REPORT
STRUCTURE FOUNDATION EXPLORATION
CULVERT #1 #3 AND #6
MED-18-13.54
MEDINA COUNTY, OHIO
PID#: 92953

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NEAS PROJECT 15-0091

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EXECUTIVE SUMMARY

The Ohio Department of Transportation (ODOT) has proposed a project for improvements to State Route 18 (MED-18-13.54, PID 92953) in the City of Medina, Medina County, Ohio. The SR-18 roadway alignment is located in the Killbuck-Glaciated Pittsburgh Plateau physiographic region, which is part of the Glaciated Allegheny Plateaus. This area is characterized by ridges and flat uplands dissected by steep valleys. This topography is reflected in the steep valley of the West Branch Rocky River which crosses MED-18 midway at an elevation of about 910 feet (ft) as compared to the western and eastern ends of the alignment which rise to ~1,000 ft and 1,060, respectively. The alignment is underlain by till from 80 to 320 ft deep.

National Engineering & Architectural Services, Inc. (NEAS), formerly Barr Engineering, Inc., has been contracted to perform geotechnical engineering services for the project. The purpose of the geotechnical engineering services was to perform geotechnical explorations within the project limits to obtain information concerning the subsurface soil and groundwater conditions relevant to the design and construction of the project. The scope of work performed by NEAS as part of the referenced project included: a review of published geotechnical information; performing 10 test borings for Culverts #1 #3, and #6; laboratory testing of soil samples in accordance with the SGE; performing geotechnical engineering analysis to assess culvert design and construction considerations; and development of this summary report.

NEAS presents this Structure Foundation Exploration Report for the proposed construction of Culverts #1 #3, and #6 for the MED-18-13.54 Improvements to State Route 18 (SR-18) within the City of Medina, Ohio. The stations for Culverts #1, #3 and #6 are SR-18 STA. 102+57.34, SR-18 STA.127+35.43, and River Styx Road (Rd.) STA. 911+39.85, respectively. This report presents a summary of the encountered superficial and subsurface conditions and our recommendations for culvert foundation design and construction in accordance with Load and Resistance Factor Design (LRFD) method as set forth in AASHTO's Publication LRFD Bridge Design Specifications, (AASHTO, 2014) and ODOT's 2007 LRFD Bridge Design Manual (BDM) (ODOT, 2007).

For Culvert #1, to accommodate widening of SR-18 pavement it is proposed that the culvert be extended on the inlet and outlet ends with full-height walls. Geotechnical analyses consisting of external stability (i.e., overall stability, bearing capacity, and sliding), global stability, and settlement analysis were performed for the proposed culvert. Based on our analyses, the factored bearing resistances are from 4.0 ksf to 8.4 ksf. The minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5. The estimated maximum total settlement is estimated to be about 0.8 inches.

For Culvert #3, widening the existing SR-18 pavement that will required the construction of a new full height headwall at the outlet. Geotechnical analyses consisting of deep foundation design, global stability, and settlement analysis were performed for the proposed culvert. Deep foundation design includes estimating pile length for CIP piles of different sizes, pile drivability analysis, and lateral loaded pile analysis. The minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5. The estimated long-term settlement is estimated to be about 1.8 inches.

For Culvert #6, the existing inlet will be removed and the inlet of the proposed structure will be extended a length of 32 ft approximately in the north (an angle of about 50˚to the existing culvert direction) with a half-height headwall. Geotechnical analyses consisting of bearing resistance and global stability were performed for the proposed culvert. Based on our analyses, the factored bearing resistances are from 3.3 ksf to 5.6 ksf. The minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5.

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1. INTRODUCTION

1.1. General

NEAS, formerly Barr Engineering, Inc. (BEI), presents our Structure Foundation Exploration Report for the proposed extension of existing Culverts #1 #3, and #6, as part of the State Route 18 (SR-18) widening and improvement project (MED-18-13.54, PID 92953) in the City of Medina, Medina County, Ohio. The referenced culverts are located in the eastside of Medina City, Medina County, Ohio. The stations for Culverts #1, #3 and #6 are SR-18 STA. 102+57.34, SR-18 STA.127+35.43, and River Styx Road (Rd.) STA. 911+39.85, respectively. This report presents a summary of the encountered surficial and subsurface conditions and our recommendations for culverts foundation design and construction in accordance with Load and Resistance Factor Design (LRFD) method as set forth in AASHTO's Publication *LRFD Bridge Design Specifications 7th Edition* with 2015 interim revisions (AASHTO, 2014) and *ODOT Bridge Design Manual* (BDM), [2007 including revisions through 2015 (ODOT, 2007)].

MED-18-13.54 Phase 3 project consists of:

- Culverts #1, #3 and #6 with full height headwalls;
- Retaining Wall #1 at SR-18 stationing 126+89.28;
- Retaining Wall #4 Goodwill Building side hill cut section.

The exploration was conducted in general accordance with National Engineering & Architectural Services, Inc.'s (NEAS's) proposal to GPD Group (GPD), dated April 17, 2017 and with the provisions of ODOT's *Specifications for Geotechnical Explorations* (SGE) (ODOT, 2016).

The scope of work performed by NEAS as part of the referenced project included: a review of published geotechnical information; performing 10 test borings for Culverts #1 #3, and #6; laboratory testing of soil samples in accordance with the SGE; performing geotechnical engineering analysis to assess culvert wall design and construction considerations; and development of this summary report.

1.2. Proposed Construction

Culvert #1: the proposed MED SR-18 widening and improvement project will include widening of the pavement on the northbound and southbound directions of SR-18 at the culvert location approximately STA 102+57.34. To accommodate widening of the pavement it is proposed that the culvert #1 be extended on the inlet and outlet ends with full-height headwalls.

Culvert #3: the proposed MED-18 project will widen the existing SR-18 pavement that will required the construction of a new culvert. The structure will be constructed at the outlet utilizing a full-height headwall which has a maximum exposed wall height of approximately 15.5 ft. The culvert is located at the historical landslide area, the proposed construction of culvert will help retain the embankment slope and support the SR-18.

Culvert #6: The culvert on River Styx Rd at STA. 911+39.85 will be extended. The existing inlet will be removed and the inlet of the proposed structure will be extended a length of 32 ft approximately in the north (an angle of about 50˚to the existing culvert direction) with a half-height headwall.

2. GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1. Geology and Physiography

The project site is located in the Killbuck-Glaciated Pittsburgh Plateau physiographic region, which is part of the Glaciated Allegheny Plateaus (Brockman, 1998). This area is characterized by ridges and flat uplands dissected by steep valleys. This topography is reflected in the steep valley of the W Branch Rocky River which crosses MED-18 midway at an elevation of about 910 ft as compared to the western and eastern ends of the alignment which rise to ~1,000 ft and 1,060 ft, respectively.

The project site is underlain by Wisconsinan-age till (unsorted mix of clay, silt, sand, gravel and boulders) over sandstone and shale deposited in Mississippian-age (ODNR, 2000). Bedrock topography maps indicated depth of bedrock ranging from elevation 650 ft to 1,000 ft, placing it between 50 ft and 260 ft deep (Schumacher, et al, 1996). It is mapped as Mississippian-age Cuyahoga Formation (Slucher, et al, 1996).

2.2. Hydrology/Hydrogeology

SR-18 crosses over West Branch Rocky River at approximately STA 741+00 where the flow line elevation is 910 ft and likely represents the local groundwater table. Broadway Creek, a tributary to West Branch flows under SR-18 at approximately STA 702+50 (U.S. Department of the Interior, 2013) and a tributary to Broadway flows under the alignment at ~STA 711+50.

The West Branch Rocky River and the area immediately adjacent to it are located in a special flood hazard zone subject to inundation by the 1% annual chance flood (US Department of Homeland Security, 2013). The base flood elevation where SR-18 crosses West Branch is 917 ft.

2.3. Mining and Oil/Gas Production

No abandoned mines are noted on ODNR's Abandoned Underground Mine Locator in the vicinity of the proposed project site (ODNR [1], 2016).

The following (Table 1) gas wells were noted in the vicinity of the alignment (ODNR, 2015[(2)]). All but three are abandoned and/or plugged. The remaining three have not produced gas since 1993.

Table 1: Gas wells in Proximity to the Alignment

Well Name	Owner	Well No.	Formation	Status	Direction from Alignment
Medina Community Hospital	Ohio Fuel Gas Co.	Well No. 8	Gas-Clinton Sand	Plugged & Abandoned	~520 ft south
	Hydrocarbon Resources LTD	MCZ#1		Not Drilled	
	Buckeye Well Surveys	1	Gas-Clinton Sand	Abandoned 1996	
J H Witzel	O.F.S	2	Gas	Plugged & Abandoned	~765 ft south
ES Johnson	Martin H Lax	1	Gas	Abandoned 1991	~380 ft north
-	-	5	Gas	Plugged & Abandoned	~601 ft south
Tru-Fit	Tru-Filt Products Corp	5, 6A	Gas	Installed 1983 -Ohio Shale – Berea Sandstone – no production since 1993	~120 ft south

2.4. Historical Records and Previous Phases of Project Exploration

The following report/plans were available for review and evaluation for this report (ODOT, 2016):

- The August 19, 2015 Draft subgrade exploration report for Project MED-18-13.54 prepared by Barr Engineering, INC. (BEI, 2015).

2.5. Site Reconnaissance

The site reconnaissance was conducted on July 16, 2015 and August 7, 2015. The existing embankment slope at the proposed Culvert #1 location appeared to have an estimated average slope of about 2 Horizontal to 1 Vertical (2H:1V). The slope is heavily vegetated and appeared to be in good condition with no signs of instability observed. The existing vegetation (i.e., trees, saplings, etc.) was observed be vertical on the side slopes. Furthermore, the pavement condition was observed to be in fair to good condition (see Photograph 1).

Culvert #3 runs from the southernmost point of the lake (see Photograph 2) under SR-18 to connect with a pond (see Photograph 3) on the opposite side of the road. Several of the older trees in the area are also slanted downslope slightly, while the newer trees are slanted slightly more upslope (Photograph 4). Several sources of water flow into and out of this area, including 1 culvert, a lake, the roadway, and potential overflow of the pond, making high water levels during heavy rainfall extremely likely.

The existing embankment slope at the proposed culvert #6 location appeared to have an estimated average slope of about 4 Horizontal to 1 Vertical (4H:1V). The slope is heavily vegetated and appeared to be in good condition with no signs of instability observed. Furthermore, the existing vegetation (i.e., trees, saplings, etc.) was observed be vertical on the side slopes.

Photograph 1: View of MED-18 at Culvert #1

Photograph 2: Lake South of MED-18 at Culvert #3

Photograph 3: Lake North of MED-18 at Culvert #3

Photograph 4: Lake South of MED-18 at Culvert #3

3. GEOTECHNICAL EXPLORATION

3.1. Field Exploration Program

The exploration for these culverts were conducted by NEAS between July 2, 2015 and September 23, 2016 and included 10 borings drilled up to depths 61.5 ft bgs. The boring locations were selected by NEAS in general accordance with the guidelines contained in the SGE with the intent to evaluate subsurface soil and groundwater conditions. The borings were typically located near the proposed culverts in locations that were not restricted by maintenance of traffic, underground utilities or dictated by terrain (i.e. steep embankment slopes).

Stationing, offset, elevations and latitude and longitude locations of the borings are provided in Table 2 below.

Table 2: Project Boring Summary

Boring Number	Location (Sta/Offset)[2]	Latitude[1]	Longitude[1]	Elevation (NAVD 88) (ft)	Depth (ft)
Culvert #1					
B-006-0-14	102+49, 32' RT	41.138723	-81.836074	985.1	31.5
B-007-0-14	102+85, 32' RT	41.138708	-81.835945	983.9	31.5
B-006-1-16	102+89, 3' LT	41.138799	-81.835908	983.8	46.5
Culvert #3					
B-014-1-16	126+68, 27' LT	41.137761	-81.827385	959.2	61.5
B-015-0-14	127+12, 23' LT	41.137745	-81.827227	959.6	31.5
B-015-1-16	127+62, 22' LT	41.137721	-81.827046	960.0	61.5
B-016-0-14	127+42, 19' RT	41.137619	-81.827141	959.9	30.0
B-016-1-16	127+78, 18' RT	41.137607	-81.827014	960.9	51.5
Culvert #6					
B-043-0-14	911+83, 21' RT	41.133550	-81.812528	944.8	31.5
B-043-1-16	911+53, 44' LT	41.133472	-81.812766	944.3	36.5

Notes:
1. *As-drilled boring location and corresponding ground surface elevation were surveyed in the field by GPD Group.*
2. *Stationing in reference to centerline of Construction SR-18, except B-043-0-14 and B-043-1-16 stationing in reference to centerline of Construction River Styx Road.*

The boring was drilled using a CME 45B and CME 55 truck mounted drilling rig utilizing 3.25-inch diameter hollow stem augers. Soil samples were recovered at intervals of 2.5-ft using 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. Standard penetration tests (SPT) were conducted using a CME auto hammer that has been calibrated to be 77.4% and 81.8% efficient 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 (using a hand-penetrometer). Groundwater measurements were attempted during the boring drilling procedures and immediately following the completion of the borehole. These groundwater level observations are included on the individual boring log. After completing the boring, the borehole was backfilled with auger cuttings and asphalt patch following SGE section 407.

3.2. Laboratory Testing Program

The laboratory testing program consisted of classification testing and moisture content determinations. Data from the laboratory-testing program were incorporated onto the borings 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 31% of the samples. At the 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 (commonly known as split-spoon) sampling of soils were performed at varying intervals (i.e., 2.5-ft or 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.

4. GEOTECHNICAL FINDINGS

The subsurface conditions encountered during NEAS’s explorations are described in the following subsections and on the boring log presented in Appendix B. The boring log represents NEAS’s interpretation of the subsurface conditions encountered at the boring location based on our site observations, field log, 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 log 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 explorations performed by NEAS as part of the referenced project, results of historical explorations, and consideration of the geological history of the site.

4.1. Subsurface Conditions

4.1.1. Overburden Soil

At the Culvert #1 site, the soil profile consists of surficial materials comprised of asphalt pavement and granular base section underlain by "man-made" fill comprised of very stiff to hard silty clay (A-6b), very dense gravel with sand (A-1-b), very dense gravel with sand, silt and clay (A-2-6), loose to dense gravel with sand (A-1-b) at elevations between 982.8 ft and 962.6 ft. The "man-made" fill is underlain by 12.5 ft deep very stiff to hard silt and clay (A-6a) and 12 ft deep medium stiff to very stiff sandy silty (A-4a). Bedrock was not encountered within depths of the boring performed.

At the Culvert #3 site, the soil profile consists of top layer of asphalt pavement, brick and granular base section. The top layer is underlain by stiff to hard silty clay (A-6b), over medium stiff to very stiff silt and clay (A-6a), following by stiff to very stiff silty clay (A-6b). Below that, very soft to medium stiff sandy silt (A-4a), very stiff clay (A-7-6), stiff to very stiff silt and clay (A-6a) were encountered. This layer is overlain by medium stiff to hard silt (A-4b), followed is harr silt and clay (A-6a). Bedrock was not encountered within depths of the boring performed.

At the Culvert #6 site, the soil profile consists of top soil "man-made" fill comprised of medium dense sandy silt (A-4a) and hard clay (A-7-6) to depth of 4.5 ft bgs (approximate elevation of 939.8 ft), following by about 2.5 ft in thickness of medium dense gravel with sand, silt and clay. The next layer is medium stiff to stiff sandy silt (A-4a), with an interlayer about 2.5 ft deep medium dense gravel with sand and silt (A-2-4). Below is stiff to very stiff silt and clay (A-6a), stiff to very stiff sandy silt (A-4a), very stiff silty clay (A-6b), stiff clay (A-7-6), very stiff silty clay (A-6b), stiff silt (A-4b). The last layer encountered in the boring is hard sandy silt (A-4a). Bedrock was not encountered within depths of the boring performed.

4.1.2. Groundwater

Groundwater measurements were attempted during the boring drilling procedures and immediately following the completion of the borehole.

Table 3: Groundwater Summary

Boring ID	Free Water Depth (ft)	Free Water Elevation (ft)	Static Water Depth (ft)	Static Water Elevation (ft)
Culvert #1				
B-006-0-14	22.0	963.1	-	-
B-007-0-14	13.0	970.9	-	-
B-006-1-16	14.0	969.8	-	-
Culvert #3				
B-014-1-16	14.0	945.2	-	-
B-015-0-14	23.5	936.1	-	-
B-015-1-16	22.0	938.0	-	-
B-016-0-14	15.0	44.9	-	-
B-016-1-16	-	-	-	-
Culvert #6				
B-043-0-14	11.0	933.8	10.0	934.8
B-043-1-16	28.0	916.3	-	-

Free water was encountered in six out of seven borings (see Table 3) during drilling performed as part of the referenced project. Static water elevation after completion of drilling was recorded in one (B-043-0-14) of the project borings. 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.

5. ANALYSIS AND RECOMMENDATIONS

The proposed extension of existing Culverts #1 #3, and #6 is as part of the State Route 18 (SR-18) widening and improvement project (MED-18-13.54, PID 92953) in the City of Medina, Medina County, Ohio. For Culvert #1, the proposed MED SR-18 widening and improvement project will include widening of the pavement on the northbound and southbound directions of SR-18 at the culvert location approximately STA 102+57.34. To accommodate widening of the pavement it is proposed that the culvert #1 be extended on the inlet and outlet ends with full-height walls. For Culvert #3, the proposed MED-18 project will widen the existing SR-18 pavement that will required the construction of a new culvert. The structure will be constructed at the outlet utilizing a full height headwall which has a maximum exposed wall height of approximately 15.5 ft. For Culvert #6 on River Styx Rd at STA. 911+39.85, the existing inlet will be removed and the inlet of the proposed structure will be extended a length of 32 ft approximately in the north (an angle of about 50˚ to the existing culvert direction) with a half-height headwall.

According to the Culvert Detail of the three culverts provided by GPD Group, the existing Culvert #1 is a 10’ x 8’ box concrete culvert with approximately 103 ft in length; the existing Culvert #3 is a 4’ x 4’ box concrete culvert with approximately 181 ft in length; the existing Culvert #6 is a 60 in circular concrete pipe culvert with approximately 88 ft in length. For analysis purposes, it is assumed that: 1) the streambed elevation at Culvert #1, #3 and #6 is 965 ft amsl, 935.3 ft amsl and 936.1 ft amsl, respectively; 2) the groundwater elevation is assumed the same as the streambed elevation at each culvert site; 3) no scour consideration was included in the analyses.

The analyses performed are based on the above information in addition to: 1) the soil characteristics gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.) presented in Section 5.1 of this report; 2) the developed generalized soil profile at the proposed culverts locations and other design assumptions presented in subsequent sections of this report; and, 3) the proposed sheet titled "Culvert Detail" for Culvert #1, #3, and #6 provided by GPD Group, geotechnical analyses consisting of deep foundation design, external stability (i.e., overall stability, bearing capacity, and sliding), bearing resistance, global stability, and settlement analysis were performed for the proposed culverts. The geotechnical engineering analyses were performed in accordance with ODOT's BDM (ODOT, 2007) and AASHTO's LRFD BDS (AASHTO, 2014).

5.1. Generalized Soil Profile for Analysis

For analysis purposes, each boring log was reviewed and the engineering properties for each soil strata 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 using correlations provided in published engineering manuals, research reports and guidance documents. Engineering soil properties were estimated for each individual classified layer per boring location. Soil layers with 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) and weighted average values of the estimated engineering soil properties were assigned to each Soil Type to develop a generalized soil profile for

analysis. The summary of the generalized soil profile including designated Soil Types, elevations, average engineering soil properties per boring location are presented in Tables 4-13 below.

Table 4: Soil Profile and Estimated Engineering Properties at Culvert #1 (B-006-0-14)

Culvert #1: Soil Profile, B-006-0-14						
Soil Description	**Unit Weight[(1)] (pcf)**	**Moist Unit Weight[(1)] (pcf)**	**Saturated Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Gravel Depth (983.8 ft - 982.1 ft)	115	115	125	-	-	40
Gravel with Sand and Silt Depth (982.1 ft - 979.1 ft)	112	112	122	-	-	33
Gravel with Sand Depth (979.1 ft - 970.6 ft)	112	112	122	-	-	34
Silt and Clay Depth (970.6 ft - 953.6 ft)	122	112	122	1850	200	24

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.*

Table 5: Soil Profile and Estimated Engineering Properties at Culvert #1 (B-007-0-14)

Culvert #1: Soil Profile, B-007-0-14						
Soil Description	**Unit Weight[(1)] (pcf)**	**Moist Unit Weight[(1)] (pcf)**	**Saturated Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Silt and Clay Depth (983.8 ft - 980.9 ft)	105	105	115	750	75	21
Silty Clay Depth (980.9 ft - 974.4 ft)	108	108	118	900	100	22
Silty Clay Depth (974.4 ft - 971.9 ft)	108	108	118	1100	100	22
Silty Clay Depth (971.9 ft - 967.4 ft)	122	112	122	1750	200	24
Gravel Depth (967.4 ft - 964.4 ft)	120	110	120	-	-	34
Sandy Silt Depth (964.4 ft - 959.4 ft)	125	115	125	2850	250	27
Silt and Clay Depth (959.4 ft - 952.4 ft)	122	112	122	1900	200	24

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.*

Table 6: Soil Profile and Estimated Engineering Properties at Culvert #1 (B-006-1-16)

Culvert #1: Soil Profile, B-006-1-16						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Silty Clay Depth (983.8 ft - 970.6 ft)	112	112	122	2450	200	25
Gravel with Sand Depth (970.6 ft - 969.3 ft)	125	125	135	-	-	43
Gravel with Sand, Silt and Clay Depth (969.3 ft - 966.8 ft)	140	130	140	-	-	41
Gravel with Sand Depth (966.8 ft - 962.6 ft)	125	115	125	-	-	37
Sandy Silt Depth (962.6 ft - 961.8 ft)	130	120	130	-	-	36
Silt and Clay Depth (961.8 ft - 949.3 ft)	125	115	125	2750	250	26
Sandy Silt Depth (949.3 ft - 948.4 ft)	122	112	122	1850	200	25
Sandy Silt Depth (948.4 ft - 937.3 ft)	125	115	125	2700	250	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.*

Table 7: Soil Profile and Estimated Engineering Properties at Culvert #3 (B-014-1-16)

Culvert #3: Soil Profile, B-014-1-16						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Silty Clay Depth (959.2 ft - 947.2 ft)	110	110	120	1550	150	23
Silt and Clay Depth (947.2 ft - 942.2 ft)	125	115	125	3400	250	27
Silty Clay Depth (942.2 ft - 937.2 ft)	120	110	120	1600	150	23
Clay Depth (937.2 ft - 935.2 ft)	120	110	120	1500	150	22
Silt and Clay Depth (935.2 ft - 929.7 ft)	122	112	122	1900	200	24
Sandy Silt Depth (929.7 ft - 924.7 ft)	128	118	128	4350	300	30
Silt and Clay Depth (924.7 ft - 919.7 ft)	135	125	135	5550	400	32
Sandy Silt Depth (919.7 ft - 912.2 ft)	135	125	135	5500	400	33
Silt Elevation (912.2 ft - 899.7 ft)	125	115	125	2800	250	27
Silt and Clay Elevation (899.7 ft - 897.7 ft)	135	125	135	5600	400	32

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.*

Table 8: Soil Profile and Estimated Engineering Properties at Culvert #3 (B-015-0-14)

Culvert #3: Soil Profile, B-015-0-14						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Silty Clay Depth (959.6 ft - 950.1 ft)	115	115	125	3150	250	27
Silty Clay Depth (950.1 ft - 947.6 ft)	118	118	128	3500	300	28
Silt and Clay Depth (947.6 ft - 940.3 ft)	125	125	135	6150	400	33
Silty Clay Depth (940.3 ft - 938.6 ft)	110	110	120	1600	150	23
Sandy Silt Depth (938.6 ft - 928.1 ft)	120	110	120	1550	150	24

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.*

Table 9: Soil Profile and Estimated Engineering Properties at Culvert #3 (B-015-1-16)

Culvert #3: Soil Profile, B-015-1-16						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Depth (959.2 ft - 927.5 ft)				-		
Silt and Clay Depth (927.5 ft - 915.5 ft)	130	120	130	5250	350	31
Silty Clay Depth (915.5 ft - 908 ft)	128	118	128	3850	300	28
Clay Depth (908 ft - 898.5 ft)	125	115	125	3450	250	26

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.*

Table 10: Soil Profile and Estimated Engineering Properties at Culvert #3 (B-016-0-14)

Culvert #3: Soil Profile, B-016-0-14						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Silt and Clay Depth (959.9 ft - 956.9 ft)	108	108	118	1100	100	22
Clay Depth (956.9 ft - 952.6 ft)	110	110	120	1550	150	22
Silty Clay Depth (952.6 ft - 948.6 ft)	110	110	120	1500	150	23
Clay Depth (948.6 ft - 944.6 ft)	110	110	120	1250	150	22
Gravel with Sand and Silt Depth (944.6 ft - 940.6 ft)	132	122	132	-	-	40
Silty Clay Depth (940.6 ft - 936.6 ft)	135	125	135	6100	400	33
Silt and Clay Depth (936.6 ft - 932.6 ft)	118	108	118	1100	100	22
Sandy Silt Depth (932.6 ft - 929.9 ft)	125	115	125	3100	250	28

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.*

Table 11: Soil Profile and Estimated Engineering Properties at Culvert #3 (B-016-1-16)

Culvert #3: Soil Profile, B-016-1-16						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Depth (960.9 ft - 928.4 ft)				-		
Sandy Silt Depth (928.4 ft - 925.5 ft)	115	115	125	2750	250	27
Silt and Clay Depth (925.5 ft - 909.4 ft)	120	120	130	5050	350	31

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.*

Table 12: Soil Profile and Estimated Engineering Properties at Culvert #6 (B-043-0-14)

Culvert #6: Soil Profile, B-043-0-14						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Silt and Clay Depth (944.3 ft - 943.3 ft)	108	108	118	1000	100	22
Silt and Clay Depth (943.3 ft - 938.8 ft)	108	108	118	900	100	22
Sandy Silt Depth (938.8 ft - 935.3 ft)	105	105	115	650	75	22
Silt and Clay Depth (935.3 ft - 922.8 ft)	122	112	122	2100	200	25
Sandy Silt Depth (922.8 ft - 913.3 ft)	122	112	122	-	-	30

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.*

Table 13: Soil Profile and Estimated Engineering Properties at Culvert #6 (B-043-1-16)

Culvert #6: Soil Profile, B-043-1-16						
Soil Description	**Unit Weight[1] (pcf)**	**Moist Unit Weight[1] (pcf)**	**Saturated Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Sandy Silt Depth (944.3 ft - 942.3 ft)	118	118	128	-	-	37
Clay Depth (942.3 ft - 939.8 ft)	112	112	122	2000	200	23
Gravel with Sand, Silt and Clay Depth (939.8 ft - 937.3 ft)	115	115	125	-	-	34
Sandy Silt Depth (937.3 ft - 932.3 ft)	110	110	120	1250	150	24
Gravel with Sand and Silt Depth (932.3 ft - 929.8 ft)	115	115	125	-	-	34
Sandy Silt Depth (929.8 ft - 927.3 ft)	112	112	122	-	-	30
Silt and Clay Depth (927.3 ft - 922.3 ft)	112	112	122	2050	200	24
Sandy Silt Depth (922.3 ft - 919.8 ft)	115	115	125	-	-	30
Silty Clay Elevation (919.8 ft - 917.3 ft)	112	112	122	2000	200	24
Clay Elevation (917.3 ft - 914.8 ft)	118	108	118	1000	100	21
Silty Clay Elevation (914.8 ft - 912.3 ft)	125	115	125	2850	250	26
Silt Elevation (912.3 ft - 909.8 ft)	128	118	128	3600	300	29
Sandy Silt Elevation (909.8 ft - 907.8 ft)	130	120	130	4600	350	31

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.*

5.1. Culvert #1 Analysis

A review was completed for the proposed Culvert #1 which includes an inlet cast-in-place (CIP) full-height headwall and an outlet CIP full-height headwall of both approximate 13 ft tall.

5.1.1. Cast-in-place Headwall Design Assumptions

For the design of the proposed culvert structure, ODOT's BDM, AASHTO's LRFD BDS, and the project conditions dictate analysis parameters and design minimums/constraints are to be used in the analysis and design process. The referenced parameters and design minimums/constraints that where significant to our analyses consist of the following:

- Porous backfill is to be placed from back of the wall extending from top of footing elevation to top of earth backfill with a width not less than 2 feet.
- Retained soils behind the porous backfill are to consist of material placed and compacted in accordance with Item 203, Roadway Excavation and Embankment, of the ODOT CMS;
- Retained fill soils will meet the minimum design soil parameters per ODOT's Geotechnical Bulletin 6 "Shear Strength of Proposed Embankments" as shown in Table 14 below.

Table 14: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Retained Soil	On-site soil classified as (A-4a or A-6a)	120	32	400

Notes:
1. *Table soil parameters based on Table 1 - Estimated Shear Strengths within ODOT's Geotechnical Bulletin 6 "Shear Strength of Proposed Embankments".*

5.1.2. External Stability

Based on our estimated engineering soil properties and the CIP headwall design assumptions provided in Section 5.1.1 of this report, an external stability analyses of the proposed CIP full-height headwalls for Culvert #1 were performed. The footings of the inlet headwall and the outlet headwall are at the similar elevations, 966.3 ft amsl for the inlet headwall and 965.0 ft amsl for the outlet headwall.

LRFD Parameters

The CIP headwall was evaluated resistance to bearing pressure, sliding forces and overturning at the Strength Limit State in accordance with Section 11.5.3 of the AASHTO's LRFD BDS. These design issues have been evaluated using a MathCAD-based software solution that follows the AASHTO BDS, as described in Appendix C. Load and resistance factors applicable to the design of a CIP headwall are presented below in Table 15 based on AASHTO LRFD Sections 11.5.6, 11.5.7 and 10.5.5.2.2.

Table 15: Load and Resistance Factors for Culvert Headwall Analysis

Load Factors						
Group	Condition	Earth-Vertical	Earth-Horizontal	Dead load of structural components	Live Load Surcharge	Reference
		EV	EH	DC	LL	
Strength Ia	Sliding and Eccentricity	1.00	1.50	0.90	1.75	11.5.6
Strength Ib	Bearing Capacity	1.35	1.50	1.25	1.75	11.5.6
Resistance Factors						
Bearing resistance					0.55	11.5.7-1
Sliding resistance of permanent wall					1.00	11.5.7-1
Sliding resistance of passive earth pressure					0.50	10.5.5.2.2-1

Based on the sheet “Design Detail” of Culvert #1 provided by GDP Group, external stability was evaluated at both inlet and outlet cross-sections using three borings. Each cross-section was evaluated for resistance to bearing pressure, sliding forces and overturning at the Strength Limit State in accordance with Section 11.5.3 of the AASHTO's LRFD BDS.

Results are expressed in terms of Capacity to Demand Ratios (CDR) that compare the available factored resistances to the factored load. CDRs >=1 indicate a safe design. The CDRs calculated for the referenced cross sections with respect to bearing, sliding and overturning, as well as the calculated factored bearing resistances are presented in Table 16 below. (External Stability Results can be found in Appendix C).

Table 16: External Stability Analysis Summary for Culvert #1

Culvert #1 External Stability Analysis Summary			
Top of Wall (feet)	976.0	976.0	975.0
Bottom of Footing (feet)	963.2	963.2	962.0
Exposed Wall Height (feet)	10.0	10.0	10.0
Design Wall Height (feet)	13.0	13.0	13.0
Boring Log Used in Calculation	B-006-0-14	B-007-0-14	B-006-1-16
Capactiy Demand Ratio (CDR)			
Sliding	1.00	1.07	1.04
Overturning / Eccentricity	1.12	1.05	1.05
Bearing Capacity (Undrained/Drained)	1.39/1.02	2.00/1.39	1.93/1.27
Factored Bearing Resistance (ksf)[(1)] (Undrained/Drained)	5.5/4.0	8.4/5.8	8.1/5.3
Notes: 1. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of 2014 LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of 2014 LRFD BDS.*			

5.1.3. Global Stability

The slope geometry at the Culvert #1 site on SR-18 is assumed to be consistent with that shown in the site plans provided by GPD Group. ODOT's SGE and AASHTO's LRFD BDS dictate analysis parameters to be used in the analysis process. Based on planned roadway grades and alignment, AASHTO's LRFD BDS dictates that the slopes shall be evaluated for a live load surcharge of 250 pound per square foot (psf).

For purposes of evaluating the stability of the headwalls, NEAS developed one representative cross-sectional model of the tallest headwall section (at the outlet location) to use as the basis for global stability analyses. The model was developed from NEAS's interpretation of the available information which included: 1) the sheet set provided by GPD Group titled "Culvert Detail" for the Culvert #1 site; and, 2) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the estimated engineering properties of the Soil Profile at project boring B-006-1-16 presented in Section 5.1. of this report were used in our analyses.

The above referenced slope stability models were analyzed for long-term (Effective Stress) and short-term (Total Stress) slope stability utilizing the software entitled *Slide 7.0* by Rocscience, Inc. Specifically, the Modified Bishop and Simplified Janbu analysis methods were used to calculate a factor of safety (FOS) for circular type slope failure. The FOS is the ratio of the resisting forces to the driving forces, with the desired safety factor being more than about 1.5 which approximately equates to an AASHTO resistance factor of less than 0.65 (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 the analysis, a resistance factor of 0.65 or lower is targeted as the slope does not support a structural element.

Based on our slope stability analyses for the referenced outlet headwall section, the minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5. The results of the analyses are summarized in Table 17. The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) is presented in Appendix C.

Table 17: Global Stability Analysis Summary for Culvert #1

Global Stability Analsysis at Culvert #1				
Boring No.	**Description**	**Minimum Factor of Safety**	**Equivalent Resistance Factor**	**Status (OK/NG)**
B-006-1-16	Short Term	4.34	0.23	OK
	Long Term	1.58	0.63	OK

5.1.4. Settlement

In order to estimate the maximum settlement that could result within the subsurface soils supporting the proposed culvert headwalls, NEAS reviewed: 1) the sheet "Design Detail" of Culvert #1 provided by GDP Group; 2) Service Limit State loading conditions; and, 3) test borings and laboratory data developed as part of this report. Utilizing this information, a settlement model was developed and analyzed for both elastic (immediate) and consolidation (long term) settlement in accordance with LRFD BDS Section 10.6.2.4.3.

Based on our analysis the ground surface at the culvert site is estimated to experience at most about 0.5 inches of immediate settlement and 0.8 inches of long term (consolidation) settlement from the induced 7-ft embankment fill loads. The elastic (immediate) settlement will take place during construction prior to traffic loading and is not expected to be a concern. Since there will not be a large amount of new fills and the over-consolidated nature of the cohesive soil underlying the proposed culvert, this long-term (consolidation) settlement magnitude is not anticipated to be a concern. Furthermore, it should be noted, that it is NEAS's experience that current settlement estimate methodology typically provides conservative (increased) values and settlement is generally observed to be less in construction. The settlement analysis results can be found in Appendix C.

5.2. Culvert #3 Analysis

A foundation review was completed for the foundations of the proposed Culvert #3 which includes an outlet headwall consisting of an approximate 21 ft tall CIP full-height headwall.

5.2.1. Cast-in-place Headwall Design Assumptions

As the proposed culvert structure is to include an outlet headwall consisting of an approximate 21 ft tall CIP headwall, ODOT's BDM, AASHTO's LRFD BDS, and the project conditions dictate analysis parameters and design minimums/constraints are also to be used in the analysis and design process. The CIP headwall design assumptions provided in Section 5.1.1 of this report for Culvert #1 are also applicable to the design of Culvert #3 CIP headwall.

5.2.2. Deep Foundation Design

1) Deep Foundation Analysis

According to the proposed Culvert #3 site plan provided by GPD Group, the CIP headwall will be supported on Cast-in-place piles from the elevation of 929.25 ft at the bottom of footing.

Based on our estimated engineering soil properties, a pile analysis was performed using the computer program *Driven* to determine the estimated geotechnical pile length at Culvert #3. For the purposes of this report and our analysis the term 'geotechnical pile length' has been assumed to represent the length of pile

from bottom of pile cap (pile cap bearing elevation) to the depth at which the required Ultimate Bearing Value (UBV) is obtained. The UBV is determined in accordance with Section 202.2.3.2.b of the BDM in which the given total factored load for the pile at each substructure is divided by the appropriate driven pile resistance factor. The piles for the referenced project are to be installed according the ODOT Construction and Materials Specifications (CMS) 507 and CMS 523 and as such, a driven pile resistance factor of 0.7 was used in our analysis. The "Estimated Length" and "Order Length" definitions and formulas are presented in Section 303.4.2 "Pile Foundations" of the BDM. The calculated "Estimated Length" assumes one-foot embedment in the pile cap and rounding up to the nearest 5 ft. The "Order Length" is the calculated "Estimated Length" plus 5 ft. Pile lengths are expected to be as shown in Table 18 (worst case if there are more than one boring logs at the location). The *Driven* results can be found in Appendix D. Furthermore, based on our engineering experience and the settlement analysis presented in Section 5.2.4, the possible downdrag loads can be ignored.

Table 18: Estimated CIP Pile Lengths at Culvert #3

Culvert #3 Pile Length Summary							
Pile Size	**Nearby Boring**	**Max Ultimate Bearing Value (kips)**	**Pile Cap Elevation (ft)**	**Pile Tip Elevation (ft)**	**Geotechnical Design Length (ft)**	**Estimated Length (ft)**	**Order Length (ft)**
12-inch CIP pile	B-015-0-14 & B-015-1-16	183	929.25	877.2	53	55	60
14-inch CIP pile				888.3	41	45	50
16-inch CIP pile				897.1	33	35	40

2) Pile Drivability

NEAS's drivability evaluation estimated a Delmag D30 diesel hammer to determine if the CIP pile of different sizes (12-in, 14-in and 16-in) with a typical wall thickness of 0.25 inches for ASTM A 252 Grade 2 steel would be overstressed at any time during pile installation. The results of the evaluation indicated that CIP pile of different sizes with wall thickness of 0.25 inches would be overstressed during the pile installation process at select locations assuming the referenced piles are driven to the recommended depths. Therefore, it is recommended to use ASTM A 252 Grade 3 steel CIP pile instead of Grade 2 CIP pile with same 0.25-inch thick pile wall thickness. GRLWEAP Results for Culvert #3 can be found in Appendix D. It should be noted that the minimum pile wall thickness should be 0.203 inches according to Section 507.03 "Cast-in-Place Reinforced Concrete Piles" of the CMS.

The driving resistance of CIP piles through the glacial deposited soil is expected to be high. Driveability is difficult to assess quantitatively as the field test results (i.e., STP N60 Values, pocket penetrometer values, etc.) tend to be very high. Furthermore, pile drivability is highly reliant upon the specific equipment used in construction. Therefore, it is recommended that the contractor provide an analysis to demonstrate that the equipment and piles planned for use are capable to be driven to refusal on bedrock without over-stressing the piles.

3) Lateral Load Pile Analysis

For purposes of evaluating the pile resistance in the lateral direction, deep foundation elements subjected to horizontal loads and/or moments have been analyzed by using the software entitled Lpile by Ensoft, Inc for maximum bending moments and lateral deflections. The lateral loads were provided by GPD Group for Culvert #3 piles through Emails on March 2, 2018 and March 28, 2018, respectively. Based on the Service Limit State, the max lateral load is 4.79 klf/pile, and the max moment is 16 k-ft/pile. The soil profile provided in Section 5.1 of this report were used in our analyses.

The results of laterally loaded pile based on the available boring logs (maximum bending moments and lateral deflections) are summarized in Table 19. The Lpile analysis output can be found in Appendix D.

Table 19: Summary of Lateral Load Pile Analysis

Culvert #3 Lpile Analysis Summary							
Pile Size	Nearby Boring	Max Lateral Load at Pile Head (lb)	Maximum Moment at Pile Head (inch-lbs)	Max Bending Moment in Pile (inch-lbs)	First Fixty Point Depth (ft)	Second Fixty Point Depth (ft)	Pile-Head Deflection (inch)
12-inch CIP pile	B-014-1-16	23,950	192,000	538,550	4.03	7.75	0.15
14-inch CIP pile				533,124	4.34	8.37	0.10
16-inch CIP pile				538,851	4.65	8.99	0.08
12-inch CIP pile	B-015-0-14 & B-015-1-16	23,950	192,000	568,959	3.60	7.80	0.14
14-inch CIP pile				572,040	3.90	8.10	0.10
16-inch CIP pile				582,776	3.90	8.40	0.07
12-inch CIP pile	B-016-0-14 & B-016-1-16	23,950	192,000	627,670	4.56	8.74	0.23
14-inch CIP pile				616,360	4.75	9.12	0.15
16-inch CIP pile				626,437	4.94	9.69	0.12

5.2.3. Global Stability

The slope geometry at the Culvert #3 site on SR-18 Station 127+35 is assumed to be consistent with that shown in the site plans provided by GPD Group. ODOT's SGE and AASHTO's LRFD BDS dictate analysis parameters to be used in the analysis process. Based on planned roadway grades and alignment, AASHTO's LRFD BDS dictates that the slopes shall be evaluated for a live load surcharge of 250 pound per square foot (psf).

For purposes of evaluating the stability of the outlet headwall, NEAS developed two representative cross-sectional models of the tallest headwall section to use as the basis for global stability analyses. The models were developed from NEAS's interpretation of the available information which included: 1) the sheet set provided by GPD Group titled "Cross-sections – S.R. 18" and "Culvert Detail" for the Culvert #3 site; and, 2) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the estimated engineering properties of the Soil Profile at project boring B-014-1-16, and of the combined Soil Profile using borings B-015-0-14 and B-015-1-16 presented in Section 5.1. of this report were used in our analyses.

Based on our slope stability analyses for the referenced outlet headwall section, the minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5. The results of the analyses are summarized in Table 21. The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) is presented in Appendix D.

Table 20: Global Stability Analysis Summary for Culvert #3

Global Stability Analsysis at Culvert #3 Sta 127+00				
Boring No.	**Description**	**Minimum Factor of Safety**	**Equivalent Resistance Factor**	**Status (OK/NG)**
B-014-1-16	Short Term	4.03	0.25	OK
	Long Term	1.56	0.64	OK
	Flood	1.47	0.68	OK
B-015-0-14 & B-015-1-16	Short Term	4.95	0.20	OK
	Long Term	1.65	0.61	OK
	Flood	1.56	0.64	OK

5.2.4. Settlement

In order to estimate the maximum settlement that could result within the subsurface soils supporting the proposed culvert headwalls, NEAS reviewed: 1) the sheet "Design Detail" of Culvert #3 provided by GDP Group; 2) Service Limit State loading conditions; and, 3) test borings and laboratory data developed as part of this report. Utilizing this information, a settlement model was developed and analyzed for both elastic (immediate) and consolidation (long term) settlement in accordance with LRFD BDS Section 10.6.2.4.3.

Based on our analysis the ground surface at the culvert site is estimated to experience at most about 1.3 inches of immediate settlement and 1.8 inches of long term (consolidation) settlement from the induced 10-ft embankment fill loads. The elastic (immediate) settlement will take place during construction prior to traffic loading and is not expected to be a concern. Since there will not be a large amount of new fills and the over-consolidated nature of the cohesive soil underlying the proposed culvert, this long-term (consolidation) settlement magnitude is not anticipated to be a concern. Furthermore, it should be noted that it is NEAS's experience that current settlement estimate methodology typically provides conservative (increased) values and settlement is generally observed to be less in construction. The settlement analysis results can be found in Appendix D.

5.3. Culvert #6 Analysis

5.3.1. Bearing Resistance

A preliminary shallow foundation bearing analysis was performed at Culvert #6 location in accordance with the *LRFD Bridge Design Specifications, 7th Edition* with 2015 interim revisions, Section 10.6.3.1.2a, utilizing the information provided in Section 5.1. The proposed shallow foundation systems were assumed to be consistent with ODOT's Standard Construction Drawings (SCD). For the culvert, a SCD HW-2.2 with a circular concrete pipe diameter of 60 inches (in.) was assumed and the foundation system was assumed to be a continuous spread footing bearing at an elevation of 935.2 ft and 933.1 ft for the inlet and outlet, respectively.

The estimated nominal and factored bearing resistance is presented in Table 22 below. Bearing resistance calculations for the assumed conditions are presented in Appendix E.

Table 21: Estimated Bearing Resistances at Culvert #6

Culvert #6 Bearing Resistance							
Substructure	**Boring ID**	**Condition**	**Width of Footing (in)**	**Assumed Bearing Elevation (ft)**	**Nominal Bearing Resistance (ksf)**	**LRFD Resistance Factor**	**Factored Bearing Resistance (ksf)**
Inlet Headwall	B-043-0-14	Drained	12	935.2	6.7	0.5	3.4
		Undrained			11.2	0.5	5.6
Onlet Headwall	B-043-1-16	Drained	12	933.1	6.9	0.5	3.5
		Undrained			6.9	0.5	3.5
Notes: 1. Assumed Bearing Elevations based on standard foundation thicknesses and proposed invert elevations from the provided plans. 2. Per LRFD Bridge Design Specifications Article 10.5.5.2.2-1							

It should be noted that at the time of this document, a depth of scour analysis had **not** been conducted; therefore, it is assumed that the indicated bearing elevation for analysis is below the depth of potential scour. If the assumed foundation bearing elevation is later determined to be above the depth of potential scour, NEAS should be notified and further analysis be performed.

5.3.2. Global Stability

The slope geometry at the Culvert #6 site on River Styx Road is assumed to be consistent with that shown in the site plans provided by GPD Group. ODOT's SGE and AASHTO's LRFD BDS dictate analysis parameters to be used in the analysis process. Based on planned roadway grades and alignment, AASHTO's LRFD BDS dictates that the slopes shall be evaluated for a live load surcharge of 250 pound per square foot (psf).

For purposes of evaluating the stability of the outlet headwall, NEAS developed one representative cross-sectional model of the tallest headwall section to use as the basis for global stability analyses. The model was developed from NEAS's interpretation of the available information which included: 1) the sheet set provided by GPD Group titled "Cross-sections – S.R. 18" and "Culvert Detail" for the Culvert #6 site; and, 2) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the estimated engineering properties of the Soil Profile at project boring B-043-1-16 presented in Section 5.1. of this report was used in our analyses.

Based on our slope stability analyses for the referenced outlet headwall section, the minimum slope stability safety factor for both short-term and long-term conditions exceeded the desired value of 1.5. The results of the analyses are summarized in Table 23. The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) is presented in Appendix E.

Table 22: Global Stability Analysis Summary for Culvert #6

Global Stability Analsysis at Culvert #6				
Boring No.	**Description**	**Minimum Factor of Safety**	**Equivalent Resistance Factor**	**Status (OK/NG)**
B-043-1-16	Short Term	2.97	0.34	OK
	Long Term	1.54	0.65	OK

5.3.3. Settlement

A settlement analysis was not performed at the proposed Culvert #6 foundation. However, due to the consistency of the soils at the culvert sites and the small amount of new embankment fills, it is our opinion that settlement should not be an issue.

5.4. Seismic Design Parameters

ODOT has indicated that the whole state lies within Seismic Zone 1. Based on the results of the subsurface exploration, the laboratory test data, and our review of the AASHTO Site Class Definition from Table 3.10.3.1-1 of the AASHTO LRFD Bridge Design Specifications, NEAS recommends a project site classification of D – stiff soil. Typically, SPT N-values within the upper 90 ft of the profile are between 15 bpf and 60 bpf. Seismic design parameters for the site were developed using USGS Seismic Design Maps per AASHTO Guide Specifications for LRFD Seismic Bridge Design and are presented in Table 24 below. The detailed report is presented in Appendix F. These values were interpreted for use in our slope stability analysis where seismic forces are considered.

Table 23: AASHTO Spectrum for 7% PE in 75 Years

Variable	Symbol (AASHTO 3.10)	Value
Latitude		41.136413
Longitude		-81.811627
Site Class		D
Peak Ground Acceleration	PGA	0.042g
Short Period Acceleration	S_s	0.090g
Long Period Acceleration	S_1	0.032g
Site Factor (zero period)	F_{PGA}	1.6
Site Factor (short period)	F_a	1.6
Site Factor (long period)	F_v	2.4
Zero period response seismic coefficient	$A_s = F_{PGA} * PGA$	0.067g
Short period response seismic coefficient (0.2 seconds)	$S_{DS} = F_a * S_s$	0.144g
Long period response seismic coefficient (1.0 second)	$S_{D1} = F_v * S_1$	0.077g

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 Culvert #1, #3 and #6 for the MED-18-13.54 project. This report has been prepared for GPD Group, ODOT and their design consultants to be used solely in evaluating the soils underlying the culverts 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 tests 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 Culvert #1, #3 and #6 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 GPD Group in performing this geotechnical exploration for the MED-18-13.54 project. Please call if there are any questions, or if we can be of further service.

