Undrained Cyclic Loading of Low Plasticity Silty Soils in the Pacific Northwest Using Laboratory and Field Cyclic Shear Testing

Angelica Melissa Preciado Reyes
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Undrained Cyclic Loading of Low Plasticity Silty Soils in the Pacific Northwest Using Laboratory and Field Cyclic Shear Testing

by

Angelica Melissa Preciado Reyes

A thesis submitted in partial fulfillment of the requirements for the degree of

Master of Science
in
Civil and Environmental Engineering

Thesis Committee:
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Diane M. Moug
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Portland State University
2021
ABSTRACT

The cyclic behavior of a fine-grained low plasticity silty soil (plasticity index of approximately 15) at a site in Portland, Oregon, is characterized using a field and laboratory cyclic shear test program. The field cyclic tests were performed using the NHERI@UTexas large mobile shakers T-Rex and Rattler. The results of this testing program are used to evaluate the soil’s potential to develop excess pore water pressure with cyclic shear strains ranging from 0.00001% to 0.5%. The results of laboratory cyclic tests are compared against the results of field cyclic tests to predict the soil’s cyclic behavior during earthquakes. The field shaking and resonant column torsional shear tests showed significantly lower pore pressure ratios at shear strains up to 0.5% when compared to cyclic direct simple shear tests. These data will contribute to the larger body of knowledge of the cyclic behavior of low plasticity silts.

This study includes additional laboratory cyclic shear tests from the following: low plasticity silts from Longview, Washington, diatomaceous soils (high plasticity silts) obtained from Klamath Falls, Oregon, silty sands from the Columbia River Slough in Oregon, and low plasticity silt and low plasticity clay from Beaverton, Oregon. The objective of the cyclic shear tests on different soils is to understand how these soils may potentially behave in the event of a large magnitude earthquake.
ACKNOWLEDGEMENTS

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CHAPTER 1. INTRODUCTION

1.1 Soil Liquefaction and Cyclic Softening

Liquefaction is described as the loss of soil shear strength and stiffness due to excess pore water pressure induced from earthquake shaking or other cyclic loadings. This phenomenon transfers the normal stress from the soil skeleton onto the pore water, resulting in the loss of shear strength and stiffness from the lack of confining stress around a soil element. During liquefaction, the soil is saturated and not allowed to drain freely (undrained condition). Particle-to-particle contact is lost during this time; the soil stops behaving like a solid and starts behaving like a liquid. The term liquefaction is specific to cohesionless soils (sands). Cyclic softening refers to the cyclic behavior in cohesive soils (clays), where the shear strains accumulate gradually over the entire sequence of loading cycles as stiffness is reduced. Liquefaction of sands (Figure 1a) and cyclic softening of clays (Figure 1b)-respectively-has been studied by Idriss and Boulanger 2008, and many others. However, intermediate, or transitional soils such as silts still need to be studied to understand better their behavior under cyclic loading (Figure 1c).
Figure 1. (a) Sand-like behavior, (b) clay-like cyclic behavior from Idriss and Boulanger 2008, (c) example of a reconstituted silt sample tested at Portland State University.
The effects on plasticity index (PI) on liquefaction susceptibility has been studied by many, including Boulanger and Idriss 2006, Bray and Sancio 2006, and Seed et al 2003. Figure 2. Schematic of PI Transition from sand-like behavior to clay like behavior for fine-grained soils by Boulanger and Idriss, 2006. shows Boulanger and Idriss’ recommended guideline for differentiating fine-grained soil behavior from sand-like to clay-like with increasing PI. Based on their criteria, a soil of PI ≥ 7 is expected to exhibit clay-like behavior in the absence of detailed laboratory testing. Bray and Sancio’s 2006 liquefaction susceptibility criteria is based on the idea of the amount and type of clay minerals present in fine-grained soils, electing PI and water content (Wc) to liquid limit (LL) ratio (Wc/LL), as indicators of liquefaction susceptibility. Figure 3 shows Bray and Sancio’s 2006 liquefaction susceptibility criteria, where loose soils with PI < 12 and Wc/LL > 0.85 are susceptible to liquefaction, loose soils with 12 < PI < 18 and Wc/LL > 0.8 are moderately susceptible to liquefaction, and soils greater with a PI > 18 were not susceptible to liquefaction. Finally, Seed et al.’s liquefaction susceptibility recommendations for soils with significant fines contents is shown in Figure 4. Based on their recommendations, soils within Zone A (PI < 12, and Wc > 0.8*LL) are considered potentially liquefiable, and the soils in Zone B (12 < PI <20, and Wc ≥ 0.85*LL) may be liquefiable. Based on the aforementioned criteria, soils might be characterized as liquefiable, or potentially liquefiable based on one method, yet be characterized as non-liquefiable based on another researcher’s liquefaction susceptibility criteria. Here lies the importance of performing cyclic shear testing to evaluate the liquefaction susceptibility of the soils in the Pacific Northwest.
Figure 2. Schematic of PI Transition from sand-like behavior to clay like behavior for fine-grained soils by Boulanger and Idriss, 2006.

Figure 3. Liquefaction susceptibility criteria by Bray and Sancio, 2006.
Figure 4. Liquefaction susceptibility criteria by Seed et al., 2003.

1.2 Research Importance

Liquefaction can cause excessive structural and ground failures due to soil deformations and strength loss during and after cyclic loading (post-cyclic). Structural and foundation failures observed in past earthquakes due to the effects of liquefaction include: failures in dams, bearing capacity failures and floating of underground utilities and buried infrastructure in Christchurch earthquakes (GEER 2011), retaining wall failures, lateral spreading (Boulanger et al. 1997), slope failures, loss of port functionality, rapid catastrophic loss of function, and possible loss of life (Esteva 1988).

The anticipated magnitude 9.0 Cascadia Subduction Zone earthquake, other predicted earthquake motions, and the related consequences of these future events have been major driving factors for local infrastructure performance research. However, a
deeper understanding of the soils that underlay critical infrastructure is necessary for the preparation of future sites and the mitigation and reinforcement of already existing infrastructure. Knowledge of the effects of large magnitude earthquakes has been studied for events such as the multiple earthquakes in Chile (“Chile Earthquake” Earthquake Spectra, 1986), Mexico (“Mexico Earthquake” Earthquake Spectra, 1988), New Zealand (“Christchurch” GEER, 2011), and others. This research has shown the effects of an earthquake on a region’s access to emergency supplies, evacuation plans, rescue efforts (Schiff, 1988), economic recovery (“Chile Earthquake” Earthquake Spectra, 1986), and critical structures' vulnerabilities during and post-earthquake.

Understanding soil behavior during and after a seismic event in the Pacific Northwest (PNW) will help engineers and planners design resilient infrastructures. The potential for liquefaction of PNW soils is shown in Figure 2; many of the locations indicated on the map consist of soils known as intermediate or transitional soils.

Figure 5 shows the high to moderate liquefaction locations with respect to the sites studied for the research presented in the following chapters. Much of the critical infrastructure along the Willamette and Columbia Rivers is in the moderate to high liquefaction hazard areas (Wang et al. 2012). Critical infrastructure includes ports, runways, high voltage electric substations and transmission lines, liquefied natural gas tanks, water treatment plants, railroads, bridges, and roads (Wang et al. 2012). Many of the bridges and roads will act as part of emergency response and supply access roads.

Existing knowledge of the cyclic behavior of sand soils and clay soils by Idriss and Boulanger (2008), Bray and Sancio (2006), and many others is well understood as
it has been researched extensively. However, there is a need to fill the knowledge gap for soils known as “intermediate soils, specifically those soils native to the PNW since they are susceptible to liquefaction in the case of a large magnitude Cascadia Subduction Zone event.

Other soils’ cyclic responses were studied to understand the cyclic behavior of other Pacific Northwest soils. The cyclic studies of soils obtained from sites in Longview WA, Klamath Falls, OR, from Beaverton, OR, and the Columbia River Slough, OR, were only studied in a lab setting. They will be hereby referenced as “other testing”.

Figure 5. Test sample locations with respect to liquefaction susceptibility as estimated by Madin & Burns (2013).
2.1 Introduction

The cyclic response of saturated soils to earthquake loading can cause ground failures, severely damaging lifeline infrastructures. While the majority of past research has focused on cyclic behavior of sands and clays, some studies have investigated the cyclic response of silts using laboratory tests, in-situ tests, centrifuge modeling, and case histories, e.g., Bray and Sancio (2006), Hazirbaba and Rathje (2009), Price et al. (2017), Towhata et al. (2013), and Wijewickreme et al. (2019). While opinions vary on how silts behave cyclically, one common opinion is that the behavior of soils that are intermediate to sands and clays (“intermediate soils”), such as non-plastic or low plasticity silt, changes from sand-like (liquefaction) to clay-like (cyclic softening) over a narrow range of plasticity indices (Boulanger and Idriss 2006).

It is imperative to study the cyclic behavior of low plasticity intermediate soils in the Pacific Northwest since many critical infrastructures and lifelines in this region overlay young, fine-grained, low plasticity silty soils. Furthermore, the anticipated magnitude 9.0 Cascadia Subduction Zone earthquake is expected to result in high-intensity and long duration shaking. The soils studied in this research project include fine-grained low plasticity soils (plasticity index of approximately 15) at a site in
Portland, Oregon. The soils at the site are similar to those that underlie the nearby critical infrastructure, e.g., the Portland International Airport (PDX) and the levees along the Columbia River which are known to be underlain by silts that are susceptible to liquefaction/cyclic softening.

The research presented in this chapter is part of a large Microbially Induced Desaturation (MID) research project in collaboration with University of Texas at Austin’s Natural Hazards Engineering Research Infrastructure (NHERI@UTexas), and Arizona State University’s Center for Bio-mediated and Bio-inspired Geotechnics (CBBG). MID is a developing mitigation method for earthquake induced liquefaction. Part of the process includes stimulating the naturally occurring bacteria in the groundwater to create nitrogen gas. Gas bubbles are formed by the bacteria as they are fed nutrients (calcium acetate and calcium nitrate) to displace water from the soil voids, therefore desaturating the soils and reducing the risk of liquefaction. Field trials of MID were performed at two sites underlain by silty soils in Portland, OR. Along with the MID treatment, NHERI@UTexas Large Mobile Shakers (T-Rex and Rattler) were used to induce large cyclic motions onto the soil pre-and post MID treatment. The field cyclic tests were conducted as part of a study to evaluate the effectiveness of microbially induced desaturation as a liquefaction mitigation method. However, only the results of the tests on untreated soils are presented in this paper. Further information on the MID studies can be found in Kayla Sorenson’s (Sorenson 2021) thesis dissertation, and Moug et at (2020). The MID research was funded by the National Science Foundation (NSF).
The cyclic behavior of these soils was characterized using a unique testing program that included field cyclic tests and laboratory tests on intact soils. The field cyclic tests were performed using two mobile field shaking trucks from NHERI@UTexas. In addition, soil samples were tested using resonant column torsional shear (RCTS), and cyclic direct simple shear (CDSS) tests at the geotechnical laboratories at the University of Texas at Austin (UT Austin) and Portland State University (PSU), respectively. As part of this study, Atterberg limit tests and grain size distribution tests were performed to classify the soil to the United Classification System. In-situ tests, including the seismic cone penetration test (SCPT), standard penetration test (SPT), and direct push crosshole (DPCH) measurements, were made to investigate subsurface conditions.

2.2 Site Location

The primary soils of this study are from the Sunderland site, located near the PDX airport in Northeast Portland. The soils are Holocene-age flood deposits classified as liquefiable low-plasticity silty soils, underlain by coarse alluvial river deposits from the adjacent Columbia River (Hull 1991). The site's location is shown in Figure 6 with respect to the liquefaction susceptibility estimates by DOGAMI (Bauer et al., 2012). The site’s proximity to other critical infrastructures in Portland highlights the importance of characterizing these soils' cyclic shear behavior under seismic loading.
2.3 Subsurface Conditions at Sunderland

Subsurface conditions at the site were determined using SCPT, hand auger samples, SPT and split-spoon sampling, and laboratory index testing on disturbed and undisturbed specimens. A schematic of in-situ testing locations and field shaking instrumentation are shown in Figure 7. The depth to fully saturated conditions was delineated with DPCH, crosshole measurements, and SCPT soundings. The silty soils' cyclic behavior was characterized using field cyclic tests, RCTS tests, and CDSS tests, which will be discussed later in this paper.
Cone Penetration Tests and Soil Sampling

SCPT profiles of the cone tip resistance ($q_t$) and the soil behavior index ($I_c$) are shown in Figure 8a and 8b, respectively. Figure 8a also shows the locations of the collected Shelby tube samples. Figure 8c and 8d show the shear wave velocity ($V_s$) and constrained-compression wave velocity ($V_p$) measurements collected from SCPT and DPCH. The SCPT $V_s$ values are calculated using the interval method which can be improved using other interpretation techniques, e.g. by accounting for ray path orientation. The RCTS and CDSS tests presented in this paper are performed on one Shelby tube obtained from 1.2 m to 2.0 m below ground surface (bgs), hereafter referred to as “shallow” specimens, and three Shelby tubes obtained from 4.3 m to 5.3 m (referred to as “deep” specimens). Shelby tubes were obtained from five boreholes spaced 3.5 m apart, as shown in Figure 7. The $q_t$ corresponding to the Shelby tube
sample locations ranges from 450 kPa to 480 kPa. The $I_c$ values estimated from SCPT measurements with Robertson (2009) at the sampling depths were approximately 3.0 and 2.8 for the shallow and deep specimens.

**Shear-Wave and Constrained-Compression-Wave Velocities**

$V_s$ and $V_p$ were measured using SCPT, DPCH, and crosshole measurements to establish the degree of saturation and small-strain stiffness profiles. Detailed procedures for performing DPCH are provided by Cox et al. (2018). The crosshole measurements were performed using source rods and motion sensors (i.e., 3D geophones) at four depths (1.45 m, 1.85 m, 2.55 m, and 4.45 m bgs) installed as part of the sensor array under the T-Rex baseplate for field shaking. A detailed cross section of the sensor array is provided later in the Field Cyclic Testing section. $V_s$ ranged from 80 m/s to 100 m/s over the shallow Shelby tube interval and 95 m/s to 110 m/s over the deep Shelby tube interval based on DPCH and crosshole measurements. The SCPT measurements were approximately 50% greater than the other values obtained.

$V_p$ profiles were used to establish the depth to full saturation and evaluate the silty soils' potential to develop pore water pressure ($\Delta u$) during cyclic loading. While the groundwater table was measured at 1.1 m bgs, it was found that the soils were not fully saturated to 2.0 m bgs as indicated by a relatively low $V_p$ (approximately 200 m/s based on DPCH and crosshole measurements). The $V_p$ for the soils between 1.5 m and 2.0 m were in the medium range between 600 m/s and 1000 m/s, and the degree of saturation could not be determined with certainty. The soils below 2.0 m showed high $V_p$ values ranging from 1450 m/s to 1675 m/s, implying a saturation ratio higher than...
99.7% (Valle-Mollina and Stokoe 2012). While $V_p$ values measured from SCPT did not match the $V_p$ values from DPCH and crosshole measurements, they were useful in delineating the boundary between fully saturated and unsaturated soils.
**Figure 8.** (a) CPT-measured cone tip resistance, (b) soil behavior type index, (c) shear-wave velocity, and (d) constrained-compression wave velocity profiles at Sunderland.
Index Properties and Grain Size Distribution

The soil samples were characterized using index tests, including Atterberg limits, hydrometer testing, and No. 200 sieve washes. The index tests were performed on samples obtained from hand auguring, split-spoon sampling, and Shelby tube sampling; Table 1 summarizes these findings.

