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MEMORANDUM

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19478
7/29/19

DATE: July 29, 2019

TO: Scott Kuebler, PE, SE and Adam Bergman, PE
KPFF Consulting Engineers

FROM: Jenna Jacoby, Lorne Arnold, PE and Garry Horvitz, PE
Hart Crowser, Inc.

RE: **Geotechnical Design Recommendations for Wapato Creek Bridge at Parcel 15**
19433-01

1.0 Introduction

This memorandum presents our approach and recommendations of design parameters for the Wapato Creek Bridge at Parcel 15, which is part of the Wapato Creek Culvert Replacement project. This memorandum addresses the design of drilled shaft foundations proposed for the permanent bridge. As part of the project, the existing culvert will be demolished, and a new bridge will be constructed south of the existing culvert. The new bridge will span Wapato Creek and will consist of 2 piers supported by drilled shafts.

This memorandum was prepared in general accordance with the Washington State Department of Transportation (WSDOT) Geotechnical Design Manual (GDM). The geotechnical basis of the soil parameters for this project is the AASHTO LRFD Bridge Design Specification (2017) and the WSDOT GDM (2015).

Figure 1 shows the project location, Figure 2 provides the relevant explorations, and Figure 3 shows the generalized subsurface profile. Boring logs are provided in Appendix A. Figures showing slope stability analysis results are provided in Appendix B. Drilled shaft vertical capacity recommendation charts and lateral capacity parameter recommendations are provided in Appendix C. Lateral earth pressure recommendations are provided in Appendix D.

2.0 Subsurface Conditions

2.1 Soil Parameters

As part of this project, 3 new soil borings were completed (HC-1, HC-2, and HC-3), with HC-2 and HC-3 being the most relevant borings. The soil borings range in depth from 30 feet to 140 feet below ground surface (bgs).

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The near-surface soils (approximately the upper 70 feet) consist of poorly graded sand, silty sand, and low plasticity silt and clay. The sand and silty sand deposits' density ranges from very loose to medium dense and the silt is generally very soft to soft. This material is generally alluvial deposits. Below 70 feet, materials encountered were generally poorly graded sand, silty sand, and silt. The densities are generally medium dense to very dense. These materials are typically alluvial deposits. Fill material was also encountered at the east end of the bridge alignment, up to a depth of approximately 7.5 feet.

The subsurface profile is presented in Figure 3. Soils were categorized based on liquefaction susceptibility, relative density, soil type, and strength, and grouped into general engineering stratigraphic units (ESUs). A brief description of each ESU is below:

- **ESU 1.** This unit is generally comprised of low to moderate plasticity silt, silty sand, and occasional lean clay and peat. Organics and wood fragments were occasionally encountered. Densities are typically very soft to firm or very loose to loose, with N values less than 10 blows per foot (bpf). The risk of soil liquefaction is considered high for this soil unit.

- **ESU 2.** This unit is characterized predominantly by poorly graded sand and silty sand, with occasional organics and wood fragments. This unit is generally considered alluvial deposits. The density ranges from loose to medium dense, and blowcounts are typically less than 20 bpf. The risk of soil liquefaction is considered high for this soil unit.

- **ESU 3.** This unit is similar to ESU 1 but encountered at greater depths than ESU 1 (approximately 100 feet or deeper). This unit includes higher plasticity silt and low plasticity clay. The density is typically very soft. N values are generally less than 5 bpf. The risk of soil liquefaction is considered high for this unit.

- **ESU 4.** This unit typically contains poorly graded sand with silty sand, and interbedded silt layers. The densities range from medium dense to very dense. The risk of soil liquefaction is considered moderate for this soil unit.

- **ESU 5.** This unit is comprised of silty sand with poorly graded sand, with occasional organics and shell fragments. Densities are generally medium dense to very dense. This unit is alluvial deposits. The risk of soil liquefaction is considered low for this soil unit.

- **ESU 6.** This unit consists of existing fill material. This material is generally medium dense to dense poorly graded sand with varying amounts of silt and gravel. ESU 6 was not encountered in HC-2. The risk of soil liquefaction is considered low for this soil unit.

Table 1 below presents the assigned static and liquefied strength properties for each ESU.

Table 1 – ESU Design Soil Parameters, Static and Liquefied Properties

Soil Unit	Representative $(N1)_{60}$	Static Properties		Liquefied Properties
		Total Unit Weight, γ (pcf[1])	Friction Angle, φ (degrees)	Su/Sigma (dim.)
ESU 1	3	115	29	0.1
ESU 2	15	125	35	0.2
ESU 3	0	115	28	0.1
ESU 4	23	125	36	0.4
ESU 5	26	125	37	0.7
ESU 6	60	125	40	N/A

[1] pcf = pounds per cubic foot
[2] ksf = kips per square foot

2.2 Groundwater Conditions

The site is located approximately 0.25 miles south of Puget Sound, which can experience tidal fluctuations up to approximately 12 feet throughout the day, with a Mean Higher High Water (MHHW) elevation of 11.8 feet. Additionally, we performed a slug test on January 18, 2019, where a water level elevation of 11.5 feet was observed. This is generally consistent with the tidal level at that time. Therefore, it is expected that the water level in Wapato Creek is generally consistent with the water level of Puget Sound. For the purpose of our analyses, we have assumed a water level elevation of 10 feet. Our results are not highly sensitive to water levels in the expected range.

2.2.1 Slug Testing

Slug tests are performed by suddenly inserting or removing two solid PVC rods in a well and measuring the recovery of the water levels during the test. A test conducted by the insertion of the PVC rods into the well is referred to as a falling head test and the following removal of the rods is called a rising head test. The water level data generated from the tests were analyzed using the commercial software Aquifer$^{\text{Win32}}$ Version 5 (Environmental Simulations, Inc., 2017). The slug test analysis is based on the Bouwer and Rice method (Bouwer and Rice 1976; Bouwer 1989) to obtain an estimated value of hydraulic conductivity of the aquifer.

Six falling head tests and six rising head tests were conducted in HC-1 on January 17, 2019 to estimate the hydraulic conductivity of the soils in the 10-foot zone below the water table. The slug test results indicated that the hydraulic conductivity of these soils ranged from 5E-03 to 9E-03 cm/sec (1.6E-04 to 2.9E-04 ft/sec).

3.0 Site Seismicity and Seismic Design

The site class for the site is Site Class E. The Site Class B (soft rock) peak ground acceleration (PGA) for an earthquake with a 7 percent probability of exceedance in 75 years, as determined from the WSDOT BridgeLink (Version 4.1.1.0) module *Spectra*, is 0.406g. The Site Class E F_{PGA} is 1.388; therefore, a PGA of 0.56g is used for design.

3.1 Liquefaction

Factors of safety against liquefaction were evaluated where loose to medium dense, saturated soils were encountered. Per Section *6.4.2 Liquefaction* of the GDM, a soil is considered potentially liquefiable if the factor of safety against liquefaction is below 1.2.

The liquefaction potential for each ESU was evaluated using the method presented by Idriss and Boulanger (2008), in accordance with the GDM, which evaluates liquefaction susceptibility based on standard penetration test (SPT) blowcounts. Our analysis used the following seismic parameters based on our site-specific response analysis:

- Earthquake magnitude, M = 7.1;
- Peak ground acceleration, PGA = 0.56; and
- Return period = 975 years.

Based on our liquefaction assessment using the SPT correlations, the site soils are expected to liquefy during a design earthquake. However, per Section 6.1.2.3 of the GDM, only soils in the upper 80 feet of the subsurface profile must be considered potentially liquefiable. For the shaft capacity analyses, only soils in the upper 80 feet were considered susceptible to liquefaction because the soils deeper than 80 feet were generally observed to be medium dense or dense. However, pockets or lenses of potentially liquefiable materials were encountered at depths greater than 80 feet in some of the borings; therefore, we recommend that all shafts extend down to ESU 4 regardless of whether liquefaction effects are considered below 80 feet bgs.

3.2 Downdrag

Based on our liquefaction analysis using the permanent bridge ground motion parameters, liquefaction-induced downdrag on the drilled shafts is anticipated. The difference between Service and Extreme resistances in the figures in Appendix C is due to loss of strength in side friction and end bearing, as well as different resistance factors between limit states. No inference should be made between the strength loss and downdrag load magnitude. We have estimated the magnitude of downdrag based on the full residual shear strength of the liquefied soil applicable all the way to the bottom of liquefaction (up to 80 feet bgs). Although settlement will likely occur as soil strengths are increasing, in our opinion, our assumption that the neutral plane is located at the bottom of the lowest liquefiable soil layer more than offsets the potential to underestimate the strength of the soils when they settle. The magnitude of downdrag for each pier is provided in Table 3 in Section 4.1 Drilled Shaft Vertical Resistance.

3.3 Pseudostatic Slope Stability, Lateral Spreading, and Flow Failure

For the design of the permanent bridge, we have decoupled the post-earthquake liquefaction and the peak ground shaking, because less than 20 percent of the associated PGA events are of a long duration seismic source (magnitude 7.5 or greater), per Section 6.4.2.7 of the GDM. The GDM defines flow failure as liquefaction-induced slope instability driven by static shearing stresses, *often occurring near the end of or following shaking*. In contrast to flow failure, the GDM describes the lateral spreading mechanism as liquefied slope instability driven by *inertial forces during an earthquake*, which incrementally exceeds the soil shear strength. According to the GDM, the assumption of decoupling ground shaking, and liquefaction precludes the project from lateral spreading susceptibility, as described above.

We completed a multiple-scenario (static, pseudostatic, and post-liquefied conditions) slope stability assessment for proposed Piers 1 and 2 using the two-dimensional commercial software Slide 8.0 (RocScience 2018, version 8.026). The Spencer and Morgenstern-Price slope stability analysis methods were used and compared against one another to determine the factor of safety (FS) against failure. The FS can be generalized as the ratio of the forces resisting slope movement (soil strength, soil mass, etc.) and the forces driving slope movement (gravity, earth pressure, and seismic shaking). A FS equal to or less than 1.0 indicates a condition when the shear stresses required to maintain equilibrium in the slope reach or exceed the available soil shear resistance. Slide predicts the location and geometry of “critical failure planes”, where the lowest FS is computed.

In accordance with the GDM, slope stability of the bridge abutments must be designed with resistance factors of 0.65 (FS = 1.5), 0.9 (FS = 1.1), and 0.9 (FS = 1.1) under static, pseudostatic, and post-liquefied loading conditions, respectively.

Using this approach, we determined that Piers 1 and 2 are susceptible to flow failure following the design earthquake.

To analyze the load of the slope on the drilled shafts caused by flow failure, we used the Japanese Force method. This method, as outlined in the GDM, assumes that the liquefied soil exerts a pressure equal to 30 percent of the total overburden pressure, and non-liquefied crustal layers exert full passive pressure on the shaft. If designing the simply supported bridge shaft foundations to resist flow failure is desired, these lateral spreading forces should be applied over one shaft diameter. The equivalent earth pressure diagrams can be seen in Figures D1 and D2 in Appendix D.

For pseudostatic stability, the static shear strengths presented in Table 1 were used. For the pseudostatic analysis, a horizontal seismic coefficient, k_h, of 0.28 g (1/2 PGA_M) was applied. The slip surfaces intersecting Piers 1 and 2 were stable with factors of safety of at least 1.1.

A summary of all analyses and respective factors of safety can be seen in Table 2. Figures with slope stability results for all analyses can be found in Appendix B.

Table 2 – Slope Stability Analyses Summary

Figure Number	Pier Number	Analysis Case	Seismic Coefficient, k_h	Factor of Safety
B1	1	Static	0	1.99
B2	1	Pseudostatic	0.28	1.10
B3	1	Post-liquefied	0	0.96
B4	2	Static	0	1.85
B5	2	Pseudostatic	0.28	1.10
B6	2	Post-liquefied	0	0.90[1]

[1] FS < 1.1. See Appendix D for kinematic loading due to flow failure.

4.0 Drilled Shaft Foundations

The following sections detail design recommendations for vertical and lateral pile resistance.

4.1 Drilled Shaft Vertical Resistance

We calculated nominal single-drilled shaft resistances using effective stress methods outlined in the Federal Highway Administration (FHWA) Drilled Shaft Manual (2010). The current design does not include permanent casing. If the project includes groups of shafts in a single row, a reduction to the resistance of 0.9 should be applied for center-to-center spacing of 2D, and 1.0 for 3D or greater. Figures for axial shaft resistance for 2-foot diameter drilled shafts are provided on Figures C1 and C2 in Appendix C.

Due to the generally soft and loose nature of the soils, temporary casing may not be able to be removed during construction. We have provided axial shaft resistances that include permanent casing to a depth of 80 feet on Figures C3 and C4. To avoid punching into the very soft silts and clays below ESU 4, we recommend not extending the shafts below elevation –80 feet. Therefore, we recommend that shafts be designed so that, in the event that the temporary casing must be left in place during construction, the shaft capacities with casing meet design criteria. If the shaft capacities with permanent casing are not acceptable with the design number of shafts, additional shafts may be necessary.

Based on the FHWA Drilled Shaft Manual, we evaluated side shaft and tip resistances using the beta method with the correlations for soil properties described for the method. The representative N_{60} values and friction angles presented in Table 1 were used for the respective ESU in the capacity calculations. We applied resistance factors to nominal pile resistances that were calculated as specified in AASHTO 2017 to calculate the design resistances for the individual drilled shafts. The Service Limit State was designed with the curves from O'Neill and Reese (1999), as referenced by the GDM.

For the Extreme I Limit State, we have provided the liquefaction-induced downdrag in Table 3 below. This load should be applied to the top of the shafts in the Extreme Limit State only and should not be considered for the Strength or Service Limit States.

The Extreme I Limit State resistances provided in Figures C1 and C2 use a substantially-reduced side friction resistance due to liquefaction. This is consistent with the Modified Unified Approach as described in WSDOT research report WA-RD 865.1 "Liquefaction-Induced Downdrag on Drilled Shafts".

A summary of the axial capacity resistance analyses can be seen in Table 3 below.

Table 3 – Axial Resistance Analysis Summary

Figure Number	Pier Number	Analysis Case	Shaft Diameter (feet)	Downdrag (kips)
C1	1 and 2	Compression[1]	2	144
C2	1 and 2	Uplift[1]	2	--
C3	1 and 2	Compression[2]	2	126
C4	1 and 2	Uplift[2]	2	--

[1] Assumes no permanent casing is used.

[2] Assumes permanent steel casing is used to an approximate depth of 80 feet (approximate elevation -65 feet).

4.2 Drilled Shaft Lateral Resistance

We recommend the computer program LPILE using the model parameters for each ESU shown in Table C1, located in Appendix C. The LPILE parameters in Appendix C were determined based on the ESU friction angles and the API Sand correlation in the LPILE Technical Manual. Liquefaction is addressed by the liquefied p-multipliers in the tables. The soil layering is based on the current ground surface and should be adjusted for scour accordingly. Table 4 provides p-multipliers for group effects which are applicable to non-liquefied soil conditions in LPILE, as shown in Table 10.7.2.4-1 of the AASHTO LRFD Bridge Design Specifications.

