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Geotechnical Engineering Report: Wall 10.18R

WSDOT I-405 Renton to Bellevue Design-Build

Renton to Bellevue, Washington

Project # PS19-20316-0

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List of acronyms

ESU	Engineering Stratigraphic Unit
FS	factor of safety
I-405	Interstate 405
MSE	mechanically stabilized earth
Project GDM	Project Geotechnical Design Manual, consisting of WSDOT's 2015 *Geotechnical Design Manual*, along with project-specific Chapters 6 (Seismic) and 15 (Retaining Walls) from Request for Proposal Addendum 9
Wood	Wood Environment & Infrastructure Solutions, Inc.
WSDOT	Washington State Department of Transportation

1.0 Description of Structures

This document presents our geotechnical engineering analysis for wall 10.18R in support of the Washington State Department of Transportation (WSDOT) Interstate 405 (I-405) Renton to Bellevue Design-Build project. The scope of this report is limited to wall 10.18R, which is located on the east side of southbound I-405 approaching Bridge 30W (the new southbound I-405 bridge). This report has been prepared in accordance with the requirements presented in the I-405 Renton to Bellevue Widening Project Request for Proposal, specifically Section 2.6.5.3, and the applicable sections of the WSDOT *Geotechnical Design Manual* M 46-03.11 (WSDOT 2015). The Project Geotechnical Design Manual (GDM) consists of WSDOT's 2015 *Geotechnical Design Manual*, along with project-specific Chapters 6 (Seismic) and 15 (Retaining Walls) from the Request for Proposal Addendum 9.

1.1 Structure Location

Wall 10.18R is located on the east side of southbound I-405 and extends approximately 475 feet north of the north end of Bridge 30W. The bridge being constructed as a part of this project will become Bridge 30W (southbound I-405), and the existing Bridge 30W will become the northbound I-405 express toll lanes. Wall 10.18R is a geosynthetic-wrapped soil wall (geosynthetic) from Station (Sta.) 1+50.00 to Sta. 2+09.97 and a mechanically stabilized earth (MSE) wall from Sta. 2+09.97 to Sta. 6+26.42:

- ***Sta. 1+50 to Sta. 2+09.97 (wall 10.18R-A):*** A 13-foot-high geosynthetic wall was considered and checked for stability for the exposed wall height of 13 feet.
- ***Sta. 2+09.97 to Sta. 6+26.42 (wall 10.18R-B):*** A 2- to 10-foot high MSE was considered and checked for stability for the exposed wall height of 7 feet.

The portion of wall proposed to be a geosynthetic wall is identified as wall 10.18R-A, and the portion of wall proposed to be an MSE is identified as wall 10.18R-B in the plans. A horizontal step of 4 feet and 1½ inches, at the transition (Sta. 2+09.97) from wall 10.18R-A to wall 10.18R-B, shall be constructed as part of wall 10.18R-B. The approximate location of the wall is shown on the plans provided in Appendix A.

For the design of wall 10.18R, one critical cross section was considered for the two segments, as the stability analysis for both types of the wall (i.e., geosynthetic and MSE) is the same. Table 1 presents a summary of the design section. The three borings nearest to the wall 10.18R design station, which were used in the analysis, are shown in Table 1 for reference.

Table 1: Summary of Wall 10.18R Design Section

Exploration	Design Station	Max. Exposed Height (feet)	Fore slope (deg)	Back slope (deg)
R2B-82vw-17, W-154-20, and H-4-64 NW	1+75	13	0	0

Abbreviations:
deg = degrees

The approximate locations of the subsurface explorations are shown on the plans provided in Appendix A, and the referenced subsurface explorations are presented in Appendix B.

1.2 Site Conditions

The existing ground surface at wall 10.18R varies from Elevation 127.0 feet in the north to Elevation 86.5 feet in the south. Elevations referenced in this report are based on the North American Vertical Datum of 1988.

A 12-inch diameter stormwater drain line will be located along the southbound I-405 corridor and will run parallel to wall 10.18R. Three catch basins will be located along this stormwater drain line. There is also an existing 18-inch storm sewer cross-drain (CDS 10.20) that will be abandoned and that passes beneath wall 10.18R. A new 18-inch storm sewer pipe cross-drain will replace the existing 18-inch CDS 10.20 and is shown in Appendix A.

2.0 Exploration and Laboratory Testing

Geotechnical explorations were performed as part of Subsurface Investigation Plan No. 5 (Wood 2020a) to supplement existing boreholes at the project site. The exploration locations are shown on the site plan for the bridge (Appendix A). Soil boring logs in the vicinity of wall 10.18R are included in Appendix B. Results of soil laboratory testing are presented in the project Geotechnical Data Report (WSDOT 2018a) and additional testing performed for this report is included in Appendix C. The borings identified below are considered to be within proximity to wall segments 10.18R-A and 10.18R-B. The exploration and testing program comprised the following elements:

- Soil borings W-154-20, W-155-20, and W-158-20, which were performed by Wood using the Standard Penetration Test;
- Laboratory testing consisting of grain-size analyses, moisture content, and Atterberg Limits determination; and
- Review of previous subsurface explorations in the vicinity of wall 10.18R, consisting of GEO-33, H-1A-81-CC, H-4-64-NW, and R2B-82vw-17, as provided in the contract documents.

3.0 Subsurface Conditions

3.1 Regional and Site Geology

The project lies within the southern portion of the Puget Sound Lowland physiographic region. The Puget Sound Lowland has undergone physiographic and depositional changes due to at least five glacial episodes. The last glaciation that occurred in the region was the Vashon Stade of the Fraser Glaciation, which ended approximately 13,500 years ago.

The advance of the Vashon Glacier deepened and widened the north/south trending valleys situated between the Olympic Mountains and the Cascade Range in western Washington. In the Seattle area, the Vashon Stade is represented by four stratigraphic units (from oldest to youngest): Lawton Clay, Esperance Sand, Vashon Till, and Vashon recessional deposits, which make up the Vashon Drift (Galster and Laprade 1991).

As the Vashon glacial lobe advanced south and blocked the northern portion of the Puget Sound basin, a lake was formed, and fine-grained sediments were deposited. The glaciolacustrine deposit, known as the Lawton Clay, is reported to be present in the Seattle area as high as 150 feet above mean sea level. A fine-to-medium-grained sand unit was deposited above the Lawton Clay by meltwater streams issuing from the advancing ice sheet as it neared the Seattle area. That sand unit is called the Esperance Sand Member. The Lawton Clay and Esperance Sand are sometimes intermixed and interbedded, and the contact between the two soil types may be gradational. Both deposits were overridden by an estimated 3,000 feet of ice, which consolidated them into hard or dense layers. A mantle of the Vashon Till was deposited on top of the Esperance Sand and Lawton Clay. The Esperance Sand and Lawton Clay deposits were overlain by Vashon Till, also overridden by the ice sheet. These units are mantled by recessional deposits that were formed during the retreat of the ice sheet. Holocene modification of the glacial landscape in the last 11,700 years and recent activities helped sculpt the landform that is today.

The geologic unit descriptions and stratigraphy used by Wood Environment & Infrastructure Solutions, Inc. (Wood) are based on the mapped and structural geology (McKnight 1923, Waldron et al. 1962, Mullineaux 1965, Yount et al. 1993, Johnson et al. 1994, Liberty and Pratt 2008, Troost 2012, and WSDOT 2018a and 2018b) and as described by others (Golder 1993, Shannon & Wilson 2000, and GeoEngineers 2008) in the project vicinity. Wood simplified the geologic units for converting them into Engineering Stratigraphic Units (ESUs), which were used for foundation design of the structure. Details of the ESU soil properties and a sample calculation of the Standard Penetration Test N-value corrected for effective overburden stress are included in Appendix D-1 and Appendix D-2, respectively. These modifications to the geologic units consisted of combining the Quaternary period Pleistocene and Holocene epoch soils.

The geologic units encountered at the subject site, along with a brief discussion of their descriptions used for the project geology are provided in Table 2.

Table 2: Wall 10.18R Geologic Unit Descriptions

Geologic Unit Name		Abbrev.	Geologic Unit Description
Quaternary	Fill	Af	Fill placed by humans, both engineered and uncontrolled fill consisting of various materials, including debris; typically dense or stiff if engineered, but very loose to dense or very soft to stiff if uncontrolled fill
	Alluvium	Qal	Mainly river, creek, or overbank deposits, consisting of sand, silty sand; gravelly sand, and sandy gravel with scattered organics that are typically very loose to dense, and includes interbedded slack water or lake deposits that consist of silts, clays, and sandy silts.
	Recessional Deposits	Qvr	Sediments deposited after glacial ice retreated that have not been glacially overridden. These recessional deposits include: • Outwash—glaciofluvial sediment deposited off the retreating glacier consisting of sand or silty sand; locally gravelly; loose to dense; • Ablation Till—heterogeneous soils deposited during the wasting of glacial ice; generally not reworked, consisting of gravelly, silty sand, gravelly, sandy silt, or clayey silt; loose to dense or soft to very stiff; • Ice Contact Deposits—heterogeneous soils deposited against or adjacent to ice during the wasting of glacial ice; commonly reworked, consisting of stratified to irregular bodies of gravel, sand, and silt; loose to dense; and • Lacustrine Deposits—sediments deposited as glacial ice retreated, consisting of silt and clay; locally fine sand; soft to very stiff.
	Vashon Glacial Till	Qvt	Lodgment till laid down along the base of the glacial ice and overridden by the weight of glacial ice, consisting of gravelly, silty sand, or gravelly, sandy silt ("hardpan"); boulders and cobbles common; gray and very dense, and in its weathered state may be oxidized brown and medium dense to dense. Sometimes referred to as a diamicton.
	Advance Outwash	Qva	Glaciofluvial sediments deposited as the glacial ice advanced through the Puget Lowland and overridden by the weight of glacial ice; typically stratified, light brown to gray, sand, gravelly sand, and sandy gravel; dense to very dense
	Proglacial Lacustrine Deposits (Lawton Clay)	Qgl	Fine-grained glacial sediments deposited in pro-glacial lake in Puget Lowland consisting of interbedded brown, gray, to blue-gray silt, clayey silt; silty clay; fine sand; massive to locally laminated or locally disturbed (fractures and slickensides); scattered wood near base; very stiff to hard or dense to very dense.

3.2 Site Soil Conditions

Soil conditions disclosed by project and historic borings within the immediate vicinity of wall 10.18R are characterized by fill soils overlying glacially consolidated deposits on the northern end of the Bridge 30W alignment. The conditions are consistent with the mapped "Eastgate Channel," a subglacial drainage feature developed during the Vashon glaciation, which likely eroded the upper portion of the deposits and was subsequently infilled with recessional deposits during retreat of the glacial advance and later the alluvial deposits from the Coal Creek drainage basin.

Boring W-154-20, located closest to the design station (Sta. 1+75), encountered approximately 15 feet of medium-dense fill that was found to mantle dense to very dense advance outwash deposits consisting of silty sand with gravel. The advance outwash in turn mantled hard to very hard lean clay interpreted as glaciolacustrine deposits that extended to the full depths explored. Boring W-155-20, located near Sta. 3+50 encountered approximately 7 feet of medium-dense fill that was found to mantle dense to very dense advance outwash deposits consisting of silty sand with gravel. Boring W-158-20, located near Sta. 5+80, encountered approximately 2 feet of medium-dense fill that was found to mantle very dense advance outwash deposits consisting of silty sand with gravel. West of the wall, the recent alluvium and recessional deposits were noted to have isolated pockets of sand comprising coal, likely derived from nearby outcroppings of coal seams within the Renton Formation.

The exploration logs included in Appendix B provide a detailed description of the soil stratigraphy encountered in our subsurface explorations.

3.3 Site Groundwater Conditions

Groundwater was encountered in all the borings at elevations ranging from 28.0 to 96.7 feet, after completion of drilling. A piezometer was installed in boring R2B-82vw-17. Groundwater elevations were measured in this boring from March 22, 2017, to May 17, 2018, with elevations ranging from 33.5 to 28.5 feet. At all times of the year, groundwater levels could fluctuate in response to stream levels, precipitation patterns, and site activities. The geotechnical engineering calculations and recommendations assumed a groundwater elevation of 33 feet for wall 10.18R-A, based on the highest elevation recorded in Boring R2B-82vw-17.

4.0 Geologic Hazards

The seismic design parameters for Segments 1A to 2B were evaluated. The site class was determined based on the methods in *LRFD Bridge Design Specifications* Section 3.10.3.1 (AASHTO 2017). Standard Penetration Test blow count (blows per foot) for the upper 100 feet of the soil profiles (N_{60}) were used to determine the site class. The average blow count ranged from 46 to 100 with an average value of 78, based on seven soil borings at the site. As a result, it was determined that wall 10.18R is classified as a Site Class C. The seismic parameters for the area are summarized in Table 3 for the Safety Evaluation Earthquake and Functional Evaluation Earthquake and correspond to return periods for the hazards of about 1,000 years for the Safety Evaluation Earthquake and 210 years for the Functional Evaluation Earthquake. The design calculation package presenting detailed evaluations according to WSDOT-specific project requirements for determining the seismic parameters for wall 10.18R is located in Appendix E-1.

Table 3: Seismic Site Class and Design Parameters

Parameter	Return Period	
	1,000-year (SEE)	210-year (FEE)
Site Class	C	C
Peak Ground Acceleration (PGA)	0.422g	0.198g
F_{PGA}	1. 200	1.202
Site-Adjusted Peak Ground Acceleration (A_S)	0.506g	0.238g
Short-period (0.2 second) spectral acceleration (S_S)	0.959g	0.447g
Site coefficient (Fa)	1.200	1.300
Short Period design response acceleration (S_{DS}) = S_S x F_a	1.151	0.581g
1.0 second period spectral acceleration (S_1)	0.278g	0.108g
Site coefficient (F_v)	1.500	1.500
1.0 second design response acceleration S_{D1} = S_1 x F_v	0.417g	0.162g
Mean Earthquake Magnitude (M_w)	7.0	6.8

Abbreviations:
FEE = functional evaluation earthquake
SEE = safety evaluation earthquake

5.0 Design Soil Properties

5.1 Engineering Stratigraphic Units

The exploration logs (Appendix B) provide a detailed description of the soil strata encountered in our subsurface explorations. Table 4 summarizes the geological units and assigned ESUs used to develop engineering recommendations for the wall design.

Table 4: Wall 10.18R Geologic and ESU Units and Descriptions

Geologic Unit Name	Assigned ESU	ESU Description
Fill (Af)	1B	Embankment fill placed during existing bridge construction. Predominantly silty SAND and silty SAND with gravel, medium dense to dense.
Advance Outwash (Qva)	4A	Predominantly silty SAND, silty SAND with gravel, sandy Gravel, dense to very dense.
Glacial Till (Qvt)	4C	Predominantly silty SAND, silty SAND with gravel, Gravelly SAND, medium dense to very dense.
Proglacial Lacustrine Deposits (Lawton Clay) (Qgl)	4E	Predominantly CLAY, silty CLAY, sandy CLAY, SILT, sandy SILT, trace gravel, hard.

Abbreviations:
ESU = Engineering Stratigraphic Unit

5.2 ESU Soil Profiles and Design Soil Properties

The project site plans, ESU cross sections, and soil profiles at cross section A–A' are presented in Appendix A. The ESU soil properties were assigned based on laboratory testing and the Soil Properties Methodology report (Wood 2020b). Appendix D-1 describes the ESU soil properties in detail. The borings closest to wall 10.18R were used to establish the ESUs. The soil properties for the bridge abutments are listed in Table 5.

Table 5: Design Soil Properties for Retaining Wall

Project: I-405 Renton to Bellevue Widening and Express Toll Lanes Project

Wall 10.18R

Cross-section A-A' at Station 1+75

Elevation (feet)		Depth (feet)		Layer Depth (feet)	ESU	USCS	$(N_1)_{60}$	Ymoist (pcf)	Effective Peak ϕ' (deg)	Effective Peak c' (psf)	Fully-softened ϕ' (deg)	Su (psf)
from	to	from	to									
94.5	81.5	0	13	13	ESU 1B	SM	51	130	38	-	-	-
81.5	68.5	13	26	13	ESU 4A	SM	91	130	40	-	-	-
See cross-section for the area					ESU 4C	SM	95	130	40	-	-	-
68.5	-	26	-	-	ESU 4E	ML/CL	79	125	30	627	30	6,000

Groundwater Elevation: 33 feet (Based on highest level observed in R2B-82vw-17)
Contact elevations based on wall location of A-A' Cross-section

Abbreviations:
ϕ' = effective peak friction angle
c' = effective peak cohesion
deg = degrees
ESU = Engineering Stratigraphic Unit
$(N_1)_{60}$ = SPT N-value corrected for effective overburden stress
pcf = pounds per cubic foot
psf = pounds per square foot
SPT = Standard Penetration Test
S_u = undrained shear strength
USCS = United Soil Classification System

5.3 Soil Parameters for Standard WSDOT Materials

Table 6 presents design soil properties to be used for typical WSDOT backfill materials, as suggested in the Project GDM.

Table 6: WSDOT Specified Backfill Engineering Soil Parameters

Material	WSDOT Standard Specification	Soil Type (USCS classification)	Soil Friction Angle (degree)	Cohesion (psf)	Wet Unit Weight (pcf)
Common Borrow	9-03.14(3)	ML, SM, GM	32	0	120
Select Borrow	9-03.14(2)	GP, GP-GM, SP, SP-SM	36	0	125
Gravel Borrow	9-03-14(1)	GW, GW-GM, SW, SW-SM	38	0	130
Gravel Backfill for Walls	9-03.12(2)	GW, GP, SW, SP	38	0	130

Source: Project GDM 5.2 - Presumptive Design Ranges for Compacted Borrow and WSDOT Standard Specifications (WSDOT 2018c).

Abbreviations
pcf = pounds per cubic foot
psf = pounds per square foot
USCS = Unified Soil Classification System
WSDOT = Washington State Department of Transportation

6.0 Geotechnical Analyses

The governing cross section has been analyzed for global stability, compound stability, external stability, and settlement for both geosynthetic and MSE walls. Additional analyses will be carried out by the selected proprietary wall manufacturer and reviewed by Wood.

6.1 Global Slope Stability Analysis Method

Wood performed two-dimensional, limit equilibrium stability analyses, based on the method of slices according to Spencer and Morgenstern-Price. Analysis was performed using the commercial software Slope/W, developed by Geo-Slope International, Ltd. This program employs limit equilibrium methods in accordance with Chapter 7 of the Project GDM. The components required to carry out a Slope/W analysis, such as slope geometry, slip surfaces, and material properties, were established and were input into the software. The material properties describe the shear strength of a soil, and are generally defined by unit weight, cohesion, and friction angle. Pore-water pressures were specified by piezometric lines. Surcharge loads (see Appendix E-2) were also input. During the analysis, the trial slip surfaces were created using the entry and exit method. The sections of the ground surface line, where the slip plane must enter and exit, were established; subsequent iterations narrowed the exit and entry zones. Slope/W computes the factor of safety (FS) for numerous slip surfaces. The slip surface with the lowest FS, or the critical slip surface, is displayed in the results view. This represents the potential sliding mass most likely to exhibit failure based on the input parameters.

Wood selected one cross section to analyze the wall, based on maximum wall height and subsurface conditions. The selected cross section was analyzed for global and compound stability considering the critical slip surfaces for static (Service 1) loading conditions, and pseudo-static (Extreme 1) loading. The cross section analyzed for the wall is shown in Appendix A.

Table 7: WSDOT Wall 10.18R Wall Cross Section Details

Cross Section	Range of Applicability (feet)	Elevation (feet)		Exposed Wall Height (feet)	Design Wall Height (feet)
		Top	Bottom		
A–A’	Sta. 1+50 to 6+26.42	110	95	13	15

Abbreviations:
Sta. = Station

A resistance factor of 0.65 (i.e., FS = 1.5) was targeted for the serviceability limit state and was used for the global stability analysis. Stability analysis for seismic loading event cases targeted a resistance factor of 0.9 (i.e., FS = 1.1). A live load of 250 pounds per square foot was considered for the service load and 125 pounds per square foot for the extreme event cases (seismic loading). The vertical surcharge was applied to the top, and behind the wall, at a distance of 1.5 times the wall height.

7.0 Retaining Wall Design and Recommendations

The approximate location of the proposed retaining wall is shown in Appendix A. The engineering analyses for external stability and recommendations presented in this report are based on cross section A–A' (Appendix A). Wall descriptions and design considerations and recommendations are presented in this section.

Wall Design: Based on the soil conditions, groundwater table, the Project GDM, and the *LRFD Bridge Design Specifications* (AASHTO 2017), the design of wall 10.18R is considered a non-standard geosynthetic wall (wall 10.18R-A) and an MSE wall with reinforcement (wall 10.18R-B). The non-standard geosynthetic wall (10.18R-A) is a corner extension of wall 10.17GR. The design of wall 10.17GR is presented in the Bridge 30W foundation report (Wood 2021) for Pier 2. Global stability for the bridge foundation retaining wall (10.17GR) was performed and is described in the Bridge 30W geotechnical report (Wood 2021). Section 6.3.5 of Geotechnical Engineering Report: Bridge 30W Foundations (Wood 2021) states, "*For the pseudo-static seismic (Extreme 1) case, loading was carried out incorporating a horizontal acceleration, k_h, of 0.249g* [the wall 10.18R analyses used 0.253g], *in accordance with Project GDM Section 15.4.10 … Note that the reduction factor of 0.5 is used based on Article 11.8.6.2 and Article 11.6.5.2.2 in the LRFD Bridge Design Specifications (AASHTO 2017) by considering that permanent ground displacement of the wall would be approximately less than 1.0 to 2.0 inches. The bridge is an essential bridge, and it is confirmed by the project Structural Engineer that such ground movements are tolerable and will not affect the performance of the bridge structures."* As with the bridge foundation retaining wall (10.17GR), wall 10.18R was estimated to have permanent ground displacement less than 1.0 to 2.0 inches. Thus, ground movements are tolerable and will not affect the performance of the bridge structures. The results of the analysis for global, compound, and external stability are shown in Appendix E-2 and the results of the analysis for settlement are shown in Appendix E-3.

The length of the reinforcement for the geosynthetic wall (10.18R-A) shall be a minimum of 70 percent of the height of the wall and not less than 8 feet. The length of the reinforcement for the MSE wall (10.18R-B) shall be a minimum of 70 percent of the height of the wall and not less than 8 feet.

Cross section A–A' was first checked for global stability. Spencer and Morgenstern-Price methods were used to calculate the FS for each case. The global stability analysis results showed that cross section A–A' is stable for Service 1 (FS ≥1.5) and Extreme 1 (FS ≥ 1.1) loading states. A yield acceleration of $k_h = 0.253$ was used for the extreme load on wall 10.18R, in accordance with the Project GDM.

The geosynthetic wall is classified as non-standard since it must be specifically designed to accommodate the shallow foundation of Bridge 30W.

Calculations of internal stability for the non-standard geosynthetic wall and preparation of shop drawings for construction will be performed and provided by the wall designer prior to the construction. Based on information provided by the Contractor, the wall internal stability design will require that vertical spacing between the geosynthetic reinforcement layers is no greater than 16 inches, and the geosynthetic reinforcement will have a minimum ultimate tensile capacity of 7,550 pounds per linear foot. These conditions were considered in the wall compound stability analysis.

The output figures from our global and compound stability analyses are shown in the calculation package (Appendix E-2) and the calculated FS values are summarized in Table 8.

Table 8: Factor of Safety: Global and Compound Stability

Cross Section	Limit State	Minimum Achieved FS (no ground improvement)
A–A' Geosynthetic and MSE wall	Spencer Method, Static Service 1 (FS ≥ 1.5)	Global Stability 3.1 (Okay)
		Compound Stability 3.2 (Okay)
	Spencer Method, Pseudo-static Extreme 1 (FS ≥ 1.1)	Global Stability 2.3 (Okay)
		Compound Stability 3.3 (Okay)
A–A' Geosynthetic and MSE wall	Morgenstern-Price Method, Static Service 1 (FS ≥ 1.5)	Global Stability 3.1 (Okay)
		Compound Stability 3.2 (Okay)
	Morgenstern-Price Method, Pseudo-static Extreme 1 (FS ≥ 1.1)	Global Stability 2.2 (Okay)
		Compound Stability 2.7 (Okay)

Abbreviations:
FS = factor of safety
MSE = mechanically stabilized earth

Limit State Design: The *LRFD Bridge Design Specifications* (AASHTO 2017) and the Project GDM were used for design of the retaining wall. The eccentricity, sliding, and bearing resistance at the Strength I and Extreme I Limit State were evaluated for cross section A–A'. The calculations were performed using the backfill properties recommended in the Project GDM. For foundation soils, the estimated strength parameters for the ESU were used.

The calculations show that the eccentricity, sliding, overturning, and bearing stresses for the Strength 1 and Extreme Event 1 are all within acceptable limits. The bearing resistance calculations also show that under the Strength 1 and the Extreme 1 load cases, the capacity-to-demand ratio is larger than one for all the cross sections. The calculation packages are presented in Appendix E-2.

Settlement: A bearing stress analysis considering a transient live load was performed and is presented in Appendix E-3. Service 1 limit settlement calculations were performed for the cross section, using the modified Hough method. The detailed discussions and calculations are presented Appendix E-3 and results are summarized in Table 9. We understand that wall 10.18R at this location along I-405 will be constructed in one phase. We anticipate that settlement of the wall will be short term and will occur within approximately two to four weeks of construction. Consolidation settlement is estimated to occur within 30 days of construction. Therefore, one set of settlement analyses were performed, considering the full height of the wall at cross sections A–A'.

Table 9: Wall 10.18R Estimated Total and Differential Settlement

Cross Section	Station	Maximum Total Settlement ΔH	Differential Settlement ΔH_{100}
A–A' Geosynthetic	Sta. 1+75 Initial Construction Height (no ground improvement)	0.72 inch ≤ 2 inches (Okay)	Center: 0.94 inch

Abbreviations:
Sta. = Station

As these segments are located adjacent to each other, a comparison of the center-to-edge settlement was not considered valid. This is because the edge of the foundation would see approximately the same amount of load for all the central segments.

Comparison of the center-to-edge settlement would only be valid for the end segments. For central segments, the maximum differential settlement was estimated on the basis of the center-to-center settlement.

Wall 10.18R will be a geosynthetic wall from Sta. 1+50 to Sta. 2+09.97 (wall 10.18R-A) and an MSE wall from Sta. 2+09.97 to Sta. 6+26.42 (wall 10.18R-B). Wall panels for this type of wall are precast and considered to be rigid concrete facing panels. Hence, the maximum settlement for these walls is limited to 2 inches, as stated in the Project GDM Section 15-4.7. (The entire wall may be geosynthetic, which will not change the analysis.)

As can be seen from the settlement analysis, the total settlements are within the Project GDM allowable limit of 2 inches. Differential settlement requirements are within the allowable limit of 1.5 inches given in Table 15-3 of the Project GDM. For rigid concrete facing panels, the differential settlement limits are based on the area of the panel and the joint width as given in Table C11.10.4.1-1 of the *LRFD Bridge Design Specifications* (AASHTO 2017). The wall designer shall therefore select the appropriate joint width based on the estimated differential settlements in Table 9.

Minimum Footing Embedment: As per the Project GDM and the *LRFD Bridge Design Specifications* (AASHTO 2017), the wall footing should have a minimum embedment per Section 11.10.2.2 of the *LRFD Bridge Design Specifications* (AASHTO 2017) depending on the foreslope. Since there is not a foreslope condition, the minimum front face embedment is equivalent to the depth of prevailing frost depth, or 2 feet (whichever is greater). Minimum embedment of 2 feet is based on recommendations provided in WSDOT's Standard Plans for permanent geosynthetic walls.

Additional Design Considerations:

- The Contractor will construct an underdrain system behind the wall to prevent hydrostatic pressure. The wall foundation is higher than the groundwater; thus, underdrains shown in WSDOT Standard Plan D-4 are considered adequate.
- If workers need to be below the temporary cut slope, it will need to be sloped per the Occupational Safety and Health Administration standards for Soil Type C. The site conditions will need to be verified during construction.
- The minimum reinforcement length is 8 feet, regardless of wall height, but no less than 70 percent of the forward compatibility wall height.
- The wall designer shall select the appropriate joint width based on the estimated differential settlements in Table 9.
- Design considerations for reinforcement are to include utilities, such as stormwater drain manholes or light pole foundations.
- WSDOT specified Gravel Backfill for geosynthetic and MSE walls shall be used. Silt content of the wall fill shall be less than 15 percent if steel reinforced systems are used. It is recommended that the fill material extend at least 18 inches behind the steel reinforcement for corrosion protection.
- WSDOT Common Borrow shall be used for the retained fill.

8.0 Construction and Maintenance Considerations

In addition to the design recommendations, the following construction and maintenance concerns shall be implemented as applicable.

We anticipate the wall construction will require temporary shoring to retain the fill (ESUs 1B); localized construction dewatering and excavation may be required. Existing utility trenches, if present, typically are loosely compacted and could pose challenges for construction, especially for soil cuts. Temporary erosion and sediment control plans, implementation, and maintenance will be needed to prevent surface water and sediment from affecting adjacent areas. For equipment access across the alignment, specifically for areas where groundwater is near or at surface, the access road may have to be locally improved.

Temporary cut slopes should be constructed and maintained for safety and slope stability. Work below any slopes located above workers must follow Occupational Safety and Health Administration/Washington Industrial Safety and Health Act regulations.

Geosynthetic and MSE walls require maintenance throughout their lifetime. There will be drainage behind the wall to prevent hydrostatic pressure, and these drainage systems need to be maintained. Additional maintenance considerations may be provided by the wall manufacturer during final design.

9.0 References

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Appendix A
ESU Cross Sections and Profiles

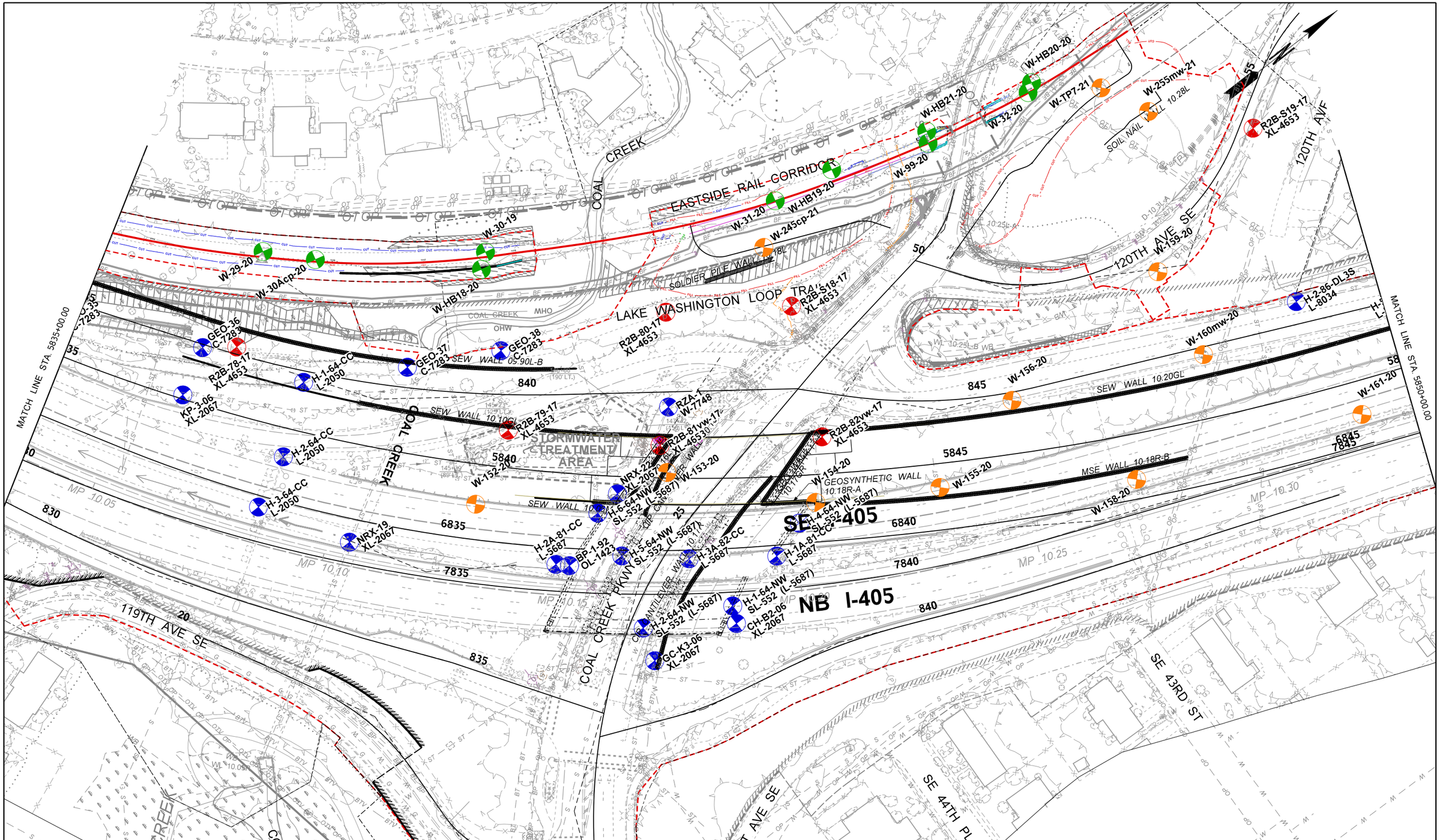
ESU CLASSIFICATION

ESU GROUP #1	FILL MATERIAL			
DESCRIPTION	DENSITY/CONSISTENCY	PRIMARY CONSITIUENT	ESU #	COLOR
UNCONTROLLED FILL	LOOSE TO MEDIUM DENSE	SAND	1A	
UNCONTROLLED FILL	MEDIUM DENSE TO DENSE	SILTY SAND WITH GRAVEL	1B	

ESU GROUP #3	RECENT DEPOSITS (ALLUVIUM, RECESSIONAL, LACUSTRINE)			
DESCRIPTION	DENSITY/CONSISTENCY	PRIMARY CONSITIUENT	ESU #	COLOR
ALLUVIUM	MEDIUM DENSE	SAND	3A	
ALLUVIUM	VERY LOOSE TO LOOSE	SAND	3A-1	
RECESSIONAL OUTWASH	MEDIUM DENSE TO VERY DENSE	SAND	3B	
RECESSIONAL OUTWASH	LOOSE TO MEDIUM DENSE	SAND	3B-1	
LACUSTRINE	MEDIUM STIFF TO VERY STIFF	SILT/CLAY	3E	

ESU GROUP #4	GLACIALLY OVERRIDDEN DEPOSITS			
DESCRIPTION	DENSITY/CONSISTENCY	PRIMARY CONSITIUENT	ESU #	COLOR
ADVANCE OUTWASH	DENSE TO VERY DENSE	SAND	4A	
GLACIAL TILL	DENSE TO VERY DENSE	SAND	4C	
GLACIOLACUSTRINE	MASSIVE	SILT/CLAY	4E	

THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES. THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.



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PLOTTED BY	patrick.mccarthy							
DESIGNED BY								
ENTERED BY								
CHECKED BY								
PROJ. ENGR.								
REGIONAL ADM.		REVISION	DATE	BY				

REGION NO.	STATE	FED.AID PROJ.NO.
10	WASH	
JOB NUMBER XL5467		
CONTRACT NO.		LOCATION NO.

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

FLATIRON LANE

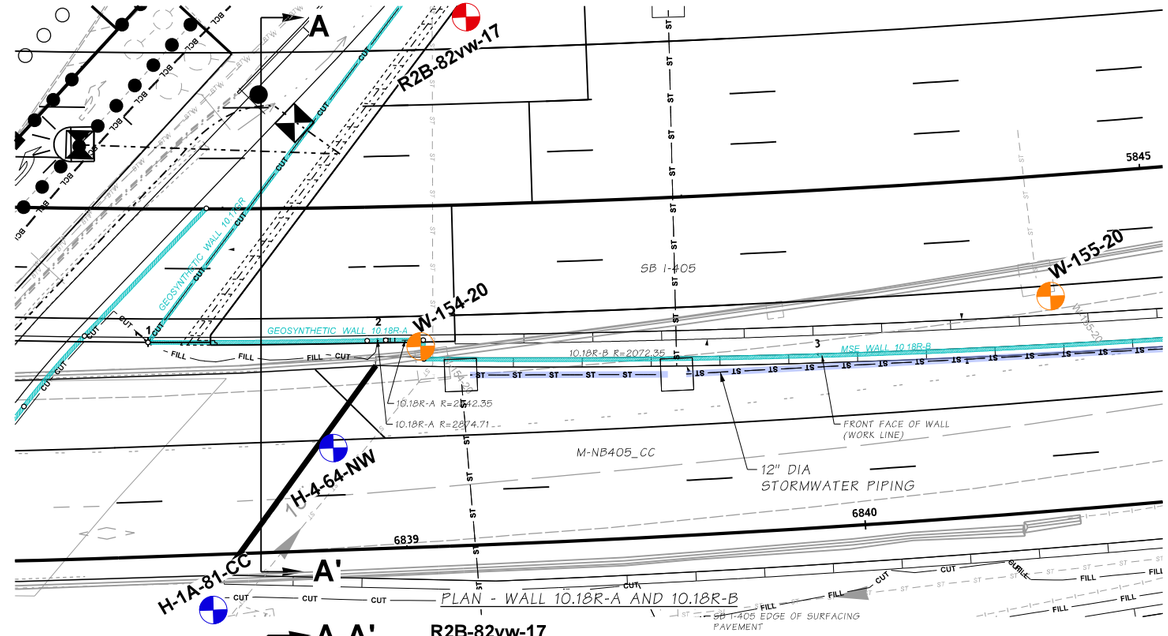
wood.

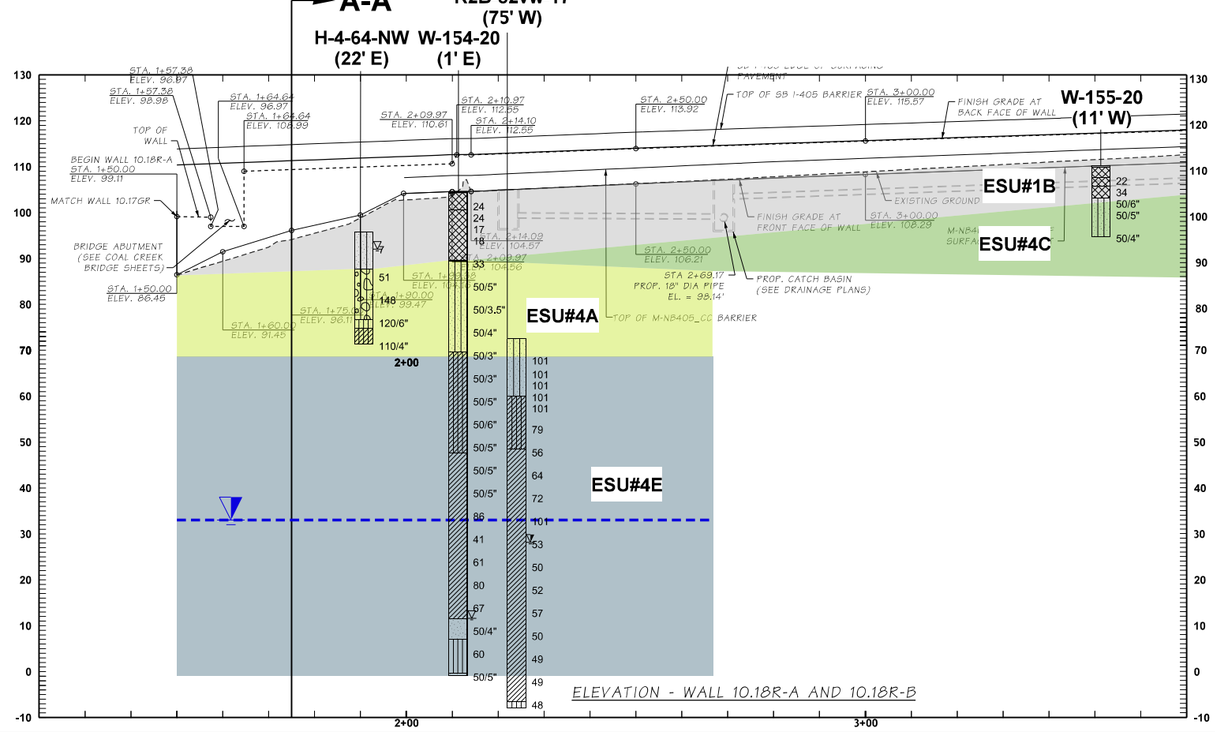
I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

SIP-5 SHEET STA 5835+00 TO STA 5850+00

PLAN REF NO EP-37

SHEET 37 OF SHEETS





THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES, THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.

WALL TYPE (10.18R-A): MSE
WALL TYPE (10.18R-B): MSE

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CHECKED BY	M. RADIC				CONTRACT NO.		LOCATION NO.
PROJ. ENGR.	T. WENTWORTH						
REGIONAL ADM.	S. WOODRUFF	REVISION	DATE	BY			

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

FLATIRON LANE

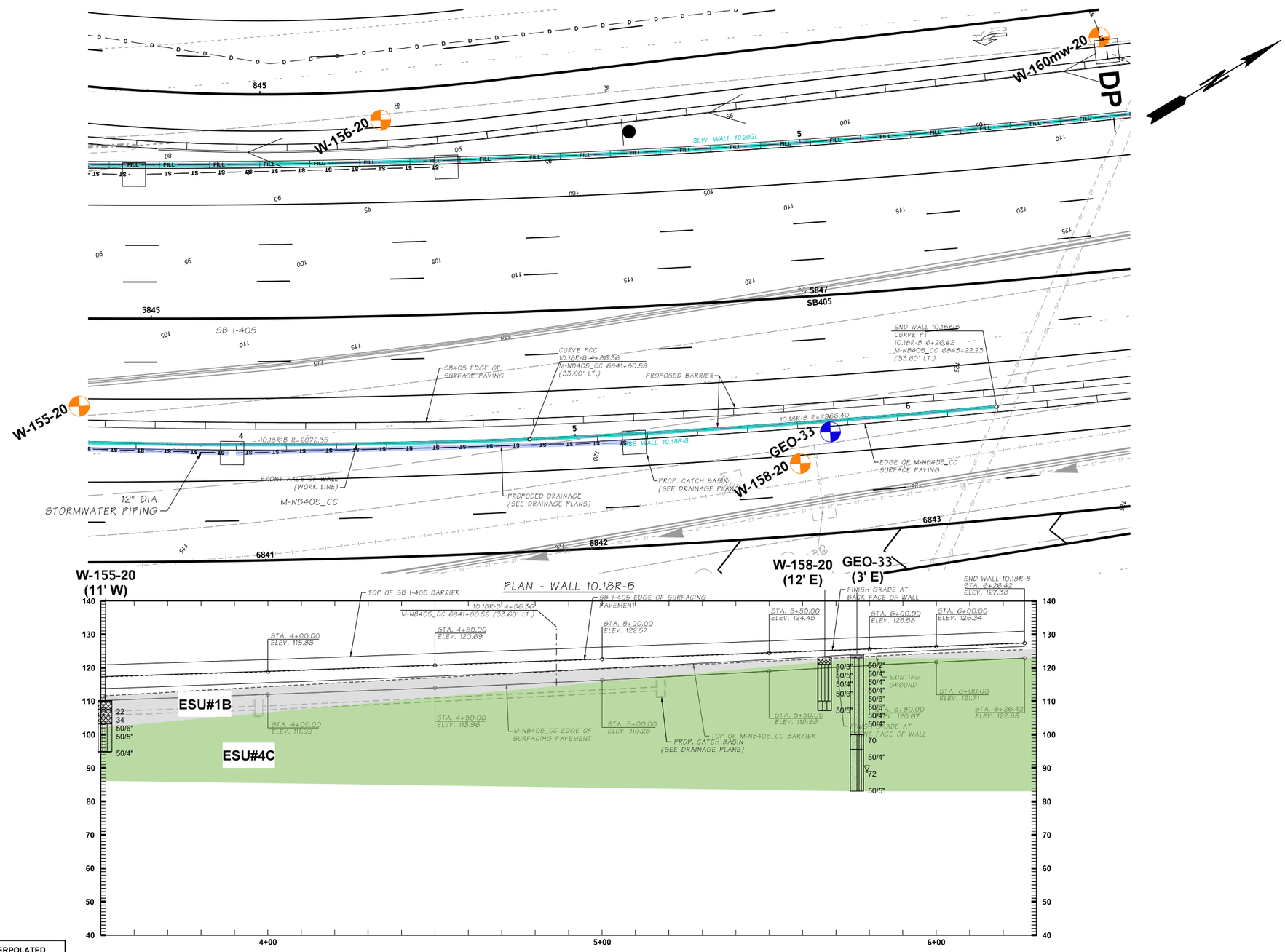
wood.

I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

RETAINING WALL PLAN AND PROFILE
WALL 10.18R-A AND 10.18R-B (1 of 2)

PLAN REF NO W64-1

SHEET OF SHEETS



THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES, THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.

WALL TYPE: MSE

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PROJ. ENGR.	T. WENTWORTH						
REGIONAL ADM.	S. WOODRUFF	REVISION	DATE	BY			

P.E. STAMP BOX DATE

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Washington State Department of Transportation

FLATIRON LANE

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I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

RETAINING WALL PLAN AND PROFILE WALL 10.18R-B (2 OF 2)

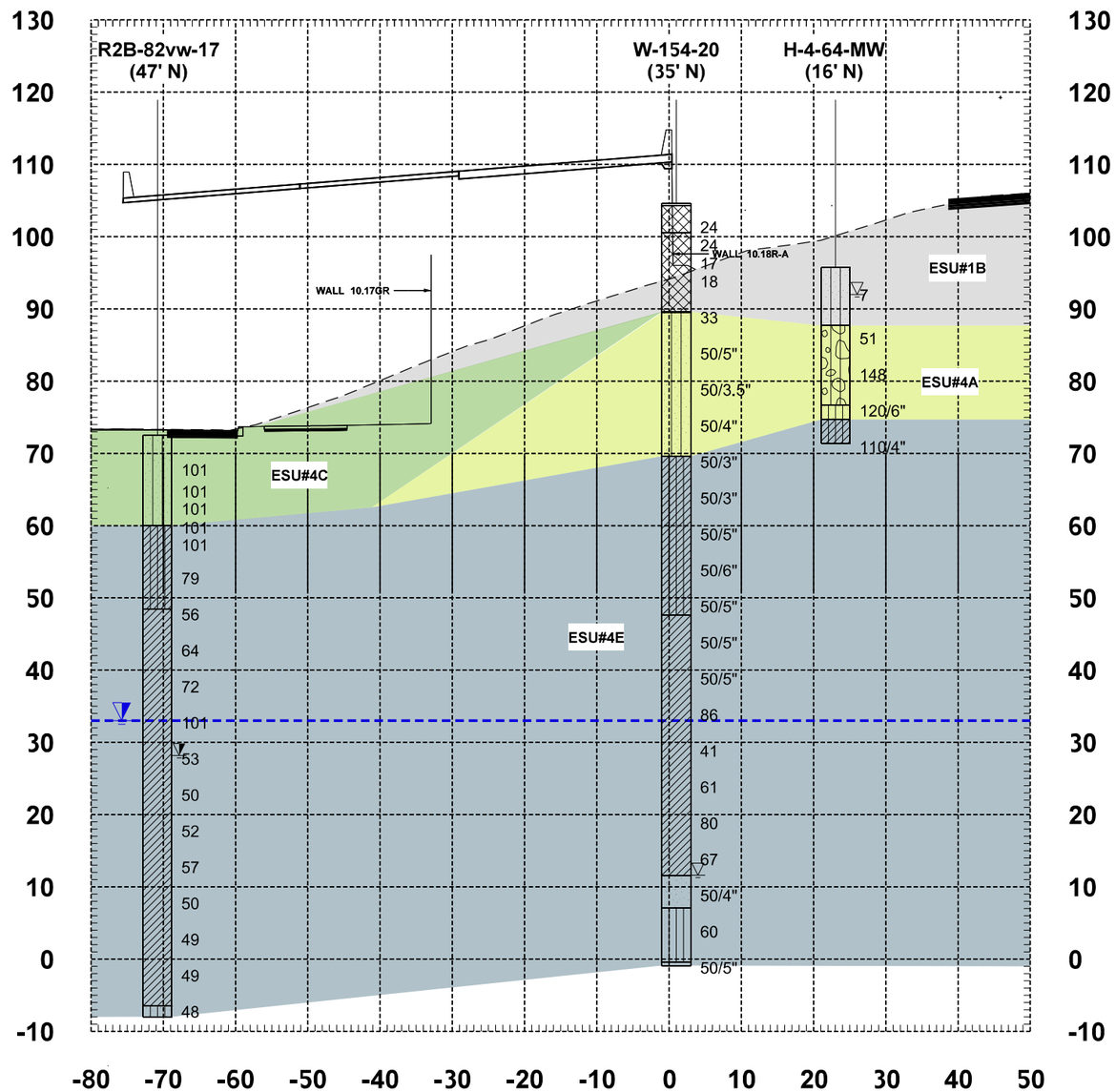
PLAN REF NO W64-2

SHEET OF SHEETS

A (WEST)

WALL 10.18R, XS A-A'
AT STATION 1+75

A' (EAST)



THE ESU STRATIFICATION HAVE BEEN INTERPRETED, INTERPOLATED BETWEEN EXPLORATIONS, AND EXTRAPOLATED BEYOND EXPLORATIONS FOR ENGINEERING DESIGN PURPOSES, THE STRATA MAY NOT REPRESENT ACTUAL SUBSURFACE CONDITIONS. SEE THE EXPLORATION LOGS FOR DETAILED SUBSURFACE CONDITIONS AT THE LOCATION EXPLORED.

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PROJ. ENGR.	T. WENTWORTH
REGIONAL ADM.	S. WOODRUFF

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Washington State Department of Transportation

FLATIRON LANE

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I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

WALL 10.18R
CROSS SECTION A-A' AT STA, 1+75

PLAN REF NO

SHEET OF SHEETS

T.24N. R.5E. W.M.

PROPOSED CULVERTS

C1
BEGIN 120SE 51+72.79 (20.12' LT.)
END 120SE 51+27.98 (23.03' LT.)
LENGTH: 40.7 FT
SLOPE: 10.6%
DIA: 12 IN
MATERIAL: D.I.
UP IE = 78.01
DN IE = 73.70

C2
BEGIN 120SE 53+32.80 (19.84' RT.)
END 120SE 52+25.01 (25.49' RT.)
LENGTH: 116.7 FT
SLOPE: 10.3%
DIA: 12 IN
MATERIAL: D.I.
UP IE = 100.25
DN IE = 88.18

ITS DRAINAGE

86 NB405 STA 7836+05.43 (62.03' RT.)
DAYLIGHT 2" DRAIN PIPE AT MIN. 2% GRADE
IE OUT = 90.00

92 CC-NB405 STA 840+32.72 (25.95' RT.)
DAYLIGHT 2" DRAIN PIPE AT 2% GRADE
IE OUT = 110.09

93 NB405-CC STA 835+28.46 (65.71' RT.)
DAYLIGHT 2" DRAIN PIPE AT 1% GRADE
IE OUT = 79.75

9A CC-CB405 STA 841+41.45 (62.82' LT.)
DAYLIGHT 2" DRAIN PIPE AT MIN. 2% GRADE
IE OUT = 67.0

FORCE MAIN INFLECTION POINTS

F1 CC STA 27+51.23 (65.15' LT.)
SWEEP ANGLE = 33.75 DEG

F2 SB405-CC STA 844+06.89 (23.90' LT.)
SWEEP ANGLE = 22.50 DEG

F3 SB405-CC STA 844+46.26 (15.31' LT.)
SWEEP ANGLE = 11.25 DEG

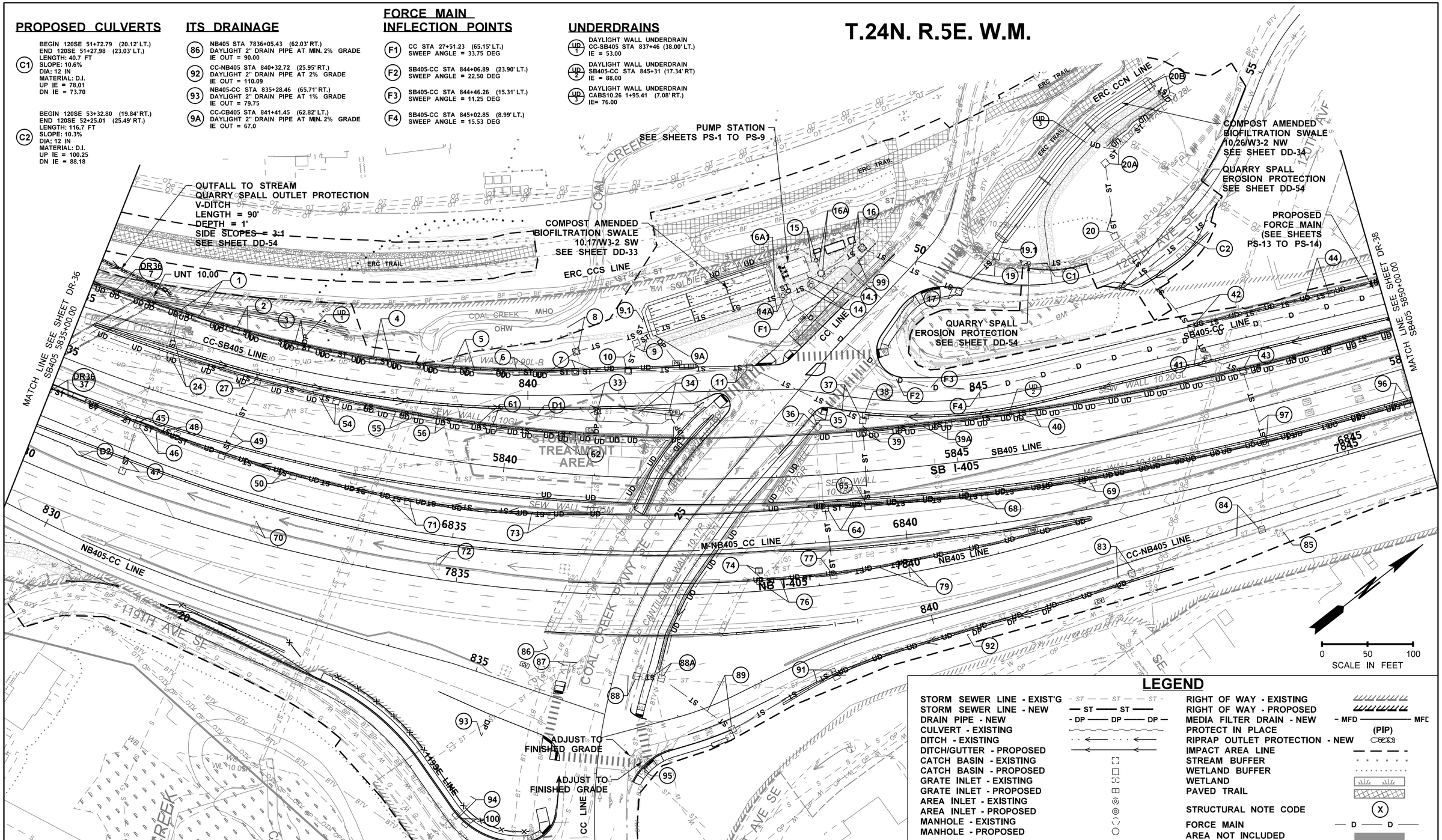
F4 SB405-CC STA 845+02.85 (8.99' LT.)
SWEEP ANGLE = 15.53 DEG

UNDERDRAINS

UD 1 DAYLIGHT WALL UNDERDRAIN
CC-SB405 STA 837+46 (38.00' LT.)
IE = 53.00

UD 2 DAYLIGHT WALL UNDERDRAIN
SB405-CC STA 845+31 (17.34' RT)
IE = 88.00

UD 3 DAYLIGHT WALL UNDERDRAIN
CABS10.26 1+95.41 (7.08' RT.)
IE= 76.00



LEGEND

STORM SEWER LINE - EXIST'G	ST	RIGHT OF WAY - EXISTING	
STORM SEWER LINE - NEW	ST	RIGHT OF WAY - PROPOSED	
DRAIN PIPE - NEW	DP	MEDIA FILTER DRAIN - NEW	MFD
CULVERT - EXISTING		PROTECT IN PLACE	(PIP)
DITCH - EXISTING		RIPRAP OUTLET PROTECTION - NEW	
DITCH/GUTTER - PROPOSED		IMPACT AREA LINE	
CATCH BASIN - EXISTING		STREAM BUFFER	
CATCH BASIN - PROPOSED		WETLAND BUFFER	
GRATE INLET - EXISTING		WETLAND	
GRATE INLET - PROPOSED		PAVED TRAIL	
AREA INLET - EXISTING		STRUCTURAL NOTE CODE	X
AREA INLET - PROPOSED		FORCE MAIN	D
MANHOLE - EXISTING		AREA NOT INCLUDED	
MANHOLE - PROPOSED			

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PROJ. ENGR.	J. LEFOTU
REGIONAL ADM.	L. HODGSON

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REV 0 FINAL SUBMITTAL	11/15/21	XX

C9242

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FOR INFORMATIONAL PURPOSES ONLY.
NOT FOR CONSTRUCTION.

WOOD.

VUE WIDENING
NES PROJECT

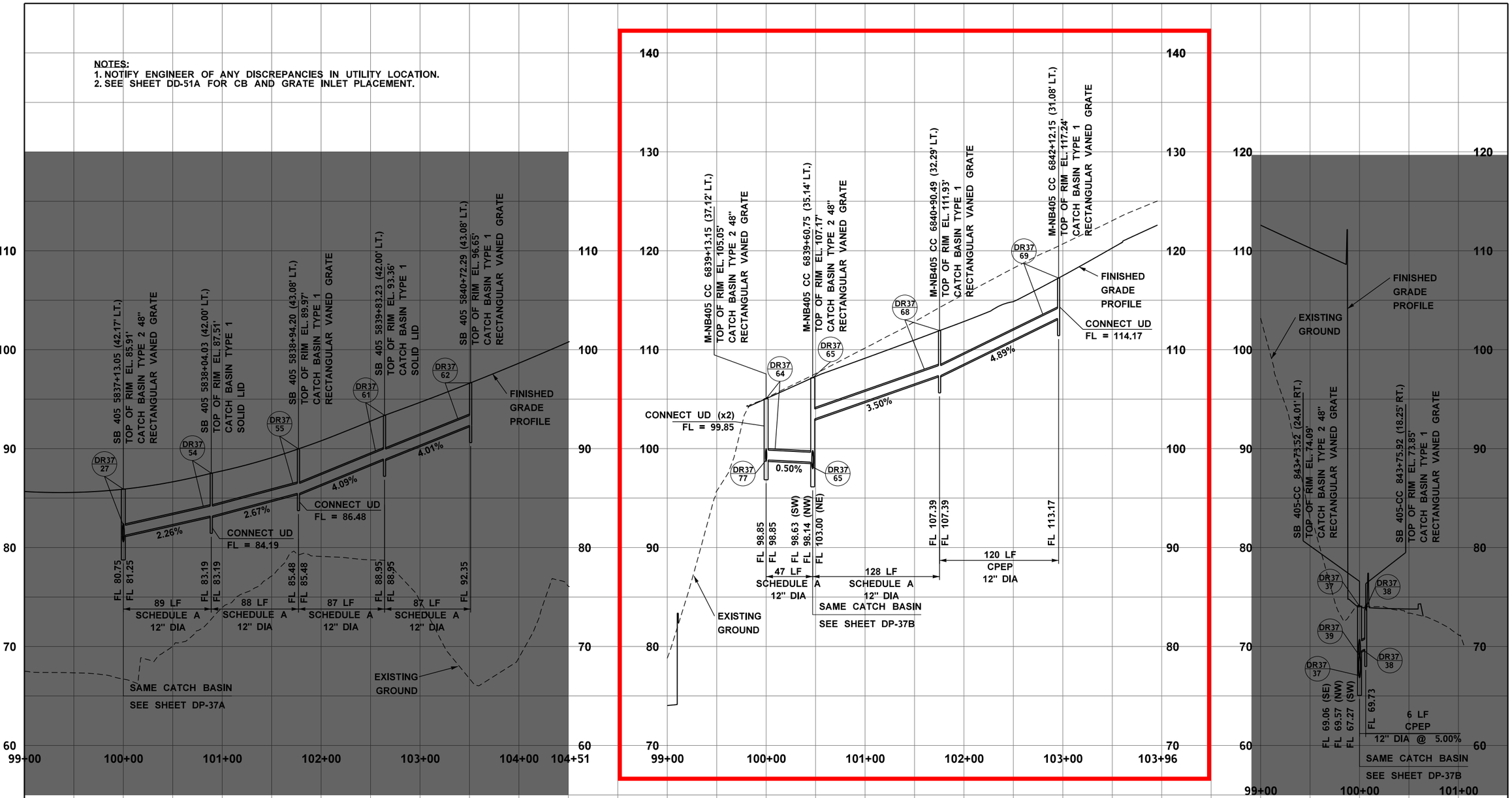
AN

STA 5835+00 TO STA 5850+00

PLAN REF NO
DR-37

SHEET
OF
SHEETS

NOTES:
1. NOTIFY ENGINEER OF ANY DISCREPANCIES IN UTILITY LOCATION.
2. SEE SHEET DD-51A FOR CB AND GRATE INLET PLACEMENT.



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PROJ. ENGR.	J. LEFOTU						
REGIONAL ADM.	L. HODGSON	REVISION	DATE	BY			

P.E. STAMP BOX DATE

P.E. STAMP BOX DATE

Washington State Department of Transportation

FLATIRON LANE

wood.

I-405; RENTON TO BELLEVUE WIDENING AND EXPRESS TOLL LANES PROJECT

DRAINAGE PROFILES
STA. 5835+00 TO STA. 5850+00

PLAN REF NO DP-37E

SHEET XX OF XX SHEETS

In Association with

Appendix B
Field Exploration Procedures and Logs

Appendix B – Field exploration procedures and logs

The following paragraphs describe the procedures used for field explorations and field tests that Wood conducted for this project. Descriptive logs of our explorations are enclosed in this appendix.

