GEOTECHNICAL DESIGN MEMORANDUM

TO: Matthew Hurst, P.E., District 9 Geotechnical Engineer

COPY: Christopher Pridemore, P.E., District 9 Capital Programs Director

FROM: Evan Holcombe, P.E., Office of Geotechnical Engineering

DATE: November 26, 2024

SUBJECT: ROS-35-22.67, PID 119951, Sheet Pile Retaining Wall Geotechnical Design Memo

Design and Exploration Specifications:

- The ODOT Specifications for Geotechnical Explorations (SGE), July 2024.
- The ODOT Bridge Design Manual (BDM), July 2024.
- The ODOT Geotechnical Design Manual (GDM), July 2024.
- The AASHTO LRFD Bridge Design Specifications (AASHTO LRFD), 9th Edition, 2020.
- The ODOT 2023 Construction & Material Specifications (C&MS), 2023 Edition, July 2024.

DESCRIPTION:

This document includes the design recommendations for the proposed sheet pile retaining wall between the Scioto River and U.S. 35 near Chillicothe, Ohio. The project site is located approximately 1.0 mile south of the intersection between U.S. 35 and U.S.23. The existing riverbank at the site location is experiencing significant erosion due to the meandering nature of the river. ODOT's Office of Geotechnical Engineering (OGE) has been requested by District 9 to perform the geotechnical exploration and perform the retaining wall design and recommendations for this project.

HISTORICAL RECORDS:

Historical geotechnical records were obtained and reviewed from ODOT's transportation information mapping system (TIMS) for ROS-35-22.82 (1962) for the current US 35 roadway alignment. Results of the exploration presented shallow roadway borings indicating cohesive soils overlying predominately granular deposits. The historic boring information was used to verify the estimated soil types and properties derived from the project CPT soundings.

GEOLOGY:

The project is located within the Illinoian Glaciated Allegheny Plateau Physiographic region, which is characterized by moderate relief with elevations ranging from 600 to 1400 feet. The soils in this region are described as colluvium and Illinoian-age till over Devonian to Pennsylvanian-age sandstones, conglomerates and shales. Based on the Ohio Department of Natural resources Ohio Geology Interactive Map, the top of bedrock elevation within the site ranges from 474 to 468. With ground surface elevation along the proposed wall alignment of approximately 596, the depth to bedrock is estimated to be 122 to 128 feet below existing grade.

RECONNAISSANCE:

A site reconnaissance visit was completed by personnel from the Office of Geotechnical Engineering (OGE) on April 27, 2023. The project area is along the slope between U.S. 35 and the Scioto River. Significant erosion was observed along the riverbank with vegetation noticeably removed. Areas of erosion rills were observed with no current signs of slope instability. Sand banks were observed within the meandered portion of the river. A benched road is located within the slope between U.S. 35 and the Scioto River. The erosion has progressed to within the benched area.

SUBSURFACE EXPLORATION

Five CPT soundings, labeled C-001-0-24 through C-004-24 and C-003-1-24, were performed for this project on July 1, 2024 near the proposed alignment of the retaining wall. The soundings were extended to depths ranging from 14.57 to 61.68 below existing ground surface. The soundings were performed using an A.P. van den Berg, 23 ton Crawler, Hyson 200kN tracked CPT rig. Details of the results from the CPT soundings, including the location of the performed soundings, can be found in the attachment to this report.

ANALYSES AND RECOMMENDATIONS

The purpose of the proposed sheet pile retaining wall is to protect future bank erosion between the Scioto River and WB U.S. 35 embankment. The current slope is experiencing erosion at a meandered portion of the river. The proposed wall is to be constructed within the benched area of the slope between the river and roadway along the approximate elevation 596 contour.

The estimated lateral earth pressure load calculations and results of a p-y analysis (using Ensoft LPILE© software) can be found as attachments to this memo. Based on the results of these analyses, the wall should be constructed using the recommendations presented in Figure 1 and Table 1 below.

Figure 1. Proposed Wall Layout

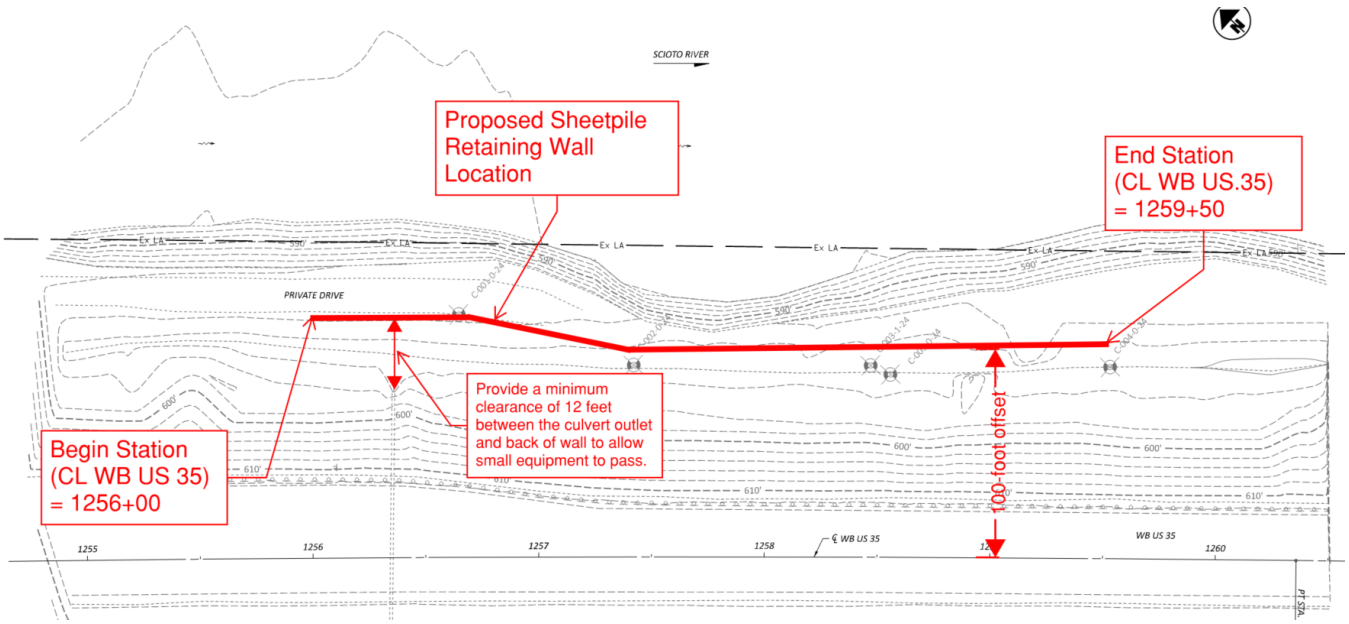


Table 1. Sheetpile Retaining Wall Recommendations

Estimated Top of Wall Elev. (ft)	596.0
Retaining Wall Design Grade (ft)	581.0
Retained Height (ft)	15.0
Design Height (ft)	20.0
Sheeting Tip Elev. (ft)	576.0
Sheetpile Section Length (ft)	40.0
Minimum Yield Stress (ksi)	50
Minimum Section Modulus ($in.^3/ft$)	48.4
Minimum Moment of Inertia($in.^4/ft$)	428.1

The following Geotechnical Plan Notes should be included in the project plan set.

Design Data

- Provide the steel grade for the sheet piling as:

  Steel Sheet Piles - ASTM A572 Grade 50 - yield strength 50 ksi

General Notes

- ODOT BDM Plan Note 701.1-1 – STEEL SHEET PILING left in place shall have a minimum section modulus of 48.4 in^3 per foot of wall.

Estimated Quantities

- Include a quantity for 504E11101 (SF), Steel Sheet Piling Left In Place, As Per Plan.

Retaining Wall Details

- Include the top of wall elevation.

- Include a callout or dimension line for length of steel sheet pile sections (40 feet), or a bottom of wall elevation (40 feet below the top of wall elevation).

- Include a callout or footnote for the Steel Sheet Pile Minimum Section Modulus, S_x, = 48.4 in^3/ft.

- Include the following plan note;

  Item 623 Monument, Misc.: Wall As-Built Survey
  At completion of wall construction, establish permanent survey marks (brass disk with a well-defined center point) on the wall at 50-foot intervals along the entire length (including begin and end of wall). Record locations of the survey marks from Type A primary control points established and positioned per the Survey and Mapping Specifications to an accuracy of +\-0.02 feet and provide this data to the District Survey Operations Manager. The survey control points should be no closer than 50 feet, and no further than 150 feet from the wall. The District is to continue survey monitoring of the wall at set intervals to be established by the District. If any wall survey point is found to deflect greater than 0.75 feet from the initial as-built wall location, take immediate action to remediate, repair, or replace the retaining wall.

If you have any questions, please feel free to contact either myself at evan.holcombe@dot.ohio.gov, or Alex Dettloff, at 614-275-1308.

Thank you,
EH

PC: Reading File, File

ATTACHMENTS:

- Exploration Plan
- CPT Soundings Report
- Historic Boring Logs
- Sheetpile Wall Analysis

ATTACHMENTS

Exploration Plan


ROS-35-22.67
PID 119951
Legend
CPT Sounding Loction
Historic Boring Location
C-001-0-24
C-002-0-24
C-003-1-24
C-003-0-24
C-004-0-24
1315+00
1316+00
1320+00
50
50
35
Google Earth
200 ft

CPT Sounding Reports

CONE PENETRATION TEST SOUNDINGS REPORT

Office of Geotechnical Engineering
Division of Engineering

Project: ROS-35-22.67

PID: 119951

Date: July 1, 2024

Number of Soundings: 5

Equipment: A.P. van den Berg, 23 Ton Crawler, Hyson 200kN

Sounding ID	Completion Date	Probe SN	Calibration Date	Elevation	Latitude	Longitude	Depth (ft.)
C-001-0-24	6/13/2024	201039	8/11/2023	596.4	39.312582	-82.926953	51.51
C-002-0-24	6/13/2024	090304	8/9/2023	592.6	39.312383	-82.926827	34.58
C-003-0-24	6/13/2024	201039	8/11/2023	592.1	39.312144	-82.926568	31.36
C-003-1-24	6/12/2024	090304	8/9/2023	592.5	39.312169	-82.926578	14.57
C-004-0-24	6/12/2024	201039	8/11/2023	592.2	39.311952	-82.926328	61.68

Project Information

Five soundings were completed for this project. All soundings were completed off road. The static water levels reported on the attached logs were determined by dissipation test results. Soundings C-002-0-24, C-003-0-24, and C-003-1-24 were terminated due to excessive tip resistance and hydraulic down pressure. All other soundings reached the target depths. The latitude, longitude, and elevation values are from district survey grade instruments. The exploration locations are shown on the attached exploration plan.

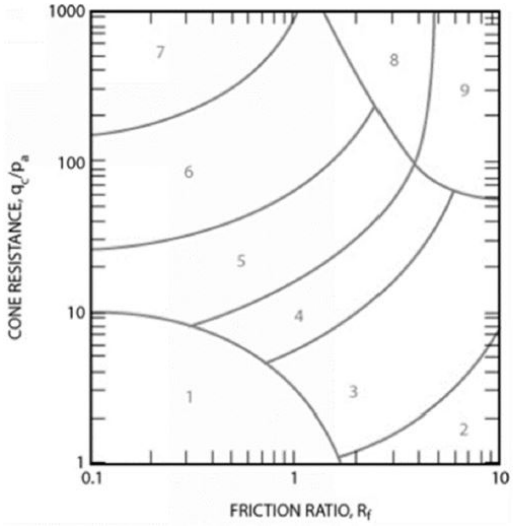
The raw CPT data is available upon request. The included CPT logs are for informational purposes only. The CPT logs have been filtered for negative values, corrected for inclination at depth, and filtered for data spikes. Additionally, for each sounding, the measured values of q_c and f_s were shifted relative to one another with a cross-correlation function.

Cone Penetration Test Data and Interpretation

These Cone Penetration Test (CPT) Soundings follow ASTM D 5778 and were made by ordinary and conventional methods and with care deemed adequate for the Department's design purposes. The CPT data collected are presented as graphical plots in the report, generated by CPeT-IT software. The plots include interpreted Soil Behavior Type (SBT) based on the method described by Robertson (2010) & equivalent SPT N_{60}, described by Jefferies and Davies (1993) and presented in Robertson (2022). The interpretations are presented only as a guide for geotechnical use and should be carefully reviewed.

The department does not warrant the correctness or the applicability of any of the geotechnical parameters interpreted by the software and does not assume any liability for use of the results in any design or review.

The user should be fully aware of the techniques and limitations of any method used in the software. Furthermore, the Department will not be responsible for any interpretations, assumptions, projections, or interpolations made by the contractor, or other users of this report. While the Department believes that the information as to the condition and materials reported is accurate, it does not warrant that the information is necessarily complete. Water pressure measurements and subsequent interpreted water levels shown in this report should be used with discretion since they represent dynamic conditions. Dynamic pore water pressure measurements may deviate substantially from hydrostatic conditions, especially in cohesive soils.