Table 4 – Group Effects for LPILE Analysis

Shaft Center-to-Center Spacing (In the Direction of Loading)	P-Multipliers Applicable to LPILE		
	Row 1	Row 2	Row 3 and Higher
3B	0.8	0.4	0.3
5B	1.0	0.85	0.7

4.3 Abutment Earth Pressures

The lateral earth pressure distribution and coefficients are provided on Figure D3 in Appendix D. The lateral earth pressure coefficients for the abutment assumes a friction angle of 34 degrees for new fill. An interface friction angle of 17 degrees (half of the soil internal friction angle) was assumed for the new fill.

The abutment wall design recommendations assume that the backfill directly behind the wall for at least 12 inches is free-draining and meets the requirements in 2018 WSDOT Standard Specifications Section 9-03.12(2) (Gravel Backfill for Walls). We also recommend installing and maintaining adequate drainage measures to prevent hydrostatic pressures from building up behind the abutment walls. The drainage system should be capable of diverting and removing groundwater, perched or otherwise, and stormwater. If a drainage system is not installed, the wall must be designed for full hydrostatic pressure.

A typical drainage system generally consists of a perforated drainage pipe behind and at the base of the walls, with a minimum diameter of 4 inches. The perforated pipe should be surrounded on all sides by free-draining material. A non-woven geotextile should be placed between the drainage material and surrounding soil, and the gradation of the drainage material should be compatible with the perforations in the drainage pipe such that soil intrusion into the pipe does not take place. If they are not compatible, a non-woven geotextile should be used to provide separation and filtration.

5.0 Construction Considerations

This section presents considerations and our recommendations for construction of the bridge piers and abutments. We developed our conclusions and recommendations based on our current understanding of the project and existing subsurface explorations. If significant variations are observed at any time, we may need to modify our conclusions and recommendations.

Some construction considerations for the drilled shaft foundations are as follows:

- Groundwater was generally observed around an elevation of 10 feet.
- Subgrade soils generally consist of loose sand and soft silt. Due to the poorly graded nature of many of the materials encountered in the borings and the generally loose/soft consistency, unsupported

side walls of the shaft excavations have significant potential to slough during construction. Temporary casing and slurries can be used to aid side wall stabilization.

- The shaft toe shall be cleaned out no more than 6 hours before placing concrete to limit the impact of suspended solids settling to the toe and reducing the geotechnical stiffness of the toe.
- For drilled shaft construction where multiple drilled shafts are planned, the timing of excavation and concrete placement of the adjacent shafts should be considered. Providing adequate cure time of the adjacent drilled shaft before proceeding to excavate the next drilled shaft will not only minimize the potential for communication between adjacent shafts but will also reduce the likelihood of disturbing the set and cure of the concrete in a recently poured shaft. The time required for adequate curing will depend on the concrete mix used in the shafts. We recommend following WSDOT Standard Specifications 6-02.3(6)D1 and 6-02.3(6)D2 for the concrete mix used in the shafts to determine the appropriate timing between pouring and drilling adjacent shafts.

We recommend that a field representative of the geotechnical engineer-of-record be on site to observe the drilled shaft installations.

6.0 References

AASHTO LRFD Bridge Design Specifications. Washington, D.C.: American Association of State Highway and Transportation Officials, 2017.

FHWA Drilled Shafts: Construction Procedures and LRFD Design Methods, NHI Course No. 132014, Geotechnical Engineering Circular No. 10. Washington, D.C.: U.S. Department of Transportation National Highway Institute, 2010.

FHWA Geotechnical Engineering Circular No. 5 – Evaluation of Soil and Rock Properties. Washington, D.C.: U.S. Department of Transportation Federal Highway Administration, 2002.

Majunthan, B., Vijayathasan, N., and Abbasi, B. Liquefaction-Induced Downdrag on Drilled Shafts. Washington State Department of Transportation Report No. WA-RD 865.1, 2017.

WSDOT Geotechnical Design Manual (M46-03.11). Tumwater, WA: Washington State Department of Transportation, 2015.

Washington State Department of Transportation (WSDOT) 2018. *Standard Specifications for Road, Bridge, and Municipal Construction*, Publication M 41 10.

Attachments:
Figure 1 – Vicinity Map
Figure 2 – Site and Exploration Plan
Figure 3 – Generalized Subsurface Profile
Appendix A – Subsurface Explorations
Appendix B – Slope Stability Analysis Results
Appendix C – Drilled Shaft Vertical Resistance Charts and Lateral Resistance Input Parameters
Appendix D – Lateral Earth Pressure Diagrams

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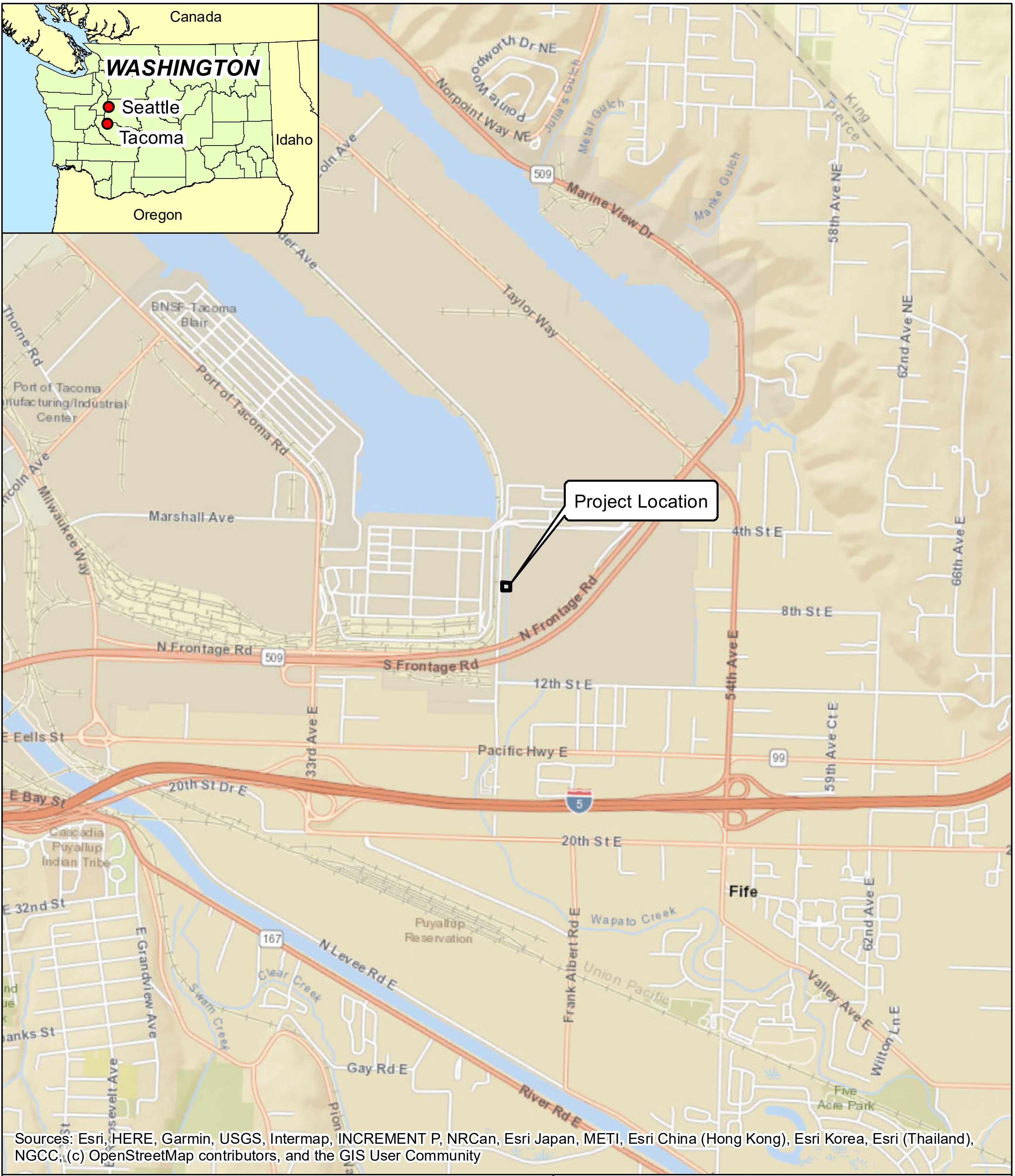

Sources: Esri, HERE, Garmin, USGS, Intermap, INCREMENT P, NRCan, Esri Japan, METI, Esri China (Hong Kong), Esri Korea, Esri (Thailand), NGCC, (c) OpenStreetMap contributors, and the GIS User Community

0 1,000 2,000 4,000
Feet

Note: Feature locations are approximate.

N

Wapato Creek Culvert Replacement
Tacoma, Washington

Vicinity Map

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Figure
1

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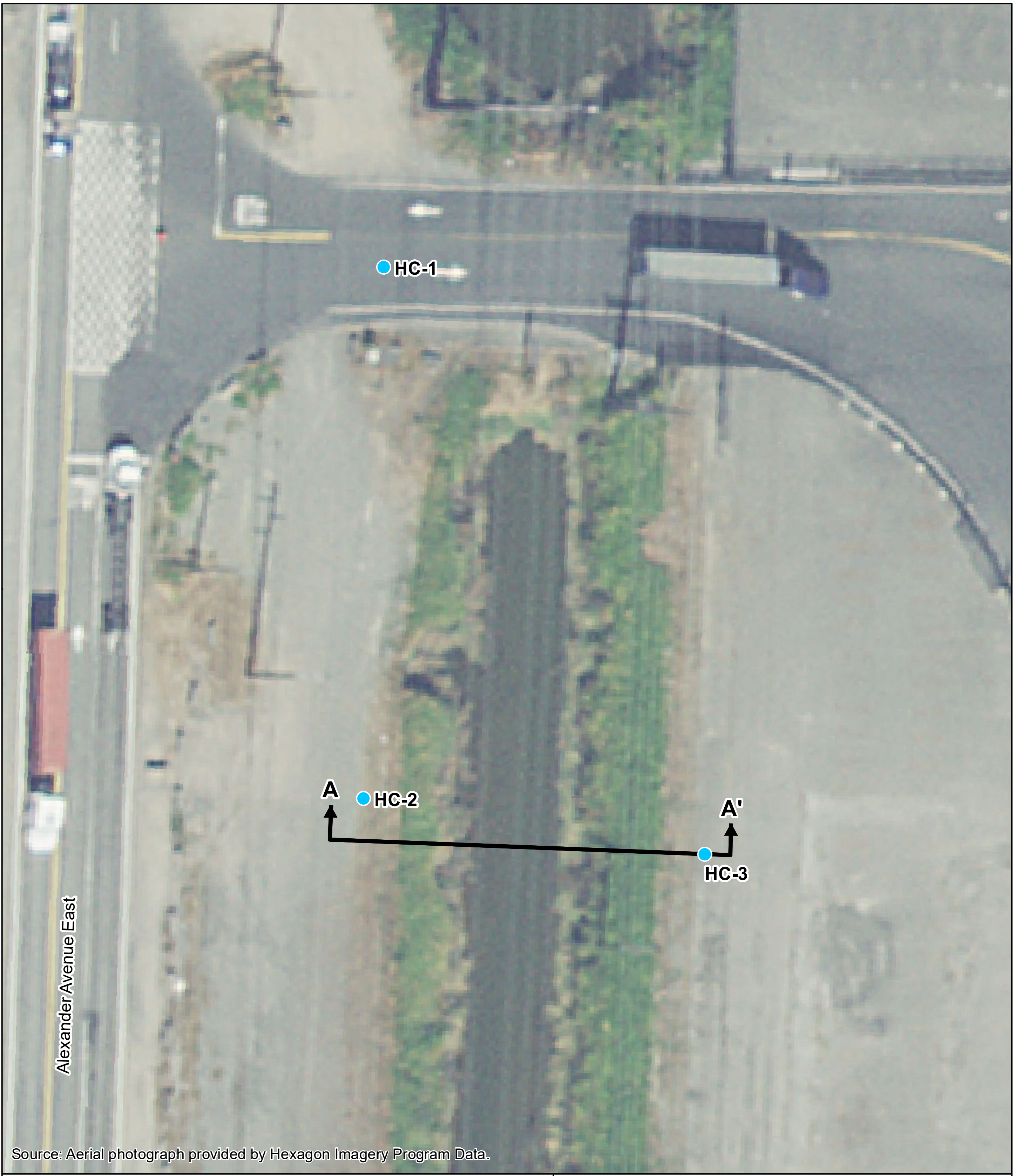

Source: Aerial photograph provided by Hexagon Imagery Program Data.

Legend

● Boring (Hart Crowser 2019)

⟷ Cross Section Location and Direction

0 20 40 80 Feet

Note: Feature locations are approximate.

