Number: *25-82*

Proposed Title: Cyclic Shear Testing Procedure for Liquefaction Evaluation of Silts: Mechanical Consolidation vs. Recompression

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

Soil liquefaction during earthquakes can cause significant damage to highway bridges. While most past research has focused on sand liquefaction, few studies have explored the liquefaction susceptibility of silts. Many ODOT assets, including highway bridges, are in areas abundant with silt-rich soil deposits, such as the fine-grained Missoula Flood deposits in the Willamette Valley and the silt deposits of the Columbia River and Willamette River. Consequently, assessing the liquefaction potential of these soils is often part of the seismic evaluation for these projects.

The recommended practice involves sampling and testing these soils in the laboratory using either Cyclic Direct Simple Shear (CDSS) or Cyclic Triaxial (CTX) testing. The recent availability of cyclic testing services at research institutes (PSU and OSU) for industry projects as well as several local geotechnical consulting firms in Oregon has led to an encouraging trend. This trend is projected to enhance the seismic evaluation of these silty soils for Oregon projects. However, several questions persist regarding the execution of these advanced laboratory tests, limiting the refinement of engineering solutions beyond a certain threshold.

One crucial question, arguably the most important, revolves around how to consolidate soil samples in the laboratory to replicate field stress conditions. There are two primary approaches to consolidating soil samples in CDSS tests:

- Recompression: This approach involves loading the soil specimen to the in-situ stress, followed by cyclic loading. Some engineers opt to load the specimen to a stress 10% higher to mitigate, to some extent, the negative effects of sample disturbance incurred during sampling, transportation, and specimen preparation.

- Mechanical Consolidation (also known as SHANSEP or quasi-SHANSEP): Here, the soil specimen is loaded to a stress greater than the pre-consolidation stress and then unloaded to a smaller stress, effectively mechanically replicating the in-situ overconsolidation ratio (OCR) in the device. This phase is then followed by cyclic loading.

Theoretically, these two consolidation approaches (recompression vs. mechanical consolidation) should yield similar results. However, in practice, they may lead to significantly different conclusions. To highlight the importance of this issue in seismic studies and its impact on projects, an example project is presented here. Figure 1 displays the results of CDSS tests conducted at PSU for a local project in Beaverton, OR. The tested soils are fine-grained Missoula Flood deposits from a depth of approximately 20 ft, possessing a plasticity index of PI < 6 and Fines Content > 90%. These soils fall under the USCS classification of low-plasticity silts (ML). The estimated OCR was close to OCR = 11, based on 1D consolidation tests, CPT correlations, and data from adjacent sites.

Two test series were carried out: one employing the recompression approach, and the other utilizing mechanical consolidation (i.e., SHANSEP). Figure 1 illustrates a significant difference in liquefaction resistance: samples consolidated through mechanical consolidation displayed roughly three times higher liquefaction resistance compared to those consolidated via recompression. Several factors contribute to this variance:

- The value for OCR might have been overestimated, leading to an overestimation of liquefaction resistance in the specimens subjected to mechanical overconsolidation. This possibility is particularly pronounced in low-plasticity silts, where consolidation tests often yield a notable range in estimated preconsolidation stress.

- Recompression tests could have underestimated liquefaction resistance due to potential sample disturbance, particularly significant given the low plasticity nature of these soils, rendering them more susceptible to sample disturbance.

It's speculated that the "correct" response lies somewhere between the two curves depicted in Figure 1. The challenge for engineers is the current absence of a method to quantitatively assess the effects of the aforementioned factors. Research is needed to:

a) Quantify, to the extent possible, the impact of sample disturbance when employing the recompression approach.

b) Quantify the influence of uncertainty in OCR estimates on liquefaction resistance when utilizing the mechanical consolidation approach (SHANSEP).

c) Provide guidance on soil types where these factors are either significant or negligible and provide recommendations regarding the preferred consolidation method for CDSS and CTX testing.

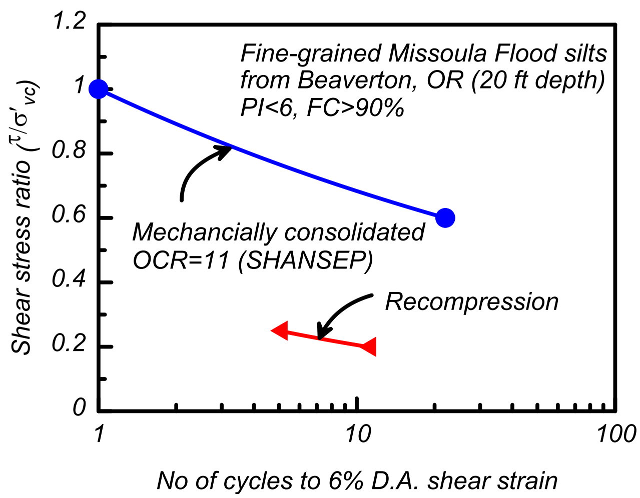

Figure 1. Cyclic direct simple shear (CDSS) results on fine-grained Missoula flood deposits using mechanical reconsolidation (SHANSEP) and recompression approaches.

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. The 2021 Oregon Transportation Systems Regional Resilience Assessment Program by the Department of Homeland Security identified 989 bridges in Oregon susceptible to severe damage due to liquefaction following a Cascadia Subduction Zone earthquake. Some of these bridges could face reopening times of up to 2.5 years. This research aims to establish guidelines for a more precise seismic evaluation of these bridges. Consequently, it might downgrade some of these bridges from high-level concern status, eliminating the necessity for costly ground improvements for liquefaction mitigation. This approach enables ODOT to concentrate on a smaller subset of bridges for liquefaction mitigation, ultimately fostering increased confidence in overall bridge performance.

Moreover, this research aligns with ODOT's ongoing efforts to establish a more equitable transportation network. The coastal region's seismicity is heavily affected by intense shaking and long-duration earthquakes from the Cascadia Subduction Zone, which raises widespread liquefaction concerns. These routes frequently pass through tribal lands or High Disparity areas identified by the ODOT Social Equity map. Ensuring the reliability of lifeline routes along the Oregon Coast that need to be operational after major earthquakes is not only important for having an equitable transportation system but also constitutes a crucial element 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 involves a recommended laboratory cyclic testing procedure to assess the liquefaction resistance of silt soils. These recommendations may be used to guide upcoming testing programs for ODOT projects. The results will be detailed in a practice-ready recommended amendment to the ODOT Geotechnical Design Manual (GDM) to facilitate the adoption and implementation of the proposed methods in ODOT projects.

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.

Name	Title	Email	Phone
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5. Other comments:

The objectives in this research can be effectively achieved using a large database of cyclic shear tests on silt-rich soils. This database includes over 200 cyclic tests from 38 sites in Oregon, Washington, British Columbia, and Alaska, compiled by PSU researchers and their collaborators. Additionally, a small number of CDSS tests will be conducted to fill specific knowledge gaps. The soil samples and supplementary data will be contributed by our industry collaborators at no cost to this project. No further site exploration or sampling is required.

This Stage 1 Research Problem Statement is developed by Arash Khosravifar and Diane Moug from Portland State University.

6. Corresponding Submitter's Contact Information:

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