Respectfully Submitted,

Zhao Mankoci, Ph.D. E.I.
Geotechnical Engineer

Chunmei He, Ph.D., P.E.
Project Manager

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APPENDIX A

SITE PLAN

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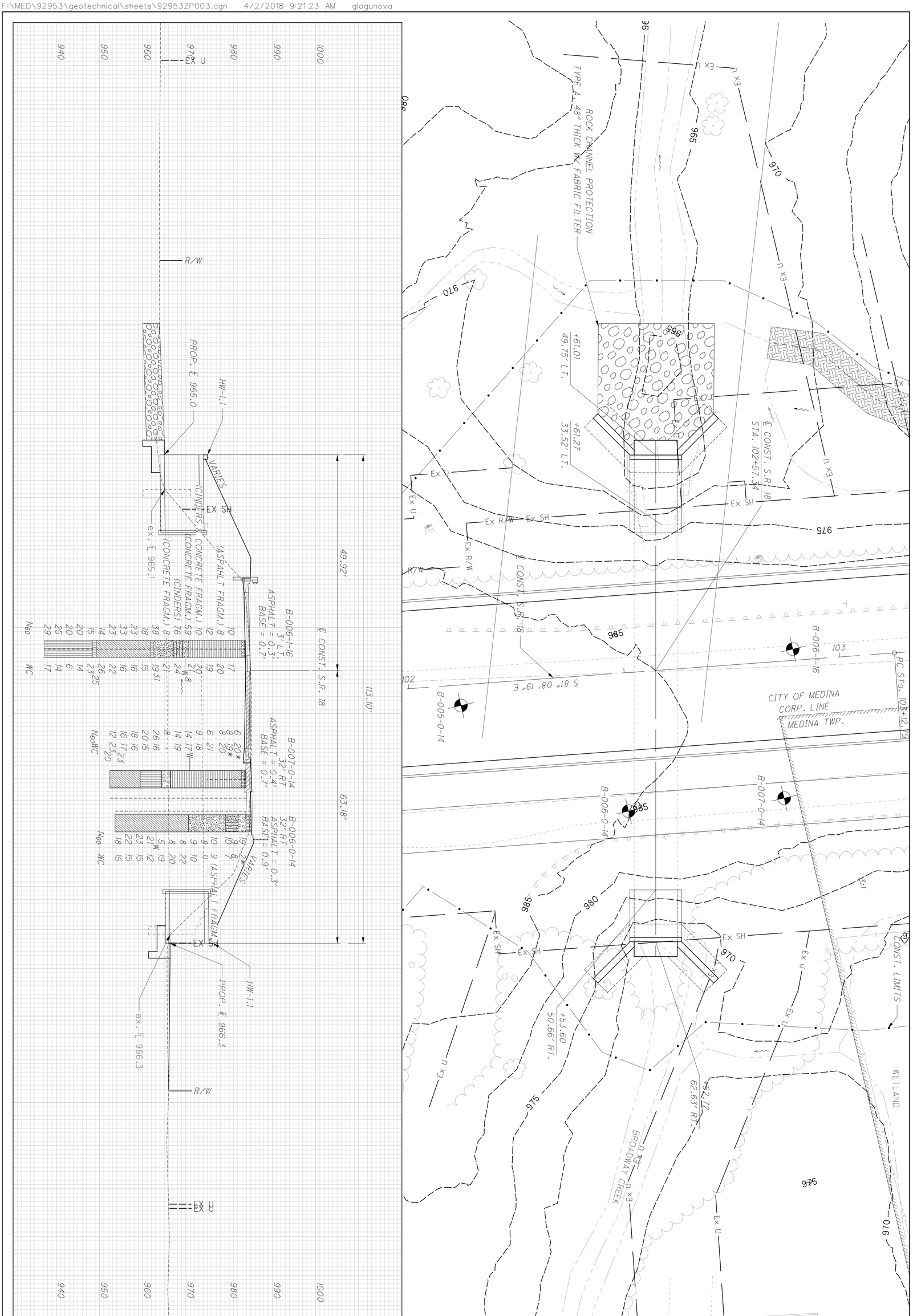
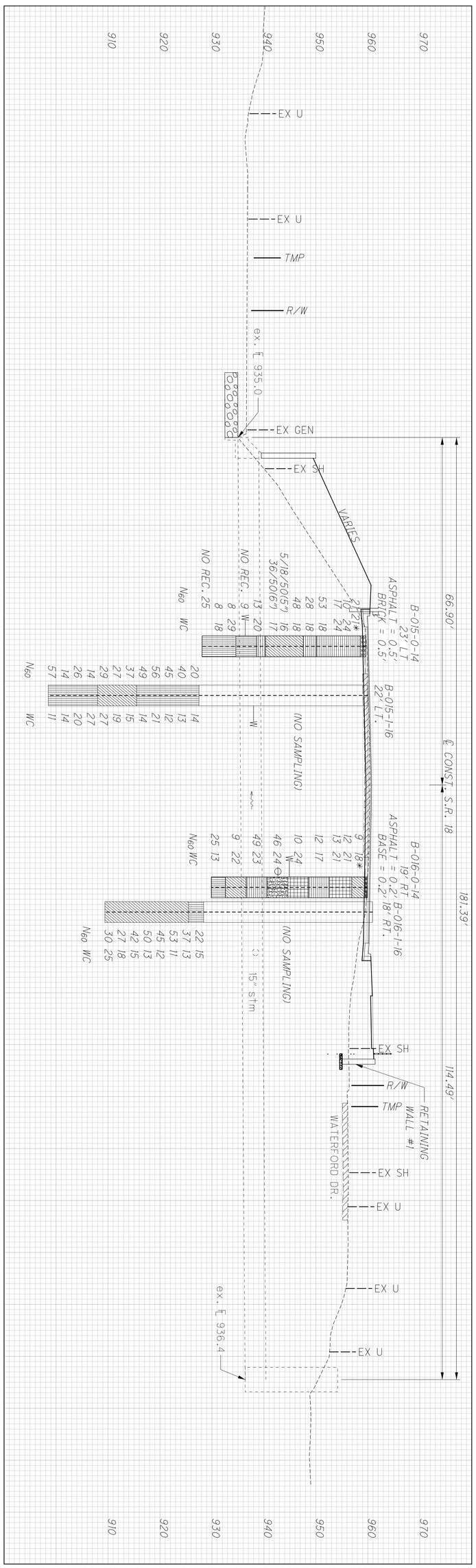
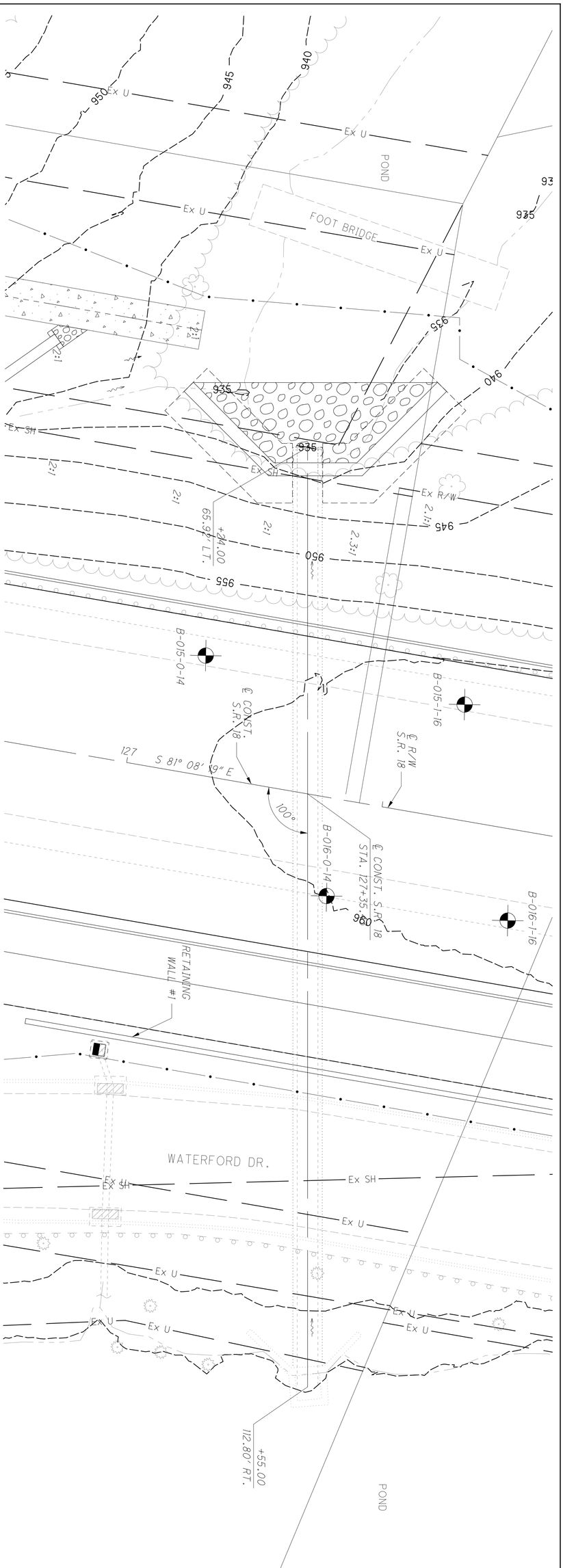


	14/68	MED-18-13.54	STRUCTURE FOUNDATION EXPLORATION CULVERT NO. 1 - STA. 102+57	DRAWN GL CHECKED CH	HORIZONTAL SCALE IN FEET

F:\MED\92953\geotechnical\sheets\92953ZP005.dgn 4/2/2018 9:21:35 AM glogunova





	19/68	**MED-18-13.54**	**STRUCTURE FOUNDATION EXPLORATION** **CULVERT NO. 3 - STA. 127+35**	DRAWN GL CHECKED CH	0 10 5 20 HORIZONTAL SCALE IN FEET

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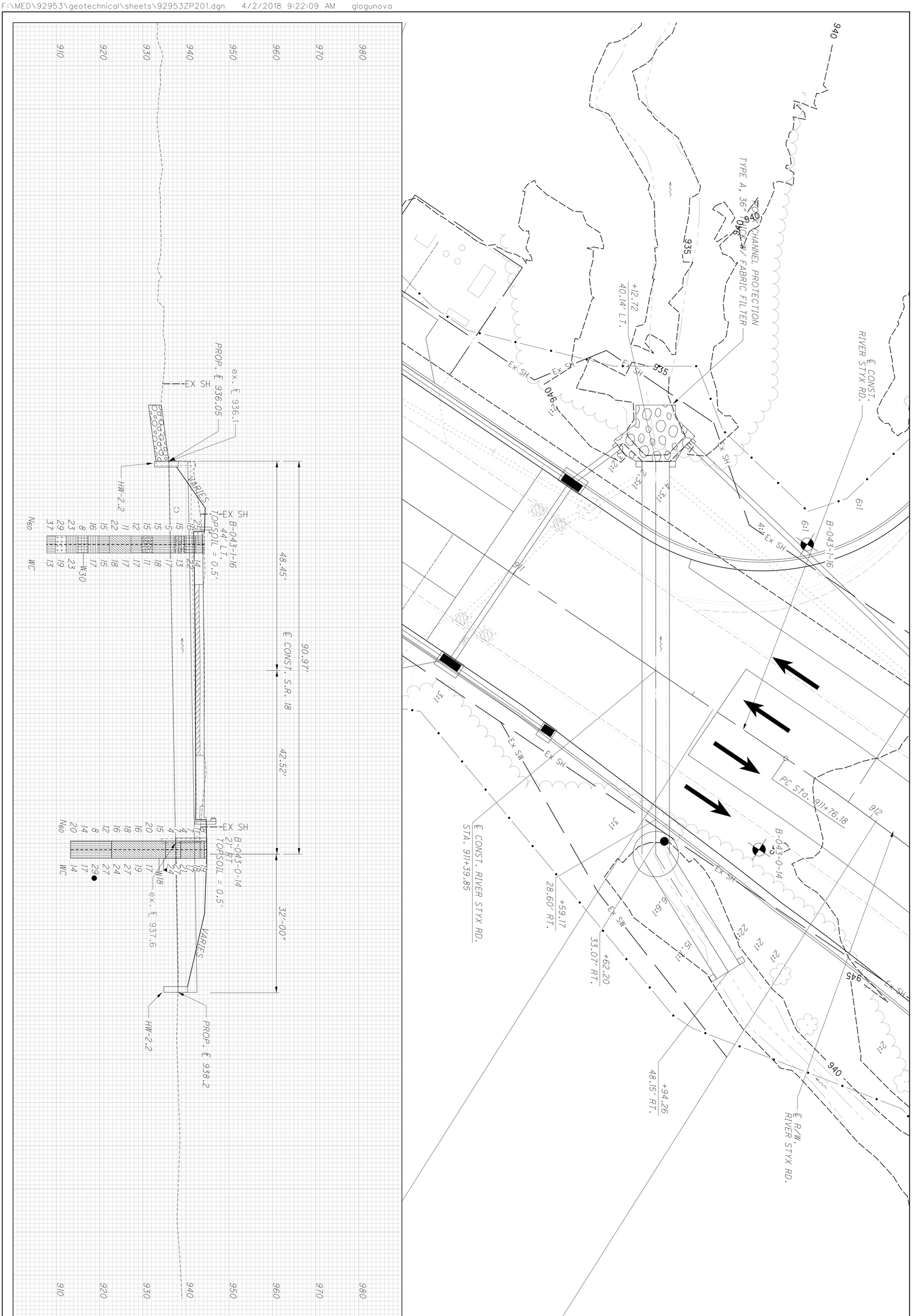


	35/68	MED-18-13.54	STRUCTURE FOUNDATION EXPLORATION CULVERT NO. 6 - STA. 911+40	DRAWN GL CHECKED CH	0 10 5 20 HORIZONTAL SCALE IN FEET

APPENDIX B

SOIL BORING LOGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 8/18/15 14:37 - \\COLUMBUSLAB\LAB\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\MED-18-13.54 (ODOT)\GINT FILES\MED-18-13.5

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BARR / ASHBAUGH	DRILL RIG: CME 45B	STATION / OFFSET:	EXPLORATION ID B-006-0-14
TYPE: CULVERT	SAMPLING FIRM / LOGGER: BARR / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT:	
PID: 92953 BR ID:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 985.1 (MSL), EOB: 31.5 ft.	PAGE 1 OF 2
START: 7/9/15 END: 7/10/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 77.4	COORD: 41.138723, -81.836074	

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
4", **ASPHALT**	985.1																	
11", **GRANULAR BASE**	984.8																	
MEDIUM DENSE, DARK BROWN AND GRAY, **GRAVEL**, TRACE SAND, TRACE SILT, TRACE CLAY, DRY **(FILL)**	983.9		6 7 8	19	6	SS-1	-	-	-	-	-	-	-	-	-	2	A-1-a (V)	
LOOSE, BROWN, **GRAVEL WITH SAND AND SILT**, TRACE CLAY, DAMP **(FILL)**	982.1		6 4 3	9	56	SS-2	-	38	29	16	12	5	26	19	7	8	A-2-4 (0)	
			3 4 4	10	28	SS-3	-	-	-	-	-	-	-	-	-	7	A-2-4 (V)	
LOOSE, BROWN, **GRAVEL WITH SAND**, SS-4 CONTAINS ASPHALT, DAMP **(FILL)**	979.1																	
			5 4 4	10	17	SS-4	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
@10.0'; SS-5 CONTAINS FEW ROOTS			4 3 3	8	22	SS-5	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
			4 3 4	9	28	SS-6	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
MEDIUM STIFF TO HARD, GRAY MOTTLED WITH BROWN, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST TO DAMP	970.6		4 3 3	8	78	SS-7	1.5 - 3.2	2	5	12	43	38	34	19	15	22	A-6a (10)	
@17.5'; SS-8 BECOMES GRAY, "AND" SAND			3 3 3	8	100	SS-8	0.7 - 1.4	5	15	34	28	18	29	18	11	20	A-6a (3)	
@20.0'; SS-9 TO SS-10 BECOME GRAY MOTTLED WITH BROWN, LITTLE SAND		W	2 2 2	5	56	SS-9	0.5 - 1.3	-	-	-	-	-	-	-	-	19	A-6a (V)	
			7 9 7	21	83	SS-10	1.6 - 3.1	-	-	-	-	-	-	-	-	12	A-6a (V)	
@25.0'; SS-11 TO SS-13 BECOME GRAYISH BROWN			5 8 10	23	100	SS-11	3.4 - 3.9	5	6	11	40	38	28	16	12	15	A-6a (9)	
			5 8 9	22	100	SS-12	2.6 - 4.5+	4	7	12	40	37	28	17	11	15	A-6a (8)	

NOTES: GROUNDWATER ENCOUNTERED AT 22.0' DURING DRILLING. CAVE DEPTH 20.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

PID: 92953	BR ID:	PROJECT: MED-18-13.54	STATION / OFFSET:	START: 7/9/15	END: 7/10/15	PG 2 OF 2	B-006-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 955.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
	953.6	31 EOB	4 5 9	18	100	SS-13	2.2 - 4.5+	-	-	-	-	-	-	-	-	15	A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 22.0' DURING DRILLING. CAVE DEPTH 20.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BEI / ASHBAUGH	DRILL RIG: CME 55	STATION / OFFSET: 102+89, 3' LT.	EXPLORATION ID B-006-1-16
TYPE: CULVERT	SAMPLING FIRM / LOGGER: BEI / K.BAME	HAMMER: CME AUTOMATIC	ALIGNMENT: PR S.R. 18	
PID: 92953 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/3/15	ELEVATION: 983.8 (MSL) EOB: 46.5 ft.	PAGE 1 OF 2
START: 9/22/16 END: 9/22/16	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.8	LAT / LONG: 41.138799, -81.835908	

MATERIAL DESCRIPTION AND NOTES	ELEV. 983.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
4.0", **ASPHALT**	983.5																	
8.0", **GRANULAR BASE**	982.8																	
VERY STIFF TO HARD, BROWN MOTTLED WITH GRAY CHANGING TO BROWN MOTTLED WITH GRAY AND DARK GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP TO MOIST **(FILL)**			5 3 4	10	39	SS-1	2.6 - 3.9	-	-	-	-	-	-	-	-	17	A-6b (V)	
@5.0'; SS-2 CONTAINS FEW ASPHALT FRAGMENTS			3 3 3	8	50	SS-2	3.0 - 4.5+	-	-	-	-	-	-	-	-	20	A-6b (V)	
			3 3 6	12	67	SS-3	4.0 - 4.5+	3	4	8	35	50	38	19	19	19	A-6b (12)	
@10.0'; SS-4 CONTAINS CINDERS AND CONCRETE FRAGMENTS			3 3 4	10	89	SS-4	2.25 - 4.2	-	-	-	-	-	-	-	-	20	A-6b (V)	
@12.5'; SS-5A CONTAINS FEW IRON STAINS	970.6		2 26 17	59	67	SS-5A	2.75 - 4.5+	-	-	-	-	-	-	-	-	21	A-6b (V)	
VERY DENSE, BROWN AND GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, GRAVEL IS CONCRETE FRAGMENTS, DRY **(FILL)**	969.3	W				SS-5B	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
VERY DENSE, BROWN AND GRAY, **GRAVEL WITH SAND, SILT, AND CLAY**, CONTAINS CINDERS, MOIST **(FILL)**	966.8		12 17 39	76	39	SS-6	-	-	-	-	-	-	-	-	-	24	A-2-6 (V)	
LOOSE TO DENSE, GRAY AND BROWN, **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, CONTAINS CONCRETE FRAGMENTS, WET **(FILL)**			4 2 4	8	94	SS-7	-	23	27	29	15	6	NP	NP	NP	21	A-1-b (0)	
	962.6		12 15 13	38	50	SS-8A	-	-	-	-	-	-	-	-	-	31	A-1-b (V)	
STIFF, GRAY, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, MOIST	961.8					SS-8B	1.3 - 1.75	-	-	-	-	-	-	-	-	19	A-4a (V)	
VERY STIFF TO HARD, GRAYISH BROWN, **SILT AND CLAY**, LITTLE GRAVEL, LITTLE SAND, SS-9 CONTAINS SILT LENSES, DAMP TO MOIST			3 5 8	18	100	SS-9	4.0 - 4.5+	15	5	8	38	34	29	18	11	15	A-6a (8)	
			4 7 10	23	100	SS-10	4.4 - 4.5+	-	-	-	-	-	-	-	-	16	A-6a (V)	
@27.5'; SS-11 AND SS-12 BECOME GRAY AND SS-11 CONTAINS A COARSE AND FINE SAND SEAM			5 9 15	33	100	SS-11	2.5 - 4.3	-	-	-	-	-	-	-	-	16	A-6a (V)	

PID: 92953	SFN:	PROJECT: MED-18-13.54	STATION / OFFSET: 102+89, 3' LT.	START: 9/22/16	END: 9/22/16	PG 2 OF 2	B-006-1-16

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF TO HARD, GRAYISH BROWN, **SILT AND CLAY**, LITTLE GRAVEL, LITTLE SAND, SS-9 CONTAINS SILT LENSES, DAMP TO MOIST *(continued)*	953.8	31	6 8 9	23	11	SS-12	-	-	-	-	-	-	-	-	-	22	A-6a (V)	
@32.5'; SS-13 BECOMES STIFF, CONTAINS SILT LENSES		32																
		33	3 4 6	14	100	SS-13	1.8 - 2.0	-	-	-	-	-	-	-	-	26	A-6a (V)	
	949.3	34																
MEDIUM STIFF TO STIFF, GRAYISH BROWN, **SANDY SILT**, "AND" CLAY, MOIST	948.4	35	4 5 6	15	100	SS-14A	0.5 - 1.75	0	2	4	48	46	30	20	10	25	A-4a (8)	
STIFF TO VERY STIFF, GRAY, **SANDY SILT**, "AND" GRAVEL, SOME CLAY, DAMP TO MOIST		36				SS-14B	1.0 - 2.25	-	-	-	-	-	-	-	-	23	A-4a (V)	
@37.0'; SS-15 TO SS-18 BECOME TRACE TO LITTLE GRAVEL		37																
		38	5 7 8	20	83	SS-15	2.5 - 3.75	7	10	12	48	23	23	16	7	14	A-4a (7)	
		39																
		40																
		41	2 6 9	20	100	SS-16	2.5 - 2.75	-	-	-	-	-	-	-	-	6	A-4a (V)	
		42																
		43	6 8 10	25	100	SS-17	1.25	-	-	-	-	-	-	-	-	14	A-4a (V)	
		44																
		45																
	937.3	46 EOB	4 7 14	29	100	SS-18	1.75 - 2.0	-	-	-	-	-	-	-	-	17	A-4a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 14.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED ASPHALT PATCH; PUMPED 68 GAL. BENTONITE GROUT

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BARR / ASHBAUGH	DRILL RIG: CME 45B	STATION / OFFSET:	EXPLORATION ID B-007-0-14
TYPE: EXISTING PAVEMENT SUBGRADE	SAMPLING FIRM / LOGGER: BARR / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT:	
PID: 92953 BR ID:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 983.9 (MSL), EOB: 31.5 ft.	PAGE 1 OF 2
START: 7/10/15 END: 7/10/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 77.4	COORD: 41.138708, -81.835945	

MATERIAL DESCRIPTION AND NOTES	ELEV. 983.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
5", **ASPHALT**	983.5																	
8.5", **GRANULAR BASE**	982.8																	
STIFF TO VERY STIFF, BROWN AND GRAY, **SILT AND CLAY**, LITTLE SAND, LITTLE GRAVEL, MOIST **(FILL)**	980.9		3 2 3	6	72	SS-1	1.4 - 2.2	15	8	12	29	36	32	17	15	20	A-6a (8)	
STIFF TO VERY STIFF, BROWN AND GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP TO MOIST **(FILL)**			2 2 4	8	61	SS-2	2.0 - 3.4	-	-	-	-	-	-	-	-	19	A-6b (V)	
			WOH 2 4	8	56	SS-3	1.4 - 1.9	-	-	-	-	-	-	-	-	20	A-6b (V)	
			2 2 3	6	78	SS-4	1.2 - 2.8	-	-	-	-	-	-	-	-	21	A-6b (V)	
STIFF TO VERY STIFF, BROWN AND GRAY, **SILTY CLAY**, TRACE SAND, TRACE GRAVEL, DAMP **(POSSIBLE FILL)**	974.4		4 3 4	9	61	SS-5	1.2 - 3.7	-	-	-	-	-	-	-	-	18	A-6b (V)	
STIFF TO VERY STIFF, BROWN MOTTLED WITH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP	971.9	W	4 6 5	14	67	SS-6	1.4 - 3.2	6	6	10	35	43	35	17	18	17	A-6b (11)	
@15.0'; SS-7 BECOMES MOIST, BROWN AND DARK GRAY **@ 16.6' SWITCHED RIG DUE TO BREAKDOWN** **CME 55X: CME Automatic Hammer Energy Ratio: 81.2%** **Drilled by: J. Hodges Logged By: D.Lyon**			3 6 5	14	22	SS-7	0.7 - 0.9	-	-	-	-	-	-	-	-	19	A-6b (V)	
LOOSE, BROWN, **GRAVEL**, TRACE SAND, TRACE SILT, TRACE CLAY, (POSSIBLE CUTTINGS), DAMP	967.4		5 3 3	8	28	SS-8	-	-	-	-	-	-	-	-	-	-	A-1-a (V)	
VERY STIFF TO HARD, GRAY MOTTLED WITH BROWN, **SANDY SILT**, "AND" CLAY, TRACE GRAVEL, DAMP	964.4		5 8 11	26	83	SS-9	3.7 - 4.5+	-	-	-	-	-	-	-	-	16	A-4a (V)	
@22.5'; BECOMES GRAYISH BROWN			5 6 9	20	100	SS-10	2.4 - 4.5+	8	6	12	38	36	26	16	10	15	A-4a (8)	
MEDIUM STIFF TO VERY STIFF, GRAYISH BROWN, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, DAMP TO MOIST	959.4		5 5 8	18	100	SS-11	2.0 - 3.75	-	-	-	-	-	-	-	-	16	A-6a (V)	
			7 5 7	16	100	SS-12	1.7 - 3.0 / 1.5 - 3.0	3 / -	6 / -	13 / -	37 / -	41 / -	29 / -	17 / -	12 / -	17 / 23	A-6a (9) / A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 13.0' DURING DRILLING. CAVE DEPTH 9.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 8/18/15 11:15 - C:\USERS\SCONLEY.BRIDGE\DESKTOP\MED-18-13.54 REVISED.GPJ

PID: 92953	BR ID:	PROJECT: MED-18-13.54	STATION / OFFSET:	START: 7/10/15	END: 7/10/15	PG 2 OF 2	B-007-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
Continued From Above	953.9																	
	952.4	31 EOB	3 3 6	12	100	SS-13	0.9 - 2.0 / 1.5 - 2.2	2	4	6	35	53	33	20	13	23	A-6a (9)	
								-	-	-	-	-	-	-	-	20	A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 13.0' DURING DRILLING. CAVE DEPTH 9.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 3/8/17 14:57 - \\COLUMBUSLAB\LAB\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2016 ARCHIVE\MED-18-13.5

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BEI / ASHBAUGH	DRILL RIG: CME 55	STATION / OFFSET: 126+68, 27' LT.	EXPLORATION ID B-014-1-16
TYPE: LANDSLIDE	SAMPLING FIRM / LOGGER: BEI / K.BAME	HAMMER: CME AUTOMATIC	ALIGNMENT: PR S.R. 18	
PID: 92953 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/3/15	ELEVATION: 959.2 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 9/20/16 END: 9/21/16	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.8	LAT / LONG: 41.137761, -81.827385	

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
6.0", **ASPHALT**	959.2																	
8.0", **BRICK**	958.7																	
10.0", **GRANULAR BASE**	958.0																	
VERY STIFF TO HARD, BROWN MOTTLED WITH GRAY BECOMING GRAYISH BROWN, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP TO MOIST	957.2		3 3 4	10	72	SS-1	2.5 - 3.75	8	9	10	28	45	39	18	21	19	A-6b (12)	
			4 4 5	12	50	SS-2	3.0 - 3.5	-	-	-	-	-	-	-	-	19	A-6b (V)	
			4 3 7	14	83	SS-3	4.5+	-	-	-	-	-	-	-	-	15	A-6b (V)	
@10.0'; SS-4 CONTAINS FEW ROOTS AND DECAYED ORGANICS			3 5 6	15	61	SS-4	4.0- 4.5+	-	-	-	-	-	-	-	-	17	A-6b (V)	
	947.2																	
MEDIUM STIFF TO VERY STIFF, BROWN MOTTLED WITH GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP TO MOIST		W	3 4 7	15	78	SS-5	3.9 - 4.0	4	6	11	37	42	33	19	14	17	A-6a (10)	
@15.0'; SS-6 BECOMES GRAYISH BROWN			5 20 9	40	33	SS-6	0.5 - 2.75	-	-	-	-	-	-	-	-	23	A-6a (V)	
	942.2																	
STIFF TO VERY STIFF, GRAYISH BROWN MOTTLED WITH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST			4 4 7	15	56	SS-7	1.5 - 2.3	5	7	9	31	48	40	20	20	23	A-6b (12)	
			4 4 4	11	17	SS-8	1.50	-	-	-	-	-	-	-	-	28	A-6b (V)	
	937.2																	
VERY STIFF, GRAYISH BROWN MOTTLED WITH BROWN, **CLAY**, "AND" SILT, TRACE SAND, TRACE GRAVEL, CONTAINS FEW ROOT HAIRS AND HAS SLIGHT ORGANIC ODOR, MOIST	935.2		3 4 5	12	83	SS-9	2.25	1	1	4	48	46	47	27	20	33	A-7-6 (13)	
STIFF TO VERY STIFF, GRAYISH BROWN MOTTLED WITH BROWN AND ORANGISH BROWN, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, DAMP TO MOIST @25.0'; SS-10 CONTAINS IRON STAINS			3 5 7	16	100	SS-10	1.75 - 2.5	-	-	-	-	-	-	-	-	25	A-6a (V)	
@27.0'; SS-11 BECOMES BROWN MOTTLED WITH GRAY			2 4 7	15	94	SS-11	1.75 - 2.0	3	3	4	43	47	34	21	13	25	A-6a (9)	
	929.7																	

PID: 92953	SFN:	PROJECT: MED-18-13.54	STATION / OFFSET: 126+68, 27' LT.	START: 9/20/16	END: 9/21/16	PG 2 OF 2	B-014-1-16

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF TO HARD, BROWNISH GRAY, **SANDY SILT**, SOME CLAY, LITTLE GRAVEL, DAMP *(continued)*	929.2	31			92	ST-12	2.5 - 4.5+	11	9	14	38	28	23	15	8	13	A-4a (6)	
	924.7	32																
HARD, BROWNISH GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP		33	7 12 14	35	100	SS-13	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
		34																
		35	7 13 19	44	100	SS-14	4.5+	5	7	13	41	34	26	15	11	12	A-6a (8)	
		36																
		37																
		38	8 15 18	45	94	SS-15	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)	
	919.7	39																
HARD, GRAYISH BROWN, **SANDY SILT**, "AND" CLAY, TRACE GRAVEL, DAMP		40																
		41	10 19 24	59	100	SS-16	4.5+	3	5	14	40	38	28	18	10	15	A-4a (8)	
		42																
		43	7 15 18	45	100	SS-17	4.5+	-	-	-	-	-	-	-	-	16	A-4a (V)	
		44																
		45																
		46	7 9 12	29	100	SS-18	4.5+	-	-	-	-	-	-	-	-	16	A-4a (V)	
	912.2	47																
MEDIUM STIFF TO HARD, GRAYISH BROWN, **SILT**, SOME TO "AND" CLAY, TRACE SAND, TRACE GRAVEL, MOIST TO WET		48	4 8 10	25	100	SS-19	3.3 - 4.2	1	1	1	50	47	31	21	10	24	A-4b (8)	
		49																
		50																
		51	8 6 8	19	100	SS-20	2.0 - 2.2	-	-	-	-	-	-	-	-	23	A-4b (V)	
		52																
		53	3 3 3	8	100	SS-21	1.6 - 2.25	0	1	3	61	35	27	20	7	26	A-4b (8)	
		54																
		55																
@55.0'; ST-22 NO RECOVERY		56			0	ST-22	-	-	-	-	-	-	-	-	-	-		
		57																
		58	5 10 18	38	100	SS-23	0.5 - 1.5	-	-	-	-	-	-	-	-	27	A-4b (V)	
	899.7	59																
HARD, GRAYISH BROWN, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, DAMP		60																
	897.7	61	9 14 19	45	100	SS-24	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	
		EOB																

NOTES: GROUNDWATER ENCOUNTERED AT 14.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; PUMPED 90 GAL. BENTONITE GROUT

PROJECT: MED-18-12.99	DRILLING FIRM / OPERATOR: BARR / ASHBAUGH	DRILL RIG: CME 45B	STATION / OFFSET: 127+12, 23 LT	EXPLORATION ID B-015-0-14
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-18	
PID: 92953 BR ID:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 959.6 (MSL), EOB: 31.5 ft.	PAGE 1 OF 2
START: 7/8/15 END: 7/8/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 77.4	COORD: 41.137745, -81.827227	

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
6", **ASPHALT**	959.1																	
6", **BRICK**	958.6																	
SOFT TO VERY STIFF, BROWN CHANGING TO BROWN AND GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST **(FILL)**		1	4 7 9	21	44	SS-1	1.7 - 2.1	-	-	-	-	-	-	-	-	21	A-6b (V)	
		2																
		3	3 4 4	10	6	SS-2	0.4 - 0.5	-	-	-	-	-	-	-	-	24	A-6b (V)	
		4																
		5	4 6 7	17	39	SS-3	1.2 - 1.5	-	-	-	-	-	-	-	-	24	A-6b (V)	
		6																
		7																
@7.5'; CHANGES TO VERY STIFF TO HARD		8	8 16 25	53	56	SS-4	2.0 - 4.5+	7	8	11	32	42	38	19	19	18	A-6b (11)	
	950.1	9																
VERY STIFF TO HARD, BROWN, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP		10	7 10 12	28	67	SS-5	2.0 - 4.5+	-	-	-	-	-	-	-	-	18	A-6b (V)	
	947.6	11																
STIFF TO HARD, SILT AND CLAY, **LITTLE SAND, TRACE GRAVEL**, DAMP		12																
		13	4 8 29	48	72	SS-6	2.0 - 4.5+	5	6	12	34	43	33	18	15	18	A-6a (10)	
		14																
		15																
		16	5 18 50/5"	-	88	SS-7	1.7 - 4.5+	-	-	-	-	-	-	-	-	16	A-6a (V)	
@16.4'; ENCOUNTERED COBBLE		17																
		18	36 50	-	83	SS-8	4.5+	-	-	-	-	-	-	-	-	17	A-6a (V)	
	940.3	19																
STIFF, BROWN MOTTLED WITH GRAY, **SILTY CLAY**, SOME SAND, LITTLE GRAVEL, MOIST		20																
	938.6	21	3 5 5	13	100	SS-9	1.2 - 1.6	16	10	12	29	33	36	19	17	20	A-6b (8)	
		22																
@22.5'; SS-10 NO RECOVERY		23 W	5 3 4	9	0	SS-10	-	-	-	-	-	-	-	-	-	-		
		24																
		25																
VERY SOFT TO MEDIUM STIFF, BROWN MOTTLED WITH GRAY, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, MOIST		26	4 3 3	8	22	SS-11	0.5 - 0.8	-	-	-	-	-	-	-	-	29	A-4a (V)	
		27																
		28	WOH 3 3	8	100	SS-12	0.2 - 0.6	6	8	12	46	28	26	16	10	18	A-4a (8)	
		29																

NOTES: GROUNDWATER ENCOUNTERED AT 23.5' DURING DRILLING. CAVE DEPTH 26.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SOIL MIXED WITH BENTONITE PELLETS

PID: 92953	BR ID:	PROJECT: MED-18-12.99	STATION / OFFSET: 127+11.51, 23.0 LT	START: 7/8/15	END: 7/8/15	PG 2 OF 2	B-015-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
@30.0'; SS-13 NO RECOVERY	929.6																	
	928.1	31 EOB	7 9 10	25	0	SS-13	-	-	-	-	-	-	-	-	-	-		

NOTES: GROUNDWATER ENCOUNTERED AT 23.5' DURING DRILLING. CAVE DEPTH 26.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SOIL MIXED WITH BENTONITE PELLETS

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BEI / ASHBAUGH	DRILL RIG: CME 55	STATION / OFFSET: 127+62, 22' LT.	EXPLORATION ID B-015-1-16
TYPE: LANDSLIDE	SAMPLING FIRM / LOGGER: BEI / K.BAME	HAMMER: CME AUTOMATIC	ALIGNMENT: PR S.R. 18	
PID: 92953 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/3/15	ELEVATION: 960.0 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 9/20/16 END: 9/20/16	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.8	LAT / LONG: 41.137721, -81.827046	

MATERIAL DESCRIPTION AND NOTES	ELEV. 960.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
AUGERED DOWN (NO SAMPLING)		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 W 22 23 24 25 26 27 28 29																

PID: 92953	SFN:	PROJECT: MED-18-13.54	STATION / OFFSET: 127+62, 22' LT.	START: 9/20/16	END: 9/20/16	PG 2 OF 2	B-015-1-16

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
AUGERED DOWN *(continued)*	930.0	31																
	927.5	32																
VERY STIFF TO HARD, GRAYISH BROWN, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP		33	4 6 9	20	89	SS-1	2.25 - 3.25	6	9	13	41	31	24	16	8	14	A-4a (7)	
		34																
		35																
		36	6 12 17	40	100	SS-2	4.5+	-	-	-	-	-	-	-	-	13	A-4a (V)	
		37																
		38	6 13 20	45	100	SS-3	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)	
		39																
		40																
		41	7 19 22	56	89	SS-4	4.0 - 4.5+	-	-	-	-	-	-	-	-	21	A-4a (V)	
		42																
		43	8 15 21	49	94	SS-5	4.5+	-	-	-	-	-	-	-	-	14	A-4a (V)	
	915.5	44																
STIFF TO HARD, GRAYISH BROWN, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP		45																
		46	8 11 16	37	100	SS-6	2.5 - 4.25	4	6	12	36	42	27	16	11	15	A-6a (8)	
		47																
		48	7 8 12	27	100	SS-7	2.0 - 4.0	-	-	-	-	-	-	-	-	19	A-6a (V)	
		49																
@50.0'; SS-8 BECOMES BROWN, TRACE SAND (INTERBEDDED SILT AND CLAY), MOIST		50																
		51	8 10 11	29	100	SS-8	1.75 - 2.25	-	-	-	-	-	-	-	-	27	A-6a (V)	
	908.0	52																
MEDIUM STIFF TO HARD, GRAYISH BROWN, **SANDY SILT**, "AND" TO LITTLE CLAY, MOIST		53	4 4 6	14	100	SS-9	0.5 - 1.0	0	0	1	44	55	31	21	10	27	A-4a (8)	
		54																
		55																
@55.0'; SS-10 TO SS-12 BECOME TRACE GRAVEL, DAMP		56	7 9 10	26	100	SS-10	1.25 - 2.0	-	-	-	-	-	-	-	-	20	A-4a (V)	
		57																
		58	2 3 7	14	89	SS-11	4.0 - 4.25	-	-	-	-	-	-	-	-	14	A-4a (V)	
		59																
@60.0'; SS-12 CONTAINS IRON STAINS		60																
	898.5	61 EOB	13 17 25	57	100	SS-12	4.5+	10	14	18	38	20	20	15	5	11	A-4a (5)	

NOTES: GROUNDWATER ENCOUNTERED AT 22.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 90 GAL. BENTONITE GROUT

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 11/17/15 11:02 - \\COLUMBUSLABLABACTIVE PROJECTS\ACTIVE SOIL PROJECTS\MED-18-13.54 (ODOT)\GINT FILES\MED-18-13.

PROJECT: MED-18-12.99	DRILLING FIRM / OPERATOR: BARR / J.HODGES	DRILL RIG: CME 45B	STATION / OFFSET: 127+42, 19 RT	EXPLORATION ID B-016-0-14
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / C.PATRICK	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-18	
PID: 92953 BR ID:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 959.9 (MSL), EOB: 30.0 ft.	PAGE 1 OF 1
START: 7/2/15 END: 7/2/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 77.4	COORD: 41.137619, -81.827141	

MATERIAL DESCRIPTION AND NOTES	ELEV. 959.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
3", **ASPHALT**	959.7																	
2", **GRANULAR BASE**	959.5																	
HARD, BROWN WITH GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP **(FILL)**	956.9		3 3 4	9	56	SS-1	4.5+	-	-	-	-	-	-	-	-	18	A-6a (V)	
VERY STIFF TO HARD, BROWN WITH GRAY, **CLAY**, SOME SILT, LITTLE SAND, TRACE GRAVEL, CONTAINS FEW ROOT HAIRS, MOIST **(FILL)** @4.5'; SS-3 CONTAINS FIELD TILL FRAGMENTS	952.6		3 4 5	12	100	SS-2	2.75 - 3.0	1	3	9	28	59	47	20	27	21	A-7-6 (16)	
			3 4 6	13	100	SS-3	2.5 - 4.5+	-	-	-	-	-	-	-	-	21	A-7-6 (V)	
VERY STIFF, BROWN WITH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP **(POSSIBLE FILL)**	948.6		4 4 5	12	100	SS-4	2.6 - 4.0	-	-	-	-	-	-	-	-	17	A-6b (V)	
STIFF TO VERY STIFF, GRAYISH BROWN MOTTLED W/ GRAY BROWN AND DARK GRAY, **CLAY**, "AND" SILT, LITTLE SAND, CONTAINS FEW FINE ROOTS, MOIST	944.6	W	3 3 5	10	100	SS-5	1.4 - 3.2	0	4	9	36	51	49	21	28	24	A-7-6 (17)	
DENSE, GRAYISH BROWN, **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, MOIST	940.6		7 23 13	46	78	SS-6	-	-	-	-	-	-	-	-	-	24	A-2-4 (V)	
STIFF, BROWN MOTTLED WITH GRAYISH BROWN, **SILTY CLAY**, LITTLE SAND,TRACE GRAVEL, MOIST	936.6		6 11 27	49	78	SS-7	1.4 - 1.7	-	-	-	-	-	-	-	-	23	A-6b (V)	
STIFF TO VERY STIFF, OLIVE GRAY MOTTLED WITH GRAY, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST	932.6		3 3 4	9	100	SS-8	1.25 - 4.0	-	-	-	-	-	-	-	-	22	A-6a (V)	
VERY STIFF, GRAY, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, DAMP	929.9	EOB	4 8 11	25	100	SS-9	2.75 - 3.25	8	15	16	42	19	22	16	6	13	A-4a (5)	

NOTES: GROUNDWATER ENCOUNTERED AT 15.0' DURING DRILLING. CAVE DEPTH 20.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED .5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 3/8/17 14:57 - \\COLUMBUSLAB\LAB\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2016 ARCHIVE\MED-18-13.5

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BEI / ASHBAUGH	DRILL RIG: CME 55	STATION / OFFSET: 127+78, 18' RT.	EXPLORATION ID B-016-1-16
TYPE: CULVERT	SAMPLING FIRM / LOGGER: BEI / K.BAME	HAMMER: CME AUTOMATIC	ALIGNMENT: PR S.R. 18	
PID: 92953 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/3/15	ELEVATION: 960.9 (MSL) EOB: 51.5 ft.	PAGE 1 OF 2
START: 9/22/16 END: 9/22/16	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.8	LAT / LONG: 41.137607, -81.827014	

MATERIAL DESCRIPTION AND NOTES	ELEV. 960.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
AUGERED DOWN (No sampling)		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																

PID: 92953	SFN:	PROJECT: MED-18-13.54	STATION / OFFSET: 127+78, 18' RT.	START: 9/22/16	END: 9/22/16	PG 2 OF 2	B-016-1-16

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
AUGERED DOWN *(continued)*	930.9	31 32																
	928.4																	
VERY STIFF, GRAY TO BROWN, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP		33 34	5 6 10	22	83	SS-1	3.75 - 4.0	5	7	12	45	31	26	17	9	15	A-4a (8)	
	925.5	35 36	5 10 17	37	100	SS-2	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)	
VERY STIFF TO HARD, GRAY, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, CONTAINS SILT LENSES, DAMP		37 38 39	8 15 24	53	100	SS-3	4.5+	10	10	11	37	32	26	15	11	11	A-6a (7)	
		40 41 42	8 13 20	45	100	SS-4	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
		43 44	7 16 21	50	100	SS-5	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)	
		45 46 47	7 12 19	42	100	SS-6	4.5+	-	-	-	-	-	-	-	-	15	A-6a (V)	
@47.5'; SS-7 AND SS-8 BECOME LITTLE SAND		48 49	6 8 12	27	89	SS-7	3.0 - 4.5+	3	4	9	37	47	31	18	13	18	A-6a (9)	
@50.0'; SS-8 BECOMES BROWN, (INTERBEDDED SILT AND CLAY), MOIST	909.4	50 51 EOB	6 9 13	30	100	SS-8	2.75 - 3.75	-	-	-	-	-	-	-	-	25	A-6a (V)	

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

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; PUMPED 76 GAL. BENTONITE GROUT

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BARR / J.HODGES	DRILL RIG: CME 55X	STATION / OFFSET:	EXPLORATION ID B-043-0-14
TYPE: CULVERT	SAMPLING FIRM / LOGGER: BARR / D. LYON	HAMMER: CME AUTOMATIC	ALIGNMENT:	
PID: 92953 BR ID:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 944.8 (MSL), EOB: 31.5 ft.	PAGE 1 OF 2
START: 7/7/15 END: 7/8/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.2	COORD: 41.133550, -81.812528	

MATERIAL DESCRIPTION AND NOTES	ELEV. 944.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
6.5", **TOPSOIL**	944.2																	
STIFF TO HARD, BROWN MOTTLED WITH BLACK, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, MOIST **(FILL)**	943.3	1	3 2 4	8	67	SS-1	1.25 - 4.5+	-	-	-	-	-	-	-	-	19	A-6a (V)	
STIFF TO VERY STIFF, DARK GRAY MOTTLED WITH BROWN, **SILT AND CLAY**, SOME SAND, LITTLE GRAVEL, DAMP TO MOIST		2	4 4 4	11	94	SS-2	1.75 - 4.0	13	7	20	32	28	33	18	15	18	A-6a (7)	
@4.5'; SS-4 BECOMES SOFT TO STIFF		3	2 3 2	7	39	SS-3	2.5 - 4.0	-	-	-	-	-	-	-	-	17	A-6a (V)	
	938.8	4																
SOFT TO STIFF, DARK GRAY TO DARK GRAYISH BROWN, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, CONTAINS WOOD FRAGMENTS, MOIST		5	2 1 2	4	78	SS-4	0.25 - 1.5	11	12	19	30	28	29	17	12	21	A-6a (5)	
		6	WOH 2 3	7	100	SS-5	0.25 - 1.0	-	-	-	-	-	-	-	-	27	A-4a (V)	
		7	1 2 1	4	89	SS-6	0.25 - 0.75	-	-	-	-	-	-	-	-	24	A-4a (V)	
	935.3	8																
STIFF TO HARD, GRAY, **SILT AND CLAY**, TRACE TO LITTLE SAND, TRACE GRAVEL, MOIST		9																
		10																
		W 11	3 4 7	15	89	SS-7	2.5 - 3.75	-	-	-	-	-	-	-	-	18	A-6a (V)	
		12																
		13	4 6 9	20	100	SS-8	3.75 - 4.5+	1	0	1	64	34	27	16	11	17	A-6a (8)	
		14																
		15																
		16	4 5 7	16	100	SS-9	1.25 - 2.0	4	5	9	37	45	30	16	14	19	A-6a (10)	
		17																
		18	4 5 8	18	100	SS-10	1.5 - 4.0	-	-	-	-	-	-	-	-	27	A-6a (V)	
		19																
		20																
		21	4 5 7	16	72	SS-11	1.0 - 2.25	-	-	-	-	-	-	-	-	24	A-6a (V)	
	922.8	22																
STIFF TO VERY STIFF, GRAY, **SANDY SILT**, SOME CLAY, DAMP TO MOIST		23	2 2 7	12	100	SS-12	1.5 - 3.5	-	-	-	-	-	-	-	-	27	A-4a (V)	
		24																
		25																
		26	3 3 3	8	94	SS-13	1.0 - 2.25	0	2	19	46	33	27	21	6	29	A-4a (8)	
		27																
@27.5'; SS-14 TO SS-15 BECOME "AND" GRAVEL		28	3 4 6	14	100	SS-14	1.0 - 2.25	-	-	-	-	-	-	-	-	17	A-4a (V)	
		29																

NOTES: GOUNDWATER ENCOUNTERED AT 11.0' DURING DRILLING, 10.0" UPON COMPLETION. CAVE DEPTH 10.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 0.5 BAG BENTONITE GROUT; SHOVELED SOIL CUTTINGS

PID: 92953	BR ID:	PROJECT: MED-18-13.54	STATION / OFFSET:	START: 7/7/15	END: 7/8/15	PG 2 OF 2	B-043-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
STIFF TO VERY STIFF, GRAY, **SANDY SILT**, SOME CLAY, DAMP TO MOIST *(continued from above)*	914.8																	
	913.3	31	4 6 9	20	89	SS-15	3.25 - 4.5+	-	-	-	-	-	-	-	-	14	A-4a (V)	
		EOB																

NOTES: GOUNDWATER ENCOUNTERED AT 11.0' DURING DRILLING, 10.0" UPON COMPLETION. CAVE DEPTH 10.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 0.5 BAG BENTONITE GROUT; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 3/8/17 14:57 - \\COLUMBUSLAB\LAB\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2016 ARCHIVE\MED-18-13.5

PROJECT: MED-18-13.54	DRILLING FIRM / OPERATOR: BEI / ASHBAUGH	DRILL RIG: CME 55	STATION / OFFSET: 911+53, 44' LT.	EXPLORATION ID B-043-1-16
TYPE: CULVERT	SAMPLING FIRM / LOGGER: BEI / K.BAME	HAMMER: CME AUTOMATIC	ALIGNMENT: PR RIVER STYX RD	
PID: 92953 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/3/15	ELEVATION: 944.3 (MSL) EOB: 36.5 ft.	PAGE 1 OF 2
START: 9/23/16 END: 9/23/16	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.8	LAT / LONG: 41.133472, -81.812766	

