, such as silty sand mixtures. Additionally, 3D finite-element models will be made and calibrated to the same experimental data used in the calibration of 2D models. The 3D models will be used to study the local effects of liquefaction around piles that have been shown in past studies to affect load transfer mechanism to the piles, but cannot be directly captured in 2D models (e.g. dilation of liquefying sand around piles.)

2) ***Evaluate the procedures in ODOT Geotechnical Design Manual (2014)***

   Our working hypothesis is that the static procedure by Caltrans (2012), adopted by ODOT GDM (2014) underestimates inelastic demands of piles subjected to lateral spreading induced by Cascadia subduction

earthquakes. The accuracy of these procedures will be evaluated against same cases analyzed in Task 1, and by comparing the estimated inelastic demands with those obtained from nonlinear dynamic analyses.

3) ***Propose a new design guideline***
New design guidelines will be developed for the specific seismic demands expected in Oregon by back-calculating the load combination factor for inertia to better estimate the inelastic demands estimated in Task 1 (this factor is currently 50% in Caltrans (2012) and, subsequently, in ODOT GDM (2014) guidelines).

Several past and current projects funded by ODOT address some of the issues with Cascadia subduction earthquakes. For example, Olsen el at. (2015) provide maps of free-field landslide displacements due to Cascadia subduction earthquakes in Oregon. These maps will be used by the proposed design guideline (developed under Task 3) to estimate lateral spreading demands. Dusicka et al. (2015) studied seismic retrofit measures for bridge columns subjected to Cascadia subduction earthquakes. The experimental results of their study will be used to calibrate the numerical models for cyclic response of RC bridge columns described in Task 1. Ashford et al. (2013) describe Caltrans (2012) guideline. As explained earlier, this guideline was developed based on centrifuge tests using elastic piles. The applicability of their recommended procedure for inelastic piles will be evaluated in the proposed research. Dickenson et al. (2002) provide an overview of available methods to estimate liquefaction-induced lateral spreading displacements and potential failure mechanisms of bridge foundations in liquefied soils. However, they do not recommend a specific guideline to address the above discussed issues.

IV. POTENTIAL BENEFITS

The accuracy of the Caltrans (2012) guideline (state-of-the-practice) in estimating pile demands under liquefaction-induced lateral spreading is unknown in regard to two issues: (a) inelastic demands, and (b) long-duration shakings. The completion of this project will provide new guidelines to adequately analyze existing bridges, identify unsafe structures and evaluate the effectiveness of different retrofit measures. The new guidelines will also be used in designing new bridges where liquefiable soils are encountered. This research has direct design implications that address the goals of ODOT's Structure and Geotechnical committees in studying the effects of slopes and embankments on transportation systems, reducing the impact of earthquakes on bridges, and enhancing public safety. *Not meeting* this need results in potential unconservative designs of new bridges and failure to adequately retrofit existing bridges to survive earthquakes that are expected in Oregon.

V. IMPLEMENTATION

The proposed guideline will be prepared with the goal of being appended to ODOT Geotechnical Design Manual.

VI. LIST OF REFERENCES *(optional)*

Ashford, S.A., Scott, M.H., and Rayamajhi, D. (2013). Reducing Seismic Risk to Highway Mobility: Assessment and Design Examples for Pile Foundations Affected by Lateral Spreading, ODOT Research Report SRS 500-300.

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Dickenson S. E., McCullough N., Barkau M. G., and Wavra B. J. (2002). Assessment and mitigation of liquefaction hazards to bridge approach embankments in Oregon. Oregon Department of Transportation, Salem OR, p. 210.

Dusicka, P., Bazaez, R., and Knoles, S. (2015). Bridge Seismic Retrofit Measures Considering Subduction Zone Earthquakes. Oregon Department of Transportation, Salem OR, p. 150.

Khosravifar, A., Boulanger, R. W., and Kunnath, S. K., (2014). Design of Extended Pile Shafts for the Effects of Liquefaction. Earthquake Spectra, 2014; 30 (9).

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Oregon Department of Transportation (2009). Seismic Vulnerability of Oregon State Highway Bridges: Mitigation Strategies to Reduce Major Mobility Risks. OR-RD-10-08, ODOT, Salem, OR, p. 63.

Oregon Department of Transportation (2014). Geotechnical Design Manual. Technical Services Branch, Salem, OR

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