Hollow Stem Auger drilling procedures

Exploratory borings were advanced by hollow stem auger using a track-mounted drill rig operated by an independent drilling firm working under subcontract to Wood. An engineering geologist from Wood continuously observed the borings, logged the subsurface conditions, and collected representative soil samples. All samples were stored in watertight containers and later transported to the laboratory for further visual examination and testing. After each boring was completed, the borehole was backfilled with a mixture of bentonite chips and soil cuttings, and the surface was patched with asphalt or concrete (where appropriate).

Throughout the drilling operation, soil samples were obtained at 2.5- or 5-foot depth intervals by means of the Standard Penetration Test (SPT) per ASTM D-1586. This testing and sampling procedure consists of driving a standard 2-inch-diameter steel split-spoon sampler 18 inches into the soil with a 140-pound hammer free-falling 30 inches. The number of blows required to drive the sampler through each 6-inch interval was counted, and the total number of blows struck during the final 12 inches was recorded as the Standard Penetration Resistance, or "SPT blow count." If a total of 50 blows were struck within any 6-inch interval, the driving was stopped and the blow count was recorded as 50 blows for the actual penetration distance. The resulting Standard Penetration Resistance values indicate the relative density of granular soils and the relative consistency of cohesive soils.

The enclosed boring logs describe the vertical sequence of soils and materials encountered in each boring, based primarily on field classifications and supported by subsequent laboratory examination and testing. Where a soil contact was observed to be gradational, boring logs indicate the average contact depth. Where a soil type changed between sample intervals, we inferred the contact depth. The boring logs also graphically indicate the blow count, sample type, sample number, and approximate depth of each soil sample obtained from the borings, as well as any laboratory tests performed on these soil samples. If any groundwater was encountered in a borehole, the approximate groundwater depth is depicted on the boring log. Groundwater depth estimates are typically based on the moisture content of soil samples, the wetted height on the sampling spoon, and the water level measured in the borehole after the auger has been extracted, although the drilling mud makes it difficult to determine groundwater levels accurately at the time of drilling.

Date(s) Drilled	08/09/07	Logged By	BHC	Checked By	KGO
Drilling Contractor	Gregory Drilling	Drilling Method	Hollow-stem Auger	Sampling Methods	SPT
Auger Data	4½-inch ID	Hammer Data	140 lb hammer/30 in drop automatic	Drilling Equipment	CME-75
Total Depth (ft)	41	Surface Elevation (ft)	124	Groundwater Elevation (ft)	90.5
Vertical Datum	NAVD 88	Datum/ System	WSDOT Project Coordinates	Easting(x): Northing(y):	

Elevation feet	Depth feet	SAMPLES Interval	Recovered (in)	Blows/foot	Sub-Sample Sample Number	Water Level	Graphic Log	Group Symbol	MATERIAL DESCRIPTION	Moisture Content %	Dry Unit Weight, lbs/ft³	OTHER TESTS AND NOTES
0								AS	5 inches asphalt			
								GP	8 inches base course			
								SM	Gray silty fine to medium sand with gravel (very dense, moist) (glacial till)			
			8	50/2"	1							
120												
	5		8	50/4"	2							
			8	50/4"	3							
115												
	10		10	50/4"	4							
			6	50/6"	5							
110												
	15		10	50/6"	6							
			10	50/4"	7							
105												
	20		16	50/4"	8							
100								SP-SM	Grayish brown fine sand with silt and occasional interbedded layers of silt (very dense, moist) (advance outwash)			
	25		18	70	9							
95								SP-SM	Gray fine to medium sand with silt (very dense, moist)			
	30											

Note: See Figure A-1 for explanation of symbols.

LOG OF BORING GEO-33

GEOENGINEERS

Project: WSDOT/I-405 Design Build Project
Project Location: Bellevue, Washington
Project Number: 0180-197-01

Figure A-34
Sheet 1 of 2

V6_GTBORING P:\0\0180197\01\FINALS\018019701.GPJ GEIV6_1.GDT 6/9/08

Elevation feet	Depth feet	SAMPLES Interval	Recovered (in)	Blows/foot	Sub-Sample	Sample Number	Water Level	Graphic Log	Group Symbol	MATERIAL DESCRIPTION	Moisture Content %	Dry Unit Weight, lbs/ft^3	OTHER TESTS AND NOTES
	30		10	50/4"		10							Layer of gravel
90													
	35		18	72		11				(wet)			1 foot of heave
85													
	40		10	50/5"		12							
80													
	45												
75													
	50												
70													
	55												
65													
	60												
60													
	65												

LOG OF BORING GEO-33 (continued)

GEOENGINEERS

Project: WSDOT/I-405 Design Build Project
Project Location: Bellevue, Washington
Project Number: 0180-197-01

Figure A-34
Sheet 2 of 2

V6_GTBORING P:\0\0180197\01\FINALS\018019701.GPJ GEIV6_1.GDT 6/9/08

LOG OF TEST BORING

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

H-1A-81-CC

S.H. ____ S.R. 405 SECTION NPS SR-169 O'Xing to NPS 90 O'Xing Job No. L-5687

Hole No. H-1A Sub Section Coal Creek Parkway O/Xing Widening Cont. Sec. 1744

Station L 148+15 Offset 27' Rt. L Line Ground El. +98 (USGS)

Type of Boring Augers Casing Augers 30' W.T. El. 69

Inspector ____ Date 11/10/81 Sheet 1 of 2

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
	14		2 6 8 9 STD PEN 1	Medium dense, brown, dry, silty, slightly organic, fine gravelly, fine to coarse SAND.
5				6" to 10" layer of asphalt.
	29		15 15 14 14 STD PEN 2	Dense, brown, moist, fine gravelly, fine to coarse sandy SILT.
10	29		8 17 12 11 STD PEN 3	Dense, brown, dry to moist, slightly organic, very silty, fine gravelly, fine SAND - with a trace of medium to coarse sand.
15	41		15 21 20 19 STD PEN 4	Dense, brown, dry, very silty, gravelly, fine to medium SAND - with a trace of coarse sand.
20				

This is a summary Log of Test Boring. Soil/rock descriptions are derived from visual field identifications and laboratory tests.

DOT FORM 351-003 REVISED 12/79

Original to Materials Engineer
Copy to Bridge Engineer
Copy to District Administrator

Copy to ____

IWY Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

H-1A-81-CC

Hole No. H-1A Sub Section Coal Creek Parkway Sheet 2 of 2

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
	50 / 6"		28 STD 50 PEN 5	Very dense, gray-brown, dry, very silty, gravelly, fine to medium SAND - with a trace of coarse sand.
25				
	125		29 STD 40 PEN 85 6	Very dense, gray, dry to moist, gravelly, fine sandy SILT - with a trace of medium to coarse sand.
30				
	100 / 4"		100 / 4" STD PEN 7	Very dense, gray, dry to moist, fine gravelly, fine to coarse sandy SILT.
				Stopped test boring 30'4" below ground elevation.
35				

For explanation of description see sheet 1, hole no. H-1A.

LOG OF TEST BORING

WASHINGTON STATE DEPARTMENT OF TRANSPORTATION

H-4-64-NW

S.H. ____ S.R. 405 SECTION Newport Way Interchange Job No. SL-552(L-5687)

Hole No. H-4 Sub Section Newport Way Overcrossing Cont. Sec. 1744 (94 USGS)

Station L^R 148+29 Offset 80' Lt. ℄ Ground El. 86.0 City of Seattle

Type of Boring Wash and Chop Casing 19' X 3" W.T. El. 82.3

Inspector ____ Date 3-12-64 Sheet 1 of 2

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
				Brown, silty, gravelly fine SAND.
	7		4 4 3 2 STD PEN 1	Loose, brown, silty fine SAND - with traces of organic material.
5			B C U-2	
10	51		25 26 25 23 STD PEN 3	Very dense, brown, silty sandy GRAVEL.
15	148		43 78 70 STD PEN 4	Very dense, brown, silty sandy GRAVEL.
			STD	Very dense, brown, sandy SILT - with a trace of gravel.
20	120 / 6"		120 PEN 5	

DOT FORM 351-003 REVISED 12/79

Original to Materials Engineer
Copy to Bridge Engineer
Copy to District Administrator

Copy to ____

WY Form 351-003-a (H. F. 26.66-A).
Revised 5-67.

H-4-64-NW

Hole No. H-4 Sub Section Newport Way Overcrossing Sheet 2 of 2

DEPTH	BLOWS PER FT.	PROFILE	SAMPLE TUBE NOS.	DESCRIPTION OF MATERIAL
			STD	Very hard, gray, silty CLAY - with boulders and a trace of fine gravel.
25	110/4"		110/4" PEN 6	
				Final depth of drilling 24.3' below ground elevation.

LOG OF TEST BORING

WSDOT

Start Card RE-14068
HOLE No. R2B-82vw-17
Sheet 1 of 4

Job No. XL-4653 SR 405 Elevation 72.5 ft

Project I-405 Renton to Bellevue - ETL - Envir & Traff
Driller Henderson, Danny Lic# 2742

Component New Bridge at I-405 Over Coal Creek PKWY SE
Inspector Harvey, Thomas #2599

Start March 21, 2017 Completion March 22, 2017 Well ID# BJT-559
Equipment CME 55 (9C7-1)

Station SB405 5843+59.651 Offset 40.9 feet left Hole Dia (inches) 4
Historical SPT Efficiency 89.2%

Northing 210272.648 Easting 1308036.223 Collected by Region Survey Crew
Method Casing Advancer

Lat 47.5684791 Long -122.1798091 Datum NAD 83/91 HARN, NAVD88, SPN (ft)
Drill Fluid Bentonite

Depth (ft)	Elevation (ft)	Profile	SPT Efficiency / Field SPT (N) / Moisture Content / RQD (20 40 60 80)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
									Groundwater readings were taken from 03-22-2017 to 06-17-2018	
	70.0									
5			>>	50/6" (REF)		D-1		Silty SAND with gravel, sub-angular, very dense, gray, moist, homogeneous. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft		
	65.0		>>	50/5" (REF)		D-2		Silty SAND with gravel, sub-rounded, very dense, gray, moist, homogeneous. HCl not tested. Recovered: 0.5 ft Retained: 0.5 ft		
10			>>	50/6" (REF)		D-3		Silty SAND with gravel, sub-rounded, very dense, gray, moist, homogeneous. HCl not tested. Recovered: 0.6 ft Retained: 0.6 ft		
	60.0		>>	20 35 50/3" (REF)		D-4		Silty SAND with gravel, sub-rounded, very dense, gray, moist, homogeneous. HCl not tested. Recovered: 1.3 ft Retained: 1.3 ft		
15			>>	50/4" (REF)		D-5		Silty CLAY with sand, very hard, gray, moist, homogeneous. HCl not tested. Recovered: 0.4 ft Retained: 0.4 ft		
	55.0									
20				18 35		D-6	MC GS	CL-ML, MC=21%, PI=7 Silty CLAY with sand, very hard, gray, moist,		

ENTERPRISE BORING LOG XL-5467 (OLD XL-4653) 405 RENTON TO BELLEVUE ETL - ENVIRO AND TRAFF.GPJ ENTERPRISE DATA TEMPLATE.GDT 6/8/18

LOG OF TEST BORING

WSDOT

Job No. XL-4653 SR 405 Elevation 72.5 ft

HOLE No. R2B-82vw-17

Sheet 2 of 4

Project I-405 Renton to Bellevue - ETL - Envir & Traff

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
		44 (79)			AL HT SG	homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	50							
25		17 26 30 (56)		D-7		Lean CLAY with sand, hard, gray, moist, stratified. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	45							
30		15 25 39 (64)		D-8	MC GS AL HT SG	CL, MC=21%, PI=13 Lean CLAY with sand, very hard, gray, moist, stratified. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	40							
35		18 34 38 (72)		D-9		Lean CLAY with sand, very hard, gray, moist, stratified. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	35						03-31-2017	
40		>> 16 50/6" (REF)		D-10		Lean CLAY with sand, very hard, gray, moist, stratified. HCl not tested. Recovered: 1.0 ft Retained: 1.0 ft		
	30						09-20-2017	
45		24 27		D-11		Lean CLAY with sand, hard, gray, wet, stratified. HCl not tested.		

LOG OF TEST BORING

WSDOT

Job No. XL-4653 SR 405 Elevation 72.5 ft

HOLE No. R2B-82vw-17

Sheet 3 of 4

Project I-405 Renton to Bellevue - ETL - Envir & Traff

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Profile	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
			26 (53)				Recovered: 1.5 ft Retained: 1.5 ft		
	25								
50			22 24 26 (50)		D-12	MC GS AL HT SG	CL, MC=25%, PI=8 Lean CLAY, hard, gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	20								
55			21 26 26 (52)		D-13		Lean CLAY with sand, hard, gray, moist, stratified. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	15								
60			19 26 31 (57)		D-14		Lean CLAY with sand, hard, gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	10								
65			16 24 26 (50)		D-15		Lean CLAY with sand, hard, gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	5								
70			18 24		D-16		Lean CLAY with sand, hard, gray, moist, homogeneous. HCl not tested.		

LOG OF TEST BORING

WSDOT

Job No. XL-4653 SR 405 Elevation 72.5 ft

HOLE No. R2B-82vw-17

Sheet 4 of 4

Project I-405 Renton to Bellevue - ETL - Envir & Traff

Driller Henderson, Danny

SPT Efficiency
Field SPT (N)
Moisture Content
RQD

Depth (ft)	Elevation (ft)	Blows/6" (N) and/or RQD FF	Sample Type	Sample No. (Tube No.)	Lab Tests	Description of Material	Groundwater	Instrument
		25 (49)				Recovered: 1.5 ft Retained: 1.5 ft		
	0							
75		17 22 27 (49)		D-17	MC GS AL HT SG	CL, MC=17%, PI=9 Lean CLAY with sand, hard, gray, moist, homogeneous. HCl not tested. Recovered: 1.5 ft Retained: 1.5 ft		
	-5							
80		20 22 26 (48)		D-18		Sandy SILT, dense, gray, moist, homogeneous. HCl not tested. A Vibrating Wire Piezometer installed at 78.4 ft. (SN:1602241). Recovered: 1.5 ft Retained: 1.5 ft A standpipe monument was installed on this boring.		
	-10							
85						The implied accuracy of the borehole location information displayed on this boring log is typically sub-meter in (X,Y) when collected by the HQ Geotech Office and sub-centimeter in (X,Y,Z) when collected by the Region Survey Crew.		
	-15					End of test hole boring at 80.5 ft below ground elevation. This is a summary Log of Test Boring. Soil/Rock descriptions are derived from visual field identifications and laboratory test data. Note: REF = SPT Refusal		
90						Bail/Recharge test: Hole Diameter: 4 inches Depth of boring during bail test: 80.5 ft. Depth of casing during bail test: 79 ft. Water depth before bailing: 3.2 ft. Bailed bore hole water level to 63.2 ft. Recharge after 5 minutes: 63 ft. Recharge after 10 minutes: 61.9 ft. Recharge after 15 minutes: 62 ft. Recharge after 20 minutes: 61.9 ft. Recharge after 30 minutes: 61.9 ft.		
	-20							
95								

wood. 4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-154-20
CLIENT WSDOT **PROJECT LOCATION** Renton, WA
DATE STARTED 7/15/20 **COMPLETED** 7/17/20 **GROUND ELEVATION** 104.6 ft NAVD88 **HOLE SIZE** 8 inches
DRILLING CONTRACTOR Holt Services **DRILL RIG** B-57 ID:#10 **SPT HAMMER EFFICIENCY** 87%
DRILLING METHOD HSA **STATION (FT)** 5843+42.42 **OFFSET (FT)** 30.6 R
LOGGED BY Chris Lopez **CHECKED BY** Pat Reed **NORTHING** 210222.742 **EASTING** 1308088.714
NOTES **GW LEVEL (ATD)** 93.0 ft / Elev 11.6 ft perched water table

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
	0		ASPHALT (3 inches) over Silty SAND with gravel, medium dense, gray, moist, [FILL] (SM)				
				50	SPT-1 15 12 12	▲ 24	
100	5			33	SPT-2 10 12 12	▲ 24	
				50	SPT-3 11 10 7	●▲ ☐ 17	MC = 12% Fines = 29%
95	10			50	SPT-4 5 7 11	▲ 18	
90	15		SILT, hard, tan, moist, oxidized in places (ML) Silty SAND with gravel, medium dense, gray, moist, [Qva] (SM)	50	SPT-5 15 15 18	● ▲ ⊡ 33	MC = 14% Fines = 41%
85	20						

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-154-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE (20 40 60 80) / PL MC LL / FINES CONTENT (%)	TESTS AND REMARKS
	20		Silty SAND with gravel, medium dense, gray, moist, [Qva] (SM) *(continued)*	67	SPT-6 50	50/5"	
80	25			50	SPT-7 50	50/3.9"	
75	30			67	SPT-8 50	50/4"	
70	35		Lean CLAY with sand, silty, very hard, gray, moist, [Qgl] (CL-ML)	50	SPT-9 50	50/3"	
65	40			67	SPT-10 45 50	50/3"	MC = 19% LL = 22 PL = 15

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-154-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
			Lean CLAY with sand, silty, very hard, gray, moist, [Qgl] (CL-ML) *(continued)*				
60	45			83	SPT-11 50	50/5"	
55	50			100	SPT-12 50	50/6"	
50	55			83	SPT-13 50	50/5"	
			Lean CLAY with sand, very hard, gray, moist, [Qgl] (CL)				
45	60			94	SPT-14 17 40 50	50/5"	LL = 38 PL = 20 Fines = 77%
40	65			50	SPT-15 30	50/5"	

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-154-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
			Lean CLAY with sand, very hard, gray, moist, [Qgl] (CL) *(continued)*		50		
35	70			100	SPT-16 31 40 46	86	
30	75		Becomes hard	100	SPT-17 12 16 25	41	
25	80		Becomes very hard	100	SPT-18 32 26 26 35	● 61	MC = 16%
20	85			100	SPT-19 39 44 44 36	80	

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-154-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
			Lean CLAY with sand, very hard, gray, moist, [Qgl] (CL) *(continued)*				
15	90		Lean CLAY, very hard, gray, moist, [Qgl] (CL)	100	SPT-20 19 35 32	67	LL = 34 PL = 18 Fines = 71%
			Poorly graded SAND, very dense, gray, wet, [Qgl] (SP)				
10	95			67	SPT-21 47 50	50/4"	
			Lean CLAY, very hard, gray, moist, [Qgl] (ML)				
5	100			100	SPT-22 11 23 37	60	MC = 17%
0	105		Poorly graded SAND, very dense, gray, wet, [Qgl] (SP)	83	SPT-23 50	50/5"	

Bottom of borehole at 105.5 feet.

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-155-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

DATE STARTED 7/15/20 **COMPLETED** 7/16/20 **GROUND ELEVATION** 111.1 ft NAVD88 **HOLE SIZE** 6 inches

DRILLING CONTRACTOR Gregory Drilling **DRILL RIG** LAR ID: #309 **SPT HAMMER EFFICIENCY** 80%

DRILLING METHOD HSA **STATION (FT)** 5844+78.67 **OFFSET (FT)** 26.3 R

LOGGED BY Carlos Mendoza **CHECKED BY** Pat Reed **NORTHING** 210340.581 **EASTING** 1308159.903

NOTES **GW LEVEL (ATD)** Dry

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE (20 40 60 80) / PL MC LL / FINES CONTENT (%)	TESTS AND REMARKS
	0		ASPHALT (3 inches) over Silty SAND with gravel, brown, dry to moist, [FILL] (SM)				
110			Poorly graded SAND with gravel, medium dense, brownish yellow, dry to moist, [FILL] (SP)	67	SPT-1 4 10 12	22	
	5		Silty SAND, dense, brownish yellow, moist, [FILL] (SM)	78	SPT-2 9 14 20	34	MC = 9% Fines = 33%
105			Silty SAND, very dense, bluish gray, moist, with oxidation [Qvt] (SM)	100	SPT-3 50	50/6"	
	10			50	SPT-4 34 50	50/5"	MC = 8% Fines = 35%
100							
	15			67	SPT-5 50	50/4"	

Bottom of borehole at 15.4 feet.

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wood.

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-156-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

DATE STARTED 7/21/20 **COMPLETED** 7/22/20 **GROUND ELEVATION** 84.9 ft NAVD88 **HOLE SIZE** 4 inches

DRILLING CONTRACTOR Gregory Drilling **DRILL RIG** CME 55 ID: #310 **SPT HAMMER EFFICIENCY** 88%

DRILLING METHOD Mud Rotary **STATION (FT)** 5845+70.07 **OFFSET (FT)** 58.6 L

LOGGED BY Carlos Mendoza **CHECKED BY** Pat Reed **NORTHING** 210462.028 **EASTING** 1308133.241

NOTES **GW LEVEL (ATD)** 2.0 ft / Elev 82.9 ft

ELEVATION (ft)	DEPTH	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE (▲) / PL MC LL (●) / FINES CONTENT (%) (□)	TESTS AND REMARKS
	0	ASPHALT (6 inches) over				
		Well graded SAND with gravel, brownish yellow to olive yellow, dry to moist, [FILL] (SW)				
		Silty SAND with gravel, dense, greenish gray, wet, [FILL] (SM)	39	SPT-1 3 18 29	▲ 47	
80	5	Becomes very dense, bluish gray	61	SPT-2 16 43 34	● □ ▲ 77	MC = 8% Fines = 16%
		Poorly graded SAND with silt, dense, bluish gray, wet, [Qva] (SP-SM)	100	SPT-3 14 20 24	□ ● ▲ 44	MC = 21% Fines = 9%
75	10	No Recovery	0	SPT-4 7 10 12	▲ 22	
70	15	Poorly graded GRAVEL, very dense, grayish blue, wet, [Qva] (GP)	17	SPT-5 5 28 50	50/2"	
65	20					

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-156-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	SPT N VALUE (20 40 60 80) / PL MC LL / FINES CONTENT (%)	TESTS AND REMARKS
	20	SILT, hard, bluish gray, wet, [Qgl] (ML)	92	SPT-6 27 50	50/5"	
		Poorly graded GRAVEL, subrounded, very dense, grayish brown, wet, [Qva] (GP)				
60	25	Silty SAND, very dense, grayish blue, wet, homogeneous, [Qva] (SM)	67	SPT-7 16 50	50/6"	MC = 19% LL = NP PL = NP Fines = 32%
55	30		44	SPT-8 21 48 50	50/6"	
50	35		67	SPT-9 18 25 40	65	
45	40		44	SPT-10 3 28 42	70	

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PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-156-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
			Silty SAND, very dense, grayish blue, wet, homogeneous, [Qva] (SM) *(continued)*				
40	45			44	SPT-11 20 35 25	60	

Bottom of borehole at 46.5 feet.

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wood.

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-158-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

DATE STARTED 6/16/20 **COMPLETED** 6/16/20 **GROUND ELEVATION** 123.0 ft NAVD88 **HOLE SIZE** 8 inches

DRILLING CONTRACTOR Holt Services **DRILL RIG** CME 85 ID: #7 **SPT HAMMER EFFICIENCY** 88%

DRILLING METHOD HSA **STATION (FT)** 5846+91.06 **OFFSET (FT)** 49.7 R

LOGGED BY Chris Lopez **CHECKED BY** Pat Reed **NORTHING** 210516.438 **EASTING** 1308286.09

NOTES **GW LEVEL (ATD)** Dry

ELEVATION (ft)	DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
	0		ASPHALT (5 inches) over				
			Silty SAND with gravel, very dense, grayish brown, dry, [FILL] (SM)				
			Sandy SILT, very dense, grayish brown, dry to moist, [Qvt] (ML)				
120				78	SPT-1 18 50/3"	50/3"	
	5			91	SPT-2 50/6"	50/5"	MC = 7% Fines = 56%
115			Silty SAND, very dense, grayish brown, moist, [Qvt] (SM)	100	SPT-3 38 50/4"	50/4"	MC = 6% Fines = 46%
	10			83	SPT-4 50	50/6"	
110							
	15			100	SPT-5 22 50/5"	50/5"	MC = 8% LL = 17 PL = 14 Fines = 27%

Bottom of borehole at 15.9 feet.

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wood.
4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-160mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

DATE STARTED 6/16/20 **COMPLETED** 6/18/20 **GROUND ELEVATION** 101.6 ft NAVD88 **HOLE SIZE** 8 inches

DRILLING CONTRACTOR Holt Testing **DRILL RIG** CME 85 ID: #7 **SPT HAMMER EFFICIENCY** 88%

DRILLING METHOD HSA **Well Tag #** BME-293 **STATION (FT)** 5847+91.22 **OFFSET (FT)** 69.9 L

LOGGED BY Chris Lopez **CHECKED BY** Pat Reed **NORTHING** 210658.879 **EASTING** 1308223.112

NOTES **GW LEVEL (ATD)** Dry **GW LEVEL (7/23/2020)** Elev 96.7 ft

ELEVATION (ft) / DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	WELL DIAGRAM	SPT N VALUE (20 40 60 80) / PL MC LL / FINES CONTENT (%)	TESTS AND REMARKS
0		ASPHALT (10 inches) over: gravel base course [FILL]					
100		Poorly graded SAND, very dense, grayish brown, dry, [Qva] (SP)					
			83	SPT-1 17 27 27		54	
5			83	SPT-2 17 23 46		69	
95			100	SPT-3 14 24 26		50	MC = 3% Fines = 3%
10			83	SPT-4 15 32 39		71	
90							
15		Becomes gray, wet	100	SPT-5 18 32 50/5"		50/5"	
85							
20							

(Continued Next Page)

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wood.
4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-160mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft) / DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	WELL DIAGRAM	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
20		Silty SAND with gravel, dark gray, wet, [Qva] (SM)	100	SPT-6 28 36 50/5"		● ☐ 50/5"	MC = 12% Fines = 22%
80		Drill action indicates gravel					
		Poorly graded SAND with gravel, very dense, gray, wet, [Qva] (SP)					
25			100	SPT-7 12 17 32		▲ 49	
75							
30		increasing silt	100	SPT-8 42 50/3"		50/3"	
70							
		SILT with sand, very dense, gray, wet, homogeneous, [Qgl] (ML)					
35			99	SPT-9 29 50/6"		50/5.5"	
65							
40			92	SPT-10 50		50/5.5"	
60							

(Continued Next Page)

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wood.
4020 Lake Washington Blvd Suite 200
Kirkland, WA 98033

PROJECT NAME I-405 Renton to Bellevue Widening **PROJECT NUMBER** 20316 **BORING NUMBER** W-160mw-20

CLIENT WSDOT **PROJECT LOCATION** Renton, WA

ELEVATION (ft) / DEPTH	GRAPHIC LOG	SOIL & ROCK DESCRIPTION	RECOVERY % (RQD)	SAMPLE TYPE NUMBER	WELL DIAGRAM	▲ SPT N VALUE ▲ 20 40 60 80 / PL MC LL 20 40 60 80 / ☐ FINES CONTENT (%) ☐ 20 40 60 80	TESTS AND REMARKS
		Poorly graded SAND with silt, very dense, dark gray, wet, homogeneous, [Qgl] (SP)					
45			100	SPT-11 7 24 36		☐ ● ▲ 60	MC = 19% Fines = 5%

Bottom of borehole at 46.5 feet.

WSDOT GEOTECH W/ WELL - I405 WSDOT.GDT - 8/26/20 12:35 - C:\USERS\CHELSEA.FOSTER\DOCUMENTS\PROJECTWISE\WORKINGDIR\WSDOT\DMS08722\I405 WSDOT - SEG.2.GPJ

In Association with

Appendix C
Laboratory Testing Procedures and Results

Appendix C – Laboratory testing procedures and results

This appendix describes procedures associated with the laboratory tests Wood assigned for this project. Geotechnical laboratory testing was performed by a local, accredited geotechnical testing laboratory, subcontracted to Wood. Results of certain laboratory tests are enclosed in this appendix.

Visual classification procedures

Visual soil classifications were conducted on all samples in the field and on selected samples in the laboratory. All soils were classified in general accordance with the Unified Soil Classification System, which includes color, relative moisture content, primary soil type (based on grain size), and any accessory soil types. The resulting soil classifications are presented on the exploration logs contained in Appendix B.

Moisture content determination procedures

Moisture content determinations were performed on representative samples to aid in identification and correlation of soil types. All determinations were made in general accordance with ASTM D-2216. The results of these tests are shown on the exploration logs contained in Appendix B.

Grain-size analysis procedures

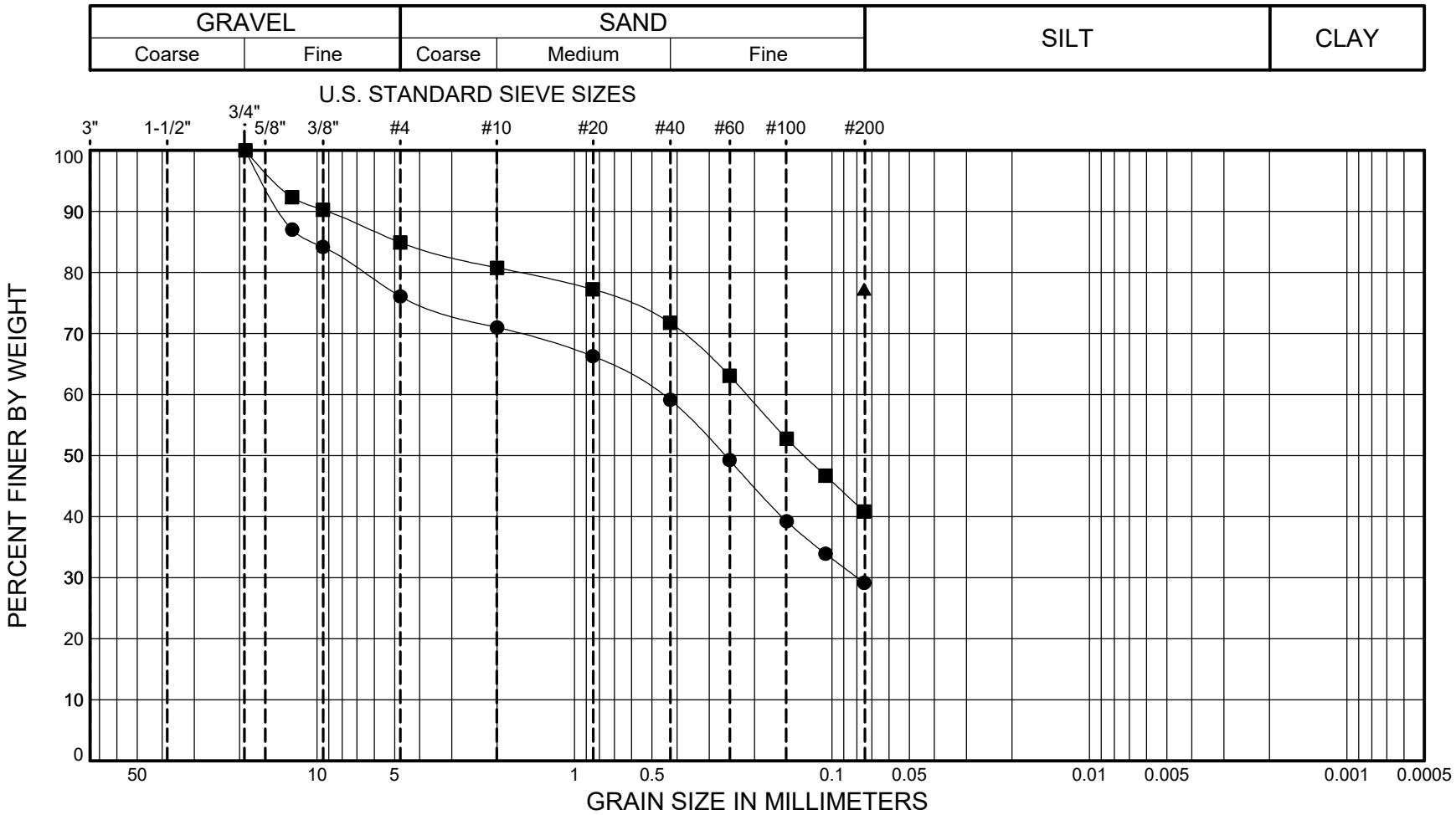
A grain-size analysis indicates the range of soil particle diameters included in a particular sample. Grain-size analyses were performed on representative samples in general accordance with ASTM D-422. The results of these tests are presented on the enclosed grain-size distribution graphs and were used in soil classifications shown on the exploration logs contained in Appendix B.

Atterberg limit determination procedures

Atterberg limits are used primarily for classifying and indexing cohesive soils. The liquid and plastic limits, which are defined as the moisture contents of a cohesive soil at arbitrarily established limits for liquid and plastic behavior, were determined for selected samples in general accordance with ASTM D-4318. The results of these tests are presented on the enclosed Atterberg limit graphs and on the boring logs contained in Appendix B.

EXPLORATION DESIGNATION	TOP DEPTH (feet)	BOTTOM DEPTH (feet)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SPECIFIC GRAVITY	ATTERBERG LIMITS (%)			% GRAVEL	% SAND	% FINES	ASTM SOIL CLASSIFICATION	SAMPLE DESCRIPTION
						LL	PL	PI					
W-154-20,S-3	7.5	7.5	12.0						23.9	46.9	29.2	SM	Olive-brown, silty SAND with gravel
W-154-20,S-5	15.0	15.0	14.3						15.1	44.1	40.8	SM	Olive-brown, silty SAND with gravel
W-154-20,S-10	40.0	40.0	18.9			22	15	7				CL-ML	Dark gray, sandy silty CLAY
W-154-20,S-14	60.0	60.0	18.9			38	20	18			77.2	CL	Gray, lean CLAY with sand
W-154-20,S-18	80.0	80.0	16.3									CL	Gray, lean CLAY
W-154-20,S-20	90.0	90.0	20.2			34	18	16			71.3	CL	Gray, lean CLAY with sand
W-154-20,S-22	100.0	100.0	17.2									CL	Dark gray, lean CLAY
W-162-20,S-3	7.5	7.5	9.5						11.2	45.3	43.5	SM	Grayish-brown, silty SAND
W-162-20,S-7	25.0	25.0	6.2									SM	Grayish-brown, silty SAND with gravel
W-171-20,S-2	5.0	5.0	9.5						10.3	59.2	30.6	SM	Grayish-brown, silty SAND
W-171-20,S-5	15.0	15.0	9.0									SM	Grayish-brown, silty SAND with gravel

Notes:
1. This table summarizes information presented elsewhere in the report and should be used in conjunction with the report test, other graphs and tables, and the exploration logs.
2. The soil classifications in this table are based on ASTM D2487 and D2488 as applicable.



SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-154-20	S-3	7.5 - 7.5	(SM) Olive-brown, silty SAND with gravel	12				23.9	46.9	29.2
■	W-154-20	S-5	15.0 - 15.0	(SM) Olive-brown, silty SAND with gravel	14				15.1	44.1	40.8
▲	W-154-20	S-14	60.0 - 60.0	(CL) Gray, lean CLAY with sand	19	38	20	18			77.2

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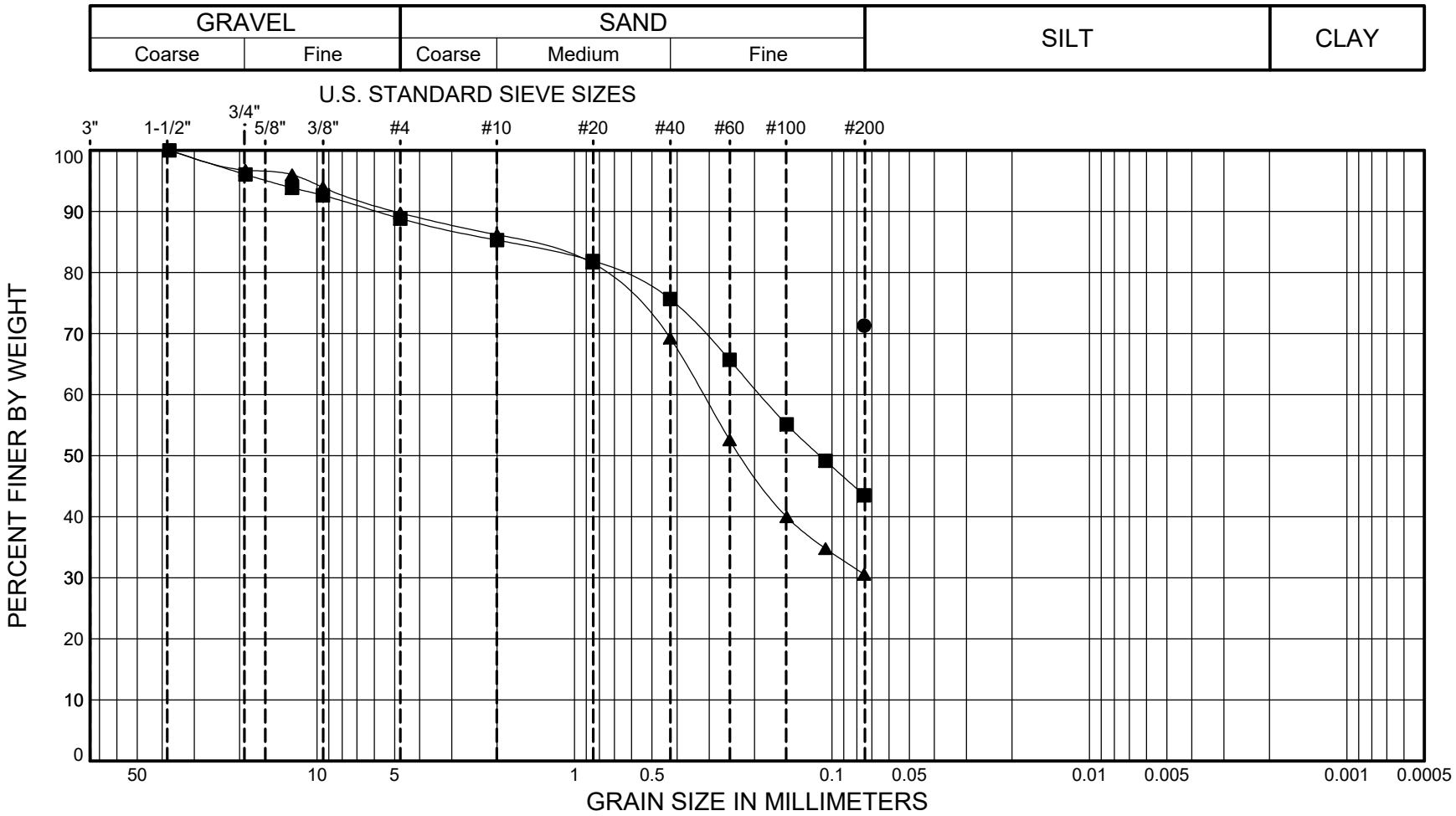
I-405 Renton to Bellevue
Widening and Express Toll Lanes
Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 2



SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-154-20	S-20	90.0 - 90.0	(CL) Gray, lean CLAY with sand	20	34	18	16			71.3
■	W-162-20	S-3	7.5 - 7.5	(SM) Grayish-brown, silty SAND	9				11.2	45.3	43.5
▲	W-171-20	S-2	5.0 - 5.0	(SM) Grayish-brown, silty SAND	10				10.3	59.2	30.6

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PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 3

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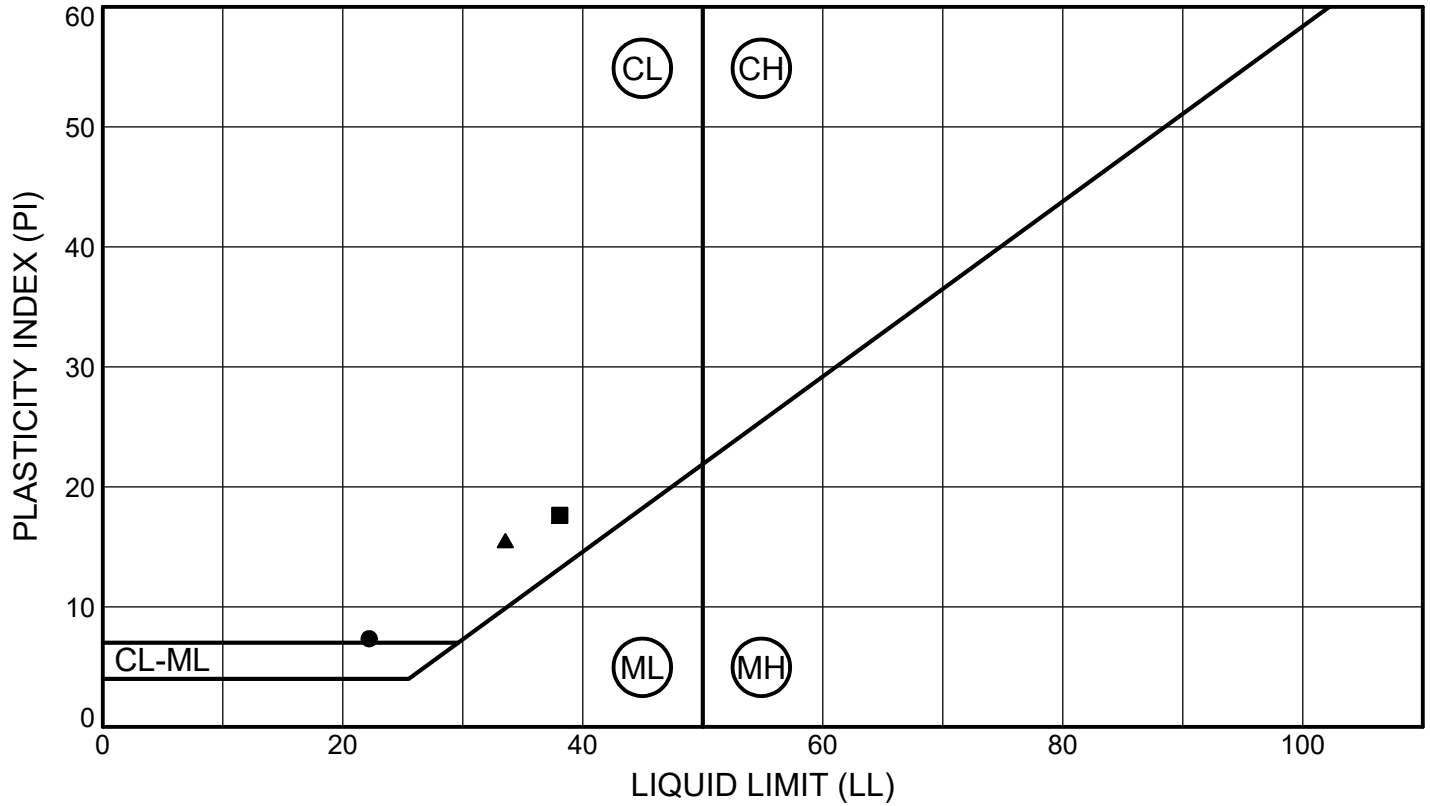

SYMBOL	SAMPLE		DEPTH (ft)	CLASSIFICATION	% MC	LL	PL	PI	% Fines
●	W-154-20	S-10	40.0 - 40.0	(CL-ML) Dark gray, sandy silty CLAY	19	22	15	7	
■	W-154-20	S-14	60.0 - 60.0	(CL) Gray, lean CLAY with sand	19	38	20	18	77.2
▲	W-154-20	S-20	90.0 - 90.0	(CL) Gray, lean CLAY with sand	20	34	18	16	71.3

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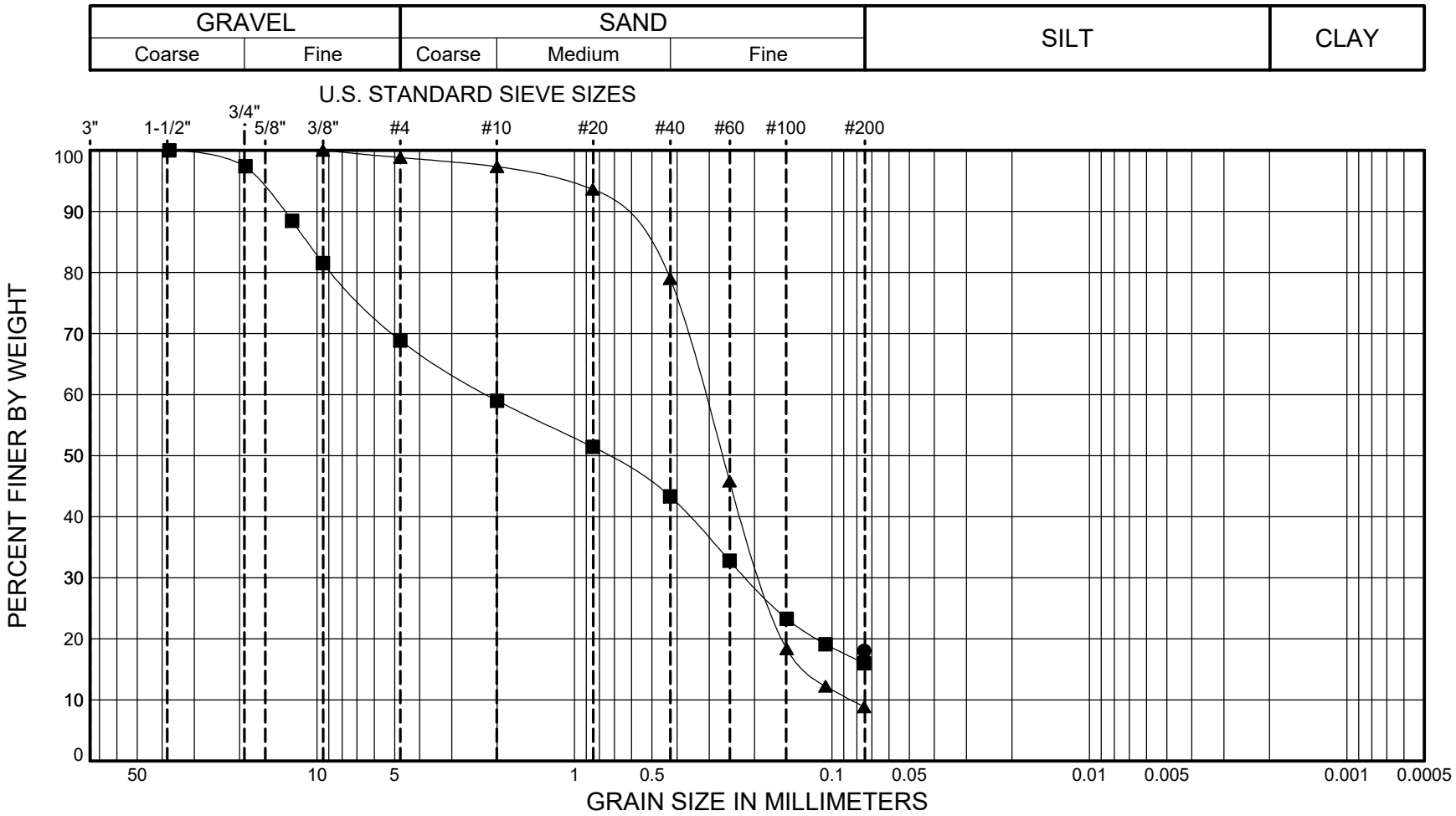
LIQUID LIMIT, PLASTIC LIMIT AND
PLASTICITY INDEX OF SOILS
METHOD ASTM D4318

PROJECT NO.: 2019-015-21 T200 FIGURE: 4

EXPLORATION DESIGNATION	TOP DEPTH (feet)	BOTTOM DEPTH (feet)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SPECIFIC GRAVITY	ATTERBERG LIMITS (%)			% GRAVEL	% SAND	% FINES	ASTM SOIL CLASSIFICATION	SAMPLE DESCRIPTION
						LL	PL	PI					
W-153-20,S-6	20.0	20.0	22.1	4.1					10.3	70.6	19.1	SM	Dark gray, silty SAND
W-153-20,S-9	35.0	35.0	19.1			28	21	7				CL-ML	Gray, silty CLAY with gravel
W-153-20,S-12	50.0	50.0	16.3			31	17	14				CL	Gray, lean CLAY
W-153-20,S-16	70.0	70.0	19.1			32	22	10				CL	Gray, lean CLAY
W-153-20,S-19	85.0	85.0	19.8			NP	NP	NP			18.0	SM	Dark gray, silty SAND
W-156-20,S-2	5.0	6.5	8.3						31.1	52.8	16.0	SM	Dark grayish-brown, silty SAND with gravel
W-156-20,S-3	7.5	9.0	20.8						1.2	90.0	8.8	SP-SM	Dark grayish-brown, poorly graded SAND with silt
W-156-20,S-7	25.0	26.5	19.2			NP	NP	NP			31.9	SM	Dark gray, silty SAND
W-170-20,S-2	5.0	6.5	25.3			30	27	3			91.7	ML	Dark yellowish-brown, SILT
W-170-20,S-4	10.0	11.5	7.1									SP-SM	Light olive-brown, poorly graded SAND with silt
W-172-20,S-2	5.0	6.5	10.4									SM	Dark olive-brown, silty SAND with gravel
W-172-20,S-5	15.0	16.5	5.7						0.4	93.2	6.5	SP-SM	Light olive-brown, poorly graded SAND with silt
W-173-20,S-2	5.0	6.5	9.3									SM	Olive-brown, silty SAND
W-173-20,S-4	10.0	11.5	10.1						24.9	46.7	28.4	SM	Grayish-brown, silty SAND with gravel
W-173-20,S-5	15.0	16.5	22.4									ML	Yellowish-brown, SILT
W-174-20,S-2	5.0	6.5	8.2						27.8	46.5	25.7	SM	Dark grayish-brown, silty SAND with gravel
W-174-20,S-3	7.5	9.0	22.4	4.4								CL	Dark grayish-brown, lean CLAY with gravel
W-174-20,S-4	10.0	11.5	19.4								41.2	GC	Dark grayish-brown, clayey GRAVEL
W-184-20,S-3	7.5	9.0	11.0						22.9	47.6	29.5	SM	Dark yellowish-brown, silty SAND with gravel
W-184-20,S-6	20.0	21.5	14.0						21.3	50.5	28.2	SM	Olive-brown, silty SAND with gravel

Notes: 1. This table summarizes information presented elsewhere in the report and should be used in conjunction with the report test, other graphs and tables, and the exploration logs.
2. The soil classifications in this table are based on ASTM D2487 and D2488 as applicable.



SYMBOL	SAMPLE		DEPTH (ft.)	ASTM SOIL CLASSIFICATION	% MC	LL	PL	PI	Gravel %	Sand %	Silt %	Clay %	Fines %
●	W-153-20	S-19	85.0 - 85.0	(SM) Dark gray, silty SAND	20	NP	NP	NP					18.0
■	W-156-20	S-2	5.0 - 6.5	(SM) Dark grayish-brown, silty SAND with gravel	8				31.1	52.8			16.0
▲	W-156-20	S-3	7.5 - 9.0	(SP-SM) Dark grayish-brown, poorly graded SAND with silt	21				1.2	90.0			8.8

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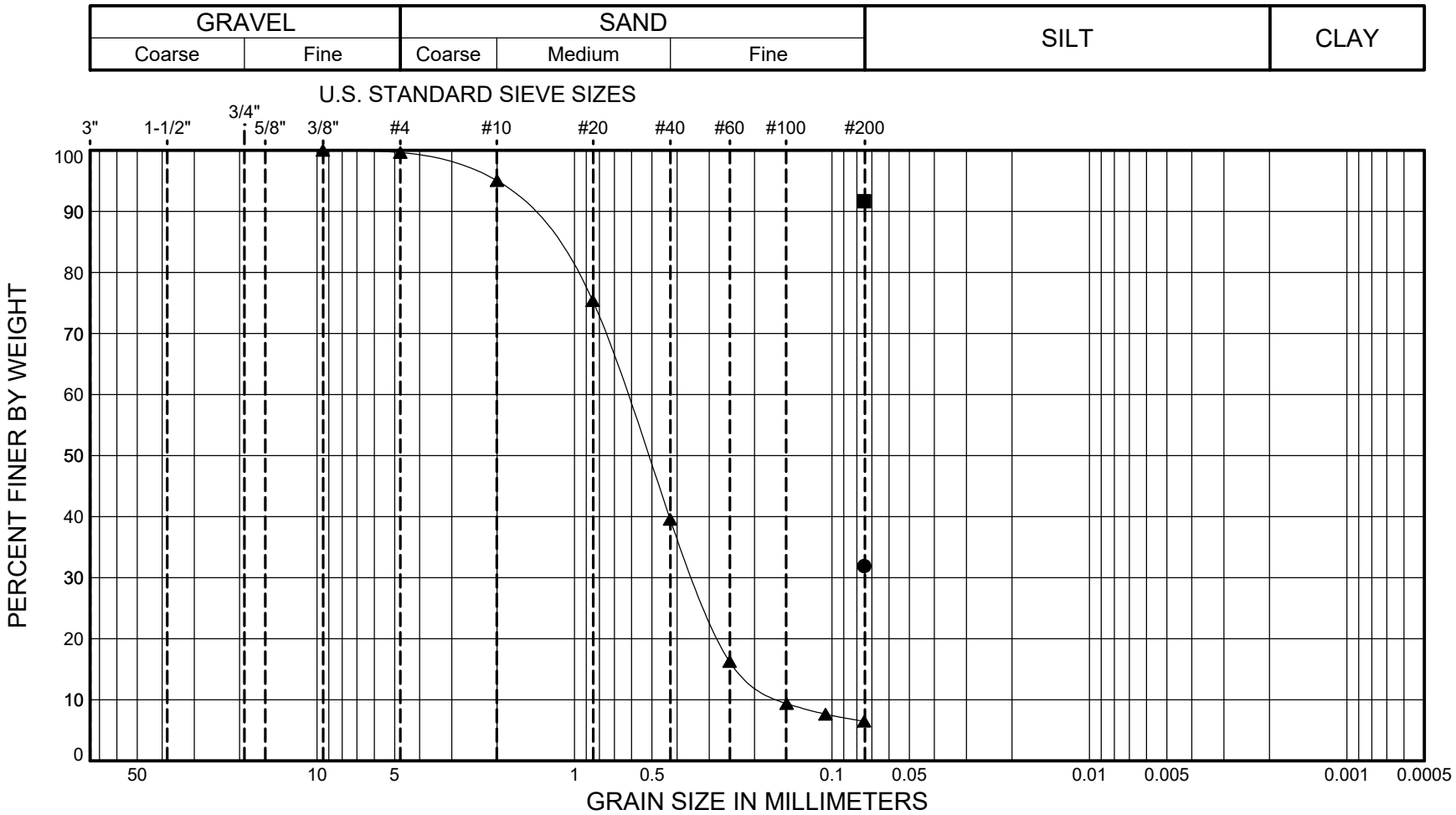
PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 8



SYMBOL	SAMPLE		DEPTH (ft.)	ASTM SOIL CLASSIFICATION	% MC	LL	PL	PI	Gravel %	Sand %	Silt %	Clay %	Fines %
●	W-156-20	S-7	25.0 - 26.5	(SM) Dark gray, silty SAND	19	NP	NP	NP					31.9
■	W-170-20	S-2	5.0 - 6.5	(ML) Dark yellowish-brown, SILT	25	30	27	3					91.7
▲	W-172-20	S-5	15.0 - 16.5	(SP-SM) Light olive-brown, poorly graded SAND with silt	6				0.4	93.2			6.5

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I-405 Renton to Bellevue
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Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 9

EXPLORATION DESIGNATION	TOP DEPTH (feet)	BOTTOM DEPTH (feet)	MOISTURE CONTENT (%)	ORGANIC CONTENT (%)	SPECIFIC GRAVITY	ATTERBERG LIMITS (%)			% GRAVEL	% SAND	% FINES	ASTM SOIL CLASSIFICATION	SAMPLE DESCRIPTION
						LL	PL	PI					
W-152-20,S-2	5.0	6.5	11.4						4.6	59.6	35.8	SM	Dark olive-brown, silty SAND
W-152-20,S-7	25.0	26.5	15.1						7.5	46.1	46.3	SM	Olive-brown, silty SAND
W-158-20,S-2	5.0	5.5	7.3						7.9	36.2	55.9	ML	Light olive-brown, sandy SILT
W-158-20,S-5	15.0	15.9	8.2			17	14	3			26.9	SM	Light olive-brown, silty SAND
W-167-20,S-2	5.0	6.5	16.7			21	16	5			59.7	CL-ML	Olive-brown, sandy silty CLAY
W-167-20,S-5	15.0	16.5	4.5							87.6	12.4	SM	Olive-brown, silty SAND
W-169-20,S-2	5.0	6.5	7.9						17.8	54.6	27.6	SM	Olive-brown, silty SAND with gravel
W-169-20,S-5	15.0	16.5	14.1			19	18	1			24.6	SM	Light olive-brown, silty SAND
W-199-20,S-4	10.0	11.5	15.5						1.8	47.7	50.5	ML	Olive-brown, sandy SILT
W-199-20,S-8	30.0	31.5	17.3			27	19	8				CL	Olive-brown, lean CLAY with sand
W-199-20,S-10	40.0	41.5	18.0	8.8					11.5	59.7	28.8	SM	Dark grayish-brown, silty SAND with organics

Notes:
1. This table summarizes information presented elsewhere in the report and should be used in conjunction with the report test, other graphs and tables, and the exploration logs.
2. The soil classifications in this table are based on ASTM D2487 and D2488 as applicable.

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I-405 Renton to Bellevue
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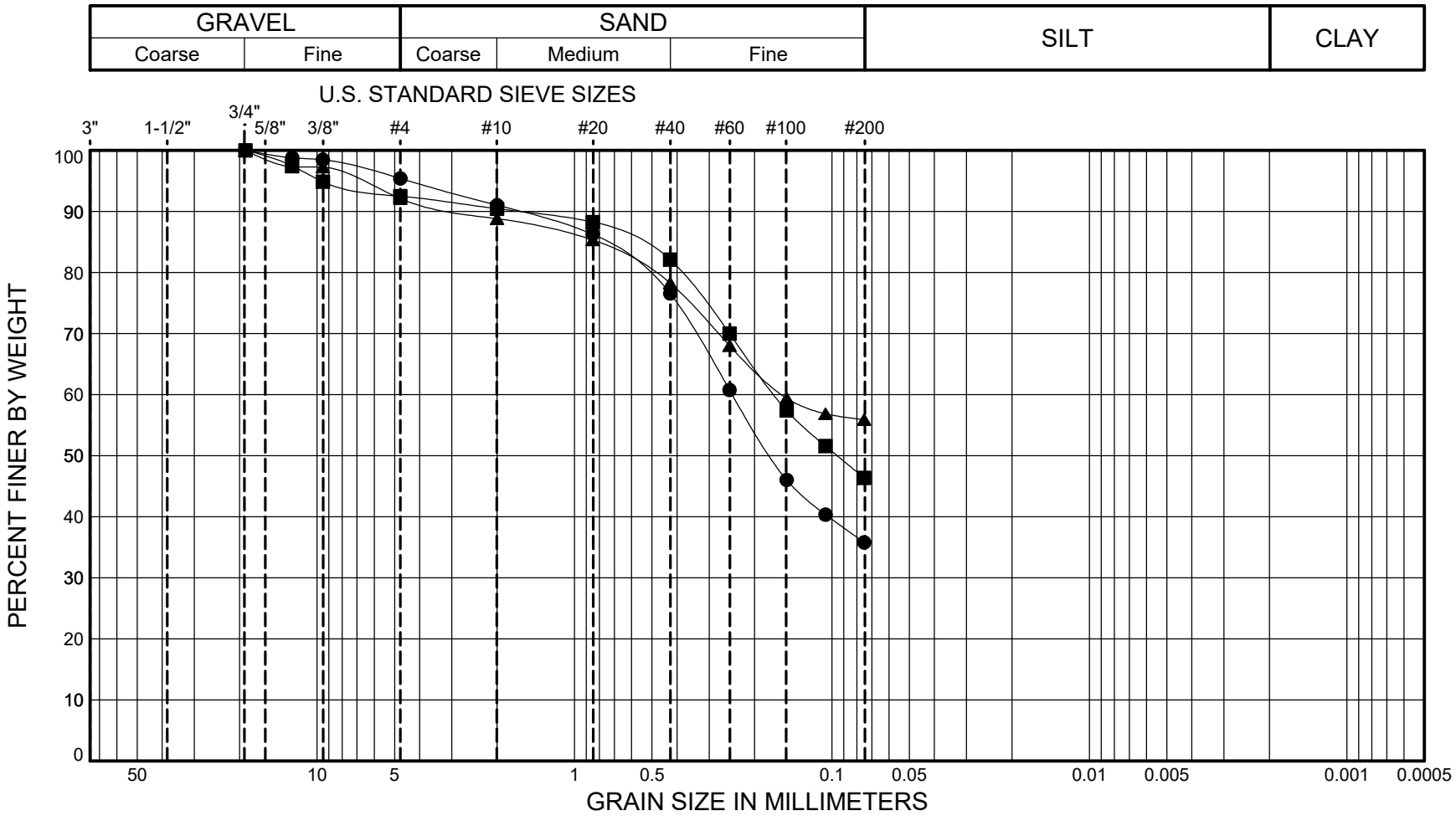
Client Project No.: PS19203160

SUMMARY OF
MATERIAL PROPERTIES

PROJECT NO.: 2019-015-21 T200 FIGURE: 1



SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-152-20	S-2	5.0 - 6.5	(SM) Dark olive-brown, silty SAND	11				4.6	59.6	35.8
■	W-152-20	S-7	25.0 - 26.5	(SM) Olive-brown, silty SAND	15				7.5	46.1	46.3
▲	W-158-20	S-2	5.0 - 5.5	(ML) Light olive-brown, sandy SILT	7				7.9	36.2	55.9

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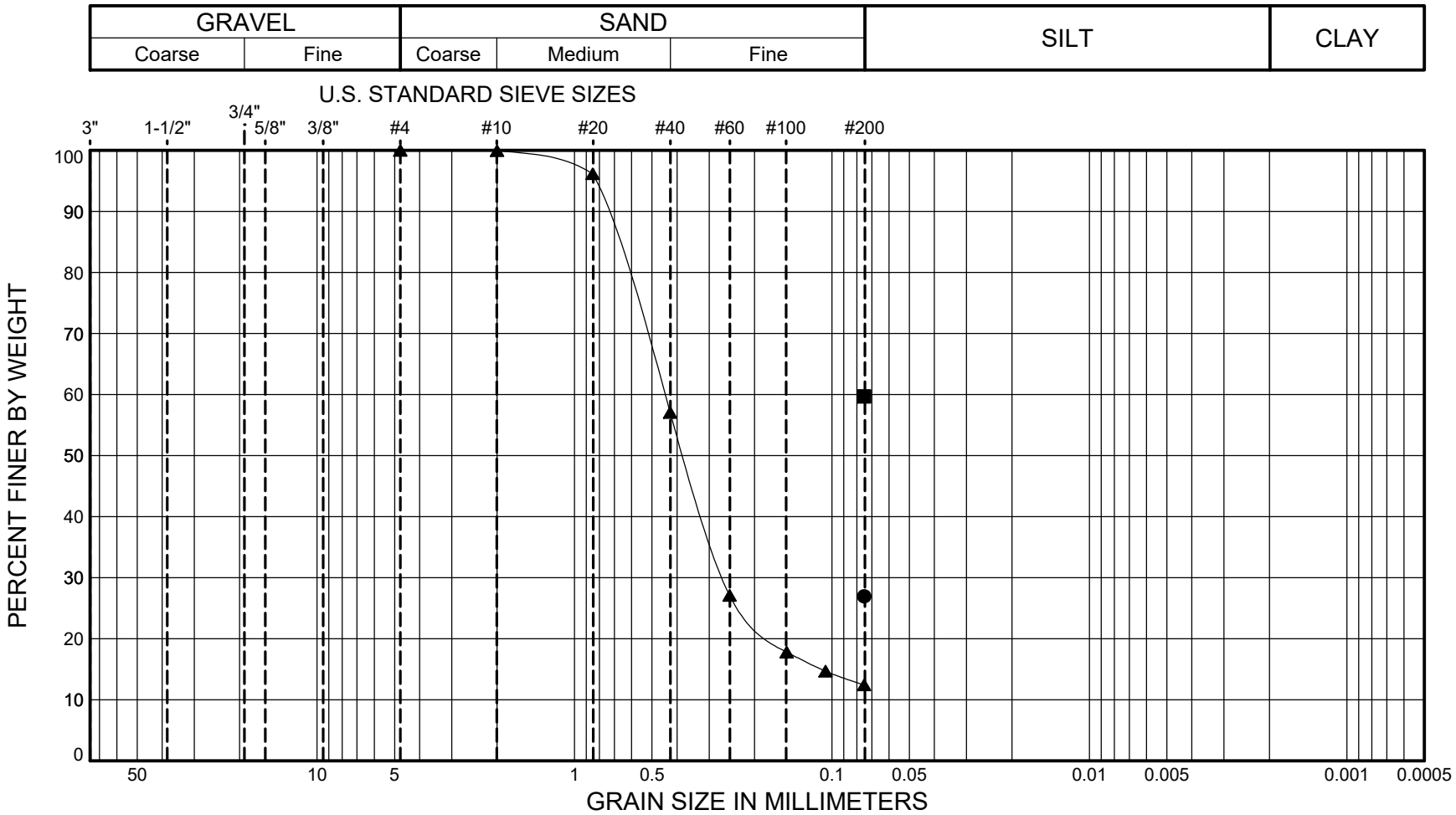
Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 2



SYMBOL	SAMPLE		DEPTH (ft.)	CLASSIFICATION OF SOIL- ASTM D2487 Group Symbol and Name	% MC	LL	PL	PI	Gravel %	Sand %	Fines %
●	W-158-20	S-5	15.0 - 15.9	(SM) Light olive-brown, silty SAND	8	17	14	3			26.9
■	W-167-20	S-2	5.0 - 6.5	(CL-ML) Olive-brown, sandy silty CLAY	17	21	16	5			59.7
▲	W-167-20	S-5	15.0 - 16.5	(SM) Olive-brown, silty SAND	5					87.6	12.4

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I-405 Renton to Bellevue
Widening and Express Toll Lanes
Client Project No.: PS19203160

PARTICLE-SIZE ANALYSIS
OF SOILS
METHOD ASTM D6913

PROJECT NO.: 2019-015-21 T200 FIGURE: 3

Appendix D
ESU Soil Properties and Sample Calculation of $(N_1)_{60}$

Appendix D – ESU Soil Properties

This appendix describes procedures associated with the assignment of soil properties based on laboratory tests, field exploration, and soil property methodology. The data from the borehole logs and laboratory tests were imported into our spreadsheet and associated $(N_1)_{60}$ values were calculated.

