SPR RESEARCH PROGRAM
SECOND-STAGE PROPOSAL SUMMARY

PROBLEM NUMBER AND TITLE

26-32: Design Guidelines for Bridge Pile Foundations Subjected to Combined Inertial and Liquefaction-Induced Lateral Spreading Loads

PROBLEM SUMMARY

Earthquake induced soil liquefaction can result in significant displacements in sloping ground. This type of displacement is referred to as lateral spreading and is considered a substantial hazard to Oregon bridges. One current challenge facing bridge foundation design is the knowledge gap regarding appropriate selection of load factors for combining lateral spreading loads (kinematic) and superstructure inertial loads (inertia). Unfortunately, there is **no consensus** in design codes for how to combine inertial and kinematic loads. Failure to address this knowledge gap presents challenges for ODOT engineers and designers. If lateral spreading and superstructure inertial loads interact during an earthquake, neglecting their combined effects could lead to inadequate and unsafe designs. Conversely, overconservatively combining these loads may result in costly, non-constructible foundations, particularly for piles passing through stiff, non-liquefiable crusts overlying deep liquefiable soils on sloped grounds.

ODOT OBJECTIVES

The primary objective of this research is to solidify ODOT's design guidelines for combining superstructure inertial and lateral spreading loads in a pseudo-static analysis. The inertial and kinematic load interaction factors will be characterized by accounting for differences in seismicity in Eastern and Western Oregon, foundation types, and the complexity levels of design methods utilized in various ODOT projects. 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).

BENEFITS

Considering the need for guidance on this design issue in AASHTO's Specifications or ODOT's BDM and GDM, recommendations from this study will likely be readily adopted into ODOT design manuals. These recommendations are expected to enhance safety in Western Oregon, where seismic contributions are dominated by long-duration motions from Cascadia Subduction Zone, while reducing potential over-conservatism in Eastern Oregon, where seismicity is primarily influenced by shallow crustal faults. 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, enabling prioritization and recategorization.

SCHEDULE, BUDGET AND AGENCY SUPPORT

Estimated Project Length: 42 months.
Estimated Project Budget: $585,000
ODOT Support: Ray Bottenberg (State Bridge Engineer), Albert Nako (Seismic Bridge Engineer), Susan Ortiz (State Geotechnical Engineer)

FOR MORE INFORMATION

For additional detail, please see the complete STAGE 2 RESEARCH PROBLEM STATEMENT online at:
https://www.oregon.gov/odot/Programs/ResearchDocuments/26-32

SPR RESEARCH PROGRAM
SECOND-STAGE PROBLEM STATEMENT
FY 2026

PROBLEM NUMBER AND TITLE

<u>26-32:</u> Design Guidelines for Bridge Pile Foundations Subjected to Combined Inertial and Liquefaction-Induced Lateral Spreading Loads

RESEARCH PROBLEM STATEMENT

Soil liquefaction during earthquakes can result in significant displacements in sloping ground, referred to as 'lateral spreading' (Figure 1). 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 Oregon's 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 of this research is to improve the design methods applied so that they address the effects of liquefaction and lateral spreading for these numerous, smaller bridge projects.

Figure 1: *Damage to Showa Bridge in the 1964 Niigata earthquake due to liquefaction-induced lateral spreading (source: NISEE)*

One current challenge facing bridge foundation design is the knowledge gap regarding appropriate selection of load factors for combining lateral spreading loads (kinematic) and superstructure inertial loads (inertia). Unfortunately, there is **<u>no consensus</u>** in design codes for how to combine inertial and kinematic loads. Failure to address this knowledge gap presents challenges for ODOT engineers and designers. If, indeed, lateral spreading and superstructure inertial loads interact during an earthquake, failure to combine the two loads could lead to *inadequate and unsafe designs*. On the other hand, combining inertia and lateral spreading loads can sometimes result in *expensive, non-constructible foundations*, 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.

Recent findings from PSU successfully address the effects of long-duration motion on inertia and lateral spreading load factors, and this guidance has now been incorporated into the 2022 BC Supplement to the Canadian Bridge Design Code S6:19. Similarly, WSDOT adopted guidance whereby 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 <u>will enhance safety</u> in Western Oregon, where seismic contributions are dominated by long-duration motions from Cascadia Subduction Zone, and *reduce potential over-conservatism* in Eastern Oregon, where seismicity is primarily influenced by shallow crustal faults.

RESEARCH OBJECTIVES

The primary objective of this research is to improve ODOT's design guidelines for combining superstructure inertial and lateral spreading loads in a pseudo-static analysis. The inertial and kinematic load interaction factors will be characterized by accounting for differences in seismicity in Eastern and Western Oregon, foundation types, and the complexity levels of design methods utilized in various ODOT projects. 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).

WORK TASKS, COST ESTIMATE AND DURATION

Task 1: Form a Technical Advisory Committee (TAC) consisting of structural and geotechnical engineers from ODOT, bridge engineering consultants, and academic partners.