The interpreted site conditions are summarized in Figure 9a. The site is primarily composed of low plasticity silt to about 6.1 m bgs. The T-Rex sensor array for field cyclic testing was installed from 1.4 m to 4.6 m bgs. A summary of the measured plastic limits, liquid limits, and natural water contents is shown in Figure 9b. Generally, the natural water content at the site is close to or larger than the liquid limit. Grain size distribution and clay/silt contents are shown in Figure 9c. The tested soils (from 1.2 m to 5.3 m) consisted of approximately 5-10% sand, 70-75% silt, and 20% clay. Soils from 0.5 m to 2.3 m bgs (including the shallow Shelby tube samples) were classified as low plasticity brown silt (ML) using the United Soil Classification System. The soils between 2.3 m to 6.1 m bgs (including the deep Shelby tube samples) were classified as low plasticity grey silt (ML), as shown in Figure 9d. The soils from 6.1 to approximately 9.0 m bgs are classified as low plasticity silt (ML) with sand; however, these soils are not the focus of this thesis.
Table 1. Details of tested soil at the Sunderland, OR site

<table>
<thead>
<tr>
<th>Depth range below ground surface</th>
<th>Water content (%)</th>
<th>Void ratio</th>
<th>Atterberg Limits</th>
<th>Gradation</th>
<th>In situ OCR</th>
<th>Estimated in situ vertical effective stress (kPa)</th>
<th>CPT, qc (kPa)</th>
<th>Ic&lt;sup&gt;e&lt;/sup&gt;</th>
<th>V&lt;sub&gt;s&lt;/sub&gt;&lt;sup&gt;f&lt;/sup&gt; (m/s)</th>
<th>V&lt;sub&gt;p&lt;/sub&gt;&lt;sup&gt;f&lt;/sup&gt; (m/s)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.2 m – 2.0 m</td>
<td>34-45</td>
<td>1.06-1.24</td>
<td>LL = 38% PL = 25% PI = 13&lt;sup&gt;a&lt;/sup&gt; (5)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Sand = 10% Silt = 70% Clay = 20%</td>
<td>4&lt;sup&gt;c&lt;/sup&gt;</td>
<td>26</td>
<td>450</td>
<td>3.0</td>
<td>80-100</td>
<td>600-1000</td>
</tr>
<tr>
<td>4.3 m – 5.3 m</td>
<td>40-59</td>
<td>1.23-1.32</td>
<td>LL = 48% PL = 31% PI = 17&lt;sup&gt;a&lt;/sup&gt; (6)&lt;sup&gt;b&lt;/sup&gt;</td>
<td>Sand = 5% Silt = 75% Clay = 20%</td>
<td>2.3&lt;sup&gt;d&lt;/sup&gt;</td>
<td>48</td>
<td>480</td>
<td>2.8</td>
<td>95-110</td>
<td>1450-1675</td>
</tr>
</tbody>
</table>

<sup>a</sup> average value, <sup>b</sup> standard deviation, <sup>c</sup> estimated from CPT correlations, <sup>d</sup> measured from consolidation test, <sup>e</sup> based on Robertson (2009), <sup>f</sup> based on DPCH and crosshole measurements.
Figure 9. Sunderland (a) soil profile, (b) Atterberg limits and natural water contents, (c) sand, silt, and clay content percentage, and (d) USCS classification from plasticity chart.
Stress History

The tested soils' stress history was estimated using consolidation test data and correlations with CPT measurements. Figure 10 shows the estimated overconsolidation ratio (OCR) with depth. OCR was calculated using the Casagrande method; the values obtained agree with supplemental data obtained from local geotechnical firms. The data includes one consolidation test performed on a deep Shelby tube sample (denoted as “PSU”), six consolidation tests performed by others on the same soils from same or adjacent sites (denoted as “GRI 1989” and “GRI 1995”), and OCR estimated using the relationship of $\sigma'_p = k \times (q_t - \sigma_{v0})$ by Chen and Mayne (1994), where $\sigma'_p$ is preconsolidation pressure, $\sigma_{v0}$ is total vertical stress, and $k$ is a constant (typically 0.33). A $k$ value of 0.33 was used in CPT correlations which matched tests results at depths where consolidation test data was available. The estimated OCR values corresponding to the shallow and deep Shelby tubes were approximately 6 and 2.3, respectively.

$$\sigma'_p = k \times (q_t - \sigma_{v0}) \quad \text{Equation 1}$$
Figure 10. OCR profiles measured from consolidation tests and estimated using CPT correlations.

2.4 Field Cyclic Testing

The potential of the intermediate soils to generate pore water pressure under cyclic loading was evaluated using in-situ cyclic testing with mobile field shakers from NHERI@UTexas (T-Rex and Rattler). These hydraulic shakers apply cyclic shear loading at the ground surface through a baseplate. The tests were performed as part of a study to evaluate the effectiveness of microbial induced desaturation as a liquefaction mitigation method. However, only the test results before the treatment was applied are presented in this paper. The cyclic response of the soils was recorded using an array of pore pressure transducers (PPTs) and motion sensors (geophones). Horizontal and vertical displacements from the motion sensors were used to estimate shear strain ($\gamma$)
imparted on the soil around the PPTs. The pore pressures are normalized with the initial effective stress adjusted for the weight of the shaker trucks. The cross-section and plan view of the sensor array are shown in Figure 11. Cyclic testing was performed over multiple shaking events, where a single shaking event involved multiple, increasingly stronger shakes that subjected the ground to larger levels of $\gamma$. Each shaking event included $N=36$ equivalent uniform cycles applied at a frequency of 10 Hz. One large shaking event was applied at the end that lasted 50 seconds to develop larger pore water pressures. The maximum $\gamma$ that was achieved using field cyclic testing was 0.25%.
Figure 11. In-situ sensor array cyclic testing and crosshole seismic measurements (a) cross section view, and (b) top view. Modified from Stokoe et al. (2020).
The results of excess pore pressure ratios \( r_u = \Delta u/\sigma'_{vo} \) versus shear strains \( \gamma \) from field cyclic tests are shown in Figure 7. While the magnitude of induced pore pressure ratios over the range of experienced cyclic strains were very small, the incrementally increasing shaking amplitudes were used to identify the threshold shear strain for initiation of excess pore water pressure generation \( (\gamma_{pp}) \). The test results at sensor 1P (1.55 m bgs) showed that \( r_u \) begins to increase at cyclic shear strain of \( \gamma_{pp} = 0.009\% \) to 0.02\%. The test results for sensor 2P (1.75 m bgs) showed that the threshold cyclic shear strain is \( \gamma_{pp} = 0.012\% \) to 0.034\%. The test results at 2.55 m bgs showed a threshold cyclic shear strain of \( \gamma_{pp} = 0.014\% \) to 0.028\%. The \( r_u \) for a longer shaking event (50 sec) is also plotted, which shows much higher \( r_u \) for an equivalent number of cycles of approximately \( N=500 \). Sensor P4 (4.55 m) produced very small negative pore pressures showing a dilative response. The \( \gamma \) at P4 did not exceed 0.03\% during cyclic shaking likely due to the attenuation of waves with depth. While the magnitudes of induced \( \Delta u \) were very small, the data suggest a threshold cyclic shear strain of \( \gamma_{pp} = 0.01\% \) which is consistent with data from shallower sensors. These findings were generally consistent across different shaking events. The values of \( r_u \) reported in Figure 12 are estimated from \( \Delta u \) when shaking stops. The time series at sensor 2P are plotted in Figure 13 as an example which indicates that \( \Delta u \) increases after shaking stops. The rise in \( \Delta u \) after shaking is possibly due to non-uniform distribution of cyclic-induced \( \Delta u \) and further migration of pore pressures from nearby zones of higher \( \Delta u \). It is noteworthy that the pore pressure transducers were carefully saturated prior to testing (Cox et al., 2009).
Figure 12. PPTs results during field cyclic tests with the T-Rex and Rattler mobile shakers.
Figure 13. Example time series of ru measured (a) during shaking and (b) during and after shaking in sensor 2P.

- Shaking event 2
  - 2P (1.75 m)
  - Cyclic shear strain = 0.24%
- End of shaking
  - ru = 0.7%
- Peak ru = 6.4%
- Duration of shaking = 4 sec
2.5 Lab Cyclic Testing

Resonant Column Torsional Shear

Resonant column torsional shear (RCTS) tests were performed at UT Austin’s geotechnical lab on Shelby tubes specimens obtained from 1.8 m and 4.6 m bgs. The goal was to characterize $r_u$ at cyclic $\gamma$ ranging from 0.00005\% to 0.38\%. The specimens were consolidated to the estimated in-situ mean effective stress of 27.6 kPa and 34.5 kPa for the shallow and deep specimens, respectively. The specimens were then cyclically loaded for 30 cycles at a frequency of 0.5 Hz. The details of the testing procedures are provided in Wang (2018). The results of RCTS tests are plotted in Figure 14 and compared against the field cyclic tests results in the Discussion section.

Cyclic Direct Simple Shear Testing

CDSS tests were performed at PSU’s geotechnical lab on Shelby tube specimens obtained from 5.0 m bgs. The cyclic phase of the tests was performed under the constant volume condition using an NGI-type device. The $\Delta u$ were calculated by the change in vertical stress as proposed by Dyvik et al. (1987). The test results are presented for two individual specimens which were consolidated using the recompression method similar to the RCTS tests. The specimens were consolidated in the CDSS device to the in situ vertical effective stress of 48 kPa and then cyclically loaded for N=30 cycles at a frequency of 0.1 Hz at a constant cyclic $\gamma$ of 0.2\% and 0.5\%. The results of CDSS tests are plotted in Figure 15. and compared against field cyclic tests and RCTS tests in the next section.
2.6 Discussion

The results of G/Gmax from RCTS and CDSS testing are presented in Figure 14. Cyclic loops obtained from a specimen tested at γ ranging between 0.5-3% are shown in Figure 15. The cyclically-induced ru are compiled from field cyclic tests, and RCTS and CDSS laboratory tests in Figure 16 to characterize the potential of silty soils to generate Δu for γ ranging from 0.00005% to 0.5%. All ru values from lab tests correspond to N=30. The ru values from field shaking correspond to N=36 which is slightly different than the N=30 for laboratory tests. The field cyclic tests provide the least amount of soil disturbance. Field cyclic testing and RCTS provide the most accurate estimates of γ threshold for Δu generation (γpp) since these methods can capture the response at small γ. Figure 16 shows how RCTS testing and field testing follow the same trend at small strains, this may be attributed to the very small strains applied in field testing and RCTS testing. For shears strains up to 0.5% the CDSS tests resulted in significantly larger Δu compared to the field cyclic tests and RCTS tests. The variability in results from each method may be attributed to different levels of sample disturbance, loading conditions, drainage, as well as cyclic loading frequency. While the CDSS specimens were carefully collected following procedures outlined by ASTM D4452 and prepared using methods recommended by DeGroot and Ladd (2012), the field cyclic tests were believed to have the least amount of disturbance during sensor installation compared to RCTS and CDSS testing. While the soils tested in field shaking might have been subjected to some amount of disturbance due to installation of sensors, we believe that they were less disturbed compared to the specimens that were tested in CDSS. This might have
contributed to the lower $r_u$ values for $\gamma$ up to 0.5%. The higher $r_u$ in CDSS could also be related to the consolidation loading method. Additional tests are needed to evaluate the effect of different consolidation methods (recompression versus SHANSEP) on cyclic-induced $\Delta u$ in silt-rich soils. Different loading frequencies may contribute to some of the variability in the results. For example, T-Rex has the highest frequency at 10 Hz, followed by RCTS at 0.5 Hz, and CDSS with the lowest at 0.1 Hz. The variability in results may also have been affected by drainage conditions. While drainage was naturally allowed during the field tests, the CDSS tests were performed under constant volume conditions.

For comparison purposes, results of strain-controlled CDSS tests from four other projects on silty soils in the Pacific Northwest are plotted in Figure 16. This comparison shows that the results of CDSS tests in this study are comparable to other CDSS tests on silty soils. As a practical measure, the data in this figure were enveloped by two upper bound and lower bound curves to provide the likely range of cyclic response. The two curves were developed using the V&D relationships for sand by Dobry et al. (1985), and the input parameters were simply fit to envelope the observed responses from various testing methods. The input parameters to recreate the lower bound and upper bound curves are provided in the figure. It is important to consider this range of responses when evaluating the consequences of liquefaction on infrastructure. This is particularly important when using CDSS tests in practice to evaluate the liquefaction susceptibility of silty soils where plasticity is high enough to sample using Shelby tubes.
Figure 14. G/Gmax results for RCTS and CDSS testing.
Figure 15. Cyclic loops for CDSS tests performed at 0.5%, 1.0%, and 3.0% shear strain.
Figure 16. Results of pore pressure generation from field and lab cyclic testing.
CHAPTER 3. CYCLIC SHEAR TESTS ON SILTY SOILS FROM PACIFIC NORTHWEST

Stress-controlled cyclic shear tests were performed on soils from four different sites: Longview, WA, Beaverton, OR, Klamath Falls, OR, and the Columbia River Slough in Portland, OR. Testing included determining site history performing 1-D consolidation. After determining the OCR, confining stresses were chosen for testing the soil samples. Post cyclic shear and post cyclic consolidation were performed on the samples, and their data is presented in this thesis. Atterberg limits and other soil index properties were determined at PSU’s geotechnical lab or by others when necessary. PI, Wn/LL, and testing designations for each site are tabulated below in Table 2.
Table 2. Testing designations for other sites in the PACNW.

<table>
<thead>
<tr>
<th>Site</th>
<th>USCS Soil Classification</th>
<th>Plasticity Index (PI)</th>
<th>Wn/LL</th>
<th>1-D Consol ASTM 2435</th>
<th>CDSS</th>
<th>MDSS</th>
<th>Post-Cyc Shear (PCS)</th>
<th>Post-Cyc Consolidation (PCC)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longview, WA</td>
<td>ML</td>
<td>7.4</td>
<td>1.08, 1.23</td>
<td>2</td>
<td>10</td>
<td>4</td>
<td>10</td>
<td>N/A</td>
</tr>
<tr>
<td>Klamath Falls, OR</td>
<td>MH</td>
<td>45</td>
<td>1.3</td>
<td>N/A</td>
<td>4</td>
<td>N/A</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>Beaverton, OR</td>
<td>ML, CL</td>
<td>4, 10</td>
<td>0.97, 0.88</td>
<td>N/A</td>
<td>14</td>
<td>N/A</td>
<td>12</td>
<td>1</td>
</tr>
<tr>
<td>Columbia River Slough, Portland, OR</td>
<td>SM</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
<td>3</td>
<td>N/A</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>
3.1 Longview, Washington: Low Plasticity Silt

Soil obtained from this site underwent testing for Atterberg limits, fines content analysis, 1-D consolidation, monotonic shear testing, and stress-controlled cyclic testing. Soils tested at PSU’s geotechnical lab ranged between 90ft bgs and 120ft bgs. The soil at this site has been characterized as a low plasticity silt (ML) with a PI of 4 for depths of approximately 120 ft and a PI of 7 for soils of 90 ft bgs. Percent passing the #200 sieve (fines content) for these soils is 73%. 1-D consolidation (Figure 17) testing results yielded an OCR of approximately 2. Monotonic shear test parameters shown in Table 3 were used to develop soil history and normalized soil engineering (SHANSEP) analysis, based on Ladd and Foote (1974). The undrained shear strengths from monotonic shear tests, along with the SHANSEP equation developed for this site, are shown in Figure 18. Cyclic testing parameters are shown in Table 4. Results of cyclic shear tests are shown in Figure 19 and Figure 20. Results of monotonic and post-cyclic shear tests are shown in Figures 21-24.
Figure 17. 1-D Consolidation testing for Longview WA, low plasticity silt
Table 3. Monotonic Shear Test Parameters and Results for Longview WA, (ML).