Stratigraphic unit grouping

Geologic strata as defined in Section 5.2 of the Project GDM were identified based on review of the available borehole logs, laboratory testing and published geologic maps. Geologic cross sections were initially developed using the interpreted geologic strata. A geotechnical engineer then assigned Engineering Stratigraphic Units (ESUs) based on review of the geologic cross sections, grouping geologic strata with similar engineering properties.

Evaluate Statistical Analysis

The $(N_1)_{60}$ parameters were accumulated for each ESU. The average, geomean, and standard deviation were calculated for $(N_1)_{60.}$ The blow count values were evaluated for outliers that are associated with mislabeling, testing errors, and statistics. The outliers were either reassigned to another ESU, remained in the statistical evaluation, or were removed from the statistical valuation. The blow counts vs depth chart, standard deviations, and covariance were utilized to make these assessments. The covariance was verified to be between 15 and 45 percent per the *LRFD Bridge Design Specifications* (AASHTO 2017).

Review Soil Property Values

Soil properties were assigned per the Geotechnical Soil Properties Methodology report (Wood 2020b).

In most cases, the effective friction angle was assigned to the ESU group in accordance with Table 5-1 in the Project GDM using the average $(N_1)_{60}$ value. Within the range of values presented in Table 5-1, information on the fines content and soil plasticity was also considered to assign the effective friction angle. Values at or near the upper limit of Table 5-1 were selected when fines content was determined as below 5 percent passing U.S. sieve No.200. Values at or near the lower limit were selected for soil with “significant” fines, taken as soil with fines content greater than 30 percent passing US No.200 sieve, based on the 2014 Caltrans *Geotechnical Manual*. For samples where the fines content was between 5 and 30 percent, interpolation was used between the upper and lower limit to select the effective friction angle. For low plasticity fine grained material, material with a plasticity index less than 5, Table 5-1 was used to determine the effective friction angle using lower limit in comparison with the value that was derived based on the plasticity index value as referenced in the Geotechnical Soil Properties Methodology report (Wood 2020b). In circumstances where the ESU has high covariance and outside the soil parameters for the referenced volume of *Engineering Geology in Washington*, then the lower or higher value will be chosen.

The unit weight for each ESU was determined based on the Caltrans (2014) method of USCS classification with blow counts. The value for unit weight was compared to the ranges in Coduto (2001) and the Project GDM for verification. If the unit weight is outside the range of the reference documents, then the value will be adjusted to fit within the range.

Other soil engineering properties were determined based on results of Cone Penetrometer Test probes, laboratory testing and correlations as described in the Geotechnical Soil Properties Methodology report (Wood 2020b).

In Association with

Appendix D-1
ESU Soil Properties

Tab	Description
Summary	Input available information on historic boring log ID, location, elevation, drill rig ID and hammer efficiency
Summary	Correct to NAVD88 vertical datum
Samples	Input each SPT sample and 6-inch interval blow count; formula calculates N Field
Samples	Input available lab test data and USCS classification from Lab
Samples	For R2B borings, this is all listed in Table B-1 of the GDR
Samples	Use lab data and boring log information to estimate USCS for all samples
Calc $(N_1)_{60}$	Input for other fields in yellow highlight
Calc $(N_1)_{60}$	Use Coduto (2001) to estimate Unit weight for all samples (Unless we have Unit weight measurements)
Calc $(N_1)_{60}$	Use GDM to estimate Unit weight for organic / peat samples (Unless we have Unit weight measurements)
Calc $(N_1)_{60}$	Assign ESUs based on SPM for borings being used for specific structure design
ESU 1, 2, etc.	1 - List data with $(N_1)_{60}$ values; give justification for deleting any values. Find Average, Std Deviation, Geomean.
ESU 1, 2, etc.	2 - Check COV is within limits (15 to 45% for N values); consider if ESU needs subdividing or if OK.
ESU 1, 2, etc.	3 - Plot Histogram and visually compare to GEOMEAN.
ESU 1, 2, etc.	4 - Correlate $(N_1)_{60}$ with friction angle; use average unless other factors. Select design friction angle.
ESU 1, 2, etc.	5 - Assign predominent USCS classification for ESU.
ESU 1, 2, etc.	6 - Select design unit weight. Use CALTRANS, Chart 2 (2014) and correlate with Table 3.2 Coduto (2001).
ESU 1, 2, etc.	7, 8, etc. (if needed) Select/ assign other soil properties for ESUs per I405 Soil Property Methodology report.

REFERENCES:

California Department of Transportation (Caltrans). 2014. *Geotechnical Manual.*

Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.

BOREHOLE SUMMARY

PointID	Hole Depth	Elevation	Northing	Easting	Hole Size	Method	Equipment	Historical Efficiency
R2B-82vw-17	80.5	72.5	210272.648	1308036.223	4	Casing Advancer	CME 55	89
GEO-33	41.0	124.0	Note 1	Note 1	4.5	HSA	CME 75	80
H-1A-81-CC	30.3	101.6	210152.590	1308108.910	6	HSA	Note 1	60
H-4-64-NW	24.3	89.6	210194.390	1308095.580	3	Chop/Wash	Note 1	60
W-154-20	105.5	104.6	210222.742	1308088.714	8	HSA	Mobile B57 ID: #10	87
W-155-20	15.4	111.1	210340.581	1308159.903	6	HSA	LAR ID: #309	80
W-156-20	46.5	84.9	210462.028	1308133.241	4	Mud Rotary	CME 55 ID: #310	88
W-158-20	15.9	123.0	210516.438	1308286.09	8	HSA	CME 85 ID: #7	88
W-160mw-20	46.5	101.6	210658.879	1308223.112	8	HSA	CME 85 ID: #7	88

Note 1 - Information not available

SAMPLE SUMMARY

PointID	PointID (Historic, WSDOT R2B, WOOD)	Top Depth (ft)	Sample Number	Blow Counts[1]			Length[1]			Field N	USCS from Lab	Lab Description	Estimated USCS	Water Content (%)	Atterberg Limits			Total Wet Unit Weight	Estimated Total Unit Weight (pcf)	Dry Density (pcf)	Specific Gravity	Sieve analysis					% Organics
				1	2	3	1	2	3						Liquid Limit	Plastic Limit	Plasticity Index					% Gravel	% Sand	Fines Content From Lab	% Silt	% Clay	
R2B-82vw-17	WSDOT R2B	4	D-1	50			6			100	SM		SM						--	--					--	--	
R2B-82vw-17	WSDOT R2B	7	D-2	50			6			100	SM		SM						--	--					--	--	
R2B-82vw-17	WSDOT R2B	9	D-3	50			6			100	SM		SM						--	--					--	--	
R2B-82vw-17	WSDOT R2B	12	D-4	20	35	50	6	6	4	102	SM		SM						--	--					--	--	
R2B-82vw-17	WSDOT R2B	14	D-5	50			5			120	CL-ML		CL-ML						--	--					--	--	
R2B-82vw-17	WSDOT R2B	19	D-6	18	35	44	6	6	6	79	CL-ML	Silty CLAY with sand (CL-ML)	CL-ML	21	27	20	7	125	--	--	2.71	5.3	13.8	80.9	60.9	20	--
R2B-82vw-17	WSDOT R2B	24	D-7	17	26	30	6	6	6	56	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	29	D-8	15	25	39	6	6	6	64	CL	Lean CLAY with sand (CL)	CL	21	30	17	13	124	--	--	2.68	0	20.7	79.3	51.3	28	--
R2B-82vw-17	WSDOT R2B	34	D-9	18	34	38	6	6	6	72	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	39	D-10	16	50		6	6		100	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	44	D-11	24	27	26	6	6	6	53	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	49	D-12	22	24	26	6	6	6	50	CL	Lean CLAY (CL)	CL	25	30	22	8	122	--	--	2.73	0	6	94	83	11	--
R2B-82vw-17	WSDOT R2B	54	D-13	21	26	26	6	6	6	52	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	59	D-14	19	26	31	6	6	6	57	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	64	D-15	16	24	26	6	6	6	50	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	69	D-16	18	24	25	6	6	6	49	CL		CL						--	--					--	--	
R2B-82vw-17	WSDOT R2B	74	D-17	17	22	27	6	6	6	49	CL	Lean CLAY with sand (CL)	CL	17	26	17	9	131	--	--	2.72	2.8	21.5	75.7	53.7	22	--
R2B-82vw-17	WSDOT R2B	79	D-18	20	22	26	6	6	6	48	ML		ML						--	--					--	--	
W-154-20	WOOD	2.5	SPT-1	15	12	12	6	6	6	24	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	5	SPT-2	10	12	12	6	6	6	24	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	7.5	SPT-3	11	10	7	6	6	6	17	SM		SM	12	--	--	--	--	--	--	--	23.9	46.9	29.2	--	--	--
W-154-20	WOOD	10	SPT-4	5	7	11	6	6	6	18	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	15	SPT-5	15	15	18	6	6	6	33	ML		ML	14	--	--	--	--	--	--	--	15.1	44.1	40.8	--	--	--
W-154-20	WOOD	20	SPT-6	50			5			120	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	25	SPT-7	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	30	SPT-8	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	35	SPT-9	50			3			200	CL-ML		CL-ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	40	SPT-10	45	50		6	3		200	CL-ML		CL-ML	19	22	15	7	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	45	SPT-11	50			5			120	CL-ML		CL-ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	50	SPT-12	50			6			100	CL-ML		CL-ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	55	SPT-13	50			5			120	CL-ML		CL-ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	60	SPT-14	17	40	50	6	6	6	90	CL	Lean CLAY (CL)	CL	19	38	20	18	--	--	--	--	--	--	77.2	--	--	--
W-154-20	WOOD	65	SPT-15	30	50		6	5		120	CL		CL	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	70	SPT-16	31	40	46	6	6	6	86	CL		CL	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	75	SPT-17	12	16	25	6	6	6	41	CL		CL	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	80	SPT-18	32	26	35	6	6	6	61	CL		CL	16	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	85	SPT-19	39	44	36	6	6	6	80	CL		CL	20	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	90	SPT-20	19	35	32	6	6	6	67	CL	Lean CLAY (CL)	CL	20	34	18	16	--	--	--	--	--	--	71.3	--	--	--
W-154-20	WOOD	95	SPT-21	47	50		6	4		150	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	100	SPT-22	11	23	37	6	6	6	60	CL		CL	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-154-20	WOOD	105	SPT-23	50			5			120	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-155-20	WOOD	2.5	SPT-1	4	10	12	6	6	6	22	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-155-20	WOOD	5	SPT-2	9	14	20	6	6	6	34	SM		SM	9	--	--	--	--	--	--	--	13.4	53.6	33	--	--	--
W-155-20	WOOD	7.5	SPT-3	50			6			100	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-155-20	WOOD	10	SPT-4	34	50		6	5		120	SM		SM	8	--	--	--	--	--	--	--	14.1	51.4	34.5	--	--	--
W-155-20	WOOD	15	SPT-5	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--

PointID	PointID (Historic, WSDOT R2B, WOOD)	Top Depth (ft)	Sample Number	Blow Counts[1]			Length[1]			Field N	USCS from Lab	Lab Description	Estimated USCS	Water Content (%)	Atterberg Limits			Total Wet Unit Weight	Estimated Total Unit Weight (pcf)	Dry Density (pcf)	Specific Gravity	Sieve analysis					% Organics
				1	2	3	1	2	3						Liquid Limit	Plastic Limit	Plasticity Index					% Gravel	% Sand	Fines Content From Lab	% Silt	% Clay	
W-156-20	WOOD	2.5	SPT-1	3	18	29	6	6	6	47	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	5	SPT-2	16	43	34	6	6	6	77	SM		SM	8	--	--	--	--	--	--	--	31.1	52.9	16	--	--	--
W-156-20	WOOD	7.5	SPT-3	14	20	24	6	6	6	44	SP-SM		SP-SM	21	--	--	--	--	--	--	--	1.2	90	8.8	--	--	--
W-156-20	WOOD	10	SPT-4	7	10	12	6	6	6	22	SP-SM		SP-SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	15	SPT-5	5	28	50	6	6	2	117	GP		GP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	20	SPT-6	27	50		6	5		120	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	25	SPT-7	16	50		6	6		100	SM	Silty Sand (SM)	SM	19	NP	NP	--	--	--	--	--	0	68.1	31.9	--	--	--
W-156-20	WOOD	30	SPT-8	21	48	50	6	6	6	98	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	35	SPT-9	18	25	40	6	6	6	65	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	40	SPT-10	3	28	42	6	6	6	70	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-156-20	WOOD	45	SPT-11	20	35	25	6	6	6	60	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-158-20	WOOD	2.5	SPT-1	18	50		6	3		200	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-158-20	WOOD	5	SPT-2	50			5			120	ML		ML	7	--	--	--	--	--	--	--	7.9	36.2	55.9	--	--	--
W-158-20	WOOD	7.5	SPT-3	38	50		6	4		150	ML		ML	6	--	--	--	--	--	--	--	10.8	42.7	46.5	--	--	--
W-158-20	WOOD	10	SPT-4	50			6			100	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-158-20	WOOD	15	SPT-5	22	50		6	5		120	SM	Silty Sand (SM)	SM	8	17	14	3	--	--	--	--	0	73.1	26.9	--	--	--
W-160mw-20	WOOD	2.5	SPT-1	17	27	27	6	6	6	54	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	5	SPT-2	17	23	46	6	6	6	69	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	7.5	SPT-3	14	24	26	6	6	6	50	SP		SP	3	--	--	--	--	--	--	--	0.1	96.8	3.1	--	--	--
W-160mw-20	WOOD	10	SPT-4	15	32	39	6	6	6	71	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	15	SPT-5	18	32	50	6	6	5	89	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	20	SPT-6	28	36	50	6	6	5	94	SM		SM	12	--	--	--	--	--	--	--	0	77.7	22.3	--	--	--
W-160mw-20	WOOD	25	SPT-7	12	17	32	6	6	6	49	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	30	SPT-8	42	50		6	3		200	SP		SP	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	35	SPT-9	29	50		6	5.5		109	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	40	SPT-10	50			5.5			109	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
W-160mw-20	WOOD	45	SPT-11	7	24	36	6	6	6	60	SP		SP	19	--	--	--	--	--	--	--	0	94.6	5.4	--	--	--
GEO-33	Historic	2.5	SPT-1	50			2			300	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	5	SPT-2	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	7.5	SPT-3	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	10	SPT-4	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	12.5	SPT-5	50			6			100	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	15	SPT-6	50			6			100	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	17.5	SPT-7	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	20	SPT-8	50			4			150	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	25	SPT-9	70			12			70	SP-SM		SP-SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	30	SPT-10	50			4			150	SP-SM		SP-SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	35	SPT-11	72			12			72	SP-SM		SP-SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
GEO-33	Historic	39.5	SPT-12	50			5			120	SP-SM		SP-SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	0	SPT-1	2	6	8	6	6	6	14	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	5	SPT-2	15	15	14	6	6	6	29	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	10	SPT-3	8	17	12	6	6	6	29	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	15	SPT-4	15	21	20	6	6	6	41	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	20	SPT-5	28	50		6	6		100	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	25	SPT-6	29	40	85	6	6	6	125	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-1A-81-CC	Historic	30	SPT-7	100			4			300	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	3	SPT-1	4	4	3	6	6	6	7	SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	5	UD-2								SM		SM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	9	SPT-3	25	26	25	6	6	6	51	GM		GM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	14	SPT-4	43	78	70	6	6	6	148	GM		GM	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	19	SPT-5	120			6			240	ML		ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--
H-4-64-NW	Historic	24	SPT-6	110			4			330	CL-ML		CL-ML	--	--	--	--	--	--	--	--	--	--	--	--	--	--

Notes:

1. Blank cells in the Blow Counts and Length columns signify that eiter no SPT was performed, that refusal was encountered, or that only an overall "blows per foot" N value was recorded.

-- = not tested

STANDARD PENETRATION TEST DATA [1]

PointID	PointID (Historic, WSDOT R2B, WOOD)	Sample Top Depth (ft)	Sample Number	Field SPT	Sampler Type (spt = standard penetrometer w/ 1.375-inch I.D., m = Modified California)	Samplers Have Space for Liners But didn't Use?	Borehole Diameter (in)	C_R, Rod Length Correction Factor	C_s, Sampling Method Correction Factor	C_S, Correction for Sampler without Liners	Hammer efficiency (%)	C_E, Energy Ratio Correction	C_B, Boring Dia Correction	N_{60}, Blowcount Corrected for All Factors except Overburden	Groundwater Depth (ft)	Avg Unit Wt of Sample (pcf) [or corrleation based on Coduto and USCS info or GDM for Peats]	Total Overburden Stress (psf)	Effective Overburden Stress (psf)	C_N, Over-burden Correction (Eq 41, Idriss & Boulanger, 2008^2) = $(pa/\sigma vo')$^0.5	$(N_1)_{60}$, Corrected Blowcount for All Factors	Limit $(N_1)_{60}$ to 46	C_N, Over-burden Correction (Eq 39, Idriss & Boulanger, 2008^2) = $f(N_1)_{60}$	$(N_1)_{60}$, Corrected Blowcount for All Factors refined for relative density	Estimated USCS Classification	Assign ESU
				N	Sampler Type	(y/n)		C_R	C_s	C_S	ER(%)	C_E	C_B	N_{60}	gwt (ft)	γ (pcf)	σ (psf)	σ' (psf)	C_N	$(N_1)_{60}$	Limit $(N_1)_{60}$ to 46	C_N refined	$(N_1)_{60}$ refined	USCS	
R2B-82vw-17	WSDOT R2B	4.0	D-1	100	SPT	n	4	0.75	1	1.0	89	1.48	1.00	111	44.34	108	432.0	432.0	1.7	189	46	1.5	169	SM	4C
R2B-82vw-17	WSDOT R2B	7.0	D-2	100	SPT	n	4	0.8	1	1.0	89	1.48	1.00	119	44.34	108	756.0	756.0	1.7	199	46	1.3	156	SM	4C
R2B-82vw-17	WSDOT R2B	9.0	D-3	100	SPT	n	4	0.85	1	1.0	89	1.48	1.00	126	44.34	108	972.0	972.0	1.5	186	46	1.2	155	SM	4C
R2B-82vw-17	WSDOT R2B	12.0	D-4	102	SPT	n	4	0.85	1	1.0	89	1.48	1.00	129	44.34	108	1296.0	1296.0	1.3	164	46	1.1	146	SM	4C
R2B-82vw-17	WSDOT R2B	14.0	D-5	120	SPT	n	4	0.85	1	1.0	89	1.48	1.00	151	44.34	94	1484.0	1484.0	1.2	181	46	1.1	166	CL-ML	4E
R2B-82vw-17	WSDOT R2B	19.0	D-6	79	SPT	n	4	0.95	1	1.0	89	1.48	1.00	111	44.34	94	1954.0	1954.0	1.0	116	46	1.0	114	CL-ML	4E
R2B-82vw-17	WSDOT R2B	24.0	D-7	56	SPT	n	4	0.95	1	1.0	89	1.48	1.00	79	44.34	95	2429.0	2429.0	0.9	74	46	1.0	76	CL	4E
R2B-82vw-17	WSDOT R2B	29.0	D-8	64	SPT	n	4	1	1	1.0	89	1.48	1.00	95	44.34	95	2904.0	2904.0	0.9	81	46	0.9	87	CL	4E
R2B-82vw-17	WSDOT R2B	34.0	D-9	72	SPT	n	4	1	1	1.0	89	1.48	1.00	107	44.34	95	3379.0	3379.0	0.8	85	46	0.9	94	CL	4E
R2B-82vw-17	WSDOT R2B	39.0	D-10	100	SPT	n	4	1	1	1.0	89	1.48	1.00	148	44.34	95	3854.0	3854.0	0.7	110	46	0.9	127	CL	4E
R2B-82vw-17	WSDOT R2B	44.0	D-11	53	SPT	n	4	1	1	1.0	89	1.48	1.00	79	44.34	95	4329.0	4329.0	0.7	55	46	0.8	65	CL	4E
R2B-82vw-17	WSDOT R2B	49.0	D-12	50	SPT	n	4	1	1	1.0	89	1.48	1.00	74	44.34	103	4844.0	4553.2	0.7	51	46	0.8	61	CL	4E
R2B-82vw-17	WSDOT R2B	54.0	D-13	52	SPT	n	4	1	1	1.0	89	1.48	1.00	77	44.34	103	5359.0	4756.2	0.7	51	46	0.8	62	CL	4E
R2B-82vw-17	WSDOT R2B	59.0	D-14	57	SPT	n	4	1	1	1.0	89	1.48	1.00	85	44.34	103	5874.0	4959.2	0.7	55	46	0.8	68	CL	4E
R2B-82vw-17	WSDOT R2B	64.0	D-15	50	SPT	n	4	1	1	1.0	89	1.48	1.00	74	44.34	103	6389.0	5162.2	0.6	48	46	0.8	59	CL	4E
R2B-82vw-17	WSDOT R2B	69.0	D-16	49	SPT	n	4	1	1	1.0	89	1.48	1.00	73	44.34	103	6904.0	5365.2	0.6	46	46	0.8	57	CL	4E
R2B-82vw-17	WSDOT R2B	74.0	D-17	49	SPT	n	4	1	1	1.0	89	1.48	1.00	73	44.34	103	7419.0	5568.2	0.6	45	45	0.8	56	CL	4E
R2B-82vw-17	WSDOT R2B	79.0	D-18	48	SPT	n	4	1	1	1.0	89	1.48	1.00	71	44.34	105	7944.0	5781.2	0.6	43	43	0.8	54	ML	4E
W-154-20	WOOD	2.5	SPT-1	24	SPT	n	8	0.75	1	1.0	87	1.45	1.15	30	93	108	270.0	270.0	1.7	51	46	1.7	51	SM	1B
W-154-20	WOOD	5.0	SPT-2	24	SPT	n	8	0.8	1	1.0	87	1.45	1.15	32	93	108	540.0	540.0	1.7	54	46	1.4	46	SM	1B
W-154-20	WOOD	7.5	SPT-3	17	SPT	n	8	0.8	1	1.0	87	1.45	1.15	23	93	108	810.0	810.0	1.6	37	37	1.4	31	SM	1B
W-154-20	WOOD	10.0	SPT-4	18	SPT	n	8	0.85	1	1.0	87	1.45	1.15	26	93	108	1080.0	1080.0	1.4	36	36	1.2	32	SM	1B
W-154-20	WOOD	15.0	SPT-5	33	SPT	n	8	0.95	1	1.0	87	1.45	1.15	52	93	93	1545.0	1545.0	1.2	61	46	1.1	57	ML	4A
W-154-20	WOOD	20.0	SPT-6	120	SPT	n	8	0.95	1	1.0	87	1.45	1.15	190	93	108	2085.0	2085.0	1.0	192	46	1.0	191	SM	4A
W-154-20	WOOD	25.0	SPT-7	150	SPT	n	8	0.95	1	1.0	87	1.45	1.15	238	93	108	2625.0	2625.0	0.9	213	46	0.9	224	SM	4A
W-154-20	WOOD	30.0	SPT-8	150	SPT	n	8	1	1	1.0	87	1.45	1.15	250	93	108	3165.0	3165.0	0.8	204	46	0.9	225	SM	4A
W-154-20	WOOD	35.0	SPT-9	200	SPT	n	8	1	1	1.0	87	1.45	1.15	334	93	94	3635.0	3635.0	0.8	254	46	0.9	289	CL-ML	4E
W-154-20	WOOD	40.0	SPT-10	200	SPT	n	8	1	1	1.0	87	1.45	1.15	334	93	94	4105.0	4105.0	0.7	239	46	0.8	280	CL-ML	4E
W-154-20	WOOD	45.0	SPT-11	120	SPT	n	8	1	1	1.0	87	1.45	1.15	200	93	94	4575.0	4575.0	0.7	136	46	0.8	163	CL-ML	4E
W-154-20	WOOD	50.0	SPT-12	100	SPT	n	8	1	1	1.0	87	1.45	1.15	167	93	94	5045.0	5045.0	0.6	108	46	0.8	133	CL-ML	4E
W-154-20	WOOD	55.0	SPT-13	120	SPT	n	8	1	1	1.0	87	1.45	1.15	200	93	94	5515.0	5515.0	0.6	124	46	0.8	156	CL-ML	4E
W-154-20	WOOD	60.0	SPT-14	90	SPT	n	8	1	1	1.0	87	1.45	1.15	150	93	95	5990.0	5990.0	0.6	89	46	0.8	114	CL	4E
W-154-20	WOOD	65.0	SPT-15	120	SPT	n	8	1	1	1.0	87	1.45	1.15	200	93	95	6465.0	6465.0	0.6	114	46	0.7	149	CL	4E
W-154-20	WOOD	70.0	SPT-16	86	SPT	n	8	1	1	1.0	87	1.45	1.15	143	93	95	6940.0	6940.0	0.6	79	46	0.7	105	CL	4E
W-154-20	WOOD	75.0	SPT-17	41	SPT	n	8	1	1	1.0	87	1.45	1.15	68	93	95	7415.0	7415.0	0.5	37	37	0.7	46	CL	4E
W-154-20	WOOD	80.0	SPT-18	61	SPT	n	8	1	1	1.0	87	1.45	1.15	102	93	95	7890.0	7890.0	0.5	53	46	0.7	72	CL	4E
W-154-20	WOOD	85.0	SPT-19	80	SPT	n	8	1	1	1.0	87	1.45	1.15	133	93	95	8365.0	8365.0	0.5	67	46	0.7	93	CL	4E
W-154-20	WOOD	90.0	SPT-20	67	SPT	n	8	1	1	1.0	87	1.45	1.15	112	93	95	8840.0	8840.0	0.5	55	46	0.7	77	CL	4E
W-154-20	WOOD	95.0	SPT-21	150	SPT	n	8	1	1	1.0	87	1.45	1.15	250	93	128	9480.0	9355.2	0.5	119	46	0.7	169	SP	4E
W-154-20	WOOD	100.0	SPT-22	60	SPT	n	8	1	1	1.0	87	1.45	1.15	100	93	103	9995.0	9558.2	0.5	47	46	0.7	67	CL	4E
W-154-20	WOOD	105.0	SPT-23	120	SPT	n	8	1	1	1.0	87	1.45	1.15	200	93	128	10635.0	9886.2	0.5	93	46	0.7	133	SP	4E
W-155-20	WOOD	2.5	SPT-1	22	SPT	n	6	0.75	1	1.0	80	1.33	1.05	23		110	275.0	275.0	1.7	39	39	1.7	39	SP	1B
W-155-20	WOOD	5.0	SPT-2	34	SPT	n	6	0.8	1	1.0	80	1.33	1.05	38		108	545.0	545.0	1.7	65	46	1.4	54	SM	1B
W-155-20	WOOD	7.5	SPT-3	100	SPT	n	6	0.8	1	1.0	80	1.33	1.05	112		108	815.0	815.0	1.6	180	46	1.3	144	SM	4C
W-155-20	WOOD	10.0	SPT-4	120	SPT	n	6	0.85	1	1.0	80	1.33	1.05	143		108	1085.0	1085.0	1.4	199	46	1.2	170	SM	4C
W-155-20	WOOD	15.0	SPT-5	150	SPT	n	6	0.95	1	1.0	80	1.33	1.05	200		108	1625.0	1625.0	1.1	228	46	1.1	214	SM	4C

PointID	PointID (Historic, WSDOT R2B, WOOD)	Sample Top Depth (ft)	Sample Number	Field SPT	Sampler Type (spt = standard penetrometer w/ 1.375-inch I.D., m = Modified California)	Samplers Have Space for Liners But didn't Use?	Borehole Diameter (in)	C_R, Rod Length Correction Factor	C_s, Sampling Method Correction Factor	C_S, Correction for Sampler without Liners	Hammer efficiency (%)	C_E, Energy Ratio Correction	C_B, Boring Dia Correction	N_{60}, Blowcount Corrected for All Factors except Overburden	Groundwater Depth (ft)	Avg Unit Wt of Sample (pcf) [or corrleation based on Coduto and USCS info or GDM for Peats]	Total Overburden Stress (psf)	Effective Overburden Stress (psf)	C_N, Over-burden Correction (Eq 41, Idriss & Boulanger, 2008[2]) = (pa/σvo')^0.5	$(N_1)_{60}$, Corrected Blowcount for All Factors	Limit $(N_1)_{60}$ to 46	C_N, Over-burden Correction (Eq 39, Idriss & Boulanger, 2008[2]) = $f(N_1)_{60}$	$(N_1)_{60}$, Corrected Blowcount for All Factors refined for relative density	Estimated USCS Classification	Assign ESU
				N	Sampler Type	(y/n)		C_R	C_s	C_S	ER(%)	C_E	C_B	N_{60}	gwt (ft)	γ (pcf)	σ (psf)	σ' (psf)	C_N	$(N_1)_{60}$	Limit $(N_1)_{60}$ to 46	C_N refined	$(N_1)_{60}$ refined	USCS	
W-156-20	WOOD	2.5	SPT-1	47	SPT	n	4	0.75	1	1.0	88	1.47	1.00	52	2	125	312.5	281.3	1.7	88	46	1.7	88	SM	1B
W-156-20	WOOD	5.0	SPT-2	77	SPT	n	4	0.8	1	1.0	88	1.47	1.00	90	2	125	625.0	437.8	1.7	154	46	1.5	137	SM	1B
W-156-20	WOOD	7.5	SPT-3	44	SPT	n	4	0.8	1	1.0	88	1.47	1.00	52	2	127	942.5	599.3	1.7	88	46	1.4	72	SP-SM	4A
W-156-20	WOOD	10.0	SPT-4	22	SPT	n	4	0.85	1	1.0	88	1.47	1.00	27	2	127	1260.0	760.8	1.7	46	46	1.3	36	SP-SM	4A
W-156-20	WOOD	15.0	SPT-5	117	SPT	n	4	0.95	1	1.0	88	1.47	1.00	163	2	133	1925.0	1113.8	1.4	225	46	1.2	193	GP	4A
W-156-20	WOOD	20.0	SPT-6	120	SPT	n	4	0.95	1	1.0	88	1.47	1.00	167	2	105	2450.0	1326.8	1.3	211	46	1.1	189	ML	4A
W-156-20	WOOD	25.0	SPT-7	100	SPT	n	4	0.95	1	1.0	88	1.47	1.00	139	2	125	3075.0	1639.8	1.1	158	46	1.1	149	SM	4A
W-156-20	WOOD	30.0	SPT-8	98	SPT	n	4	1	1	1.0	88	1.47	1.00	144	2	125	3700.0	1952.8	1.0	150	46	1.0	147	SM	4A
W-156-20	WOOD	35.0	SPT-9	65	SPT	n	4	1	1	1.0	88	1.47	1.00	95	2	125	4325.0	2265.8	1.0	92	46	1.0	94	SM	4A
W-156-20	WOOD	40.0	SPT-10	70	SPT	n	4	1	1	1.0	88	1.47	1.00	103	2	125	4950.0	2578.8	0.9	93	46	0.9	97	SM	4A
W-156-20	WOOD	45.0	SPT-11	60	SPT	n	4	1	1	1.0	88	1.47	1.00	88	2	125	5575.0	2891.8	0.9	75	46	0.9	81	SM	4A
W-158-20	WOOD	2.5	SPT-1	200	SPT	n	8	0.75	1	1.0	88	1.47	1.15	253		93	232.5	232.5	1.7	430	46	1.7	430	ML	4C
W-158-20	WOOD	5.0	SPT-2	120	SPT	n	8	0.8	1	1.0	88	1.47	1.15	162		93	465.0	465.0	1.7	275	46	1.5	241	ML	4C
W-158-20	WOOD	7.5	SPT-3	150	SPT	n	8	0.8	1	1.0	88	1.47	1.15	202		93	697.5	697.5	1.7	344	46	1.3	271	ML	4C
W-158-20	WOOD	10.0	SPT-4	100	SPT	n	8	0.85	1	1.0	88	1.47	1.15	143		93	930.0	930.0	1.5	216	46	1.2	178	ML	4C
W-158-20	WOOD	15.0	SPT-5	120	SPT	n	8	0.95	1	1.0	88	1.47	1.15	192		108	1470.0	1470.0	1.2	231	46	1.1	212	SM	4C
W-160mw-20	WOOD	2.5	SPT-1	54	SPT	n	8	0.75	1	1.0	88	1.47	1.15	68	4.9	110	275.0	275.0	1.7	116	46	1.7	116	SP	4A
W-160mw-20	WOOD	5.0	SPT-2	69	SPT	n	8	0.8	1	1.0	88	1.47	1.15	93	4.9	128	595.0	588.8	1.7	158	46	1.4	130	SP	4A
W-160mw-20	WOOD	7.5	SPT-3	50	SPT	n	8	0.8	1	1.0	88	1.47	1.15	68	4.9	128	915.0	752.8	1.7	113	46	1.3	89	SP	4A
W-160mw-20	WOOD	10.0	SPT-4	71	SPT	n	8	0.85	1	1.0	88	1.47	1.15	102	4.9	128	1235.0	916.8	1.5	155	46	1.2	127	SP	4A
W-160mw-20	WOOD	15.0	SPT-5	89	SPT	n	8	0.95	1	1.0	88	1.47	1.15	143	4.9	128	1875.0	1244.8	1.3	186	46	1.1	164	SP	4A
W-160mw-20	WOOD	20.0	SPT-6	94	SPT	n	8	0.95	1	1.0	88	1.47	1.15	151	4.9	125	2500.0	1557.8	1.2	176	46	1.1	163	SM	4A
W-160mw-20	WOOD	25.0	SPT-7	49	SPT	n	8	0.95	1	1.0	88	1.47	1.15	79	4.9	128	3140.0	1885.8	1.1	83	46	1.0	81	SP	4A
W-160mw-20	WOOD	30.0	SPT-8	200	SPT	n	8	1	1	1.0	88	1.47	1.15	337	4.9	128	3780.0	2213.8	1.0	330	46	1.0	333	SP	4A
W-160mw-20	WOOD	35.0	SPT-9	109	SPT	n	8	1	1	1.0	88	1.47	1.15	184	4.9	105	4305.0	2426.8	0.9	172	46	1.0	177	ML	4E
W-160mw-20	WOOD	40.0	SPT-10	109	SPT	n	8	1	1	1.0	88	1.47	1.15	184	4.9	105	4830.0	2639.8	0.9	165	46	0.9	173	ML	4E
W-160mw-20	WOOD	45.0	SPT-11	60	SPT	n	8	1	1	1.0	88	1.47	1.15	101	4.9	128	5470.0	2967.8	0.8	85	46	0.9	93	SP	4E
GEO-33	Historic	2.5	SPT-1	300	SPT	n	4.5	0.75	1	1.0	80	1.33	1.00	300	35	108	270.0	270.0	1.7	510	46	1.7	510	SM	4C
GEO-33	Historic	5.0	SPT-2	150	SPT	n	4.5	0.8	1	1.0	80	1.33	1.00	160	35	108	540.0	540.0	1.7	272	46	1.4	229	SM	4C
GEO-33	Historic	7.5	SPT-3	150	SPT	n	4.5	0.8	1	1.0	80	1.33	1.00	160	35	108	810.0	810.0	1.6	259	46	1.3	206	SM	4C
GEO-33	Historic	10.0	SPT-4	150	SPT	n	4.5	0.85	1	1.0	80	1.33	1.00	170	35	108	1080.0	1080.0	1.4	238	46	1.2	203	SM	4C
GEO-33	Historic	12.5	SPT-5	100	SPT	n	4.5	0.85	1	1.0	80	1.33	1.00	113	35	108	1350.0	1350.0	1.3	142	46	1.1	128	SM	4C
GEO-33	Historic	15.0	SPT-6	100	SPT	n	4.5	0.95	1	1.0	80	1.33	1.00	127	35	108	1620.0	1620.0	1.1	145	46	1.1	136	SM	4C
GEO-33	Historic	17.5	SPT-7	150	SPT	n	4.5	0.95	1	1.0	80	1.33	1.00	190	35	108	1890.0	1890.0	1.1	201	46	1.0	196	SM	4C
GEO-33	Historic	20.0	SPT-8	150	SPT	n	4.5	0.95	1	1.0	80	1.33	1.00	190	35	108	2160.0	2160.0	1.0	188	46	1.0	189	SM	4C
GEO-33	Historic	25.0	SPT-9	70	SPT	n	4.5	0.95	1	1.0	80	1.33	1.00	89	35	109	2705.0	2705.0	0.9	78	46	0.9	83	SP-SM	4A
GEO-33	Historic	30.0	SPT-10	150	SPT	n	4.5	1	1	1.0	80	1.33	1.00	200	35	109	3250.0	3250.0	0.8	161	46	0.9	179	SP-SM	4A
GEO-33	Historic	35.0	SPT-11	72	SPT	n	4.5	1	1	1.0	80	1.33	1.00	96	35	127	3885.0	3885.0	0.7	71	46	0.9	82	SP-SM	4A
GEO-33	Historic	39.5	SPT-12	120	SPT	n	4.5	1	1	1.0	80	1.33	1.00	160	35	127	4456.5	4175.7	0.7	114	46	0.8	134	SP-SM	4A
H-1A-81-CC	Historic	0.0	SPT-1	14	SPT	n	6	0.75	1	1.0	60	1.00	1.05	11	29	108	0.0	0.0	1.0	11	11	1.0	11	SM	1A
H-1A-81-CC	Historic	5.0	SPT-2	29	SPT	n	6	0.8	1	1.0	60	1.00	1.05	24	29	93	465.0	465.0	1.7	41	41	1.6	38	ML	1B
H-1A-81-CC	Historic	10.0	SPT-3	29	SPT	n	6	0.85	1	1.0	60	1.00	1.05	26	29	108	1005.0	1005.0	1.5	38	38	1.3	33	SM	4C
H-1A-81-CC	Historic	15.0	SPT-4	41	SPT	n	6	0.95	1	1.0	60	1.00	1.05	41	29	108	1545.0	1545.0	1.2	48	46	1.1	44	SM	4C
H-1A-81-CC	Historic	20.0	SPT-5	100	SPT	n	6	0.95	1	1.0	60	1.00	1.05	100	29	108	2085.0	2085.0	1.0	101	46	1.0	100	SM	4C
H-1A-81-CC	Historic	25.0	SPT-6	125	SPT	n	6	0.95	1	1.0	60	1.00	1.05	125	29	93	2550.0	2550.0	0.9	114	46	1.0	119	ML	4E
H-1A-81-CC	Historic	30.0	SPT-7	300	SPT	n	6	1	1	1.0	60	1.00	1.05	315	29	105	3075.0	3012.6	0.8	264	46	0.9	287	ML	4E
H-4-64-NW	Historic	3.0	SPT-1	7	SPT	n	3	0.75	1	1.0	60	1.00	1.00	5	3.7	108	324.0	324.0	1.7	9	9	1.7	9	SM	1A
H-4-64-NW	Historic	9.0	SPT-3	51	SPT	n	3	0.85	1	1.0	60	1.00	1.00	43	3.7	133	1122.0	791.3	1.6	71	46	1.3	56	GM	4A
H-4-64-NW	Historic	14.0	SPT-4	148	SPT	n	3	0.85	1	1.0	60	1.00	1.00	126	3.7	133	1787.0	1144.3	1.4	171	46	1.2	148	GM	4A
H-4-64-NW	Historic	19.0	SPT-5	240	SPT	n	3	0.95	1	1.0	60	1.00	1.00	228	3.7	105	2312.0	1357.3	1.2	285	46	1.1	256	ML	4E
H-4-64-NW	Historic	24.0	SPT-6	330	SPT	n	3	0.95	1	1.0	60	1.00	1.00	314	3.7	104	2832.0	1565.3	1.2	365	46	1.1	339	CL-ML	4E

Notes:

1. Yellow highlighting indicates fields where input data was required.
2. Source: Idriss, I.M. and R.W. Boulanger. 2008. *Soil Liquefaction During Earthquakes.* Earthquake Engineering Research Institute.

ASSIGNED ESUs

Point ID	PointID (HISTORIC, WSDOT R2B, WOOD)	Sample ID	Sample Top Depth (ft)	Field N	N_{60}	$(N_1)_{60}$	Estimated USCS Classification	ESU	LL	PI	% Fines (Lab)
R2B-82vw-17	WSDOT R2B	D-1	4.0	100	111	189	SM	4C			
R2B-82vw-17	WSDOT R2B	D-2	7.0	100	119	199	SM	4C			
R2B-82vw-17	WSDOT R2B	D-3	9.0	100	126	186	SM	4C			
R2B-82vw-17	WSDOT R2B	D-4	12.0	102	129	164	SM	4C			
R2B-82vw-17	WSDOT R2B	D-5	14.0	120	151	181	CL-ML	4E			
R2B-82vw-17	WSDOT R2B	D-6	19.0	79	111	116	CL-ML	4E	27	7	80.9
R2B-82vw-17	WSDOT R2B	D-7	24.0	56	79	74	CL	4E			
R2B-82vw-17	WSDOT R2B	D-8	29.0	64	95	81	CL	4E	30	13	79.3
R2B-82vw-17	WSDOT R2B	D-9	34.0	72	107	85	CL	4E			
R2B-82vw-17	WSDOT R2B	D-10	39.0	100	148	110	CL	4E			
R2B-82vw-17	WSDOT R2B	D-11	44.0	53	79	55	CL	4E			
R2B-82vw-17	WSDOT R2B	D-12	49.0	50	74	51	CL	4E	30	8	94.0
R2B-82vw-17	WSDOT R2B	D-13	54.0	52	77	51	CL	4E			
R2B-82vw-17	WSDOT R2B	D-14	59.0	57	85	55	CL	4E			
R2B-82vw-17	WSDOT R2B	D-15	64.0	50	74	48	CL	4E			
R2B-82vw-17	WSDOT R2B	D-16	69.0	49	73	46	CL	4E			
R2B-82vw-17	WSDOT R2B	D-17	74.0	49	73	45	CL	4E	26	9	75.7
R2B-82vw-17	WSDOT R2B	D-18	79.0	48	71	43	ML	4E			
W-154-20	WOOD	SPT-1	2.5	24	30	51	SM	1B	--	--	--
W-154-20	WOOD	SPT-2	5.0	24	32	54	SM	1B	--	--	--
W-154-20	WOOD	SPT-3	7.5	17	23	37	SM	1B	--	--	29.2
W-154-20	WOOD	SPT-4	10.0	18	26	36	SM	1B	--	--	--
W-154-20	WOOD	SPT-5	15.0	33	52	61	ML	4A	--	--	40.8
W-154-20	WOOD	SPT-6	20.0	120	190	192	SM	4A	--	--	--
W-154-20	WOOD	SPT-7	25.0	150	238	213	SM	4A	--	--	--
W-154-20	WOOD	SPT-8	30.0	150	250	204	SM	4A	--	--	--
W-154-20	WOOD	SPT-9	35.0	200	334	254	CL-ML	4E	--	--	--
W-154-20	WOOD	SPT-10	40.0	200	334	239	CL-ML	4E	22	7.3	--
W-154-20	WOOD	SPT-11	45.0	120	200	136	CL-ML	4E	--	--	--
W-154-20	WOOD	SPT-12	50.0	100	167	108	CL-ML	4E	--	--	--
W-154-20	WOOD	SPT-13	55.0	120	200	124	CL-ML	4E	--	--	--
W-154-20	WOOD	SPT-14	60.0	90	150	89	CL	4E	38	18	77.2
W-154-20	WOOD	SPT-15	65.0	120	200	114	CL	4E	--	--	--
W-154-20	WOOD	SPT-16	70.0	86	143	79	CL	4E	--	--	--
W-154-20	WOOD	SPT-17	75.0	41	68	37	CL	4E	--	--	--
W-154-20	WOOD	SPT-18	80.0	61	102	53	CL	4E	--	--	--
W-154-20	WOOD	SPT-19	85.0	80	133	67	CL	4E	--	--	--
W-154-20	WOOD	SPT-20	90.0	67	112	55	CL	4E	34	16	71.3
W-154-20	WOOD	SPT-21	95.0	150	250	119	SP	4E	--	--	--
W-154-20	WOOD	SPT-22	100.0	60	100	47	CL	4E	--	--	--
W-154-20	WOOD	SPT-23	105.0	120	200	93	SP	4E	--	--	--
W-155-20	WOOD	SPT-1	2.5	22	23	39	SP	1B	--	--	--
W-155-20	WOOD	SPT-2	5.0	34	38	65	SM	1B	--	--	33.0
W-155-20	WOOD	SPT-3	7.5	100	112	180	SM	4C	--	--	--
W-155-20	WOOD	SPT-4	10.0	120	143	199	SM	4C	--	--	34.5
W-155-20	WOOD	SPT-5	15.0	150	200	228	SM	4C	--	--	--
W-156-20	WOOD	SPT-1	2.5	47	52	88	SM	1B	--	--	--
W-156-20	WOOD	SPT-2	5.0	77	90	154	SM	1B	--	--	16.0
W-156-20	WOOD	SPT-3	7.5	44	52	88	SP-SM	4A	--	--	8.8
W-156-20	WOOD	SPT-4	10.0	22	27	46	SP-SM	4A	--	--	--
W-156-20	WOOD	SPT-5	15.0	117	163	225	GP	4A	--	--	--
W-156-20	WOOD	SPT-6	20.0	120	167	211	ML	4A	--	--	--
W-156-20	WOOD	SPT-7	25.0	100	139	158	SM	4A	NP	--	31.9
W-156-20	WOOD	SPT-8	30.0	98	144	150	SM	4A	--	--	--
W-156-20	WOOD	SPT-9	35.0	65	95	92	SM	4A	--	--	--
W-156-20	WOOD	SPT-10	40.0	70	103	93	SM	4A	--	--	--
W-156-20	WOOD	SPT-11	45.0	60	88	75	SM	4A	--	--	--
W-158-20	WOOD	SPT-1	2.5	200	253	430	ML	4C	--	--	--
W-158-20	WOOD	SPT-2	5.0	120	162	275	ML	4C	--	--	55.9
W-158-20	WOOD	SPT-3	7.5	150	202	344	ML	4C	--	--	46.5
W-158-20	WOOD	SPT-4	10.0	100	143	216	ML	4C	--	--	--
W-158-20	WOOD	SPT-5	15.0	120	192	231	SM	4C	17	3	26.9

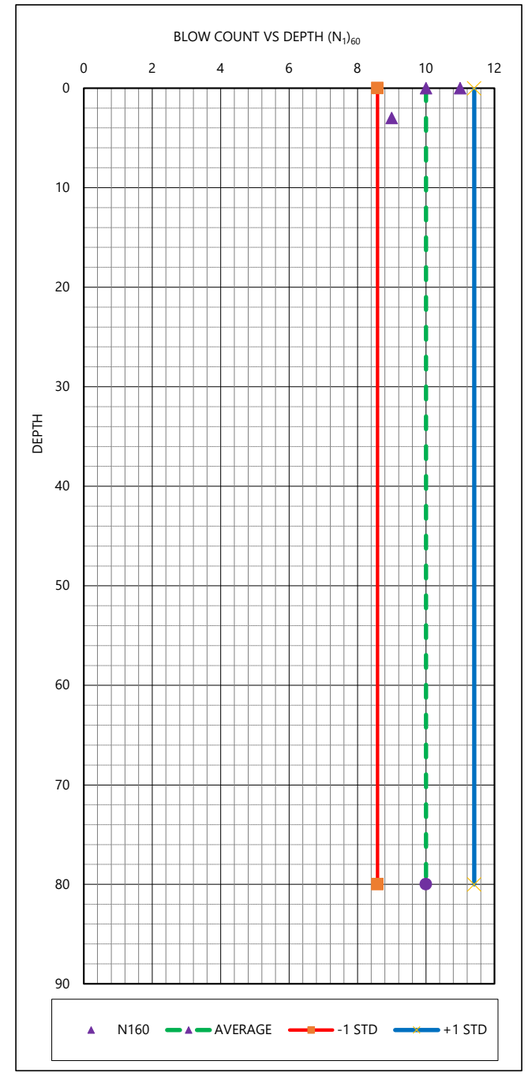
Point ID	PointID (HISTORIC, WSDOT R2B, WOOD)	Sample ID	Sample Top Depth (ft)	Field N	N_{60}	$(N_1)_{60}$	Estimated USCS Classification	ESU	LL	PI	% Fines (Lab)
W-160mw-20	WOOD	SPT-1	2.5	54	68	116	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-2	5.0	69	93	158	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-3	7.5	50	68	113	SP	4A	--	--	3.1
W-160mw-20	WOOD	SPT-4	10.0	71	102	155	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-5	15.0	89	143	186	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-6	20.0	94	151	176	SM	4A	--	--	22.3
W-160mw-20	WOOD	SPT-7	25.0	49	79	83	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-8	30.0	200	337	330	SP	4A	--	--	--
W-160mw-20	WOOD	SPT-9	35.0	109	184	172	ML	4E	--	--	--
W-160mw-20	WOOD	SPT-10	40.0	109	184	165	ML	4E	--	--	--
W-160mw-20	WOOD	SPT-11	45.0	60	101	85	SP	4E	--	--	5.4
GEO-33	Historic	SPT-1	2.5	300	300	510	SM	4C	--	--	--
GEO-33	Historic	SPT-2	5.0	150	160	272	SM	4C	--	--	--
GEO-33	Historic	SPT-3	7.5	150	160	259	SM	4C	--	--	--
GEO-33	Historic	SPT-4	10.0	150	170	238	SM	4C	--	--	--
GEO-33	Historic	SPT-5	12.5	100	113	142	SM	4C	--	--	--
GEO-33	Historic	SPT-6	15.0	100	127	145	SM	4C	--	--	--
GEO-33	Historic	SPT-7	17.5	150	190	201	SM	4C	--	--	--
GEO-33	Historic	SPT-8	20.0	150	190	188	SM	4C	--	--	--
GEO-33	Historic	SPT-9	25.0	70	89	78	SP-SM	4A	--	--	--
GEO-33	Historic	SPT-10	30.0	150	200	161	SP-SM	4A	--	--	--
GEO-33	Historic	SPT-11	35.0	72	96	71	SP-SM	4A	--	--	--
GEO-33	Historic	SPT-12	39.5	120	160	114	SP-SM	4A	--	--	--
H-1A-81-CC	Historic	SPT-1	0.0	14	11	11	SM	1A	--	--	--
H-1A-81-CC	Historic	SPT-2	5.0	29	24	41	ML	1B	--	--	--
H-1A-81-CC	Historic	SPT-3	10.0	29	26	38	SM	4C	--	--	--
H-1A-81-CC	Historic	SPT-4	15.0	41	41	48	SM	4C	--	--	--
H-1A-81-CC	Historic	SPT-5	20.0	100	100	101	SM	4C	--	--	--
H-1A-81-CC	Historic	SPT-6	25.0	125	125	114	ML	4E	--	--	--
H-1A-81-CC	Historic	SPT-7	30.0	300	315	264	ML	4E	--	--	--
H-4-64-NW	Historic	SPT-1	3.0	7	5	9	SM	1A	--	--	--
H-4-64-NW	Historic	SPT-3	9.0	51	43	71	GM	4A	--	--	--
H-4-64-NW	Historic	SPT-4	14.0	148	126	171	GM	4A	--	--	--
H-4-64-NW	Historic	SPT-5	19.0	240	228	285	ML	4E	--	--	--
H-4-64-NW	Historic	SPT-6	24.0	330	314	365	CL-ML	4E	--	--	--

ESU #1A Fill (Loose to dense SAND/GRAVEL)

1 **REVIEW $(N_1)_{60}$ PARAMETERS AND CHECK FOR OUTLIERS**

Point ID	Depth	$(N_1)_{60}$	PI	USCS	Check $(N_1)_{60}$ data for outliers	
					deleted	why
H-1A-81-CC	0	11		SM		
H-4-64-NW	3	9		SM		

AVERAGE	10.0
STD DEV	1.4
GEOMEAN	9.9



Depth (ft)	A	B	C
0	10.0	11.4	8.6
80	10.0	11.4	8.6

A = Average $(N_1)_{60}$

B = Average $[(N_1)_{60}$ + (STD Dev $(N_1)_{60})]$

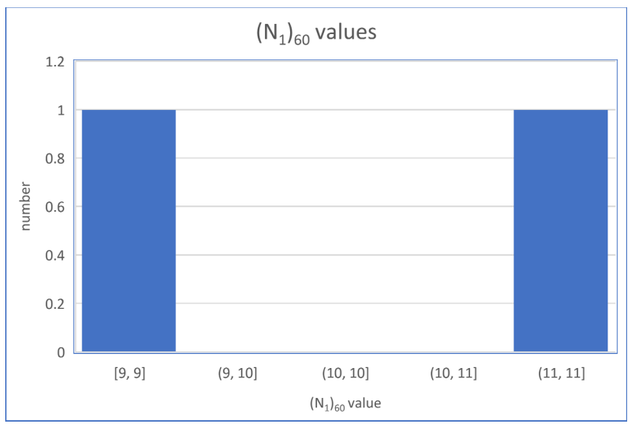
C = Average $[(N_1)_{60}$ - (STD Dev $(N_1)_{60})]$

2 **CHECK COV IS BETWEEN 15 AND 45%**

(consider revising ESU limits if outside range)

Coefficient of Variation (V) = standard deviation/average	14%
(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	15%
(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	45%

3 **PLOT HISTOGRAM AND COMPARE TO GEOMEAN VALUE**

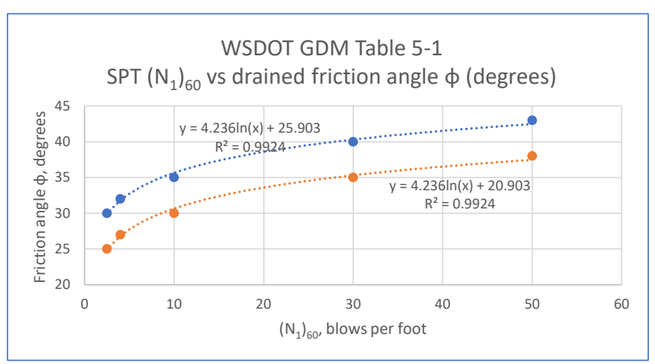


GEOMEAN	10

4 **ESTIMATE PEAK FRICTION ANGLE (deg)**

Using WSDOT correlation

$(N_1)_{60}$ (blows per foot)	Friction angle ϕ (degrees)
2.5	25
2.5	30
4	27
4	32
10	30
10	35
30	35
30	40
50	38
50	43



	$(N_1)_{60}$	ϕ (high)	ϕ (low)	ϕ (avg)
Geomean	9.9	36	31	33
Average	10.0	36	31	33
Average minus one standard deviation	8.6	35	30	33

	PEAK FRICTION ANGLE (deg)	**31**	Selected value from lower end of the range based on soil type of SM w/o tested data of fine content
5	**USCS**	SM	USE PREDOMINANT USCS CLASSIFICATION
6	**Unit Weight (pcf)**	110	USE CALTRANS, verify with CODUTO (2001) or GDM for PEAT/ ORGANICS if no measurements.

Notes:

= selected soil design properties

REFERENCES:

California Department of Transportation (Caltrans). 2014. *Geotechnical Manual.*

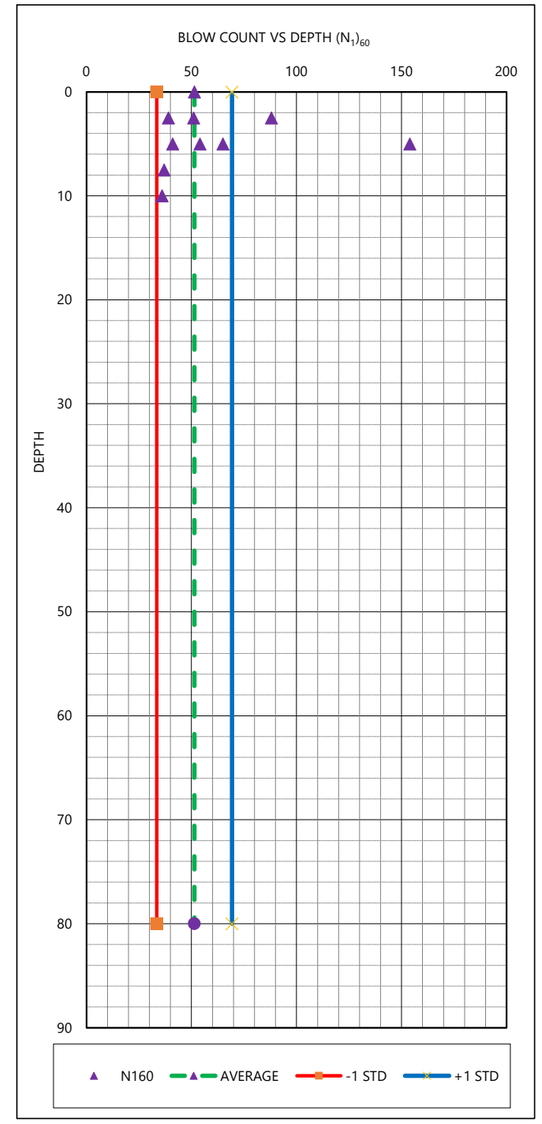
Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.

Sabatini, P.J., R.C. Bachus, P.W. Mayne, T.E. Schneider, and T. E. Zettler. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties.* FHWA-IF-02-034.

ESU #1B Fill (Medium dense to dense SAND/GRAVEL)

1	REVIEW $(N_1)_{60}$ PARAMETERS AND CHECK FOR OUTLIERS

Point ID	Depth	$(N_1)_{60}$	PI	% Fine	USCS	Check $(N_1)_{60}$ data for outliers	
						deleted	why
H-1A-81-CC	5	41			ML		
W-154-20	2.5	51			SM		
W-154-20	5	54			SM		
W-154-20	7.5	37		29.2	SM		
W-154-20	10	36			SM		
W-155-20	2.5	39			SP		
W-155-20	5	65		33.0	SM		
W-156-20	2.5	88			SM		
W-156-20	5			16.0	SM	154	Note 1
	AVERAGE	51.4		26.1			
	STD DEV	17.9					
	GEOMEAN	49.1					



Depth (ft)	A	B	C
0	51.4	69.3	33.5
80	51.4	69.3	33.5

A = Average $(N_1)_{60}$

B = Average $[(N_1)_{60}$ + (STD Dev $(N_1)_{60})]$

C = Average $[(N_1)_{60}$ - (STD Dev $(N_1)_{60})]$

Outlier Notes:

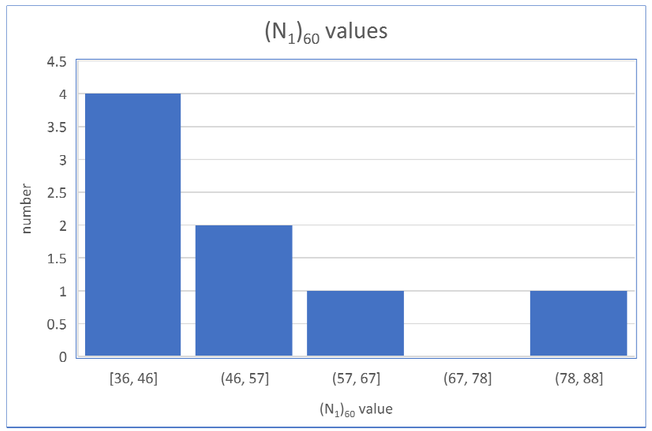
1. Maximum value removed to reduce the standard deviation, which is a conservative practice for design values.