Zone	Soil Behavior Type
1	Sensitive, fine grained
2	Organic soils - clay
3	Clay – silty clay to clay
4	Silt mixtures – clayey silt to silty clay
5	Sand mixtures – silty sand to sandy silt
6	Sands – clean sand to silty sand
7	Gravelly sand to dense sand
8	Very stiff sand to clayey sand*
9	Very stiff fine grained*

* Heavily overconsolidated or cemented
P_a = atmospheric pressure = 100 kPa = 1 tsf

Non-normalized CPT Soil Behavior Type (SBT) chart
(Robertson et al., 1986, updated by Robertson, 2010, 2022)

$$\frac{(q_t/p_a)}{N_{60}} = 8.5\left(1 - \frac{I_c}{4.6}\right)$$

q_t = Cone resistance I_c= SBTn Index

CPT Equivalent SPT N_{60} Correlation
Robertson (2022)

References

Robertson, P.K. and Cabal, K.L, 2022. *Guide to Cone Penetration Testing for Geotechnical Engineering, 7th Edition*. Signal Hill, California: 29, 38.
https://www.greggdrilling.com/wp-content/uploads/2022/11/CPT-Guide-7th-Final-sm.pdf
Accessed June 20, 2024

Jefferies, M.G. and Davies, M.P, "Use of CPTu to Estimate Equivalent SPT N_{60}," *Geotechnical Testing Journal*. GTJODJ. Vol. 16, No. 4. December 1993. pp. 458-468.
https://insitusoil.com/wp-content/uploads/2021/06/CPTU-for-Ic-SPT-N60-and-fines-content.pdf
Accessed July 1, 2024

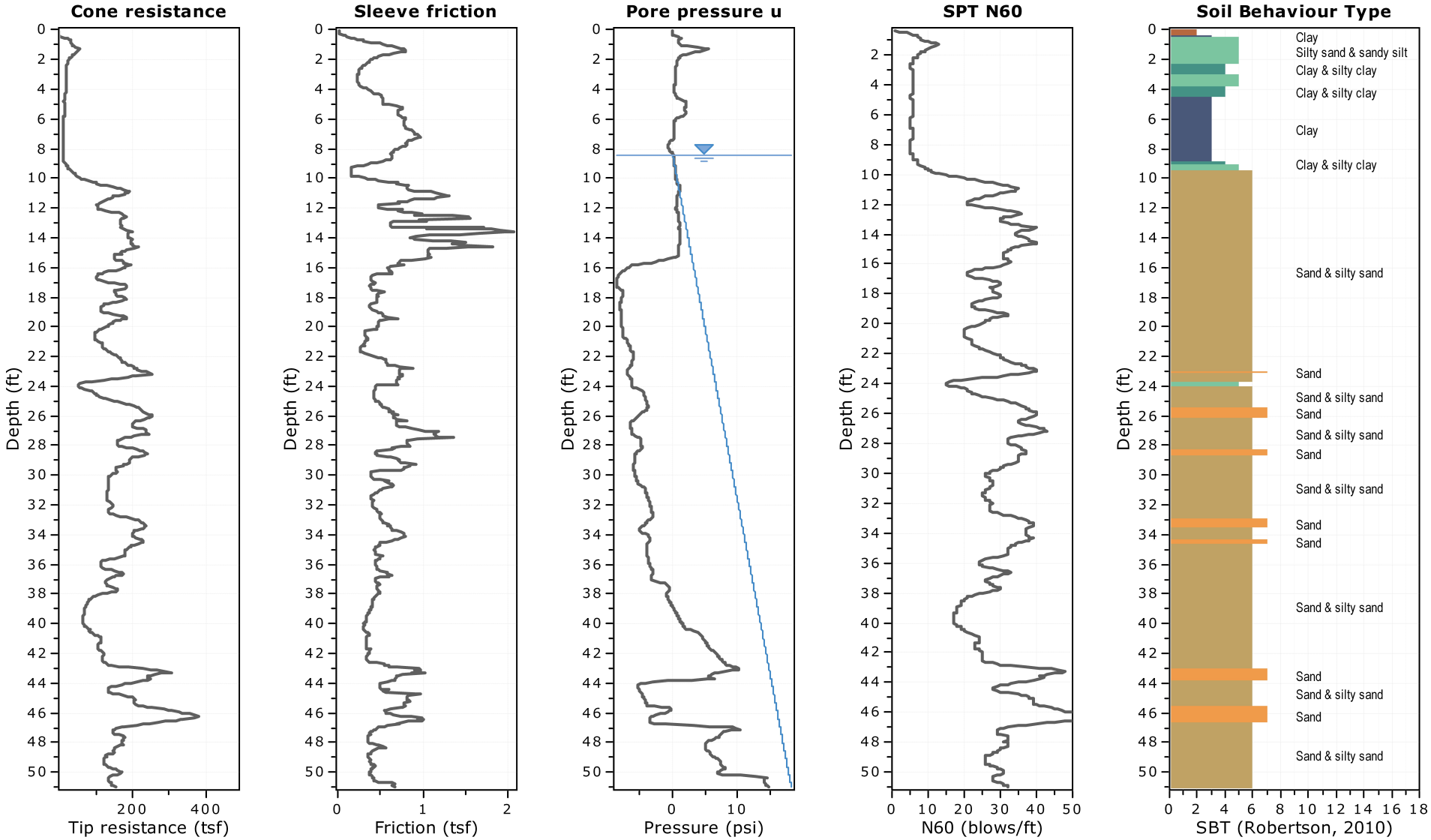
ROS-35-22.67
Exploration Plan

0 25 50 100
Feet

Office of Geotechnical Engineering
Geology, Exploration and Laboratory Section
http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical

CPT: C-001-0-24
Total depth: 50.99 ft, Date: 6/13/2024
Surface Elevation: 596.39 ft
Coords: lat 39.312582° lon -82.926953°

Project: ROS-35-22.67
Location: Ross County



Dissipation Tests Results

Dissipation tests

Dissipation tests consists of stopping the piezocone penetration and observing porepressures (u) with elapsed time (t). The data are automatic recorded by the field computer and should take place until a minimum of 50% dissipation.

The porepressures are plotted as a function of square root of (t). The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50}, which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position
r: piezocone radius
I_r: stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).
t_{50}: time corresponding to 50% consolidation

Permeability estimates based on dissipation test

The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

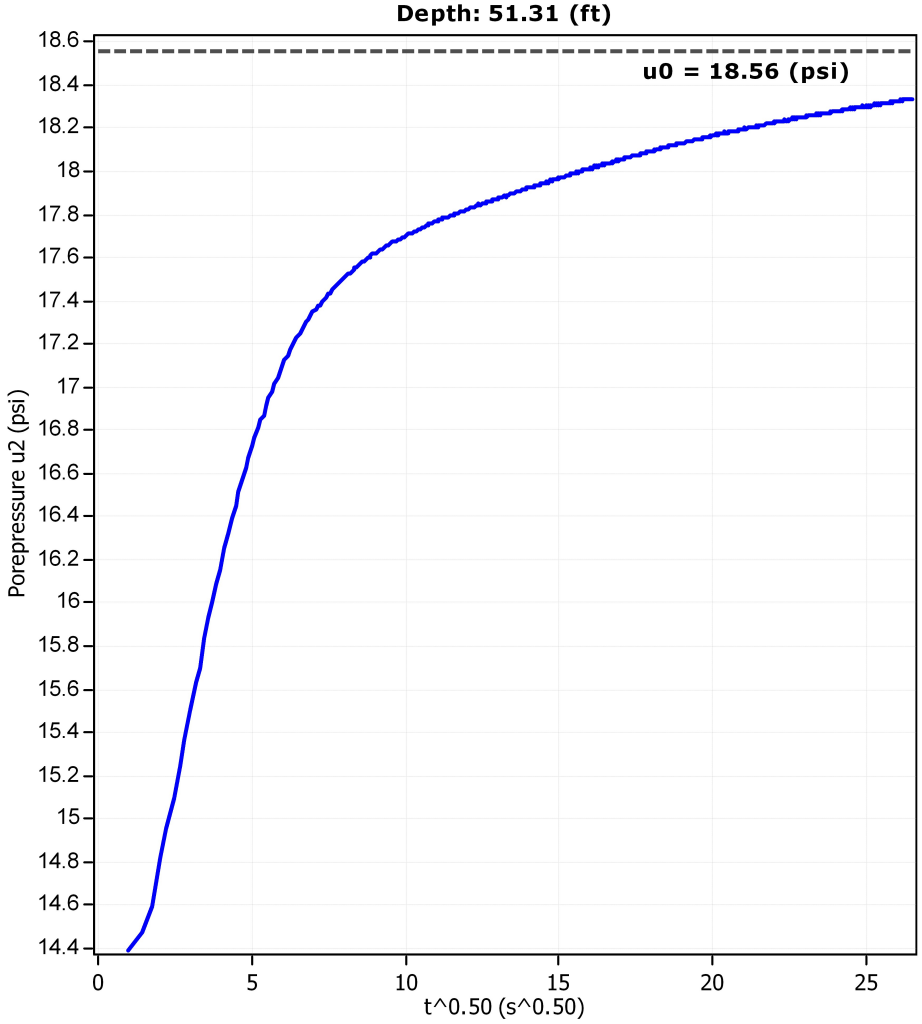
$$k_h = c_h \times \gamma_w / M$$

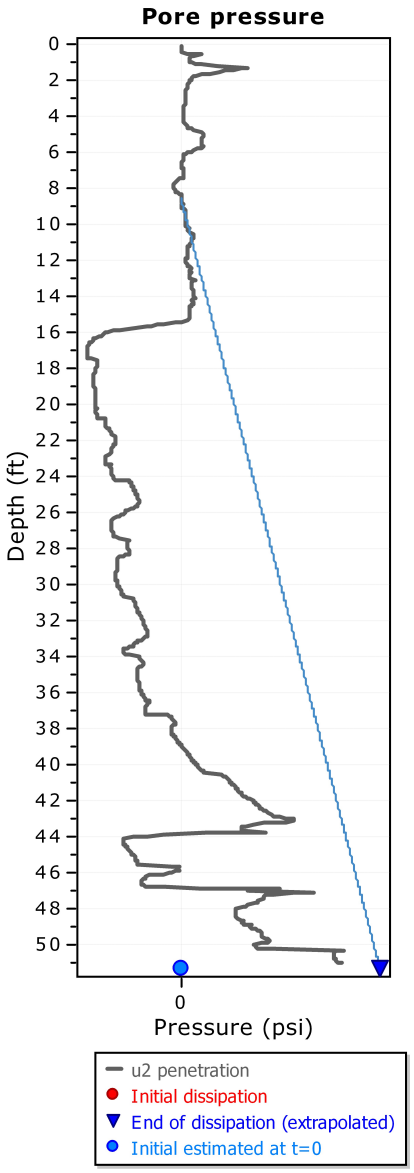
where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

CPTU Borehole	Depth (ft)	$(t_{50})^{0.50}$	t_{50} (s)	t_{50} (years)	G/S_u	c_h (ft^2/s)	c_h (ft^2/year)	M (tsf)	k_h (ft/s)
C-001-0-24	51.31	0.0	0	0.00E+000	100.00	0.00E+000	0	1069.63	-1.00E+004

Piezocone Dissipation Test: C-001-0-24
Depth: 51.31 (ft)





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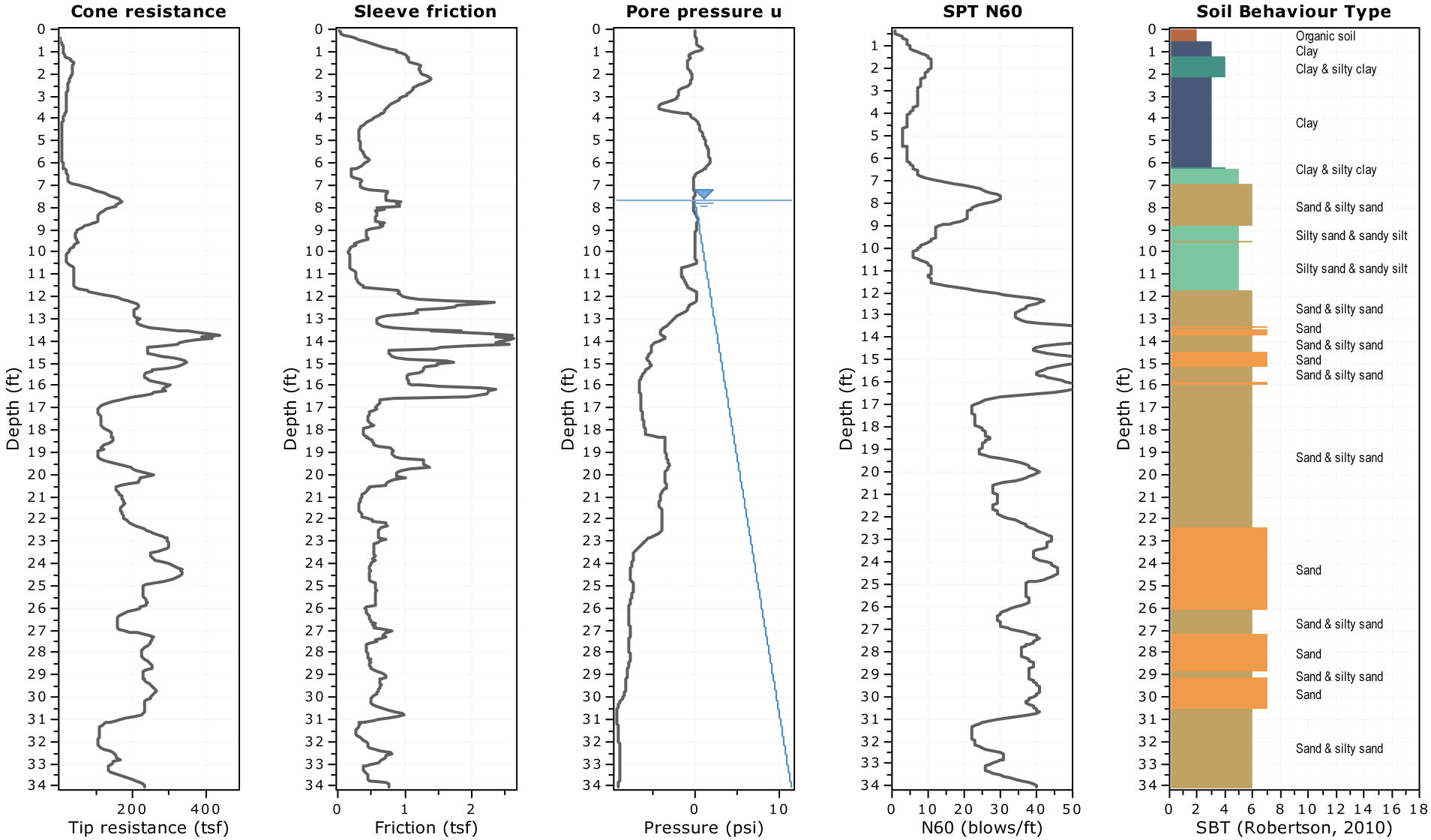
Geology, Exploration and Laboratory Section
http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical

CPT: C-002-0-24
Total depth: 34.04 ft, Date: 6/13/2024
Surface Elevation: 592.58 ft
Coords: lat 39.312383° lon -82.926827°

Project: ROS-35-22.67
Location: Ross County



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$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position
r: piezocone radius
I_r: stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).
t_{50}: time corresponding to 50% consolidation

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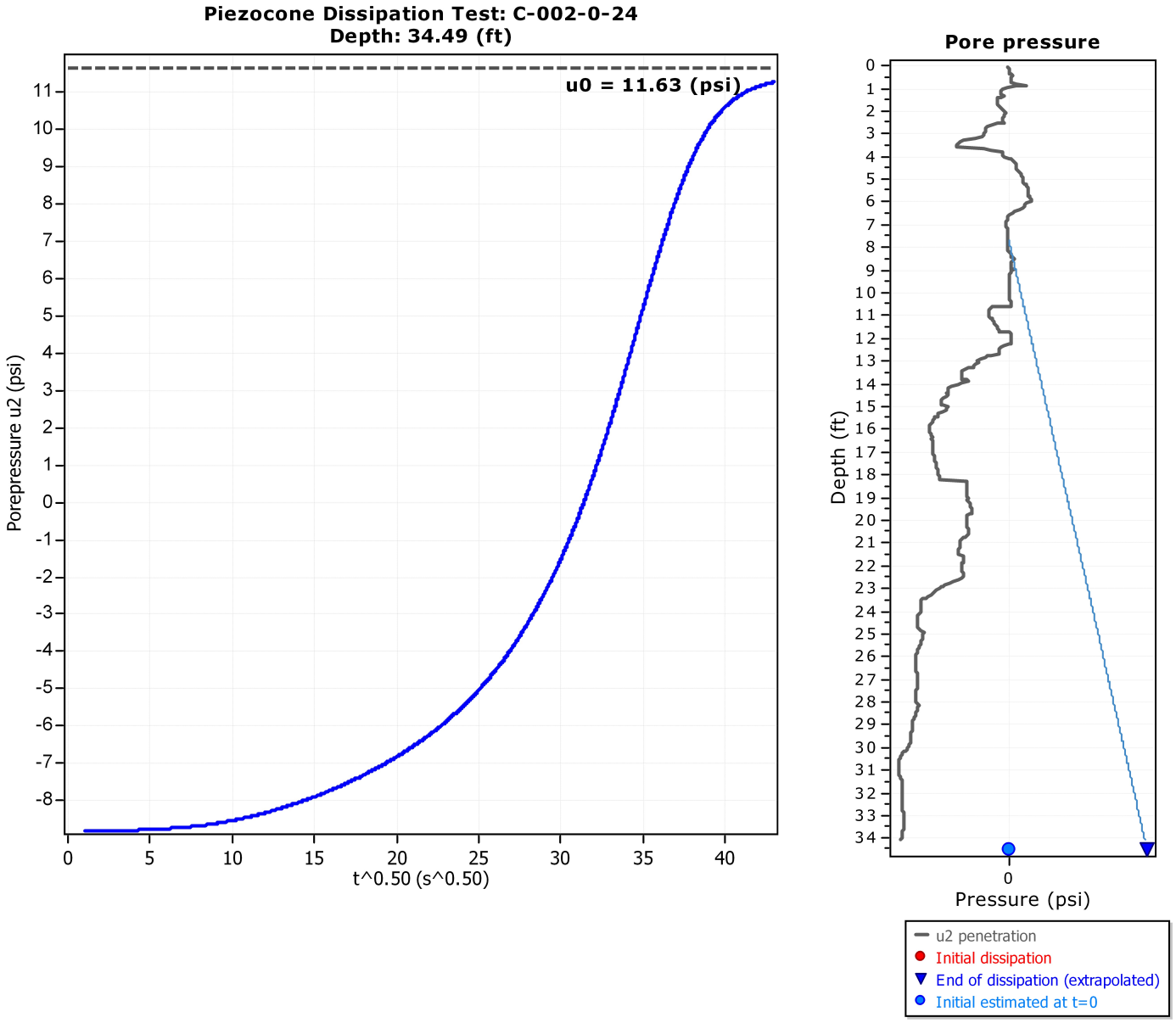
$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

CPTU Borehole	Depth (ft)	$(t_{50})^{0.50}$	t_{50} (s)	t_{50} (years)	G/S_u	c_h (ft^2/s)	c_h (ft^2/year)	M (tsf)	k_h (ft/s)
C-002-0-24	34.49	0.0	0	0.00E+000	100.00	0.00E+000	0	1134.45	-1.00E+004


Piezocone Dissipation Test: C-002-0-24
Depth: 34.49 (ft)
u0 = 11.63 (psi)
Porepressure u2 (psi)
t^0.50 (s^0.50)
Pore pressure
Depth (ft)
Pressure (psi)
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

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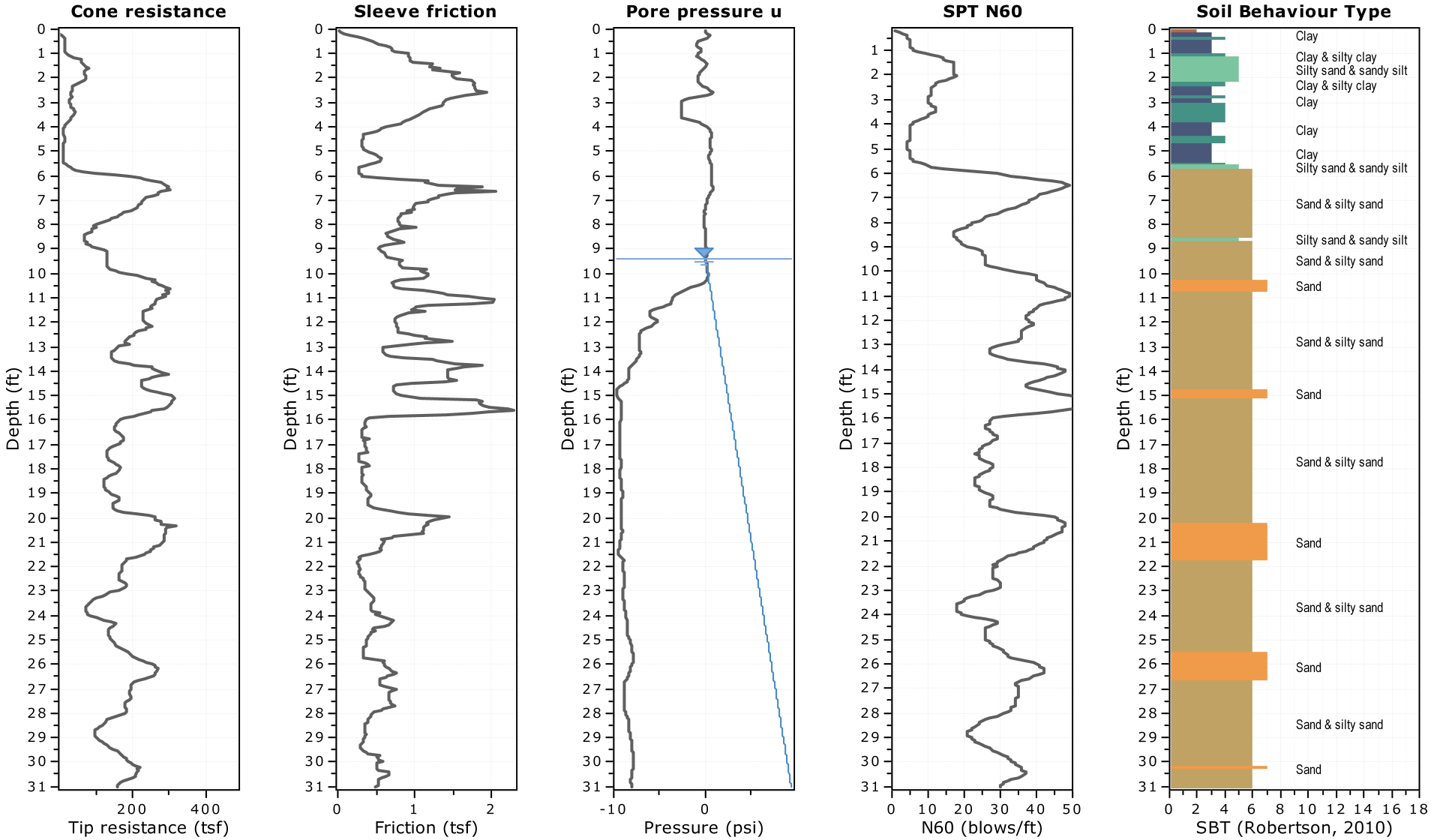
http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical

CPT: C-003-0-24
Total depth: 31.02 ft, Date: 6/13/2024
Surface Elevation: 592.13 ft
Coords: lat 39.312144° lon -82.926568°

Project: ROS-35-22.67
Location: Ross County



Dissipation Tests Results

Dissipation tests

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The porepressures are plotted as a function of square root of (t). The graphical technique suggested by Robertson and Campanella (1989), yields a value for t_{50}, which corresponds to the time for 50% consolidation.

The value of the coefficient of consolidation in the radial or horizontal direction c_h was then calculated by Houlsby and Teh's (1988) theory using the following equation:

$$c_h = \frac{T \times r^2 \times I_r^{0.5}}{t_{50}}$$

where:

T: time factor given by Houlsby and Teh's (1988) theory corresponding to the porepressure position
r: piezocone radius
I_r: stiffness index, equal to shear modulus G divided by the undrained strength of clay (S_u).
t_{50}: time corresponding to 50% consolidation

Permeability estimates based on dissipation test

The dissipation of pore pressures during a CPTu dissipation test is controlled by the coefficient of consolidation in the horizontal direction (c_h) which is influenced by a combination of the soil permeability (k_h) and compressibility (M), as defined by the following:

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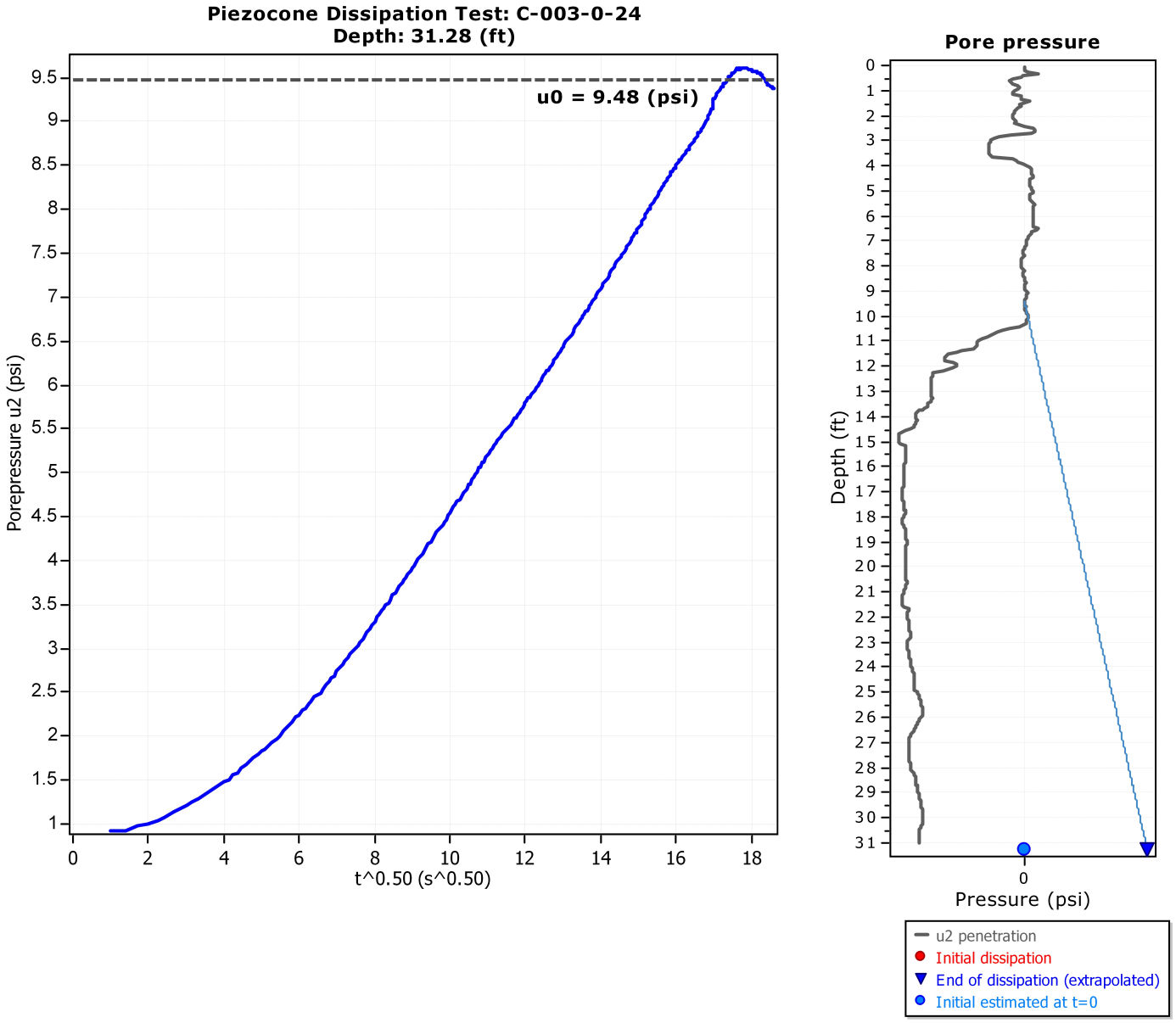
where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

