Oregon Department of Transportation

Research Stage 1 Problem Statement

Number 26-27 – "Empirical Models for Improved Ground Failure Analysis of Oregon's Silty Soils"

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

Numerous bridge substructures, bridge approaches, and embankments are underlain by the silt soils of the Willamette and Columbia River Valleys, which is home to Oregon's largest population centers. These soils are frequently susceptibility to liquefaction ("sand-like") or cyclic softening ("clay-like") depending on their local characteristics. Seismic loading of these materials will produce varying degrees of severity in the consequences such as lateral spreading displacement, global instability, and settlement and corresponding drag loads to bridge foundations, all of which have the potential to severely impact our critical transportation lifelines. Even gentle slopes thought to be reliably stable during shaking may be prone to large deformations associated with lateral spreading due to cyclic failure, which is exacerbated by the static shear stresses inherent with sloping ground and rising groundwater tables which are expected as a result of climate change. Furthermore, the new specifications currently being developed by the AASHTO Soil Structures Committee will require the post-earthquake settlement of all soils to be assessed, including silts and clays. Unfortunately, empirical methodologies to calculate the effect of sloping and settling ground on lateral and vertical displacements for Oregon's silts do not exist. Simplified empirical methods are necessary for the seismic evaluation of all of Oregon's bridges, from the low-volume structures in our sparsely populated and economically-disadvantaged communities which may not justify advanced numerical analyses to the multi-lane, multi-span Interstate bridges during scoping and 30% design analyses.

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

This research will produce specific design guidance, models, and spreadsheet-based tools for: (1) accounting for static shear stress in the factor of safety against liquefaction/cyclic softening calculations, (2) calculating lateral displacements of sloping ground, and (3) calculating vertical settlements of level and sloping ground, and will culminate in a decision matrix for ODOT engineers and their consultants to guide the selection of a particular model (existing and proposed) given the site-specific soil conditions. These products will ready ODOT for the upcoming revisions to Sections 3 and 10 of the AASHTO Bridge Design Specifications where the effects of cyclic failure (e.g., lateral and vertical displacements) will need to be directly analyzed and treated in design, e.g., to calculate dragloads following ground failure.

This research will leverage the significant amount of laboratory data generated by the PI under his supervision and related data gathered by the Proposer through the Next Generation Liquefaction project to accomplish the research objectives. The decision matrix and specific guidelines for conducting cyclic failure analyses and simplified displacement estimates will guide the need for the use or avoidance of larger bridge foundations and/or ground improvements at river crossings (i.e., bridges) and would be implemented within ODOTs Bridge and Geotechnical Design Manuals to aid the envisioned revisions to the Seismic Design Chapters of these manuals.

3. (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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4. Decision making lenses

Please complete the following three sections. Your answers to these questions will be applied on a programmatic basis to support agency decisions. Answering yes to the questions below is not required. Resolving a narrowly focused technical research problem may meet agency needs without answering yes to any of the following questions. The ODOT Research Section will seek a balanced portfolio some projects will answer yes to one of the three categories below (e.g. climate, equity, and/ or safety) and other projects in a different category.

We are looking for an overall program balance and no one project is expected to balance all categories. Generally, a research problem statement is expected to be able to answer yes with clear and verifiable information in only one of the three categories below, some projects may be able to answer yes in two or even three categories. Some projects (i.e. needs focused on specific elements of infrastructure design), may have no yes answers but may still be high value research need.

Climate

Oregon recognizes the climate crisis and makes systemic changes to reduce emissions caused by travel. Every mile driven in Oregon is powered by a clean source of fuel. We seek research that supports construction and maintenance operations are carbon neutral and investments in mobility that support travel by low and no emission modes. While every research project may not result in a reduction in emissions, transportation investments overall support emission reductions to achieve state goals. Oregon envisions a transportation system that is resilient in the face of seismic and climate events and impacts to the degradation of the natural environment are reduced. Our vision includes a transportation infrastructure is built in a way that avoids impacts on key habitat and results in better environmental conditions for wildlife and native vegetation. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

4f. Will addressing the **transportation issue** identified as a need in Question 1 develop, or validate methods for the estimation, measurement, or monitoring of transportation generated greenhouse gasses (GHG)?

☐Yes ☒No ☐Unsure

4g. If climate or GHG is not the focus of this **transportation issue** identified in this problem statement, will the research apply a GHG analysis to transportation infrastructure, planning, operations, maintenance, or materials?

☐Yes ☒No ☐Unsure

4h. Will the addressing the **transportation issue** include development or testing of construction practices, methods, or materials to establish potential reductions in greenhouse gas emissions?