2 **CHECK COV IS BETWEEN 15 AND 45%**

(consider revising ESU limits if outside range)

Coefficient of Variation (V) = standard deviation/average	35%
(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	15%
(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	45%

3 **PLOT HISTOGRAM AND COMPARE TO GEOMEAN VALUE**

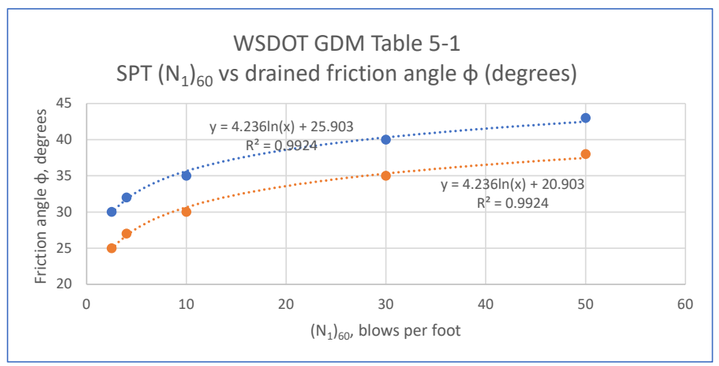


GEOMEAN	49

4 **ESTIMATE PEAK FRICTION ANGLE (deg)**

Using WSDOT correlation

$(N_1)_{60}$ (blows per foot)	Friction angle ϕ (degrees)
2.5	25
2.5	30
4	27
4	32
10	30
10	35
30	35
30	40
50	38
50	43



	$(N_1)_{60}$	ϕ (high)	ϕ (low)	ϕ (avg)
Geomean	49.1	42	37	40
Average	51.4	43	38	40
Average minus one standard deviation	33.5	41	36	38

	ESTIMATE PEAK FRICTION ANGLE (deg)	**38**	Selected value from lower end of the range plus one degree based on the average fine content
5	**USCS**	SM	USE PREDOMINANT USCS CLASSIFICATION
6	**Unit Weight (pcf)**	130	USE CALTRANS, verify with CODUTO (2001) or GDM for PEAT/ ORGANICS if no measurements.

Notes:

= selected soil design properties

REFERENCES:

California Department of Transportation (Caltrans). 2014. *Geotechnical Manual.*

Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.

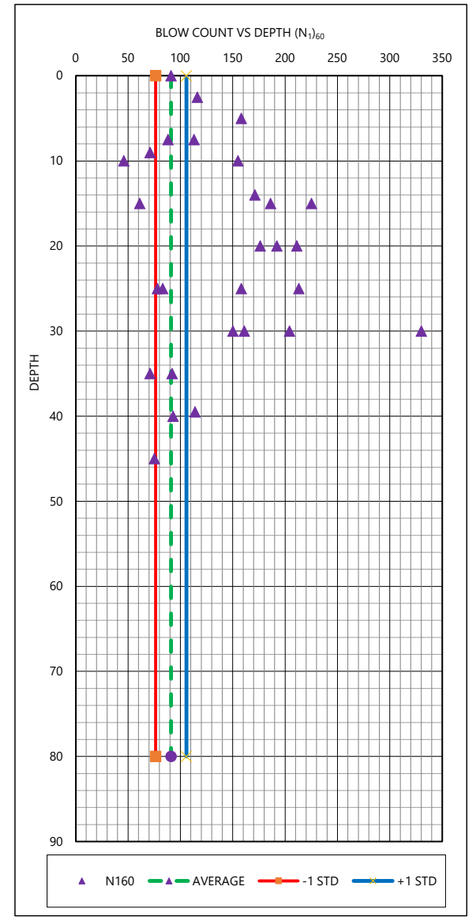
Sabatini, P.J., R.C. Bachus, P.W. Mayne, T.E. Schneider, and T. E. Zettler. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties.* FHWA-IF-02-034.

ESU #4A Advance Outwash (Dense to very dense SAND/GRAVEL)

1 **REVIEW $(N_1)_{60}$ PARAMETERS AND CHECK FOR OUTLIERS**

Point ID	Depth	$(N_1)_{60}$	PI	USCS	Check $(N_1)_{60}$ data for outliers	
					deleted	why
H-4-64-NW	9	71		GM		
H-4-64-NW	14	100		GM	171	Capped to 100
W-154-20	15	61		ML		
W-154-20	20	100		SM	192	Capped to 100
W-154-20	25	100		SM	213	Capped to 100
W-154-20	30	100		SM	204	Capped to 100
W-156-20	7.5	88		SP-SM		
W-156-20	10	46		SP-SM		
W-156-20	15	100		GP	225	Capped to 100
W-156-20	20	100		ML	211	Capped to 100
W-156-20	25	100		SM	158	Capped to 100
W-156-20	30	100		SM	150	Capped to 100
W-156-20	35	92		SM		
W-156-20	40	93		SM		
W-156-20	45	75		SM		
W-160mw-20	2.5	100		SP	116	Capped to 100
W-160mw-20	5	100		SP	158	Capped to 100
W-160mw-20	7.5	100		SP	113	Capped to 100
W-160mw-20	10	100		SP	155	Capped to 100
W-160mw-20	15	100		SP	186	Capped to 100
W-160mw-20	20	100		SM	176	Capped to 100
W-160mw-20	25	83		SP		
W-160mw-20	30	100		SP	330	Capped to 100
GEO-33	25	78		SP-SM		
GEO-33	30	100		SP-SM	161	Capped to 100
GEO-33	35	71		SP-SM		
GEO-33	39.5	100		SP-SM	114	Capped to 100

AVERAGE	**91.0**
STD DEV	**14.7**
GEOMEAN	**89.6**



Depth (ft)	A	B	C
0	91.0	105.7	76.4
80	91.0	105.7	76.4

A = Average $(N_1)_{60}$

B = Average $[(N_1)_{60}$ + (STD Dev $(N_1)_{60})]$

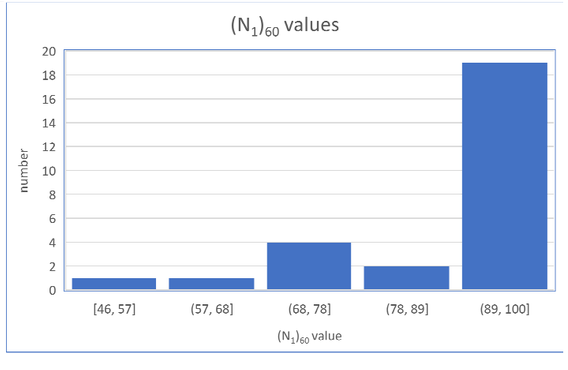
C = Average $[(N_1)_{60}$ - (STD Dev $(N_1)_{60})]$

2 **CHECK COV IS BETWEEN 15 AND 45%**

(consider revising ESU limits if outside range)

Coefficient of Variation (V) = standard deviation/average	16%
(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	15%
(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	45%

3 **PLOT HISTOGRAM AND COMPARE TO GEOMEAN VALUE**

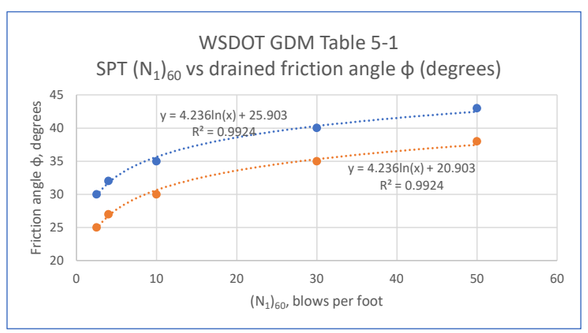


GEOMEAN	90

4 **ESTIMATE PEAK FRICTION ANGLE (deg)**

Using WSDOT correlation

$(N_1)_{60}$ (blows per foot)	Friction angle ϕ (degrees)
2.5	25
2.5	30
4	27
4	32
10	30
10	35
30	35
30	40
50	38
50	43



	$(N_1)_{60}$	ϕ (high)	ϕ (low)	ϕ (avg)
Geomean	89.6	45	40	42
Average	91.0	45	40	43
Average minus one standard deviation	76.4	44	39	42

	PEAK FRICTION ANGLE (deg)	**40**	Selected value based on varies fines content
5	**USCS**	SM	USE PREDOMINANT USCS CLASSIFICATION
6	**Unit Weight (pcf)**	130	USE CALTRANS, verify with CODUTO (2001) or GDM for PEAT/ ORGANICS if no measurements.

Notes:

= selected soil design properties

REFERENCES:

California Department of Transportation (Caltrans). 2014.*Geotechnical Manual.*

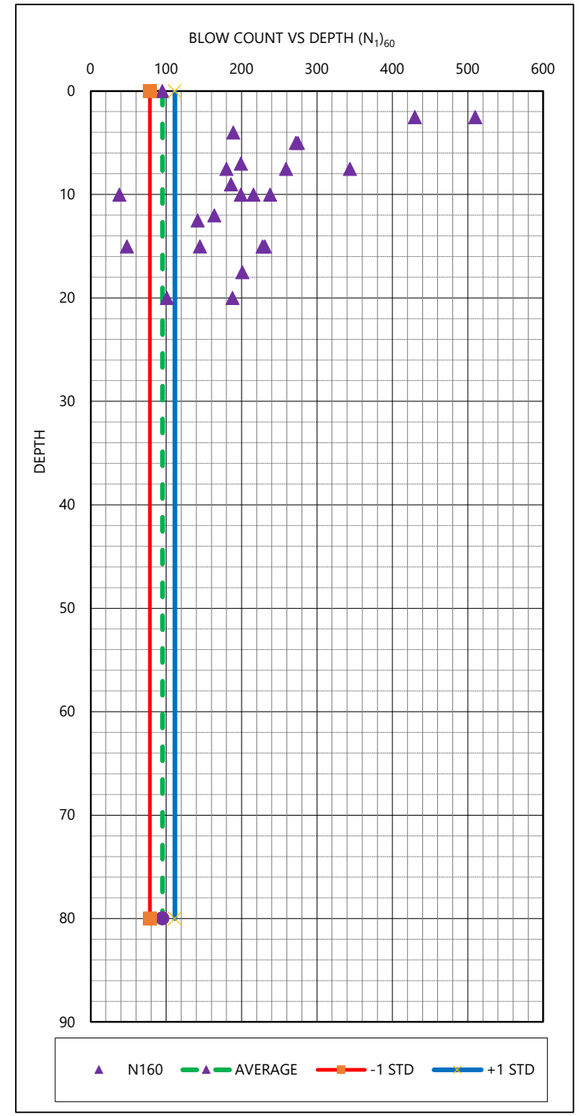
Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.

Sabatini, P.J., R.C. Bachus, P.W. Mayne, T.E. Schneider, and T. E. Zettler. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties.* FHWA-IF-02-034.

ESU #4C Glacial Till (Dense to very dense Silty SAND)

1 **REVIEW $(N_1)_{60}$ PARAMETERS AND CHECK FOR OUTLIERS**

Point ID	Depth	$(N_1)_{60}$	PI	%Fine	USCS	Check $(N_1)_{60}$ data for outliers	
						deleted	why
H-1A-81-CC	10	38			SM		
H-1A-81-CC	15	48			SM		
H-1A-81-CC	20	100			SM	101	Capped at 100
R2B-82vw-17	4	100			SM	189	Capped at 100
R2B-82vw-17	7	100			SM	199	Capped at 100
R2B-82vw-17	9	100			SM	186	Capped at 100
R2B-82vw-17	12	100			SM	164	Capped at 100
W-155-20	7.5	100			SM	180	Capped at 100
W-155-20	10	100		34.5	SM	199	Capped at 100
W-155-20	15	100			SM	228	Capped at 100
W-158-20	2.5	100			ML	430	Capped at 100
W-158-20	5	100		55.9	ML	275	Capped at 100
W-158-20	7.5	100		46.5	ML	344	Capped at 100
W-158-20	10	100			ML	216	Capped at 100
W-158-20	15	100	3	26.9	SM	231	Capped at 100
GEO-33	2.5	100			SM	510	Capped at 100
GEO-33	5	100			SM	272	Capped at 100
GEO-33	7.5	100				259	Capped at 100
GEO-33	10	100				238	Capped at 100
GEO-33	12.5	100				142	Capped at 100
GEO-33	15	100				145	Capped at 100
GEO-33	20	100			SM	188	Capped at 100
GEO-33	17.5	100			SM	201	Capped at 101
	AVERAGE	**95.0**		**41.0**			
	STD DEV	**16.5**					
	GEOMEAN	**92.9**					



Depth (ft)	A	B	C
0	95.0	111.5	78.6
80	95.0	111.5	78.6

A = Average $(N_1)_{60}$

B = Average $[(N_1)_{60}$ + (STD Dev $(N_1)_{60})]$

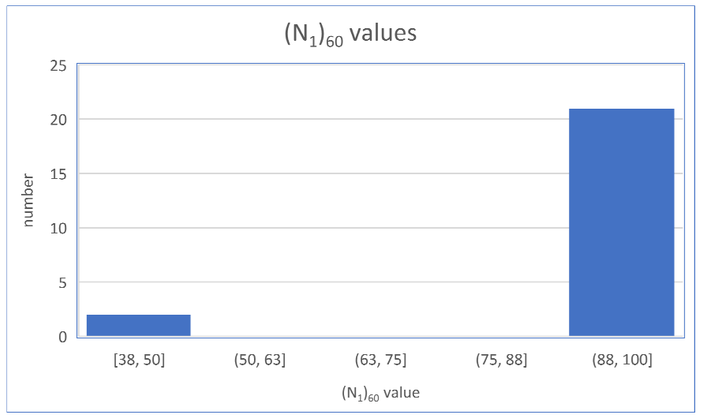
C = Average $[(N_1)_{60}$ - (STD Dev $(N_1)_{60})]$

2 **CHECK COV IS BETWEEN 15 AND 45%**

(consider revising ESU limits if outside range)

Coefficient of Variation (V) = standard deviation/average	17%
(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	15%
(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	45%

3 **PLOT HISTOGRAM AND COMPARE TO GEOMEAN VALUE**

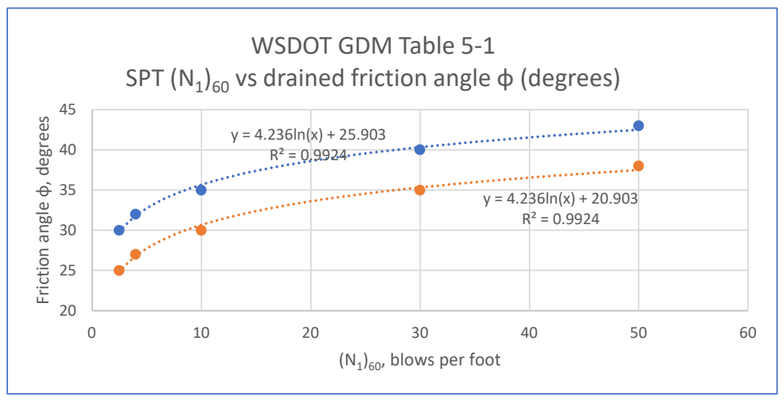


GEOMEAN	93

4 **ESTIMATE PEAK FRICTION ANGLE (deg)**

Using WSDOT correlation

$(N_1)_{60}$ (blows per foot)	Friction angle ϕ (degrees)
2.5	25
2.5	30
4	27
4	32
10	30
10	35
30	35
30	40
50	38
50	43



	$(N_1)_{60}$	ϕ (high)	ϕ (low)	ϕ (avg)
Geomean	92.9	45	40	43
Average	95.0	45	40	43
Average minus one standard deviation	78.6	44	39	42

	PEAK FRICTION ANGLE (deg)	**40**	Selected value from the low end of the range based on average fines content of 41%.
5	**USCS**	SM	USE PREDOMINANT USCS CLASSIFICATION
6	**Unit Weight (pcf)**	130	USE CALTRANS, verify with CODUTO (2001) or GDM for PEAT/ ORGANICS if no measurements.

Notes:

= selected soil design properties

REFERENCES:

California Department of Transportation (Caltrans). 2014. *Geotechnical Manual.*

Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.

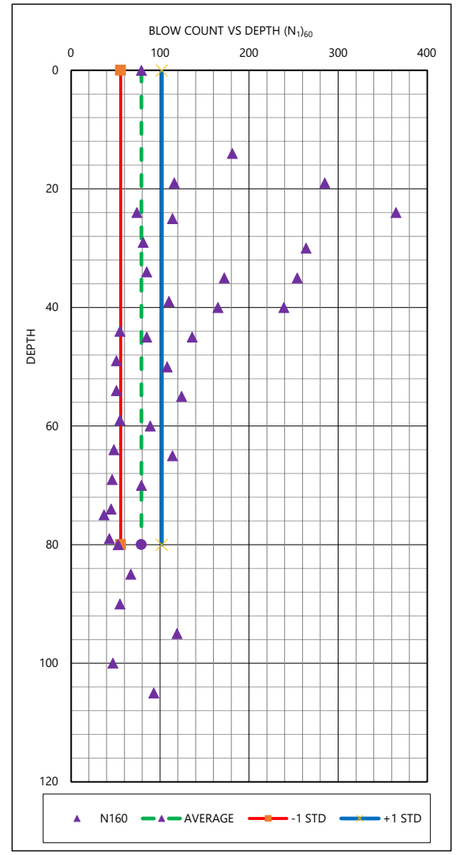
Sabatini, P.J., R.C. Bachus, P.W. Mayne, T.E. Schneider, and T. E. Zettler. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties.* FHWA-IF-02-034.

ESU #4E Glaciolacustrine Deposit (Massive SILT/CLAY)

Note: Massive - Undisturbed deposit

1 **REVIEW $(N_1)_{60}$ PARAMETERS AND CHECK FOR OUTLIERS**

Point ID	Depth	$(N_1)_{60}$	PI	USCS	Check $(N_1)_{60}$ data for outliers	
					deleted	why
H-1A-81-CC	25	100		ML	114	Capped at 100
H-1A-81-CC	30	100		ML	264	Capped at 100
H-4-64-NW	19	100		ML	285	Capped at 100
H-4-64-NW	24	100		CL-ML	365	Capped at 100
R2B-82vw-17	14	100		CL-ML	181	Capped at 100
R2B-82vw-17	19	100	7	CL-ML	116	Capped at 100
R2B-82vw-17	24	74		CL		
R2B-82vw-17	29	81	13	CL		
R2B-82vw-17	34	85		CL		
R2B-82vw-17	39	100		CL	110	Capped at 100
R2B-82vw-17	44	55		CL		
R2B-82vw-17	49	51	8	CL		
R2B-82vw-17	54	51		CL		
R2B-82vw-17	59	55		CL		
R2B-82vw-17	64	48		CL		
R2B-82vw-17	69	46		CL		
R2B-82vw-17	74	45	9	CL		
R2B-82vw-17	79	43		ML		
W-154-20	35	100		CL-ML	254	Capped at 100
W-154-20	40	100	7	CL-ML	239	Capped at 100
W-154-20	45	100		CL-ML	136	Capped at 100
W-154-20	90	55	16	CL		
W-154-20	50	100		CL-ML	108	Capped at 100
W-154-20	55	100		CL-ML	124	Capped at 100
W-154-20	60	89	18	CL		
W-154-20	65	100		CL	114	Capped at 100
W-154-20	70	79		CL		
W-154-20	75	37		CL		
W-154-20	80	53		CL		
W-154-20	85	67		CL		
W-154-20	95	100		SP	119	Capped at 100
W-154-20	100	47		CL		
W-154-20	105	93		SP		
W-160mw-20	35	100		ML	172	Capped at 100
W-160mw-20	40	100		ML	165	Capped at 100
W-160mw-20	45	85		SP		
	AVERAGE (Ip)	**78.9**	**11.1**			
	STD DEV	**23.2**				
	GEOMEAN	**75.0**				



Depth (ft)	A	B	C
0	78.9	102.1	55.6
80	78.9	102.1	55.6

A = Average $(N_1)_{60}$

B = Average $[(N_1)_{60}$ + (STD Dev $(N_1)_{60})]$

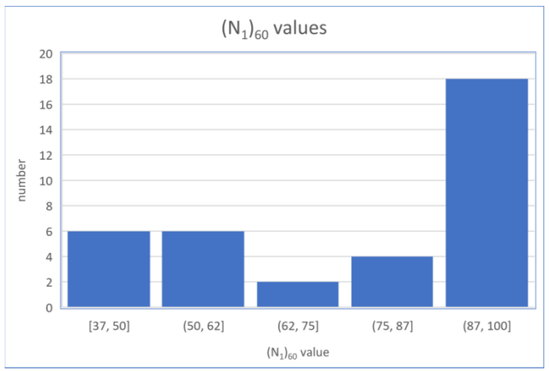
C = Average $[(N_1)_{60}$ - (STD Dev $(N_1)_{60})]$

2 **CHECK COV IS BETWEEN 15 AND 45%**

(consider revising ESU limits if outside range)

Coefficient of Variation (V) = standard deviation/average	29%
(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	15%
(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	45%

3 **PLOT HISTOGRAM AND COMPARE TO GEOMEAN VALUE**

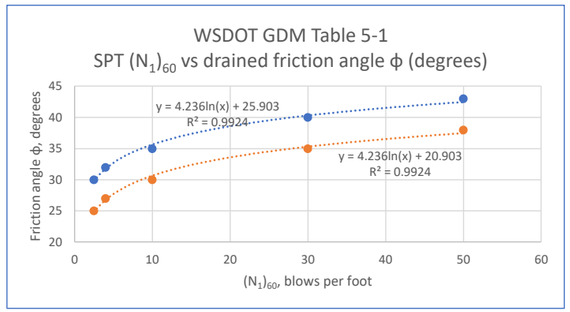


GEOMEAN	75

4 **ESTIMATE PEAK FRICTION ANGLE (deg)**

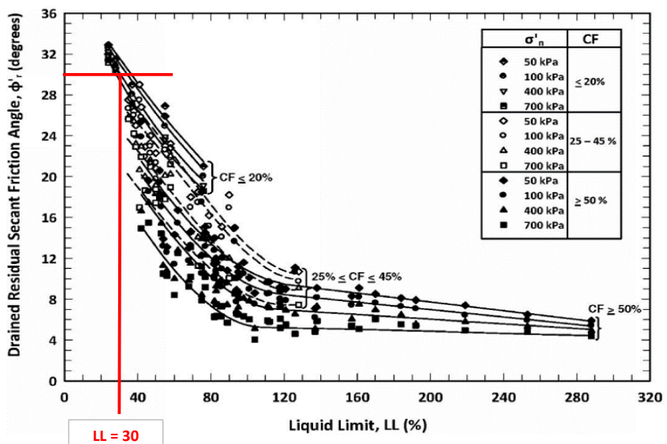
Using WSDOT correlation

$(N_1)_{60}$ (blows per foot)	Friction angle ϕ (degrees)
2.5	25
2.5	30
4	27
4	32
10	30
10	35
30	35
30	40
50	38
50	43



	$(N_1)_{60}$	ϕ (high)	ϕ (low)	ϕ (avg)
Geomean	75.0	44	39	42
Average	78.9	44	39	42
Average minus one standard deviation	55.6	43	38	40

	PEAK FRICTION ANGLE (deg)	**39**	Based on $(N_1)_{60}$, used for reference
5	**USCS**	ML/CL	USE PREDOMINANT USCS CLASSIFICATION
6	**Unit Weight (pcf)**	125	USE CALTRANS, verify with CODUTO (2001) or GDM for PEAT/ ORGANICS if no measurements.
7	**Effective Friction Angle (deg)**	**30**	Per I-405 SPM, Page 7, Line 20, Equation 4, plasticity index (Ip), 4 < Ip < 50, Phi' = 45 - 14*log(Ip), => Ip = 10
8	**Effective Cohesion (psf)**	627	Per I-405 SPM, Page 8, Line 2, Equation 6, plasticity index (Ip), 7 < Ip < 30, c' = 30 Kpa, => c' = 600 psf
9	**Estimate Residual Angle (deg)**	**30**	Per GDM, Figure 5-6 (After Stark and Hussain, 2013)



Boring	Depth	Sample	Clay Fraction (%)
R2B-82vw-17	19	D-6	20
R2B-82vw-17	29	D-8	28
R2B-82vw-17	49	D-12	11
R2B-82vw-17	74	D-17	22
		Average =	20

Correlation Between Residual Shear Strength of Overconsolidated Clays and Plasticity Index, Clay Fraction Cf, and Effective Normal Stress (After Stark and Hussain 2013)

Figure 5-6

10	**Estimate Undrained Shear Strength (psf)**	Estimated using Equation 9, Wood SPM, to assess short-term condition	Equation 9:	$s_u = f_1 N_{60} \frac{p_a}{100}$

Point ID	Sample Top Depth (ft)	USCS	N_{60}	Plasticity Index	Su (psf)	Check for Outliers	Why Removed
H-1A-81-CC	25.0	ML	125		14,514		
H-1A-81-CC	30.0	ML	315			36,663	Note 1
H-4-64-NW	19.0	ML	228			26,537	Note 1
H-4-64-NW	24.0	CL-ML	314			36,489	Note 1
R2B-82vw-17	14.0	CL-ML	151		17,610		
R2B-82vw-17	19.0	CL-ML	111	7	12,954		
R2B-82vw-17	24.0	CL	79		9,183		
R2B-82vw-17	29.0	CL	95	13	11,046		
R2B-82vw-17	34.0	CL	107		12,431		
R2B-82vw-17	39.0	CL	148		17,261		
R2B-82vw-17	44.0	CL	79		9,148		
R2B-82vw-17	49.0	CL	74	8	8,636		
R2B-82vw-17	54.0	CL	77		8,974		
R2B-82vw-17	59.0	CL	85		9,847		
R2B-82vw-17	64.0	CL	74		8,636		
R2B-82vw-17	69.0	CL	73		8,462		
R2B-82vw-17	74.0	CL	73	9	8,462		
R2B-82vw-17	79.0	ML	71		8,287		
W-154-20	35.0	CL-ML	334			38,817	Note 1
W-154-20	40.0	CL-ML	334	7		38,817	Note 1
W-154-20	45.0	CL-ML	200			23,290	Note 1
W-154-20	90.0	CL	112	16	13,001		
W-154-20	50.0	CL-ML	167		19,414		
W-154-20	55.0	CL-ML	200			23,290	Note 1
W-154-20	60.0	CL	150	18	17,470		
W-154-20	65.0	CL	200			23,290	Note 1
W-154-20	70.0	CL	143		16,691		
W-154-20	75.0	CL	68		7,961		
W-154-20	80.0	CL	102		11,837		
W-154-20	85.0	CL	133		15,527		
W-154-20	95.0	SP	250			29,110	Note 2
W-154-20	100.0	CL	100		11,651		
W-154-20	105.0	SP	200			23,290	Note 2
W-160mw-20	35.0	ML	184		21,393		
W-160mw-20	40.0	ML	184		21,393		
W-160mw-20	45.0	SP	101			11,779	Note 2

AVERAGE	**11**	**12872**
STD DEV	**4**	**4424**
GEOMEAN	**10**	**12213**
Pa =	2116	psf
F1 =	5.5	for PI < or = 15
F1 =	4.5	for PI > or = 30
F1 =	5	for PI between 15 and 30

Note: For samples where PI (lab obtained) is between 15 and 30, Wood used F1 = 5 (between 4.5 and 5.5). For samples where PI was not determined and where USCS is MH, CL, CH, used F1 = 5.

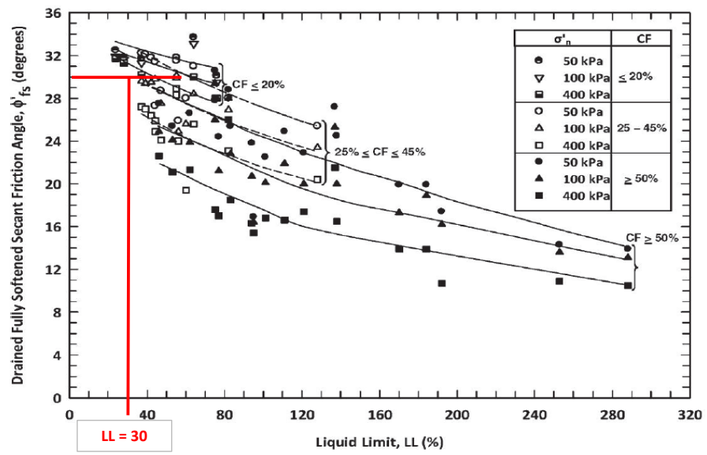
Outlier Notes:

1. Maximum values removed to reduce the standard deviation, which is a conservative practice for design values.
2. Removed SP samples from Su calculation.

11	**CHECK COV IS BETWEEN 13 AND 40%** (consider revising ESU limits if outside range)	
	Coefficient of Variation (V) = standard deviation/average	34%
	(V_{low}) from Table 52 in GEC 5 Sabatini (2002)	13%
	(V_{high}) from Table 52 in GEC 5 Sabatini (2002)	40%

12	**Selected Su**	6,000 **psf**	F1 = 5.5, Pa = 2116

13	**Estimate Fully Softened Friction Angle**	**30**	Estimated using Figure 5-7 of the GDM



Correlation Between Fully Softened Shear Strength of Overconsolidated Clays and Plasticity Index (After Stark and Hussain 2013)
Figure 5-7

Boring	Depth	Sample	Clay Fraction (%)
R2B-82vw-17	19	D-6	20
R2B-82vw-17	29	D-8	28
R2B-82vw-17	49	D-12	11
R2B-82vw-17	74	D-17	22
		Average =	20

Notes:
= final selected soil design properties

REFERENCES:

California Department of Transportation (Caltrans). 2014. *Geotechnical Manual.*
Coduto, D.P. 2001. *Foundation Design Principles and Practices.* 2nd Edition. Prentice-Hall, Inc., New Jersey.
Sabatini, P.J., R.C. Bachus, P.W. Mayne, T.E. Schneider, and T. E. Zettler. 2002. *Geotechnical Engineering Circular No. 5: Evaluation of Soil and Rock Properties.* FHWA-IF-02-034.

Project: **I-405 Renton to Bellevue Widening and Express Toll Lanes Project**

Wall 10.18R

Cross Section A–A' at Station 1+75

Elevation (feet)		Depth (feet)		Layer Depth (feet)	ESU	USCS	$(N_1)_{60}$	Ymoist (pcf)	Effective Peak ϕ' (deg)	Effective Peak c' (psf)	Fully-softened ϕ' (deg)	Su (psf)
from	to	from	to									
94.5	81.5	0	13	13	ESU 1B	SM	51	130	38	-	-	-
81.5	68.5	13	26	13	ESU 4A	SM	91	130	40	-	-	-
See cross-section for the area					ESU 4C	SM	95	130	40	-	-	-
68.5	-	26	-	-	ESU 4E	ML/CL	79	125	30	627	30	6,000

Groundwater Elevation: 33 feet (Based on highest level observed in R2B-82vw-17)

Contact elevations based on wall location of A–A' cross section

Appendix D-2
Sample Calculation of $(N_1)_{60}$

CALCULATION COVER SHEET

Project	Structure/ Location/ Segment	Wood Project No.
WSDOT I-405	May Creek Bridge	PS19-203160.032100.0001

Title
Engineering Stratigraphic Units (ESUs)

Applicable for the use of Overall Project

Computer Program (if used) Microsoft Excel	Version / Release No.

Purpose and Objective
Calculation Verification Submittals for Spreadsheet

- **For determination of Nmeasured from Nfield**
- **For determination of $(N_1)_{60}$ from Nmeasured**

Comments
Sample calculations

Revision Log

Rev. No.	Revision Description
00	Initial submittal.

Sign Off

Rev. No.	Originator (Print) Sign / Date		Reviewer (Print) Sign / Date	
00	Jim Dransfield		Kevin Burlingham	
		3/4/2020		3/20/2020

Project: I 405 R2B	Sheet 1 of 3
Project No. PS19 203160	Phase: _____ Task: _____
Calculation: NFIELD → Nm	
By: JSD	Date: 1/30/2020
Checked By: KB	Date: 3/20/20

wood.

CALCULATION VERIFICATION

INPUT NFIELD VALUES to DETERMINE N_m (measured N)

SPT N-FIELD VALUE IS TYPICALLY RECORDED AS THE NUMBER OF BLOWS N, FOR (3) 6-INCH INTERVALS.

REFERRED TO HERE AS N_1, N_2, and N_3 BLOWS

FOR DEPTH INTERVALS L_1, L_2 and L_3.

PRACTICAL REFUSAL IS 50 BLOWS FOR ANY 6-INCH INTERVAL.

CASE 1 - TYPICALLY, IF THE SAMPLE TUBE CAN BE DRIVEN THE FULL 18-INCHES,

$$N_{FIELD} = \frac{N_2 + N_3}{L_2 + L_3} = \frac{N_2 + N_3}{12}$$

FOR EXAMPLE,

SEE R2B-20-17/D-1:

SEE SHEET 3/3

$$\frac{9 + 10}{12} = \frac{19 \text{ BLOWS}}{12''} = \boxed{19 \text{ BLOWS/FOOT}}$$

CASE 2 - IF ONLY ABLE TO DRIVE SAMPLER > 12" BUT < 18"

$$N_{FIELD} = \frac{N_2 + N_3}{\left[\frac{(L_2 + L_3)}{12}\right]}$$

IF FOR EXAMPLE $N_2 = 42$ $L_2 = 6$

SEE R2B-21-17/D-12:

$N_3 = 50$ $L_3 = 4$

$$N_{FIELD} = \frac{43 + 50}{\left[\frac{10}{12}\right] \text{inches}} = 93 \times \left[\frac{12}{10}\right] = \boxed{112 \text{ BLOWS/FOOT}} = N_m$$

CASE 3 - IF ONLY ABLE TO DRIVE SAMPLER 12 INCHES

$$N_{FIELD} = \frac{N_2}{\left[\frac{L_2}{12}\right]}$$

IF FOR EXAMPLE $N_1 = 41$ $L_1 = 6$

SEE R2B-20-17/D-16:

$N_2 = 50$ $L_2 = 6$

(NO N_3) $L_3 = 0$

$$N_{FIELD} = \frac{50}{\left[\frac{6}{12}\right]} = 50 \times \frac{12}{6} = \boxed{100 \text{ BLOWS/FOOT}} = N_m$$

Project: I 405 R2B	Sheet 2 of 3
Project No. PS19 203160	Phase: ____ Task: ____
Calculation: NFIELD → Nm	
By: JSD	Date: 1/30/2020
Checked By: KB	Date: 3/20/20

wood.

CASE 4 IF ONLY ABLE TO DRIVE SAMPLER >6" BUT <12"

SAY $N_1 = 24$ $L_1 = 6$

SEE R2B-20-17/D-15

$N_2 = 50$ $L_2 = 4$

$N_3 = -$ $L_3 = -$

$$N_{FIELD} = \frac{N_2}{\left[\frac{L_2}{12}\right]} = N_2\left[\frac{12}{L_2}\right]$$

$$= 50\left[\frac{12}{4}\right] = \boxed{150 \text{ BLOWS/FOOT}}$$

CASE 5 IF ONLY ABLE TO DRIVE SAMPLER 6 INCHES

SAY $N_1 = 50$ $L_1 = 6$

$N_2 = -$ $L_2 = -$

SEE R2B-21-17/D-17

$N_3 = -$ $L_3 = -$

$$N_{FIELD} = \frac{50}{\left[\frac{6}{12}\right]} = 50\left[\frac{12}{6}\right] = 50[2] = \boxed{100 \text{ BLOWS/FT}}$$

$= N_m$

CASE 6 IF ONLY ABLE TO DRIVE SAMPLER <6"

SAY $N_1 = 50$ $L_1 = 5$

SEE R2B-22vw-17 Sample D-12

$N_2 = -$ $L_2 = -$

$N_3 = -$ $L_3 = -$

$$N_{FIELD} = \frac{50}{\left[\frac{5}{12}\right]} = 50\left[\frac{12}{5}\right] = 50[2.4] = \boxed{120 \text{ BLOWS/FT}}$$

$= N_m$

WSDOT I-405 R2B DESIGN BUILD

CALCULATION VERIFICATION FOR $N_{FIELD} \rightarrow N_M$

Sheet 3/3

	PointID	Top Depth (ft)	Sample Number	N FIELD BlowCounts1	BlowCounts2	BlowCounts3	Length1	Length2	Length3	N_M
1	R2B-20-17	4	D-1	9	9	10	6	6	6	19
	R2B-20-17	7	D-2	7	10	12	6	6	6	22
	R2B-20-17	9	D-3	2	8	16	6	6	6	24
	R2B-20-17	12	D-4	9	7	7	6	6	6	14
	R2B-20-17	14	D-5	3	6	8	6	6	6	14
	R2B-20-17	19	D-6	9	10	11	6	6	6	21
	R2B-20-17	24	D-7	7	11	11	6	6	6	22
	R2B-20-17	29	D-8	10	9	10	6	6	6	19
	R2B-20-17	34	D-9	7	9	9	6	6	6	18
	R2B-20-17	39	D-10	2	2	4	6	6	6	6
	R2B-20-17	44	D-11	24	30	27	6	6	6	57
	R2B-20-17	49	D-12	26	26	50	6	6	6	76
	R2B-20-17	54	D-13	11	17	20	6	6	6	37
	R2B-20-17	59	D-14	25	36	47	6	6	6	83
4	R2B-20-17	69	D-15	24	50		6	4		150
3	R2B-20-17	79	D-16	41	50		6	6		100
	R2B-20-17	89	D-17	41	50		6	5		120
	R2B-20-17	99	D-18	50			6			100
	R2B-21-17	4	D-1	6	3	3	6	6	6	6
	R2B-21-17	7	D-2	3	2	1	6	6	6	3
	R2B-21-17	9	D-3	6	5	5	6	6	6	10
	R2B-21-17	12	D-4	1	1	1	6	6	6	2
	R2B-21-17	14	D-5	3	7	8	6	6	6	15
	R2B-21-17	19	D-6	10	12	15	6	6	6	27
	R2B-21-17	24	D-7	11	15	15	6	6	6	30
	R2B-21-17	29	D-8	22	50		6	2		300
	R2B-21-17	34	D-9	26	32	33	6	6	6	65
	R2B-21-17	39	D-10	31	50		6	6		100
	R2B-21-17	44	D-11	31	50		6	6		100
2	R2B-21-17	49	D-12	33	43	50	6	6	4	112
	R2B-21-17	54	D-13	39	42	47	6	6	6	89
	R2B-21-17	59	D-14	33	42	50	6	6	4	110
	R2B-21-17	64	D-15	35	50		6	5		120
	R2B-21-17	69	D-16	41	50		6	6		100
5	R2B-21-17	74	D-17	50			6			100
	R2B-22vw-17	4	D-1	6	9	10	6	6	6	19
	R2B-22vw-17	7	D-2	7	7	9	6	6	6	16
	R2B-22vw-17	9	D-3	3	4	5	6	6	6	9
	R2B-22vw-17	12	D-4	5	7	7	6	6	6	14
	R2B-22vw-17	14	D-5	5	5	5	6	6	6	10
	R2B-22vw-17	19	D-6	7	11	11	6	6	6	22
	R2B-22vw-17	24	D-7	10	11	17	6	6	6	28
	R2B-22vw-17	29	D-8	2	1	2	6	6	6	3
	R2B-22vw-17	34	D-9	3	5	5	6	6	6	10
	R2B-22vw-17	39	D-10	9	19	22	6	6	6	41
	R2B-22vw-17	44	D-11	24	27	20	6	6	6	47
6	R2B-22vw-17	49	D-12	50			5			120
	R2B-22vw-17	54	D-13	27	36	50	6	6	3	115
	R2B-22vw-17	59	D-14	50			6			100
	R2B-22vw-17	64	D-15	44	50		6	4		150

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Calculation: NFIELD → $(N_1)_{60}$	
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Checked By: KB	Date: 3/20/20

wood.

CALCULATION VERIFICATION SUBMITTAL, OF SPREADSHEET USED TO CALCULATE $(N)_{60}$ AND $(N_1)_{60}$ FROM $(N)_{FIELD} = (N_m)$

GDM Section 5.5 references Youd & Idriss (1997)

$$(N)_{60} = N_m \cdot C_E \cdot C_B \cdot C_R \cdot C_S$$

and $$(N_1)_{60} = C_N \cdot (N)_{60}$$

TABLE 2. Corrections to SPT (Modified from Skempton 1986) as Listed by Robertson and Wride (1998)

Factor	Equipment variable	Term	Correction
Overburden pressure	—	C_N	$(P_a/\sigma'_{vo})^{0.5}$
Overburden pressure	—	C_N	$C_N \leq 1.7$
Energy ratio	Donut hammer	C_E	~~0.5–1.0~~
Energy ratio	Safety hammer	C_E	~~0.7–1.2~~
Energy ratio	Automatic-trip Donut-type hammer	C_E	~~0.8–1.3~~
Borehole diameter	65–115 mm (2.5–4.5 in.)	C_B	1.0
Borehole diameter	150 mm (6 in.)	C_B	1.05
Borehole diameter	200 mm (8 in.)	C_B	1.15
Rod length	<3 m (<10 ft.)	C_R	0.75
Rod length	3–4 m (10–13 ft)	C_R	0.8
Rod length	4–6 m (13–20 ft)	C_R	0.85
Rod length	6–10 m (20–33 ft)	C_R	0.95
Rod length	10–30 m (33–100 ft)	C_R	1.0
Sampling method	Standard sampler	C_S	1.0
Sampling method	Sampler without liners	C_S	1.1–1.3

PER GDM, $C_E = ER/60\%$
ER = measured hammer efficiency
or ER = 60% rope & cathead
ER = 80% automatic trip hammer

A FURTHER REFINEMENT OF C_N IS EQ 39 FROM IDRISS & BOULANGER (2008) FOR THE RELATIVE DENSITY-DEPENDENT C_N

$$C_N = \left(\frac{P_a}{\sigma'_{vc}}\right)^{0.784-0.0768\sqrt{(N_1)_{60}}} \leq 1.7 \qquad (39)$$

with $(N_1)_{60}$ limited to values ≤ 46 for use in this expression

(σ'_{vc} in Idriss & Boulanger (2008) = total vertical effective stress $= \sigma_v'$)

Project: 405 R 213	Sheet 2 of 7
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Calculation: N FIELD → (N1)60	
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wood.

SPREADSHEET OPERATIONS (SEE SHEET 7/7)

COL #	INPUT	/ COMMENTS	
A	BORING NUMBER		
B	TOP DEPTH (FT)		
C	N FIELD		
D	SAMPLER TYPE	"SPT" or "m"	
E	SPACE FOR LINERS, BUT DID NOT USE	(Y/N)	
F	BOREHOLE DIAMETER (INCHES)		
G	CR	ROD CORRECTION FACTOR	SAMPLE DEPTH + 5 FEET = ROD LENGTH. ≥10, CR = 0.75 >13 CR = 0.85 >20 CR = 0.95 >33 CR = 1.0
H	Cs 1	IF D = "SPT" or "m", Cs = 1	Cs = 1.0 FOR SPT, m
I	Cs 2	IF E = "n", Cs = 1.2	Cs = 1.0 for standard samplers Cs = 1.2 if no liners were used in a sampler that was supposed to have liners.
J	ER (%)	Input measured value, otherwise assume ER = 60%	
K	CE	$C_E = \frac{J}{60}$	$C_E = \frac{ER(\%)}{60\%}$
L	CB	correction based on boring dia F (SEE TABLE 2)	
M	N60	$N_{60} = E \cdot K \cdot L \cdot G \cdot H \cdot I = N_{FIELD} \cdot C_E \cdot C_B \cdot C_R \cdot C_{s_1} \cdot C_{s_2}$	
N	groundwater depth (ft)		
O	γ	Average Unit weight (pcf)	SELECT BASED ON CODUTO (2011) TABLE (see next page) USCS ESTIMATED BASED ON LAB OR VISUAL

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Project No. PS192031 60	Phase: _____ Task: _____
Calculation: NFIELD → $(N_1)_{60}$	
By: JSD	Date: 3/4/2020
Checked By: KB	Date: 3/20/20

wood.

CHECK UNIT WEIGHTS AGAINST CODUTO (2001)

TABLE 3.2 TYPICAL UNIT WEIGHTS

Soil Type and Unified Soil Classification (See Figure 3.3)	Typical Unit Weight, γ: Above Groundwater Table (lb/ft³)	Above Groundwater Table (kN/m³)	Below Groundwater Table (lb/ft³)	Below Groundwater Table (kN/m³)
GP—Poorly-graded gravel	110–130	17.5–20.5	125–140	19.5–22.0
GW—Well-graded gravel	110–140	17.5–22.0	125–150	19.5–23.5
GM—Silty gravel	100–130	16.0–20.5	125–140	19.5–22.0
GC—Clayey gravel	100–130	16.0–20.5	125–140	19.5–22.0
SP—Poorly-graded sand	95–125	15.0–19.5	120–135	19.0–21.0
SW—Well-graded sand	95–135	15.0–21.0	120–145	19.0–23.0
SM—Silty sand	80–135	12.5–21.0	110–140	17.5–22.0
SC—Clayey sand	85–130	13.5–20.5	110–135	17.5–21.0
ML—Low plasticity silt	75–110	11.5–17.5	80–130	12.5–20.5
MH—High plasticity silt	75–110	11.5–17.5	75–130	11.5–20.5
CL—Low plasticity clay	80–110	12.5–17.5	75–130	11.5–20.5
CH—High plasticity clay	80–110	12.5–17.5	70–125	11.0–19.5

CHECK UNIT WEIGHTS AGAINST CODUTO (2001)

	Above GW			Below GW		
USCS	Min (pcf)	Max (pcf)	Ave	Min (pcf)	Max (pcf)	Ave
GP	110	130	120	125	140	133
GW	110	140	125	125	150	138
GM	100	130	115	125	140	133
GC	100	130	115	125	140	133
SP	95	125	110	120	135	128
SW	95	135	115	120	145	133
SM	80	135	108	110	140	125
SC	85	130	108	110	135	123
ML	75	110	93	80	130	105
MH	75	110	93	75	130	103
CL	80	110	95	75	130	103
CH	80	110	95	70	125	98

Project: 405	Sheet 4 of 7
Project No.	Phase: Task:
Calculation: $N_{FIELD} \rightarrow (N_1)_{60-CS}$	
By: JSD	Date: 3/4/2020
Checked By: KB	Date: 3/20/20

wood.

COL # INPUT / COMMENTS

(P) $\boxed{\sigma_v}$ TOTAL OVERBURDEN STRESS (FOR EACH DEPTH INTERVAL) = (O) x (B) (FOR EACH DEPTH INTERVAL) (THEN SUMMED FOR σ_v cumulative)

(Q) $\boxed{\sigma_v'}$ EFFECTIVE OVERBURDEN STRESS (FOR EACH DEPTH INTERVAL)

IF (N) < (B), $\left[(P) - ((B)-(N)) \cdot 62.4\right]$

IF NOT, → (THEN SUMMED FOR σ_v' CUMULATIVE)

(R) $$\boxed{C_N} = \left(\frac{P_{atmospheric}}{\sigma_v'}\right)^{0.5} \leq 1.7 = \left(\frac{2116\ psf}{\sigma_v'}\right)^{0.5} \leq 1.7$$

(S) $(N_1)_{60}$ = (M) x (R) $= (N_{60} \times C_N)$

(T) Limit $(N_1)_{60}$ to ≤ 46 for following calculation:

(U) $$C_N\,(refined) = \left(\frac{P_{atm}}{\sigma_v'}\right)^{0.784 - 0.0768\sqrt{(N_1)_{60}}}$$

σ_{vc}' in Idriss & Boulanger (2008) = total vertical effective stress $= \sigma_v'$

(V) $(N_1)_{60}$ Refined $= (N_{60} \times C_N\,(refined))$

ITERATE: RECALCULATE C_N(Refined) USING RESULTING VALUE OF $(N_1)_{60}$ UNTIL VALUES CONVERGE.

(W) ESTIMATED USCS CLASSIFICATION (BASED ON EITHER LAB TESTING, WHERE AVAILABLE; OR VISUAL CLASSIFICATION REPORTED ON BORING LOGS)

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Calculation: N FIELD → (N1)60	
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wood.

EXAMPLE CALCULATION:

ROW 8

(A) R2B-20-17

(B) Depth (top) = 12 ft

(C) N = 14

(D) sampler type = SPT

(E) space for liners, did not use? NO (standard sampler)

(F) Borehole DIA = 4 inches

(G) CR ROD LENGTH IS [TOP DEPTH + 5 ft] = 12 + 5 = 17 ft (>13 ft) ∴ $C_R = 0.85$

(H) C_{S_1} for SPT = 1.0

(I) C_{S_2} for standard sampler = 1.0

(J) ER% = 87.1%

(K) $C_E = ER/60 = 87.1/60 = 1.45$

(L) C_B: for Borehole dia = 4 inches, $C_B = 1.0$

(M) $N_{60} = (C) \times (K) \times (L) \times (G) \times (H) \times (I) = 14 \times 1.45 \times 1.0 \times 0.85 \times 1.0 \times 1.0$

$N_{60} = 17.3 = 17$

(N) gw depth = 23 ft

(O) γ = unit weight. USCS = SM

sample @ 12 ft is above gw table @ 23 ft

By Table 3.2 (coduto) γ = 80 – 135 pcf

ave γ = 108 pcf

(P) σ_v = (Depth interval from previous sample × unit weight) + σ_v above

$[(12-9) \times 108] + 1035$

$324 + 1035 = 1359$ psf

(Q) σ'_v since above groundwater table, no correction = 1359 psf

(R) $C_N = \left(\frac{P_{atm}}{\sigma'_{v_0}}\right)^{0.5} = \left(\frac{2116}{1359}\right)^{0.5} = 1.248 = 1.2$

(S) $(N_1)_{60} = N_{60} \times C_N$ = 17

$17.3 \times 1.248 = 21.59 = 22$

(T) $(N_1)_{60} \doteq 46 = 22$

Project: I 405 R2B	Sheet 6 of 7
Project No. PS19 203160	Phase: _____ Task: _____
Calculation: N FIELD → $(N_1)_{60}$	
By: JSD	Date: 3/4/2020
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wood.

(u) C_N Refined $= \left(\frac{2116}{1359}\right)^{0.784 - 0.0768\sqrt{22}}$

$= (1.557)^{0.424}$

$= 1.207$

(v) $(N_1)_{60}$ refined $= N_{60} \times C_{N\,Refined} = 17.3 \times 1.207$

$(N_1)_{60\,Refined} = 21 = (20.873)$

ITERATE:

(u1) $C_{N\,Refined\,(1)} = \left(\frac{2116}{1359}\right)^{0.784 - 0.0768\sqrt{20.873}}$

$= (1.557)^{0.433}$

$= 1.211$

(v1) $(N_1)_{60\,refined\,(1)} = N_{60} \times C_{N\,Ref\,(1)} = 17.3 \times 1.211 = 20.957$

$= 21$

(u2) $C_{N\,Ref\,(2)} = (1.557)^{0.784 - 0.0768\sqrt{20.957}}$

$= (1.557)^{0.432}$

$= 1.211$

(v2) $(N_1)_{60\,refined\,(2)} = N_{60} \times C_{N\,ref\,(2)} = 17.3 \times 1.211 = 20.957 = 21$

(w) = USCS (BASED ON LAB TESTING IF AVAILABLE; OTHERWISE BASED ON VISUAL DESCRIPTION). IN THIS CASE, LAB. ⇒ SM

A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Parameter	Value	Units	Notes																			
Boring Number	Sample Depth (ft)	Field Blowcounts	Sampler Type (spt = standard penetrometer w/ 1.375-inch I.D., m = Modified California	Samplers Have Space for Liners But didn't Use? (y/n)	Borehole Diameter (in)	C_R, Rod Length Correction Factor	C_s, Sampling Method Correction Factor	C_S, Correction for Sampler without Liners	Hammer efficiency (%)	C_E, Energy Ratio Correction	B_E, Boring Dia Correction	N_{60}, Blowcount Corrected for All Factors except Overburden	Groundwater Depth (ft)	Avg Unit Wt of Sample (pcf) [or corrleation based on Coduto and USCS info or GDM for Peats]	Total Overburden Stress (psf)	Effective Overburden Stress (psf)	C_N, Overburden Correction (Eq 41, Idriss Boulanger, 2008) = (pa/σvo')^0.5	$(N_1)_{60}$, Corrected Blowcount for All Factors	Limit $(N_1)_{60}$ to 46	C_N, Overburden Correction (Eq 39, Idriss Boulanger, 2008) = f(N1)60	$(N_1)_{60}$, Corrected Blowcount for All Factors refined for relative density	Estimated USCS Classification
Boring Number	Top Depth (ft)	N	Sampler Type	(y/n)		C_R	C_s	C_S	ER(%)	C_E	C_B	N_{60}	gwt (ft)	γ (pcf)	σ (psf)	σ' (psf)	C_N	$(N_1)_{60}$	Limit $(N_1)_{60}$ to 46	C_N refined	$(N_1)_{60}$ refined	USCS
R2B-20-17	4.0	19	SPT	n	4	0.75	1	1.0	87.1	1.45	1.00	21	23	115	460.0	460.0	1.7	35	35	1.7	34	SW
R2B-20-17	7.0	22	SPT	n	4	0.8	1	1.0	87.1	1.45	1.00	26	23	115	805.0	805.0	1.6	41	41	1.3	34	SW
R2B-20-17	9.0	24	SPT	n	4	0.85	1	1.0	87.1	1.45	1.00	30	23	115	1035.0	1035.0	1.4	42	42	1.2	36	SW
== > R2B-20-17	12.0	14	SPT	n	4	0.85	1	1.0	87.1	1.45	1.00	17	23	108	1359.0	1359.0	1.2	22	22	1.2	21	SM
R2B-20-17	14.0	14	SPT	n	4	0.85	1	1.0	87.1	1.45	1.00	17	23	108	1575.0	1575.0	1.2	20	20	1.1	20	SM
R2B-20-17	19.0	21	SPT	n	4	0.95	1	1.0	87.1	1.45	1.00	29	23	108	2115.0	2115.0	1.0	29	29	1.0	29	SM
R2B-20-17	24.0	22	SPT	n	4	0.95	1	1.0	87.1	1.45	1.00	30	23	125	2740.0	2677.6	0.9	27	27	0.9	28	SM
R2B-20-17	29.0	19	SPT	n	4	1	1	1.0	87.1	1.45	1.00	28	23	125	3365.0	2990.6	0.8	23	23	0.9	24	SM
R2B-20-17	34.0	18	SPT	n	4	1	1	1.0	87.1	1.45	1.00	26	23	125	3990.0	3303.6	0.8	21	21	0.8	22	SM
R2B-20-17	39.0	6	SPT	n	4	1	1	1.0	87.1	1.45	1.00	9	23	105	4515.0	3516.6	0.8	7	7	0.7	6	ML
R2B-20-17	44.0	57	SPT	n	4	1	1	1.0	87.1	1.45	1.00	83	23	133	5180.0	3869.6	0.7	61	46	0.9	71	GM
R2B-20-17	49.0	76	SPT	n	4	1	1	1.0	87.1	1.45	1.00	110	23	133	5845.0	4222.6	0.7	78	46	0.8	92	GM
R2B-20-17	54.0	37	SPT	n	4	1	1	1.0	87.1	1.45	1.00	54	23	133	6510.0	4575.6	0.7	37	37	0.8	42	GM
R2B-20-17	59.0	83	SPT	n	4	1	1	1.0	87.1	1.45	1.00	121	23	105	7035.0	4788.6	0.7	80	46	0.8	97	ML
R2B-20-17	69.0	150	SPT	n	4	1	1	1.0	87.1	1.45	1.00	218	23	105	8085.0	5214.6	0.6	139	46	0.8	172	ML
R2B-20-17	79.0	100	SPT	n	4	1	1	1.0	87.1	1.45	1.00	145	23	125	9335.0	5840.6	0.6	87	46	0.8	111	SM
R2B-20-17	89.0	120	SPT	n	4	1	1	1.0	87.1	1.45	1.00	174	23	125	10585.0	6466.6	0.6	100	46	0.7	130	SM
R2B-20-17	99.0	100	SPT	n	4	1	1	1.0	87.1	1.45	1.00	145	23	125	11835.0	7092.6	0.5	79	46	0.7	106	SM
R2B-21-17	4.0	6	SPT	n	4	0.75	1	1.0	88.4	1.47	1.00	7	8	108	432.0	432.0	1.7	11	11	1.7	11	SM
R2B-21-17	7.0	3	SPT	n	4	0.8	1	1.0	88.4	1.47	1.00	4	8	80	672.0	672.0	1.7	6	6	1.7	6	OL-PT
R2B-21-17	9.0	10	SPT	n	4	0.85	1	1.0	88.4	1.47	1.00	13	8	125	922.0	859.6	1.6	20	20	1.5	19	SM
R2B-21-17	12.0	2	SPT	n	4	0.85	1	1.0	88.4	1.47	1.00	3	8	80	1162.0	912.4	1.5	4	4	1.7	4	OL-PT
R2B-21-17	14.0	15	SPT	n	4	0.85	1	1.0	88.4	1.47	1.00	19	8	128	1418.0	1043.6	1.4	27	27	1.3	25	SP
R2B-21-17	19.0	27	SPT	n	4	0.95	1	1.0	88.4	1.47	1.00	38	8	133	2083.0	1396.6	1.2	47	46	1.1	42	SW
R2B-21-17	24.0	30	SPT	n	4	0.95	1	1.0	88.4	1.47	1.00	42	8	138	2773.0	1774.6	1.1	46	46	1.0	44	GW
R2B-21-17	29.0	300	SPT	n	4	1	1	1.0	88.4	1.47	1.00	442	8	138	3463.0	2152.6	1.0	438	46	1.0	440	GW
R2B-21-17	34.0	65	SPT	n	4	1	1	1.0	88.4	1.47	1.00	96	8	128	4103.0	2480.6	0.9	88	46	1.0	92	SP-SM
R2B-21-17	39.0	100	SPT	n	4	1	1	1.0	88.4	1.47	1.00	147	8	128	4743.0	2808.6	0.9	128	46	0.9	137	SP-SM
R2B-21-17	44.0	100	SPT	n	4	1	1	1.0	88.4	1.47	1.00	147	8	128	5383.0	3136.6	0.8	121	46	0.9	133	SP-SM
R2B-21-17	49.0	112	SPT	n	4	1	1	1.0	88.4	1.47	1.00	165	8	128	6023.0	3464.6	0.8	129	46	0.9	145	SP-SM
R2B-21-17	54.0	89	SPT	n	4	1	1	1.0	88.4	1.47	1.00	131	8	128	6663.0	3792.6	0.7	98	46	0.9	112	SP-SM
R2B-21-17	59.0	110	SPT	n	4	1	1	1.0	88.4	1.47	1.00	162	8	128	7303.0	4120.6	0.7	116	46	0.8	136	SP-SM
R2B-21-17	64.0	120	SPT	n	4	1	1	1.0	88.4	1.47	1.00	177	8	128	7943.0	4448.6	0.7	122	46	0.8	145	SP-SM
R2B-21-17	69.0	100	SPT	n	4	1	1	1.0	88.4	1.47	1.00	147	8	128	8583.0	4776.6	0.7	98	46	0.8	119	SP-SM
R2B-21-17	74.0	100	SPT	n	4	1	1	1.0	88.4	1.47	1.00	147	8	128	9223.0	5104.6	0.6	95	46	0.8	117	SP-SM

In Association with

Appendix E
Calculation Packages

Contents

Appendix E-1 Seismic Hazard Calculations

Appendix E-2 Global, Compound, and External Stability Calculations

Appendix E-3 Settlement Calculations

In Association with

Appendix E-1
Seismic Hazard Calculations

CALCULATION COVER SHEET

Project	Structure/ Location/ Segment	Wood Project No.
WSDOT I-405	Project Alignment	PS19-203160.032100.0001

Title
Seismic Hazard

Computer Program (if used) Microsoft Excel, BridgeLink (SPECTRA)	Version / Release No.

Purpose and Objective
Evaluate seismic design parameters for Segments 1A to 2B for the project for all likely site classes and seismic performance objective levels of hazard.

Comments

Revision Log

Rev. No.	Revision Description
00	Initial submittal.