CPTU Borehole	Depth (ft)	$(t_{50})^{0.50}$	t_{50} (s)	t_{50} (years)	G/S_u	c_h (ft^2/s)	c_h (ft^2/year)	M (tsf)	k_h (ft/s)
C-003-0-24	31.28	0.0	0	0.00E+000	100.00	0.00E+000	0	906.02	-1.00E+004


Piezocone Dissipation Test: C-003-0-24
Depth: 31.28 (ft)
u0 = 9.48 (psi)
Porepressure u2 (psi)
t^0.50 (s^0.50)
Pore pressure
Depth (ft)
Pressure (psi)
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

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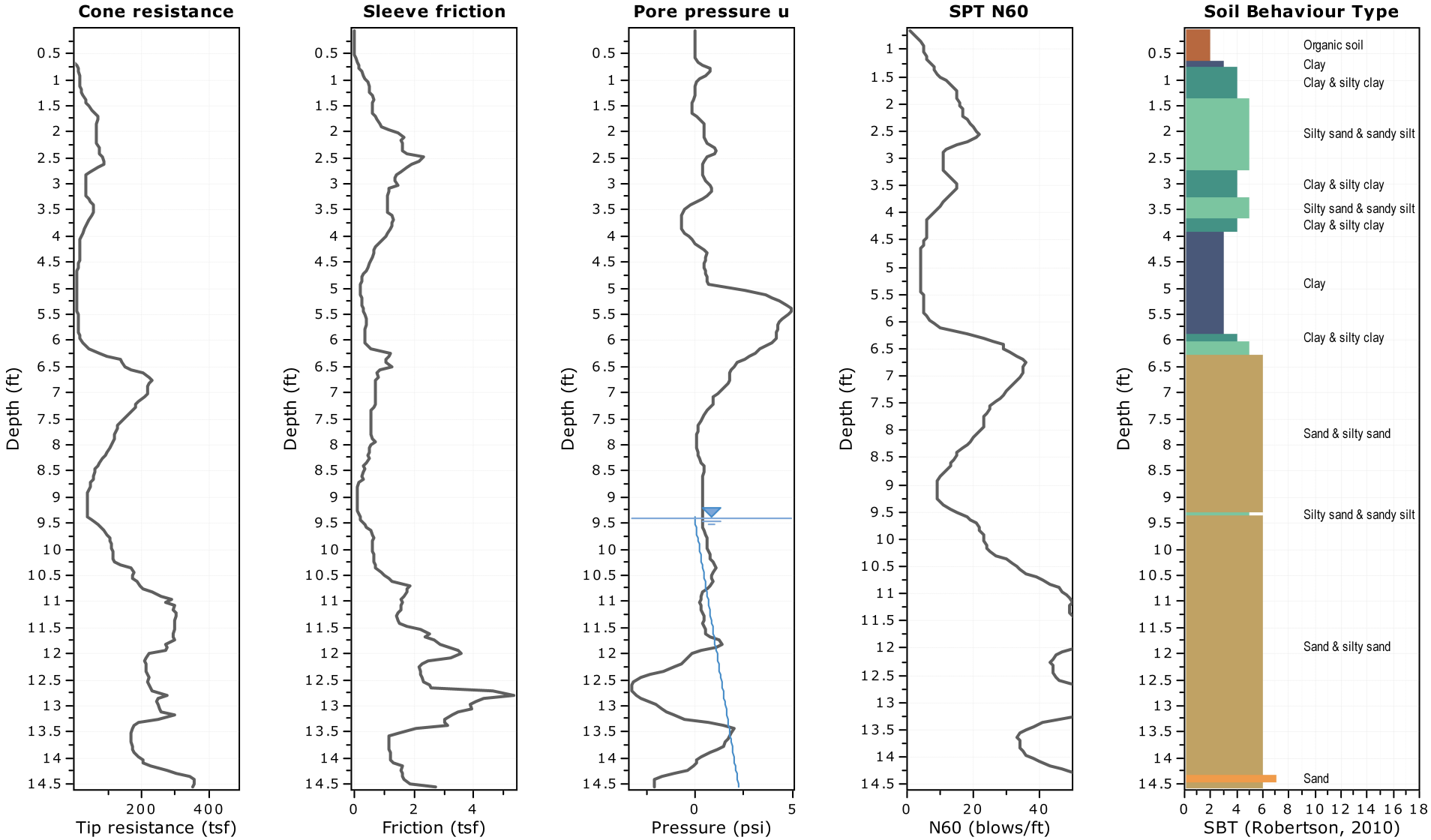
CPT: C-003-1-24
Total depth: 14.55 ft, Date: 6/13/2024
Surface Elevation: 592.54 ft
Coords: lat 39.312169° lon -82.926578°

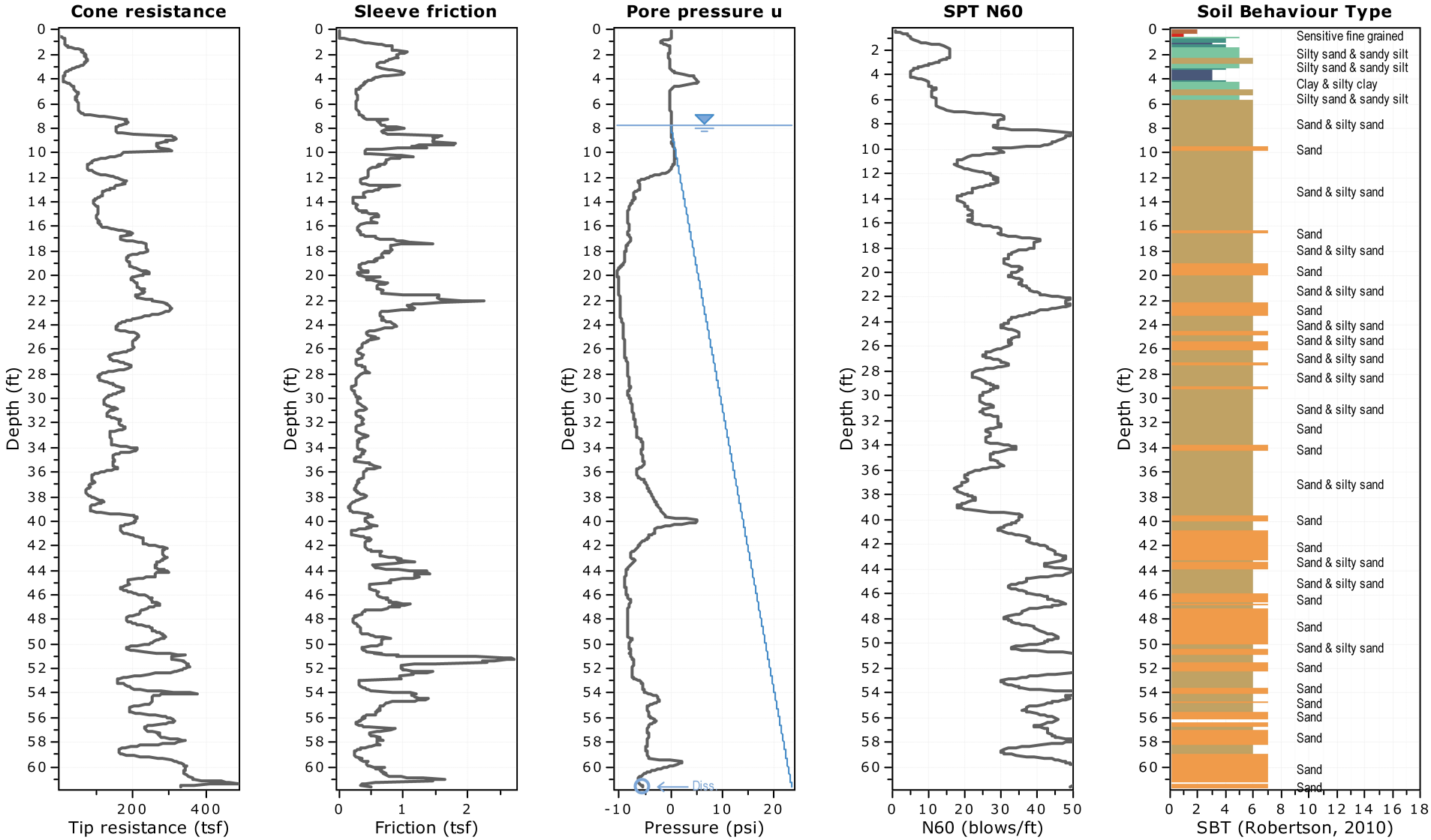
Project: ROS-35-22.67
Location: Ross County



Office of Geotechnical Engineering
Geology, Exploration and Laboratory Section
http://www.dot.state.oh.us/Divisions/Engineering/Geotechnical

CPT: C-004-0-24
Total depth: 61.64 ft, Date: 6/13/2024
Surface Elevation: 592.18 ft
Coords: lat 39.311952° lon -82.926328°

Project: ROS-35-22.67
Location: Ross County



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where:

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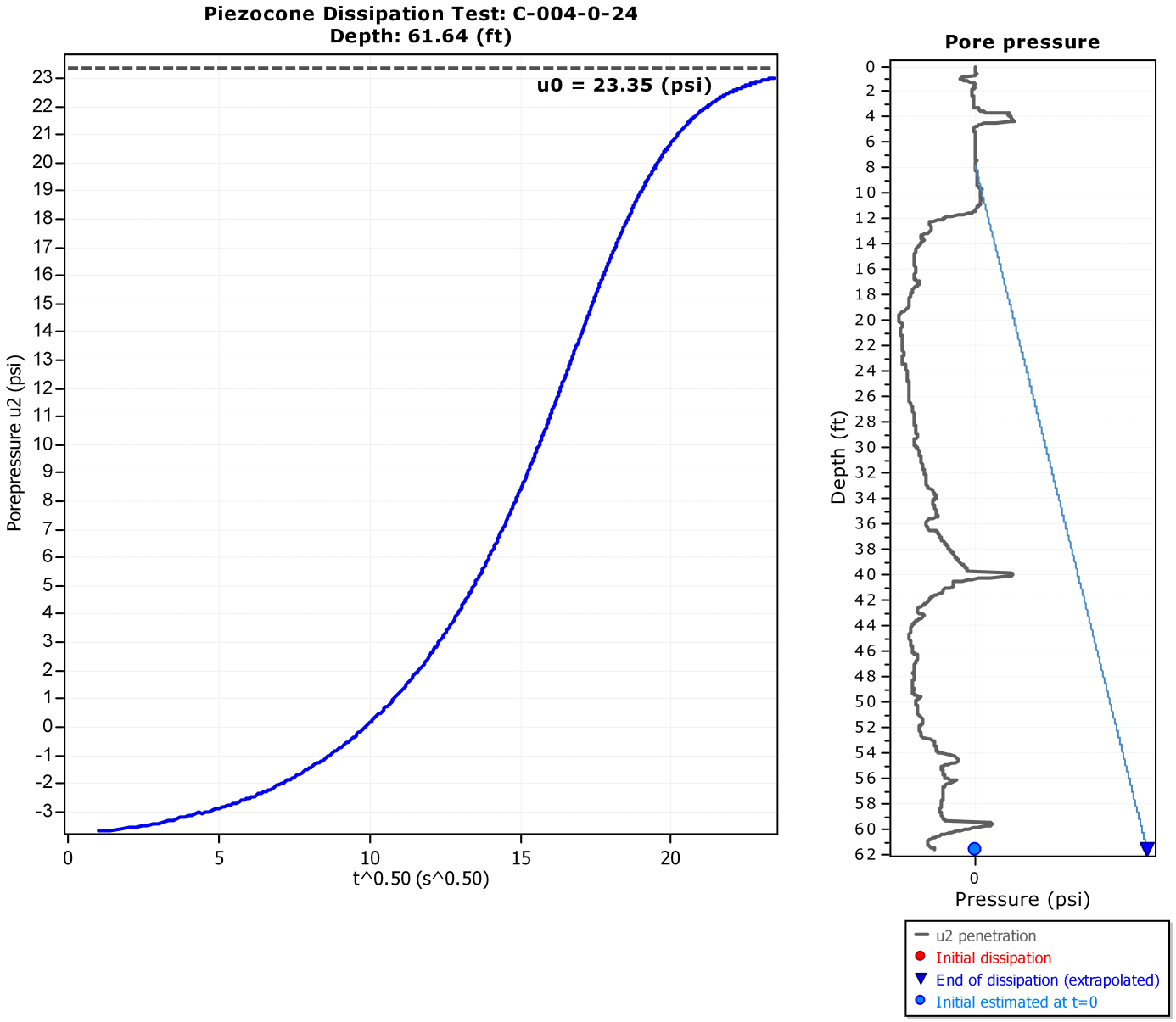
$$k_h = c_h \times \gamma_w / M$$

where: M is the 1-D constrained modulus and γ_w is the unit weight of water, in compatible units.