<table>
<thead>
<tr>
<th>Sample, Test</th>
<th>Void Ratio(^{(1)}), Wn (%), and PI</th>
<th>Consolidation Stage</th>
<th>Max Shear and Rate of Loading</th>
<th>Su at 10% Shear Strain (psf, kPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCL2 S20-A5</td>
<td>e = 1.30, Wn = 43%, PI = 4</td>
<td>Sample was consolidated to 16708 psf and unloading to 8354 psf (OCR = 1)</td>
<td>20% shear strain @ rate of 1.4%/hour</td>
<td>4000 psf, 192 kPa</td>
</tr>
<tr>
<td>HCL2 S20-A4</td>
<td>e = 1.18, Wn = 43%, PI = 4</td>
<td>Sample was consolidated to 16708 psf and unloaded to 8354 psf (400 kPa) (OCR = 2)</td>
<td>20% shear strain @ rate of 1.4%/hour</td>
<td>3700 psf, 177 kPa</td>
</tr>
<tr>
<td>HCL2 S20-A6</td>
<td>e = 1.23, Wn = 43%, PI = 4</td>
<td>Sample was consolidated to 16708 psf and unloaded to 5576 psf (267 kPa) (OCR = 3)</td>
<td>20% shear strain @ rate of 1.4%/hour</td>
<td>3600 psf, 172 kPa</td>
</tr>
<tr>
<td>HCL2 S20-A3</td>
<td>e = 1.2, Wn = 43%, PI = 4</td>
<td>Sample was consolidated to 16708 psf (800 kPa) and unloaded to 4177 psf (200 kPa) (OCR = 4)</td>
<td>20% shear strain @ rate of 1.4%/hour</td>
<td>3300 psf, 158 kPa</td>
</tr>
</tbody>
</table>

1. Calculated from weight of specimen inside a rigid ring with 2.5-inch diameter and 1-inch height.
Figure 18. Undrained shear strength results from monotonic undrained shear tests on samples from Longview, WA.

\[ \frac{S_u}{\sigma'_v} = 0.25 \cdot OCR^{0.88} \]
Table 4. Cyclic Test Parameters for Longview WA, Low Plasticity Silt

<table>
<thead>
<tr>
<th>Sample</th>
<th>Void Ratio(1), Wn (%), PI</th>
<th>Consolidation Stage</th>
<th>Stress-Controlled Cyclic Shear Test CSR= (τcyc/σ’vc) @ 0.1 Hz until peak-to-peak γ of 5% is reached</th>
<th>Post-Cyclic Shear (PCS) Post-cyclic monotonic shear (τPCS) to γ=20% @ rate of 1.4%/hour</th>
</tr>
</thead>
<tbody>
<tr>
<td>HCL2 S17-B1</td>
<td>e = 1.70, Wn = 39%, PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 8354 psf (400kPa), (OCR = 2)</td>
<td>Cyclic stress ratio, CSR=0.3 Cycles to 3% γ S.A, N=70</td>
<td>Shear Resistance at γ=10% τPCS=3500 psf (168 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B2</td>
<td>e = 1.40, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 8354 (400kPa), (OCR = 2)</td>
<td>Cyclic stress ratio, CSR=0.5 Cycles to 3% γ S.A, N=1</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B3</td>
<td>e = 1.30, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 8354psf (400kPa), (OCR = 2)</td>
<td>Cyclic stress ratio, CSR=0.37 Cycles to 3% γ S.A, N= 1</td>
<td>Shear Resistance at γ=10% τPCS=3200 psf (153 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B4</td>
<td>e = 0.67, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 8354 psf (400kPa), (OCR = 2)</td>
<td>Cyclic stress ratio, CSR=0.34 Cycles to 3% γ S.A, N=3</td>
<td>Shear Resistance at γ=10% τPCS=3250 psf (156 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B5</td>
<td>e = 1.40, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 5576 psf (267kPa), (OCR = 3)</td>
<td>Cyclic stress ratio, CSR=0.4 Cycles to 3% γ S.A, N=6</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B6</td>
<td>e = 1.26, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 5576 psf (267kPa), (OCR = 3)</td>
<td>Cyclic stress ratio, CSR=0.35 Cycles to 3% γ S.A, N=85</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B7</td>
<td>e = 1.23, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 5576 psf (267kPa), (OCR = 3)</td>
<td>Cyclic stress ratio, CSR=0.37 Cycles to 3% γ S.A, N=34</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S17-B8</td>
<td>e = 1.18, Wn = 39% PI = 7</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 5576 psf (267kPa), (OCR = 3)</td>
<td>Cyclic stress ratio, CSR=0.38 Cycles to 3% γ S.A., N=23</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S20-A7</td>
<td>e = 1.34, Wn = 43% PI = 4</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 4177 psf (200kPa), (OCR = 4)</td>
<td>Cyclic stress ratio, CSR=0.50 Cycles to 3% γ S.A., N=24</td>
<td>Shear Resistance at γ=10% τPCS=3000 psf (144 kPa)</td>
</tr>
<tr>
<td>HCL2 S20-A8</td>
<td>e = 1.01, Wn = 43% PI = 4</td>
<td>Sample consolidated to 16708 psf (800kPa) and unloaded to 4177 (200kPa), (OCR = 4)</td>
<td>Cyclic stress ratio, CSR=0.65 Cycles to 3% γ S.A, N=2</td>
<td>Shear Resistance at γ=10% τPCS=3350 psf (160 kPa)</td>
</tr>
</tbody>
</table>
Figure 19. Cyclic Results at 3% Single Amplitude Shear Strain for Longview, WA.
Figure 20. Normalized cyclic shear strain with undrained shear strength vs. number of cycles.
Figure 21. Post-Cyclic Shear ($\tau_{PCS}$) and Monotonic Shear Test Results Normalized with effective stress
Figure 22. Post Cyclic Shear Results Normalized with Static Shear Values.
**Figure 23.** Ratio of Post-Cyclic to Static Shear Resistance vs. Strain.
Figure 24. Ratio of Post-Cyclic to Static Shear Resistance vs. Ru.
3.2 Klamath Falls, OR: High Plasticity Silt (Diatomaceous Soil)

Soil obtained from this site underwent testing for Atterberg limits, fines content analysis, and stress-controlled cyclic testing. Soils tested at PSU’s geotechnical lab were sampled at 13 ft bgs. The soil at this site has been characterized as high plasticity silt, USCS classification of MH, with PI of 45. Percent passing the #200 sieve (fines content) for these soils is 100%. Cyclic testing for this soil was done by consolidating the sample to 2005 psf and unloading to 940 psf (45 kPa) to test the samples at an OCR or 2.1. A total of three samples were tested at CSR 0.23, 0.4, and 0.58. Cyclic results are presented in Figure 25 and Figure 26, and test parameters are shown in Table 5. Samples tested at CSR 0.23 and 0.58 underwent post-cyclic shear, whereas the sample tested at a CSR of 0.4 underwent post-cyclic consolidation.

![Figure 25. Cyclic Results at 5% Double Amplitude Shear Strain for Klamath Falls, OR.](image)
Figure 26. Cyclic Loops for Klamath Falls, OR.
Figure 27. a) Klamath Falls diatomaceous sample S3-T1 trimmed into trimming ring. b) Sample S3-T1 after being transferred to CDSS set-up. S3-T1 tested at CSR 0.23 at σvc = 940 psf (45 kPa).
Table 5. Test Parameters for Klamath Falls, OR High Plasticity Silt

<table>
<thead>
<tr>
<th>Sample - Test</th>
<th>Total Density(^1) and Water Content</th>
<th>Consolidation Stage</th>
<th>Stress-Controlled Cyclic Shear Test</th>
<th>Post-Cyclic Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2 – T1</td>
<td>(\rho = 1214.6) Kg/m(^3) (w = 147%) (pre-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.58 ((\tau_{cyc}/\sigma_{vc})) @ 0.1 Hz until peak-to-peak shear strain of 5% is reached, (\sigma_{vc} = 940) psf (45 kPa)</td>
<td>Post-cyclic monotonic shear to 20% shear strain @ rate of 1.4%/hour</td>
</tr>
<tr>
<td>S3 – T1</td>
<td>(\rho = 1207.1) Kg/m(^3) (w = 181%) (pre-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.23 ((\tau_{cyc}/\sigma_{vc})) @ 0.1 Hz for 220 cycles(^2), (\sigma_{vc} = 940) psf (45 kPa)</td>
<td>Post-cyclic monotonic shear to 20% shear strain @ rate of 1.4%/hour</td>
</tr>
<tr>
<td>S4 – T1</td>
<td>(\rho = 1101.4) Kg/m(^3) (w = 247%) (after-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.4 ((\tau_{cyc}/\sigma_{vc})) @ 0.1 Hz until peak-to-peak shear strain of 8% is reached, (\sigma_{vc} = 940) psf (45 kPa)</td>
<td>Post-cyclic re-consolidation to 940 psf (45 kPa)</td>
</tr>
<tr>
<td>S4 – T2</td>
<td>N/A</td>
<td>Sample from previous test was re-consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.5 ((\tau_{cyc}/\sigma_{vc})) @ 0.1 Hz until peak-to-peak shear strain of 8% is reached, (\sigma_{vc} = 940) psf (45 kPa)</td>
<td>Post-cyclic re-consolidation to 940 psf (45 kPa)</td>
</tr>
</tbody>
</table>

1. Calculated from weight of specimen inside a rigid ring with 2.5-inch diameter and 1-inch height
2. Sample did not reach 5% shear strain, and the cyclic stage was stopped after 220 cycles

3.3. Beaverton Oregon: Low Plasticity Silt with Trace Sand, and Low Plasticity Clay with Trace to Some Sand

This site's location is near the Oregon Highway 217 (OR-217) by the Allen Blvd exit. OR 217 connects the U.S Route 26 (U.S 26) with Interstate 5 (I-5). Soil obtained from this site underwent testing for Atterberg limits, fines content, and stress-controlled
cyclic shear testing followed by post-cyclic testing. Soils tested at PSU’s geotechnical lab were sampled at 8 and 19ft bgs. A summary of tests completed for this site is shown in Table 6.

**Shallow Sample:**

The soil at 8 ft has been characterized as a low plasticity clay (CL) trace to some sand, with a PI of 10, a natural water content of 29%, and an SPT N value of 6. Cyclic testing for this soil was completed by consolidating the sample to 417 psf to test the samples at an OCR of 1. A total of 9 samples were tested at CSR values ranging between 0.1 and 0.69, as shown in Table 6. Eight Samples underwent post-cyclic shear, and one sample tested at a CSR of 0.3 underwent post-cyclic consolidation.

**Deep Sample:**

The soil at 19 ft bgs is classified as low plasticity silt with sand (ML) with a PI of 4, a natural water content of 29%, and an SPT N value of 14. Cyclic testing for this soil was done by consolidating the sample to 856 psf, testing the soil at an OCR of 1. A trimmed sample from this depth can be seen in Figure 25. These soils were cyclically loaded to the CSR values shown in Table 5. All samples from this depth were tested for post-cyclic shear. Test results from the deep and shallow samples are shown in Figure 28. Figure 29 shows post-cyclic consolidation results.
Table 6. Test Parameters for Beaverton, OR soils

<table>
<thead>
<tr>
<th>Sample – Test</th>
<th>Total Density$^1$ and Water Content</th>
<th>Consolidation Stage</th>
<th>Stress-Controlled Cyclic Shear Test</th>
<th>Post-Cyclic Test</th>
</tr>
</thead>
<tbody>
<tr>
<td>S2 – T1</td>
<td>( \rho = 1214.6 ) Kg/m³ ( w = 147% ) (pre-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.58 (( \tau_{cyc}/\sigma'<em>{vc} )) @ 0.1 Hz until peak-to-peak shear strain of 5% is reached, ( \sigma'</em>{vc} = 940 ) psf (45 kPa)</td>
<td>Post-cyclic monotonic shear to 20% shear strain @ rate of 1.4%/hour</td>
</tr>
<tr>
<td>S3 – T1</td>
<td>( \rho = 1207.1 ) Kg/m³ ( w = 181% ) (pre-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.23 (( \tau_{cyc}/\sigma'<em>{vc} )) @ 0.1 Hz for 220 cycles, ( \sigma'</em>{vc} = 940 ) psf (45 kPa)</td>
<td>Post-cyclic monotonic shear to 20% shear strain @ rate of 1.4%/hour</td>
</tr>
<tr>
<td>S4 – T1</td>
<td>( \rho = 1101.4 ) Kg/m³ ( w = 247% ) (after-test)</td>
<td>New sample was consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.4 (( \tau_{cyc}/\sigma'<em>{vc} )) @ 0.1 Hz until peak-to-peak shear strain of 8% is reached, ( \sigma'</em>{vc} = 940 ) psf (45 kPa)</td>
<td>Post-cyclic re-consolidation to 940 psf (45 kPa)</td>
</tr>
<tr>
<td>S4 – T2</td>
<td>N/A</td>
<td>Sample from previous test was re-consolidated to 2005 psf (96 kPa) and unloaded to 940 psf (45 kPa) (OCR = 2)</td>
<td>Cyclic stress ratio, CSR = 0.5 (( \tau_{cyc}/\sigma'<em>{vc} )) @ 0.1 Hz until peak-to-peak shear strain of 8% is reached, ( \sigma'</em>{vc} = 940 ) psf (45 kPa)</td>
<td>Post-cyclic re-consolidation to 940 psf (45 kPa)</td>
</tr>
</tbody>
</table>
**Figure 28.** Cyclic Shear Ratios (CSR) versus number of cycles to 5% double amplitude shear strain
Figure 29. Post-cyclic consolidation results of Beaverton OR, low plasticity clay with silt. Volumetric strain results with respect to: \(a\): max shear strain, \(b\): Maximum pore water pressure during cyclic loading.
3.4 Columbia River Slough: Silty Sand

Soil obtained from this site underwent testing to determine soil classification, fines content analysis, and stress-controlled cyclic testing followed by post-cyclic shear. Soils tested at PSU’s geotechnical lab were sampled at 40 ft bgs. The soil at this site has been characterized as silty sand (SM). Percent passing the #200 sieve (fines content) for these soils is 34%. Cyclic testing for this soil was done by consolidating the sample to 5139 psf and unloading to 3676 psf, to test the samples at an OCR of 1.4. A total of three samples were tested at CSR 0.15, 0.20, and 0.23. Cyclic shear and post cyclic shear test results are shown in Figure 30 through Figure 32. An example of a trimmed sample from this site is shown in Figure 33. Testing parameters for this site are shown in Table 7.

![Figure 30](image-url)  
**Figure 30.** Cyclic Shear Ratios (CSR) versus number of cycles to 3% single-amplitude shear strain
Figure 31. Pore pressure generation at 3% single-amplitude shear strain
Figure 32. Post-cyclic shear results normalized with effective stress versus shear strain
Figure 33. a) Sample trimmed into trimming ring. b) Columbia River Slough, OR trimmed sample before cyclic shear testing
<table>
<thead>
<tr>
<th>Boring</th>
<th>Shelby Tube</th>
<th>Specimen</th>
<th>Dry Unit Weight (kN/m³)</th>
<th>Water Content (%)</th>
<th>Consolidation Stress (kPa)</th>
<th>OCR</th>
<th>CSR</th>
<th>No. of Cycles to 5% Double Amp. Shear Strain</th>
<th>Post Cyclic Monotonic Shear</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>Before Test</td>
<td>After Test</td>
<td>Before Test</td>
<td>After Test</td>
<td>Phase I</td>
<td>Phase II</td>
<td>Rate (in/hr)</td>
</tr>
<tr>
<td>TB 2018-01</td>
<td>40'-42'</td>
<td>S1</td>
<td>14.6</td>
<td>15.2</td>
<td>31.7</td>
<td>28.3</td>
<td>246</td>
<td>176</td>
<td>1.4</td>
</tr>
<tr>
<td>TB 2018-01</td>
<td>40'-42'</td>
<td>S2</td>
<td>13.8</td>
<td>14.5</td>
<td>35.2</td>
<td>32.1</td>
<td>246</td>
<td>176</td>
<td>1.4</td>
</tr>
<tr>
<td>TB 2018-01</td>
<td>40'-42'</td>
<td>S3</td>
<td>13.7</td>
<td>14.4</td>
<td>33.5</td>
<td>28.2</td>
<td>246</td>
<td>176</td>
<td>1.4</td>
</tr>
</tbody>
</table>
CHAPTER 4. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

Site characterization and cyclic shear testing were performed on soils underlying critical infrastructure. These sites included Sunderland- a location near the Port of Portland, the Columbia River Slough, a site in Longview, WA, a site in Klamath Falls, OR, and a site by highway OR-217 in Beaverton, OR. Comparison of the b-values from CRR-versus-N relation, as described in Idriss and Boulanger 2008 (Equation 2) was done for these sites and presented in Table 8. The values presented include the b-values obtained from CDSS tests performed on reconstituted soil tests samples from Beaverton, OR as presented in Almoumen (2020).

$$CRR = a \times N^{15-b} \quad Equation \, 2.$$
Table 8. Testing summary for other sites in the PACNW.