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Wapato Creek Culvert Replacement
Tacoma, Washington

Site and Exploration Plan

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Figure

2

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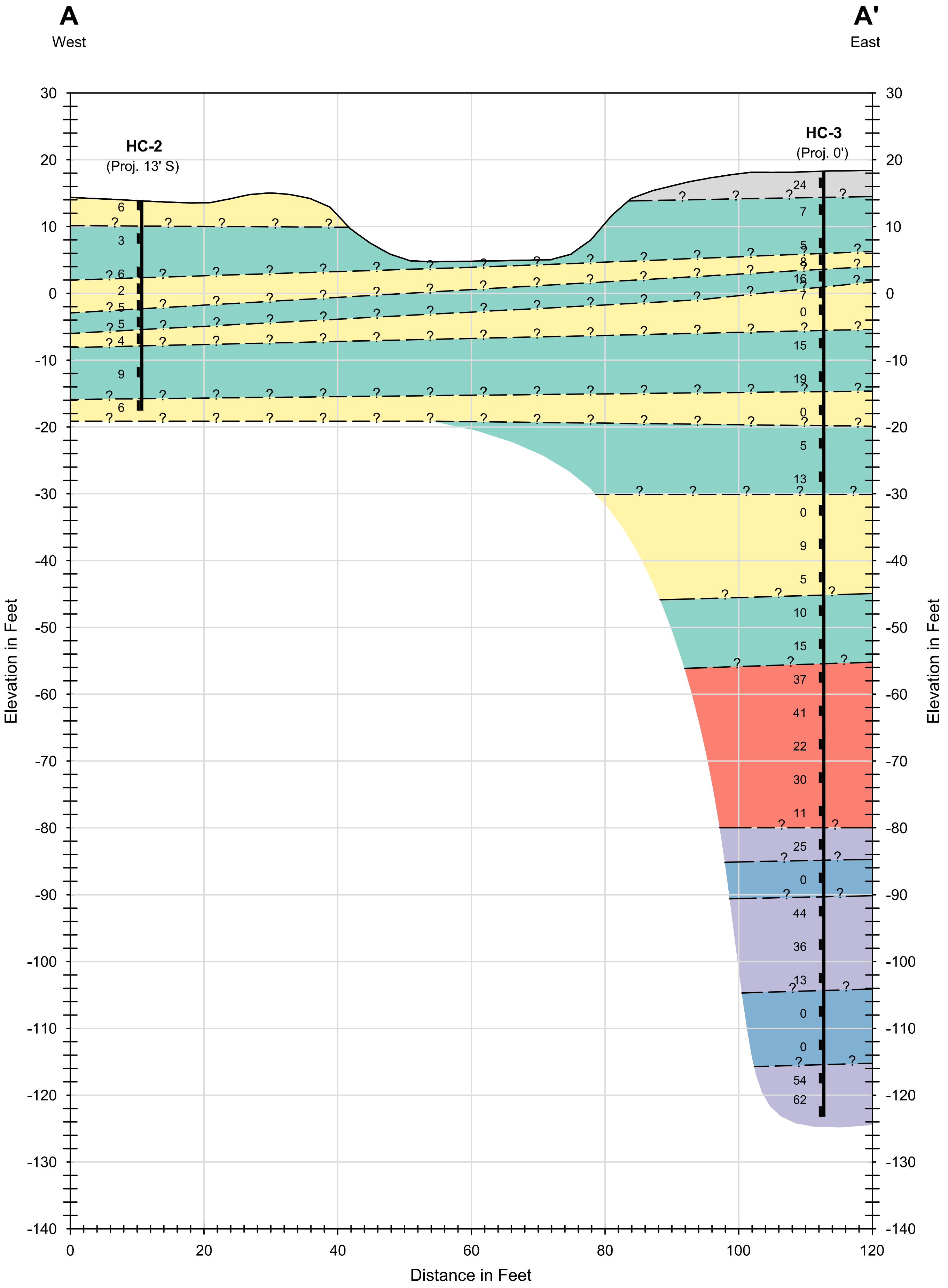

Legend

🟨 ESU 1 - Very soft silt and clay, occasional peat

🟩 ESU 2 - Loose sand and silty sand

🟦 ESU 3 - Soft silt and clay

🟥 ESU 4 - Medium dense sand

🟪 ESU 5 - Dense sand and silty sand

⬜ ESU 6 - Fill

HC-102 (34.5' E) Exploration Number (Offset Distance and Direction)

Exploration Location

9 Standard Penetration Resistance in Blows per Foot

Sample Location

0 20 40
Scale in Feet

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Wapato Creek Culvert Replacement
Tacoma, Washington

Generalized Subsurface Cross Section A-A'

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Figure
3

APPENDIX A
Subsurface Explorations

Sample Description

Identification of soils in this report is based on visual field and laboratory observations which include density/consistency, moisture condition, grain size, and plasticity estimates and should not be construed to imply field nor laboratory testing unless presented herein. ASTM D 2488 visual-manual identification methods were used as a guide. Where laboratory testing confirmed visual-manual identifications, then ASTM D 2487 was used to classify the soils.

Relative Density/Consistency

Soil density/consistency in borings is related primarily to the standard penetration resistance (N). Soil density/consistency in test pits and probes is estimated based on visual observation and is presented parenthetically on the logs.

SAND or GRAVEL Relative Density	N (Blows/Foot)	SILT or CLAY Consistency	N (Blows/Foot)
Very loose	0 to 4	Very soft	0 to 1
Loose	5 to 10	Soft	2 to 4
Medium dense	11 to 30	Medium stiff	5 to 8
Dense	31 to 50	Stiff	9 to 15
Very dense	>50	Very stiff	16 to 30
		Hard	>30

Moisture

Dry	Absence of moisture, dusty, dry to the touch
Moist	Damp but no visible water
Wet	Visible free water, usually soil is below water table

USCS Soil Classification Chart (ASTM D 2487)

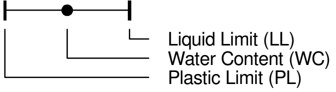
Major Divisions			Symbols Graph	Symbols USCS	Typical Descriptions
Coarse Grained Soils More than 50% of Material Retained on No. 200 Sieve	Gravel and Gravelly Soils More than 50% of Coarse Fraction Retained on No. 4 Sieve	Clean Gravels *(<5% fines)*	▨	GW	Well-Graded Gravel; Well-Graded Gravel with Sand
			▨	GP	Poorly Graded Gravel; Poorly Graded Gravel with Sand
		Gravels *(5-12% fines)*	▨	GW-GM	Well-Graded Gravel with Silt; Well-Graded Gravel with Silt and Sand
			▨	GW-GC	Well-Graded Gravel with Clay; Well-Graded Gravel with Clay and Sand
			▨	GP-GM	Poorly Graded Gravel with Silt; Poorly Graded Gravel with Silt and Sand
			▨	GP-GC	Poorly Graded Gravel with Clay; Poorly Graded Gravel with Clay and Sand
		Gravels with Fines *(>12% fines)*	▨	GM	Silty Gravel; Silty Gravel with Sand
			▨	GC	Clayey Gravel; Clayey Gravel with Sand
	Sand and Sandy Soils More than 50% of Coarse Fraction Passing No. 4 Sieve	Sands with few Fines *(<5% fines)*	▨	SW	Well-Graded Sand; Well-Graded Sand with Gravel
			▨	SP	Poorly Graded Sand; Poorly Graded Sand with Gravel
		Sands *(5-12% fines)*	▨	SW-SM	Well-Graded Sand with Silt Well-Graded Sand with Silt and Gravel
			▨	SW-SC	Well-Graded Sand with Clay; Well-Graded Sand with Clay and Gravel
			▨	SP-SM	Poorly Graded Sand with Silt; Poorly Graded Sand with Silt and Gravel
			▨	SP-SC	Poorly Graded Sand with Clay; Poorly Graded Sand with Clay and Gravel
		Sands with Fines *(>12% fines)*	▨	SM	Silty Sand; Silty Sand with Gravel
			▨	SC	Clayey Sand; Clayey Sand with Gravel
Fine Grained Soils More than 50% of Material Passing No. 200 Sieve	Silts		▨	ML	Silt; Silt with Sand or Gravel; Sandy or Gravelly Silt
			▨	MH	Elastic Silt; Elastic Silt with Sand or Gravel; Sandy or Gravelly Elastic Silt
	Silty Clay *(based on Atterberg Limits)*		▨	CL-ML	Silty Clay; Silty Clay with Sand or Gravel; Gravelly or Sandy Silty Clay
	Clays		▨	CL	Lean Clay; Lean Clay with Sand or Gravel; Sandy or Gravelly Lean Clay
			▨	CH	Fat Clay; Fat Clay with Sand or Gravel; Sandy or Gravelly Fat Clay
	Organics		▨	OL/OH	Organic Soil; Organic Soil with Sand or Gravel; Sandy or Gravelly Organic Soil
Highly Organic *(>50% organic material)*			▨	PT	Peat - Decomposing Vegetation - Fibrous to Amorphous Texture

Minor Constituents

	Estimated Percentage
Sand, Gravel	
Trace	<5
Few	5 - 15
Cobbles, Boulders	
Trace	<5
Few	5 - 10
Little	15 - 25
Some	30 - 45

Soil Test Symbols

%F	Percent Passing No. 200 Sieve
AL	Atterberg Limits (%)



CA	Chemical Analysis
CAUC	Consolidated Anisotropic Undrained Compression
CAUE	Consolidated Anisotropic Undrained Extension
CBR	California Bearing Ratio
CIDC	Consolidated Drained Isotropic Triaxial Compression
CIUC	Consolidated Isotropic Undrained Compression
CK0DC	Consolidated Drained k0 Triaxial Compression
CK0DSS	Consolidated k0 Undrained Direct Simple Shear
CK0UC	Consolidated k0 Undrained Compression
CK0UE	Consolidated k0 Undrained Extension
CRSCN	Constant Rate of Strain Consolidation
DSS	Direct Simple Shear
DT	In Situ Density
GS	Grain Size Classification
HYD	Hydrometer
ILCN	Incremental Load Consolidation
K0CN	k0 Consolidation
kc	Constant Head Permeability
kf	Falling Head Permeability
MD	Moisture Density Relationship
OC	Organic Content
OT	Tests by Others
P	Pressuremeter
PID	Photoionization Detector Reading
PP	Pocket Penetrometer
SG	Specific Gravity
TRS	Torsional Ring Shear
TV	Torvane
UC	Unconfined Compression
UUC	Unconsolidated Undrained Triaxial Compression
VS	Vane Shear
WC	Water Content (%)

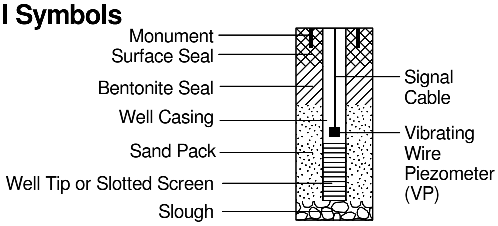
Groundwater Indicators

∇	Groundwater Level on Date or At Time of Drilling (ATD)
▼	Groundwater Level on Date Measured in Piezometer
♀	Groundwater Seepage (Test Pits)

Sample Symbols

☒ 1.5" I.D. Split Spoon	◨ Core Run	☒ Grab
◩ 3.0" I.D. Split Spoon	☐ Sonic Core	▥ Cuttings
◨ Modified California Sampler	◫ Thin-walled Sampler	

Well Symbols



HARTCROWSER

Project: Wapato Creek Culvert
Location:
Project No.: 19433-00

Key to Exploration Logs

Figure **A-1**
Sheet **1 of 1**

Date Started: 1/16/19 Date Completed: 1/16/19
Logged by: M. Espinoza Checked by: C. Kroskie
Location: Lat: 47.251126 Long: -122.372645
Ground Surface Elevation: 16.524 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Well Tag ID: VLI-180 Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc. / J. Bennett
Drilling Method: Hollow Stem Auger
Rig Model/Type: CME-85 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140 Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: Casing Diameter:
Total Depth: 51.5 feet Depth to Groundwater: 9.8 feet

Blow Count	Type	Recovery	Length (inches)	Number Tests	SPT N Value
4 19 24	☒	18in.	18	S-1	43
10 24 19	☒	18in.	18	S-2	43
3 5 6	☒	12in.	18	S-3	11
2 1 5	☒	12in.	18	S-4	6
1 1 0	☒		18	S-5	1
0	☒	18in.	18	S-6	
3 4 5	☒	12in.	18	S-7	9
8 9 12	☒	12in.	18	S-8	21
16 50	☒	12in.	18	S-9	

Material Description

9 inches of Asphaltic Concrete.

POORLY GRADED SAND WITH SILT AND GRAVEL (SP-SM), dense, brown to dark brown, moist. [FILL]

SANDY SILT (ML), stiff, gray with red-orange, moist, iron oxide staining. [NATIVE]

Becomes medium stiff, wet, gray-brown.

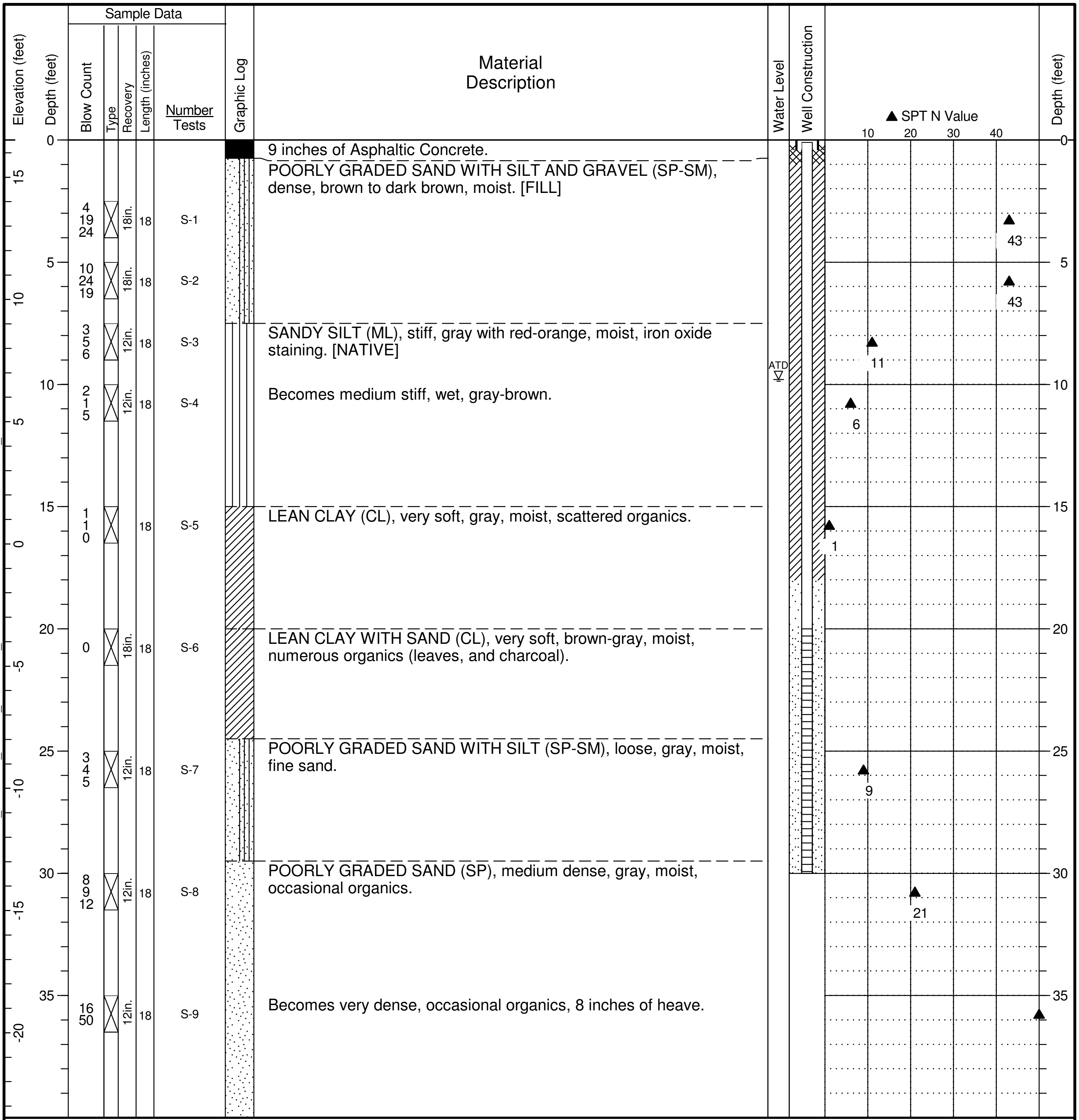
LEAN CLAY (CL), very soft, gray, moist, scattered organics.

