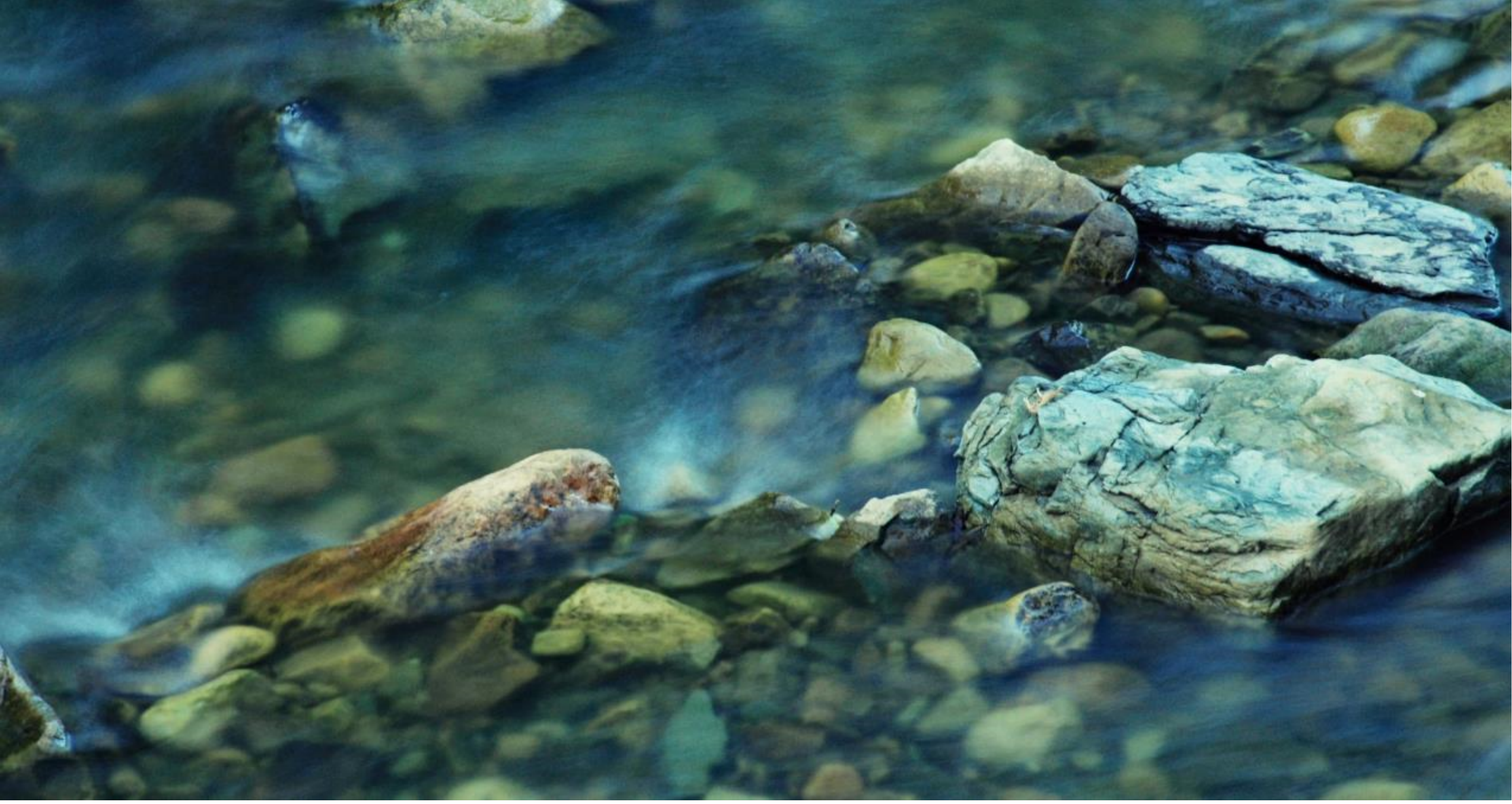

July 2021
Parcel 86 Bank Stabilization Project

100% Basis of Design Report

Prepared for Port of Tacoma

July 2021
Parcel 86 Bank Stabilization Project

100% Basis of Design Report

Prepared for
Port of Tacoma
One Sitcum Plaza
Tacoma, Washington 98421

Prepared by
Anchor QEA, LLC
1119 Pacific Avenue, Suite 1600
Tacoma, Washington 98402

Project Number: 200092-01.05

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TABLES

FIGURES

APPENDICES

ABBREVIATIONS

bgs	below ground surface
MHHW	mean higher high water
MLLW	mean lower low water
NOAA	National Oceanic and Atmospheric Administration
pcf	pound per cubic foot
Port	Port of Tacoma
psf	pound per square foot
RCP	Representative Concentration Pathway

1 Introduction

1.1 Basis of Design Report Purposes and Objectives

This Basis of Design Report has been prepared for the Port of Tacoma (Port). This report documents the basis of design criteria for the construction of a bulkhead composed of sheet pile wall to prevent erosion along the bank of the Hylebos Creek at the Port of Tacoma Parcel 86. This Basis of Design Report includes a summary of investigations, which serve as the basis for characterizing site conditions and establishing design criteria.

1.2 Document Organization

The remainder of this document is organized into the following sections:

- Section 2: Project Area Background and Conditions
- Section 3: Bulkhead Design
- Section 4: Schedule

The following appendices are attached to this Report:

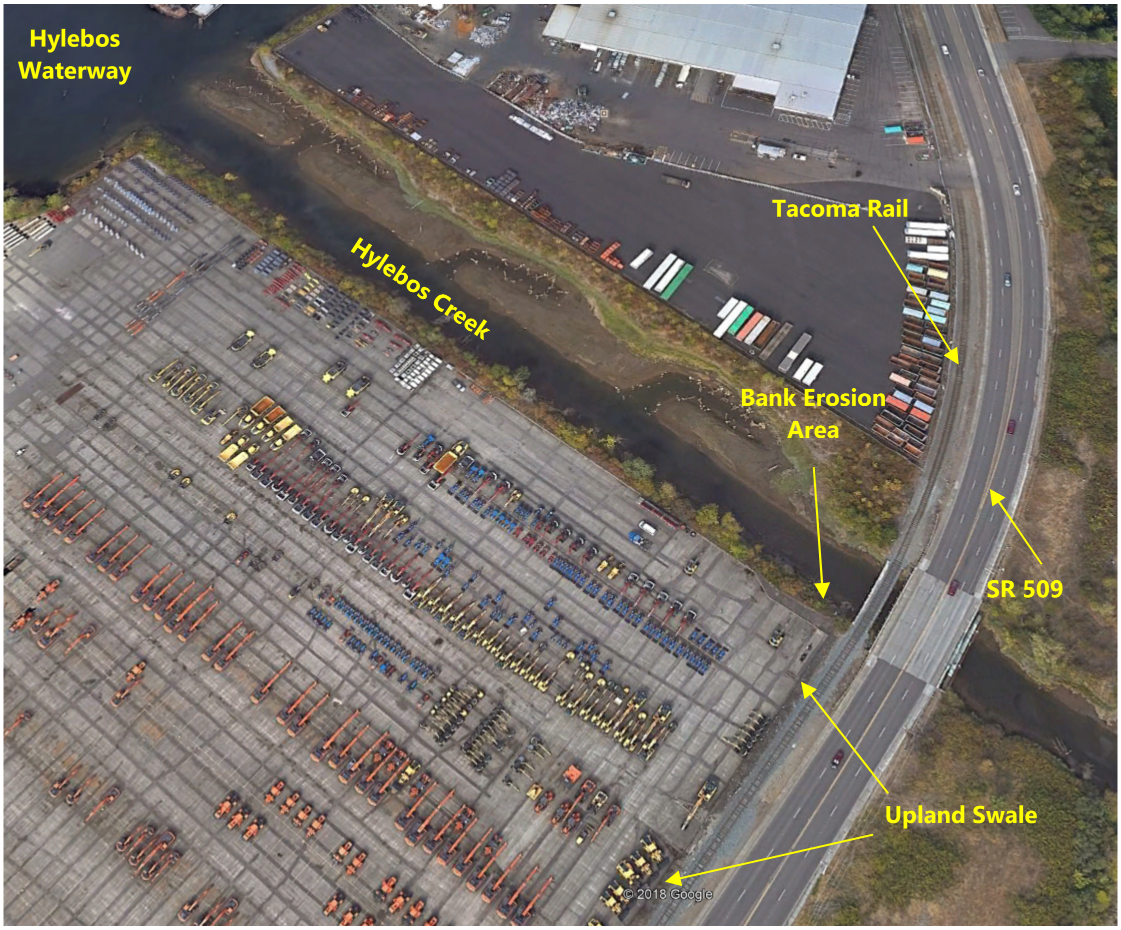
- Appendix A: SupportIT Model Documentation

2 Project Area Background and Conditions

2.1 Project Area Description

Parcel 86, located within the Port at 3701 Taylor Way, is a former cleanup site, regulated by the Washington State Department of Ecology. The property runs adjacent to the south bank of the Hylebos Creek. The former owner and operator, Louisiana Pacific, placed Asarco slag and road ballast across the site to stabilize the ground for operation of heavy log-yard machinery. The remedy was implemented in 1993 and consists of a low-permeability asphalt cap and stormwater drainage system. The Enforcement Order (DE92TC-S312) and Restrictive Covenant prohibits disturbance of the cap and exposure to contaminated soil and slag under the cap. Erosion of the shoreline bank in the southeast corner has progressed landward having exposed a manhole that is part of the Parcel 86 stormwater management system. The area of erosion is within clean backfill surrounding the exposed manhole.

Figure 1
Overview of Parcel 86



2.2 Land Ownership

The property is currently owned by the Port and is leased to Wallenius Wilhelmsen Logistics Services who uses the site for post assembly of construction equipment and staging of equipment before delivery to clients.

2.3 Site Conditions

Anchor QEA and Port staff previously conducted a site visit in June 2019 to observe the conditions of the shoreline. The site visit was part of the scope of work for a Bank Erosion Assessment Report (Anchor QEA 2019). Based on the analyses performed under that scope, it was determined that there were three potential causes of bank erosion:

- Leakage from the stormwater conveyance system
- Inundation and drainage of the stormwater system conveyance piping gravel bedding layer during tidal cycles
- Upland runoff

Further information about the erosion assessment can be found in the Bank Erosion Assessment Report (Anchor QEA 2019).

2.3.1 Survey

A topographical survey of the project area, including the bank of the Hylebos Waterway down to the creek centerline, was performed by Sitts & Hill Engineers, Inc., on June 23, 2020. The survey also included the four on-site groundwater monitoring wells and documentation of the stormwater conveyance system adjacent to the bank erosion area. Further information regarding the survey can be found in the Conceptual Design Options Evaluation Report (Anchor QEA 2020).

2.3.2 Subsurface Conditions

A geotechnical subsurface field investigation including the advancement of one soil boring was performed to collect necessary data for the design of a bulkhead and remediation measures. The general lithology of the subsurface beneath the asphalt cap includes a layer of soft silt to a depth of 25 feet followed by a layer of poorly graded sand with silt to a depth of 35.3 feet. The subsurface information obtained during the subsurface geotechnical investigation was used for design analysis of a sheet pile bulkhead wall. Further information about the subsurface conditions can be found in the Conceptual Options Evaluation Report (Anchor QEA 2020).

2.3.3 Hydrogeology

The estimated zone of groundwater fluctuation between elevation +10 and +12 feet mean lower low water (MLLW) is based on seasonal water level observations made during the long-term monitoring events required by the Washington State Department of Ecology cleanup (under Enforcement Order No. DE 92TC-S312) for the Former Louisiana Pacific/Pony Lumber Facility. This monitoring occurred periodically between 2007 and 2019. After review of these data, the following was concluded about groundwater at the site: 1) the horizontal gradient towards the creek is relatively flat, and 2) there is a slight downward gradient from the upper silt into the underlying sand layer.

The survey also documented the stormwater manholes and confirmed that the gravel bedding below the manholes sits within the zone of groundwater fluctuation at approximately +10.3 feet MLLW. This elevation is consistent with observations of groundwater seeps that emanate from the bank adjacent to MH7.

2.3.4 Creek Bank Conditions

The creek bank erosion is occurring just downstream of the SR 509 and rail bridges that cross over the Hylebos Creek. Figure 2 shows a photograph of bank erosion at the project site; the vault for manhole MH7 is visible in the photograph. On-site observations suggested that the erosion had been caused by a flow originating at the top of the tank, from within the bedding layer for the manhole vault, or both. The flow was large enough to move the gravel bedding layer away from the vault and down the bank as well as cutting an approximate 1-foot-deep incised channel down the mud bank.

Figure 2
Bank Erosion at Parcel 86 at Low Tide

Note: Photograph looking southwest from rail bridge. Photograph taken April 2019.

2.3.5 Tides

Tidal heights in the adjacent Hylebos Waterway were taken from National Oceanic and Atmospheric Administration (NOAA) tidal station #9446484 located on the Sitcum Waterway, in Tacoma, Washington. Table 1 summarizes tidal datums relative to NAVD88 and MLLW based on NOAA tidal station #9446484.

Table 1
Tidal Datums at Tacoma, Washington (NOAA Tidal Station #9446484)

Tidal Datum	Elevation (feet relative to MLLW)	Elevation (feet relative to NAVD88)
Mean Higher High Water (MHHW)	+11.8	+9.4
Mean High Water (MHW)	+10.9	+8.5
Mean Sea Level (MSL)	+6.8	+4.4
Mean Low Water (MLW)	+2.8	+0.4
North American Vertical Datum (NAVD88)	+2.4	0
Mean Lower Low Water (MLLW)	0	-2.4

2.3.6 *Extreme Water Levels*

The Federal Emergency Management Agency 100-year flood elevation for the Hylebos Waterway adjacent to the site location is 12 feet NAVD88 (+14.6 feet MLLW). This elevation is derived from coastal processes (based on the Federal Emergency Management Agency flood map number 52053C0788E from March 7, 2017) and is approximately equal to the highest observed water level at the NOAA tidal station #9446484 (+14.8 feet MLLW). Based on the elevations of the site topography, the 100-year floodplain elevation is only expected to interface with a small portion of the bulkhead local to the critical area of scour and is not expected to interface with any other exposed portions of the bulkhead.

2.3.7 *Sea Level Rise*

A report prepared for the Washington Coastal Resiliency Project in 2018 provided an updated assessment of projected sea level rise and the associated hazards for Washington state. The updated projections for sea level rise are more comprehensive than past estimates, taking into consideration recent research, land movement, and greenhouse gas emissions. Greenhouse gas emission projections depend on a variety of factors related to human behavior. Therefore, probabilistic projections for sea level rise have been made based on both low and high greenhouse gas scenarios. Climate projections are made for two greenhouse gas emissions scenarios in this report: Representative Concentration Pathway (RCP) 4.5 and RCP 8.5. RCP 4.5 is a low scenario in which greenhouse gas estimates stabilize by mid-century and decrease thereafter. RCP 8.5 is a high scenario in which there is continued increase in greenhouse gasses until the end of the 21st century (Mauger et al. 2015).

The Washington Coastal Network used the information presented in this report to develop a visualization tool (SLR Visualization Tools[1]) to assess projected sea level rise over the next century.

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[1] https://wacoastalnetwork.com/chrn/research/slr-visualization/

The site-specific sea level rise estimates for the Port under the RCP 4.5 low scenario for a 50% probability is 2.1 feet by the year 2100, which would result in a new MHHW level of approximately +13.9 feet MLLW. The minimum final elevation of the bulkhead will be established at +18 feet MLLW; therefore, it is not expected that the wall would be overtopped within its design life.