Tabular results

CPTU Borehole	Depth (ft)	$(t_{50})^{0.50}$	t_{50} (s)	t_{50} (years)	G/S_u	c_h (ft^2/s)	c_h (ft^2/year)	M (tsf)	k_h (ft/s)
C-004-0-24	61.64	0.0	0	0.00E+000	100.00	0.00E+000	0	1198.98	-1.00E+00


Piezocone Dissipation Test: C-004-0-24
Depth: 61.64 (ft)
u0 = 23.35 (psi)
Porepressure u2 (psi)
t^0.50 (s^0.50)
Pore pressure
Depth (ft)
Pressure (psi)
u2 penetration
Initial dissipation
End of dissipation (extrapolated)
Initial estimated at t=0

HISTORIC BORING LOGS

FE-26

FIELD LOG
CORE BORING

T.H. 8 Surf. Elev. 5990 Co., Rt.; Sec. ROST-35
Sta. 115+00 Offset 2 Rt. Bridge No. RJH

Date Started 12-6-62 Completed Water Elev.
Crew THOMSEN CLARK PARTE V LEASURE

General Notes

Depth	Elev.	No. Of Blows	Sample Number	Water Color	Recovery	Description
0-5			1			BROWN CLAY SILT
5-10			2			BROWN CLAY SILT
10-15			3			BROWN CLAY SAND SILT
17-15			4			BROWN SILTY SAND - WET
15-20			5			BROWN SILTY SAND
20-25			6			BROWN SILT GRAVEL SAND

FE-23

VISUAL CLASSIFICATION OF DRIVE SAMPLES

PROJECT: 105-55

BORING LOCATION: 1315+00 ℄

DRILLER: Thompson, CLASSIFIED BY: DAC, DATE: 12-10-62

Field No.	Visual Description	No. Of Blows	Density	Moist. Cont.
1	BR C M TO G GRAVEL			M
2	BR C M		M	M
3	BR C M		M	M
4	BR S SMALL GRAVEL			MT
5	BR S SMALL GRAVEL			WET
6	BR SM W/SOME GRAVEL			M

PE-23

VISUAL CLASSIFICATION OF DRIVE SAMPLES

PROJECT: RDS - 35

BORING LOCATION: 1315 + 00 ℄

DRILLER: Thompson, CLASSIFIED BY: DAR, DATE: 12-10-62

1 * BAG SAMPLES

Field No.	Visual Description	No. Of Blows	Density	Moist. Cont.
1	Br C M			D
2	Br C M T.O. GRAVEL		m	m
3	Br C M		M	M
4	Br m S + GRAVEL -			D
5	Br S W/ SOME SMALL GRAVEL			D
6	Br m SW/ SOME GRAVEL			D
x	denotes "A" test to be run			

TE 36 (FORMERLY TE 24 B)
2000 10-68

SOIL PROFILE

ROSS COUNTY

ROS-35-22.82

OHIO STATE HIGHWAY
TESTING LABORATORY
1920 W. BROAD ST. COLUMBUS 23, OHIO

9
16

Sta. 1286+70.29 Back Equation Sta. 1297+55.06 Ahead

Station

630
620
610
600
590
580

℄ Proposed Eastern Ave.
Proposed Grade Eastern Ave.

℄ TS=0.5'
21
13
3

℄ TS=0.5'
23
5
Hole caved in at elev. 592.0'

℄ TS=0.5'
21
24
7
Hole squeezed in at elev. 594.6'

℄ TS=0.5'
6
3
Hole caved in at elev. 594.9'

℄ TS=0.5'
24
28
12
11
Hole squeezed in at elev. 599.3'

℄ TS=0.5'
28
9
9

℄ TS=0.5'
25
34
13

Westbound Lanes

1295 1296 1297 1298 1299 1300 1301 1302 1303 1304 1305 1306 1307 1308 1309 1310 1311 1312 1314 1315 1316 1317 1318 1319 1320 1321 1322 1323

SHEETPILE WALL ANALYSES

Project: ROS-35-22.67

PID: 119951

No traffic surcharge loading included in analysis

Station: 1257+75

CPT Sounding: C-001-0-24

Backslope Angle* = 18 deg

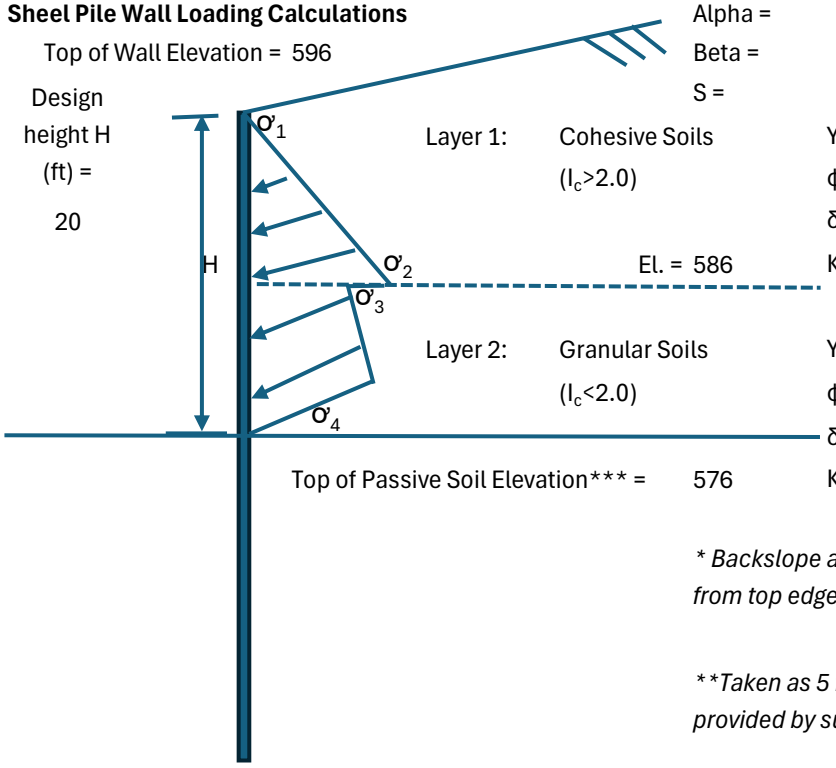
Sheel Pile Wall Loading Calculations

Alpha = 0 deg

Beta = 18 deg

Top of Wall Elevation = 596

S = 1 feet



Layer 1: Cohesive Soils (I_c>2.0)

$Y_{soil\ 1}$ = 120 pcf

$\phi_{soil\ 1}$ = 25 deg

$\delta_{soil\ 1}$ = 0 deg

El. = 586

$K_{a\ 1\ (Coulomb)}$ = 0.5405

Layer 2: Granular Soils (I_c<2.0)

$Y_{soil\ 2}$ = 128 pcf

$\phi_{soil\ 2}$ = 35 deg

$\delta_{soil\ 2}$ = 0 deg

Top of Passive Soil Elevation*** = 576

$K_{a\ 2\ (Coulomb)}$ = 0.3328

** Backslope angle calculated using cross section 1257+75 from top edge of river bank to top of roadway slope.*

***Taken as 5 feet lower than the river bottom elevation provided by survey.*

Y_{EH} = 1.50 (AASHTO LRFD Table 3.4.1-2)

Y_{WA} = 1.00 (AASHTO LRFD Table 3.4.1-1)

Unfactored Service Loads

$\sigma'_{1\ Service}$ =	0 psf/ft	=	0.00	lb/in at depth =	0	ft	
$\sigma'_{2\ Service}$ =	$K_{a\ 1}*Y_{soil\ 1}*H_{layer\ 1}$ =	648.6	psf/ft =	54.05	lb/in at depth =	10	ft
$\sigma'_{3\ Service}$ =	$K_{a\ 2}*Y_{soil\ 1}*H_{layer\ 1}$ =	399.36	psf/ft =	33.28	lb/in at depth =	10	ft
$\sigma'_{4\ Service}$ =	$\sigma'_3+(K_{a\ 2}*Y_{soil\ 2}*H_{layer\ 2})$=	825.34	psf/ft =	68.78	lb/in at depth =	20	ft

Factored Strength Loads

$\sigma'_{1\ Strength} = Y_{EH}*\sigma'_1$ =	0	psf/ft =	0.00	lb/in at depth =	0	ft
$\sigma'_{2\ Strength} = Y_{EH}*\sigma'_2$ =	972.9	psf/ft =	81.08	lb/in at depth =	10	ft
$\sigma'_{3\ Strength} = Y_{EH}*\sigma'_3$ =	599.04	psf/ft =	49.92	lb/in at depth =	10	ft
$\sigma'_{4\ Strength} = Y_{EH}*\sigma'_4$ =	1238.016	psf/ft =	103.17	lb/in at depth =	20	ft

Minimum Steel Section Required = PZC 26

I_x = 428.1 in^4/ft

S_x = 48.4 in^3/ft

$D_w t_w$ = 4.038 in^2/ft

LPILE Results

Maximum Service Limit State Deflection (y_{Max}) = 5.0732 inches (Load Case1)

Maximum Strength Limit State Shear (V_{Max}) = 24.142 kips (Load Case2)

Maximum Strength Limit State Moment (M_{Max}) = 2039.631 in-kips (Load Case2)

$S_{x\,minimum} = M_{max}/(\phi_f * F_y)$ = 45.33 in^3/ft < 48.4 in^3/ft **OK**

*Where ϕ_f = 0.90

F_y = 50 ksi

$D_w T_{w\,minimum} = V_{max}/(\phi_{v*0.58*} F_y)$ = 0.83 in^3/ft < 4.038 in^2/ft **OK**

