DRAFT REPORT
STRUCTURE FOUNDATION EXPLORATION
PROPOSED RETAINING WALL
HAM-COLUMBIA CONNECTOR
HAMILTON COUNTY, OHIO
PID#: 114496

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NEAS PROJECT 23-0064

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National Engineering & Architectural Services Inc.

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1. INTRODUCTION

1.1. General

National Engineering and Architectural Services Inc. (NEAS) presents our Structure Foundation Exploration Report for the retaining wall proposed as part of the Ohio Department of Transportation (ODOT) project HAM-Columbia Connector (PID 114496) within Columbia Township and the Village of Mariemont, Hamilton County, Ohio. As part of the referenced project, Great Parks of Hamilton County, Columbia Township, the Village of Mariemont as well as ODOT are planning the construction of a new shared-use path connection from the proposed Mariemont Connector Trail at Pocahontas Avenue to the Columbia Connector Trail near US-50 (Wooster Pike). To facilitate the construction of the new shared-use path, a new retaining wall is required. This report presents: 1) a summary of the encountered surficial and subsurface conditions at the proposed retaining wall site; and, 2) our evaluation and recommendations for retaining wall design and construction in accordance with the Load and Resistance Factor Design (LRFD) method as set forth in AASHTO's Publication *LRFD Bridge Design Specifications, 9th Edition* (BDS) (AASHTO, 2020) and the 2024 revision of *ODOT's Bridge Design Manual 2020 Edition* (BDM) (ODOT [1], 2024).

The exploration was conducted in general accordance with Barr Engineering, Inc.'s (DBA National Engineering and Architectural Services Inc.) proposal to Stantec dated April 5, 2023, and with the provisions of ODOT's *Specifications for Geotechnical Explorations* (SGE) (ODOT, 2024).

The scope of work performed by NEAS as part of the referenced retaining wall project included: a review of published geotechnical information; performing 3 test borings; laboratory testing of soil samples in accordance with the SGE; performing geotechnical engineering analyses to assess retaining wall design and construction considerations; and development of this summary report.

1.2. Proposed Construction

It is our understanding that the construction of the new shared-use path connection will require the replacement and widening of a segment of the existing sidewalk along the south side of Wooster Pike between the existing Kroger Fuel Center and the Mariemont Promenade (commercial development). The proposed retaining wall will enable the placement of new fill on the existing slope which will support the proposed 12 ft wide, shared-use path at the referenced location.

It should be noted that an existing drilled shaft wall with a modular block wall acting as a fascia for the drilled shafts exists downslope of the proposed wall location. The existing wall(s) were designed for, owned, and maintained by the homeowner's association of the Mariemont Landing community located immediately downslope. Stantec and NEAS met with ODOT to discuss the existing drilled shaft wall concerns as well as the potential impact of the existing wall(s) on the newly proposed wall. Based on this meeting, ODOT stated that: 1) the new wall construction should be designed such that no additional load is to be transferred to the existing wall(s); and, 2) it should be assumed that the existing drilled shaft wall does not support any loads (soils, structures, etc.) located upslope of US-50. It is to be assumed that the existing wall(s) was designed to support loading associated with soils and elements (Mariemont Promenade pavement) extending from the front face of the existing wall(s) upslope to US-50.

Based on constructability, existing topography, subsurface soil/rock conditions and the configuration of the proposed bike path, the proposed retaining wall will likely be constructed utilizing a combination of top-down and bottom-up construction scheme with soldier pile and lagging (SPL) as the wall type. The proposed wall will be approximately 150 ft in length with a maximum exposed wall height of about 12 ft.

2. GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1. Geology and Physiography

The project site is located within the Illinoian Till Plain. This area is characterized by broad, level to rolling uplands of moderately low relief (50 ft) dissected by steep-sided stream valleys (ODGS, 1998). The uplands consist of ground moraine of older till generally lacking ice-constructional features such as moraines, kames and eskers, but contains many buried valleys, as well as modern valleys alternating between broad floodplains and bedrock gorges.

The geology underlying the project site is mapped as an average of 60 ft of Illinoian-age sand followed by an average of 60 ft of Illinoian-age loam till all over Ordovician-age shale and limestone bedrock (ODGS, 2005). The sand mapped underlying the project site is described as a fluvial unit containing minor amounts of disseminated gravel and thin lenses of silt and gravel. These soils are found in high-level terraces and buried valleys in thicknesses usually less than 20 ft. The loam till underlying the project site is described as predominantly fine-grained glacially deposited material that includes silt, sand and gravel lenses and can be present in thicknesses of up to 90 ft.

Based on the Bedrock Geologic Units Map of Ohio (USGS & ODGS, 2005), bedrock within the project area, consists of the Kope formation. The Kope formation is comprised of interbedded shale (75 percent) and limestone (25 percent) that is thin to thick bedded. The bedrock in the Kope formation is described as gray to bluish gray in color weathering to light gray to yellowish gray and generally planar. Based on the ODNR bedrock topography map of Ohio, bedrock elevation at the wall site can be expected to be at an elevation of about 500 ft above mean sea level (amsl), putting bedrock at a depth ranging from 10 to 50 ft below ground surface (bgs) in locations (ODGS, 2003).

The soil at the project site have been mapped (Web Soil Survey) by the Natural Resources Conservation Service (NRCS) as predominantly Urban land-Udorthents. Urban land consists of areas where the ground surface has been covered by houses, garages, roads, driveways, sidewalks, parking lots and other forms of impervious surfaces. Udorthents are soils in these areas that have been disturbed, graded, smoothed and/or replaced in order to develop the area. As these soils are variable in nature, NRCS does not rate them for local roads (USDA, 2015).

2.2. Hydrology/Hydrogeology

At the retaining wall site, groundwater can be expected at an elevation consistent with that of the immediately adjacent Little Miami River, as it is the most dominant hydraulic influence in the immediate vicinity of the site. The elevation of the adjacent portions of the Little Miami River is approximately 477 to 480 ft amsl. The water level of the indicated river may be generally representative of the local groundwater table, though perched groundwater systems may exist due to the presence of fine-grained soils making it difficult for groundwater to permeate to the natural phreatic surface.

The retaining wall site is not located within a 1% Annual Chance Flood Hazard area based on available mapping by the Federal Emergency Management Agency's (FEMA) National Flood Hazard mapping program (FEMA, 2016).

2.3. Mining and Oil/Gas Production

No abandoned mines are noted on ODNR’s Abandoned Underground Mine Locator within a mile of the project's boundaries (ODNR [1], 2016).

No active gas wells are noted on ODNR’s Ohio Oil & Gas Locator in the vicinity of the project site (ODNR [1], 2016).

2.4. Historical Records and Previous Phases of Project Exploration

A historic record search was performed through ODOT's Transportation Information Mapping System (TIMS); however, no historic boring information was available for review within the limits of the (HAM-Columbia Connector, PID 114496) project. Therefore; historic borings are not referenced within this report nor within the project developed Soil Profile Sheets.

2.5. Site Reconnaissance

A site reconnaissance visit for the HAM-Columbia Connector project was conducted on February 22, 2024, during which site conditions were noted and photographed along the project portion of US-50 (Woster Pike) and Mariemont Crescent. During our field reconnaissance, no geohazards were observed within the immediate vicinity of the proposed retaining wall site. Land use at this location can be described as a combination of residential, wooded land and commercial.

The site of the proposed retaining wall runs along the top of the existing slope that is immediately south of the US-50 (Wooster Pike) roadway. The existing slope was observed to be heavily vegetated with a combination of large mature trees and shrubs. The referenced slope descends from north to south at slope grades ranging from an approximate 1 Horizontal to 1 Vertical (1H:1V) near the top of the slope to an approximate 3H:1V towards the toe of the slope (Photograph 1). The toe of the existing slope was supported by an existing drilled shaft wall with a modular block wall approximately 4 ft in front of the drilled shaft wall. Both existing retaining walls appeared to be in good condition with no visual signs of geotechnical distress observed at the time of our reconnaissance (Photograph 2).

The existing pavement segments as well as the sidewalk segment in the vicinity of the proposed retaining wall were observed to be in good condition at the time of our reconnaissance with no significant distress noted. The portions of the project site adjacent to the proposed retaining all alignment appeared to be well-drained with no notable signs of erosion or standing water observed at the time of our site visit.

Photograph 1: Top of existing slope

Photograph 2: Existing retaining walls downslope of US-50

3. GEOTECHNICAL EXPLORATION

3.1. Field Exploration Program

The geotechnical exploration for the proposed retaining wall was conducted by NEAS between March 13, 2024 and March 20, 2024 and included 3 borings drilled to depths between 31.5 and 66.5 ft bgs. The boring locations were selected by NEAS with the intent to evaluate subsurface soil and groundwater conditions. Borings were located at/near the proposed retaining wall site in areas that were not restricted by maintenance of traffic, underground utilities or dictated by terrain (i.e., steep embankment slopes). Each individual project boring log (included within Appendix B) includes the recorded boring latitude and longitude location (based on the surveyed Ohio State Plane South, NAD83, location) and the corresponding ground surface elevation. Coordinates, elevations and depths of the borings are shown in Table 1 below and the boring locations are depicted on the boring location plan provided in Appendix A.

Table 1: Project Boring Summary

Boring Number	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Relative Location
B-001-0-23	39.143491	-84.364675	543.8	66.5	Top of Slope (West)
B-002-0-23	39.143183	-84.364547	512.5	31.5	Toe of Slope (Center)
B-003-0-23	39.143315	-84.364214	536.8	66.5	Top of Slope (East)

Notes:
1. *As-drilled boring location and corresponding ground surface elevation were surveyed in the field by NEAS Inc.*

Borings were drilled using a CME 55X track mounted drilling rig utilizing 3.25-inch diameter hollow stem augers. In general, soil samples were recovered at intervals of 2.5-ft to depths between 20 and 50 ft bgs, and at 5.0-ft intervals thereafter using a split spoon sampler (AASHTO T-206 “Standard Method for Penetration Test and Split Barrel Sampling of Soils.”). The soil samples obtained from the exploration program were visually observed in the field by the NEAS field representative and preserved for review by a Geologist and possible laboratory testing. SPT were conducted using a CME auto hammer that has been calibrated to be 79.0 % efficient with the most recent calibration date of January 24, 2022 as indicated on the boring logs.

Field boring logs were prepared by drilling personnel, and included lithological description, SPT results recorded as blows per 6-inch increment of penetration and estimated unconfined shear strength values on specimens exhibiting cohesion (estimated by means of hand-penetrometer). Groundwater level observations were recorded both during and after the completion of drilling. These groundwater level observations are included on the individual boring logs (Appendix B). After completing the borings, the boreholes were backfilled with either auger cuttings, bentonite chips, or a combination of these materials and patched with cold patch asphalt and/or quickset concrete where necessary and appropriate.

3.2. Laboratory Testing Program

The laboratory testing program consisted of classification testing, moisture content determinations, direct shear testing, and unconfined compressive strength of soil testing. Data from the laboratory-testing program were incorporated onto the boring logs (Appendix B). Soil samples are retained at the laboratory for 60 days following report submittal, after which time they will be discarded.

3.2.1. Classification Testing

Representative soil samples were selected for index properties (Atterberg Limits) and gradation testing for classification purposes on approximately 26% of the soil samples. At each boring location, samples were selected for testing with the intent of identification and classification of all significant soil units. Soils not selected for testing were compared to laboratory tested samples/strata and classified visually. Moisture content testing was conducted on all samples. The laboratory testing was performed in general accordance with applicable AASHTO specifications.

A final classification of the soil strata was made in accordance with AASHTO M-145 "Classification of Soils and Soil-Aggregate Mixtures for Highway Construction Purposes," as modified by ODOT "Classification of Soils" once laboratory test results became available. The results of the soil classification are presented on the boring logs in Appendix B.

3.2.2. Standard Penetration Test Results

Standard Penetration Tests (SPT) and split-barrel (split-spoon) sampling of soils were performed at varying intervals (i.e., 2.5-ft and 5.0-ft intervals) in the project borings performed. To account for the high efficiency (automatic) hammers used during SPT sampling, field SPT N-values were converted based on the calibrated efficiency (energy ratio) of the specific drill rig's hammer. Field N-values were converted to an equivalent rod energy of 60% (N_{60}) for use in analysis or for correlation purposes. The resulting N_{60} values are presented on the boring logs provided in Appendix B.

3.2.3. Direct Shear Testing

Direct Shear Testing was conducted in accordance with AASHTO T-236 "Standard Method of Test for Direct Shear Test of Soils under Consolidated Drained Conditions" on one (1) relatively undisturbed sample obtained during the exploration program. The sample tested was obtained from boring B-002-0-23 at a depth of 19.0 to 21.0 ft bgs (between elevations 493.5 and 491.5 ft amsl). The soils from the sample was classified as Silt (A-4b). The Direct Shear Test results are shown in Table 2 below. The lab testing report is provided in Appendix B.

Table 2: Direct Shear Test Results

Boring Number	Depth of Sample (ft)	Classification	Average Wet Density (1) (pcf)	Average Void Ratio (1)	Cohesion - Effective (psf)	Angle of Friction - Effective (°)
B-002-0-23	19.0 - 21.0	A-4b	129.8	0.671	230	26.4

Notes:
1. *Indicated average values were collected prior to Direct Shear testing (i.e., initial readings).*

3.2.4. Consolidated-Undrained Triaxial Compression Test Results

Consolidated-Undrained (CU) Triaxial Compression testing was performed in accordance with AASHTO T-297 "Standard Method of Test for Consolidated, Undrained Triaxial Compression Test on Cohesive Soils" on one (1) relatively undisturbed (Shelby Tube), cohesive sample obtained during the exploration programs. The sample tested was obtained from boring B-001-0-23 at a depth of 33.0 to 35.0 ft bgs (between elevations 510.8 and 508.8 ft amsl). The tested sample was classified as Clay (A-7-6). A summary of the

Unconfined Compressive Strength of Cohesive Soil test is shown in Table 3 below, while the laboratory testing reports are included within Appendix B.

Table 3: Unconfined Compressive Strength Test Results

Boring Number	Depth of Sample (ft)	Classification	Average Wet Density [(1)] (pcf)	Average Void Ratio[(1)]	Cohesion - Effective (psf)	Angle of Friction Effective (°)	Cohesion - Total (psf)	Angle of Friction Total (°)
B-001-0-23	33.0 - 35.0	A-4a	127.5	0.638	346	30	418	22

Notes:
1. *Indicated average values were collected prior to Direct Shear testing (i.e., initial readings).*

4. GEOTECHNICAL FINDINGS

The subsurface conditions encountered during NEAS's explorations are described in the following subsections and on each boring log presented in Appendix B. The boring logs represent NEAS's interpretation of the subsurface conditions encountered at each boring location based on our site observations, field logs, visual review of the soil samples by NEAS's geologist, and laboratory test results. The lines designating the interfaces between various soil strata on the boring logs represent the approximate interface location; the actual transition between strata may be gradual and indistinct. The subsurface soil and groundwater characterizations included herein, including summary test data, are based on the subsurface findings from the geotechnical exploration performed by NEAS as part of the referenced project and consideration of the geological history of the site.

4.1. Subsurface Conditions

The general subsurface profile is relatively uniform at the retaining wall location. The subsurface profile at the proposed wall site consists of an existing pavement section underlain by predominantly fine-grained cohesive and non-cohesive loam till overburden soil containing occasional granular soil layers. The natural overburden soils at the site generally consisted of either soft to hard, cohesive material or medium dense to very dense non-cohesive material. Interbedded layers of medium dense to very dense, granular soils comprised of gravel, stone fragments, sand, silt and clay combinations were encountered. Bedrock was not encountered within the depths of the borings performed at the proposed retaining wall site.

4.1.1. Overburden Soil

At the proposed retaining wall site, two different materials were encountered below the existing pavement section. The referenced materials consisted of: 1) fine-grained cohesive and non-cohesive till soils; and, 2) interbedded layers of coarse-grained non-cohesive soils. These materials and the general profile are further described below.

Till soils were encountered within each project boring immediately below the pavement section and extending to termination depths between 31.5 ft and 66.5 ft bgs (elevations 481.0 and 470.3 ft amsl). Based on laboratory testing results and a visual review of the samples obtained, the till at the site is comprised of both cohesive and non-cohesive, fine-grained materials that are classified on the boring logs as Sandy Silt (A-4a), Silt (A-4b), Silt and Clay (A-6a), Silt Clay (A-6b) and Clay (A-7-6). With respect to the soil strength of the cohesive till recovered, these soils can be described as having a consistency of soft to hard correlating to converted SPT-N values (N_{60}) between 4 and 57 blows per foot (bpf) and hand penetrometer values between 1.5 and 4.5 tons per square foot (tsf). The natural moisture content of the cohesive till ranged from 10 to 47 percent. Based on Atterberg Limits tests performed on representative samples of the till, the liquid and plastic limits were estimated to range from 28 to 47 percent and 16 to 23 percent, respectively. With respect to the soil strength of the non-cohesive till recovered, these soils can be described as medium dense to very dense correlating to N_{60} values between 12 bpf and SPT-N refusal (i.e., less than 6 inches of penetration over 50 blows).

In each boring performed, occasional interbedded layers of natural non-cohesive, coarse-grained material was encountered within the till at depths between 7.0 and 17.0 ft bgs (elevations 536.8 and 501.5 ft amsl). The thickness of these layers ranged from approximately 2.5-ft to 8.5-ft. The granular soils encountered is classified on the boring logs as Gravel and Stone Fragments with Sand and Silt (A-2-4) and Gravel and Stone Fragments with Sand, Silt and Clay (A-2-6). The soil strength of the granular soils can be described as having a relative compactness of medium dense to very dense correlating to converted N_{60} between 30 bpf and SPT-N refusal. The natural moisture content of these granular soils ranged from 6 to 16 percent.

4.1.2. Groundwater

Groundwater measurements were taken during the boring drilling procedures and immediately following the completion of each borehole. Groundwater was observed during drilling within 2 of the 3 boring locations (B-001-0-23 and B-002-0-23) performed as part of the referenced exploration. Based on the project borings, groundwater was encountered at depths ranging from 13 to 15 ft bgs (approximate elevations 530.8 to 497.5 ft amsl). It should be noted that groundwater is affected by many hydrologic characteristics in the area and may vary from those measured at the time of the exploration. The specific groundwater readings are included on the boring logs located within Appendix B.

5. ANALYSES AND RECOMMENDATIONS

We understand that Great Parks of Hamilton County, Columbia Township, the Village of Mariemont as well as ODOT are planning the construction of a new shared-use path connection that will require the replacement and widening of a segment of the existing sidewalk along the south side of Wooster Pike between the existing Kroger Fuel Center and the Mariemont Promenade. Furthermore, we understand that the proposed project will require the construction of a soldier pile and lagging (SPL) retaining wall approximately 150 ft in length to enable the placement of new fill to support the proposed path on the existing slope at that location. A summary and results of our evaluation as well as recommendations are presented in the subsequent sections.

5.1. Soil Profile for Analysis

For analysis purposes, each boring location was reviewed and a generalized material profile was developed for analysis. To accomplish this, soil layers from each boring location exhibiting similar behavior (i.e., cohesive or non-cohesive/granular) and characteristics (i.e., relative compactness/consistency, moisture content, etc.) were grouped into generalized soil units (i.e., Soil Types). Utilizing the generalized soil profile, engineering properties for each 'Soil Type' were estimated based on their field (i.e., SPT N_{60} values, hand penetrometer values, etc.) and laboratory (i.e., Atterberg Limits, grain size, etc.) test results from both boring locations using correlations provided in published engineering manuals, research reports and guidance documents. The estimated engineering soil properties (with sited correlation/reference material) at each boring location are summarized within Tables 4 through 6. Soil parameters estimated to evaluate the reaction of soils at the site to lateral loading for each of the assigned 'Soil Types' are presented in Table 7.

Table 4: Soil Profile and Estimated Engineering Properties - Boring B-001-0-23

Proposed Retaining Wall: Profile for Analysis, B-001-0-23				
Soil Description	**Unit Weight$^{(1)}$ (pcf)**	**Undrained Shear Strength$^{(2)}$ (psf)**	**Effective Cohesion$^{(3)}$ (psf)**	**Effective Friction Angle$^{(3)}$ (degrees)**
Soil Type 1 - Granular/Cohesive Depth (543.8 ft - 534.3 ft)	120	-	-	31
Soil Type 2 - Granular Depth (534.3 ft - 524.3 ft)	130	-	-	38
Soil Type 3 - Cohesive Depth (524.3 ft - 514.3 ft)	130	4500	350	27
Soil Type 4 - Cohesive$^{(4)}$ Depth (514.3 ft - 501.8 ft)	122	2400	200	27
Soil Type 6 - Cohesive Depth (501.8 ft - 494.3 ft)	120	1350	230	26
Soil Type 8 - Cohesive Depth (494.3 ft - 477.3 ft)	128	3850	300	27

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and LRFD BDS Table 10.4.6.2.4-1 and ODOT GDM Table 400-3 for granular soils.*
4. *Based on laboratory testing results. See Appendix B for lab testing report.*

Table 5: Soil Profile and Estimated Engineering Properties - Boring B-002-0-23

Proposed Retaining Wall: Profile for Analysis, B-002-0-23				
Soil Description	**Unit Weight$^{(1)}$ (pcf)**	**Undrained Shear Strength$^{(2)}$ (psf)**	**Effective Cohesion$^{(3)}$ (psf)**	**Effective Friction Angle$^{(3)}$ (degrees)**
Soil Type 4 - Cohesive$^{(4)}$ Depth (512.5 ft - 505.5 ft)	122	2400	200	27
Soil Type 5 - Granular Depth (505.5 ft - 503 ft)	128	-	-	38
Soil Type 6 - Cohesive$^{(4)}$ Depth (503 ft - 481 ft)	120	1350	230	26

:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and LRFD BDS Table 10.4.6.2.4-1 and ODOT GDM Table 400-3 for granular soils.*
4. *Based on laboratory testing results. See Appendix B for lab testing report.*

Table 6: Soil Profile and Estimated Engineering Properties - Boring B-003-0-23

Proposed Retaining Wall: Profile for Analysis, B-003-0-23				
Soil Description	**Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Soil Type 1 - Granular/Cohesive Depth (536.8 ft - 527.3 ft)	120	1750	200	25
Soil Type 2 - Granular Depth (527.3 ft - 517.3 ft)	130	-	-	38
Soil Type 3 - Cohesive Depth (517.3 ft - 510.3 ft)	130	4500	350	27
Soil Type 4 - Cohesive[4] Depth (510.3 ft - 502.3 ft)	122	2400	200	27
Soil Type 7 - Granular Depth (502.3 ft - 483.5 ft)	130	-	-	33
Soil Type 8 - Cohesive Depth (483.5 ft - 470.3 ft)	128	3850	300	27

Notes:

1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if* $N1_{60}$*<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and LRFD BDS Table 10.4.6.2.4-1 and ODOT GDM Table 400-3 for granular soils.*
4. *Based on laboratory testing results. See Appendix B for lab testing report.*

Table 7: Soil Parameters for Lateral Load Analysis

Proposed Retaining Wall: Lateral Load Analysis Soil Parameters for Analysis					
Soil Description	**p-y Model**	**Unit Weight (pcf)**	**Effective Unit Weight (pcf)**	**p-y k (pci)**	**Strain Factor** ε_{50}
Soil Type 2 - Granular (excludes B-002-0-23) Elevation (534.3 ft - 517.3 ft)	Sand (Reese)	130	67.6	175	-
Soil Type 3 - Cohesive (excludes B-002-0-23) Elevation (524.3 ft - 510.3 ft)	Stiff Clay w/o Water	130	67.6	1510	0.0043
Soil Type 4 - Cohesive Elevation (514.3 ft - 501.8 ft)	Stiff Clay w/o Water	122	59.6	805	0.0057
Soil Type 5 - Granular (B-002-0-23 only) Elevation (505.5 ft - 503.0 ft)	Sand (Reese)	128	65.6	175	-
Soil Type 6 - Cohesive (excludes B-003-0-23) Elevation (503.0 ft - 481.0 ft)	Stiff Clay w/o Water	120	57.6	420	0.0077
Soil Type 7 - Granular (B-003-0-23 only) Elevation (1144.8 ft - 1147.3 ft)	Sand (Reese)	130	67.6	55	-
Soil Type 8 - Cohesive (excludes B-002-0-23) Elevation (1147.3 ft - 1132.3 ft)	Stiff Clay w/o Water	128	65.6	1285	0.0046

Additionally, a model depicting our developed generalized soil profile utilized for analysis is included within Appendix C. The generalized subsurface profile includes: a color-coded general interpretation of the 'Soil Types' between borings, a graphical interpretation of the soil strata identified by the project soil borings along the length of the proposed wall site, and representative boring data (N_{60}-values, moisture contents, and groundwater levels).