LEAN CLAY WITH SAND (CL), very soft, brown-gray, moist, numerous organics (leaves, and charcoal).

POORLY GRADED SAND WITH SILT (SP-SM), loose, gray, moist, fine sand.

POORLY GRADED SAND (SP), medium dense, gray, moist, occasional organics.

Becomes very dense, occasional organics, 8 inches of heave.



General Notes:
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3. USCS designations are based on visual-manual identification (ASTM D 2488) unless otherwise supported by laboratory testing (ASTM D 2487).
4. Groundwater level, if indicated, is at time of drilling/excavation (ATD) or for date specified. Level may vary with time.

HARTCROWSER
Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

Boring Log
HC-1

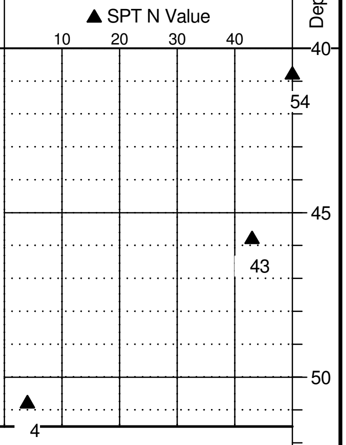
Figure **A-2**
Sheet **1 of 2**

Date Started: 1/16/19
Date Completed: 1/16/19
Logged by: M. Espinoza
Checked by: C. Kroskie
Location: Lat: 47.251126 Long: -122.372645
Ground Surface Elevation: 16.524 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Well Tag ID: VLI-180 Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc. / J. Bennett
Drilling Method: Hollow Stem Auger
Rig Model/Type: CME-85 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter:
Casing Diameter:
Total Depth: 51.5 feet
Depth to Groundwater: 9.8 feet

Elevation (feet)	Depth (feet)	Blow Count	Type	Recovery	Length (inches)	Number Tests	Material Description	Water Level	Well Construction
-25	40	14 14 40	☒	2in.	18	S-10	POORLY GRADED SAND (SP), very dense, gray, moist, occasional organics.		
-30	45	10 11 32	☒	0in.	18	S-11	Becomes dense.		
-35	50	2 2 2	☒	18in.	18	S-12	LEAN CLAY (CL), very loose, gray, moist, frequent laminations of peat.		

Bottom of Borehole at 51.5 feet.



General Notes:
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HC BORING LOG - J:\GINT\HC_LIBRARY.GLB - 7/10/19 11:29 - L:\NOTEBOOKS\1943300_WAPATO_CREEK_CULVERT_REPLACEMENT\FIELD DATA\PERM_GINT FILES\1943300-BL.GPJ - kzl

HARTCROWSER
Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00
Boring Log
HC-1
Figure **A-2**
Sheet **2 of 2**

Date Started: 4/19/19
Date Completed: 4/19/19
Logged by: J. Jacoby
Checked by: A. Hossley
Location: Lat: 47.250693 Long: -122.372654
Ground Surface Elevation: 13.978 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc.
Drilling Method: Hollow Stem Auger
Rig Model/Type: CME-75 / Track-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: 5 inches
Casing Diameter: NA
Total Depth: 31.5 feet
Depth to Groundwater: Not Identified

		Sample Data						
Elevation (feet)	Depth (feet)	Blow Count	Type	Recovery	Length (inches)	Number Tests	Material Description	▲ SPT N Value
	0	2 2 4	☒	15in.	18	S-1	SANDY SILT (ML), medium stiff, brown with red staining, moist.	6
10								
	5	2 1 2	☒	12in.	18	S-2	SILTY SAND (SM), very loose, gray, moist.	3
5								
	10	3 4 2	☒	15in.	18	S-3	Becomes loose, trace wood fibers.	6
		1 1 1	☒	18in.	18	S-4	SILT (ML), very soft, brown and black, moist, organic odor, numerous organics, occasional peat laminations.	2
0								
	15	0 0 5	☒	18in.	18	S-5	1.5-inch silty sand seam observed at 15 feet. Becomes medium stiff, no peat laminations.	5
		7 3 2	☒	9in.	18	S-6A S-6B	Scattered organics. SILTY SAND (SM), loose, gray, moist.	5
-5								
	20	3 2 2	☒	14in.	18	S-7	SANDY SILT to SILT (ML), soft, moist, gray, sandier in top 4 inches, transitioning to less sand in the bottom 10 inches.	4
-10								
	25	5 6 3	☒	9in.	18	S-8	SILTY SAND (SM), loose, gray, moist.	9
-15								
	30	5 4 2	☒	18in.	18	S-9	SANDY SILT (ML) to SILTY SAND (SM), medium stiff to loose, moist, gray. Grades from sandy silt from 0 to 5 inches, to silty sand from 5 to 12 inches, to sandy silty from 12 to 18 inches.	6
							Bottom of Borehole at 31.5 feet.	
-20								
	35							
-25								

SPT N Value scale: 10 20 30 40

General Notes:
1. Refer to Figure A-1 for explanation of descriptions and symbols.
2. Material descriptions and stratum lines are interpretive and actual changes may be gradual. Solid stratum lines indicate distinct contact between material strata or geologic units. Dashed stratum lines indicate gradual or approximate change between material strata or geologic units.
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HARTCROWSER

Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

Boring Log
HC-2

Figure **A-3**
Sheet **1 of 1**

HC BORING LOG - J:\GINT\HC_LIBRARY.GLB - 7/10/19 11:29 - L:\NOTEBOOKS\1943300_WAPATO_CREEK_CULVERT_REPLACEMENT\FIELD DATA\PERM_GINT FILES\1943300-BL.GPJ - kzl

Date Started: 4/16/19
Date Completed: 4/17/19
Logged by: J. Jacoby/Y. Tao
Checked by: A. Hossley
Location: Lat: 47.250654 Long: -122.372244
Ground Surface Elevation: 18.291 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc.
Drilling Method: Hollow Stem Auger
Rig Model/Type: Mobile B-58 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: 6 inches
Casing Diameter: NA
Total Depth: 141.5 feet
Depth to Groundwater: Not Identified

Elevation (feet)	Depth (feet)	Blow Count	Type	Recovery	Length (inches)	Number Tests	Material Description	SPT N Value
	0						Asphalt.	
15		10 12 12	☒	12in.	18	S-1	POORLY GRADED SAND WITH SILT (SP-SM), medium dense, gray, moist. [FILL]	24
	5	4 5 2	☒	0in.	18	S-2	SILTY SAND (SM) to SANDY SILT (ML), loose to soft, moist, gray. No recovery at 5-foot sample. Soil description inferred from drill action and blowcounts.	7
10								
	10	3 3 2	☒	12in.	18	S-3	Sandier in top 6 inches, transitioning to siltier in bottom 6 inches.	5
5		3 5 3	☒	13in.	18	S-4A S-4B	POORLY GRADED SAND WITH SILT (SP-SM), loose, gray, wet. LEAN CLAY WITH SAND (CL), medium stiff, gray, wet, fine sand.	8
	15	4 8 8	☒	12in.	18	S-5	POORLY GRADED SAND WITH SILT (SP-SM), medium dense, gray, wet, fine sand, traces of wood debris.	16
0		5 4 3	☒	12in.	18	S-6A S-6B	POORLY GRADED SAND (SP), loose, gray, wet, fine sand. SANDY LEAN CLAY (CL), medium stiff, gray, wet, fine sand, numerous organics.	7
	20	0 0 0	☒	18in.	18	S-7	LEAN CLAY WITH SAND (CL), very soft, brown, moist, scattered wood debris.	0
-5								
	25	2 6 9	☒	18in.	18	S-8	SANDY SILT (ML) to SILTY SAND (SM), stiff to medium dense, moist, gray, trace organics, fine sand. Siltier in top 6 inches, transitioning to sandier in bottom 6 inches.	15
-10								
	30	7 9 10	☒	18in.	18	S-9	POORLY GRADED SAND (SP), medium dense, gray, moist, fine sand.	19
-15								
	35	0 0 0	☒	18in.	18	S-10A S-10B	LEAN CLAY WITH SAND to SANDY LEAN CLAY (CL), very soft, moist, brown, scattered organics, becomes sandier in bottom 3 inches.	0
-20								

▲ SPT N Value: 10 20 30 40

General Notes:
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HARTCROWSER

Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

Boring Log
HC-3

Figure **A-4**
Sheet **1 of 4**

Date Started: 4/16/19
Date Completed: 4/17/19
Logged by: J. Jacoby/Y. Tao
Checked by: A. Hossley
Location: Lat: 47.250654 Long: -122.372244
Ground Surface Elevation: 18.291 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc.
Drilling Method: Hollow Stem Auger
Rig Model/Type: Mobile B-58 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: 6 inches
Casing Diameter: NA
Total Depth: 141.5 feet
Depth to Groundwater: Not Identified

Elevation (feet)	Depth (feet)	Sample Data: Blow Count	Type	Recovery	Length (inches)	Number Tests	Graphic Log	Material Description	▲ SPT N Value	Depth (feet)
	40	4 2 3	☒	18in.	18	S-11		POORLY GRADED SAND WITH SILT (SP-SM), loose, gray, moist.	5	40
-25										
	45	0 7 6	☒	18in.	18	S-12A S-12B		LEAN CLAY (CL), stiff, gray and brown, moist, numerous organics, peat laminations. POORLY GRADED SAND (SP), medium dense, gray, moist.	13	45
-30										
	50	0 0 0	☒	18in.	18	S-13		SANDY LEAN CLAY (CL), very soft, brown-gray, moist.	0	50
-35										
	55	3 4 5	☒	18in.	18	S-14		POORLY GRADED SAND WITH CLAY (SP-SC), loose, gray, moist, scattered organics. Lean clay seam in bottom 3 inches.	9	55
-40										
	60	4 5 0	☒	11in.	18	S-15A S-15B		LEAN CLAY (CL), medium stiff, green-gray, moist, numerous organics.	5	60
-45										
	65	6 6 4	☒	12in.	18	S-16		POORLY GRADED SAND (SP), loose, gray, moist, fine to medium sand.	10	65
-50										
	70	1 3 12	☒	10in.	18	S-17A S-17B		SANDY LEAN CLAY (CL), stiff, gray, moist, occasional organics. POORLY GRADED SAND (SP), medium dense, gray, moist, fine to medium sand.	15	70
-55										
	75	15 18 19	☒	12in.	18	S-18		Becomes dense.	37	75
-60										

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HARTCROWSER

Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

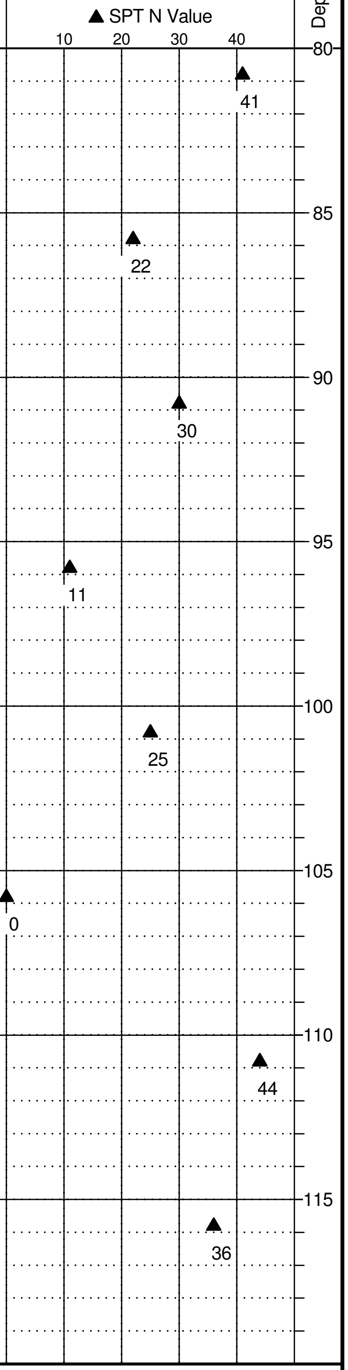
Boring Log
HC-3

Figure **A-4**
Sheet **2 of 4**

Date Started: 4/16/19
Date Completed: 4/17/19
Logged by: J. Jacoby/Y. Tao
Checked by: A. Hossley
Location: Lat: 47.250654 Long: -122.372244
Ground Surface Elevation: 18.291 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc.
Drilling Method: Hollow Stem Auger
Rig Model/Type: Mobile B-58 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: 6 inches
Casing Diameter: NA
Total Depth: 141.5 feet
Depth to Groundwater: Not Identified

Elevation (feet)	Depth (feet)	Sample Data Blow Count	Type	Recovery	Length (inches)	Number Tests	Material Description
	80	18 19 22	☒	14in.	18	S-19	POORLY GRADED SAND (SP), medium dense, gray, moist, fine to medium sand. *(continued)* Fine sand.
-65							
	85	0 11 11	☒	18in.	18	S-20	SILT WITH SAND (ML), very stiff, gray, moist, occasional organics.
-70							
	90	0 15 15	☒	18in.	18	S-21	SANDY LEAN CLAY (CL) to SANDY SILT (ML), very stiff, moist, gray, numerous shell fragments.
-75							
	95	2 3 8	☒	18in.	18	S-22	SILTY SAND (SM), medium dense, gray, moist, fine sand, scattered shell fragments. Hard drilling interval, drill chatter observed.
-80							
	100	16 16 9	☒	12in.	18	S-23	POORLY GRADED SAND (SP), medium dense, gray, moist, fine sand, occasional wood debris.
-85							
	105	0 0 0	☒	6in.	18	S-24	SANDY LEAN CLAY (CL), very soft, gray, moist.
-90							
	110	7 14 30	☒	2in.	18	S-25	SILT WITH SAND (ML), hard, gray, moist, occasional shell fragments.
-95							
	115	11 15 21	☒	12in.	18	S-26	POORLY GRADED SAND (SP), dense, gray, moist, occasional shell fragments.
-100							



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HARTCROWSER

Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

Boring Log
HC-3

Figure **A-4**
Sheet **3 of 4**

Date Started: 4/16/19
Date Completed: 4/17/19
Logged by: J. Jacoby/Y. Tao
Checked by: A. Hossley
Location: Lat: 47.250654 Long: -122.372244
Ground Surface Elevation: 18.291 feet
Horizontal Datum: WGS 84
Vertical Datum: NAVD 88
Comments: Location and ground surface elevations are approximate.