*Where ϕ_v = 1.00

F_y = 50 ksi

* Specify $S_{x\,minimum}$ " = 48.4 in^3/ft in the plans

* Specify ASTM A572 Grade 50 Steel to be used for the sheet piling

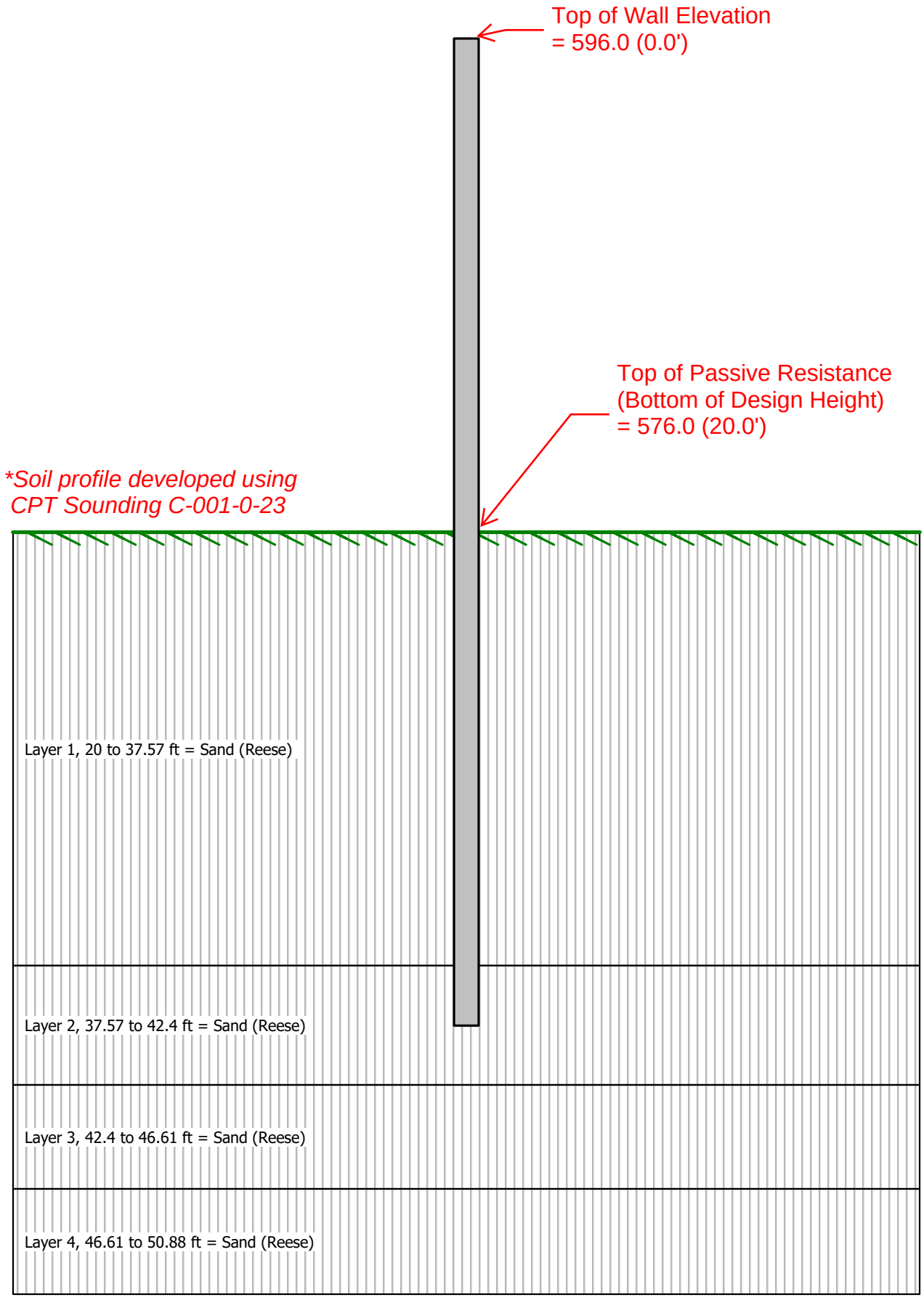
Calculated by: EH

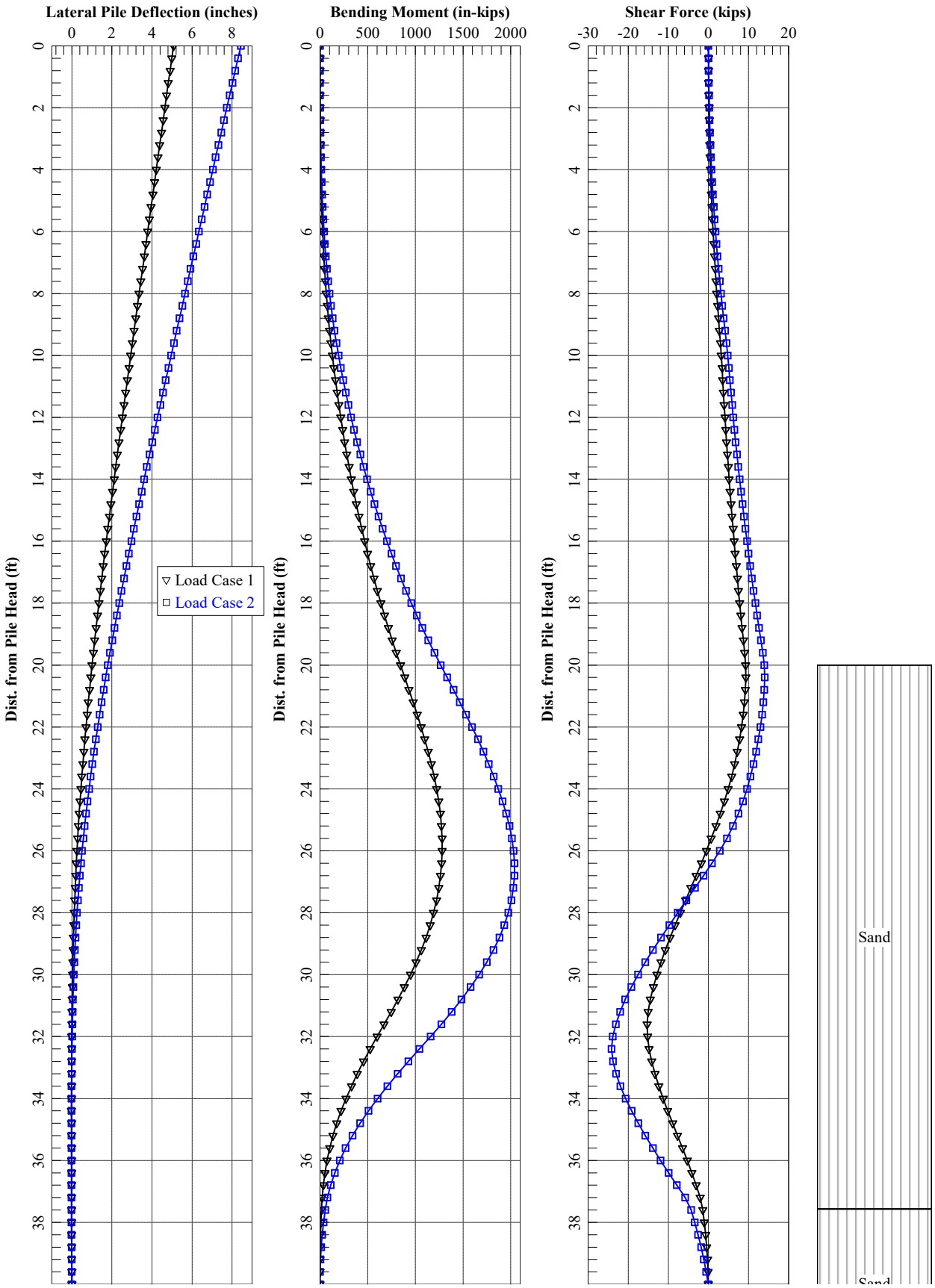
Date: 11/26/2024

Checked by: ABCD

Date: 11/16/2024

Cross Section: 1257+75




Lateral Pile Deflection (inches)
Bending Moment (in-kips)
Shear Force (kips)
Dist. from Pile Head (ft)
Load Case 1
Load Case 2
Sand
Sand

```
================================================================================

                     LPile for Windows, Version 2022-12.011

                  Analysis of Individual Piles and Drilled Shafts
                 Subjected to Lateral Loading Using the p-y Method
                           © 1985-2022 by Ensoft, Inc.
                               All Rights Reserved

================================================================================

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--------------------------------------------------------------------------------
                             Files Used for Analysis
--------------------------------------------------------------------------------

Path to file locations:
\\itcfs007\idrive\ProjectData\ROS\119951 ROS-35-22.67\Design\Geotechnical\EngData\LPILE\

Name of input data file:
1257+75 C-001-0-24.lp12d

Name of output report file:
```

1257+75 C-001-0-24.lp12o

Name of plot output file:
1257+75 C-001-0-24.lp12p

Name of runtime message file:
1257+75 C-001-0-24.lp12r

Date and Time of Analysis

Date: October 23, 2024 Time: 14:06:30

Problem Title

Project Name: ROS-35-22.67

Job Number: PID 119951

Client: ODOT District 9

Engineer: EH

Description: Sheetpile Wall Analysis Station 1257+75

```
--------------------------------------------------------------------------------
                          Program Options and Settings
--------------------------------------------------------------------------------

Computational Options:
 - Conventional Analysis
Engineering Units Used for Data Input and Computations:
 - US Customary System Units (pounds, feet, inches)

Analysis Control Options:
 - Maximum number of iterations allowed                =          500
 - Deflection tolerance for convergence                =   1.0000E-05 in
 - Maximum allowable deflection                        =     100.0000 in
 - Number of pile increments                           =          100

Loading Type and Number of Cycles of Loading:
 - Static loading specified

 - Analysis uses p-y modification factors for p-y curves
 - Analysis uses layering correction (Method of Georgiadis)
 - Analysis includes loading by multiple distributed lateral loads acting on pile
 - Loading by lateral soil movements acting on pile not selected
 - Input of shear resistance at the pile tip not selected
 - Input of moment resistance at the pile tip not selected
 - Computation of pile-head foundation stiffness matrix not selected
 - Push-over analysis of pile not selected
 - Buckling analysis of pile not selected

Output Options:
 - Output files use decimal points to denote decimal symbols.
 - Values of pile-head deflection, bending moment, shear force, and
   soil reaction are printed for full length of pile.
 - Printing Increment (nodal spacing of output points) = 1
 - No p-y curves to be computed and reported for user-specified depths
 - Print using wide report formats
```

Pile Structural Properties and Geometry

Number of pile sections defined = 1
Total length of pile = 40.000 ft
Depth of ground surface below top of pile = 20.0000 ft

Pile diameters used for p-y curve computations are defined using 2 points.

p-y curves are computed using pile diameter values interpolated with depth over the length of the pile. A summary of values of pile diameter vs. depth follows.

Point No.	Depth Below Pile Head feet	Pile Diameter inches
1	0.000	12.0000
2	40.000	12.0000

Input Structural Properties for Pile Sections:

Pile Section No. 1:

Section 1 is an elastic pile
Cross-sectional shape = rectangular
Length of section = 40.000000 ft
Width of top of section = 12.000000 in
Width of bottom of section = 12.000000 in
Top Section Depth = 0.600000 in
Bottom Section Depth = 0.600000 in
Top Area = 9.350000 sq. in
Bottom Area = 9.350000 sq. in

```
   Moment of Inertia at Top                          =   428.100000 in^4
   Moment of Inertia at Bottom                       =   428.100000 in^4
   Elastic Modulus                                   =    29000000. psi



--------------------------------------------------------------------------------
                       Soil and Rock Layering Information
--------------------------------------------------------------------------------

The soil profile is modelled using 4 layers

Layer 1 is sand, p-y criteria by Reese et al., 1974

   Distance from top of pile to top of layer         =    20.000000 ft
   Distance from top of pile to bottom of layer      =    37.570000 ft
   Effective unit weight at top of layer             =    55.000000 pcf
   Effective unit weight at bottom of layer          =    55.000000 pcf
   Friction angle at top of layer                    =    37.000000 deg.
   Friction angle at bottom of layer                 =    37.000000 deg.
   Subgrade k at top of layer                        =   149.000000 pci
   Subgrade k at bottom of layer                     =   149.000000 pci


Layer 2 is sand, p-y criteria by Reese et al., 1974

   Distance from top of pile to top of layer         =    37.570000 ft
   Distance from top of pile to bottom of layer      =    42.400000 ft
   Effective unit weight at top of layer             =    51.200000 pcf
   Effective unit weight at bottom of layer          =    51.200000 pcf
   Friction angle at top of layer                    =    33.000000 deg.
   Friction angle at bottom of layer                 =    33.000000 deg.
   Subgrade k at top of layer                        =    69.000000 pci
   Subgrade k at bottom of layer                     =    69.000000 pci


Layer 3 is sand, p-y criteria by Reese et al., 1974
```

```
   Distance from top of pile to top of layer           =    42.400000 ft
   Distance from top of pile to bottom of layer        =    46.610000 ft
   Effective unit weight at top of layer               =    57.400000 pcf
   Effective unit weight at bottom of layer            =    57.400000 pcf
   Friction angle at top of layer                      =    37.000000 deg.
   Friction angle at bottom of layer                   =    37.000000 deg.
   Subgrade k at top of layer                          =   149.000000 pci
   Subgrade k at bottom of layer                       =   149.000000 pci


Layer 4 is sand, p-y criteria by Reese et al., 1974

   Distance from top of pile to top of layer           =    46.610000 ft
   Distance from top of pile to bottom of layer        =    50.880000 ft
   Effective unit weight at top of layer               =    53.500000 pcf
   Effective unit weight at bottom of layer            =    53.500000 pcf
   Friction angle at top of layer                      =    39.000000 deg.
   Friction angle at bottom of layer                   =    39.000000 deg.
   Subgrade k at top of layer                          =   208.000000 pci
   Subgrade k at bottom of layer                       =   208.000000 pci


 (Depth of the lowest soil layer extends 10.880 ft below the pile tip)
```

Summary of Input Soil Properties

Layer Num.	Soil Type Name (p-y Curve Type)	Layer Depth ft	Effective Unit Wt. pcf	Angle of Friction deg.	kpy pci
1	Sand	20.0000	55.0000	37.0000	149.0000
	(Reese, et al.)	37.5700	55.0000	37.0000	149.0000
2	Sand	37.5700	51.2000	33.0000	69.0000
	(Reese, et al.)	42.4000	51.2000	33.0000	69.0000

3	Sand	42.4000	57.4000	37.0000	149.0000
	(Reese, et al.)	46.6100	57.4000	37.0000	149.0000
4	Sand	46.6100	53.5000	39.0000	208.0000
	(Reese, et al.)	50.8800	53.5000	39.0000	208.0000

Modification Factors for p-y Curves

Distribution of p-y modifiers with depth defined using 2 points

Point No.	Depth X ft	p-mult	y-mult
1	20.000	0.6400	1.0000
2	40.000	0.6400	1.0000

Static Loading Type

Static loading criteria were used when computing p-y curves for all analyses.

Distributed Lateral Loading for Individual Load Cases

Distributed lateral load intensity for Load Case 1 defined using 4 points

Point No.	Depth X ft	Dist. Load lb/in

1	0.000	0.000
2	10.000	54.050
3	10.000	33.280
4	20.000	68.780

Distributed lateral load intensity for Load Case 2 defined using 4 points

Point No.	Depth X ft	Dist. Load lb/in
1	0.000	0.000
2	10.000	81.080
3	10.000	49.920
4	20.000	103.170

Load Case 1 = Service Limit State Loading
Load Case 2 = Strength Limit State Loading

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 2

Load No.	Load Type	Condition 1		Condition 2		Axial Thrust Force, lbs	Compute Top y vs. Pile Length	Run Analysis
1	1	V =	0.0000 lbs	M =	0.0000 in-lbs	0.0000000	Yes	Yes
2	1	V =	0.0000 lbs	M =	0.0000 in-lbs	0.0000000	Yes	Yes

V = shear force applied normal to pile axis
M = bending moment applied to pile head

y = lateral deflection normal to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applied to pile head
Values of top y vs. pile lengths can be computed only for load types with
specified shear loading (Load Types 1, 2, and 3).
Thrust force is assumed to be acting axially for all pile batter angles.

Computations of Nominal Moment Capacity and Nonlinear Bending Stiffness

---

Axial thrust force values were determined from pile-head loading conditions

Number of Pile Sections Analyzed = 1

Pile Section No. 1:

Moment-curvature properties were derived from elastic section properties

---

Layering Correction Equivalent Depths of Soil & Rock Layers

Layer No.	Top of Layer Below Pile Head ft	Equivalent Top Depth Below Grnd Surf ft	Same Layer Type As Layer Above	Layer is Rock or is Below Rock Layer	F0 Integral for Layer lbs	F1 Integral for Layer lbs
1	20.0000	0.00	N.A.	No	0.00	339218.
2	37.5700	20.2220	Yes	No	339218.	91857.
3	42.4000	22.4000	No	No	431075.	0.00
4	46.6100	26.6100	No	No	0.00	N.A.

Notes: The F0 integral of Layer n+1 equals the sum of the F0 and F1 integrals
for Layer n. Layering correction equivalent depths are computed only
for soil types with both shallow-depth and deep-depth expressions for
peak lateral load transfer. These soil types are soft and stiff clays,
non-liquefied sands, and cemented c-phi soil.