MATERIAL DESCRIPTION AND NOTES	ELEV. 944.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
6.0", **TOPSOIL**	943.8																	
MEDIUM DENSE, BROWN, **SANDY SILT**, SOME GRAVEL, LITTLE CLAY, CONTAINS IRON STAINS, DAMP **(FILL)**	942.3	1	9 8 10	25	83	SS-1	-	-	-	-	-	-	-	-	-	14	A-4a (V)	
HARD, DARK BROWN, **CLAY**, "AND" SILT, LITTLE SAND, TRACE GRAVEL, DAMP **(FILL)**	939.8	2 3 4	4 5 7	16	94	SS-2	4.25 - 4.5+	1	2	10	43	44	45	25	20	22	A-7-6 (13)	
MEDIUM DENSE, BROWN AND ORANGISH BROWN, **GRAVEL WITH SAND, SILT, AND CLAY**, CONTAINS MANY IRON STAINS, DAMP	937.3	5 6 7	4 5 6	15	67	SS-3	-	27	20	21	16	16	28	17	11	13	A-2-6 (0)	
MEDIUM STIFF TO STIFF, BROWN MOTTLED WITH ORANGISH BROWN, **SANDY SILT**, LITTLE CLAY, LITTLE TO SOME GRAVEL, DAMP TO MOIST		8 9	3 2 2	5	78	SS-4	0.5 - 1.25	11	13	28	29	19	25	17	8	17	A-4a (3)	
@10.0'; SS-5 BECOMES BROWN AND GRAY	932.3	10 11 12	1 4 7	15	89	SS-5	4.5+	-	-	-	-	-	-	-	-	18	A-4a (V)	
MEDIUM DENSE, GRAYISH BROWN, **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP	929.8	13 14	3 5 6	15	83	SS-6	-	28	16	24	18	14	19	14	5	11	A-2-4 (0)	
STIFF TO VERY STIFF, GRAYISH BROWN, **SANDY SILT**, LITTLE CLAY, CONTAINS FEW ROOT HAIRS, MOIST	927.3	15 16 17	2 3 6	12	72	SS-7	1.25- 4.0	-	-	-	-	-	-	-	-	17	A-4a (V)	
STIFF TO VERY STIFF, GRAYISH BROWN, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST	922.3	18 19 20 21	3 3 5	11	94	SS-8	1.75 - 3.25	3	5	12	36	44	28	16	12	17	A-6a (9)	
			3 7 9	22	11	SS-9	-	-	-	-	-	-	-	-	-	18	A-6a (V)	
STIFF TO VERY STIFF, GRAYISH BROWN, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, MOIST	919.8	23 24	3 5 6	15	78	SS-10	1.75 - 3.0	1	4	35	43	17	NP	NP	NP	15	A-4a (5)	
VERY STIFF, GRAYISH BROWN, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP	917.3	25 26 27	2 5 7	16	100	SS-11	2.25 - 3.0	-	-	-	-	-	-	-	-	17	A-6b (V)	
STIFF, GRAYISH BROWN, **CLAY**, SOME SILT, TRACE SAND, MOIST	914.8	W 28 29	3 2 4	8	100	SS-12	1.0 - 1.75	0	1	0	23	76	43	23	20	30	A-7-6 (13)	

PID: 92953	SFN:	PROJECT: MED-18-13.54	STATION / OFFSET: 911+53, 44' LT.	START: 9/23/16	END: 9/23/16	PG 2 OF 2	B-043-1-16

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF, BROWN MOTTLED WITH GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST *(continued)*	914.3	31	3 8 9	23	94	SS-13	2.0 - 3.0	-	-	-	-	-	-	-	-	23	A-6b (V)	
	912.3	32																
STIFF, BROWN MOTTLED WITH GRAY, **SILT**, SOME CLAY, LITTLE SAND, TRACE GRAVEL, DAMP		33	6 9 12	29	100	SS-14	1.0 -1.5	6	5	6	59	24	25	20	5	19	A-4b (8)	
	909.8	34																
HARD, GRAY, **SANDY SILT**, LITTLE CLAY, LITTLE GRAVEL, DAMP		35	6 10 17	37	100	SS-15	4.0 - 4.5+	-	-	-	-	-	-	-	-	13	A-4a (V)	
	907.8	36 EOB																

NOTES: GROUNDWATER ENCOUNTERED AT 28.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 54 GAL. BENTONITE GROUT

APPENDIX C

CULVERT #1 ANALYSES

CULVERT #1

EXTERNAL STABILITY ANALYSIS

Objective: **To evaluate the external stability of CIP wall design.**
Method: **In accordance with ODOT Bridge Design Manual, 2017 [Sect. 204.6.2.2] LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 11.6.1, Sect. 11.6.2, and Sect. 11.6.3].**

Givens:

Backfill Soil Design Parameters:

$\phi'_f := 32\ deg$ — Effective angle of internal friction

$\gamma_f := 120\ \frac{lbf}{ft^3}$ — Unit weight

$c'_f := 400\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 17\ deg$ — Friction angle between fill and wall taken as specified in **LRFD Table 3.11.5.3-1 (degrees)**

Soil Design Parameters for Bearing Resistance (Average Below Footing):

Drained Conditions (Effective Stress):

$\phi'_{fd} := 24\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 120\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 200\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{fdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$Su_{fdu} := 1850\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Soil Design Parameters for Sliding Resistance (Below Footing)

Drained Conditions (Effective Stress):

$\phi'_{sd} := 24\ deg$ — Effective angle of internal friction

$\gamma_{sd} := 120\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{sd} := 200\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{sdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

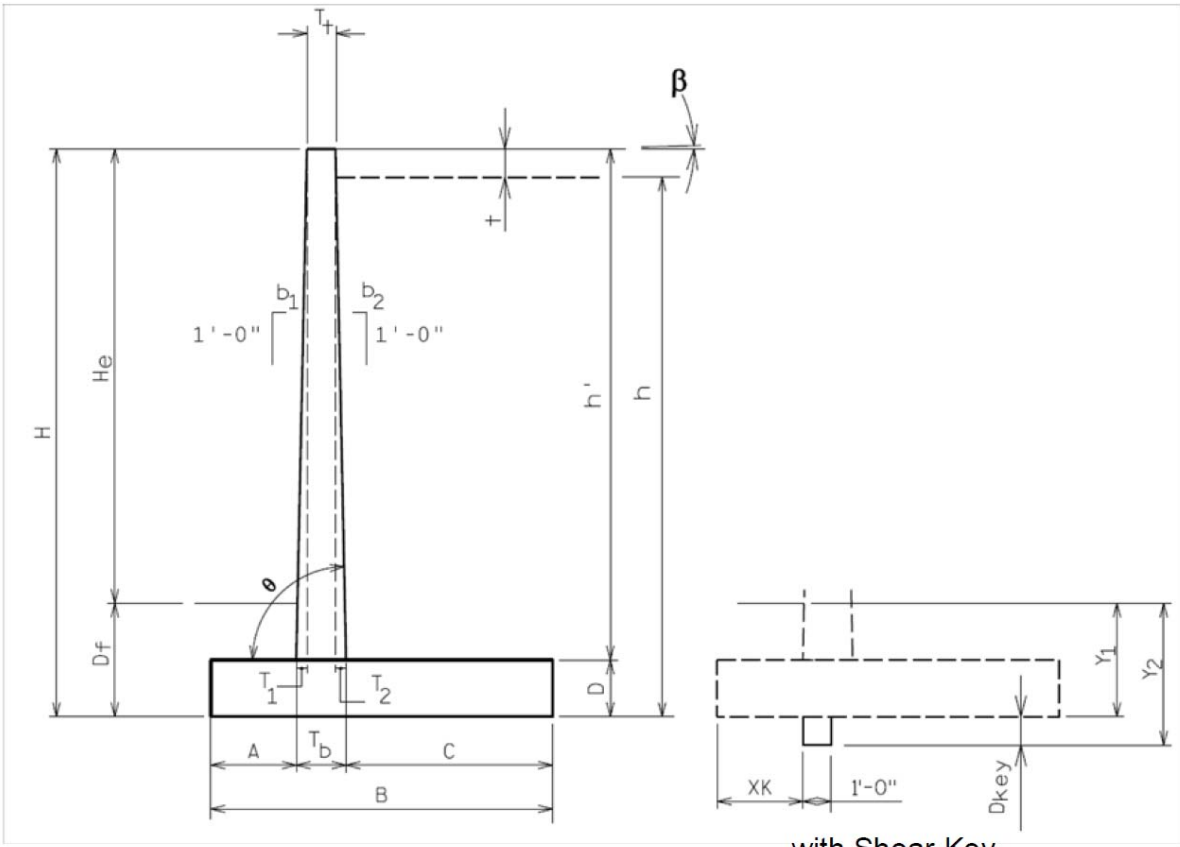
$Su_{sdu} := 1850\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Other Parameters:

$\gamma_c := 150\ \frac{lbf}{ft^3}$ — Concete Unit weight

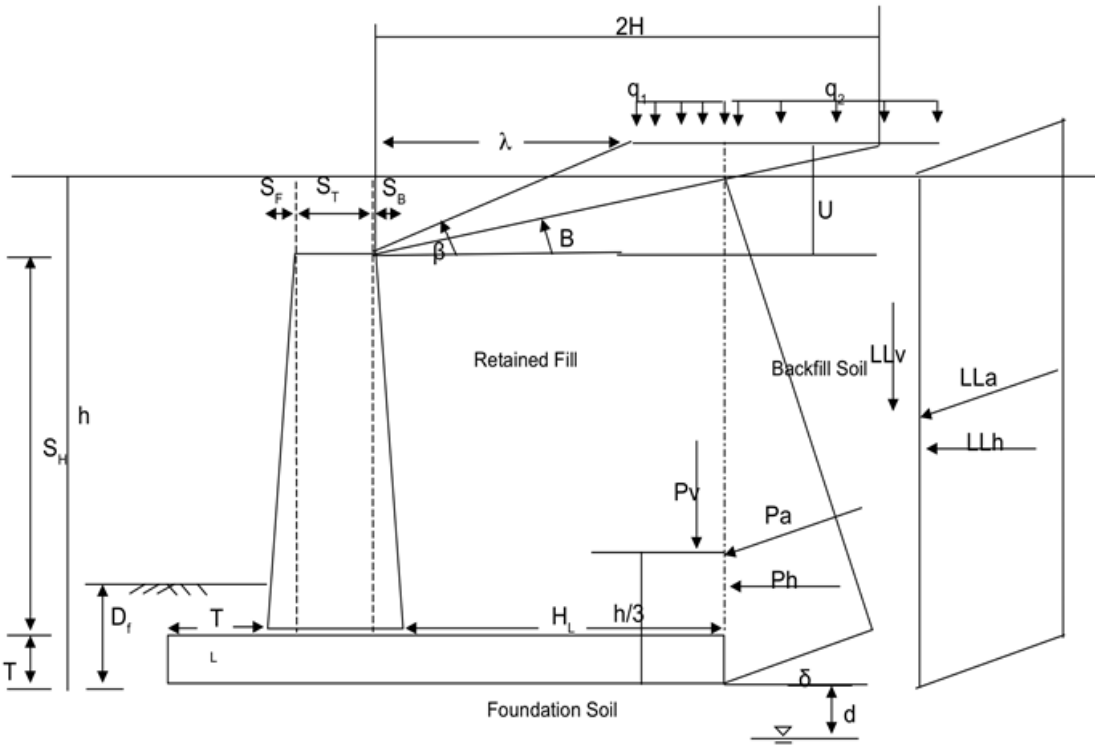
$\gamma_p := 150\ \frac{lbf}{ft^3}$ — Pavement Unit weight

Wall Geometry:



with Shear Key

$H_e := 10\ ft$		Exposed wall height
$B := 8\ ft$		Footing base width (2/5H to 3/5H)
$A := 1.5\ ft$		Toe projection (H/8 to H/5)
$D := 2\ ft$		Footing thickness (H/8 to H/5)
$D_f := 3\ ft$		Footing cover at Toe
$H := H_e + D_f$	$H = 13\ ft$	Design Wall Height
$h' := H - D$	$h' = 11\ ft$	Stem height
$t := 0 \cdot ft$		Pavement thickness
$T_t := 1.5\ ft$		Stem thickness at top of wall
$b_1 := 0 \cdot \left(\frac{in}{ft}\right)$		Front wall batter, (b1H:12V)
$b_2 := 0 \cdot \left(\frac{in}{ft}\right)$		Backwall batter, (b2H:12V)
$T_1 := b_1 \cdot h'$	$T_1 = 0\ ft$	Stem front batter width
$T_2 := b_2 \cdot h'$	$T_2 = 0\ ft$	Stem back batter width
$T_b := T_1 + T_2 + T_t$	$T_b = 1.5\ ft$	Stem thickness at bottom of wall
$C := B - A - T_b$	$C = 5\ ft$	Heel projection



Inclination of ground slope behind face of wall :

- Horizontal: **0**
- 3H:1V: **18.435**
- 2H:1V: **26.565**
- 1.5H:1V: **33.690**

$\theta := 90 \cdot deg$ Angle of back face of wall to horizontal

$\beta_{BackSlope} := 26.565\ deg$ Inclination of ground slope behind face of wall. If it is horizontal backfill behind CIP wall, $\beta_{Backslope}$ = 0 deg

$\lambda := 23\ ft$ Horizontal distance from the back of the wall to the top of the slope (for broken-back slopes). If it is infinite slope behind CIP Wall, input λ larger than 2H; If it is horizontal backfill behind MSE wall, λ = 0 ft

$H_{BackSlope} := \lambda \cdot \tan\left(\beta_{BackSlope}\right)$ $H_{BackSlope} = 11.5\ ft$ Height of broken slope behind the wall

$\beta := \text{if}\left(\lambda < 2 \cdot H, \text{atan}\left(\frac{H_{BackSlope}}{2 \cdot H}\right), \beta_{BackSlope}\right) = 23.9\ deg$ Equivalent backslope angle

$h := \text{if}\left(\lambda < T_2 + C, H - t + H_{BackSlope}, H - t + \left(T_2 + C\right) \cdot \tan\left(\beta_{BackSlope}\right)\right) = 15.5\ ft$ Retained soil height

Shear Key Dimensioning:

$D_{key} := 1.5\ ft$ Depth of shear key from bottom of footing

$D_w := 1\ ft$ Width of shear key

$XK := 0\ ft$ Distance from toe to shear key

$y_1 := D_f$ $y_1 = 3\ ft$ Bottom of footing depth

$y_2 := D_f + D_{key}$ $y_2 = 4.5\ ft$ Bottom of shear key depth

Live Load Surcharge Parameters:

$SUR := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 100\ \frac{lbf}{ft^2}\right) = 100\ \frac{lbf}{ft^2}$ Live load surcharge (per LRFD BDS [3.11.6.4])
Note: when it is infinite slope, SUR equal 100 psf to account for construction loads

$SUR_{@Backfill} := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 0\ \frac{lbf}{ft^2}\right) = 0\ \frac{lbf}{ft^2}$ Live load surcharge above the MSE Wall soil reinforcement (per LRFD BDS [3.11.6.4])

Calculations:

Earth Pressure Coefficients:

Backfill Active Earth:

$$\Gamma := \left(1 + \sqrt{\frac{\left(\sin\left(\phi'_f + \delta\right) \cdot \sin\left(\phi'_f - \beta\right)\right)}{\left(\sin\left(\theta - \delta\right) \cdot \sin\left(\theta + \beta\right)\right)}}\right)^2 \qquad \Gamma = 1.821$$

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_f\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.4129$$

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

Foundation Soil Passive Earth:

Drained Conditions assuming($\phi'_{sd} > 0$):

Input Parameters for **LRFD Figure 3.11.5.4-2**, assumes θ = 90 degrees

$$\frac{\beta}{\phi'_{sd}} = 0.994 \qquad \frac{-\delta}{\phi'_{sd}} = -0.708$$

$k'_p := 7.0$ Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

Determine Reduction Factor (R) by interpolation:

$\phi x_1 := 20$ Lower Bound Angle of Friction

$\phi x_2 := 25$ Upper Bound Angle of Friction

$ratio_L := -.7$ Lower bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$ratio_U := -.6$ Upper bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$R_{x1L} := 0.860$ Reduction Factor at ϕx1 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x1U} := 0.912$ Reduction Factor at ϕx1 and Upper bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2L} := 0.811$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2U} := 0.878$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$$R_L := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2L} - R_{x1L}\right) + R_{x1L} \qquad R_U := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2U} - R_{x1U}\right) + R_{x1U}$$

$$R := \frac{\left(\frac{-\delta}{\phi'_{sd}} - ratio_L\right)}{\left(ratio_U - ratio_L\right)} \cdot \left(R_U - R_L\right) + R_L \qquad R = 0.815$$ Reduction Factor

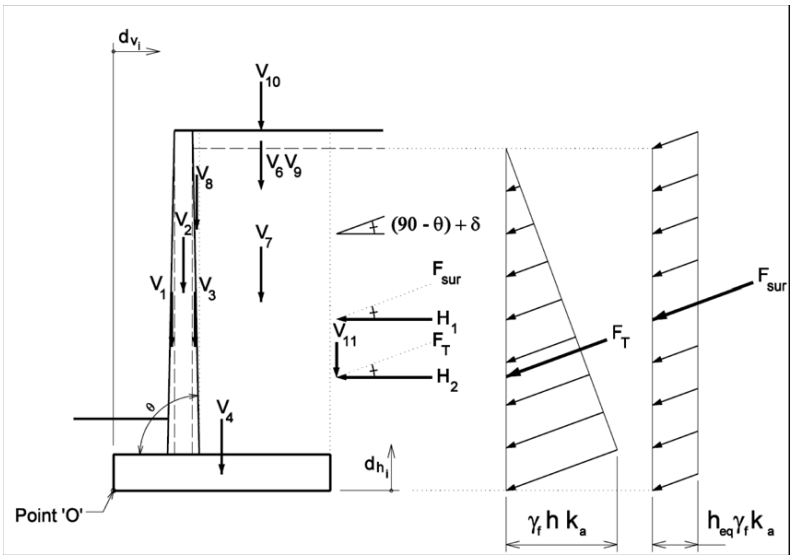
$k_{pd} := R \cdot k'_p \qquad k_{pd} = 5.708$ Passive Earth Pressure Coefficient for Drained Conditions

Undrained Conditions:

$Check := \text{if}\left(\phi_{sdu} > 0, \text{“See LRFD Figure 3.11.5.4-2”}, \text{“Passive Pressure Coeff. is 1.0”}\right) \qquad Check = \text{“Passive Pressure Coeff. is 1.0”}$

$k_{pu} := \text{if}\left(\phi_{sdu} > 0, R \cdot k'_p, 1\right) \qquad k_{pu} = 1$ Passive Earth Pressure Coefficient for Undrained Conditions

Compute Unfactored Loads LRFD [Tables 3.4.1-1 and 3.4.1-2]:



$F_T := \frac{1}{2} \cdot \gamma_f \cdot h^2 \cdot k_{af}$ $F_T = 5952.3 \ \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot h \cdot k_{af}$ $F_{SUR} = 640 \ \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \frac{1}{2} \cdot T_1 \cdot h' \cdot \gamma_c$ $V_1 = 0 \ \frac{lbf}{ft}$ Wall stem front batter (DC)

$V_2 := T_t \cdot h' \cdot \gamma_c$ $V_2 = 2475 \ \frac{lbf}{ft}$ Wall stem (DC)

$V_3 := \frac{1}{2} \cdot T_2 \cdot h' \cdot \gamma_c$ $V_3 = 0 \ \frac{lbf}{ft}$ Wall stem back batter (DC)

$V_4 := D \cdot B \cdot \gamma_c$ $V_4 = 2400 \ \frac{lbf}{ft}$ Wall Footing (DC)

$V_6 := \text{if}\left(\lambda < (T_2 + C), t \cdot (T_2 + C - \lambda) \cdot \gamma_p, 0 \ \frac{lbf}{ft}\right)$ $V_6 = 0 \ \frac{lbf}{ft}$ Pavement (DC)

$V_7 := C \cdot (h' - t) \cdot \gamma_f$ $V_7 = 6600 \ \frac{lbf}{ft}$ Soil Backfill - Heel (EV)

$V_8 := \frac{1}{2} \cdot T_2 \cdot (h' - t) \cdot \gamma_f$ $V_8 = 0 \ \frac{lbf}{ft}$ Soil Backfill - Batter (EV)

$V_{9T} := \text{if}\left(\lambda < (T_2 + C), \frac{1}{2} \cdot \lambda \cdot H_{BackSlope} \cdot \gamma_f, \frac{1}{2} \cdot (T_2 + C) \cdot (T_2 + C) \cdot \tan(\beta_{BackSlope}) \cdot \gamma_f\right)$

$V_{9T} = 750 \ \frac{lbf}{ft}$ Triangular Soil Backfill - Backslope (EV)

$V_{9R} := \text{if}\left(\lambda < (T_2 + C), \gamma_f \cdot (C + T_2 - \lambda) \cdot H_{BackSlope}, 0 \ \frac{lbf}{ft}\right)$

$V_{9R} = 0 \ \frac{lbf}{ft}$ Rectangular Soil Backfill - Backslope (EV)

$V_{10} := SUR_{@Backfill} \cdot (T_2 + C - \lambda)$ $V_{10} = 0 \ \frac{lbf}{ft}$ Live Load Surcharge above Backfill- (LS)

$V_{11} := F_T \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{11} = 1740.3 \ \frac{lbf}{ft}$ Active earth force resultant (vertical component - EH)

$V_{12} := F_{SUR} \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{12} = 187.1 \ \frac{lbf}{ft}$ Live Load Surcharge (vertical component - LS)

Moment Arm: Moment:

Moments produced from vertical loads about Point 'O'

$d_{v1} := A + \frac{2}{3} \cdot T_1 = 1.5\ ft$ $MV_1 := V_1 \cdot d_{v1} = 0\ lbf$

$d_{v2} := A + T_1 + \frac{T_t}{2} = 2.3\ ft$ $MV_2 := V_2 \cdot d_{v2} = 5568.8\ lbf$

$d_{v3} := A + T_1 + T_t + \frac{T_2}{3} = 3\ ft$ $MV_3 := V_3 \cdot d_{v3} = 0\ lbf$

$d_{v4} := \frac{B}{2} = 4\ ft$ $MV_4 := V_4 \cdot d_{v4} = 9600\ lbf$

$d_{v6} := B - \frac{T_2 + C}{2} = 5.5\ ft$ $MV_6 := V_6 \cdot d_{v6} = 0\ lbf$

$d_{v7} := B - \frac{C}{2} = 5.5\ ft$ $MV_7 := V_7 \cdot d_{v7} = 36300\ lbf$

$d_{v8} := A + T_1 + T_t + \frac{2\ T_2}{3} = 3\ ft$ $MV_8 := V_8 \cdot d_{v8} = 0\ lbf$

$d_{v9T} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \frac{2 \cdot \lambda}{3}, A + T_1 + T_t + \frac{2 \cdot (T_2 + C)}{3}\right) = 6.3\ ft$ $MV_{9T} := V_{9T} \cdot d_{v9T} = 4750\ lbf$

$d_{v9R} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ $MV_{9R} := V_{9R} \cdot d_{v9R} = 0\ lbf$

$d_{v10} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ $MV_{10} := V_{10} \cdot d_{v10} = 0\ lbf$

$d_{v11} := B = 8\ ft$ $MV_{11} := V_{11} \cdot d_{v11} = 13922.2\ lbf$

$d_{v12} := B = 8\ ft$ $MV_{12} := V_{12} \cdot d_{v12} = 1497\ lbf$

Horizontal Loads:

$H_1 := F_{SUR} \cdot \cos(90 \cdot deg - \theta + \delta)$ $H_1 = 612.1\ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

$H_2 := F_T \cdot \cos(90 \cdot deg - \theta + \delta)$ $H_2 = 5692.2\ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

Moment Arm: Moment:

$d_{h1} := \frac{h}{2}$ $d_{h1} = 7.7\ ft$ $MH_1 := H_1 \cdot d_{h1}$ $MH_1 = 4743.5\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{h}{3}$ $d_{h2} = 5.2\ ft$ $MH_2 := H_2 \cdot d_{h2}$ $MH_2 = 29409.5\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type:

$V_{DC} := V_1 + V_2 + V_3 + V_4 + V_6$ $V_{DC} = 4875\ \frac{lbf}{ft}$

$V_{EV} := V_7 + V_8 + V_{9T} + V_{9R}$ $V_{EV} = 7350\ \frac{lbf}{ft}$

$V_{LS} := V_{10} + V_{12}$ $V_{LS} = 187.1\ \frac{lbf}{ft}$

$V_{EH} := V_{11}$ $V_{EH} = 1740.3\ \frac{lbf}{ft}$

$H_{LS} := H_1$ $\quad H_{LS} = 612.1 \ \frac{lbf}{ft}$

$H_{EH} := H_2$ $\quad H_{EH} = 5692.2 \ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{DC} := MV_1 + MV_2 + MV_3 + MV_4 + MV_6$ $\quad M_{DC} = 15168.8 \ \frac{lbf \cdot ft}{ft}$

$M_{EV} := MV_7 + MV_8 + MV_{9T} + MV_{9R}$ $\quad M_{EV} = 41050 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1} := MV_{10} + MV_{12}$ $\quad M_{LS1} = 1497 \ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_{11}$ $\quad M_{EH1} = 13922.2 \ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_1$ $\quad M_{LS2} = 4743.5 \ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_2$ $\quad M_{EH2} = 29409.5 \ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

Strength Limit State I: EV(min) = 1.00 EV(max) = 1.35
EH(min) = 0.90 EH(max) = 1.50
LS = 1.75

Strength Limit State Ia: (Sliding and Eccentricity)	$Ia_{DC} := 0.9$	$Ia_{EV} := 1$	$Ia_{EH} := 1.5$	$Ia_{LS} := 1.75$
Strength Limit State Ib: (Bearing Capacity)	$Ib_{DC} := 1.25$	$Ib_{EV} := 1.35$	$Ib_{EH} := 1.5$	$Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot V_{DC} \right) + \left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + \left(0 \cdot V_{LS} \right) \right)$ $\quad V_{Ia} = 14347.9 \ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot V_{DC} \right) + \left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + \left(Ib_{LS} \cdot V_{LS} \right) \right)$ $\quad V_{Ib} = 18954.1 \ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS} \right) + \left(Ia_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ia} = 9609.4 \ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS} \right) + \left(Ib_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ib} = 9609.4 \ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot M_{DC} \right) + \left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + \left(0 \cdot M_{LS1} \right) \right)$ $\quad MV_{Ia} = 75585.1 \ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot M_{DC} \right) + \left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + \left(Ib_{LS} \cdot M_{LS1} \right) \right)$ $\quad MV_{Ib} = 97881.4 \ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LS2} \right) + \left(Ia_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ia} = 52415.4 \ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LS2} \right) + \left(Ib_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ib} = 52415.4 \ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the resultant location about the toe of the base length (distance from "O") Strength Ib:

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 97881.4 \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 52415.4 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 18954.1 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 2.4\ ft$ Distance from Point "O" the resultant intersects the base

$e := \max\left(\frac{B}{2} - x, 0\right)$ $e = 1.6\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Foundation Layout:

$B' := B - 2 \cdot e$ $B' = 4.8\ ft$ Effective Footing Width

$L' := 40\ ft$ Effective Footing Length (Assumed)

$H' := H_{Ib}$ $H' = 9609.4 \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 18954.1 \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

$D_f = 3\ ft$ Footing embedment

$d_w := D_f$ Depth of Groundwater below Bearing Grade

$\theta' := 90 \cdot deg$ Direction of H' and V' resultant measured from wall backface **LRFD [Figure C10.6.3.1.2a-1]**

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45\ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right)$ $N_q = 9.6$

$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right)$ $N_c = 19.32$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd})$ $N_\gamma = 9.4$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L'}\right)\right)$ $s_c = 1.06$

$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'} \cdot \tan(\phi'_{fd})\right), 1\right)$ $s_q = 1.053$

$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right), 1\right)$ $s_\gamma = 0.952$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2+\left(\frac{L'}{B'}\right)}{1+\left(\frac{L'}{B'}\right)}\right)\cdot\cos(\theta)^2\right)+\left(\left(\frac{2+\left(\frac{B'}{L'}\right)}{1+\left(\frac{B'}{L'}\right)}\right)\cdot\sin(\theta)^2\right) \qquad n = 1.893$$

$$i_q := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\frac{1}{\tan(\phi'_{fd})}}{1\cdot ft}\right)}\right)^n,1\right)\right) \qquad i_q = 0.834$$

$$i_\gamma := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\left(\frac{1}{\tan(\phi'_{fd})}\right)}{1\cdot ft}\right)}\right)^{n+1},1\right)\right) \qquad i_\gamma = 0.758$$

$$i_c := \text{if}\left(\phi'_{fd}>0,i_q-\left(\frac{1-i_q}{N_q-1}\right),1-\left(\frac{n\cdot H'}{\left(c'_{fd}\cdot B'\cdot L'\cdot N_c\right)\cdot 1\cdot ft}\right)\right) \qquad i_c = 0.815$$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$$C_{wq} := \text{if}\left(d_w>D_f,1.0,\frac{(1.0-0.5)}{(D_f-0)}\cdot(d_w-0)+0.5\right) \qquad C_{wq} = 1$$

$$C_{w\gamma} := \text{if}\left(d_w<D_f,0.5,\text{if}\left(d_w>1.5\cdot B'+D_f,1.0,\frac{(1.0-0.5)}{(1.5\cdot B'+D_f-D_f)}\cdot(d_w-D_f)+0.5\right)\right) \qquad C_{w\gamma} = 0.5$$

Depth Correction Factor Compute depth correction factor per **LRFD [Table 10.6.3.1.2a-4]**. It can be assumed that the soils above the footing are as competent as those beneath the footing. Therefore; the depth correction factor is taken as 1.0 since Df/B is less than 1.0.

$\frac{D_f}{B'} = 0.6$ **<---- CHECK** **The depth correction factor is taken as 1.0 since Df/B is less than 1.0.** $d_q := 1.0$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c\cdot s_c\cdot i_c$ $N_{cm} = 16.684$

$N_{qm} := N_q\cdot s_q\cdot i_q$ $N_{qm} = 8.438$

$N_{\gamma m} := N_\gamma\cdot s_\gamma\cdot i_\gamma$ $N_{\gamma m} = 6.813$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$$q_{nd} := c'_{fd}\cdot N_{cm}+\gamma_{fd}\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq}+0.5\cdot\gamma_{fd}\cdot B'\cdot N_{\gamma m}\cdot C_{w\gamma} \qquad q_{nd} = 7354.9\ \frac{lbf}{ft^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b\cdot q_{nd}$ $q_{Rd} = 4\ ksf$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi_{fdu} > 0\,,\, e^{\pi \cdot \tan\left(\phi_{fdu}\right)} \cdot \tan\left(45\ \textit{deg} + \frac{\phi_{fdu}}{2}\right)^2\,,\, 1.0\right) \qquad N_q = 1$$

$$N_c := \text{if}\left(\phi_{fdu} > 0\,,\, \frac{N_q - 1}{\tan\left(\phi_{fdu}\right)}\,,\, 5.14\right) \qquad N_c = 5.14$$

$$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_{fdu}\right) \qquad N_\gamma = 0$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right)\,,\, 1 + \left(\frac{B'}{5 \cdot L'}\right)\right) \qquad s_c = 1.024$$

$$s_q := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'} \cdot \tan\left(\phi_{fdu}\right)\right)\,,\, 1\right) \qquad s_q = 1$$

$$s_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right)\,,\, 1\right) \qquad s_\gamma = 1$$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2 + \left(\frac{L'}{B'}\right)}{1 + \left(\frac{L'}{B'}\right)}\right) \cdot \cos\left(\theta\right)^2\right) + \left(\left(\frac{2 + \left(\frac{B'}{L'}\right)}{1 + \left(\frac{B'}{L'}\right)}\right) \cdot \sin\left(\theta\right)^2\right) \qquad n = 1.893$$

$$i_q := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \frac{1}{\tan\left(\phi_{fdu}\right)}}{1 \cdot \textit{ft}}\right)}\right)\right)^n\,,\, 1\right) \qquad i_q = 1$$

$$i_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \left(\frac{1}{\tan\left(\phi_{fdu}\right)}\right)}{1 \cdot \textit{ft}}\right)}\right)\right)^{n+1}\,,\, 1\right) \qquad i_\gamma = 1$$

$$i_c := \text{if}\left(\phi_{fdu} > 0\,,\, i_q - \left(\frac{1 - i_q}{N_q - 1}\right)\,,\, 1 - \left(\frac{n \cdot H'}{\frac{\left(Su_{fdu} \cdot B' \cdot L' \cdot N_c\right)}{1 \cdot \textit{ft}}}\right)\right) \qquad i_c = 0.99$$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$$N_{cm} := N_c \cdot s_c \cdot i_c \qquad N_{cm} = 5.211$$

$$N_{qm} := N_q \cdot s_q \cdot i_q \qquad N_{qm} = 1$$

$$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma \qquad N_{\gamma m} = 0$$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$$q_{nu} := Su_{fdu} \cdot N_{cm} + \gamma_{fd} \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 10000\ \frac{\textit{lbf}}{\textit{ft}^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 5.5\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 4\ ksf$

Undrained Conditions: $q_{Ru} = 5.5\ ksf$

Evaluate External Stability of Wall:

Compute the ultimate bearing stress :

$e = 1.6\ ft$

$\sigma_V := \frac{\Sigma V}{B - 2 \cdot e}$ $\sigma_V = 3.951\ ksf$

Bearing Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_D} := \frac{q_{Rd}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_D} = 1.02$

Undrained Conditions: $CDR_{Bearing\_U} := \frac{q_{Ru}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_U} = 1.39$

Limiting Eccentricity at Base of MSE Wall (Strength Ia):

Compute the resultant location about the toe "O" of the base length (distance from Pivot):

$e_{max} := \frac{B}{3}$ $e_{max} = 2.7\ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 75585.1\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 52415.4\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 14347.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 1.6\ ft$ Distance from Point "O" the resultant intersects the base

$e := \text{abs}\left(\frac{B}{2} - x\right)$ $e = 2.39\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.12$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $\quad R_u = 9609.4\ \frac{lbf}{ft}$

Compute passive resistance throughout the design life of the wall **LRFD [Eq 3.11.5.4-1]:**:

Drained Conditions:

$r_{ep1} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epd} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epd} = 5.1\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Undrained Conditions:

$r_{ep1} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epu} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epu} = 6\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Nominal Passive Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{epd} = 5.056\ \frac{kip}{ft}$

Undrained Conditions: $R_{epu} = 5.953\ \frac{kip}{ft}$

Nominal Passive Resistance to be used in CDR Calculations: $R_{ep} := R_{epu}$ **LRFD [11.6.3.5]**

Passive Resistance, **Note:** Passive Resistance shall be neglected in stability computations, unless the base of the wall extends below the depth of maximum scour, freeze-thaw or other disturbances. In the latter case, only the embed below the greater of these depths shall be considered effective **LRFD [11.6.3.5]**.

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14347.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_{sd}\right)$ $\quad R_{\tau d} = 6388.1\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Undrained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14347.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau u} := min\left(0.5 \cdot V_{Ia}, Su_{sdu} \cdot (B')\right)$ $\quad R_{\tau u} = 7174\ \frac{lbf}{ft}$ Nominal sliding resistance Undrained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 6.388 \ \frac{kip}{ft}$

Undrained Conditions: $R_{\tau u} = 7.174 \ \frac{kip}{ft}$

Nominal Sliding Resistance to be used in CDR Calculations: $R_\tau := R_{\tau d}$

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_{ep} := 0.5$ Resistance factor for passive resistance specified in **LRFD Table 10.5.5.2.2-1**

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

$\phi R_n := \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep}$ $R_R := \phi R_n$

Factored Sliding Resistance to be used in CDR Calculations: $R_R = 9364.598 \ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.0$

Objective: **To evaluate the external stability of CIP wall design.**
Method: **In accordance with ODOT Bridge Design Manual, 2017 [Sect. 204.6.2.2] LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 11.6.1, Sect. 11.6.2, and Sect. 11.6.3].**

Givens:

Backfill Soil Design Parameters:

$\phi'_f := 32\ deg$ — Effective angle of internal friction

$\gamma_f := 120\ \frac{lbf}{ft^3}$ — Unit weight

$c'_f := 400\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 17\ deg$ — Friction angle between fill and wall taken as specified in **LRFD Table 3.11.5.3-1 (degrees)**

Soil Design Parameters for Bearing Resistance (Average Below Footing):

Drained Conditions (Effective Stress):

$\phi'_{fd} := 27\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 115\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 250\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{fdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$Su_{fdu} := 2850\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Soil Design Parameters for Sliding Resistance (Below Footing)

Drained Conditions (Effective Stress):

$\phi'_{sd} := 27\ deg$ — Effective angle of internal friction

$\gamma_{sd} := 115\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{sd} := 250\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{sdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

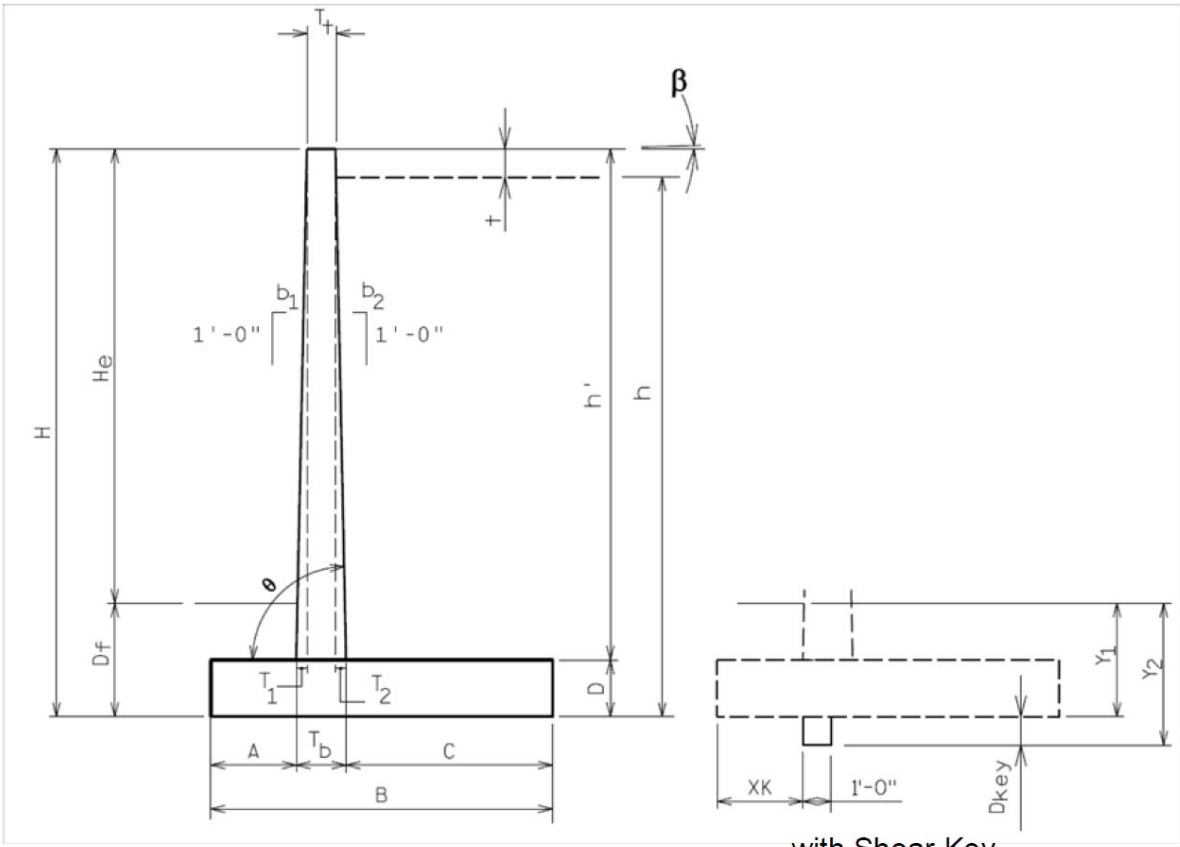
$Su_{sdu} := 2850\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Other Parameters:

$\gamma_c := 150\ \frac{lbf}{ft^3}$ — Concete Unit weight

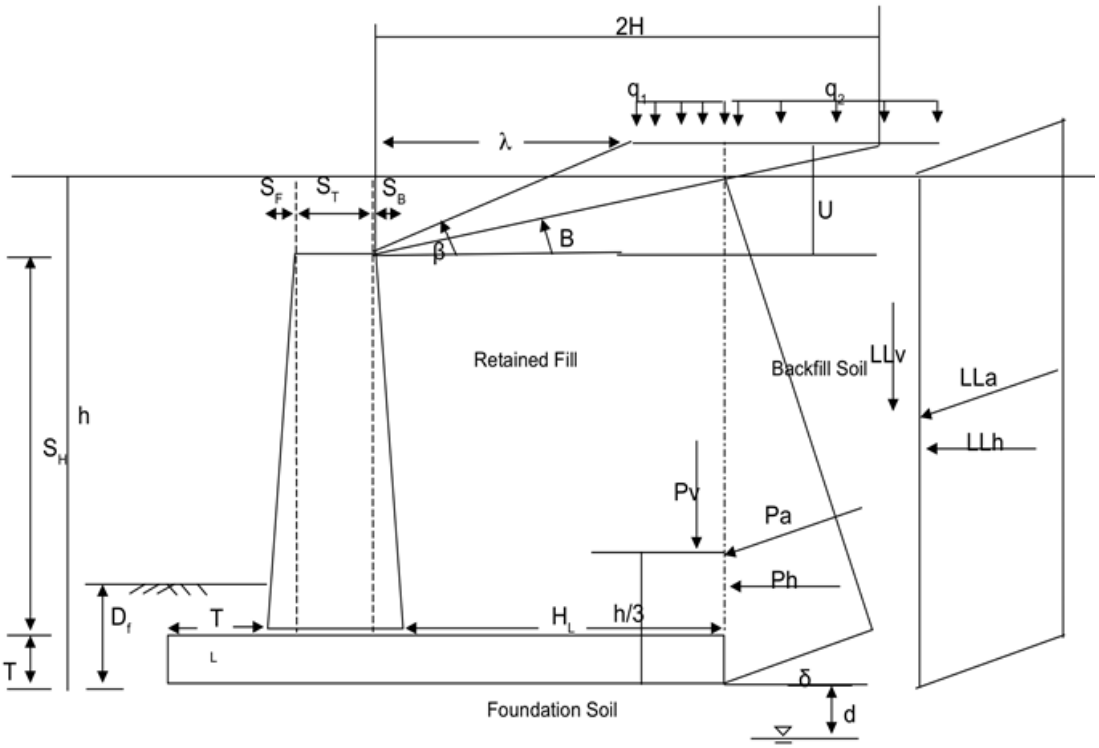
$\gamma_p := 150\ \frac{lbf}{ft^3}$ — Pavement Unit weight

Wall Geometry:



with Shear Key

$H_e := 10\ ft$		Exposed wall height
$B := 8\ ft$		Footing base width (2/5H to 3/5H)
$A := 1.5\ ft$		Toe projection (H/8 to H/5)
$D := 2\ ft$		Footing thickness (H/8 to H/5)
$D_f := 3\ ft$		Footing cover at Toe
$H := H_e + D_f$	$H = 13\ ft$	Design Wall Height
$h' := H - D$	$h' = 11\ ft$	Stem height
$t := 0 \cdot ft$		Pavement thickness
$T_t := 1.5\ ft$		Stem thickness at top of wall
$b_1 := 0 \cdot \left(\frac{in}{ft}\right)$		Front wall batter, (b1H:12V)
$b_2 := 0 \cdot \left(\frac{in}{ft}\right)$		Backwall batter, (b2H:12V)
$T_1 := b_1 \cdot h'$	$T_1 = 0\ ft$	Stem front batter width
$T_2 := b_2 \cdot h'$	$T_2 = 0\ ft$	Stem back batter width
$T_b := T_1 + T_2 + T_t$	$T_b = 1.5\ ft$	Stem thickness at bottom of wall
$C := B - A - T_b$	$C = 5\ ft$	Heel projection



Inclination of ground slope behind face of wall :

- Horizontal: **0**
- 3H:1V: **18.435**
- 2H:1V: **26.565**
- 1.5H:1V: **33.690**

$\theta := 90 \cdot deg$ Angle of back face of wall to horizontal

$\beta_{BackSlope} := 26.565\ deg$ Inclination of ground slope behind face of wall. If it is horizontal backfill behind CIP wall, $\beta_{Backslope}$ = 0 deg

$\lambda := 25\ ft$ Horizontal distance from the back of the wall to the top of the slope (for broken-back slopes). If it is infinite slope behind CIP Wall, input λ larger than 2H; If it is horizontal backfill behind MSE wall, λ = 0 ft

$H_{BackSlope} := \lambda \cdot \tan\left(\beta_{BackSlope}\right)$ $H_{BackSlope} = 12.5\ ft$ Height of broken slope behind the wall

$\beta := \text{if}\left(\lambda < 2 \cdot H, \text{atan}\left(\frac{H_{BackSlope}}{2 \cdot H}\right), \beta_{BackSlope}\right) = 25.7\ deg$ Equivalent backslope angle

$h := \text{if}\left(\lambda < T_2 + C, H - t + H_{BackSlope}, H - t + \left(T_2 + C\right) \cdot \tan\left(\beta_{BackSlope}\right)\right) = 15.5\ ft$ Retained soil height

Shear Key Dimensioning:

$D_{key} := 1.5\ ft$ Depth of shear key from bottom of footing

$D_w := 1\ ft$ Width of shear key

$XK := 0\ ft$ Distance from toe to shear key

$y_1 := D_f$ $y_1 = 3\ ft$ Bottom of footing depth

$y_2 := D_f + D_{key}$ $y_2 = 4.5\ ft$ Bottom of shear key depth

Live Load Surcharge Parameters:

$SUR := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 100\ \frac{lbf}{ft^2}\right) = 100\ \frac{lbf}{ft^2}$ Live load surcharge (per LRFD BDS [3.11.6.4])
Note: when it is infinite slope, SUR equal 100 psf to account for construction loads

$SUR_{@Backfill} := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 0\ \frac{lbf}{ft^2}\right) = 0\ \frac{lbf}{ft^2}$ Live load surcharge above the MSE Wall soil reinforcement (per LRFD BDS [3.11.6.4])

Calculations:

Earth Pressure Coefficients:

Backfill Active Earth:

$$\Gamma := \left(1 + \sqrt{\frac{\left(\sin\left(\phi'_f + \delta\right) \cdot \sin\left(\phi'_f - \beta\right)\right)}{\left(\sin\left(\theta - \delta\right) \cdot \sin\left(\theta + \beta\right)\right)}}\right)^2 \qquad \Gamma = 1.718$$

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_f\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.4379$$

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

Foundation Soil Passive Earth:

Drained Conditions assuming($\phi'_{sd} > 0$):

Input Parameters for **LRFD Figure 3.11.5.4-2**, assumes θ = 90 degrees

$$\frac{\beta}{\phi'_{sd}} = 0.951 \qquad \frac{-\delta}{\phi'_{sd}} = -0.63$$

$k'_p := 9.2$ Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

Determine Reduction Factor (R) by interpolation:

$\phi x_1 := 25$ Lower Bound Angle of Friction

$\phi x_2 := 30$ Upper Bound Angle of Friction

$ratio_L := -.7$ Lower bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$ratio_U := -.6$ Upper bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$R_{x1L} := 0.860$ Reduction Factor at ϕx1 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x1U} := 0.912$ Reduction Factor at ϕx1 and Upper bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2L} := 0.811$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2U} := 0.878$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$$R_L := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2L} - R_{x1L}\right) + R_{x1L} \qquad R_U := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2U} - R_{x1U}\right) + R_{x1U}$$

$$R := \frac{\left(\frac{-\delta}{\phi'_{sd}} - ratio_L\right)}{\left(ratio_U - ratio_L\right)} \cdot \left(R_U - R_L\right) + R_L \qquad R = 0.881$$ Reduction Factor

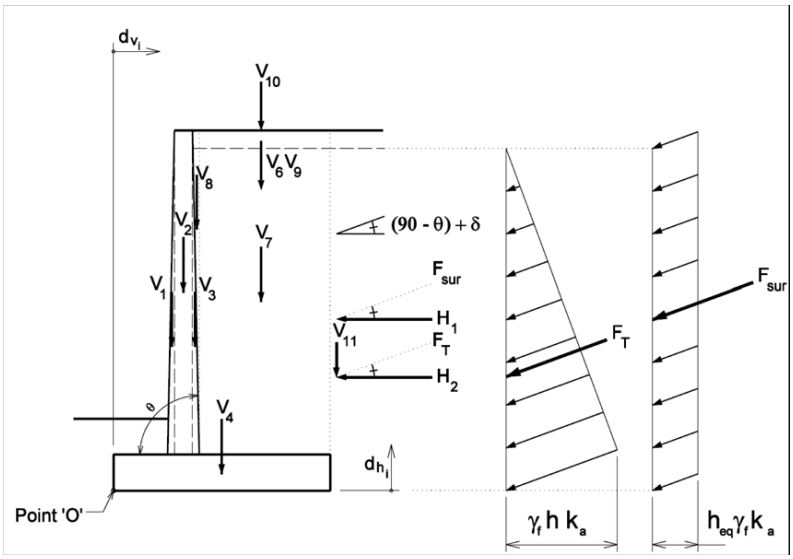
$k_{pd} := R \cdot k'_p \qquad k_{pd} = 8.107$ Passive Earth Pressure Coefficient for Drained Conditions

Undrained Conditions:

$Check := \text{if}\left(\phi_{sdu} > 0, \text{“See LRFD Figure 3.11.5.4-2”}, \text{“Passive Pressure Coeff. is 1.0”}\right) \qquad Check = \text{“Passive Pressure Coeff. is 1.0”}$

$k_{pu} := \text{if}\left(\phi_{sdu} > 0, R \cdot k'_p, 1\right) \qquad k_{pu} = 1$ Passive Earth Pressure Coefficient for Undrained Conditions

Compute Unfactored Loads LRFD [Tables 3.4.1-1 and 3.4.1-2]:



$F_T := \frac{1}{2} \cdot \gamma_f \cdot h^2 \cdot k_{af}$ $F_T = 6311.7 \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot h \cdot k_{af}$ $F_{SUR} = 678.7 \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \frac{1}{2} \cdot T_1 \cdot h' \cdot \gamma_c$ $V_1 = 0 \frac{lbf}{ft}$ Wall stem front batter (DC)

$V_2 := T_t \cdot h' \cdot \gamma_c$ $V_2 = 2475 \frac{lbf}{ft}$ Wall stem (DC)

$V_3 := \frac{1}{2} \cdot T_2 \cdot h' \cdot \gamma_c$ $V_3 = 0 \frac{lbf}{ft}$ Wall stem back batter (DC)

$V_4 := D \cdot B \cdot \gamma_c$ $V_4 = 2400 \frac{lbf}{ft}$ Wall Footing (DC)

$V_6 := \text{if}\left(\lambda < (T_2 + C), t \cdot (T_2 + C - \lambda) \cdot \gamma_p, 0 \frac{lbf}{ft}\right)$ $V_6 = 0 \frac{lbf}{ft}$ Pavement (DC)

$V_7 := C \cdot (h' - t) \cdot \gamma_f$ $V_7 = 6600 \frac{lbf}{ft}$ Soil Backfill - Heel (EV)

$V_8 := \frac{1}{2} \cdot T_2 \cdot (h' - t) \cdot \gamma_f$ $V_8 = 0 \frac{lbf}{ft}$ Soil Backfill - Batter (EV)

$V_{9T} := \text{if}\left(\lambda < (T_2 + C), \frac{1}{2} \cdot \lambda \cdot H_{BackSlope} \cdot \gamma_f, \frac{1}{2} \cdot (T_2 + C) \cdot (T_2 + C) \cdot \tan(\beta_{BackSlope}) \cdot \gamma_f\right)$

$V_{9T} = 750 \frac{lbf}{ft}$ Triangular Soil Backfill - Backslope (EV)

$V_{9R} := \text{if}\left(\lambda < (T_2 + C), \gamma_f \cdot (C + T_2 - \lambda) \cdot H_{BackSlope}, 0 \frac{lbf}{ft}\right)$

$V_{9R} = 0 \frac{lbf}{ft}$ Rectangular Soil Backfill - Backslope (EV)

$V_{10} := SUR_{@Backfill} \cdot (T_2 + C - \lambda)$ $V_{10} = 0 \frac{lbf}{ft}$ Live Load Surcharge above Backfill- (LS)

$V_{11} := F_T \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{11} = 1845.4 \frac{lbf}{ft}$ Active earth force resultant (vertical component - EH)

$V_{12} := F_{SUR} \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{12} = 198.4 \frac{lbf}{ft}$ Live Load Surcharge (vertical component - LS)

Moment Arm: | Moment:

Moments produced from vertical loads about Point 'O'

$d_{v1} := A + \frac{2}{3} \cdot T_1 = 1.5\ ft$ | $MV_1 := V_1 \cdot d_{v1} = 0\ lbf$

$d_{v2} := A + T_1 + \frac{T_t}{2} = 2.3\ ft$ | $MV_2 := V_2 \cdot d_{v2} = 5568.8\ lbf$

$d_{v3} := A + T_1 + T_t + \frac{T_2}{3} = 3\ ft$ | $MV_3 := V_3 \cdot d_{v3} = 0\ lbf$

$d_{v4} := \frac{B}{2} = 4\ ft$ | $MV_4 := V_4 \cdot d_{v4} = 9600\ lbf$

$d_{v6} := B - \frac{T_2 + C}{2} = 5.5\ ft$ | $MV_6 := V_6 \cdot d_{v6} = 0\ lbf$

$d_{v7} := B - \frac{C}{2} = 5.5\ ft$ | $MV_7 := V_7 \cdot d_{v7} = 36300\ lbf$

$d_{v8} := A + T_1 + T_t + \frac{2\ T_2}{3} = 3\ ft$ | $MV_8 := V_8 \cdot d_{v8} = 0\ lbf$

$d_{v9T} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \frac{2 \cdot \lambda}{3}, A + T_1 + T_t + \frac{2 \cdot (T_2 + C)}{3}\right) = 6.3\ ft$ | $MV_{9T} := V_{9T} \cdot d_{v9T} = 4750\ lbf$

$d_{v9R} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ | $MV_{9R} := V_{9R} \cdot d_{v9R} = 0\ lbf$

$d_{v10} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ | $MV_{10} := V_{10} \cdot d_{v10} = 0\ lbf$

$d_{v11} := B = 8\ ft$ | $MV_{11} := V_{11} \cdot d_{v11} = 14763\ lbf$

$d_{v12} := B = 8\ ft$ | $MV_{12} := V_{12} \cdot d_{v12} = 1587.4\ lbf$

Horizontal Loads:

$H_1 := F_{SUR} \cdot \cos(90 \cdot deg - \theta + \delta)$ $\quad H_1 = 649\ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

$H_2 := F_T \cdot \cos(90 \cdot deg - \theta + \delta)$ $\quad H_2 = 6036\ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

Moment Arm: | Moment:

$d_{h1} := \frac{h}{2}$ $\quad d_{h1} = 7.7\ ft$ | $MH_1 := H_1 \cdot d_{h1}$ $\quad MH_1 = 5030\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{h}{3}$ $\quad d_{h2} = 5.2\ ft$ | $MH_2 := H_2 \cdot d_{h2}$ $\quad MH_2 = 31185.8\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type:

$V_{DC} := V_1 + V_2 + V_3 + V_4 + V_6$ $\quad V_{DC} = 4875\ \frac{lbf}{ft}$

$V_{EV} := V_7 + V_8 + V_{9T} + V_{9R}$ $\quad V_{EV} = 7350\ \frac{lbf}{ft}$

$V_{LS} := V_{10} + V_{12}$ $\quad V_{LS} = 198.4\ \frac{lbf}{ft}$

$V_{EH} := V_{11}$ $\quad V_{EH} = 1845.4\ \frac{lbf}{ft}$

$H_{LS} := H_1$ $\quad H_{LS} = 649 \ \frac{lbf}{ft}$

$H_{EH} := H_2$ $\quad H_{EH} = 6036 \ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{DC} := MV_1 + MV_2 + MV_3 + MV_4 + MV_6$ $\quad M_{DC} = 15168.8 \ \frac{lbf \cdot ft}{ft}$

$M_{EV} := MV_7 + MV_8 + MV_{9T} + MV_{9R}$ $\quad M_{EV} = 41050 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1} := MV_{10} + MV_{12}$ $\quad M_{LS1} = 1587.4 \ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_{11}$ $\quad M_{EH1} = 14763 \ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_1$ $\quad M_{LS2} = 5030 \ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_2$ $\quad M_{EH2} = 31185.8 \ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

Strength Limit State I: EV(min) = 1.00 EV(max) = 1.35
EH(min) = 0.90 EH(max) = 1.50
LS = 1.75

Strength Limit State Ia: (Sliding and Eccentricity)	$Ia_{DC} := 0.9$	$Ia_{EV} := 1$	$Ia_{EH} := 1.5$	$Ia_{LS} := 1.75$
Strength Limit State Ib: (Bearing Capacity)	$Ib_{DC} := 1.25$	$Ib_{EV} := 1.35$	$Ib_{EH} := 1.5$	$Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot V_{DC} \right) + \left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + \left(0 \cdot V_{LS} \right) \right)$ $\quad V_{Ia} = 14505.6 \ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot V_{DC} \right) + \left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + \left(Ib_{LS} \cdot V_{LS} \right) \right)$ $\quad V_{Ib} = 19131.6 \ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS} \right) + \left(Ia_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ia} = 10189.7 \ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS} \right) + \left(Ib_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ib} = 10189.7 \ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot M_{DC} \right) + \left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + \left(0 \cdot M_{LS1} \right) \right)$ $\quad MV_{Ia} = 76846.4 \ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot M_{DC} \right) + \left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + \left(Ib_{LS} \cdot M_{LS1} \right) \right)$ $\quad MV_{Ib} = 99300.9 \ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LS2} \right) + \left(Ia_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ia} = 55581.1 \ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LS2} \right) + \left(Ib_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ib} = 55581.1 \ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the resultant location about the toe of the base length (distance from "O") Strength Ib:

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 99300.9 \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 55581.1 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 19131.6 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 2.3\ ft$ Distance from Point "O" the resultant intersects the base

$e := \max\left(\frac{B}{2} - x, 0\right)$ $e = 1.71\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Foundation Layout:

$B' := B - 2 \cdot e$ $B' = 4.6\ ft$ Effective Footing Width

$L' := 40\ ft$ Effective Footing Length (Assumed)

$H' := H_{Ib}$ $H' = 10189.7 \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 19131.6 \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

$D_f = 3\ ft$ Footing embedment

$d_w := D_f$ Depth of Groundwater below Bearing Grade

$\theta' := 90 \cdot deg$ Direction of H' and V' resultant measured from wall backface **LRFD [Figure C10.6.3.1.2a-1]**

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45\ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right)$ $N_q = 13.2$

$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right)$ $N_c = 23.94$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd})$ $N_\gamma = 14.5$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L'}\right)\right)$ $s_c = 1.063$

$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'} \cdot \tan(\phi'_{fd})\right), 1\right)$ $s_q = 1.058$

$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right), 1\right)$ $s_\gamma = 0.954$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2+\left(\frac{L'}{B'}\right)}{1+\left(\frac{L'}{B'}\right)}\right)\cdot\cos(\theta)^2\right)+\left(\left(\frac{2+\left(\frac{B'}{L'}\right)}{1+\left(\frac{B'}{L'}\right)}\right)\cdot\sin(\theta)^2\right) \qquad n = 1.897$$

$$i_q := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\frac{1}{\tan(\phi'_{fd})}}{1\cdot ft}\right)}\right)\right)^n,1\right) \qquad i_q = 0.83$$

$$i_\gamma := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\left(\frac{1}{\tan(\phi'_{fd})}\right)}{1\cdot ft}\right)}\right)\right)^{n+1},1\right) \qquad i_\gamma = 0.752$$

$$i_c := \text{if}\left(\phi'_{fd}>0,i_q-\left(\frac{1-i_q}{N_q-1}\right),1-\left(\frac{n\cdot H'}{\left(c'_{fd}\cdot B'\cdot L'\cdot N_c\right)}\right)\right) \qquad i_c = 0.816$$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$$C_{wq} := \text{if}\left(d_w>D_f,1.0,\frac{(1.0-0.5)}{(D_f-0)}\cdot(d_w-0)+0.5\right) \qquad C_{wq} = 1$$

$$C_{w\gamma} := \text{if}\left(d_w<D_f,0.5,\text{if}\left(d_w>1.5\cdot B'+D_f,1.0,\frac{(1.0-0.5)}{(1.5\cdot B'+D_f-D_f)}\cdot(d_w-D_f)+0.5\right)\right) \qquad C_{w\gamma} = 0.5$$

Depth Correction Factor Compute depth correction factor per **LRFD [Table 10.6.3.1.2a-4]**. It can be assumed that the soils above the footing are as competent as those beneath the footing. Therefore; the depth correction factor is taken as 1.0 since Df/B is less than 1.0.

$\frac{D_f}{B'} = 0.7$ **<---- CHECK** **The depth correction factor is taken as 1.0 since Df/B is less than 1.0.** $d_q := 1.0$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c\cdot s_c\cdot i_c$ $N_{cm} = 20.764$

$N_{qm} := N_q\cdot s_q\cdot i_q$ $N_{qm} = 11.591$

$N_{\gamma m} := N_\gamma\cdot s_\gamma\cdot i_\gamma$ $N_{\gamma m} = 10.386$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$$q_{nd} := c'_{fd}\cdot N_{cm}+\gamma_{fd}\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq}+0.5\cdot\gamma_{fd}\cdot B'\cdot N_{\gamma m}\cdot C_{w\gamma} \qquad q_{nd} = 10554.6\ \frac{lbf}{ft^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b\cdot q_{nd}$ $q_{Rd} = 5.8\ ksf$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi_{fdu} > 0\,,\, e^{\pi \cdot \tan\left(\phi_{fdu}\right)} \cdot \tan\left(45\ \textit{deg} + \frac{\phi_{fdu}}{2}\right)^2\,,\, 1.0\right) \qquad N_q = 1$$

$$N_c := \text{if}\left(\phi_{fdu} > 0\,,\, \frac{N_q - 1}{\tan\left(\phi_{fdu}\right)}\,,\, 5.14\right) \qquad N_c = 5.14$$

$$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_{fdu}\right) \qquad N_\gamma = 0$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right)\,,\, 1 + \left(\frac{B'}{5 \cdot L'}\right)\right) \qquad s_c = 1.023$$

$$s_q := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'} \cdot \tan\left(\phi_{fdu}\right)\right)\,,\, 1\right) \qquad s_q = 1$$

$$s_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right)\,,\, 1\right) \qquad s_\gamma = 1$$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2 + \left(\frac{L'}{B'}\right)}{1 + \left(\frac{L'}{B'}\right)}\right) \cdot \cos\left(\theta\right)^2\right) + \left(\left(\frac{2 + \left(\frac{B'}{L'}\right)}{1 + \left(\frac{B'}{L'}\right)}\right) \cdot \sin\left(\theta\right)^2\right) \qquad n = 1.897$$

$$i_q := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \frac{1}{\tan\left(\phi_{fdu}\right)}}{1 \cdot \textit{ft}}\right)}\right)\right)^n\,,\, 1\right) \qquad i_q = 1$$

$$i_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \left(\frac{1}{\tan\left(\phi_{fdu}\right)}\right)}{1 \cdot \textit{ft}}\right)}\right)\right)^{n+1}\,,\, 1\right) \qquad i_\gamma = 1$$

$$i_c := \text{if}\left(\phi_{fdu} > 0\,,\, i_q - \left(\frac{1 - i_q}{N_q - 1}\right)\,,\, 1 - \left(\frac{n \cdot H'}{\frac{\left(Su_{fdu} \cdot B' \cdot L' \cdot N_c\right)}{1 \cdot \textit{ft}}}\right)\right) \qquad i_c = 0.993$$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$$N_{cm} := N_c \cdot s_c \cdot i_c \qquad N_{cm} = 5.22$$

$$N_{qm} := N_q \cdot s_q \cdot i_q \qquad N_{qm} = 1$$

$$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma \qquad N_{\gamma m} = 0$$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$$q_{nu} := Su_{fdu} \cdot N_{cm} + \gamma_{fd} \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 15220.6\ \frac{\textit{lbf}}{\textit{ft}^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 8.4$ *ksf* Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 5.8$ *ksf*

Undrained Conditions: $q_{Ru} = 8.4$ *ksf*

Evaluate External Stability of Wall:

Compute the ultimate bearing stress :

$e = 1.7$ *ft*

$\sigma_V := \frac{\Sigma V}{B - 2 \cdot e}$ $\sigma_V = 4.186$ *ksf*

Bearing Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_D} := \frac{q_{Rd}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_D} = 1.39$

Undrained Conditions: $CDR_{Bearing\_U} := \frac{q_{Ru}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_U} = 2.00$

Limiting Eccentricity at Base of MSE Wall (Strength Ia):

Compute the resultant location about the toe "O" of the base length (distance from Pivot):

$e_{max} := \frac{B}{3}$ $e_{max} = 2.7$ *ft* Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 76846.4 \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 55581.1 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 14505.6 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 1.5$ *ft* Distance from Point "O" the resultant intersects the base

$e := \text{abs}\left(\frac{B}{2} - x\right)$ $e = 2.53$ *ft* Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.05$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $\quad R_u = 10189.7\ \frac{lbf}{ft}$

Compute passive resistance throughout the design life of the wall **LRFD [Eq 3.11.5.4-1]:**:

Drained Conditions:

$r_{ep1} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epd} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epd} = 7.1\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Undrained Conditions:

$r_{ep1} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epu} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epu} = 8.8\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Nominal Passive Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{epd} = 7.057\ \frac{kip}{ft}$

Undrained Conditions: $R_{epu} = 8.795\ \frac{kip}{ft}$

Nominal Passive Resistance to be used in CDR Calculations: $R_{ep} := R_{epd}$ **LRFD [11.6.3.5]**

Passive Resistance, **Note:** Passive Resistance shall be neglected in stability computations, unless the base of the wall extends below the depth of maximum scour, freeze-thaw or other disturbances. In the latter case, only the embed below the greater of these depths shall be considered effective **LRFD [11.6.3.5]**.

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14505.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_{sd}\right)$ $\quad R_{\tau d} = 7391\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Undrained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14505.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau u} := min\left(0.5 \cdot V_{Ia}, Su_{sdu} \cdot (B')\right)$ $\quad R_{\tau u} = 7252.8\ \frac{lbf}{ft}$ Nominal sliding resistance Undrained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 7.391 \ \frac{kip}{ft}$

Undrained Conditions: $R_{\tau u} = 7.253 \ \frac{kip}{ft}$

Nominal Sliding Resistance to be used in CDR Calculations: $R_\tau := R_{\tau d}$

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_{ep} := 0.5$ Resistance factor for passive resistance specified in **LRFD Table 10.5.5.2.2-1**

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

$\phi R_n := \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep}$ $R_R := \phi R_n$

Factored Sliding Resistance to be used in CDR Calculations: $R_R = 10919.629 \ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.07$

Objective: **To evaluate the external stability of CIP wall design.**
Method: **In accordance with ODOT Bridge Design Manual, 2017 [Sect. 204.6.2.2] LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 11.6.1, Sect. 11.6.2, and Sect. 11.6.3].**

Givens:

Backfill Soil Design Parameters:

$\phi'_f := 32\ deg$ — Effective angle of internal friction

$\gamma_f := 120\ \frac{lbf}{ft^3}$ — Unit weight

$c'_f := 400\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 17\ deg$ — Friction angle between fill and wall taken as specified in **LRFD Table 3.11.5.3-1 (degrees)**

Soil Design Parameters for Bearing Resistance (Average Below Footing):

Drained Conditions (Effective Stress):

$\phi'_{fd} := 26\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 115\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 250\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{fdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$Su_{fdu} := 2750\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Soil Design Parameters for Sliding Resistance (Below Footing)

Drained Conditions (Effective Stress):

$\phi'_{sd} := 26\ deg$ — Effective angle of internal friction

$\gamma_{sd} := 115\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{sd} := 250\ \frac{lbf}{ft^2}$ — Effective Cohesion

Undrained Conditions (Total Stress):

$\phi_{sdu} := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

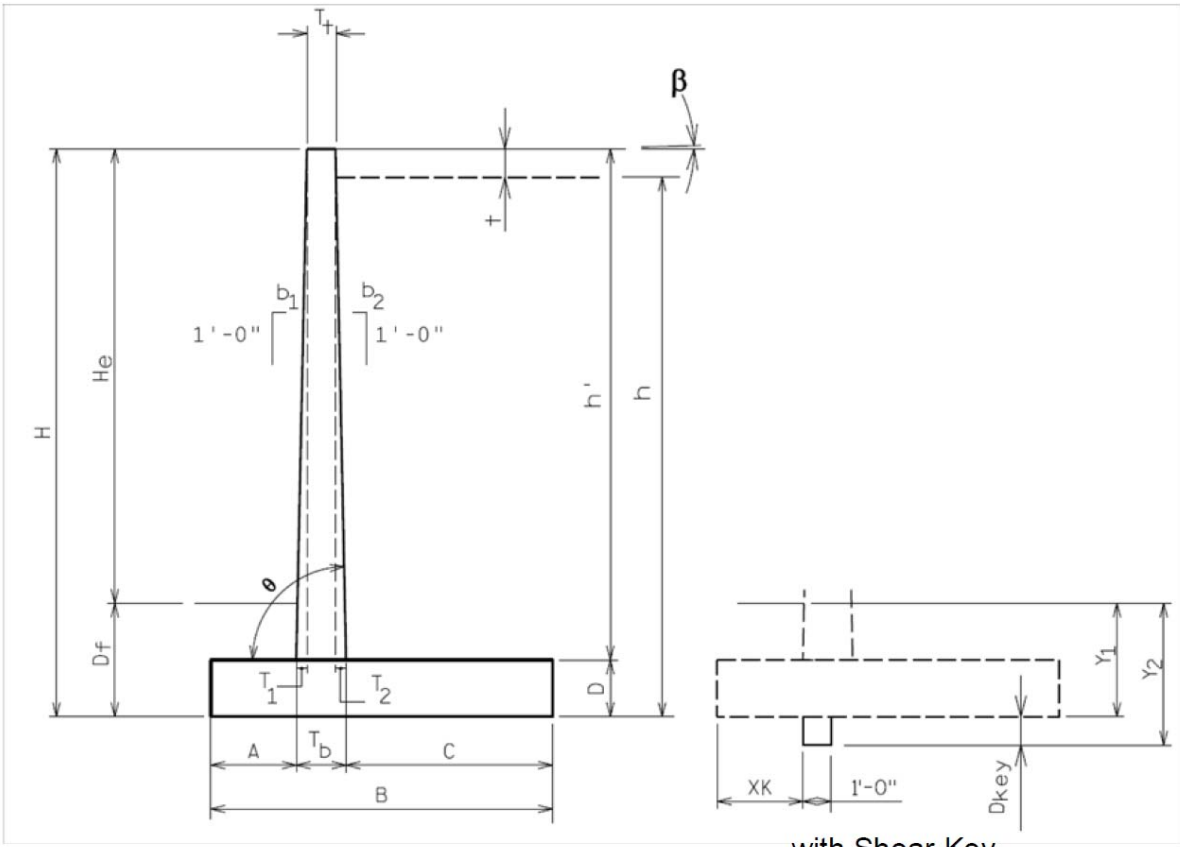
$Su_{sdu} := 2750\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

Other Parameters:

$\gamma_c := 150\ \frac{lbf}{ft^3}$ — Concete Unit weight

$\gamma_p := 150\ \frac{lbf}{ft^3}$ — Pavement Unit weight

Wall Geometry:



with Shear Key

$H_e := 10\ ft$ — Exposed wall height

$B := 8\ ft$ — Footing base width (2/5H to 3/5H)

$A := 1.5\ ft$ — Toe projection (H/8 to H/5)

$D := 2\ ft$ — Footing thickness (H/8 to H/5)

$D_f := 3\ ft$ — Footing cover at Toe

$H := H_e + D_f$ $H = 13\ ft$ — Design Wall Height

$h' := H - D$ $h' = 11\ ft$ — Stem height

$t := 0 \cdot ft$ — Pavement thickness

$T_t := 1.5\ ft$ — Stem thickness at top of wall

$b_1 := 0 \cdot \left(\frac{in}{ft}\right)$ — Front wall batter, (b1H:12V)

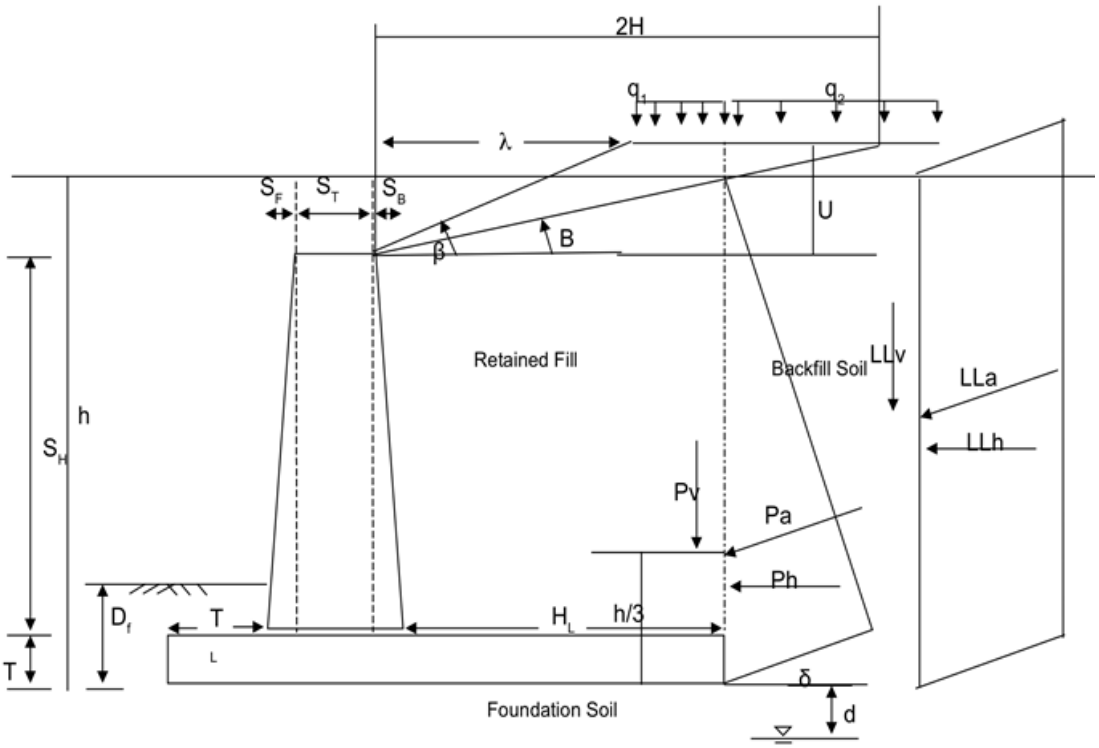
$b_2 := 0 \cdot \left(\frac{in}{ft}\right)$ — Backwall batter, (b2H:12V)

$T_1 := b_1 \cdot h'$ $T_1 = 0\ ft$ — Stem front batter width

$T_2 := b_2 \cdot h'$ $T_2 = 0\ ft$ — Stem back batter width

$T_b := T_1 + T_2 + T_t$ $T_b = 1.5\ ft$ — Stem thickness at bottom of wall

$C := B - A - T_b$ $C = 5\ ft$ — Heel projection



Inclination of ground slope behind face of wall :

- Horizontal: **0**
- 3H:1V: **18.435**
- 2H:1V: **26.565**
- 1.5H:1V: **33.690**

$\theta := 90 \cdot deg$ Angle of back face of wall to horizontal

$\beta_{BackSlope} := 26.565\ deg$ Inclination of ground slope behind face of wall. If it is horizontal backfill behind CIP wall, $\beta_{Backslope}$ = 0 deg

$\lambda := 25\ ft$ Horizontal distance from the back of the wall to the top of the slope (for broken-back slopes). If it is infinite slope behind CIP Wall, input λ larger than 2H; If it is horizontal backfill behind MSE wall, λ = 0 ft

$H_{BackSlope} := \lambda \cdot \tan\left(\beta_{BackSlope}\right)$ $H_{BackSlope} = 12.5\ ft$ Height of broken slope behind the wall

$\beta := \text{if}\left(\lambda < 2 \cdot H, \text{atan}\left(\frac{H_{BackSlope}}{2 \cdot H}\right), \beta_{BackSlope}\right) = 25.7\ deg$ Equivalent backslope angle

$h := \text{if}\left(\lambda < T_2 + C, H - t + H_{BackSlope}, H - t + \left(T_2 + C\right) \cdot \tan\left(\beta_{BackSlope}\right)\right) = 15.5\ ft$ Retained soil height

Shear Key Dimensioning:

$D_{key} := 1.5\ ft$ Depth of shear key from bottom of footing

$D_w := 1\ ft$ Width of shear key

$XK := 0\ ft$ Distance from toe to shear key

$y_1 := D_f$ $y_1 = 3\ ft$ Bottom of footing depth

$y_2 := D_f + D_{key}$ $y_2 = 4.5\ ft$ Bottom of shear key depth

Live Load Surcharge Parameters:

$SUR := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 100\ \frac{lbf}{ft^2}\right) = 100\ \frac{lbf}{ft^2}$ Live load surcharge (per LRFD BDS [3.11.6.4])
Note: when it is infinite slope, SUR equal 100 psf to account for construction loads

$SUR_{@Backfill} := \text{if}\left(\lambda < T_2 + C, 240\ \frac{lbf}{ft^2}, 0\ \frac{lbf}{ft^2}\right) = 0\ \frac{lbf}{ft^2}$ Live load surcharge above the MSE Wall soil reinforcement (per LRFD BDS [3.11.6.4])

Calculations:

Earth Pressure Coefficients:

Backfill Active Earth:

$$\Gamma := \left(1 + \sqrt{\frac{\left(\sin\left(\phi'_f + \delta\right) \cdot \sin\left(\phi'_f - \beta\right)\right)}{\left(\sin\left(\theta - \delta\right) \cdot \sin\left(\theta + \beta\right)\right)}}\right)^2 \qquad \Gamma = 1.718$$

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_f\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.4379$$

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

Foundation Soil Passive Earth:

Drained Conditions assuming($\phi'_{sd} > 0$):

Input Parameters for **LRFD Figure 3.11.5.4-2**, assumes θ = 90 degrees

$$\frac{\beta}{\phi'_{sd}} = 0.988 \qquad \frac{-\delta}{\phi'_{sd}} = -0.654$$

$k'_p := 9.2$ Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

Determine Reduction Factor (R) by interpolation:

$\phi x_1 := 25$ Lower Bound Angle of Friction

$\phi x_2 := 30$ Upper Bound Angle of Friction

$ratio_L := -.7$ Lower bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$ratio_U := -.6$ Upper bound $\frac{-\delta}{\phi'_{fd}}$ ratio

$R_{x1L} := 0.860$ Reduction Factor at ϕx1 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x1U} := 0.912$ Reduction Factor at ϕx1 and Upper bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2L} := 0.811$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$R_{x2U} := 0.878$ Reduction Factor at ϕx2 and Lower bound $\frac{-\delta}{\phi'_{fd}}$

$$R_L := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2L} - R_{x1L}\right) + R_{x1L} \qquad R_U := \frac{\left(\frac{\phi'_{sd}}{\mathbf{deg}} - \phi x_1\right)}{\left(\phi x_2 - \phi x_1\right)} \cdot \left(R_{x2U} - R_{x1U}\right) + R_{x1U}$$

$$R := \frac{\left(\frac{-\delta}{\phi'_{sd}} - ratio_L\right)}{\left(ratio_U - ratio_L\right)} \cdot \left(R_U - R_L\right) + R_L \qquad R = 0.876$$ Reduction Factor

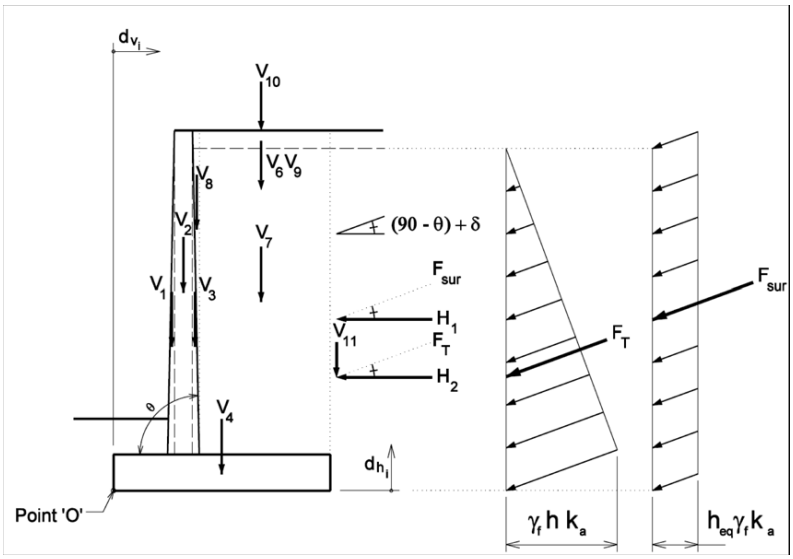
$k_{pd} := R \cdot k'_p \qquad k_{pd} = 8.055$ Passive Earth Pressure Coefficient for Drained Conditions

Undrained Conditions:

$Check := \text{if}\left(\phi_{sdu} > 0, \text{“See LRFD Figure 3.11.5.4-2”}, \text{“Passive Pressure Coeff. is 1.0”}\right) \qquad Check = \text{“Passive Pressure Coeff. is 1.0”}$

$k_{pu} := \text{if}\left(\phi_{sdu} > 0, R \cdot k'_p, 1\right) \qquad k_{pu} = 1$ Passive Earth Pressure Coefficient for Undrained Conditions

Compute Unfactored Loads LRFD [Tables 3.4.1-1 and 3.4.1-2]:



$F_T := \frac{1}{2} \cdot \gamma_f \cdot h^2 \cdot k_{af}$ $F_T = 6311.7 \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot h \cdot k_{af}$ $F_{SUR} = 678.7 \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \frac{1}{2} \cdot T_1 \cdot h' \cdot \gamma_c$ $V_1 = 0 \frac{lbf}{ft}$ Wall stem front batter (DC)

$V_2 := T_t \cdot h' \cdot \gamma_c$ $V_2 = 2475 \frac{lbf}{ft}$ Wall stem (DC)

$V_3 := \frac{1}{2} \cdot T_2 \cdot h' \cdot \gamma_c$ $V_3 = 0 \frac{lbf}{ft}$ Wall stem back batter (DC)

$V_4 := D \cdot B \cdot \gamma_c$ $V_4 = 2400 \frac{lbf}{ft}$ Wall Footing (DC)

$V_6 := \text{if}\left(\lambda < (T_2 + C), t \cdot (T_2 + C - \lambda) \cdot \gamma_p, 0 \frac{lbf}{ft}\right)$ $V_6 = 0 \frac{lbf}{ft}$ Pavement (DC)

$V_7 := C \cdot (h' - t) \cdot \gamma_f$ $V_7 = 6600 \frac{lbf}{ft}$ Soil Backfill - Heel (EV)

$V_8 := \frac{1}{2} \cdot T_2 \cdot (h' - t) \cdot \gamma_f$ $V_8 = 0 \frac{lbf}{ft}$ Soil Backfill - Batter (EV)

$V_{9T} := \text{if}\left(\lambda < (T_2 + C), \frac{1}{2} \cdot \lambda \cdot H_{BackSlope} \cdot \gamma_f, \frac{1}{2} \cdot (T_2 + C) \cdot (T_2 + C) \cdot \tan(\beta_{BackSlope}) \cdot \gamma_f\right)$

$V_{9T} = 750 \frac{lbf}{ft}$ Triangular Soil Backfill - Backslope (EV)

$V_{9R} := \text{if}\left(\lambda < (T_2 + C), \gamma_f \cdot (C + T_2 - \lambda) \cdot H_{BackSlope}, 0 \frac{lbf}{ft}\right)$

$V_{9R} = 0 \frac{lbf}{ft}$ Rectangular Soil Backfill - Backslope (EV)

$V_{10} := SUR_{@Backfill} \cdot (T_2 + C - \lambda)$ $V_{10} = 0 \frac{lbf}{ft}$ Live Load Surcharge above Backfill- (LS)

$V_{11} := F_T \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{11} = 1845.4 \frac{lbf}{ft}$ Active earth force resultant (vertical component - EH)

$V_{12} := F_{SUR} \cdot \sin(90 \cdot deg - \theta + \delta)$ $V_{12} = 198.4 \frac{lbf}{ft}$ Live Load Surcharge (vertical component - LS)

Moment Arm: | Moment:

Moments produced from vertical loads about Point 'O'

$d_{v1} := A + \frac{2}{3} \cdot T_1 = 1.5\ ft$ | $MV_1 := V_1 \cdot d_{v1} = 0\ lbf$

$d_{v2} := A + T_1 + \frac{T_t}{2} = 2.3\ ft$ | $MV_2 := V_2 \cdot d_{v2} = 5568.8\ lbf$

$d_{v3} := A + T_1 + T_t + \frac{T_2}{3} = 3\ ft$ | $MV_3 := V_3 \cdot d_{v3} = 0\ lbf$

$d_{v4} := \frac{B}{2} = 4\ ft$ | $MV_4 := V_4 \cdot d_{v4} = 9600\ lbf$

$d_{v6} := B - \frac{T_2 + C}{2} = 5.5\ ft$ | $MV_6 := V_6 \cdot d_{v6} = 0\ lbf$

$d_{v7} := B - \frac{C}{2} = 5.5\ ft$ | $MV_7 := V_7 \cdot d_{v7} = 36300\ lbf$

$d_{v8} := A + T_1 + T_t + \frac{2\ T_2}{3} = 3\ ft$ | $MV_8 := V_8 \cdot d_{v8} = 0\ lbf$

$d_{v9T} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \frac{2 \cdot \lambda}{3}, A + T_1 + T_t + \frac{2 \cdot (T_2 + C)}{3}\right) = 6.3\ ft$ | $MV_{9T} := V_{9T} \cdot d_{v9T} = 4750\ lbf$

$d_{v9R} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ | $MV_{9R} := V_{9R} \cdot d_{v9R} = 0\ lbf$

$d_{v10} := \text{if}\left(\lambda < (T_2 + C), A + T_1 + T_t + \lambda + \frac{(T_2 + C - \lambda)}{2}, 0\ ft\right) = 0\ ft$ | $MV_{10} := V_{10} \cdot d_{v10} = 0\ lbf$

$d_{v11} := B = 8\ ft$ | $MV_{11} := V_{11} \cdot d_{v11} = 14763\ lbf$

$d_{v12} := B = 8\ ft$ | $MV_{12} := V_{12} \cdot d_{v12} = 1587.4\ lbf$

Horizontal Loads:

$H_1 := F_{SUR} \cdot \cos(90 \cdot deg - \theta + \delta)$ $\quad H_1 = 649\ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

$H_2 := F_T \cdot \cos(90 \cdot deg - \theta + \delta)$ $\quad H_2 = 6036\ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

Moment Arm: | Moment:

$d_{h1} := \frac{h}{2}$ $\quad d_{h1} = 7.7\ ft$ | $MH_1 := H_1 \cdot d_{h1}$ $\quad MH_1 = 5030\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{h}{3}$ $\quad d_{h2} = 5.2\ ft$ | $MH_2 := H_2 \cdot d_{h2}$ $\quad MH_2 = 31185.8\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type:

$V_{DC} := V_1 + V_2 + V_3 + V_4 + V_6$ $\quad V_{DC} = 4875\ \frac{lbf}{ft}$

$V_{EV} := V_7 + V_8 + V_{9T} + V_{9R}$ $\quad V_{EV} = 7350\ \frac{lbf}{ft}$

$V_{LS} := V_{10} + V_{12}$ $\quad V_{LS} = 198.4\ \frac{lbf}{ft}$

$V_{EH} := V_{11}$ $\quad V_{EH} = 1845.4\ \frac{lbf}{ft}$

$H_{LS} := H_1$ $\quad H_{LS} = 649 \ \frac{lbf}{ft}$

$H_{EH} := H_2$ $\quad H_{EH} = 6036 \ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{DC} := MV_1 + MV_2 + MV_3 + MV_4 + MV_6$ $\quad M_{DC} = 15168.8 \ \frac{lbf \cdot ft}{ft}$

$M_{EV} := MV_7 + MV_8 + MV_{9T} + MV_{9R}$ $\quad M_{EV} = 41050 \ \frac{lbf \cdot ft}{ft}$

$M_{LS1} := MV_{10} + MV_{12}$ $\quad M_{LS1} = 1587.4 \ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_{11}$ $\quad M_{EH1} = 14763 \ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_1$ $\quad M_{LS2} = 5030 \ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_2$ $\quad M_{EH2} = 31185.8 \ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

Strength Limit State I: EV(min) = 1.00 EV(max) = 1.35
EH(min) = 0.90 EH(max) = 1.50
LS = 1.75

Strength Limit State Ia: (Sliding and Eccentricity)	$Ia_{DC} := 0.9$	$Ia_{EV} := 1$	$Ia_{EH} := 1.5$	$Ia_{LS} := 1.75$
Strength Limit State Ib: (Bearing Capacity)	$Ib_{DC} := 1.25$	$Ib_{EV} := 1.35$	$Ib_{EH} := 1.5$	$Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot V_{DC} \right) + \left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + \left(0 \cdot V_{LS} \right) \right)$ $\quad V_{Ia} = 14505.6 \ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot V_{DC} \right) + \left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + \left(Ib_{LS} \cdot V_{LS} \right) \right)$ $\quad V_{Ib} = 19131.6 \ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS} \right) + \left(Ia_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ia} = 10189.7 \ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS} \right) + \left(Ib_{EH} \cdot H_{EH} \right) \right)$ $\quad H_{Ib} = 10189.7 \ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot M_{DC} \right) + \left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + \left(0 \cdot M_{LS1} \right) \right)$ $\quad MV_{Ia} = 76846.4 \ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot M_{DC} \right) + \left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + \left(Ib_{LS} \cdot M_{LS1} \right) \right)$ $\quad MV_{Ib} = 99300.9 \ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LS2} \right) + \left(Ia_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ia} = 55581.1 \ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LS2} \right) + \left(Ib_{EH} \cdot M_{EH2} \right) \right)$ $\quad MH_{Ib} = 55581.1 \ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the resultant location about the toe of the base length (distance from "O") Strength Ib:

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 99300.9 \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 55581.1 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 19131.6 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 2.3\ ft$ Distance from Point "O" the resultant intersects the base

$e := \max\left(\frac{B}{2} - x, 0\right)$ $e = 1.71\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Foundation Layout:

$B' := B - 2 \cdot e$ $B' = 4.6\ ft$ Effective Footing Width

$L' := 40\ ft$ Effective Footing Length (Assumed)

$H' := H_{Ib}$ $H' = 10189.7 \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 19131.6 \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

$D_f = 3\ ft$ Footing embedment

$d_w := D_f$ Depth of Groundwater below Bearing Grade

$\theta' := 90 \cdot deg$ Direction of H' and V' resultant measured from wall backface **LRFD [Figure C10.6.3.1.2a-1]**

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45\ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right)$ $N_q = 11.85$

$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right)$ $N_c = 22.25$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd})$ $N_\gamma = 12.5$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L'}\right)\right)$ $s_c = 1.061$

$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'} \cdot \tan(\phi'_{fd})\right), 1\right)$ $s_q = 1.056$

$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right), 1\right)$ $s_\gamma = 0.954$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2+\left(\frac{L'}{B'}\right)}{1+\left(\frac{L'}{B'}\right)}\right)\cdot\cos(\theta)^2\right)+\left(\left(\frac{2+\left(\frac{B'}{L'}\right)}{1+\left(\frac{B'}{L'}\right)}\right)\cdot\sin(\theta)^2\right) \qquad n = 1.897$$

$$i_q := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\frac{1}{\tan(\phi'_{fd})}}{1\cdot ft}\right)}\right)^n,1\right)\right) \qquad i_q = 0.836$$

$$i_\gamma := \text{if}\left(\phi'_{fd}>0,\left(1-\left(\frac{H'}{\left(V'+\frac{c'_{fd}\cdot B'\cdot L'\cdot\left(\frac{1}{\tan(\phi'_{fd})}\right)}{1\cdot ft}\right)}\right)^{n+1},1\right)\right) \qquad i_\gamma = 0.76$$

$$i_c := \text{if}\left(\phi'_{fd}>0,i_q-\left(\frac{1-i_q}{N_q-1}\right),1-\left(\frac{n\cdot H'}{\left(c'_{fd}\cdot B'\cdot L'\cdot N_c\right)\cdot 1\cdot ft}\right)\right) \qquad i_c = 0.82$$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$$C_{wq} := \text{if}\left(d_w>D_f,1.0,\frac{(1.0-0.5)}{(D_f-0)}\cdot(d_w-0)+0.5\right) \qquad C_{wq} = 1$$

$$C_{w\gamma} := \text{if}\left(d_w<D_f,0.5,\text{if}\left(d_w>1.5\cdot B'+D_f,1.0,\frac{(1.0-0.5)}{(1.5\cdot B'+D_f-D_f)}\cdot(d_w-D_f)+0.5\right)\right) \qquad C_{w\gamma} = 0.5$$

Depth Correction Factor Compute depth correction factor per **LRFD [Table 10.6.3.1.2a-4]**. It can be assumed that the soils above the footing are as competent as those beneath the footing. Therefore; the depth correction factor is taken as 1.0 since Df/B is less than 1.0.

$\frac{D_f}{B'} = 0.7$ **<---- CHECK** **The depth correction factor is taken as 1.0 since Df/B is less than 1.0.** $d_q := 1.0$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c\cdot s_c\cdot i_c$ $N_{cm} = 19.371$

$N_{qm} := N_q\cdot s_q\cdot i_q$ $N_{qm} = 10.458$

$N_{\gamma m} := N_\gamma\cdot s_\gamma\cdot i_\gamma$ $N_{\gamma m} = 9.096$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$$q_{nd} := c'_{fd}\cdot N_{cm}+\gamma_{fd}\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq}+0.5\cdot\gamma_{fd}\cdot B'\cdot N_{\gamma m}\cdot C_{w\gamma} \qquad q_{nd} = 9645.7\ \frac{lbf}{ft^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b\cdot q_{nd}$ $q_{Rd} = 5.3\ ksf$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi_{fdu} > 0\,,\, e^{\pi \cdot \tan\left(\phi_{fdu}\right)} \cdot \tan\left(45\ \textit{deg} + \frac{\phi_{fdu}}{2}\right)^2\,,\, 1.0\right) \qquad N_q = 1$$

$$N_c := \text{if}\left(\phi_{fdu} > 0\,,\, \frac{N_q - 1}{\tan\left(\phi_{fdu}\right)}\,,\, 5.14\right) \qquad N_c = 5.14$$

$$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_{fdu}\right) \qquad N_\gamma = 0$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right)\,,\, 1 + \left(\frac{B'}{5 \cdot L'}\right)\right) \qquad s_c = 1.023$$

$$s_q := \text{if}\left(\phi_{fdu} > 0\,,\, 1 + \left(\frac{B'}{L'} \cdot \tan\left(\phi_{fdu}\right)\right)\,,\, 1\right) \qquad s_q = 1$$

$$s_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right)\,,\, 1\right) \qquad s_\gamma = 1$$

Compute load inclination factors using **LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$n := \left(\left(\frac{2 + \left(\frac{L'}{B'}\right)}{1 + \left(\frac{L'}{B'}\right)}\right) \cdot \cos\left(\theta\right)^2\right) + \left(\left(\frac{2 + \left(\frac{B'}{L'}\right)}{1 + \left(\frac{B'}{L'}\right)}\right) \cdot \sin\left(\theta\right)^2\right) \qquad n = 1.897$$

$$i_q := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \frac{1}{\tan\left(\phi_{fdu}\right)}}{1 \cdot \textit{ft}}\right)}\right)\right)^n\,,\, 1\right) \qquad i_q = 1$$

$$i_\gamma := \text{if}\left(\phi_{fdu} > 0\,,\, \left(1 - \left(\frac{H'}{\left(V' + \frac{Su_{fdu} \cdot B' \cdot L' \cdot \left(\frac{1}{\tan\left(\phi_{fdu}\right)}\right)}{1 \cdot \textit{ft}}\right)}\right)\right)^{n+1}\,,\, 1\right) \qquad i_\gamma = 1$$

$$i_c := \text{if}\left(\phi_{fdu} > 0\,,\, i_q - \left(\frac{1 - i_q}{N_q - 1}\right)\,,\, 1 - \left(\frac{n \cdot H'}{\frac{\left(Su_{fdu} \cdot B' \cdot L' \cdot N_c\right)}{1 \cdot \textit{ft}}}\right)\right) \qquad i_c = 0.993$$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$$N_{cm} := N_c \cdot s_c \cdot i_c \qquad N_{cm} = 5.218$$

$$N_{qm} := N_q \cdot s_q \cdot i_q \qquad N_{qm} = 1$$

$$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma \qquad N_{\gamma m} = 0$$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$$q_{nu} := Su_{fdu} \cdot N_{cm} + \gamma_{fd} \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 14694.8\ \frac{\textit{lbf}}{\textit{ft}^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 8.1\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 5.3\ ksf$

Undrained Conditions: $q_{Ru} = 8.1\ ksf$

Evaluate External Stability of Wall:

Compute the ultimate bearing stress :

$e = 1.7\ ft$

$\sigma_V := \frac{\Sigma V}{B - 2 \cdot e}$ $\sigma_V = 4.186\ ksf$

Bearing Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_D} := \frac{q_{Rd}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_D} = 1.27$

Undrained Conditions: $CDR_{Bearing\_U} := \frac{q_{Ru}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_U} = 1.93$

Limiting Eccentricity at Base of MSE Wall (Strength Ia):

Compute the resultant location about the toe "O" of the base length (distance from Pivot):

$e_{max} := \frac{B}{3}$ $e_{max} = 2.7\ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 76846.4\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 55581.1\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 14505.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 1.5\ ft$ Distance from Point "O" the resultant intersects the base

$e := \text{abs}\left(\frac{B}{2} - x\right)$ $e = 2.53\ ft$ Wall eccentricity, **Note:**The vertical stress is assumed to be uniformly distributed over the effective bearing width, B', since the wall is supported by a soil foundation **LRFD [11.6.3.2**]. The effective bearing width is equal to B-2e. When the foundation eccentricity is negative the actual bearing width, B, will be used.

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.05$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $\quad R_u = 10189.7\ \frac{lbf}{ft}$

Compute passive resistance throughout the design life of the wall **LRFD [Eq 3.11.5.4-1]:**:

Drained Conditions:

$r_{ep1} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pd} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot c'_{sd} \cdot \sqrt{k_{pd}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epd} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epd} = 7\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Undrained Conditions:

$r_{ep1} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_1 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y1

$r_{ep2} := \left(k_{pu} \cdot \gamma_{sd} \cdot y_2 + 2 \cdot Su_{sdu} \cdot \sqrt{k_{pu}}\right) \cdot \cos(\delta)$ Nominal passive pressure at y2

$R_{epu} := \frac{r_{ep1} + r_{ep2}}{2} \cdot (y_2 - y_1)$ $\quad R_{epu} = 8.5\ \frac{kip}{ft}$ Nominal passive resistance Drained Conditions

Nominal Passive Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{epd} = 7.019\ \frac{kip}{ft}$

Undrained Conditions: $R_{epu} = 8.508\ \frac{kip}{ft}$

Nominal Passive Resistance to be used in CDR Calculations: $R_{ep} := R_{epd}$ **LRFD [11.6.3.5]**

Passive Resistance, **Note:** Passive Resistance shall be neglected in stability computations, unless the base of the wall extends below the depth of maximum scour, freeze-thaw or other disturbances. In the latter case, only the embed below the greater of these depths shall be considered effective **LRFD [11.6.3.5]**.

