Oregon Department of Transportation

Stage 1 Research Problem Statement

Number*: 25-43*

Proposed Title: Design Guidelines for Bridge Pile Foundations Subjected to Combined Inertial and Liquefaction-Induced Lateral Spreading Loads

1. Concisely describe the **transportation issue** (including problems, improvements, or untested solutions) that Oregon needs to research.

Soil liquefaction during earthquakes can result in significant displacements in sloping ground, referred to as 'lateral spreading.' This phenomenon poses a substantial hazard to numerous bridges crossing rivers and streams in Oregon. Both AASHTO Design Specifications and the ODOT Geotechnical Design Manual (GDM) provide considerable flexibility in addressing liquefaction in the design process. While large projects like the Abernethy Bridge allow for the exploration of creative solutions, ODOT undertakes the construction or rehabilitation of many smaller bridges annually, often with much smaller scopes (e.g., typically single-span bridges with a length < 300 ft.). Despite their smaller scale, these projects share similar susceptibility to liquefaction and lateral spreading due to their subsurface conditions. The objective in this research is to improve the design methods applied to address the effects of liquefaction and lateral spreading for these numerous, smaller bridge projects.

The design of bridge foundations in liquefiable soils faces a knowledge gap concerning the appropriate load factors for combining lateral spreading loads (kinematic) and superstructure inertial loads (inertia). There is <u>no consensus</u> in design codes on how to combine inertial and kinematic loads in design. Recommendations from AASHTO and transportation agencies in California, Oregon, and Washington range from "no combination" to "full combination" of the two loads.

The absence of consensus in design codes and standards has posed numerous challenges for design engineers. If, indeed, lateral spreading and superstructure inertial loads interact during an earthquake, failure to combine the two loads could lead to <u>inadequate and unsafe</u> designs. On the other hand, combining inertia and lateral spreading loads can sometimes result in <u>expensive, non-constructible foundations</u>, particularly for piles passing through stiff, non-liquefiable crusts overlaying deep liquefiable soils in sloped grounds. Overly conservative designs frequently yield large-diameter shafts and congested rebar cages, potentially causing constructability issues for contractors.

The uncertainty in design stems from the complex behavior of pile foundations in liquefied soils. The combination of inertial and liquefaction-induced lateral spreading loads appears to vary based on site and project-specific factors, including soil profile (e.g., soil type, topography, presence of non-liquefiable crust), foundation type (e.g., small diameter pile groups vs. large-diameter shafts, buried pile caps or seal slabs), dynamic response of the structure (e.g., bridge deck response in the longitudinal vs. transverse directions, restraining effects of approach embankments or bents outside the zone of lateral spreading on the global response of the bridge, and boundary conditions at each bent or pier where the superstructure and substructure meet), bridge geometry (skewed vs. non-skewed, curved vs.. tangent layout), and ground motion characteristics (e.g., subduction vs. crustal motions with varying durations). It is important to characterize the inertial and kinematic load interaction factors that account for differences in seismicity in Eastern and Western Oregon, foundation types, and the complexity levels of design methods utilized in various ODOT projects.

2. Document how this **transportation issue** is important to Oregon and will meet the Oregon Research Advisory Committee Priorities

The proposed research will directly address the Safety and Mobility research focus areas. A 2021 study by DHS (Oregon Transportation Systems Regional Resilience Assessment Program) found that liquefaction constitutes the primary cause of severe damage to 989 bridges in Oregon (18% of state-owned bridges) following a Cascadia Subduction Zone earthquake, with reopening times of up to 2.5 years for bridges over waterways or impassable topography. The challenge facing ODOT lies in the fact that ground improvement methods for liquefaction mitigation can sometimes be cost-prohibitive. This research aims to enable ODOT to accurately remove some of the 989 bridges from a high-level concern by potentially demonstrating that their foundations exhibit satisfactory seismic performance without requiring ground improvement. This approach will allow ODOT to concentrate on a smaller subset of bridges for liquefaction mitigation, leading to increased confidence in the performance of bridges affected by liquefaction issues.

This research will further support ODOT's ongoing initiatives to establish a more equitable transportation network. Our research at PSU indicates that bridge foundations in the Oregon Coast may be more susceptible to damage from lateral spreading, especially because seismic activity in these areas is dominated by the Cascadia Subduction Zone capable of generating long-duration ground motions. These routes often traverse tribal lands or High Disparity areas as identified by the ODOT Social Equity map. Ensuring the reliability of lifeline routes in the Oregon Coast that remain operational after large earthquakes is not only crucial for fostering an equitable transportation system but also constitutes a vital component of a resilient transportation network for the entire state of Oregon.