Task 2: Large-scale centrifuge tests will be conducted at the 9-m geotechnical centrifuge at the University of California, Davis (Figure 2). The model will include a full bridge deck supported by pile foundations, with Willamette Silt (a low-plasticity fine-grained soil) representing the natural soil unit susceptible to liquefaction and lateral spreading. The subsurface conditions and structural properties will be designed to reflect those of ODOT bridges. The dynamic response of the bridge deck, piles, and surrounding soil will be monitored with accelerometers, pore water pressure transducers, linear potentiometers, and high-speed cameras. Two centrifuge test results will be used to calibrate and validate numerical models in subsequent tasks.

Task 3: Validation of a numerical model. A global numerical bridge model will be developed in the finite-difference software FLAC for nonlinear dynamic analysis. The numerical model will be calibrated and validated using the results of the centrifuge tests. The numerical model will simulate pore pressure generation and accumulation of shear strains in silt, and the dynamic response of the bridge deck and pile foundations. The validated model will be used in the subsequent parametric study.

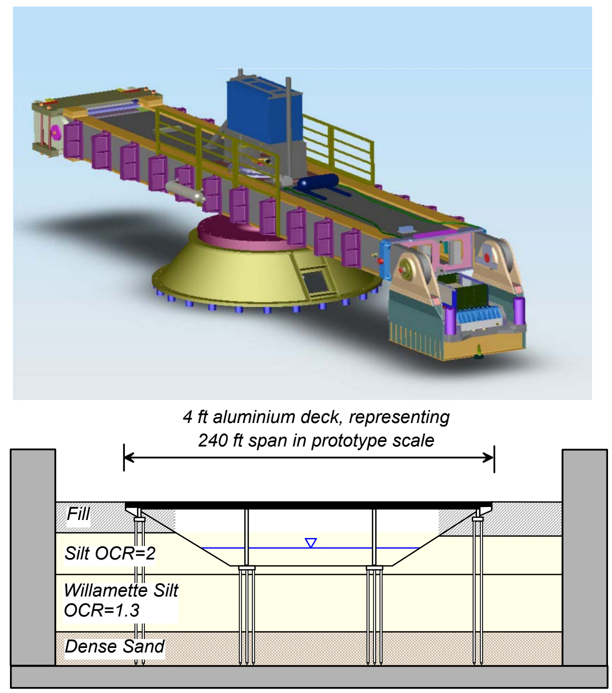

Figure 2: (left) 9-m geotechnical centrifuge at UC Davis (source: Center for Geotechnical Modeling at UC Davis), (right) Proposed model of a full bridge supported on piles in liquefiable soils.

Task 4: Development of ground motions: Select ground motions and spectral matching/scaling based on the contribution of various seismic sources, accounting for long-duration earthquakes expected from Cascadia Subduction Zone and short to medium duration earthquakes from shallow crustal faults. Three suites of earthquake time histories will be developed for representative sites in Western, Central, and Eastern Oregon.

Task 5: Complete parametric study using nonlinear dynamic analysis. The validated numerical model will be modified to represent the range of soil, foundation, and structural properties found in ODOT bridges. The analysis will incorporate the ground motions developed in the previous task. The results of the parametric study will be used to identify correlations between load interaction factors and key parameters, and to develop a methodology for combining superstructure inertia and lateral spreading loads in pseudo-static analysis.

Task 6: Case study. The applicability of the developed load interaction factors will be illustrated by applying the proposed methodology in multiple case studies covering representative range of bridge conditions in

Oregon. The case studies will be selected in collaboration with TAC.
Task 7: Implementation: Following a thorough assessment of the proposed load interaction factors through multiple case studies, the derived guidelines will be utilized to formulate a practice-ready recommended amendment to Oregon Bridge Design Manual (BDM) and Geotechnical Design Manual (GDM).

Key Deliverables: *ODOT Bridge Design Manual and Geotechnical Design Manual recommended amendments, final report, proposed load factors, case studies.*
Estimated Project Length: 42 months.
Estimated Project Budget: $585,000

IMPLEMENTATION

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 BDM and GDM. This recommended amendment aims to facilitate the adoption and implementation of the proposed methodology in design projects.

POTENTIAL BENEFITS

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.

PEOPLE

ODOT champion(s): Ray Bottenberg (State Bridge Engineer), Albert Nako (Seismic Bridge Engineer), Susan Ortiz (State Geotechnical Engineer)

Problem Statement Contributors: Arash Khosravifar (Portland State University), Kira Glover-Cutter (ODOT)

STAFF REVIEW PAGE

LITERATURE CHECK

TRID&RIP

☒ A review of TRID & RIP databases found no existing research that answers the research question

ODOT DECISION LENSES

Climate: The transportation issue that will be addressed in this study will improve seismic resilience of the transportation system (reference to “natural disaster”).

Equity: 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.

Safety: 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.

TECHNOLOGY & DATA ASSESSMENT

☒ No Identified T&D output

☐ At the end of this project, the implementing unit(s) within ODOT will need to coordinate the adoption of new technology or data in order to realize the full potential of this research.

CROSS-AGENCY IMPACTS

- List ODOT partners or impacted units. Bridge Section; Geotechnical, Engineering, Engineering Geology, Hazmat (GEEGH)