☐Yes ☐No ☒Unsure

4i. Will the solving the **transportation issue** in question 1 study or support the reduction of vehicle miles traveled and single occupancy vehicle travel or support transition to electric vehicles (or other types of zero emission vehicles) or low-carbon alternative fuels?

☐Yes ☒No ☐Unsure

4j. Will the solving the **transportation issue** in question 1 lead to work that will support, measure, monitor, transportation system resilience in response to expected climate events, effects, or natural disasters in general?

☒Yes ☐No ☐Unsure

4k. Will the solving the **transportation issue** in question 1 lead to work that may result in better environmental conditions for wildlife and native vegetation ?

☐Yes ☐No ☒Unsure

4l. If you answered yes to any of the climate questions above or can provide alternative details related to climate, please provide additional information:

It is absolutely clear that climate change will result in altered weather patterns and sea level rise (SLR). Although the increased frequency and severity of precipitation events and thus persistently increased groundwater tables in Oregon is unknown with any certainty, we are certain that sea levels will rise dramatically along the coast and up the Columbia River valley in the easterly expanding intertidal zone. Estimates of sea level rise (SLR) cited by the Oregon Department of Land Conservation and Development and the Oregon Coastal Management Program range from one to six feet over the next 80 years for Newport and Astoria, with 22.2 and 9.1 miles of roadway in Yaquina and Alsea Bays expected to be inundated under a 50% annual chance coastal flooding and SLR in long-term projections (i.e., in the year 2100), along with numerous impacts to railways. However, these estimates do not account for the land subsidence expected following the rupture of the Cascadia Subduction zone, which will produce an additional six to ten feet of estimated relative SLR.

The net result of both consequences of climate change is that groundwater tables will rise and saturate greater thicknesses of loose soils. When subject to earthquake shaking, saturated loose soils will generate excess pore pressure, lose strength, and displace; the degree of vertical and lateral movements depends on the duration and intensity of ground shaking. It is well known that the severity of liquefaction and cyclic softening increases with increasing thickness of near-surface soils; ODOT infrastructure subject to ground failure can pose a significant threat to community resilience, particularly to economically-disadvantaged residents of Oregon that reside in our coastal communities.

Equity

Equity can have many dimensions and impacts relating to communities, and transportation. It is important that problem statement proposals clearly explain in what capacities are equity dimensions or impacts being examined within problem statements. It is a goal of the OTP to "Improve access to safe and affordable transportation for all, recognizing the unmet mobility needs of people who have been systemically excluded and underserved. Create an equitable and transparent engagement and communications decision-making structure that builds public trust". Proposed research may have the intent of studying elements of this goal or apply analysis to specific transportation topics to ensure the resulting research recommendations is consistent with our equity goals. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan and Oregon Transportation Plan.

4a Is the **transportation issue** identified as a need in Question 1 specifically focused on transportation equity?

☐Yes ☐No ☒Unsure

4b If the **transportation issue** is not focused on transportation equity, will the primary topic be assessed for equity benefits or impacts within the research project?

☐Yes ☐No ☒Unsure

4c Is the implementation of potential findings from this research likely to directly involve participation from an identified group that would benefit from an equitable process or outcome?

☐Yes ☐No ☒Unsure

4d Is the intended final product or information expected to support ODOT's equity efforts (Including but not limited to supporting one of the equity related objectives of the ODOT's Strategic Action Plan or Oregon Transportation Plan) ?

☒Yes ☐No ☐Unsure

4e If you answered yes to any of the equity questions above or can provide alternative details related to equity, please provide additional information:

The 2023 Oregon Transportation Plan (OTP) sets clear goals for achieving resilience in the face of climate change and natural hazards, while balancing economic and community vitality and social equity, among other important goals. Specifically, this research addresses OTP Objectives EC.2, EC.4, SP.3.3, SP.6, and SC.2. Economic investment into the expansion and repair of highway infrastructure must achieve resilience in the face of climate change-driven and natural hazards, and must serve critical lifelines and evacuation routes for underserved rural low-income and tribal communities. These hazards manifest in the form of short-term, acute storm, flooding, and seismic events, and long-term SLR-driven changes to our shared environment.

Safety

Research outcomes may include interventions and countermeasures to prevent or reduce the frequency of crashes or other causes of transportation-related injury or death; or may include measures to reduce severity of injury (including prevention of death) after a crash or other injurious event. For definitions and details please review the equity vision, goals, and objectives of the ODOT Strategic Action Plan, Oregon Transportation Safety Action Plan and Oregon Transportation Plan.