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14505.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_{sd}\right)$ $\quad R_{\tau d} = 7074.8\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Undrained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 14505.6\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau u} := min\left(0.5 \cdot V_{Ia}, Su_{sdu} \cdot (B')\right)$ $\quad R_{\tau u} = 7252.8\ \frac{lbf}{ft}$ Nominal sliding resistance Undrained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 7.075 \ \frac{kip}{ft}$

Undrained Conditions: $R_{\tau u} = 7.253 \ \frac{kip}{ft}$

Nominal Sliding Resistance to be used in CDR Calculations: $R_\tau := R_{\tau d}$

Compute factored resistance against failure by sliding **LRFD [10.6.3.4]**:

$\phi_{ep} := 0.5$ Resistance factor for passive resistance specified in **LRFD Table 10.5.5.2.2-1**

$\phi_\tau := 1.0$ Resistance factor for sliding resistance specified in **LRFD Table 11.5.7-1.**

$\phi R_n := \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep}$ $R_R := \phi R_n$

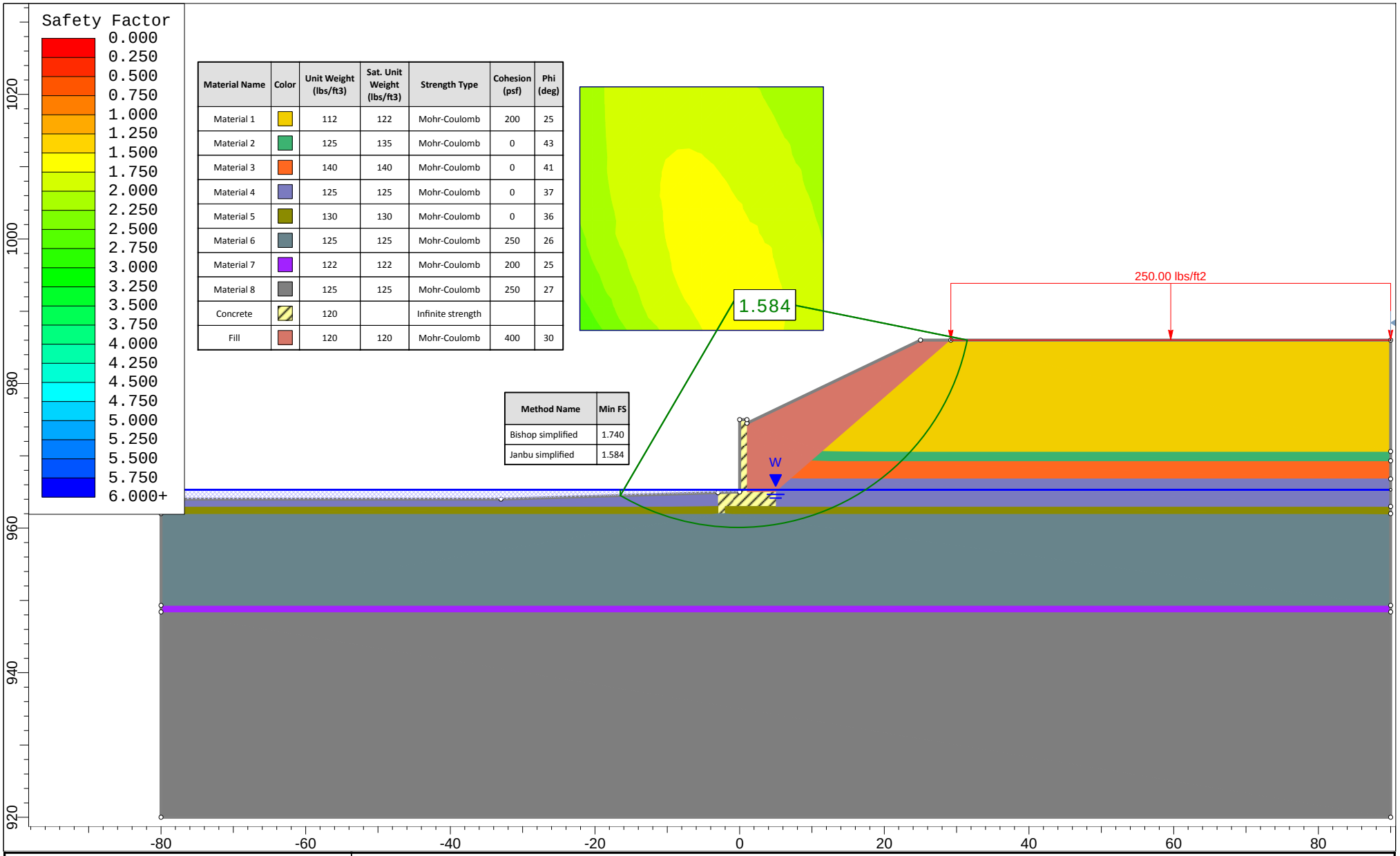
Factored Sliding Resistance to be used in CDR Calculations: $R_R = 10584.223 \ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.04$

CULVERT #1

GLOBAL STABILITY ANALYSIS

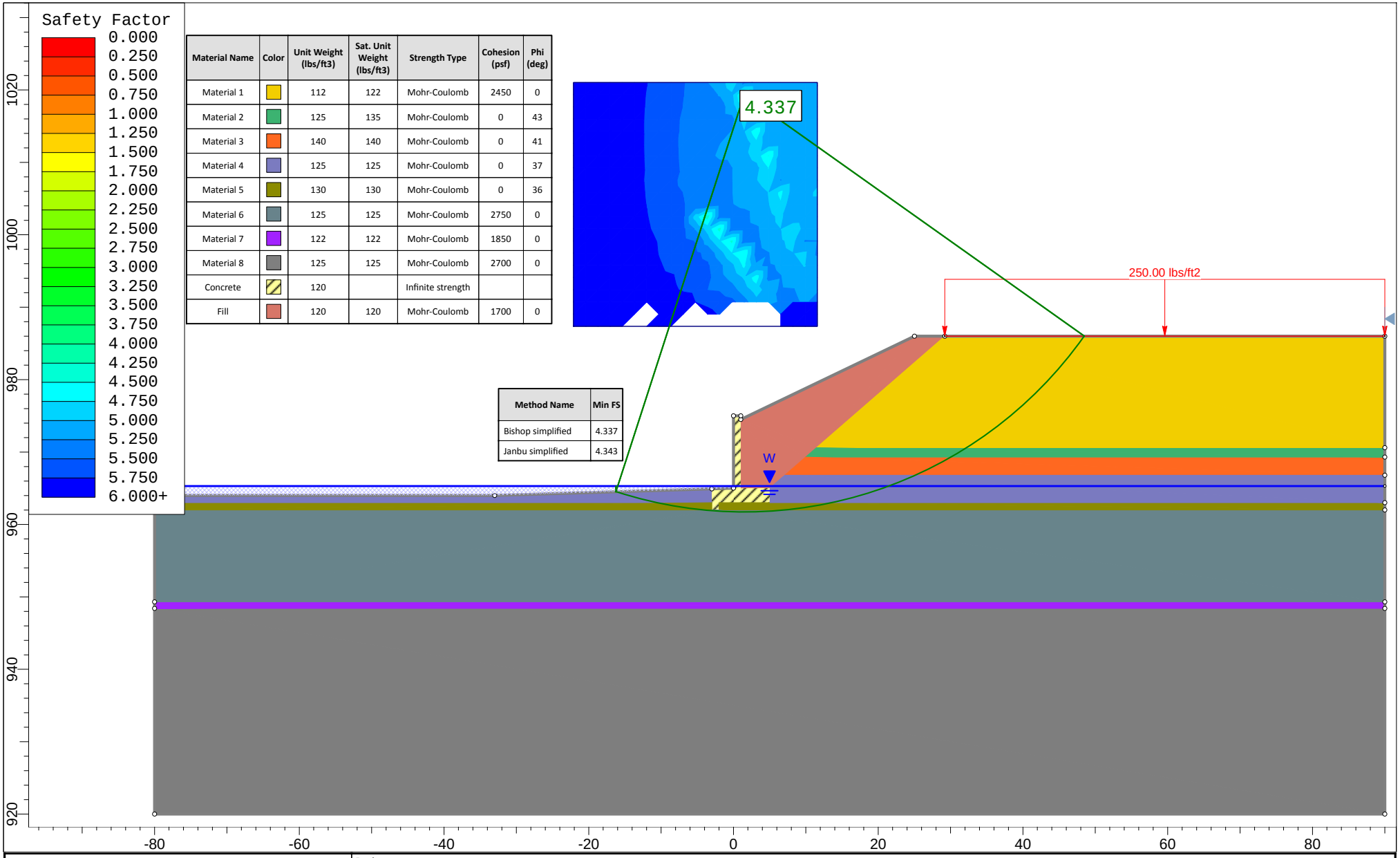


Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Material 1		112	122	Mohr-Coulomb	200	25
Material 2		125	135	Mohr-Coulomb	0	43
Material 3		140	140	Mohr-Coulomb	0	41
Material 4		125	125	Mohr-Coulomb	0	37
Material 5		130	130	Mohr-Coulomb	0	36
Material 6		125	125	Mohr-Coulomb	250	26
Material 7		122	122	Mohr-Coulomb	200	25
Material 8		125	125	Mohr-Coulomb	250	27
Concrete		120		Infinite strength		
Fill		120	120	Mohr-Coulomb	400	30

Method Name	Min FS
Bishop simplified	1.740
Janbu simplified	1.584

Project	MED-18 Culvert #1		
Analysis Description	Circular_Effective Stress Analysis		
Drawn By	ZM	Scale 1:220	Company National Engineering & Architectural Services, Inc
Date	3/7/2017, 4:13:49 PM		File Name Culvert1_Circular_Effective_1ft_withHeadwall.slim

SLIDEINTERPRET 7.022



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Material 1		112	122	Mohr-Coulomb	2450	0
Material 2		125	135	Mohr-Coulomb	0	43
Material 3		140	140	Mohr-Coulomb	0	41
Material 4		125	125	Mohr-Coulomb	0	37
Material 5		130	130	Mohr-Coulomb	0	36
Material 6		125	125	Mohr-Coulomb	2750	0
Material 7		122	122	Mohr-Coulomb	1850	0
Material 8		125	125	Mohr-Coulomb	2700	0
Concrete		120		Infinite strength		
Fill		120	120	Mohr-Coulomb	1700	0

Method Name	Min FS
Bishop simplified	4.337
Janbu simplified	4.343

Project	MED-18 Culvert #1		
Analysis Description	Circular_Total Stress Analysis		
Drawn By	ZM	Scale	1:220
Company	National Engineering & Architectural Services, Inc		
Date	3/7/2017, 4:13:49 PM	File Name	Culvert1_Circular_Total_1ft_withHeadwall.slim

SLIDEINTERPRET 7.022

CULVERT #1

SETTLEMENT ANALYSES

MED-18-13.54

PROJECT IDENTIFICATION

Title: MED-18-13.54
Project Number: -
Client: GPD/ODOT
Designer: ZM
Station Number:

Description:
Culvert #1

Company's information:

Name: NEAS, Inc.
Street:
Columbus, OH 43231
Telephone #:
Fax #:
E-Mail:

Original file path and name: P:\15-0091 ..... lvert #1\Settlement\MED18_Culvert#1_B-006-1-16.2ST
Original date and time of creating this file: Sun Apr 8 11:27:50 2018

GEOMETRY: Analysis of a 3D-Approximate geometry

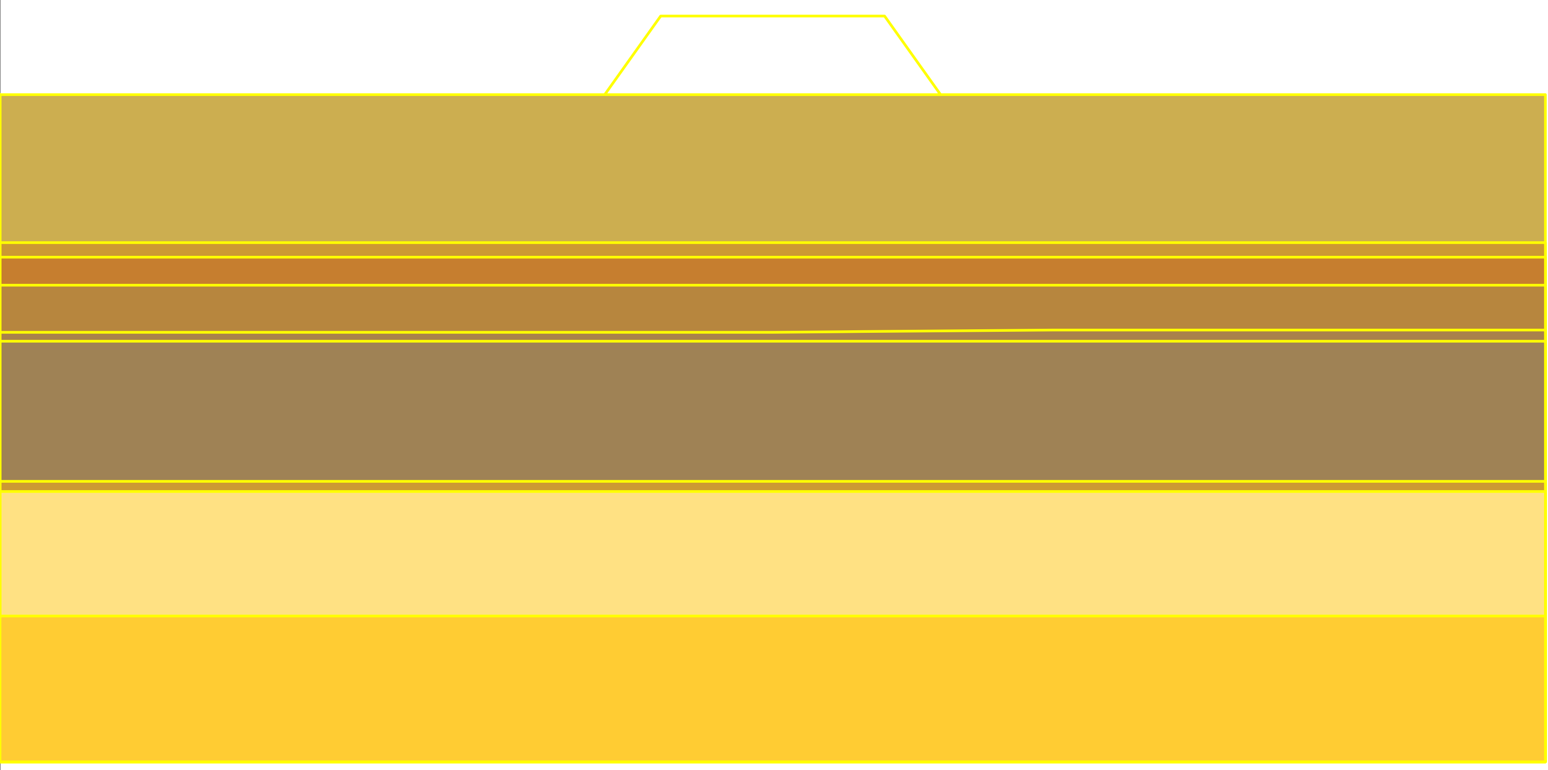
INPUT DATA -- FOUNDATION LAYERS -- 9 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	122.00	0.40	A-6b
2	135.00	0.30	A-1-b
3	140.00	0.30	A-2-6
4	125.00	0.30	A-1-b
5	130.00	0.30	A-4a
6	125.00	0.30	A-6a
7	122.00	0.30	A-4a
8	125.00	0.30	A-4a
9	130.00	0.30	Granular Material

INPUT DATA -- EMBANKMENT LAYERS -- 1 layers

	Wet Unit Weight, γ [lb/ft³]	Description of Soil
1	120.00	

DRAWING OF SPECIFIED GEOMETRY



INPUT DATA FOR CONSOLIDATION -- α = 1/2

Layer #	Underging Consolidation [Yes/No]	OCR = Pc / Po	Cc	Cr	e0	Cv [ft ²/day]	Drains at :
1	Yes	5.00	0.20	0.02	0.78	0.2000	Top & Bot.
2	No	N/A	N/A	N/A	N/A	N/A	N/A
3	No	N/A	N/A	N/A	N/A	N/A	N/A
4	No	N/A	N/A	N/A	N/A	N/A	N/A
5	No	N/A	N/A	N/A	N/A	N/A	N/A
6	Yes	4.00	0.10	0.01	0.61	0.2153	Top & Bot.
7	Yes	3.00	0.10	0.01	0.73	0.2153	Top & Bot.
8	Yes	2.00	0.10	0.01	0.54	0.2153	Top & Bot.
9	No	N/A	N/A	N/A	N/A	N/A	N/A

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	-20.00	0.00	1	500000	0.4000	-0.0007	983.80	983.79	0.01
			2	900000	0.3000	0.0001			
			3	1000000	0.3000	0.0003			
			4	300000	0.3000	0.0020			
			5	600000	0.3000	0.0003			
			6	500000	0.3000	0.0044			
			7	400000	0.3000	0.0004			
			8	500000	0.3000	0.0036			
			9	555400	0.3000	0.0019			
2	-15.00	0.00	1	500000	0.4000	0.0015	983.80	983.78	0.02
			2	900000	0.3000	0.0003			
			3	1000000	0.3000	0.0006			
			4	300000	0.3000	0.0035			
			5	600000	0.3000	0.0004			
			6	500000	0.3000	0.0061			
			7	400000	0.3000	0.0005			
			8	500000	0.3000	0.0044			
			9	555400	0.3000	0.0022			
3	-10.00	0.00	1	500000	0.4000	0.0095	983.80	983.77	0.03
			2	900000	0.3000	0.0006			
			3	1000000	0.3000	0.0010			
			4	300000	0.3000	0.0052			
			5	600000	0.3000	0.0006			
			6	500000	0.3000	0.0078			
			7	400000	0.3000	0.0006			
			8	500000	0.3000	0.0051			
			9	555400	0.3000	0.0025			
4	-5.00	0.00	1	500000	0.4000	0.0118	983.80	983.76	0.04
			2	900000	0.3000	0.0008			
			3	1000000	0.3000	0.0013			
			4	300000	0.3000	0.0065			
			5	600000	0.3000	0.0007			
			6	500000	0.3000	0.0091			
			7	400000	0.3000	0.0007			
			8	500000	0.3000	0.0055			
			9	555400	0.3000	0.0026			
5	0.00	0.00	1	500000	0.4000	0.0121	983.80	983.76	0.04
			2	900000	0.3000	0.0008			
			3	1000000	0.3000	0.0014			
			4	300000	0.3000	0.0070			
			5	600000	0.3000	0.0007			
			6	500000	0.3000	0.0096			
			7	400000	0.3000	0.0007			
			8	500000	0.3000	0.0057			
			9	555400	0.3000	0.0027			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
6	5.00	0.00	1	500000	0.4000	0.0118	983.80	983.76	0.04
			2	900000	0.3000	0.0008			
			3	1000000	0.3000	0.0013			
			4	300000	0.3000	0.0065			
			5	600000	0.3000	0.0007			
			6	500000	0.3000	0.0091			
			7	400000	0.3000	0.0007			
			8	500000	0.3000	0.0056			
			9	555400	0.3000	0.0026			
7	10.00	0.00	1	500000	0.4000	0.0095	983.80	983.77	0.03
			2	900000	0.3000	0.0006			
			3	1000000	0.3000	0.0010			
			4	300000	0.3000	0.0052			
			5	600000	0.3000	0.0006			
			6	500000	0.3000	0.0078			
			7	400000	0.3000	0.0006			
			8	500000	0.3000	0.0051			
			9	555400	0.3000	0.0025			
8	15.00	0.00	1	500000	0.4000	0.0015	983.80	983.78	0.02
			2	900000	0.3000	0.0003			
			3	1000000	0.3000	0.0006			
			4	300000	0.3000	0.0035			
			5	600000	0.3000	0.0004			
			6	500000	0.3000	0.0061			
			7	400000	0.3000	0.0005			
			8	500000	0.3000	0.0044			
			9	555400	0.3000	0.0022			
9	20.00	0.00	1	500000	0.4000	-0.0007	983.80	983.79	0.01
			2	900000	0.3000	0.0001			
			3	1000000	0.3000	0.0003			
			4	300000	0.3000	0.0020			
			5	600000	0.3000	0.0003			
			6	500000	0.3000	0.0044			
			7	400000	0.3000	0.0004			
			8	500000	0.3000	0.0036			
			9	555400	0.3000	0.0019			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	-20.00	0.00	983.80	0.01	983.79
2	-15.00	0.00	983.80	0.02	983.78
3	-10.00	0.00	983.80	0.05	983.75
4	-5.00	0.00	983.80	0.07	983.73
5	0.00	0.00	983.80	0.07	983.73
6	5.00	0.00	983.80	0.07	983.73
7	10.00	0.00	983.80	0.05	983.75
8	15.00	0.00	983.80	0.02	983.78
9	20.00	0.00	983.80	0.01	983.79

*Note: Final Z is calculated assuming only 'Ultimate Settlement' exists.

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	D E S C R I P T I O N
1	1	-25.00	983.80	A-6b
	2	0.00	983.80	
	3	25.00	983.80	
2	1	-25.00	970.60	A-1-b
	2	0.00	970.60	
	3	25.00	970.60	
3	1	-25.00	969.30	A-2-6
	2	0.00	969.30	
	3	25.00	969.30	
4	1	-25.00	966.80	A-1-b
	2	0.00	966.80	
	3	25.00	966.80	
5	1	-25.00	962.60	A-4a
	2	0.00	962.60	
	3	25.00	962.80	
6	1	-25.00	961.80	A-6a
	2	0.00	961.80	
	3	25.00	961.80	
7	1	-25.00	949.30	A-4a
	2	0.00	949.30	
	3	25.00	949.30	
8	1	-25.00	948.40	A-4a
	2	0.00	948.40	
	3	25.00	948.40	
9	1	-25.00	937.30	Granular Material
	2	0.00	937.30	
	3	25.00	937.30	

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	D E S C R I P T I O N
1	X1 = -15.00 [ft]	1	-10.00	990.80	
	X2 = 15.00 [ft]	2	10.00	990.80	

APPENDIX D

CULVERT #3 ANALYSES

CULVERT #3

DEEP FOUNDATION ANALYSIS

DRIVEN 1.2

GENERAL PROJECT INFORMATION

Filename: C:\PROGRA~1\DRIVEN\CULVER~1\CULB15.DVN
Project Name: MED-18-13.54 Culvert #3 Project Date: 03/24/2018
Project Client: GPD/ODOT
Computed By: ZM
Project Manager: CH

PILE INFORMATION

Pile Type: Pipe Pile - Closed End
Top of Pile: 30.35 ft
Diameter of Pile: 12.00 in

ULTIMATE CONSIDERATIONS

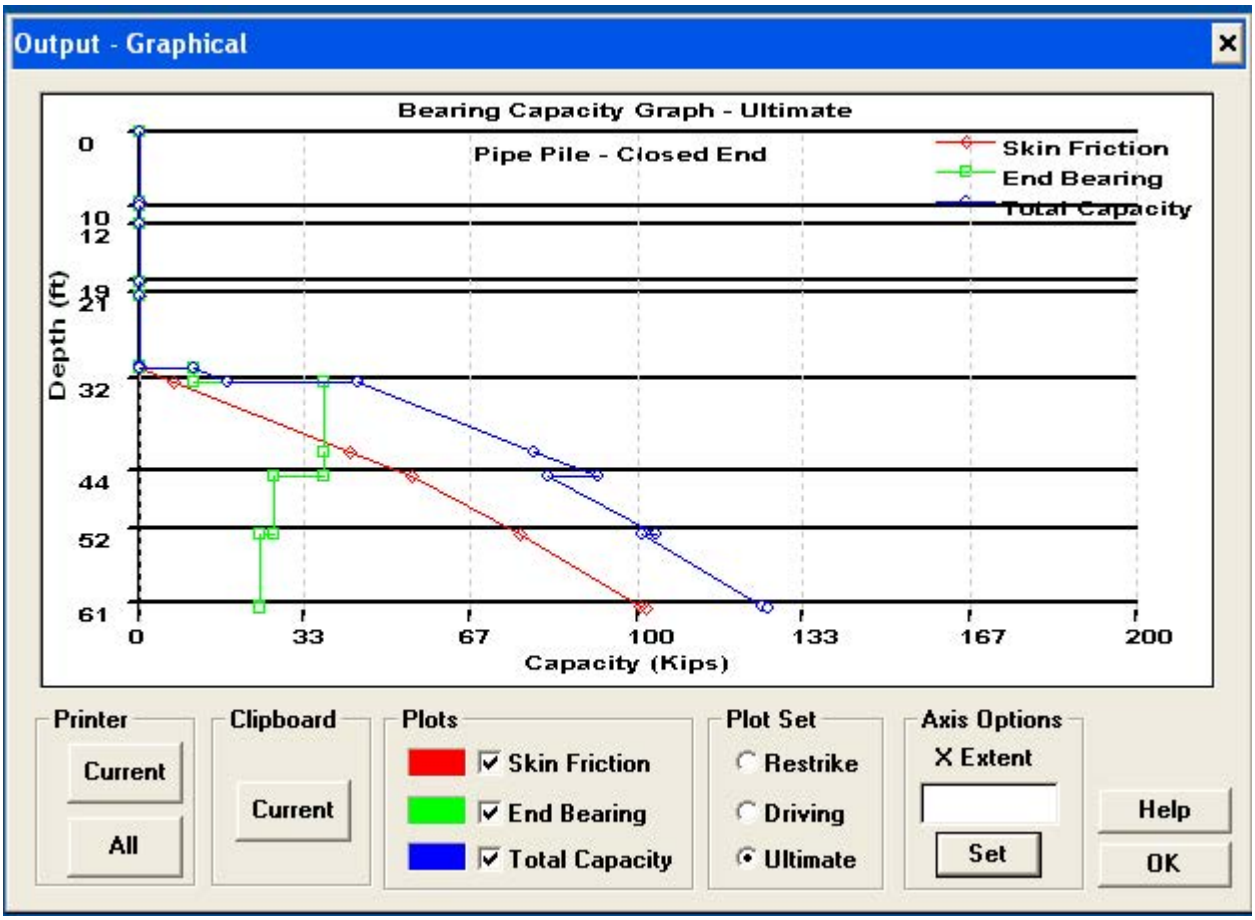
Water Table Depth At Time Of:	- Drilling:	22.00 ft
	- Driving/Restrike	22.00 ft
	- Ultimate:	24.30 ft
Ultimate Considerations:	- Local Scour:	0.00 ft
	- Long Term Scour:	0.00 ft
	- Soft Soil:	0.00 ft

ULTIMATE PROFILE

Layer	Type	Thickness	Driving Loss	Unit Weight	Strength	Ultimate Curve
1	Cohesive	9.50 ft	0.00%	125.00 pcf	3150.00 psf	T-80 Same
2	Cohesive	2.50 ft	0.00%	128.00 pcf	3500.00 psf	T-80 Same
3	Cohesive	7.30 ft	0.00%	135.00 pcf	6150.00 psf	T-80 Same
4	Cohesive	1.70 ft	0.00%	120.00 pcf	1600.00 psf	T-80 Same
5	Cohesive	11.10 ft	0.00%	120.00 pcf	1550.00 psf	T-80 Same
6	Cohesive	12.00 ft	0.00%	130.00 pcf	5250.00 psf	T-80 Same
7	Cohesive	7.50 ft	0.00%	128.00 pcf	3850.00 psf	T-80 Same
8	Cohesive	9.50 ft	0.00%	125.00 pcf	3450.00 psf	T-80 Same

ULTIMATE - SUMMARY OF CAPACITIES

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.49 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.51 ft	0.00 Kips	0.00 Kips	0.00 Kips
11.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
12.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.29 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.31 ft	0.00 Kips	0.00 Kips	0.00 Kips
20.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
21.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.34 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.35 ft	0.00 Kips	10.96 Kips	10.96 Kips
32.09 ft	6.98 Kips	10.96 Kips	17.93 Kips
32.11 ft	7.06 Kips	37.11 Kips	44.17 Kips
41.11 ft	42.38 Kips	37.11 Kips	79.49 Kips
44.09 ft	54.88 Kips	37.11 Kips	91.99 Kips
44.11 ft	54.96 Kips	27.21 Kips	82.17 Kips
51.59 ft	76.49 Kips	27.21 Kips	103.70 Kips
51.61 ft	76.54 Kips	24.39 Kips	100.93 Kips
60.61 ft	100.60 Kips	24.39 Kips	124.99 Kips
61.09 ft	101.88 Kips	24.39 Kips	126.27 Kips



DRIVEN 1.2

GENERAL PROJECT INFORMATION

Filename: C:\PROGRA~1\DRIVEN\CULVER~1\CULB15.DVN
Project Name: MED-18-13.54 Culvert #3 Project Date: 03/24/2018
Project Client: GPD/ODOT
Computed By: ZM
Project Manager: CH

PILE INFORMATION

Pile Type: Pipe Pile - Closed End
Top of Pile: 30.35 ft
Diameter of Pile: 14.00 in

ULTIMATE CONSIDERATIONS

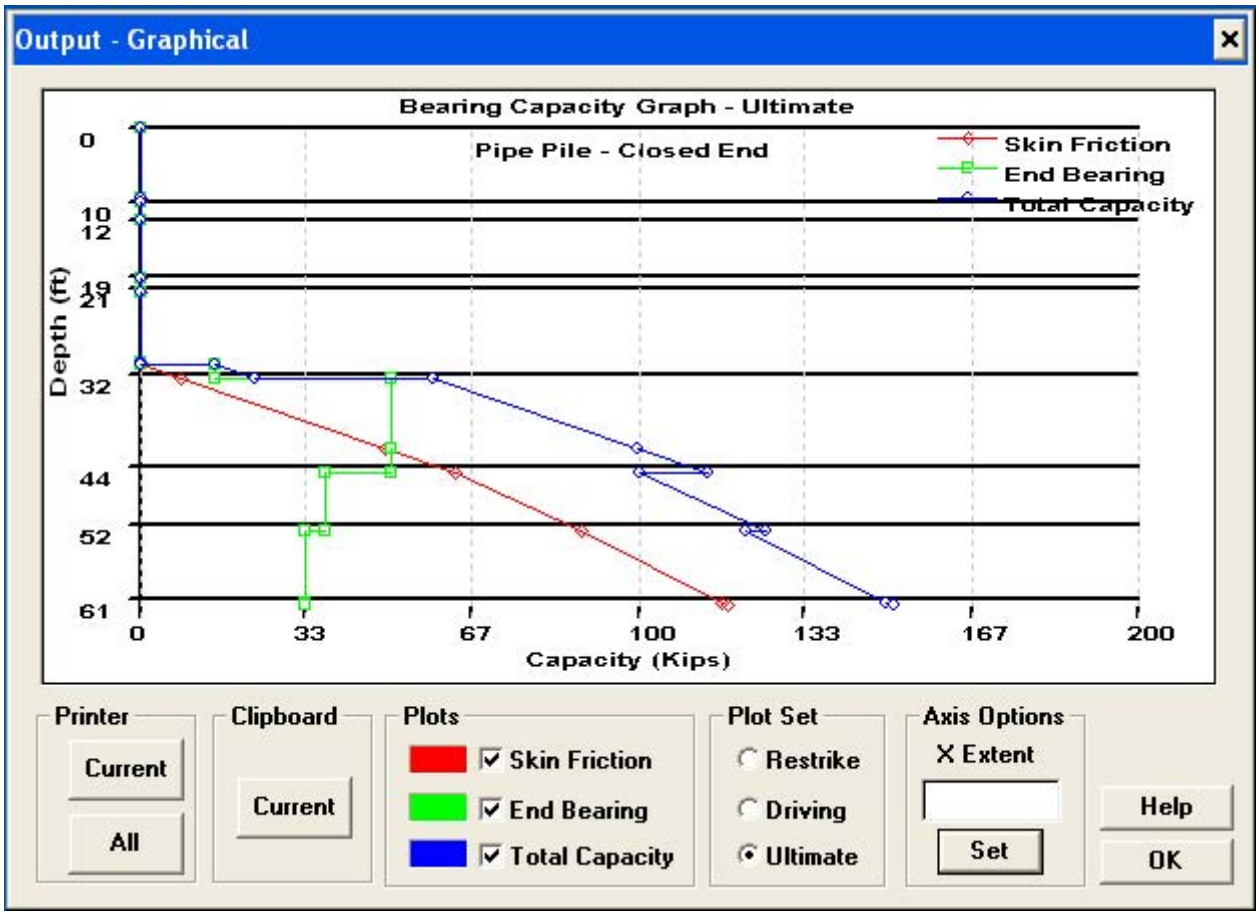
Water Table Depth At Time Of:	- Drilling:	22.00 ft
	- Driving/Restrike	22.00 ft
	- Ultimate:	24.30 ft
Ultimate Considerations:	- Local Scour:	0.00 ft
	- Long Term Scour:	0.00 ft
	- Soft Soil:	0.00 ft

ULTIMATE PROFILE

Layer	Type	Thickness	Driving Loss	Unit Weight	Strength	Ultimate Curve
1	Cohesive	9.50 ft	0.00%	125.00 pcf	3150.00 psf	T-80 Same
2	Cohesive	2.50 ft	0.00%	128.00 pcf	3500.00 psf	T-80 Same
3	Cohesive	7.30 ft	0.00%	135.00 pcf	6150.00 psf	T-80 Same
4	Cohesive	1.70 ft	0.00%	120.00 pcf	1600.00 psf	T-80 Same
5	Cohesive	11.10 ft	0.00%	120.00 pcf	1550.00 psf	T-80 Same
6	Cohesive	12.00 ft	0.00%	130.00 pcf	5250.00 psf	T-80 Same
7	Cohesive	7.50 ft	0.00%	128.00 pcf	3850.00 psf	T-80 Same
8	Cohesive	9.50 ft	0.00%	125.00 pcf	3450.00 psf	T-80 Same

ULTIMATE - SUMMARY OF CAPACITIES

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.49 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.51 ft	0.00 Kips	0.00 Kips	0.00 Kips
11.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
12.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.29 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.31 ft	0.00 Kips	0.00 Kips	0.00 Kips
20.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
21.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.34 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.35 ft	0.00 Kips	14.91 Kips	14.91 Kips
32.09 ft	8.07 Kips	14.91 Kips	22.99 Kips
32.11 ft	8.17 Kips	50.51 Kips	58.68 Kips
41.11 ft	49.38 Kips	50.51 Kips	99.89 Kips
44.09 ft	63.16 Kips	50.51 Kips	113.67 Kips
44.11 ft	63.24 Kips	37.04 Kips	100.29 Kips
51.59 ft	88.36 Kips	37.04 Kips	125.41 Kips
51.61 ft	88.43 Kips	33.19 Kips	121.62 Kips
60.61 ft	116.49 Kips	33.19 Kips	149.69 Kips
61.09 ft	117.99 Kips	33.19 Kips	151.18 Kips



DRIVEN 1.2

GENERAL PROJECT INFORMATION

Filename: C:\PROGRA~1\DRIVEN\CULVER~1\CULB15.DVN
Project Name: MED-18-13.54 Culvert #3 Project Date: 03/24/2018
Project Client: GPD/ODOT
Computed By: ZM
Project Manager: CH

PILE INFORMATION

Pile Type: Pipe Pile - Closed End
Top of Pile: 30.35 ft
Diameter of Pile: 16.00 in

ULTIMATE CONSIDERATIONS

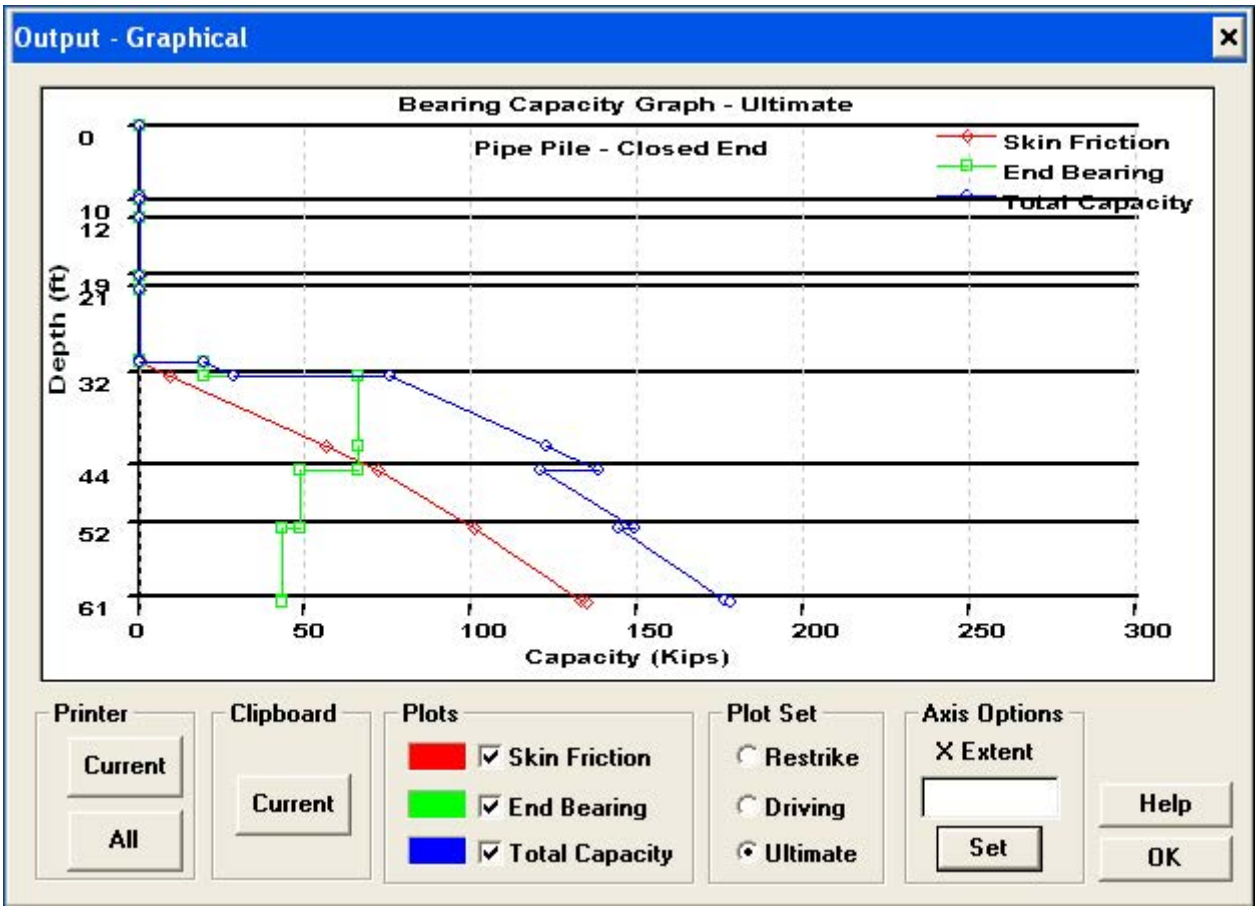
Water Table Depth At Time Of:	- Drilling:	22.00 ft
	- Driving/Restrike	22.00 ft
	- Ultimate:	24.30 ft
Ultimate Considerations:	- Local Scour:	0.00 ft
	- Long Term Scour:	0.00 ft
	- Soft Soil:	0.00 ft

ULTIMATE PROFILE

Layer	Type	Thickness	Driving Loss	Unit Weight	Strength	Ultimate Curve
1	Cohesive	9.50 ft	0.00%	125.00 pcf	3150.00 psf	T-80 Same
2	Cohesive	2.50 ft	0.00%	128.00 pcf	3500.00 psf	T-80 Same
3	Cohesive	7.30 ft	0.00%	135.00 pcf	6150.00 psf	T-80 Same
4	Cohesive	1.70 ft	0.00%	120.00 pcf	1600.00 psf	T-80 Same
5	Cohesive	11.10 ft	0.00%	120.00 pcf	1550.00 psf	T-80 Same
6	Cohesive	12.00 ft	0.00%	130.00 pcf	5250.00 psf	T-80 Same
7	Cohesive	7.50 ft	0.00%	128.00 pcf	3850.00 psf	T-80 Same
8	Cohesive	9.50 ft	0.00%	125.00 pcf	3450.00 psf	T-80 Same

ULTIMATE - SUMMARY OF CAPACITIES

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.49 ft	0.00 Kips	0.00 Kips	0.00 Kips
9.51 ft	0.00 Kips	0.00 Kips	0.00 Kips
11.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
12.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.29 ft	0.00 Kips	0.00 Kips	0.00 Kips
19.31 ft	0.00 Kips	0.00 Kips	0.00 Kips
20.99 ft	0.00 Kips	0.00 Kips	0.00 Kips
21.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.01 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.34 ft	0.00 Kips	0.00 Kips	0.00 Kips
30.35 ft	0.00 Kips	19.48 Kips	19.48 Kips
32.09 ft	9.23 Kips	19.48 Kips	28.71 Kips
32.11 ft	9.33 Kips	65.97 Kips	75.31 Kips
41.11 ft	56.44 Kips	65.97 Kips	122.41 Kips
44.09 ft	72.03 Kips	65.97 Kips	138.01 Kips
44.11 ft	72.13 Kips	48.38 Kips	120.51 Kips
51.59 ft	100.84 Kips	48.38 Kips	149.22 Kips
51.61 ft	100.91 Kips	43.35 Kips	144.26 Kips
60.61 ft	132.98 Kips	43.35 Kips	176.34 Kips
61.09 ft	134.69 Kips	43.35 Kips	178.05 Kips



CULVERT #3

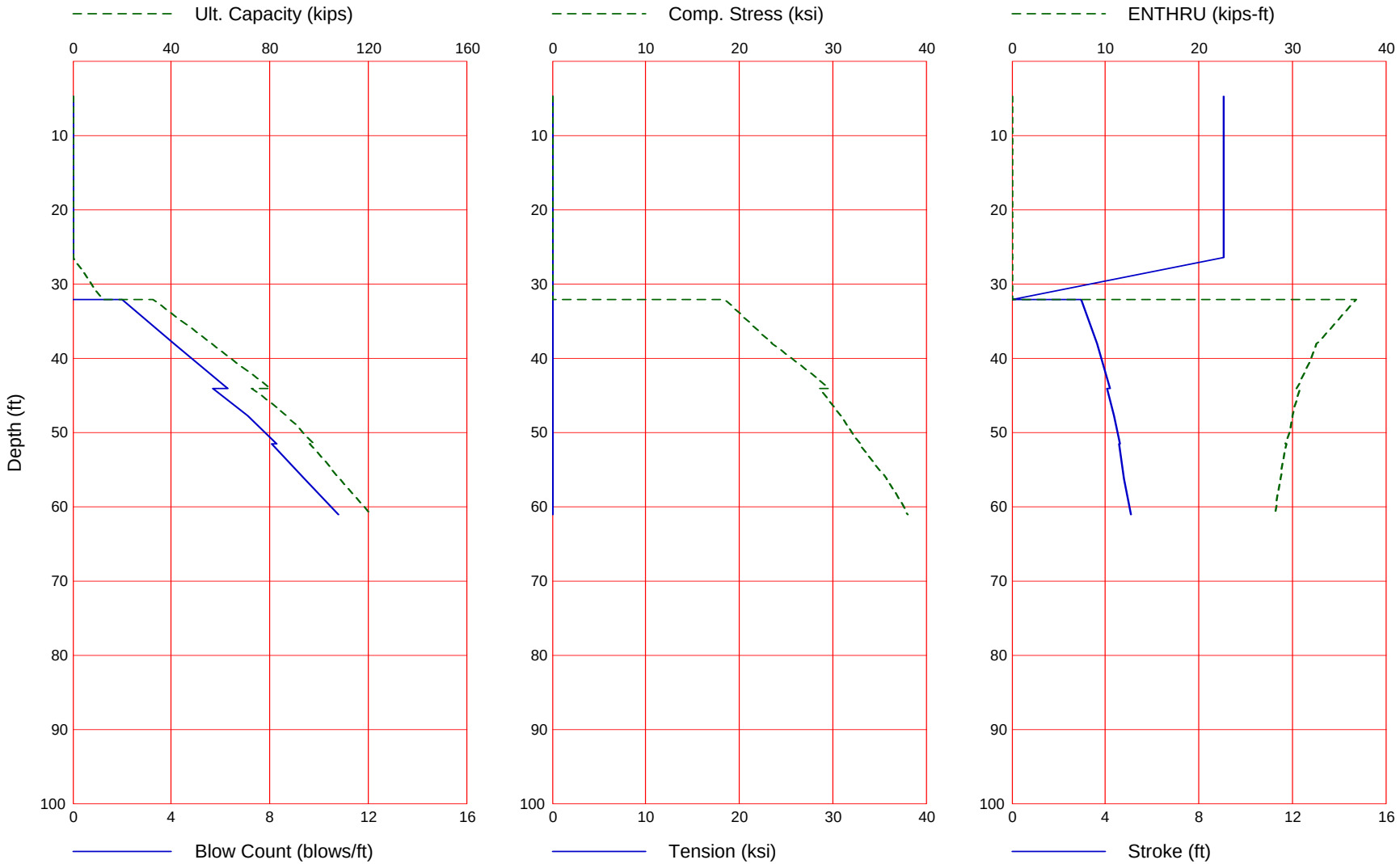
PILE DRIVABILITY ANALYSIS

12 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural
MED-18-13.54 Culvert #3 : 03/24/2018 : Z

Apr 08 2018
GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000



12 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural — Apr 08 2018
MED-18-13.54 Culvert #3 : 03/24/2018 : Z — GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000

Depth ft	Ultimate Capacity kips	Friction kips	End Bearing kips	Blow Count blows/ft	Comp. Stress ksi	Tension Stress ksi	Stroke ft	ENTHRU kips-ft
4.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
10.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
15.6	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
20.1	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
26.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
32.1	12.1	3.4	8.6	-1.0	0.000	0.000	0.00	0.0
32.1	32.7	3.6	29.1	2.0	18.454	0.000	2.97	36.8
38.1	56.5	27.4	29.1	4.1	23.468	0.000	3.65	32.6
44.1	80.4	51.3	29.1	6.3	29.639	0.000	4.21	30.4
44.1	72.8	51.4	21.4	5.7	28.670	0.000	4.08	30.9
47.8	86.7	65.3	21.4	7.1	30.854	0.000	4.38	30.0
51.6	98.4	77.1	21.4	8.3	32.933	0.000	4.62	29.3
51.6	96.3	77.2	19.1	8.1	32.804	0.000	4.59	29.4
56.3	108.3	89.1	19.1	9.4	35.750	0.000	4.82	28.7
61.1	120.8	101.7	19.1	10.8	37.997	0.000	5.08	28.2

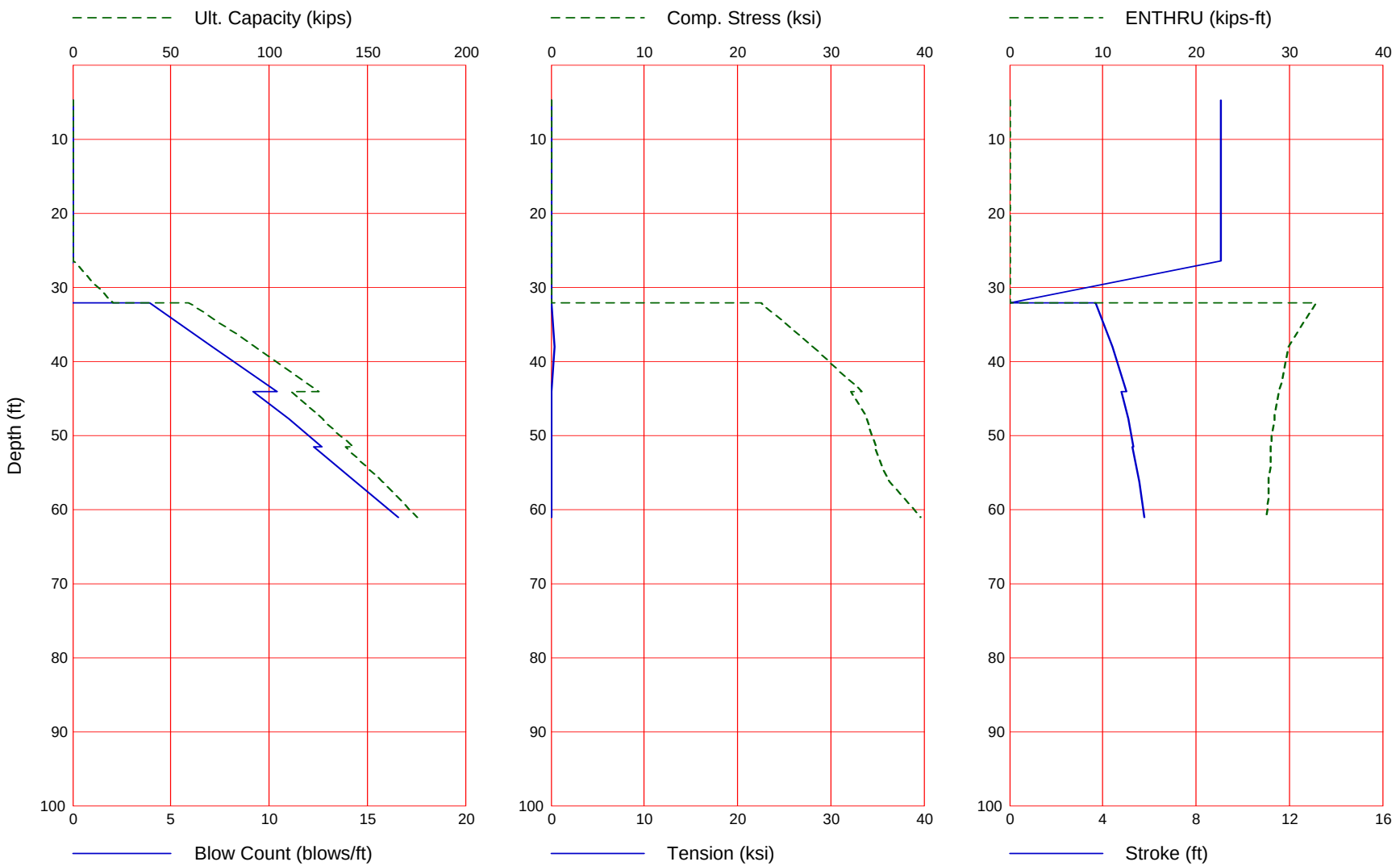
Total Continuous Driving Time 3.00 minutes; Total Number of Blows 191 (starting at penetration 4.8 ft)