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 1

Pile-head conditions are Shear and Moment (Loading Type 1)

Shear force at pile head = 0.0 lbs
Applied moment at pile head = 0.0 in-lbs
Axial thrust load on pile head = 0.0 lbs

Depth	Deflect.	Bending	Shear	Slope	Total	Bending	Soil Res.	Soil Spr.	Distrib.
X	y	Moment	Force	S	Stress	Stiffness	p	Es*H	Lat. Load
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/inch	lb/inch	lb/inch
0.00	5.0732	9.57E-07	-4.99E-08	-0.01788	1.34E-08	1.24E+10	0.00	0.00	0.5405
0.4000	4.9874	6.2266	6.4860	-0.01788	0.08727	1.24E+10	0.00	0.00	2.1620
0.8000	4.9015	62.2656	22.0524	-0.01788	0.8727	1.24E+10	0.00	0.00	4.3240
1.2000	4.8157	217.9296	47.9964	-0.01788	3.0544	1.24E+10	0.00	0.00	6.4860
1.6000	4.7299	523.0310	84.3180	-0.01788	7.3305	1.24E+10	0.00	0.00	8.6480

2.0000	4.6441	1027.	131.0172	-0.01788	14.3992	1.24E+10	0.00	0.00
10.8100								
2.4000	4.5583	1781.	188.0940	-0.01788	24.9586	1.24E+10	0.00	0.00
12.9720								
2.8000	4.4725	2833.	255.5484	-0.01788	39.7069	1.24E+10	0.00	0.00
15.1340								
3.2000	4.3866	4234.	333.3804	-0.01788	59.3421	1.24E+10	0.00	0.00
17.2960								
3.6000	4.3008	6034.	421.5900	-0.01787	84.5625	1.24E+10	0.00	0.00
19.4580								
4.0000	4.2151	8281.	520.1772	-0.01787	116.0662	1.24E+10	0.00	0.00
21.6200								
4.4000	4.1293	11027.	629.1420	-0.01787	154.5513	1.24E+10	0.00	0.00
23.7820								
4.8000	4.0435	14321.	748.4844	-0.01786	200.7160	1.24E+10	0.00	0.00
25.9440								
5.2000	3.9578	18213.	878.2044	-0.01786	255.2584	1.24E+10	0.00	0.00
28.1060								
5.6000	3.8721	22752.	1018.	-0.01785	318.8767	1.24E+10	0.00	0.00
30.2680								
6.0000	3.7865	27988.	1169.	-0.01784	392.2689	1.24E+10	0.00	0.00
32.4300								
6.4000	3.7009	33972.	1330.	-0.01783	476.1333	1.24E+10	0.00	0.00
34.5920								
6.8000	3.6153	40753.	1501.	-0.01781	571.1680	1.24E+10	0.00	0.00
36.7540								
7.2000	3.5299	48380.	1682.	-0.01779	678.0711	1.24E+10	0.00	0.00
38.9160								
7.6000	3.4445	56905.	1874.	-0.01777	797.5407	1.24E+10	0.00	0.00
41.0780								
8.0000	3.3592	66375.	2077.	-0.01775	930.2751	1.24E+10	0.00	0.00
43.2400								
8.4000	3.2741	76842.	2290.	-0.01772	1077.	1.24E+10	0.00	0.00
45.4020								
8.8000	3.1891	88355.	2513.	-0.01769	1238.	1.24E+10	0.00	0.00
47.5640								
9.2000	3.1043	100964.	2746.	-0.01765	1415.	1.24E+10	0.00	0.00
49.7260								

9.6000	3.0196	114718.	2990.	-0.01761	1608.	1.24E+10	0.00	0.00
51.8880								
10.0000	2.9352	129668.	3219.	-0.01757	1817.	1.24E+10	0.00	0.00
43.5723								
10.4000	2.8510	145622.	3407.	-0.01751	2041.	1.24E+10	0.00	0.00
34.7000								
10.8000	2.7671	162375.	3577.	-0.01745	2276.	1.24E+10	0.00	0.00
36.1200								
11.2000	2.6834	179961.	3754.	-0.01739	2522.	1.24E+10	0.00	0.00
37.5400								
11.6000	2.6001	198411.	3937.	-0.01731	2781.	1.24E+10	0.00	0.00
38.9600								
12.0000	2.5172	217760.	4128.	-0.01723	3052.	1.24E+10	0.00	0.00
40.3800								
12.4000	2.4347	238038.	4325.	-0.01714	3336.	1.24E+10	0.00	0.00
41.8000								
12.8000	2.3526	259280.	4529.	-0.01705	3634.	1.24E+10	0.00	0.00
43.2200								
13.2000	2.2710	281517.	4740.	-0.01694	3946.	1.24E+10	0.00	0.00
44.6400								
13.6000	2.1900	304783.	4958.	-0.01683	4272.	1.24E+10	0.00	0.00
46.0600								
14.0000	2.1095	329110.	5182.	-0.01671	4613.	1.24E+10	0.00	0.00
47.4800								
14.4000	2.0296	354531.	5413.	-0.01658	4969.	1.24E+10	0.00	0.00
48.9000								
14.8000	1.9503	381079.	5652.	-0.01643	5341.	1.24E+10	0.00	0.00
50.3200								
15.2000	1.8718	408786.	5896.	-0.01628	5729.	1.24E+10	0.00	0.00
51.7400								
15.6000	1.7940	437685.	6148.	-0.01612	6134.	1.24E+10	0.00	0.00
53.1600								
16.0000	1.7171	467809.	6407.	-0.01594	6557.	1.24E+10	0.00	0.00
54.5800								
16.4000	1.6410	499190.	6672.	-0.01576	6996.	1.24E+10	0.00	0.00
56.0000								
16.8000	1.5658	531862.	6944.	-0.01556	7454.	1.24E+10	0.00	0.00
57.4200								

17.2000	1.4916	565856.	7223.	-0.01534	7931.	1.24E+10	0.00	0.00	58.8400
17.6000	1.4185	601207.	7509.	-0.01512	8426.	1.24E+10	0.00	0.00	60.2600
18.0000	1.3465	637945.	7802.	-0.01488	8941.	1.24E+10	0.00	0.00	61.6800
18.4000	1.2757	676105.	8101.	-0.01462	9476.	1.24E+10	0.00	0.00	63.1000
18.8000	1.2061	715719.	8408.	-0.01436	10031.	1.24E+10	0.00	0.00	64.5200
19.2000	1.1379	756819.	8721.	-0.01407	10607.	1.24E+10	0.00	0.00	65.9400
19.6000	1.0710	799439.	9041.	-0.01377	11204.	1.24E+10	0.00	0.00	67.3600
20.0000	1.0057	843610.	9284.	-0.01345	11824.	1.24E+10	0.00	0.00	34.2125
20.4000	0.9419	888570.	9329.	-0.01312	12454.	1.24E+10	-15.532	79.1566	0.00
20.8000	0.8797	933172.	9208.	-0.01277	13079.	1.24E+10	-35.017	191.0574	0.00
21.2000	0.8193	976967.	8990.	-0.01240	13693.	1.24E+10	-55.653	326.0385	0.00
21.6000	0.7607	1019479.	8676.	-0.01201	14288.	1.24E+10	-75.517	476.4936	0.00
22.0000	0.7040	1060252.	8268.	-0.01161	14860.	1.24E+10	-94.292	642.8766	0.00
22.4000	0.6493	1098853.	7776.	-0.01119	15401.	1.24E+10	-110.630	817.8524	0.00
22.8000	0.5966	1134904.	7206.	-0.01076	15906.	1.24E+10	-126.871	1021.	0.00
23.2000	0.5460	1168032.	6552.	-0.01031	16370.	1.24E+10	-145.815	1282.	0.00
23.6000	0.4976	1197801.	5798.	-0.00986	16788.	1.24E+10	-168.256	1623.	0.00
24.0000	0.4514	1223693.	4939.	-0.00939	17151.	1.24E+10	-189.504	2015.	0.00
24.4000	0.4074	1245219.	3988.	-0.00891	17452.	1.24E+10	-207.008	2439.	0.00

24.8000	0.3658	1261976.	2960.	-0.00843	17687.	1.24E+10	-221.404	2905.
0.00								
25.2000	0.3266	1273631.	1866.	-0.00794	17850.	1.24E+10	-234.417	3446.
0.00								
25.6000	0.2896	1279886.	710.6787	-0.00744	17938.	1.24E+10	-246.802	4090.
0.00								
26.0000	0.2551	1280454.	-498.859	-0.00695	17946.	1.24E+10	-257.172	4839.
0.00								
26.4000	0.2229	1275097.	-1753.	-0.00645	17871.	1.24E+10	-265.575	5718.
0.00								
26.8000	0.1931	1263621.	-3044.	-0.00596	17710.	1.24E+10	-272.081	6762.
0.00								
27.2000	0.1657	1245876.	-4359.	-0.00548	17461.	1.24E+10	-275.796	7989.
0.00								
27.6000	0.1406	1221777.	-5683.	-0.00500	17124.	1.24E+10	-276.153	9430.
0.00								
28.0000	0.1177	1191315.	-7001.	-0.00453	16697.	1.24E+10	-272.982	11134.
0.00								
28.4000	0.09703	1154564.	-8295.	-0.00408	16182.	1.24E+10	-266.137	13166.
0.00								
28.8000	0.07851	1111681.	-9547.	-0.00364	15581.	1.24E+10	-255.488	15620.
0.00								
29.2000	0.06206	1062912.	-10738.	-0.00322	14897.	1.24E+10	-240.902	18633.
0.00								
29.6000	0.04758	1008592.	-11850.	-0.00282	14136.	1.24E+10	-222.209	22418.
0.00								
30.0000	0.03497	949152.	-12861.	-0.00244	13303.	1.24E+10	-199.148	27336.
0.00								
30.4000	0.02412	885125.	-13750.	-0.00209	12405.	1.24E+10	-171.226	34073.
0.00								
30.8000	0.01492	817152.	-14491.	-0.00176	11453.	1.24E+10	-137.384	44211.
0.00								
31.2000	0.00723	746013.	-15043.	-0.00146	10456.	1.24E+10	-92.625	61519.
0.00								
31.6000	9.23E-04	672741.	-15294.	-0.00118	9429.	1.24E+10	-12.250	63716.
0.00								
32.0000	-0.00413	599187.	-15188.	-9.37E-04	8398.	1.24E+10	56.7525	65913.
0.00								

32.4000	-0.00808	526940.	-14776.	-7.20E-04	7385.	1.24E+10	114.6044	68110.
0.00								
32.8000	-0.01104	457333.	-14121.	-5.29E-04	6410.	1.24E+10	158.4801	68889.
0.00								
33.2000	-0.01316	391378.	-13292.	-3.65E-04	5485.	1.24E+10	187.0706	68234.
0.00								
33.6000	-0.01455	329733.	-12337.	-2.26E-04	4621.	1.24E+10	210.6245	69483.
0.00								
34.0000	-0.01533	272941.	-11280.	-1.09E-04	3825.	1.24E+10	229.9078	71990.
0.00								
34.4000	-0.01560	221446.	-10139.	-1.39E-05	3104.	1.24E+10	245.3683	75490.
0.00								
34.8000	-0.01546	175604.	-8933.	6.28E-05	2461.	1.24E+10	257.3064	79873.
0.00								
35.2000	-0.01500	135691.	-7689.	1.23E-04	1902.	1.24E+10	260.8761	83490.
0.00								
35.6000	-0.01428	101788.	-6451.	1.69E-04	1427.	1.24E+10	254.9531	85687.
0.00								
36.0000	-0.01338	73759.	-5252.	2.03E-04	1034.	1.24E+10	244.9157	87884.
0.00								
36.4000	-0.01233	51373.	-4108.	2.27E-04	720.0148	1.24E+10	231.4807	90081.
0.00								
36.8000	-0.01120	34320.	-3036.	2.44E-04	481.0155	1.24E+10	215.2587	92278.
0.00								
37.2000	-0.01000	22227.	-2047.	2.55E-04	311.5265	1.24E+10	196.7418	94475.
0.00								
37.6000	-0.00875	14667.	-1379.	2.62E-04	205.5685	1.24E+10	81.6397	44768.
0.00								
38.0000	-0.00748	8988.	-1012.	2.66E-04	125.9731	1.24E+10	71.3845	45785.
0.00								
38.4000	-0.00620	4954.	-695.478	2.69E-04	69.4289	1.24E+10	60.4283	46803.
0.00								
38.8000	-0.00490	2312.	-433.245	2.70E-04	32.3980	1.24E+10	48.8353	47820.
0.00								
39.2000	-0.00360	794.5988	-228.082	2.71E-04	11.1366	1.24E+10	36.6494	48837.
0.00								
39.6000	-0.00230	122.0051	-82.771	2.71E-04	1.7100	1.24E+10	23.8971	49855.
0.00								

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   40.0000  -9.99E-04       0.00       0.00   2.71E-04       0.00   1.24E+10    10.5907     25436.
0.00

* The above values of total stress are combined axial and bending stresses.


Output Summary for Load Case No. 1:

Pile-head deflection             =     5.07318593 inches
Computed slope at pile head      =     -0.0178792 radians
Maximum bending moment           =       1280454. inch-lbs
Maximum shear force              =        -15294. lbs
Depth of maximum bending moment  =    26.00000000 feet below pile head
Depth of maximum shear force     =    31.60000000 feet below pile head
Number of iterations             =             15
Number of zero deflection points =              2
Pile deflection at ground        =     1.00566868 inches



--------------------------------------------------------------------------------
            Pile-head Deflection vs. Pile Length for Load Case 1
--------------------------------------------------------------------------------

Boundary Condition Type 1, Shear and Moment

Shear      =              0. lbs
Moment     =              0. in-lbs
Axial Load =              0. lbs