Drilling Contractor/Crew: Holt Services, Inc.
Drilling Method: Hollow Stem Auger
Rig Model/Type: Mobile B-58 / Truck-mounted drill rig
Hammer Type: Auto-hammer
Hammer Weight (pounds): 140
Hammer Drop Height (inches): 30
Measured Hammer Efficiency (%): NA
Hole Diameter: 6 inches
Casing Diameter: NA
Total Depth: 141.5 feet
Depth to Groundwater: Not Identified

Elevation (feet)	Depth (feet)	Sample Data					Graphic Log	Material Description	▲ SPT N Value (10 20 30 40)	Depth (feet)
		Blow Count	Type	Recovery	Length (inches)	Number Tests				
-105	120	6 10 3	☒	18in.	18	S-27		SILTY SAND (SM) to SANDY SILT (ML), medium dense to stiff, moist, gray, occasional organics. Bottom 6 inches becomes siltier, last hammer blow observed to be very soft, drill rod sunk several inches under weight of hammer.	13	120
-110	125	0 0 0	☒	18in.	18	S-28		ELASTIC SILT (MH), trace sand, very soft, gray, moist.	0	125
-115	130	0 0 0	☒	18in.	18	S-29		Drill rod fell under self weight, no hammer applied.	0	130
-120	135	27 30 24	☒	12in.	18	S-30		POORLY GRADED SAND (SP), very dense, gray, moist, fine sand, occasional shell fragments.	54	135
	140	16 30 32	☒	12in.	18	S-31			62	140
-125								Bottom of Borehole at 141.5 feet.		
-130	145									145
-135	150									150
-140	155									155

General Notes:
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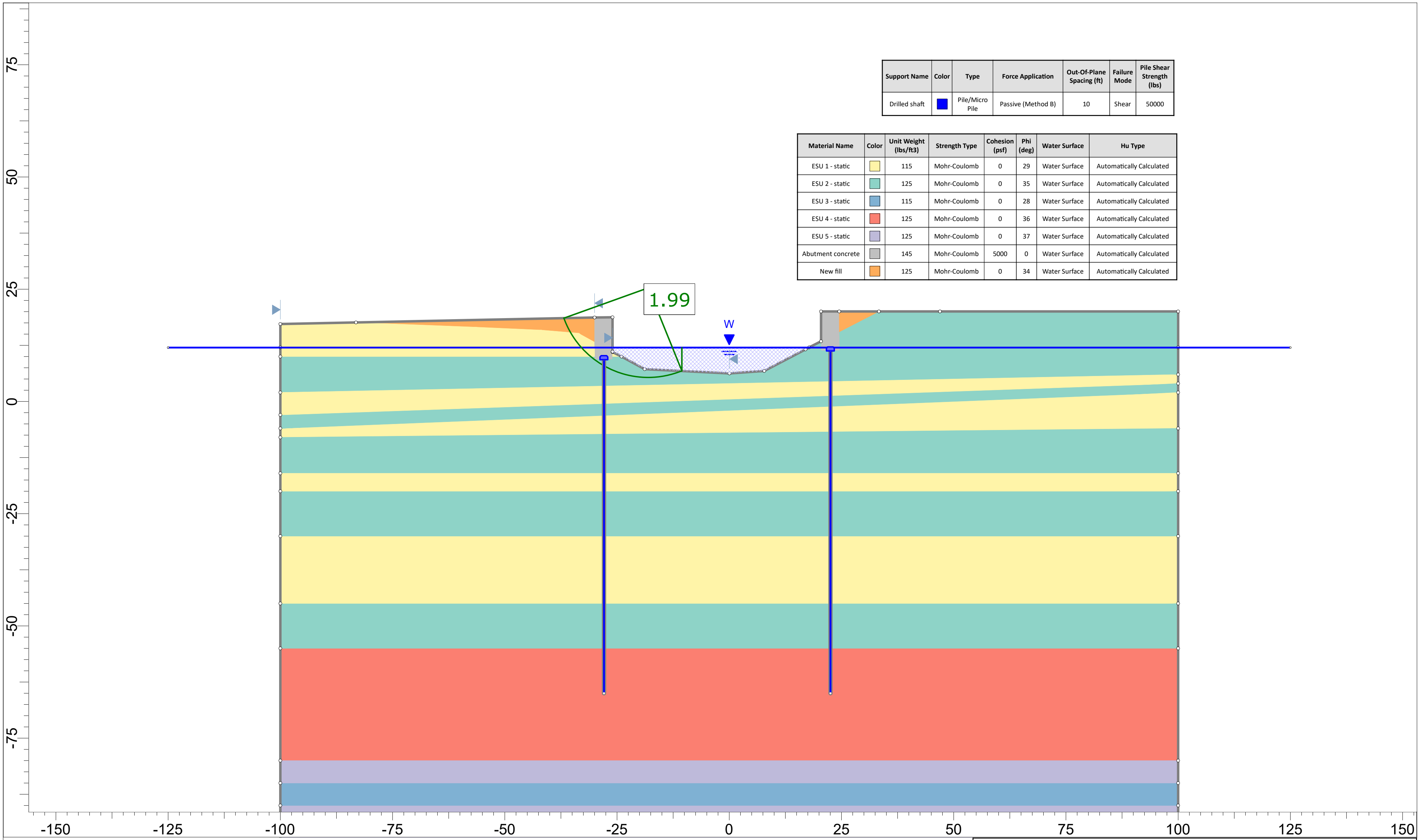
HARTCROWSER

Project: Wapato Creek Culvert
Location: Tacoma, WA
Project No.: 19433-00

Boring Log
HC-3

Figure **A-4**
Sheet **4 of 4**

APPENDIX B
Slope Stability Analysis Results



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29	Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35	Water Surface	Automatically Calculated
ESU 3 - static	🟦	115	Mohr-Coulomb	0	28	Water Surface	Automatically Calculated
ESU 4 - static	🟥	125	Mohr-Coulomb	0	36	Water Surface	Automatically Calculated
ESU 5 - static	🟪	125	Mohr-Coulomb	0	37	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0	Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34	Water Surface	Automatically Calculated

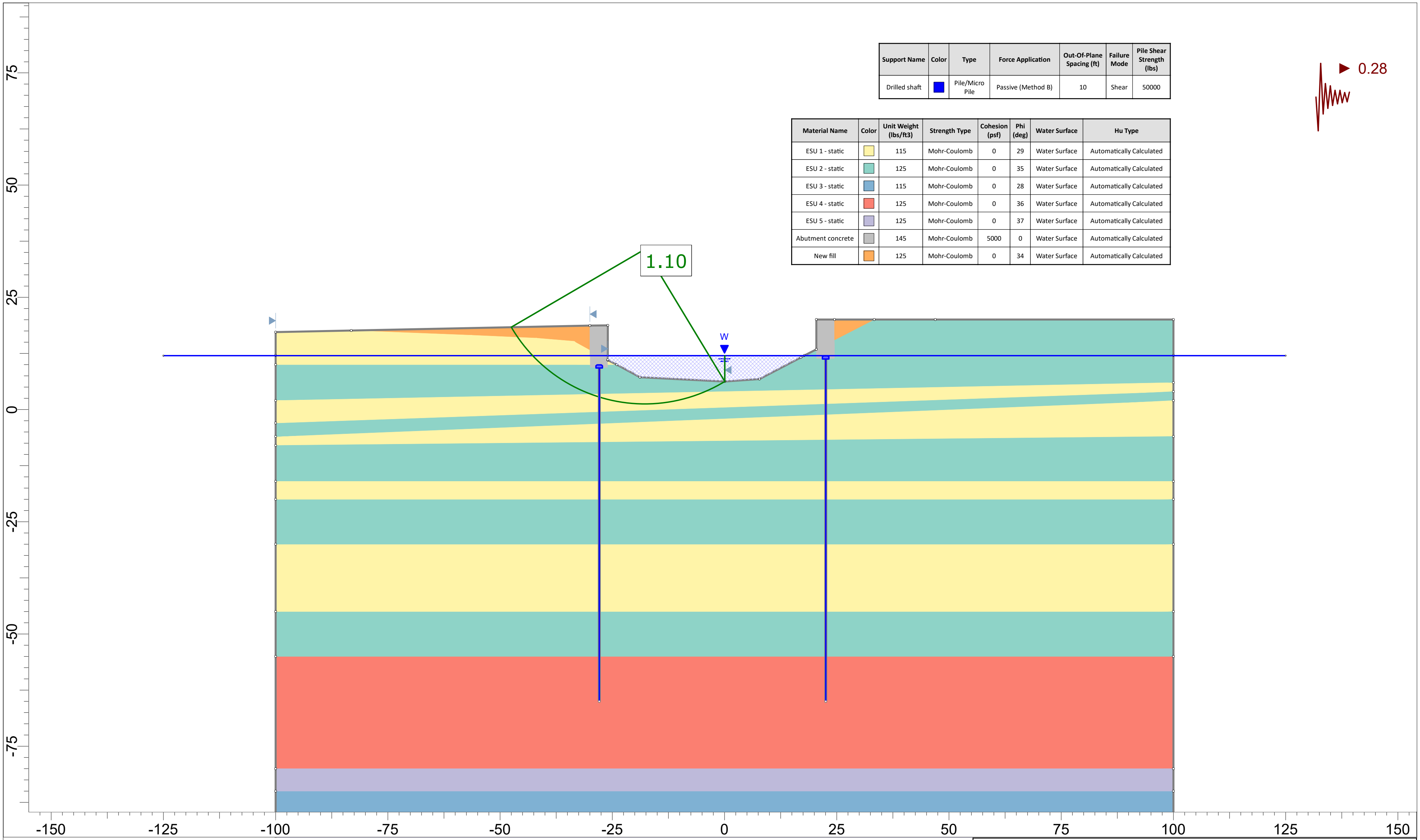
Wapato Creek Culvert Replacement

Pier 1 - Static

19433-01 Scale 1:360 7/19

HARTCROWSER

Figure
B1



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29	Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35	Water Surface	Automatically Calculated
ESU 3 - static	🟦	115	Mohr-Coulomb	0	28	Water Surface	Automatically Calculated
ESU 4 - static	🟥	125	Mohr-Coulomb	0	36	Water Surface	Automatically Calculated
ESU 5 - static	🟪	125	Mohr-Coulomb	0	37	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0	Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34	Water Surface	Automatically Calculated

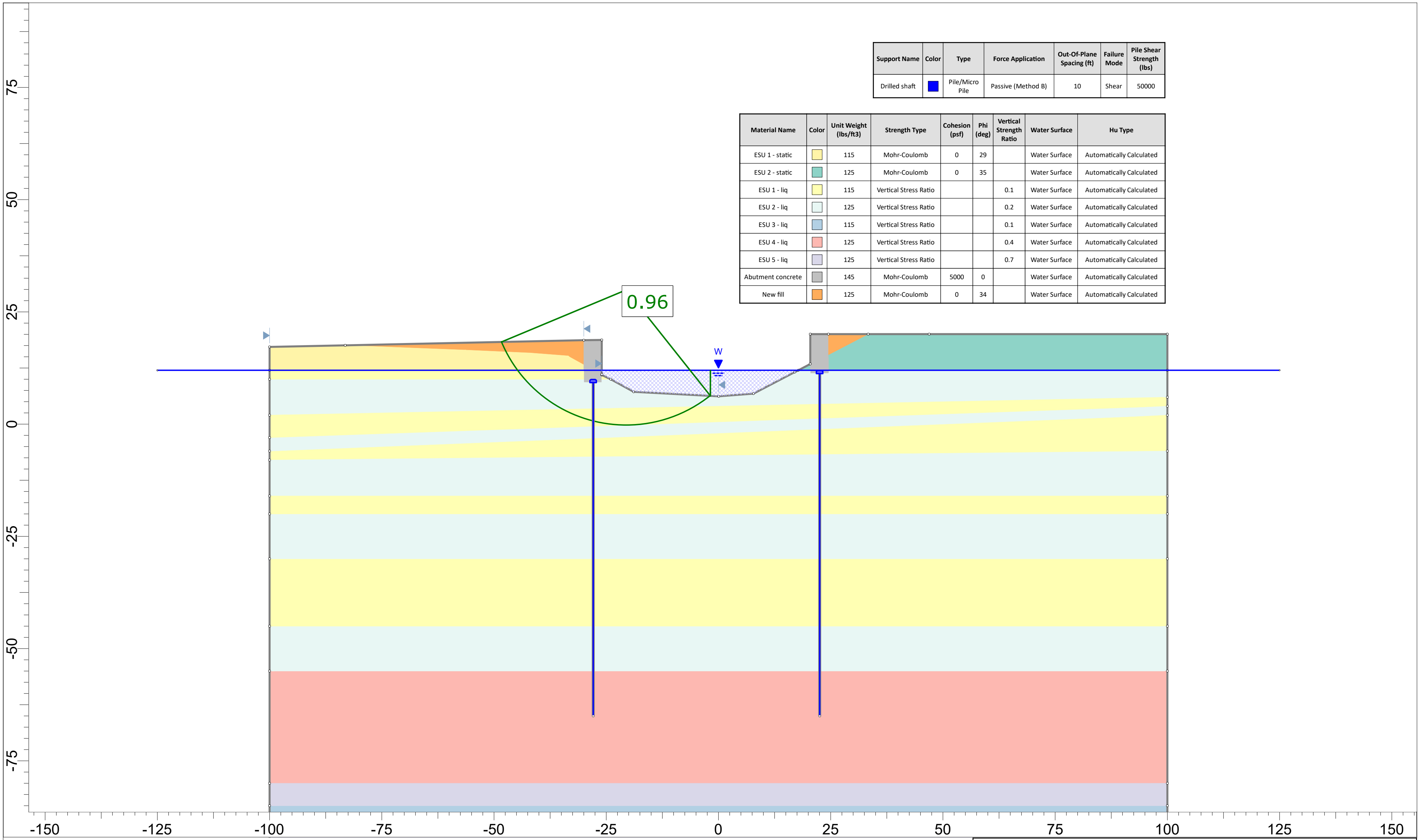
Wapato Creek Culvert Replacement

Pier 1 - Pseudostatic

19433-01 Scale 1:360 7/19

HARTCROWSER

Figure
B2



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Vertical Strength Ratio	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29		Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35		Water Surface	Automatically Calculated
ESU 1 - liq	🟨	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 2 - liq	⬜	125	Vertical Stress Ratio			0.2	Water Surface	Automatically Calculated
ESU 3 - liq	🟦	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 4 - liq	🟥	125	Vertical Stress Ratio			0.4	Water Surface	Automatically Calculated
ESU 5 - liq	🟪	125	Vertical Stress Ratio			0.7	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0		Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34		Water Surface	Automatically Calculated