5.1. SPL Wall Design

A foundation review was completed for the foundations of the proposed SPL retaining wall based on: 1) information gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.); 2) the soil profile, estimated engineering properties and other design assumptions presented in previous sections of this report; and, 3) cross-sectional information for the proposed SPL wall provided by Stantec on November 13, 2023. Geotechnical analyses consisting of global stability, moment equilibrium and lateral load resistance were performed for the proposed SPL wall. The geotechnical engineering analyses were performed in accordance with the January 2024 revision of ODOT's 2020 BDM (ODOT [1], 2024) and AASHTO's LRFD BDS 9th Edition (AASHTO, 2020).

5.1.1. SPL Wall Design Assumptions

As the construction of a newly proposed SPL retaining wall is required as part of the project, ODOT's BDM and AASHTO's LRFD BDS dictate analysis parameters and design minimums/constraints to be used in analysis and design process. The referenced parameters and design minimums/constraints that were significant to our analysis consist of the following:

- Minimum SPL wall embedment depths (as measured from top of drilled shaft to the proposed ground surface) shall be 3 ft;
- SPL wall analyses performed assuming a simplified earth distribution as shown in LRFD BDS Figure 3.11.5.6-4 "Unfactored Simplified Earth Pressure Distribution for Temporary Nongravity Cantilevered Walls with Discrete Vertical Elements Embedded in Cohesive Soils and Retaining Granular Soils";
- Simplified Earth Pressure "Design Grade" is equal to top of shaft/bottom of facing elevation of the proposed wall;
- Soldier pile analyzed in software L-pile as an "Elastic Section (Non-yielding)" type with "Circular without Void" shape with section properties equal to that of the steel section assuming a yield strength of 50 kips per square inch (ksi) and an elastic modulus of 29,000 ksi;
- Retained Fill soils will be compacted on-site fill material as specified and meeting the minimum design soil parameters per ODOT BDM Table 307-1 and provided in Table 8 below.

Table 8: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
SPL Wall Backfill	On-site soil varying from sandy lean clay to silty sand, per 703.16.A	120	30	0

Notes:
1. Per Section Table 307-1 of the ODOT BDM.

With respect to design constraints and assumptions specific to the proposed SPL retaining wall, the geometry of the proposed wall (i.e., exposed heights, existing ground elevations, proposed final grade behind/at the toe of the well, etc.) is assumed to be consistent with the cross-sectional information for the proposed SPL wall provided by Stantec on November 13, 2023.

5.1.2. Global Stability Analysis

For purposes of evaluating the stability of the SPL retaining wall, NEAS reviewed cross-sections along the length of the proposed retaining wall to determine the subsurface conditions that posed the greatest potential for slope instability. In general, cross-sections along the proposed wall alignment were reviewed to determine the section that would represent a combination of existing subsurface conditions and planned site grading that would be most critical to slope stability (i.e., maximum total wall height, maximum embankment height measured from toe of slope to top of wall, proposed/existing grades behind and in front of the wall, proposed cut into existing embankment slopes, weak or thick soil layer, etc.). Based on our review of the available information at the referenced location and the associated soil properties, two (2) cross-sections were estimated to be most "critical" and were analyzed for global stability. The two cross-sections analyzed for global stability include: the maximum total and exposed wall height section (STA 46+50), and the section where the existing wall downslope of the proposed SPL retaining wall is at it's tallest height (STA 46+00).

For the indicated cross-sections, NEAS developed a representative cross-sectional model to use as the basis for global stability analysis. The model was developed from NEAS's interpretation of the available information which included: 1) the cross-sectional information for the proposed SPL wall provided by Stantec on November 13, 2023; 2) a live load surcharge of 250 pounds per square foot (psf) accounting for traffic induced loads and a live load surcharge of 100 psf accounting for pedestrian and/or construction related loads; 3) a static groundwater table equal to the highest level encountered in the test borings; and, 4) test borings and laboratory data developed as part of this project. With respect to the soil's engineering properties, the provided generalized soil profile and estimated engineering properties presented in Tables 4 through 6 were used in our analyses as indicated.

The above referenced global stability models were analyzed for long-term (Effective Stress) and short-term (Total Stress) slope stability utilizing the software entitled *Slide2* by Rocscience, Inc. Specifically, the Modified Bishop and Spencer analysis methods were used to calculate a factor of safety (FOS) for circular and block type slope failures, respectively. The FOS is the ratio of the resisting forces and the driving forces, with the desired safety factor being more than about 1.3 which equates to an AASHTO resistance factor less than 0.75 (per AASHTO's LRFD BDS, the specified resistance factors are essentially the inverse of the FOS that should be targeted in slope stability programs). For this analysis, a resistance factor of 0.75 or lower is targeted as the retaining wall slope does not contain or support a structural element.

Based on our slope stability analysis for the referenced SPL wall sections, the minimum slope stability safety factor is about 1.49 (0.67 resistance factor) at the cross-section at STA 46+00. The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) for each analyzed section is presented in Appendix D.

5.1.3. Moment Equilibrium Analysis

In order to estimate the minimum drilled shaft soil embedment depth for the proposed SPL wall to demonstrate moment equilibrium along the length of the wall at varying wall panel heights, a moment equilibrium analysis was performed. Our analysis was performed based on: 1) composite engineering soil design parameters based on the soil properties presented in Tables 4 through 6 of this report; 2) SPL design assumptions provided in Section 5.1.1. of this report; and, 3) a drilled shaft diameter of 42-inches.

The moment equilibrium analysis was performed in accordance with LRFD BDS Section 3.11.5.6 assuming the simplified earth distribution as shown in LRFD BDS Figure 3.11.5.6-4. Specifically, the SPL wall section at the tallest panel height (STA 46+50) was analyzed for moment equilibrium. The results of our analysis indicate the required minimum soil embedment required for the drilled shafts in order to demonstrate moment equilibrium along the length of the wall. These results are presented in our moment equilibrium analysis included within Appendix E.

5.1.4. Lateral Load Analysis

For the purpose of determining an adequate pile section to be use in the construction of the proposed SPL wall, a lateral load analysis was performed utilizing the software entitled LPILE v2016 by Ensoft, Inc. The SPL wall section analyzed included the tallest panel height section (STA 46+50). Our lateral load analysis was performed based on: 1) our estimated engineering soil properties and lateral load analysis soil parameters provided in Section 5.1. of this report; 2) SPL wall design assumptions presented Section 5.1.1. of this report; 3) minimum shaft diameter of 42-inches and a shaft center-to-center spacing of 8-ft; 4) lateral loads generated by horizontal earth pressures acting on the wall calculated assuming a simplified earth distribution as shown in Section 3.11.5.6 of the LRFD BDS (AASHTO, 2020); and, 5) p-y modification factor for group effects applied in accordance with Section 10.7.2.4 of the LRFD BDS (AASHTO, 2020).

To evaluate the proposed SPL wall at the Service Limit State, unfactored loads were inputted into LPILE and lateral pile head deflection was determined. In the Service Limit State, the pile head deflections are limited to 1 percent of the wall height as measured from the pile head to the assumed “Design Grade” per ODOT BDM Section 307.1.6. In an iterative process, varying pile sections were analyzed at the Service Limit State until a section was determined to meet the indicated maximum deflection criteria. Based on our Lateral Load analysis in the Service Limit State, it was estimated that the maximum allowable pile head deflection would not be exceeded utilizing a W33x141 steel pile section for construction of the proposed SPL wall.

To evaluate the proposed SPL wall at the Strength Limit State, the indicated horizontal earth loads were multiplied by a load factor of 1.5 in accordance with Section 3.4.1 of the AASHTO LRFD BDS for input into LPILE. For our analysis of STA 46+50, the results of the LPILE analysis indicate an induced maximum shear force of 98.0 kips at a depth of 34.4 ft below pile head and a maximum moment of 9,560.9 inch-kips at a depth of 26.0 ft below pile head. The LPILE outputs for both Service and Strength Limit State are included within Appendix F.

Utilizing the maximum shear and moment forces estimated by the LPILE analysis, the selected steel pile section was reviewed to determine if it is structurally capable of resisting the calculated factored maximum moment and shear forces. The analysis indicated that the W33x141 steel section with a yield stress of 50 ksi would be structurally capable of supporting the calculated maximum factored shear force and moment. It should be noted that as the required spacing of the soldier piles is less than 3.75 shaft diameters, a reduction of the p-multiplier was applied for the soils overlying bedrock in our LPILE analysis model per LRFD BDS Section 10.7.2.4. The reduction factor accounts for the loss in resistance due to the soil-structure-soil interaction and an overlap (bridging) in the region of the soil that provides passive resistance to the deflection of the drilled shaft foundations. Structural resistance calculations for the W33x141 pile are included within Appendix G.

5.1.5. Settlement

As a maximum of 11 ft of additional embankment fill is planned at locations behind the proposed SPL wall, settlement is anticipated in these areas and may affect the shared-use aesthetics. However, due to the either the granular nature of the dense to very dense soil directly underlying the proposed wall, or the over-consolidated nature of the very stiff to hard cohesive soils encountered at the site, long-term (consolidation) settlement is anticipated to be minimal and is not anticipated to be a concern to the functionality of the shared-use path.

5.2. Recommendations

5.2.1. SPL Wall Design

Based on the results of our analyses of the SPL wall sections indicated above, it is our opinion that the subsurface conditions encountered are generally satisfactory and will provide adequate resistance to horizontal earth pressures and global stability failure assuming: 1) the proposed SPL wall will consist of a W33x141 steel section embedded in 3.5-ft diameter drilled shafts embedded 25-ft below design grade at a spacing of 8-ft center-to-center; and, 2) constructed in accordance with the recommendations provided within this report, as well as all applicable standards and specifications (i.e., ODOT BDM, ODOT CMS, Supplemental Specifications, etc.) for SPL wall construction and drilled shaft installation. If cast-in-place (CIP) lagging panels are to be utilized for wall construction, it is recommended that timber lagging be utilized during backfill placement prior to CIP lagging forming and construction.

For SPL wall backfill, we recommend the use of on-site soil varying from sandy lean clay to silty sand meeting the requirements of ODOT's Item 703.16.A. We recommend that fill placed against existing or temporary slopes exceeding 10 Horizontal to 1 Vertical (10H:1V) be properly benched into the slopes. The purpose of benching into a slope is to provide better shear resistance along a potential failure plane. The fill should be placed in a series of horizontal benches that begin at the toe of the slope/bottom of proposed SPL wall and extend upslope. Each bench should be excavated to a minimum depth as needed to expose firm foundation soils throughout the height of the bench and should be at least 10 feet in width.

5.2.2. Construction Recommendations

5.2.2.1. Temporary Cut Slopes

As temporary cut slope sections required as part of the proposed SPL wall construction are anticipated to be less than 20 ft in height, it is recommended for all temporary excavations comply with the most recent Occupational Safety and Health Administration (OSHA) Excavating and Trenching Standard, Title 29 of the Code of Federal Regulation (CFR) Part 1926, Subpart P. The contractor is responsible for designing and constructing stable, temporary excavations and should shore, slope, or bench the sides of the excavations as required to maintain stability of both the excavation sides and bottom. Per Title 29 CFR Part 1926, the contractor's competent person should evaluate the soil exposed in the excavations as part of their safety procedures. In no case should slope height, slope inclination, or excavation depth, including utility trench excavation depth, exceed those specified in local, state, and federal safety regulations. Based on the natural soils encountered at the site (Type C Soil), it is recommended that temporary excavation slopes (exceeding a depth of 3 ft and less than 20 ft) be laid back to at least 1.5H:1V and these slopes should be braced or backfilled if the excavation slope will be maintained for more than a day.

5.2.2.2. Drainage Considerations

It is recommended that adequate drainage is maintained/controlled during and after construction of the SPL retaining wall, and that roadway and shared-use path drainage is carefully controlled around the retaining wall location in order to prevent ponding, erosion of retained backfill soil, loss of shear strength of foundation soils due to saturation, and other drainage related issues.

It is recommended that internal drainage of the retaining wall be designed to provide positive drainage behind the wall and limit the buildup of hydrostatic pressure. The designer should anticipate and address in design and detailing the possibility of water runoff from extreme events which will overtop and run down the wall face.

6. QUALIFICATIONS

This investigation was performed in accordance with accepted geotechnical engineering practice for the purpose of characterizing the subsurface conditions at the site of proposed HAM-Columbia Connector retaining wall. This report has been prepared for Stantec, Great Parks of Hamilton County, Columbia Township, the Village of Mariemont, ODOT and their design consultants to be used solely in evaluating the soils underlying the project site and presenting geotechnical engineering recommendations specific to this project. The assessment of general site environmental conditions or the presence of pollutants in the soil, rock and groundwater of the site was beyond the scope of this geotechnical exploration. Our recommendations are based on the results of our field explorations, laboratory test results from representative soil samples, and geotechnical engineering analyses. The results of the field explorations and laboratory tests, which form the basis of our recommendations, are presented in the appendices as noted. This report does not reflect any variations that may occur between the borings or elsewhere on the site, or variations whose nature and extent may not become evident until a later stage of construction. In the event that any changes in the nature, design or location of the proposed retaining wall is made, the conclusions and recommendations contained in this report should not be considered valid until they are reviewed, and have been modified or verified in writing by a geotechnical engineer.

It has been a pleasure to be of service to Stantec in performing this geotechnical exploration for the HAM-Columbia Connector project. Please call if there are any questions, or if we can be of further service.

Respectfully Submitted,

Brendan P. Andrews, P.E.	Kevin C. Arens, P.E.
Geotechnical Engineer	*Geotechnical Engineer*

REFERENCES

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APPENDIX A

BORING LOCATION PLAN

HAM-LMST-POCAHONTAS EXT

MODEL: 2D Metric Design PAPERSIZE: 17x11 (in.) DATE: 2/21/2023 TIME: 1:15:15 PM USER: karens
C:\CONNECT\CustomConfig\WorkSpaces\OHDOT\WorkSets\114497\dgn\PocahontasExt_TargetBoringPlan022123.dgn

⊕ *TARGET BORING LOCATION*

HORIZONTAL
SCALE IN FEET
0 10 20 40

TARGET BORING LOCATION PLAN
POCAHONTAS CONNECTION

DESIGN AGENCY
NEAS
National Engineering & Architectural Services Inc.
2800 CORPORATE
EXCHANGE DR,
SUITE 240
COLUMBUS, OH,
43231
TEL:614.714.0299
WWW.NEASINC.COM

DESIGNER
KCA

REVIEWER
BPA 02-21-23

PROJECT ID
114497

SHEET 1
TOTAL 1

APPENDIX B

SOIL BORING LOGS & LABORATORY TEST RESULTS

PROJECT: COLUMBIA CONNECTOR
TYPE: RETAINING WALL
PID: SFN:
START: 3/18/24 END: 3/18/24

DRILLING FIRM / OPERATOR: NEAS / J. HODGES
SAMPLING FIRM / LOGGER: NEAS / J. HODGES
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT / ST

DRILL RIG: CME 55X
HAMMER: CME AUTOMATIC
CALIBRATION DATE: 1/24/22
ENERGY RATIO (%): 79

STATION / OFFSET:
ALIGNMENT: US-50 (WOOSTER PIKE)
ELEVATION: 543.8 (MSL) EOB: 66.5 ft.
LAT / LONG: 39.143491, -84.364675

EXPLORATION ID
B-001-0-23

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 543.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
5.0" ASPHALT AND 7.0" CONCRETE AND 6.0" BASE (DRILLERS DESCRIPTION)	542.3	1																
STIFF, BROWN, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, CONTAINS NO INTACT SOIL FOR HP READINGS, DAMP	539.3	2 3 4	7 4 5	12	50	SS-1	-	-	-	-	-	-	-	-	-	11	A-4a (V)	
MEDIUM DENSE, BROWN, **SILT**, SOME SAND, LITTLE CLAY, TRACE GRAVEL, WET		5 6	3 4 5	12	22	SS-2	-	-	-	-	-	-	-	-	-	21	A-4b (V)	
	534.3	7 8 9	3 5 7	16	100	SS-3	-	2	1	21	61	15	NP	NP	NP	21	A-4b (8)	
VERY STIFF, GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP	532.8	10 11	2 6 50/4"	-	63	SS-4	3.50	-	-	-	-	-	-	-	-	15	A-6a (V)	
MEDIUM DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND AND SILT**, TRACE CLAY, DAMP	529.3	12 13 14	10 12 11	30	22	SS-5	-	-	-	-	-	-	-	-	-	8	A-2-4 (V)	
DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND, SILT, AND CLAY**, WET		W 528.8 15 16	5 40 19	78	33	SS-6	-	-	-	-	-	-	-	-	-	15	A-2-6 (V)	
	524.3	17 18 19	15 16 22	50	78	SS-7	-	-	-	-	-	-	-	-	-	16	A-2-6 (V)	
VERY STIFF TO HARD, GRAY, **SILT AND CLAY**, TRACE TO LITTLE SAND, TRACE TO LITTLE GRAVEL, DAMP TO MOIST		20 21	12 12 17	38	72	SS-8	4.00	11	6	11	39	33	29	16	13	14	A-6a (9)	
		22 23	12 14 18	42	100	SS-9	4.50	-	-	-	-	-	-	-	-	16	A-6a (V)	
		24 25 26	15 19 20	51	89	SS-10	4.50	-	-	-	-	-	-	-	-	23	A-6a (V)	
	514.3	27 28 29	24 16 16	42	61	SS-11	4.50	-	-	-	-	-	-	-	-	23	A-6a (V)	

PID: ________ SFN: ______________ PROJECT: COLUMBIA CONNECTOR STATION / OFFSET: ______________ START: 3/18/24 END: 3/18/24 PG 2 OF 3 B-001-0-23

MATERIAL DESCRIPTION AND NOTES	ELEV. 513.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
STIFF TO VERY STIFF, GRAY, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST *(continued)*		31	3 5 7	16	100	SS-12	3.75	-	-	-	-	-	-	-	-	25	A-7-6 (V)	
		32 33																
		34			100	ST-13	3.50	0	0	1	24	75	47	21	26	25	A-7-6 (16)	
		35 36	3 6 9	20	100	SS-14	2.75	-	-	-	-	-	-	-	-	25	A-7-6 (V)	
		37																
		38	4 7 8	20	100	SS-15	3.25	-	-	-	-	-	-	-	-	26	A-7-6 (V)	
		39 40																
		41	3 6 7	17	100	SS-16	1.50	-	-	-	-	-	-	-	-	27	A-7-6 (V)	
	501.8	42																
VERY STIFF, GRAY, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, MOIST TO WET SS-17 CONTAINS NO INTACT SOIL FOR HP READINGS		43	2 1 2	4	39	SS-17	-	-	-	-	-	-	-	-	-	31	A-6a (V)	
		44																
		45 46	2 5 6	14	100	SS-18	3.25	0	0	1	59	40	30	19	11	25	A-6a (8)	
		47																
		48	3 6 8	18	100	SS-19	4.00	-	-	-	-	-	-	-	-	27	A-6a (V)	
	494.3	49																
VERY STIFF TO HARD, GRAY, **SILT**, LITTLE TO SOME CLAY, TRACE SAND, TRACE GRAVEL, WET TO MOIST ST-20 CONTAINS NO RECOVERY		50			0	ST-20	-	-	-	-	-	-	-	-	-	-		
		51 52	6 8 8	21	100	SS-21	3.00	-	-	-	-	-	-	-	-	26	A-4b (V)	
		53 54																
		55 56	8 10 11	28	100	SS-22	3.50	-	-	-	-	-	-	-	-	25	A-4b (V)	
		57 58 59																
		60 61	5 7 11	24	100	SS-23	4.50	0	0	0	80	20	28	21	7	22	A-4b (8)	

PID: ________ SFN: ________________ PROJECT: COLUMBIA CONNECTOR STATION / OFFSET: ________________ START: 3/18/24 END: 3/18/24 PG 3 OF 3 B-001-0-23

MATERIAL DESCRIPTION AND NOTES	ELEV. 481.7	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
									GR	CS	FS	SI	CL	LL	PL	PI			
VERY STIFF TO HARD, GRAY, **SILT**, LITTLE TO SOME CLAY, TRACE SAND, TRACE GRAVEL, WET TO MOIST *(continued)*			63 64																
	477.3	EOB	65 66	9 9 12	28	100	SS-24	4.00	-	-	-	-	-	-	-	-	22	A-4b (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 15.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 4/15/24 12:30 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\COLUMBIA CONNECTOR 23-0064\GINT FILES\COLUMBIA_CONNE

Consolidated-Undrained Triaxial Compression Test (AASHTO T 297 / ASTM D4767)