<table>
<thead>
<tr>
<th>Site</th>
<th>USCS Soil Classification</th>
<th>Sampling Depth(s) ft</th>
<th>Plasticity Index (PI)</th>
<th>Wn/LL</th>
<th>FC (%)</th>
<th>CRR&lt;sub&gt;LR&lt;/sub&gt;</th>
<th>b-value CRR= a*N&lt;sub&gt;15&lt;/sub&gt;</th>
<th>Post-cyc Consolidation e&lt;sub&gt;v&lt;/sub&gt; (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Longview, WA</td>
<td>ML</td>
<td>90, 120</td>
<td>7.4</td>
<td>1.08, 1.23</td>
<td>73</td>
<td>OCR=2: 0.36</td>
<td>OCR=3: 0.37 OCR=4: 0.57</td>
<td>OCR=2: 0.05 OCR=3: 0.05 OCR=4: 0.11</td>
</tr>
<tr>
<td>Klamath Falls, OR</td>
<td>MH</td>
<td>13</td>
<td>45</td>
<td>1.3</td>
<td>100</td>
<td>0.38</td>
<td>0.17</td>
<td>0.2</td>
</tr>
<tr>
<td>Beaverton, OR</td>
<td>ML, CL</td>
<td>8, 20</td>
<td>4, 10</td>
<td>0.97, 0.88</td>
<td>N/A</td>
<td>CL: 0.17</td>
<td>ML: 0.08 CL: 0.17 ML 0.08</td>
<td>1.3</td>
</tr>
<tr>
<td>Columbia River Slough,</td>
<td>SM</td>
<td>40-42</td>
<td>N/A</td>
<td>N/A</td>
<td>48</td>
<td>0.22</td>
<td>0.15</td>
<td>N/A</td>
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<tr>
<td>Portland, OR</td>
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<td></td>
<td></td>
<td></td>
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<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Reconstituted Silt,</td>
<td>ML</td>
<td>N/A</td>
<td>8</td>
<td>N/A</td>
<td>N/A</td>
<td>OCR=1: 0.15</td>
<td>OCR=1: 0.19</td>
<td>N/A</td>
</tr>
<tr>
<td>Beaverton, OR&lt;sup&gt;*&lt;/sup&gt;</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

*Reconstituted test results from Almoumén (2020).
Cyclic shear testing of the soils at these sites will help understand these soils' behavior during a Cascadia Subduction Zone event, or rupture of nearby faults. Further analysis on the effect of fines content, stress history, and depositional environment on cyclic shear resistance is necessary. The results presented for these studies will contribute towards a database currently being developed by PSU’s geotechnical department.

4.1 Sunderland Site by the Port of Portland

Columbia River floodplain deposits in Portland, Oregon consist of low plasticity silts (ML) with a PI range of 8-20 and a fines content of 95%. These soils were deposited in the Holocene age with an OCR that varying between 1.5 to 6. The cyclic behavior of these soils was studied using field cyclic tests with mobile field shakers from NHERI@UTexas, and RCTS and CDSS laboratory tests covering a range of $\gamma$ from 0.00005% to 0.5%. The threshold cyclic $\gamma$ for pore water pressure ($\gamma_{pp}$) was found to range between 0.01% to 0.03% based on field cyclic and RCTS tests results. For $\gamma$ up to 0.5%, the CDSS tests produced significantly larger pore pressures ($r_u$ of 25% to 40%) compared to field cyclic and RCTS tests that produced $r_u$ less than 10% for 30 uniform loading cycles. This variation in results is attributed to various factors including different loading conditions, sample disturbance, and drainage between various tests. It is important to consider this difference in pore pressures when interpreting the results of CDSS tests for liquefaction susceptibility studies for infrastructure.
4.2 Other Silty Soils from the Pacific Northwest

**Longview, WA**

Soil obtained from the Longview, WA site underwent Atterberg limit testing, fines content analysis, 1-D consolidation, monotonic shear testing, and stress-controlled shear testing with post cyclic shear. The PI of the soils at this site are 4 and 7 and classified as low plasticity silt (ML). The fines content for these soils is 73%. The over-consolidation ratio determined from 1-D consolidation is an OCR of 2. The static shear behavior of these soils was studied by completing four monotonic shear tests at OCRs 1, 2, 3, and 4. These soils' cyclic behavior was studied by completing ten cyclic-shear tests at CSR values ranging between 0.3 and 0.65 and tested at OCRs or 2, 3, and 4.

**Klamath Falls, OR**

Soil obtained from Klamath Falls underwent testing for Atterberg limits, fines content analysis, and stress-controlled testing with post cyclic shear and post cyclic consolidation. The soil at this site consists of high plasticity silt (MH) with a PI of 45. Fines content for these soils is 100%. Cyclic behavior of this soil was studied by performing three cyclic-shear tests loaded to an OCR of 2.1

**Beaverton, OR**

Soil sampled at 8 ft consists of low plasticity clay (CL) trace to some sand, with a PI of 10 based on Atterberg limit testing. Samples from this depth were tested at an OCR of 1. Soil sampled at 19 ft consists of low plasticity silt (ML) with trace sand, with a PI of 4.
**Columbia River Slough, OR**

Soil obtained at this site is characterized as silty sand (SM), with 34% fines content. The cyclic behavior of these soils was studied by performing three cyclic-shear tests at an OCR of 1.4.

### 4.3 Recommendations

Future work for any site undergoing cyclic shear testing should include a full site characterization by performing: Atterberg limits, fines content analysis, hydrometer testing, 1-D consolidation, monotonic shear testing, and cyclic testing with post cyclic shear and post cyclic consolidation. Future work should also include cyclic shear testing of slurry samples to compare to the undisturbed sample results and determine the effects of depositional environment and geology, aging and stress history, and soil fabric and structure. Careful sample extrusion and trimming were considered when preparing soil samples used for 1-D consolidation, cyclic-shear testing, and monotonic shear testing. Sample trimming and extrusion followed recommendations from DeGroot and Ladd (2012). Sample trimming quality must be considered when preparing samples for any advanced testing (1-D Consolidation, CDSS, RCTS, or MDSS). Samples with large voids, or highly disturbed during sample extraction of sample trimming should never be tested.

In closing, civil engineers of the Pacific Northwest need to consider the additional roles and duties of the profession. Roles that include community outreach on the potential for damage of critical infrastructure from CSZ and shallow-crustal
earthquakes. We need the public to be aware of the earthquake risks of the region, prepare themselves and their communities for the CSZ event, and understand the needs to retrofit existing infrastructure and efforts to mitigate liquefaction.
REFERENCES


APPENDIX A. Using the CDSS Device at Portland State University

Set-up of Cyclic Direct Simple Shear Machine (CDSS) Shear Track-3 – Geocomp

Written by Melissa Preciado, Rawan Almoumen, Kayla Sorenson, and Max Miller

STAGE 1- Before the test:
1. Extrude Shelby tube and follow Shelby tube extrusion protocols, including taking torvanes where possible considering the number of samples needed for cyclic, monotonic, and consolidation testing.
2. Prepare the sample as required by the test (remolded vs. undisturbed).

Figure 1. Sample set-up components. Top (left to right): bottom plate with bottom porous stone (attached), note the vertical bolts on the bottom left and top right of the bottom plate. Black O-rings. Bottom (left to right): Teflon stackable rings, top cap with attached porous stone, Teflon ring pins, suction ring with vacuum hose attachment.

3. Save trimmings to perform Atterberg limits and washes.
   **Measurements at this point:** Weight of ring, weight of ring+moist soil.

**Undisturbed sample:**
   a. After soaking bottom plate and top cap’s porous stones, place wetted filter paper on top and bottom porous stones and puncture through porous stone pins to ensure contact between pins and soil.
b. Place and center trimming ring with undisturbed sample on the bottom cap, push sample out of the trimming ring using the piece shown below:

c. Wrap membrane around the suction ring and ensure it is against the inner wall of the suction ring with no wrinkles using the hose tube.
d. Place the membrane around the undisturbed sample making sure to not touch the sample during the process. Before releasing the suction, place the top cap on the soil. Release the suction and place the membrane around the bottom cap, the sample and the top cap ensure there are no folds in the membrane. Put an O-ring on the bottom cap as shown below:
e. With the same ring, place the O-rings on the bottom cap grooves.

f. Stack the Teflon rings using the pins (typically you need around 30-34 Teflon rings for a 1-in. high sample.

g. When placing the stack of Teflon rings around the membrane, be sure not to bump the sample too much or force down. You may need to stack the rings individually if there is too much resistance along the sample walls. Finally, put another O-ring on the top cap to secure the membrane down. Both top and bottom caps have grooves where the O-rings need to be placed. Be sure the O-rings are in the correct location.
You are now ready to take your sample set up to the CDSS device

Geocomp Shear-Trac Instructions
Figure 2. Geocomp’s ShearTrack-II
A. LVDT
B. Four prong nuts (4-star knobs)
C. Piston Cap screws
D. Bolts for lowering and lifting arm
E. Large Piston Screw
F. Shear box T-bolts
G. Water bath box
H. Horizontal control keypad
STAGE 2- Setting up the sample in the CDSS:

1. Open the CDSS software on the computer.

2. Select the pre-filled template from the Desktop depending on which type of test you will need to run. Options are:
   - Stress-controlled cyclic test,
   - Strain-controlled cyclic test, and
   - Static/Monotonic shear tests.

3. Open the System Monitor and Calibration windows side by side. At this point with the bath box centered, and the crossbar hanging (no load), your System monitor should read ‘0’ load in the Vertical Load and Horizontal load outputs. If that is not the case, you can tell the device there are no loads at this point by typing in the “counts”, a five digit number shown in the System Monitor next to the load, into the Calibration window. Press [Okay], then [Apply].

4. If the test requires the sample to be submerged add water to the bath halfway as to not overflow when adding the sample set up assembly. Water needs to be above and below the porous stones. The membrane needs to be rolled up and have water added as shown below- or rolled down and have the water bath [G] filled up.
5. Ensure the sample’s top cap horizontal bolt (green in figure 3) is loose before placing a sample in the CDSS device. When placing the sample into the bath box, make sure the bottom plate is pushed all the way to the right and that it is fitting snug, it should not wiggle out of place. The large vertical bottom plate bolts (Figure 1) should always be on the top left and bottom right sides of the bath box.

6. Tighten bottom plate to shear box (bath box) using T-bolts [F]. Ensure the bath box is centered before continuing onto the next step.

7. Raise the vertical threads for the load cell crossbar to the highest position before each test. This will allow your sample to consolidate without hitting the bottom vertical limits, therefore ending your test too early. You can raise the crossbar by pressing 2-Position, then 4-Jog on the VERTICAL control panel of the CDSS.

8. Lower arm with piston. Tighten arm bolts [D]. If the top cap hole does not line up with the piston significantly (more than a couple millimeters) turn the sample set up 180 degrees (making sure the large shear box vertical screws are on the top left and bottom right sides of the bath box. Use the Horizontal control panel to align the shear box with the piston (2-Position, then press 4-Jog) while making sure the bath box remains within the CENTER boundaries labeled manually. The Position and Jog functions should be used to make final adjustments, and to make sure the sample is fully centered and aligned with the piston.

9. Lower piston onto the top cap, then secure piston by tightening the adjacent screw [E] hereby called the “piston screw”. This will keep any unwanted load from transferring to your sample while you are finishing up the setup of the device. Keep this screw tightened until right before you start your test.

10. At this point screws/bolts F, D and E should have been tightened in that sequential order. You will now make sure the top cap is around the piston tightly. (Refer to Figure 3):

   a. Tighten the red screws as seen below. Tighten top cap bolt
   b. Tighten piston cap bolts. These screws connect the pop and bottom portions of the top cap together.
Figure 3. Schematic for top cap set up.

11. Now fill in all necessary information about your project, sample inputs, loading conditions, and other necessary information onto the software:

*** At any point, if you must change units or see different units displayed, you can go to the [Options] tab, scroll down to units, and select the units you feel the most comfortable with, or the units given by the PM, to ensure the correct loading is applied to your sample during testing.

   a. PROJECT tab: Fill in any relevant project information such as the project name/number, location of soil tested, preparation, test date, etc.
   b. SPECIMEN tab: Make sure your sample height is included and sample diameter as 2.5-in.
   c. WATER CONTENT tab: Fill in the necessary information that was obtained from STAGE 1 (Left side only)
   d. READ TABLE tab: you do not need to change anything in this tab.
   e. TEST PARAMETERS: Choose which test you will begin with from the options given, this should be selected as Consolidation.
   f. CONSOLIDATION TABLE tab: fill out the consolidation parameters you wish to apply to the soil sample.
   g. CYCLIC TABLE: fill out the cyclic parameters you wish to apply to the soil sample,
   h. SHEAR TABLE: fill out any shear parameters you wish to apply to the soil sample (if you have the CYCLIC TABLE filled out, this step will be post-cyclic shear. You can perform a monotonic DSS test (MDSS) by making sure the CYCLIC table does not have any rows filled.
12. **Save!** File naming convention:

```
Machine_Job#_Boring#_Sample#_TestID(puck or test#)_CDSSorMDSS
_CyclicTestParameter_OCR
```

**Example for a 1.2% shear strain-controlled, OCR3 Test:**

```
ST3_6238_B-14_U-3_Puck3_CDSS1.2_OCR3
```

13. Open the **System Monitor** window and observe how your loads change as you tighten the screws you will be directed to tighten below. Be sure to follow the tightening sequence provided in this document as doing so can decrease the chance of you applying incorrect loads!

   a. At this point, the piston bolt [E] should be tightened to keep loads from being transferred onto the sample.

   b. Adjust the lower cross bar hex nuts to make sure your crossbar is making full contact with the piston.

   c. Turn the lower hex nuts two rotations, leaving < 1mm gap between the load cell and the piston. You can check you have a gap by sliding a piece of paper between the load cell and the piston and it should move freely.

   d. At this point, lower the 4-star knobs [B] to secure the cross bar down. Make sure your sample is level. Again, look at the System monitor to make sure you do not over-tighten the 4 Star knobs. Your load should not read higher than |8lbs|.

   e. Place the LVDT on the crossbar and secure it in place with the 4-Star knob.

   f. Place the piston cap [C] and loosely screw it onto the load cell. One last time, open the **System Monitor Window** and **Calibration** windows and zero out the load.

   g. Release the piston bolt [E]. Be sure the piston bolt [E] is **not** tight before proceeding!
h. Open [Control] tab, select Vertical Load and Horizontal Load. Two windows will pop up, one for vertical control and one for horizontal control. Type in zero for the load (lb), then click [Go]. You will hear the gears in the device make noise, observe the System Monitor until you see the loads get as close to zero as possible and you no longer hear the machine making much noise and/or the machine lights (below) have stopped flashing. Click [Stop] once the machine is not flashing or making noise.

i. Your load in the System Monitor should be lower than 1lb before starting your test. With experience, you will learn how hard to tighten the screws to prevent your loads higher than 1lb when releasing screw [E]. It is suggested you practice this method or dummy samples until you feel confident with the procedures and you are consistently achieving the <1lb load threshold before starting each test.