14 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural
MED-18-13.54 Culvert #3 : 03/24/2018 : Z

Apr 08 2018
GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000



14 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural — Apr 08 2018
MED-18-13.54 Culvert #3 : 03/24/2018 : Z — GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000

Depth ft	Ultimate Capacity kips	Friction kips	End Bearing kips	Blow Count blows/ft	Comp. Stress ksi	Tension Stress ksi	Stroke ft	ENTHRU kips-ft
4.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
10.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
15.6	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
20.1	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
26.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
32.1	20.6	4.7	15.9	-1.0	0.000	0.000	0.00	0.0
32.1	58.9	4.9	54.0	3.9	22.512	0.000	3.69	32.9
38.1	92.8	38.8	54.0	7.1	28.127	-0.383	4.41	29.9
44.1	125.1	71.1	54.0	10.4	33.290	0.000	5.03	28.8
44.1	110.9	71.3	39.6	9.2	32.160	0.000	4.80	28.9
47.8	127.5	88.0	39.6	11.0	33.918	0.000	5.11	28.4
51.6	142.9	103.3	39.6	12.7	34.877	0.000	5.32	28.0
51.6	138.9	103.4	35.5	12.3	34.723	0.000	5.28	28.0
56.3	157.5	122.0	35.5	14.4	36.323	0.000	5.55	27.8
61.1	175.2	139.7	35.5	16.6	39.623	0.000	5.80	27.6

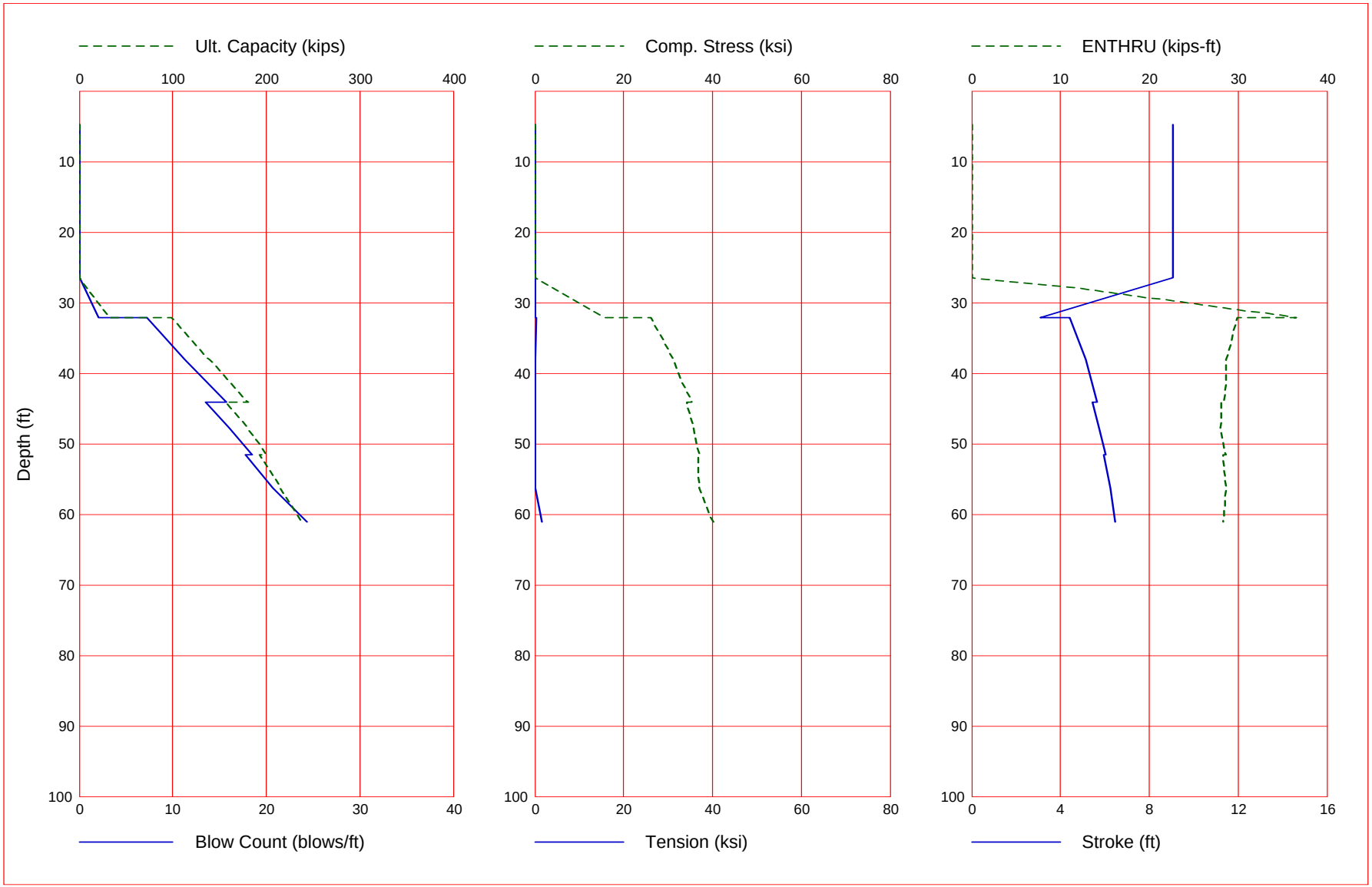
Total Continuous Driving Time 6.00 minutes; Total Number of Blows 304 (starting at penetration 4.8 ft)

16 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural
MED-18-13.54 Culvert #3 : 03/24/2018 : Z

Apr 08 2018
GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000



16 in CIP with 0.25 in Wall Thickness

National Engineering & Architectural — Apr 08 2018
MED-18-13.54 Culvert #3 : 03/24/2018 : Z — GRLWEAP Version 2010

Gain/Loss 1 at Shaft and Toe 1.000 / 1.000

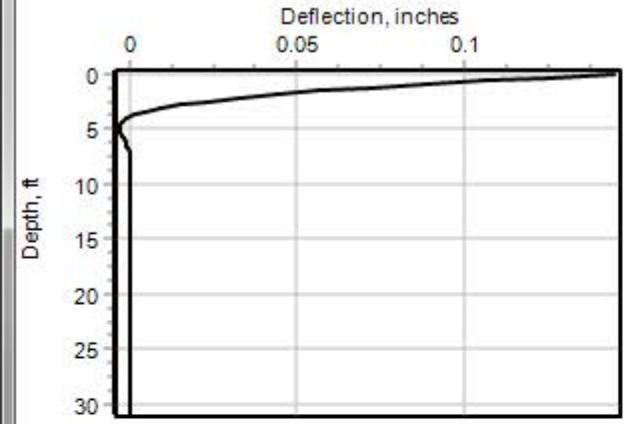
Depth ft	Ultimate Capacity kips	Friction kips	End Bearing kips	Blow Count blows/ft	Comp. Stress ksi	Tension Stress ksi	Stroke ft	ENTHRU kips-ft
4.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
9.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
10.8	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
12.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
15.6	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
19.3	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
20.1	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
21.0	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
26.5	0.0	0.0	0.0	0.0	0.000	0.000	9.05	0.0
32.1	33.3	6.1	27.2	2.1	15.648	0.000	3.08	36.5
32.1	98.5	6.4	92.1	7.2	26.134	-0.317	4.43	29.9
38.1	139.0	46.8	92.1	11.3	31.240	0.000	5.16	28.6
44.1	180.6	88.5	92.1	15.7	35.276	0.000	5.66	28.4
44.1	156.3	88.8	67.6	13.5	34.266	0.000	5.44	28.1
47.8	179.7	112.2	67.6	16.1	35.800	0.000	5.72	28.0
51.6	200.2	132.7	67.6	18.5	37.065	0.000	6.04	28.6
51.6	193.4	132.9	60.5	17.8	36.742	0.000	5.96	28.3
56.3	215.4	154.8	60.5	20.7	36.924	0.000	6.27	28.6
61.1	237.7	177.2	60.5	24.4	40.241	-1.630	6.45	28.3

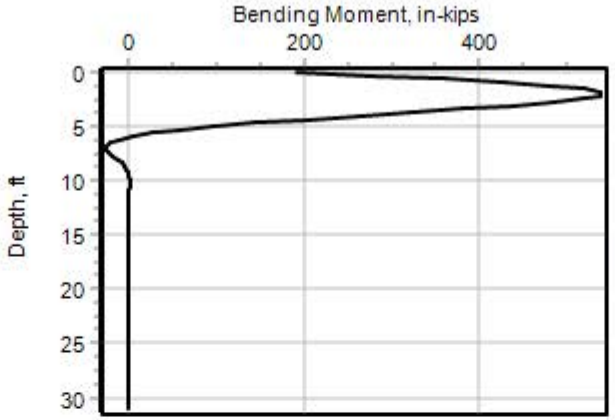
Total Continuous Driving Time 9.00 minutes; Total Number of Blows 460 (starting at penetration 4.8 ft)

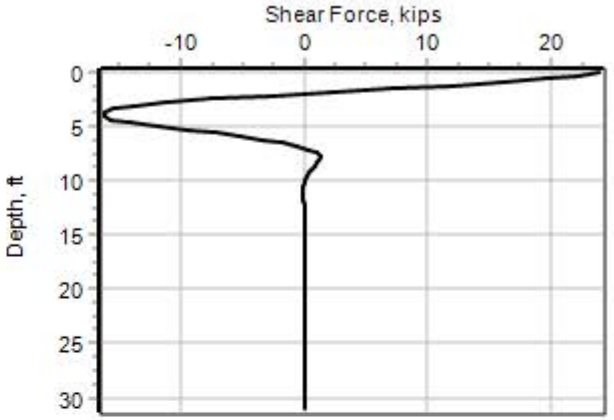
CULVERT #3

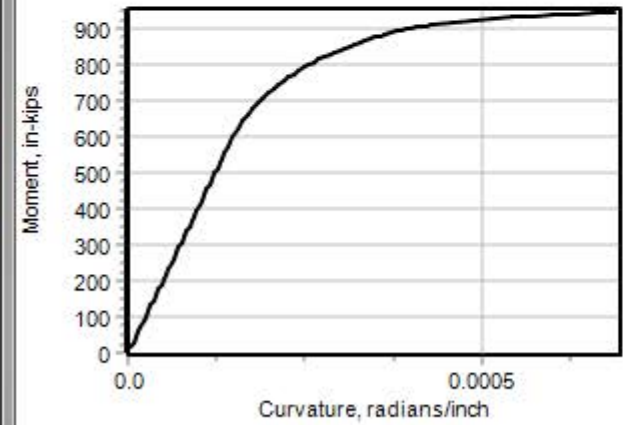
LPILE ANALYSIS

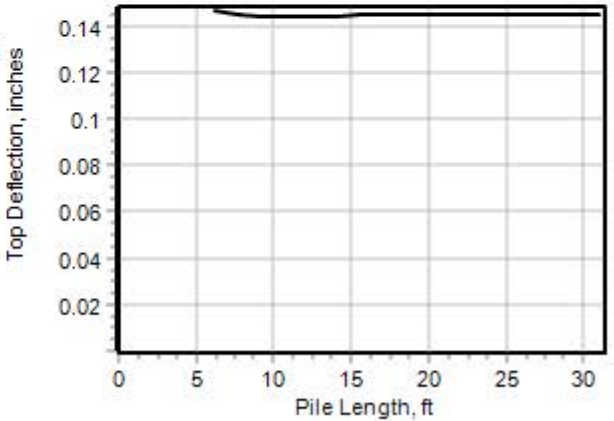
Results for Culvert#3_12inCIP_B-014-1-16.lp7d











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LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_12inCIP_B-014-1-16.lp7d
Name of output report file: Culvert#3_12inCIP_B-014-1-16.lp7o
Name of plot output file: Culvert#3_12inCIP_B-014-1-16.lp7p
Name of runtime messeage file: Culvert#3_12inCIP_B-014-1-16.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:21:59

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-014-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	31.00 ft
Depth of ground surface below top of pile	=	-0.45 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	12.0000000
2	31.000000	12.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	31.00000 ft
Pile Diameter	=	12.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 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 stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.45000 ft
Distance from top of pile to bottom of layer	=	4.55000 ft
Effective unit weight at top of layer	=	65.60000 pcf
Effective unit weight at bottom of layer	=	65.60000 pcf
Undrained cohesion at top of layer	=	4350.00000 psf
Undrained cohesion at bottom of layer	=	4350.00000 psf
Epsilon-50 at top of layer	=	0.00440
Epsilon-50 at bottom of layer	=	0.00440
Subgrade k at top of layer	=	1458.00000 pci
Subgrade k at bottom of layer	=	1458.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	4.55000 ft
Distance from top of pile to bottom of layer	=	9.55000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5550.00000 psf
Undrained cohesion at bottom of layer	=	5550.00000 psf
Epsilon-50 at top of layer	=	0.00400
Epsilon-50 at bottom of layer	=	0.00400
Subgrade k at top of layer	=	1854.00000 pci
Subgrade k at bottom of layer	=	1854.00000 pci

Layer 3 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	9.55000 ft
Distance from top of pile to bottom of layer	=	17.05000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5500.00000 psf

Undrained cohesion at bottom of layer	=	5500.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1847.00000	pci
Subgrade k at bottom of layer	=	1847.00000	pci

Layer 4 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	17.05000	ft
Distance from top of pile to bottom of layer	=	29.55000	ft
Effective unit weight at top of layer	=	62.60000	pcf
Effective unit weight at bottom of layer	=	62.60000	pcf
Undrained cohesion at top of layer	=	2800.00000	psf
Undrained cohesion at bottom of layer	=	2800.00000	psf
Epsilon-50 at top of layer	=	0.00530	
Epsilon-50 at bottom of layer	=	0.00530	
Subgrade k at top of layer	=	938.00000	pci
Subgrade k at bottom of layer	=	938.00000	pci

Layer 5 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	29.55000	ft
Distance from top of pile to bottom of layer	=	31.55000	ft
Effective unit weight at top of layer	=	72.60000	pcf
Effective unit weight at bottom of layer	=	72.60000	pcf
Undrained cohesion at top of layer	=	5600.00000	psf
Undrained cohesion at bottom of layer	=	5600.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1875.00000	pci
Subgrade k at bottom of layer	=	1875.00000	pci

(Depth of lowest soil layer extends 0.55 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-0.450	65.600	4350.000	0.00440	1458.000
		4.550	65.600	4350.000	0.00440	1458.000
2	Stiff Clay with Free Water	4.550	72.600	5550.000	0.00400	1854.000
		9.550	72.600	5550.000	0.00400	1854.000
3	Stiff Clay with Free Water	9.550	72.600	5500.000	0.00400	1847.000
		17.050	72.600	5500.000	0.00400	1847.000

4	Stiff Clay with Free Water	17.050	62.600	2800.000	0.00530	938.000
		29.550	62.600	2800.000	0.00530	938.000
5	Stiff Clay with Free Water	29.550	72.600	5600.000	0.00400	1875.000
		31.550	72.600	5600.000	0.00400	1875.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	31.00000 ft
Outer Diameter of Pipe	=	12.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	8.10543 sq. in.
Moment of Inertia	=	140.66969 in^4

Elastic Bending Stiffness = 4079421. kip-in^2
Plastic Modulus, Z = 30.39894 in^3
Plastic Moment Capacity = Fy Z = 1094.36186 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 291.796 kips
Nominal Axial Tensile Capacity = -291.796 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003590	14.6460293	4079661.	113.8378926	11.8454549	
0.000007180	29.2920585	4079661.	59.9189463	12.4638702	
0.0000108	43.9380878	4079661.	41.9459642	13.0822859	
0.0000144	58.5841170	4079661.	32.9594731	13.7007012	
0.0000180	73.2301463	4079661.	27.5675785	14.3191164	
0.0000215	87.8761755	4079661.	23.9729821	14.9375320	
0.0000251	102.5222048	4079661.	21.4054132	15.5559474	
0.0000287	117.1682340	4079661.	19.4797366	16.1743628	
0.0000323	131.8142633	4079661.	17.9819881	16.7927782	
0.0000359	146.4602925	4079661.	16.7837893	17.4111937	
0.0000395	161.1063218	4079661.	15.8034448	18.0296091	
0.0000431	175.7523510	4079661.	14.9864910	18.6480245	
0.0000467	190.3983803	4079661.	14.2952225	19.2664399	
0.0000503	205.0444095	4079661.	13.7027066	19.8848553	
0.0000539	219.6904388	4079661.	13.1891928	20.5032707	
0.0000574	234.3364680	4079661.	12.7398683	21.1216861	
0.0000610	248.9824973	4079661.	12.3434054	21.7401015	
0.0000646	263.6285265	4079661.	11.9909940	22.3585170	
0.0000682	278.2745558	4079661.	11.6756786	22.9769324	
0.0000718	292.9205850	4079661.	11.3918946	23.5953478	
0.0000754	307.5666143	4079661.	11.1351377	24.2137632	
0.0000790	322.2126435	4079661.	10.9017224	24.8321787	
0.0000826	336.8586728	4079661.	10.6886040	25.4505941	
0.0000862	351.5047020	4079661.	10.4932455	26.0690095	
0.0000898	366.1507313	4079661.	10.3135157	26.6874249	
0.0000933	380.7967605	4079661.	10.1476113	27.3058403	
0.0000969	395.4427898	4079661.	9.9939960	27.9242558	
0.0001005	410.0888190	4079661.	9.8513533	28.5426712	
0.0001041	424.7348483	4079661.	9.7185480	29.1610866	
0.0001077	439.3808775	4079661.	9.5945964	29.7795020	
0.0001113	454.0269068	4079661.	9.4786417	30.3979174	
0.0001149	468.6729360	4079661.	9.3699341	31.0163328	

0.0001185	483.3189653	4079661.	9.2678149	31.6347483	
0.0001221	497.9649945	4079661.	9.1717027	32.2531637	
0.0001257	512.6110238	4079661.	9.0810826	32.8715791	
0.0001292	527.2570530	4079661.	8.9954970	33.4899945	
0.0001328	541.9030823	4079661.	8.9145376	34.1084099	
0.0001364	556.5491115	4079661.	8.8378393	34.7268254	
0.0001400	571.1951408	4079661.	8.7650742	35.3452408	
0.0001472	599.6344915	4073867.	8.6343588	36.0000000	Y
0.0001544	623.3530116	4038032.	8.5382521	36.0000000	Y
0.0001616	644.0460965	3986654.	8.4650284	36.0000000	Y
0.0001687	662.4878832	3926307.	8.4087481	36.0000000	Y
0.0001759	679.2447437	3861307.	8.3651071	36.0000000	Y
0.0001831	694.5892106	3793691.	8.3316408	36.0000000	Y
0.0001903	708.7299375	3724852.	8.3064628	36.0000000	Y
0.0001975	721.8361938	3655780.	8.2880733	36.0000000	Y
0.0002046	734.0244235	3587070.	8.2753779	36.0000000	Y
0.0002118	745.3737266	3519056.	8.2675803	36.0000000	Y
0.0002190	756.0452315	3452408.	8.2635576	36.0000000	Y
0.0002262	766.0342523	3386973.	8.2630781	36.0000000	Y
0.0002334	775.4849822	3323259.	8.2652247	36.0000000	Y
0.0002405	784.3549062	3260934.	8.2700477	36.0000000	Y
0.0002477	792.7762630	3200411.	8.2767617	36.0000000	Y
0.0002549	800.7765111	3141645.	8.2851318	36.0000000	Y
0.0002621	808.3405346	3084435.	8.2951545	36.0000000	Y
0.0002693	815.5356212	3028906.	8.3064327	36.0000000	Y
0.0002764	822.3962712	2975052.	8.3187484	36.0000000	Y
0.0002836	828.9444308	2922823.	8.3319577	36.0000000	Y
0.0002908	835.2011007	2872170.	8.3459303	36.0000000	Y
0.0002980	841.1864013	2823048.	8.3605481	36.0000000	Y
0.0003052	846.9196303	2775412.	8.3757035	36.0000000	Y
0.0003123	852.4193143	2729218.	8.3912976	36.0000000	Y
0.0003195	857.7032544	2684424.	8.4072394	36.0000000	Y
0.0003267	862.7885675	2640992.	8.4234443	36.0000000	Y
0.0003339	867.6492325	2598755.	8.4400462	36.0000000	Y
0.0003411	872.3273732	2557761.	8.4568425	36.0000000	Y
0.0003482	876.8469211	2518003.	8.4737218	36.0000000	Y
0.0003554	881.2229244	2479446.	8.4906174	36.0000000	Y
0.0003626	885.3840426	2441825.	8.5072690	36.0000000	Y
0.0003698	889.1600436	2404622.	8.5222170	36.0000000	Y
0.0003770	892.8414077	2368586.	8.5370928	36.0000000	Y
0.0003841	896.0296021	2332613.	8.5489267	36.0000000	Y
0.0003913	899.0077186	2297424.	8.5601198	36.0000000	Y
0.0003985	901.8403521	2263137.	8.5703638	36.0000000	Y
0.0004057	904.3215113	2229198.	8.5791569	36.0000000	Y
0.0004129	906.7900746	2196408.	8.5877275	36.0000000	Y
0.0004200	908.9791698	2164075.	8.5954938	36.0000000	Y
0.0004272	911.0928382	2132651.	8.6022827	36.0000000	Y
0.0004559	918.3846071	2014304.	8.6271859	36.0000000	Y
0.0004847	924.2341408	1907007.	8.6461098	36.0000000	Y
0.0005134	929.0046884	1809614.	8.6613777	36.0000000	Y
0.0005421	933.0001087	1721111.	8.6739223	36.0000000	Y
0.0005708	936.3786810	1640433.	8.6845929	36.0000000	Y
0.0005995	939.2026031	1566560.	8.6930479	36.0000000	Y
0.0006283	941.6355550	1498818.	8.7003694	36.0000000	Y
0.0006570	943.7786942	1436558.	8.7070009	36.0000000	Y
0.0006857	945.6523584	1379121.	8.7122537	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load	Axial Thrust	Nominal Mom. Cap.

No.	kips	in-kip
1	91.000	945.7

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. Distrib. p
Es*h	Lat. Load						
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in
lb/inch	lb/inch						
0.00	0.1452	192000.	23950.	-0.005502	19416.	4.080E+09	
-328.4690	4206.2456	0.000					
0.310	0.1251	280654.	22242.	-0.005287	23198.	4.080E+09	
-589.7551	17536.	0.000					
0.620	0.1059	361061.	19560.	-0.004994	26627.	4.080E+09	
-852.3586	29937.	0.000					
0.930	0.0880	429560.	16004.	-0.004634	29549.	4.080E+09	
-1059.2871	44804.	0.000					
1.240	0.0714	483268.	11780.	-0.004217	31840.	4.080E+09	
-1211.9340	63106.	0.000					
1.550	0.0566	520056.	7088.1444	-0.003760	33409.	4.080E+09	
-1310.3752	86166.	0.000					
1.860	0.0435	538550.	2133.1791	-0.003277	34198.	4.080E+09	
-1353.5847	115844.	0.000					
2.170	0.0322	538146.	-2869.4875	-0.002787	34181.	4.080E+09	
-1336.0210	154406.	0.000					
2.480	0.0227	519087.	-7522.2331	-0.002305	33368.	4.080E+09	
-1165.4551	190699.	0.000					
2.790	0.0150	483741.	-11276.	-0.001847	31860.	4.080E+09	
-852.7024	210876.	0.000					
3.100	0.008991	436445.	-13901.	-0.001428	29843.	4.080E+09	
-558.4220	231052.	0.000					
3.410	0.004420	381286.	-15495.	-0.001055	27490.	4.080E+09	
-298.4782	251229.	0.000					
3.720	0.001142	321880.	-16205.	-0.000734	24956.	4.080E+09	

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-83.3092    271405.      0.000
     4.030  -0.001044    261221.    -16207.  -0.000469     22369.  4.080E+09
81.8354    291581.      0.000
     4.340  -0.002344    201614.    -15690.  -0.000258     19826.  4.080E+09
196.4338    311758.      0.000
     4.650  -0.002960    144663.    -14150. -9.963E-05     17397.  4.080E+09
631.6838    793902.      0.000
     4.960  -0.003085     96409.    -11775.  1.028E-05     15339.  4.080E+09
644.9243    777631.      0.000
     5.270  -0.002883     57050. -9415.7763  8.024E-05     13660.  4.080E+09
623.4898    804388.      0.000
     5.580  -0.002488     26301. -7178.7941   0.000118     12349.  4.080E+09
579.1888    865939.      0.000
     5.890  -0.002004  3559.4011 -5134.7522   0.000132     11379.  4.080E+09
519.7585    964983.      0.000
     6.200  -0.001507    -11991. -3329.5406   0.000128     11738.  4.080E+09
450.7854   1112673.      0.000
     6.510  -0.001051    -21299. -1790.8034   0.000113     12136.  4.080E+09
376.4927   1332300.      0.000
     6.820  -0.000668    -25391.  -532.4522  9.155E-05     12310.  4.080E+09
300.0402   1671896.      0.000
     7.130  -0.000370    -25322.   441.1627  6.843E-05     12307.  4.080E+09
223.4086   2245629.      0.000
     7.440  -0.000158    -22155.  1058.1727  4.678E-05     12172.  4.080E+09
108.3172   2542599.      0.000
     7.750 -2.201E-05    -17481.  1287.9107  2.871E-05     11973.  4.080E+09
15.1979   2568255.      0.000
     8.060  5.515E-05    -12592.  1244.6500  1.500E-05     11764.  4.080E+09
-38.4563   2593912.      0.000
     8.370  8.960E-05 -8231.3122  1055.7614  5.508E-06     11578.  4.080E+09
-63.0968   2619568.      0.000
     8.680  9.613E-05 -4741.0534   811.2548 -4.061E-07     11429.  4.080E+09
-68.3583   2645225.      0.000
     8.990  8.658E-05 -2195.3013   568.4841 -3.569E-06     11321.  4.080E+09
-62.1636   2670881.      0.000
     9.300  6.958E-05  -509.1157   359.0430 -4.801E-06     11249.  4.080E+09
-50.4392   2696537.      0.000
     9.610  5.086E-05   479.2293   195.8781 -4.815E-06     11247.  4.080E+09
-37.2839   2727114.      0.000
     9.920  3.376E-05   951.4770    80.0667 -4.163E-06     11268.  4.080E+09
-24.9803   2752674.      0.000
    10.230  1.989E-05  1077.7438     5.9784 -3.238E-06     11273.  4.080E+09
-14.8521   2778233.      0.000
    10.540  9.670E-06   998.1485   -35.2034 -2.291E-06     11270.  4.080E+09
-7.2887   2803793.      0.000
    10.850  2.840E-06   817.3816   -52.7779 -1.463E-06     11262.  4.080E+09
-2.1600   2829352.      0.000
    11.160 -1.218E-06   606.4719   -55.0568 -8.143E-07     11253.  4.080E+09
0.9348   2854912.      0.000
    11.470 -3.219E-06   408.3105   -48.6824 -3.517E-07     11244.  4.080E+09
2.4923   2880471.      0.000
    11.780 -3.834E-06   244.5127   -38.4752 -5.404E-08     11237.  4.080E+09
2.9954   2906031.      0.000
    12.090 -3.621E-06   122.0914   -27.5964  1.131E-07     11232.  4.080E+09
2.8534   2931590.      0.000
    12.400 -2.993E-06    39.1187   -17.8639  1.866E-07     11229.  4.080E+09
2.3792   2957150.      0.000
    12.710 -2.232E-06   -10.9422   -10.1093  1.995E-07     11228.  4.080E+09
1.7900   2982709.      0.000
    13.020 -1.509E-06   -36.2295    -4.5102  1.779E-07     11229.  4.080E+09
1.2203   3008269.      0.000
    13.330 -9.085E-07   -44.6185    -0.8623  1.411E-07     11229.  4.080E+09
0.7409   3033828.      0.000
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    13.640 -4.594E-07   -42.7405     1.2185  1.013E-07     11229.  4.080E+09
0.3778   3059388.      0.000
    13.950 -1.552E-07   -35.6214     2.1605  6.553E-08     11229.  4.080E+09
0.1287   3084947.      0.000
    14.260  2.818E-08   -26.7106     2.3560  3.711E-08     11228.  4.080E+09
-0.0236   3110507.      0.000
    14.570  1.209E-07   -18.1177     2.1226  1.667E-08     11228.  4.080E+09
-0.1019   3136067.      0.000
    14.880  1.522E-07   -10.9299     1.6923  3.429E-09     11228.  4.080E+09
-0.1294   3161626.      0.000
    15.190  1.464E-07    -5.5291     1.2183 -4.075E-09     11227.  4.080E+09
-0.1255   3187186.      0.000
    15.500  1.219E-07    -1.8628     0.7891 -7.446E-09     11227.  4.080E+09
-0.1053   3212745.      0.000
    15.810  9.104E-08     0.3472     0.4459 -8.137E-09     11227.  4.080E+09
-0.0793   3238305.      0.000
    16.120  6.136E-08     1.4603     0.1984 -7.313E-09     11227.  4.080E+09
-0.0538   3263864.      0.000
    16.430  3.664E-08     1.8280     0.0380 -5.813E-09     11227.  4.080E+09
-0.0324   3289424.      0.000
    16.740  1.811E-08     1.7467    -0.0523 -4.184E-09     11227.  4.080E+09
-0.0161   3314983.      0.000
    17.050  5.513E-09     1.4416    -0.0885 -2.730E-09     11227.  4.080E+09
-0.003298   2225603.      0.000
    17.360 -2.198E-09     1.0904    -0.0921 -1.576E-09     11227.  4.080E+09
0.001323   2238583.      0.000
    17.670 -6.209E-09     0.7571    -0.0827 -7.332E-10     11227.  4.080E+09
0.003758   2251563.      0.000
    17.980 -7.653E-09     0.4756    -0.0670 -1.712E-10     11227.  4.080E+09
0.004659   2264544.      0.000
    18.290 -7.483E-09     0.2584    -0.0499  1.634E-10     11227.  4.080E+09
0.004582   2277524.      0.000
    18.600 -6.437E-09     0.1046    -0.0340  3.290E-10     11227.  4.080E+09
0.003963   2290505.      0.000
    18.910 -5.036E-09   0.005574    -0.0208  3.792E-10     11227.  4.080E+09
0.003118   2303485.      0.000
    19.220 -3.616E-09    -0.0503    -0.0108  3.588E-10     11227.  4.080E+09
0.002252   2316466.      0.000
    19.530 -2.367E-09    -0.0750  -0.003853  3.017E-10     11227.  4.080E+09
0.001482   2329446.      0.000
    19.840 -1.372E-09    -0.0792   0.000510  2.314E-10     11227.  4.080E+09
0.000864   2342426.      0.000
    20.150 -6.451E-10    -0.0714   0.002876  1.627E-10     11227.  4.080E+09
0.000408   2355407.      0.000
    20.460 -1.607E-10    -0.0579   0.003826  1.038E-10     11227.  4.080E+09
0.000102   2368387.      0.000
    20.770  1.273E-10    -0.0430   0.003865  5.784E-11     11227.  4.080E+09
-8.151E-05   2381368.      0.000
    21.080  2.696E-10    -0.0292   0.003390  2.495E-11     11227.  4.080E+09
-0.000174   2394348.      0.000
    21.390  3.130E-10    -0.0178   0.002691  3.556E-12     11227.  4.080E+09
-0.000203   2407329.      0.000
    21.700  2.961E-10  -0.009151   0.001956 -8.713E-12     11227.  4.080E+09
-0.000193   2420309.      0.000
    22.010  2.482E-10  -0.003204   0.001296 -1.435E-11     11227.  4.080E+09
-0.000162   2433289.      0.000
    22.320  1.894E-10   0.000498   0.000762 -1.558E-11     11227.  4.080E+09
-0.000125   2446270.      0.000
    22.630  1.322E-10   0.002477   0.000368 -1.422E-11     11227.  4.080E+09
-8.742E-05   2459250.      0.000
    22.940  8.353E-11   0.003245   0.000102 -1.161E-11     11227.  4.080E+09
-5.551E-05   2472231.      0.000
    23.250  4.583E-11   0.003243 -5.822E-05 -8.657E-12     11227.  4.080E+09
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-3.062E-05	2485211.	0.000				
23.560	1.913E-11	0.002817	-0.000139	-5.894E-12	11227.	4.080E+09
-1.285E-05	2498191.	0.000				
23.870	1.982E-12	0.002213	-0.000165	-3.600E-12	11227.	4.080E+09
-1.338E-06	2511172.	0.000				
24.180	-7.659E-12	0.001589	-0.000158	-1.867E-12	11227.	4.080E+09
5.197E-06	2524152.	0.000				
24.490	-1.191E-11	0.001036	-0.000133	0.000	11227.	4.080E+09
8.124E-06	2537133.	0.000				
24.800	-1.265E-11	0.000596	-0.000102	0.000	11227.	4.080E+09
8.670E-06	2550113.	0.000				
25.110	-1.136E-11	0.000276	-7.156E-05	0.000	11227.	4.080E+09
7.829E-06	2563094.	0.000				
25.420	-9.144E-12	6.326E-05	-4.522E-05	0.000	11227.	4.080E+09
6.332E-06	2576074.	0.000				
25.730	-6.709E-12	-6.138E-05	-2.476E-05	0.000	11227.	4.080E+09
4.670E-06	2589054.	0.000				
26.040	-4.484E-12	-0.000121	-1.024E-05	0.000	11227.	4.080E+09
3.136E-06	2602035.	0.000				
26.350	-2.669E-12	-0.000138	-9.191E-07	0.000	11227.	4.080E+09
1.877E-06	2615015.	0.000				
26.660	-1.323E-12	-0.000129	4.310E-06	0.000	11227.	4.080E+09
9.348E-07	2627996.	0.000				
26.970	0.000	-0.000106	6.594E-06	0.000	11227.	4.080E+09
2.932E-07	2640976.	0.000				
27.280	0.000	-7.959E-05	6.957E-06	0.000	11227.	4.080E+09
-9.799E-08	2653956.	0.000				
27.590	0.000	-5.441E-05	6.218E-06	0.000	11227.	4.080E+09
-2.995E-07	2666937.	0.000				
27.900	0.000	-3.336E-05	4.973E-06	0.000	11227.	4.080E+09
-3.700E-07	2679917.	0.000				
28.210	0.000	-1.742E-05	3.616E-06	0.000	11227.	4.080E+09
-3.593E-07	2692898.	0.000				
28.520	0.000	-6.446E-06	2.380E-06	0.000	11227.	4.080E+09
-3.055E-07	2705878.	0.000				
28.830	0.000	3.022E-07	1.374E-06	0.000	11227.	4.080E+09
-2.351E-07	2718859.	0.000				
29.140	0.000	3.796E-06	6.302E-07	0.000	11227.	4.080E+09
-1.649E-07	2731839.	0.000				
29.450	0.000	5.007E-06	1.312E-07	0.000	11227.	4.080E+09
-1.034E-07	2744819.	0.000				
29.760	0.000	4.786E-06	-2.021E-07	0.000	11227.	4.080E+09
-7.577E-08	3871668.	0.000				
30.070	0.000	3.514E-06	-3.853E-07	0.000	11227.	4.080E+09
-2.272E-08	3897615.	0.000				
30.380	0.000	1.927E-06	-3.932E-07	0.000	11227.	4.080E+09
1.848E-08	3923562.	0.000				
30.690	0.000	5.949E-07	-2.598E-07	0.000	11227.	4.080E+09
5.328E-08	3949509.	0.000				
31.000	0.000	0.000	0.000	0.000	11227.	4.080E+09
8.638E-08	1987728.	0.000				

* This analysis computed pile response using nonlinear moment-curvature relationships.
  Values of total stress due to combined axial and bending stresses are computed only
  for elastic sections only and do not equal the actual stresses in concrete and steel.
  Stresses in concrete and steel may be interpolated from the output for nonlinear
  bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection = 0.1452489 inches
Computed slope at pile head = -0.0055022 radians
Maximum bending moment = 538550. inch-lbs
Maximum shear force = 23950. lbs
Depth of maximum bending moment = 1.8600000 feet below pile head
Depth of maximum shear force = 0.000000 feet below pile head
Number of iterations = 15
Number of zero deflection points = 9

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

Boundary Condition Type 1, Shear and Moment

Shear = 23950. lb
Moment = 192000. in- lb
Axial Load = 91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
31.0000	0.1452494	538551.	23950.
29.4500	0.1450713	540201.	23950.
27.9000	0.1451632	539955.	23950.
26.3500	0.1449247	539051.	23950.
24.8000	0.1449988	539733.	23950.
23.2500	0.1448319	538774.	23950.
21.7000	0.1446643	538925.	23950.
20.1500	0.1446679	538981.	23950.
18.6000	0.1446099	538621.	23950.
17.0500	0.1445010	538421.	23950.
15.5000	0.1444941	538420.	23950.
13.9500	0.1444102	538022.	23950.
12.4000	0.1444038	538160.	23950.
10.8500	0.1443437	537773.	23950.
9.3000	0.1443359	537781.	23950.
7.7500	0.1445730	537897.	23950.
6.2000	0.1465724	537917.	23950.

Summary of Pile Response(s)

Definitions of Pile-head Loading Conditions:

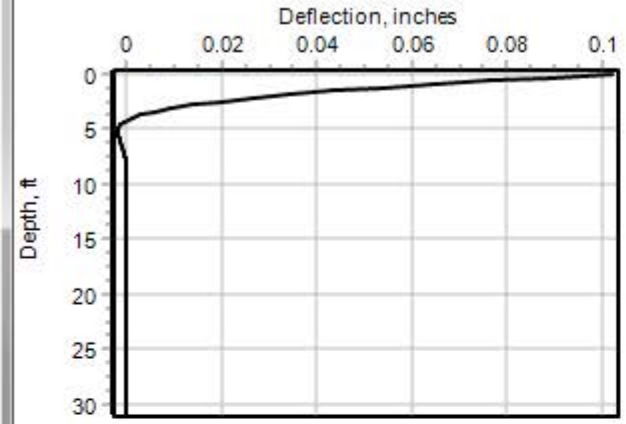
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

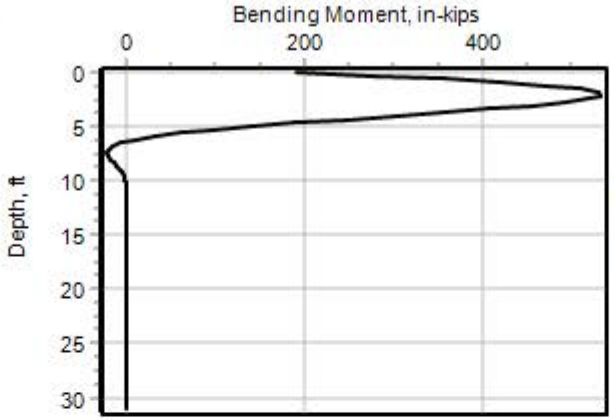
Pile-head Pile-head Maximum

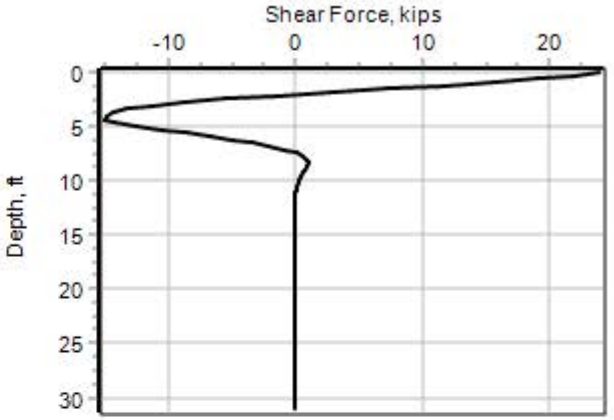
Load Case	Maximum Load Type in Pile No.	Condition 1 Shear V(lbs) or y(inches)	Condition 2 in-lb, rad., or in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Moment in Pile in-lbs
1	1	V = 23950.	M = 192000.	91000.	0.14524887	538550.
		23950.	-0.00550219			

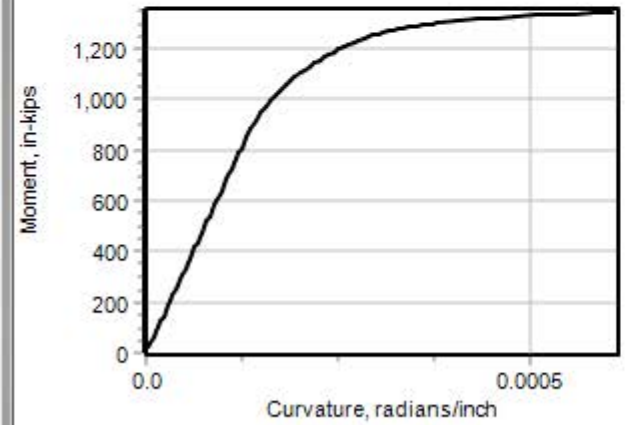
The analysis ended normally.

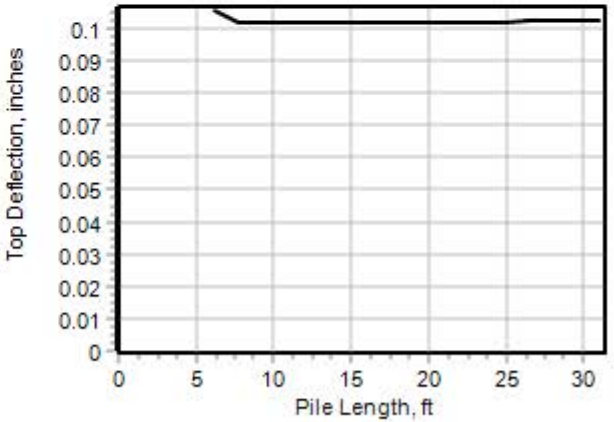
Results for Culvert#3_14inCIP_B-014-1-16.lp7d











Show All Legends

Close

LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_14inCIP_B-014-1-16.lp7d
Name of output report file: Culvert#3_14inCIP_B-014-1-16.lp7o
Name of plot output file: Culvert#3_14inCIP_B-014-1-16.lp7p
Name of runtime messeage file: Culvert#3_14inCIP_B-014-1-16.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:24:35

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-014-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	31.00 ft
Depth of ground surface below top of pile	=	-0.45 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	14.0000000
2	31.000000	14.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	31.00000 ft
Pile Diameter	=	14.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 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 stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.45000 ft
Distance from top of pile to bottom of layer	=	4.55000 ft
Effective unit weight at top of layer	=	65.60000 pcf
Effective unit weight at bottom of layer	=	65.60000 pcf
Undrained cohesion at top of layer	=	4350.00000 psf
Undrained cohesion at bottom of layer	=	4350.00000 psf
Epsilon-50 at top of layer	=	0.00440
Epsilon-50 at bottom of layer	=	0.00440
Subgrade k at top of layer	=	1458.00000 pci
Subgrade k at bottom of layer	=	1458.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	4.55000 ft
Distance from top of pile to bottom of layer	=	9.55000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5550.00000 psf
Undrained cohesion at bottom of layer	=	5550.00000 psf
Epsilon-50 at top of layer	=	0.00400
Epsilon-50 at bottom of layer	=	0.00400
Subgrade k at top of layer	=	1854.00000 pci
Subgrade k at bottom of layer	=	1854.00000 pci

Layer 3 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	9.55000 ft
Distance from top of pile to bottom of layer	=	17.05000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5500.00000 psf

Undrained cohesion at bottom of layer	=	5500.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1847.00000	pci
Subgrade k at bottom of layer	=	1847.00000	pci

Layer 4 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	17.05000	ft
Distance from top of pile to bottom of layer	=	29.55000	ft
Effective unit weight at top of layer	=	62.60000	pcf
Effective unit weight at bottom of layer	=	62.60000	pcf
Undrained cohesion at top of layer	=	2800.00000	psf
Undrained cohesion at bottom of layer	=	2800.00000	psf
Epsilon-50 at top of layer	=	0.00530	
Epsilon-50 at bottom of layer	=	0.00530	
Subgrade k at top of layer	=	938.00000	pci
Subgrade k at bottom of layer	=	938.00000	pci

Layer 5 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	29.55000	ft
Distance from top of pile to bottom of layer	=	31.55000	ft
Effective unit weight at top of layer	=	72.60000	pcf
Effective unit weight at bottom of layer	=	72.60000	pcf
Undrained cohesion at top of layer	=	5600.00000	psf
Undrained cohesion at bottom of layer	=	5600.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1875.00000	pci
Subgrade k at bottom of layer	=	1875.00000	pci

(Depth of lowest soil layer extends 0.55 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-0.450	65.600	4350.000	0.00440	1458.000
		4.550	65.600	4350.000	0.00440	1458.000
2	Stiff Clay with Free Water	4.550	72.600	5550.000	0.00400	1854.000
		9.550	72.600	5550.000	0.00400	1854.000
3	Stiff Clay with Free Water	9.550	72.600	5500.000	0.00400	1847.000
		17.050	72.600	5500.000	0.00400	1847.000

4	Stiff Clay with Free Water	17.050	62.600	2800.000	0.00530	938.000
		29.550	62.600	2800.000	0.00530	938.000
5	Stiff Clay with Free Water	29.550	72.600	5600.000	0.00400	1875.000
		31.550	72.600	5600.000	0.00400	1875.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust is assumed to be acting axially for all pile batter angles.

Computations of Nominal Moment Capacity and Nonlinear Bending Stiffness

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

Number of Pile Sections Analyzed = 1

Pile Section No. 1:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	31.00000 ft
Outer Diameter of Pipe	=	14.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	9.48145 sq. in.
Moment of Inertia	=	225.14166 in^4

Elastic Bending Stiffness = 6529108. kip-in^2
Plastic Modulus, Z = 41.59510 in^3
Plastic Moment Capacity = Fy Z = 1497.42348 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 341.332 kips
Nominal Axial Tensile Capacity = -341.332 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003177	20.7442314	6528512.	111.1562973	10.2362676	
0.000006355	41.4884628	6528512.	59.0781487	10.8748464	
0.000009532	62.2326942	6528512.	41.7187658	11.5134250	
0.0000127	82.9769257	6528512.	33.0390743	12.1520036	
0.0000159	103.7211571	6528512.	27.8312595	12.7905822	
0.0000191	124.4653885	6528512.	24.3593829	13.4291607	
0.0000222	145.2096199	6528512.	21.8794710	14.0677394	
0.0000254	165.9538513	6528512.	20.0195372	14.7063179	
0.0000286	186.6980827	6528512.	18.5729219	15.3448967	
0.0000318	207.4423142	6528512.	17.4156297	15.9834752	
0.0000350	228.1865456	6528512.	16.4687543	16.6220539	
0.0000381	248.9307770	6528512.	15.6796914	17.2606325	
0.0000413	269.6750084	6528512.	15.0120229	17.8992112	
0.0000445	290.4192398	6528512.	14.4397355	18.5377898	
0.0000477	311.1634712	6528512.	13.9437532	19.1763684	
0.0000508	331.9077026	6528512.	13.5097686	19.8149470	
0.0000540	352.6519341	6528512.	13.1268410	20.4535257	
0.0000572	373.3961655	6528512.	12.7864610	21.0921043	
0.0000604	394.1403969	6528512.	12.4819104	21.7306829	
0.0000635	414.8846283	6528512.	12.2078149	22.3692616	
0.0000667	435.6288597	6528512.	11.9598237	23.0078402	
0.0000699	456.3730911	6528512.	11.7343772	23.6464188	
0.0000731	477.1173226	6528512.	11.5285347	24.2849975	
0.0000763	497.8615540	6528512.	11.3398457	24.9235761	
0.0000794	518.6057854	6528512.	11.1662519	25.5621547	
0.0000826	539.3500168	6528512.	11.0060114	26.2007333	
0.0000858	560.0942482	6528512.	10.8576406	26.8393120	
0.0000890	580.8384796	6528512.	10.7198678	27.4778906	
0.0000921	601.5827111	6528512.	10.5915965	28.1164692	
0.0000953	622.3269425	6528512.	10.4718766	28.7550479	
0.0000985	643.0711739	6528512.	10.3598806	29.3936265	
0.0001017	663.8154053	6528512.	10.2548843	30.0322051	

0.0001049	684.5596367	6528512.	10.1562514	30.6707837	
0.0001080	705.3038681	6528512.	10.0634205	31.3093624	
0.0001112	726.0480995	6528512.	9.9758942	31.9479410	
0.0001144	746.7923310	6528512.	9.8932305	32.5865196	
0.0001176	767.5365624	6528512.	9.8150351	33.2250983	
0.0001207	788.2807938	6528512.	9.7409552	33.8636769	
0.0001239	809.0250252	6528512.	9.6706743	34.5022555	
0.0001303	850.5134880	6528512.	9.5403975	35.7794128	Y
0.0001366	888.4840391	6502765.	9.4358717	36.0000000	Y
0.0001430	920.1116790	6434946.	9.3647454	36.0000000	Y
0.0001493	948.2061189	6349240.	9.3131648	36.0000000	Y
0.0001557	973.5796758	6253055.	9.2761998	36.0000000	Y
0.0001621	996.7217948	6150645.	9.2506833	36.0000000	Y
0.0001684	1017.9829880	6044794.	9.2343152	36.0000000	Y
0.0001748	1037.6368196	5937444.	9.2253228	36.0000000	Y
0.0001811	1055.9080589	5829994.	9.2222894	36.0000000	Y
0.0001875	1072.9877235	5723472.	9.2240523	36.0000000	Y
0.0001938	1088.9145376	5617988.	9.2301495	36.0000000	Y
0.0002002	1103.9047270	5514522.	9.2394839	36.0000000	Y
0.0002065	1117.9907765	5413046.	9.2517411	36.0000000	Y
0.0002129	1131.3329838	5314134.	9.2661462	36.0000000	Y
0.0002192	1143.8756909	5217309.	9.2828157	36.0000000	Y
0.0002256	1155.7964593	5123183.	9.3009630	36.0000000	Y
0.0002320	1167.1335274	5031698.	9.3203812	36.0000000	Y
0.0002383	1177.9180972	4942773.	9.3409073	36.0000000	Y
0.0002447	1188.1476750	4856200.	9.3625254	36.0000000	Y
0.0002510	1197.9142415	4772165.	9.3848537	36.0000000	Y
0.0002574	1207.2484173	4690601.	9.4077648	36.0000000	Y
0.0002637	1216.1795120	4611439.	9.4311429	36.0000000	Y
0.0002701	1224.7356134	4534614.	9.4548828	36.0000000	Y
0.0002764	1232.9436671	4460061.	9.4788879	36.0000000	Y
0.0002828	1240.5526340	4386742.	9.5012324	36.0000000	Y
0.0002892	1247.5425917	4314504.	9.5221386	36.0000000	Y
0.0002955	1253.7132389	4242600.	9.5394456	36.0000000	Y
0.0003019	1259.3857384	4172074.	9.5549624	36.0000000	Y
0.0003082	1264.4962325	4102633.	9.5678278	36.0000000	Y
0.0003146	1269.2541211	4034876.	9.5804411	36.0000000	Y
0.0003209	1273.5749871	3968442.	9.5911348	36.0000000	Y
0.0003273	1277.7067624	3904009.	9.6011995	36.0000000	Y
0.0003336	1281.4341893	3840819.	9.6105721	36.0000000	Y
0.0003400	1284.9888204	3779483.	9.6189486	36.0000000	Y
0.0003463	1288.3094478	3719723.	9.6272544	36.0000000	Y
0.0003527	1291.3844866	3661419.	9.6341828	36.0000000	Y
0.0003591	1294.3438283	3604857.	9.6416218	36.0000000	Y
0.0003654	1297.0610132	3549600.	9.6475361	36.0000000	Y
0.0003718	1299.6293589	3495832.	9.6536994	36.0000000	Y
0.0003781	1302.1524425	3443751.	9.6595104	36.0000000	Y
0.0004035	1310.6043232	3247766.	9.6787469	36.0000000	Y
0.0004290	1317.5678936	3071539.	9.6940785	36.0000000	Y
0.0004544	1323.2738340	2912263.	9.7070292	36.0000000	Y
0.0004798	1328.0556807	2767937.	9.7175539	36.0000000	Y
0.0005052	1332.1017391	2636678.	9.7263358	36.0000000	Y
0.0005306	1335.5733438	2516913.	9.7339093	36.0000000	Y
0.0005561	1338.5986350	2407294.	9.7405798	36.0000000	Y
0.0005815	1341.1306317	2306412.	9.7455102	36.0000000	Y
0.0006069	1343.3708889	2213499.	9.7507176	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load	Axial Thrust	Nominal Mom. Cap.