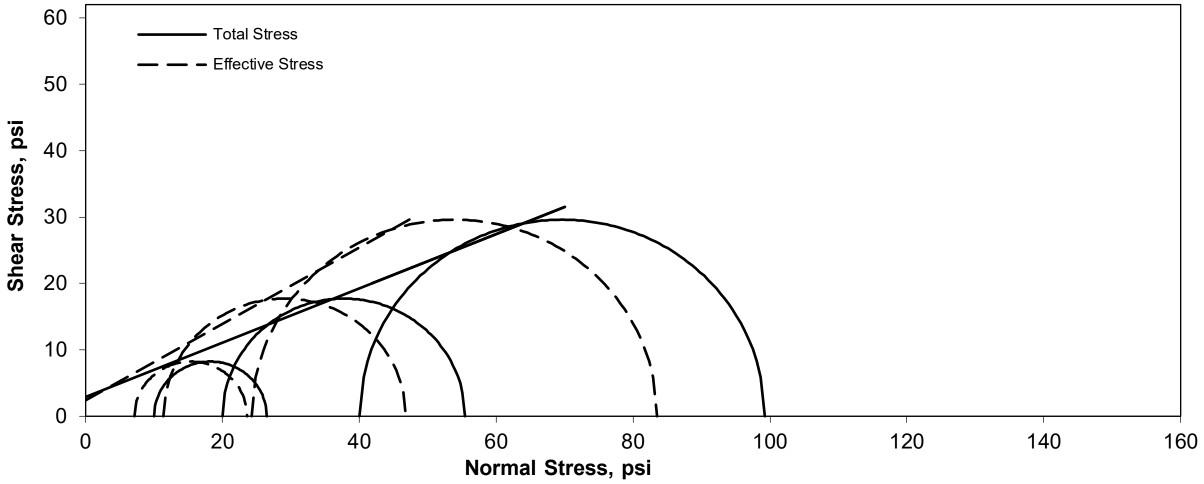
Project: Columbia Connector Project ID: 114497
Sample ID: B-001-0-23 / ST-13 (@33.0-35.0') Page: 1/3
Description: Stiff to very stiff, gray, CLAY, some silt, trace sand, trace gravel, moist

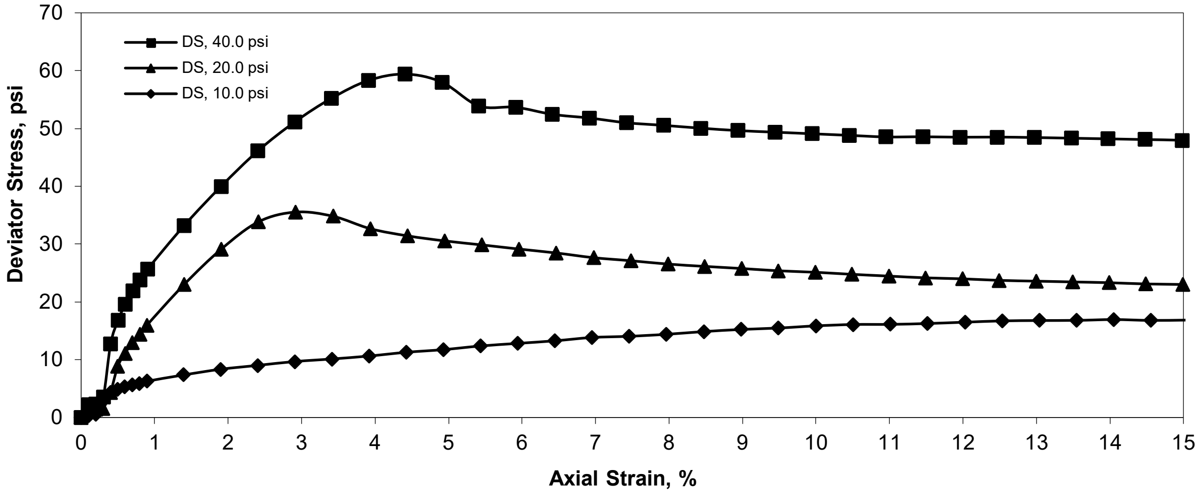
Sample No.	Height (in)	Diameter (in)	Moisture (%)	Bulk Density (pcf)	Dry Density (pcf)	Void Ratio
1	5.75	2.88	25.8%	128.1	101.8	0.637
2	5.75	2.86	24.3%	127.2	102.4	0.628
3	5.74	2.84	25.8%	127.1	101.0	0.650

Liquid Limit: 47 Plastic Limit: 21

Failure Criterion: Maximum Deviator Stress

	Total	Effective
C, psi	2.9	2.4
ϕ, deg	22.2	29.9
Tan (ϕ)	0.41	0.58





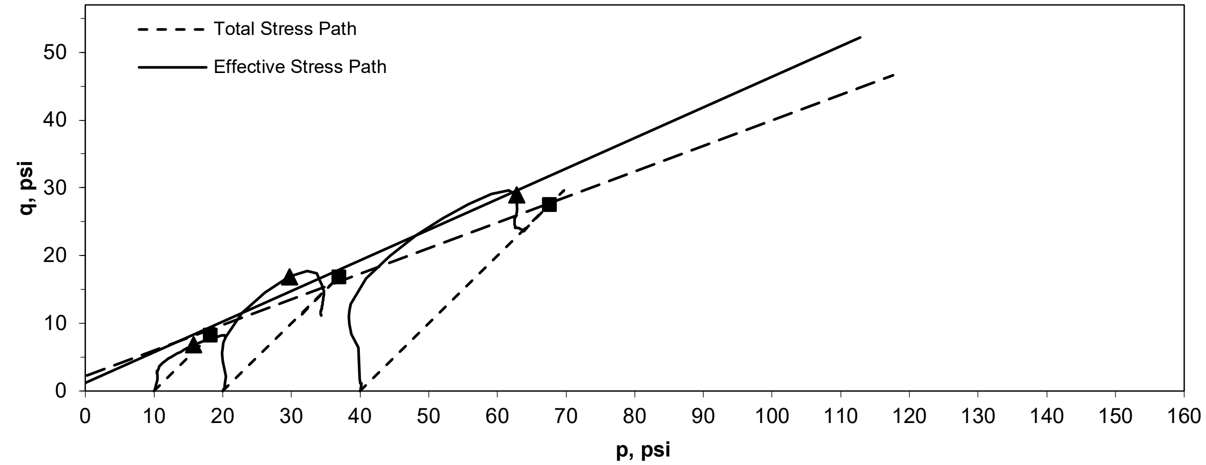
Assumed Specific Gravity Gs = 2.67

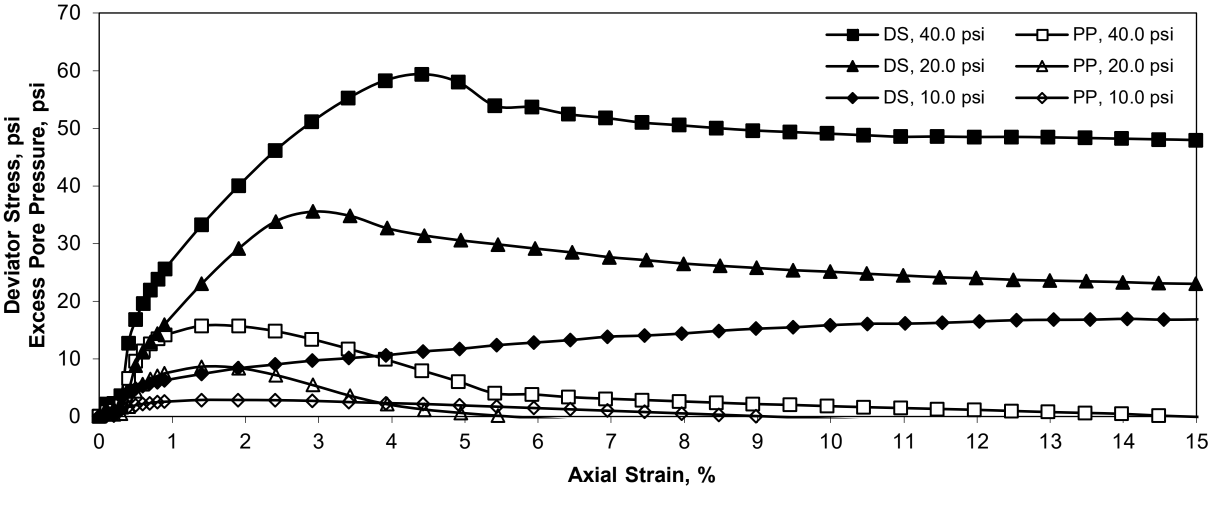
Consolidated-Undrained Triaxial Compression Test (AASHTO T 297 / ASTM D4767)

Project: Columbia Connector
Project ID: 114497
Sample ID: B-001-0-23 / ST-13 (@33.0-35.0')
Page: 2/3
Description: Stiff to very stiff, gray, CLAY, some silt, trace sand, trace gravel, moist

Failure Criterion: Maximum Effective Principal Stress Ratio

	Total	Effective
c, psi	1.8	1.4
φ, deg	22.8	26.8
Tan (φ)	0.42	0.50





Notes: "Mushroom" deformation of the 10 psi specimen during compression occurred above an intebedded silt layer in the lower third of the specimen (see photo), and two additional narrow interbedded silt layers were observed in the specimen when split after compression. The 20 psi and 40 psi specimens did not exhibit similar interbedded silt layers and sheared along long diagaonal planes.

NEAS
National Engineering & Architectural Services Inc.

5710 Westbourne Avenue
Columbus, OH 43213
614-892-0162

Consolidated-Undrained Triaxial Compression Test (AASHTO T 297 / ASTM D4767)

Project: Columbia Connector
Project ID: 114497
Sample ID: B-001-0-23 / ST-13 (@33.0-35.0')
Page: 3/3
Description: Stiff to very stiff, gray, CLAY, some silt, trace sand, trace gravel, moist

MODE OF FAILURE		ADDITIONAL PHOTOS
 Sample 1 (10 psi): View 1	 Sample 1 (10 psi): View 2	 Sample 1 (10 psi): Cross Sectional View
 Sample 2 (20 psi): View 1	 Sample 2 (20 psi): View 2	 Sample 2 (20 psi): Cross Sectional View
 Sample 3 (40 psi): View 1	 Sample 3 (40 psi): View 2	 Sample 3 (40 psi): Cross Sectional View

PROJECT: COLUMBIA CONNECTOR
TYPE: RETAINING WALL
PID: SFN:
START: 3/13/24 END: 3/13/24

DRILLING FIRM / OPERATOR: NEAS / J. HODGES
SAMPLING FIRM / LOGGER: NEAS / J. HODGES
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT / ST

DRILL RIG: CME 55X
HAMMER: CME AUTOMATIC
CALIBRATION DATE: 1/24/22
ENERGY RATIO (%): 79

STATION / OFFSET:
ALIGNMENT: US-50 (WOOSTER PIKE)
ELEVATION: 512.5 (MSL) EOB: 31.5 ft.
LAT / LONG: 39.143183, -84.364547

EXPLORATION ID
B-002-0-23

PAGE
1 OF 2

MATERIAL DESCRIPTION AND NOTES	ELEV. 512.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
10.0" ASPHALT AND 6.0" BASE (DRILLERS DESCRIPTION)	511.2	1																
VERY STIFF TO HARD, BROWN, **SILTY CLAY**, LITTLE SAND, LITTLE GRAVEL, SS-2 IS SLIGHTLY ORGANIC, MOIST TO WET		2 3 4	4 6 6	16	22	SS-1	3.50	-	-	-	-	-	-	-	-	20	A-6b (V)	
	505.5	5 6	6 6 9	20	100	SS-2	4.50	18	8	10	34	30	34	18	16	47	A-6b (8)	
MEDIUM DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND AND SILT**, LITTLE CLAY, MOIST	503.0	7 8 9	7 10 12	29	89	SS-3	-	-	-	-	-	-	-	-	-	15	A-2-4 (V)	
STIFF, BROWN AND GRAY, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, MOIST	500.5	10 11	4 5 6	14	100	SS-4	1.50	0	0	1	57	42	30	19	11	26	A-6a (8)	
STIFF TO HARD, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, MOIST		12 W 499.5 13 14	2 1 2	4	100	SS-5	1.50	-	-	-	-	-	-	-	-	28	A-4b (V)	
		15 16	2 3 5	11	100	SS-6	4.50	0	0	1	65	34	32	23	9	25	A-4b (8)	
		17 18 19	3 4 5	12	100	SS-7	4.50	-	-	-	-	-	-	-	-	24	A-4b (V)	
		20			100	ST-8	3.25	0	0	0	71	29	30	20	10	25	A-4b (8)	
		21 22	4 5 6	14	100	SS-9	3.75	-	-	-	-	-	-	-	-	25	A-4b (V)	
		23 24 25 26	4 5 5	13	100	SS-10	4.50	-	-	-	-	-	-	-	-	23	A-4b (V)	
		27 28 29																

PID: ________ | SFN: ________ | PROJECT: COLUMBIA CONNECTOR | STATION / OFFSET: ________ | START: 3/13/24 | END: 3/13/24 | PG 2 OF 2 | B-002-0-23

MATERIAL DESCRIPTION AND NOTES	ELEV. 482.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
STIFF TO HARD, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, MOIST *(continued)*	481.0	EOB 31	3 4 6	13	100	SS-11	4.50	-	-	-	-	-	-	-	-	23	A-4b (V)	

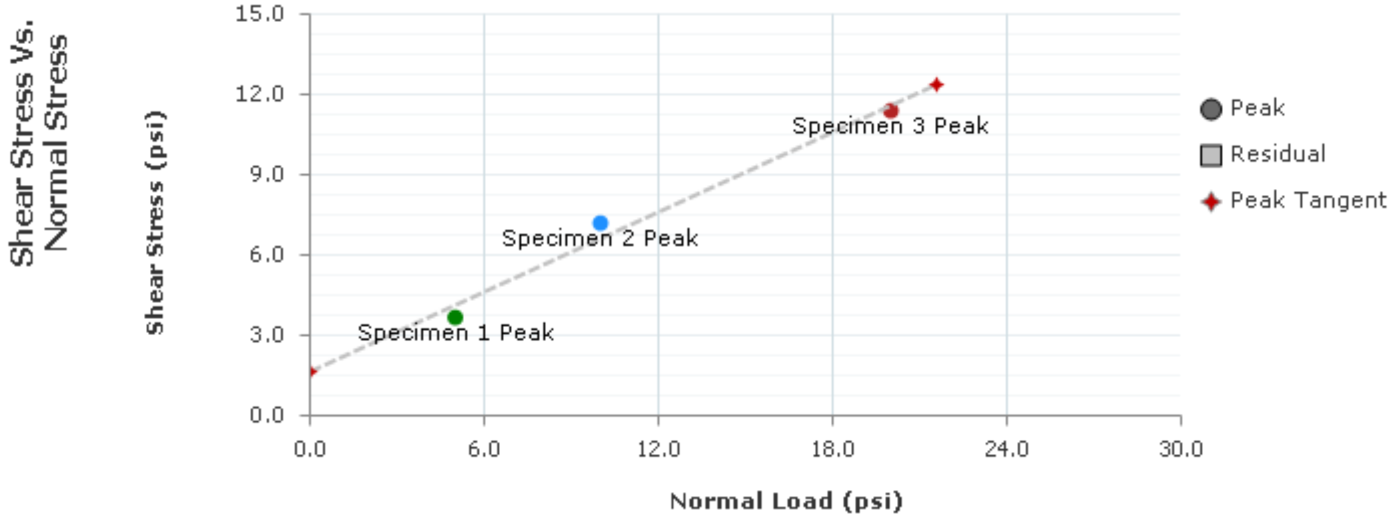
NOTES: GROUNDWATER ENCOUNTERED AT 13.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; POURED 2 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

Direct Shear Test

T236

Project: Columbia Connector
Project Number: 114496
Location: B-002-0-23
Client Name: Stantec



C (psi): 1.6
Phi (°): 26.4

Residual C (psi): NA
Residual Phi (°): NA

	Specimen Number							
Initial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture (%):	24.2	24.9	24.9					
Dry Density (pcf):	100.6	99.1	99.5					
Void Ratio:	0.657	0.682	0.675					
Saturation (%):	98.4	97.5	98.5					
Diameter (in):	2.5000	2.5000	2.5000					
Height (in):	0.9985	0.9970	0.9970					
Final	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture (%):	26.3	27.9	27.4					
Dry Density (pcf):	102.1	102.3	101.7					
Void Ratio:	0.633	0.629	0.640					
Saturation (%):	111.0	118.5	114.5					
Height (in):	0.9946	0.9880	0.9859					
Normal Stress (psi):	5.0	10.0	20.0					
Peak Shear Stress (psi):	3.7	7.2	11.4					
Residual Stress (psi):	NA	NA	NA					
Horizontal Deformation (%):	0.8	1.4	1.3					
Rate (in/min):	0.001253	0.001340	0.001741					

Direct Shear Test

T236

Project: Columbia Connector
Project Number: 114496
Sampling Date: 3/18/2024
Sample Number: ST-8 B-002-0-23
Sample Depth: 19.0-21.0 ft
Location: Hamilton County, OH
Client Name: Stantec
Remarks:

Information Parameters	Specimen Number							
	1	2	3	4	5	6	7	8
Liquid Limit:	30	30	30					
Plastic Limit:	20	20	20					
Specific Gravity:	2.67	2.67	2.67					
Specific Gravity Method:	ASSUMED	ASSUMED	ASSUMED					

Initial Parameters	1	2	3	4	5	6	7	8
Test Temperature (°C):	22.0	22.0	22.0					
Sample Shape:	ROUND	ROUND	ROUND					
Height (in):	0.9985	0.9970	0.9970					
Diameter (in):	2.5000	2.5000	2.5000					
Area (in²):	4.909	4.909	4.909					
Volume (in³):	4.9014	4.8940	4.8940					
Moisture (%):	24.2	24.9	24.9					
Dry Density (pcf):	100.6	99.1	99.5					
Wet Density (pcf):	125.0	123.8	124.3					
Saturation (%):	98.4	97.5	98.5					
Void Ratio:	0.657	0.682	0.675					
Porosity (%):	39.6	40.5	40.3					

Consolidation Parameters	1	2	3	4	5	6	7	8
Initial Reference Height (in):	0.9985	0.9970	0.9970					
Final Reference Height (in):	0.9946	0.9880	0.9859					
Height (in):	0.9946	0.9880	0.9859					

Final Parameters	1	2	3	4	5	6	7	8
Moisture Content (%)	26.3	27.9	27.4					
Dry Density (pcf):	102.1	102.3	101.7					
Wet Density (pcf):	128.9	130.9	129.6					
Saturation (%):	111.0	118.5	114.5					
Void Ratio:	0.633	0.629	0.640					
Porosity (%):	38.8	38.6	39.0					

Direct Shear Test

T236

Specimen 1

Test Description: Direct Shear
Other Associated Tests: ODOT AASHTO Full Classification
Device Details: HM5760
Test Specification:
Test Time: 3/19/2024
Technician: LR
Sampling Method: Undisturbed
Specimen Code: 19.5-19.6FT
Specimen Lab #: A
Specimen Description: Very stiff, gray, SILT, some clay, trace sand, trace gravel, moist.
Specific Gravity: 2.67
Plastic Limit: 20
Liquid Limit: 30
Test Remarks:

Specimen 2

Test Description: Direct Shear
Other Associated Tests: ODOT AASHTO Full Classification
Device Details: HM5760
Test Specification:
Test Time: 3/20/2024
Technician: LR
Sampling Method: Undisturbed
Specimen Code: 19.8-19.9FT
Specimen Lab #: B
Specimen Description: Very stiff, gray, SILT, some clay, trace sand, trace gravel, moist.
Specific Gravity: 2.67
Plastic Limit: 20
Liquid Limit: 30
Test Remarks:

Direct Shear Test

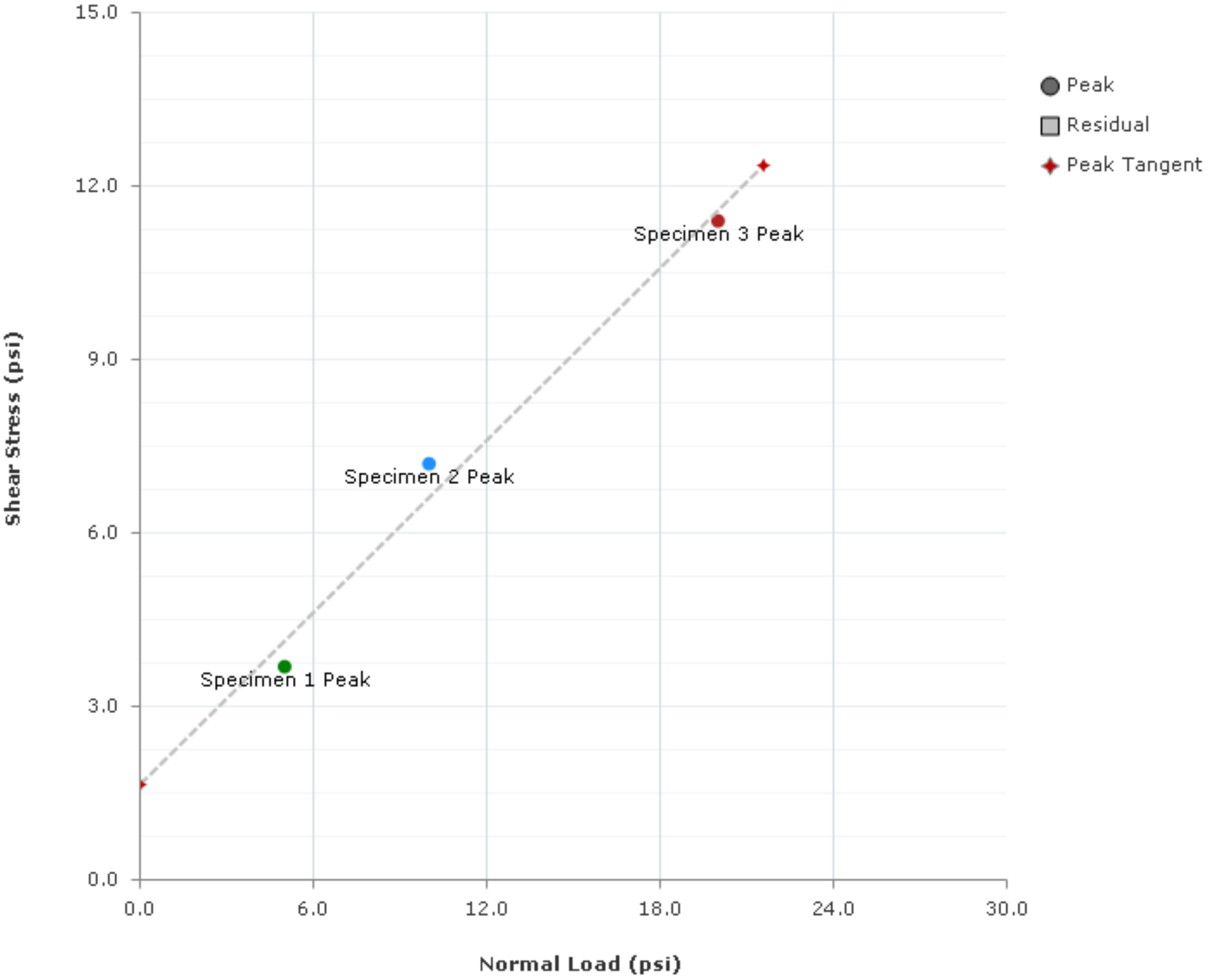
T236

Specimen 3

Test Description:	Direct Shear		
Other Associated Tests:	ODOT AASHTO Full Classification		
Device Details:	HM5760		
Test Specification:			
Test Time:	3/21/2024		
Technician:	LR	Sampling Method:	Undisturbed
Specimen Code:	20.1-20.2FT	Specimen Lab #:	C
Specimen Description:	Very stiff, gray, SILT, some clay, trace sand, trace gravel, moist.		
Specific Gravity:	2.67		
Plastic Limit:	20	Liquid Limit:	30
Test Remarks:			