2.4 Existing Site Structures

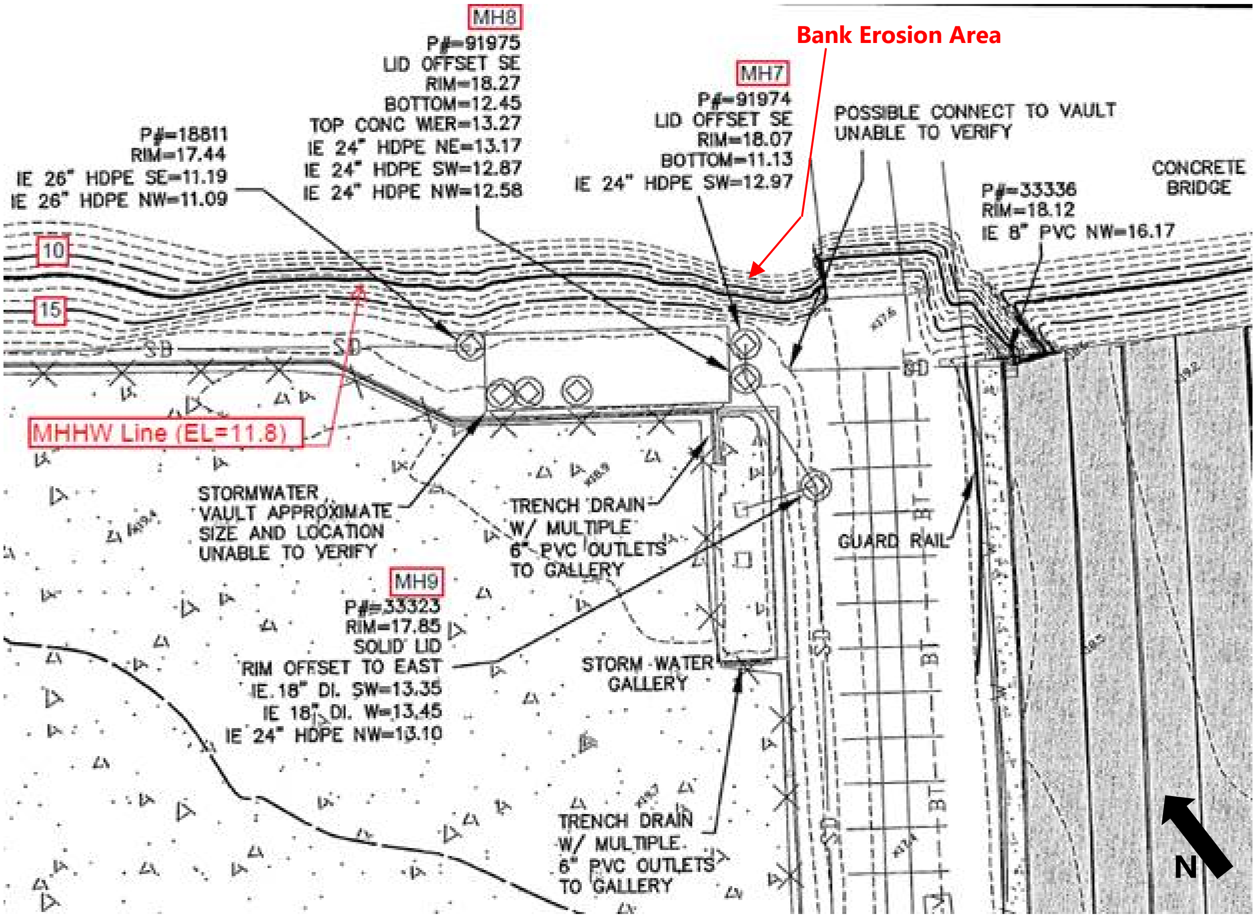
2.4.1 Railway

A rail line runs adjacent to SR 509 approximately 15 feet southeast from the boundary of Parcel 86. The rail line is owned and operated by Tacoma Rail as part of the Tidelands Division.

2.4.2 Stormwater Infrastructure

Adjacent to the creek bank exist numerous manhole vaults. Figure 3 shows the elevations in feet MLLW (Table 1) of the stormwater system just upland of the observed bank erosion; the locations of MH7, MH8, and MH9; and the MHHW elevation. The erosion along the bank is adjacent to existing stormwater infrastructure for Parcel 86, especially MH7. There exists an underground stormwater vault that extends to the northwest of MH7 and MH8. A supplemental survey was completed by Sitts & Hill Engineers, Inc., on April 14, 2021, to verify the location and position of MH7. The location of this structure is shown on the engineering drawings.

Figure 3
Stormwater Infrastructure Elevations



Source: Port of Tacoma 2008; Elevations in MLLW.

3 Bulkhead Design

This section describes the preliminary design for the sheet pile bulkhead, including design criteria and limitations.

3.1 Design Objectives

The objective of the bulkhead design is to stabilize the upper bank of the Hylebos Creek above the MHHW mark to prevent damage to the environmental cap and stormwater system.

3.2 Design Constraints

There are several design constraints within the project area that were addressed during preliminary design. First, the project area is bounded by the railroad to the southeast. Because the project is located within the rail right-of-way, discussions with the owner were held to verify that the alignment of the bulkhead would not impede rail operations. In general, the rail operates overnight and construction should not coincide with operations.

Second, the location of stormwater infrastructure, primarily MH7 and the adjacent stormwater vault in the upland portion of the creek bank provided a constraint to design. The stormwater vault proved to be an added constraint as it cannot support excessive loading, requiring the need for a crane with sufficient reach to perform the work from behind the vault.

Finally, the project area is constrained by the Hylebos Creek to the north, where the creek bank begins immediately north of the property. Based on the topographical survey and due to the locations of stormwater structures that exist at the site, the alignment of the bulkhead was modified from the preliminary alignment as shown in A-01.

3.3 Design Assumptions and Criteria

As detailed in the Conceptual Options Evaluation (Anchor QEA 2020), the geotechnical investigation that was completed in Fall 2020 indicated soft conditions in the upper 25 feet of the subsurface. The sheet pile wall sections were modeled using SupportIT, a design software package used to model earth pressures acting on cantilevered sheet pile walls (GTSoft 2007). The model utilizes subsurface soil properties combined with sheet pile wall structural strength data to determine design criteria such as minimum embedment depth requirements and anticipated bending moments. Computer runs for various sheet pile sections and embedments were performed to establish the relationship between wall embedment and deflection. Anchor QEA consulted a steel supplier, NucorSkyline, to determine available and appropriate steel sheet pile sections for use at the site based on existing site conditions and long-term maintenance expectations. Embedment depths for each section of the bulkhead were determined by modeling each section using NZ19 ASTM A690 Grade 50 Hot Rolled Sheet Pile. The NZ19 sheet pile section was selected due to its availability and ability to be rolled using ASTM A690 steel. Data for the NZ19 panels as well as the subsurface soil profile determined by the geotechnical investigation and lab results we input to this model. Note that ASTM A690 steel was selected for this preliminary design due in part to its maintenance-free use in the marine environment while not requiring protective coatings or a cathodic protection system.

For each section, reasonable assumptions were made for exposed sheet pile to conservatively account for any future erosion that may occur seaward of the bulkhead due to fluid flow and tidal cycles. The maximum deflection[2] and embedment depths along each cross section were estimated using the SupportIt model. Six total cross sections were developed to characterize changes in the bank topography, as shown in Figure A-01. A critical cross section was determined at the area of scour adjacent to MH7. During this interim design phase, it was determined that the NZ19 bulkhead was sufficient to meet acceptable deflection tolerances at the critical cross section. The maximum deflection for sections A-A′, B-B′, C-C′, D-D′, F-F′, and G-G′ was less than 1 inch. The maximum deflection for the critical cross section E-E′ was less than 2 inches. The predicted deflections along the length of the bulkhead are within the tolerance of the sheet pile interlocks. Table 2 summarizes the alignment lengths and depths for each section of bulkhead.

Table 2
Summary of Sheet Pile Lengths along the Bulkhead Alignment

Evaluated Section[1]	Approximate Length of Segment along Alignment	Sheet Depth (bgs)	Notes about Slope Condition at Cross-Section
Sections A-A′, B-B′, and C-C′	3 pair (~14 feet)	10 feet	West of observed bank erosion. Shoreline is stable and vegetated.
Sections D-D′, and F-F′	3 pair (~14 feet)	Varies, 15 to 20 feet	Adjacent to main bank erosion area. Shoreline appears relatively stable and is vegetated on the upper slope, but potential future erosion may be expected as the adjacent erosion area expands.
Section E-E′	2 pair (~9 feet)	30 feet	Shoreline is not stable and significant erosion has occurred. Multiple groundwater seeps are observed and gravel base layer around and below the stormwater system provides continuous flow path. Erosion will continue until bulkhead is constructed.
Section G-G′	2 pair (~9 feet)	10 feet	Wall segment is perpendicular to the slope and is stable.

Note:

1. Section references are based on Figure A-01 in Appendix A and do not correspond to the sections shown on the Plans.

Engineering drawings C3.0 and C4.0 show the plan view of the bulkhead alignment and the sectional views. The bulkhead alignment will run parallel to the Hylebos creek north to south utilize a delta 3

---

[2] Deflection is generally defined as the horizontal displacement of the top of a cantilever bulkhead that will occur over time.

connected to create a 110-degree elbow angling the bulkhead south as it approaches the rail line to the south east. The 110-degree elbow was selected to route the perpendicular segment of the bulkhead around existing natural features and to maintain function of the stormwater swale that runs along the railroad. Further information regarding the details of the bulkhead design can be found in the engineering drawings.

3.3.1 Geotechnical

Table 3 summarizes the subsurface geologic profile observed in the boring and associated modeling parameters used to develop a conceptual bulkhead configuration. Modeling parameters were established using geotechnical laboratory test results, as well as standard empirical correlations of measured SPT-N values to soil engineering design properties. Selection of the design properties was based on experience with similar materials on other projects and consistent with geotechnical engineering design guidance.

Table 3
Subsurface Soil Profile and Preliminary Soil Engineering Properties

Subsurface Layer	Depth below Ground Surface (feet)	Total Unit Weight (ɣ) (pcf)	Effective Cohesion (c′) (psf)	Friction Angle (φ′) (degrees)
Asphalt	0–0.8	135	4,175.7	0
Gravel Base	0.8–2	110	0	40
Layer 1: Silt (ML)	2–25	100	500	18
Layer 2: Poorly Graded Sand with Silt (SP-SM)	25–35.3	115	0	32
Layer 3: Silt (MH)	35.3–41.8	95	500	16
Layer 4: Poorly Graded Sand with Silt (SP-SM)	41.8–45.6	110	0	30
Layer 5: Silty Sand (SM)	45.6–55.3	110	0	28
Layer 6: Poorly Graded Sand with Silt (SP-SM)	55.3–80.1	125	0	32

3.3.2 Structural

There were a few structural considerations addressed during the preliminary design phase. Because several segments of the bulkhead may be exposed to saline water, the evaluations focused on available sections composed of ASTM A690 steel, which is a weathering steel alloy that develops an oxidizing layer to protects against erosion without supplemental coating or active corrosion protection anode systems. This steel is slightly more expensive than more common grades of steel used for sheet pile, but will not require any near- or long-term maintenance. Sheet piles composed of A690 steel may become a long-lead item since it is generally not carried in-stock and requires special runs of fabrication.

The top surface of steel sheet piles can be a bit jagged based on installation procedures and should be capped to create a finished appearance. We suggest a carbon steel inverted channel to be bolted to the top of the steel bulkhead. Since this channel is accessible for maintenance, unlike portions of the steel sheet piles, we have chosen a channel section of common A36 steel, blasted, primed, and painted with a quality epoxy marine-grade coating. Obviously, this channel could be fabricated from A690 material, or even obtained in stainless steel, although at much higher cost.

3.4 Installation

Sheet piles are typically installed using vibratory and impact hammer. The use of a diesel vibratory hammer may potentially cause a liquefaction effect immediately adjacent to the piling, which temporarily reduces localized soil strength. The Washington Department of Natural Resources geologic portal3 categorizes the area in and around the Port as highly susceptible to liquefaction. It is likely that very little driving force will be required to install the sheet piles into this layer, and so a silent pile driver will be used to install the bulkhead, thus significantly reducing the potential for installation to cause bank failure. For the approximately 10-foot (two pairs of sheet pile) segment of bulkhead with embedment depths of 30 feet below ground surface (bgs), the deeper soils consist of medium dense sand and soft silt. Increased hammer energy may be required to drive the piles into the layer of medium dense sand; however, this could be accomplished using an impact hammer which have a lower potential to cause a strength reduction in adjacent soils. Given the potential for surficial bank soils to fail, we plan to specify the use of a silent pile driver and an impact hammer, only if required, for this project.

We have assumed that the bulkhead will be installed from a landside position. Landside access to the location of the proposed bulkhead is limited by the railroad and the infrastructure associated with the stormwater management system. Based on our preliminary outreach to local pile installation contractors, we believe that American Crane models 9299 or 9310 will be suitable to support pile installation for this project. These cranes have the reach and load capacity to facilitate pile installation while the crane is positioned landward of the stormwater treatment vault.

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3 https://geologyportal.dnr.wa.gov/

4 Schedule

Based on the elements of the design, Table 4 presents the preliminary schedule for construction. Working days are considered Monday to Friday. Please note that this schedule is preliminary and may be altered based on feedback from contractors.

Table 4
Preliminary Construction Schedule

Task	Expected Time to Complete
Mobilization and Site Preparation	10 Working Days
Sheet Pile Installation	6 Working Days
Backfill and Grading	2 Working Days
Steel Cap Installation	6 Working Days
Site Cleanup and Restoration	5 Working Days

5 References

Anchor QEA, 2019. *Parcel 86 Bank Erosion Assessment*. Prepared for Port of Tacoma. December 2019.

Anchor QEA, 2020. *Conceptual Design Options Evaluation*. Prepared for Port of Tacoma. October 2020.

GTSoft, 2007. SupportIT Sheet Pile Design Software, User Guide, v 2.38. GTSoft, LTD, Prestwick, United Kingdom.

Mauger, G.S., J.H. Casola, H.A. Morgan, R.L. Strauch, B. Jones, B. Curry, T.M. Busch Isaksen, L. Whitely Binder, M.B. Krosby, and A.K. Snover, 2015. *State of Knowledge: Climate Change in Puget Sound*. Report prepared for the Puget Sound Partnership and the National Oceanic and Atmospheric Administration. Climate Impacts Group, University of Washington, Seattle.

Port of Tacoma, 2008. EV001-V27, Sheet 3 of 5.

Appendix A

SupportIT Model Documentation

BINDING EDGE

LEGEND:

↥	CROSS SECTION LOCATION AND DESIGNATION
P86-B-01 ●	EXISTING GEOTECHNICAL BORING LOCATION
🟧	PROPOSED STEEL WALL LOCATION (40' DEEP SHEET SECTION)
🟩	PROPOSED STEEL WALL LOCATION (25' DEEP SHEET SECTION)
🟦	PROPOSED STEEL WALL LOCATION (15' DEEP SHEET SECTION)
—5—	EXISTING CONTOURS (1' & 5' INTERVALS)
🟪	ORDINARY HIGH WATER (OHW, SEE NOTE 1)
🟦	MEAN HIGHER-HIGH WATER (MHHW), +11.78'
🟩	MEAN LOW WATER (MLW), +2.84'
0321364024	PARCEL BOUNDARY AND IDENTIFICATION
🟪	PARCEL 86 PROPERTY BOUNDARY
⬛	EXISTING RIGHT-OF-WAY
🟥	50-FOOT FWHCA MARINE BUFFER

NORTH

0 8 16
SCALE IN FEET

SOURCE: AERIAL ©2020 MICROSOFT CORPORATION ©2020 DIGITALGLOBE ©CNES (2020) DISTRIBUTION AIRBUS DS. SURVEY BY SITTS & HILL, DATED JUNE 2020.
HORIZONTAL DATUM: WASHINGTON STATE PLANE SOUTH ZONE, NORTH AMERICAN DATUM OF 1983/2011 (NAD83/2011), U.S. SURVEY FEET
VERTICAL DATUM: MEAN LOWER LOW WATER (MLLW)

NOTES:
1. LOCATION OF OHW MARK SHOWN ALONG SECTION E-E' WAS APPROXIMATED BASED ON OBSERVATIONS ALONG ADJACENT NON-ERODED SHORELINE AREAS.
2. 40' DEEP SHEET PILE SECTION MAY CONSIST OF A BOX PILE CONFIGURATION (I.E., TWO ROWS OF SHEET PILES WELDED TOGETHER TO INCREASE STRUCTURAL STIFFNESS). OTHER SECTIONS WILL CONSIST OF A SINGLE SHEET.