No.	kips	in-kip
1	91.000	1343.4

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Es*h	Soil Spr. Distrib. p Lat. Load
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in	lb/inch
0.00	0.1023	192000.	23950.	-0.003633	15567.	6.529E+09	-446.4990	8121.0426
0.310	0.0890	279216.	21861.	-0.003499	18279.	6.529E+09	-676.6565	28298.
0.620	0.0762	357014.	18995.	-0.003318	20698.	6.529E+09	-864.2316	42173.
0.930	0.0643	422784.	15506.	-0.003096	22743.	6.529E+09	-1011.3019	58537.
1.240	0.0532	474478.	11545.	-0.002840	24350.	6.529E+09	-1118.3447	78199.
1.550	0.0431	510603.	7261.6988	-0.002559	25473.	6.529E+09	-1184.6367	102154.
1.860	0.0342	530237.	2821.0103	-0.002263	26084.	6.529E+09	-1202.8303	130986.
2.170	0.0263	533124.	-1573.9925	-0.001960	26173.	6.529E+09	-1160.0745	164055.
2.480	0.0196	519854.	-5598.6613	-0.001660	25761.	6.529E+09	-1003.7260	190699.
2.790	0.0140	492593.	-8937.1428	-0.001371	24913.	6.529E+09	-791.1565	210876.
3.100	0.009377	454290.	-11492.	-0.001102	23722.	6.529E+09	-582.4413	231052.
3.410	0.005761	407838.	-13299.	-0.000856	22278.	6.529E+09	-389.0866	251229.
3.720	0.003010	355924.	-14431.	-0.000638	20664.	6.529E+09		

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-219.5772    271405.      0.000
     4.030   0.001012    300902.    -14987.  -0.000451     18953.  6.529E+09
-79.3542    291581.      0.000
     4.340  -0.000347    244725.    -15081.  -0.000296     17207.  6.529E+09
29.0808    311758.      0.000
     4.650  -0.001188    188902.    -14223.  -0.000172     15471.  6.529E+09
432.1923   1353709.      0.000
     4.960  -0.001628    139024.    -12478. -7.874E-05     13920.  6.529E+09
506.0087   1156294.      0.000
     5.270  -0.001773     96121.    -10554. -1.174E-05     12586.  6.529E+09
528.1557   1107843.      0.000
     5.580  -0.001715     60509. -8605.6415  3.288E-05     11479.  6.529E+09
519.4265   1126490.      0.000
     5.890  -0.001529     32073. -6727.3801  5.926E-05     10595.  6.529E+09
490.3915   1193218.      0.000
     6.200  -0.001274     10417. -4982.4607  7.136E-05  9921.5797  6.529E+09
447.7372   1306928.      0.000
     6.510  -0.000998 -5044.6039 -3412.7286  7.289E-05  9754.5335  6.529E+09
396.2048   1476961.      0.000
     6.820  -0.000732    -15023. -2044.5709  6.718E-05     10065.  6.529E+09
339.3639   1724407.      0.000
     7.130  -0.000498    -20302.  -892.6716  5.711E-05     10229.  6.529E+09
279.9368   2090577.      0.000
     7.440  -0.000307    -21703.    21.5308  4.514E-05     10272.  6.529E+09
211.5698   2562127.      0.000
     7.750  -0.000162    -20172.   624.9776  3.321E-05     10225.  6.529E+09
112.8639   2587783.      0.000
     8.060 -6.007E-05    -17076.   913.3932  2.260E-05     10129.  6.529E+09
42.1982   2613439.      0.000
     8.370  5.919E-06    -13392.   984.0714  1.392E-05     10014.  6.529E+09
-4.1992   2639096.      0.000
     8.680  4.352E-05 -9763.4562   918.2797  7.325E-06  9901.2498  6.529E+09
-31.1727   2664752.      0.000
     8.990  6.042E-05 -6564.6842   779.0213  2.673E-06  9801.7951  6.529E+09
-43.6974   2690409.      0.000
     9.300  6.341E-05 -3969.3477   611.6347 -3.278E-07  9721.1021  6.529E+09
-46.2954   2716065.      0.000
     9.610  5.798E-05 -2013.9002   445.9006 -2.032E-06  9660.3042  6.529E+09
-42.8090   2746559.      0.000
     9.920  4.829E-05  -650.4715   299.3481 -2.791E-06  9617.9131  6.529E+09
-35.9827   2772118.      0.000
    10.230  3.721E-05   215.1396   180.3658 -2.916E-06  9604.3780  6.529E+09
-27.9863   2797678.      0.000
    10.540  2.659E-05   693.4239    90.7695 -2.657E-06  9619.2486  6.529E+09
-20.1838   2823238.      0.000
    10.850  1.745E-05   892.2632    28.3762 -2.205E-06  9625.4308  6.529E+09
-13.3610   2848797.      0.000
    11.160  1.019E-05   906.0357   -11.1206 -1.693E-06  9625.8590  6.529E+09
-7.8739   2874357.      0.000
    11.470  4.854E-06   810.6717   -32.8046 -1.203E-06  9622.8940  6.529E+09
-3.7842   2899916.      0.000
    11.780  1.237E-06   662.7846   -41.6519 -7.837E-07  9618.2960  6.529E+09
-0.9725   2925476.      0.000
    12.090 -9.762E-07   501.3120   -42.0203 -4.520E-07  9613.2755  6.529E+09
0.7744   2951035.      0.000
    12.400 -2.126E-06   350.4594   -37.4152 -2.093E-07  9608.5853  6.529E+09
1.7015   2976595.      0.000
    12.710 -2.534E-06   223.0848   -30.4472 -4.594E-08  9604.6250  6.529E+09
2.0448   3002154.      0.000
    13.020 -2.468E-06   123.9637   -22.9074  5.294E-08  9601.5432  6.529E+09
2.0089   3027714.      0.000
    13.330 -2.140E-06    52.6181   -15.9041  1.032E-07  9599.3250  6.529E+09
1.7563   3053273.      0.000
```

```
    13.640 -1.700E-06     5.5673   -10.0203  1.198E-07  9597.8621  6.529E+09
1.4070   3078833.      0.000
    13.950 -1.248E-06   -22.0138    -5.4655  1.151E-07  9598.3734  6.529E+09
1.0418   3104392.      0.000
    14.260 -8.434E-07   -35.1740    -2.2079  9.885E-08  9598.7826  6.529E+09
0.7096   3129952.      0.000
    14.570 -5.130E-07   -38.5074    -0.0787  7.785E-08  9598.8862  6.529E+09
0.4351   3155511.      0.000
    14.880 -2.642E-07   -35.8119     1.1508  5.668E-08  9598.8024  6.529E+09
0.2259   3181071.      0.000
    15.190 -9.127E-08   -29.9835     1.7174  3.793E-08  9598.6212  6.529E+09
0.0787   3206630.      0.000
    15.500  1.806E-08   -23.0605     1.8345  2.282E-08  9598.4060  6.529E+09
-0.0157   3232190.      0.000
    15.810  7.852E-08   -16.3503     1.6774  1.159E-08  9598.1973  6.529E+09
-0.0688   3257749.      0.000
    16.120  1.043E-07   -10.5884     1.3783  3.918E-09  9598.0182  6.529E+09
-0.0921   3283309.      0.000
    16.430  1.077E-07    -6.0985     1.0289 -8.361E-10  9597.8786  6.529E+09
-0.0958   3308869.      0.000
    16.740  9.809E-08    -2.9327     0.6872 -3.409E-09  9597.7802  6.529E+09
-0.0879   3334428.      0.000
    17.050  8.230E-08    -0.9831     0.4317 -4.525E-09  9597.7195  6.529E+09
-0.0495   2235450.      0.000
    17.360  6.443E-08     0.2823     0.2673 -4.724E-09  9597.6978  6.529E+09
-0.0389   2248430.      0.000
    17.670  4.715E-08     1.0087     0.1415 -4.357E-09  9597.7203  6.529E+09
-0.0287   2261410.      0.000
    17.980  3.202E-08     1.3383     0.0518 -3.688E-09  9597.7306  6.529E+09
-0.0196   2274391.      0.000
    18.290  1.971E-08     1.3967  -0.007137 -2.909E-09  9597.7324  6.529E+09
-0.0121   2287371.      0.000
    18.600  1.037E-08     1.2872    -0.0416 -2.144E-09  9597.7290  6.529E+09
-0.006415   2300352.      0.000
    18.910  3.763E-09     1.0886    -0.0579 -1.467E-09  9597.7228  6.529E+09
-0.002340   2313332.      0.000
    19.220 -5.416E-10     0.8574    -0.0616 -9.128E-10  9597.7156  6.529E+09
0.000339   2326313.      0.000
    19.530 -3.029E-09     0.6307    -0.0575 -4.888E-10  9597.7086  6.529E+09
0.001904   2339293.      0.000
    19.840 -4.179E-09     0.4303    -0.0490 -1.866E-10  9597.7024  6.529E+09
0.002642   2352273.      0.000
    20.150 -4.416E-09     0.2663    -0.0389  1.191E-11  9597.6973  6.529E+09
0.002808   2365254.      0.000
    20.460 -4.090E-09     0.1412    -0.0288  1.280E-10  9597.6934  6.529E+09
0.002615   2378234.      0.000
    20.770 -3.464E-09     0.0522    -0.0198  1.831E-10  9597.6906  6.529E+09
0.002227   2391215.      0.000
    21.080 -2.728E-09  -0.005998    -0.0123  1.963E-10  9597.6892  6.529E+09
0.001763   2404195.      0.000
    21.390 -2.004E-09    -0.0398  -0.006643  1.832E-10  9597.6902  6.529E+09
0.001302   2417176.      0.000
    21.700 -1.365E-09    -0.0555  -0.002563  1.561E-10  9597.6907  6.529E+09
0.000891   2430156.      0.000
    22.010 -8.429E-10    -0.0590   0.000124  1.234E-10  9597.6908  6.529E+09
0.000554   2443136.      0.000
    22.320 -4.462E-10    -0.0547   0.001702  9.104E-11  9597.6907  6.529E+09
0.000295   2456117.      0.000
    22.630 -1.655E-10    -0.0464   0.002454  6.225E-11  9597.6904  6.529E+09
0.000110   2469097.      0.000
    22.940  1.690E-11    -0.0365   0.002638  3.864E-11  9597.6901  6.529E+09
-1.128E-05   2482078.      0.000
    23.250  1.220E-10    -0.0268   0.002464  2.062E-11  9597.6898  6.529E+09
```

-8.181E-05	2495058.	0.000				
23.560	1.703E-10	-0.0182	0.002099	7.819E-12	9597.6895	6.529E+09
-0.000115	2508038.	0.000				
23.870	1.801E-10	-0.0112	0.001658	0.000	9597.6893	6.529E+09
-0.000122	2521019.	0.000				
24.180	1.663E-10	-0.005832	0.001220	-5.376E-12	9597.6892	6.529E+09
-0.000113	2533999.	0.000				
24.490	1.401E-10	-0.002075	0.000831	-7.629E-12	9597.6890	6.529E+09
-9.596E-05	2546980.	0.000				
24.800	1.096E-10	0.000356	0.000512	-8.119E-12	9597.6890	6.529E+09
-7.540E-05	2559960.	0.000				
25.110	7.975E-11	0.001742	0.000269	-7.521E-12	9597.6890	6.529E+09
-5.516E-05	2572941.	0.000				
25.420	5.361E-11	0.002366	9.755E-05	-6.351E-12	9597.6891	6.529E+09
-3.727E-05	2585921.	0.000				
25.730	3.250E-11	0.002472	-1.400E-05	-4.972E-12	9597.6891	6.529E+09
-2.270E-05	2598901.	0.000				
26.040	1.662E-11	0.002265	-7.794E-05	-3.622E-12	9597.6890	6.529E+09
-1.167E-05	2611882.	0.000				
26.350	5.546E-12	0.001895	-0.000107	-2.437E-12	9597.6890	6.529E+09
-3.913E-06	2624862.	0.000				
26.660	-1.512E-12	0.001471	-0.000112	-1.478E-12	9597.6890	6.529E+09
1.073E-06	2637843.	0.000				
26.970	-5.453E-12	0.001061	-0.000103	0.000	9597.6890	6.529E+09
3.886E-06	2650823.	0.000				
27.280	-7.144E-12	0.000705	-8.624E-05	0.000	9597.6890	6.529E+09
5.116E-06	2663803.	0.000				
27.590	-7.341E-12	0.000420	-6.690E-05	0.000	9597.6890	6.529E+09
5.282E-06	2676784.	0.000				
27.900	-6.648E-12	0.000207	-4.814E-05	0.000	9597.6890	6.529E+09
4.807E-06	2689764.	0.000				
28.210	-5.515E-12	6.146E-05	-3.174E-05	0.000	9597.6890	6.529E+09
4.007E-06	2702745.	0.000				
28.520	-4.252E-12	-2.901E-05	-1.852E-05	0.000	9597.6890	6.529E+09
3.104E-06	2715725.	0.000				
28.830	-3.050E-12	-7.653E-05	-8.581E-06	0.000	9597.6890	6.529E+09
2.237E-06	2728706.	0.000				
29.140	-2.011E-12	-9.306E-05	-1.663E-06	0.000	9597.6890	6.529E+09
1.482E-06	2741686.	0.000				
29.450	-1.169E-12	-8.907E-05	2.704E-06	0.000	9597.6890	6.529E+09
8.656E-07	2754666.	0.000				
29.760	0.000	-7.308E-05	5.317E-06	0.000	9597.6890	6.529E+09
5.394E-07	3891415.	0.000				
30.070	0.000	-4.962E-05	6.354E-06	0.000	9597.6890	6.529E+09
1.816E-08	3917362.	0.000				
30.380	0.000	-2.589E-05	5.647E-06	0.000	9597.6890	6.529E+09
-3.985E-07	3943309.	0.000				
30.690	0.000	-7.672E-06	3.488E-06	0.000	9597.6890	6.529E+09
-7.621E-07	3969256.	0.000				
31.000	1.036E-12	0.000	0.000	0.000	9597.6890	6.529E+09
-1.113E-06	1997601.	0.000				

* This analysis computed pile response using nonlinear moment-curvature relationships.
  Values of total stress due to combined axial and bending stresses are computed only
  for elastic sections only and do not equal the actual stresses in concrete and steel.
  Stresses in concrete and steel may be interpolated from the output for nonlinear
  bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.1022637 inches
Computed slope at pile head	=	-0.0036332 radians
Maximum bending moment	=	533124. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.1700000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	12
Number of zero deflection points	=	8

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950.	lb
Moment	=	192000.	in- lb
Axial Load	=	91000.	lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
31.0000	0.1022641	533125.	23950.
29.4500	0.1021907	533742.	23950.
27.9000	0.1021094	532391.	23950.
26.3500	0.1020836	533156.	23950.
24.8000	0.1020117	532476.	23950.
23.2500	0.1019813	532804.	23950.
21.7000	0.1019738	531749.	23950.
20.1500	0.1018981	532251.	23950.
18.6000	0.1018569	532301.	23950.
17.0500	0.1018376	532134.	23950.
15.5000	0.1017972	531806.	23950.
13.9500	0.1017688	531862.	23950.
12.4000	0.1017482	531663.	23950.
10.8500	0.1017168	531687.	23950.
9.3000	0.1017359	531566.	23950.
7.7500	0.1018192	531479.	23950.
6.2000	0.1054327	529887.	23950.

Summary of Pile Response(s)

Definitions of Pile-head Loading Conditions:

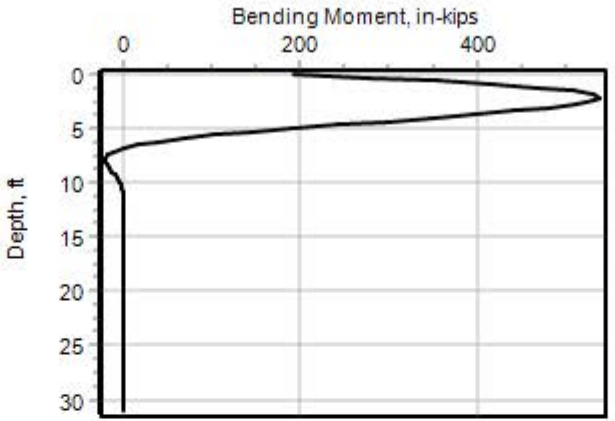
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

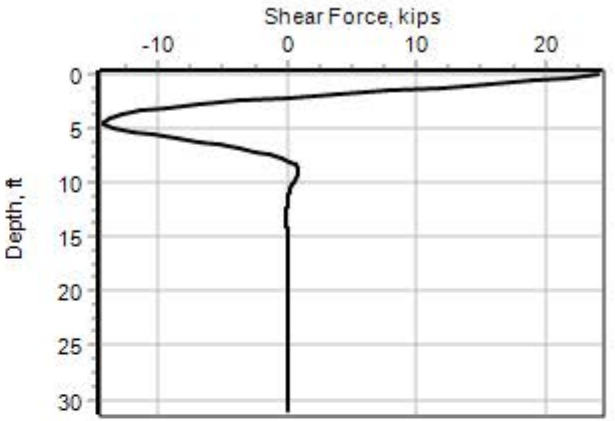
	Pile-head	Pile-head		Maximum

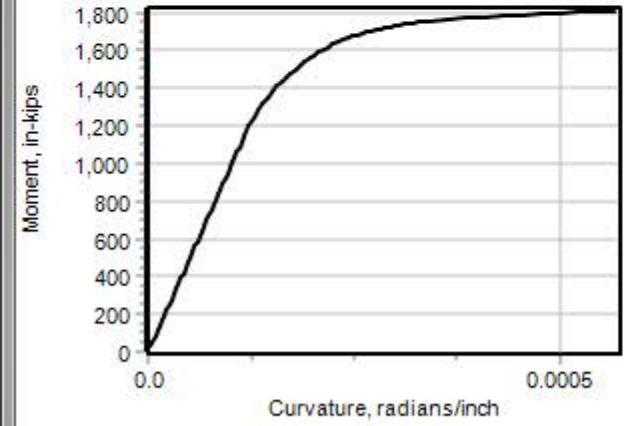
Load Case No.	Maximum Load Type No.	Condition 1 Shear V(lbs) or y(inches)	Condition 2 in-lb, rad., or in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Moment in Pile in-lbs
	Shear in Pile No.	Pile-head Rotation lbs	radians			
1	1	V = 23950.	M = 192000.	91000.	0.10226374	533124.
		23950.	-0.00363320			

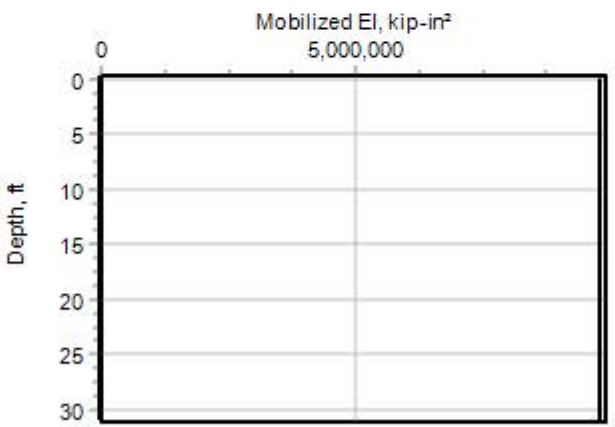
The analysis ended normally.

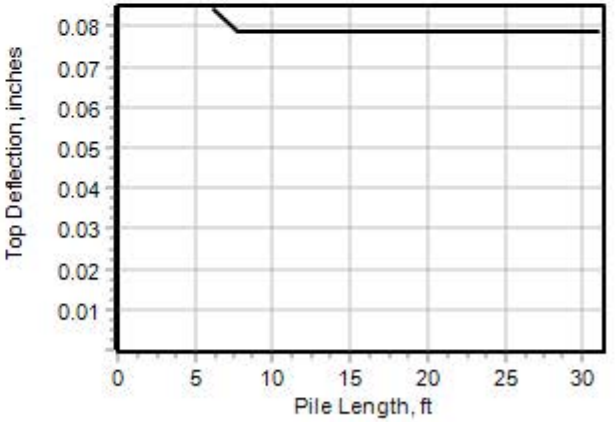
Results for Culvert#3_16inCIP_B-014-1-16.lp7d











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LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_16inCIP_B-014-1-16.lp7d
Name of output report file: Culvert#3_16inCIP_B-014-1-16.lp7o
Name of plot output file: Culvert#3_16inCIP_B-014-1-16.lp7p
Name of runtime messeage file: Culvert#3_16inCIP_B-014-1-16.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:26:48

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-014-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	31.00 ft
Depth of ground surface below top of pile	=	-0.45 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	16.0000000
2	31.000000	16.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	31.00000 ft
Pile Diameter	=	16.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 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 stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.45000 ft
Distance from top of pile to bottom of layer	=	4.55000 ft
Effective unit weight at top of layer	=	65.60000 pcf
Effective unit weight at bottom of layer	=	65.60000 pcf
Undrained cohesion at top of layer	=	4350.00000 psf
Undrained cohesion at bottom of layer	=	4350.00000 psf
Epsilon-50 at top of layer	=	0.00440
Epsilon-50 at bottom of layer	=	0.00440
Subgrade k at top of layer	=	1458.00000 pci
Subgrade k at bottom of layer	=	1458.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	4.55000 ft
Distance from top of pile to bottom of layer	=	9.55000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5550.00000 psf
Undrained cohesion at bottom of layer	=	5550.00000 psf
Epsilon-50 at top of layer	=	0.00400
Epsilon-50 at bottom of layer	=	0.00400
Subgrade k at top of layer	=	1854.00000 pci
Subgrade k at bottom of layer	=	1854.00000 pci

Layer 3 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	9.55000 ft
Distance from top of pile to bottom of layer	=	17.05000 ft
Effective unit weight at top of layer	=	72.60000 pcf
Effective unit weight at bottom of layer	=	72.60000 pcf
Undrained cohesion at top of layer	=	5500.00000 psf

Undrained cohesion at bottom of layer	=	5500.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1847.00000	pci
Subgrade k at bottom of layer	=	1847.00000	pci

Layer 4 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	17.05000	ft
Distance from top of pile to bottom of layer	=	29.55000	ft
Effective unit weight at top of layer	=	62.60000	pcf
Effective unit weight at bottom of layer	=	62.60000	pcf
Undrained cohesion at top of layer	=	2800.00000	psf
Undrained cohesion at bottom of layer	=	2800.00000	psf
Epsilon-50 at top of layer	=	0.00530	
Epsilon-50 at bottom of layer	=	0.00530	
Subgrade k at top of layer	=	938.00000	pci
Subgrade k at bottom of layer	=	938.00000	pci

Layer 5 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	29.55000	ft
Distance from top of pile to bottom of layer	=	31.55000	ft
Effective unit weight at top of layer	=	72.60000	pcf
Effective unit weight at bottom of layer	=	72.60000	pcf
Undrained cohesion at top of layer	=	5600.00000	psf
Undrained cohesion at bottom of layer	=	5600.00000	psf
Epsilon-50 at top of layer	=	0.00400	
Epsilon-50 at bottom of layer	=	0.00400	
Subgrade k at top of layer	=	1875.00000	pci
Subgrade k at bottom of layer	=	1875.00000	pci

(Depth of lowest soil layer extends 0.55 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-0.450	65.600	4350.000	0.00440	1458.000
		4.550	65.600	4350.000	0.00440	1458.000
2	Stiff Clay with Free Water	4.550	72.600	5550.000	0.00400	1854.000
		9.550	72.600	5550.000	0.00400	1854.000
3	Stiff Clay with Free Water	9.550	72.600	5500.000	0.00400	1847.000
		17.050	72.600	5500.000	0.00400	1847.000

4	Stiff Clay with Free Water	17.050	62.600	2800.000	0.00530	938.000
		29.550	62.600	2800.000	0.00530	938.000
5	Stiff Clay with Free Water	29.550	72.600	5600.000	0.00400	1875.000
		31.550	72.600	5600.000	0.00400	1875.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	31.00000 ft
Outer Diameter of Pipe	=	16.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	10.85747 sq. in.
Moment of Inertia	=	338.05798 in^4

Elastic Bending Stiffness = 9803681. kip-in^2
Plastic Modulus, Z = 54.54325 in^3
Plastic Moment Capacity = Fy Z = 1963.55709 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 390.869 kips
Nominal Axial Tensile Capacity = -390.869 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000002846	27.8945447	9801889.	109.5559504	9.0349600	
0.000005692	55.7890894	9801889.	58.7779752	9.6885910	
0.000008538	83.6836340	9801889.	41.8519835	10.3422222	
0.0000114	111.5781787	9801889.	33.3889876	10.9958533	
0.0000142	139.4727234	9801889.	28.3111901	11.6494843	
0.0000171	167.3672681	9801889.	24.9259917	12.3031154	
0.0000199	195.2618128	9801889.	22.5079929	12.9567465	
0.0000228	223.1563575	9801889.	20.6944938	13.6103776	
0.0000256	251.0509021	9801889.	19.2839945	14.2640087	
0.0000285	278.9454468	9801889.	18.1555950	14.9176397	
0.0000313	306.8399915	9801889.	17.2323591	15.5712708	
0.0000342	334.7345362	9801889.	16.4629959	16.2249019	
0.0000370	362.6290809	9801889.	15.8119962	16.8785330	
0.0000398	390.5236255	9801889.	15.2539965	17.5321641	
0.0000427	418.4181702	9801889.	14.7703967	18.1857952	
0.0000455	446.3127149	9801889.	14.3472469	18.8394263	
0.0000484	474.2072596	9801889.	13.9738794	19.4930574	
0.0000512	502.1018043	9801889.	13.6419972	20.1466884	
0.0000541	529.9963490	9801889.	13.3450500	20.8003195	
0.0000569	557.8908936	9801889.	13.0777975	21.4539506	
0.0000598	585.7854383	9801889.	12.8359976	22.1075817	
0.0000626	613.6799830	9801889.	12.6161796	22.7612128	
0.0000655	641.5745277	9801889.	12.4154761	23.4148439	
0.0000683	669.4690724	9801889.	12.2314979	24.0684749	
0.0000711	697.3636170	9801889.	12.0622380	24.7221060	
0.0000740	725.2581617	9801889.	11.9059981	25.3757371	
0.0000768	753.1527064	9801889.	11.7613315	26.0293682	
0.0000797	781.0472511	9801889.	11.6269982	26.6829993	
0.0000825	808.9417958	9801889.	11.5019293	27.3366304	
0.0000854	836.8363404	9801889.	11.3851983	27.9902614	
0.0000882	864.7308851	9801889.	11.2759984	28.6438925	
0.0000911	892.6254298	9801889.	11.1736234	29.2975236	

0.0000939	920.5199745	9801889.	11.0774530	29.9511547	
0.0000968	948.4145192	9801889.	10.9869397	30.6047858	
0.0000996	976.3090639	9801889.	10.9015986	31.2584169	
0.0001025	1004.2036085	9801889.	10.8209986	31.9120480	
0.0001053	1032.0981532	9801889.	10.7447554	32.5656790	
0.0001081	1059.9926979	9801889.	10.6725250	33.2193101	
0.0001110	1087.8872426	9801889.	10.6039987	33.8729412	
0.0001167	1143.6763319	9801889.	10.4769744	35.1802034	
0.0001224	1198.1090748	9790805.	10.3662110	36.0000000	Y
0.0001281	1243.6109150	9710967.	10.2938089	36.0000000	Y
0.0001338	1283.3508937	9594847.	10.2459050	36.0000000	Y
0.0001394	1319.0834079	9459467.	10.2147074	36.0000000	Y
0.0001451	1351.5945763	9312510.	10.1962604	36.0000000	Y
0.0001508	1381.4164312	9158814.	10.1878253	36.0000000	Y
0.0001565	1408.9517314	9001687.	10.1873471	36.0000000	Y
0.0001622	1434.5252101	8843493.	10.1932115	36.0000000	Y
0.0001679	1458.4093728	8685962.	10.2041103	36.0000000	Y
0.0001736	1480.6615391	8529360.	10.2195538	36.0000000	Y
0.0001793	1501.5977795	8375361.	10.2382681	36.0000000	Y
0.0001850	1521.2701184	8224007.	10.2599116	36.0000000	Y
0.0001907	1539.8782834	8076107.	10.2837034	36.0000000	Y
0.0001964	1557.3877960	7931187.	10.3096716	36.0000000	Y
0.0002021	1574.0275434	7790126.	10.3369970	36.0000000	Y
0.0002077	1589.8507759	7652864.	10.3654688	36.0000000	Y
0.0002134	1604.8447131	7519037.	10.3951112	36.0000000	Y
0.0002191	1619.1116034	7388845.	10.4255766	36.0000000	Y
0.0002248	1632.7293955	7262357.	10.4566111	36.0000000	Y
0.0002305	1645.2778322	7137477.	10.4856004	36.0000000	Y
0.0002362	1656.7404260	7014018.	10.5120844	36.0000000	Y
0.0002419	1666.4962254	6889313.	10.5320564	36.0000000	Y
0.0002476	1675.4900520	6767264.	10.5503623	36.0000000	Y
0.0002533	1683.6050104	6647230.	10.5663824	36.0000000	Y
0.0002590	1690.9507104	6529502.	10.5805613	36.0000000	Y
0.0002647	1697.8782759	6415257.	10.5941423	36.0000000	Y
0.0002704	1704.1280745	6303316.	10.6050739	36.0000000	Y
0.0002760	1710.0414337	6194773.	10.6165575	36.0000000	Y
0.0002817	1715.3820402	6088582.	10.6259222	36.0000000	Y
0.0002874	1720.5795793	5986099.	10.6353391	36.0000000	Y
0.0002931	1725.1763589	5885546.	10.6434922	36.0000000	Y
0.0002988	1729.7140234	5788626.	10.6516739	36.0000000	Y
0.0003045	1733.7598184	5693714.	10.6586115	36.0000000	Y
0.0003102	1737.7121426	5601984.	10.6655041	36.0000000	Y
0.0003159	1741.3402898	5512532.	10.6719068	36.0000000	Y
0.0003216	1744.8032643	5425734.	10.6775237	36.0000000	Y
0.0003273	1748.0944257	5341430.	10.6838703	36.0000000	Y
0.0003330	1751.1507726	5259303.	10.6881761	36.0000000	Y
0.0003387	1754.0194355	5179382.	10.6936149	36.0000000	Y
0.0003614	1764.2808887	4881514.	10.7106576	36.0000000	Y
0.0003842	1772.5149920	4613671.	10.7244801	36.0000000	Y
0.0004070	1779.3832122	4372441.	10.7357798	36.0000000	Y
0.0004297	1785.1557706	4154222.	10.7452183	36.0000000	Y
0.0004525	1790.0576895	3956037.	10.7533818	36.0000000	Y
0.0004753	1794.2422813	3775332.	10.7602677	36.0000000	Y
0.0004980	1797.8122768	3609913.	10.7653565	36.0000000	Y
0.0005208	1800.9570816	3458142.	10.7702091	36.0000000	Y
0.0005436	1803.6711664	3318291.	10.7752934	36.0000000	Y
0.0005663	1806.0555818	3189103.	10.7783424	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	1806.1

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X feet	Deflect. y inches	Bending Moment in-lbs	Shear Force lbs	Slope S radians	Total Stress psi*	Bending Stiffness lb-in^2	Soil Res. Es*h lb/inch	Soil Spr. p Lat. Load lb/inch	Distrib.
0.00	0.0788	192000.	23950.	-0.002615	12925.	9.802E+09	-517.6399	12225.	0.000
0.310	0.0692	278385.	21693.	-0.002526	14969.	9.802E+09	-695.8529	37425.	0.000
0.620	0.0600	355105.	18833.	-0.002406	16785.	9.802E+09	-841.6502	52212.	0.000
0.930	0.0513	420133.	15490.	-0.002259	18324.	9.802E+09	-955.8782	69361.	0.000
1.240	0.0432	471878.	11781.	-0.002090	19548.	9.802E+09	-1037.9682	89463.	0.000
1.550	0.0357	509200.	7841.2187	-0.001903	20431.	9.802E+09	-1080.2964	112505.	0.000
1.860	0.0290	531506.	3830.2040	-0.001706	20959.	9.802E+09	-1076.1631	138050.	0.000
2.170	0.0230	538851.	-125.5774	-0.001503	21133.	9.802E+09	-1050.6010	169713.	0.000
2.480	0.0178	531589.	-3778.6975	-0.001300	20961.	9.802E+09	-913.4421	190699.	0.000
2.790	0.0134	511618.	-6886.2726	-0.001102	20489.	9.802E+09	-757.2972	210876.	0.000
3.100	0.009622	481101.	-9406.4598	-0.000913	19766.	9.802E+09	-597.6422	231052.	0.000
3.410	0.006564	442252.	-11343.	-0.000738	18847.	9.802E+09	-443.3202	251229.	0.000

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     3.720   0.004131    397211.    -12728.  -0.000579     17781.  9.802E+09
-301.3816    271405.      0.000
     4.030   0.002258    347949.    -13618.  -0.000437     16615.  9.802E+09
-177.0014    291581.      0.000
     4.340   0.000877    296193.    -14083.  -0.000315     15391.  9.802E+09
-73.4759    311758.      0.000
     4.650 -8.654E-05    243381.    -14118.  -0.000213     14141.  9.802E+09
54.6866   2350724.      0.000
     4.960  -0.000706    191296.    -13354.  -0.000130     12908.  9.802E+09
356.3415   1877039.      0.000
     5.270  -0.001056    144116.    -11881. -6.663E-05     11792.  9.802E+09
435.7115   1535164.      0.000
     5.580  -0.001202    102948.    -10206. -1.975E-05     10818.  9.802E+09
464.8980   1438848.      0.000
     5.890  -0.001203     68200. -8475.8316  1.273E-05  9995.2637  9.802E+09
465.0631   1438412.      0.000
     6.200  -0.001107     39880. -6780.8220  3.324E-05  9325.0610  9.802E+09
446.2324   1499204.      0.000
     6.510  -0.000955     17729. -5179.8000  4.417E-05  8800.8693  9.802E+09
414.5321   1613967.      0.000
     6.820  -0.000779  1311.9039 -3712.7070  4.778E-05  8412.3746  9.802E+09
374.2276   1787940.      0.000
     7.130  -0.000600 -9926.2701 -2405.6151  4.615E-05  8616.2299  9.802E+09
328.5099   2036960.      0.000
     7.440  -0.000435    -16617. -1274.0939  4.111E-05  8774.5660  9.802E+09
279.8348   2391548.      0.000
     7.750  -0.000294    -19433.  -370.2354  3.427E-05  8841.2113  9.802E+09
206.1106   2607288.      0.000
     8.060  -0.000180    -19395.   250.4954  2.690E-05  8840.3004  9.802E+09
127.6157   2632944.      0.000
     8.370 -9.392E-05    -17588.   612.7054  1.988E-05  8797.5390  9.802E+09
67.1208   2658601.      0.000
     8.680 -3.236E-05    -14850.   780.9838  1.373E-05  8732.7433  9.802E+09
23.3515   2684257.      0.000
     8.990  8.229E-06    -11787.   813.2681  8.675E-06  8660.2554  9.802E+09
-5.9944   2709913.      0.000
     9.300  3.218E-05 -8804.9647   758.1049  4.767E-06  8589.6947  9.802E+09
-23.6633   2735570.      0.000
     9.610  4.370E-05 -6149.5936   653.6574  1.930E-06  8526.8565  9.802E+09
-32.4913   2765980.      0.000
     9.920  4.654E-05 -3943.0599   528.2715  1.442E-08  8474.6398  9.802E+09
-34.9205   2791539.      0.000
    10.230  4.381E-05 -2219.2636   401.6174 -1.155E-06  8433.8469  9.802E+09
-33.1730   2817099.      0.000
    10.540  3.794E-05  -954.2441   285.9871 -1.757E-06  8403.9107  9.802E+09
-28.9938   2842658.      0.000
    10.850  3.073E-05   -90.3302   187.9853 -1.955E-06  8383.4666  9.802E+09
-23.6953   2868218.      0.000
    11.160  2.339E-05   445.6904   110.0628 -1.888E-06  8391.8760  9.802E+09
-18.1985   2893777.      0.000
    11.470  1.669E-05   729.8156    51.8576 -1.665E-06  8398.5997  9.802E+09
-13.0947   2919337.      0.000
    11.780  1.101E-05   832.6379    11.2929 -1.368E-06  8401.0330  9.802E+09
-8.7143   2944896.      0.000
    12.090  6.505E-06   814.7612   -14.5777 -1.056E-06  8400.6099  9.802E+09
-5.1946   2970456.      0.000
    12.400  3.153E-06   724.8948   -28.9630 -7.636E-07  8398.4833  9.802E+09
-2.5394   2996015.      0.000
    12.710  8.242E-07   599.7936   -34.9316 -5.122E-07  8395.5228  9.802E+09
-0.6695   3021575.      0.000
    13.020 -6.578E-07   465.3508   -35.1745 -3.101E-07  8392.3413  9.802E+09
0.5389   3047134.      0.000
    13.330 -1.483E-06   338.3051   -31.8940 -1.576E-07  8389.3348  9.802E+09
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1.2249   3072694.      0.000
    13.640 -1.830E-06   228.1663   -26.7802 -5.011E-08  8386.7284  9.802E+09
1.5245   3098254.      0.000
    13.950 -1.856E-06   139.0943   -21.0462  1.958E-08  8384.6205  9.802E+09
1.5583   3123813.      0.000
    14.260 -1.685E-06    71.5691   -15.4949  5.956E-08  8383.0226  9.802E+09
1.4263   3149373.      0.000
    14.570 -1.413E-06    23.7717   -10.5997  7.765E-08  8381.8915  9.802E+09
1.2056   3174932.      0.000
    14.880 -1.107E-06    -7.3450    -6.5858  8.077E-08  8381.5027  9.802E+09
0.9524   3200492.      0.000
    15.190 -8.117E-07   -25.2815    -3.5052  7.458E-08  8381.9272  9.802E+09
0.7039   3226051.      0.000
    15.500 -5.521E-07   -33.4740    -1.2983  6.343E-08  8382.1211  9.802E+09
0.4826   3251611.      0.000
    15.810 -3.398E-07   -34.9842     0.1560  5.044E-08  8382.1568  9.802E+09
0.2993   3277170.      0.000
    16.120 -1.768E-07   -32.3476     1.0047  3.766E-08  8382.0944  9.802E+09
0.1570   3302730.      0.000
    16.430 -5.957E-08   -27.5343     1.3959  2.630E-08  8381.9805  9.802E+09
0.0533   3328289.      0.000
    16.740  1.882E-08   -21.9799     1.4635  1.690E-08  8381.8491  9.802E+09
-0.0170   3353849.      0.000
    17.050  6.618E-08   -16.6574     1.3576  9.570E-09  8381.7231  9.802E+09
-0.0399   2245280.      0.000
    17.360  9.002E-08   -11.8855     1.1817  4.154E-09  8381.6102  9.802E+09
-0.0546   2258261.      0.000
    17.670  9.708E-08    -7.8684     0.9698  4.052E-10  8381.5151  9.802E+09
-0.0593   2271241.      0.000
    17.980  9.303E-08    -4.6704     0.7533 -1.974E-09  8381.4394  9.802E+09
-0.0571   2284221.      0.000
    18.290  8.239E-08    -2.2624     0.5524 -3.290E-09  8381.3825  9.802E+09
-0.0509   2297202.      0.000
    18.600  6.856E-08    -0.5582     0.3786 -3.825E-09  8381.3421  9.802E+09
-0.0426   2310182.      0.000
    18.910  5.394E-08     0.5569     0.2368 -3.825E-09  8381.3421  9.802E+09
-0.0337   2323163.      0.000
    19.220  4.010E-08     1.2059     0.1273 -3.491E-09  8381.3575  9.802E+09
-0.0252   2336143.      0.000
    19.530  2.796E-08     1.5062     0.0476 -2.976E-09  8381.3646  9.802E+09
-0.0177   2349124.      0.000
    19.840  1.796E-08     1.5619  -0.006475 -2.394E-09  8381.3659  9.802E+09
-0.0114   2362104.      0.000
    20.150  1.015E-08     1.4596    -0.0397 -1.820E-09  8381.3635  9.802E+09
-0.006483   2375084.      0.000
    20.460  4.413E-09     1.2674    -0.0571 -1.303E-09  8381.3589  9.802E+09
-0.002833   2388065.      0.000
    20.770  4.603E-10     1.0359    -0.0629 -8.659E-10  8381.3534  9.802E+09
-0.000297   2401045.      0.000
    21.080 -2.030E-09     0.8001    -0.0610 -5.175E-10  8381.3479  9.802E+09
0.001317   2414026.      0.000
    21.390 -3.390E-09     0.5824    -0.0544 -2.552E-10  8381.3427  9.802E+09
0.002212   2427006.      0.000
    21.700 -3.928E-09     0.3953    -0.0455 -6.968E-11  8381.3383  9.802E+09
0.002577   2439986.      0.000
    22.010 -3.909E-09     0.2438    -0.0359  5.159E-11  8381.3347  9.802E+09
0.002577   2452967.      0.000
    22.320 -3.545E-09     0.1279    -0.0268  1.221E-10  8381.3320  9.802E+09
0.002350   2465947.      0.000
    22.630 -3.000E-09     0.0445    -0.0187  1.548E-10  8381.3300  9.802E+09
0.001999   2478928.      0.000
    22.940 -2.393E-09    -0.0112    -0.0120  1.611E-10  8381.3292  9.802E+09
0.001603   2491908.      0.000
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23.250	-1.801E-09	-0.0448	-0.006747	1.505E-10	8381.3300	9.802E+09	0.001213	2504889.	0.000
23.560	-1.273E-09	-0.0615	-0.002888	1.303E-10	8381.3304	9.802E+09	0.000862	2517869.	0.000
23.870	-8.319E-10	-0.0664	-0.000232	1.060E-10	8381.3305	9.802E+09	0.000566	2530849.	0.000
24.180	-4.843E-10	-0.0633	0.001436	8.142E-11	8381.3304	9.802E+09	0.000331	2543830.	0.000
24.490	-2.261E-10	-0.0557	0.002342	5.883E-11	8381.3302	9.802E+09	0.000155	2556810.	0.000
24.800	-4.664E-11	-0.0460	0.002691	3.953E-11	8381.3300	9.802E+09	3.222E-05	2569791.	0.000
25.110	6.797E-11	-0.0357	0.002663	2.402E-11	8381.3298	9.802E+09	-4.719E-05	2582771.	0.000
25.420	1.321E-10	-0.0262	0.002403	1.228E-11	8381.3295	9.802E+09	-9.218E-05	2595752.	0.000
25.730	1.593E-10	-0.0179	0.002024	3.920E-12	8381.3293	9.802E+09	-0.000112	2608732.	0.000
26.040	1.613E-10	-0.0111	0.001605	-1.579E-12	8381.3292	9.802E+09	-0.000114	2621712.	0.000
26.350	1.476E-10	-0.005926	0.001199	-4.812E-12	8381.3291	9.802E+09	-0.000105	2634693.	0.000
26.660	1.255E-10	-0.002186	0.000839	-6.352E-12	8381.3290	9.802E+09	-8.930E-05	2647673.	0.000
26.970	1.003E-10	0.000319	0.000539	-6.706E-12	8381.3289	9.802E+09	-7.174E-05	2660654.	0.000
27.280	7.558E-11	0.001830	0.000305	-6.298E-12	8381.3290	9.802E+09	-5.432E-05	2673634.	0.000
27.590	5.344E-11	0.002590	0.000132	-5.459E-12	8381.3290	9.802E+09	-3.860E-05	2686614.	0.000
27.900	3.496E-11	0.002816	1.294E-05	-4.434E-12	8381.3290	9.802E+09	-2.537E-05	2699595.	0.000
28.210	2.046E-11	0.002689	-6.199E-05	-3.389E-12	8381.3290	9.802E+09	-1.492E-05	2712575.	0.000
28.520	9.747E-12	0.002357	-0.000103	-2.431E-12	8381.3290	9.802E+09	-7.141E-06	2725556.	0.000
28.830	2.366E-12	0.001925	-0.000120	-1.619E-12	8381.3290	9.802E+09	-1.742E-06	2738536.	0.000
29.140	-2.299E-12	0.001468	-0.000120	0.000	8381.3290	9.802E+09	1.700E-06	2751517.	0.000
29.450	-4.890E-12	0.001035	-0.000110	0.000	8381.3290	9.802E+09	3.634E-06	2764497.	0.000
29.760	-6.019E-12	0.000653	-9.116E-05	0.000	8381.3289	9.802E+09	6.329E-06	3911138.	0.000
30.070	-6.228E-12	0.000357	-6.713E-05	0.000	8381.3289	9.802E+09	6.591E-06	3937085.	0.000
30.380	-5.932E-12	0.000153	-4.312E-05	0.000	8381.3289	9.802E+09	6.319E-06	3963032.	0.000
30.690	-5.420E-12	3.632E-05	-2.056E-05	0.000	8381.3289	9.802E+09	5.811E-06	3988979.	0.000
31.000	-4.856E-12	0.000	0.000	0.000	8381.3289	9.802E+09	5.241E-06	2007463.	0.000

* This analysis computed pile response using nonlinear moment-curvature relationships.
  Values of total stress due to combined axial and bending stresses are computed only
  for elastic sections only and do not equal the actual stresses in concrete and steel.
  Stresses in concrete and steel may be interpolated from the output for nonlinear
  bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.0787597	inches
Computed slope at pile head	=	-0.0026154	radians
Maximum bending moment	=	538851.	inch-lbs
Maximum shear force	=	23950.	lbs
Depth of maximum bending moment	=	2.1700000	feet below pile head
Depth of maximum shear force	=	0.000000	feet below pile head
Number of iterations	=	9	
Number of zero deflection points	=	7	

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950.	lb
Moment	=	192000.	in- lb
Axial Load	=	91000.	lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
31.0000	0.0787603	538853.	23950.
29.4500	0.0787778	537700.	23950.
27.9000	0.0787348	538135.	23950.
26.3500	0.0787200	537983.	23950.
24.8000	0.0786738	537776.	23950.
23.2500	0.0786668	537517.	23950.
21.7000	0.0785981	537859.	23950.
20.1500	0.0786067	537516.	23950.
18.6000	0.0785887	537235.	23950.
17.0500	0.0785665	537281.	23950.
15.5000	0.0785493	537354.	23950.
13.9500	0.0785393	536944.	23950.
12.4000	0.0785228	536907.	23950.
10.8500	0.0785042	537117.	23950.
9.3000	0.0785412	536943.	23950.
7.7500	0.0785693	536934.	23950.
6.2000	0.0841697	531143.	23950.

Summary of Pile Response(s)

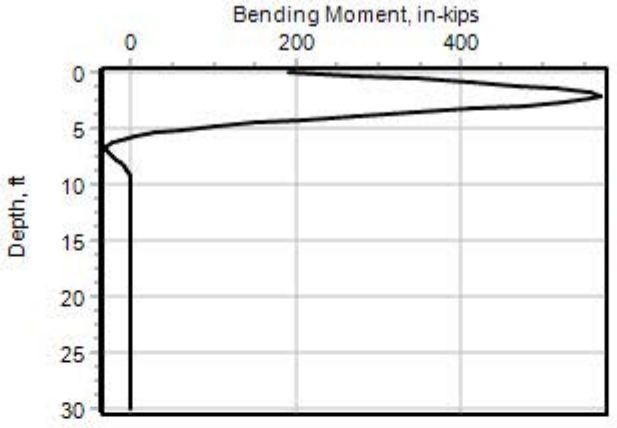
Definitions of Pile-head Loading Conditions:

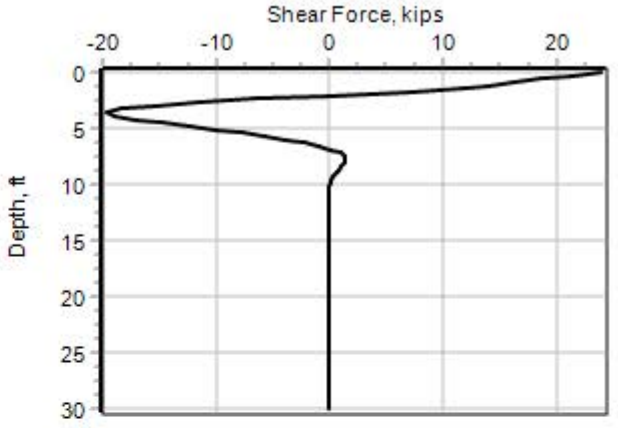
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

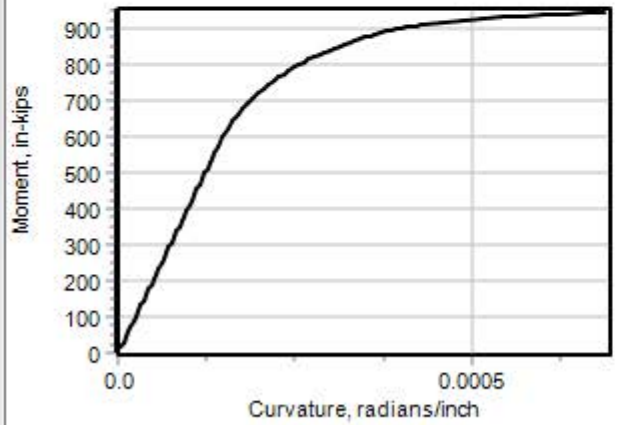
Load Case No.	Load Type No.	Pile-head Shear V(lbs) or y(inches)	Condition 1 Pile-head in-lb, rad., or in-lb/rad.	Condition 2 Pile-head Loading lbs	Axial Load in Pile lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Shear in Pile lbs	Maximum Pile-head Rotation radians
1	1	V = 23950.	M = 192000.	91000.	0.07875971	538851.	23950.	-0.00261537	

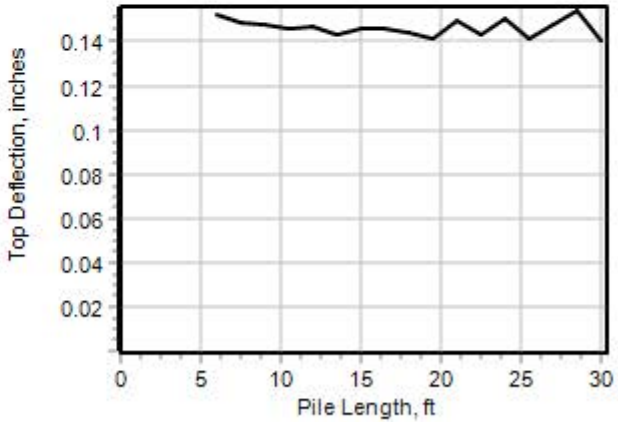
The analysis ended normally.

Results for Culvert#3_12inCIP_B-015s.lp7d









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LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_12inCIP_B-015s.lp7d
Name of output report file: Culvert#3_12inCIP_B-015s.lp7o
Name of plot output file: Culvert#3_12inCIP_B-015s.lp7p
Name of runtime messeage file: Culvert#3_12inCIP_B-015s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:35:22

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-015-0-14 & B-015-0-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	30.00 ft
Depth of ground surface below top of pile	=	-9.35 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	12.0000000
2	30.000000	12.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	30.00000 ft
Pile Diameter	=	12.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 4 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-9.35000 ft
Distance from top of pile to bottom of layer	=	1.75000 ft
Effective unit weight at top of layer	=	72.50000 pcf
Effective unit weight at bottom of layer	=	72.50000 pcf
Undrained cohesion at top of layer	=	1550.00000 psf
Undrained cohesion at bottom of layer	=	1550.00000 psf
Epsilon-50 at top of layer	=	0.00720
Epsilon-50 at bottom of layer	=	0.00720
Subgrade k at top of layer	=	521.00000 pci
Subgrade k at bottom of layer	=	521.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	1.75000 ft
Distance from top of pile to bottom of layer	=	13.75000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5250.00000 psf
Undrained cohesion at bottom of layer	=	5250.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1750.00000 pci
Subgrade k at bottom of layer	=	1750.00000 pci

Layer 3 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	13.75000 ft
Distance from top of pile to bottom of layer	=	21.25000 ft
Effective unit weight at top of layer	=	65.60000 pcf
Effective unit weight at bottom of layer	=	65.60000 pcf
Undrained cohesion at top of layer	=	3850.00000 psf

Undrained cohesion at bottom of layer	=	3850.00000 psf
Epsilon-50 at top of layer	=	0.00460
Epsilon-50 at bottom of layer	=	0.00460
Subgrade k at top of layer	=	1292.00000 pci
Subgrade k at bottom of layer	=	1292.00000 pci

Layer 4 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	21.25000 ft
Distance from top of pile to bottom of layer	=	30.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	3450.00000 psf
Undrained cohesion at bottom of layer	=	3450.00000 psf
Epsilon-50 at top of layer	=	0.00480
Epsilon-50 at bottom of layer	=	0.00480
Subgrade k at top of layer	=	1156.00000 pci
Subgrade k at bottom of layer	=	1156.00000 pci

(Depth of lowest soil layer extends 0.75 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-9.350	72.500	1550.000	0.00720	521.000
		1.750	72.500	1550.000	0.00720	521.000
2	Stiff Clay with Free Water	1.750	67.600	5250.000	0.00410	1750.000
		13.750	67.600	5250.000	0.00410	1750.000
3	Stiff Clay with Free Water	13.750	65.600	3850.000	0.00460	1292.000
		21.250	65.600	3850.000	0.00460	1292.000
4	Stiff Clay with Free Water	21.250	62.600	3450.000	0.00480	1156.000
		30.750	62.600	3450.000	0.00480	1156.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Compute Type	Condition 1	Condition 2	Axial Thrust Force, lbs Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000. Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	30.00000 ft
Outer Diameter of Pipe	=	12.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	8.10543 sq. in.
Moment of Inertia	=	140.66969 in^4
Elastic Bending Stiffness	=	4079421. kip-in^2
Plastic Modulus, Z	=	30.39894 in^3
Plastic Moment Capacity = Fy Z	=	1094.36186 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As	=	291.796 kips
Nominal Axial Tensile Capacity	=	-291.796 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips

1 91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003590	14.6460293	4079661.	113.8378926	11.8454549	
0.000007180	29.2920585	4079661.	59.9189463	12.4638702	
0.0000108	43.9380878	4079661.	41.9459642	13.0822859	
0.0000144	58.5841170	4079661.	32.9594731	13.7007012	
0.0000180	73.2301463	4079661.	27.5675785	14.3191164	
0.0000215	87.8761755	4079661.	23.9729821	14.9375320	
0.0000251	102.5222048	4079661.	21.4054132	15.5559474	
0.0000287	117.1682340	4079661.	19.4797366	16.1743628	
0.0000323	131.8142633	4079661.	17.9819881	16.7927782	
0.0000359	146.4602925	4079661.	16.7837893	17.4111937	
0.0000395	161.1063218	4079661.	15.8034448	18.0296091	
0.0000431	175.7523510	4079661.	14.9864910	18.6480245	
0.0000467	190.3983803	4079661.	14.2952225	19.2664399	
0.0000503	205.0444095	4079661.	13.7027066	19.8848553	
0.0000539	219.6904388	4079661.	13.1891928	20.5032707	
0.0000574	234.3364680	4079661.	12.7398683	21.1216861	
0.0000610	248.9824973	4079661.	12.3434054	21.7401015	
0.0000646	263.6285265	4079661.	11.9909940	22.3585170	
0.0000682	278.2745558	4079661.	11.6756786	22.9769324	
0.0000718	292.9205850	4079661.	11.3918946	23.5953478	
0.0000754	307.5666143	4079661.	11.1351377	24.2137632	
0.0000790	322.2126435	4079661.	10.9017224	24.8321787	
0.0000826	336.8586728	4079661.	10.6886040	25.4505941	
0.0000862	351.5047020	4079661.	10.4932455	26.0690095	
0.0000898	366.1507313	4079661.	10.3135157	26.6874249	
0.0000933	380.7967605	4079661.	10.1476113	27.3058403	
0.0000969	395.4427898	4079661.	9.9939960	27.9242558	
0.0001005	410.0888190	4079661.	9.8513533	28.5426712	
0.0001041	424.7348483	4079661.	9.7185480	29.1610866	
0.0001077	439.3808775	4079661.	9.5945964	29.7795020	
0.0001113	454.0269068	4079661.	9.4786417	30.3979174	
0.0001149	468.6729360	4079661.	9.3699341	31.0163328	
0.0001185	483.3189653	4079661.	9.2678149	31.6347483	
0.0001221	497.9649945	4079661.	9.1717027	32.2531637	
0.0001257	512.6110238	4079661.	9.0810826	32.8715791	
0.0001292	527.2570530	4079661.	8.9954970	33.4899945	
0.0001328	541.9030823	4079661.	8.9145376	34.1084099	
0.0001364	556.5491115	4079661.	8.8378393	34.7268254	
0.0001400	571.1951408	4079661.	8.7650742	35.3452408	
0.0001472	599.6344915	4073867.	8.6343588	36.0000000	Y
0.0001544	623.3530116	4038032.	8.5382521	36.0000000	Y
0.0001616	644.0460965	3986654.	8.4650284	36.0000000	Y
0.0001687	662.4878832	3926307.	8.4087481	36.0000000	Y
0.0001759	679.2447437	3861307.	8.3651071	36.0000000	Y
0.0001831	694.5892106	3793691.	8.3316408	36.0000000	Y
0.0001903	708.7299375	3724852.	8.3064628	36.0000000	Y
0.0001975	721.8361938	3655780.	8.2880733	36.0000000	Y
0.0002046	734.0244235	3587070.	8.2753779	36.0000000	Y
0.0002118	745.3737266	3519056.	8.2675803	36.0000000	Y
0.0002190	756.0452315	3452408.	8.2635576	36.0000000	Y

0.0002262	766.0342523	3386973.	8.2630781	36.0000000	Y
0.0002334	775.4849822	3323259.	8.2652247	36.0000000	Y
0.0002405	784.3549062	3260934.	8.2700477	36.0000000	Y
0.0002477	792.7762630	3200411.	8.2767617	36.0000000	Y
0.0002549	800.7765111	3141645.	8.2851318	36.0000000	Y
0.0002621	808.3405346	3084435.	8.2951545	36.0000000	Y
0.0002693	815.5356212	3028906.	8.3064327	36.0000000	Y
0.0002764	822.3962712	2975052.	8.3187484	36.0000000	Y
0.0002836	828.9444308	2922823.	8.3319577	36.0000000	Y
0.0002908	835.2011007	2872170.	8.3459303	36.0000000	Y
0.0002980	841.1864013	2823048.	8.3605481	36.0000000	Y
0.0003052	846.9196303	2775412.	8.3757035	36.0000000	Y
0.0003123	852.4193143	2729218.	8.3912976	36.0000000	Y
0.0003195	857.7032544	2684424.	8.4072394	36.0000000	Y
0.0003267	862.7885675	2640992.	8.4234443	36.0000000	Y
0.0003339	867.6492325	2598755.	8.4400462	36.0000000	Y
0.0003411	872.3273732	2557761.	8.4568425	36.0000000	Y
0.0003482	876.8469211	2518003.	8.4737218	36.0000000	Y
0.0003554	881.2229244	2479446.	8.4906174	36.0000000	Y
0.0003626	885.3840426	2441825.	8.5072690	36.0000000	Y
0.0003698	889.1600436	2404622.	8.5222170	36.0000000	Y
0.0003770	892.8414077	2368586.	8.5370928	36.0000000	Y
0.0003841	896.0296021	2332613.	8.5489267	36.0000000	Y
0.0003913	899.0077186	2297424.	8.5601198	36.0000000	Y
0.0003985	901.8403521	2263137.	8.5703638	36.0000000	Y
0.0004057	904.3215113	2229198.	8.5791569	36.0000000	Y
0.0004129	906.7900746	2196408.	8.5877275	36.0000000	Y
0.0004200	908.9791698	2164075.	8.5954938	36.0000000	Y
0.0004272	911.0928382	2132651.	8.6022827	36.0000000	Y
0.0004559	918.3846071	2014304.	8.6271859	36.0000000	Y
0.0004847	924.2341408	1907007.	8.6461098	36.0000000	Y
0.0005134	929.0046884	1809614.	8.6613777	36.0000000	Y
0.0005421	933.0001087	1721111.	8.6739223	36.0000000	Y
0.0005708	936.3786810	1640433.	8.6845929	36.0000000	Y
0.0005995	939.2026031	1566560.	8.6930479	36.0000000	Y
0.0006283	941.6355550	1498818.	8.7003694	36.0000000	Y
0.0006570	943.7786942	1436558.	8.7070009	36.0000000	Y
0.0006857	945.6523584	1379121.	8.7122537	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	945.7

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. Distrib. p
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in
Es*h lb/inch	Lat. Load lb/inch						
0.00	0.1408	192000.	23950.	-0.005469	19416.	4.080E+09	
-753.4019	9633.7474	0.000					
0.300	0.1214	275102.	21281.	-0.005263	22961.	4.080E+09	
-729.2509	21628.	0.000					
0.600	0.1029	348673.	18711.	-0.004988	26099.	4.080E+09	
-698.5887	24446.	0.000					
0.900	0.0855	413090.	16264.	-0.004652	28847.	4.080E+09	
-661.1188	27845.	0.000					
1.200	0.0694	468819.	13964.	-0.004262	31224.	4.080E+09	
-616.4811	31986.	0.000					
1.500	0.0548	516423.	11840.	-0.003828	33254.	4.080E+09	
-563.5524	37032.	0.000					
1.800	0.0418	556574.	6991.4487	-0.003354	34967.	4.080E+09	
-2130.0316	183338.	0.000					
2.100	0.0306	568959.	-252.5124	-0.002858	35495.	4.080E+09	
-1894.3911	222626.	0.000					
2.400	0.0212	556628.	-6509.0169	-0.002361	34969.	4.080E+09	
-1581.4447	267921.	0.000					
2.700	0.0136	523641.	-11636.	-0.001884	33562.	4.080E+09	
-1266.7558	334486.	0.000					
3.000	0.007682	474085.	-15627.	-0.001444	31448.	4.080E+09	
-950.8629	445626.	0.000					
3.300	0.003235	412070.	-18450.	-0.001053	28803.	4.080E+09	
-617.1320	686689.	0.000					
3.600	9.816E-05	341936.	-19655.	-0.000721	25812.	4.080E+09	
-52.2694	1916896.	0.000					
3.900	-0.001953	271027.	-18886.	-0.000450	22787.	4.080E+09	
479.3432	883684.	0.000					
4.200	-0.003143	206252.	-16929.	-0.000240	20024.	4.080E+09	
608.1378	696622.	0.000					
4.500	-0.003677	149298.	-14650.	-8.267E-05	17595.	4.080E+09	
657.8608	644000.	0.000					
4.800	-0.003738	100827.	-12272.	2.769E-05	15528.	4.080E+09	
663.2572	638779.	0.000					
5.100	-0.003478	60923.	-9926.2978	9.906E-05	13826.	4.080E+09	
639.7976	662216.	0.000					
5.400	-0.003025	29293.	-7700.6908	0.000139	12476.	4.080E+09	
596.6507	710121.	0.000					
5.700	-0.002478	5387.0117	-5654.5712	0.000154	11457.	4.080E+09	
540.0824	784517.	0.000					
6.000	-0.001915	-11521.	-3827.9072	0.000151	11718.	4.080E+09	
474.7309	892538.	0.000					
6.300	-0.001388	-22273.	-2245.8818	0.000137	12177.	4.080E+09	