Direct Shear Test - Shear Stress Vs. Normal Stress

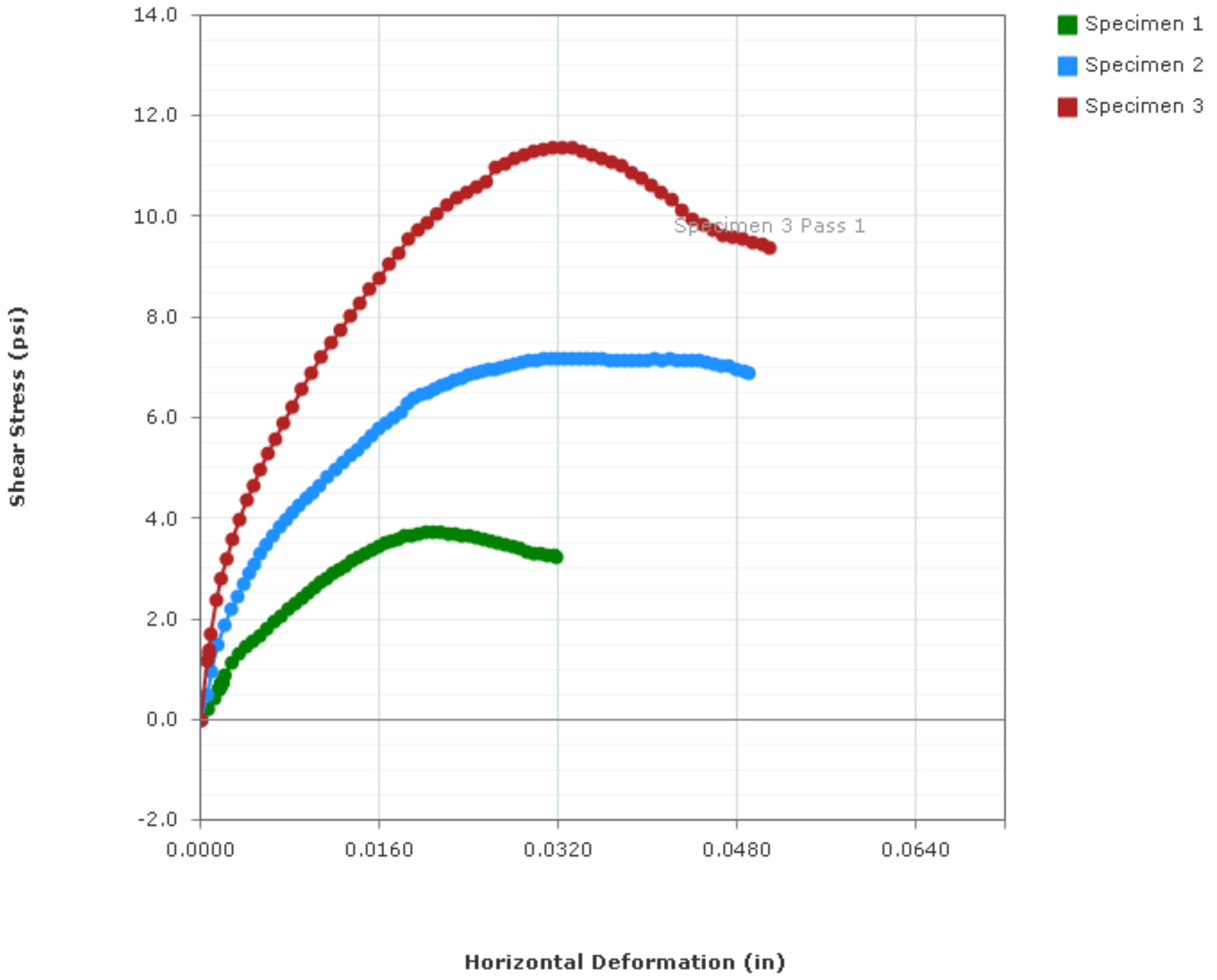
T236



Tangent Results	C (psi)	Phi (°)
Peak Tangent:	1.6	26.4
Residual Tangent:	NA	NA

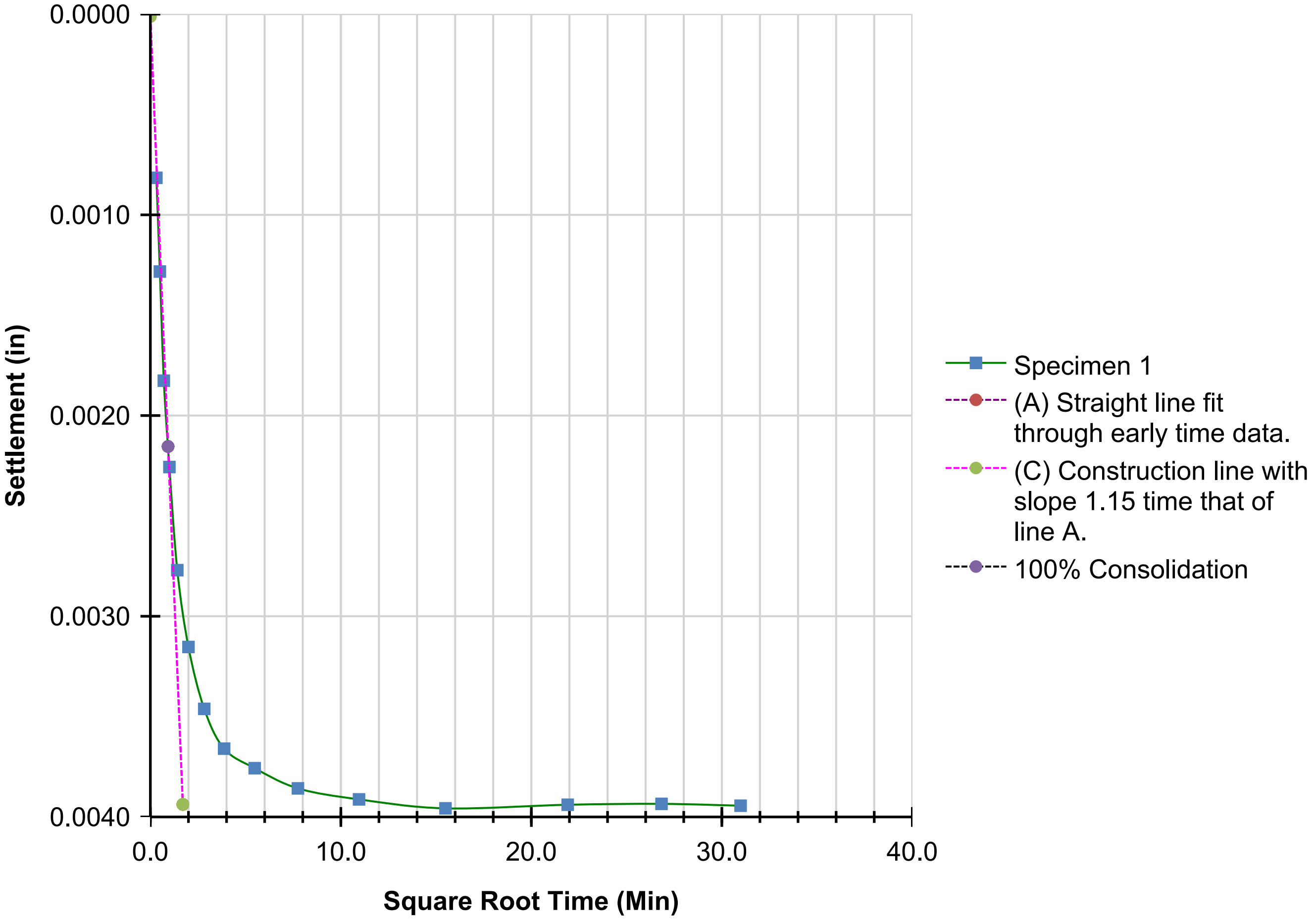
Graph - Stress Deformation

T236



Square Root Time - Specimen 1 - Sequence 1 - 5.0 (psi)

T236

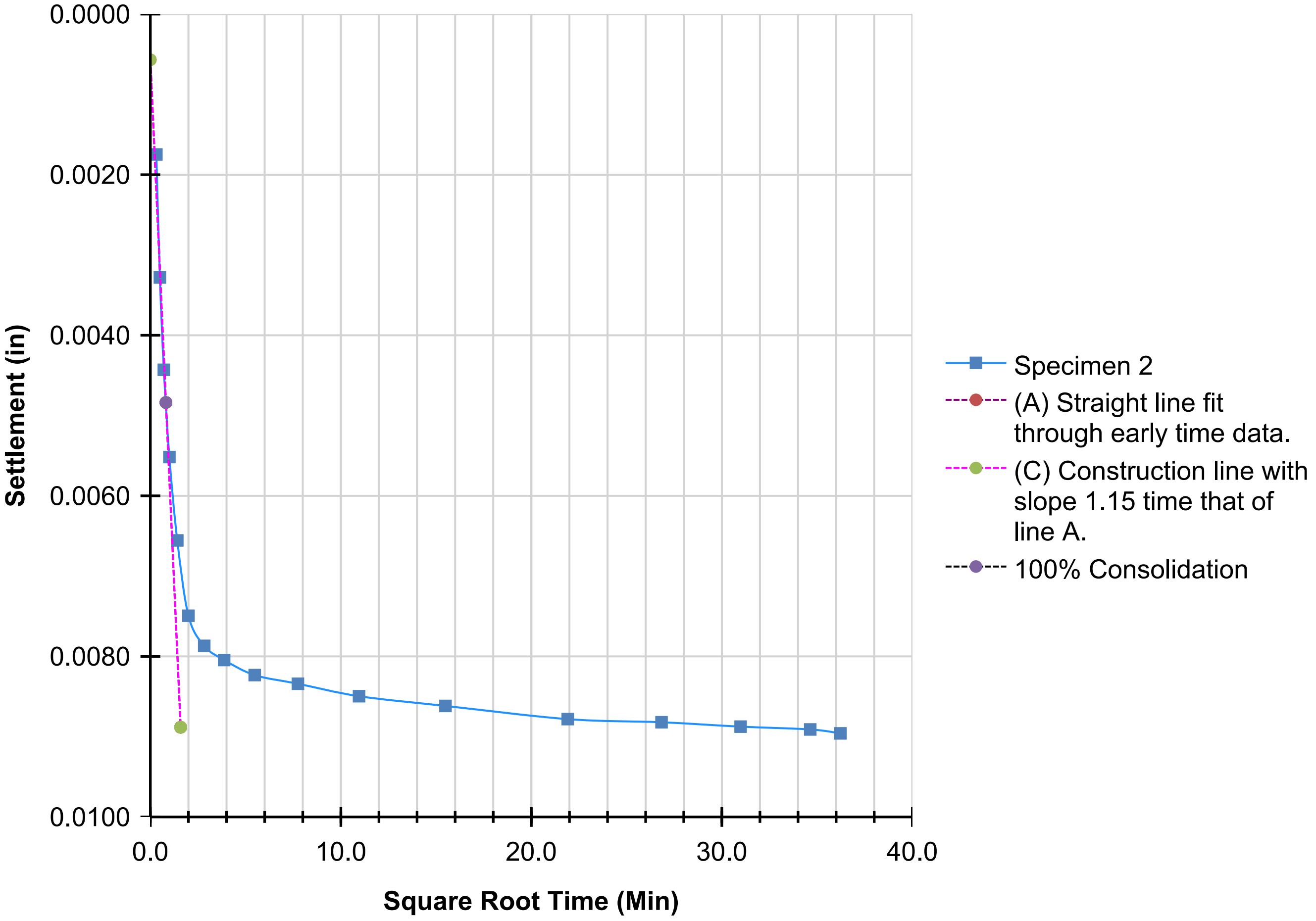


Tangent Construction Results

T90 (Min):	0.865
T50 (Min):	0.219
Cv (in²/Min):	0.24235

Square Root Time - Specimen 2 - Sequence 1 - 10.0 (psi)

T236

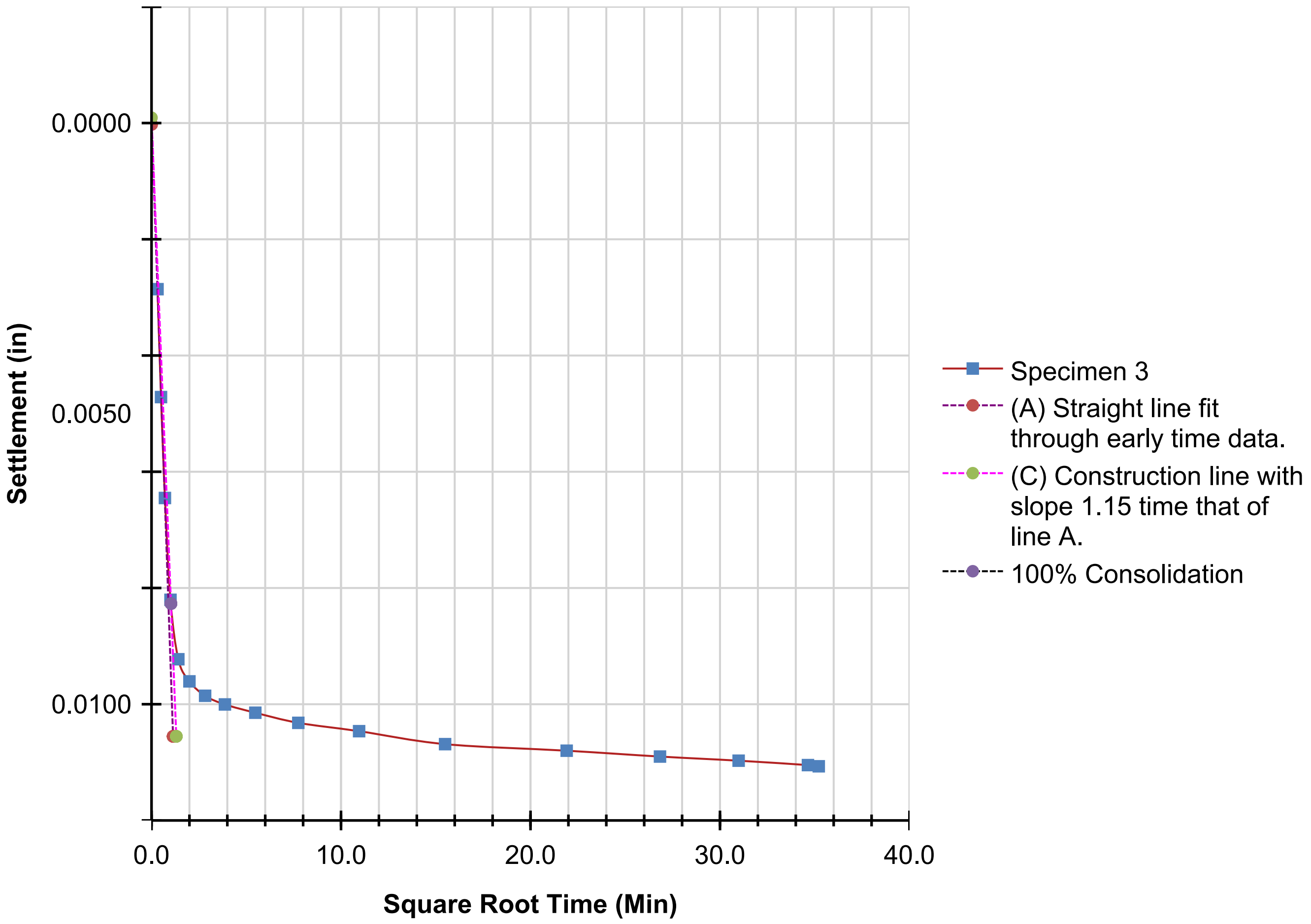


Tangent Construction Results

T90 (Min):	0.667
T50 (Min):	0.213
Cv (in²/Min):	0.31012

Square Root Time - Specimen 3 - Sequence 1 - 20.0 (psi)

T236



Tangent Construction Results

T90 (Min):	1.053
T50 (Min):	0.236
Cv (in²/Min):	0.19563

PROJECT: COLUMBIA CONNECTOR
TYPE: RETAINING WALL
PID: SFN:
START: 3/20/24 END: 3/20/24

DRILLING FIRM / OPERATOR: NEAS / J. HODGES
SAMPLING FIRM / LOGGER: NEAS / J. HODGES
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55X
HAMMER: CME AUTOMATIC
CALIBRATION DATE: 1/24/22
ENERGY RATIO (%): 79

STATION / OFFSET:
ALIGNMENT: US-50 (WOOSTER PIKE)
ELEVATION: 536.8 (MSL) EOB: 66.5 ft.
LAT / LONG: 39.143315, -84.364214

EXPLORATION ID
B-003-0-23

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 536.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
4.0" ASPHALT AND 8.0" CONCRETE AND 6.0" BASE (DRILLERS DESCRIPTION)	535.3	1																
HARD, BROWN AND ORANGISH BROWN, **SILT AND CLAY**, SOME SAND, TRACE TO LITTLE GRAVEL, IRON STAINING, DAMP		2																
		3 4	13 7 7	18	22	SS-1	4.50	-	-	-	-	-	-	-	-	11	A-6a (V)	
		5 6	3 4 8	16	11	SS-2	4.50	-	-	-	-	-	-	-	-	10	A-6a (V)	
		7																
	527.3	8 9	11 21 22	57	39	SS-3	4.25	13	10	13	37	27	29	17	12	12	A-6a (7)	
VERY STIFF TO HARD, BROWN AND BROWNISH GRAY, **SILT AND CLAY**, SOME TO "AND" STONE FRAGMENTS, LITTLE SAND, DAMP		10 11	18 23 50/2"	-	43	SS-4	4.00	-	-	-	-	-	-	-	-	11	A-6a (V)	
		12																
		13 14	20 17 18	46	89	SS-5	4.50	51	7	6	20	16	30	17	13	7	A-6a (1)	
	519.8	15 16	7 11 12	30	100	SS-6	4.50	-	-	-	-	-	-	-	-	10	A-6a (V)	
DENSE, BROWNISH GRAY, **STONE FRAGMENTS WITH SAND AND SILT**, TRACE CLAY, DAMP		17																
	517.3	18 19	14 13 11	32	28	SS-7	-	-	-	-	-	-	-	-	-	6	A-2-4 (V)	
HARD, GRAY, **SILT AND CLAY**, SOME STONE FRAGMENTS, LITTLE SAND, DAMP		20 21	5 11 12	30	100	SS-8	4.50	23	7	11	33	26	28	16	12	11	A-6a (6)	
		22																
	512.3	23 24	5 14 15	38	17	SS-9	4.50	-	-	-	-	-	-	-	-	14	A-6a (V)	
VERY STIFF, GRAY AND ORANGISH BROWN, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, INTERBEDDED, MOIST	510.3	25 26	5 8 13	28	100	SS-10	2.75	-	-	-	-	-	-	-	-	22	A-6a (V)	
MEDIUM DENSE, GRAY, **SILT**, LITTLE CLAY, TRACE SAND, TRACE GRAVEL, DAMP		27																
	507.3	28 29	3 6 11	22	100	SS-11	-	-	-	-	-	-	-	-	-	19	A-4b (V)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 4/15/24 12:30 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\COLUMBIA CONNECTOR 23-0064\GINT FILES\COLUMBIA_CONNE

PID: ________	SFN: ________________	PROJECT: COLUMBIA CONNECTOR	STATION / OFFSET: ________________	START: 3/20/24	END: 3/20/24	PG 2 OF 3	B-003-0-23

MATERIAL DESCRIPTION AND NOTES	ELEV. 506.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY STIFF, GRAY, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST *(continued)*		31	4 9 12	28	100	SS-12	3.50	0	0	1	29	70	45	20	25	24	A-7-6 (15)	
	504.8	32																
VERY STIFF, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, DAMP		33	5 7 11	24	100	SS-13	4.00	-	-	-	-	-	-	-	-	20	A-4b (V)	
	502.3	34																
DENSE TO VERY DENSE, ORANGISH BROWN, **SILT**, LITTLE CLAY, TRACE SAND, TRACE GRAVEL, SS-14 CONTAINS HEAVY IRON STAINING, DAMP		35 36	5 11 25	47	100	SS-14	-	-	-	-	-	-	-	-	-	17	A-4b (V)	
		37																
BECOMES BROWN		38	11 20 25	59	100	SS-15	-	-	-	-	-	-	-	-	-	19	A-4b (V)	
		39 40																
BECOMES GRAY, WET		41	7 12 16	37	100	SS-16	-	-	-	-	-	-	-	-	-	25	A-4b (V)	
		42																
		43	8 12 17	38	100	SS-17	-	-	-	-	-	-	-	-	-	23	A-4b (V)	
		44 45																
		46	7 11 15	34	100	SS-18	-	0	0	1	81	18	NP	NP	NP	22	A-4b (8)	
		47																
		48	9 12 16	37	100	SS-19	-	-	-	-	-	-	-	-	-	23	A-4b (V)	
		49 50																
		51	6 9 15	32	100	SS-20	-	-	-	-	-	-	-	-	-	22	A-4b (V)	
		52																
	483.5	53																
VERY STIFF TO HARD, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, SS-22 AND SS-23 CONTAIN NO INTACT SOIL FOR HP READINGS, MOIST TO DAMP		54																
		55 56	7 13 19	42	100	SS-21	4.00	-	-	-	-	-	-	-	-	22	A-4b (V)	
		57 58 59																
		60 61	8 13 17	40	100	SS-22	-	-	-	-	-	-	-	-	-	21	A-4b (V)	

PID: ________ SFN: ________________ PROJECT: COLUMBIA CONNECTOR STATION / OFFSET: ________________ START: 3/20/24 END: 3/20/24 PG 3 OF 3 B-003-0-23

MATERIAL DESCRIPTION AND NOTES	ELEV. 474.7	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
									GR	CS	FS	SI	CL	LL	PL	PI			
VERY STIFF TO HARD, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, SS-22 AND SS-23 CONTAIN NO INTACT SOIL FOR HP READINGS, MOIST TO DAMP *(continued)*			63 64 65																
	470.3	EOB	66	9 16 19	46	100	SS-23	-	0	0	4	65	31	28	21	7	21	A-4b (8)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