Port of Tacoma
P.O. BOX 1837 TACOMA, WA 98401 (253)383-5841

MARK:	REVISION:	BY:	APPR:	DATE:

APPROVED:
CHECKED BY DATE
DIRECTOR ENG. DATE
PROJ. ENGR DATE
PRINTED BY: jbigsby Feb 26, 2021
PORT ADDRESS: ONE SITCUM PLAZA
TACOMA, WA 98401-1837

PARCEL 86 SHORELINE REPAIR PROJECT
PIERCE COUNTY, WASHINGTON
CONCEPTUAL LAYOUT OF PROPOSED SHEET PILE WALL
CONCEPTUAL DESIGN ALTERNATIVES

TOWNSHIP: RANGE: SECTION:
DAT-HRZ: NSRS11.WA-SF VERT: MLLW 16.37
PARCEL: DRAWING SCALE: AS NOTED

A-01
SH # OF #
CONT/CONS:
M. ID:
PHASE:

PORT OF TACOMA FILE: K:\Projects\0092-Port of Tacoma\Parcel 86 Shoreline Repair Project_Conceptual Design Alternatives\0092-WK-001 (Plan_Section)

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Date: 4.13.21

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Analysis: Net Pressure
FOS: 1.52
Toe: Cantilever

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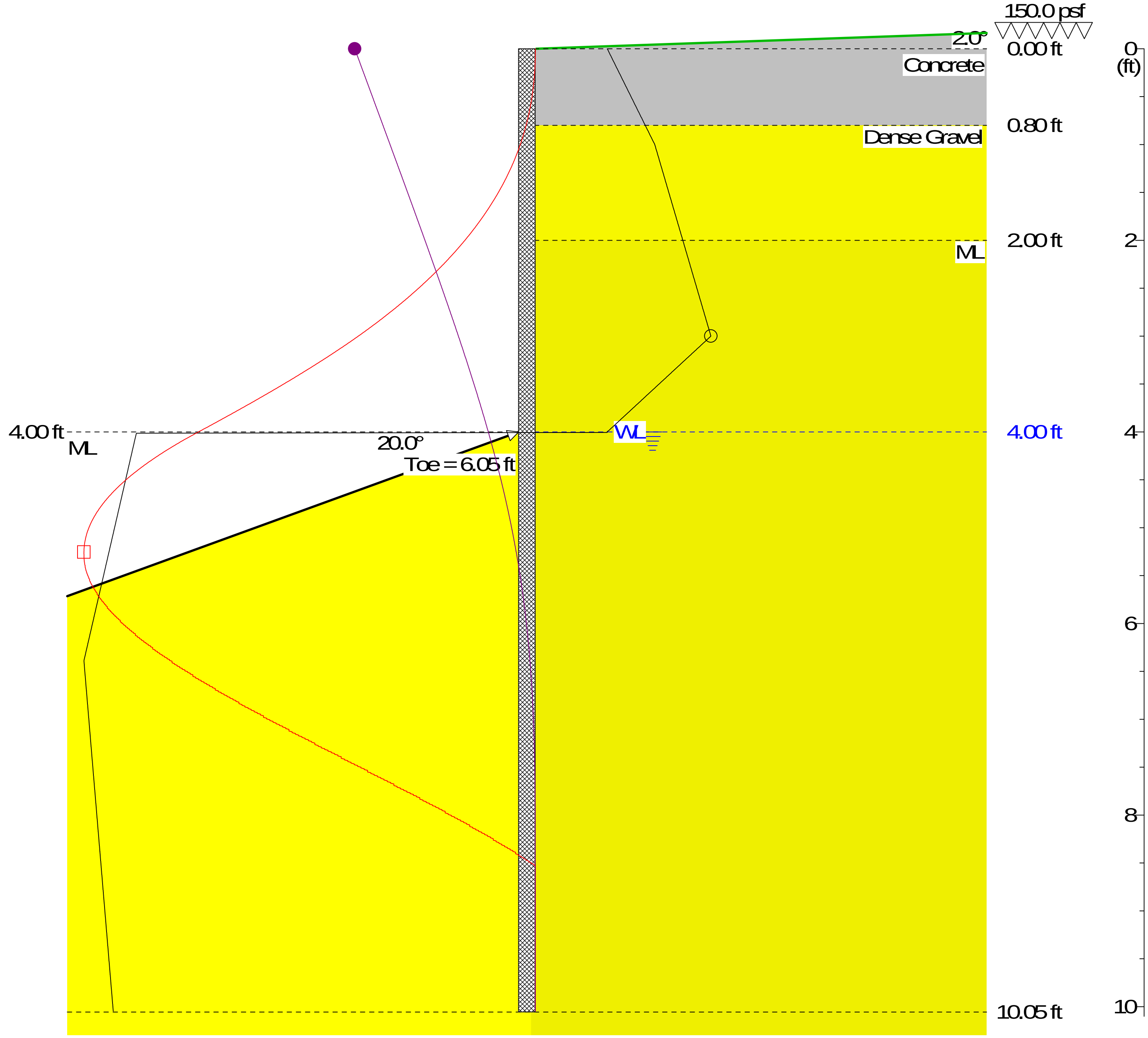
□	2770.4 ftlb/ft	5.25
●	0.0 in	0.00



ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

SupportIT, v2.38

Page: 2 Section A-A', B-B', C-C'
Date: 4.13.21

Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.52
Toe: Cantilever

Input Data

Depth Of Excavation = 4.00ft
Surcharge = 150.0psf
Slope (active) = 2.0degrees

Depth Of Active Water = 4.00ft
Depth Of Passive Water = 17.00ft
Slope (passive) = 20.0degrees

Water Density = 64.00pcf
Minimum Fluid Density = 31.82pcf

Soil Profile — Active Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	φ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	Concrete	135.00	71.00	4175.7	0.0	0.0	0.0	1.00	2.00	1.00	2.00
0.80	Dense Gravel	110.00	46.00	0.0	0.0	40.0	0.0	0.22	0.00	4.60	0.00
2.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	130.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Soil Profile — Passive Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	φ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	130.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Solution

Sheet

Sheet Name	E (psi)	I (in^4/ft)	f (psi)	Z (in^3/ft)	Allowed M_{max} (ftlb/ft)	b (in)	A (in^2/ft)	W (lb/ft)	Upstand (ft)	Toe (ft)	Length (ft)
Arbed AZ18	3.04E+07	283.10	24966.8	41.33	85989.8	27.56	7.07	35.0	0.00	6.05	10.05

Pressure Model: Terzaghi (m=1.0; a=0.4); Apply hydrostatic pressure in cohesive soils

Maxima

	Maximum	Depth (ft)
Pressure	373.3 psf	3.00
Bending Moment	2770.4 ftlb/ft	5.25
Deflection	0.0 in	0.00
Shear Force	1096.0 lb/ft	4.01

Page: 3 Section A-A', B-B', C-C'
Date: 4.13.21

Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.52
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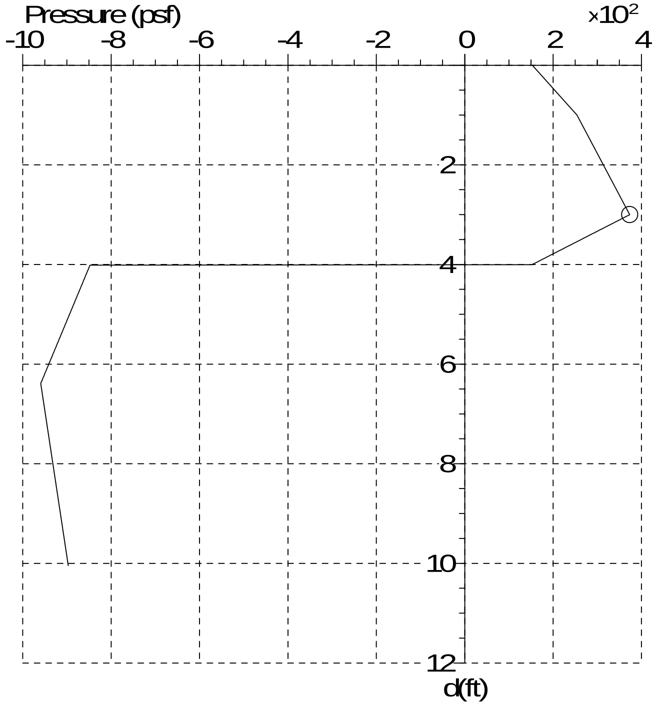
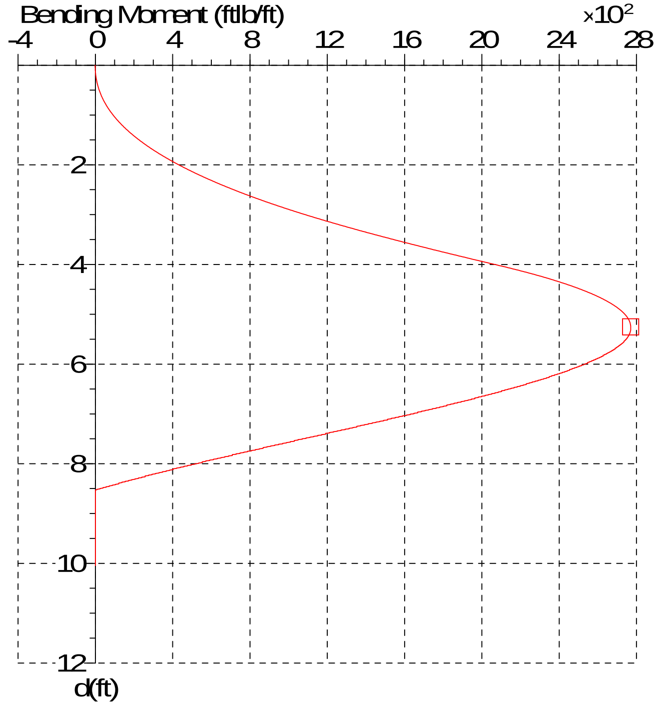
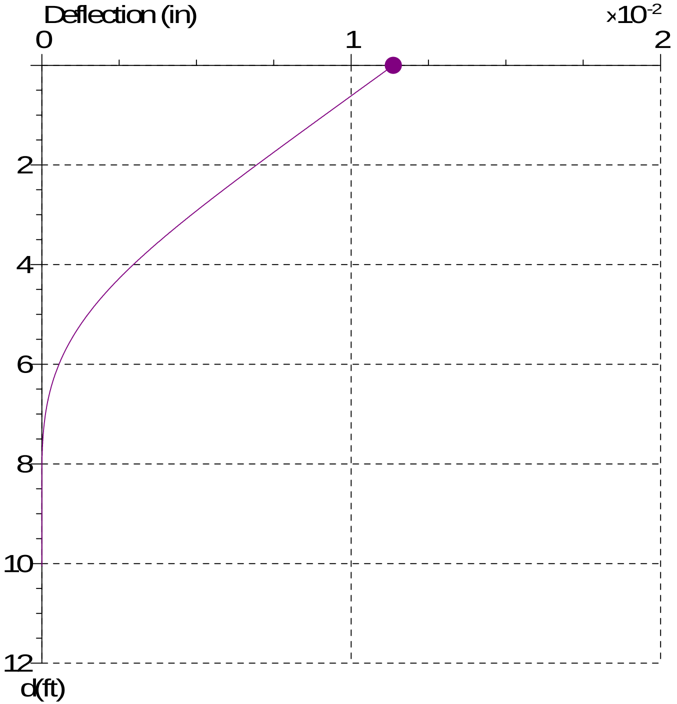
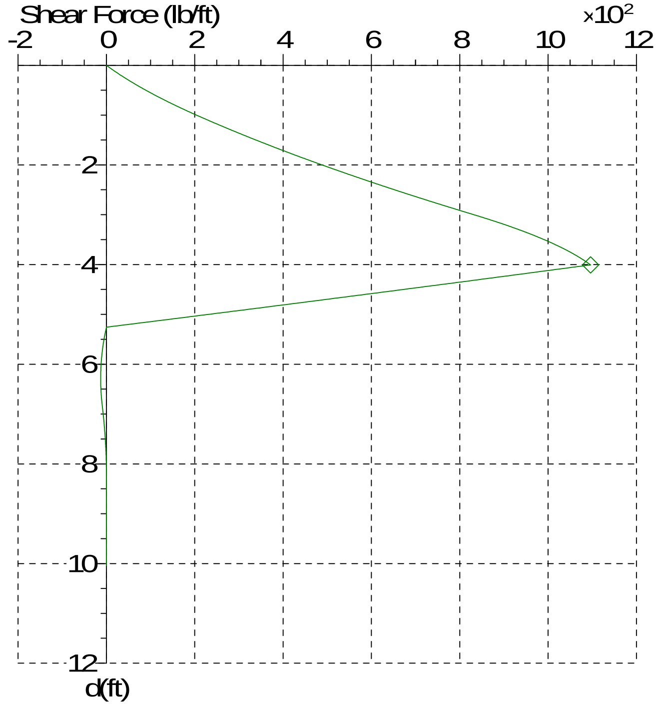
●	0.0 in	0.00









ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Tel/Fax: +44 (0)1292 477754
Email: GTSoftLtd@aol.com
Web: www.GTSoft.org

Page: 4 Section A-A', B-B', C-C'
Date: 4.13.21

Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.52
Toe: Cantilever

depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
0.00	153.0	-0.9	0.0	0.0
0.07	160.6	-0.5	0.0	11.9
0.14	167.4	0.6	0.0	22.9
0.22	175.0	2.7	0.0	35.9
0.29	181.8	5.5	0.0	47.9
0.36	189.4	9.6	0.0	61.9
0.43	196.2	14.1	0.0	74.9
0.50	203.8	20.2	0.0	90.0
0.57	211.4	27.5	0.0	105.7
0.65	218.1	35.0	0.0	120.1
0.72	225.8	44.7	0.0	136.9
0.79	232.5	54.3	0.0	152.3
0.86	240.1	66.4	0.0	170.2
0.93	246.9	78.3	0.0	186.6
1.01	254.3	93.0	0.0	205.5
1.08	258.8	109.1	0.0	224.9
1.15	262.8	124.7	0.0	242.4
1.22	267.3	143.7	0.0	262.5
1.29	271.3	161.8	0.0	280.6
1.36	275.8	183.6	0.0	301.2
1.44	279.8	204.4	0.0	319.9
1.51	284.3	229.2	0.0	341.2
1.58	288.8	255.7	0.0	362.9
1.65	292.8	280.6	0.0	382.4
1.72	297.3	310.1	0.0	404.7
1.80	301.3	337.8	0.0	424.8
1.87	305.8	370.6	0.0	447.7
1.94	309.8	401.3	0.0	468.4
2.01	314.3	437.4	0.0	492.0
2.08	318.8	475.3	0.0	515.9
2.15	322.8	510.5	0.0	537.4
2.23	327.3	551.8	0.0	562.0
2.30	331.3	590.2	0.0	584.1
2.37	335.8	635.0	0.0	609.3
2.44	339.8	676.6	0.0	632.0
2.51	344.3	725.1	0.0	657.9
2.59	348.8	775.6	0.0	684.0
2.66	352.8	822.1	0.0	707.6
2.73	357.3	876.4	0.0	734.4
2.80	361.3	926.3	0.0	758.5
2.87	365.8	984.4	0.0	786.0
2.94	369.8	1037.8	0.0	810.7
3.02	369.7	1099.9	0.0	838.8
3.09	353.1	1164.1	0.0	866.0
3.16	338.3	1222.8	0.0	889.1
3.23	321.7	1290.7	0.0	914.0
3.30	306.9	1352.6	0.0	935.0
3.38	290.3	1423.8	0.0	957.5
3.45	275.6	1488.6	0.0	976.4
3.52	259.0	1562.9	0.0	996.5
3.59	242.3	1638.7	0.0	1015.4
3.66	227.6	1707.2	0.0	1031.1
3.73	211.0	1785.5	0.0	1047.5
3.81	196.2	1856.1	0.0	1061.1
3.88	179.6	1936.6	0.0	1075.3
3.95	164.8	2009.1	0.0	1086.8
4.02	-848.3	2091.3	0.0	1081.8
4.09	-851.8	2170.8	0.0	1017.7
4.17	-855.0	2237.3	0.0	960.5
4.24	-858.5	2307.6	0.0	895.9
4.31	-861.7	2366.0	0.0	838.3
4.38	-865.2	2427.0	0.0	773.2
4.45	-868.3	2477.1	0.0	715.1
4.52	-871.9	2528.8	0.0	649.5
4.60	-875.4	2575.6	0.0	583.6
4.67	-878.6	2613.0	0.0	524.9
4.74	-882.1	2650.4	0.0	458.5
4.81	-885.3	2679.4	0.0	399.3
4.88	-888.8	2707.2	0.0	332.4
4.96	-891.9	2727.8	0.0	272.7
5.03	-895.5	2746.1	0.0	205.4
5.10	-899.0	2759.3	0.0	137.7
5.17	-902.2	2766.8	0.0	77.4
5.24	-905.7	2770.3	0.0	9.2
5.31	-908.8	2769.9	0.0	-1.4
5.39	-912.4	2765.0	0.0	-3.0
5.46	-915.5	2754.8	0.0	-4.5
5.53	-919.1	2740.1	0.0	-5.9
5.60	-922.6	2720.5	0.0	-7.3
5.67	-925.7	2696.5	0.0	-8.4
5.75	-929.3	2668.1	0.0	-9.4
5.82	-932.4	2635.7	0.0	-10.2
5.89	-936.0	2599.1	0.0	-11.1
5.96	-939.1	2558.6	0.0	-11.6
6.03	-942.7	2514.6	0.0	-12.2
6.10	-946.2	2454.4	0.0	-12.6
6.18	-949.3	2415.9	0.0	-12.8
6.25	-952.9	2348.0	0.0	-13.0
6.32	-956.0	2305.1	0.0	-13.0
6.39	-959.3	2230.0	0.0	-12.8
6.46	-958.1	2182.9	0.0	-12.6
6.54	-956.8	2101.5	0.0	-12.2
6.61	-955.6	2033.8	0.0	-11.6
6.68	-954.4	1964.0	0.0	-11.0
6.75	-953.1	1892.4	0.0	-10.3
6.82	-952.0	1819.1	0.0	-9.4
6.89	-950.7	1744.3	0.0	-8.5
6.97	-949.6	1668.0	0.0	-7.7
7.04	-948.3	1590.6	0.0	-6.8
7.11	-947.0	1512.1	0.0	-6.0
7.18	-945.9	1432.8	0.0	-5.3
7.25	-944.6	1352.8	0.0	-4.6
7.33	-943.4	1272.3	0.0	-4.0
7.40	-942.1	1191.4	0.0	-3.3
7.47	-941.0	1110.4	0.0	-2.8
7.54	-939.7	1029.4	0.0	-2.3
7.61	-938.4	948.6	0.0	-1.8
7.68	-937.3	868.1	0.0	-1.4
7.76	-936.0	788.2	0.0	-1.0
7.83	-934.9	709.0	0.0	-0.7
7.90	-933.6	630.6	0.0	-0.4
7.97	-932.4	553.3	0.0	-0.2
8.04	-931.1	477.2	0.0	0.0
8.12	-929.9	402.5	0.0	0.1
8.19	-928.7	329.3	0.0	0.2
8.26	-927.4	257.8	0.0	0.2
8.33	-926.3	188.4	0.0	0.3
8.40	-925.0	120.9	0.0	0.2
8.47	-923.9	55.7	0.0	0.1
8.55	-922.6	0.0	0.0	0.0
8.62	-921.3	0.0	0.0	0.0
8.69	-920.1	0.0	0.0	0.0
8.76	-918.9	0.0	0.0	0.0
8.83	-917.7	0.0	0.0	0.0
8.91	-916.4	0.0	0.0	0.0
8.98	-915.3	0.0	0.0	0.0
9.05	-914.0	0.0	0.0	0.0
9.12	-912.7	0.0	0.0	0.0
9.19	-911.6	0.0	0.0	0.0
9.26	-910.3	0.0	0.0	0.0
9.34	-909.2	0.0	0.0	0.0
9.41	-907.9	0.0	0.0	0.0
9.48	-906.7	0.0	0.0	0.0
9.55	-905.4	0.0	0.0	0.0
9.62	-904.2	0.0	0.0	0.0
9.70	-903.0	0.0	0.0	0.0
9.77	-901.7	0.0	0.0	0.0
9.84	-900.6	0.0	0.0	0.0
9.91	-899.3	0.0	0.0	0.0
9.98	-898.2	0.0	0.0	0.0
10.05	-897.0	0.0	0.0	0.0