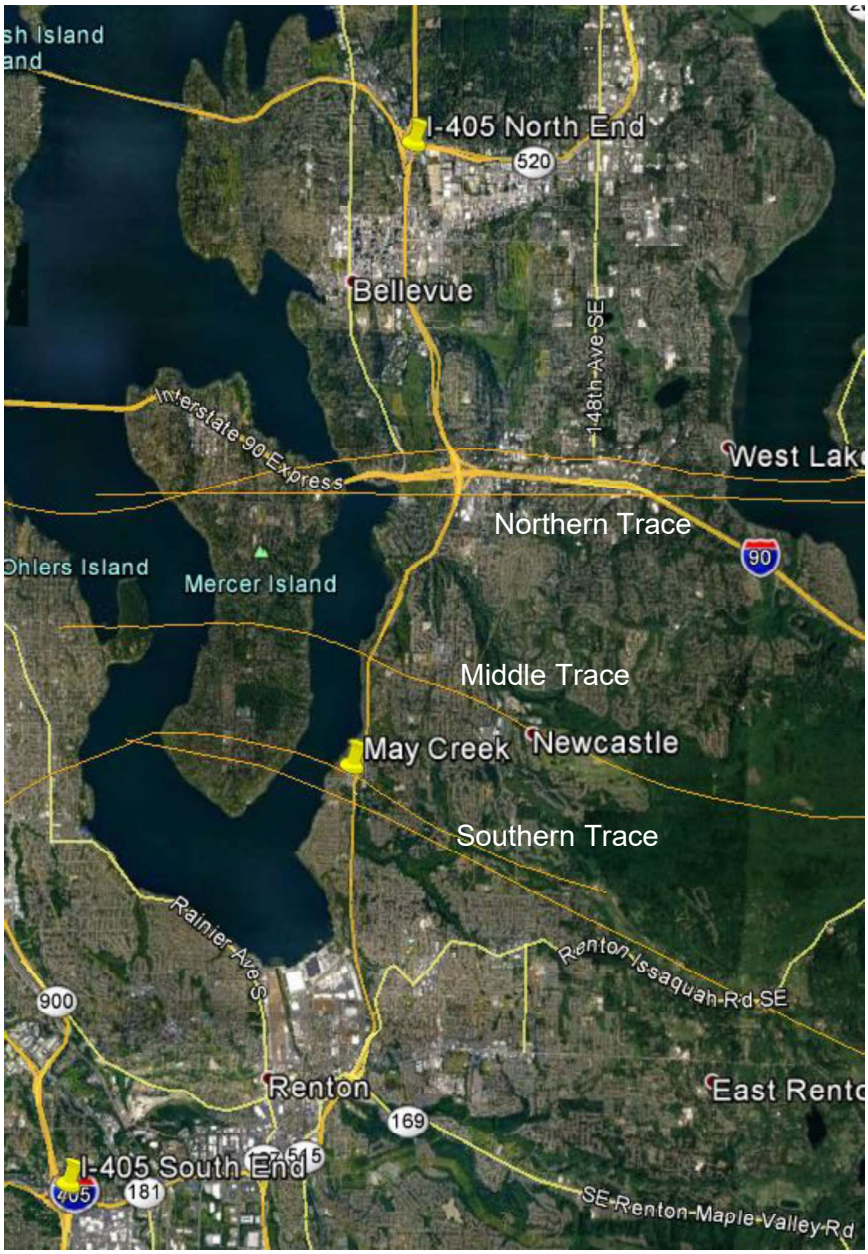
Sign Off

Rev. No.	Originator (Print) Sign / Date		Reviewer (Print) Sign / Date	
00	Kevin Burlingham		James French	
	K B	3/30/2020	James B French	3/31/2020

1.0 Background:

Wood is providing geotechnical engineering services for the I-405 improvements project. Below is an image of the alignment with the southern and northern ends marked and also the location of the bridge crossing at May Creek. Also shown are fault traces that cross the alignment for the Seattle fault (northern, middle, and southern traces).

Figure 1: Project Alignment with Fault Traces



The project is broken down into 5 segments (1A, 1B, 2A, 2B, and 2C). The geotechnical design for Segment 2C is being perfromed by Hart Crowser and so is not covered in this calculation. Below is a summary of the segments covered in this calculation.

Table 1: Project Segments Covered in this Calculation

Segment	Approximate Mile Range	Brief Description
1A	0-6.0	Southern end at intersection with I-5 up to Lake Washington near 24th St
1B	6.0-8.5	Southern end of Lake Washington near 24th St up to near 64th St
2A	8.5-10.0	Near 64th St up to where I-405 diverges from Lake Washington near 46th St
2B	10.0-12.0	Centered on intersection with I-90, from near 46th St up to near 22nd St

2.0 Problem:

Evaluate seismic design parameters for Segments 1A to 2B for the project for all likely site classes and seismic performance objective levels of hazard.

3.0 Approach:

The controlling specifications for the seismic design are the WSDOT Geotechnical Design Manual (GDM) Chapter 6 per Addendum 9 dated January 2019. Another specification is the WSDOT Bridge Design Manual (BDM) Chapter 4.

All structures are to be designed for a 7 percent probability of exceedance in 75 years seismic hazard, which is about a 1,034 year return period event (described in the GDM as an “approximate” return period of 1,000 yrs; this is similar to a 5% in 50 year probability of exceedance hazard, which has a 975 year return period as used by Caltrans). Essential or critical bridges should also be designed for the 30 percent probability of exceedance in 75 years seismic hazard, which has a year return period of about 210 years. The 1034 year return period event is designated as the Safety Evaluation Earthquake (SEE) and the 210 year return period event is designated as the Functional Evaluation Earthquake (FEE). These designations are from GDM Section 6-1.2.1.

For this project we are using the General Procedure method as outlined in GDM Section 6-2.1. This includes using specification/code based hazard (from GDM Section 6-3.1) with specification/code based ground motion response (from GDM Section 6-3.2.1).

To determine the seismic hazard for the SEE (1,000 yr RP) the ground motion tool called Spectra was used as recommended in Section 4.2.3.1 of the BDM. This tool uses the information published in the USGS National Seismic Hazards Mapping Project (USGS, 2014) as well as the updated site coefficients that are included in GDM Section 6-3.2.1.

For the FEE level of hazard (210 yr RP) we used the data from the USGS website at:

https://earthquake.usgs.gov/hazards/interactive

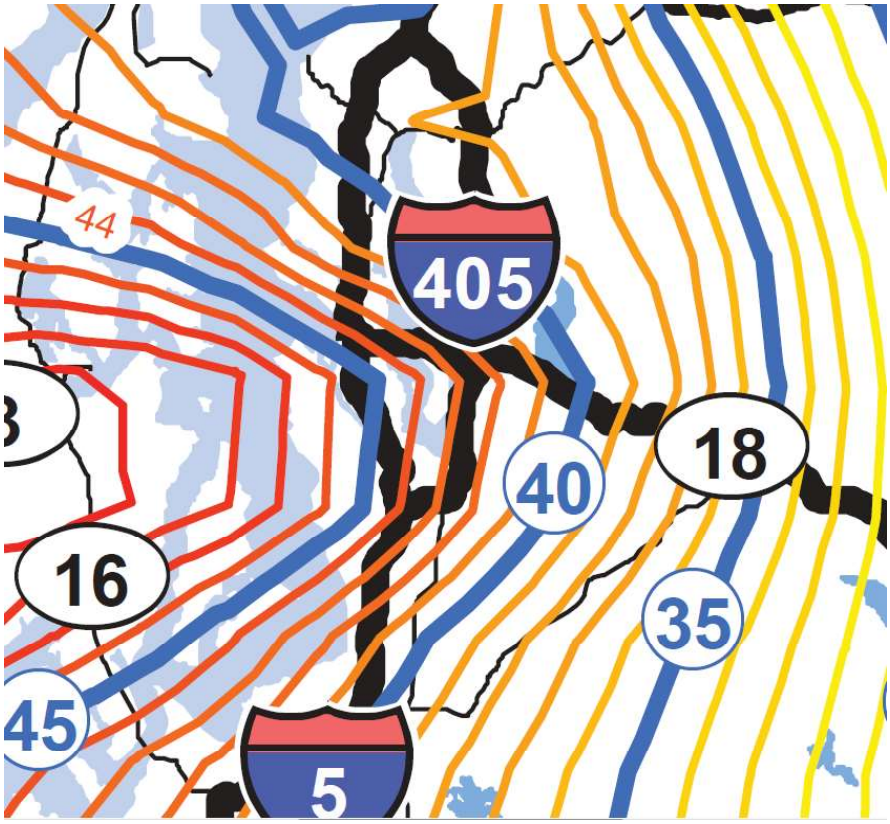
This is recommended in Section 6-3.1 of the GDM. The data was used to determine the spectral values for the site class B/C boundary at periods of PGA, 0.2 sec, and 1.0 sec for the 210 year return period. The site coefficients that are included in GDM Section 6-3.2.1 were then applied.

As recommended in GDM Section 6-1.3 the USGS website (https://earthquake.usgs.gov/hazards/interactive) was used to evaluate the magnitude-distance deaggregation at the periods of interest for the SEE and FEE seismic hazard levels.

4.0 Evaluations:

The first task was determining whether the seismic hazard should be evaluated for each segment, or if any segments needed to be divided into smaller portions based on the seismic hazard changing along the segment. The figures in Appendix 6-B of the GDM were reviewed in order to make this determination. Below is a portion of the figure for the peak horizontal acceleration (PHA) values. As shown the spectral acceleration values generally decrease going along the portion of I-405 from the intersection with I-5 to about the intersection with Highway 167 (portion that goes west-east) where the alignment turns to the north. The values are then relatively constant (i.e., the project route runs roughly along the contour lines, so the seismic accelerations are not expected to vary significantly along the segment) up to about the north end of the project at the intersection with I-90.

Figure 2: Portion of PHA Figure from Appendix 6-B of GDM



Based on the above figure (and the corresponding figures for the spectral accelerations at 0.2 and 1 second present a similar picture), it was determined that Segment 1A of the alignment should be divided into two areas. Area 1A-1 would go from the southwestern end of the alignment (at the intersection with I-5) over to the intersection with Highway 167 (i.e., the portion that goes east-west). Area 1A-2 would cover the remainder of Segment 1A (i.e., the portion that goes north-south). The other segments were not subdivided further as Segments 1B and 2A are along the contour lines and Segment 2B covers the area where the PHA values are changing in the northern area of the alignment. Below is a table summarizing these segment divisions along with the latitude and longitude values for their midpoints.

Table 2: Division of Project Segments for Evaluations

Segment	Midpoint Latitude	Midpoint Longitude	Approximate Mile Midpoint	Approximate Mile Range
1A-1	47.465145	-122.24191	1.2	0.0-2.3
1A-2	47.48641	-122.19447	4.1	2.3-6.0
1B	47.528242	-122.19771	7.3	6.0-8.5
2A	47.555697	-122.19083	9.3	8.5-10.0
2B	47.577447	-122.17425	11	10.0-12.0

The midpoint latitude and longitude were then copied into the Spectra program and the USGS website. For the USGS website the *Dynamic: Conterminous U.S. 2014 (update) (v4.2.0)* option was selected for the *Edition* option. The spectral acceleration values for the PGA, S_s (0.2 sec value), and the S_1 (1.0 sec value) for the B/C boundary site class were then taken from Spectra (to be used for the SEE) and the USGS website (to be used for the FEE).

These values were copied into a spreadsheet (Seismic Hazard I-405.xlsx) onto separate tabs (Summary 1A-1, Summary 1A-2, etc.) for each segment in columns C and D. The site coefficients from GDM Section 6-3.2.1 were then input into the spreadsheet tabs below the spectral acceleration values so that they could be used to calculate the site-class-dependent design values.

Columns E, G, I, and K of each tab then calculate the F_{PGA}, F_a, and F_v values to use for the FEE and SEE hazard levels for site classes of C and D. Linear interpolation is used for spectral values between the values given in the tables.

Site Class C and D were chosen for the evaluations as those site classes should cover the various geologic conditions along the alignment. This was based on a quick review of boring logs and available shear wave velocity data along the alignment. The site class for each structure should be determined at the time of design of that particular structure and the appropriate seismic parameters chosen for that site class. If additional site classes are required to cover the conditions along the alignment then this calculation should be revised.

Columns F, H, J, and L of each tab calculate the design spectral acceleration values by multiplying the B/C boundary values for PGA, 0.2 sec, and 1.0 sec by the corresponding F_{PGA}, F_a, and F_v values.

To evaluate the magnitudes to use in liquefaction evaluations along the alignment the USGS website was used. The values from the hazard at PGA were tabulated based on that being the dominant

period for liquefaction hazard (typical equations for the cyclic stress ratio are based on PGA for liquefaction). The mean magnitudes are summarized below for the segments for which the data was tabulated. As shown the mean magnitude does not vary significantly along the alignment. Also tabulated below are the percent contribution to the hazard from the Cascadia Subduction zone sources per the USGS website. This is tabulated for use in determination of whether large magnitude events are a significant contributor to the seismic hazard at the site; this determination is used in evaluations for liquefaction lateral spreading. Plots for the deaggregations are also included for Segments 1A-1 and 2B to show that there is insignificant variation along the alignment.

Table 3: Deaggregation Values in Percent

Segment	Mean Magnitude, SEE	Mean Magnitude, FEE	Subduction Zone Contribution, SEE	Subduction Zone Contribution, FEE
1A-1	7.0	6.8	9.0	8.9
1B	7.0	6.8	8.7	8.7
2B	7.0	6.8	8.9	8.6

Figure 3: Deaggregation for Segment 1A-1, 1,000 year RP, PGA

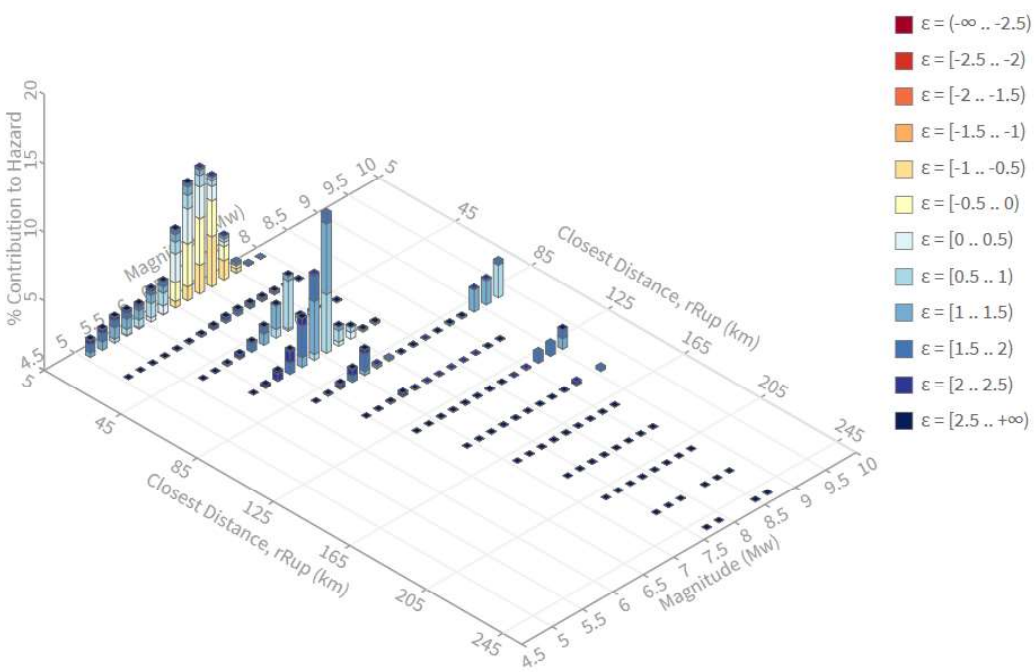


Figure 4: Deaggregation for Segment 1A-1, 210 year RP, PGA

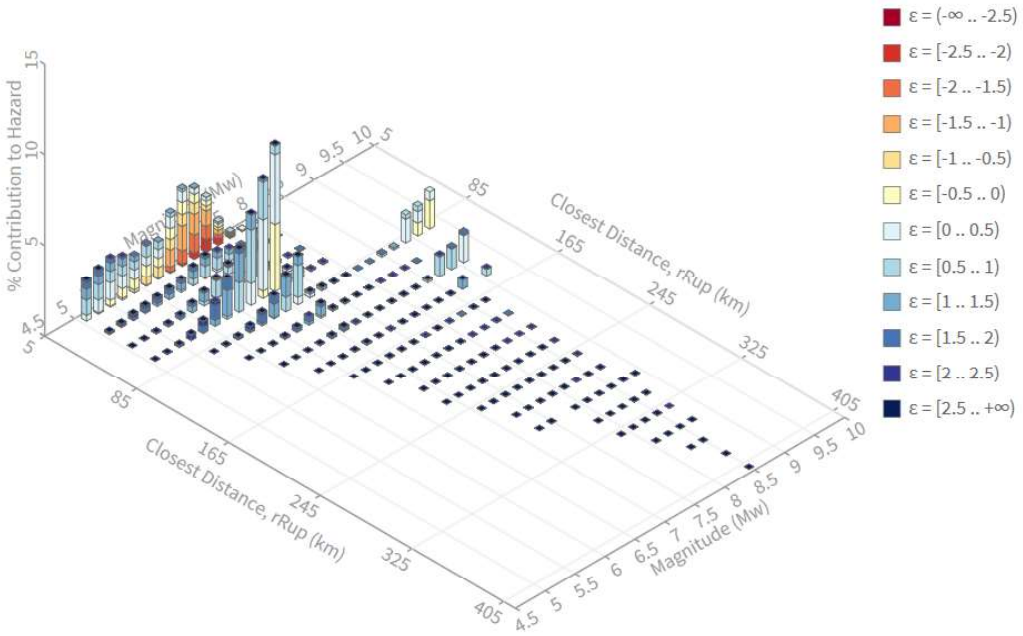


Figure 5: Deaggregation for Segment 2B, 1,000 year RP,PGA

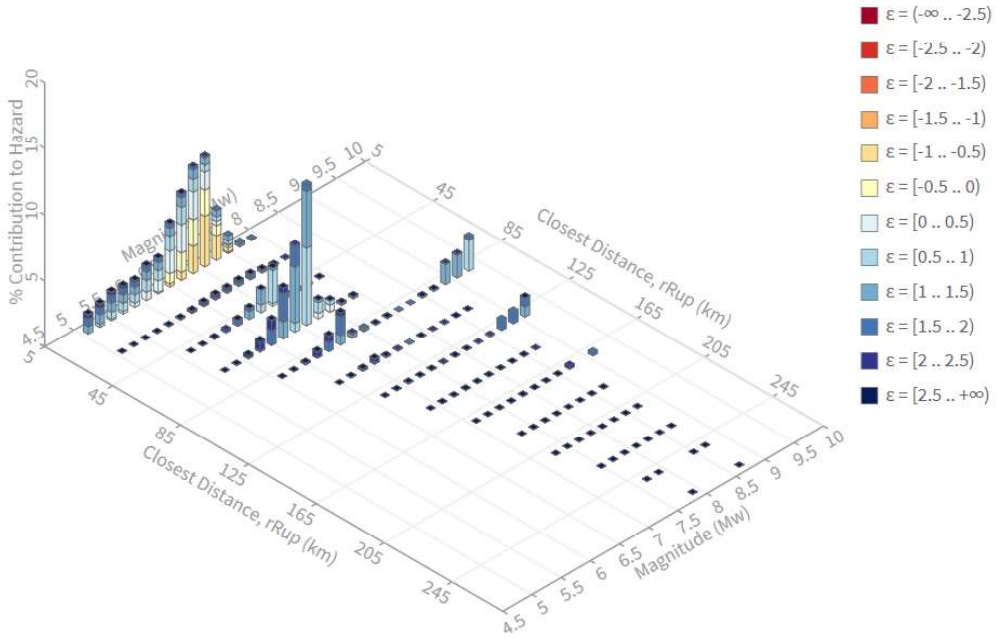
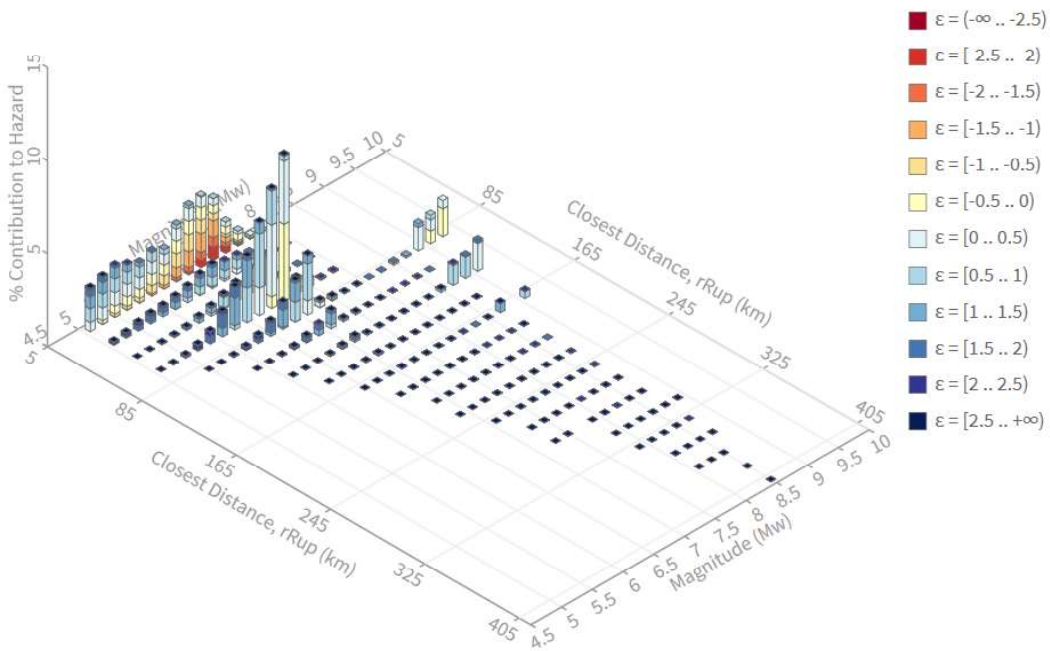


Figure 6: Deaggregation for Segment 2B, 210 year RP, PGA



5.0 Conclusions:

The following are the evaluated seismic parameters for the I-405 project segments as defined above.

Segment 1A-1 (MP 0.0 to 2.3, South End to Highway 167):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.438g	0.438g	0.207g	0.207g
F_{PGA}	1.162	1.200	1.393	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.509g	0.526g	0.288g	0.248g
Short-period (0.2 second) spectral acceleration (S_S)	1g	1g	0.467g	0.467g

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site coefficient (Fa)	1.100	1.200	1.427	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.1g	1.2g	0.666g	0.607g
1.0 second period spectral acceleration (S_1)	0.286g	0.286g	0.112g	0.112g
Site coefficient (Fv)	2.028	1.500	2.376	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.58g	0.429g	0.266g	0.168g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 1A-2 (MP 2.3 to 6.0, Highway 167 to near 24th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.43g	0.43g	0.202g	0.202g
F_{PGA}	1.170	1.200	1.398	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.503g	0.516g	0.282g	0.242g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.456g	0.456g
Site coefficient (Fa)	1.108	1.200	1.435	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.654g	0.592g
1.0 second period spectral acceleration (S_1)	0.28g	0.28g	0.11g	0.11g
Site coefficient (Fv)	2.040	1.500	2.380	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.571g	0.42g	0.262g	0.165g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 1B (MP 6.0 to 8.5, near 24th St to near 64th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.434g	0.434g	0.202g	0.202g
F_{PGA}	1.166	1.200	1.398	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.506g	0.521g	0.282g	0.242g
Short-period (0.2 second) spectral acceleration (S_S)	0.988g	0.988g	0.455g	0.455g
Site coefficient (Fa)	1.105	1.200	1.436	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.092g	1.186g	0.654g	0.592g
1.0 second period spectral acceleration (S_1)	0.284g	0.284g	0.11g	0.11g
Site coefficient (Fv)	2.032	1.500	2.380	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.577g	0.426g	0.262g	0.165g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 2A (MP 8.5 to 10.0, near 64th St to near 46th St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.431g	0.431g	0.2g	0.2g
F_{PGA}	1.169	1.200	1.400	1.200
Site-Adjusted Peak Ground Acceleration (A_S)	0.504g	0.517g	0.28g	0.24g
Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.451g	0.451g
Site coefficient (Fa)	1.108	1.200	1.439	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.649g	0.587g
1.0 second period spectral acceleration (S_1)	0.283g	0.283g	0.109g	0.109g

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site coefficient (Fv)	2.034	1.500	2.382	1.500
1.0 second design response acceleration $S_{D1} = S_1 \times Fv$	0.576g	0.425g	0.26g	0.164g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

Segment 2B (MP 10.0 to 12.0, near 46th St to near 22nd St):

	1,000 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.422g	0.422g	0.198g	0.198g
F_{PGA}	1.178	1.200	1.403	1.202
Site-Adjusted Peak Ground Acceleration (A_S)	0.497g	0.506g	0.278g	0.238g
Short-period (0.2 second) spectral acceleration (S_S)	0.959g	0.959g	0.447g	0.447g
Site coefficient (Fa)	1.116	1.200	1.442	1.300
Short Period design response acceleration (S_{DS}) = $S_S \times Fa$	1.071g	1.151g	0.645g	0.581g
1.0 second period spectral acceleration (S_1)	0.278g	0.278g	0.108g	0.108g
Site coefficient (Fv)	2.044	1.500	2.385	1.500
1.0 second design response acceleration $S_{D1} = S_1 \times Fv$	0.568g	0.417g	0.257g	0.162g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

6.0 Attachments:

No	Name of document	Tabs (if any)	Pages
1	Seismic Hazard I-405.xlsx	*Summary 1A-1, Summary 1A-2, Summary 1B, Summary 2A, Summary 2B*	-

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.207	0.438	1.393	0.288	1.162	0.509	1.200	0.248	1.200	0.526
6	Ss	0.2	0.467	1.000	1.427	0.666	1.100	1.100	1.300	0.607	1.200	1.200
7	S1	1	0.112	0.286	2.376	0.266	2.028	0.580	1.500	0.168	1.500	0.429
8												
9												
10												
11												
12		Fpga										
13		PGA	PGA	PGA	PGA	PGA	PGA					
14	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
15	A											
16	B											
17	C		1.3	1.2	1.2	1.2	1.2	1.2				
18	D		1.6	1.4	1.3	1.2	1.1	1.1				
19	E											
20												
21		Fa										
22		PGA	PGA	PGA	PGA	PGA	PGA					
23	Site Class		0.25	0.5	0.75	1	1.25	1.5				
24	A											
25	B											
26	C		1.3	1.3	1.2	1.2	1.2	1.2				
27	D		1.6	1.4	1.2	1.1	1	1				
28	E											
29												
30		Fv										
31		PGA	PGA	PGA	PGA	PGA	PGA					
32	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
33	A											
34	B											
35	C		1.5	1.5	1.5	1.5	1.5	1.4				
36	D		2.4	2.2	2	1.9	1.8	1.7				
37	E											

	M	N	O	P	Q
10		975 year RP		210 year RP	
11		SEE	SEE	FEE	FEE
12	**Parameter**	**Value**	**Value**	**Value**	**Value**
13	Site Class	D	C	D	C
14	Peak Ground Acceleration (PGA)	0.438g	0.438g	0.207g	0.207g
15	F_{PGA}	1.162	1.200	1.393	1.200
16	Site-Adjusted Peak Ground Acceleration (A_S)	0.509g	0.526g	0.288g	0.248g
17	Short-period (0.2 second) spectral acceleration (S_S)	1g	1g	0.467g	0.467g
18	Site coefficient (Fa)	1.100	1.200	1.427	1.300
19	Short Period design response acceleration (S_{DS}) = S_S x Fa	1.1g	1.2g	0.666g	0.607g
20	1.0 second period spectral acceleration (S_1)	0.286g	0.286g	0.112g	0.112g
21	Site coefficient (Fv)	2.028	1.500	2.376	1.500
22	1.0 second design response acceleration S_{D1} = S_1 x Fv	0.58g	0.429g	0.266g	0.168g
23	Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.202	0.43	1.398	0.282	1.170	0.503	1.200	0.242	1.200	0.516
6	Ss	0.2	0.456	0.98	1.435	0.654	1.108	1.086	1.300	0.592	1.200	1.176
7	S1	1	0.110	0.28	2.380	0.262	2.040	0.571	1.500	0.165	1.500	0.420
8												
9												
10												
11												
12		Fpga										
13		PGA	PGA	PGA	PGA	PGA	PGA					
14	Site Class	0.1	0.2	0.3	0.4	0.5	0.6					
15	A											
16	B											
17	C	1.3	1.2	1.2	1.2	1.2	1.2					
18	D	1.6	1.4	1.3	1.2	1.1	1.1					
19	E											
20												
21		Fa										
22		PGA	PGA	PGA	PGA	PGA	PGA					
23	Site Class	0.25	0.5	0.75	1	1.25	1.5					
24	A											
25	B											
26	C	1.3	1.3	1.2	1.2	1.2	1.2					
27	D	1.6	1.4	1.2	1.1	1	1					
28	E											
29												
30		Fv										
31		PGA	PGA	PGA	PGA	PGA	PGA					
32	Site Class	0.1	0.2	0.3	0.4	0.5	0.6					
33	A											
34	B											
35	C	1.5	1.5	1.5	1.5	1.5	1.4					
36	D	2.4	2.2	2	1.9	1.8	1.7					
37	E											

	M	N	O	P	Q
		975 year RP		210 year RP	
		SEE	SEE	FEE	FEE
	Parameter	**Value**	**Value**	**Value**	**Value**
	Site Class	D	C	D	C
	Peak Ground Acceleration (PGA)	0.43g	0.43g	0.202g	0.202g
	F_{PGA}	1.170	1.200	1.398	1.200
	Site-Adjusted Peak Ground Acceleration (A_S)	0.503g	0.516g	0.282g	0.242g
	Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.456g	0.456g
	Site coefficient (Fa)	1.108	1.200	1.435	1.300
	Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.654g	0.592g
	1.0 second period spectral acceleration (S_1)	0.28g	0.28g	0.11g	0.11g
	Site coefficient (Fv)	2.040	1.500	2.380	1.500
	1.0 second design response acceleration S_{D1} = S_1 x Fv	0.571g	0.42g	0.262g	0.165g
	Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.202	0.434	1.398	0.282	1.166	0.506	1.200	0.242	1.200	0.521
6	Ss	0.2	0.455	0.988	1.436	0.654	1.105	1.092	1.300	0.592	1.200	1.186
7	S1	1	0.110	0.284	2.380	0.262	2.032	0.577	1.500	0.165	1.500	0.426
8												
9												
10												
11												
12		Fpga										
13		PGA	PGA	PGA	PGA	PGA	PGA					
14	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
15	A											
16	B											
17	C		1.3	1.2	1.2	1.2	1.2	1.2				
18	D		1.6	1.4	1.3	1.2	1.1	1.1				
19	E											
20												
21		Fa										
22		PGA	PGA	PGA	PGA	PGA	PGA					
23	Site Class		0.25	0.5	0.75	1	1.25	1.5				
24	A											
25	B											
26	C		1.3	1.3	1.2	1.2	1.2	1.2				
27	D		1.6	1.4	1.2	1.1	1	1				
28	E											
29												
30		Fv										
31		PGA	PGA	PGA	PGA	PGA	PGA					
32	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
33	A											
34	B											
35	C		1.5	1.5	1.5	1.5	1.5	1.4				
36	D		2.4	2.2	2	1.9	1.8	1.7				
37	E											

	M	N	O	P	Q
		975 year RP		210 year RP	
		SEE	SEE	FEE	FEE
	Parameter	**Value**	**Value**	**Value**	**Value**
	Site Class	D	C	D	C
	Peak Ground Acceleration (PGA)	0.434g	0.434g	0.202g	0.202g
	F_{PGA}	1.166	1.200	1.398	1.200
	Site-Adjusted Peak Ground Acceleration (A_S)	0.506g	0.521g	0.282g	0.242g
	Short-period (0.2 second) spectral acceleration (S_S)	0.988g	0.988g	0.455g	0.455g
	Site coefficient (Fa)	1.105	1.200	1.436	1.300
	Short Period design response acceleration (S_{DS}) = S_S x Fa	1.092g	1.186g	0.654g	0.592g
	1.0 second period spectral acceleration (S_1)	0.284g	0.284g	0.11g	0.11g
	Site coefficient (Fv)	2.032	1.500	2.380	1.500
	1.0 second design response acceleration S_{D1} = S_1 x Fv	0.577g	0.426g	0.262g	0.165g
	Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.200	0.431	1.400	0.280	1.169	0.504	1.200	0.240	1.200	0.517
6	Ss	0.2	0.451	0.98	1.439	0.649	1.108	1.086	1.300	0.587	1.200	1.176
7	S1	1	0.109	0.283	2.382	0.260	2.034	0.576	1.500	0.164	1.500	0.425
8												
9												
10												
11												
12		Fpga										
13		PGA	PGA	PGA	PGA	PGA	PGA					
14	Site Class	0.1	0.2	0.3	0.4	0.5	0.6					
15	A											
16	B											
17	C	1.3	1.2	1.2	1.2	1.2	1.2					
18	D	1.6	1.4	1.3	1.2	1.1	1.1					
19	E											
20												
21		Fa										
22		PGA	PGA	PGA	PGA	PGA	PGA					
23	Site Class	0.25	0.5	0.75	1	1.25	1.5					
24	A											
25	B											
26	C	1.3	1.3	1.2	1.2	1.2	1.2					
27	D	1.6	1.4	1.2	1.1	1	1					
28	E											
29												
30		Fv										
31		PGA	PGA	PGA	PGA	PGA	PGA					
32	Site Class	0.1	0.2	0.3	0.4	0.5	0.6					
33	A											
34	B											
35	C	1.5	1.5	1.5	1.5	1.5	1.4					
36	D	2.4	2.2	2	1.9	1.8	1.7					
37	E											

	M	N	O	P	Q
		975 year RP		210 year RP	
		SEE	SEE	FEE	FEE
	Parameter	**Value**	**Value**	**Value**	**Value**
	Site Class	D	C	D	C
	Peak Ground Acceleration (PGA)	0.431g	0.431g	0.2g	0.2g
	F_{PGA}	1.169	1.200	1.400	1.200
	Site-Adjusted Peak Ground Acceleration (A_S)	0.504g	0.517g	0.28g	0.24g
	Short-period (0.2 second) spectral acceleration (S_S)	0.98g	0.98g	0.451g	0.451g
	Site coefficient (Fa)	1.108	1.200	1.439	1.300
	Short Period design response acceleration (S_{DS}) = S_S x Fa	1.086g	1.176g	0.649g	0.587g
	1.0 second period spectral acceleration (S_1)	0.283g	0.283g	0.109g	0.109g
	Site coefficient (Fv)	2.034	1.500	2.382	1.500
	1.0 second design response acceleration S_{D1} = S_1 x Fv	0.576g	0.425g	0.26g	0.164g
	Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

	A	B	C	D	E	F	G	H	I	J	K	L
1			FEE	SEE	FEE		SEE		FEE		SEE	
2			210 yrs	975 yrs	210 yrs		975 yrs		210 yrs		975 yrs	
3			B/C Boundary		Site Class		D		Site Class		C	
4	Parameter	Period (sec)	Sa (g)	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)	F	Sa (g)
5	PGA	0	0.198	0.422	1.403	0.278	1.178	0.497	1.202	0.238	1.200	0.506
6	Ss	0.2	0.447	0.959	1.442	0.645	1.116	1.071	1.300	0.581	1.200	1.151
7	S1	1	0.108	0.278	2.385	0.257	2.044	0.568	1.500	0.162	1.500	0.417
8					1.403							
9												
10												
11												
12												
13												
14		Fpga										
15		PGA	PGA	PGA	PGA	PGA	PGA					
16	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
17	A											
18	B											
19	C		1.3	1.2	1.2	1.2	1.2	1.2				
20	D		1.6	1.4	1.3	1.2	1.1	1.1				
21	E											
22												
23		Fa										
24		PGA	PGA	PGA	PGA	PGA	PGA					
25	Site Class		0.25	0.5	0.75	1	1.25	1.5				
26	A											
27	B											
28	C		1.3	1.3	1.2	1.2	1.2	1.2				
29	D		1.6	1.4	1.2	1.1	1	1				
30	E											
31												
32		Fv										
33		PGA	PGA	PGA	PGA	PGA	PGA					
34	Site Class		0.1	0.2	0.3	0.4	0.5	0.6				
35	A											
36	B											
37	C		1.5	1.5	1.5	1.5	1.5	1.4				
38	D		2.4	2.2	2	1.9	1.8	1.7				
39	E											

	975 year RP		210 year RP	
	SEE	SEE	FEE	FEE
Parameter	**Value**	**Value**	**Value**	**Value**
Site Class	D	C	D	C
Peak Ground Acceleration (PGA)	0.422g	0.422g	0.198g	0.198g
F_{PGA}	1.178	1.200	1.403	1.202
Site-Adjusted Peak Ground Acceleration (A_S)	0.497g	0.506g	0.278g	0.238g
Short-period (0.2 second) spectral acceleration (S_S)	0.959g	0.959g	0.447g	0.447g
Site coefficient (Fa)	1.116	1.200	1.442	1.300
Short Period design response acceleration (S_{DS}) = S_S x Fa	1.071g	1.151g	0.645g	0.581g
1.0 second period spectral acceleration (S_1)	0.278g	0.278g	0.108g	0.108g
Site coefficient (Fv)	2.044	1.500	2.385	1.500
1.0 second design response acceleration S_{D1} = S_1 x Fv	0.568g	0.417g	0.257g	0.162g
Mean Earthquake Magnitude (Mw)	7	7	6.8	6.8

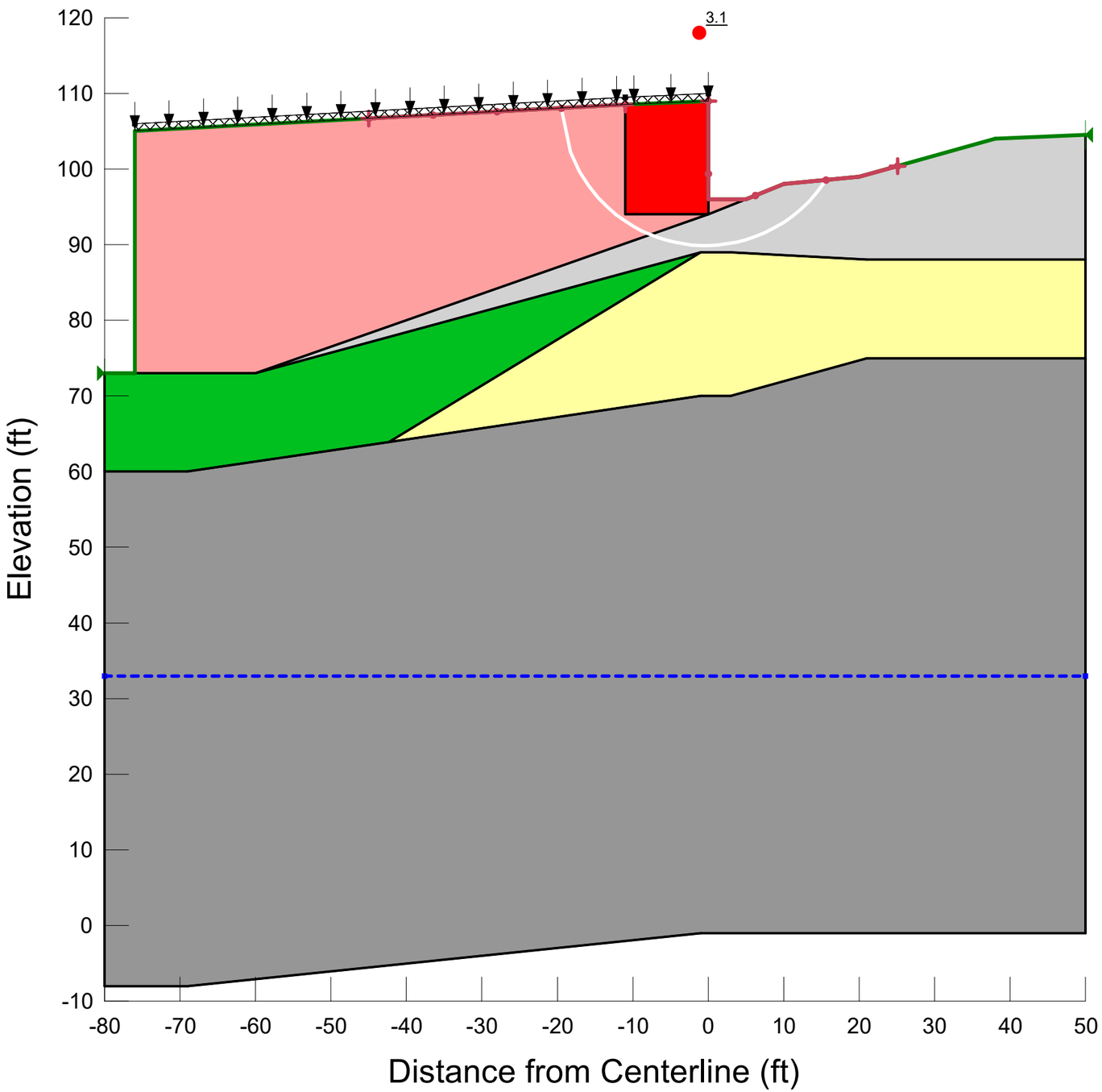
In Association with

Appendix E-2
Global, Compound, and External Stability Calculations

In Association with

GLOBAL STABILITY ANALYSIS

Section A - A'

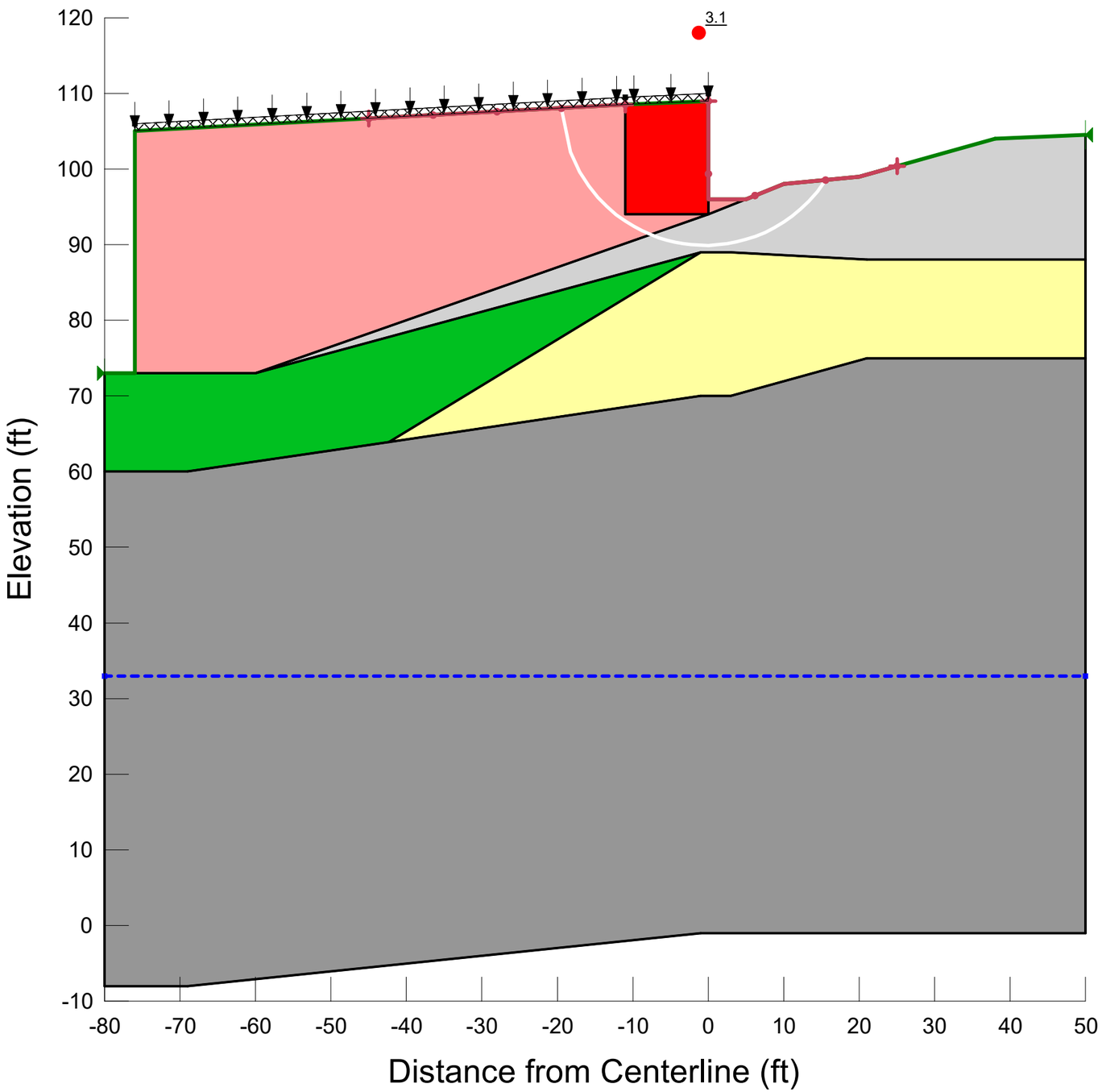


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Geosynthetic Wall	High Strength	130			

Title: Wall 10.18R Section A - A' (Station 1+75)
Name: Static - Spencer
Method: Spencer
Surcharge (Unit Weight): 250 pcf
Horz Seismic Coef.:

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'

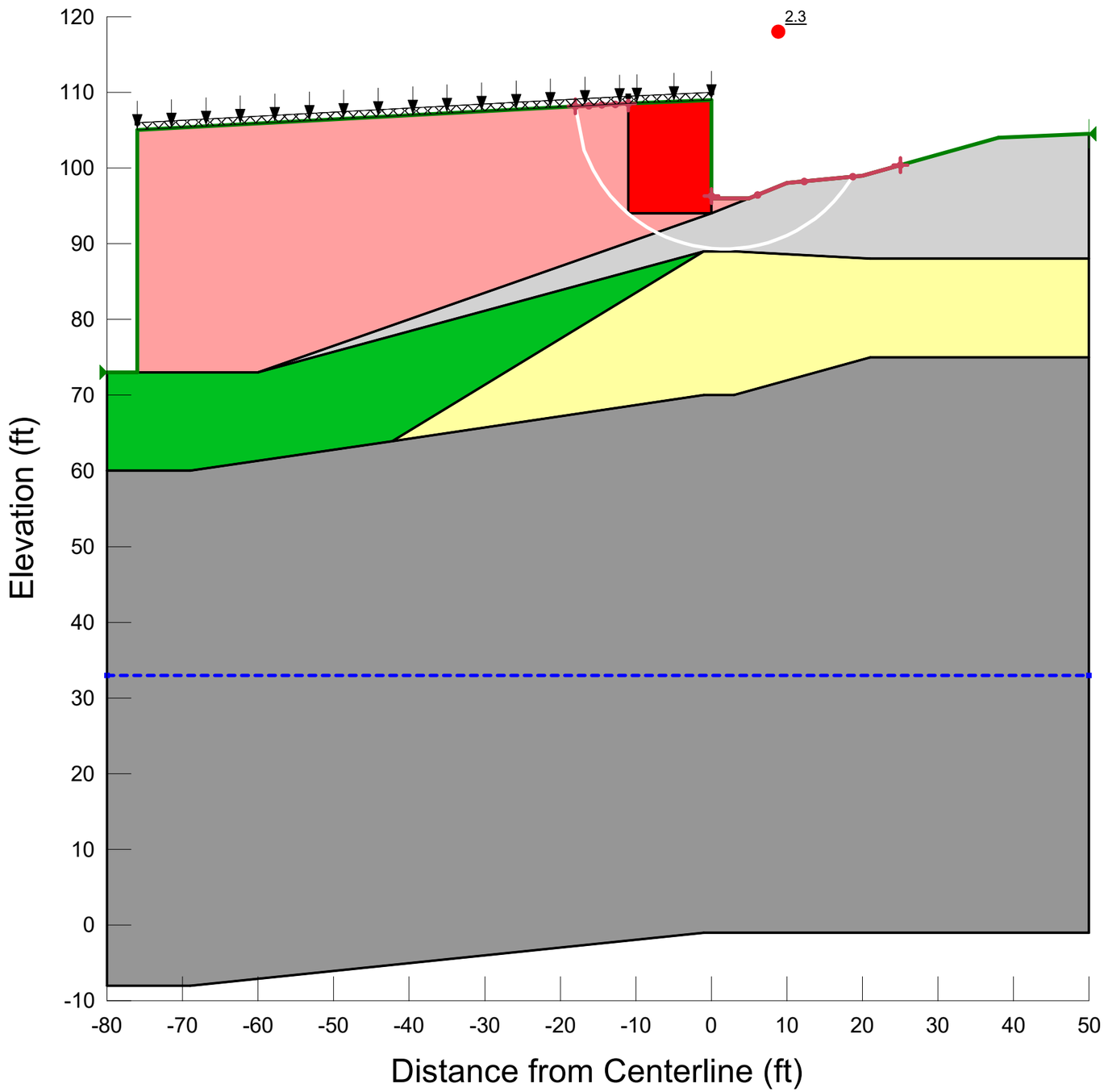


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Geosynthetic Wall	High Strength	130			

Title: Wall 10.18R Section A - A' (Station 1+75)
Name: Static - Morgenstern
Method: Morgenstern-Price
Surcharge (Unit Weight): 250 pcf
Horz Seismic Coef.:

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'

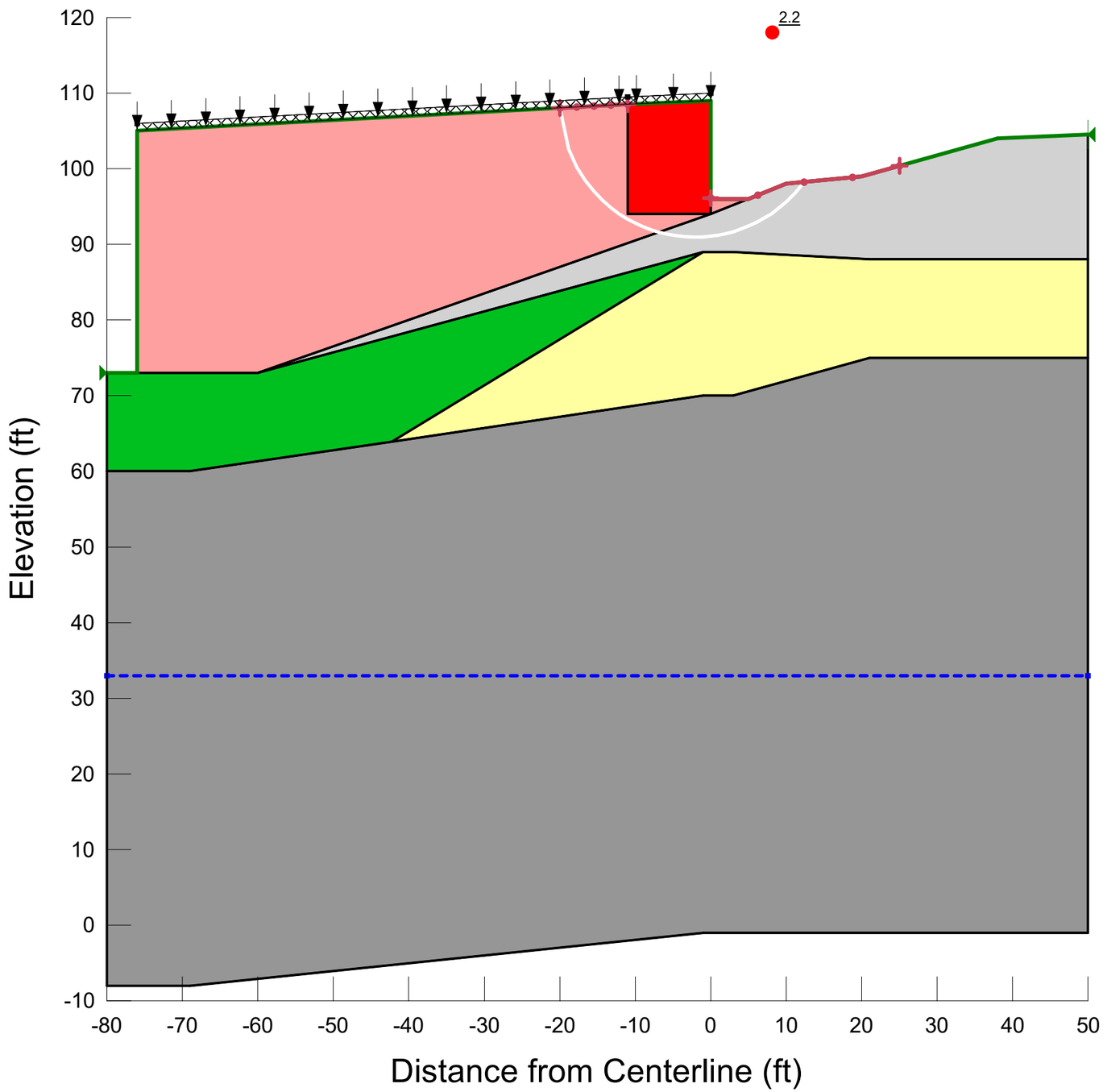


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Geosynthetic Wall	High Strength	130			

Title: Wall 10.18R Section A - A' (Station 1+75)
Name: PseudoStatic - Spencer
Method: Spencer
Surcharge (Unit Weight): 125 pcf
Horz Seismic Coef.: 0.253

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'



Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Geosynthetic Wall	High Strength	130			

Title: Wall 10.18R Section A - A' (Station 1+75)
Name: PseudoStatic - Morgenstern
Method: Morgenstern-Price
Surcharge (Unit Weight): 125 pcf
Horz Seismic Coef.: 0.253

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

In Association with

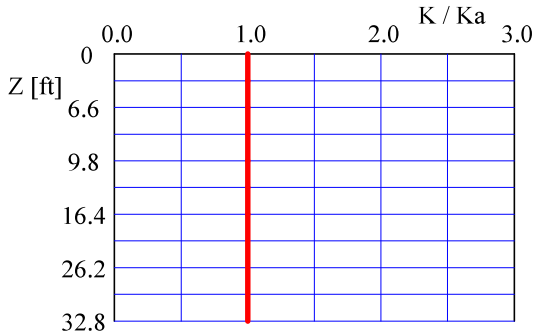
COMPOUND STABILITY ANALYSIS

INPUT DATA: Geogrids (Analysis)

D A T A	Geogrid type #1	Geogrid type #2	Geogrid type #3	Geogrid type #4	Geogrid type #5
Tult [lb/ft]	7550.0	9000.0	14500.0		
Durability reduction factor, RFd	1.30	1.30	1.30		
Installation-damage reduction factor, RFid	1.11	1.11	1.11		
Creep reduction factor, RFc	1.51	1.51	1.51	N/A	N/A
CDR for strength	N/A	N/A	N/A		
Coverage ratio, Rc	1.000	1.000	1.000		
Friction angle along geogrid-soil interface, ρ	27.63	27.63	27.63		
Pullout resistance factor, F*	$0.67 \cdot \tan\phi$	$0.67 \cdot \tan\phi$	$0.67 \cdot \tan\phi$	N/A	N/A
Scale-effect correction factor, α	0.8	0.8	0.8		

Variation of Lateral Earth Pressure Coefficient With Depth

Z	K / Ka
0 ft	1.00
3.3 ft	1.00
6.6 ft	1.00
9.8 ft	1.00
13.1 ft	1.00
16.4 ft	1.00
19.7 ft	1.00



Assigned Vertical Spacing = 1.3 feet
Starting Elevation = Bottom Elevation
Length = Required Reinforced Length

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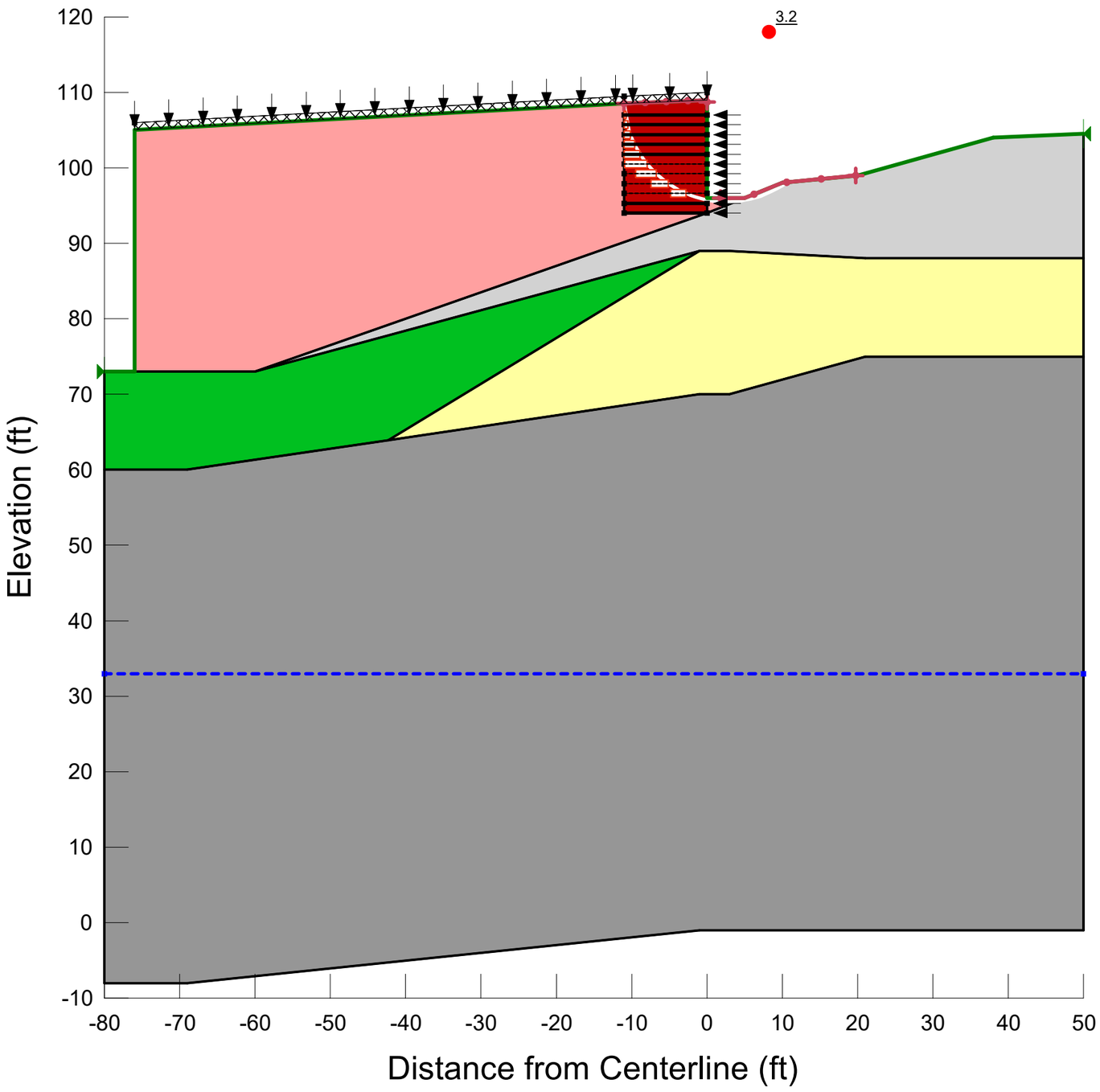
Section A - A'

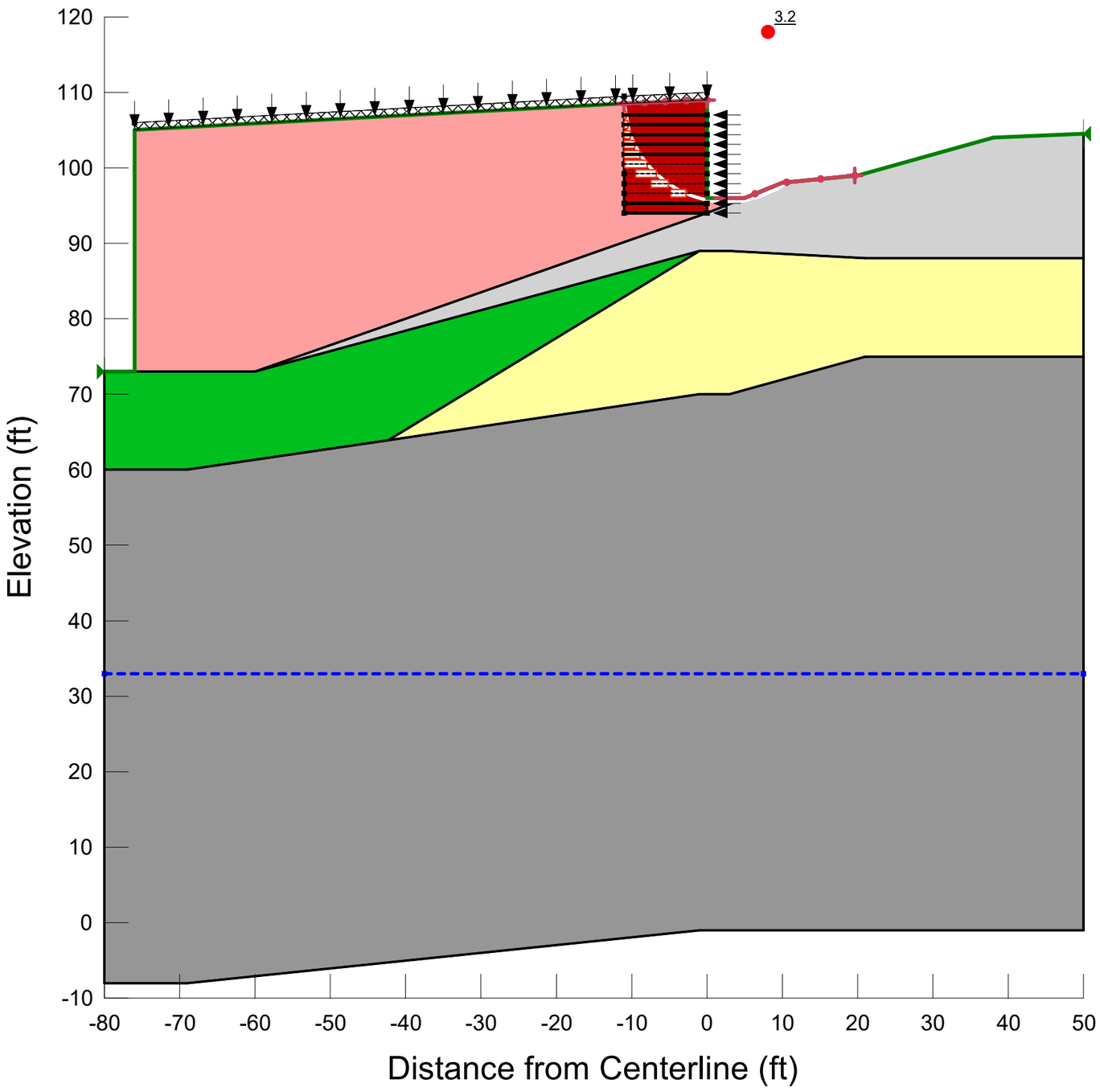


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Gravel Borrow	Mohr-Coulomb	130	0	38	0

Title: Wall 10.18R Section A - A' (Station 1+75) Compound Stability
Name: Static (Spencer) - Compound Stability
Method: Spencer
Surcharge (Unit Weight): 250 pcf
Horz Seismic Coef.:

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'

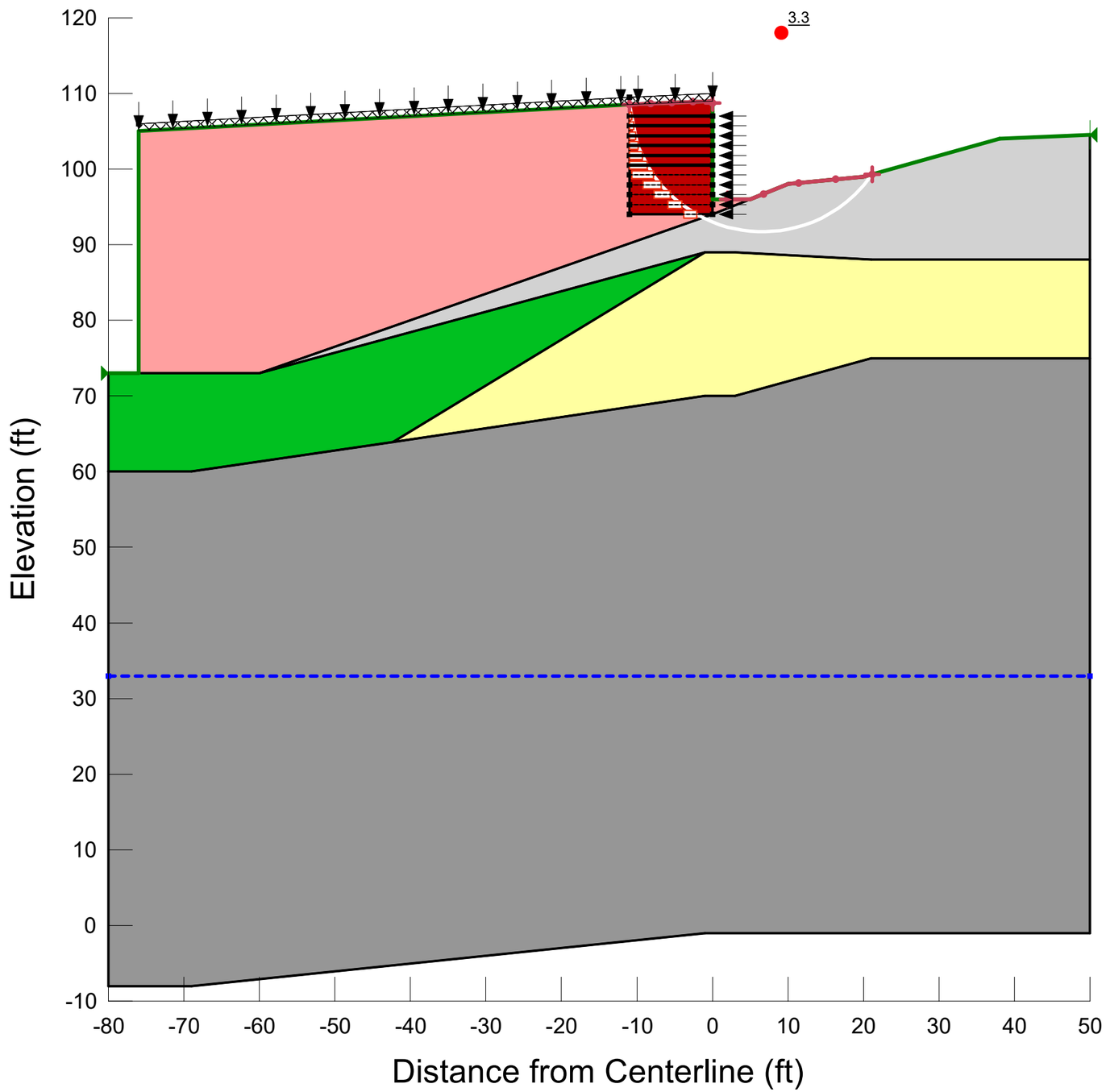


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Gravel Borrow	Mohr-Coulomb	130	0	38	0

Title: Wall 10.18R Section A - A' (Station 1+75) Compound Stability
Name: Static (Morgenstern) - Compound Stability
Method: Morgenstern-Price
Surcharge (Unit Weight): 250 pcf
Horz Seismic Coef.:

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'

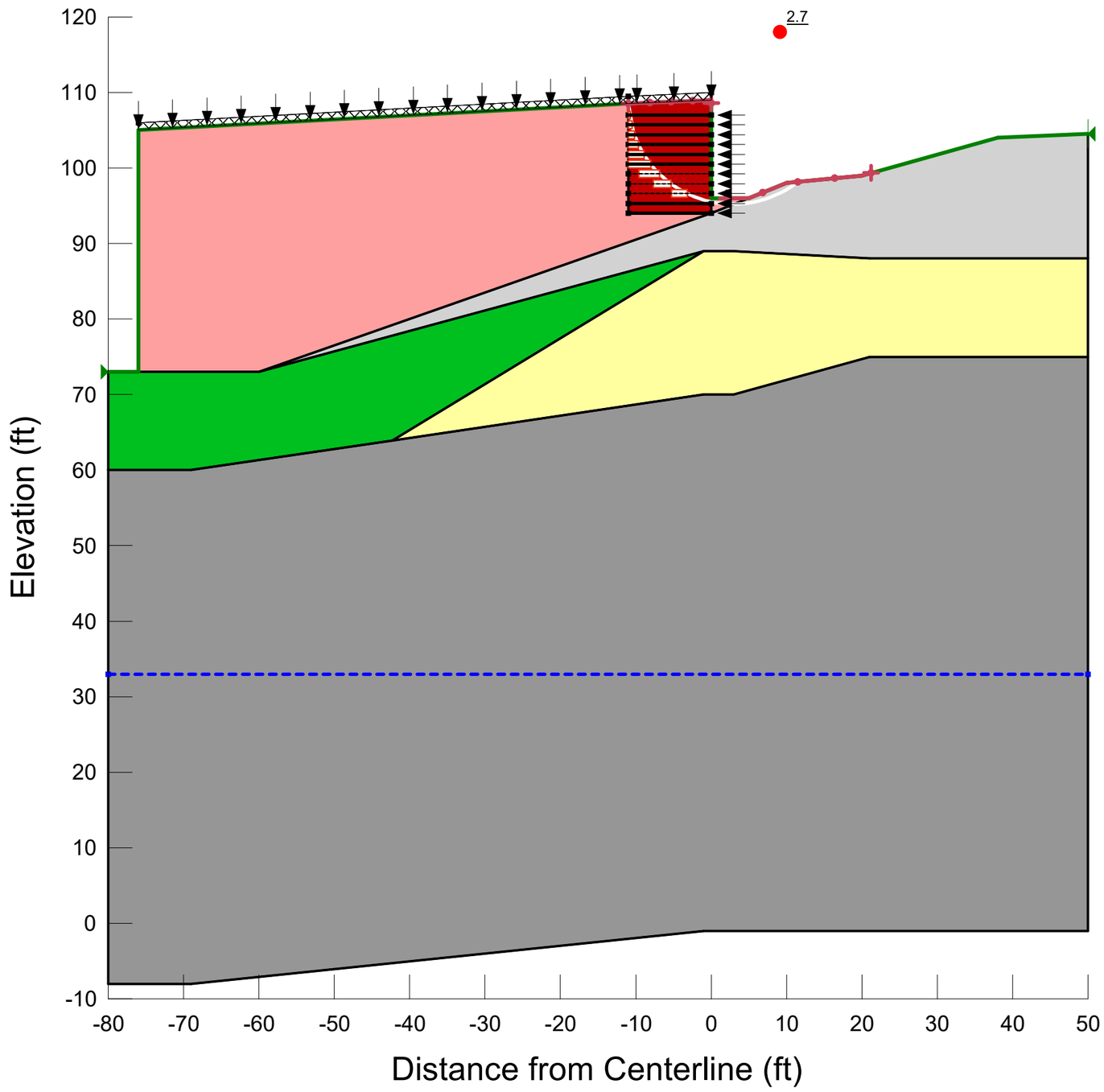


Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Gravel Borrow	Mohr-Coulomb	130	0	38	0

Title: Wall 10.18R Section A - A' (Station 1+75) Compound Stability
Name: PseudoStatic (Spencer) - Compound Stability
Method: Spencer
Surcharge (Unit Weight): 125 pcf
Horz Seismic Coef.: 0.253

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

Section A - A'



Color	Name	Model	Unit Weight (pcf)	Cohesion' (psf)	Phi' (°)	Phi-B (°)
	Common Borrow	Mohr-Coulomb	120	0	32	0
	ESU #1B	Mohr-Coulomb	130	0	38	0
	ESU #4A	Mohr-Coulomb	130	0	40	0
	ESU #4C	Mohr-Coulomb	130	0	40	0
	ESU #4E	Mohr-Coulomb	125	627	30	0
	Gravel Borrow	Mohr-Coulomb	130	0	38	0

Title: Wall 10.18R Section A - A' (Station 1+75) Compound Stability
Name: PseudoStatic (Morgenstern) - Compound Stability
Method: Morgenstern-Price
Surcharge (Unit Weight): 125 pcf
Horz Seismic Coef.: 0.253

Elevation at the bottom of the Wall = 94.0 feet
Design Wall Height = 15.0 feet
Design Reinforcement Width = 11.0 feet

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I-405 R2B Express Toll Lanes
Segment 2B Wall 10.18R-A
STA -1+75 Section A-A'

Hand Calculations for Geosynthetic Wall

Date: January 2022

Prepared For: ***Flatiron-Lane Joint Venture***

Prepared By:

8519 Jefferson Street NE
Albuquerque, NM 87113
www.woodplc.com

1.0 PURPOSE

The purpose of this design calculation package is to evaluate external stability of the wall; i.e., the eccentricity, sliding, and bearing resistance at the Strength I and Extreme I Limit State in accordance with *AASHTO LRFD Bridge Design Specifications* (8th edition). Results of global stability based on AASHTO and WSDOT GDM procedures for Service I limit state are also presented. Note settlement analysis of wall performed under separate cover.