Wapato Creek Culvert Replacement

Pier 1 - Liquefied

19433-01 Scale 1:360 7/19

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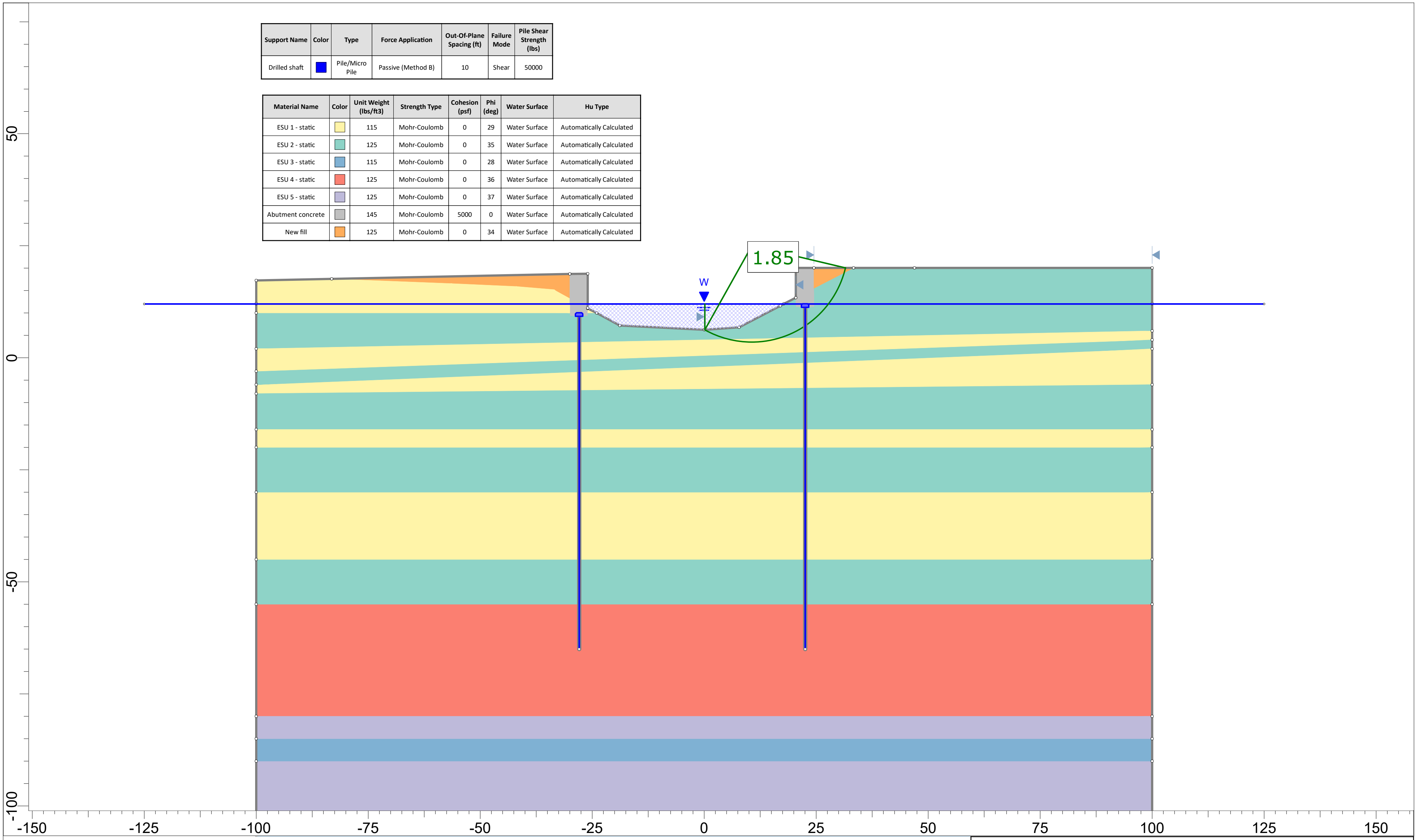
Figure
B3



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29	Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35	Water Surface	Automatically Calculated
ESU 3 - static	🟦	115	Mohr-Coulomb	0	28	Water Surface	Automatically Calculated
ESU 4 - static	🟥	125	Mohr-Coulomb	0	36	Water Surface	Automatically Calculated
ESU 5 - static	🟪	125	Mohr-Coulomb	0	37	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0	Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34	Water Surface	Automatically Calculated

Wapato Creek Culvert Replacement

Pier 2 - Static

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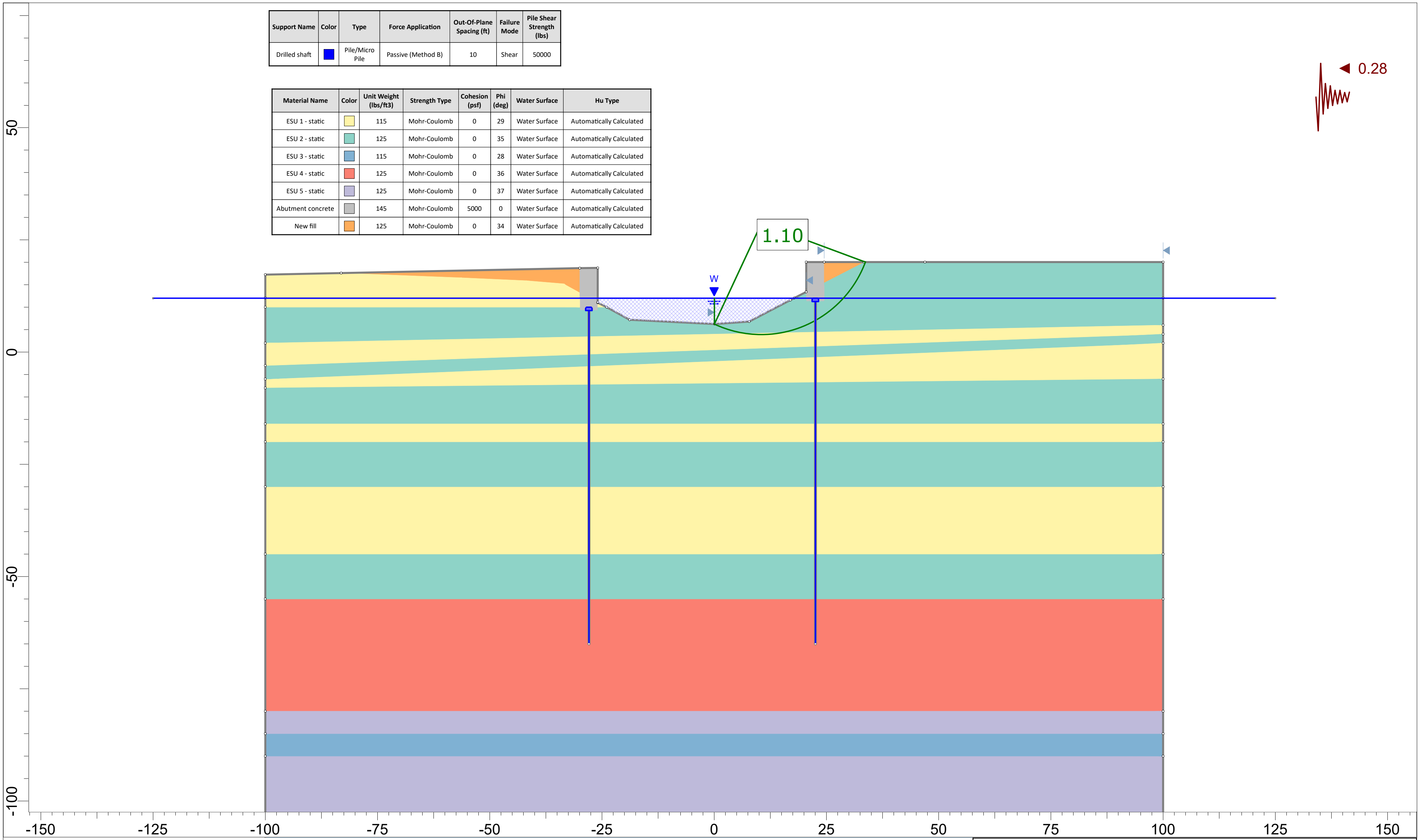
Figure
B4



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29	Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35	Water Surface	Automatically Calculated
ESU 3 - static	🟦	115	Mohr-Coulomb	0	28	Water Surface	Automatically Calculated
ESU 4 - static	🟥	125	Mohr-Coulomb	0	36	Water Surface	Automatically Calculated
ESU 5 - static	🟪	125	Mohr-Coulomb	0	37	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0	Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34	Water Surface	Automatically Calculated

Wapato Creek Culvert Replacement

Pier 2 - Pseudostatic

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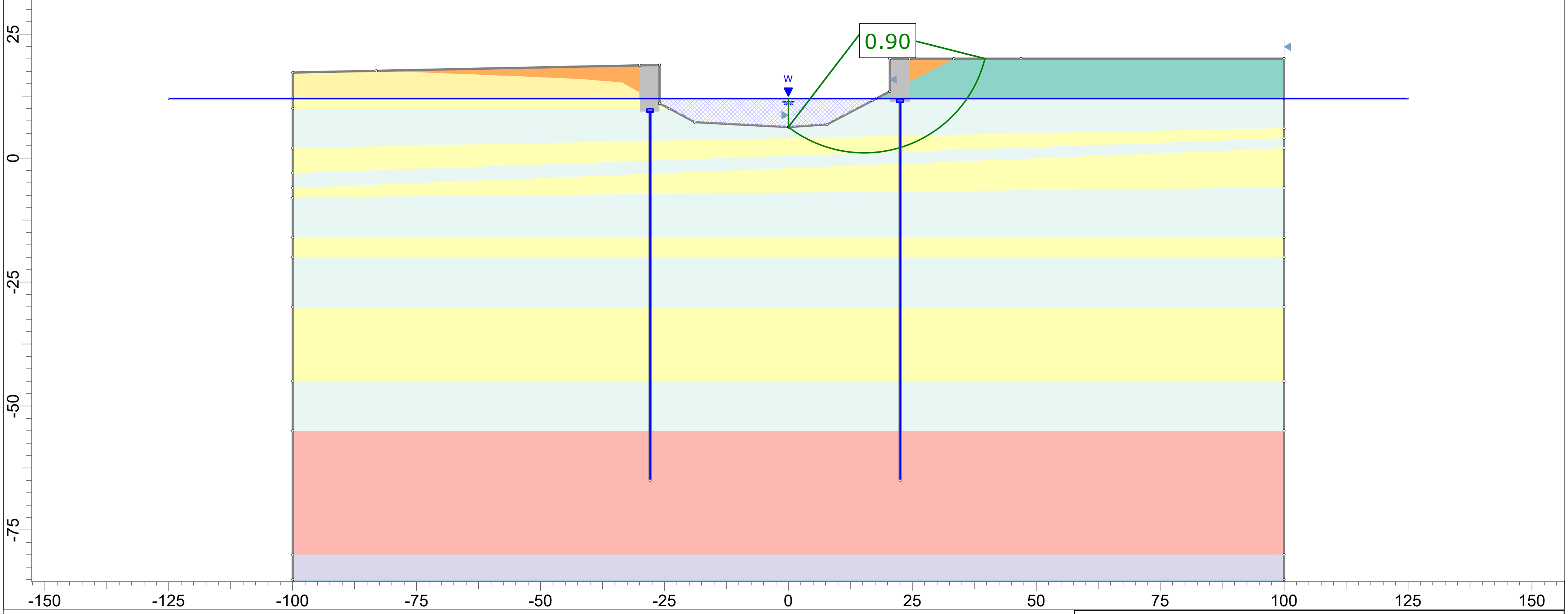
Figure
B5

Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Vertical Strength Ratio	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29		Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35		Water Surface	Automatically Calculated
ESU 1 - liq	🟨	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 2 - liq	⬜	125	Vertical Stress Ratio			0.2	Water Surface	Automatically Calculated
ESU 3 - liq	🟦	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 4 - liq	🟥	125	Vertical Stress Ratio			0.4	Water Surface	Automatically Calculated
ESU 5 - liq	🟪	125	Vertical Stress Ratio			0.7	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0		Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34		Water Surface	Automatically Calculated



Wapato Creek Culvert Replacement

Pier 2 - Liquefied

19433-01

Scale 1:360

7/19

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Figure

B6

APPENDIX C

Drilled Shaft Vertical Resistance Charts and Lateral Resistance Input Parameters

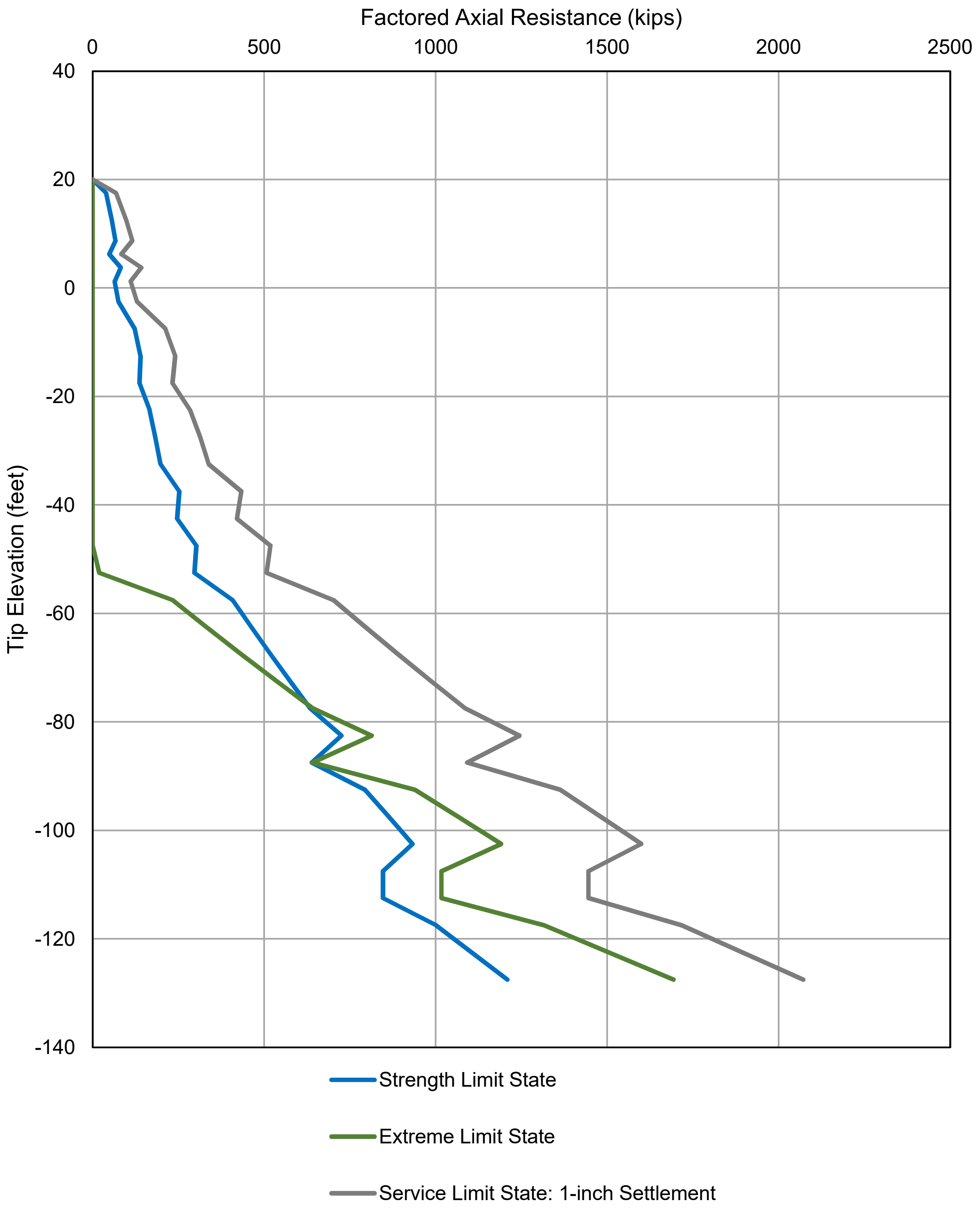
Table C1 - Piers 1 and 2 Lateral Capacity Input Parameters

ESU	Bottom of Layer Depth (feet)	Bottom of Layer Elevation (feet, NAVD 88)	Layer Thickness (feet)	Soil Model	Representative (N1)60	Total Unit Weight (pcf)	Effective Unit Weight (pcf)	Friction Angle (degrees)	K (pci)	P-multiplier for Liquefaction
1 and 2	70	-60	70	API Sand	9	115	62.6	32	48	0.15
4	80	-70	10	API Sand	23	125	62.6	36	93	0.5
4	90	-80	10	API Sand	23	125	62.6	36	93	1

Top of Pier	10 feet (NAVD 88)

LDA 07/29/2019 \\seafs\Projects\Notebooks\1943301_Emergency_Portac_Culvert_ Replacement\Analysis and Calcs\7-11-19_ soil properties updates\2-foot diam - Wapato Creek Drilled Shaft_JRJ.xlsx

Wapato Creek Factored 2-ft Diameter Drilled Shaft Axial Resistance (Compression)



Notes:

1. Assumes no permanent steel casing.
2. Layers of soft soil create uncertainty in end bearing resistance as reflected in resistance curve shape.
3. Charts include factored resistances based on resistance factors from 2017 AASHTO LRFD Bridge Design Specifications, Table 10.5.5.2.4-1.
4. The net weight of the shaft should be treated as a load applied to the top of the shaft. This load is not accounted for in these charts.