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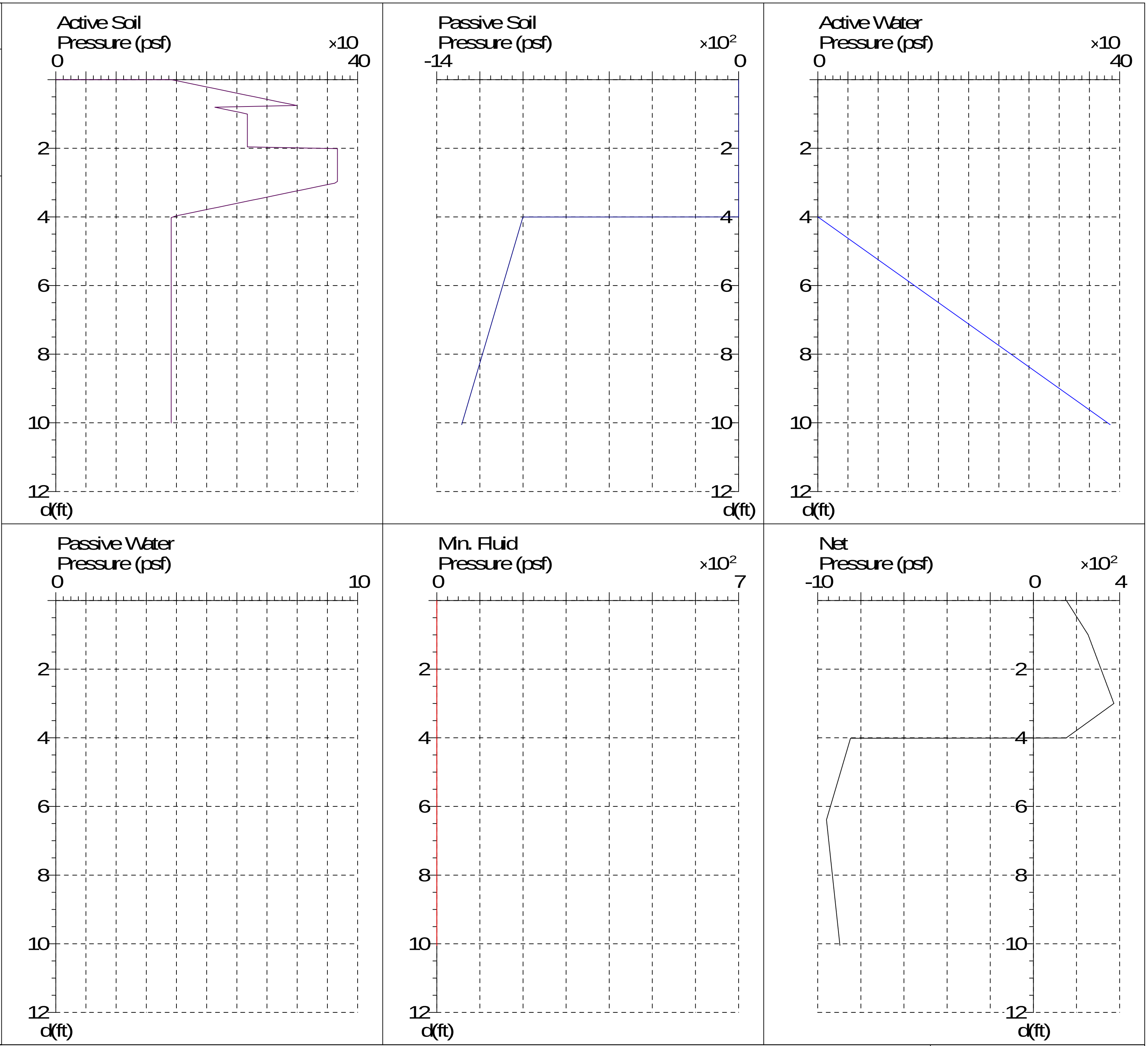
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.52
Toe: Cantilever



Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
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Design Report

1. The standard surcharge is 150.0psf. The Piling Handbook recommends a minimum surcharge of 200.0psf.

2. Are water depths correct? Passive water depth is not normally below the active water depth AND excavation depth.

3. Terzaghi was used for the active pressure. Rankine was used for the passive pressure.

4. Total stress values are being used (i.e. C>0). Note that the Piling Handbook and CIRIA SP95 recommend that effective stress values be used in 'long term' excavations.

5. BSPH approximation used for slope calculation. i.e. Pressure modified by 5% for each 5° of slope.

6. Maximum bending moment = 2770.4ftlb/ft and f = 24966.8psi. MINIMUM required sheet section modulus is: Z = 1.33in^3/ft (= M/f).
Sheet section modulus in this design is Z = 41.33in^3/ft, and is satisfactory.

7. FOS = 1.52 (Net Pressure)
This is the factor of safety against rotation about the toe.
The FOS can be changed using 'Defined FOS' or 'Manual' in the 'Wall' page.

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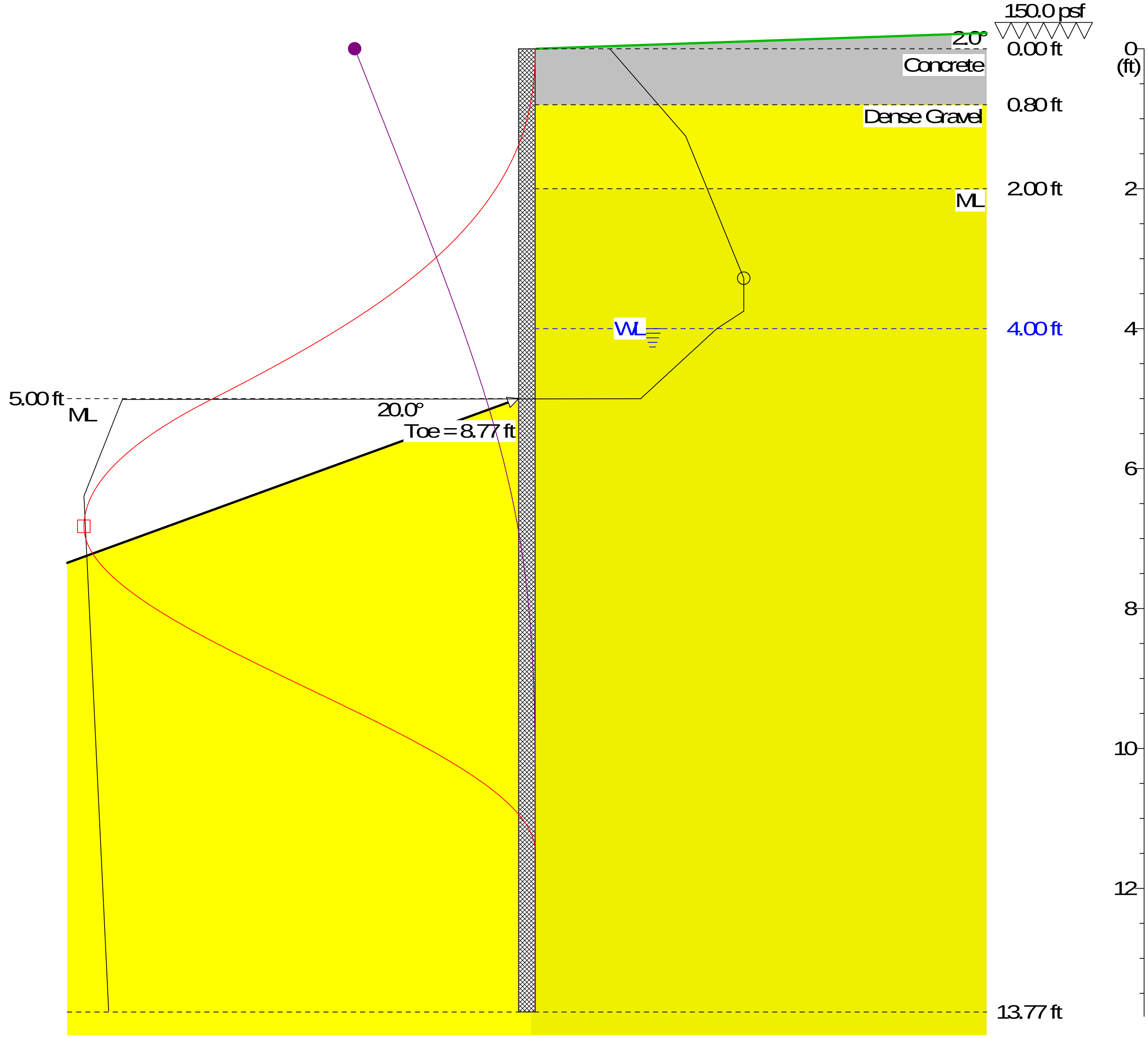
Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.53
Toe: Cantilever

	Maximum	d (ft)
○	428.4 psf	3.28
□	5349.9 ftlb/ft	6.83
●	0.0 in	0.00



Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Page: 2 Section D-D'
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Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.53
Toe: Cantilever

Input Data

Depth Of Excavation = 5.00ft
Surcharge = 150.0psf
Slope (active) = 2.0degrees

Depth Of Active Water = 4.00ft
Depth Of Passive Water = 17.00ft
Slope (passive) = 20.0degrees

Water Density = 64.00pcf
Minimum Fluid Density = 31.82pcf

Soil Profile — Active Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	φ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	Concrete	135.00	71.00	4175.7	0.0	0.0	0.0	1.00	2.00	1.00	2.00
0.80	Dense Gravel	110.00	46.00	0.0	0.0	40.0	0.0	0.22	0.00	4.60	0.00
2.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	125.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Soil Profile — Passive Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	φ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	130.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Solution

Sheet

Sheet Name	E (psi)	I (in^4/ft)	f (psi)	Z (in^3/ft)	Allowed M_{max} (ftlb/ft)	b (in)	A (in^2/ft)	W (lb/ft)	Upstand (ft)	Toe (ft)	Length (ft)
Arbed AZ18	3.04E+07	283.10	24966.8	33.50	69698.9	24.80	7.09	24.1	0.00	8.77	13.77

Pressure Model: Terzaghi (m=1.0; a=0.4); Apply hydrostatic pressure in cohesive soils

Maxima

	Maximum	Depth (ft)
Pressure	428.4 psf	3.28
Bending Moment	5349.9 ftlb/ft	6.83
Deflection	0.0 in	0.00
Shear Force	1636.3 lb/ft	5.00

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Pressure: Terzaghi (m=1.0; a=0.4)
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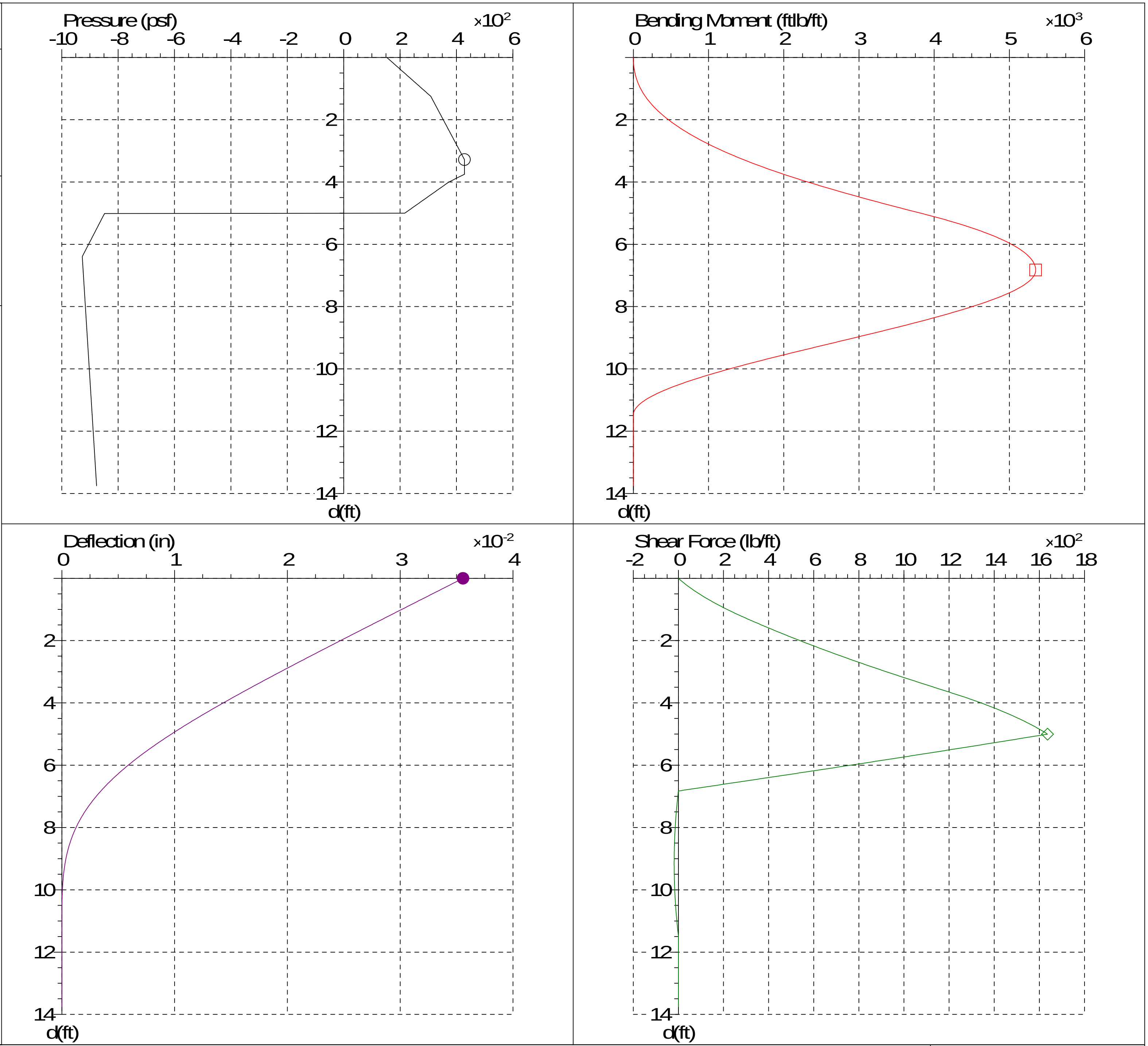
Toe: Cantilever