APPENDIX C

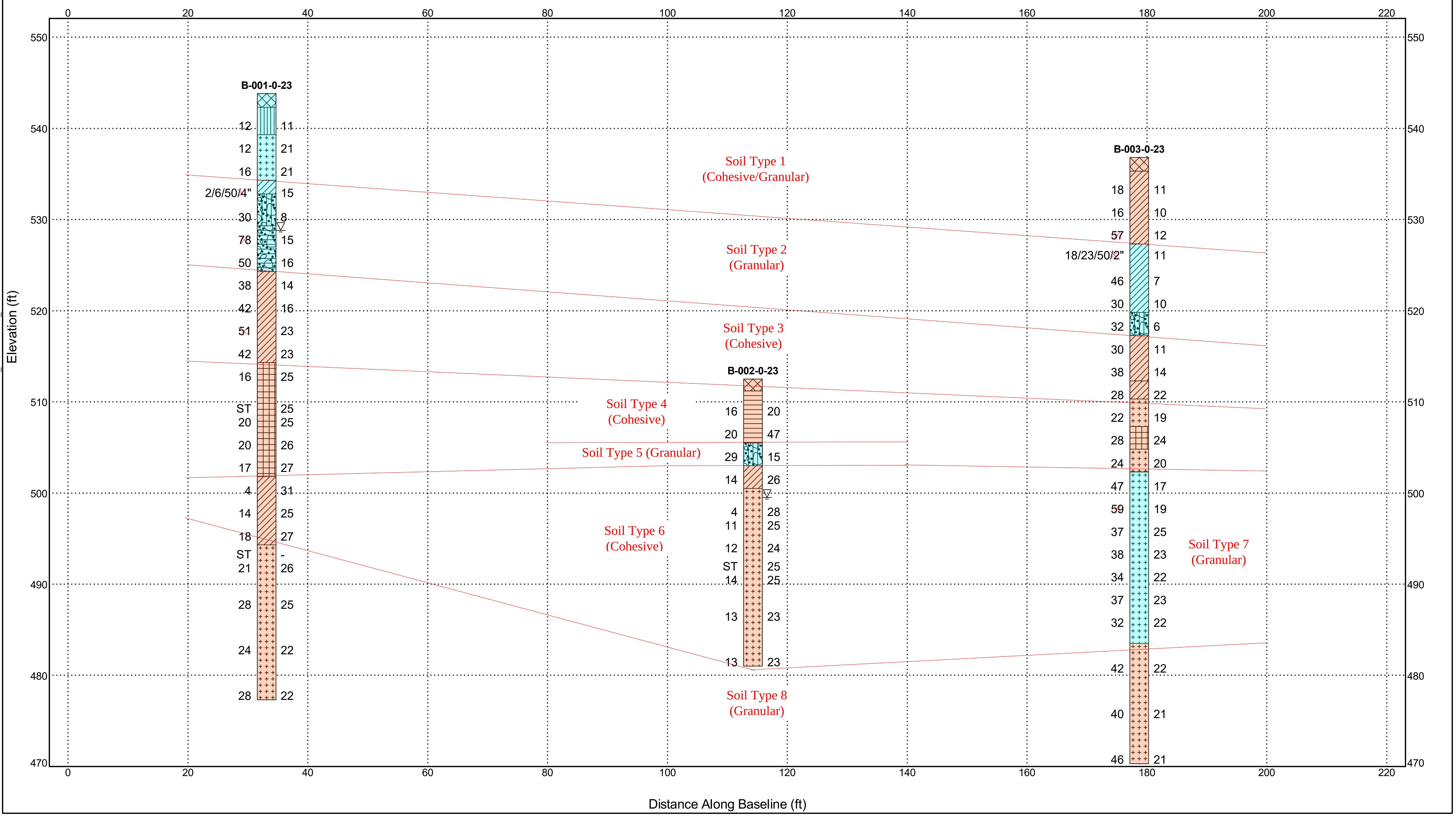
GENREALIZED SOIL PROFILE FOR ANALYSIS

OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

SUBSURFACE DIAGRAM

CLIENT Stantec
PROJECT NUMBER PID 114497
PROJECT NAME HAM-Columbia Connector
PROJECT LOCATION Mariemont, OH

⊠	Ohio DOT: Pavement or Aggregate base
▨	Ohio DOT: A-6a, silt and clay
▦	Ohio DOT: A-7-6, clay
▥	Ohio DOT: A-4a, sandy silt
⁘	Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt
▤	Ohio DOT: A-6b, silty clay
⁜	Ohio DOT: A-4b, silt
⁘	Ohio DOT: A-2-6, gravel and/or stone fragments with sand, silt and clay

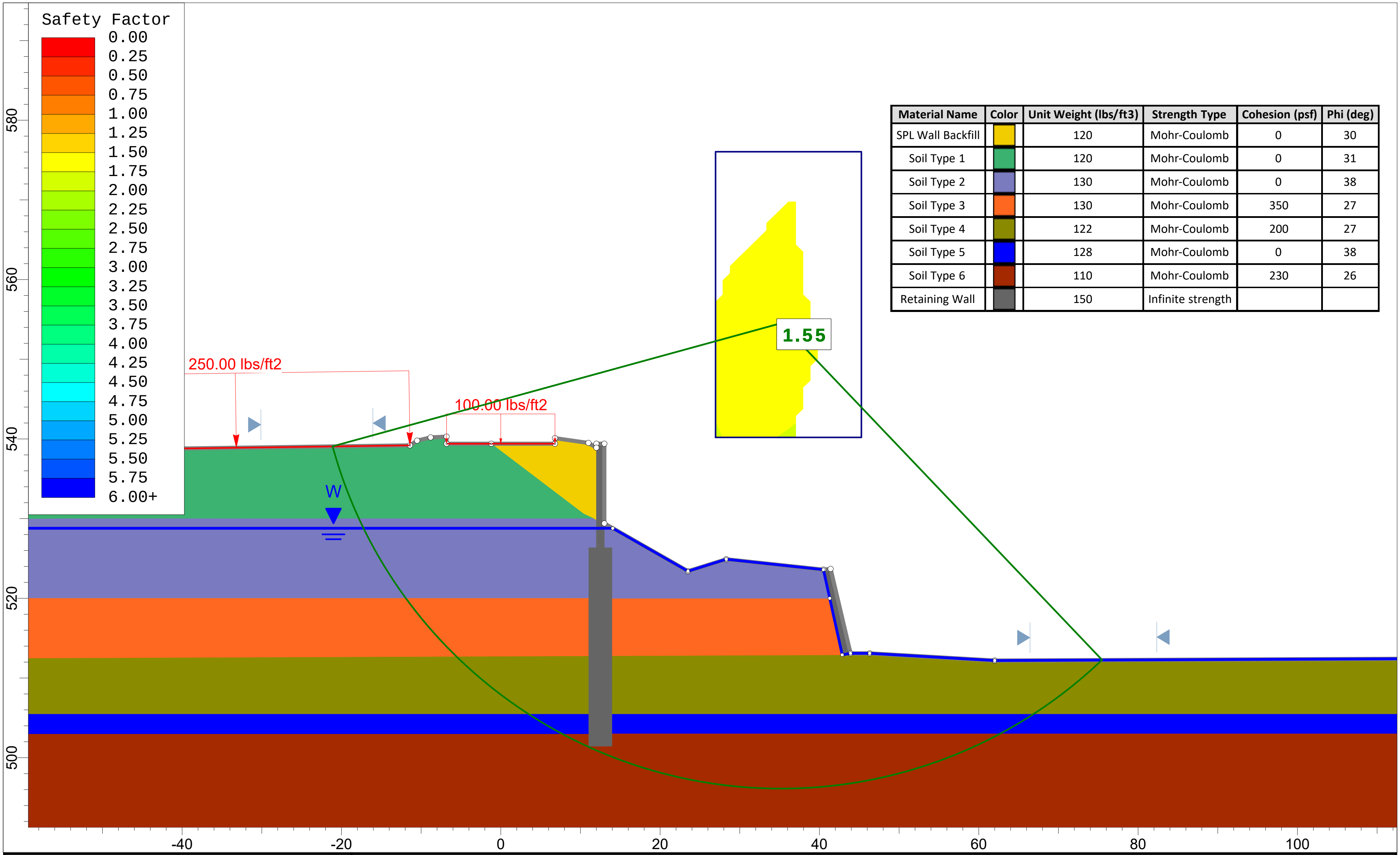


STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 4/9/24 10:51 - C:\USERS\KARENS\DESKTOP\GINT PROFILE\COLUMBIA_CONNECTOR_23-0064.GPJ

APPENDIX D

SPL WALL GLOBAL STABILITY ANALYSIS

STA. 46+00



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	350	27
Soil Type 4	🟩	122	Mohr-Coulomb	200	27
Soil Type 5	🟦	128	Mohr-Coulomb	0	38
Soil Type 6	🟫	110	Mohr-Coulomb	230	26
Retaining Wall	⬛	150	Infinite strength		

Project
HAM-Columbia Connector - PID 114496

Analysis Description
SPL Wall Stability Analysis - At STA. 46+00 - Effective Stress, Circular Failure

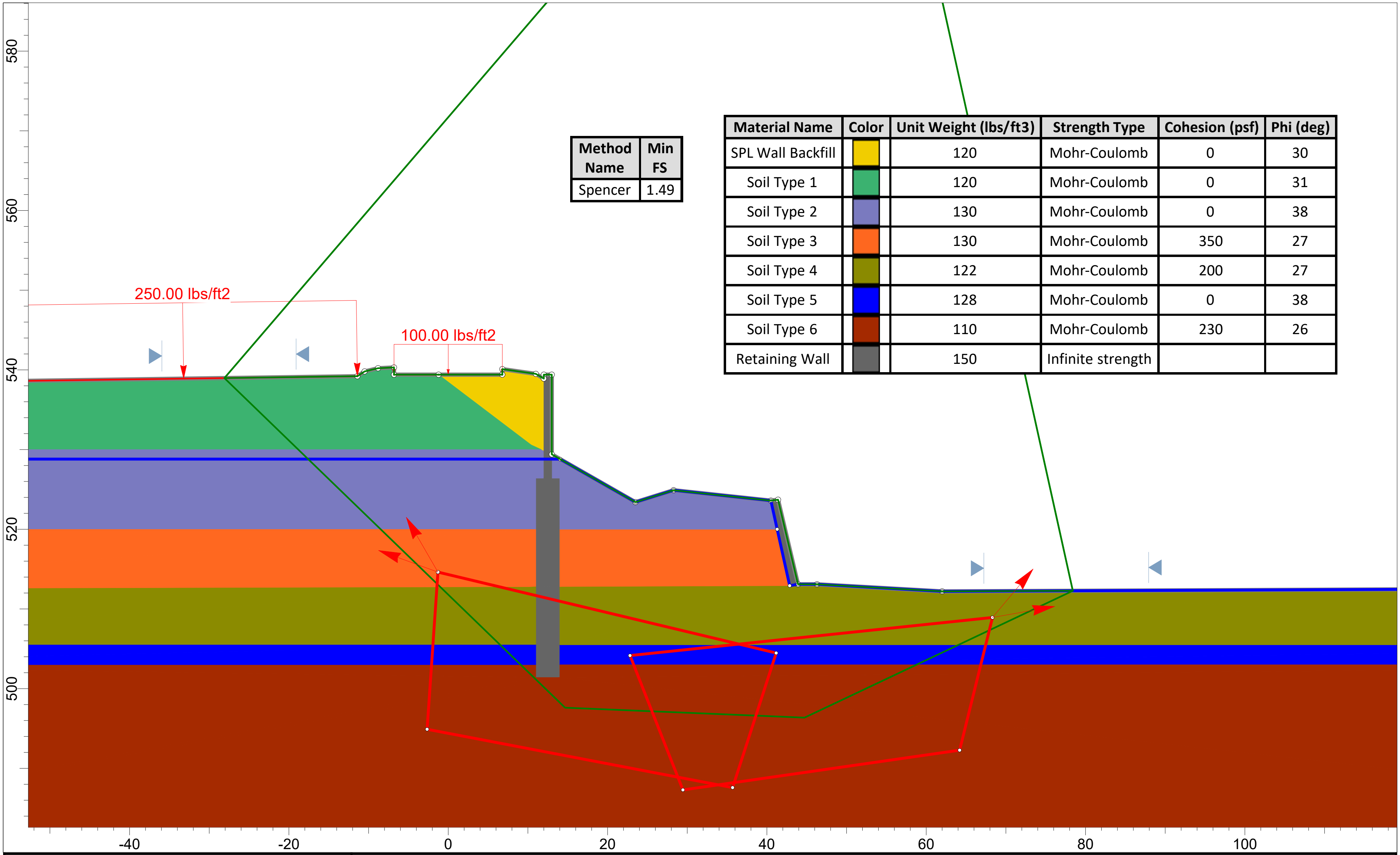
Drawn By KCA

Company NEAS Inc.

Date 4/15/2024, 3:37:58 PM

File Name Slide_STA_46+00_041524.slmd

SLIDEINTERPRET 9.025



Method Name	Min FS
Spencer	1.49

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	350	27
Soil Type 4	🟫	122	Mohr-Coulomb	200	27
Soil Type 5	🟦	128	Mohr-Coulomb	0	38
Soil Type 6	🟥	110	Mohr-Coulomb	230	26
Retaining Wall	⬛	150	Infinite strength		

Project HAM-Columbia Connector - PID 114496

Analysis Description SPL Wall Stability Analysis - At STA. 46+00 - Effective Stress, Block Failure

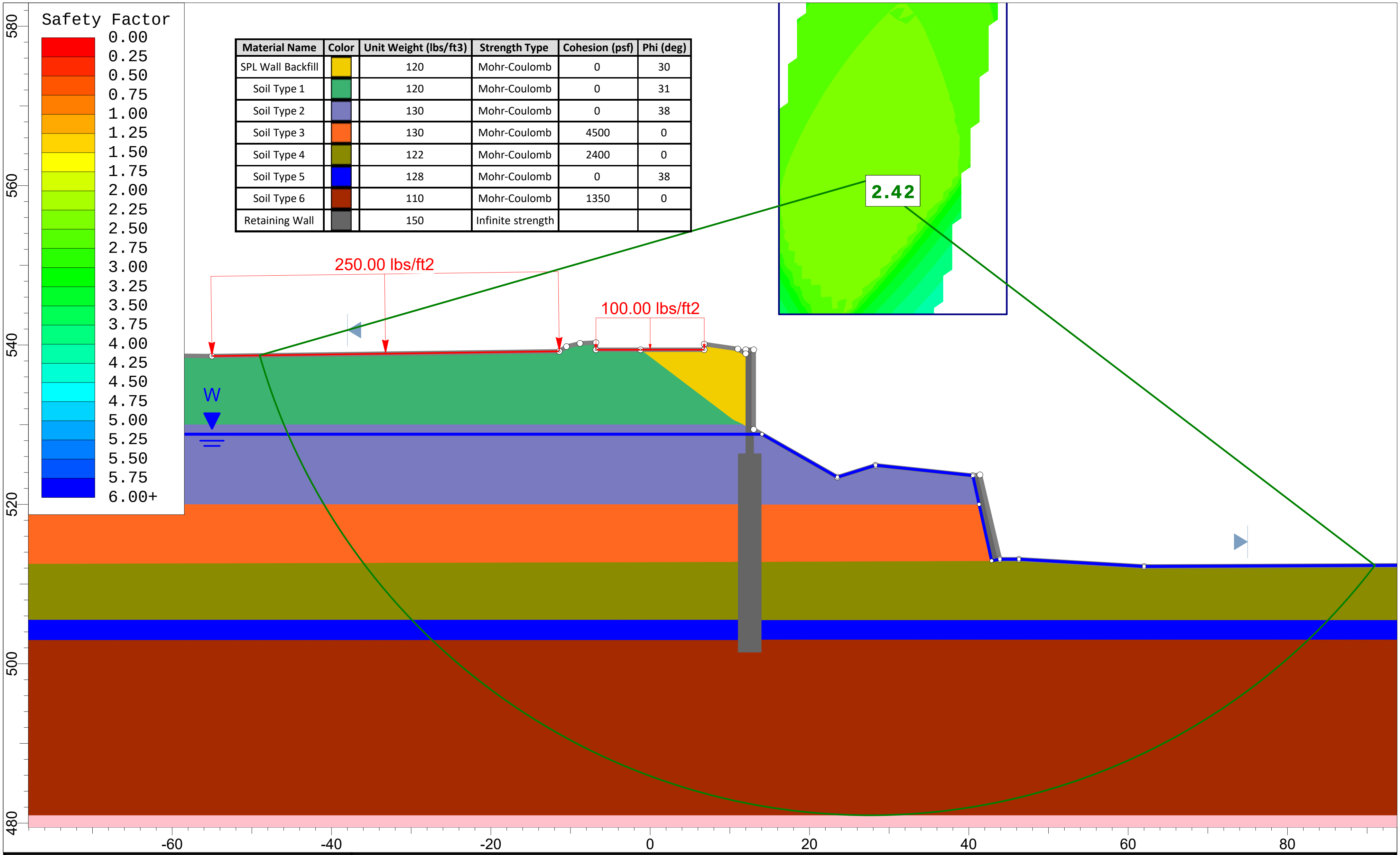
Drawn By KCA

Company NEAS Inc.

Date 4/15/2024, 3:37:58 PM

File Name SlideEffectiveBlock_STA_46+00_041524.slmd

SLIDEINTERPRET 9.025

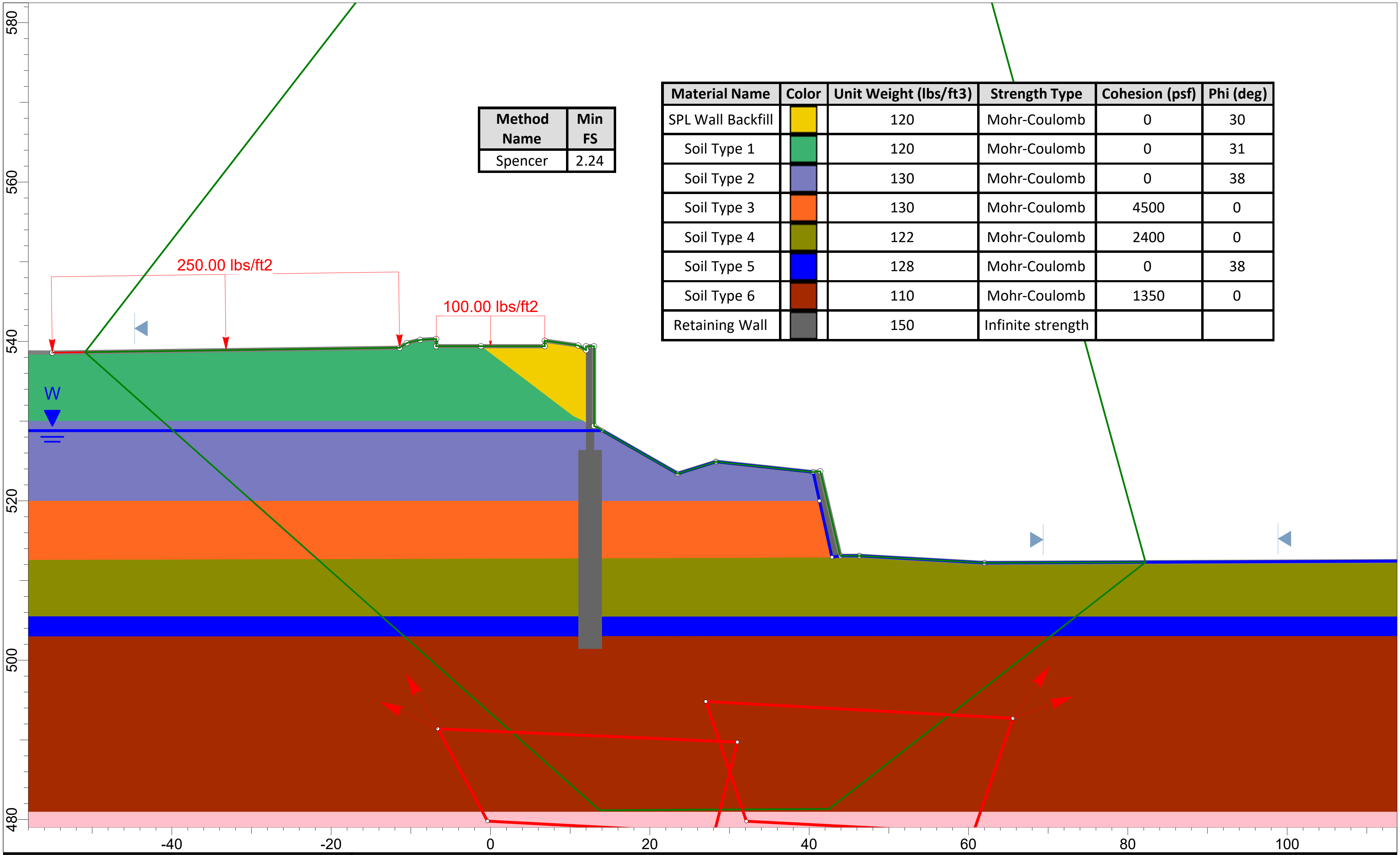


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	4500	0
Soil Type 4	🟫	122	Mohr-Coulomb	2400	0
Soil Type 5	🟦	128	Mohr-Coulomb	0	38
Soil Type 6	🟥	110	Mohr-Coulomb	1350	0
Retaining Wall	⬛	150	Infinite strength		

rocscience

SLIDEINTERPRET 9.025

Project	HAM-Columbia Connector - PID 114496
Analysis Description	SPL Wall Stability Analysis - At STA. 46+00 - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	4/15/2024, 3:37:58 PM
File Name	SlideTotal_STA_46+00_041524.slmd



Method Name	Min FS
Spencer	2.24

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	4500	0
Soil Type 4	🟫	122	Mohr-Coulomb	2400	0
Soil Type 5	🟦	128	Mohr-Coulomb	0	38
Soil Type 6	🟥	110	Mohr-Coulomb	1350	0
Retaining Wall	⬛	150	Infinite strength		

rocscience

SLIDEINTERPRET 9.025

Project
HAM-Columbia Connector - PID 114496

Analysis Description
SPL Wall Stability Analysis - At STA. 46+00 - Total Stress, Block Failure

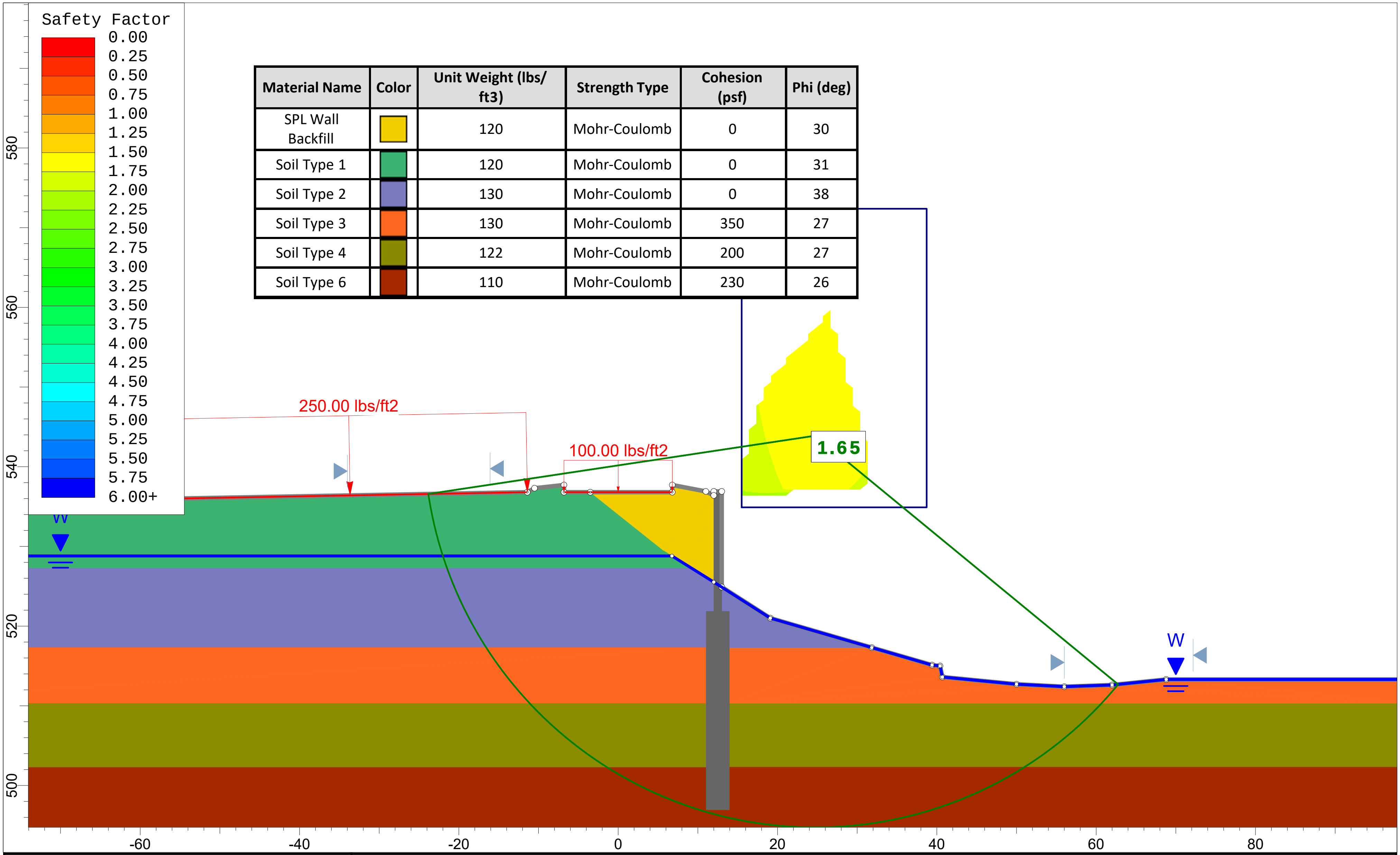
Drawn By
KCA

Company
NEAS Inc.