4m. Will solving the **transportation issue** in question 1 support improving **safety culture** for either transportation workers or the traveling public?

☐Yes ☒No ☐Unsure

4n. Will the solving the **transportation issue** support improving safety through **healthy and livable communities**?

☐Yes ☐No ☒Unsure

4o. Will solving the **transportation issue** support improving safety through using **best available technologies**?

☒Yes ☐No ☐Unsure

4p. Will solving the **transportation issue** support improving safety through **communication and collaboration**?

☐Yes ☐No ☒Unsure

4q. Will the solving the **transportation issue** support improving safety through **investing strategically**?

☒Yes ☐No ☐Unsure

4r. If you answered yes to any of the safety questions above or can provide alternative details related to safety, please provide additional information:

In the proposer's opinion, transportation safety encompasses an extremely wide scope. Safety includes (or should include) the prevention of injury and death on a massive scale, such as ensuring that one or more bridges carrying 10, 20, 200^{+} people do not collapse during rush hour owing to an unfortunate time-of-rupture of any one of the faults threatening our State. Making our bridges resilient to earthquakes can not only provide the single most impactful activity to prevent death but will lead to a more rapid emergency response and economic recovery, which in turn will lead to significantly less chaos (e.g., looting and violence) after the Big One because rescue and recovery can proceed and law and order can be maintained. Infrastructure resilience *is* safety.

Critically, use of the proposed empirical models to help screen for potential hazards could lead to savings which could be applied to address additional seismic needs or reduce the risk of safety issues at poor-condition bridges. Better decision making will lead to improved design and construction efficiencies.

5. Other comments:

There are *no* empirical methods to estimate the lateral spreading of silt soils. Likewise, there are *no* volumetric strain (i.e., post-shaking consolidation settlement) models for silt soils. Existing models for lateral spreading and post-shaking settlement are based on sands, and consistently produce over-estimates of displacement because they are based on very conservative estimates of cyclic resistance. Having assisted members of the AASHTO Soil Structures Committee to adapt the recommendations of FHWA Project 12-116A on downdrag and dragloads, as well as liquefaction and cyclic softening revisions, into the proposed revisions of Sections 3 and 10 of the AASHTO Bridge Design Specifications, it is clear to the proposer that the post-seismic settlement of *any* soil subject to cyclic failure will need to be assessed, including the magnitude of lateral displacements and the impact of settlement on drag loads and the structural strength limit state of bridge foundations. *This project will help ODOT meet the design needs that will be required as part of the revised AASHTO Specifications.* The availability of empirical models will lead to cost-effective decision making which can be universally applied to low volume bridges in design and high-volume bridges during scoping studies, facilitating early decision making and reducing design risk and surprises.

The research team proposed to provide the models and decision matrix addressing improved seismic resilience of ODOTs transportation assets will be led by PI Armin W. Stuedlein. The work tasks necessary to accomplish the research objectives include the following specific steps:

Task 1: Conduct a review of the effects of the literature on static shear stress on monotonic and cyclic resistance and lateral displacement, and the very little available literature on the effects of varying plasticity and overconsolidation ratio on post-cyclic volumetric strain (settlement) of silty and clayey soils.

Task 2: Leverage the existing data developed and gathered by the Proposer to identify data gaps, if any. Conduct limited drilling, sampling, and cone penetration and laboratory tests at sloping ground sites adjacent to rivers at specific ODOT bridge sites where liquefiable/cyclic softening susceptible deposits exist to address data gaps. Boone Bridge represents one such opportunity where the results of targeted testing can be directly used in the seismic stability of the bridge, with significant impact to resiliency assessment and upgrading.

Task 3: Develop empirical/statistical models to: (1) determine the static shear stress correction for the cyclic resistance of silty soils, (2) calculate lateral displacements, and (3) calculate volumetric strain and settlement, as a function of the factor of safety against cyclic failure, plasticity index, and overconsolidation ratio.

Task 4: Develop step-by-step analysis flow charts, spreadsheet-based calculation tools, and a decision matrix for ODOTs engineers and their design consultants to implement the newly-developed models and inform the evaluation or design of seismically- and climate change-resilient bridge retrofits or replacements.

Task 5: The work conducted in Tasks 1 – 4 will be documented in a Final Report and presented during an interactive, statewide seminar to ODOTs engineers and their consultants. The Final Report will provide proposed revisions to the Seismic Design Chapters of the ODOT BDM and GDM in coordination with the responsible engineer(s) at ODOT.

6. Corresponding Submitter's Contact Information:

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