2.0 REFERENCES

The following references for developing this calculation package:

1. *AASHTO LRFD Bridge Design Specifications* (2017), 8th Edition;
2. *WSDOT Geotechnical Design Manual* (GDM) M 46-03.11, May 2015 and Addendum M 46-03.12 Revision Chapters 6 & 15;
3. *WSDOT Design Manual M22-01.18*, December 2019 and *M22-01.05* June 2009;
4. WSDOT "Backfill and Drainage for Retaining Walls Standard Plan D-4" dated December 11, 1998;
5. "I-405 Seismic Hazard" (calculations) dated March 31, 2020 and prepared by Wood.
6. *NCHRP Report 611 Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments* (2008).

3.0 METHODOLOGY

The intent of this calculation is to evaluate the eccentricity, sliding, bearing, and global resistance at the specified design height (see below). In general, the effective wall footing width and rectangular bearing stress were calculated. These were then compared to the calculated strength and extreme event bearing resistance of the foundation soils.

The used design backfill properties are within the suggested range in the GDM Table 5-2. For the foundation soils, the estimated strength parameters for the engineering stratigraphic unit (ESU) (calculated under separate cover) were used.

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Worksheet Input Parameters

Analyzed Wall and Section: Wall 10.18R-A Section A-A' at Sta. 1+75

Bottom of Geosythetic wall = Elev. 94.0 ft and Top of Geosynthetic wall = 109.0 ft

4.0 ASSUMPTIONS

Shear strength parameters of wall foundation subgrade, $\phi_{fnd} := 37\ °$, are based on the weighted average strength parameters within zone of influence.

The ground surface in front of the wall is horizontal, the minimum embedment shall be 2ft or 10% of height whichever is exposed height whichever is larger.

5.0 SOIL PROPERTIES AND DESIGN PARAMETERS USED FOR CALCULATIONS

Retained Fill/ Backfill for Wall: GDM 15.6

$\gamma_f := 120\ pcf$

$\phi_f := 32\ °$

$c_f := 0\ psf$

Foundation Soil: (weighted average)

$\gamma_{fnd} := 128\ pcf$ $c_{fnd} := 0\ psf$

$\phi_{fnd} := 37\ °$

$\phi_{slide_interface} := 0.7 \cdot \phi_{fnd} = 25.9\ °$

Gravel Backfill for Walls: GDM Table 5-2

$\gamma_b := 130\ pcf$

Unit weight of water:

$\gamma_w := 62.4\ pcf$

Sliding interface friction angle equal to 0.7 times the interface foundation layer friction angle, based on WSDOT GDM Section 15.6

Exposed wall height: $H' := 13\ ft$ Based on structure cross sections

Live load surcharge: $q_L := 250\ psf$ (AASHTO 3.11.6.4 and GDM 15.4.9)

Min. Embedment of wall: $E := \max(0.1 \cdot H', 2\ ft) = 2\ ft$ WSDOT Standard Drawing D-3.09-00

Design height (included embedment): $H := H' + E = 15\ ft$

WSDOT standard wall height: $H := 15\ ft$ Wall height used in calculations

Minimum Length of reinforcement: $L := 0.7 \cdot H = 10.5\ ft$

Length of reinforcement: $L := 11\ ft$ WSDOT Standard Drawing D-3.09-00

Precast or CIP wall facing width: $w_u := 6\ in$

Angle of backfill incline: $\beta := \operatorname{atan}\left(\frac{0}{2}\right) = 0\ °$

Wall batter: $\theta := 90\ °$

Friction angle between fill and wall: $\delta := \frac{2}{3} \cdot \phi_f = 21.33\ °$ (AASHTO C3.11.5.3)

Assumed unit weight of concrete: $\gamma_c := 145\ pcf$ (AASHTO Table 3.5.1-1)

Peak Ground Acceleration: $PGA := 0.422$

Site factor at zero period: $F_{PGA} := 1.200$

Wood Calculation for I-405 Project "Seismic Hazard" dated March 31, 2020" for Site Class C

6.0 Load and Resistance Factors:

Resistance factors

Resistance factors for bearing capacity: $\phi_{bST} := 0.65$ (AASHTO Table 11.5.7.1)

Resistance factors for extreme event: $\phi_{EE} := 1.0$ (AASHTO 10.5.5.3.3)

Resistance factors for extreme event (bearing): $\phi_{bEE} := 0.9$ (AASHTO 11.5.8)

Resistance factors for MSE sliding: $\phi_{slide} := 1.0$ (AASHTO Table 11.5.7.1)

Load factors - Service I (AASHTO Table 3.4.1-1):

Vertical earth pressure load factor: $EV_s := 1.0$

Horizontal earth pressure load factor: $EH_s := 1.0$

Live load traffic surcharge load factor: $LS_s := 1.0$

Dead load traffic surcharge load factor: $DC_s := 1.0$

Load factors - Strength I (AASHTO Table 3.4.1-1 and 3.4.1-2):

Vertical earth pressure load factor: $EV_{Imax} := 1.35$ $EV_{Imin} := 1.0$

Horizontal earth pressure load factor: $EH_{Imax} := 1.5$ $EH_{Imin} := 0.9$

Live load traffic surcharge load factor: $LS_I := 1.75$

Dead load of structure load factor: $DC_{Imax} := 1.25$ $DC_{Imin} := 0.9$

Earth Pressure Coefficients for External Wall Loading

$$\Gamma := \left(1 + \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f - \beta)}{\sin(\theta - \delta) \cdot \sin(\theta + \beta)}}\right)^2 = 2.81$$

Active soil pressure coefficient for retained soil (AASHTO 3.11.5.3)

$$k_a := \frac{\sin(\theta + \phi_f)^2}{\Gamma\left(\sin(\theta)^2 \cdot \sin(\theta - \delta)\right)} = 0.275$$

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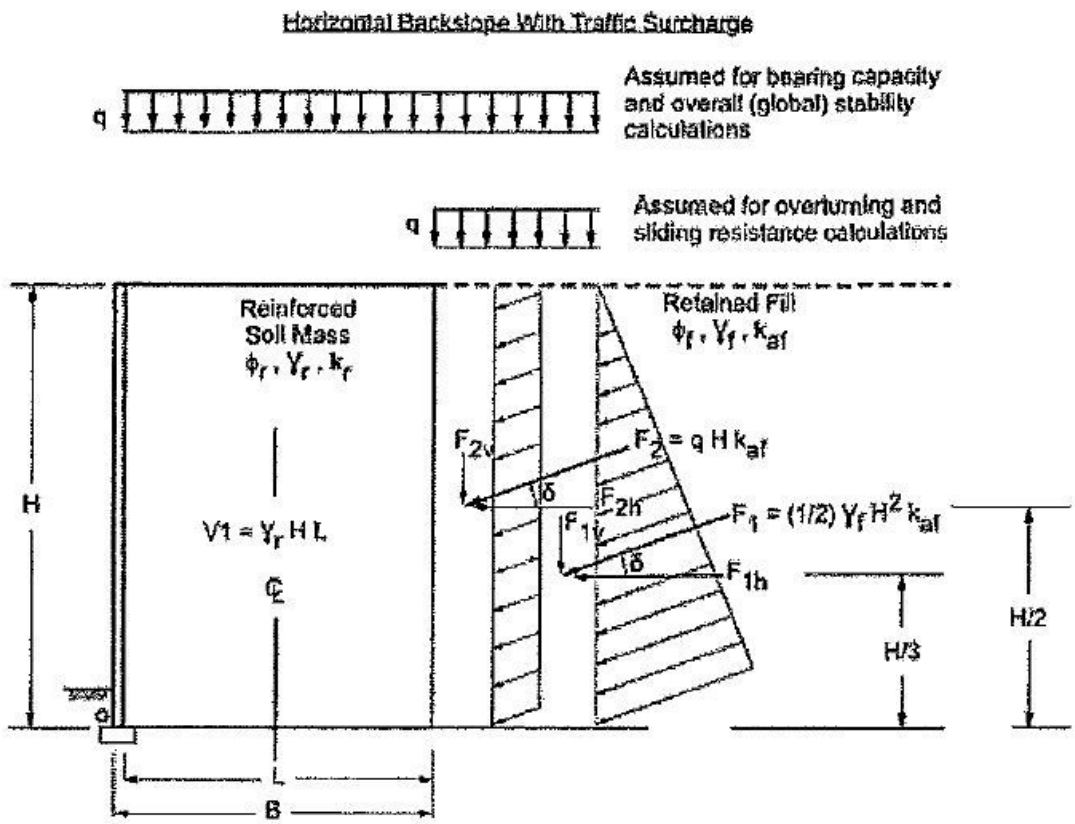
Free body Diagram for Wall Geometry and Load Locations (AASHTO 11.10.5.2-1)



7.0 Wall Loading - Service I (AASHTO Figure C11.5.6-1 and C11.5.6-3 using Service Limit Load Factors)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_s \cdot \gamma_b \cdot H \cdot L = 21.45\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_s \cdot q_L \cdot L = 2.75\ \frac{kip}{ft}$

<u>Factored horizontal load due to active earth pressure:</u> $F_1 := 0.5 \cdot EH_s \cdot \gamma_f \cdot H^2 \cdot k_a = 3.71\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 1.35\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 3.46\ \frac{kip}{ft}$

<u>Factored horizontal load due to LL surcharge:</u> $F_2 := LS_s \cdot q_L \cdot H \cdot k_a = 1.03\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.38\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 0.96\ \frac{kip}{ft}$

Sum of vertical factored loads: $\Sigma V := (V_1 + V_2) + (F_{1v} + F_{2v}) = 25.93\ \frac{kip}{ft}$

Horizontal distance of toe to center of vertical weight/load

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Moment due to vertical loads about the toe of wall:

$$M_{ov} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 152.08\ \frac{kip \cdot ft}{ft}$$

Moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 24.5\ \frac{kip \cdot ft}{ft}$$

Net moment due to vertical and horizontal loads about toe of wall: $M_{net} := M_{ov} - M_{oh} = 127.59\ \frac{kip \cdot ft}{ft}$

Overturning eccentricity: $X_o := \frac{M_{net}}{\Sigma V} = 4.92\ ft$

Eccentricity of wall (bearing): $e_{wall_s} := \left| \frac{L}{2} - X_o \right| = 0.58\ ft$

Maximum bearing stress (Service I): $\sigma_{v_s} := \frac{\Sigma V}{L - 2 \cdot e_{wall_s}} = 2634.08\ psf$ (AASHTO 11.6.3.2-1)

Settlement analysis should be evaluated (under separate cover) for a length of footing of $L = 11.0\ ft$ and a maximum bearing pressure at the base of the reinforcement zone of $\sigma_{v_s} = 2634\ psf$.

8.0 Wall Loading - Strength I (AASHTO Figure C11.5.6-1 and C11.5.6-3)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_{Imax} \cdot \gamma_b \cdot H \cdot L = 28.958\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_I \cdot q_L \cdot L = 4.813\ \frac{kip}{ft}$

Factored vertical load of reinforced soil mass (min): $V_3 := EV_{Imin} \cdot \gamma_f \cdot H \cdot L = 19.8\ \frac{kip}{ft}$

Factored horizontal load due to active earth pressure: $F_1 := 0.5 \cdot EH_{Imax} \cdot \gamma_f \cdot H^2 \cdot k_a = 5.569\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 2.026\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 5.188\ \frac{kip}{ft}$

Factored horizontal load due to LL surcharge: $F_2 := LS_I \cdot q_L \cdot H \cdot k_a = 1.805\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.657\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 1.681\ \frac{kip}{ft}$

Sum of maximum vertical factored loads (bearing): $\Sigma V_{max} := (V_1 + V_2) + (F_{1v} + F_{2v}) = 36.453 \ \frac{kip}{ft}$

Sum of minimum vertical factored loads (Ecc/Slide): $\Sigma V_{min} := V_3 + (F_{1v} + F_{2v}) = 22.483 \ \frac{kip}{ft}$

Maximum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 215.244 \ \frac{kip \cdot ft}{ft}$$

Minimum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_min} := V_3 \cdot x_{V1} + (F_{1v} + F_{2v}) \cdot L = 138.409 \ \frac{kip \cdot ft}{ft}$$

Driving moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 38.547 \ \frac{kip \cdot ft}{ft}$$

Maximum net moment due to vertical and horizontal loads about toe of wall (bearing):

$$M_{net_max} := M_{ov_max} - M_{oh} = 176.697 \ \frac{kip \cdot ft}{ft}$$

Minimum net moment due to vertical and horizontal loads about toe of wall (Ecc/slide):

$$M_{net_min} := M_{ov_min} - M_{oh} = 99.862 \ \frac{kip \cdot ft}{ft}$$

Overturning eccentricity (bearing): $X_o := \frac{M_{net_max}}{\Sigma V_{max}} = 4.8473 \ ft$

Eccentricity of wall about the center of footing (bearing): $e_{wall_max} := \left| \frac{L}{2} - X_o \right| = 0.65 \ ft$

Maximum bearing stress (Strength 1) to be used in bearing check: $\sigma_{v_max} := \frac{\Sigma V_{max}}{L - 2 \cdot e_{wall_max}} = 3760.09 \ psf$ (AASHTO 11.6.3.2-1)

Maximum bearing stress (Strength I): $\sigma_{v_st} := \sigma_{v_max} = 3760.09 \ psf$

8.1 Evaluate Wall Eccentricity Limits - Strength I

Overturning eccentricity (Ecc/sliding): $X_{o_min} := \frac{M_{net_min}}{\Sigma V_{min}} = 4.4417 \ ft$

Eccentricity of wall about the center of footing (Ecc/sliding): $e_{wall_min} := \left| \frac{L}{2} - X_{o_min} \right| = 1.06 \ ft$

Check Eccentricity (AASHTO 10.6.3.3):

$$check_{ecc} := \begin{cases} \text{if } e_{wall_min} \le \frac{L}{3} \\ \quad \text{"OK"} \\ \text{if } e_{wall_min} > \frac{L}{3} \\ \quad \text{"Revise"} \end{cases} = \text{"OK"}$$

8.2 Evaluate Wall Sliding - Strength I

Normal sliding resistance: $R_T := \Sigma V_{min} \cdot \tan(\phi_{fnd}) = 16.9419 \ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1/2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 16.9419 \ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{F_{1h} + F_{2h}} = 2.467$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \geq F_{1h} + F_{2h} \\ \quad \text{"OK"} \\ \text{if } R_R < F_{1h} + F_{2h} \\ \quad \text{"Revise"} \end{array} \right\| = \text{"OK"}$

9.0 Bearing Resistance Calculation (AASHTO 10.6.3.1.2a) - Strength I

Footing Geometry based on structure submittals and cross sections

Total footing width: $B := L = 11 \ ft$ Define B as L for length of minimum grid above

Footing length: $L_{wall} := 58 \ ft$ Station 1+50 to 2+08

Groundwater depth: $D_w := 61 \ ft$ Based on Station 1+75 (Section A - A')

Footing embedment depth: $D_f := 2 \ ft$

Check Bearing Resistance (AASHTO 10.6.3.2)

Effective B (reduced due to moment): $B' := B - 2 \cdot e_{wall_max} = 9.69 \ ft$

Bearing Capacity Factors (Equations used to tabulate AASHTO Table 10.6.3.1.2a-1)
Equations in Das, Braja M., 2019, "Principles of Foundation Engineering", 9th edition

$N_q := e^{\pi \cdot \tan(\phi_{fnd})} \cdot \tan\left(45° + \frac{\phi_{fnd}}{2}\right)^2 = 42.92$ (Reissner, 1924)

$N_c := \text{if}\left(\phi_{fnd} = 0°, 5.14, (N_q - 1) \cdot \cot(\phi_{fnd})\right) = 55.63$ (Prandtl, 1921)

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fnd}) = 66.19$ (Vesic, 1975)

Shape factors (AASHTO Table 10.6.3.1.2a-3)

$S_c := \text{if}\left(\phi_{fnd} = 0, 1 + \left(\frac{B'}{5 \cdot L_{wall}}\right), 1 + \frac{B'}{L_{wall}} \cdot \frac{N_q}{N_c}\right) = 1.13$

$S_\gamma := \text{if}\left(\phi_{fnd} = 0, 1, 1 - 0.40 \cdot \left(\frac{B'}{L_{wall}}\right)\right) = 0.93$

$S_q := \text{if}\left(\phi_{fnd} = 0, 1, 1 + \left(\frac{B'}{L_{wall}}\right) \cdot \tan(\phi_{fnd})\right) = 1.13$

Groundwater coefficients (AASHTO Table 10.6.3.1.2a-2)

$C_{wq} := \text{if}(D_w = 0, 0.5, 1.0) = 1$

$C_{w\gamma} := \text{if}(D_w = 0, 0.5, \text{if}(D_w > 1.5 \cdot B' + D_f, 1.0, 0.5)) = 1$

Depth correction factor (AASHTO 10.6.3.1.2a): Conservatively taken as 1.0

$d_q := 1.0$

Nominal bearing resistance (AASHTO 10.6.3.1.2a-1)

$q_n := c_{fnd} \cdot N_c \cdot S_c + \gamma_{fnd} \cdot D_f \cdot N_q \cdot S_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fnd} \cdot B' \cdot N_\gamma \cdot S_\gamma \cdot C_{w\gamma} = 50694.79\ psf$

Factored bearing resistance

$q_R := \phi_{bST} \cdot q_n = 32951.62\ psf$

Capacity to bearing resistance

$CBR_{bearing} := \dfrac{q_R}{\sigma_{v_st}} = 8.76$

Check bearing: $check_{bearing} := \begin{cases} \text{if } q_R \geq \sigma_{v_st} \\ \quad \text{"OK"} \\ \text{if } q_R < \sigma_{v_st} \\ \quad \text{"Revise No Good"} \end{cases} = \text{"OK"}$

10.0 Estimation of seismic earth pressure loading (Extreme event I - Pseudostatic)

Peak Ground Acceleration: $PGA = 0.422$

Site factor at zero period: $F_{PGA} = 1.200$

Peak seismic ground acceleration modified by short-period site factor: $A_s := F_{PGA} \cdot PGA = 0.506$ (AASHTO 3.10.4.2-2)

Seismic horizontal coefficient assuming zero wall displacement: $k_{ho} := A_s = 0.506$ (AASHTO 11.5.6.2.1)

Seismic horizontal coefficient for analysis: $k_h := 0.5 \cdot k_{ho} = 0.253$ (AASHTO C11.6.5.2.2)

Seismic horizontal coefficient for analysis (Generally taken as 0): $k_v := 0$ (AASHTO C11.6.5.2.1)

Monoabe-Okabe factor: $\theta_{MO} := \operatorname{atan}\left(\dfrac{k_h}{1 - k_v}\right) = 14.209\ °$ (AASHTO C11.6.5.3)

Backslope behind wall: $i := \beta = 0\ °$ (AASHTO A11.3.1)

Slope on face: $\beta_{face} := 0\ °$ (AASHTO A11.3.1)

<u>Seismic active earth pressure coefficient (AASHTO A11.3.1-1)</u>

$$K_{AE} := \frac{\cos\left(\phi_f - \theta_{MO} - \beta_{face}\right)^2}{\cos\left(\theta_{MO}\right) \cdot \cos\left(\beta_{face}\right)^2 \cdot \cos\left(\delta + \beta_{face} + \theta_{MO}\right)} \cdot \left(1 + \sqrt{\frac{\sin\left(\phi_f + \delta\right) \cdot \sin\left(\phi_f - \theta_{MO} - i\right)}{\cos\left(\delta + \beta_{face} + \theta_{MO}\right) \cdot \cos\left(i - \beta_{face}\right)}}\right)^{-2} = 0.479$$

Load factor for Extreme Event I, seismic forces: $EE := 1.0$ (AASHTO Fig. C11.5.6-4)

Load factor for live loads applied with seismic loads: $\gamma_{EQ} := 0.5$ (AASHTO C3.4.1)

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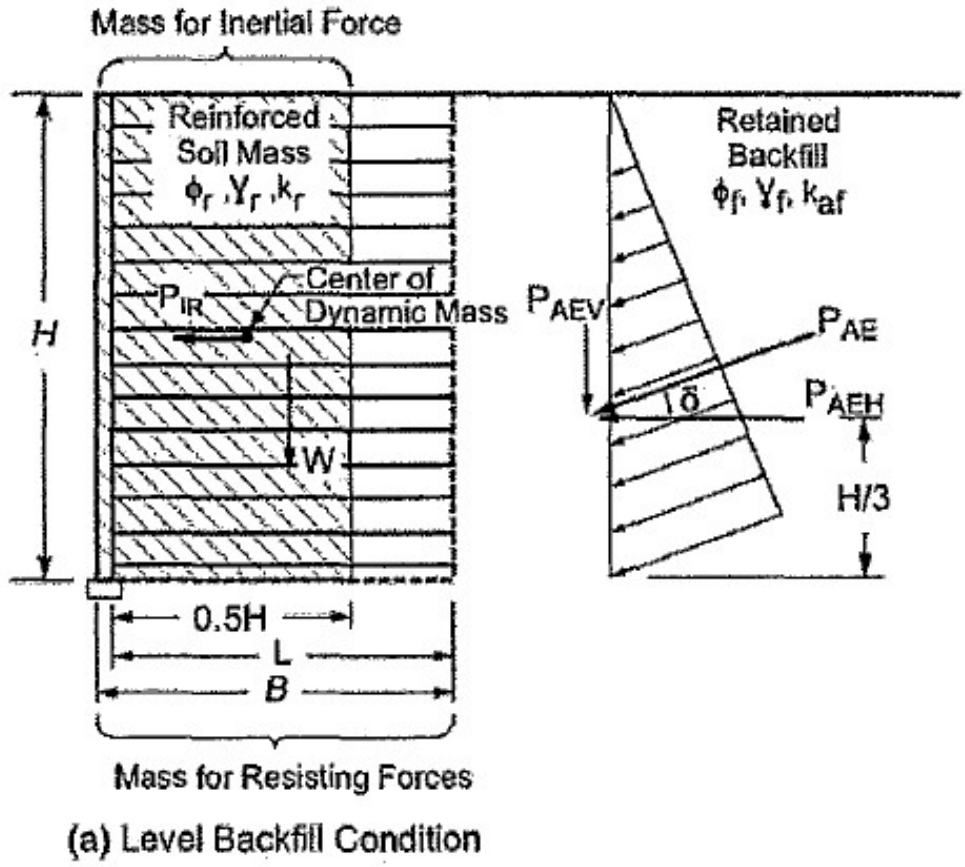
Seismic External Stability of an MSE Wall (AASHTO 11.10.5.2-1)



(a) Level Backfill Condition

Dynamic lateral earth pressure force: (AASHTO 11.10.7.1-1):

$$P_{AE} := 0.5 \cdot \gamma_f \cdot H^2 \cdot K_{AE} = 6.468 \ \frac{kip}{ft}$$

$$P_{AEh} := P_{AE} \cdot \cos(\delta) = 6.025 \ \frac{kip}{ft}$$

$$P_{AEv} := P_{AE} \cdot \sin(\delta) = 2.353 \ \frac{kip}{ft}$$

Dynamic lateral earth pressure due to live load: (AASHTO Figure 11.6.5.1-1)

$$F_P := K_{AE} \cdot \gamma_{EQ} \cdot q_L \cdot H = 0.898 \ \frac{kip}{ft}$$

$$F_{Ph} := F_P \cdot \cos(\delta) = 0.837 \ \frac{kip}{ft}$$

$$F_{Pv} := F_P \cdot \sin(\delta) = 0.327 \ \frac{kip}{ft}$$

Seismic Vertical Loading

Factored vertical load of reinforced soil mass (max): $V_1 := EE \cdot \gamma_b \cdot H \cdot L = 21.45 \ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := \gamma_{EQ} \cdot q_L \cdot L = 1.375 \ \frac{kip}{ft}$

Horizontal distance of centroid to center of wall footing

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Inertial horizontal force of wall and soil (AASHTO 11.10.7.1-1):

$$P_{IR} := \left(0.5 \cdot H^2 \cdot \gamma_b + w_u \cdot H \cdot \gamma_c\right) \cdot k_h = 3.978\ \frac{kip}{ft}$$

Unfactored load due to active earth pressure: $F_{1h} := 0.5 \cdot \gamma_f \cdot H^2 \cdot k_a \cdot \cos(\delta) = 3.458\ \frac{kip}{ft}$

Sum of vertical factored loads (maximum/bearing):

$$\Sigma V_{EE_max} := \left(V_1 + V_2\right) + \left(P_{AEv} + F_{Pv}\right) = 25.505\ \frac{kip}{ft}$$

Sum of vertical factored loads (minimum/eccentricity):

$$\Sigma V_{EE_min} := V_1 + \left(P_{AEv} + F_{Pv}\right) = 24.13\ \frac{kip}{ft}$$

Determine seismic force load cases for stability (AASHTO 11.6.5)

Case 1: 100% PAE with 50% PIR:

Horizontal loading due to seismic event: $T_{LC1} := EE \cdot P_{AEh} + 0.5 \cdot P_{IR} + F_{Ph} = 8.8512\ \frac{kip}{ft}$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov1_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 125.5375\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity): $M_{ov1_min} := V_1 \cdot x_{V1} = 117.975\ \frac{kip \cdot ft}{ft}$

Moment due to horizontal loads about toe of wall :

$$M_{oh1} := P_{AEh} \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + \left(0.5 \cdot P_{IR} \cdot \frac{H}{2}\right) = 51.321\ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1max} := M_{ov1_max} - M_{oh1} = 74.216\ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1min} := M_{ov1_min} - M_{oh1} = 66.654\ \frac{kip \cdot ft}{ft}$$

Case 2: max (50% PAE and static) with 100% PIR:

Horizontal loading due to seismic event:

$$T_{LC2} := EE \cdot \max\left(0.5 \cdot P_{AE}, F_{1h}\right) + P_{IR} + F_{Ph} = 8.2736\ \frac{kip}{ft}$$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov2_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 125.5375\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity):

$$M_{ov2_min} := V_1 \cdot x_{V1} = 117.975 \ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall:

$$M_{oh2} := \max\left(0.5 \cdot P_{AEh}, F_{1h}\right) \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + P_{IR} \cdot \frac{H}{2} = 53.406 \ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2max} := M_{ov2_max} - M_{oh2} = 72.131 \ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2min} := M_{ov2_min} - M_{oh2} = 64.569 \ \frac{kip \cdot ft}{ft}$$

Case 1: 100% PAE with 50% PIR:

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1max}}{\Sigma V_{EE_max}}\right| = 2.91 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 2.59 \ ft$

Maximum bearing stress: $\sigma_{v_LC1} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC1}} = 4382.5 \ psf$

Case 2: max (50% PAE and static) with 100% PIR:

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2max}}{\Sigma V_{EE_max}}\right| = 2.83 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left|\frac{L}{2} - X_{o_LC2}\right| = 2.67 \ ft$

Maximum bearing stress: $\sigma_{v_LC2} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC2}} = 4509.18 \ psf$

Maximum eccentricity of the wall (bearing): $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 2.67 \ ft$

Minimum calculated bearing stress: $\sigma_{vc} := \max\left(\sigma_{v_LC1}, \sigma_{v_LC2}\right) = 4509.18 \ psf$

10.1 Evaluate Wall Eccentricity Limits - Extreme I

Case 1: 100% PAE with 50% PIR:

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1min}}{\Sigma V_{EE_min}}\right| = 2.76 \ ft$

Eccentricity of wall (Eccentricity): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 2.74 \ ft$

Case 2: max (50% PAE and static) with 100% PIR:

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2min}}{\Sigma V_{EE_min}}\right| = 2.68 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left| \frac{L}{2} - X_{o_LC2} \right| = 2.82\ ft$

Eccentricity of wall about center of footing: $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 2.82\ ft$

Seismic eccentricity requirement (AASHTO 11.6.5.1):

1st ordered pair $x := \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ value of γ_{EQ}

2nd ordered pair $y := \begin{bmatrix} \frac{L}{3} \\ \frac{2 \cdot L}{5} \end{bmatrix}$ minimum eccentricity

Enter value to be interpolated: $e_{min} := \text{linterp}\left(x, y, \gamma_{EQ}\right) = 4.0333\ ft$

Check Eccentricity: $check_{ecc} := \left\| \begin{array}{l} \text{if } e_{wall_EE} \le e_{min} \\ \quad \text{"OK"} \\ \text{if } e_{wall_EE} > e_{min} \\ \quad \text{"Revise No Good"} \end{array} \right. = \text{"OK"}$

10.2 Evaluate Wall Sliding - Extreme I

Normal sliding resistance: $R_T := \Sigma V_{EE_min} \cdot \tan\left(\phi_{fnd}\right) = 18.183\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 18.183\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{\max\left(T_{LC1}, T_{LC2}\right)} = 2.054$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \ge \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"OK"} \\ \text{if } R_R < \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"Revise"} \end{array} \right. = \text{"OK"}$

11.0 Bearing Resistance Calculation (AASHTO 10.6.3.1.2a) - Extreme Event I

Footing Geometry based on structure submittals and cross sections

Total footing width: $B = 11\ ft$ Define B as L for length of minimum grid above

Footing length: $L_{wall} = 58\ ft$ Station 1+50 to 2+08

Groundwater depth: $D_w = 61\ ft$ Based on Station 1+75 (Section A - A')

Footing embedment depth: $D_f := 2\ ft$

Check Bearing Resistance (AASHTO 10.6.3.2)

Effective B (reduced due to moment): $B' := B - 2 \cdot e_{wall_EE} = 5.3517\ ft$

Bearing Capacity Factors (Equations used to tabulate AASHTO Table 10.6.3.1.2a-1)
Equations in Das, Braja M., 2019, "Principles of Foundation Engineering", 9th edition

$$N_q := e^{\pi \cdot \tan(\phi_{fnd})} \cdot \tan\left(45\,° + \frac{\phi_{fnd}}{2}\right)^2 = 42.92$$ (Reissner, 1924)

$$N_c := \text{if}\left(\phi_{fnd} = 0\,°, 5.14, (N_q - 1) \cdot \cot(\phi_{fnd})\right) = 55.63$$ (Prandtl, 1921)

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fnd}) = 66.19$$ (Vesic, 1975)

Shape factors (AASHTO Table 10.6.3.1.2a-3)

$$S_c := \text{if}\left(\phi_{fnd} = 0, 1 + \left(\frac{B'}{5 \cdot L_{wall}}\right), 1 + \frac{B'}{L_{wall}} \cdot \frac{N_q}{N_c}\right) = 1.07$$

$$S_\gamma := \text{if}\left(\phi_{fnd} = 0, 1, 1 - 0.40 \cdot \left(\frac{B'}{L_{wall}}\right)\right) = 0.96$$

$$S_q := \text{if}\left(\phi_{fnd} = 0, 1, 1 + \left(\frac{B'}{L_{wall}}\right) \cdot \tan(\phi_{fnd})\right) = 1.07$$

Groundwater coefficients (AASHTO Table 10.6.3.1.2a-2)

$$C_{wq} := \text{if}(D_w = 0, 0.5, 1.0) = 1$$

$$C_{w\gamma} := \text{if}\left(D_w = 0, 0.5, \text{if}\left(D_w > 1.5 \cdot B' + D_f, 1.0, 0.5\right)\right) = 1$$

Depth correction factor (AASHTO 10.6.3.1.2a): Conservatively taken as 1.0

$$d_q := 1.0$$

Nominal bearing resistance (AASHTO 10.6.3.1.2a-1)

$$q_n := c_{fnd} \cdot N_c \cdot S_c + \gamma_{fnd} \cdot D_f \cdot N_q \cdot S_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fnd} \cdot B' \cdot N_\gamma \cdot S_\gamma \cdot C_{w\gamma} = 33.59\ ksf$$

Factored bearing resistance

$$q_R := \phi_{bEE} \cdot q_n = 30.23\ ksf$$

Capacity to bearing resistance

$$CBR_{bearing} := \frac{q_R}{\sigma_{vc}} = 6.7$$

Check bearing: $check_{bearing} := \begin{cases} \text{if } q_R \geq \sigma_{vc} \\ \quad \text{"OK"} \\ \text{if } q_R < \sigma_{vc} \\ \quad \text{"Revise No Good"} \end{cases} = \text{"OK"}$

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I-405 R2B Express Toll Lanes
Segment 2B Wall 10.18R-A
STA -2+08
Hand Calculations for Geosynthetic Wall

Date: January 2022

Prepared For: ***Flatiron-Lane Joint Venture***

Prepared By:

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1.0 PURPOSE

The purpose of this design calculation package is to evaluate external stability of the wall; i.e., the eccentricity, sliding, and bearing resistance at the Strength I and Extreme I Limit State in accordance with *AASHTO LRFD Bridge Design Specifications* (8th edition). Results of global stability based on AASHTO and WSDOT GDM procedures for Service I limit state are also presented. Note settlement analysis of wall performed under separate cover.

2.0 REFERENCES

The following references for developing this calculation package:

1. *AASHTO LRFD Bridge Design Specifications* (2017), 8th Edition;
2. *WSDOT Geotechnical Design Manual* (GDM) M 46-03.11, May 2015 and Addendum M 46-03.12 Revision Chapters 6 & 15;
3. *WSDOT Design Manual M22-01.18*, December 2019 and *M22-01.05* June 2009;
4. WSDOT "Backfill and Drainage for Retaining Walls Standard Plan D-4" dated December 11, 1998;
5. "I-405 Seismic Hazard" (calculations) dated March 31, 2020 and prepared by Wood.
6. *NCHRP Report 611 Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments* (2008).

3.0 METHODOLOGY

The intent of this calculation is to evaluate the eccentricity, sliding, bearing, and global resistance at the specified design height (see below). In general, the effective wall footing width and rectangular bearing stress were calculated. These were then compared to the calculated strength and extreme event bearing resistance of the foundation soils.

The used design backfill properties are within the suggested range in the GDM Table 5-2. For the foundation soils, the estimated strength parameters for the engineering stratigraphic unit (ESU) (calculated under separate cover) were used.

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Worksheet Input Parameters

Analyzed Wall and Section: Wall 10.18R-A Station 2+08

Bottom of Geosynthetic wall = Elev. 102.0 ft and Top of Geosynthetic wall = 111.0 ft

4.0 ASSUMPTIONS

Shear strength parameters of wall foundation subgrade, $\phi_{fnd} := 37\ °$, are based on the weighted average strength parameters within zone of influence.

The ground surface in front of the wall is horizontal, the minimum embedment shall be 2ft or 10% of height whichever is exposed height whichever is larger.

5.0 SOIL PROPERTIES AND DESIGN PARAMETERS USED FOR CALCULATIONS

Retained Fill/ Backfill for Wall: GDM 15.6

$\gamma_f := 120\ pcf$

$\phi_f := 32\ °$

$c_f := 0\ psf$

Foundation Soil: (weighted average)

$\gamma_{fnd} := 128\ pcf$ $c_{fnd} := 0\ psf$

$\phi_{fnd} := 37\ °$

$\phi_{slide_interface} := 0.7 \cdot \phi_{fnd} = 25.9\ °$

Gravel Backfill for Walls: GDM Table 5-2

$\gamma_b := 130\ pcf$

Unit weight of water:

$\gamma_w := 62.4\ pcf$

Sliding interface friction angle equal to 0.7 times the interface foundation layer friction angle, based on WSDOT GDM Section 15.6

Exposed wall height: $H' := 7\ ft$ Based on structure cross sections

Live load surcharge: $q_L := 250\ psf$ (AASHTO 3.11.6.4 and GDM 15.4.9)

Min. Embedment of wall: $E := \max(0.1 \cdot H', 2\ ft) = 2\ ft$ WSDOT Standard Drawing D-3.09-00

Design height (included embedment): $H := H' + E = 9\ ft$

WSDOT standard wall height: $H := 9\ ft$ Wall height used in calculations

Minimum Length of reinforcement: $L := 0.7 \cdot H = 6.3\ ft$

Length of reinforcement: $L := 11\ ft$ WSDOT Standard Drawing D-3.09-00

Precast or CIP wall facing width: $w_u := 6\ in$

Angle of backfill incline: $\beta := \operatorname{atan}\left(\frac{0}{2}\right) = 0\ °$

Wall batter: $\theta := 90\ °$

Friction angle between fill and wall: $\delta := \frac{2}{3} \cdot \phi_f = 21.33\ °$ (AASHTO C3.11.5.3)

Assumed unit weight of concrete: $\gamma_c := 145\ pcf$ (AASHTO Table 3.5.1-1)

Peak Ground Acceleration: $PGA := 0.422$

Site factor at zero period: $F_{PGA} := 1.200$

Wood Calculation for I-405 Project "Seismic Hazard" dated March 31, 2020" for Site Class C

6.0 Load and Resistance Factors:

Resistance factors

Resistance factors for bearing capacity: $\phi_{bST} := 0.65$ (AASHTO Table 11.5.7.1)

Resistance factors for extreme event: $\phi_{EE} := 1.0$ (AASHTO 10.5.5.3.3)

Resistance factors for extreme event (bearing): $\phi_{bEE} := 0.9$ (AASHTO 11.5.8)

Resistance factors for MSE sliding: $\phi_{slide} := 1.0$ (AASHTO Table 11.5.7.1)

<u>Load factors - Service I (AASHTO Table 3.4.1-1):</u>

Vertical earth pressure load factor: $EV_s := 1.0$

Horizontal earth pressure load factor: $EH_s := 1.0$

Live load traffic surcharge load factor: $LS_s := 1.0$

Dead load traffic surcharge load factor: $DC_s := 1.0$

<u>Load factors - Strength I (AASHTO Table 3.4.1-1 and 3.4.1-2):</u>

Vertical earth pressure load factor: $EV_{Imax} := 1.35$ $EV_{Imin} := 1.0$

Horizontal earth pressure load factor: $EH_{Imax} := 1.5$ $EH_{Imin} := 0.9$

Live load traffic surcharge load factor: $LS_I := 1.75$

Dead load of structure load factor: $DC_{Imax} := 1.25$ $DC_{Imin} := 0.9$

<u>Earth Pressure Coefficients for External Wall Loading</u>

$$\Gamma := \left(1 + \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f - \beta)}{\sin(\theta - \delta) \cdot \sin(\theta + \beta)}}\right)^2 = 2.81$$

Active soil pressure coefficient for retained soil (AASHTO 3.11.5.3)

$$k_a := \frac{\sin(\theta + \phi_f)^2}{\Gamma\left(\sin(\theta)^2 \cdot \sin(\theta - \delta)\right)} = 0.275$$

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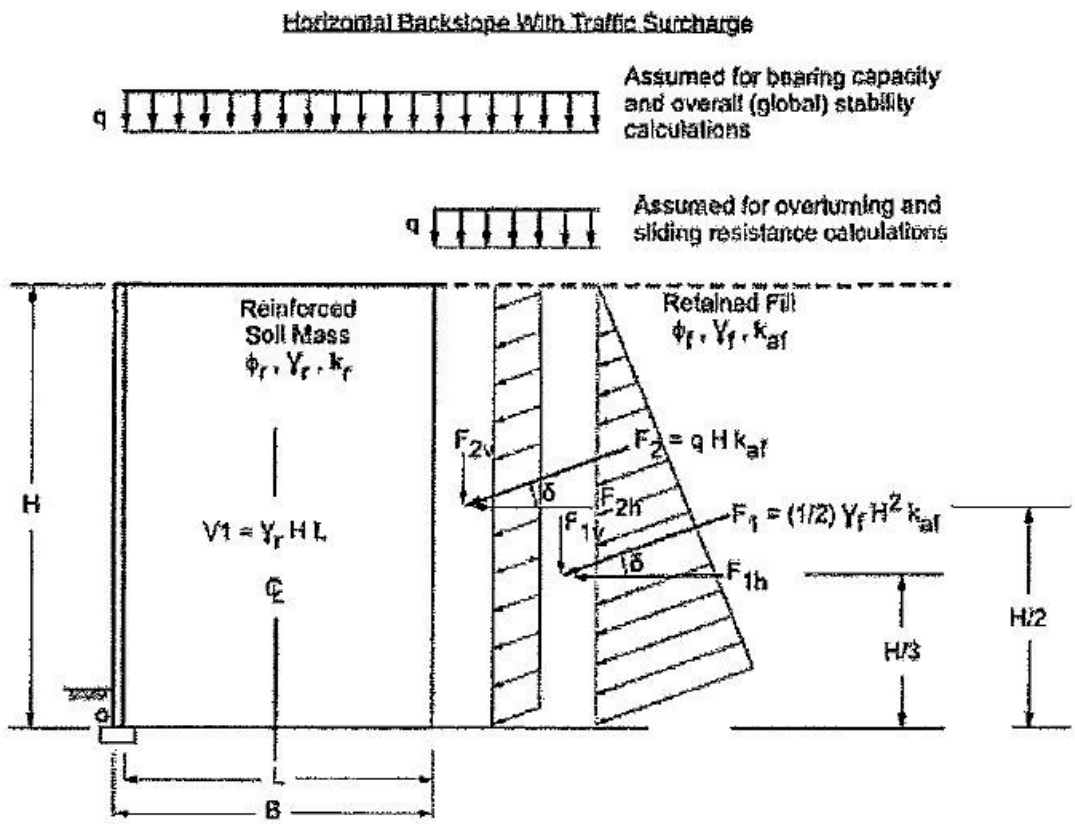
Free body Diagram for Wall Geometry and Load Locations (AASHTO 11.10.5.2-1)



7.0 Wall Loading - Service I (AASHTO Figure C11.5.6-1 and C11.5.6-3 using Service Limit Load Factors)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_s \cdot \gamma_b \cdot H \cdot L = 12.87\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_s \cdot q_L \cdot L = 2.75\ \frac{kip}{ft}$

<u>Factored horizontal load due to active earth pressure:</u> $F_1 := 0.5 \cdot EH_s \cdot \gamma_f \cdot H^2 \cdot k_a = 1.34\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 0.49\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 1.25\ \frac{kip}{ft}$

<u>Factored horizontal load due to LL surcharge:</u> $F_2 := LS_s \cdot q_L \cdot H \cdot k_a = 0.62\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.23\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 0.58\ \frac{kip}{ft}$

Sum of vertical factored loads: $\Sigma V := (V_1 + V_2) + (F_{1v} + F_{2v}) = 16.33\ \frac{kip}{ft}$

Horizontal distance of toe to center of vertical weight/load

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Moment due to vertical loads about the toe of wall:

$$M_{ov} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 93.74\ \frac{kip \cdot ft}{ft}$$

Moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 6.33\ \frac{kip \cdot ft}{ft}$$

Net moment due to vertical and horizontal loads about toe of wall: $M_{net} := M_{ov} - M_{oh} = 87.41\ \frac{kip \cdot ft}{ft}$

Overturning eccentricity: $X_o := \frac{M_{net}}{\Sigma V} = 5.35\ ft$

Eccentricity of wall (bearing): $e_{wall_s} := \left| \frac{L}{2} - X_o \right| = 0.15\ ft$

Maximum bearing stress (Service I): $\sigma_{v_s} := \frac{\Sigma V}{L - 2 \cdot e_{wall_s}} = 1525.71\ psf$ (AASHTO 11.6.3.2-1)

Settlement analysis should be evaluated (under separate cover) for a length of footing of $L = 11.0\ ft$ and a maximum bearing pressure at the base of the reinforcement zone of $\sigma_{v_s} = 1526\ psf$.

8.0 Wall Loading - Strength I (AASHTO Figure C11.5.6-1 and C11.5.6-3)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_{Imax} \cdot \gamma_b \cdot H \cdot L = 17.375\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_I \cdot q_L \cdot L = 4.813\ \frac{kip}{ft}$

Factored vertical load of reinforced soil mass (min): $V_3 := EV_{Imin} \cdot \gamma_f \cdot H \cdot L = 11.88\ \frac{kip}{ft}$

Factored horizontal load due to active earth pressure: $F_1 := 0.5 \cdot EH_{Imax} \cdot \gamma_f \cdot H^2 \cdot k_a = 2.005\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 0.729\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 1.868\ \frac{kip}{ft}$

Factored horizontal load due to LL surcharge: $F_2 := LS_I \cdot q_L \cdot H \cdot k_a = 1.083\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.394\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 1.009\ \frac{kip}{ft}$

Sum of maximum vertical factored loads (bearing): $\Sigma V_{max} := (V_1 + V_2) + (F_{1v} + F_{2v}) = 23.31 \ \frac{kip}{ft}$

Sum of minimum vertical factored loads (Ecc/Slide): $\Sigma V_{min} := V_3 + (F_{1v} + F_{2v}) = 13.003 \ \frac{kip}{ft}$

Maximum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 134.385 \ \frac{kip \cdot ft}{ft}$$

Minimum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_min} := V_3 \cdot x_{V1} + (F_{1v} + F_{2v}) \cdot L = 77.697 \ \frac{kip \cdot ft}{ft}$$

Driving moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 10.142 \ \frac{kip \cdot ft}{ft}$$

Maximum net moment due to vertical and horizontal loads about toe of wall (bearing):

$$M_{net_max} := M_{ov_max} - M_{oh} = 124.243 \ \frac{kip \cdot ft}{ft}$$

Minimum net moment due to vertical and horizontal loads about toe of wall (Ecc/slide):

$$M_{net_min} := M_{ov_min} - M_{oh} = 67.555 \ \frac{kip \cdot ft}{ft}$$

Overturning eccentricity (bearing): $X_o := \frac{M_{net_max}}{\Sigma V_{max}} = 5.33 \ ft$

Eccentricity of wall about the center of footing (bearing): $e_{wall_max} := \left| \frac{L}{2} - X_o \right| = 0.17 \ ft$

Maximum bearing stress (Strength 1) to be used in bearing check: $\sigma_{v_max} := \frac{\Sigma V_{max}}{L - 2 \cdot e_{wall_max}} = 2186.72 \ psf$ (AASHTO 11.6.3.2-1)

Maximum bearing stress (Strength I): $\sigma_{v_st} := \sigma_{v_max} = 2186.72 \ psf$

8.1 Evaluate Wall Eccentricity Limits - Strength I

Overturning eccentricity (Ecc/sliding): $X_{o_min} := \frac{M_{net_min}}{\Sigma V_{min}} = 5.1952 \ ft$

Eccentricity of wall about the center of footing (Ecc/sliding): $e_{wall_min} := \left| \frac{L}{2} - X_{o_min} \right| = 0.3 \ ft$

Check Eccentricity (AASHTO 10.6.3.3):

$$check_{ecc} := \begin{cases} \text{"OK"} & \text{if } e_{wall_min} \le \frac{L}{3} \\ \text{"Revise"} & \text{if } e_{wall_min} > \frac{L}{3} \end{cases} = \text{"OK"}$$

8.2 Evaluate Wall Sliding - Strength I

Normal sliding resistance: $R_T := \Sigma V_{min} \cdot \tan(\phi_{fnd}) = 9.7987 \frac{kip}{ft}$ (AASHTO 10.6.3.4-1/2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 9.7987 \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{F_{1h} + F_{2h}} = 3.407$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \geq F_{1h} + F_{2h} \\ \quad \text{"OK"} \\ \text{if } R_R < F_{1h} + F_{2h} \\ \quad \text{"Revise"} \end{array} \right\| = \text{"OK"}$

10.0 Estimation of seismic earth pressure loading (Extreme event I - Pseudostatic)

Peak Ground Acceleration: $PGA = 0.422$

Site factor at zero period: $F_{PGA} = 1.200$

Peak seismic ground acceleration modified by short-period site factor: $A_s := F_{PGA} \cdot PGA = 0.506$ (AASHTO 3.10.4.2-2)

Seismic horizontal coefficient assuming zero wall displacement: $k_{ho} := A_s = 0.506$ (AASHTO 11.5.6.2.1)

Seismic horizontal coefficient for analysis: $k_h := 0.5 \cdot k_{ho} = 0.253$ (AASHTO C11.6.5.2.2)

Seismic horizontal coefficient for analysis (Generally taken as 0): $k_v := 0$ (AASHTO C11.6.5.2.1)

Monoabe-Okabe factor: $\theta_{MO} := \operatorname{atan}\left(\frac{k_h}{1 - k_v}\right) = 14.209\ °$ (AASHTO C11.6.5.3)

Backslope behind wall: $i := \beta = 0\ °$ (AASHTO A11.3.1)

Slope on face: $\beta_{face} := 0\ °$ (AASHTO A11.3.1)

<u>Seismic active earth pressure coefficient (AASHTO A11.3.1-1)</u>

$$K_{AE} := \frac{\cos(\phi_f - \theta_{MO} - \beta_{face})^2}{\cos(\theta_{MO}) \cdot \cos(\beta_{face})^2 \cdot \cos(\delta + \beta_{face} + \theta_{MO})} \cdot \left(1 + \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f - \theta_{MO} - i)}{\cos(\delta + \beta_{face} + \theta_{MO}) \cdot \cos(i - \beta_{face})}}\right)^{-2} = 0.479$$

Load factor for Extreme Event I, seismic forces: $EE := 1.0$ (AASHTO Fig. C11.5.6-4)

Load factor for live loads applied with seismic loads: $\gamma_{EQ} := 0.5$ (AASHTO C3.4.1)

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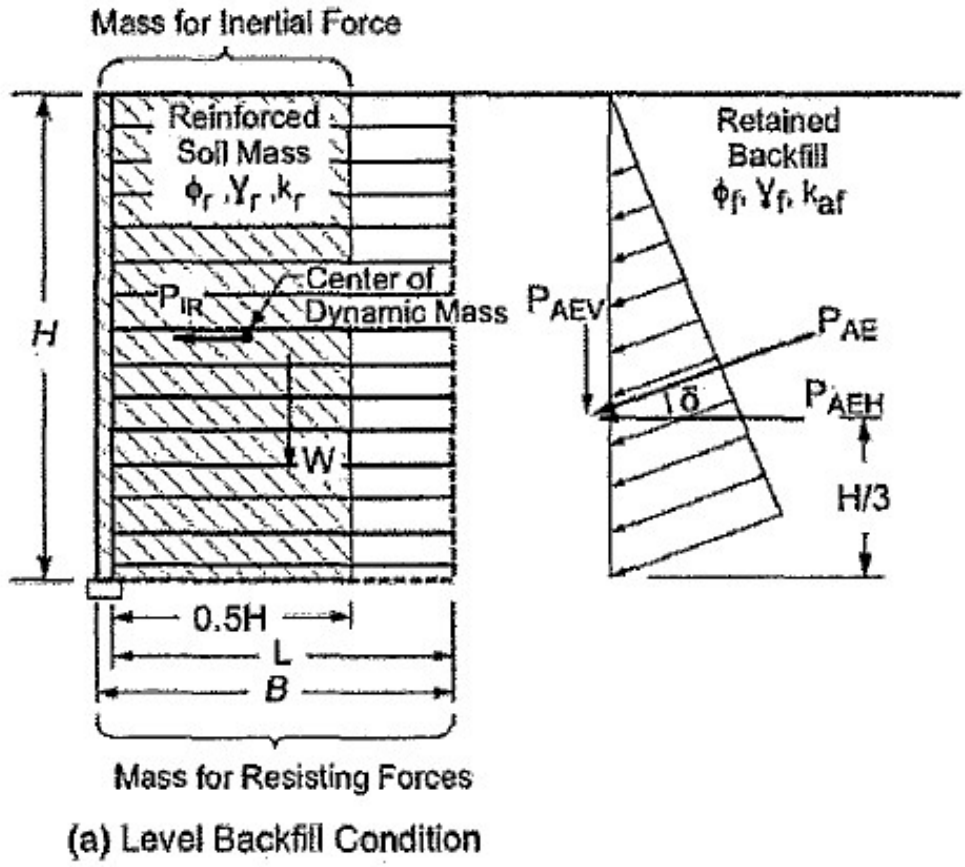
Seismic External Stability of an MSE Wall (AASHTO 11.10.5.2-1)



(a) Level Backfill Condition

Dynamic lateral earth pressure force: (AASHTO 11.10.7.1-1):

$$P_{AE} := 0.5 \cdot \gamma_f \cdot H^2 \cdot K_{AE} = 2.329 \ \frac{kip}{ft}$$

$$P_{AEh} := P_{AE} \cdot \cos(\delta) = 2.169 \ \frac{kip}{ft}$$

$$P_{AEv} := P_{AE} \cdot \sin(\delta) = 0.847 \ \frac{kip}{ft}$$

Dynamic lateral earth pressure due to live load: (AASHTO Figure 11.6.5.1-1)

$$F_P := K_{AE} \cdot \gamma_{EQ} \cdot q_L \cdot H = 0.539 \ \frac{kip}{ft}$$

$$F_{Ph} := F_P \cdot \cos(\delta) = 0.502 \ \frac{kip}{ft}$$

$$F_{Pv} := F_P \cdot \sin(\delta) = 0.196 \ \frac{kip}{ft}$$

Seismic Vertical Loading

Factored vertical load of reinforced soil mass (max): $V_1 := EE \cdot \gamma_b \cdot H \cdot L = 12.87 \ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := \gamma_{EQ} \cdot q_L \cdot L = 1.375 \ \frac{kip}{ft}$

Horizontal distance of centroid to center of wall footing

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Inertial horizontal force of wall and soil (AASHTO 11.10.7.1-1):

$$P_{IR} := \left(0.5 \cdot H^2 \cdot \gamma_b + w_u \cdot H \cdot \gamma_c\right) \cdot k_h = 1.498\ \frac{kip}{ft}$$

Unfactored load due to active earth pressure: $F_{1h} := 0.5 \cdot \gamma_f \cdot H^2 \cdot k_a \cdot \cos(\delta) = 1.245\ \frac{kip}{ft}$

Sum of vertical factored loads (maximum/bearing):

$$\Sigma V_{EE_max} := \left(V_1 + V_2\right) + \left(P_{AEv} + F_{Pv}\right) = 15.288\ \frac{kip}{ft}$$

Sum of vertical factored loads (minimum/eccentricity):

$$\Sigma V_{EE_min} := V_1 + \left(P_{AEv} + F_{Pv}\right) = 13.913\ \frac{kip}{ft}$$

Determine seismic force load cases for stability (AASHTO 11.6.5)

Case 1: 100% PAE with 50% PIR:

Horizontal loading due to seismic event: $T_{LC1} := EE \cdot P_{AEh} + 0.5 \cdot P_{IR} + F_{Ph} = 3.4203\ \frac{kip}{ft}$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov1_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 78.3475\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity): $M_{ov1_min} := V_1 \cdot x_{V1} = 70.785\ \frac{kip \cdot ft}{ft}$

Moment due to horizontal loads about toe of wall :

$$M_{oh1} := P_{AEh} \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + \left(0.5 \cdot P_{IR} \cdot \frac{H}{2}\right) = 12.138\ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1max} := M_{ov1_max} - M_{oh1} = 66.210\ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1min} := M_{ov1_min} - M_{oh1} = 58.647\ \frac{kip \cdot ft}{ft}$$

Case 2: max (50% PAE and static) with 100% PIR:

Horizontal loading due to seismic event:

$$T_{LC2} := EE \cdot \max\left(0.5 \cdot P_{AE}, F_{1h}\right) + P_{IR} + F_{Ph} = 3.2454\ \frac{kip}{ft}$$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov2_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 78.3475\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity):

$$M_{ov2_min} := V_1 \cdot x_{V1} = 70.785 \ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall:

$$M_{oh2} := \max\left(0.5 \cdot P_{AEh}, F_{1h}\right) \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + P_{IR} \cdot \frac{H}{2} = 12.737 \ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2max} := M_{ov2_max} - M_{oh2} = 65.611 \ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2min} := M_{ov2_min} - M_{oh2} = 58.048 \ \frac{kip \cdot ft}{ft}$$

Case 1: 100% PAE with 50% PIR:

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1max}}{\Sigma V_{EE_max}}\right| = 4.33 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 1.17 \ ft$

Maximum bearing stress: $\sigma_{v_LC1} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC1}} = 1765.08 \ psf$

Case 2: max (50% PAE and static) with 100% PIR:

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2max}}{\Sigma V_{EE_max}}\right| = 4.29 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left|\frac{L}{2} - X_{o_LC2}\right| = 1.21 \ ft$

Maximum bearing stress: $\sigma_{v_LC2} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC2}} = 1781.19 \ psf$

Maximum eccentricity of the wall (bearing): $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 1.21 \ ft$

Minimum calculated bearing stress: $\sigma_{vc} := \max\left(\sigma_{v_LC1}, \sigma_{v_LC2}\right) = 1781.19 \ psf$

10.1 Evaluate Wall Eccentricity Limits - Extreme I

Case 1: 100% PAE with 50% PIR:

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1min}}{\Sigma V_{EE_min}}\right| = 4.22 \ ft$

Eccentricity of wall (Eccentricity): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 1.28 \ ft$

Case 2: max (50% PAE and static) with 100% PIR:

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2min}}{\Sigma V_{EE_min}}\right| = 4.17 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left| \frac{L}{2} - X_{o_LC2} \right| = 1.33\ ft$

Eccentricity of wall about center of footing: $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 1.33\ ft$

Seismic eccentricity requirement (AASHTO 11.6.5.1):

1st ordered pair $x := \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ value of γ_{EQ}

2nd ordered pair $y := \begin{bmatrix} \frac{L}{3} \\ \frac{2 \cdot L}{5} \end{bmatrix}$ minimum eccentricity

Enter value to be interpolated: $e_{min} := \text{linterp}\left(x, y, \gamma_{EQ}\right) = 4.0333\ ft$

Check Eccentricity: $check_{ecc} := \left\| \begin{array}{l} \text{if } e_{wall_EE} \le e_{min} \\ \quad \text{"OK"} \\ \text{if } e_{wall_EE} > e_{min} \\ \quad \text{"Revise No Good"} \end{array} \right. = \text{"OK"}$

10.2 Evaluate Wall Sliding - Extreme I

Normal sliding resistance: $R_T := \Sigma V_{EE_min} \cdot \tan\left(\phi_{fnd}\right) = 10.484\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 10.484\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{\max\left(T_{LC1}, T_{LC2}\right)} = 3.065$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \ge \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"OK"} \\ \text{if } R_R < \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"Revise"} \end{array} \right. = \text{"OK"}$

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I-405 R2B Express Toll Lanes
Segment 2B Wall 10.18R-B
STA ~6+00
Hand Calculations for MSE

Date: January 2022

Prepared For: ***Flatiron-Lane Joint Venture***

Prepared By:

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1.0 PURPOSE

The purpose of this design calculation package is to evaluate external stability of the wall; i.e., the eccentricity, sliding, and bearing resistance at the Strength I and Extreme I Limit State in accordance with *AASHTO LRFD Bridge Design Specifications* (8th edition). Results of global stability based on AASHTO and WSDOT GDM procedures for Service I limit state are also presented. Note settlement analysis of wall performed under separate cover.