*** As you are tightening your loads should remain lower than 8lbs
j. You are ready to start your test. Go to the [Run] tab, select [Start]. This version of the software will prompt you to center the bath box and Position Crossbar after you have hit [Start] on your test. Select [Yes] and wait until you do not hear the gears turning/the machine making much noise. You will notice the lights shown below light up if the machine is still calibrating. Wait until the lights stop flashing before hitting [Yes].

Notes from Melissa About Software Settings and Troubleshooting

Notes from Geocomp phone call 10/31/2019:
Before every test make sure to check the following settings:
   1. Hardware Setup:
      Go to: Options > Hardware and the following window shows up:
Make sure the Enable FB box is checked. Click Apply.

2. Drive Settings:
   Go to Options > Drive. The following window shows up:

   ![Drive Settings Window](image)

   Click Scan, then Apply, then Close.

   ***If the following error message pops up two things might be the problem:
   1. The cable connecting the CDSS to the computer might be loose
   2. A test is in process
3. Check Constant Volume Gain- CVG- (based on soil type and trial/error): This value will need to be adjusted if the test results show an axial strain outside -0.005 to 0.005%.

Below is an example of what a good value chosen for CVG looks like in the report:
4. Desired Response Gain - DRG- (Based on soil stiffness, stiff soils typ. 2, soft soils 6-8):
A good value for DRG is determined by observing the sinusoidal waves during the test (View> test graph). A good value would show a sinusoidal wave like the ones below.
5. As to why we might see the silt tests have a preference to the left: Geocomp mentioned our samples may not be consolidated enough, he suggests increasing the time of consolidation, AND making sure step 1 (above) of the Hardware Setup is completed.

6. Additional Comments:
   - Minimum strains the device can capture are 1/2000"
   - Maximum strain 5%, sometimes even 10%
   - Maximum axial strain should be less than 0.5%

Readings per cycle were reduced from 512
APPENDIX B. LONGVIEW, WA TEST RESULTS

Cyclic Direct Simple Shear Test Results
HCL2_S17_B1 CSR=0.30
Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 104 psi

<table>
<thead>
<tr>
<th>Vertical Displacement, m</th>
<th>Log of Time, min</th>
</tr>
</thead>
</table>

<table>
<thead>
<tr>
<th>Vertical Displacement, m</th>
<th>Sqrt of Time, √min</th>
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</thead>
</table>

<table>
<thead>
<tr>
<th>Project Name: HC, Longview</th>
<th>Location: Longview, WA</th>
<th>Project Number: 19132/01</th>
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<tbody>
<tr>
<td>Soring Number: HCL2</td>
<td>Tester: AMP</td>
<td>Checker:</td>
</tr>
<tr>
<td>Sample Number: S17</td>
<td>Test Date: 06/14/2019</td>
<td>Depth: 90 ft</td>
</tr>
<tr>
<td>Test Number: S1</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 55 ft bgs</td>
</tr>
<tr>
<td>Description: Very Soft, wet, gray Silt WITH SAND, fine sand, low plasticity, some organic</td>
<td>Remarks:</td>
<td></td>
</tr>
</tbody>
</table>
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 1.67e+04 psf

Project Name: HC, Longview
Location: Longview WA
Project Number: 19132-01
Boring Number: HC32
Tester: AMP
Checker:
Sample Number: S17
Test Date: 06/14/2019
Depth: 90 ft
Test Number: 81
Preparation: Undisturbed
Elevation: 658 ftgs
Description: Very Soft, wet, gray SLT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

Cyclic Debug
Step 1 of 1

<table>
<thead>
<tr>
<th>Shear Stress, psf</th>
<th>Gain</th>
<th>Output, steps</th>
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<th>Project Name: HC, Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: 10132-01</th>
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<tr>
<td>Boring Number: HC-2</td>
<td>Tester: AMP</td>
<td>Checker:</td>
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<tr>
<td>Sample Number: 017</td>
<td>Test Date: 05/14/2013</td>
<td>Depth: 30 ft</td>
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<tr>
<td>Test Number: B1</td>
<td>Preparation: Undisturbed</td>
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<tr>
<td>Description: Very Soft, wet, gray Silt WITH SAND, fine sand, low plasticity, some organics</td>
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<td>Remarks:</td>
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</table>
Cyclic Simple Shear Test
Cyclic Modulus/Damping Results
Step 1 of 1

![Graphs showing cyclic simple shear test results](image)

<table>
<thead>
<tr>
<th>Project Name: HC, Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: 19122-01</th>
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<tr>
<td>Boring Number: HCL2</td>
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<td>Checker:</td>
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<td>Sample Number: 017</td>
<td>Test Date: 06/14/2019</td>
<td>Depth: 50ft</td>
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<td>Test Number: B1</td>
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<tr>
<td>Description: Very soft, wet, gray Silt &amp; Sand, fine sand, low plasticity, some organics</td>
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<td>Remarks:</td>
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</tbody>
</table>

89
Cyclic Simple Shear Test

Shear Stress, psi

Axial Strain, %

Excess Pressure, psi

Shear Strain, %

Project Name: HC, Longview  Location: Longview WA  Project Number: 19132-01
Boiling Number: HCL2  Tester: AMP  Checker:
Sample Number: 517  Test Date: 06/14/2019  Depth: 90 ft
Test Number: B1  Preparation: Undisturbed  Elevation: 65 ft nga
Description: Very Soft, wet, gray Silt with sand, fine sand, low plasticity, some organics
Remarks:
$HCL2_{S17\_B2\ CSR=0.5}$
Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 5e+03 Pa

Log of Time, min

Vertical Displacement, m

Sort of Time, s/min

Project Name: HC_Longview
Location: Longview WA
Project Number: 19132-01
Boring Number: HCL2
Tester: AMP
Sample Number: S17
Test Date: 05/19/2019
Depth: 9 ft
Test Number: B2
Preparation: Undisturbed
Elevation: 65 ft bgs
Description: Very soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: 4e+05 Pa

---

Project Name: HC_Longview  Location: Longview WA  Project Number: 19132-01
Boring Number: HCL2  Tester: AMP  Checker:
Sample Number: S17  Test Date: 9/19/2019  Depth: 90ft
Test Number: B2  Preparation: Undisturbed  Elevation: 65ft bgs
Description: Very Soft, wet, gray SILT WITH SAND. fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

Cyclic Data

Step 1 of 1

Shear Stress, Pa

Shear Strain, %

Pressure Ratio

Cycle

Project Name: HC_Longview
Location: Longview WA
Project Number: 19132-01

Boring Number: HCL2
Tester: AMP
Checker:

Sample Number: S17
Test Date: 09/19/2019
Depth: 90ft

Test Number: B2
Preparation: Undisturbed
Elevation: 65ft bgs

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics

Remarks:
Cyclic Simple Shear Test
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

Shear Stress, Pa
-200000 -100000 0 100000 200000
Shear Strain, %
-10 -5 0 5 10

Normal Stress, Pa
-200000 -100000 0 100000 200000
-200000 -100000 0 100000 200000

---

Project Name: HC_Longview
Boxing Number: H3.2
Sample Number: S17
Test Number: B2
Tester: AMP
Test Date: 06/19/2019
Preparation: Undisturbed

Location: Longview WA
Project Number: 1912-01
Checker:
Depth: 90 ft
Elevation: 65 ft lbs

Description: Very Soft, wet, gray Silt with sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

Shear Stress, Pa

Axial Strain, %

Excess Pressure, Pa

Shear Strain, %

Project Name: HC_Longview
Location: Longview WA
Project Number: 10132-01
Boring Number: HCL2
Tester: AMP
Sample Number: 817
Test Date: 09/19/2019
Test Number: 82
Preparation: Unsaturated
Depth: 90 ft
Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organic
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 5e+03 Pa

Project Name: HC_Longview
Location: Longview WA
Project Number: 19132-61

Boring Number: HCL2
Tester: JMD

Sample Number: S17
Test Date: 06/19/2019
Depth: 90ft

Test Number: B3
Preparation: Undisturbed
Elevation: 65ft bgs

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 8e+05 Pa

---

Project Name: HC; Location: Longview; WA  Project Number: 19/132-61
Boring Number: H3.2  Test: AMP  Checker:
Sample Number: S17  Test Date: 06/19/2019  Depth: 90ft
Test Number: 83  Preparation: Undisturbed  Elevation: 60ft bgs
Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:

---

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Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: $4\times10^5$ Pa

<table>
<thead>
<tr>
<th>Project Name: HC, Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: 19132-01</th>
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<tbody>
<tr>
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<td>Tester: AMP</td>
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<tr>
<td>Sample Number: 917</td>
<td>Test Date: 06/15/2019</td>
<td>Depth: 90 ft</td>
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<tr>
<td>Test Number: B3</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 65 ft bgs</td>
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<td>Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
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<td>Notes:</td>
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Log of Time, min

Vertical Displacement, m

$\sqrt{t}$, min

Vertical Displacement, m
### Cyclic Simple Shear Test

**Cyclic Stress Strain Results**  
**Step 1 of 1**  
**Cycle 0.0 to 2.0**

<table>
<thead>
<tr>
<th>Shear Stress, Pa</th>
<th>Normal Stress, Pa</th>
</tr>
</thead>
<tbody>
<tr>
<td>200000</td>
<td>200000</td>
</tr>
<tr>
<td>100000</td>
<td>100000</td>
</tr>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>-100000</td>
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<tr>
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**Data Table**

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<thead>
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<th>Project Number: 19132-09</th>
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<tbody>
<tr>
<td>Boring Number: HG-12</td>
<td>Tester: AMP</td>
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<tr>
<td>Sample Number: 017</td>
<td>Test Date: 06/19/2019</td>
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</tr>
<tr>
<td>Test Number: 03</td>
<td>Preparation: Undisturbed</td>
<td>Depth: 30 ft</td>
</tr>
<tr>
<td>Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
<td>Elevation: 65 ft bgs</td>
<td>Remarks:</td>
</tr>
</tbody>
</table>
Cyclic Simple Shear Test
Cyclic Strain Results
Step 1 of 1
Cycle 0.0 to 2.0

<table>
<thead>
<tr>
<th>Project Name: HC_Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: 19132-01</th>
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<tr>
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<td>Tested: AMP</td>
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<tr>
<td>Sample Number: S17</td>
<td>Test Date: 06/19/2019</td>
<td>Depth: 901</td>
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<tr>
<td>Test Number: 003</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 651 bgs</td>
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</tbody>
</table>

Description: Very Soft, wet gray SILT WITH SAND, fine sand, low plasticity; some organics
Remarks
HCL2_S-17_B-4 CSR=0.34

Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 5e+03 Pa

Vertical Displacement, m

Log of Time, min

Square Root of Time, √min

Project Name: HC_Longview
Boring Number: HCL2
Sample Number: S17
Test Number: E1

Location: Longview WA
Tester: AMP
Test Date: 05/15/2019
Preparation: Undisturbed

Project Number: 19132-01
Checker:
Depth: 30 ft
Elevation: 65 ft bgs

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 8e+05 Pa
Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: 4e+05 Pa

---

| Description: Very Soft, wet, gray Silt With Sand, fine sand, low plasticity, some organics |
| Remarks: |

---

| Project Name: HC_Longview | Location: Longview WA | Project Number: 19132-01 |
| Boring Number: HCL2 | Tester: AMP | Checker: |
| Sample Number: S17 | Test Date: 06/28/2019 | Depth: 90 ft |
| Test Number: B4 | Preparation: Undisturbed | Elevation: 666 bgs |
Cyclic Simple Shear Test
Cyclic Stress Strain Results
Step 1 of 1
Cycle 1.0 to 7.0

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>Location:</th>
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<td>S17</td>
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<th>Preparation:</th>
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<tbody>
<tr>
<td>B4</td>
<td>Undisturbed</td>
<td>65 ft bgs</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Description:</th>
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<tbody>
<tr>
<td>Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
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<table>
<thead>
<tr>
<th>Remarks:</th>
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<tbody>
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Cyclic Simple Shear Test

Cyclic Strain Results

Step 1 of 1
Cycle 1.0 to 7.0

<table>
<thead>
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<th>Project Name: HC_Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: 19132-01</th>
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<tbody>
<tr>
<td>Boring Number: HC12</td>
<td>Tester: AMP</td>
<td>Checker:</td>
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<tr>
<td>Sample Number: S17</td>
<td>Test Date: 09/10/2019</td>
<td>Depth: 90'</td>
</tr>
<tr>
<td>Test Number: B4</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 65' bgs</td>
</tr>
</tbody>
</table>

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics

Remarks:
Cyclic Simple Shear Test

![Graph of Cyclic Simple Shear Test](image)

<table>
<thead>
<tr>
<th>Project Name: MC_Longview</th>
<th>Location: Longview PA</th>
<th>Project Number: 19132-01</th>
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<tbody>
<tr>
<td>Boxing Number: HC.2</td>
<td>Tester: AMP</td>
<td>Checker:</td>
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<td>Sample Number: S17</td>
<td>Test Date: 06/19/2019</td>
<td>Depth: 50ft</td>
</tr>
<tr>
<td>Test Number: B4</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 65ft bgs</td>
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</tbody>
</table>

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics

Remarks:
Cyclic Simple Shear Test

Shear Modulus, Pa

10^7

10^6

10^5

10^4

10^3

10^2

10^1

10

0.01

0.1

1

10

100

Shear Strain, %

Project Name: HC, Longview
Location: Longview, WA
Project Number: 15132-01
Doing Number: HCL2
Tester: AMP
Checker:
Sample Number: 517
Test Date: 06/19/2019
Depth: 90 ft
Test Number: B4
Preparation: Undisturbed
Elevation: 550 ft bgs
Description: Very soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Cyclic Data
Step 1 of 1

Shear Stress, Pa

Shear Strain, %

Pressure Ratio

Cycle

<table>
<thead>
<tr>
<th>Project Name: HC_Longview</th>
<th>Location: Longview WA</th>
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<tr>
<td>Bor ing Number: WCL2</td>
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<td>Sample Number: S17</td>
<td>Test Date: 06/14/2019</td>
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<tr>
<td>Test Number: B5</td>
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Cyclic Simple Shear Test
Cyclic Modulus/Damping Results
Step 1 of 1

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<th>Cycle</th>
<th>Peak-to-Peak Stress, Pa</th>
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<td>195000</td>
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<tr>
<td>1</td>
<td>200000</td>
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<tr>
<td>2</td>
<td>205000</td>
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<td>210000</td>
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<td>4</td>
<td>215000</td>
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<th>Cycle</th>
<th>Peak-to-Peak Strain, %</th>
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<td>4</td>
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<td>1</td>
<td>5</td>
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<tr>
<td>2</td>
<td>6</td>
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<td>3</td>
<td>7</td>
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<thead>
<tr>
<th>Cycle</th>
<th>Modulus, Pa</th>
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<td>4500000</td>
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<tr>
<td>2</td>
<td>3500000</td>
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<td>3</td>
<td>3000000</td>
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<tr>
<th>Cycle</th>
<th>Damping Ratio, %</th>
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<tbody>
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<td>10.0</td>
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<tr>
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<tr>
<td>2</td>
<td>11.0</td>
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<tr>
<td>3</td>
<td>11.5</td>
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Project Name: HC_Longview
Location: Longview WA
Project Number: 19132-01
Boring Number: HCL2
Tester: AMP
Checker:
Sample Number: S17
Test Date: 05/14/2019
Depth: 9 ft
Test Number: 85
Preparation: Undisturbed
Elevation: 85 ft bgs
Description: Very Soft, wet, gray Silt WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 8.0
Cyclic Simple Shear Test

Cyclic Strain Results
Step 1 of 1
Cycle 0.0 to 8.0

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<thead>
<tr>
<th>Project Name: LC_Langley</th>
<th>Location: Langley WA</th>
<th>Project Number: 9132-01</th>
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<tbody>
<tr>
<td>Boring Number: HCL2</td>
<td>Tester: AMP</td>
<td>Checkers</td>
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<tr>
<td>Sample Number: S17</td>
<td>Test Date: 06/14/2019</td>
<td>Depth: 90'</td>
</tr>
<tr>
<td>Test Number: 83</td>
<td>Preparation: Undisturbed</td>
<td>Sample: 65'EGS</td>
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</table>