    Pile       Pile Head       Maximum       Maximum
   Length      Deflection      Moment         Shear
    feet         inches        ln-lbs          lbs
------------  ------------  ------------  ------------
   40.00000    5.07318593      1280454.       -15294.
   38.00000    5.07625491      1280401.       -15490.
   36.00000    5.19973817      1277502.       -17335.
```

34.00000 6.22688757 1274919. -21320.

Computed Values of Pile Loading and Deflection
for Lateral Loading for Load Case Number 2

Pile-head conditions are Shear and Moment (Loading Type 1)

Shear force at pile head = 0.0 lbs
Applied moment at pile head = 0.0 in-lbs
Axial thrust load on pile head = 0.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. p	Soil Spr. Es*H	Distrib. Lat. Load
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/inch	lb/inch	lb/inch
0.00	8.4345	1.63E-05	9.97E-08	-0.02906	2.28E-07	1.24E+10	0.00	0.00	0.8108
0.4000	8.2950	9.3404	9.7296	-0.02906	0.1309	1.24E+10	0.00	0.00	3.2432
0.8000	8.1555	93.4042	33.0806	-0.02906	1.3091	1.24E+10	0.00	0.00	6.4864
1.2000	8.0160	326.9146	71.9990	-0.02906	4.5818	1.24E+10	0.00	0.00	9.7296
1.6000	7.8765	784.5949	126.4848	-0.02906	10.9964	1.24E+10	0.00	0.00	12.9728
2.0000	7.7370	1541.	196.5379	-0.02906	21.6001	1.24E+10	0.00	0.00	16.2160
2.4000	7.5975	2671.	282.1584	-0.02906	37.4402	1.24E+10	0.00	0.00	19.4592
2.8000	7.4580	4250.	383.3462	-0.02906	59.5640	1.24E+10	0.00	0.00	22.7024

3.2000	7.3185	6351.	500.1014	-0.02906	89.0187	1.24E+10	0.00	0.00
25.9456								
3.6000	7.1790	9051.	632.4240	-0.02906	126.8516	1.24E+10	0.00	0.00
29.1888								
4.0000	7.0396	12423.	780.3139	-0.02905	174.1101	1.24E+10	0.00	0.00
32.4320								
4.4000	6.9001	16542.	943.7712	-0.02905	231.8413	1.24E+10	0.00	0.00
35.6752								
4.8000	6.7607	21483.	1123.	-0.02904	301.0926	1.24E+10	0.00	0.00
38.9184								
5.2000	6.6213	27321.	1317.	-0.02903	382.9112	1.24E+10	0.00	0.00
42.1616								
5.6000	6.4820	34130.	1528.	-0.02902	478.3445	1.24E+10	0.00	0.00
45.4048								
6.0000	6.3428	41985.	1753.	-0.02900	588.4397	1.24E+10	0.00	0.00
48.6480								
6.4000	6.2036	50961.	1995.	-0.02898	714.2440	1.24E+10	0.00	0.00
51.8912								
6.8000	6.0645	61133.	2251.	-0.02896	856.8048	1.24E+10	0.00	0.00
55.1344								
7.2000	5.9256	72575.	2524.	-0.02894	1017.	1.24E+10	0.00	0.00
58.3776								
7.6000	5.7867	85362.	2812.	-0.02891	1196.	1.24E+10	0.00	0.00
61.6208								
8.0000	5.6481	99569.	3115.	-0.02887	1395.	1.24E+10	0.00	0.00
64.8640								
8.4000	5.5096	115270.	3435.	-0.02883	1616.	1.24E+10	0.00	0.00
68.1072								
8.8000	5.3713	132541.	3769.	-0.02878	1858.	1.24E+10	0.00	0.00
71.3504								
9.2000	5.2333	151455.	4120.	-0.02873	2123.	1.24E+10	0.00	0.00
74.5936								
9.6000	5.0955	172088.	4485.	-0.02866	2412.	1.24E+10	0.00	0.00
77.8368								
10.0000	4.9581	194514.	4829.	-0.02859	2726.	1.24E+10	0.00	0.00
65.3608								
10.4000	4.8210	218446.	5111.	-0.02851	3062.	1.24E+10	0.00	0.00
52.0500								

10.8000	4.6844	243578.	5366.	-0.02842	3414.	1.24E+10	0.00	0.00
54.1800								
11.2000	4.5482	269958.	5631.	-0.02832	3784.	1.24E+10	0.00	0.00
56.3100								
11.6000	4.4125	297635.	5906.	-0.02821	4171.	1.24E+10	0.00	0.00
58.4400								
12.0000	4.2773	326658.	6192.	-0.02809	4578.	1.24E+10	0.00	0.00
60.5700								
12.4000	4.1428	357078.	6488.	-0.02796	5005.	1.24E+10	0.00	0.00
62.7000								
12.8000	4.0089	388941.	6794.	-0.02782	5451.	1.24E+10	0.00	0.00
64.8300								
13.2000	3.8757	422299.	7110.	-0.02766	5919.	1.24E+10	0.00	0.00
66.9600								
13.6000	3.7433	457199.	7437.	-0.02749	6408.	1.24E+10	0.00	0.00
69.0900								
14.0000	3.6118	493691.	7773.	-0.02731	6919.	1.24E+10	0.00	0.00
71.2200								
14.4000	3.4812	531824.	8120.	-0.02711	7454.	1.24E+10	0.00	0.00
73.3500								
14.8000	3.3516	571647.	8478.	-0.02690	8012.	1.24E+10	0.00	0.00
75.4800								
15.2000	3.2230	613209.	8845.	-0.02667	8594.	1.24E+10	0.00	0.00
77.6100								
15.6000	3.0956	656559.	9223.	-0.02642	9202.	1.24E+10	0.00	0.00
79.7400								
16.0000	2.9693	701747.	9611.	-0.02616	9835.	1.24E+10	0.00	0.00
81.8700								
16.4000	2.8444	748820.	10009.	-0.02588	10495.	1.24E+10	0.00	0.00
84.0000								
16.8000	2.7209	797829.	10417.	-0.02558	11182.	1.24E+10	0.00	0.00
86.1300								
17.2000	2.5989	848823.	10835.	-0.02526	11897.	1.24E+10	0.00	0.00
88.2600								
17.6000	2.4784	901850.	11264.	-0.02492	12640.	1.24E+10	0.00	0.00
90.3900								
18.0000	2.3596	956959.	11703.	-0.02456	13412.	1.24E+10	0.00	0.00
92.5200								

18.4000	2.2426	1014200.	12152.	-0.02418	14214.	1.24E+10	0.00	0.00	94.6500
18.8000	2.1275	1073622.	12612.	-0.02378	15047.	1.24E+10	0.00	0.00	96.7800
19.2000	2.0143	1135274.	13081.	-0.02335	15911.	1.24E+10	0.00	0.00	98.9100
19.6000	1.9033	1199204.	13561.	-0.02290	16807.	1.24E+10	0.00	0.00	101.0400
20.0000	1.7945	1265463.	13927.	-0.02242	17736.	1.24E+10	0.00	0.00	51.3188
20.4000	1.6880	1332904.	14013.	-0.02192	18681.	1.24E+10	-15.532	44.1671	0.00
20.8000	1.5841	1399987.	13892.	-0.02139	19621.	1.24E+10	-35.017	106.1074	0.00
21.2000	1.4827	1466263.	13674.	-0.02084	20550.	1.24E+10	-55.653	180.1697	0.00
21.6000	1.3840	1531257.	13359.	-0.02026	21461.	1.24E+10	-75.517	261.9091	0.00
22.0000	1.2882	1594512.	12952.	-0.01965	22348.	1.24E+10	-94.292	351.3499	0.00
22.4000	1.1953	1655593.	12460.	-0.01903	23204.	1.24E+10	-110.630	444.2534	0.00
22.8000	1.1055	1714126.	11890.	-0.01838	24024.	1.24E+10	-126.871	550.8500	0.00
23.2000	1.0189	1769736.	11235.	-0.01770	24804.	1.24E+10	-145.815	686.9204	0.00
23.6000	0.9356	1821986.	10482.	-0.01701	25536.	1.24E+10	-168.255	863.2285	0.00
24.0000	0.8556	1870359.	9623.	-0.01629	26214.	1.24E+10	-189.504	1063.	0.00
24.4000	0.7792	1914367.	8633.	-0.01556	26831.	1.24E+10	-222.916	1373.	0.00
24.8000	0.7062	1953238.	7477.	-0.01481	27375.	1.24E+10	-258.639	1758.	0.00
25.2000	0.6370	1986150.	6142.	-0.01405	27837.	1.24E+10	-297.946	2245.	0.00
25.6000	0.5713	2012198.	4607.	-0.01328	28202.	1.24E+10	-341.350	2868.	0.00

26.0000	0.5095	2030381.	2858.	-0.01250	28457.	1.24E+10	-387.681	3653.
0.00								
26.4000	0.4514	2039631.	878.5834	-0.01171	28586.	1.24E+10	-436.938	4647.
0.00								
26.8000	0.3970	2038815.	-1237.	-0.01092	28575.	1.24E+10	-444.372	5372.
0.00								
27.2000	0.3465	2027760.	-3376.	-0.01014	28420.	1.24E+10	-446.932	6191.
0.00								
27.6000	0.2997	2006408.	-5519.	-0.00936	28121.	1.24E+10	-445.932	7142.
0.00								
28.0000	0.2567	1974782.	-7649.	-0.00859	27677.	1.24E+10	-441.751	8261.
0.00								
28.4000	0.2173	1932978.	-9753.	-0.00783	27091.	1.24E+10	-434.837	9606.
0.00								
28.8000	0.1815	1881155.	-11817.	-0.00709	26365.	1.24E+10	-425.218	11247.
0.00								
29.2000	0.1492	1819535.	-13823.	-0.00638	25502.	1.24E+10	-410.591	13212.
0.00								
29.6000	0.1202	1748455.	-15745.	-0.00569	24505.	1.24E+10	-390.446	15587.
0.00								
30.0000	0.09455	1668380.	-17557.	-0.00503	23383.	1.24E+10	-364.600	18510.
0.00								
30.4000	0.07196	1579904.	-19231.	-0.00440	22143.	1.24E+10	-332.795	22199.
0.00								
30.8000	0.05230	1483760.	-20737.	-0.00381	20796.	1.24E+10	-294.577	27036.
0.00								
31.2000	0.03539	1380829.	-22042.	-0.00326	19353.	1.24E+10	-249.054	33776.
0.00								
31.6000	0.02105	1272160.	-23105.	-0.00274	17830.	1.24E+10	-194.209	44284.
0.00								
32.0000	0.00907	1159017.	-23870.	-0.00227	16244.	1.24E+10	-124.202	65743.
0.00								
32.4000	-7.63E-04	1043011.	-24142.	-0.00185	14618.	1.24E+10	10.8272	68110.
0.00								
32.8000	-0.00866	927256.	-23811.	-0.00147	12996.	1.24E+10	126.8247	70307.
0.00								
33.2000	-0.01483	814422.	-23024.	-0.00113	11414.	1.24E+10	201.1952	65106.
0.00								

33.6000	-0.01950	706224.	-21937.	-8.35E-04	9898.	1.24E+10	251.6374	61953.
0.00								
34.0000	-0.02285	603824.	-20630.	-5.82E-04	8463.	1.24E+10	293.0559	61563.
0.00								
34.4000	-0.02508	508175.	-19141.	-3.67E-04	7122.	1.24E+10	327.4736	62671.
0.00								
34.8000	-0.02637	420072.	-17501.	-1.87E-04	5887.	1.24E+10	355.9575	64793.
0.00								
35.2000	-0.02688	340170.	-15736.	-4.04E-05	4768.	1.24E+10	379.1802	67712.
0.00								
35.6000	-0.02676	269004.	-13872.	7.74E-05	3770.	1.24E+10	397.6283	71330.
0.00								
36.0000	-0.02614	206999.	-11930.	1.69E-04	2901.	1.24E+10	411.6910	75608.
0.00								
36.4000	-0.02513	154480.	-9929.	2.39E-04	2165.	1.24E+10	421.6969	80543.
0.00								
36.8000	-0.02384	111677.	-7890.	2.91E-04	1565.	1.24E+10	427.9211	86162.
0.00								
37.2000	-0.02234	78733.	-5830.	3.28E-04	1103.	1.24E+10	430.5740	92514.
0.00								
37.6000	-0.02069	55710.	-4333.	3.54E-04	780.7944	1.24E+10	193.0085	44768.
0.00								
38.0000	-0.01895	37133.	-3436.	3.72E-04	520.4362	1.24E+10	180.7143	45785.
0.00								
38.4000	-0.01713	22720.	-2602.	3.83E-04	318.4334	1.24E+10	167.0068	46803.
0.00								
38.8000	-0.01527	12155.	-1836.	3.90E-04	170.3596	1.24E+10	152.1087	47820.
0.00								
39.2000	-0.01339	5095.	-1144.	3.93E-04	71.4041	1.24E+10	136.1926	48837.
0.00								
39.6000	-0.01149	1172.	-530.696	3.94E-04	16.4272	1.24E+10	119.3803	49855.
0.00								
40.0000	-0.00960	0.00	0.00	3.95E-04	0.00	1.24E+10	101.7429	25436.
0.00								

* The above values of total stress are combined axial and bending stresses.

Output Summary for Load Case No. 2:

```
Pile-head deflection             =     8.43448736 inches
Computed slope at pile head      =     -0.0290635 radians
Maximum bending moment           =       2039631. inch-lbs
Maximum shear force              =        -24142. lbs
Depth of maximum bending moment  =    26.40000000 feet below pile head
Depth of maximum shear force     =    32.40000000 feet below pile head
Number of iterations             =             19
Number of zero deflection points =              1
Pile deflection at ground        =     1.79449953 inches
```

Pile-head Deflection vs. Pile Length for Load Case 2

Boundary Condition Type 1, Shear and Moment

```
Shear      =             0. lbs
Moment     =             0. in-lbs
Axial Load =             0. lbs
```

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
40.00000	8.43448736	2039631.	-24142.
38.00000	8.48673192	2039999.	-25159.
36.00000	9.16263182	2039817.	-29944.

Summary of Pile-head Responses for Conventional Analyses

Definitions of Pile-head Loading Conditions:

Load Type 1: Load 1 = Shear, V, lbs, and Load 2 = Moment, M, in-lbs
Load Type 2: Load 1 = Shear, V, lbs, and Load 2 = Slope, S, radians
Load Type 3: Load 1 = Shear, V, lbs, and Load 2 = Rot. Stiffness, R, in-lbs/rad.
Load Type 4: Load 1 = Top Deflection, y, inches, and Load 2 = Moment, M, in-lbs
Load Type 5: Load 1 = Top Deflection, y, inches, and Load 2 = Slope, S, radians

Load Case No.	Load Type 1	Pile-head Load 1	Load Type 2	Pile-head Load 2	Axial Loading lbs	Pile-head Deflection inches	Pile-head Rotation radians	Max Shear in Pile lbs	Max Moment in Pile in-lbs
1	V, lb	0.00	M, in-lb	0.00	0.00	5.0732	-0.01788	-15294.	1280454.
2	V, lb	0.00	M, in-lb	0.00	0.00	8.4345	-0.02906	-24142.	2039631.

Maximum pile-head deflection = 8.4344873554 inches
Maximum pile-head rotation = -0.0290635354 radians = -1.665218 deg.

The analysis ended normally.

Moment of Inertia (in4)	Service Limit State Deflection (in)	Strength Limit State Deflection (in)
428.1	5.07	8.4345
400	5.3791	8.9663
350	6.0387	10.1137
300	6.9116	11.6453
250	8.1262	13.7792
200	9.9349	16.9687
150	12.9314	22.265
100	18.8785	32.8113
50	36.5827	64.3132
40	45.4101	80.0038
35	51.7019	91.239