	Maximum	d (ft)
○	428.4 psf	3.28
□	5349.9 ftlb/ft	6.83
◇	1636.3 lb/ft	5.00
●	0.0 in	0.00



ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Tel/Fax: +44 (0)1292 477754
Email: GTSoftLtd@aol.com
Web: www.GTSoft.org

Page: 4 Section D-D'
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Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.53
Toe: Cantilever

depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
0.00	153.0	0.0	0.0	0.0
0.10	165.9	0.7	0.0	16.6
0.20	177.3	2.9	0.0	32.4
0.30	190.2	7.1	0.0	51.5
0.39	201.7	12.5	0.0	69.5
0.49	214.6	20.7	0.0	91.1
0.59	226.0	29.9	0.0	111.4
0.69	238.9	42.5	0.0	135.5
0.79	251.8	57.6	0.0	161.0
0.89	263.3	73.3	0.0	184.7
0.98	276.2	93.6	0.0	212.7
1.08	287.6	114.2	0.0	238.6
1.18	300.5	140.2	0.0	269.1
1.28	310.4	166.0	0.0	297.3
1.38	316.5	198.2	0.0	329.7
1.48	322.6	233.7	0.0	362.8
1.57	328.0	268.2	0.0	392.7
1.67	334.0	310.3	0.0	426.9
1.77	339.4	350.7	0.0	457.9
1.87	345.5	399.6	0.0	493.3
1.97	350.9	446.1	0.0	525.4
2.07	357.0	502.0	0.0	562.0
2.16	363.0	561.7	0.0	599.2
2.26	368.4	618.0	0.0	632.9
2.36	374.5	685.1	0.0	671.3
2.46	379.9	748.1	0.0	706.0
2.56	385.9	822.8	0.0	745.6
2.66	391.3	892.6	0.0	781.3
2.75	397.4	975.1	0.0	822.1
2.85	403.5	1061.8	0.0	863.5
2.95	408.9	1142.5	0.0	900.9
3.05	414.9	1237.5	0.0	943.5
3.15	420.3	1325.6	0.0	981.9
3.25	426.4	1428.9	0.0	1025.7
3.34	428.4	1524.6	0.0	1065.0
3.44	428.4	1636.5	0.0	1109.3
3.54	428.4	1753.1	0.0	1153.6
3.64	428.4	1860.5	0.0	1193.0
3.74	428.4	1985.6	0.0	1237.2
3.84	410.4	2100.7	0.0	1275.8
3.93	387.6	2234.3	0.0	1316.9
4.03	368.9	2356.5	0.0	1351.5
4.13	352.7	2497.7	0.0	1388.7
4.23	336.6	2642.7	0.0	1424.2
4.33	322.3	2774.5	0.0	1454.4
4.43	306.1	2926.1	0.0	1486.8
4.52	291.8	3063.6	0.0	1514.2
4.62	275.6	3221.3	0.0	1543.4
4.72	261.3	3363.9	0.0	1568.0
4.82	245.2	3526.9	0.0	1594.1
4.92	229.0	3692.6	0.0	1618.5
5.02	-848.3	3841.9	0.0	1626.6
5.11	-854.2	4005.7	0.0	1538.7
5.21	-859.5	4143.7	0.0	1460.1
5.31	-865.4	4290.3	0.0	1371.1
5.41	-870.6	4412.9	0.0	1291.5
5.51	-876.5	4542.1	0.0	1201.3
5.61	-882.4	4661.9	0.0	1110.5
5.70	-887.7	4760.5	0.0	1029.3
5.80	-893.6	4862.6	0.0	937.4
5.90	-898.8	4945.3	0.0	855.2
6.00	-904.7	5029.3	0.0	762.1
6.10	-909.9	5095.8	0.0	678.9
6.20	-915.8	5161.6	0.0	584.6
6.29	-921.7	5217.6	0.0	489.8
6.39	-927.0	5259.1	0.0	405.0
6.49	-926.5	5296.5	0.0	309.3
6.59	-925.9	5321.5	0.0	224.3
6.69	-925.1	5340.2	0.0	128.7
6.79	-924.5	5348.6	0.0	43.8
6.88	-923.8	5348.0	0.0	-0.9
6.98	-923.1	5332.5	0.0	-2.5
7.08	-922.5	5306.3	0.0	-3.8
7.18	-921.7	5263.5	0.0	-5.3
7.28	-921.1	5214.1	0.0	-6.5
7.38	-920.4	5146.4	0.0	-7.8
7.47	-919.8	5076.1	0.0	-8.9
7.57	-919.0	4986.1	0.0	-10.0
7.67	-918.3	4885.3	0.0	-11.1
7.77	-917.7	4787.2	0.0	-12.0
7.87	-917.0	4667.9	0.0	-13.0
7.97	-916.4	4554.5	0.0	-13.8
8.06	-915.6	4419.3	0.0	-14.6
8.16	-915.0	4292.8	0.0	-15.2
8.26	-914.3	4144.1	0.0	-15.9
8.36	-913.6	3989.3	0.0	-16.5
8.46	-912.9	3847.1	0.0	-17.0
8.56	-912.2	3682.7	0.0	-17.4
8.65	-911.6	3533.1	0.0	-17.8
8.75	-910.9	3361.6	0.0	-18.1
8.85	-910.3	3206.8	0.0	-18.3
8.95	-909.5	3030.7	0.0	-18.5
9.05	-908.8	2853.2	0.0	-18.6
9.15	-908.2	2694.8	0.0	-18.6
9.24	-907.5	2516.5	0.0	-18.6
9.34	-906.8	2358.6	0.0	-18.5
9.44	-906.1	2182.1	0.0	-18.3
9.54	-905.5	2026.9	0.0	-18.1
9.64	-904.8	1854.7	0.0	-17.8
9.74	-904.1	1685.8	0.0	-17.4
9.83	-903.4	1539.0	0.0	-17.0
9.93	-902.7	1378.2	0.0	-16.5
10.03	-902.1	1239.8	0.0	-16.0
10.13	-901.4	1089.6	0.0	-15.3
10.23	-900.7	961.8	0.0	-14.7
10.33	-900.0	824.8	0.0	-13.9
10.42	-899.3	695.8	0.0	-13.0
10.52	-898.7	588.4	0.0	-12.1
10.62	-898.0	476.5	0.0	-11.1
10.72	-897.3	385.3	0.0	-10.2
10.82	-896.6	292.9	0.0	-9.0
10.92	-896.0	220.2	0.0	-7.9
11.01	-895.3	149.8	0.0	-6.6
11.11	-894.6	92.0	0.0	-5.3
11.21	-893.9	51.9	0.0	-4.0
11.31	-893.2	20.1	0.0	-2.5
11.41	-892.6	4.1	0.0	-1.1
11.51	-891.9	0.0	0.0	0.0
11.60	-891.2	0.0	0.0	0.0
11.70	-890.5	0.0	0.0	0.0
11.80	-889.8	0.0	0.0	0.0
11.90	-889.2	0.0	0.0	0.0
12.00	-888.5	0.0	0.0	0.0
12.10	-887.8	0.0	0.0	0.0
12.19	-887.1	0.0	0.0	0.0
12.29	-886.5	0.0	0.0	0.0
12.39	-885.8	0.0	0.0	0.0
12.49	-885.1	0.0	0.0	0.0
12.59	-884.4	0.0	0.0	0.0
12.69	-883.7	0.0	0.0	0.0
12.78	-883.1	0.0	0.0	0.0
12.88	-882.4	0.0	0.0	0.0
12.98	-881.7	0.0	0.0	0.0
13.08	-881.0	0.0	0.0	0.0
13.18	-880.3	0.0	0.0	0.0
13.28	-879.7	0.0	0.0	0.0
13.37	-879.0	0.0	0.0	0.0
13.47	-878.3	0.0	0.0	0.0
13.57	-877.6	0.0	0.0	0.0
13.67	-877.0	0.0	0.0	0.0
13.77	-876.4	0.0	0.0	0.0

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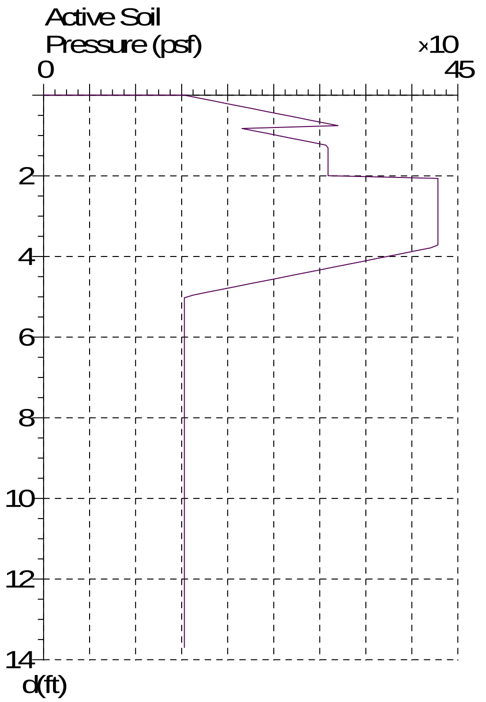
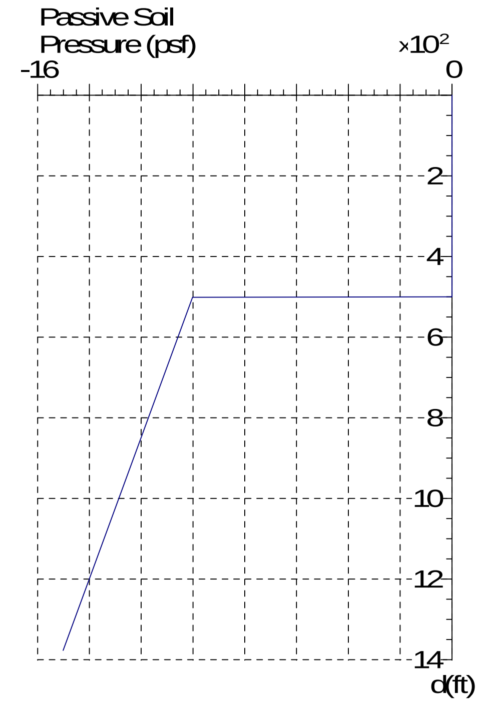
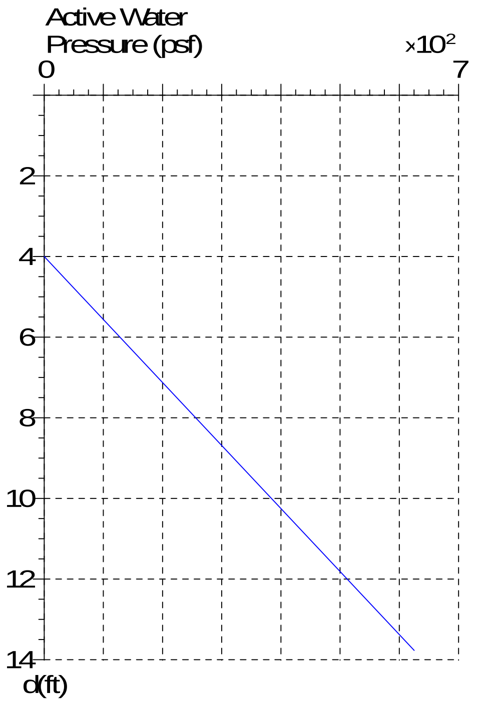
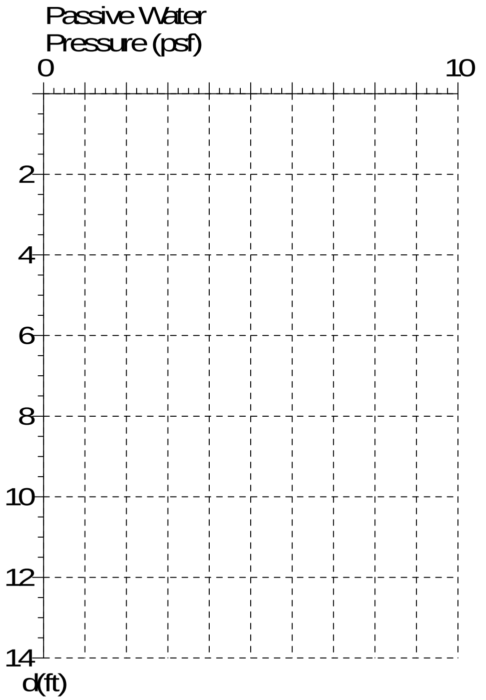
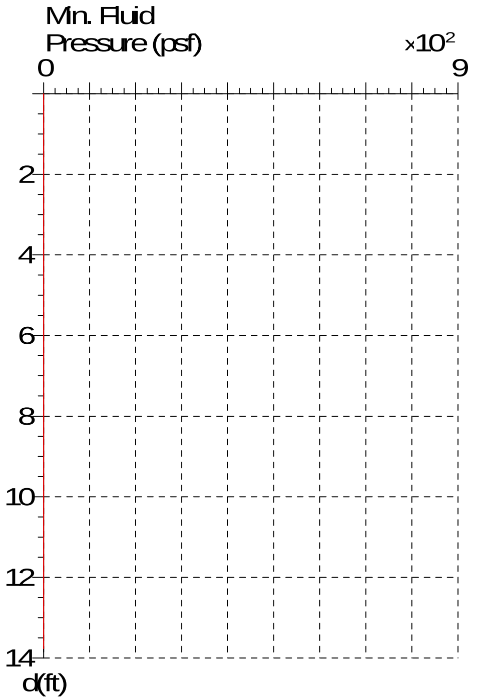
Toe: Cantilever

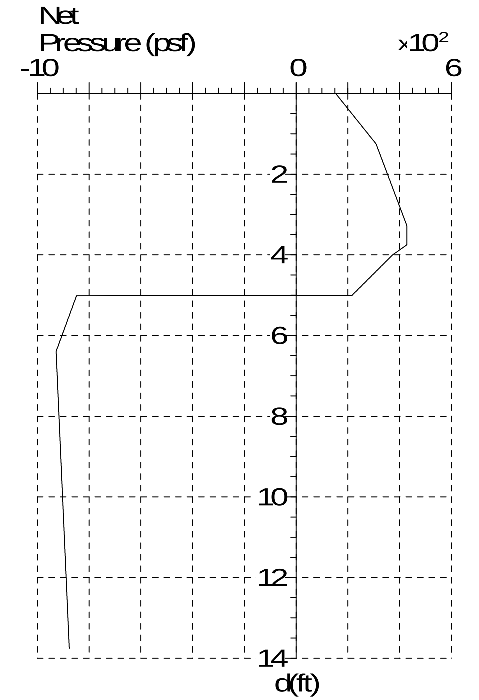












ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Design Report

1. The standard surcharge is 150.0psf. The Piling Handbook recommends a minimum surcharge of 200.0psf.

2. Are water depths correct? Passive water depth is not normally below the active water depth AND excavation depth.

3. Terzaghi was used for the active pressure. Rankine was used for the passive pressure.

4. Total stress values are being used (i.e. C > 0). Note that the Piling Handbook and CIRIA SP95 recommend that effective stress values be used in 'long term' excavations.

5. BSPH approximation used for slope calculation. i.e. Pressure modified by 5% for each 5° of slope.

6. Maximum bending moment = 5349.9ftlb/ft and f = 24966.8psi. MINIMUM required sheet section modulus is: Z = 2.57in^3/ft (= M/f).
Sheet section modulus in this design is Z = 33.50in^3/ft, and is satisfactory.

7. FOS = 1.53 (Net Pressure)
This is the factor of safety against rotation about the toe.
The FOS can be changed using 'Defined FOS' or 'Manual' in the 'Wall' page.