Description: Very soft, wet, grey Silt with sand, fine sand, low plasticity, some organic
Remarks:
Cyclic Simple Shear Test

Shear Stress, Pa

Axial Strain, %

Excess Pressure, Pa

Shear Strain, %

Project Name: HC_Longview  Location: Longview WA  Project Number: 19122-01
Boring Number: HCL2  Tester: MMP  Checker:
Sample Number: S17  Test Date: 06/14/2019  Depth: 90 ft
Test Number: BS  Preparation: Undisturbed  Elevation: 650 ft
Description: Very Soft, wet, gray Silt with Sand, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

![Graph showing cyclic simple shear test results with stress plotted against effective normal stress.](image)

**Project Name:** HC, Longview  
**Location:** Longview WA  
**Project Number:** 19132-01

**Boring Number:** HCL2  
**Tester:** AMP  
**Checker:**

**Sample Number:** S17  
**Test Date:** 06/14/2019  
**Depth:** 90 ft

**Test Number:** 65  
**Preparation:** Undisturbed  
**Elevation:** 66 ft

**Description:** Very soft, wet gray SILT WITH SAND, fine sand, low plasticity, some organics

**Remarks:**
HCL2_S-17_B6 CSR=0.35

Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 104 psf

---

Project Name: HC_Longview  Location: Longview WA  Project Number: 19122-01
Boring Number: HCL2  Tester: AMP  Checker:  3rd Party
Sample Number: S17  Test Date: 06/14/2019  Depth: 90ft
Test Number: B6  Preparation: Undisturbed  Elevation: 65ft bgs
Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 1.67e+04 psf

<table>
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<th>Project Name: HC_Longview</th>
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<th>Project Number: 19112-01</th>
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<td>Boring Number: HCL2</td>
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<td>Sample Number: 317</td>
<td>Test Date: 06/14/2019</td>
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<td>Test Number: B6</td>
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<td>Elevation: 65 ft bgs</td>
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<tr>
<td>Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
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<tr>
<td>Remarks:</td>
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</table>
Cyclic Simple Shear Test
Cyclic Data
Step 1 of 1

Shear Stress, psf

Shear Strain, %

Pressure Ratio

Cycle

Project Name: HC_Longview  Location: Langview WA  Project Number: 19132-01
Boring Number: HCL2  Tester: AMP  Checker:
Sample Number: 517  Test Date: 06/14/2010  Depth: 90ft
Test Number: 66  Preparation: Unsaturated  Elevation: 65R bgs
Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

Shear Stress, psf

Effective Normal Stress, psf

Project Name: HC_Longview
Location: Longview WA
Project Number: TM132-01
Boxing Number: MCL2
Tester: AMP
Sample Number: S17
Test Date: 06/14/2013
Depth: 90 ft
Test Number: B6
Preparation: Undisturbed
Elevation: 59 ft bgs
Description: Very soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
HCL2_S-17_B7 CSR=0.37
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 1.67e+04 psf

Vertical Displacement, m

Log of Time, min

Vertical Displacement, m

Sqrt of Time, √min

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<thead>
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<th>Project Name: H2_Longview</th>
<th>Location: Longview WA</th>
<th>Project Number: H132-01</th>
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<td>Boring Number: H2.3</td>
<td>Tester: AMP</td>
<td>Checker:</td>
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<td>Sample Number: 517</td>
<td>Test Date: 05/14/2019</td>
<td>Depth: 90 ft</td>
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<tr>
<td>Test Number: B7</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 658 bgs</td>
</tr>
<tr>
<td>Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: 5.58e+03 psi
Cyclic Simple Shear Test

Cyclic Data
Step 1 of 1

Shear Stress, psf

Shear Strain, %

Pressure Ratio

Cycle

Project Name: RC, Longview
Location: Longview WA
Project Number: 19152-01
Drilling Number: HCL2
Tester: AMP
Checker:
Sample Number: S17
Test Date: 05/14/2019
Depth: 90 ft
Test Number: D7
Preparation: Undisturbed
Elevation: 606.6 bg
Description: Very soft, wet, gray SLT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

Cyclic Modulus/Damping Results

Step 1 of 1

Project Name: HC_Longview
Location: Longview WA
Project Number: 19132-01

Boring Number: WCL2
Tester: AMP
Checker:

Sample Number: S17
Test Date: 9/12/2019
Depth: 90 ft

Test Number: E7
Preparation: Undisturbed
Elevation: 68 ft bgs

Description: Very Soft, wet, gray Silt with Sand, fine sand, low plasticity, some organics

Remarks:
Cyclic Simple Shear Test
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 40.0

<table>
<thead>
<tr>
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<th>Project Number: 19132-01</th>
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<tbody>
<tr>
<td>Boring Number: HCL2</td>
<td>Tester: AMP</td>
<td>Checker:</td>
</tr>
<tr>
<td>Sample Number: S17</td>
<td>Test Date: 06/14/2019</td>
<td>Depth: 99ft</td>
</tr>
<tr>
<td>Test Number: B7</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 65ft bgs</td>
</tr>
</tbody>
</table>

Description: Very Soft, wet gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Cyclic Simple Shear Test

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Location</th>
<th>Project Number</th>
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<td>Longview WA</td>
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<td>Boxing Number</td>
<td>Tester</td>
<td>Checker</td>
</tr>
<tr>
<td>HCL2</td>
<td>ATP</td>
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<tr>
<td>Sample Number</td>
<td>Test Date</td>
<td>Depth</td>
</tr>
<tr>
<td>517</td>
<td>9/14/2019</td>
<td>65 ft bgs</td>
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<td>Test Number</td>
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<td>Elevation</td>
</tr>
<tr>
<td>67</td>
<td>Undisturbed</td>
<td>65 ft bgs</td>
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</table>

Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics

Remarks:
HCL2_S-17_B8 CSR=0.38
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 1.67e-04 psf

![Graph showing vertical displacement vs. log of time]

<table>
<thead>
<tr>
<th>Project Name:</th>
<th>HC, Longview</th>
<th>Location: Longview WA</th>
<th>Project Number:</th>
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</thead>
<tbody>
<tr>
<td>Boring Number:</td>
<td>HCL2</td>
<td>Tester: AMP</td>
<td>Checker:</td>
<td></td>
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<tr>
<td>Sample Number:</td>
<td>S17</td>
<td>Test Date: 06/14/2019</td>
<td>Depth: 90ft</td>
<td></td>
</tr>
<tr>
<td>Test Number:</td>
<td>B8</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 65ft bgs</td>
<td></td>
</tr>
<tr>
<td>Description:</td>
<td>Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks:</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cyclic Simple Shear Test

- Shear Stress, psf
- Effective Normal Stress, psf

Project Name: HC, Longelow | Location: Longelow WA | Project Number: 19/32-01
Boring Number: HCL2 | Tester: JMP | Checker:
Sample Number: S17 | Test Date: 06/14/2019 | Depth: 30ft
Test Number: B11 | Preparation: Undisturbed | Elevation: 65ft bgs
Description: Very soft, wet, gray SILT WITH SAND, fine sand, low plasticity, some organics
Remarks:
Monotonic Direct Simple Shear Test Results

HCL2_S-20_A3 OCR 4
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 800 kPa

![Graphs showing vertical displacement vs. time and square root of time.]

<table>
<thead>
<tr>
<th>Project No.</th>
<th>Location</th>
<th>Project No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>MC1, Longview</td>
<td>Longview</td>
<td>19132-01</td>
</tr>
<tr>
<td>Boring No.</td>
<td>Tested By</td>
<td>Checked By</td>
</tr>
<tr>
<td>HCL2</td>
<td>AMP</td>
<td></td>
</tr>
<tr>
<td>Sample No.</td>
<td>Test Date</td>
<td>Depth</td>
</tr>
<tr>
<td>S20</td>
<td>03/27/15</td>
<td>120 ft</td>
</tr>
<tr>
<td>Test No.: A3</td>
<td>Sample Type</td>
<td>Elevation</td>
</tr>
<tr>
<td></td>
<td>Undisturbed</td>
<td>936 BGS</td>
</tr>
<tr>
<td>Description:</td>
<td></td>
<td>Remarks:</td>
</tr>
<tr>
<td>Very Soft, wet, gray SLT WITH SAND, fine sand, low plasticity, trace organics</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: 200 kPa

Graph showing vertical displacement vs. time and square root of time.

Project: HC Longview
Location: Longview
Project No.: 18122-01
Boring No.: HCL2
Tested By: JPP
Sample No.: 520
Test Date: 03/27/19
Depth: 1208
Test No.: A3
Sample Type: Undisturbed
Elevation: 9985 CS

Description: Very Soft, wet gray SILT WITH SAND, fine sand, low plasticity, trace organics
Remarks:
CYCLIC SIMPLE SHEAR TEST

![Graphs showing shear stress, axial strain, and excess pressure vs. shear strain.]

**Table:**

<table>
<thead>
<tr>
<th>Project: HC_Longview</th>
<th>Location: Longview</th>
<th>Project No: 19132-01</th>
</tr>
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<tbody>
<tr>
<td>Boring No.: HCL2</td>
<td>Tested By: AMP</td>
<td>Checked By:</td>
</tr>
<tr>
<td>Sample No.: S20</td>
<td>Test Date: 03/27/19</td>
<td>Depth: 120 ft</td>
</tr>
<tr>
<td>Test No: A3</td>
<td>Sample Type: Undisturbed</td>
<td>Elevation: 99 RBGS</td>
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</tbody>
</table>

**Description:** Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, trace organics

**Remarks:**
CYCLIC SIMPLE SHEAR TEST

<table>
<thead>
<tr>
<th>Project: HC, Longview</th>
<th>Location: Longview</th>
<th>Project No: 19132.01</th>
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<tbody>
<tr>
<td>Boring No: HCL2</td>
<td>Tested By: AMP</td>
<td>Checked By:</td>
</tr>
<tr>
<td>Sample No: 520</td>
<td>Test Date: 03/27/19</td>
<td>Depth: 120 ft</td>
</tr>
<tr>
<td>Test No: A3</td>
<td>Sample Type: Undisturbed</td>
<td>Elevation: 098BCS</td>
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<tr>
<td>Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, trace organics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: $4\times10^5\text{ Pa}$

**Graphs:**
- **Top Graph:** Log of Time vs. Vertical Displacement
- **Bottom Graph:** Square Root of Time vs. Vertical Displacement

**Project Details:**
- **Project Name:** HC_Longview
- **Location:** Longview
- **Project Number:** 1913261
- **Boring Number:** HC12
- **Tester:** AMP
- **Checker:**
- **Sample Number:** 020
- **Test Date:** 03/27/19
- **Depth:** 120 ft
- **Test Number:** A4
- **Preparation:** Undisturbed
- **Elevation:** 95.5 RGS

**Description:** Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, trace organics

**Remarks:**
Cyclic Simple Shear Test

Shear Stress, Pa

Effective Normal Stress, Pa

Project Name: HC_Longview
Location: Longview
Project Number: 19132-01
Boring Number: H0_2
Tester: AMP
Checker
Sample Number: 520
Test Date: 03/27/19
Depth: 120 ft
Test Number: A4
Preparation: Undisturbed
Elevation: 998
Description: Very Soft, wet, gray SILT WITH SAND, fine sand, low plasticity, trace organics
Remarks:
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 2
Constant Load Step
Stress: 800 kPa

Project: HC_Longview  Location: Longview  Project No.: 19132-01
Boring No.: HCL2  Tested By: AMP  Checked By:
Sample No.: S20  Test Date: 03/27/19  Depth: 120ft
Test No.: A5  Sample Type: Undisturbed  Elevation: 95ft
Description: Very Silt, wet, gray SILT w/ sand, low plasticity, trace organics
Remarks:
## CYCLIC SIMPLE SHEAR TEST

![Cyclic Simple Shear Test Graph](image)

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Project No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>HC_Longview</td>
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<td>19132-01</td>
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<table>
<thead>
<tr>
<th>Sorting No.</th>
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<tbody>
<tr>
<td>HCL2</td>
<td>AMP</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Test Date</th>
<th>Depth</th>
</tr>
</thead>
<tbody>
<tr>
<td>S201</td>
<td>3/3/77</td>
<td>120 ft</td>
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</table>

<table>
<thead>
<tr>
<th>Test No.</th>
<th>Sample Type</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>A5</td>
<td>Undisturbed</td>
<td>95′ BGS</td>
</tr>
</tbody>
</table>

Description: Very Soft, wet, gray SILT with sand, low plasticity, trace organics

Remark:
CYCLIC SIMPLE SHEAR TEST

Shear Modulus, kPa

Shear Strain, %

Project: HC, Longview
Boing No.: HCL2
Sample No.: S20
Test No.: A5
Location: Longview
Tested By: AMP
Sample Type: Undisturbed
Description: Very Soft, wet, gray SILT with sand, low plasticity, trace organics
Remarks:

Project No.: 1932-01
Checked By:
Test Date: 03/27/19
Depth: 120 ft
Elevation: SG5 MBGS
Cyclic Simple Shear Test
Consolidation Time Curve 1 of 3
Constant Load Step
Stress: 5e+03 Pa

Vertical Displacement, m

Log of Time, min

Vertical Displacement, m

Sqrt of Time, \( \sqrt{\text{min}} \)

Project Name: HC_Longview  Location: Longview  Project Number: 10133.01
Boring Number: HCL2  Tester: AMP  Checker:
Sample Number: S20  Test Date: 04/01/19  Depth: 120ft
Test Number: A5  Preparation: Undisturbed  Elevation: 90 ft
Description: Very Soft, wet, gray SILT with sand, few plastically, trace organics
Remarks:
Cyclic Simple Shear Test
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 8e+05 Pa

---

<table>
<thead>
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<th>Project Name: HC, Longview</th>
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<th>Project Number: 19132-01</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boring Number: HCL2</td>
<td>Tester: AMP</td>
<td>Check:</td>
</tr>
<tr>
<td>Sample Number: S20</td>
<td>Test Date: 04/01/19</td>
<td>Depth: 120 ft</td>
</tr>
<tr>
<td>Test Number: A5</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 95 ft BGS</td>
</tr>
<tr>
<td>Description: Very Soft, wet, gray SLT with sand, low plasticity, trace organics</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks:</td>
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</table>
Cyclic Simple Shear Test
Consolidation Time Curve 3 of 3
Constant Load Step
Stress: 2.67e+05 Pa

<table>
<thead>
<tr>
<th>Vertical Displacement m</th>
<th>Log of Time, min</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.00420</td>
<td>0.01</td>
</tr>
<tr>
<td>0.00425</td>
<td>0.1</td>
</tr>
<tr>
<td>0.00430</td>
<td>1.0</td>
</tr>
<tr>
<td>0.00435</td>
<td>10.0</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Vertical Displacement m</th>
<th>Sqrt of Time, ( \sqrt{\text{min}} )</th>
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<tbody>
<tr>
<td>0.00420</td>
<td>0.0</td>
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<tr>
<td>0.00425</td>
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<td>0.00430</td>
<td>0.0</td>
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<tr>
<td>0.00435</td>
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**Project Name:** HC_Longview  **Location:** Longview  **Project Number:** 19132-01

**Boring Number:** HCL2  **Tester:** AMP  **Checker:**

**Sample Number:** S20  **Test Date:** 04/01/19  **Depth:** 12ft

**Test Number:** A5  **Preparation:** Undisturbed  **Elevation:** 96.97BGS

**Description:** Very Soft, wet, gray Silt with sand, low plasticity, trace organics

**Remarks:**
Cyclic Simple Shear Test

Shear Stress, Pa

Axial Strain, %

Excess Pressure, Pa

Shear Strain, %

<table>
<thead>
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<th>Location</th>
<th>Project Number</th>
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<tbody>
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<td>Boring Number</td>
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<tr>
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<tr>
<td>Test Number</td>
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<tr>
<td>Description</td>
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</tr>
<tr>
<td>Remarks</td>
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</tbody>
</table>
Cyclic Simple Shear Test