Date
4/15/2024, 3:37:58 PM

File Name
SlideTotalBlock_STA_46+00_041524.slmd

STA. 46+50



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	350	27
Soil Type 4	🟫	122	Mohr-Coulomb	200	27
Soil Type 6	🟥	110	Mohr-Coulomb	230	26

rocscience

SLIDEINTERPRET 9.025

Project
HAM-Columbia Connector - PID 114496

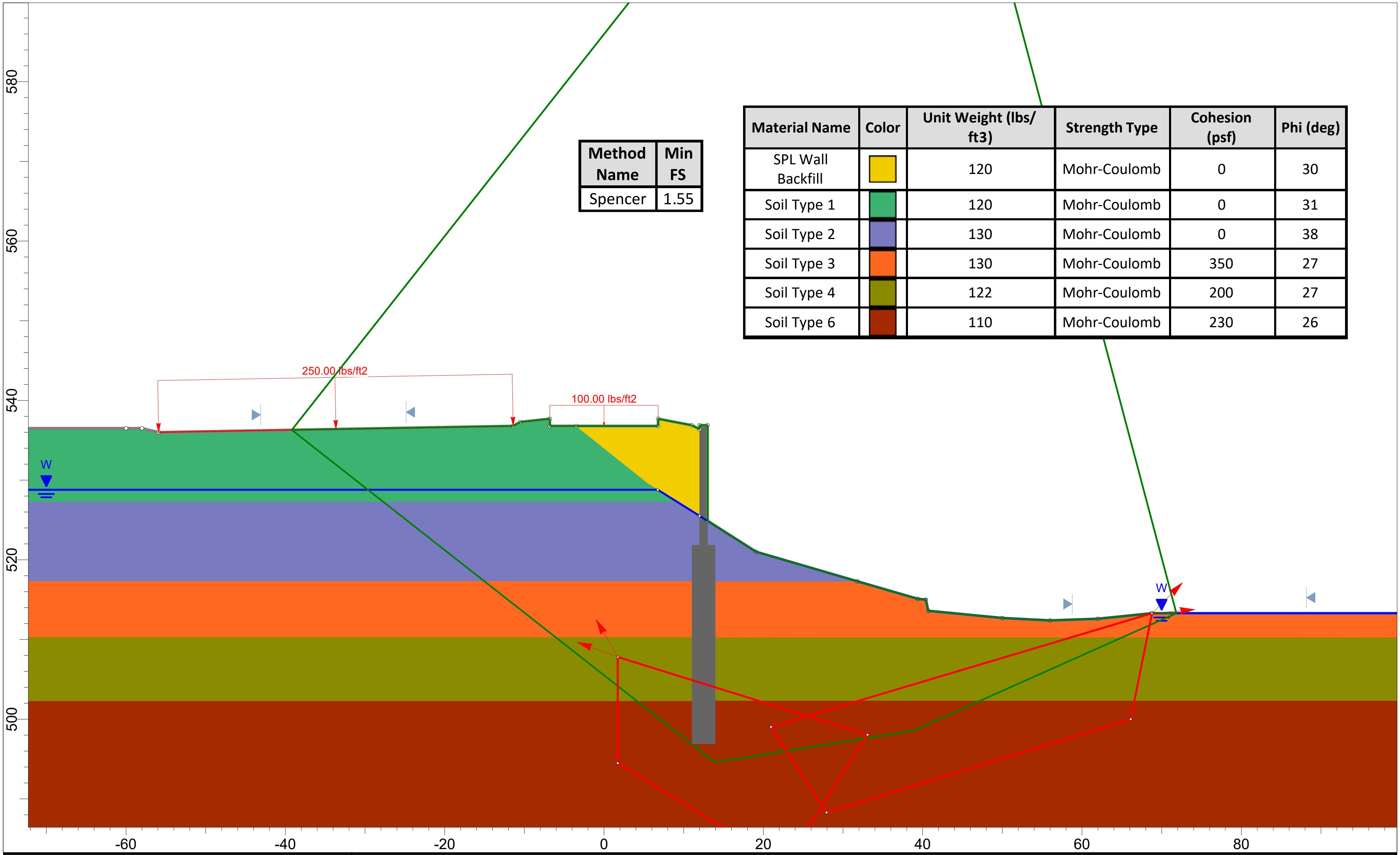
Analysis Description
SPL Wall Stability Analysis - At STA. 46+50 - Effective Stress, Circular Failure

Drawn By
KCA

Company
NEAS Inc.

Date
4/15/2024, 3:37:58 PM

File Name
SlideEffective_STA_46+50_041524.slmd

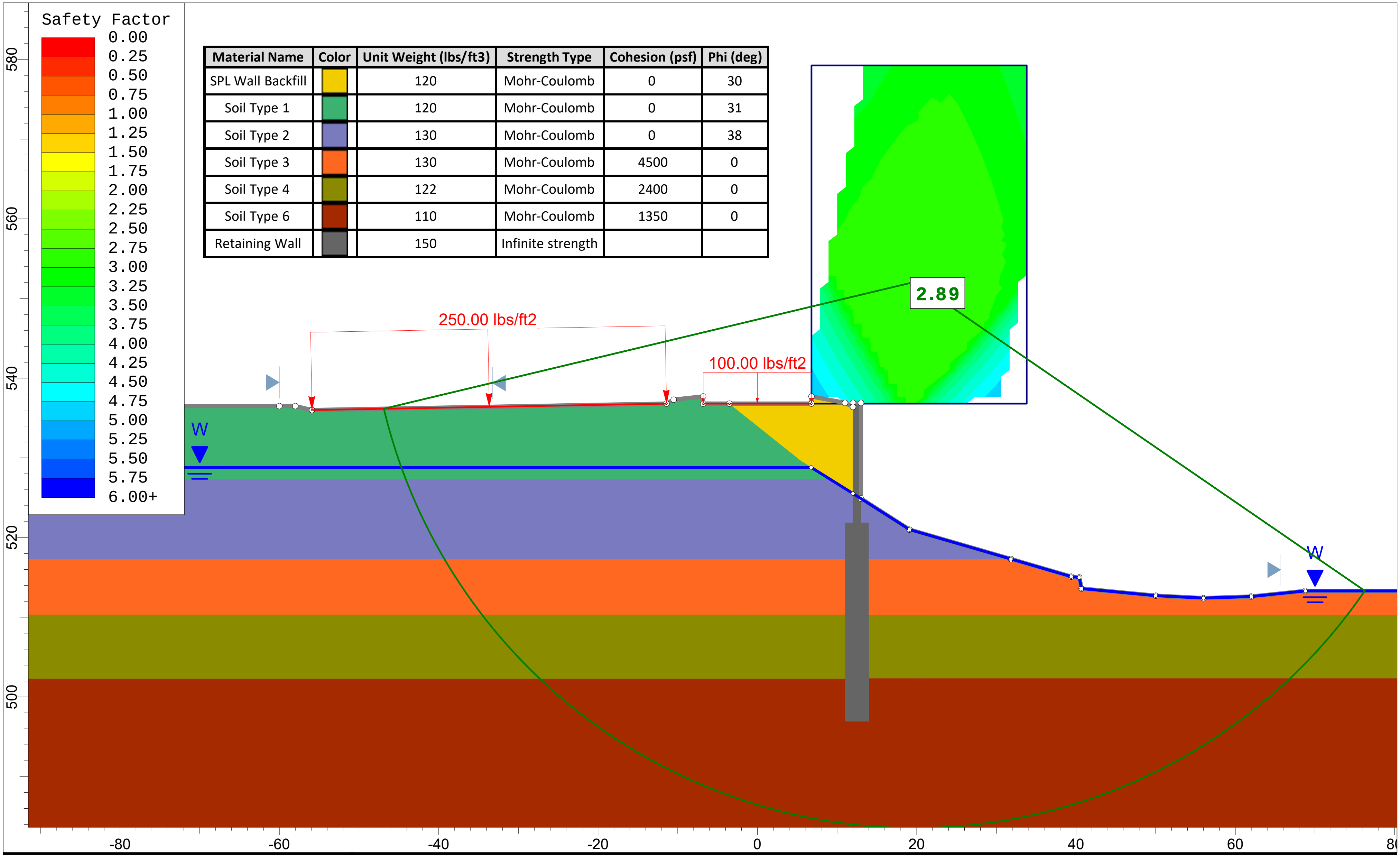


Method Name	Min FS
Spencer	1.55

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	350	27
Soil Type 4	🟫	122	Mohr-Coulomb	200	27
Soil Type 6	🟥	110	Mohr-Coulomb	230	26

Project	HAM-Columbia Connector - PID 114496
Analysis Description	SPL Wall Stability Analysis - At STA. 46+50 - Effective Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	4/15/2024, 3:37:58 PM
File Name	SlideEffectiveBlock_STA_46+50_041524.slmd

SLIDEINTERPRET 9.025

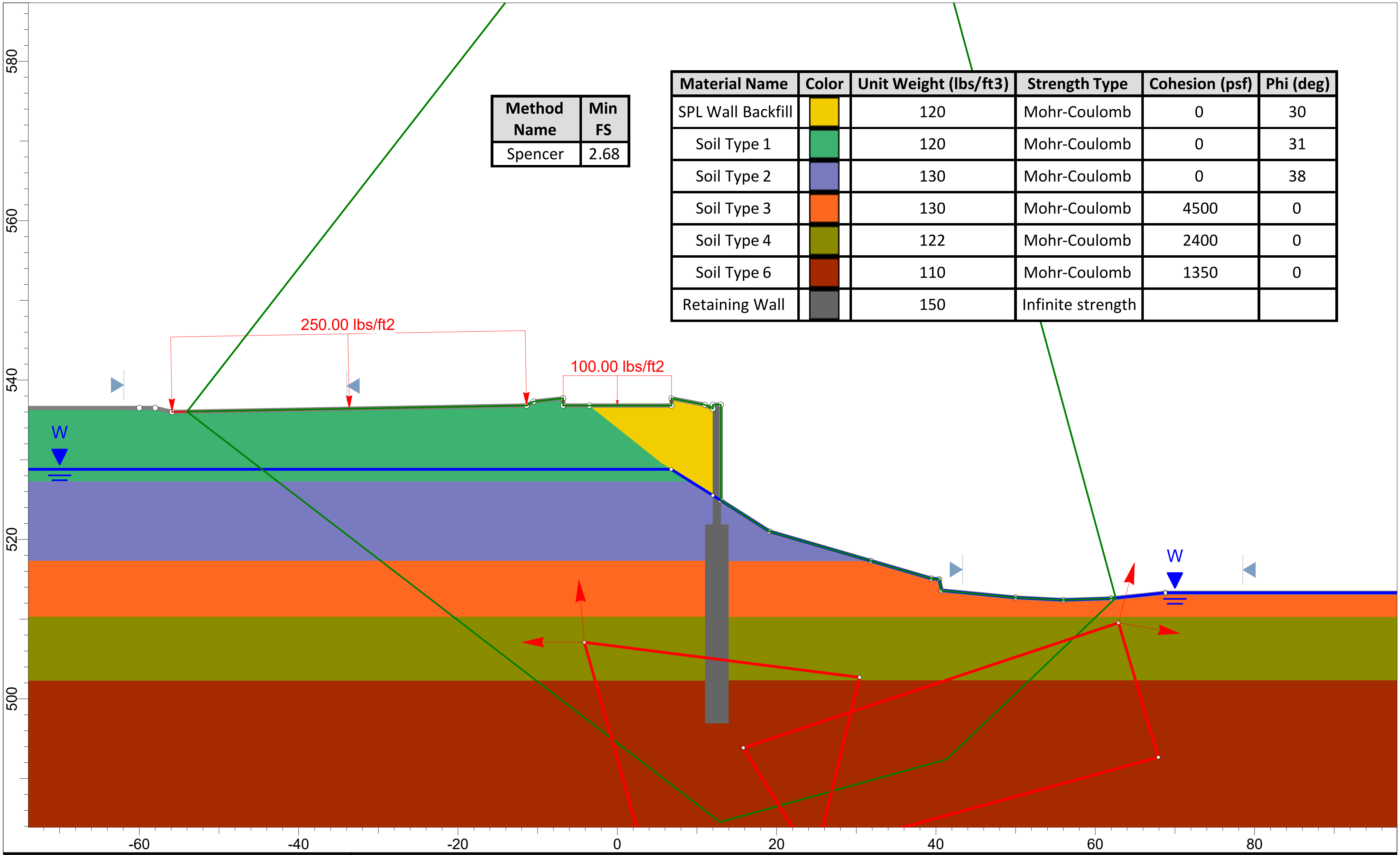


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	4500	0
Soil Type 4	🟫	122	Mohr-Coulomb	2400	0
Soil Type 6	🟥	110	Mohr-Coulomb	1350	0
Retaining Wall	⬛	150	Infinite strength		

rocscience

SLIDEINTERPRET 9.025

Project	HAM-Columbia Connector - PID 114496
Analysis Description	SPL Wall Stability Analysis - At STA. 46+50 - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	4/15/2024, 3:37:58 PM
File Name	SlideTotal_STA_46+50_041524.slmd



Method Name	Min FS
Spencer	2.68

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
SPL Wall Backfill	🟨	120	Mohr-Coulomb	0	30
Soil Type 1	🟩	120	Mohr-Coulomb	0	31
Soil Type 2	🟪	130	Mohr-Coulomb	0	38
Soil Type 3	🟧	130	Mohr-Coulomb	4500	0
Soil Type 4	🟫	122	Mohr-Coulomb	2400	0
Soil Type 6	🟥	110	Mohr-Coulomb	1350	0
Retaining Wall	⬛	150	Infinite strength		

rocscience

SLIDEINTERPRET 9.025

Project	HAM-Columbia Connector - PID 114496
Analysis Description	SPL Wall Stability Analysis - At STA. 46+50 - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	4/15/2024, 3:37:58 PM
File Name	SlideTotalBlock_STA_46+50_041524.slmd

APPENDIX E

MOMENT EQUILIBRIUM ANALYSIS

Objective: **To evaluate the Moment Equilibrium for Soldier Pile w/ Lagging wall embedment depth determination. For walls embedded in cohesive soils, with granular backfill and no live load surcharge behind wall.**

Method: **In accordance with ODOT 2020 Bridge Design Manual, 2024 [Sect. 307] LRFD Bridge Design Specifications, 8th Ed., 2017, [Sect. 3.11.5.6 & Sect. 11.8].**

Givens:

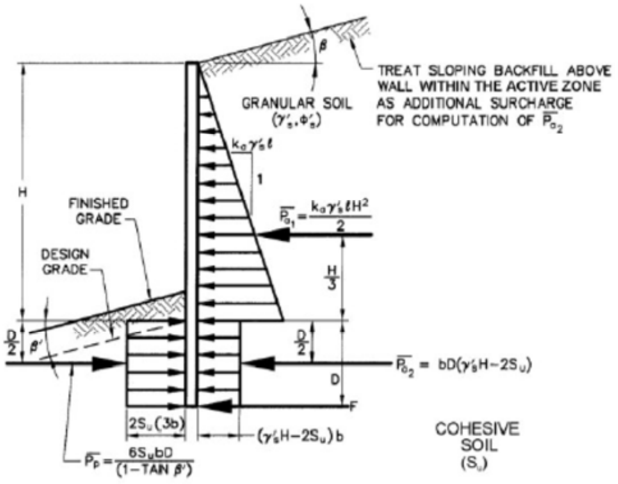
Backfill Soil Design Parameters:

$\phi'_1 := 30 \cdot deg$	Effective angle of internal friction
$\gamma_1 := 120 \cdot \frac{lbf}{ft^3}$	Unit weight
$\gamma'_1 := \gamma_1 - 62.4 \cdot \frac{lbf}{ft^3}$	Effective Unit weight
$\delta := 0\ deg$	Interface Friction Angle Between Retained Material and Wall Surface **ODOT BDM Sect. 307.7.7**

Embedment Soil Design Parameters:

$S_u := 2170\ psf$	Undrained shear strength (weighted average of cohesive layers)
$\gamma_2 := 122 \cdot \frac{lbf}{ft^3}$	Unit weight
$\gamma'_2 := \gamma_2 - 62.4 \cdot \frac{lbf}{ft^3}$	Effective Unit weight

Wall Geometry:



b = ACTUAL WIDTH OF EMBEDDED DISCRETE VERTICAL WALL ELEMENT BELOW DESIGN GRADE IN PLANE OF WALL (FT.).

Wall Design Parameters:

$\beta := 12.36\ deg$	Inclination of ground slope behind face of wall
$\beta' := 32.62\ deg$	Inclination of ground slope in front of face of wall
$\theta := 90 \cdot deg$	Angle of back face of wall to horizontal
$H := 15\ ft$	Wall Height (as measured from top of wall to top of shaft)
$H_e := 12\ ft$	Exposed Height of Wall
$H' := (4\ ft \cdot \tan(\beta')) + H_e$ $H := \text{if}(H' > H, H', H) = 15\ ft$	Design Wall Height (Top of Wall to Design Grade)
$b := 3.5\ ft$	Actual Width/Diameter of Embedded Discrete Vertical Wall Element
$l := 8\ ft$	Width of Vertical Wall Element Above Design Grade (i.e., CTC Spacing of Soldier Piles)

Earth Pressure Coefficients:

Backfill Active Earth:

$$\Gamma := \left(1 + \sqrt{\frac{(\sin(\phi'_1 + \delta) \cdot \sin(\phi'_1 - \beta))}{(\sin(\theta - \delta) \cdot \sin(\theta + \beta))}}\right)^2 \qquad \Gamma = 1.943$$

$$k_{a1} := \left(\frac{(\sin(\theta + \phi'_1))^2}{(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta))}\right) \qquad k_{a1} = 0.386$$

Active Earth Pressure Coefficient (**per LRFD Sect. 3.11.5.3**)

Load and Resistance Factors:

$\gamma_{EH} := 1.5$	Load Factor for Loads induced by Active Horizontal Earth Pressures **(LRFD Table 3.4.1-2)**
$\phi_P := 0.75$	Resistance Factor for Passive Horizontal Earth Resistance **(LRFD Table 11.5.7-1)**

Embedment Depth:

Adjust D until Sum of Moments below approaches zero

$D := 11.34823823\ ft$

Driving Forces:

$e := 45 + \frac{\phi'_1}{2} = 45.3$

Active Earth Pressures:

Overburden stress of soil wedge at top of wall:

$$\sigma_w := 0.5 \cdot \left(H \cdot \tan\left(90\ deg - \left(45\ deg + \frac{\phi'_1}{2}\right)\right)\right) \cdot \tan(\beta) \cdot \gamma_1 = 113.9\ psf$$

Factored Active Earth Load on Wall by Fill (**LRFD Figure 3.11.5.6-1** shown above)

$$P_{a1} := \frac{1}{2} \cdot k_{a1} \cdot \gamma_1 \cdot H^2 \cdot l$$

$$F_{a1} := P_{a1} \cdot \gamma_{EH} = 62538.6\ lbf$$

Factored Active Earth Load on Wall by Embedment Soils (**LRFD Figure 3.11.5.6-1** shown above)

$$P_{a2} := b \cdot D \cdot \left(\left(\gamma'_1 \cdot H + \sigma_w\right) - 2 \cdot S_u\right)$$

$$F_{a2} := \text{if}\left(P_{a2} \cdot \gamma_{EH} < 0, 0\ lbf, P_{a2} \cdot \gamma_{EH}\right) = 0\ lbf$$

Resisting Forces:

Passive Earth Pressures:

$WidthForPassive := \text{if}\left(l < 3\ b, \text{“USE CTC SPACING”}, \text{“USE 3b”}\right) = \text{“USE CTC SPACING”}$

$w := l$

Width for passive resistance calculation: If CTC spacing l<3b use l for width of passive resistance per **ODOT BDM Sect. 307.1.1**

$$P_{p1} := \frac{2\ w \cdot S_u \cdot D}{\left(1 - \tan\left(-\beta'\right)\right)}$$

$$F_{p1} := P_{p1} \cdot \phi_P = 180185.8\ lbf$$

Factored Passive Earth Resistance on Wall by Embedment Soils (**LRFD Figure 3.11.5.6-1** shown above)
If spacing <3b replace 6b in the equation with $2 \cdot l$

Moment Equilibrium:

Driving Moments:

$F_{a1} = 62538.6\ lbf$ $\quad d_{a1} := \frac{1}{3} \cdot H + D$

$M_{a1} := F_{a1} \cdot d_{a1}$

$F_{a2} = 0\ lbf$ $\quad d_{a2} := \frac{D}{2}$

$M_{a2} := F_{a2} \cdot d_{a2}$

Resisting Moments:

$F_{p1} = 180185.8\ lbf$ $\quad d_{p1} := \frac{D}{2} = 5.7\ ft$ $\quad M_{p1} := F_{p1} \cdot d_{p1}$

Sum of Moments:

$$M_{a1} + M_{a2} - M_{p1} = 0\ \frac{lb \cdot ft^2}{s^2}$$

Distributed Load for LPile Input:

$P_{a1} := k_{a1} \cdot \gamma_1 \cdot H \cdot l$

$P_{a1} = 5559\ \frac{lbf}{ft}$

$P_{a1} = 463.2\ \frac{lbf}{in}$ Nominal Horizontal Earth Load at Bottom of Design Height

$\gamma_{EH} \cdot P_{a1} = 694.9\ \frac{lbf}{in}$ Factored Horizontal Earth Load at Bottom of Design Height

APPENDIX F

LPILE ANALYSIS

SERVICE I LIMIT STATE

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

                     LPile for Windows, Version 2016-09.003

                 Analysis of Individual Piles and Drilled Shafts
                Subjected to Lateral Loading Using the p-y Method
                           © 1985-2015 by Ensoft, Inc.
                               All Rights Reserved

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

This copy of LPile is being used by:

NEAS
Columbus

Serial Number of Security Device: 136151274

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Use of this program by any entity other than Barr Engineering, Inc., Cincinna
is a violation of the software license agreement.