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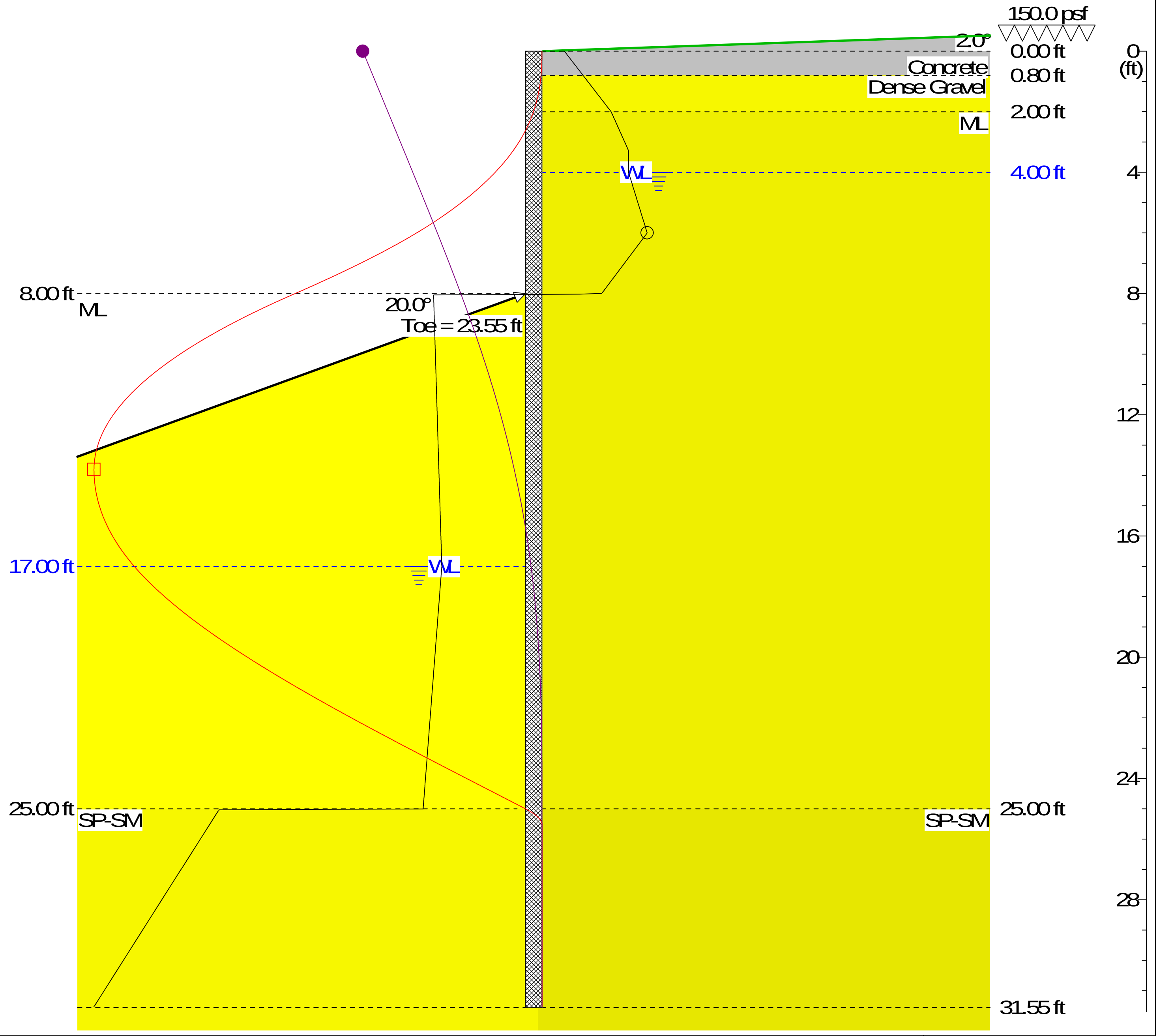
	Maximum	d (ft)
○	721.5 psf	6.00
□	27083.5 ftlb/ft	13.80
●	1.1 in	0.00



ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Tel/Fax: +44 (0)1292 477754
Email: GTSoftLtd@aol.com
Web: www.GTSoft.org

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Input Data

Depth Of Excavation = 8.00ft
Surcharge = 150.0psf
Slope (active) = 2.0degrees

Depth Of Active Water = 4.00ft
Depth Of Passive Water = 17.00ft
Slope (passive) = 20.0degrees

Water Density = 64.00pcf
Minimum Fluid Density = 31.82pcf

Soil Profile — Active Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	ϕ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	Concrete	135.00	71.00	4175.7	0.0	0.0	0.0	1.00	2.00	1.00	2.00
0.80	Dense Gravel	110.00	46.00	0.0	0.0	40.0	0.0	0.22	0.00	4.60	0.00
2.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	125.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Soil Profile — Passive Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	ϕ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	130.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Solution

Sheet

Sheet Name	E (psi)	I (in^4/ft)	f (psi)	Z (in^3/ft)	Allowed M_{max} (ftlb/ft)	b (in)	A (in^2/ft)	W (lb/ft)	Upstand (ft)	Toe (ft)	Length (ft)
Arbed AZ18	3.04E+07	283.10	24966.8	35.10	73027.9	24.80	7.07	24.0	0.00	23.55	31.55

Pressure Model: Terzaghi (m=1.0; a=0.4); Apply hydrostatic pressure in cohesive soils

Maxima

	Maximum	Depth (ft)
Pressure	721.5 psf	6.00
Bending Moment	27083.5 ftlb/ft	13.80
Deflection	1.1 in	0.00
Shear Force	4196.3 lb/ft	8.02

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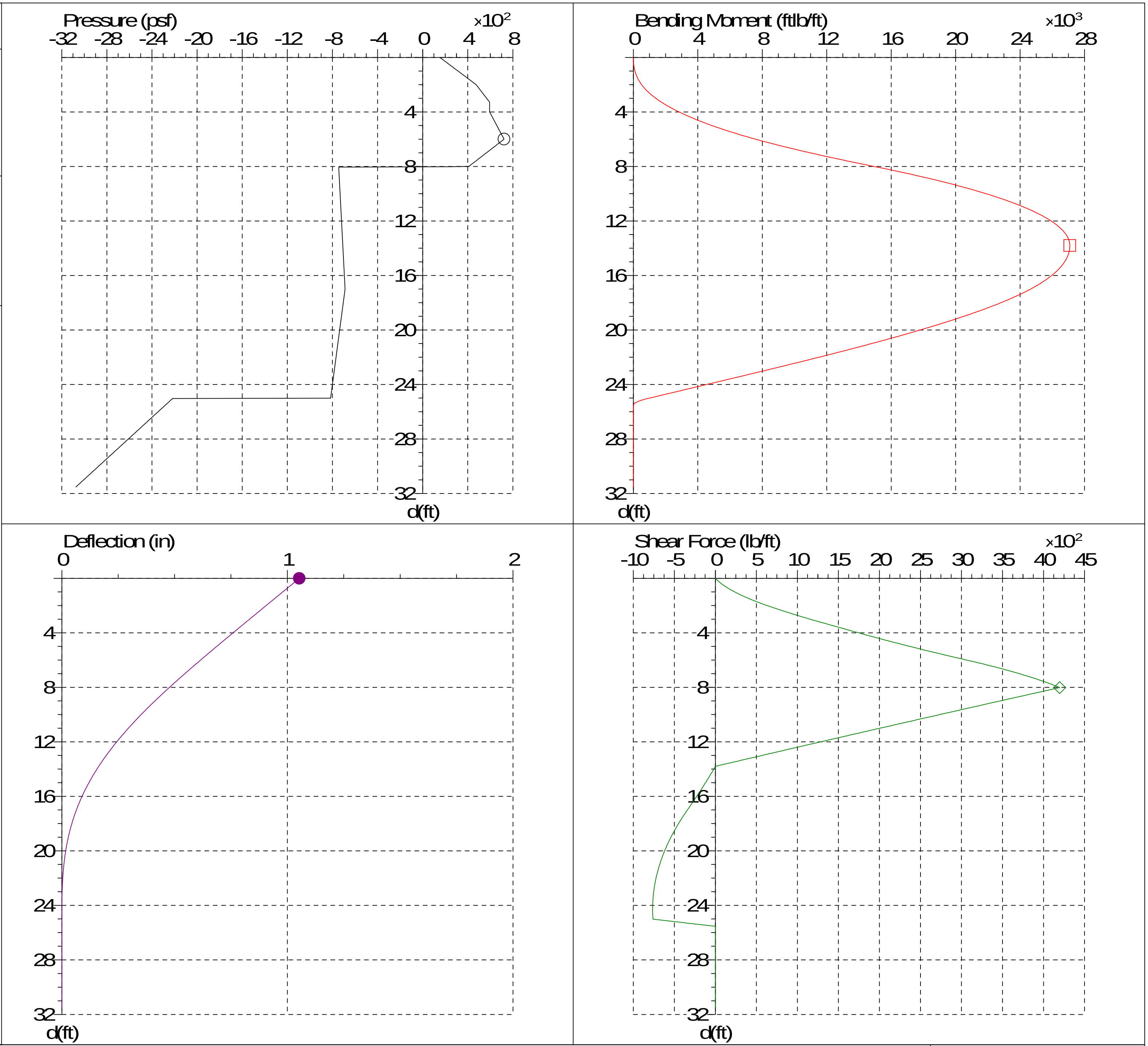
	Maximum	d (ft)
○	721.5 psf	6.00
□	27083.5 ftlb/ft	13.80
◇	4196.3 lb/ft	8.02
●	1.1 in	0.00



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1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
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Tel/Fax: +44 (0)1292 477754
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Pressure: Terzaghi (m=1.0; a=0.4)
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FOS: 1.49
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depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
0.00	153.0	0.0	1.1	0.0
0.23	191.0	4.2	1.0	41.2
0.45	224.8	16.8	1.0	85.5
0.68	262.8	43.0	1.0	143.7
0.90	296.6	78.5	1.0	203.1
1.13	334.6	134.3	1.0	278.3
1.35	368.4	199.6	1.0	352.8
1.58	406.5	292.6	0.9	445.1
1.80	444.5	408.3	0.9	546.4
2.03	476.6	532.1	0.9	643.9
2.25	498.7	696.5	0.9	759.7
2.48	518.3	866.1	0.9	867.0
2.70	540.3	1084.3	0.9	992.7
2.93	559.9	1303.7	0.8	1108.8
3.16	582.0	1580.2	0.8	1244.3
3.38	593.6	1889.2	0.8	1384.3
3.61	593.6	2191.9	0.8	1509.3
3.83	593.6	2563.8	0.8	1650.0
4.06	597.0	2922.3	0.8	1775.1
4.28	612.1	3357.2	0.7	1918.5
4.51	625.6	3772.7	0.7	2049.0
4.73	640.8	4273.1	0.7	2199.2
4.96	655.9	4809.5	0.7	2353.0
5.18	669.4	5317.2	0.7	2492.7
5.41	684.5	5923.7	0.7	2653.2
5.63	698.0	6495.1	0.6	2798.9
5.86	713.1	7174.8	0.6	2966.3
6.09	710.2	7812.5	0.6	3117.2
6.31	673.3	8567.3	0.6	3280.6
6.54	636.3	9359.9	0.6	3435.2
6.76	603.4	10094.4	0.6	3565.2
6.99	566.4	10952.6	0.5	3703.3
7.21	533.5	11742.1	0.5	3818.7
7.44	496.5	12658.5	0.5	3940.2
7.66	463.6	13496.5	0.5	4040.8
7.89	426.6	14463.8	0.5	4145.8
8.11	-743.9	15449.7	0.5	4118.1
8.34	-742.6	16301.4	0.5	3961.8
8.56	-741.1	17220.2	0.4	3786.2
8.79	-739.7	18002.2	0.4	3630.4
9.02	-738.2	18842.7	0.4	3455.5
9.24	-736.9	19555.1	0.4	3300.4
9.47	-735.4	20317.6	0.4	3126.1
9.69	-733.9	21038.9	0.4	2952.2
9.92	-732.6	21645.6	0.4	2798.0
10.14	-731.1	22289.3	0.3	2624.8
10.37	-729.8	22827.2	0.3	2471.1
10.59	-728.3	23393.7	0.3	2298.5
10.82	-727.0	23863.0	0.3	2145.5
11.04	-725.5	24352.5	0.3	1973.6
11.27	-724.0	24801.4	0.3	1802.1
11.49	-722.6	25166.3	0.3	1649.9
11.72	-721.2	25538.7	0.3	1479.0
11.95	-719.8	25835.8	0.2	1327.5
12.17	-718.3	26132.0	0.2	1157.3
12.40	-717.0	26361.5	0.2	1006.3
12.62	-715.5	26581.7	0.2	836.8
12.85	-714.0	26761.9	0.2	667.6
13.07	-712.7	26888.4	0.2	517.5
13.30	-711.2	26993.2	0.2	349.0
13.52	-709.9	27052.8	0.2	199.5
13.75	-708.4	27082.3	0.2	31.7
13.97	-707.1	27078.8	0.2	-15.3
14.20	-705.6	27050.6	0.1	-38.6
14.42	-704.1	26996.6	0.1	-62.2
14.65	-702.7	26926.6	0.1	-83.5
14.88	-701.2	26822.8	0.1	-107.8
15.10	-699.9	26707.9	0.1	-129.7
15.33	-698.4	26553.0	0.1	-154.7
15.55	-697.1	26392.0	0.1	-177.1
15.78	-695.6	26184.5	0.1	-202.8
16.00	-694.1	25948.5	0.1	-228.8
16.23	-692.8	25714.7	0.1	-252.1
16.45	-691.3	25424.0	0.1	-278.8
16.68	-690.0	25141.0	0.1	-302.8
16.90	-688.5	24794.3	0.1	-330.1
17.13	-689.8	24460.8	0.1	-354.5
17.35	-693.6	24057.3	0.1	-381.1
17.58	-697.4	23625.0	0.1	-406.9
17.81	-700.7	23217.2	0.0	-429.1
18.03	-704.5	22733.0	0.0	-453.1
18.26	-707.9	22280.6	0.0	-473.8
18.48	-711.7	21747.9	0.0	-496.2
18.71	-715.0	21254.1	0.0	-515.3
18.93	-718.8	20676.5	0.0	-536.0
19.16	-722.6	20076.6	0.0	-555.8
19.38	-726.0	19525.4	0.0	-572.7
19.61	-729.8	18886.0	0.0	-590.8
19.83	-733.1	18301.2	0.0	-606.1
20.06	-736.9	17625.8	0.0	-622.5
20.28	-740.3	17010.6	0.0	-636.3
20.51	-744.1	16302.8	0.0	-651.0
20.74	-747.9	15579.1	0.0	-664.9
20.96	-751.2	14923.5	0.0	-676.4
21.19	-755.0	14172.8	0.0	-688.5
21.41	-758.4	13494.6	0.0	-698.5
21.64	-762.2	12720.4	0.0	-709.0
21.86	-765.5	12022.9	0.0	-717.5
22.09	-769.3	11228.6	0.0	-726.2
22.31	-773.1	10425.1	0.0	-734.1
22.54	-776.5	9704.0	0.0	-740.3
22.76	-780.3	8885.9	0.0	-746.4
22.99	-783.6	8153.3	0.0	-751.1
23.21	-787.4	7324.1	0.0	-755.6
23.44	-790.8	6583.2	0.0	-758.8
23.67	-794.6	5746.3	0.0	-761.6
23.89	-798.4	4906.9	0.0	-763.4
24.12	-801.7	4159.3	0.0	-764.3
24.34	-805.5	3317.7	0.0	-764.5
24.57	-808.9	2569.7	0.0	-763.9
24.79	-812.7	1729.3	0.0	-762.4
25.02	-815.6	984.1	0.0	-760.3
25.24	-2245.2	311.5	0.0	-422.7
25.47	-2276.5	14.3	0.0	-77.7
25.69	-2304.2	0.0	0.0	0.0
25.92	-2335.5	0.0	0.0	0.0
26.14	-2363.2	0.0	0.0	0.0
26.37	-2394.5	0.0	0.0	0.0
26.60	-2422.3	0.0	0.0	0.0
26.82	-2453.5	0.0	0.0	0.0
27.05	-2484.8	0.0	0.0	0.0
27.27	-2512.5	0.0	0.0	0.0
27.50	-2543.8	0.0	0.0	0.0
27.72	-2571.5	0.0	0.0	0.0
27.95	-2602.8	0.0	0.0	0.0
28.17	-2630.6	0.0	0.0	0.0
28.40	-2661.8	0.0	0.0	0.0
28.62	-2693.1	0.0	0.0	0.0
28.85	-2720.8	0.0	0.0	0.0
29.07	-2752.1	0.0	0.0	0.0
29.30	-2779.8	0.0	0.0	0.0
29.53	-2811.1	0.0	0.0	0.0
29.75	-2838.9	0.0	0.0	0.0
29.98	-2870.1	0.0	0.0	0.0
30.20	-2901.4	0.0	0.0	0.0
30.43	-2929.1	0.0	0.0	0.0
30.65	-2960.4	0.0	0.0	0.0
30.88	-2988.1	0.0	0.0	0.0
31.10	-3019.4	0.0	0.0	0.0
31.33	-3047.2	0.0	0.0	0.0
31.55	-3074.9	0.0	0.0	0.0