3. What **final product or information** needs to be produced to enable this research to be implemented?

The primary outcome of this research includes load factors for combining superstructure inertial and lateral spreading loads in a pseudo-static analysis. The findings from our prior research at PSU, addressing the effects of long-duration motion on inertia and lateral spreading load factors, have been incorporated into the 2022 BC Supplement to the Canadian Bridge Design Code S6:19. This approach follows a similar approach adopted by WSDOT, where the load factors are dependent on seismic contribution factors. We propose a similar approach for ODOT, wherein inertia and lateral spreading load factors are dependent on seismic contribution factors. In our view, this is a technically sound approach that will enhance safety in Western Oregon, where seismic contributions are dominated by long-duration motions, and reduce potential overconservatism in Eastern Oregon, where seismicity is primarily influenced by shallow crustal faults.

The proposed methodology for combining superstructure inertial and lateral spreading loads in a pseudo-static analysis will be detailed in a practice-ready recommended amendment to the ODOT Geotechnical Design Manual (GDM) and ODOT Bridge Design Manual (BDM). This recommended amendment aims to facilitate the adoption and implementation of the proposed methodology in design standards.

4. (Optional) Are there any individuals in Oregon who will be instrumental to the success of implementing any solution that is identified by this research? If so, please list them below.

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Albert Nako	Seismic Standards Engineer	Albert.NAKO@odot.oregon.gov	971-283-5558
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5. Other comments:

The objectives in this research can be effectively achieved using numerical models that are calibrated to already available data from physical experiments on bridge foundations, including shake table tests and case studies. Two baseline numerical models are proposed to be developed, each representing distinct characteristics that are important to capture in this study:

- Model 1: This model will represent a single intermediate bridge bent. It will be constructed based on a 1-g shake table test conducted at UC San Diego by Professor Ahmed Elgamal and Dr. Ahmed Ebeido. The test involved a single 0.25-m diameter reinforced concrete pile shaft supporting a superstructure mass and subjected to 0.4 m of lateral spreading (Fig. 1a).

- Model 2: This model will represent the global response of a full bridge. It will be developed based on a case study conducted by Dr. Ben Turner, Professor Scott Brandenberg, and Professor Jon Stewart of UCLA on a highway bridge in Baja California, Mexico. The bridge experienced 4.6 m of lateral spreading displacement in the free field during the 2010 El Mayor-Cucapah earthquake (Fig. 1b). The foundations of this bridge consisted of four 1.2-m diameter extended pile shafts.

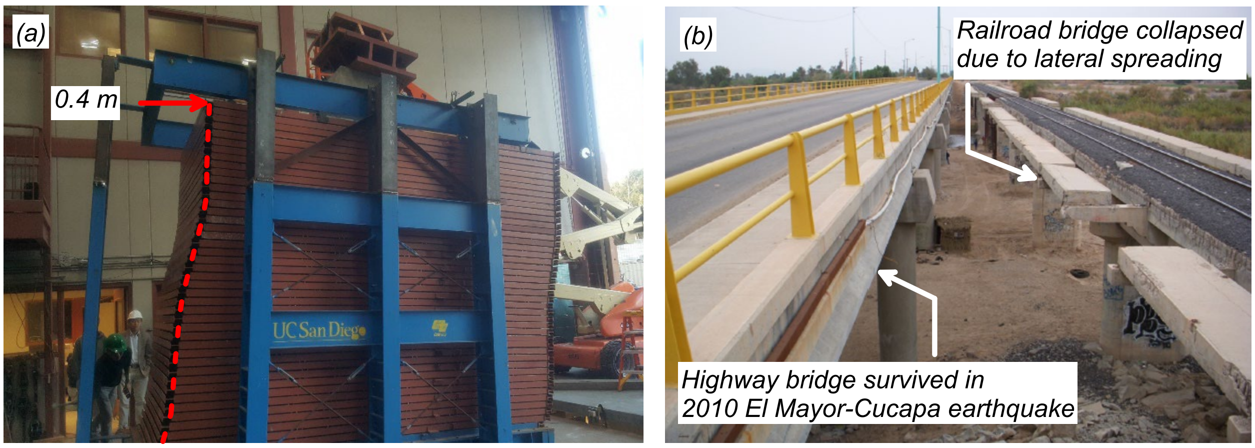

Figure 1. (a) 1-g shake table test for calibration of Model 1 (photo courtesy of Prof. Ahmed Elgamal, UC San Diego), (b) highway bridge in Baja Calif., Mexico for calibration of Model 2 (photo courtesy of Dr. Ben Turner)

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