Wapato Creek Culvert Replacement
Tacoma, WA

Wapato Creek Factored 2-ft Diameter Drilled Shaft Axial Resistance (Compression)

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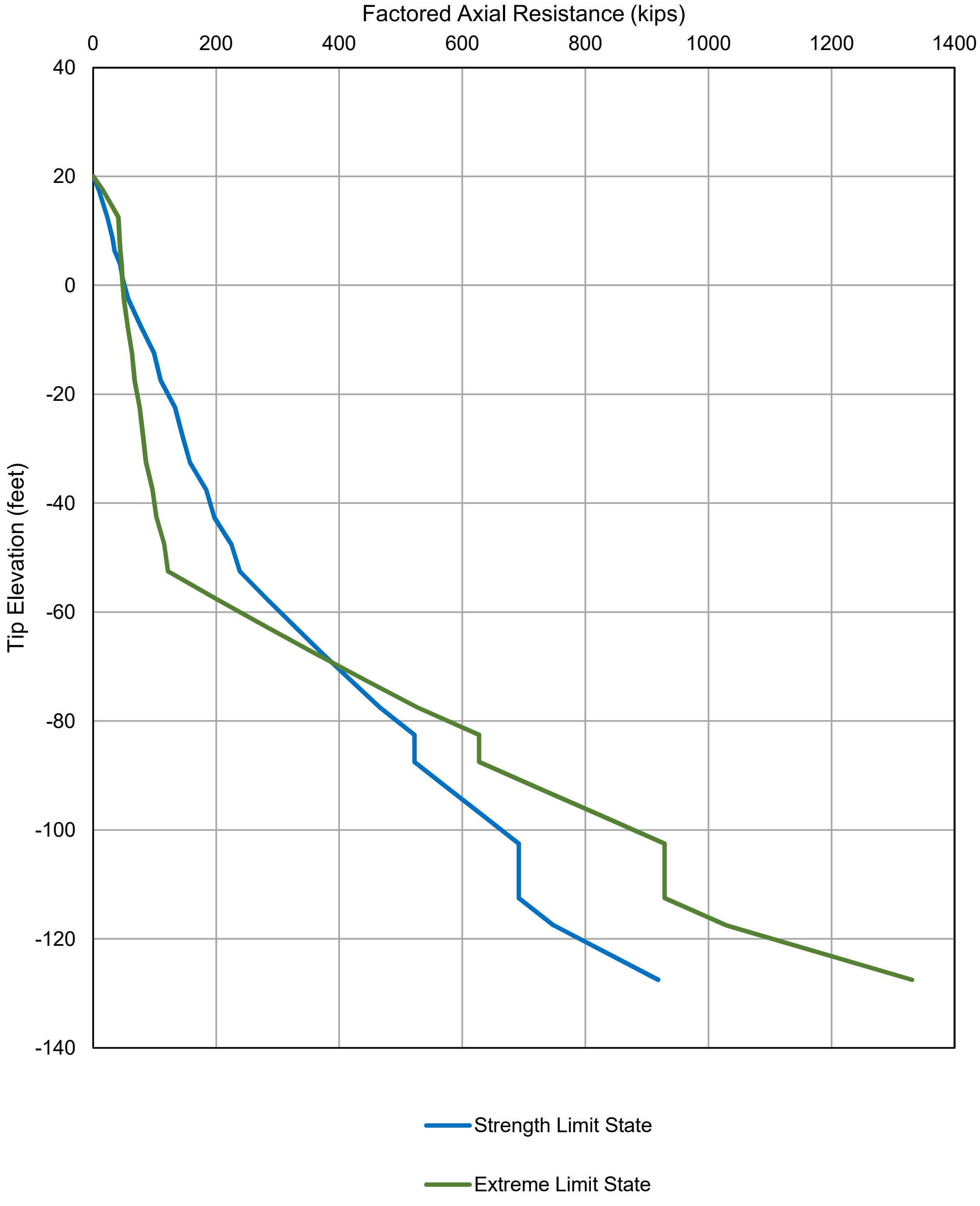
Figure

C1

Wapato Creek Factored 2-ft Diameter Drilled Shaft Axial Resistance (Uplift)



Notes:
1. Assumes no permanent steel casing.
2. Charts include factored resistances based on resistance factors from 2017 AASHTO LRFD Bridge Design Specifications, Table 10.5.5.2.4-1.
3. The net weight of the shaft should be treated as a load applied to the top of the shaft. This load is not accounted for in these charts.

Wapato Creek Culvert Replacement
Tacoma, WA

Wapato Creek Factored 2-ft Diameter Drilled Shaft Axial Resistance (Uplift)

19433-01

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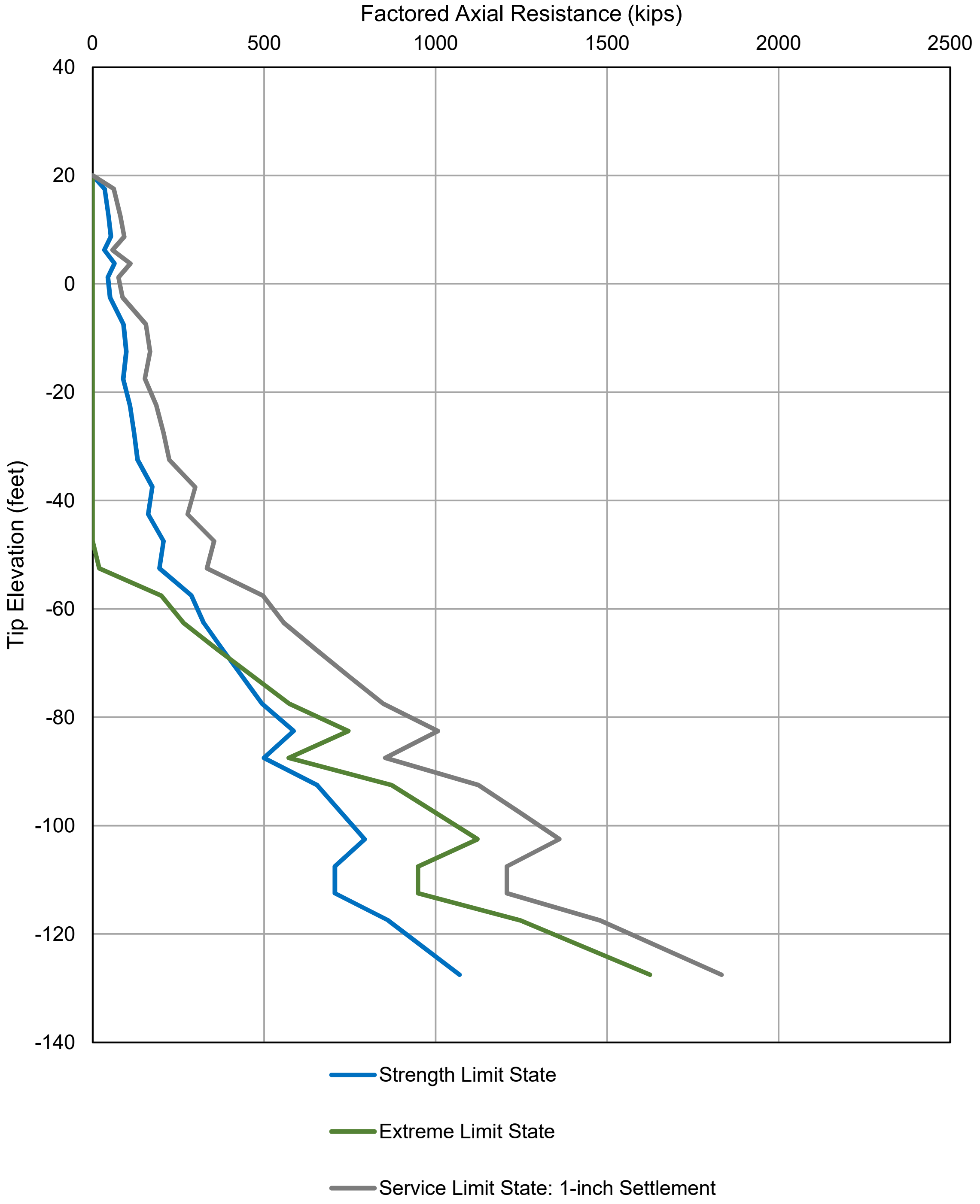
Figure

C2

Wapato Creek Factored 2-ft Diameter Drilled Shaft with Permanent Casing Axial Resistance (Compression)



Notes:

1. Assumes permanent steel casing down to approximate elevation -65 feet.
2. Layers of soft soil create uncertainty in end bearing resistance as reflected in resistance curve shape.
3. Charts include factored resistances based on resistance factors from 2017 AASHTO LRFD Bridge Design Specifications, Table 10.5.5.2.4-1.
4. The net weight of the shaft should be treated as a load applied to the top of the shaft. This load is not accounted for in these charts.

Wapato Creek Culvert Replacement
Tacoma, WA

Wapato Creek Factored 2-ft Diameter Drilled Shaft with Permanent Casing Axial Resistance (Compression)

19433-01
07/2019

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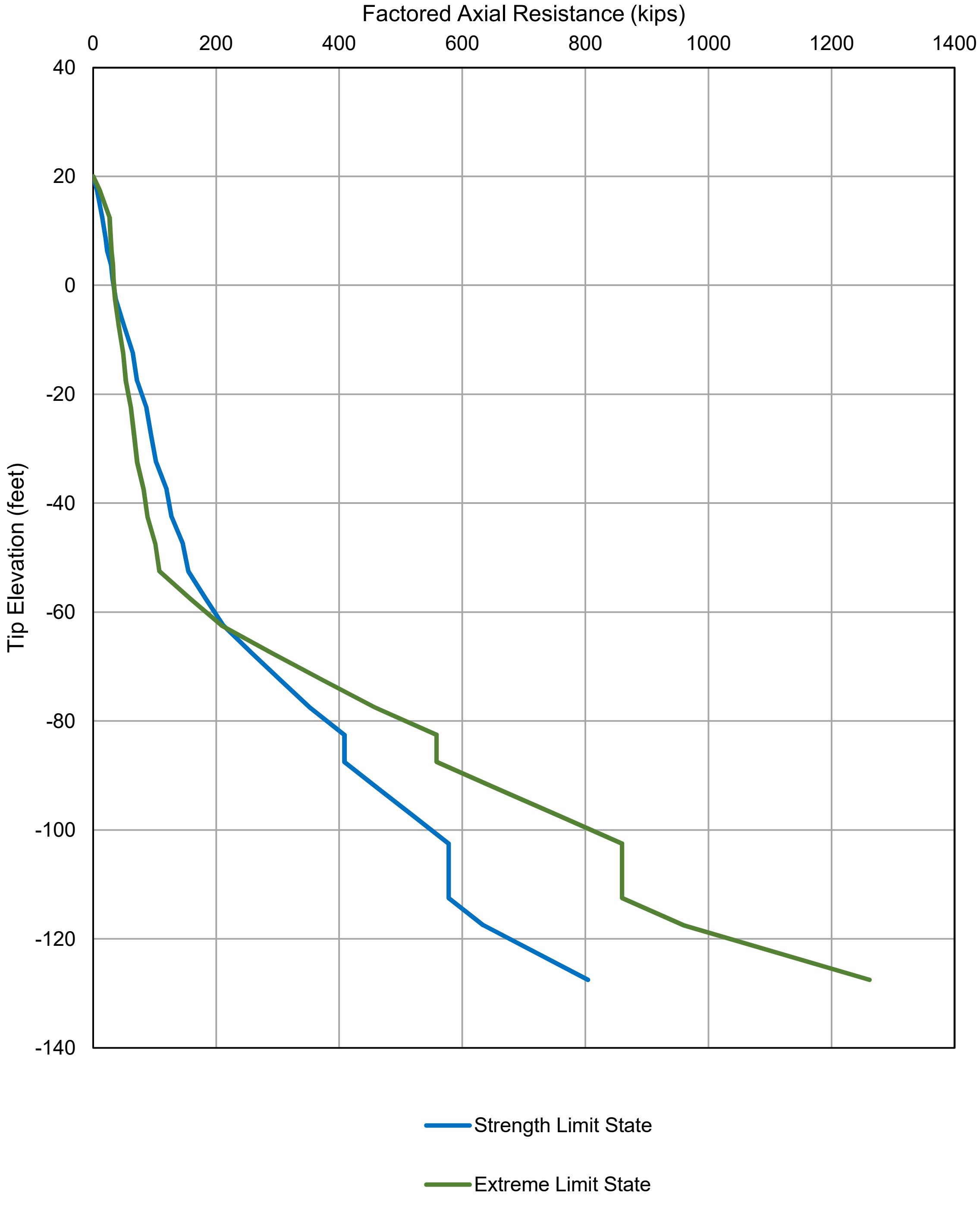
Figure
C3

LDA 07/29/2019 \\seafs\Projects\Notebooks\1943301_Emergency_Portac_Culvert_ Replacement\Analysis and Calcs\7-11-19_soil properties updates\2-foot diam - Wapato Creek Drilled Shaft - casing_JRJ.xlsx

LDA 07/29/2019 \\seafs\Projects\Notebooks\1943301_Emergency_Portac_Culvert_ Replacement\Analysis and Calcs\7-11-19_soil properties updates\2-foot diam - Wapato Creek Drilled Shaft - casing_JRJ.xlsx

Wapato Creek Factored 2-ft Diameter Drilled Shaft with Permanent Casing Axial Resistance (Uplift)



Notes:

1. Assumes permanent steel casing down to approximate elevation -65 feet.
2. Charts include factored resistances based on resistance factors from 2017 AASHTO LRFD Bridge Design Specifications, Table 10.5.5.2.4-1.
3. The net weight of the shaft should be treated as a load applied to the top of the shaft. This load is not accounted for in these charts.