2.0 REFERENCES

The following references for developing this calculation package:

1. *AASHTO LRFD Bridge Design Specifications* (2017), 8th Edition;
2. *WSDOT Geotechnical Design Manual* (GDM) M 46-03.11, May 2015 and Addendum M 46-03.12 Revision Chapters 6 & 15;
3. *WSDOT Design Manual M22-01.18*, December 2019 and *M22-01.05* June 2009;
4. WSDOT "Backfill and Drainage for Retaining Walls Standard Plan D-4" dated December 11, 1998;
5. "I-405 Seismic Hazard" (calculations) dated March 31, 2020 and prepared by Wood.
6. *NCHRP Report 611 Seismic Analysis and Design of Retaining Walls, Buried Structures, Slopes, and Embankments* (2008).

3.0 METHODOLOGY

The intent of this calculation is to evaluate the eccentricity, sliding, bearing, and global resistance at the specified design height (see below). In general, the effective wall footing width and rectangular bearing stress were calculated. These were then compared to the calculated strength and extreme event bearing resistance of the foundation soils.

The used design backfill properties are within the suggested range in the GDM Table 5-2. For the foundation soils, the estimated strength parameters for the engineering stratigraphic unit (ESU) (calculated under separate cover) were used.

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Worksheet Input Parameters

Analyzed Wall and Section: **Wall 10.18R-B Station 6+00**

Bottom of MSE wall = Elev. 119.0 ft and Top of SEW wall = 126.0 ft

4.0 ASSUMPTIONS

Shear strength parameters of wall foundation subgrade, $\phi_{fnd} := 38\ °$, are based boring GEO-33 using the lower bound parameters of ESU 1B.

The ground surface in front of the wall is horizontal, the minimum embedment shall be 2ft or 10% of height whichever is exposed height whichever is larger.

5.0 SOIL PROPERTIES AND DESIGN PARAMETERS USED FOR CALCULATIONS

Retained Fill/ Backfill for Wall: GDM 15.6

$\gamma_f := 120\ pcf$

$\phi_f := 32\ °$

$c_f := 0\ psf$

Foundation Soil: (ESU 1B)

$\gamma_{fnd} := 130\ pcf$ $c_{fnd} := 0\ psf$

$\phi_{fnd} := 38\ °$

$\phi_{slide_interface} := 0.7 \cdot \phi_{fnd} = 26.6\ °$

Gravel Backfill for Walls: GDM Table 5-2

$\gamma_b := 130\ pcf$

Unit weight of water:

$\gamma_w := 62.4\ pcf$

Sliding interface friction angle equal to 0.7 times the interface foundation layer friction angle, based on WSDOT GDM Section 15.6

Exposed wall height: $H' := 5\ ft$ Based on structure cross sections

Live load surcharge: $q_L := 250\ psf$ (AASHTO 3.11.6.4 and GDM 15.4.9)

Min. Embedment of wall: $E := \max(0.1 \cdot H', 2\ ft) = 2\ ft$ WSDOT Standard Drawing D-3.09-00

Design height (included embedment): $H := H' + E = 7\ ft$

WSDOT standard wall height: $H := 7\ ft$ Wall height used in calculations

Minimum Length of reinforcement: $L := 0.7 \cdot H = 4.9\ ft$

Length of reinforcement: $L := 11\ ft$ WSDOT Standard Drawing D-3.09-00

Precast or CIP wall facing width: $w_u := 6\ in$

Angle of backfill incline: $\beta := \operatorname{atan}\left(\frac{0}{2}\right) = 0\ °$

Wall batter: $\theta := 90\ °$

Friction angle between fill and wall: $\delta := \frac{2}{3} \cdot \phi_f = 21.33\ °$ (AASHTO C3.11.5.3)

Assumed unit weight of concrete: $\gamma_c := 145\ pcf$ (AASHTO Table 3.5.1-1)

Peak Ground Acceleration: $PGA := 0.422$

Site factor at zero period: $F_{PGA} := 1.200$

Wood Calculation for I-405 Project "Seismic Hazard" dated March 31, 2020" for Site Class C

6.0 Load and Resistance Factors:

Resistance factors

Resistance factors for bearing capacity: $\phi_{bST} := 0.65$ (AASHTO Table 11.5.7.1)

Resistance factors for extreme event: $\phi_{EE} := 1.0$ (AASHTO 10.5.5.3.3)

Resistance factors for extreme event (bearing): $\phi_{bEE} := 0.9$ (AASHTO 11.5.8)

Resistance factors for MSE sliding: $\phi_{slide} := 1.0$ (AASHTO Table 11.5.7.1)

<u>Load factors - Service I (AASHTO Table 3.4.1-1):</u>

Vertical earth pressure load factor: $EV_s := 1.0$

Horizontal earth pressure load factor: $EH_s := 1.0$

Live load traffic surcharge load factor: $LS_s := 1.0$

Dead load traffic surcharge load factor: $DC_s := 1.0$

<u>Load factors - Strength I (AASHTO Table 3.4.1-1 and 3.4.1-2):</u>

Vertical earth pressure load factor: $EV_{Imax} := 1.35$ $EV_{Imin} := 1.0$

Horizontal earth pressure load factor: $EH_{Imax} := 1.5$ $EH_{Imin} := 0.9$

Live load traffic surcharge load factor: $LS_I := 1.75$

Dead load of structure load factor: $DC_{Imax} := 1.25$ $DC_{Imin} := 0.9$

<u>Earth Pressure Coefficients for External Wall Loading</u>

$$\Gamma := \left(1 + \sqrt{\frac{\sin(\phi_f + \delta) \cdot \sin(\phi_f - \beta)}{\sin(\theta - \delta) \cdot \sin(\theta + \beta)}}\right)^2 = 2.81$$

Active soil pressure coefficient for retained soil (AASHTO 3.11.5.3)

$$k_a := \frac{\sin(\theta + \phi_f)^2}{\Gamma\left(\sin(\theta)^2 \cdot \sin(\theta - \delta)\right)} = 0.275$$

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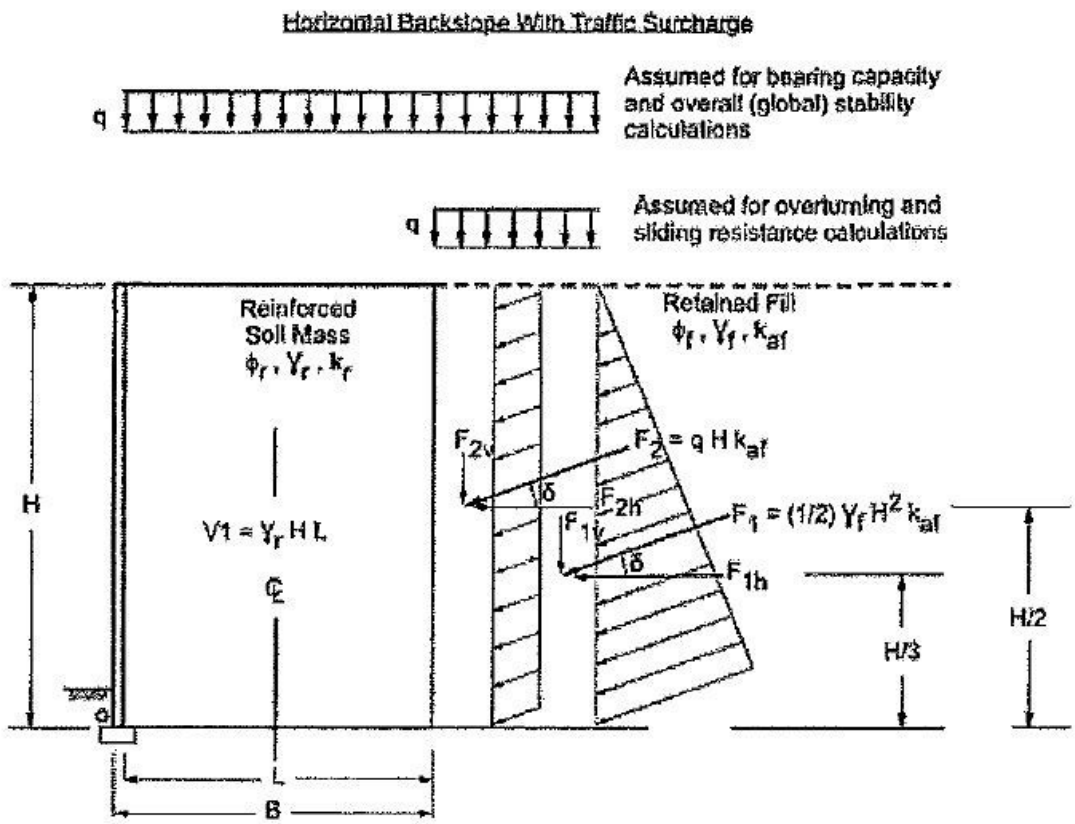
Free body Diagram for Wall Geometry and Load Locations (AASHTO 11.10.5.2-1)



7.0 Wall Loading - Service I (AASHTO Figure C11.5.6-1 and C11.5.6-3 using Service Limit Load Factors)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_s \cdot \gamma_b \cdot H \cdot L = 10.01\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_s \cdot q_L \cdot L = 2.75\ \frac{kip}{ft}$

Factored horizontal load due to active earth pressure: $F_1 := 0.5 \cdot EH_s \cdot \gamma_f \cdot H^2 \cdot k_a = \left(808.57 \cdot 10^{-3}\right)\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 0.29\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 0.75\ \frac{kip}{ft}$

Factored horizontal load due to LL surcharge: $F_2 := LS_s \cdot q_L \cdot H \cdot k_a = 0.48\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.18\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 0.45\ \frac{kip}{ft}$

Sum of vertical factored loads: $\Sigma V := (V_1 + V_2) + (F_{1v} + F_{2v}) = 13.23\ \frac{kip}{ft}$

Horizontal distance of toe to center of vertical weight/load

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Moment due to vertical loads about the toe of wall:

$$M_{ov} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 75.34\ \frac{kip \cdot ft}{ft}$$

Moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 3.33\ \frac{kip \cdot ft}{ft}$$

Net moment due to vertical and horizontal loads about toe of wall: $M_{net} := M_{ov} - M_{oh} = 72.02\ \frac{kip \cdot ft}{ft}$

Overturning eccentricity: $X_o := \frac{M_{net}}{\Sigma V} = 5.44\ ft$

Eccentricity of wall (bearing): $e_{wall_s} := \left| \frac{L}{2} - X_o \right| = 0.06\ ft$

Maximum bearing stress (Service I): $\sigma_{v_s} := \frac{\Sigma V}{L - 2 \cdot e_{wall_s}} = 1215.11\ psf$ (AASHTO 11.6.3.2-1)

Settlement analysis should be evaluated (under separate cover) for a length of footing of $L = 11.0\ ft$ and a maximum bearing pressure at the base of the reinforcement zone of $\sigma_{v_s} = 1215\ psf$.

8.0 Wall Loading - Strength I (AASHTO Figure C11.5.6-1 and C11.5.6-3)

Factored vertical load of reinforced soil mass (max): $V_1 := EV_{Imax} \cdot \gamma_b \cdot H \cdot L = 13.514\ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := LS_I \cdot q_L \cdot L = 4.813\ \frac{kip}{ft}$

Factored vertical load of reinforced soil mass (min): $V_3 := EV_{Imin} \cdot \gamma_f \cdot H \cdot L = 9.24\ \frac{kip}{ft}$

Factored horizontal load due to active earth pressure: $F_1 := 0.5 \cdot EH_{Imax} \cdot \gamma_f \cdot H^2 \cdot k_a = 1.213\ \frac{kip}{ft}$

Factored vertical component: $F_{1v} := F_1 \cdot \sin(\delta) = 0.441\ \frac{kip}{ft}$

Factored horizontal component: $F_{1h} := F_1 \cdot \cos(\delta) = 1.13\ \frac{kip}{ft}$

Factored horizontal load due to LL surcharge: $F_2 := LS_I \cdot q_L \cdot H \cdot k_a = 0.842\ \frac{kip}{ft}$

Factored vertical component: $F_{2v} := F_2 \cdot \sin(\delta) = 0.306\ \frac{kip}{ft}$

Factored horizontal component: $F_{2h} := F_2 \cdot \cos(\delta) = 0.785\ \frac{kip}{ft}$

Sum of maximum vertical factored loads (bearing): $\Sigma V_{max} := (V_1 + V_2) + (F_{1v} + F_{2v}) = 19.074 \ \frac{kip}{ft}$

Sum of minimum vertical factored loads (Ecc/Slide): $\Sigma V_{min} := V_3 + (F_{1v} + F_{2v}) = 9.988 \ \frac{kip}{ft}$

Maximum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} + (F_{1v} + F_{2v}) \cdot L = 109.017 \ \frac{kip \cdot ft}{ft}$$

Minimum resisting moment due to vertical loads about the toe of wall:

$$M_{ov_min} := V_3 \cdot x_{V1} + (F_{1v} + F_{2v}) \cdot L = 59.044 \ \frac{kip \cdot ft}{ft}$$

Driving moment due to horizontal loads about toe of wall:

$$M_{oh} := F_{1h} \cdot \frac{H}{3} + F_{2h} \cdot \frac{H}{2} = 5.382 \ \frac{kip \cdot ft}{ft}$$

Maximum net moment due to vertical and horizontal loads about toe of wall (bearing):

$$M_{net_max} := M_{ov_max} - M_{oh} = 103.635 \ \frac{kip \cdot ft}{ft}$$

Minimum net moment due to vertical and horizontal loads about toe of wall (Ecc/slide):

$$M_{net_min} := M_{ov_min} - M_{oh} = 53.662 \ \frac{kip \cdot ft}{ft}$$

Overturning eccentricity (bearing): $X_o := \frac{M_{net_max}}{\Sigma V_{max}} = 5.4334 \ ft$

Eccentricity of wall about the center of footing (bearing): $e_{wall_max} := \left| \frac{L}{2} - X_o \right| = 0.07 \ ft$

Maximum bearing stress (Strength 1) to be used in bearing check: $\sigma_{v_max} := \frac{\Sigma V_{max}}{L - 2 \cdot e_{wall_max}} = 1755.22 \ psf$ (AASHTO 11.6.3.2-1)

Maximum bearing stress (Strength I): $\sigma_{v_st} := \sigma_{v_max} = 1755.22 \ psf$

8.1 Evaluate Wall Eccentricity Limits - Strength I

Overturning eccentricity (Ecc/sliding): $X_{o_min} := \frac{M_{net_min}}{\Sigma V_{min}} = 5.3728 \ ft$

Eccentricity of wall about the center of footing (Ecc/sliding): $e_{wall_min} := \left| \frac{L}{2} - X_{o_min} \right| = 0.13 \ ft$

Check Eccentricity (AASHTO 10.6.3.3):

$$check_{ecc} := \begin{cases} \text{"OK"} & \text{if } e_{wall_min} \le \frac{L}{3} \\ \text{"Revise"} & \text{if } e_{wall_min} > \frac{L}{3} \end{cases} = \text{"OK"}$$

8.2 Evaluate Wall Sliding - Strength I

Normal sliding resistance: $R_T := \Sigma V_{min} \cdot \tan(\phi_{fnd}) = 7.8032 \ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1/2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 7.8032 \ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{F_{1h} + F_{2h}} = 4.076$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \geq F_{1h} + F_{2h} \\ \quad \text{"OK"} \\ \text{if } R_R < F_{1h} + F_{2h} \\ \quad \text{"Revise"} \end{array} \right\| = \text{"OK"}$

9.0 Bearing Resistance Calculation (AASHTO 10.6.3.1.2a) - Strength I

Footing Geometry based on structure submittals and cross sections

Total footing width: $B := L = 11 \ ft$ Define B as L for length of minimum grid above

Footing length: $L_{wall} := 413 \ ft$ Station 2+12 to 6+25

Groundwater depth: $D_w := 87 \ ft$ Based on Station 1+75 (Section A - A')

Footing embedment depth: $D_f := 2 \ ft$

Check Bearing Resistance (AASHTO 10.6.3.2)

Effective B (reduced due to moment): $B' := B - 2 \cdot e_{wall_max} = 10.87 \ ft$

Bearing Capacity Factors (Equations used to tabulate AASHTO Table 10.6.3.1.2a-1)
Equations in Das, Braja M., 2019, "Principles of Foundation Engineering", 9th edition

$N_q := e^{\pi \cdot \tan(\phi_{fnd})} \cdot \tan\left(45° + \frac{\phi_{fnd}}{2}\right)^2 = 48.93$ (Reissner, 1924)

$N_c := \text{if}\left(\phi_{fnd} = 0°, 5.14, (N_q - 1) \cdot \cot(\phi_{fnd})\right) = 61.35$ (Prandtl, 1921)

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fnd}) = 78.02$ (Vesic, 1975)

Shape factors (AASHTO Table 10.6.3.1.2a-3)

$S_c := \text{if}\left(\phi_{fnd} = 0, 1 + \left(\frac{B'}{5 \cdot L_{wall}}\right), 1 + \frac{B'}{L_{wall}} \cdot \frac{N_q}{N_c}\right) = 1.02$

$S_\gamma := \text{if}\left(\phi_{fnd} = 0, 1, 1 - 0.40 \cdot \left(\frac{B'}{L_{wall}}\right)\right) = 0.99$

$S_q := \text{if}\left(\phi_{fnd} = 0, 1, 1 + \left(\frac{B'}{L_{wall}}\right) \cdot \tan(\phi_{fnd})\right) = 1.02$

Groundwater coefficients (AASHTO Table 10.6.3.1.2a-2)

$C_{wq} := \text{if}(D_w = 0, 0.5, 1.0) = 1$

$C_{w\gamma} := \text{if}(D_w = 0, 0.5, \text{if}(D_w > 1.5 \cdot B' + D_f, 1.0, 0.5)) = 1$

Depth correction factor (AASHTO 10.6.3.1.2a): Conservatively taken as 1.0

$d_q := 1.0$

Nominal bearing resistance (AASHTO 10.6.3.1.2a-1)

$q_n := c_{fnd} \cdot N_c \cdot S_c + \gamma_{fnd} \cdot D_f \cdot N_q \cdot S_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fnd} \cdot B' \cdot N_\gamma \cdot S_\gamma \cdot C_{w\gamma} = 67516.13\ psf$

Factored bearing resistance

$q_R := \phi_{bST} \cdot q_n = 43885.48\ psf$

Capacity to bearing resistance

$CBR_{bearing} := \dfrac{q_R}{\sigma_{v_st}} = 25$

Check bearing: $check_{bearing} := \begin{cases} \text{if } q_R \geq \sigma_{v_st} \\ \quad \text{"OK"} \\ \text{if } q_R < \sigma_{v_st} \\ \quad \text{"Revise No Good"} \end{cases} = \text{"OK"}$

10.0 Estimation of seismic earth pressure loading (Extreme event I - Pseudostatic)

Peak Ground Acceleration: $PGA = 0.422$

Site factor at zero period: $F_{PGA} = 1.200$

Peak seismic ground acceleration modified by short-period site factor: $A_s := F_{PGA} \cdot PGA = 0.506$ (AASHTO 3.10.4.2-2)

Seismic horizontal coefficient assuming zero wall displacement: $k_{ho} := A_s = 0.506$ (AASHTO 11.5.6.2.1)

Seismic horizontal coefficient for analysis: $k_h := 0.5 \cdot k_{ho} = 0.253$ (AASHTO C11.6.5.2.2)

Seismic horizontal coefficient for analysis (Generally taken as 0): $k_v := 0$ (AASHTO C11.6.5.2.1)

Monoabe-Okabe factor: $\theta_{MO} := \operatorname{atan}\left(\dfrac{k_h}{1 - k_v}\right) = 14.209\ °$ (AASHTO C11.6.5.3)

Backslope behind wall: $i := \beta = 0\ °$ (AASHTO A11.3.1)

Slope on face: $\beta_{face} := 0\ °$ (AASHTO A11.3.1)

<u>Seismic active earth pressure coefficient (AASHTO A11.3.1-1)</u>

$$K_{AE} := \frac{\cos\left(\phi_f - \theta_{MO} - \beta_{face}\right)^2}{\cos\left(\theta_{MO}\right) \cdot \cos\left(\beta_{face}\right)^2 \cdot \cos\left(\delta + \beta_{face} + \theta_{MO}\right)} \cdot \left(1 + \sqrt{\frac{\sin\left(\phi_f + \delta\right) \cdot \sin\left(\phi_f - \theta_{MO} - i\right)}{\cos\left(\delta + \beta_{face} + \theta_{MO}\right) \cdot \cos\left(i - \beta_{face}\right)}}\right)^{-2} = 0.479$$

Load factor for Extreme Event I, seismic forces: $EE := 1.0$ (AASHTO Fig. C11.5.6-4)

Load factor for live loads applied with seismic loads: $\gamma_{EQ} := 0.5$ (AASHTO C3.4.1)

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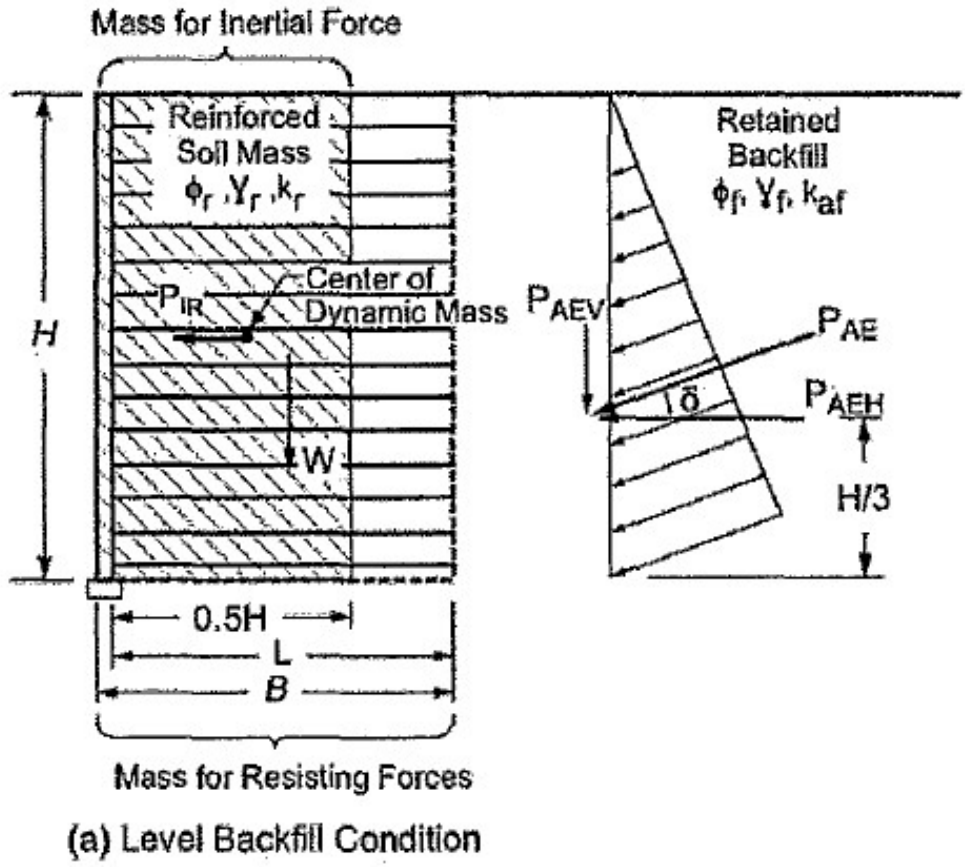
Seismic External Stability of an MSE Wall (AASHTO 11.10.5.2-1)



Dynamic lateral earth pressure force: (AASHTO 11.10.7.1-1):

$$P_{AE} := 0.5 \cdot \gamma_f \cdot H^2 \cdot K_{AE} = 1.409 \ \frac{kip}{ft}$$

$$P_{AEh} := P_{AE} \cdot \cos(\delta) = 1.312 \ \frac{kip}{ft}$$

$$P_{AEv} := P_{AE} \cdot \sin(\delta) = 0.512 \ \frac{kip}{ft}$$

Dynamic lateral earth pressure due to live load: (AASHTO Figure 11.6.5.1-1)

$$F_P := K_{AE} \cdot \gamma_{EQ} \cdot q_L \cdot H = 0.419 \ \frac{kip}{ft}$$

$$F_{Ph} := F_P \cdot \cos(\delta) = 0.391 \ \frac{kip}{ft}$$

$$F_{Pv} := F_P \cdot \sin(\delta) = 0.153 \ \frac{kip}{ft}$$

Seismic Vertical Loading

Factored vertical load of reinforced soil mass (max): $V_1 := EE \cdot \gamma_b \cdot H \cdot L = 10.01 \ \frac{kip}{ft}$

Factored vertical load due to LL surcharge: $V_2 := \gamma_{EQ} \cdot q_L \cdot L = 1.375 \ \frac{kip}{ft}$

Horizontal distance of centroid to center of wall footing

Distance to weight of reinforced fill: $x_{V1} := 0.5 \cdot L = 66\ in$

Distance to center of live load surcharge: $x_{LS} := 0.5 \cdot L = 66\ in$

Inertial horizontal force of wall and soil (AASHTO 11.10.7.1-1):

$$P_{IR} := \left(0.5 \cdot H^2 \cdot \gamma_b + w_u \cdot H \cdot \gamma_c\right) \cdot k_h = 0.935\ \frac{kip}{ft}$$

Unfactored load due to active earth pressure: $F_{1h} := 0.5 \cdot \gamma_f \cdot H^2 \cdot k_a \cdot \cos(\delta) = 0.753\ \frac{kip}{ft}$

Sum of vertical factored loads (maximum/bearing):

$$\Sigma V_{EE_max} := \left(V_1 + V_2\right) + \left(P_{AEv} + F_{Pv}\right) = 12.05\ \frac{kip}{ft}$$

Sum of vertical factored loads (minimum/eccentricity):

$$\Sigma V_{EE_min} := V_1 + \left(P_{AEv} + F_{Pv}\right) = 10.675\ \frac{kip}{ft}$$

Determine seismic force load cases for stability (AASHTO 11.6.5)

Case 1: 100% PAE with 50% PIR:

Horizontal loading due to seismic event: $T_{LC1} := EE \cdot P_{AEh} + 0.5 \cdot P_{IR} + F_{Ph} = 2.1701\ \frac{kip}{ft}$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov1_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 62.6175\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity): $M_{ov1_min} := V_1 \cdot x_{V1} = 55.055\ \frac{kip \cdot ft}{ft}$

Moment due to horizontal loads about toe of wall :

$$M_{oh1} := P_{AEh} \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + \left(0.5 \cdot P_{IR} \cdot \frac{H}{2}\right) = 6.065\ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1max} := M_{ov1_max} - M_{oh1} = 56.553\ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC1min} := M_{ov1_min} - M_{oh1} = 48.990\ \frac{kip \cdot ft}{ft}$$

Case 2: max (50% PAE and static) with 100% PIR:

Horizontal loading due to seismic event:

$$T_{LC2} := EE \cdot \max\left(0.5 \cdot P_{AE}, F_{1h}\right) + P_{IR} + F_{Ph} = 2.0786\ \frac{kip}{ft}$$

Moment due to vertical loads about toe of wall (bearing):

$$M_{ov2_max} := V_1 \cdot x_{V1} + V_2 \cdot x_{LS} = 62.6175\ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall (eccentricity):

$$M_{ov2_min} := V_1 \cdot x_{V1} = 55.055 \ \frac{kip \cdot ft}{ft}$$

Moment due to vertical loads about toe of wall:

$$M_{oh2} := \max\left(0.5 \cdot P_{AEh}, F_{1h}\right) \cdot \frac{H}{3} + F_{Ph} \cdot \frac{H}{2} + P_{IR} \cdot \frac{H}{2} = 6.397 \ \frac{kip \cdot ft}{ft}$$

Net maximum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2max} := M_{ov2_max} - M_{oh2} = 56.221 \ \frac{kip \cdot ft}{ft}$$

Net minimum moment due to vertical and horizontal loads about toe of wall:

$$M_{net_LC2min} := M_{ov2_min} - M_{oh2} = 48.658 \ \frac{kip \cdot ft}{ft}$$

<u>Case 1: 100% PAE with 50% PIR:</u>

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1max}}{\Sigma V_{EE_max}}\right| = 4.69 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 0.81 \ ft$

Maximum bearing stress: $\sigma_{v_LC1} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC1}} = 1283.77 \ psf$

<u>Case 2: max (50% PAE and static) with 100% PIR:</u>

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2max}}{\Sigma V_{EE_max}}\right| = 4.67 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left|\frac{L}{2} - X_{o_LC2}\right| = 0.83 \ ft$

Maximum bearing stress: $\sigma_{v_LC2} := \frac{\Sigma V_{EE_max}}{L - 2 \cdot e_{wall_LC2}} = 1291.35 \ psf$

Maximum eccentricity of the wall (bearing): $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 0.83 \ ft$

Minimum calculated bearing stress: $\sigma_{vc} := \max\left(\sigma_{v_LC1}, \sigma_{v_LC2}\right) = 1291.35 \ psf$

10.1 Evaluate Wall Eccentricity Limits - Extreme I

<u>Case 1: 100% PAE with 50% PIR:</u>

Overturning eccentricity: $X_{o_LC1} := \left|\frac{M_{net_LC1min}}{\Sigma V_{EE_min}}\right| = 4.59 \ ft$

Eccentricity of wall (Eccentricity): $e_{wall_LC1} := \left|\frac{L}{2} - X_{o_LC1}\right| = 0.91 \ ft$

<u>Case 2: max (50% PAE and static) with 100% PIR:</u>

Overturning eccentricity: $X_{o_LC2} := \left|\frac{M_{net_LC2min}}{\Sigma V_{EE_min}}\right| = 4.56 \ ft$

Eccentricity of wall (bearing): $e_{wall_LC2} := \left| \frac{L}{2} - X_{o_LC2} \right| = 0.94\ ft$

Eccentricity of wall about center of footing: $e_{wall_EE} := \max\left(e_{wall_LC1}, e_{wall_LC2}\right) = 0.94\ ft$

Seismic eccentricity requirement (AASHTO 11.6.5.1):

1st ordered pair $x := \begin{bmatrix} 0 \\ 1 \end{bmatrix}$ value of γ_{EQ}

2nd ordered pair $y := \begin{bmatrix} \frac{L}{3} \\ \frac{2 \cdot L}{5} \end{bmatrix}$ minimum eccentricity

Enter value to be interpolated: $e_{min} := \text{linterp}\left(x, y, \gamma_{EQ}\right) = 4.0333\ ft$

Check Eccentricity: $check_{ecc} := \left\| \begin{array}{l} \text{if } e_{wall_EE} \le e_{min} \\ \quad \text{"OK"} \\ \text{if } e_{wall_EE} > e_{min} \\ \quad \text{"Revise No Good"} \end{array} \right. = \text{"OK"}$

10.2 Evaluate Wall Sliding - Extreme I

Normal sliding resistance: $R_T := \Sigma V_{EE_min} \cdot \tan\left(\phi_{fnd}\right) = 8.34\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-2)

Factored sliding resistance of wall: $R_R := \phi_{slide} \cdot R_T = 8.34\ \frac{kip}{ft}$ (AASHTO 10.6.3.4-1)

Capacity-to-demand ratio direct sliding: $CDR_{slide} := \frac{R_R}{\max\left(T_{LC1}, T_{LC2}\right)} = 3.843$

Check direct sliding: $check_{slide} := \left\| \begin{array}{l} \text{if } R_R \ge \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"OK"} \\ \text{if } R_R < \max\left(T_{LC1}, T_{LC2}\right) \\ \quad \text{"Revise"} \end{array} \right. = \text{"OK"}$

11.0 Bearing Resistance Calculation (AASHTO 10.6.3.1.2a) - Extreme Event I

Footing Geometry based on structure submittals and cross sections

Total footing width: $B = 11\ ft$ Define B as L for length of minimum grid above

Footing length: $L_{wall} = 413\ ft$ Station 2+12 to 6+25

Groundwater depth: $D_w = 87\ ft$ Based on Station 1+75 (Section A - A')

Footing embedment depth: $D_f := 2\ ft$

Check Bearing Resistance (AASHTO 10.6.3.2)

Effective B (reduced due to moment): $B' := B - 2 \cdot e_{wall_EE} = 9.1164\ ft$

Bearing Capacity Factors (Equations used to tabulate AASHTO Table 10.6.3.1.2a-1)
Equations in Das, Braja M., 2019, "Principles of Foundation Engineering", 9th edition

$$N_q := e^{\pi \cdot \tan(\phi_{fnd})} \cdot \tan\left(45\,° + \frac{\phi_{fnd}}{2}\right)^2 = 48.93$$ (Reissner, 1924)

$$N_c := \text{if}\left(\phi_{fnd} = 0\,°, 5.14, (N_q - 1) \cdot \cot(\phi_{fnd})\right) = 61.35$$ (Prandtl, 1921)

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi_{fnd}) = 78.02$$ (Vesic, 1975)

Shape factors (AASHTO Table 10.6.3.1.2a-3)

$$S_c := \text{if}\left(\phi_{fnd} = 0, 1 + \left(\frac{B'}{5 \cdot L_{wall}}\right), 1 + \frac{B'}{L_{wall}} \cdot \frac{N_q}{N_c}\right) = 1.02$$

$$S_\gamma := \text{if}\left(\phi_{fnd} = 0, 1, 1 - 0.40 \cdot \left(\frac{B'}{L_{wall}}\right)\right) = 0.99$$

$$S_q := \text{if}\left(\phi_{fnd} = 0, 1, 1 + \left(\frac{B'}{L_{wall}}\right) \cdot \tan(\phi_{fnd})\right) = 1.02$$

Groundwater coefficients (AASHTO Table 10.6.3.1.2a-2)

$$C_{wq} := \text{if}(D_w = 0, 0.5, 1.0) = 1$$

$$C_{w\gamma} := \text{if}\left(D_w = 0, 0.5, \text{if}\left(D_w > 1.5 \cdot B' + D_f, 1.0, 0.5\right)\right) = 1$$

Depth correction factor (AASHTO 10.6.3.1.2a): Conservatively taken as 1.0

$$d_q := 1.0$$

Nominal bearing resistance (AASHTO 10.6.3.1.2a-1)

$$q_n := c_{fnd} \cdot N_c \cdot S_c + \gamma_{fnd} \cdot D_f \cdot N_q \cdot S_q \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fnd} \cdot B' \cdot N_\gamma \cdot S_\gamma \cdot C_{w\gamma} = 58.77\ ksf$$

Factored bearing resistance

$$q_R := \phi_{bEE} \cdot q_n = 52.89\ ksf$$

Capacity to bearing resistance

$$CBR_{bearing} := \frac{q_R}{\sigma_{vc}} = 40.96$$

Check bearing: $check_{bearing} := \begin{cases} \text{if } q_R \geq \sigma_{vc} \\ \quad \text{"OK"} \\ \text{if } q_R < \sigma_{vc} \\ \quad \text{"Revise No Good"} \end{cases} = \text{"OK"}$

In Association with

SLOPEW TEXT OUTPUT FILES

Static - Spencer

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File Information

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Directory: C:\Users\jason.alcantar\Desktop\PS19203160.034100.0001 WSDOT I-405 Projects – Albuquerque\Wall 10.18R\Global Stability\Global Stability Revised\
Last Solved Date: 12/6/2021
Last Solved Time: 8:19:33 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Static - Spencer

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
- F of S Calculation Option: Constant

Advanced
- Number of Slices: 30
- F of S Tolerance: 0.001
- Minimum Slip Surface Depth: 0.1 ft
- Search Method: Root Finder
- Tolerable difference between starting and converged F of S: 3
- Maximum iterations to calculate converged lambda: 20
- Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Geosynthetic Wall

Model: High Strength
Unit Weight: 130 pcf
Pore Water Pressure
- Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-44.9872, 106.66992) ft
Left-Zone Right Coordinate: (-10.97732, 108.50103) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (0, 109) ft
Right-Zone Right Coordinate: (25.06671, 100.40742) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 250 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5
	0	110

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Geosynthetic Wall	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 95
F of S: 3.1
Volume: 356.45033 ft^3

Weight: 45,245.227 lbs
Resisting Moment: 780,289.17 lbs-ft
Activating Moment: 252,955.01 lbs-ft
Resisting Force: 35,048.172 lbs
Activating Force: 11,361.322 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (15.607065, 98.560706) ft
Entry: (-19.479797, 108.0434) ft
Radius: 19.101647 ft
Center: (-0.40123389, 108.98219) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-18.874097	105.13502	-4,501.2252	210.3074	131.41465	0
Slice 2	-17.662698	100.92846	-4,238.7356	615.89561	384.85429	0
Slice 3	-16.451298	98.686074	-4,098.811	881.70009	550.94736	0
Slice 4	-15.239899	96.992269	-3,993.1176	1,104.5285	690.18601	0
Slice 5	-14.028499	95.624724	-3,907.7828	1,300.2278	812.47248	0
Slice 6	-12.817099	94.487944	-3,836.8477	1,476.0377	922.33075	0
Slice 7	-11.6057	93.529904	-3,777.066	1,636.1027	1,022.3504	0
Slice 8	-10.444542	92.747095	-3,728.2187	1,897.4924	1,185.6848	0
Slice 9	-9.333626	92.109421	-3,688.4279	2,025.8474	1,265.89	0
Slice 10	-8.22271	91.565912	-3,654.5129	2,145.5703	1,340.7011	0
Slice 11	-7.1195912	91.110583	-3,626.1004	2,241.7838	1,751.4735	0
Slice 12	-6.0242695	90.735929	-3,602.722	2,358.4202	1,842.5998	0
Slice 13	-4.9289478	90.433471	-3,583.8486	2,469.0372	1,929.0233	0
Slice 14	-3.833626	90.199706	-3,569.2616	2,574.1062	2,011.1122	0
Slice 15	-2.7383043	90.032082	-3,558.8019	2,674.0543	2,089.2002	0
Slice 16	-1.6429826	89.928848	-3,552.3601	2,769.2865	2,163.6037	0
Slice 17	-0.54766086	89.888956	-3,549.8708	2,860.2078	2,234.6393	0
Slice 18	0.625	89.918401	-3,551.7082	834.25782	651.79364	0
Slice 19	1.875	90.027099	-3,558.491	851.65473	665.3856	0

Slice 20	3.125	90.219615	-3,570.504	858.38758	670.64587	0
Slice 21	4.375	90.498579	-3,587.9114	853.36314	666.72036	0
Slice 22	5.625	90.868007	-3,610.9636	872.4941	681.6671	0
Slice 23	6.875	91.33361	-3,640.0173	918.89274	717.91769	0
Slice 24	8.125	91.903305	-3,675.5662	955.59076	746.58933	0
Slice 25	9.375	92.588024	-3,718.2927	981.19407	766.59282	0
Slice 26	10.560706	93.354018	-3,766.0907	959.77661	749.85967	0
Slice 27	11.682119	94.205827	-3,819.2436	880.79333	688.15117	0
Slice 28	12.803532	95.201622	-3,881.3812	766.7892	599.08138	0
Slice 29	13.924945	96.376116	-3,954.6696	592.78698	463.13594	0
Slice 30	15.046358	97.787019	-4,042.71	279.91632	218.69459	0

Static - Morgenstern

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File Information

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Directory: C:\Users\jason.alcantar\Desktop\PS19203160.034100.0001 WSDOT I-405 Projects – Albuquerque\Wall 10.18R\Global Stability\Global Stability Revised\
Last Solved Date: 12/6/2021
Last Solved Time: 8:19:33 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Static - Morgenstern

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Geosynthetic Wall

Model: High Strength
Unit Weight: 130 pcf

Pore Water Pressure
Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-44.9872, 106.66992) ft
Left-Zone Right Coordinate: (-10.97732, 108.50103) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (0, 109) ft
Right-Zone Right Coordinate: (25, 100.38889) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 250 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5

	0	110

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Geosynthetic Wall	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 95
F of S: 3.1
Volume: 355.6328 ft³
Weight: 45,139.905 lbs
Resisting Moment: 780,267.42 lbs-ft
Activating Moment: 252,389.23 lbs-ft
Resisting Force: 35,087.976 lbs
Activating Force: 11,349.23 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (15.555396, 98.55554) ft
Entry: (-19.479797, 108.0434) ft
Radius: 19.079243 ft
Center: (-0.4236034, 108.98095) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-18.874097	105.13649	-4,501.3171	284.4628	177.75209	0
Slice 2	-17.662698	100.93227	-4,238.9735	688.98849	430.52779	0
Slice 3	-16.451298	98.691462	-4,099.1472	906.44926	566.41236	0
Slice 4	-15.239899	96.998998	-3,993.5375	1,077.0156	672.99403	0
Slice 5	-14.028499	95.632675	-3,908.2789	1,225.0506	765.49656	0
Slice 6	-12.817099	94.497049	-3,837.4158	1,361.5852	850.81289	0
Slice 7	-11.6057	93.540125	-3,777.7038	1,492.8389	932.82929	0
Slice 8	-10.441517	92.756641	-3,728.8144	1,736.5295	1,085.1041	0
Slice 9	-9.3245521	92.117025	-3,688.9024	1,859.0081	1,161.6372	0
Slice 10	-8.2075869	91.572533	-3,654.9261	1,983.9607	1,239.7162	0
Slice 11	-7.1027397	91.118516	-3,626.5954	2,104.6006	1,644.2942	0
Slice 12	-6.0100105	90.746829	-3,603.4021	2,248.0302	1,756.3537	0
Slice 13	-4.9172813	90.446969	-3,584.6909	2,393.9931	1,870.3924	0
Slice 14	-3.8245521	90.215479	-3,570.2459	2,541.4289	1,985.5818	0
Slice 15	-2.731823	90.049843	-3,559.9102	2,688.6556	2,100.6079	0
Slice 16	-1.6390938	89.948333	-3,553.576	2,833.3293	2,213.6395	0
Slice 17	-0.54636459	89.909923	-3,551.1792	2,972.4186	2,322.3079	0
Slice	0.625	89.940827	-3,553.1076	924.2087	722.07098	0

18						
Slice 19	1.875	90.05114	-3,559.9912	975.59074	762.21503	0
Slice 20	3.125	90.245411	-3,572.1136	1,010.0512	789.13852	0
Slice 21	4.375	90.526302	-3,589.6413	1,023.6023	799.72576	0
Slice 22	5.625	90.897872	-3,612.8272	1,050.382	820.64837	0
Slice 23	6.875	91.36589	-3,642.0315	1,089.1642	850.94837	0
Slice 24	8.125	91.938353	-3,677.7532	1,097.7364	857.64566	0
Slice 25	9.375	92.626313	-3,720.6819	1,071.7955	837.37839	0
Slice 26	10.55554	93.392033	-3,768.4628	982.55928	767.65944	0
Slice 27	11.666619	94.238903	-3,821.3075	831.58666	649.7067	0
Slice 28	12.777698	95.227758	-3,883.0121	646.28836	504.9358	0
Slice 29	13.888777	96.39263	-3,955.7001	423.19976	330.63989	0
Slice 30	14.999856	97.789897	-4,042.8896	153.02266	119.5544	0

PseudoStatic - Spencer

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File Information

File Version: 8.16
Created By: Alcantar, Jason
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Tool Version: 8.16.5.15361
File Name: 10.18R Station 1+75 Revised.gsz
Directory: C:\Users\jason.alcantar\Desktop\PS19203160.034100.0001 WSDOT I-405 Projects – Albuquerque\Wall 10.18R\Global Stability\Global Stability Revised\
Last Solved Date: 1/3/2022
Last Solved Time: 12:26:44 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

PseudoStatic - Spencer

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
- F of S Calculation Option: Constant

Advanced
- Number of Slices: 30
- F of S Tolerance: 0.001
- Minimum Slip Surface Depth: 0.1 ft
- Search Method: Root Finder
- Tolerable difference between starting and converged F of S: 3
- Maximum iterations to calculate converged lambda: 20
- Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Geosynthetic Wall

Model: High Strength
Unit Weight: 130 pcf
Pore Water Pressure
- Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-18.00289, 108.12292) ft
Left-Zone Right Coordinate: (-10.97732, 108.50103) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (0, 96.27402) ft
Right-Zone Right Coordinate: (25, 100.38889) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 125 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5
	0	110

Seismic Coefficients

Horz Seismic Coef.: 0.253

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Geosynthetic Wall	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 20
F of S: 2.3
Volume: 366.13404 ft³
Weight: 46,732.077 lbs
Resisting Moment: 855,795.21 lbs-ft
Activating Moment: 365,767.71 lbs-ft
Resisting Force: 36,152.12 lbs
Activating Force: 15,449.049 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (18.721102, 98.87211) ft
Entry: (-18.00289, 108.12292) ft
Radius: 19.797605 ft
Center: (1.7705544, 109.1007) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-17.419316	105.22984	-4,507.1421	131.07011	81.901693	0
Slice 2	-16.252168	101.03308	-4,245.2643	449.66283	280.98052	0
Slice 3	-15.085019	98.776631	-4,104.4618	675.30648	421.97832	0
Slice 4	-13.917871	97.063285	-3,997.549	871.19195	544.38115	0
Slice 5	-12.750723	95.671671	-3,910.7122	1,047.7062	654.67953	0
Slice 6	-11.583574	94.506639	-3,838.0143	1,209.76	755.94197	0
Slice 7	-10.372083	93.484402	-3,774.2267	1,467.3234	916.88539	0
Slice 8	-9.11625	92.582316	-3,717.9365	1,622.5485	1,013.8808	0
Slice 9	-7.8604166	91.818549	-3,670.2775	1,767.9879	1,104.7615	0
Slice 10	-6.6297916	91.18601	-3,630.807	1,882.3295	1,470.637	0
Slice 11	-5.4243749	90.668135	-3,598.4916	2,021.5741	1,579.4268	0
Slice 12	-4.2189583	90.241461	-3,571.8672	2,155.6078	1,684.1454	0
Slice 13	-3.0135416	89.899875	-3,550.5522	2,285.1096	1,785.3233	0
Slice 14	-1.808125	89.638877	-3,534.2659	2,410.7319	1,883.4702	0
Slice 15	-0.60270833	89.45524	-3,522.807	2,533.14	1,979.1059	0
Slice 16	0.625	89.346186	-3,516.002	835.2423	652.5628	0
Slice	1.875	89.313242	-3,513.9463	878.14382	686.08114	0

17						
Slice 18	3.125	89.359422	-3,516.8279	913.67637	713.84221	0
Slice 19	4.375	89.485288	-3,524.682	941.30038	735.42446	0
Slice 20	5.625	89.692396	-3,537.6055	995.32977	777.63685	0
Slice 21	6.875	89.983399	-3,555.7641	1,080.2509	843.98448	0
Slice 22	8.125	90.362223	-3,579.4027	1,163.1029	908.71555	0
Slice 23	9.375	90.834361	-3,608.8641	1,244.7843	972.53207	0
Slice 24	10.622936	91.406203	-3,644.5471	1,290.6272	1,008.3485	0
Slice 25	11.868807	92.0876	-3,687.0662	1,293.6815	1,010.7347	0
Slice 26	13.114679	92.893364	-3,737.3459	1,287.0476	1,005.5518	0
Slice 27	14.360551	93.843414	-3,796.629	1,270.4703	992.60019	0
Slice 28	15.606422	94.967268	-3,866.7575	1,246.0747	973.54028	0
Slice 29	16.852294	96.311701	-3,950.6501	1,230.9733	961.74174	0
Slice 30	18.098166	97.959211	-4,053.4548	1,384.7591	1,081.8924	0

PseudoStatic - Morgenstern

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File Information

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File Name: 10.18R Station 1+75 Revised.gsz
Directory: C:\Users\jason.alcantar\Desktop\PS19203160.034100.0001 WSDOT I-405 Projects – Albuquerque\Wall 10.18R\Global Stability\Global Stability Revised\
Last Solved Date: 1/3/2022
Last Solved Time: 12:26:44 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

PseudoStatic - Morgenstern

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Geosynthetic Wall

Model: High Strength
Unit Weight: 130 pcf

Pore Water Pressure
Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-19.97687, 108.01663) ft
Left-Zone Right Coordinate: (-10.97732, 108.50103) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (0, 96.09449) ft
Right-Zone Right Coordinate: (25, 100.38889) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 125 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5

	0	110

Seismic Coefficients

Horz Seismic Coef.: 0.253

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Geosynthetic Wall	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2

Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 15
F of S: 2.2
Volume: 322.07506 ft³
Weight: 40,744.61 lbs
Resisting Moment: 632,590.08 lbs-ft
Activating Moment: 292,895.99 lbs-ft
Resisting Force: 31,278.537 lbs
Activating Force: 14,480.521 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (12.367959, 98.236796) ft
Entry: (-19.97687, 108.01663) ft
Radius: 17.936312 ft
Center: (-2.0618376, 108.89007) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-19.415816	105.3026	-4,511.682	165.48632	103.40733	0
Slice 2	-18.293707	101.3765	-4,266.6933	451.36666	282.0452	0
Slice 3	-17.171598	99.282098	-4,136.0029	590.56973	369.02892	0
Slice 4	-16.049489	97.698539	-4,037.1888	691.78387	432.27454	0
Slice 5	-14.927381	96.41853	-3,957.3163	776.6477	485.30335	0
Slice 6	-13.805272	95.353034	-3,890.8293	855.96595	534.86689	0
Slice 7	-12.683163	94.453535	-3,834.7006	936.71932	585.32719	0
Slice 8	-11.561054	93.690122	-3,787.0636	1,024.2012	639.99196	0
Slice 9	-10.480816	93.063313	-3,747.9507	1,217.2246	760.60632	0
Slice 10	-9.4424469	92.552588	-3,716.0815	1,323.1618	826.80329	0
Slice 11	-8.4040782	92.121673	-3,689.1924	1,446.0703	903.605	0
Slice 12	-7.3657095	91.76451	-3,666.9054	1,588.675	992.71429	0
Slice 13	-6.2759814	91.465728	-3,648.2614	1,812.1292	1,415.7905	0
Slice 14	-5.1348939	91.228467	-3,633.4564	2,049.6617	1,601.3713	0
Slice 15	-3.9938064	91.067348	-3,623.4025	2,319.1257	1,811.8995	0
Slice	-2.8527188	90.980307	-3,617.9711	2,617.8361	2,045.2777	0

16						
Slice 17	-1.7116313	90.96626	-3,617.0946	2,938.3727	2,295.7084	0
Slice 18	-0.57054376	91.025034	-3,620.7621	3,266.9038	2,552.385	0
Slice 19	0.5	91.144844	-3,628.2383	1,161.7632	907.66887	0
Slice 20	1.5	91.31838	-3,639.0669	1,274.6138	995.83747	0
Slice 21	2.5	91.551281	-3,653.5999	1,359.4936	1,062.1528	0
Slice 22	3.5	91.845992	-3,671.9899	1,404.2332	1,097.1073	0
Slice 23	4.5	92.205799	-3,694.4419	1,397.7029	1,092.0052	0
Slice 24	5.5	92.635047	-3,721.2269	1,373.1842	1,072.8491	0
Slice 25	6.5	93.13944	-3,752.7011	1,329.8727	1,039.0104	0
Slice 26	7.5	93.726524	-3,789.3351	1,225.8857	957.76685	0
Slice 27	8.5	94.406427	-3,831.761	1,067.214	833.79894	0
Slice 28	9.5	95.193098	-3,880.8493	864.89167	675.72743	0
Slice 29	10.59199	96.205721	-3,944.037	566.97432	442.96888	0
Slice 30	11.775969	97.516541	-4,025.8322	189.16136	147.78905	0

Static (Spencer) - Compound Stability

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Last Solved Date: 12/6/2021
Last Solved Time: 8:26:32 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Static (Spencer) - Compound Stability

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
- F of S Calculation Option: Constant

Advanced
- Number of Slices: 30
- F of S Tolerance: 0.001
- Minimum Slip Surface Depth: 0.1 ft
- Search Method: Root Finder
- Tolerable difference between starting and converged F of S: 3
- Maximum iterations to calculate converged lambda: 20
- Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Gravel Borrow

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-11, 108.5) ft
Left-Zone Right Coordinate: (0, 108.74344) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (1.77276, 96) ft
Right-Zone Right Coordinate: (19.71843, 98.97184) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 250 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5

	0	110

Reinforcements

Reinforcement 1

Type: Geosynthetic
Outside Point: (0, 94) ft
Inside Point: (-11, 94) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft
Governing Component: (none)

Reinforcement 2

Type: Geosynthetic
Outside Point: (0, 95.3) ft
Inside Point: (-11, 95.3) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft
Governing Component: (none)

Reinforcement 3

Type: Geosynthetic
Outside Point: (0, 96.6) ft
Inside Point: (-11, 96.6) ft
Slip Surface Intersection: (-2.7561998, 96.6) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,097.8365 lbs
Pullout Force per Length: 532.60993 lbs/ft
Available Length: 8.2438002 ft
Required Length: 2.0612393 ft
Governing Component: Tensile Capacity

Reinforcement 4

Type: Geosynthetic
Outside Point: (0, 97.9) ft
Inside Point: (-11, 97.9) ft
Slip Surface Intersection: (-5.1190319, 97.9) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,097.8365 lbs
Pullout Force per Length: 478.71874 lbs/ft
Available Length: 5.8809681 ft
Required Length: 2.2932808 ft
Governing Component: Tensile Capacity

Reinforcement 5

Type: Geosynthetic
Outside Point: (0, 99.2) ft
Inside Point: (-11, 99.2) ft
Slip Surface Intersection: (-6.721391, 99.2) ft
Length: 11 ft

Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,097.8365 lbs
Pullout Force per Length: 398.14548 lbs/ft
Available Length: 4.278609 ft
Required Length: 2.7573753 ft
Governing Component: Tensile Capacity

Reinforcement 6

Type: Geosynthetic
Outside Point: (0, 100.5) ft
Inside Point: (-11, 100.5) ft
Slip Surface Intersection: (-7.9316367, 100.5) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,097.8365 lbs
Pullout Force per Length: 362.73854 lbs/ft
Available Length: 3.0683633 ft
Required Length: 3.0265229 ft
Governing Component: Tensile Capacity

Reinforcement 7

Type: Geosynthetic
Outside Point: (0, 101.8) ft
Inside Point: (-11, 101.8) ft
Slip Surface Intersection: (-8.8722339, 101.8) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1

Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 575.20541 lbs
Pullout Force per Length: 270.33301 lbs/ft
Available Length: 2.1277661 ft
Required Length: 2.1277661 ft
Governing Component: Pullout Resistance

Reinforcement 8

Type: Geosynthetic
Outside Point: (0, 103.1) ft
Inside Point: (-11, 103.1) ft
Slip Surface Intersection: (-9.5998679, 103.1) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 286.15022 lbs
Pullout Force per Length: 204.37373 lbs/ft
Available Length: 1.4001321 ft
Required Length: 1.4001321 ft
Governing Component: Pullout Resistance

Reinforcement 9

Type: Geosynthetic
Outside Point: (0, 104.4) ft
Inside Point: (-11, 104.4) ft
Slip Surface Intersection: (-10.151962, 104.4) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs

Pullout Force: 173.31673 lbs
Pullout Force per Length: 204.37373 lbs/ft
Available Length: 0.84803823 ft
Required Length: 0.84803823 ft
Governing Component: Pullout Resistance

Reinforcement 10

Type: Geosynthetic
Outside Point: (0, 105.7) ft
Inside Point: (-11, 105.7) ft
Slip Surface Intersection: (-10.463869, 105.7) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 44.620929 lbs
Pullout Force per Length: 83.227614 lbs/ft
Available Length: 0.5361313 ft
Required Length: 0.5361313 ft
Governing Component: Pullout Resistance

Reinforcement 11

Type: Geosynthetic
Outside Point: (0, 107) ft
Inside Point: (-11, 107) ft
Slip Surface Intersection: (-10.712787, 107) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 23.904069 lbs
Pullout Force per Length: 83.227614 lbs/ft
Available Length: 0.28721319 ft
Required Length: 0.28721319 ft
Governing Component: Pullout Resistance

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Gravel Borrow	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 15
F of S: 3.2
Volume: 110.64201 ft^3

Weight: 14,363.844 lbs
Resisting Moment: 374,332.33 lbs-ft
Activating Moment: 118,642.97 lbs-ft
Resisting Force: 30,178.669 lbs
Activating Force: 9,567.7503 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (10.574383, 98.057438) ft
Entry: (-11, 108.5) ft
Radius: 13.629616 ft
Center: (2.6154225, 109.12186) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-10.633333	106.58505	-4,591.7069	150.90859	117.90271	0
Slice 2	-9.9	103.80671	-4,418.3389	435.87635	340.54392	0
Slice 3	-9.1666667	102.3092	-4,324.8943	631.50182	493.38329	0
Slice 4	-8.4333333	101.16587	-4,253.5505	790.2745	617.4301	0
Slice 5	-7.7	100.23124	-4,195.2295	950.50402	742.61513	0
Slice 6	-6.9666667	99.442819	-4,146.0319	1,101.9953	860.97306	0
Slice 7	-6.2333333	98.766504	-4,103.8299	1,221.8832	954.63976	0
Slice 8	-5.5	98.181203	-4,067.307	1,333.2834	1,041.6752	0
Slice 9	-4.7666667	97.672803	-4,035.5829	1,473.5689	1,151.2782	0
Slice 10	-4.0333333	97.231357	-4,008.0367	1,572.7503	1,228.7672	0
Slice 11	-3.3	96.849591	-3,984.2145	1,666.4006	1,301.9348	0
Slice 12	-2.5666667	96.522048	-3,963.7758	1,824.1485	1,425.181	0
Slice 13	-1.8333333	96.244571	-3,946.4612	1,910.2919	1,492.4836	0
Slice 14	-1.1	96.013966	-3,932.0715	1,992.3839	1,556.6209	0
Slice 15	-0.36666667	95.827785	-3,920.4538	2,070.7998	1,617.8861	0
Slice 16	0.38768503	95.681278	-3,911.3117	37.276097	23.292691	0
Slice 17	1.1630551	95.575455	-3,904.7084	50.834383	31.764848	0
Slice 18	1.9384251	95.514601	-3,900.9111	59.511413	37.186858	0
Slice 19	2.7137952	95.498112	-3,899.8822	63.028109	39.384334	0