![Graph of Shear Stress vs. Effective Normal Stress]

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<th>Location: Longview</th>
<th>Project Number: 19132/01</th>
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</thead>
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<td>Tester: AMP</td>
<td>Checker:</td>
</tr>
<tr>
<td>Sample Number: S20</td>
<td>Test Date: 04/01/13</td>
<td>Depth: 120 ft</td>
</tr>
<tr>
<td>Test Number: A5</td>
<td>Preparation: Undisturbed</td>
<td>Elevation: 95 ft BGS</td>
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<tr>
<td>Description: Very Soft, wet, gray SILT with sand, low plasticity, trace organics</td>
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<tr>
<td>Remarks:</td>
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</table>
Cyclic Simple Shear Test

Shear Modulus, Pa

Shear Strain, %

Project Name: HC_Longview  Location: Longview  Project Number: 10132-01
Boring Number: HCL2  Tester: AMP  Checker:
Sample Number: S20  Test Date: 04/15/19  Depth: 120 ft
Test Number: A5  Preparation: Undisturbed  Elevation: 954 BGS
Description: Very Soft, wet, gray Silt with sand, low plasticity, trace organics
Remarks:
APPENDIX C. Klamath Falls, OR Test Results
Cyclic Direct Simple Shear Test Results

$S2_{TI} \ CSR=0.58$
CYCLIC SIMPLE SHEAR TEST

Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

<table>
<thead>
<tr>
<th>Project: Diatomaceous Cyclic DDS</th>
<th>Location: Klamath Falls</th>
<th>Project No.: 2017_11</th>
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</thead>
<tbody>
<tr>
<td>Boring No.: B2</td>
<td>Tested By: SY</td>
<td>Checked By: AK</td>
</tr>
<tr>
<td>Sample No.: 2</td>
<td>Test Date: 1/17/17</td>
<td>Depth: 13.5</td>
</tr>
<tr>
<td>Test No.: 2-1</td>
<td>Sample Type:</td>
<td>Elevation:</td>
</tr>
<tr>
<td>Description: Diatomaceous extrud 1/17/17. Trimmed sample 11/15/2017</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Remarks:</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
CYCLIC SIMPLE SHEAR TEST

Cyclic Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

Shear Strain, %

Axial Strain, %

Normal Stress, kPa

<table>
<thead>
<tr>
<th>Project: Diatomaceous Cyclic DSS</th>
<th>Location: Hamath Falls</th>
<th>Project No: 2017_11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boring No: 82</td>
<td>Tested By: SY</td>
<td>Checked By: AK</td>
</tr>
<tr>
<td>Sample No.: 2</td>
<td>Test Date: 11/17/17</td>
<td>Depth: 13.5</td>
</tr>
<tr>
<td>Test No: 2-1</td>
<td>Sample Type:</td>
<td>Elevation:</td>
</tr>
<tr>
<td>Description: Diatomaceous extruded 11/15/17</td>
<td>Trimmed sample 11/15/2017</td>
<td>Remarks:</td>
</tr>
</tbody>
</table>
CYCLIC SIMPLE SHEAR TEST

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

Project: Diatomaceous Cyclic DDS  
Location: Bronson Falls  
Project No.: 2017_11

Boring No.: 02  
Tested By: DY  
Checked By: AK

Sample No.: 2  
Test Date: 11/17/17  
Depth: 13.5

Test No.: 2-1  
Sample Type:  
Elevation:

Description: Diatomaceous extruded 11/15/17. Trimmed sample 11/15/2017

Remarks:
CYCLIC SIMPLE SHEAR TEST

Shear Modulus, kPa

Shear Strain, %

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
<th>Project No.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diatomaceous Cyclic CSS</td>
<td>Klamath Falls</td>
<td>2017_11</td>
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</table>

<table>
<thead>
<tr>
<th>Boring No.</th>
<th>Sample No.</th>
<th>Test Date</th>
<th>Depth</th>
<th>Sample Type</th>
<th>Elevation</th>
</tr>
</thead>
<tbody>
<tr>
<td>B2</td>
<td>2</td>
<td>11/17/17</td>
<td>13.5</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Description: Diatomaceous entrained 11/15/17. Trimmed sample 11/15/2017

Remarks:
$S3_{T1} \text{ CSR=0.23}$
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 1 of 2
Constant Load Step
Stress: 96 kPa

![Graph of vertical displacement vs. time and square root of time]

<table>
<thead>
<tr>
<th>Project: Diatomaceous Cyclic DSS</th>
<th>Location: Klamath Falls</th>
<th>Project No.: 2017_11</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boring No.: B2</td>
<td>Tested By: SV</td>
<td>Checked By: AK</td>
</tr>
<tr>
<td>Sample No.: 3</td>
<td>Test Date: 11/17/17</td>
<td>Depth: 13.5</td>
</tr>
<tr>
<td>Test No.: 51</td>
<td>Sample Type:</td>
<td>Elevation:</td>
</tr>
<tr>
<td>Description: Diatomaceous ext 11/15/17, Trimmed sample 11/17/2017</td>
<td>Remarks:</td>
<td></td>
</tr>
</tbody>
</table>

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CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 2
Constant Load Step
Stress: 45 kPa

![Graph showing consolidation time curve with vertical displacement in inches on the y-axis and time in minutes on the x-axis.]

Project: Diatomaceous Cyclic DSS
Location: Klamath Falls
Project No.: 2017_11
Boring No.: B2
Tested By: GY
Sample No.: 3
Test Date: 11/17/17
Depth: 13.5
Sample Type:
Elevation:
Description: Diatomaceous extruded 11/15/17, Trimmed sample 11/17/2017
Remarks:

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CYCLIC SIMPLE SHEAR TEST
Cyclic Data
Step 1 of 1

Shear Stress, kPa
-20 -10 0 10 20
Shear Strain, %
-2 -1 0 1 2
Excess Pressure, kPa
-10 -5 0 5 10
Cycle

Project: Diatomaceous Cyclic DDS
Location: Klamath Falls
Project No.: 2017_11
Boring No.: 82
Tested By: SY
Sample No.: 3
Test Date: 11/17/17
Depth: 13.5
Test No.: 3-1
Sample Type: Elevation:
Description: Diatomaceous extruded 11/15/17. Trimmed sample 11/7/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST

Modulus/Damping Results
Step 1 of 1

<table>
<thead>
<tr>
<th>Cycle</th>
<th>P-P Shear Stress, kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
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<table>
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---

**Project:** Diatomaceous Cyclic D55  
**Location:** Klamath Falls  
**Project No.:** 2017_11

**Boring No.:** 82  
**Tested By:** SY  
**Checked By:** AK

**Sample No.:** 3  
**Test Date:** 11/17/17  
**Depth:** 135

**Test No.:** 3-1  
**Sample Type:**

**Description:** Diatomaceous extruded 11/15/17. Trimmed sample 11/17/2017

**Remarks:**
CYCLIC SIMPLE SHEAR TEST

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

<table>
<thead>
<tr>
<th>Project: Diatomaceous Cyclic</th>
<th>Location: Klamath Falls</th>
<th>Project No: 2017.11</th>
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<tr>
<td>Boring No: 92</td>
<td>Tested By: SY</td>
<td>Checked By: AX</td>
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<tr>
<td>Sample No: 3</td>
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<td>Depth: 13.5</td>
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<tr>
<td>Test No: 31</td>
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<tr>
<td>Description: Diatomaceous</td>
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<tr>
<td>Test: 11/3/17</td>
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<td>Remarks: Diatomaceous</td>
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<tr>
<td>Extruded 11/15/17</td>
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<tr>
<td>Trimmed sample 11/1/17/2017</td>
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CYCLIC SIMPLE SHEAR TEST

![Graph showing cyclic simple shear test results.](image)

<table>
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<th>Project No.</th>
<th>Boring No.</th>
<th>Tested By</th>
<th>Depth</th>
<th>Checked By</th>
<th>Sample Type</th>
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<td>SY</td>
<td>13.5</td>
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<td>Date</td>
<td>Sample Type</td>
<td>Test No.</td>
<td>Depth</td>
<td>Elevation</td>
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<tr>
<td>3</td>
<td>11/17/17</td>
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<td>3-1</td>
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Description: Diatomaceous extuded 11/15/17, Trimmed sample 11/17/2017

Remarks:
CYCLIC SIMPLE SHEAR TEST

---

<table>
<thead>
<tr>
<th>Project:</th>
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<th>Project No.: 2017.11</th>
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<tbody>
<tr>
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<td>Checked by: AK</td>
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<tr>
<td>Sample No.: 3</td>
<td>Test Date: 1/17/17</td>
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<td>Test No.: 3-1</td>
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<tr>
<td>Description:</td>
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<tr>
<td>Remarks:</td>
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</tr>
</tbody>
</table>

---

Shear Modulus, kPa

Shear Strain, %
$S4_{T1} CSR=0.4$
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 1 of 2
Constant Load Step
Stress: 96 kPa

Vertical Displacement, in

Time, min

Square Root of Time, √min

Vertical Displacement, in

Project: Distomaceous Cyclic DDS  Location: Klamath Falls  Project No.: 2017_11
Boring No.: B2  Tested By: AMP  Checked By: AK
Sample No.: 4  Test Date: 11/21/17  Depth: 12.75
Test No.: 4-1  Sample Type:  Elevation:  
Description: Distomaceous extruded 11/15/17. Trimmed sample 11/17/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 2
Constant Load Step
Stress: 45 kPa

Vertical Displacement, in

Time, min

Square Root of Time, √min

Vertical Displacement, in

Project: Distomaceous Cyclic D33
Location: Klamath Falls
Boiling No.: 52
Sample No.: 4
Test No.: 4-1

Description: Distomaceous Cylindrical 11/15/17. Trimmed sample 11/17/2017
Remarks:

Location: Klamath Falls
Boiling No.: 52
Sample No.: 4
Test No.: 4-1

Description: Distomaceous Cylindrical 11/15/17. Trimmed sample 11/17/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST

Debug Data
Step 1 of 1

Shear Stress, kPa

Gain

Output steps

Cycle

<table>
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<th>Project</th>
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<td>Test No.: 41</td>
<td>Sample Type:</td>
<td>Elution:</td>
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Description: Diatomaceous extruded 11/15/17, Trimmed sample 11/17/2017
Remarks:

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CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Project: Diatomaceous Cyclic D08 Location: Honolulu Falls Project No.: 2017_11
Boiling No.: B2 Tested By: AMP Checked By: AK
Sample No.: 4 Test Date: 1/21/17 Depth: 12.75
Test No.: 4-1 Sample Type: Elevation:
Description: Diatomaceous extracted 11/15/17. Trimmed sample 1/17/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results

- P-P Shear Stress, kPa
- P-P Shear Strain, %
- Modules, kPa
- Damping Ratio, %

Cycle

<table>
<thead>
<tr>
<th>Project</th>
<th>Diatomaceous Cyclic DSS</th>
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<th>Project No.</th>
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<td>Tested By</td>
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<td>Sample No.</td>
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<td>Test Date</td>
<td>11/21/17</td>
<td>Depth</td>
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<td>Test No.</td>
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<td>Sample Type</td>
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<td>Description</td>
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CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 45.0

Shear Stress, kPa

Shear Strain, %

Normal Stress, kPa

<table>
<thead>
<tr>
<th>Project: Diatomaceous Cyclic D95</th>
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<td>Description: Diatomaceous extended 11/15/17. Trimmed sample 11/17/2017</td>
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$S4_{T2} \text{ CSR}=0.5$
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 1 of 2
Constant Load Step
Stress: 96 kPa

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<tr>
<th>Project</th>
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<th>Boring No.: 92</th>
<th>Tested By</th>
<th>Checked By</th>
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<tbody>
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<td>Klamath Falls</td>
<td>2017.11</td>
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<td>AMP</td>
<td>AK</td>
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<tr>
<td>Sample No.: 4</td>
<td>Test Date: 1/21/17</td>
<td>Depth: 12.75</td>
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<tr>
<td>Test No.: 4-2</td>
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<td>Elevation:</td>
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<tr>
<td>Description: Distantaceous extruded 7/15/17. Trimmed sample 11/1/2017</td>
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<td>Remarks:</td>
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CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 2
Constant Load Step
Stress: 45 kPa

Vertical Displacement, in.

Time, min

Square Root of Time, \( \sqrt{\text{min}} \)

<table>
<thead>
<tr>
<th>Project</th>
<th>Location</th>
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<th>Boring No.</th>
<th>Sample No.</th>
<th>Test Date</th>
<th>Depth</th>
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<td>82</td>
<td>4</td>
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Description: Diatomaceous extruded 11/15/17. Trimmed sample 11/17/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: Diatomaceous Cyclic DSS  Location: Kamish Falls  Project No: 2017_11
Sorting No: B2  Tested by: AMP  Checked by: AK
Sample No: 4  Test Date: 11/2/17  Depth: 12.75
Test No: 4-2  Sample Type:  Elevation:
Description: Diatomaceous extruded 11/15/17. Trimmed sample 11/17/2017
Remarks:
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 33.0

Project: Diatomaceous Cyclic DS8
Boring No.: B2
Sample No.: 4
Test No.: 4-0

Location: Klamath Falls
Tested By: AMP
Test Date: 1/21/17
Sample Type:

Project No.: 2017-11
Checked By: AK
Depth: 12.75

Description: Diatomaceous extruded 1/19/17. Trimmed sample 1/17/2017
Remarks:
$S4_{T2} \ CSR=0.4 \ Reconsolidation$
APPENDIX D: Beaverton, OR Test Results
Cyclic Direct Simple Shear Tests

*A-Tests*
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

Shear Stress, kPa

Shear Strain, %

Normal Stress, kPa

Project: OR21755: Allen Bluffs OR6W
Location: Allen Bluffs OR6W
Boring No.: 15841-06
Sample No.: U2
Test No.: A1
Description: Extended and trimmed 07/30/2018
Remarks: YOU MUST ENTER NEW CALIBRATION FACTOR AND CORRECT SHEARFAIL ID BEFORE USING THIS FILE

Test Data: 07/01/18
Depth: 19
Sample Type: Undisturbed
Elevation: 15757

Checked By:
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: OR217 SB: Allen Blvd to OR 99W  Location: Allen Exit OR 217  Project No.: 18841
Boring No.: 18841-02  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 08/02/18  Depth: 23
Test No.: E1  Sample Type: Undisturbed  Elevation: 172.35
Description: Extruded and trimmed sample 08/03/2018. Willamette Formation
Remarks: Consolidated to: OCR= 41 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.68; Cyclic Shear Freq: 30
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

<table>
<thead>
<tr>
<th>Project: OR217 SB, Allen Blvd to DR 96W</th>
<th>Location: Allen Exit DR-217</th>
<th>Project No.: 18841</th>
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</thead>
<tbody>
<tr>
<td>Sample No.: 01</td>
<td>Test Date: 09/22/18</td>
<td>Depth: 23</td>
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<tr>
<td>Test No.: 81</td>
<td>Sample Type: Undisturbed</td>
<td>Elevation: 123.19</td>
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<tr>
<td>Description: Extruded and trimmed sample 09/22/18, Willamette Formation</td>
<td>Remarks: Consolidated to 41 kPa, Over Consolidation Ratio (CCR): 1, Cyclic Stress Ratio (CSR): 0.69, Cyclic Shear Rate: 30 s</td>
<td></td>
</tr>
</tbody>
</table>

Shear Stress, kPa

Shear Strain, %

Normal Stress, kPa

-20 0 20 40 60

-20 0 20 30 40 50 60 70
CYCLIC SIMPLE SHEAR TEST

Project: 01217 00: Allen Blvd to Off 09W  
Location: Allen Est 01-217  
Project No.: 18041

Boring No.: 18841-02  
Tested By: AMP  
Checked By: AK

Sample No.: U1  
Test Date: 08/03/18  
Depth: 23

Test No.: B1  
Sample Type: Undisturbed  
Elevation: 172.39

Description: Excavated and trimmed sample 08/02/18, Willamette Formation

Remarks: Consolidated to n=41 kPa, Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.69; Cyclic Shear Frac: 30

---

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

---

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CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: OR217 SE Allen Blvd to OR 99W
Location: Allen Exit OR-217
Project No.: 18841
Boring No.: 18841-05
Sample No.: C1
Test Date: 08/03/18
Depth: 8'

Description: Extracted and trimmed sample 09/03/2018.