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

Path to file locations:
\Users\karens\Desktop\ColumbiaConnector\

Name of input data file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9d

Name of output report file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9o

Name of plot output file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9p

Name of runtime message file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9r


--------------------------------------------------------------------------------
                            Date and Time of Analysis
--------------------------------------------------------------------------------
```

```
               Date:  April 15, 2024             Time:  14:39:01



--------------------------------------------------------------------------------
                                  Problem Title
--------------------------------------------------------------------------------

Project Name:



Job Number:



Client:



Engineer:



Description:






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

Computational Options:
 - Use unfactored loads in computations (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 includes loading by one distributed lateral load acting on pile
 - Loading by lateral soil movements acting on pile not selected
 - Input of shear 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              =      15.0000 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.

            Depth Below           Pile
Point        Pile Head          Diameter
 No.            feet             inches
-----      -------------     -------------
  1             0.000          42.0000
  2            40.000          42.0000


Input Structural Properties for Pile Sections:
----------------------------------------------

Pile Section No. 1:

   Section 1 is an elastic pile
   Cross-sectional Shape                               =   Circular Pile
   Length of section                                   =    40.000000 ft
   Width of top of section                             =    42.000000 in
   Width of bottom of section                          =    42.000000 in
   Top Area                                            =    41.600000 sq. in
```

```
   Bottom Area                                         =    41.600000 sq. in
   Moment of Inertia at Top                            =        7450. in^4
   Moment of Inertia at Bottom                         =        7450. in^4
   Elastic Modulus                                     =    29000000. psi



--------------------------------------------------------------------------------
                       Ground Slope and Pile Batter Angles
--------------------------------------------------------------------------------

Ground Slope Angle                                     =       32.600 degrees
                                                       =        0.569 radians

Pile Batter Angle                                      =        0.000 degrees
                                                       =        0.000 radians


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

The soil profile is modelled using 5 layers

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

   Distance from top of pile to top of layer           =    15.000000 ft
   Distance from top of pile to bottom of layer        =    24.600000 ft
   Effective unit weight at top of layer               =    67.600000 pcf
   Effective unit weight at bottom of layer            =    67.600000 pcf
   Friction angle at top of layer                      =    38.000000 deg.
   Friction angle at bottom of layer                   =    38.000000 deg.
   Subgrade k at top of layer                          =   175.000000 pci
   Subgrade k at bottom of layer                       =   175.000000 pci


Layer 2 is stiff clay without free water

   Distance from top of pile to top of layer           =    24.600000 ft
   Distance from top of pile to bottom of layer        =    31.600000 ft
   Effective unit weight at top of layer               =    67.600000 pcf
   Effective unit weight at bottom of layer            =    67.600000 pcf
   Undrained cohesion at top of layer                  =        4500. psf
   Undrained cohesion at bottom of layer               =        4500. psf
   Epsilon-50 at top of layer                          =     0.004300
   Epsilon-50 at bottom of layer                       =     0.004300


Layer 3 is stiff clay without free water
```

```
   Distance from top of pile to top of layer           =    31.600000 ft
   Distance from top of pile to bottom of layer        =    39.600000 ft
   Effective unit weight at top of layer               =    59.600000 pcf
   Effective unit weight at bottom of layer            =    59.600000 pcf
   Undrained cohesion at top of layer                  =        2400. psf
   Undrained cohesion at bottom of layer               =        2400. psf
   Epsilon-50 at top of layer                          =     0.005700
   Epsilon-50 at bottom of layer                       =     0.005700


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

   Distance from top of pile to top of layer           =    39.600000 ft
   Distance from top of pile to bottom of layer        =    58.400000 ft
   Effective unit weight at top of layer               =    67.600000 pcf
   Effective unit weight at bottom of layer            =    67.600000 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                          =    55.000000 pci
   Subgrade k at bottom of layer                       =    55.000000 pci


Layer 5 is stiff clay without free water

   Distance from top of pile to top of layer           =    58.400000 ft
   Distance from top of pile to bottom of layer        =    71.600000 ft
   Effective unit weight at top of layer               =    65.600000 pcf
   Effective unit weight at bottom of layer            =    65.600000 pcf
   Undrained cohesion at top of layer                  =        3850. psf
   Undrained cohesion at bottom of layer               =        3850. psf
   Epsilon-50 at top of layer                          =     0.004600
   Epsilon-50 at bottom of layer                       =     0.004600


 (Depth of the lowest soil layer extends 31.600 ft below the pile tip)



--------------------------------------------------------------------------------
                        Summary of Input Soil Properties
--------------------------------------------------------------------------------

Layer         Soil Type          Layer      Effective    Undrained    Angle of
  E50
Layer           Name             Depth       Unit Wt.    Cohesion     Friction
  or           kpy
 Num.     (p-y Curve Type)        ft           pcf          psf          deg.
  krm          pci
-----   -------------------   ----------   ----------   ----------   ----------
```

```
----------   ----------
  1           Sand              15.0000     67.6000       --          38.0000
  --        175.0000
          (Reese, et al.)       24.6000     67.6000       --          38.0000
  --        175.0000
  2         Stiff Clay          24.6000     67.6000       4500.        --
 0.00430      --
          w/o Free Water        31.6000     67.6000       4500.        --
 0.00430      --
  3         Stiff Clay          31.6000     59.6000       2400.        --
 0.00570      --
          w/o Free Water        39.6000     59.6000       2400.        --
 0.00570      --
  4           Sand              39.6000     67.6000       --          33.0000
  --         55.0000
          (Reese, et al.)       58.4000     67.6000       --          33.0000
  --         55.0000
  5         Stiff Clay          58.4000     65.6000       3850.        --
 0.00460      --
          w/o Free Water        71.6000     65.6000       3850.        --
 0.00460      --


--------------------------------------------------------------------------------
                    p-y Modification Factors for Group Action
--------------------------------------------------------------------------------

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

Point      Depth X         p-mult         y-mult
 No.          ft
-----     ----------     ----------     ----------
  1          15.000         0.8500         1.0000
  2          70.000         0.8500         1.0000



--------------------------------------------------------------------------------
                               Static Loading Type
--------------------------------------------------------------------------------

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



--------------------------------------------------------------------------------
                 Distributed Lateral Loading Used For All Load Cases
--------------------------------------------------------------------------------
```

```
Distributed lateral load intensity defined using 2 points

Point           Depth X            Dist. Load
 No.               in                lb/in
-----          ----------          ----------
  1               0.000               0.000
  2             180.000             463.200



--------------------------------------------------------------------------------
                Pile-head Loading and Pile-head Fixity Conditions
--------------------------------------------------------------------------------

Number of loads specified = 1

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

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
--------------------------------------------------------------------------------

         Top of    Equivalent
          Layer     Top Depth   Same Layer  Layer is       F0          F1
Layer     Below       Below      Type As    Rock or     Integral    Integral
 No.    Pile Head   Grnd Surf     Layer     is Below   for Layer   for Layer
            ft          ft        Above    Rock Layer     lbs         lbs
-----  ----------  ----------  ----------  ----------  ----------  ----------
  1       15.0000        0.00      N.A.         No          0.00     181476.
  2       24.6000      3.5156      No           No       181476.     462555.
  3       31.6000     10.5156      Yes          No       644031.     379486.
  4       39.6000     25.2491      No           No      1023517.      42140.
  5       58.4000     43.4000      No           No      1065658.      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*      in-lb^2
lb/inch    lb/inch    lb/inch
---------- ---------- ---------- ---------- ---------- ---------- ----------
---------- ---------- ----------
      0.00     1.7059   4.79E-05   2.17E-07   -0.00591   1.35E-07   2.16E+11
0.00       0.00     3.0880
    0.4000     1.6775    35.5739    37.0560   -0.00591     0.1003   2.16E+11
0.00       0.00    12.3520
    0.8000     1.6491   355.7377   125.9904   -0.00591     1.0028   2.16E+11
```

```
0.00       0.00    24.7040
    1.2000     1.6208      1245.   274.2144   -0.00591     3.5096   2.16E+11
0.00       0.00    37.0560
    1.6000     1.5924      2988.   481.7280   -0.00591     8.4231   2.16E+11
0.00       0.00    49.4080
    2.0000     1.5640      5870.   748.5312   -0.00591    16.5454   2.16E+11
0.00       0.00    61.7600
    2.4000     1.5357     10174.      1075.   -0.00591    28.6787   2.16E+11
0.00       0.00    74.1120
    2.8000     1.5073     16186.      1460.   -0.00591    45.6251   2.16E+11
0.00       0.00    86.4640
    3.2000     1.4789     24190.      1905.   -0.00591    68.1870   2.16E+11
0.00       0.00    98.8160
    3.6000     1.4506     34471.      2409.   -0.00591    97.1665   2.16E+11
0.00       0.00   111.1680
    4.0000     1.4222     47313.      2972.   -0.00591   133.3658   2.16E+11
0.00       0.00   123.5200
    4.4000     1.3939     63001.      3594.   -0.00591   177.5871   2.16E+11
0.00       0.00   135.8720
    4.8000     1.3655     81820.      4276.   -0.00590   230.6326   2.16E+11
0.00       0.00   148.2240
    5.2000     1.3372    104053.      5017.   -0.00590   293.3045   2.16E+11
0.00       0.00   160.5760
    5.6000     1.3089    129987.      5818.   -0.00590   366.4050   2.16E+11
0.00       0.00   172.9280
    6.0000     1.2806    159904.      6677.   -0.00590   450.7363   2.16E+11
0.00       0.00   185.2800
    6.4000     1.2523    194090.      7596.   -0.00589   547.1006   2.16E+11
0.00       0.00   197.6320
    6.8000     1.2240    232830.      8575.   -0.00589   656.3001   2.16E+11
0.00       0.00   209.9840
    7.2000     1.1957    276408.      9612.   -0.00588   779.1370   2.16E+11
0.00       0.00   222.3360
    7.6000     1.1675    325109.     10709.   -0.00588   916.4135   2.16E+11
0.00       0.00   234.6880
    8.0000     1.1393    379216.     11865.   -0.00587      1069.   2.16E+11
0.00       0.00   247.0400
    8.4000     1.1112    439016.     13081.   -0.00586      1237.   2.16E+11
0.00       0.00   259.3920
    8.8000     1.0831    504792.     14355.   -0.00585      1423.   2.16E+11
0.00       0.00   271.7440
    9.2000     1.0550    576829.     15690.   -0.00584      1626.   2.16E+11
0.00       0.00   284.0960
    9.6000     1.0271    655411.     17083.   -0.00582      1847.   2.16E+11
0.00       0.00   296.4480
   10.0000     0.9991    740824.     18535.   -0.00581      2088.   2.16E+11
0.00       0.00   308.8000
   10.4000     0.9713    833351.     20047.   -0.00579      2349.   2.16E+11
0.00       0.00   321.1520
   10.8000     0.9436    933278.     21618.   -0.00577      2631.   2.16E+11
```

```
0.00       0.00   333.5040
   11.2000     0.9159   1040888.     23249.   -0.00575      2934.   2.16E+11
0.00       0.00   345.8560
   11.6000     0.8884   1156467.     24939.   -0.00572      3260.   2.16E+11
0.00       0.00   358.2080
   12.0000     0.8610   1280300.     26688.   -0.00570      3609.   2.16E+11
0.00       0.00   370.5600
   12.4000     0.8337   1412670.     28496.   -0.00567      3982.   2.16E+11
0.00       0.00   382.9120
   12.8000     0.8066   1553862.     30364.   -0.00563      4380.   2.16E+11
0.00       0.00   395.2640
   13.2000     0.7796   1704161.     32291.   -0.00560      4804.   2.16E+11
0.00       0.00   407.6160
   13.6000     0.7528   1863852.     34277.   -0.00556      5254.   2.16E+11
0.00       0.00   419.9680
   14.0000     0.7263   2033218.     36322.   -0.00551      5731.   2.16E+11
0.00       0.00   432.3200
   14.4000     0.6999   2212546.     38427.   -0.00547      6237.   2.16E+11
0.00       0.00   444.6720
   14.8000     0.6738   2402118.     40591.   -0.00542      6771.   2.16E+11
0.00       0.00   457.0240
   15.2000     0.6479   2602221.     41663.   -0.00536      7335.   2.16E+11
-10.2858    76.2009       0.00
   15.6000     0.6223   2802086.     41561.   -0.00530      7898.   2.16E+11
-32.3101   249.2086       0.00
   16.0000     0.5970   3001207.     41350.   -0.00524      8460.   2.16E+11
-55.8411   448.9498       0.00
   16.4000     0.5721   3199041.     41023.   -0.00517      9017.   2.16E+11
-80.3658   674.3285       0.00
   16.8000     0.5474   3395024.     40577.   -0.00509      9570.   2.16E+11
-105.4245   924.3910       0.00
   17.2000     0.5232   3588578.     40009.   -0.00502     10115.   2.16E+11
-130.9640      1202.       0.00
   17.6000     0.4993   3779114.     39320.   -0.00493     10653.   2.16E+11
-156.3229      1503.       0.00
   18.0000     0.4758   3966049.     38510.   -0.00485     11179.   2.16E+11
-181.0877      1827.       0.00
   18.4000     0.4527   4148811.     37584.   -0.00476     11695.   2.16E+11
-204.8592      2172.       0.00
   18.8000     0.4301   4326854.     36545.   -0.00466     12197.   2.16E+11
-227.8525      2543.       0.00
   19.2000     0.4080   4499647.     35400.   -0.00457     12684.   2.16E+11
-249.5236      2936.       0.00
   19.6000     0.3863   4666691.     34154.   -0.00446     13154.   2.16E+11
-269.3755      3347.       0.00
   20.0000     0.3651   4827528.     32819.   -0.00436     13608.   2.16E+11
-287.0987      3775.       0.00
   20.4000     0.3444   4981750.     31401.   -0.00425     14043.   2.16E+11
-303.4345      4229.       0.00
   20.8000     0.3243   5128982.     29907.   -0.00414     14458.   2.16E+11
```

```
-319.1729      4724.       0.00
   21.2000     0.3047   5268860.     28343.   -0.00402     14852.   2.16E+11
-332.5215      5238.       0.00
   21.6000     0.2857   5401076.     26721.   -0.00390     15225.   2.16E+11
-343.2587      5767.       0.00
   22.0000     0.2672   5525384.     25055.   -0.00378     15575.   2.16E+11
-351.1822      6308.       0.00
   22.4000     0.2494   5641600.     23349.   -0.00366     15902.   2.16E+11
-359.3943      6917.       0.00
   22.8000     0.2321   5749536.     21611.   -0.00353     16207.   2.16E+11
-364.9970      7548.       0.00
   23.2000     0.2155   5849063.     19852.   -0.00340     16487.   2.16E+11
-367.8692      8195.       0.00
   23.6000     0.1995   5940114.     18086.   -0.00327     16744.   2.16E+11
-367.9112      8854.       0.00
   24.0000     0.1841   6022688.     16324.   -0.00314     16977.   2.16E+11
-366.0389      9545.       0.00
   24.4000     0.1693   6096828.     14578.   -0.00300     17186.   2.16E+11
-361.7133     10253.       0.00
   24.8000     0.1552   6162635.     11410.   -0.00287     17371.   2.16E+11
-958.2347     29629.       0.00
   25.2000     0.1418   6206364.      6823.   -0.00273     17494.   2.16E+11
-952.8745     32256.       0.00
   25.6000     0.1290   6228139.      2265.   -0.00259     17556.   2.16E+11
-946.3564     35207.       0.00
   26.0000     0.1169   6228110.     -2259.   -0.00245     17556.   2.16E+11
-938.6483     38538.       0.00
   26.4000     0.1055   6206454.     -6743.   -0.00232     17495.   2.16E+11
-929.7149     42314.       0.00
   26.8000    0.09468   6163377.    -11181.   -0.00218     17373.   2.16E+11
-919.5165     46617.       0.00
   27.2000    0.08455   6099115.    -15567.   -0.00204     17192.   2.16E+11
-908.0086     51548.       0.00
   27.6000    0.07507   6013933.    -19895.   -0.00191     16952.   2.16E+11
-895.1397     57232.       0.00
   28.0000    0.06624   5908126.    -24157.   -0.00178     16654.   2.16E+11
-880.8496     63831.       0.00
   28.4000    0.05803   5782025.    -28347.   -0.00165     16298.   2.16E+11
-865.0664     71552.       0.00
   28.8000    0.05044   5635993.    -32458.   -0.00152     15887.   2.16E+11
-847.7025     80665.       0.00
   29.2000    0.04345   5470429.    -36481.   -0.00140     15420.   2.16E+11
-828.6486     91534.       0.00
   29.6000    0.03705   5285773.    -40409.   -0.00128     14899.   2.16E+11
-807.7647    104653.       0.00
   30.0000    0.03121   5082507.    -44231.   -0.00116     14327.   2.16E+11
-784.8665    120719.       0.00
   30.4000    0.02591   4861157.    -47938.   -0.00105     13703.   2.16E+11
-759.7042    140750.       0.00
   30.8000    0.02113   4622304.    -51518.  -9.45E-04     13029.   2.16E+11
```

```
-731.9257    166290.       0.00
   31.2000    0.01684   4366587.    -54957.  -8.45E-04     12308.   2.16E+11
-701.0143    199825.       0.00
   31.6000    0.01302   4094718.    -57885.  -7.51E-04     11542.   2.16E+11
-518.8868    191343.       0.00
   32.0000    0.00963   3810895.    -59911.  -6.63E-04     10742.   2.16E+11
-325.5335    162244.       0.00
   32.4000    0.00665   3519571.    -61414.  -5.82E-04      9921.   2.16E+11
-300.7161    217005.       0.00
   32.8000    0.00405   3221319.    -62782.  -5.07E-04      9080.   2.16E+11
-269.0891    319108.       0.00
   33.2000    0.00179   2916867.    -63961.  -4.39E-04      8222.   2.16E+11
-222.1947    596784.       0.00
   33.6000  -1.62E-04   2607295.    -64254.  -3.77E-04      7349.   2.16E+11
100.1184   2961387.       0.00
   34.0000   -0.00183   2300031.    -62502.  -3.23E-04      6483.   2.16E+11
629.9661   1649084.       0.00
   34.4000   -0.00326   2007280.    -59244.  -2.75E-04      5658.   2.16E+11
727.4197   1071135.       0.00
   34.8000   -0.00447   1731290.    -55609.  -2.33E-04      4880.   2.16E+11
787.2469    845033.       0.00
   35.2000   -0.00550   1473437.    -51730.  -1.98E-04      4153.   2.16E+11
829.0245    723623.       0.00
   35.6000   -0.00637   1234686.    -47676.  -1.68E-04      3480.   2.16E+11
860.0437    648128.       0.00
   36.0000   -0.00711   1015749.    -43490.  -1.43E-04      2863.   2.16E+11
883.9647    596935.       0.00
   36.4000   -0.00774    817180.    -39202.  -1.22E-04      2303.   2.16E+11
902.9453    560088.       0.00
   36.8000   -0.00828    639414.    -34830.  -1.06E-04      1802.   2.16E+11
918.3935    532309.       0.00
   37.2000   -0.00876    482808.    -30391.  -9.36E-05      1361.   2.16E+11
931.2921    510508.       0.00
   37.6000   -0.00918    347659.    -25894.  -8.44E-05   979.9772   2.16E+11
942.3580    492745.       0.00
   38.0000   -0.00957    234221.    -21348.  -7.79E-05   660.2214   2.16E+11
952.1264    477744.       0.00
   38.4000   -0.00993    142721.    -16756.  -7.37E-05   402.3015   2.16E+11
960.9994    464642.       0.00
   38.8000   -0.01027     73362.    -12123.  -7.13E-05   206.7936   2.16E+11
969.2746    452852.       0.00
   39.2000   -0.01061     26336.     -7452.  -7.02E-05    74.2352   2.16E+11
977.1632    441981.       0.00
   39.6000   -0.01095      1823.     -2743.  -6.99E-05     5.1386   2.16E+11
984.8021    431784.       0.00
   40.0000   -0.01128       0.00       0.00  -6.99E-05       0.00   2.16E+11
158.2453     33660.       0.00

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

```
Output Summary for Load Case No. 1:

Pile-head deflection              =     1.70588000 inches
Computed slope at pile head       =    -0.00590992 radians
Maximum bending moment            =       6228139. inch-lbs
Maximum shear force               =        -64254. lbs
Depth of maximum bending moment   =    25.60000000 feet below pile head
Depth of maximum shear force      =    33.60000000 feet below pile head
Number of iterations              =             34
Number of zero deflection points  =              1


--------------------------------------------------------------------------------
            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 Load                Load                  Axial    Pile-head  Pile-head  Max
Shear Max Moment
Case Type   Pile-head    Type     Pile-head   Loading  Deflection  Rotation    in
Pile    in Pile
 No.  1      Load 1       2        Load 2       lbs      inches     radians
lbs      in-lbs
---- ----- ---------- ---------- ---------- ---------- ---------- ----------
---------- ----------
  1  V, lb       0.00  M, in-lb        0.00       0.00     1.7059   -0.00591
-64254.   6228139.


Maximum pile-head deflection = 1.7058800046 inches
Maximum pile-head rotation   = -0.0059099198 radians = -0.338613 deg.

The analysis ended normally.
```

STRENGTH I LIMIT STATE

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

                     LPile for Windows, Version 2016-09.003

                 Analysis of Individual Piles and Drilled Shafts
                Subjected to Lateral Loading Using the p-y Method
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================================================================================

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

Path to file locations:
\Users\karens\Desktop\ColumbiaConnector\

Name of input data file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9d

Name of output report file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9o

Name of plot output file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9p

Name of runtime message file:
LPILE_ColumbiaConnectorSPL_041224_Final.lp9r


--------------------------------------------------------------------------------
                            Date and Time of Analysis
--------------------------------------------------------------------------------
```

```
               Date:  April 15, 2024              Time:  14:41:01


--------------------------------------------------------------------------------
                                  Problem Title
--------------------------------------------------------------------------------

Project Name:



Job Number:



Client:



Engineer:



Description:





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

Computational Options:
 - Use unfactored loads in computations (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 includes loading by one distributed lateral load acting on pile
 - Loading by lateral soil movements acting on pile not selected
 - Input of shear 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              =      15.0000 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.