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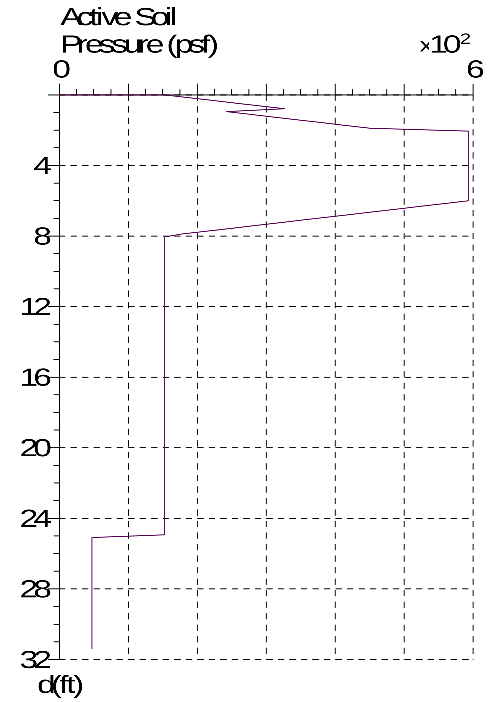
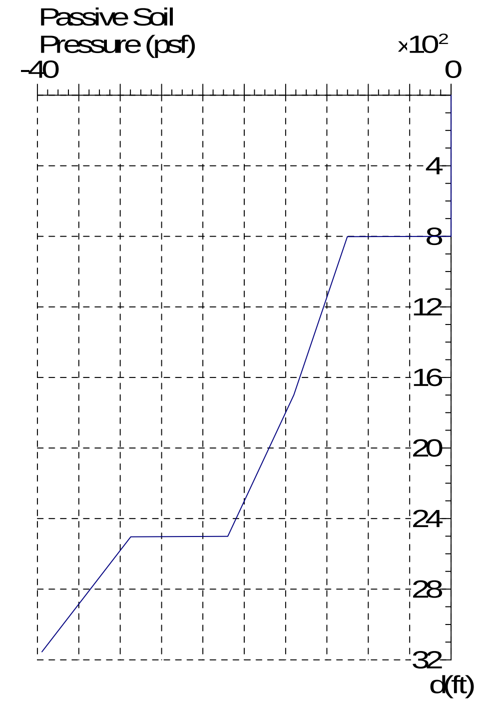
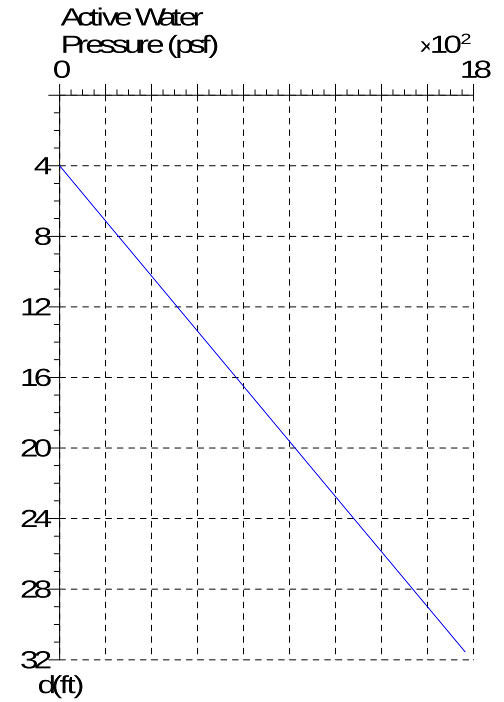
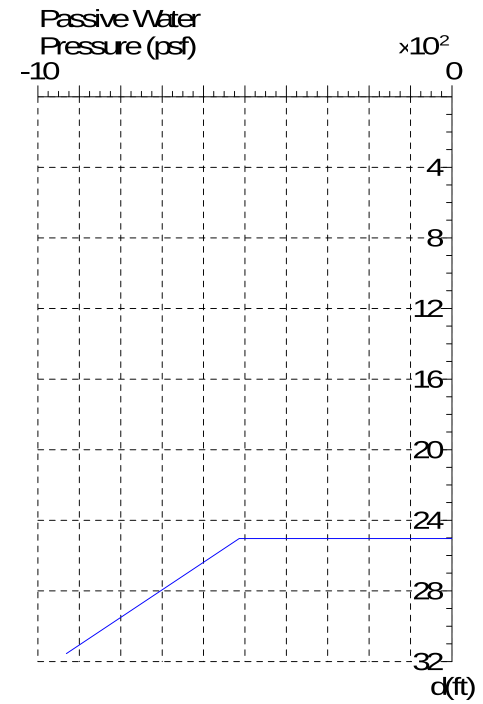
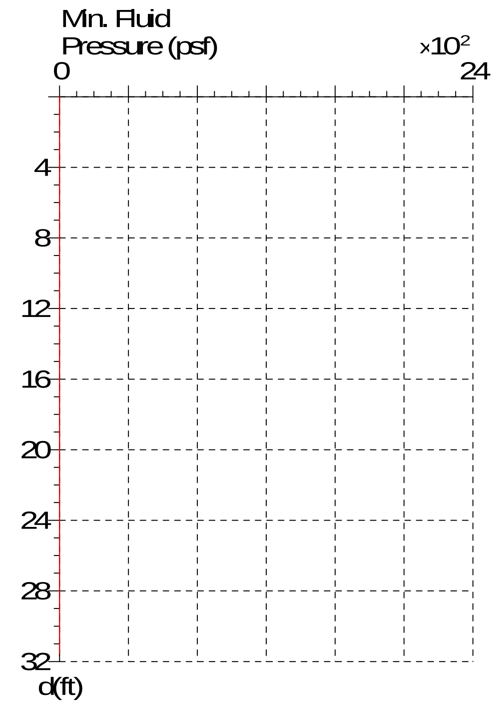
FOS: 1.49
Toe: Cantilever

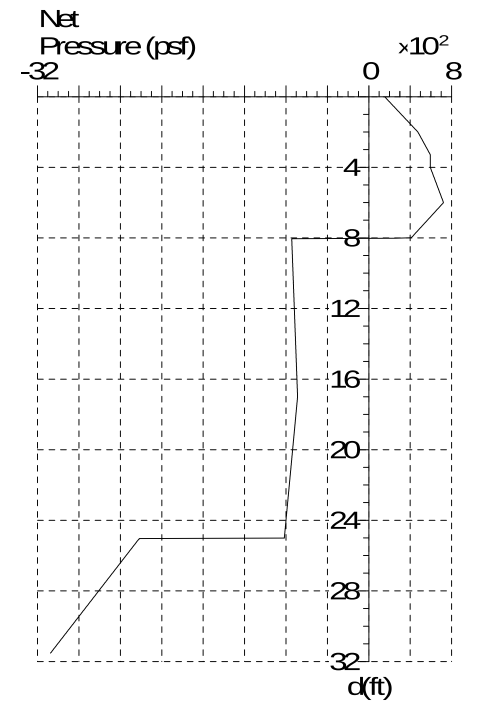












ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Tel/Fax: +44 (0)1292 477754
Email: GTSoftLtd@aol.com
Web: www.GTSoft.org

Page: 6 Section E-E'
Date: 4.13.21

Sheet: NZ19
Works: Permanent
Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.49
Toe: Cantilever

Design Report

1. The standard surcharge is 150.0psf. The Piling Handbook recommends a minimum surcharge of 200.0psf.

2. Are water depths correct? Passive water depth is not normally below the active water depth AND excavation depth.

3. Terzaghi was used for the active pressure. Rankine was used for the passive pressure.

4. Total stress values are being used (i.e. C>0). Note that the Piling Handbook and CIRIA SP95 recommend that effective stress values be used in 'long term' excavations.

5. BSPH approximation used for slope calculation. i.e. Pressure modified by 5% for each 5° of slope.

6. Maximum bending moment = 27083.5ftlb/ft and f = 24966.8psi. MINIMUM required sheet section modulus is: Z = 13.02in^3/ft (= M/f).
   Sheet section modulus in this design is Z = 35.10in^3/ft, and is satisfactory.

7. FOS = 1.49 (Net Pressure)
   This is the factor of safety against rotation about the toe.
   The FOS can be changed using 'Defined FOS' or 'Manual' in the 'Wall' page.

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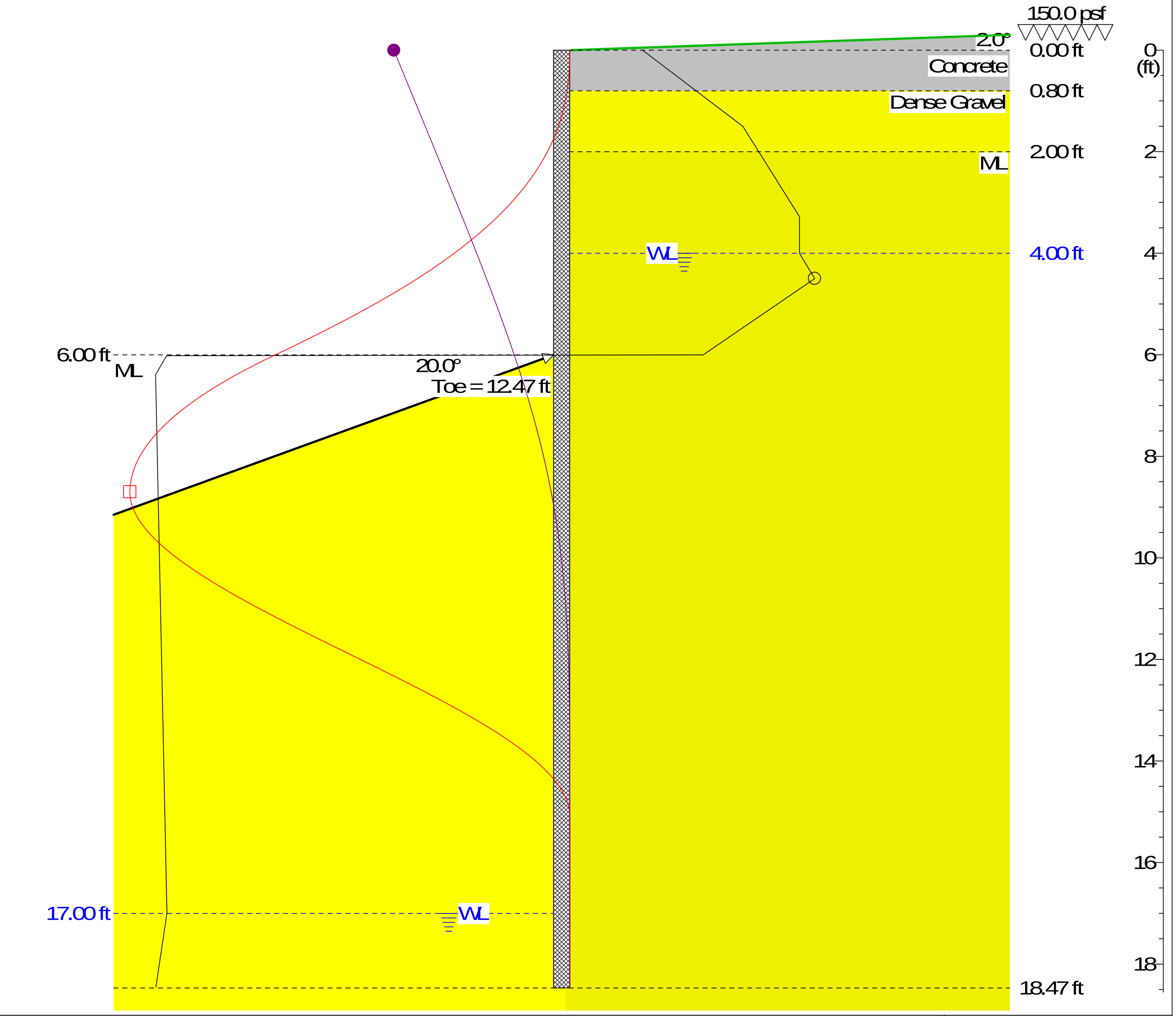
Maximum		d (ft)
○	515.0 psf	4.49
□	9618.0 ftlb/ft	8.70
●	0.1 in	0.00



ANCHOR QEA

Anchor QEA, LLC

1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Toe: Cantilever

Input Data

Depth Of Excavation = 6.00ft
Surcharge = 150.0psf
Slope (active) = 2.0degrees

Depth Of Active Water = 4.00ft
Depth Of Passive Water = 17.00ft
Slope (passive) = 20.0degrees

Water Density = 64.00pcf
Minimum Fluid Density = 31.82pcf

Soil Profile — Active Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	ϕ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	Concrete	135.00	71.00	4175.7	0.0	0.0	0.0	1.00	2.00	1.00	2.00
0.80	Dense Gravel	110.00	46.00	0.0	0.0	40.0	0.0	0.22	0.00	4.60	0.00
2.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	125.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Soil Profile — Passive Side

Depth (ft)	Soil Name	γ (pcf)	γ' (pcf)	C (psf)	C_a (psf)	ϕ (°)	δ (°)	K_a	K_{ac}	K_p	K_{pc}
0.00	ML	100.00	36.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
25.00	SP-SM	115.00	51.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00
35.30	ML	95.00	31.00	500.0	0.0	0.0	0.0	1.00	2.00	1.00	2.00
41.80	SP-SM	110.00	46.00	0.0	0.0	30.0	0.0	0.33	0.00	3.00	0.00
45.60	SM	110.00	46.00	0.0	0.0	28.0	0.0	0.36	0.00	2.77	0.00
55.30	SP-SM	130.00	61.00	0.0	0.0	32.0	0.0	0.31	0.00	3.25	0.00

Solution

Sheet

Sheet Name	E (psi)	I (in^4/ft)	f (psi)	Z (in^3/ft)	Allowed M_{max} (ftlb/ft)	b (in)	A (in^2/ft)	W (lb/ft)	Upstand (ft)	Toe (ft)	Length (ft)
Arbed AZ18	3.04E+07	283.10	24966.8	35.08	72986.3	27.56	7.07	24.0	0.00	12.47	18.47

Pressure Model: Terzaghi (m=1.0; a=0.4); Apply hydrostatic pressure in cohesive soils

Maxima

	Maximum	Depth (ft)
Pressure	515.0 psf	4.49
Bending Moment	9618.0 ftlb/ft	8.70
Deflection	0.1 in	0.00
Shear Force	2341.2 lb/ft	6.00