Remarks: Consolidated to: $\sigma_{cv} = 30$ kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.60; Cyclic Shear Freq.: 30

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CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 1.0

Project: OR217 SS, Alien Blvd to Off SW
Location: Alien Exit OR-217
Boring No.: 18941-96
Sample No.: U1
Test No.: C1

Description: Extracted and trimmed sample 3/8/02/18.
Remarks: Consolidated to c'0=20 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.69; Cyclic Shear Freq. 30 s

Checked By: AK
Test Date: 03/02/19
Depth: ft
Sample Type: Undisturbed
Elevation: 178.87

Shear Stress, kPa
-5 0 5 10 15
Shear Strain, %
-5 0 5 10 15
Normal Stress, kPa
-5 0 5 10 15 20 25 30
CYCLIC SIMPLE SHEAR TEST

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

Boring No.: 18841-05  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 08/03/19  Depth: 8'
Test No.: C1  Sample Type: Undisturbed  Elevation: 178.57
Description: Excavated and trimmed sample 08/03/2015.
Remarks: Consolidated to 20 kPa, Over Consolidation Ratio (OCR): 1, Cyclic Stress Ratio (CSR): 0.69, Cyclic Shear Freq.: 30.
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: CR217 SD: Allen Blvd to CR 999W
Location: Allen Blvd CR217
Project No.: 18941

Boring No.: 18841-06
Tested By: AMP
Checked By: AK

Sample No.: U1
Test Date: 08/04/18
Depth: 3'

Test No.: C3
Sample Type: Undisturbed
Elevation: 178.67

Description: Excavated and trimmed sample 08/03/2018
Remarks: Consolidated to dnr= 26 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.2; Cyclic Shear Freq.: 30 s
CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results
Step 1 of 1

P-P Shear Stress, kPa

P-P Shear Strain, %

Modulus, kPa

Damping Ratio, %

Cycle

Project: CR217 SB: Allen Blvd to CR 99W
Location: Allen Exit CR-217
Project No: 18841
String No: 18841-05
Tested by: AMP
Checked by: AK
Sample No.: U1
Test Date: 08/04/18
Depth: 6'
Test No: C3
Sample Type: Undisturbed
Elevation: 175.67
Description: Corroded and trimmed sample 09/03/2016
Remarks: Consolidated to φ=20 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.2; Cyclic Shear Freq: 30 s
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: OR217 SE; Allen Blvd to OR 99W  Location: Allen Exit OR-217  Project No.: 18841
Boring No.: 18841-05  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 09/05/18  Depth: 8
Test No.: C4  Sample Type: Undisturbed  Elevation: 178.67

Description: Drilled and trimmed sample 09/05/20 lb. Willamette Formation.
Remarks: Consolidated to v'vc = 20 kPa, Over Consolidation Ratio (OCR): 1, Cyclic Stress Ratio (CSR): 0.1, Cyclic Shear Freq: 30 s

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CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results
Step 1 of 1

---

**Graphs:**
- P-P Shear Stress, kPa
- P-P Shear Strain, %
- Modulus, kPa
- Damping Ratio, %

---

**Project:** OR217 SB Allen Blvd to CR 99W
**Location:** Allen Exit CR-217
**Project No.:** 18841

**Boxing No.:** 10041-06
**Tested By:** AMP
**Checked By:** AK

**Sample No.:** U1
**Test Date:** 08/06/13
**Depth:** 8'

**Test No.:** C4
**Sample Type:** Undisturbed
**Elevation:** 178.67

**Description:** Drilled and trimmed sample 08/02/2018, Willamette Formation

**Remarks:** Consolidated to d'v=20 kPa, Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.1; Cyclic Shear Freq.: 30 s
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 100.0

| Project: OR217 SE: Allen Blvd to OR 90N | Location: Allen Ext OR 217 | Project No.: 19841 |
| Boring No.: 18841-06 | Tested By: AMP | Checked By: Ak |
| Sample No.: U1 | Test Date: 3/8/18 | Depth: 8 |
| Test No.: C4 | Sample Type: Undisturbed | Elevation: 178.67 |

Remarks: Consolidated to d = 20 kPa. Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.1; Cyclic Shear Freq.: 30 s
CYCLIC SIMPLE SHEAR TEST

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

Project: OR217 SB Allen Blvd to CR 90W  Location: Allen Bilt-CR 217  Project No: 18841
Boring No: 18841-05  Tested By: AMP  Checked By: AK
Sample No: U1  Test Date: 09/05/18  Depth: 8
Test No: C4  Sample Type: Undisturbed  Elevation: 178.87
Description: Extruded and trimmed sample 09/03/2018. Willamette Formation.
Remarks: Consolidated to d'v= 20 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.1; Cyclic Shear Freq: 30 s
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: CGQ17 SB; Alien Blvd to OR 99W
Location: Alien Blvd OR-217
Project No.: 18841

Boring No.: 18841-05
Tested By: ANP

Sample No.: U1
Test Date: 08/05/15

Test No.: 5
Sample Type: Undisturbed

Description: Excavated and trimmed sample 09/03/20, Willamette Formation

Elevation: 178.87

Remarks: Consolidated to d'v= 20 kPa, Over Consolidation Ratio (OCR): 1, Cyclic Stress Ratio (CSR): 0.15, Cyclic Shear Frac. 36
CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results
Step 1 of 1

<table>
<thead>
<tr>
<th>Cycle</th>
<th>P-P Shear Stress, kPa</th>
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Project: OR217 SB: Allen Blvd to OR 99W  Location: Allen Exit OR-217  Project No.: 18841
Boring No.: 18841-06  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 09/09/18  Depth: 8
Test No.: C5  Sample Type: Undisturbed  Elevator: 176.67
Description: Extruded and trimmed sample 09/09/2018, Willamette Formation
Remarks: Consolidated to 87 kPa; Ov<sub>c</sub> = 20 kPa; OCR = 1; Cyclic Stress Ratio (CSR) = 0.16; Cyclic Shear Force = 30 kN

250
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 100.0

Shear Stress, kPa

Normal Stress, kPa

| Project: OR217 385, Allen Blvd to OR 99W | Location: Allen Exit OR-217 | Project No.: 18841 |
| Boring No.: 18841-06 | Tested By: AMP | Checked By: AK |
| Sample No.: U1 | Test Date: 08/08/18 | Depth: 8 |
| Test No.: C5 | Sample Type: Undisturbed | Elevation: 178.97 |
| Description: Extruded and trimmed sample 08/03/2018, Willamette Formation |
| Remarks: Consolidated to d' = 20 kPa, Over Consolidation Ratio (OCR) = 1, Cyclic Stress Ratio (CSR) = 0.15, Cyclic Shear Freq. 30 s |
CYCLIC SIMPLE SHEAR TEST

Shear Stress, kPa

Axial Strain, %

Excess Pressure, kPa

Shear Strain, %

Project: OR217 S8; Allen Blvd to OR 39W  Location: Allen Est OR 217  Project No: 18641
Boring No: 188-41-06  Tested By: AMP  Checked By: AK
Sample No: L1  Test Date: 08/06/18  Depth: 8'
Test No: C5  Sample Type: Undisturbed  Elevation: 176.67
Description: Exudated and trimmed sample 08/03/2018; Willamette Formation
Remarks: Consolidated to $c_v = 20$ kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.15; Cyclic Shear Freq: 30
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: 09217 DB: Allen Blvd to CR 06W
Location: Allen Est CR 217
Project No.: 18941

Boring No.: 18441-05
Tested By: AMP
Checked By: AK

Sample No.: 01
Test Date: 06/23/18
Depth: 8'

Test No.: CB
Sample Type: Undisturbed
Elevation: 1786.7

Description: Extruded and trimmed sample 08/03/2018. Willamette Formation (CL)
Remark: Consolidated to 

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CYCLIC SIMPLE SHEAR TEST

Modulus/Damping Results

Step 1 of 1

P-P Shear Stress, kPa

P-P Shear Strain, %

Modulus, kPa

Damping Ratio, %

Cycle

Project: OR217 SB: Allen Blvd in OR 99W  Location: Allen Exit OR-217  Project No.: 18811
Boring No.: 18841-06  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 06/23/18  Depth: 8'
Test No.: C8  Sample Type: Undisturbed  Elevation: 178.67
Description: Excavated and trimmed sample 06/03/2018, Willamette Formation (CL)
Remarks: Consolidated to: dv/cv = 20 kPa; Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.17; Cyclic Shear Freq.: 30 s
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 100.0

- Shear Stress, kPa vs. Shear Strain, %
- Normal Stress, kPa vs. Depth, ft

Project: OR217 SB; Allen Blvd to OR 36 W
Location: Allen Ext; OR-217
Project No.: 18841

Boring No.: 1981-06
Tested By: AMP
Checked By: AK

Sample No.: U1
Test Date: 08/22/19
Depth: 8

Test no.: C8
Sample Type: Undisturbed
Elevation: 17867

Description: Extracted and trimmed sample 04/03/2018. Willamette Formation (CL)
Remarks: Consolidated to 40 kPa. Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.17; Cyclic Shear Freq: 30 s
TB18841-05 – U1 – C9 – CSR 0.30 (confining stress = 100 kPa)
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: OR217:88; Allen Blvd to CR 99W  Location: Allen Exit OR-217  Project No.: 18841
Boring No.: 18841-05  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 09/27/18  Depth: 8'
Test No.: C9  Sample Type: Undisturbed  Elevation: 178.67
Description: Excavated and trimmed sample 06/03/2018, Willamette Formation (CL)
Remarks: Consolidated to e' o=100 kPa; Over Consolidation Ratio (OCR); 1; Cyclic Stress Ratio (CSR): 0.3; Cyclic Shear Freq.: 30 s
CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results
Step 1 of 1

- P-P Shear Stress, kPa
- P-P Shear Strain, %
- Modulus, kPa
- Damping Ratio, %

Project: OR211 Sihl St. Lund 90W  Location: Allen Ext OR 217  Project No.: 18941
Boring No.: 18941-05  Tested By: AMP  Checked By: AK
Sample No.: U1  Test Date: 08/23/13  Depth: 8
Test No.: C9  Sample Type: Undisturbed  Elevation: 178.67
Description: Extruded and trimmed sample 08/03/2018, Willamette Formation (C.)
Remarks: Consolidated to v'c=100 kPa, Over Consolidation Ratio (OCR): 1; Cyclic Stress Ratio (CSR): 0.3; Cyclic Shear Freq.: 30
CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 5.0

Project: OR217 SB; Allen Blvd to OR 96W
Location: Allen Exit OR 217
Boring No.: 18841-05
Sample No.: U1
Test No.: C9

Description: Extruded and trimmed sample 3/6/18, Williamette Formation (CL)
Remarks: Consolidated to dvc = 100 kPa, Over Consolidation Ratio (OCR): 1, Cyclic Stress Ratio (CSR): 0.3, Cyclic Shear Time: 0.5 s

Checked By: AK
Test Date: 3/22/18
Depth: 6
Sample Type: Undisturbed
Elevation: 173.67
TB18841-05 – U1 – C9 – Re-consolidated to 100 kPa
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 1 of 1
Constant Load Step
Stress: 100 kPa

Vertical Displacement in
0.000
0.005
0.010
0.015
0.020
0.025
0.030
0.035

Time, min
0.01
0.1
1
10
100

Square Root of Time, √min

Vertical Displacement in
0.000
0.005
0.010
0.015
0.020
0.025
0.030

Project: OR217 SB: Allen Blvd to OR 99W
Location: Allen Exp I OR-217
Project No.: 18841
Boring No.: 18841-05
Tested By: AMP
Checked By: AK
Sample No.: U1
Test Date: 08/27/18
Depth: 9'
Test No.: C9
Sample Type: Undisturbed
Elevation: 178.57
Description: Drilled and trimmed sample 08/03/2018, Willamette Formation (CL)
Remarks: Reconsolidated to σ' = 100 kPa
APPENDIX E: Columbia River Slough, OR Test Results
1-D Consolidation Results
Cyclic Direct Simple Shear Testing

B1 at 40'-42', CDSS Sample S1 (CSR = 0.23)
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 245 kPa
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

---

Project: CBWTP_STEP  Location: Portland, OR  Project No.: JAC-2018-005
Boring No.: 1-1  Tested By: AMP  Checked By:
Sample No.: 30'-32'  Test Date: 03/21/19  Depth: 31'-39'
Test No.: B1  Sample Type: Undisturbed  Elevation:
Description:
Remarks:
B1, 40'-42', CDSS Sample S2 (CSR = 0.15)
CYCLIC SIMPLE SHEAR TEST

Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

Project: CBWTP STEP
Location: Portland, OR
Project No.: JMC-2018-005

Boring No.: B-1
Tested by: KRS

Sample No.: S2
Test Date: 03/25/19
Depth: 4'–4.5'

Test No.: S2
Sample Type: Undisturbed

Description: Slightly disturbed, see pictures of sample

Remarks:
CYCLIC SIMPLE SHEAR TEST
Modulus/Damping Results
Step 1 of 1

- P-P Shear Stress, kPa
- P-P Shear Strain, %
- Modulus, kPa
- Damping Ratio, %

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CYCLIC SIMPLE SHEAR TEST
Cyclic Stress Strain Results
Step 1 of 1
Cycle 0.0 to 100.0

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<tr>
<td>Test No.: S2</td>
<td>Sample Type: Undisturbed</td>
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Description: Slightly disturbed, see pictures of sample
Remarks:
CYCLIC SIMPLE SHEAR TEST

![Graph showing the relationship between shear stress and effective normal stress.](image)

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CYCLIC SIMPLE SHEAR TEST

Shear Modulus, kPa

Shear Strain, %

Project: CIIWTP STEP
Location: Portland, OR
Project No.: JAC-2018-005

Boring No.: B-1
Tested By: KRS

Sample No.: S2
Test Date: 03/25/19
Depth: 40-42'

Test No.: S2
Sample Type: Undisturbed
Elevation:

Description: Slightly disturbed, see pictures of sample
Remarks:
B1, 40'-42', CDSS Sample S3 (CSR = 0.20)
CYCLIC SIMPLE SHEAR TEST
Consolidation Time Curve 2 of 3
Constant Load Step
Stress: 246 kPa

Project: CBWTP STEP  
Location: Portland, OR  
Project No.: JAC-2019-005  
Boring No.: B-1  
Tested By: SRS  
Sample No.: S3  
Test Date: 04/03/19  
Test No.: S3  
Sample Type: Undisturbed  
Description: Highly disturbed, see pictures of sample  
Remarks:
CYCLIC SIMPLE SHEAR TEST
Cyclic Data
Step 1 of 1

Shear Stress, kPa

Shear Strain, %

Excess Pressure, kPa

Cycle

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CYCLIC SIMPLE SHEAR TEST

Cyclic Stress Strain Results

Step 1 of 1
Cycle 0.0 to 27.0
CYCLIC SIMPLE SHEAR TEST

![Graph showing cyclic simple shear test results with shear stress in kPa on the y-axis and effective normal stress in kPa on the x-axis. The graph plot shows a curve indicating the relationship between shear stress and effective normal stress.]
CYCLIC SIMPLE SHEAR TEST

[Graph showing a curve on a log-log scale with Shear Modulus on the y-axis and Shear Strain on the x-axis.]

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