            Depth Below           Pile
Point        Pile Head          Diameter
 No.           feet              inches
-----      -------------     -------------
  1            0.000            42.0000
  2           40.000            42.0000


Input Structural Properties for Pile Sections:
----------------------------------------------

Pile Section No. 1:

   Section 1 is an elastic pile
   Cross-sectional Shape                               =   Circular Pile
   Length of section                                   =    40.000000 ft
   Width of top of section                             =    42.000000 in
   Width of bottom of section                          =    42.000000 in
   Top Area                                            =    41.600000 sq. in
```

```
   Bottom Area                                         =     41.600000 sq. in
   Moment of Inertia at Top                            =         7450. in^4
   Moment of Inertia at Bottom                         =         7450. in^4
   Elastic Modulus                                     =     29000000. psi



--------------------------------------------------------------------------------
                       Ground Slope and Pile Batter Angles
--------------------------------------------------------------------------------

Ground Slope Angle                                     =        32.600 degrees
                                                       =         0.569 radians

Pile Batter Angle                                      =         0.000 degrees
                                                       =         0.000 radians


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

The soil profile is modelled using 5 layers

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

   Distance from top of pile to top of layer           =     15.000000 ft
   Distance from top of pile to bottom of layer        =     24.600000 ft
   Effective unit weight at top of layer               =     67.600000 pcf
   Effective unit weight at bottom of layer            =     67.600000 pcf
   Friction angle at top of layer                      =     38.000000 deg.
   Friction angle at bottom of layer                   =     38.000000 deg.
   Subgrade k at top of layer                          =    175.000000 pci
   Subgrade k at bottom of layer                       =    175.000000 pci


Layer 2 is stiff clay without free water

   Distance from top of pile to top of layer           =     24.600000 ft
   Distance from top of pile to bottom of layer        =     31.600000 ft
   Effective unit weight at top of layer               =     67.600000 pcf
   Effective unit weight at bottom of layer            =     67.600000 pcf
   Undrained cohesion at top of layer                  =         4500. psf
   Undrained cohesion at bottom of layer               =         4500. psf
   Epsilon-50 at top of layer                          =      0.004300
   Epsilon-50 at bottom of layer                       =      0.004300


Layer 3 is stiff clay without free water
```

```
   Distance from top of pile to top of layer           =    31.600000 ft
   Distance from top of pile to bottom of layer        =    39.600000 ft
   Effective unit weight at top of layer               =    59.600000 pcf
   Effective unit weight at bottom of layer            =    59.600000 pcf
   Undrained cohesion at top of layer                  =        2400. psf
   Undrained cohesion at bottom of layer               =        2400. psf
   Epsilon-50 at top of layer                          =     0.005700
   Epsilon-50 at bottom of layer                       =     0.005700


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

   Distance from top of pile to top of layer           =    39.600000 ft
   Distance from top of pile to bottom of layer        =    58.400000 ft
   Effective unit weight at top of layer               =    67.600000 pcf
   Effective unit weight at bottom of layer            =    67.600000 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                          =    55.000000 pci
   Subgrade k at bottom of layer                       =    55.000000 pci


Layer 5 is stiff clay without free water

   Distance from top of pile to top of layer           =    58.400000 ft
   Distance from top of pile to bottom of layer        =    71.600000 ft
   Effective unit weight at top of layer               =    65.600000 pcf
   Effective unit weight at bottom of layer            =    65.600000 pcf
   Undrained cohesion at top of layer                  =        3850. psf
   Undrained cohesion at bottom of layer               =        3850. psf
   Epsilon-50 at top of layer                          =     0.004600
   Epsilon-50 at bottom of layer                       =     0.004600


 (Depth of the lowest soil layer extends 31.600 ft below the pile tip)



--------------------------------------------------------------------------------
                        Summary of Input Soil Properties
--------------------------------------------------------------------------------

Layer        Soil Type          Layer      Effective    Undrained    Angle of
  E50
Layer          Name             Depth       Unit Wt.    Cohesion     Friction
  or          kpy
 Num.    (p-y Curve Type)        ft           pcf          psf          deg.
  krm         pci
-----   ------------------   ----------   ----------   ----------   ----------
```

```
----------   ----------
  1            Sand              15.0000      67.6000       --          38.0000
 --          175.0000
          (Reese, et al.)        24.6000      67.6000       --          38.0000
 --          175.0000
  2         Stiff Clay           24.6000      67.6000        4500.       --
 0.00430       --
          w/o Free Water         31.6000      67.6000        4500.       --
 0.00430       --
  3         Stiff Clay           31.6000      59.6000        2400.       --
 0.00570       --
          w/o Free Water         39.6000      59.6000        2400.       --
 0.00570       --
  4            Sand              39.6000      67.6000       --          33.0000
 --           55.0000
          (Reese, et al.)        58.4000      67.6000       --          33.0000
 --           55.0000
  5         Stiff Clay           58.4000      65.6000        3850.       --
 0.00460       --
          w/o Free Water         71.6000      65.6000        3850.       --
 0.00460       --


--------------------------------------------------------------------------------
                    p-y Modification Factors for Group Action
--------------------------------------------------------------------------------

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

Point      Depth X         p-mult         y-mult
 No.          ft
-----     ----------     ----------     ----------
  1          15.000         0.8500         1.0000
  2          70.000         0.8500         1.0000



--------------------------------------------------------------------------------
                               Static Loading Type
--------------------------------------------------------------------------------

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



--------------------------------------------------------------------------------
               Distributed Lateral Loading Used For All Load Cases
--------------------------------------------------------------------------------
```

```
Distributed lateral load intensity defined using 2 points

Point           Depth X           Dist. Load
 No.               in               lb/in
-----          ----------         ----------
  1               0.000              0.000
  2             180.000            694.900



--------------------------------------------------------------------------------
                Pile-head Loading and Pile-head Fixity Conditions
--------------------------------------------------------------------------------

Number of loads specified = 1

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

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
--------------------------------------------------------------------------------

         Top of    Equivalent
          Layer     Top Depth  Same Layer  Layer is        F0          F1
Layer     Below       Below      Type As    Rock or     Integral    Integral
 No.    Pile Head   Grnd Surf    Layer     is Below    for Layer   for Layer
           ft          ft         Above    Rock Layer      lbs         lbs
-----  ----------  ----------  ----------  ----------  ----------  ----------
  1       15.0000        0.00      N.A.        No            0.00     181476.
  2       24.6000      3.5156      No          No         181476.     462555.
  3       31.6000     10.5156      Yes         No         644031.     379486.
  4       39.6000     25.2491      No          No        1023517.      42140.
  5       58.4000     43.4000      No          No        1065658.      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*      in-lb^2
lb/inch    lb/inch    lb/inch
---------- ---------- ---------- ---------- ---------- ---------- ----------
---------- ---------- ----------
      0.00     3.5545   2.12E-04  -4.34E-07   -0.01129   5.99E-07   2.16E+11
0.00       0.00     4.6327
    0.4000     3.5003    53.3686    55.5920   -0.01129     0.1504   2.16E+11
0.00       0.00    18.5307
    0.8000     3.4462   533.6835   189.0128   -0.01129     1.5043   2.16E+11
```

```
0.00       0.00    37.0613
    1.2000     3.3920      1868.   411.3808   -0.01129     5.2652   2.16E+11
0.00       0.00    55.5920
    1.6000     3.3378      4483.   722.6960   -0.01129    12.6365   2.16E+11
0.00       0.00    74.1227
    2.0000     3.2836      8806.      1123.   -0.01129    24.8216   2.16E+11
0.00       0.00    92.6533
    2.4000     3.2294     15263.      1612.   -0.01129    43.0242   2.16E+11
0.00       0.00   111.1840
    2.8000     3.1753     24283.      2190.   -0.01129    68.4476   2.16E+11
0.00       0.00   129.7147
    3.2000     3.1211     36290.      2857.   -0.01129   102.2953   2.16E+11
0.00       0.00   148.2453
    3.6000     3.0669     51714.      3613.   -0.01128   145.7707   2.16E+11
0.00       0.00   166.7760
    4.0000     3.0128     70980.      4458.   -0.01128   200.0775   2.16E+11
0.00       0.00   185.3067
    4.4000     2.9586     94515.      5392.   -0.01128   266.4190   2.16E+11
0.00       0.00   203.8373
    4.8000     2.9045    122747.      6415.   -0.01128   345.9986   2.16E+11
0.00       0.00   222.3680
    5.2000     2.8503    156102.      7527.   -0.01128   440.0200   2.16E+11
0.00       0.00   240.8987
    5.6000     2.7962    195008.      8728.   -0.01127   549.6865   2.16E+11
0.00       0.00   259.4293
    6.0000     2.7421    239891.     10018.   -0.01127   676.2017   2.16E+11
0.00       0.00   277.9600
    6.4000     2.6880    291178.     11396.   -0.01126   820.7689   2.16E+11
0.00       0.00   296.4907
    6.8000     2.6340    349296.     12864.   -0.01125   984.5918   2.16E+11
0.00       0.00   315.0213
    7.2000     2.5800    414672.     14421.   -0.01125      1169.   2.16E+11
0.00       0.00   333.5520
    7.6000     2.5260    487733.     16066.   -0.01124      1375.   2.16E+11
0.00       0.00   352.0827
    8.0000     2.4721    568906.     17801.   -0.01122      1604.   2.16E+11
0.00       0.00   370.6133
    8.4000     2.4183    658618.     19624.   -0.01121      1857.   2.16E+11
0.00       0.00   389.1440
    8.8000     2.3645    757296.     21536.   -0.01119      2135.   2.16E+11
0.00       0.00   407.6747
    9.2000     2.3108    865367.     23538.   -0.01118      2439.   2.16E+11
0.00       0.00   426.2053
    9.6000     2.2572    983258.     25628.   -0.01116      2772.   2.16E+11
0.00       0.00   444.7360
   10.0000     2.2037   1111395.     27807.   -0.01113      3133.   2.16E+11
0.00       0.00   463.2667
   10.4000     2.1503   1250206.     30075.   -0.01111      3524.   2.16E+11
0.00       0.00   481.7973
   10.8000     2.0971   1400118.     32432.   -0.01108      3947.   2.16E+11
```

```
0.00       0.00   500.3280
   11.2000     2.0440   1561557.     34878.   -0.01104      4402.   2.16E+11
0.00       0.00   518.8587
   11.6000     1.9911   1734951.     37413.   -0.01101      4890.   2.16E+11
0.00       0.00   537.3893
   12.0000     1.9383   1920726.     40037.   -0.01097      5414.   2.16E+11
0.00       0.00   555.9200
   12.4000     1.8858   2119309.     42750.   -0.01092      5974.   2.16E+11
0.00       0.00   574.4507
   12.8000     1.8335   2331128.     45552.   -0.01087      6571.   2.16E+11
0.00       0.00   592.9813
   13.2000     1.7814   2556609.     48443.   -0.01082      7207.   2.16E+11
0.00       0.00   611.5120
   13.6000     1.7296   2796180.     51423.   -0.01076      7882.   2.16E+11
0.00       0.00   630.0427
   14.0000     1.6781   3050266.     54491.   -0.01069      8598.   2.16E+11
0.00       0.00   648.5733
   14.4000     1.6270   3319296.     57649.   -0.01062      9356.   2.16E+11
0.00       0.00   667.1040
   14.8000     1.5761   3603696.     60895.   -0.01055     10158.   2.16E+11
0.00       0.00   685.6347
   15.2000     1.5257   3903893.     62508.   -0.01046     11004.   2.16E+11
-13.7206    43.1660       0.00
   15.6000     1.4757   4203773.     62372.   -0.01037     11850.   2.16E+11
-43.1646   140.4014       0.00
   16.0000     1.4261   4502659.     62089.   -0.01028     12692.   2.16E+11
-74.7565   251.6111       0.00
   16.4000     1.3770   4799823.     61650.   -0.01017     13530.   2.16E+11
-107.8833   376.0506       0.00
   16.8000     1.3285   5094501.     61051.   -0.01006     14360.   2.16E+11
-141.9333   512.8286       0.00
   17.2000     1.2804   5385909.     60287.   -0.00995     15182.   2.16E+11
-176.2368   660.6585       0.00
   17.6000     1.2330   5673257.     59359.   -0.00982     15992.   2.16E+11
-210.3765   818.9916       0.00
   18.0000     1.1861   5955757.     58269.   -0.00969     16788.   2.16E+11
-243.8630   986.8521       0.00
   18.4000     1.1399   6232639.     57021.   -0.00956     17569.   2.16E+11
-276.2325      1163.       0.00
   18.8000     1.0944   6503157.     55619.   -0.00942     18331.   2.16E+11
-307.6507      1349.       0.00
   19.2000     1.0495   6766586.     54071.   -0.00927     19074.   2.16E+11
-337.5287      1544.       0.00
   19.6000     1.0054   7022238.     52384.   -0.00912     19794.   2.16E+11
-365.3304      1744.       0.00
   20.0000     0.9620   7269474.     50570.   -0.00896     20491.   2.16E+11
-390.7130      1950.       0.00
   20.4000     0.9194   7507707.     48636.   -0.00879     21163.   2.16E+11
-414.7804      2166.       0.00
   20.8000     0.8776   7736383.     46588.   -0.00862     21807.   2.16E+11
```

```
-438.7064      2400.       0.00
   21.2000     0.8366   7954952.     44431.   -0.00845     22423.   2.16E+11
-460.0947      2640.       0.00
   21.6000     0.7964   8162921.     42178.   -0.00827     23010.   2.16E+11
-478.7066      2885.       0.00
   22.0000     0.7572   8359860.     39843.   -0.00809     23565.   2.16E+11
-494.3180      3134.       0.00
   22.4000     0.7188   8545410.     37432.   -0.00790     24088.   2.16E+11
-510.1633      3407.       0.00
   22.8000     0.6813   8719205.     34952.   -0.00771     24578.   2.16E+11
-523.1850      3686.       0.00
   23.2000     0.6448   8880947.     32417.   -0.00751     25034.   2.16E+11
-532.9643      3967.       0.00
   23.6000     0.6092   9030409.     29844.   -0.00731     25455.   2.16E+11
-539.2792      4249.       0.00
   24.0000     0.5746   9167446.     27241.   -0.00711     25841.   2.16E+11
-545.3522      4556.       0.00
   24.4000     0.5409   9291918.     24612.   -0.00691     26192.   2.16E+11
-549.8866      4879.       0.00
   24.8000     0.5083   9403721.     20199.   -0.00670     26507.   2.16E+11
-1289.     12173.       0.00
   25.2000     0.4766   9485825.     14009.   -0.00649     26739.   2.16E+11
-1290.     12993.       0.00
   25.6000     0.4460   9538203.      7815.   -0.00628     26886.   2.16E+11
-1290.     13888.       0.00
   26.0000     0.4164   9560851.      1624.   -0.00607     26950.   2.16E+11
-1289.     14865.       0.00
   26.4000     0.3878   9553791.     -4561.   -0.00585     26930.   2.16E+11
-1287.     15936.       0.00
   26.8000     0.3602   9517069.    -10732.   -0.00564     26827.   2.16E+11
-1284.     17114.       0.00
   27.2000     0.3336   9450759.    -16886.   -0.00543     26640.   2.16E+11
-1280.     18413.       0.00
   27.6000     0.3080   9354966.    -23015.   -0.00522     26370.   2.16E+11
-1274.     19852.       0.00
   28.0000     0.2835   9229820.    -29113.   -0.00502     26017.   2.16E+11
-1267.     21452.       0.00
   28.4000     0.2599   9075484.    -35174.   -0.00481     25582.   2.16E+11
-1258.     23242.       0.00
   28.8000     0.2373   8892154.    -41190.   -0.00461     25065.   2.16E+11
-1248.     25254.       0.00
   29.2000     0.2156   8680061.    -47154.   -0.00442     24467.   2.16E+11
-1237.     27532.       0.00
   29.6000     0.1949   8439474.    -53058.   -0.00423     23789.   2.16E+11
-1223.     30131.       0.00
   30.0000     0.1750   8170703.    -58893.   -0.00404     23032.   2.16E+11
-1208.     33122.       0.00
   30.4000     0.1561   7874103.    -64648.   -0.00386     22195.   2.16E+11
-1190.     36605.       0.00
   30.8000     0.1379   7550082.    -70312.   -0.00369     21282.   2.16E+11
```

```
-1170.     40713.       0.00
   31.2000     0.1206   7199106.    -75872.   -0.00353     20293.   2.16E+11
-1147.     45639.       0.00
   31.6000     0.1041   6821708.    -80719.   -0.00337     19229.   2.16E+11
-872.4803     40246.       0.00
   32.0000    0.08823   6424207.    -84172.   -0.00323     18109.   2.16E+11
-566.3315     30810.       0.00
   32.4000    0.07309   6013658.    -86845.   -0.00309     16951.   2.16E+11
-547.4850     35956.       0.00
   32.8000    0.05858   5590496.    -89419.   -0.00296     15758.   2.16E+11
-524.8436     43002.       0.00
   33.2000    0.04468   5155240.    -91871.   -0.00284     14532.   2.16E+11
-496.8304     53376.       0.00
   33.6000    0.03132   4708538.    -94168.   -0.00273     13272.   2.16E+11
-460.4435     70559.       0.00
   34.0000    0.01847   4251228.    -96254.   -0.00263     11983.   2.16E+11
-408.5864    106188.       0.00
   34.4000    0.00607   3784503.    -97986.   -0.00254     10668.   2.16E+11
-313.2270    247741.       0.00
   34.8000   -0.00593   3310562.    -96711.   -0.00246      9332.   2.16E+11
844.6151    683895.       0.00
   35.2000   -0.01757   2856080.    -92024.   -0.00239      8051.   2.16E+11
1108.    302749.       0.00
   35.6000   -0.02891   2427134.    -86351.   -0.00234      6842.   2.16E+11
1255.    208402.       0.00
   36.0000   -0.03999   2027109.    -80072.   -0.00229      5714.   2.16E+11
1361.    163391.       0.00
   36.4000   -0.05086   1658447.    -73335.   -0.00224      4675.   2.16E+11
1446.    136442.       0.00
   36.8000   -0.06154   1323093.    -66227.   -0.00221      3730.   2.16E+11
1516.    118255.       0.00
   37.2000   -0.07209   1022671.    -58802.   -0.00219      2883.   2.16E+11
1577.    105027.       0.00
   37.6000   -0.08253    758592.    -51101.   -0.00217      2138.   2.16E+11
1632.     94899.       0.00
   38.0000   -0.09288    532105.    -43152.   -0.00215      1500.   2.16E+11
1681.     86847.       0.00
   38.4000    -0.1032    344337.    -34978.   -0.00214   970.6147   2.16E+11
1725.     80261.       0.00
   38.8000    -0.1134    196320.    -26597.   -0.00214   553.3864   2.16E+11
1767.     74751.       0.00
   39.2000    -0.1237     89008.    -18024.   -0.00213   250.8958   2.16E+11
1805.     70059.       0.00
   39.6000    -0.1339     23290.     -9272.   -0.00213    65.6493   2.16E+11
1842.     66005.       0.00
   40.0000    -0.1441       0.00       0.00   -0.00213       0.00   2.16E+11
2022.     33660.       0.00

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

```
Output Summary for Load Case No. 1:

Pile-head deflection              =     3.55450971 inches
Computed slope at pile head       =    -0.01128732 radians
Maximum bending moment            =       9560851. inch-lbs
Maximum shear force               =        -97986. lbs
Depth of maximum bending moment   =    26.00000000 feet below pile head
Depth of maximum shear force      =    34.40000000 feet below pile head
Number of iterations              =             39
Number of zero deflection points  =              1


--------------------------------------------------------------------------------
            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 Load                Load                  Axial    Pile-head  Pile-head  Max
Shear Max Moment
Case Type   Pile-head    Type     Pile-head   Loading  Deflection  Rotation    in
Pile    in Pile
 No.  1      Load 1       2        Load 2       lbs      inches     radians
lbs      in-lbs
---- ----- ---------- ---------- ---------- ---------- ---------- ----------
---------- ----------
  1  V, lb       0.00  M, in-lb        0.00       0.00     3.5545   -0.01129
-97986.   9560851.


Maximum pile-head deflection = 3.5545097067 inches
Maximum pile-head rotation   = -0.0112873237 radians = -0.646716 deg.

The analysis ended normally.
```

APPENDIX G

PILE SECTION STRUCTURAL CHECK

Objective: To evaluate the Shear and Flexural Resistance of a Pile.
Method: In accordance with LRFD Bridge Design Specifications, 8th Ed., 2017, [Sect. 6.10.8, Sect. 6.10.9 and Sect. 6.9.4.1.2].

Givens:

Pile Parameters:

$Z_x := 514\ in^3$	Plastic Section Modulus about x-x	$A_g := 41.5\ in^2$	Section area
$r_x := 448\ in$	Radius of Gyration about x-x	$D := 29.625\ in$	Clear distance between flanges
$F_y := 50\ \frac{kip}{in^2}$	Yield strength of steel	$t_w := 0.605\ in$	Web thickness
$E := 29000\ \frac{kip}{in^2}$	Elastic modulus of steel	$l := 15\ ft$	Length of "unbraced" pile above shaft

Resistance Factors:

$\phi_f := 0.9$	Resistance Factor for Flexure per **LRFD BDS Table 11.5.7-1**
$\phi_v := 1.0$	Resistance Factor for Shear per **LRFD BDS Section 6.5.4.2**

Calculations:

Flexural Resistance:

$M := 9560851\ in \cdot lbf$

$M_{max} := \phi_f \cdot Z_x \cdot F_y$ **LRFD BDS Section 6.10.8**

$M_{max} = 23130000\ in \cdot lbf$ Maximum allowable moment in Shaft

---

$Check\_M = \text{“OK”}$ **If M$_{max}$ > M$_u$ then OK, otherwise select larger section**

Shear Resistance:

$V := 97986\ lbf$

$V_{max} := \phi_v \cdot 0.58 \cdot F_y \cdot D \cdot t_w$ **LRFD BDS Section 6.10.9**

$V_{max} = 519770.6\ lbf$ Maximum allowable moment in Shaft

$Check\_V = \text{“OK”}$ **If V$_{max}$ > V$_u$ then OK, otherwise select larger section**

Resistance to Flexural Buckling:

$F_y = 50\ ksi$ Yield stress of steel

$$P_e := \frac{\pi^2 \cdot E}{\left(\frac{2.1 \cdot l}{r_x}\right)^2}$$ **LRFD BDS Section 6.9.4.1.2**

$P_e = 402040.8\ \frac{kip}{in^2}$ Critical stress for flexural buckling

---

$Check\_P_e = \text{“OK”}$ **If P$_e$ > F$_y$ then OK, otherwise select larger section**