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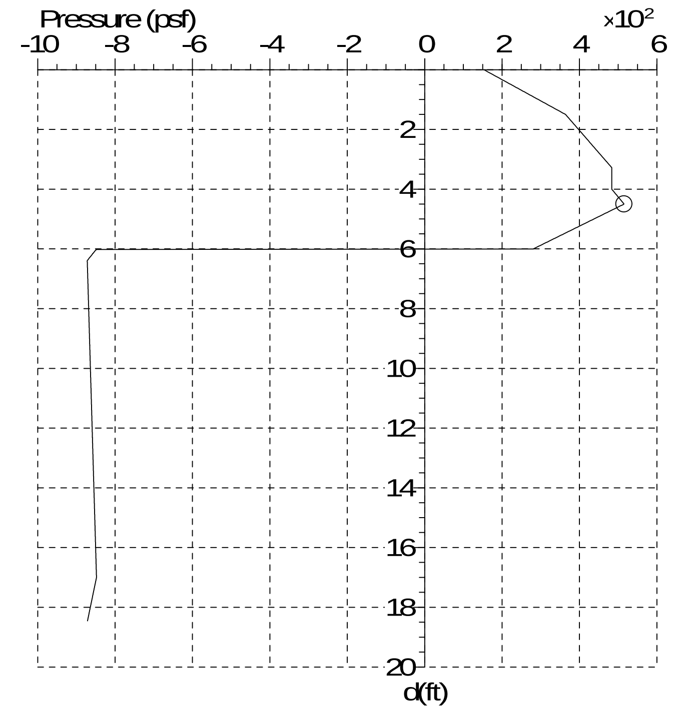
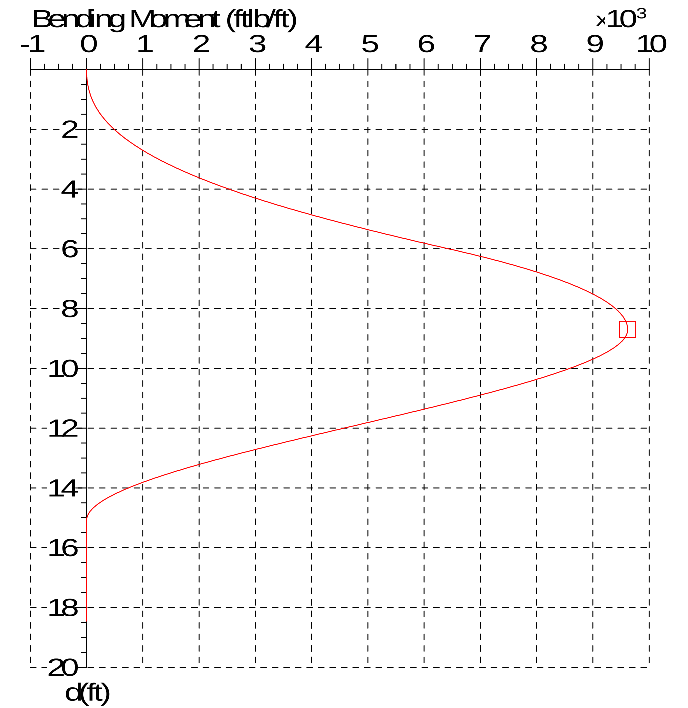
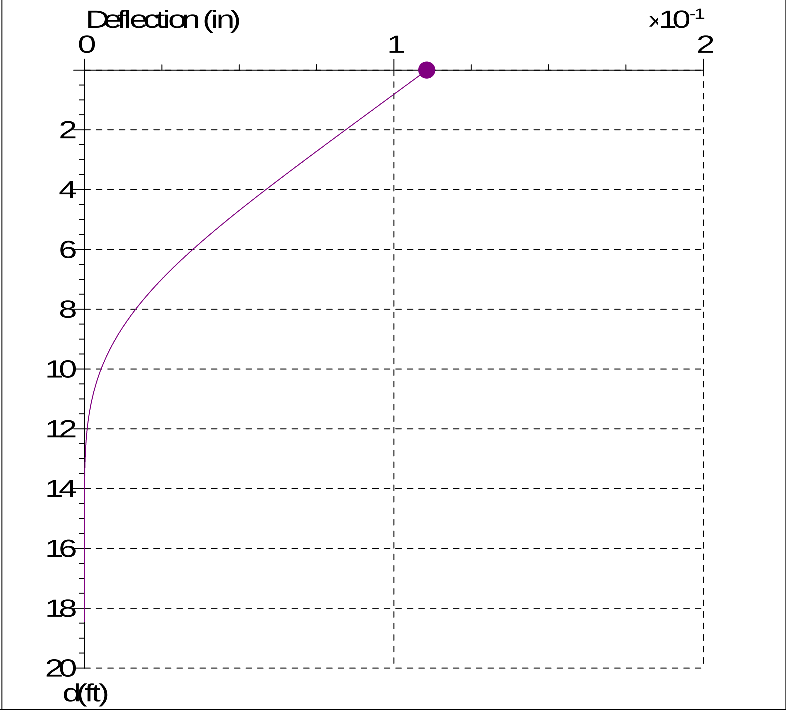
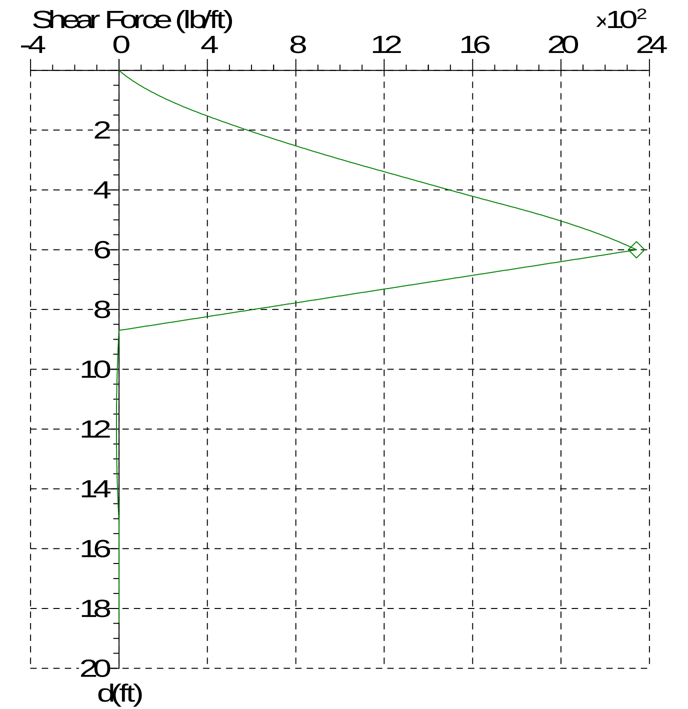
	Maximum	d (ft)
○	515.0 psf	4.49
□	9618.0 ftlb/ft	8.70
◇	2341.2 lb/ft	6.00
●	0.1 in	0.00









ANCHOR QEA

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1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

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Pressure: Terzaghi (m=1.0; a=0.4)
Analysis: Net Pressure
FOS: 1.52
Toe: Cantilever

depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
0.00	153.0	0.0	0.1	0.0
0.13	172.5	1.4	0.1	22.7
0.26	189.8	5.4	0.1	45.2
0.40	209.3	13.3	0.1	73.0
0.53	226.7	23.7	0.1	100.0
0.66	246.2	39.5	0.1	132.9
0.79	263.5	57.6	0.1	164.5
0.92	283.0	82.7	0.1	202.5
1.06	302.5	113.2	0.1	243.2
1.19	319.8	145.2	0.1	281.7
1.32	339.3	187.0	0.1	327.6
1.45	356.6	229.6	0.1	370.6
1.58	369.9	284.0	0.1	421.2
1.71	378.1	338.3	0.1	467.4
1.85	387.4	406.3	0.1	520.5
1.98	396.7	481.7	0.1	575.0
2.11	404.9	555.1	0.1	624.4
2.24	414.2	645.1	0.1	681.3
2.37	422.5	731.7	0.1	732.9
2.51	431.7	836.8	0.1	792.2
2.64	440.0	937.2	0.1	846.0
2.77	449.3	1058.1	0.1	907.7
2.90	458.6	1187.7	0.1	970.7
3.03	466.8	1310.2	0.1	1027.8
3.17	476.1	1456.6	0.1	1093.2
3.30	483.5	1594.3	0.1	1152.5
3.43	483.5	1758.0	0.1	1219.5
3.56	483.5	1911.3	0.1	1279.1
3.69	483.5	2092.6	0.1	1346.1
3.83	483.5	2283.1	0.1	1413.2
3.96	483.5	2460.2	0.1	1472.8
4.09	489.4	2668.3	0.1	1540.1
4.22	497.3	2861.1	0.1	1601.0
4.35	506.1	3087.1	0.1	1670.6
4.49	514.0	3296.1	0.1	1733.5
4.62	497.1	3540.5	0.1	1803.8
4.75	475.4	3794.4	0.0	1871.0
4.88	456.2	4027.8	0.0	1928.3
5.01	434.5	4298.7	0.0	1989.9
5.14	415.3	4546.4	0.0	2042.1
5.28	393.6	4832.7	0.0	2098.0
5.41	374.4	5093.5	0.0	2145.2
5.54	352.7	5393.6	0.0	2195.4
5.67	331.1	5700.6	0.0	2242.7
5.80	311.8	5978.7	0.0	2282.1
5.94	290.2	6297.3	0.0	2323.7
6.07	-851.6	6583.6	0.0	2288.9

depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
6.20	-860.2	6893.3	0.0	2170.4
6.33	-867.8	7154.7	0.0	2064.1
6.46	-871.7	7433.1	0.0	1943.5
6.60	-871.4	7694.8	0.0	1822.8
6.73	-871.1	7913.4	0.0	1715.5
6.86	-870.8	8143.5	0.0	1594.9
6.99	-870.5	8334.0	0.0	1487.7
7.12	-870.2	8532.6	0.0	1367.1
7.26	-870.0	8695.1	0.0	1260.0
7.39	-869.6	8862.2	0.0	1139.5
7.52	-869.3	9012.5	0.0	1019.0
7.65	-869.1	9132.2	0.0	912.0
7.78	-868.7	9251.1	0.0	791.7
7.92	-868.5	9342.7	0.0	684.7
8.05	-868.2	9430.2	0.0	564.4
8.18	-867.9	9493.9	0.0	457.5
8.31	-867.6	9549.8	0.0	337.4
8.44	-867.3	9589.2	0.0	217.2
8.57	-867.0	9610.1	0.0	110.4
8.71	-866.7	9618.0	0.0	-0.1
8.84	-866.4	9606.1	0.0	-1.0
8.97	-866.1	9568.2	0.0	-1.9
9.10	-865.8	9513.7	0.0	-2.7
9.23	-865.5	9429.8	0.0	-3.5
9.37	-865.2	9323.4	0.0	-4.3
9.50	-864.9	9210.6	0.0	-5.0
9.63	-864.6	9064.6	0.0	-5.8
9.76	-864.3	8918.6	0.0	-6.4
9.89	-864.0	8737.3	0.0	-7.0
10.03	-863.7	8561.8	0.0	-7.5
10.16	-863.4	8349.3	0.0	-8.1
10.29	-863.1	8122.1	0.0	-8.6
10.42	-862.8	7908.6	0.0	-9.0
10.55	-862.5	7656.6	0.0	-9.5
10.69	-862.2	7423.1	0.0	-9.8
10.82	-861.9	7150.6	0.0	-10.2
10.95	-861.6	6900.7	0.0	-10.5
11.08	-861.3	6611.9	0.0	-10.7
11.21	-861.0	6316.1	0.0	-11.0
11.35	-860.7	6048.4	0.0	-11.1
11.48	-860.4	5742.8	0.0	-11.3
11.61	-860.2	5468.1	0.0	-11.4
11.74	-859.8	5156.8	0.0	-11.4
11.87	-859.6	4879.0	0.0	-11.5
12.00	-859.3	4566.2	0.0	-11.5
12.14	-858.9	4254.3	0.0	-11.4
12.27	-858.7	3978.8	0.0	-11.3

depth (ft)	P (psf)	M (ftlb/ft)	D (in)	F (lb/ft)
12.40	-858.4	3671.8	0.0	-11.2
12.53	-858.1	3402.6	0.0	-11.0
12.66	-857.8	3104.8	0.0	-10.8
12.80	-857.5	2845.5	0.0	-10.6
12.93	-857.2	2561.1	0.0	-10.3
13.06	-856.9	2285.4	0.0	-9.9
13.19	-856.6	2048.6	0.0	-9.6
13.32	-856.3	1792.7	0.0	-9.1
13.46	-856.0	1575.3	0.0	-8.7
13.59	-855.7	1343.4	0.0	-8.2
13.72	-855.4	1149.2	0.0	-7.7
13.85	-855.1	945.4	0.0	-7.1
13.98	-854.8	758.2	0.0	-6.5
14.12	-854.5	606.7	0.0	-5.9
14.25	-854.2	454.1	0.0	-5.2
14.38	-853.9	335.2	0.0	-4.5
14.51	-853.6	221.4	0.0	-3.7
14.64	-853.3	138.9	0.0	-3.0
14.78	-853.0	68.1	0.0	-2.1
14.91	-852.7	21.7	0.0	-1.2
15.04	-852.4	2.0	0.0	-0.3
15.17	-852.1	0.0	0.0	0.0
15.30	-851.8	0.0	0.0	0.0
15.43	-851.5	0.0	0.0	0.0
15.57	-851.3	0.0	0.0	0.0
15.70	-850.9	0.0	0.0	0.0
15.83	-850.6	0.0	0.0	0.0
15.96	-850.4	0.0	0.0	0.0
16.09	-850.0	0.0	0.0	0.0
16.23	-849.8	0.0	0.0	0.0
16.36	-849.5	0.0	0.0	0.0
16.49	-849.2	0.0	0.0	0.0
16.62	-848.9	0.0	0.0	0.0
16.75	-848.6	0.0	0.0	0.0
16.89	-848.3	0.0	0.0	0.0
17.02	-848.4	0.0	0.0	0.0
17.15	-850.3	0.0	0.0	0.0
17.28	-852.6	0.0	0.0	0.0
17.41	-854.5	0.0	0.0	0.0
17.55	-856.7	0.0	0.0	0.0
17.68	-859.0	0.0	0.0	0.0
17.81	-860.9	0.0	0.0	0.0
17.94	-863.1	0.0	0.0	0.0
18.07	-865.1	0.0	0.0	0.0
18.21	-867.3	0.0	0.0	0.0
18.34	-869.3	0.0	0.0	0.0
18.47	-871.3	0.0	0.0	0.0

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1201 3rd Avenue Suite 2600
Seattle, WA 98101
Tel: 206-287-9130
Fax: 206-287-9131

SupportIT, v2.38

Tel/Fax: +44 (0)1292 477754
Email: GTSoftLtd@aol.com
Web: www.GTSoft.org

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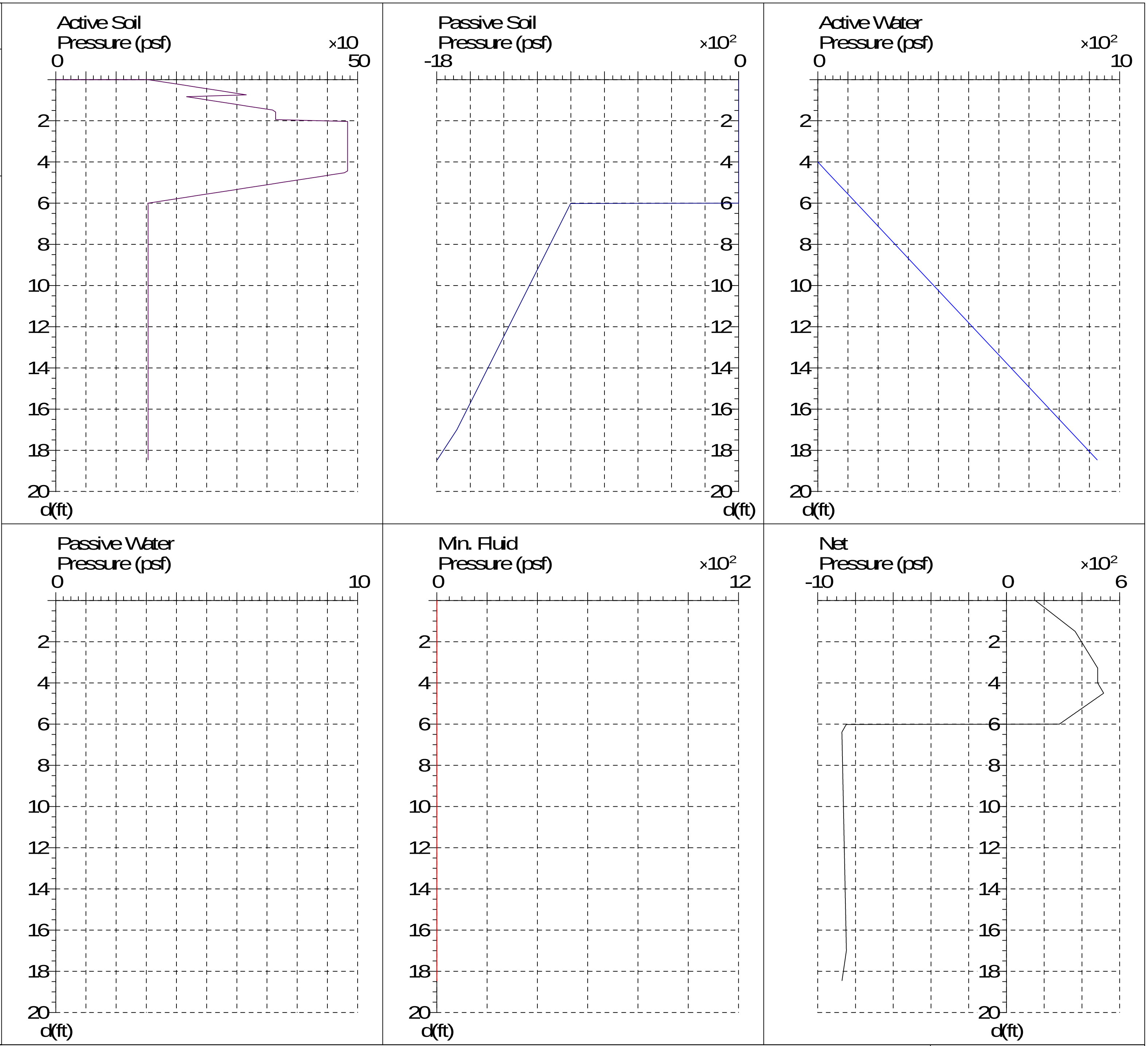

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1201 3rd Avenue Suite 2600
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FOS: 1.52
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Design Report

1. The standard surcharge is 150.0psf. The Piling Handbook recommends a minimum surcharge of 200.0psf.

2. Are water depths correct? Passive water depth is not normally below the active water depth AND excavation depth.

3. Terzaghi was used for the active pressure. Rankine was used for the passive pressure.

4. Total stress values are being used (i.e. C > 0). Note that the Piling Handbook and CIRIA SP95 recommend that effective stress values be used in 'long term' excavations.

5. BSPH approximation used for slope calculation. i.e. Pressure modified by 5% for each 5° of slope.

6. Maximum bending moment = 9618.0ftlb/ft and f = 24966.8psi. MINIMUM required sheet section modulus is: Z = 4.62in^3/ft (= M/f).
Sheet section modulus in this design is Z = 35.08in^3/ft, and is satisfactory.

7. FOS = 1.52 (Net Pressure)
This is the factor of safety against rotation about the toe.
The FOS can be changed using 'Defined FOS' or 'Manual' in the 'Wall' page.