Slice 20	3.4891652	95.525826	-3,901.6115	61.032532	38.137359	0
Slice 21	4.1576377	95.582724	-3,905.162	56.779337	44.36088	0
Slice 22	4.7192126	95.658584	-3,909.8957	49.346383	38.55362	0
Slice 23	5.3571429	95.77583	-3,917.2118	55.857492	43.640655	0
Slice 24	6.0714286	95.942854	-3,927.6341	76.238017	59.563667	0
Slice 25	6.7857143	96.151339	-3,940.6435	91.348807	71.36951	0
Slice 26	7.5	96.403329	-3,956.3677	100.40334	78.443689	0
Slice 27	8.2142857	96.701484	-3,974.9726	102.35097	79.965342	0
Slice 28	8.9285714	97.049238	-3,996.6724	95.737269	74.798152	0
Slice 29	9.6428571	97.451048	-4,021.7454	78.458683	61.298641	0
Slice 30	10.287192	97.861768	-4,047.3743	34.089337	26.633509	0

Static (Morgenstern) - Compound Stability

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File Information

File Version: 8.16
Created By: Alcantar, Jason
Last Edited By: Alcantar, Jason
Revision Number: 97
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Tool Version: 8.16.5.15361
File Name: 10.18R Station 1+75 Compound Stability.gsz
Directory: C:\Users\jason.alcantar\Desktop\PS19203160.034100.0001 WSDOT I-405 Projects – Albuquerque\Wall 10.18R\Global Stability\Compound Stability\
Last Solved Date: 12/6/2021
Last Solved Time: 8:26:32 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

Static (Morgenstern) - Compound Stability

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf

Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Gravel Borrow

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-11.00008, 108.5) ft
Left-Zone Right Coordinate: (0, 109) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (1.96632, 96) ft
Right-Zone Right Coordinate: (19.58498, 98.9585) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 250 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)

	-76	106
	-11	109.5
	0	110

Reinforcements

Reinforcement 1

Type: Geosynthetic
Outside Point: (0, 94) ft
Inside Point: (-11, 94) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft
Governing Component: (none)

Reinforcement 2

Type: Geosynthetic
Outside Point: (0, 95.3) ft
Inside Point: (-11, 95.3) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft

Governing Component: (none)

Reinforcement 3

Type: Geosynthetic
Outside Point: (0, 96.6) ft
Inside Point: (-11, 96.6) ft
Slip Surface Intersection: (-2.7703597, 96.6) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,095.3961 lbs
Pullout Force per Length: 531.68115 lbs/ft
Available Length: 8.2296403 ft
Required Length: 2.0602499 ft
Governing Component: Tensile Capacity

Reinforcement 4

Type: Geosynthetic
Outside Point: (0, 97.9) ft
Inside Point: (-11, 97.9) ft
Slip Surface Intersection: (-5.1260822, 97.9) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,095.3961 lbs
Pullout Force per Length: 477.85836 lbs/ft
Available Length: 5.8739178 ft
Required Length: 2.2923028 ft
Governing Component: Tensile Capacity

Reinforcement 5

Type: Geosynthetic
Outside Point: (0, 99.2) ft
Inside Point: (-11, 99.2) ft

Slip Surface Intersection: (-6.7250923, 99.2) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,095.3961 lbs
Pullout Force per Length: 397.41202 lbs/ft
Available Length: 4.2749077 ft
Required Length: 2.7563234 ft
Governing Component: Tensile Capacity

Reinforcement 6

Type: Geosynthetic
Outside Point: (0, 100.5) ft
Inside Point: (-11, 100.5) ft
Slip Surface Intersection: (-7.9341856, 100.5) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,095.3961 lbs
Pullout Force per Length: 362.06535 lbs/ft
Available Length: 3.0658144 ft
Required Length: 3.0254098 ft
Governing Component: Tensile Capacity

Reinforcement 7

Type: Geosynthetic
Outside Point: (0, 101.8) ft
Inside Point: (-11, 101.8) ft
Slip Surface Intersection: (-8.8735965, 101.8) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °

Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 573.75566 lbs
Pullout Force per Length: 269.82446 lbs/ft
Available Length: 2.1264035 ft
Required Length: 2.1264035 ft
Governing Component: Pullout Resistance

Reinforcement 8

Type: Geosynthetic
Outside Point: (0, 103.1) ft
Inside Point: (-11, 103.1) ft
Slip Surface Intersection: (-9.6006464, 103.1) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 285.45072 lbs
Pullout Force per Length: 203.98754 lbs/ft
Available Length: 1.3993536 ft
Required Length: 1.3993536 ft
Governing Component: Pullout Resistance

Reinforcement 9

Type: Geosynthetic
Outside Point: (0, 104.4) ft
Inside Point: (-11, 104.4) ft
Slip Surface Intersection: (-10.152546, 104.4) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18

Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 172.87009 lbs
Pullout Force per Length: 203.98754 lbs/ft
Available Length: 0.84745413 ft
Required Length: 0.84745413 ft
Governing Component: Pullout Resistance

Reinforcement 10

Type: Geosynthetic
Outside Point: (0, 105.7) ft
Inside Point: (-11, 105.7) ft
Slip Surface Intersection: (-10.464138, 105.7) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 44.534256 lbs
Pullout Force per Length: 83.107698 lbs/ft
Available Length: 0.53586199 ft
Required Length: 0.53586199 ft
Governing Component: Pullout Resistance

Reinforcement 11

Type: Geosynthetic
Outside Point: (0, 107) ft
Inside Point: (-11, 107) ft
Slip Surface Intersection: (-10.713086, 107) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 23.844723 lbs
Pullout Force per Length: 83.107698 lbs/ft
Available Length: 0.28691353 ft
Required Length: 0.28691353 ft

Governing Component: Pullout Resistance

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Gravel Borrow	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 15
F of S: 3.2
Volume: 110.81353 ft³
Weight: 14,385.802 lbs
Resisting Moment: 375,594.13 lbs-ft
Activating Moment: 118,794.67 lbs-ft
Resisting Force: 30,197.709 lbs
Activating Force: 9,551.1857 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (10.603958, 98.060396) ft
Entry: (-11.00008, 108.5) ft
Radius: 13.639378 ft
Center: (2.6250853, 109.1225) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-11.00004	108.49912	-4,711.1453	47.015336	29.378443	0
Slice 2	-10.633333	106.58353	-4,591.6124	201.63942	157.53798	0
Slice 3	-9.9	103.80513	-4,418.24	476.67238	372.41728	0
Slice 4	-9.1666667	102.30706	-4,324.7603	630.46907	492.57643	0
Slice 5	-8.4333333	101.16323	-4,253.3855	751.44668	587.09449	0
Slice 6	-7.7	100.22814	-4,195.0362	875.84805	684.28749	0
Slice 7	-6.9666667	99.439293	-4,145.8119	1,006.1685	786.10499	0
Slice 8	-6.2333333	98.762565	-4,103.5841	1,117.1657	872.82549	0
Slice 9	-5.5	98.17686	-4,067.0361	1,227.4761	959.00942	0
Slice 10	-4.7666667	97.668063	-4,035.2871	1,389.636	1,085.7027	0
Slice 11	-4.0333333	97.226221	-4,007.7162	1,510.9164	1,180.4573	0
Slice 12	-3.3	96.844057	-3,983.8691	1,632.6992	1,275.6044	0
Slice 13	-2.5666667	96.516112	-3,963.4054	1,869.7299	1,460.7931	0
Slice 14	-1.8333333	96.238226	-3,946.0653	2,000.1396	1,562.6803	0
Slice 15	-1.1	96.007204	-3,931.6495	2,123.8238	1,659.313	0
Slice 16	-0.36666667	95.820593	-3,920.005	2,237.708	1,748.2891	0
Slice 17	0.38443222	95.674075	-3,910.8623	40.011788	25.00214	0
Slice	1.1532967	95.568281	-3,904.2607	56.465751	35.283717	0

18						
Slice 19	1.9221611	95.506691	-3,900.4175	68.214129	42.624919	0
Slice 20	2.6910256	95.488704	-3,899.2951	74.659578	46.652482	0
Slice 21	3.45989	95.514146	-3,900.8827	75.15675	46.96315	0
Slice 22	4.1332417	95.56988	-3,904.3605	73.135398	57.139635	0
Slice 23	4.7110806	95.646755	-3,909.1575	66.234212	51.747838	0
Slice 24	5.3571429	95.764524	-3,916.5063	73.259244	57.236394	0
Slice 25	6.0714286	95.930874	-3,926.8865	93.276621	72.875683	0
Slice 26	6.7857143	96.138623	-3,939.8501	105.85792	82.705269	0
Slice 27	7.5	96.389805	-3,955.5239	110.25215	86.138419	0
Slice 28	8.2142857	96.687064	-3,974.0728	105.94938	82.776726	0
Slice 29	8.9285714	97.033812	-3,995.7098	92.708909	72.432138	0
Slice 30	9.6428571	97.434476	-4,020.7113	70.539741	55.111686	0
Slice 31	10.301979	97.854655	-4,046.9304	28.484989	22.254913	0

PseudoStatic (Spencer) - Compound Stability

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File Information

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Last Edited By: Alcantar, Jason
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Last Solved Date: 1/3/2022
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Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

PseudoStatic (Spencer) - Compound Stability

Kind: SLOPE/W
Method: Spencer
Settings
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °
- Optimize Critical Slip Surface Location: No
- Tension Crack
  - Tension Crack Option: (none)

F of S Distribution
- F of S Calculation Option: Constant

Advanced
- Number of Slices: 30
- F of S Tolerance: 0.001
- Minimum Slip Surface Depth: 0.1 ft
- Search Method: Root Finder
- Tolerable difference between starting and converged F of S: 3
- Maximum iterations to calculate converged lambda: 20
- Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
- Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Gravel Borrow

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-11.00008, 108.5) ft
Left-Zone Right Coordinate: (0, 108.74344) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (2, 96) ft
Right-Zone Right Coordinate: (21.1738, 99.32606) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 125 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5

	0	110

Seismic Coefficients

Horz Seismic Coef.: 0.253

Reinforcements

Reinforcement 1

Type: Geosynthetic
Outside Point: (0, 94) ft
Inside Point: (-11, 94) ft
Slip Surface Intersection: (-2.0706782, 94) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,064.7547 lbs
Pullout Force per Length: 607.44183 lbs/ft
Available Length: 8.9293218 ft
Required Length: 1.7528505 ft
Governing Component: Tensile Capacity

Reinforcement 2

Type: Geosynthetic
Outside Point: (0, 95.3) ft
Inside Point: (-11, 95.3) ft
Slip Surface Intersection: (-4.0264589, 95.3) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,064.7547 lbs
Pullout Force per Length: 573.95328 lbs/ft

Available Length: 6.9735411 ft
Required Length: 1.8551244 ft
Governing Component: Tensile Capacity

Reinforcement 3

Type: Geosynthetic
Outside Point: (0, 96.6) ft
Inside Point: (-11, 96.6) ft
Slip Surface Intersection: (-5.5554478, 96.6) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,064.7547 lbs
Pullout Force per Length: 488.78961 lbs/ft
Available Length: 5.4445522 ft
Required Length: 2.1783498 ft
Governing Component: Tensile Capacity

Reinforcement 4

Type: Geosynthetic
Outside Point: (0, 97.9) ft
Inside Point: (-11, 97.9) ft
Slip Surface Intersection: (-6.7750378, 97.9) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,064.7547 lbs
Pullout Force per Length: 433.87103 lbs/ft
Available Length: 4.2249622 ft
Required Length: 2.4540812 ft
Governing Component: Tensile Capacity

Reinforcement 5

Type: Geosynthetic

Outside Point: (0, 99.2) ft
Inside Point: (-11, 99.2) ft
Slip Surface Intersection: (-7.78751, 99.2) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,064.7547 lbs
Pullout Force per Length: 366.376 lbs/ft
Available Length: 3.21249 ft
Required Length: 2.9061804 ft
Governing Component: Tensile Capacity

Reinforcement 6

Type: Geosynthetic
Outside Point: (0, 100.5) ft
Inside Point: (-11, 100.5) ft
Slip Surface Intersection: (-8.6195487, 100.5) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 872.1402 lbs
Pullout Force per Length: 366.376 lbs/ft
Available Length: 2.3804513 ft
Required Length: 2.3804513 ft
Governing Component: Pullout Resistance

Reinforcement 7

Type: Geosynthetic
Outside Point: (0, 101.8) ft
Inside Point: (-11, 101.8) ft
Slip Surface Intersection: (-9.2652085, 101.8) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes

Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 481.8034 lbs
Pullout Force per Length: 277.72986 lbs/ft
Available Length: 1.7347915 ft
Required Length: 1.7347915 ft
Governing Component: Pullout Resistance

Reinforcement 8

Type: Geosynthetic
Outside Point: (0, 103.1) ft
Inside Point: (-11, 103.1) ft
Slip Surface Intersection: (-9.8705029, 103.1) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 313.69507 lbs
Pullout Force per Length: 277.72986 lbs/ft
Available Length: 1.1294971 ft
Required Length: 1.1294971 ft
Governing Component: Pullout Resistance

Reinforcement 9

Type: Geosynthetic
Outside Point: (0, 104.4) ft
Inside Point: (-11, 104.4) ft
Slip Surface Intersection: (-10.148104, 104.4) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes

Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 96.541144 lbs
Pullout Force per Length: 113.32502 lbs/ft
Available Length: 0.85189608 ft
Required Length: 0.85189608 ft
Governing Component: Pullout Resistance

Reinforcement 10

Type: Geosynthetic
Outside Point: (0, 105.7) ft
Inside Point: (-11, 105.7) ft
Slip Surface Intersection: (-10.418325, 105.7) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 65.918359 lbs
Pullout Force per Length: 113.32502 lbs/ft
Available Length: 0.58167522 ft
Required Length: 0.58167522 ft
Governing Component: Pullout Resistance

Reinforcement 11

Type: Geosynthetic
Outside Point: (0, 107) ft
Inside Point: (-11, 107) ft
Slip Surface Intersection: (-10.688546, 107) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 35.295573 lbs
Pullout Force per Length: 113.32502 lbs/ft

Available Length: 0.31145436 ft
Required Length: 0.31145436 ft
Governing Component: Pullout Resistance

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Gravel Borrow	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8
Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 25
F of S: 3.3
Volume: 211.45376 ft³
Weight: 27,434.46 lbs
Resisting Moment: 731,681.83 lbs-ft
Activating Moment: 224,949.04 lbs-ft
Resisting Force: 45,271.15 lbs
Activating Force: 13,918.035 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (21.173801, 99.326056) ft
Entry: (-11.00008, 108.5) ft
Radius: 17.662506 ft
Center: (6.6412587, 109.36445) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-11.00004	108.49918	-4,711.149	-79.241363	-49.515499	0
Slice 2	-10.441917	105.8135	-4,543.5625	132.95701	103.8774	0
Slice 3	-9.3257522	101.93003	-4,301.2339	466.86776	364.75707	0
Slice 4	-8.2095869	99.859464	-4,172.0306	731.76754	571.71946	0
Slice 5	-7.0934217	98.295044	-4,074.4107	957.32565	747.94477	0
Slice 6	-5.9772565	97.031578	-3,995.5705	1,170.3586	914.38435	0
Slice 7	-4.8610913	95.98093	-3,930.0101	1,339.1185	1,046.234	0
Slice 8	-3.7449261	95.095082	-3,874.7331	1,546.8167	1,208.5056	0
Slice 9	-2.6287608	94.344436	-3,827.8928	1,766.9327	1,380.4791	0
Slice 10	-1.6601637	93.781311	-3,792.7538	2,010.4929	1,256.2954	0
Slice 11	-0.62482459	93.280355	-3,761.4941	1,984.4972	1,550.4591	0
Slice 12	0.5	92.812571	-3,732.3044	326.79744	255.32215	0
Slice 13	1.5	92.474854	-3,711.2309	377.98927	295.31759	0
Slice 14	2.5	92.202003	-3,694.205	424.40713	331.58319	0
Slice 15	3.5	91.99095	-3,681.0353	465.9164	364.01378	0
Slice 16	4.5	91.839455	-3,671.582	502.34777	392.47709	0
Slice	5.5	91.745975	-3,665.7488	556.55605	434.82924	0

17						
Slice 18	6.5	91.709586	-3,663.4782	630.46567	492.57377	0
Slice 19	7.5	91.729934	-3,664.7479	701.63154	548.17463	0
Slice 20	8.5	91.807216	-3,669.5703	769.99104	601.58293	0
Slice 21	9.5	91.942193	-3,677.9928	835.49461	652.75993	0
Slice 22	10.555556	92.150564	-3,690.9952	876.51677	684.80995	0
Slice 23	11.666667	92.441874	-3,709.1729	889.5744	695.0117	0
Slice 24	12.777778	92.812826	-3,732.3204	893.59053	698.14944	0
Slice 25	13.888889	93.26896	-3,760.7831	887.16926	693.13259	0
Slice 26	15	93.817818	-3,795.0319	868.27144	678.368	0
Slice 27	16.111111	94.469731	-3,835.7112	833.72167	651.37476	0
Slice 28	17.222222	95.239099	-3,883.7198	778.09806	607.91683	0
Slice 29	18.333333	96.146681	-3,940.3529	690.77171	539.69001	0
Slice 30	19.444444	97.223993	-4,007.5772	545.70946	426.35496	0
Slice 31	20.586901	98.567966	-4,091.4411	279.7394	218.55637	0

PseudoStatic (Morgenstern) - Compound Stability

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Last Solved Date: 1/3/2022
Last Solved Time: 12:37:36 PM

Project Settings

Length(L) Units: Feet
Time(t) Units: Seconds
Force(F) Units: Pounds
Pressure(p) Units: psf
Strength Units: psf
Unit Weight of Water: 62.4 pcf
View: 2D
Element Thickness: 1

Analysis Settings

PseudoStatic (Morgenstern) - Compound Stability

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Left to Right
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 ft
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

ESU #1B

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4C

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4A

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 40 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

ESU #4E

Model: Mohr-Coulomb
Unit Weight: 125 pcf
Cohesion': 627 psf
Phi': 30 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Common Borrow

Model: Mohr-Coulomb
Unit Weight: 120 pcf
Cohesion': 0 psf
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Gravel Borrow

Model: Mohr-Coulomb
Unit Weight: 130 pcf
Cohesion': 0 psf
Phi': 38 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Range
Left-Zone Left Coordinate: (-11.00008, 108.5) ft
Left-Zone Right Coordinate: (0, 108.58596) ft
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (2.08661, 96) ft
Right-Zone Right Coordinate: (21.19278, 99.33133) ft
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (-80, 73) ft
Right Coordinate: (50, 104.5) ft

Piezometric Lines

Piezometric Line 1

Coordinates

	X (ft)	Y (ft)
Coordinate 1	-80	33
Coordinate 2	50	33

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 125 pcf
Direction: Vertical

Coordinates

	X (ft)	Y (ft)
	-76	106
	-11	109.5
	0	110

Seismic Coefficients

Horz Seismic Coef.: 0.253

Reinforcements

Reinforcement 1

Type: Geosynthetic
Outside Point: (0, 94) ft
Inside Point: (-11, 94) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft
Governing Component: (none)

Reinforcement 2

Type: Geosynthetic
Outside Point: (0, 95.3) ft
Inside Point: (-11, 95.3) ft
Slip Surface Intersection: () ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs

Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 0 lbs
Pullout Force per Length: 0 lbs/ft
Available Length: 0 ft
Required Length: 0 ft
Governing Component: (none)

Reinforcement 3

Type: Geosynthetic
Outside Point: (0, 96.6) ft
Inside Point: (-11, 96.6) ft
Slip Surface Intersection: (-3.1434995, 96.6) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,303.3911 lbs
Pullout Force per Length: 622.64485 lbs/ft
Available Length: 7.8565005 ft
Required Length: 2.0933139 ft
Governing Component: Tensile Capacity

Reinforcement 4

Type: Geosynthetic
Outside Point: (0, 97.9) ft
Inside Point: (-11, 97.9) ft
Slip Surface Intersection: (-5.3057835, 97.9) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,303.3911 lbs
Pullout Force per Length: 547.48356 lbs/ft
Available Length: 5.6942165 ft

Required Length: 2.3806946 ft
Governing Component: Tensile Capacity

Reinforcement 5

Type: Geosynthetic
Outside Point: (0, 99.2) ft
Inside Point: (-11, 99.2) ft
Slip Surface Intersection: (-6.8327197, 99.2) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,303.3911 lbs
Pullout Force per Length: 478.20519 lbs/ft
Available Length: 4.1672803 ft
Required Length: 2.7255897 ft
Governing Component: Tensile Capacity

Reinforcement 6

Type: Geosynthetic
Outside Point: (0, 100.5) ft
Inside Point: (-11, 100.5) ft
Slip Surface Intersection: (-8.0075208, 100.5) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 1,303.1159 lbs
Pullout Force per Length: 435.46366 lbs/ft
Available Length: 2.9924792 ft
Required Length: 2.9924792 ft
Governing Component: Pullout Resistance

Reinforcement 7

Type: Geosynthetic
Outside Point: (0, 101.8) ft

Inside Point: (-11, 101.8) ft
Slip Surface Intersection: (-8.9121091, 101.8) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 676.83189 lbs
Pullout Force per Length: 324.17014 lbs/ft
Available Length: 2.0878909 ft
Required Length: 2.0878909 ft
Governing Component: Pullout Resistance

Reinforcement 8

Type: Geosynthetic
Outside Point: (0, 103.1) ft
Inside Point: (-11, 103.1) ft
Slip Surface Intersection: (-9.6218529, 103.1) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 337.47502 lbs
Pullout Force per Length: 244.8759 lbs/ft
Available Length: 1.3781471 ft
Required Length: 1.3781471 ft
Governing Component: Pullout Resistance

Reinforcement 9

Type: Geosynthetic
Outside Point: (0, 104.4) ft
Inside Point: (-11, 104.4) ft
Slip Surface Intersection: (-10.167238, 104.4) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf

Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 203.92326 lbs
Pullout Force per Length: 244.8759 lbs/ft
Available Length: 0.83276163 ft
Required Length: 0.83276163 ft
Governing Component: Pullout Resistance

Reinforcement 10

Type: Geosynthetic
Outside Point: (0, 105.7) ft
Inside Point: (-11, 105.7) ft
Slip Surface Intersection: (-10.468552, 105.7) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs
Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 52.986181 lbs
Pullout Force per Length: 99.70151 lbs/ft
Available Length: 0.53144813 ft
Required Length: 0.53144813 ft
Governing Component: Pullout Resistance

Reinforcement 11

Type: Geosynthetic
Outside Point: (0, 107) ft
Inside Point: (-11, 107) ft
Slip Surface Intersection: (-10.715448, 107) ft
Length: 11 ft
Direction: 0 °
F of S Dependent: Yes
Interface Adhesion: 0 psf
Interface Shear Angle: 27.6 °
Surface Area Factor: 2
Resistance Reduction Factor: 1
Force Distribution: Distributed
Anchorage: Yes
Tensile Capacity: 7,550 lbs

Reduction Factor: 2.18
Force Orientation: 0
Max. Pullout Force: 3,463.3028 lbs
Pullout Force: 28.370229 lbs
Pullout Force per Length: 99.70151 lbs/ft
Available Length: 0.28455165 ft
Required Length: 0.28455165 ft
Governing Component: Pullout Resistance

Points

	X (ft)	Y (ft)
Point 1	-80	-8
Point 2	-69	-8
Point 3	-1	-1
Point 4	50	-1
Point 5	50	75
Point 6	21	75
Point 7	3	70
Point 8	-1	70
Point 9	-69	60
Point 10	-80	60
Point 11	-42.28366	63.92887
Point 12	-1	89
Point 13	-60	73
Point 14	-80	73
Point 15	0	94
Point 16	-11	94
Point 17	-11	108.5
Point 18	0	109
Point 19	-76	105
Point 20	-76	73
Point 21	3	89
Point 22	21	88
Point 23	50	88
Point 24	50	104.5
Point 25	38	104
Point 26	20	99
Point 27	10	98
Point 28	0	96
Point 29	5	96

Regions

	Material	Points	Area (ft^2)
Region 1	ESU #4E	1,2,3,4,5,6,7,8,11,9,10	9,285
Region 2	ESU #4C	10,9,11,12,13,20,14	766.81
Region 3	Gravel Borrow	15,16,17,18,28	162.25
Region 4	Common Borrow	15,16,17,19,20,13	1,794.8

Region 5	ESU #1B	15,13,12,21,22,23,24,25,26,27,29	753
Region 6	ESU #4A	23,5,6,7,8,11,12,21,22	1,133.2
Region 7	Common Borrow	15,28,29	5

Current Slip Surface

Slip Surface: 15
F of S: 2.7
Volume: 116.17802 ft³
Weight: 15,074.417 lbs
Resisting Moment: 360,722.74 lbs-ft
Activating Moment: 135,758.21 lbs-ft
Resisting Force: 29,138.654 lbs
Activating Force: 10,965.931 lbs
F of S Rank (Analysis): 1 of 125 slip surfaces
F of S Rank (Query): 1 of 125 slip surfaces
Exit: (11.487215, 98.148721) ft
Entry: (-11.00008, 108.5) ft
Radius: 13.936387 ft
Center: (2.921513, 109.14198) ft

Slip Slices

	X (ft)	Y (ft)	PWP (psf)	Base Normal Stress (psf)	Frictional Strength (psf)	Cohesive Strength (psf)
Slice 1	-11.00004	108.49913	-4,711.1458	20.537044	12.83297	0
Slice 2	-10.633333	106.56763	-4,590.6204	122.63198	95.810607	0
Slice 3	-9.9	103.763	-4,415.6113	314.81933	245.96382	0
Slice 4	-9.1666667	102.24624	-4,320.9652	410.40999	320.64742	0
Slice 5	-8.4333333	101.08662	-4,248.6051	474.69114	370.86936	0
Slice 6	-7.7	100.13726	-4,189.3652	571.36907	446.40244	0
Slice 7	-6.9666667	99.335057	-4,139.3075	695.76099	543.58806	0
Slice 8	-6.2333333	98.64555	-4,096.2823	780.19203	609.55282	0
Slice 9	-5.5	98.047423	-4,058.9592	970.80367	758.47495	0
Slice 10	-4.7666667	97.526407	-4,026.4478	1,089.5843	851.27659	0
Slice 11	-4.0333333	97.072431	-3,998.1197	1,217.9505	951.56718	0
Slice 12	-3.3	96.678119	-3,973.5147	1,593.4762	1,244.96	0
Slice 13	-2.5666667	96.337929	-3,952.2868	1,782.033	1,392.2768	0
Slice 14	-1.8333333	96.04762	-3,934.1715	1,982.2675	1,548.7171	0

Slice 15	-1.1	95.803923	-3,918.9648	2,192.9101	1,713.2891	0
Slice 16	-0.36666667	95.604311	-3,906.509	2,410.6961	1,883.4422	0
Slice 17	0.37684397	95.445238	-3,896.5828	52.741141	32.956322	0
Slice 18	1.1305319	95.326373	-3,889.1657	82.408942	51.494822	0
Slice 19	1.8842199	95.249384	-3,884.3616	112.09485	70.044635	0
Slice 20	2.6379078	95.213574	-3,882.127	140.71524	87.928641	0
Slice 21	3.3456265	95.215977	-3,882.277	178.69313	139.61037	0
Slice 22	4.0073759	95.25192	-3,884.5198	201.1118	157.12576	0
Slice 23	4.6691253	95.319621	-3,888.7443	215.88813	168.67029	0
Slice 24	5.3571429	95.424869	-3,895.3118	242.73696	189.6469	0
Slice 25	6.0714286	95.57118	-3,904.4416	280.56162	219.19876	0
Slice 26	6.7857143	95.757184	-3,916.0483	302.36129	236.23053	0
Slice 27	7.5	95.984569	-3,930.2371	305.28774	238.51693	0
Slice 28	8.2142857	96.255534	-3,947.1453	289.06995	225.8462	0
Slice 29	8.9285714	96.572909	-3,966.9495	256.09208	200.08106	0
Slice 30	9.6428571	96.94033	-3,989.8766	210.57017	164.51545	0
Slice 31	10.371804	97.372421	-4,016.8391	136.43909	106.5979	0
Slice 32	11.115411	97.87825	-4,048.4028	43.261929	33.799923	0

In Association with

Appendix E-3
Settlement Calculations

Project:	I-405	Sheet:	1 of 7
Project No.:		Phase:	
Calculation:	Settlement – Verification	Task:	
By:	C. T. Tang	Date:	6/15/2020
Checked By:	B. Lien	Date:	6/15/2020

wood.

Use of Hough-method EXCEL Spreadsheet - VERIFICATION CASE I

- **Input General Information** (images from MathCAD output file)

$\Delta H := 1\ in$ Allowable Total Settlement per GDM table 8-5 for concrete culvert

$\gamma := 125\ pcf$ Unit weight of soil above footing

$GS := 70\ ft$ Ground Surface elevation

$FE := 48\ ft$ Footing Elevation

$W := 8\ ft$ Footing Width

Groundwater Observed at Elevation 34'

Existing Pressure at footing:

$\sigma_{vo} := \gamma \cdot (GS - FE)$

$\sigma_{vo} = 2750\ psf$

Added Pressure applied at footing:

Concrete Culvert: 145 pcf

$W_c := 145\ pcf \cdot 2\ ft = 290\ psf$ Estimated concrete pressure over subgrade

Soil for stream & fill material: 130 pcf

$Ws := 130\ pcf \cdot 19\ ft = 2470\ psf$ Estimated soil pressure over footing

Calculate allowable bearing pressure for total settlement (service limit state):

$\sigma_v := 3300\ psf$ Plug number to find bearing resistance for allowable total settlement

- **Input Soil Layer Information and Calculation Results** (images from MathCAD output file)

$\gamma_1 := 100\ pcf$

$El_1 := 40\ ft$ Bottom elevation of layer

$C' := 30$ Refer to bearing capacity index table

$Midpoint := El_1 + ((FE - El_1) \cdot (0.5)) = 44\ ft$ Mid-point elevation of layer

$Width := (FE - Midpoint) + W = 12\ ft$ Width at mid-pt of layer

$Ipressure := \sigma_{vo} + ((Midpoint - El_1) \cdot \gamma_1) = 3150\ psf$ Initial pressure at mid-point

$Add_{pressure} := \sigma_v \cdot \left(\frac{W}{Width}\right) = (2.2 \cdot 10^3)\ psf$ Added pressure at mid-pt

$H_{o1} := FE - El_1 = 8\ ft$

$S_1 := \left(\frac{H_{o1}}{C'}\right) \cdot \log\left(\frac{(Ipressure + Add_{pressure})}{Ipressure}\right) = 0.061\ ft$

$S_1 = 0.74\ in$ Settlement from Layer

Soil Layer 2:

$\gamma_2 := 110\ pcf$

$El_2 := 30\ ft$ Bottom elevation of layer

$C'_2 := 90$ Refer to bearing capacity index table

$Midpoint_2 := El_2 + ((El_1 - El_2) \cdot (0.5)) = 35\ ft$ Mid-point elevation of layer

$Width_2 := (FE - Midpoint_2) + W = 21\ ft$ Width at mid-pt of layer

$Ipressure_2 := \sigma_{vo} + ((H_{o1} \cdot \gamma_1) + (Midpoint_2 - El_2) \cdot \gamma_2) = 4100\ psf$ Initial pressure at mid-pt

$Add_{pressure2} := \sigma_v \cdot \left(\frac{W}{Width_2}\right) = (1.26 \cdot 10^3)\ psf$ Added pressure at mid-pt

$H_{o2} := El_1 - El_2 = 10\ ft$

$S_2 := \left(\frac{H_{o2}}{C'_2}\right) \cdot \log\left(\frac{(Ipressure_2 + Add_{pressure2})}{Ipressure_2}\right) = 0.013\ ft$

$S_2 = 0.15\ in$ Settlement from Layer

Soil Layer 3:

$\gamma_3 := 57.6\ pcf$ 120 pcf for under groundwater less 62.4 pcf

$El_3 := 20\ ft$ Bottom elevation of layer

$C'_3 := 90$ Refer to bearing capacity index table

$Midpoint_3 := El_3 + ((El_2 - El_3) \cdot (0.5)) = 25\ ft$ Mid-point elevation of layer

$Width_3 := (FE - Midpoint_3) + W = 31\ ft$ Width at mid-pt of layer

$Ipressure_3 := \sigma_{vo} + ((H_{o1} \cdot \gamma_1) + H_{o2} \cdot (\gamma_2) + (Midpoint_3 - El_3) \cdot \gamma_3) = 4938\ psf$

$Add_{pressure3} := \sigma_v \cdot \left(\frac{W}{Width_3}\right) = 851.61\ psf$ Added pressure at mid-pt

$H_{o3} := El_2 - El_3 = 10\ ft$

$S_3 := \left(\frac{H_{o3}}{C'_3}\right) \cdot \log\left(\frac{(Ipressure_3 + Add_{pressure3})}{Ipressure_3}\right) = 0.008\ ft$

$S_3 = 0.09\ in$ Settlement from Layer

Total Settlement:

$S_T := S_1 + S_2 + S_3 = 0.98\ in$ if $\Delta H \geq S_T$ = "OK"

Project:	I-405	Sheet:	3 of 7
Project No.:		Phase:	
Calculation:	Settlement – Verification	Task:	
By:	C. T. Tang	Date:	6/15/2020
Checked By:	B. Lien	Date:	6/15/2020

wood.

- **Calculation Results with Input Information from Hough-method Spreadsheet**

Existing Subsurface Condition			Proposed Construction		Type =	Shallow Wall Footing	
Existing Ground Surface Elevation	70	feet	Bottom of Footing/Embankment Subrade Elevation			48	feet
Groundwater Elevation	34	feet	Foundation	Net Bearing Pressure on Bottom of Footin		3300	psf
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf		Width of Footing		8	psf
Existing Surchage pressure above BOF EL.	2750	psf	Embankment	Proposed Finished Grade Elevation			Not Appicable
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF	125	pcf		Distributed Embankment Pressure (Dp)		-8400	Not Appicable
						3300	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Satuarted Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	Soil Layer 1	SM	48	8	100	100	3550	3150	3	31	2200.0	0.71	0.71
2	Soil Layer 2	ML	40	10	110	110	4650	4100	55	90	1257.1	0.15	0.87
3	Soil Layer 3	ML	30	10	120	57.6	5226	4938	55	90	851.6	0.09	0.96
4				-		-	-	-		-	-	-	-
5				-		-	-	-		-	-	-	-
6				-		-	-	-		-	-	-	-
7				-		-	-	-		-	-	-	-
8				-		-	-	-		-	-	-	-

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:
1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of th

Estimated Settlement			= 1.0 inches
2/3 Correction =			= 0.6 inches
Prepared by:	CTT	Date:	7/2/2020
Reviewed by:		Date:	6/00/2020

NOTE: The yellow areas are the values that were entered, the reminders of sheet were auto-calculated via formulas that have been set.

Use of Hough-method EXCEL Spreadsheet - VERIFICATION CASE II

- **Input General Information** (images from MathCAD output file)

$\Delta H := 1\ in$ Allowable Total Settlement per GDM table 8-5 for concrete culvert

$\gamma := 110\ pcf$ Unit weight of soil above footing

$GS := 75\ ft$ Ground Surface elevation

$FE := 67\ ft$ Footing Elevation

$W := 8\ ft$ Footing Width

Perched Groundwater observed at Elevation 67'

Existing Pressure at footing:

$\sigma_{vo} := \gamma \cdot (GS - FE)$

$\sigma_{vo} = 880\ psf$

Added Pressure applied at footing:

Concrete Culvert: 145 pcf

$W_c := 145\ pcf \cdot 2\ ft = 290\ psf$ Estimated concrete pressure over subgrade

Soil for stream & fill material: 130 pcf

$Ws := 130\ pcf \cdot 19\ ft = 2470\ psf$ Estimated Soil pressure over footing

Calculate allowable bearing pressure for total settlement (service limit state):

$\sigma_v := 8000\ psf$ Plug Number to find bearing resistance for allowable total settlement

- **Input Soil Layer Information and Calculation Results** (images from MathCAD output file)

Soil Layer 1:

$\gamma_1 := 140\ pcf$

$El_1 := 57\ ft$ Bottom elevation of layer

$C' := 200$ Refer to bearing capacity index table

$Midpoint := El_1 + ((FE - El_1) \cdot (0.5)) = 62\ ft$ Mid-point elevation of layer

$Width := (FE - Midpoint) + W = 13\ ft$ Width at mid-pt of layer

$Ipressure := \sigma_{vo} + ((Midpoint - El_1) \cdot \gamma_1) = 1580\ psf$ Initial pressure at mid-point

$Add_{pressure} := \sigma_v \cdot \left(\frac{W}{Width}\right) = (4.92 \cdot 10^3)\ psf$ Added pressure at mid-pt

$H_{o1} := FE - El_1 = 10\ ft$

$S_1 := \left(\frac{H_{o1}}{C'}\right) \cdot \log\left(\frac{(Ipressure + Add_{pressure})}{Ipressure}\right) = 0.031\ ft$

$S_1 = 0.37\ in$ Settlement from Layer

Soil Layer 2:

$\gamma_2 := 110\ pcf$

$El_2 := 47\ ft$ Bottom elevation of layer

$C'_2 := 90$ Refer to bearing capacity index table

$Midpoint_2 := El_2 + ((El_1 - El_2) \cdot (0.5)) = 52\ ft$ Mid-point elevation of layer

$Width_2 := (FE - Midpoint_2) + W = 23\ ft$ Width at mid-pt of layer

$Ipressure_2 := \sigma_{vo} + ((H_{o1} \cdot \gamma_1) + (Midpoint_2 - El_2) \cdot \gamma_2) = 2830\ psf$ Initial pressure at mid-pt

$Add_{pressure2} := \sigma_v \cdot \left(\frac{W}{Width_2}\right) = (2.78 \cdot 10^3)\ psf$ Added pressure at mid-pt

$H_{o2} := El_1 - El_2 = 10\ ft$

$S_2 := \left(\frac{H_{o2}}{C'_2}\right) \cdot \log\left(\frac{(Ipressure_2 + Add_{pressure2})}{Ipressure_2}\right) = 0.033\ ft$

$S_2 = 0.40\ in$ Settlement from Layer

Soil Layer 3:

$\gamma_3 := 110\ pcf$

$El_3 := 37\ ft$ Bottom elevation of layer

$C'_3 := 90$ Refer to bearing capacity index table

$Midpoint_3 := El_3 + ((El_2 - El_3) \cdot (0.5)) = 42\ ft$ Mid-point elevation of layer

$Width_3 := (FE - Midpoint_3) + W = 33\ ft$ Width at mid-pt of layer

$Ipressure_3 := \sigma_{vo} + ((H_{o1} \cdot \gamma_1) + H_{o2} \cdot (\gamma_2) + (Midpoint_3 - El_3) \cdot \gamma_3) = 3930\ psf$

$Add_{pressure3} := \sigma_v \cdot \left(\frac{W}{Width_3}\right) = (1.94 \cdot 10^3)\ psf$ Added pressure at mid-pt

$H_{o3} := El_2 - El_3 = 10\ ft$

$S_3 := \left(\frac{H_{o3}}{C'_3}\right) \cdot \log\left(\frac{(Ipressure_3 + Add_{pressure3})}{Ipressure_3}\right) = 0.019\ ft$

$S_3 = 0.23\ in$ Settlement from Layer

Total Settlement:

$S_T := S_1 + S_2 + S_3 = 1\ in$ if $\Delta H \geq S_T$ = "OK"

Project:	I-405	Sheet:	6 of 7
Project No.:		Phase:	
Calculation:	Settlement – Verification	Task:	
By:	C. T. Tang	Date:	6/15/2020
Checked By:	B. Lien	Date:	6/15/2020

wood.

- **Calculation Results with Input Information from Hough-method Spreadsheet**

Existing Subsurface Condition		
Existing Ground Surface Elevation	75	feet
Groundwater Elevation	37	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	110	pcf
Existing Surchage pressure above BOF EL.	880	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF	110	pcf

Proposed Construction		Type =	Shallow Wall Footing
Bottom of Footing/Embankment Subrade Elevation		67	feet
Foundation	Net Bearing Pressure on Bottom of Footin	8000	psf
	Width of Footing	8	psf
Embankment	Proposed Finished Grade Elevation		Not Appicable
	Distributed Embankment Pressure (Dp)	-9000	Not Appicable
		8000	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Satuarted Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	Soil Layer 1	SM	67	10	140	140	2280	1580	83	199	4923.1	0.37	0.37
2	Soil Layer 2	ML	57	10	110	110	3380	2830	55	90	2782.6	0.40	0.77
3	Soil Layer 3	ML	47	10	110	110	4480	3930	55	90	1939.4	0.23	1.00
4				-		-	-	-		-	-	-	-
5				-		-	-	-		-	-	-	-
6				-		-	-	-		-	-	-	-
7				-		-	-	-		-	-	-	-
8				-		-	-	-		-	-	-	-

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

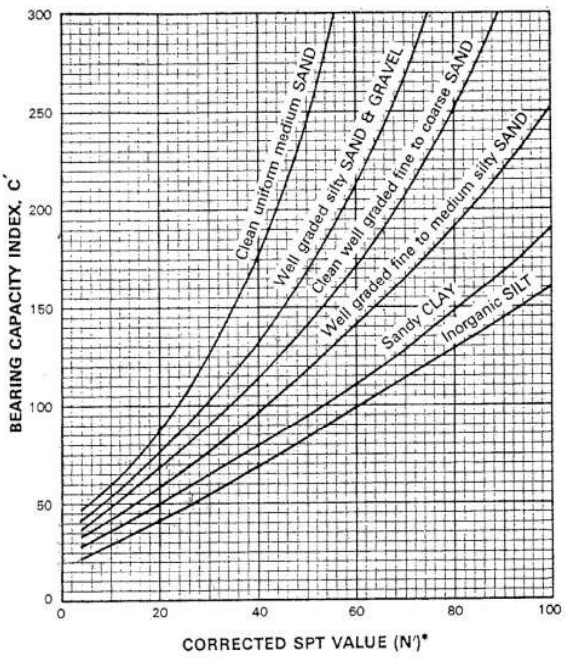
Notes:

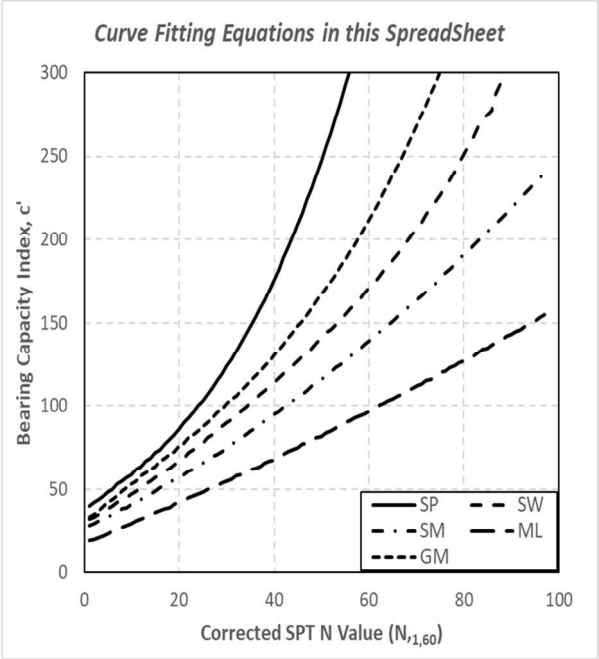
1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of th

Estimated Settlement	= 1.0 inches		
2/3 Correction =	= 0.7 inches		
Prepared by:	CTT	Date:	7/2/2020
Reviewed by:		Date:	6/00/2020

NOTE: The yellow areas are the values that were entered, the reminders of sheet were auto-calculated via formulas that have been set.

- **SUMMARY AND COMMENTS**
  - Based on the calculation results of two cases, the Hough-Method Spreadsheet produces an estimation of settlement, which is similar to the estimation from MathCAD.
  - C' values in the verification runs were based on inputs shown on the MathCAD files. In the real use of the spread sheet, correlation between N60 and C' in the spreadsheet is built based on the Chart below. (The figure on the left is the figure shown in literature, and the figure on the right is the curves plotted based on the embeded equations in the spreadsheet)





Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Section A-A' at Station 1+75 (Point 1)

Existing Subsurface Condition		
Existing Ground Surface Elevation	94	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	250	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		92	feet
Foundation	Net Bearing Pressure on Bottom of Footing	2634	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	109	Not Appicable
	Distributed Embankment Pressure (Dp)	1800	Not Appicable
		2634	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #1B (SPT-4)	SM	92	2	130	130	510	380	36	87	2414.5	0.24	0.24
2	ESU #4A (SPT-5)	ML	90	5	130	130	1160	835	50	82	1869.3	0.37	0.61
3	ESU #4A (SPT-6)	SM	85	5	130	130	1810	1485	50	116	1413.4	0.15	0.76
4	ESU #4A (SPT-7)	SM	80	5	130	130	2460	2135	50	116	1136.2	0.10	0.86
5	ESU #4A (SPT-8)	SM	75	5	130	130	3110	2785	50	116	950.0	0.07	0.92
6	ESU #4E (SPT-9)*	ML	70	5	125	125	3735	3423	50	82	816.2	0.07	0.99
7	ESU #4E (SPT-10)*	ML	65	5	125	125	4360	4048	50	82	715.4	0.05	1.04
8	ESU #4E (SPT-11)*	ML	60	5	125	125	4985	4673	50	82	636.8	0.04	1.08

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

* GDM Section 5.13.3

Estimated Settlement = 1.08 inches

2/3 Correction = = 0.72 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021

Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Station 2+08 End of Wall 10.18R-A (Point 2) - Boring W-154-20 (Elevation of boring is 104.6 ft)

Existing Subsurface Condition		
Existing Ground Surface Elevation	103	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	125	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		102	feet
Foundation	Net Bearing Pressure on Bottom of Footing	1526	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	111	Not Appicable
	Distributed Embankment Pressure (Dp)	960	Not Appicable
		1526	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #1B (SPT-1)	SM	102	5	130	130	775	450	50	116	1243.4	0.30	0.30
2	ESU #1B (SPT-3)	SM	97	5	130	130	1425	1100	37	89	907.4	0.18	0.47
3	ESU #1B (SPT-4)	SM	92	5	130	130	2075	1750	36	87	714.3	0.10	0.58
4	ESU #4A (SPT-5)	ML	87	5	130	130	2725	2400	50	82	589.0	0.07	0.65
5	ESU #4A (SPT-6)	SM	82	5	130	130	3375	3050	50	116	501.1	0.03	0.68
6	ESU #4A (SPT-7)	SM	77	5	130	130	4025	3700	50	116	436.0	0.03	0.71
7	ESU #4A (SPT-8)	SM	72	3	130	130	4415	4220	50	116	395.0	0.01	0.72
	ESU #4E (SPT-9)*	ML	69	5	125	125	5040	4728	50	82	361.0	0.02	0.74
				-		-	-	-		-	-	-	-
8													

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

* GDM Section 5.13.3

Estimated Settlement = 0.74 inches

2/3 Correction = = 0.49 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021

Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Wall 10.18R-B (Point 3) - Boring GEO-33 (Elevation of boring is 124ft)

Existing Subsurface Condition		
Existing Ground Surface Elevation	124	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	625	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		119	feet
Foundation	Net Bearing Pressure on Bottom of Footing	1215	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	126	Not Appicable
	Distributed Embankment Pressure (Dp)	240	Not Appicable
		1215	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #4C (SPT-2)	SM	119	4	130	130	1145	885	50	116	1028.1	0.14	0.14
2	ESU #4C (SPT-4)	SM	115	5	130	130	1795	1470	50	116	763.7	0.09	0.23
3	ESU #4C (SPT-6)	SM	110	5	130	130	2445	2120	50	116	594.0	0.06	0.29
4	ESU #4C (SPT-8)	SM	105	5	130	130	3095	2770	50	116	486.0	0.04	0.32
5	ESU #4A (SPT-9)	SM	100	5	130	130	3745	3420	50	116	411.2	0.03	0.35
6	ESU #4A (SPT-10)	SP	95	5	130	130	4395	4070	50	247	356.4	0.01	0.36
7	ESU #4A (SPT-11)	SP	90	5	130	130	5045	4720	50	247	314.5	0.01	0.37
8	ESU #4A (SPT-12)	SP	85	5	130	130	5695	5370	50	247	281.4	0.01	0.37

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

Estimated Settlement = 0.37 inches

2/3 Correction = = 0.25 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021

8519 Jefferson Street NE
Albuquerque, NM 87113
www.woodplc.com

Differential Settlement

As these segments are located adjacent to each other, a comparison of the center to edge settlement was not considered valid. This is because the edge of the foundation would see the approximately same amount of load for all the central segments from adjacent segments. Comparison of the center to edge settlement would only be valid for the end segments. For central segments, the maximum differential settlement would be on the basis of the center to center settlement.

Settlement was calculated using the modified Hough Method. ESU 4E was assumed to be elastic based GDM 5.13.3. N1(60) values were limited to 50bpf, however, settlement calculations using the actual N1(60) are also provided.

For the Segment from Sta. 1+75 (point 1) to Sta. 2+08 (point 2) (without ground improvement), the maximum differential using the center settlement has been estimated based on the assumption that Station 1+75 and Station 2+08 are adjacent to each other, this is considered a conservative assumption.

Center $\Delta H_{100} := (0.72\ in - 0.49\ in) \cdot \frac{100}{50} = 0.46\ in$

For the Segment from Sta. 2+08 (point 2) to Sta. 6+00 (point 3) (without ground improvement), the maximum differential using the center settlement has been estimated based on the assumption that Station 2+08 and Station 6+00 are adjacent to each other, this is considered a conservative assumption.

Center $\Delta H_{100} := (0.49\ in - 0.25\ in) \cdot \frac{100}{50} = 0.48\ in$

For the Segment from Sta. 1+75 (point 1) to Sta. 6+00 (point 3) (without ground improvement), the maximum differential using the center settlement has been estimated based on the assumption that Station 1+75 and Station 6+00 are adjacent to each other, this is considered a conservative assumption.

Center $\Delta H_{100} := (0.72\ in - 0.25\ in) \cdot \frac{100}{50} = 0.94\ in$

Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Section A-A' at Station 1+75 (Point 1)

Existing Subsurface Condition		
Existing Ground Surface Elevation	94	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	250	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		92	feet
Foundation	Net Bearing Pressure on Bottom of Footing	2634	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	109	Not Appicable
	Distributed Embankment Pressure (Dp)	1800	Not Appicable
		2634	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #1B (SPT-4)	SM	92	2	130	130	510	380	36	87	2414.5	0.24	0.24
2	ESU #4A (SPT-5)	ML	90	5	130	130	1160	835	61	98	1869.3	0.31	0.55
3	ESU #4A (SPT-6)	SM	85	5	130	130	1810	1485	192	631	1413.4	0.03	0.58
4	ESU #4A (SPT-7)	SM	80	5	130	130	2460	2135	213	745	1136.2	0.01	0.59
5	ESU #4A (SPT-8)	SM	75	5	130	130	3110	2785	204	695	950.0	0.01	0.61
6	ESU #4E (SPT-9)*	ML	70	5	125	125	3735	3423	254	472	816.2	0.01	0.62
7	ESU #4E (SPT-10)*	ML	65	5	125	125	4360	4048	239	437	715.4	0.01	0.63
8	ESU #4E (SPT-11)*	ML	60	5	125	125	4985	4673	136	222	636.8	0.01	0.64

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

* GDM Section 5.13.3

Estimated Settlement = 0.64 inches

2/3 Correction = = 0.43 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021

Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Station 2+08 End of Wall 10.18R-A (Point 2) - Boring W-154-20 (Elevation of boring is 104.6 ft)

Existing Subsurface Condition		
Existing Ground Surface Elevation	103	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	125	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		102	feet
Foundation	Net Bearing Pressure on Bottom of Footing	1526	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	111	Not Appicable
	Distributed Embankment Pressure (Dp)	960	Not Appicable
		1526	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #1B (SPT-1)	SM	102	5	130	130	775	450	51	118	1243.4	0.29	0.29
2	ESU #1B (SPT-3)	SM	97	5	130	130	1425	1100	37	89	907.4	0.18	0.47
3	ESU #1B (SPT-4)	SM	92	5	130	130	2075	1750	36	87	714.3	0.10	0.57
4	ESU #4A (SPT-5)	ML	87	5	130	130	2725	2400	61	98	589.0	0.06	0.63
5	ESU #4A (SPT-6)	SM	82	5	130	130	3375	3050	192	631	501.1	0.01	0.64
6	ESU #4A (SPT-7)	SM	77	5	130	130	4025	3700	213	745	436.0	0.00	0.64
7	ESU #4A (SPT-8)	SM	72	3	130	130	4415	4220	204	695	395.0	0.00	0.64
	ESU #4E (SPT-9)*	ML	69	5	125	125	5040	4728	254	472	361.0	0.00	0.65
				-		-	-	-		-	-	-	-
8													

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

* GDM Section 5.13.3

Estimated Settlement = 0.65 inches

2/3 Correction = = 0.43 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021

Settlement Calculation for Shallow Footing or Embankment (Modified Hough Method)

Project/Task Name: I-405: Renton to Bellevue Widening and Express Toll Lanes Project / I-405 Wall 10.18R Settlement Analysis

Notes: Wall 10.18R-B (Point 3) - Boring GEO-33 (Elevation of boring is 124ft)

Existing Subsurface Condition		
Existing Ground Surface Elevation	124	feet
Groundwater Elevation	33	feet
Total Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf
Existing Surchage pressure above BOF EL.	625	psf
Weighted Effective Unit Weight of Soil from Ex. GSE to BOF EL.)	125	pcf

Proposed Construction		Type = Shallow Wall Footing	
Bottom of Footing/Embankment Subrade Elevation		119	feet
Foundation	Net Bearing Pressure on Bottom of Footing	1215	psf
	Width of Footing	11	ft
Embankment	Proposed Finished Grade Elevation	126	Not Appicable
	Distributed Embankment Pressure (Dp)	240	Not Appicable
		1215	psf

Accept Inputs in yellow-marked Cells ONLY

Layer No.	Material	Code**	Layer Top Elevation	Layer Thickness H (feet)	Saturated Unit Weight γ (pcf)	Effective Unit Weight γ' (pcf)	Existing effective overburden Pressure Bot. of Layer psf)	Existing effective overburden Pressure Mid. of Layer Po (psf)	$N1_{60}$	Bearing Capacity Index C'	Distributed Additional Pressure Δp (Notes 1&2) (psf)	Settlement of Subdivided Layer ΔH (in.)	Cumulative Settlement ΣΔH (in.)
1	ESU #4C (SPT-2)	SM	119	4	130	130	1145	885	272	1129	1028.1	0.01	0.01
2	ESU #4C (SPT-4)	SM	115	5	130	130	1795	1470	238	896	763.7	0.01	0.03
3	ESU #4C (SPT-6)	SM	110	5	130	130	2445	2120	145	413	594.0	0.02	0.04
4	ESU #4C (SPT-8)	SM	105	5	130	130	3095	2770	188	610	486.0	0.01	0.05
5	ESU #4A (SPT-9)	SM	100	5	130	130	3745	3420	78	185	411.2	0.02	0.06
6	ESU #4A (SPT-10)	SP	95	5	130	130	4395	4070	161	3589	356.4	0.00	0.07
7	ESU #4A (SPT-11)	SP	90	5	130	130	5045	4720	71	479	314.5	0.00	0.07
8	ESU #4A (SPT-12)	SP	85	5	130	130	5695	5370	114	1443	281.4	0.00	0.07

Code**	Model
ML	INORGANIC SILT
SM	f/m silty SAND
SW	Well graded fine to coarse SAND
GM	Well graded silty SAND & Gravel
SP	Clean uniform medium SAND

Notes:

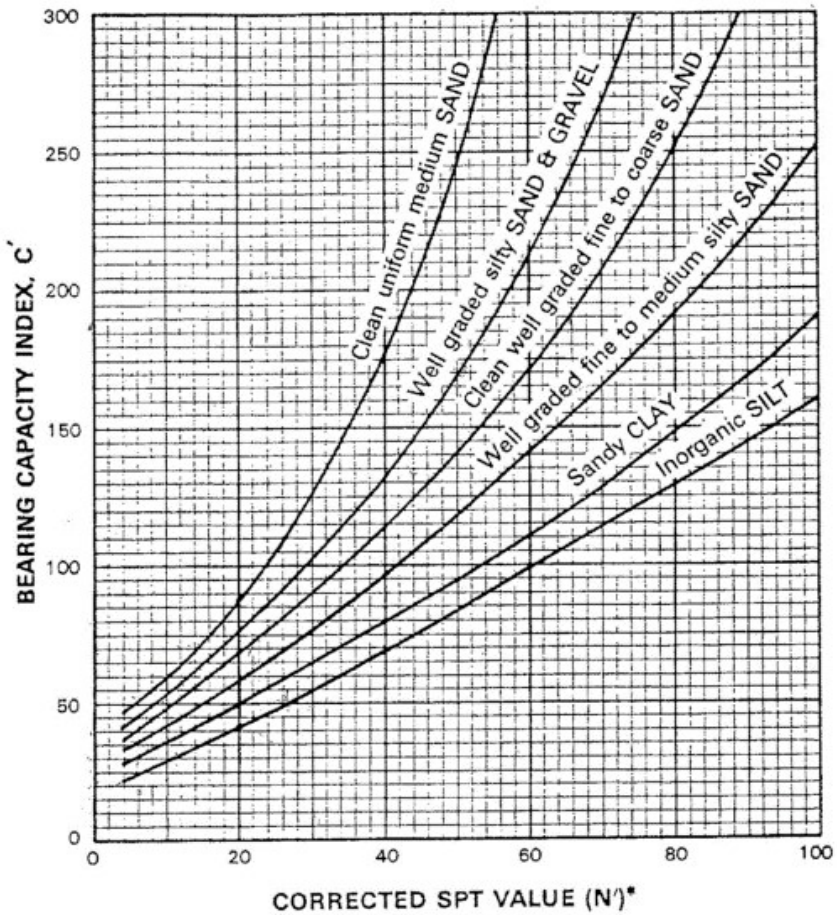
1. For Shallow Footings, a 1H:2V stress increase ditribution is considerted; one-way for wall footing and 2-way for square footing.
2. For Embankment Fill, assume no reduction of the aerial surcharge load vs.depths.

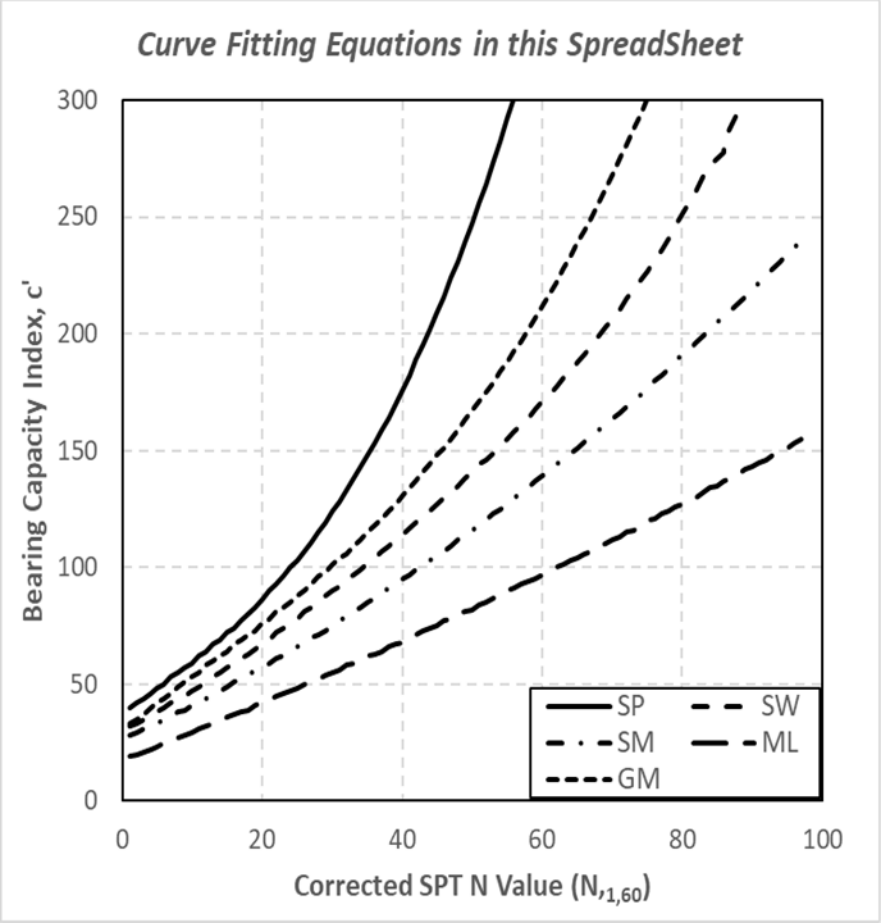
Estimated Settlement = 0.07 inches

2/3 Correction = = 0.05 inches

Prepared by: JA Date: 9/21/2021

Reviewed by: Neill Belk Date: 9/24/2021


BEARING CAPACITY INDEX, C'
CORRECTED SPT VALUE (N')*
Clean uniform medium SAND
Well graded silty SAND & GRAVEL
Clean well graded fine to coarse SAND
Well graded fine to medium silty SAND
Sandy CLAY
Inorganic SILT
0
50
100
150
200
250
300
0
20
40
60
80
100


Curve Fitting Equations in this SpreadSheet
Bearing Capacity Index, c'
Corrected SPT N Value ($N_{,1,60}$)
SP
SW
SM
ML
GM
0
50
100
150
200
250
300
0
20
40
60
80
100