Wapato Creek Culvert Replacement
Tacoma, WA

Wapato Creek Factored 2-ft Diameter Drilled Shaft with Permanent Casing Axial Resistance (Uplift)

19433-01
07/2019

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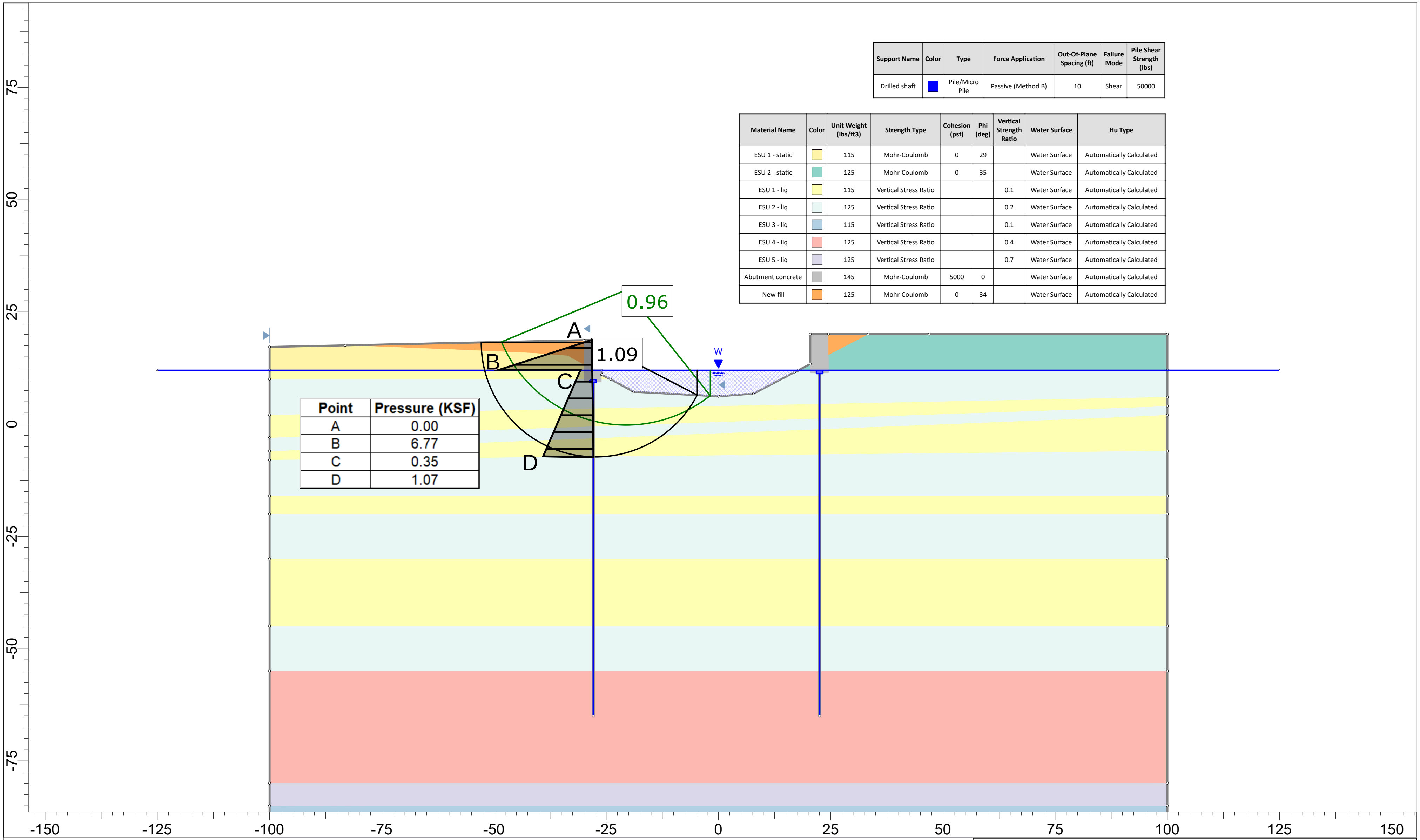
Figure
C4

APPENDIX D
Lateral Earth Pressure Diagrams



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Vertical Strength Ratio	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29		Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35		Water Surface	Automatically Calculated
ESU 1 - liq	🟨	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 2 - liq	⬜	125	Vertical Stress Ratio			0.2	Water Surface	Automatically Calculated
ESU 3 - liq	🟦	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 4 - liq	🟥	125	Vertical Stress Ratio			0.4	Water Surface	Automatically Calculated
ESU 5 - liq	🟪	125	Vertical Stress Ratio			0.7	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0		Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34		Water Surface	Automatically Calculated

Point	Pressure (KSF)
A	0.00
B	6.77
C	0.35
D	1.07

Wapato Creek Culvert Replacement

Pier 1 - Liquefied

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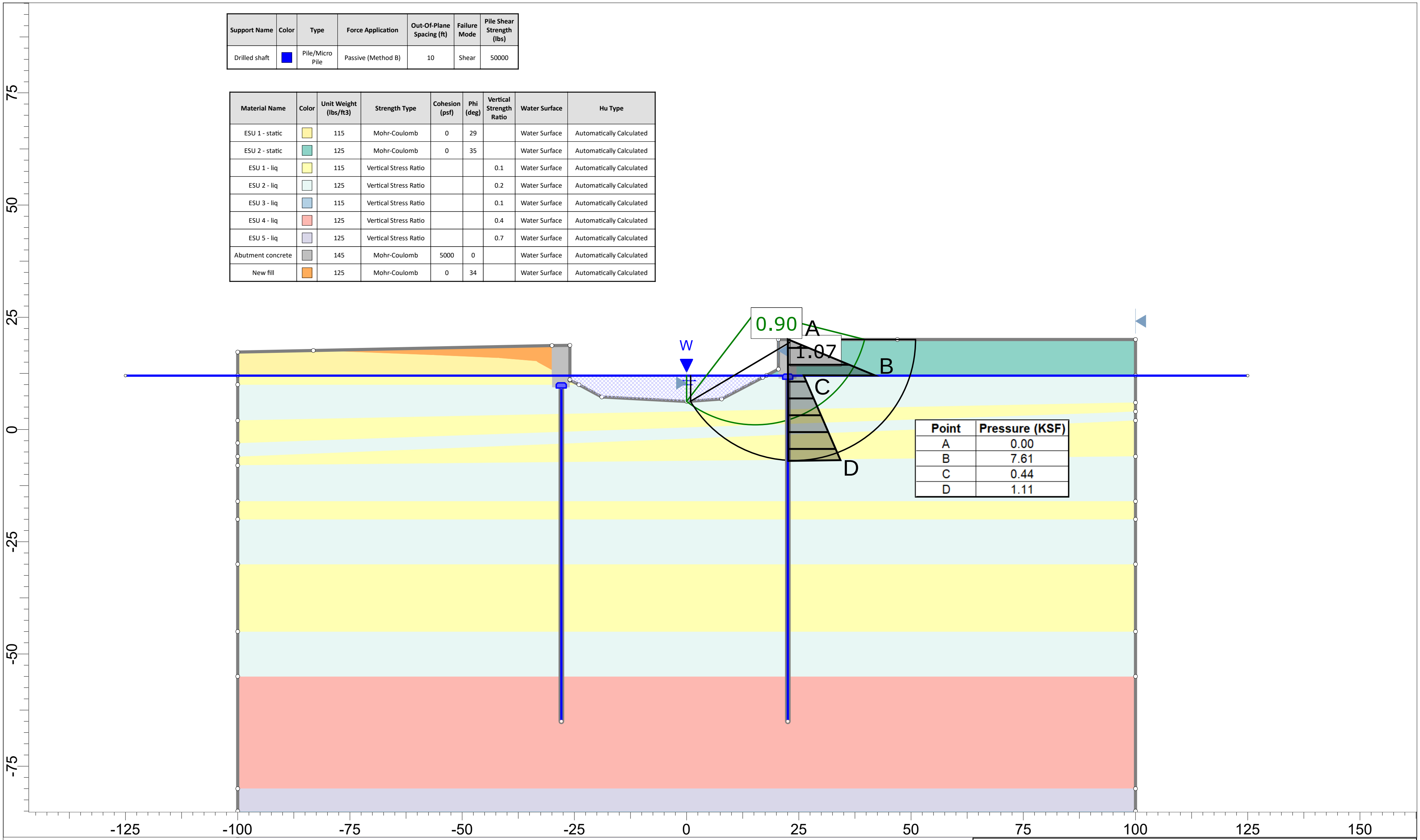
Figure
D1



Support Name	Color	Type	Force Application	Out-Of-Plane Spacing (ft)	Failure Mode	Pile Shear Strength (lbs)
Drilled shaft	🟦	Pile/Micro Pile	Passive (Method B)	10	Shear	50000

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Vertical Strength Ratio	Water Surface	Hu Type
ESU 1 - static	🟨	115	Mohr-Coulomb	0	29		Water Surface	Automatically Calculated
ESU 2 - static	🟩	125	Mohr-Coulomb	0	35		Water Surface	Automatically Calculated
ESU 1 - liq	🟨	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 2 - liq	⬜	125	Vertical Stress Ratio			0.2	Water Surface	Automatically Calculated
ESU 3 - liq	🟦	115	Vertical Stress Ratio			0.1	Water Surface	Automatically Calculated
ESU 4 - liq	🟥	125	Vertical Stress Ratio			0.4	Water Surface	Automatically Calculated
ESU 5 - liq	🟪	125	Vertical Stress Ratio			0.7	Water Surface	Automatically Calculated
Abutment concrete	⬜	145	Mohr-Coulomb	5000	0		Water Surface	Automatically Calculated
New fill	🟧	125	Mohr-Coulomb	0	34		Water Surface	Automatically Calculated

Point	Pressure (KSF)
A	0.00
B	7.61
C	0.44
D	1.11

Wapato Creek Culvert Replacement

Pier 2 - Liquefied

19433-01 Scale 1:360 7/19

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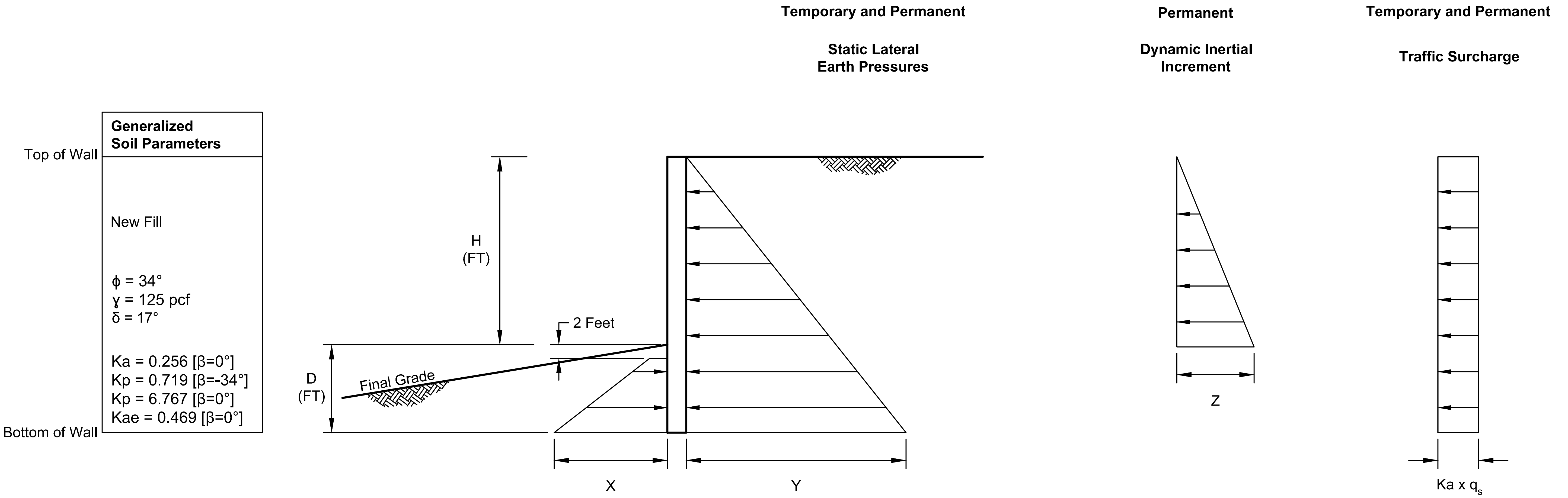
Figure
D2



Generalized Soil Parameters

New Fill

ϕ = 34°
γ = 125 pcf
δ = 17°

Ka = 0.256 [β=0°]
Kp = 0.719 [β=-34°]
Kp = 6.767 [β=0°]
Kae = 0.469 [β=0°]

Nominal Static Lateral Passive Earth Pressures (PSF)	
Sloped Ground Surface [β=-34°]	X = 90D
Flat Ground Surface [β=0°]	X =800D

\+

Nominal Static Lateral Active Earth Pressures (PSF)	
Flat Ground Surface [β=0]	Y = 32(H+D)

\+

Nominal Seismic Lateral Active Earth Pressure (PSF)	
Active	Z = 27H

\+

Nominal Traffic Surcharge (PSF)
q_s = 250 PSF

Soil Site Class C	
PGA	0.56g
Active	K_h = 0.28g

Notes:
1. All dimensions in feet.
2. We assume hydrostatic pressures do not act on the wall.
3. Seismic pressure can be ignored when analyzing for temporary conditions.
4. Ignore upper two feet of passive resistance.

NOT TO SCALE

Wapato Creek Culvert Replacement
Tacoma, Washington

Lateral Earth Pressures for Abutments

19433-01 7/19

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Figure
D3

File: L:\Notebooks\1943301_Emergency_Portac_Culvert_ Replacement\CAD\1943301-002 (LEP).dwg Layout:LEP Date: 07-11-2019 Author: ericlindquist