```
404.1721   1048388.      0.000
     6.600  -0.000932    -27781.  -922.2861   0.000114     12412.  4.080E+09
331.1589   1279589.      0.000
     6.900  -0.000564    -28989.   137.4962  8.941E-05     12463.  4.080E+09
257.6091   1645028.      0.000
     7.200  -0.000288    -26849.   916.3247  6.478E-05     12372.  4.080E+09
175.0734   2189056.      0.000
     7.500 -9.737E-05    -22434.  1339.1355  4.303E-05     12184.  4.080E+09
59.8215   2211736.      0.000
     7.800  2.191E-05    -17236.  1422.3362  2.553E-05     11962.  4.080E+09
-13.5989   2234416.      0.000
     8.100  8.644E-05    -12209.  1300.3104  1.254E-05     11748.  4.080E+09
-54.1933   2257096.      0.000
     8.400   0.000112 -7881.8133  1074.8931  3.673E-06     11563.  4.080E+09
-71.0386   2279776.      0.000
     8.700   0.000113 -4472.5917   817.0740 -1.778E-06     11418.  4.080E+09
-72.1943   2302456.      0.000
     9.000  9.937E-05 -1997.7155   571.5962 -4.633E-06     11312.  4.080E+09
-64.1822   2325136.      0.000
     9.300  7.952E-05  -354.0637   362.7180 -5.671E-06     11242.  4.080E+09
-51.8612   2347816.      0.000
     9.600  5.854E-05   617.5697   199.9791 -5.554E-06     11253.  4.080E+09
-38.5493   2370496.      0.000
     9.900  3.953E-05  1089.4253    83.2911 -4.801E-06     11274.  4.080E+09
-26.2774   2393176.      0.000
    10.200  2.397E-05  1220.4113     7.0329 -3.782E-06     11279.  4.080E+09
-16.0883   2415856.      0.000
    10.500  1.230E-05  1142.5406   -36.9187 -2.740E-06     11276.  4.080E+09
-8.3293   2438536.      0.000
    10.800  4.249E-06   956.3920   -57.1397 -1.814E-06     11268.  4.080E+09
-2.9046   2461216.      0.000
    11.100 -7.612E-07   732.3233   -61.4225 -1.068E-06     11258.  4.080E+09
0.5252   2483896.      0.000
    11.400 -3.445E-06   514.8499   -56.1601 -5.182E-07     11249.  4.080E+09
2.3984   2506576.      0.000
    11.700 -4.492E-06   328.3104   -46.1618 -1.462E-07     11241.  4.080E+09
3.1562   2529256.      0.000
    12.000 -4.497E-06   182.5809   -34.7422  7.921E-08     11235.  4.080E+09
3.1880   2551936.      0.000
    12.300 -3.922E-06    78.1148   -23.9548  1.942E-07     11230.  4.080E+09
2.8050   2574616.      0.000
    12.600 -3.099E-06     9.9788   -14.8816  2.331E-07     11227.  4.080E+09
2.2357   2597296.      0.000
    12.900 -2.244E-06   -29.1852    -7.9179  2.246E-07     11228.  4.080E+09
1.6330   2619976.      0.000
    13.200 -1.482E-06   -47.1771    -3.0209  1.909E-07     11229.  4.080E+09
1.0876   2642656.      0.000
    13.500 -8.691E-07   -51.0606     0.0950  1.476E-07     11229.  4.080E+09
0.6435   2665336.      0.000
    13.800 -4.189E-07   -46.5899     1.8130  1.045E-07     11229.  4.080E+09
0.3110   2672412.      0.000
    14.100 -1.167E-07   -38.0754     2.5297  6.715E-08     11229.  4.080E+09
0.0872   2689157.      0.000
    14.400  6.453E-08   -28.4198     2.5994  3.781E-08     11228.  4.080E+09
-0.0485   2705901.      0.000
    14.700  1.555E-07   -19.3847     2.3004  1.672E-08     11228.  4.080E+09
-0.1176   2722645.      0.000
    15.000  1.849E-07   -11.8681     1.8355  2.927E-09     11228.  4.080E+09
-0.1407   2739389.      0.000
    15.300  1.766E-07    -6.1713     1.3389 -5.033E-09     11227.  4.080E+09
-0.1352   2756134.      0.000
    15.600  1.486E-07    -2.2246     0.8895 -8.737E-09     11227.  4.080E+09
-0.1145   2772878.      0.000
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    15.900  1.137E-07     0.2388     0.5249 -9.613E-09     11227.  4.080E+09
-0.0881   2789622.      0.000
    16.200  7.943E-08     1.5607     0.2549 -8.819E-09     11227.  4.080E+09
-0.0619   2806367.      0.000
    16.500  5.016E-08     2.0796     0.0726 -7.213E-09     11227.  4.080E+09
-0.0393   2823111.      0.000
    16.800  2.750E-08     2.0881    -0.0373 -5.374E-09     11227.  4.080E+09
-0.0217   2839855.      0.000
    17.100  1.147E-08     1.8149    -0.0927 -3.652E-09     11227.  4.080E+09
-0.009101   2856600.      0.000
    17.400  1.204E-09     1.4232    -0.1108 -2.223E-09     11227.  4.080E+09
-0.000961   2873344.      0.000
    17.700 -4.539E-09     1.0187    -0.1060 -1.146E-09     11227.  4.080E+09
0.003644   2890088.      0.000
    18.000 -7.047E-09     0.6611    -0.0892 -4.049E-10     11227.  4.080E+09
0.005690   2906833.      0.000
    18.300 -7.454E-09     0.3770    -0.0680  5.315E-11     11227.  4.080E+09
0.006054   2923577.      0.000
    18.600 -6.664E-09     0.1713    -0.0473  2.951E-10     11227.  4.080E+09
0.005443   2940321.      0.000
    18.900 -5.330E-09     0.0360    -0.0296  3.865E-10     11227.  4.080E+09
0.004378   2957066.      0.000
    19.200 -3.881E-09    -0.0425    -0.0160  3.837E-10     11227.  4.080E+09
0.003206   2973810.      0.000
    19.500 -2.567E-09    -0.0794  -0.006387  3.299E-10     11227.  4.080E+09
0.002133   2990554.      0.000
    19.800 -1.506E-09    -0.0887  -0.000284  2.558E-10     11227.  4.080E+09
0.001258   3007299.      0.000
    20.100 -7.258E-10    -0.0816   0.003077  1.807E-10     11227.  4.080E+09
0.000610   3024043.      0.000
    20.400 -2.050E-10    -0.0666   0.004486  1.153E-10     11227.  4.080E+09
0.000173   3040787.      0.000
    20.700  1.041E-10    -0.0494   0.004639  6.409E-11     11227.  4.080E+09
-8.845E-05   3057532.      0.000
    21.000  2.564E-10    -0.0333   0.004086  2.762E-11     11227.  4.080E+09
-0.000219   3074276.      0.000
    21.300  3.030E-10    -0.0200   0.003225  4.132E-12     11227.  4.080E+09
-0.000259   3074976.      0.000
    21.600  2.862E-10    -0.0100   0.002317 -9.115E-12     11227.  4.080E+09
-0.000246   3089958.      0.000
    21.900  2.374E-10  -0.003288   0.001507 -1.500E-11     11227.  4.080E+09
-0.000205   3104939.      0.000
    22.200  1.782E-10   0.000815   0.000860 -1.609E-11     11227.  4.080E+09
-0.000154   3119921.      0.000
    22.500  1.216E-10   0.002917   0.000392 -1.444E-11     11227.  4.080E+09
-0.000106   3134903.      0.000
    22.800  7.422E-11   0.003645  8.421E-05 -1.155E-11     11227.  4.080E+09
-6.494E-05   3149885.      0.000
    23.100  3.845E-11   0.003530 -9.354E-05 -8.379E-12     11227.  4.080E+09
-3.380E-05   3164866.      0.000
    23.400  1.389E-11   0.002977  -0.000176 -5.508E-12     11227.  4.080E+09
-1.227E-05   3179848.      0.000
    23.700 -1.209E-12   0.002263  -0.000197 -3.196E-12     11227.  4.080E+09
1.073E-06   3194830.      0.000
    24.000 -9.120E-12   0.001563  -0.000180 -1.508E-12     11227.  4.080E+09
8.131E-06   3209812.      0.000
    24.300 -1.207E-11   0.000968  -0.000146      0.000     11227.  4.080E+09
1.081E-05   3224794.      0.000
    24.600 -1.194E-11   0.000512  -0.000107      0.000     11227.  4.080E+09
1.074E-05   3239775.      0.000
    24.900 -1.018E-11   0.000196 -7.129E-05      0.000     11227.  4.080E+09
9.202E-06   3254757.      0.000
    25.200 -7.797E-12 -1.213E-06 -4.198E-05      0.000     11227.  4.080E+09
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7.082E-06   3269739.      0.000
    25.500 -5.421E-12  -0.000107 -2.033E-05      0.000     11227.  4.080E+09
4.946E-06   3284721.      0.000
    25.800 -3.383E-12  -0.000148 -5.844E-06      0.000     11227.  4.080E+09
3.101E-06   3299702.      0.000
    26.100 -1.816E-12  -0.000149  2.747E-06      0.000     11227.  4.080E+09
1.672E-06   3314684.      0.000
    26.400      0.000  -0.000128  6.958E-06      0.000     11227.  4.080E+09
6.676E-07   3329666.      0.000
    26.700      0.000 -9.913E-05  8.220E-06      0.000     11227.  4.080E+09
3.333E-08   3344648.      0.000
    27.000      0.000 -6.936E-05  7.717E-06      0.000     11227.  4.080E+09
-3.128E-07   3359629.      0.000
    27.300      0.000 -4.362E-05  6.334E-06      0.000     11227.  4.080E+09
-4.554E-07   3374611.      0.000
    27.600      0.000 -2.377E-05  4.671E-06      0.000     11227.  4.080E+09
-4.688E-07   3389593.      0.000
    27.900      0.000 -9.984E-06  3.087E-06      0.000     11227.  4.080E+09
-4.109E-07   3404575.      0.000
    28.200      0.000 -1.524E-06  1.767E-06      0.000     11227.  4.080E+09
-3.224E-07   3419556.      0.000
    28.500      0.000  2.757E-06  7.756E-07      0.000     11227.  4.080E+09
-2.285E-07   3434538.      0.000
    28.800      0.000  4.077E-06  1.086E-07      0.000     11227.  4.080E+09
-1.421E-07   3449520.      0.000
    29.100      0.000  3.554E-06 -2.685E-07      0.000     11227.  4.080E+09
-6.741E-08   3464502.      0.000
    29.400      0.000  2.157E-06 -3.953E-07      0.000     11227.  4.080E+09
-2.994E-09   3479483.      0.000
    29.700      0.000  7.200E-07 -3.010E-07      0.000     11227.  4.080E+09
5.533E-08   3494465.      0.000
    30.000      0.000      0.000      0.000      0.000     11227.  4.080E+09
1.119E-07   1754723.      0.000

* This analysis computed pile response using nonlinear moment-curvature
relationships.
  Values of total stress due to combined axial and bending stresses are computed
only
  for elastic sections only and do not equal the actual stresses in concrete and
steel.
  Stresses in concrete and steel may be interpolated from the output for nonlinear
  bending properties relative to the magnitude of bending moment developed in the
pile.


Output Summary for Load Case No. 1:

Pile-head deflection             =      0.1407680 inches
Computed slope at pile head      =     -0.0054689 radians
Maximum bending moment           =        568959. inch-lbs
Maximum shear force              =         23950. lbs
Depth of maximum bending moment  =      2.1000000 feet below pile head
Depth of maximum shear force     =       0.000000 feet below pile head
Number of iterations             =             15
Number of zero deflection points =              9



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

Boundary Condition Type 1, Shear and Moment
```

Shear = 23950. lb
Moment = 192000. in- lb
Axial Load = 91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
30.0000	0.1407678	568959.	23950.
28.5000	0.1540423	581317.	23950.
27.0000	0.1476808	575637.	23950.
25.5000	0.1411398	568483.	23950.
24.0000	0.1505604	577954.	23950.
22.5000	0.1430903	569487.	23950.
21.0000	0.1495633	575894.	23950.
19.5000	0.1410812	568048.	23950.
18.0000	0.1444934	571778.	23950.
16.5000	0.1459815	573222.	23950.
15.0000	0.1454785	572338.	23950.
13.5000	0.1429959	569777.	23950.
12.0000	0.1464525	573399.	23950.
10.5000	0.1459405	572498.	23950.
9.0000	0.1474495	574204.	23950.
7.5000	0.1482376	574499.	23950.
6.0000	0.1522818	572958.	23950.

Summary of Pile Response(s)

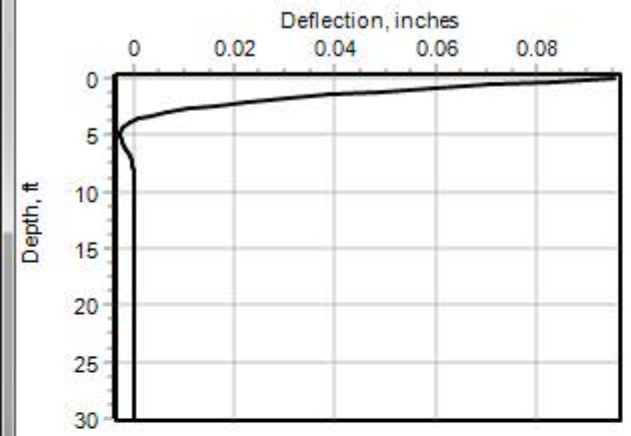
Definitions of Pile-head Loading Conditions:

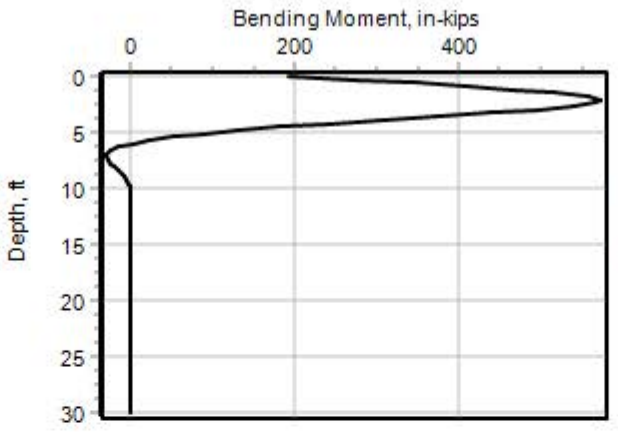
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

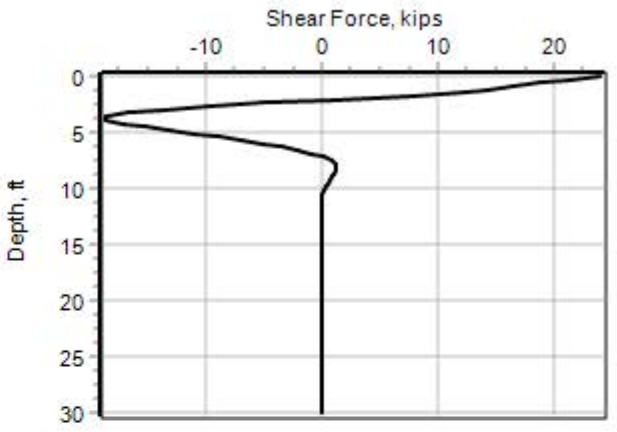
Load Case No.	Load Type No.	Pile-head Condition 1 V(lbs) or y(inches)	Pile-head Condition 2 in-lb, rad., or in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Shear in Pile lbs	Maximum Load Shear in Pile lbs	Pile-head Rotation radians
1	1	V = 23950.	M = 192000.	91000.	0.14076801	568959.	23950.		-0.00546894

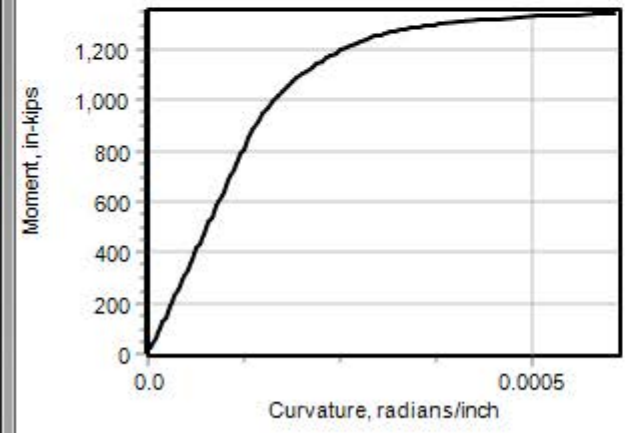
The analysis ended normally.

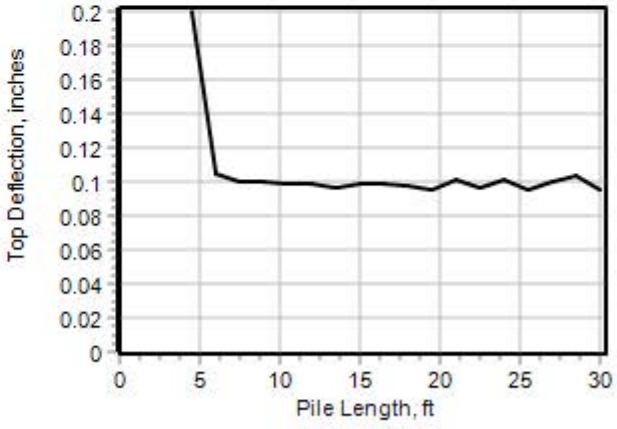
Results for Culvert#3_14inCIP_B-015s.lp7d











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LPile Plus for Windows, Version 2013-07.007

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

This copy of LPile is used by:

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_14inCIP_B-015s.lp7d
Name of output report file: Culvert#3_14inCIP_B-015s.lp7o
Name of plot output file: Culvert#3_14inCIP_B-015s.lp7p
Name of runtime messeage file: Culvert#3_14inCIP_B-015s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:37:52

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-015-0-14 & B-015-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	30.00 ft
Depth of ground surface below top of pile	=	-9.35 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	14.0000000
2	30.000000	14.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	30.00000 ft
Pile Diameter	=	14.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 4 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-9.35000 ft
Distance from top of pile to bottom of layer	=	1.75000 ft
Effective unit weight at top of layer	=	72.50000 pcf
Effective unit weight at bottom of layer	=	72.50000 pcf
Undrained cohesion at top of layer	=	1550.00000 psf
Undrained cohesion at bottom of layer	=	1550.00000 psf
Epsilon-50 at top of layer	=	0.00720
Epsilon-50 at bottom of layer	=	0.00720
Subgrade k at top of layer	=	521.00000 pci
Subgrade k at bottom of layer	=	521.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	1.75000 ft
Distance from top of pile to bottom of layer	=	13.75000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5250.00000 psf
Undrained cohesion at bottom of layer	=	5250.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1750.00000 pci
Subgrade k at bottom of layer	=	1750.00000 pci

Layer 3 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	13.75000 ft
Distance from top of pile to bottom of layer	=	21.25000 ft
Effective unit weight at top of layer	=	65.60000 pcf
Effective unit weight at bottom of layer	=	65.60000 pcf
Undrained cohesion at top of layer	=	3850.00000 psf

Undrained cohesion at bottom of layer	=	3850.00000 psf
Epsilon-50 at top of layer	=	0.00460
Epsilon-50 at bottom of layer	=	0.00460
Subgrade k at top of layer	=	1292.00000 pci
Subgrade k at bottom of layer	=	1292.00000 pci

Layer 4 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	21.25000 ft
Distance from top of pile to bottom of layer	=	30.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	3450.00000 psf
Undrained cohesion at bottom of layer	=	3450.00000 psf
Epsilon-50 at top of layer	=	0.00480
Epsilon-50 at bottom of layer	=	0.00480
Subgrade k at top of layer	=	1156.00000 pci
Subgrade k at bottom of layer	=	1156.00000 pci

(Depth of lowest soil layer extends 0.75 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-9.350	72.500	1550.000	0.00720	521.000
		1.750	72.500	1550.000	0.00720	521.000
2	Stiff Clay with Free Water	1.750	67.600	5250.000	0.00410	1750.000
		13.750	67.600	5250.000	0.00410	1750.000
3	Stiff Clay with Free Water	13.750	65.600	3850.000	0.00460	1292.000
		21.250	65.600	3850.000	0.00460	1292.000
4	Stiff Clay with Free Water	21.250	62.600	3450.000	0.00480	1156.000
		30.750	62.600	3450.000	0.00480	1156.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust is assumed to be acting axially for all pile batter angles.

Computations of Nominal Moment Capacity and Nonlinear Bending Stiffness

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

Number of Pile Sections Analyzed = 1

Pile Section No. 1:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	30.00000 ft
Outer Diameter of Pipe	=	14.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	9.48145 sq. in.
Moment of Inertia	=	225.14166 in^4
Elastic Bending Stiffness	=	6529108. kip-in^2
Plastic Modulus, Z	=	41.59510 in^3
Plastic Moment Capacity = Fy Z	=	1497.42348 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As	=	341.332 kips
Nominal Axial Tensile Capacity	=	-341.332 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips

1 91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003177	20.7442314	6528512.	111.1562973	10.2362676	
0.000006355	41.4884628	6528512.	59.0781487	10.8748464	
0.000009532	62.2326942	6528512.	41.7187658	11.5134250	
0.0000127	82.9769257	6528512.	33.0390743	12.1520036	
0.0000159	103.7211571	6528512.	27.8312595	12.7905822	
0.0000191	124.4653885	6528512.	24.3593829	13.4291607	
0.0000222	145.2096199	6528512.	21.8794710	14.0677394	
0.0000254	165.9538513	6528512.	20.0195372	14.7063179	
0.0000286	186.6980827	6528512.	18.5729219	15.3448967	
0.0000318	207.4423142	6528512.	17.4156297	15.9834752	
0.0000350	228.1865456	6528512.	16.4687543	16.6220539	
0.0000381	248.9307770	6528512.	15.6796914	17.2606325	
0.0000413	269.6750084	6528512.	15.0120229	17.8992112	
0.0000445	290.4192398	6528512.	14.4397355	18.5377898	
0.0000477	311.1634712	6528512.	13.9437532	19.1763684	
0.0000508	331.9077026	6528512.	13.5097686	19.8149470	
0.0000540	352.6519341	6528512.	13.1268410	20.4535257	
0.0000572	373.3961655	6528512.	12.7864610	21.0921043	
0.0000604	394.1403969	6528512.	12.4819104	21.7306829	
0.0000635	414.8846283	6528512.	12.2078149	22.3692616	
0.0000667	435.6288597	6528512.	11.9598237	23.0078402	
0.0000699	456.3730911	6528512.	11.7343772	23.6464188	
0.0000731	477.1173226	6528512.	11.5285347	24.2849975	
0.0000763	497.8615540	6528512.	11.3398457	24.9235761	
0.0000794	518.6057854	6528512.	11.1662519	25.5621547	
0.0000826	539.3500168	6528512.	11.0060114	26.2007333	
0.0000858	560.0942482	6528512.	10.8576406	26.8393120	
0.0000890	580.8384796	6528512.	10.7198678	27.4778906	
0.0000921	601.5827111	6528512.	10.5915965	28.1164692	
0.0000953	622.3269425	6528512.	10.4718766	28.7550479	
0.0000985	643.0711739	6528512.	10.3598806	29.3936265	
0.0001017	663.8154053	6528512.	10.2548843	30.0322051	
0.0001049	684.5596367	6528512.	10.1562514	30.6707837	
0.0001080	705.3038681	6528512.	10.0634205	31.3093624	
0.0001112	726.0480995	6528512.	9.9758942	31.9479410	
0.0001144	746.7923310	6528512.	9.8932305	32.5865196	
0.0001176	767.5365624	6528512.	9.8150351	33.2250983	
0.0001207	788.2807938	6528512.	9.7409552	33.8636769	
0.0001239	809.0250252	6528512.	9.6706743	34.5022555	
0.0001303	850.5134880	6528512.	9.5403975	35.7794128	Y
0.0001366	888.4840391	6502765.	9.4358717	36.0000000	Y
0.0001430	920.1116790	6434946.	9.3647454	36.0000000	Y
0.0001493	948.2061189	6349240.	9.3131648	36.0000000	Y
0.0001557	973.5796758	6253055.	9.2761998	36.0000000	Y
0.0001621	996.7217948	6150645.	9.2506833	36.0000000	Y
0.0001684	1017.9829880	6044794.	9.2343152	36.0000000	Y
0.0001748	1037.6368196	5937444.	9.2253228	36.0000000	Y
0.0001811	1055.9080589	5829994.	9.2222894	36.0000000	Y
0.0001875	1072.9877235	5723472.	9.2240523	36.0000000	Y
0.0001938	1088.9145376	5617988.	9.2301495	36.0000000	Y

0.0002002	1103.9047270	5514522.	9.2394839	36.0000000	Y
0.0002065	1117.9907765	5413046.	9.2517411	36.0000000	Y
0.0002129	1131.3329838	5314134.	9.2661462	36.0000000	Y
0.0002192	1143.8756909	5217309.	9.2828157	36.0000000	Y
0.0002256	1155.7964593	5123183.	9.3009630	36.0000000	Y
0.0002320	1167.1335274	5031698.	9.3203812	36.0000000	Y
0.0002383	1177.9180972	4942773.	9.3409073	36.0000000	Y
0.0002447	1188.1476750	4856200.	9.3625254	36.0000000	Y
0.0002510	1197.9142415	4772165.	9.3848537	36.0000000	Y
0.0002574	1207.2484173	4690601.	9.4077648	36.0000000	Y
0.0002637	1216.1795120	4611439.	9.4311429	36.0000000	Y
0.0002701	1224.7356134	4534614.	9.4548828	36.0000000	Y
0.0002764	1232.9436671	4460061.	9.4788879	36.0000000	Y
0.0002828	1240.5526340	4386742.	9.5012324	36.0000000	Y
0.0002892	1247.5425917	4314504.	9.5221386	36.0000000	Y
0.0002955	1253.7132389	4242600.	9.5394456	36.0000000	Y
0.0003019	1259.3857384	4172074.	9.5549624	36.0000000	Y
0.0003082	1264.4962325	4102633.	9.5678278	36.0000000	Y
0.0003146	1269.2541211	4034876.	9.5804411	36.0000000	Y
0.0003209	1273.5749871	3968442.	9.5911348	36.0000000	Y
0.0003273	1277.7067624	3904009.	9.6011995	36.0000000	Y
0.0003336	1281.4341893	3840819.	9.6105721	36.0000000	Y
0.0003400	1284.9888204	3779483.	9.6189486	36.0000000	Y
0.0003463	1288.3094478	3719723.	9.6272544	36.0000000	Y
0.0003527	1291.3844866	3661419.	9.6341828	36.0000000	Y
0.0003591	1294.3438283	3604857.	9.6416218	36.0000000	Y
0.0003654	1297.0610132	3549600.	9.6475361	36.0000000	Y
0.0003718	1299.6293589	3495832.	9.6536994	36.0000000	Y
0.0003781	1302.1524425	3443751.	9.6595104	36.0000000	Y
0.0004035	1310.6043232	3247766.	9.6787469	36.0000000	Y
0.0004290	1317.5678936	3071539.	9.6940785	36.0000000	Y
0.0004544	1323.2738340	2912263.	9.7070292	36.0000000	Y
0.0004798	1328.0556807	2767937.	9.7175539	36.0000000	Y
0.0005052	1332.1017391	2636678.	9.7263358	36.0000000	Y
0.0005306	1335.5733438	2516913.	9.7339093	36.0000000	Y
0.0005561	1338.5986350	2407294.	9.7405798	36.0000000	Y
0.0005815	1341.1306317	2306412.	9.7455102	36.0000000	Y
0.0006069	1343.3708889	2213499.	9.7507176	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	1343.4

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. Distrib. p
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in
Es*h lb/inch	Lat. Load lb/inch						
0.00	0.0954	192000.	23950.	-0.003575	15567.	6.529E+09	
-760.4639	14349.	0.000					
0.300	0.0827	274446.	21277.	-0.003446	18131.	6.529E+09	
-724.7481	31542.	0.000					
0.600	0.0706	347450.	18741.	-0.003275	20400.	6.529E+09	
-683.8600	34879.	0.000					
0.900	0.0591	411528.	16367.	-0.003066	22393.	6.529E+09	
-634.8759	38647.	0.000					
1.200	0.0485	467304.	14190.	-0.002823	24127.	6.529E+09	
-575.0087	42672.	0.000					
1.500	0.0388	515543.	12229.	-0.002552	25627.	6.529E+09	
-514.3197	47708.	0.000					
1.800	0.0301	557023.	7641.5071	-0.002257	26916.	6.529E+09	
-2034.1851	243023.	0.000					
2.100	0.0226	572040.	811.5962	-0.001945	27383.	6.529E+09	
-1760.2099	280859.	0.000					
2.400	0.0161	564142.	-5035.5074	-0.001632	27138.	6.529E+09	
-1488.1810	332215.	0.000					
2.700	0.0108	536854.	-9907.5668	-0.001329	26289.	6.529E+09	
-1218.5186	405770.	0.000					
3.000	0.006561	493678.	-13810.	-0.001044	24947.	6.529E+09	
-949.3244	520913.	0.000					
3.300	0.003291	438109.	-16729.	-0.000788	23219.	6.529E+09	
-672.4601	735655.	0.000					
3.600	0.000890	373746.	-18570.	-0.000564	21218.	6.529E+09	
-350.1429	1415541.	0.000					
3.900	-0.000768	304777.	-18616.	-0.000377	19074.	6.529E+09	
324.2461	1520206.	0.000					
4.200	-0.001821	239956.	-17133.	-0.000226	17058.	6.529E+09	
499.7970	987984.	0.000					
4.500	-0.002398	181568.	-15201.	-0.000110	15243.	6.529E+09	
573.6325	861126.	0.000					
4.800	-0.002615	130583.	-13090.	-2.414E-05	13658.	6.529E+09	
599.0161	824764.	0.000					
5.100	-0.002572	87336.	-10942.	3.594E-05	12313.	6.529E+09	
594.1308	831620.	0.000					
5.400	-0.002356	51774.	-8849.3211	7.430E-05	11207.	6.529E+09	
568.6426	868947.	0.000					
5.700	-0.002037	23573.	-6873.9712	9.507E-05	10331.	6.529E+09	
528.7740	934505.	0.000					
6.000	-0.001671	2219.4342	-5060.0165	0.000102	9666.6946	6.529E+09	
478.9786	1031696.	0.000					
6.300	-0.001301	-12927.	-3437.0911	9.923E-05	9999.5943	6.529E+09	

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422.6466   1169245.      0.000
     6.600  -0.000957    -22593. -2023.9440  8.944E-05     10300.  6.529E+09
362.4351   1363542.      0.000
     6.900  -0.000657    -27558.  -830.8340  7.561E-05     10454.  6.529E+09
300.4038   1645176.      0.000
     7.200  -0.000413    -28624.   138.2535  6.012E-05     10488.  6.529E+09
237.9781   2076863.      0.000
     7.500  -0.000224    -26601.   816.8692  4.489E-05     10425.  6.529E+09
139.0306   2229552.      0.000
     7.800 -8.928E-05    -22772.  1167.6626  3.128E-05     10306.  6.529E+09
55.8545   2252232.      0.000
     8.100  7.259E-07    -18215.  1267.3750  1.998E-05     10164.  6.529E+09
-0.4587   2274912.      0.000
     8.400  5.457E-05    -13660.  1203.8575  1.119E-05     10022.  6.529E+09
-34.8287   2297592.      0.000
     8.700  8.130E-05 -9554.3615  1046.8465  4.790E-06  9894.7488  6.529E+09
-52.3996   2320272.      0.000
     9.000  8.906E-05 -6125.9698   848.1932  4.670E-07  9788.1548  6.529E+09
-57.9633   2342952.      0.000
     9.300  8.466E-05 -3447.6761   643.7187 -2.173E-06  9704.8825  6.529E+09
-55.6337   2365632.      0.000
     9.600  7.342E-05 -1489.7719   455.9036 -3.534E-06  9644.0083  6.529E+09
-48.7081   2388312.      0.000
     9.900  5.922E-05  -162.8550   296.8408 -3.990E-06  9602.7524  6.529E+09
-39.6602   2410992.      0.000
    10.200  4.470E-05   650.0957   171.0659 -3.855E-06  9617.9015  6.529E+09
-30.2148   2433672.      0.000
    10.500  3.146E-05  1071.3454    78.0388 -3.381E-06  9630.9988  6.529E+09
-21.4670   2456352.      0.000
    10.800  2.036E-05  1214.1899    14.1678 -2.750E-06  9635.4400  6.529E+09
-14.0169   2479032.      0.000
    11.100  1.166E-05  1175.1557   -25.6461 -2.092E-06  9634.2264  6.529E+09
-8.1019   2501712.      0.000
    11.400  5.295E-06  1030.9082   -46.9134 -1.483E-06  9629.7415  6.529E+09
-3.7132   2524392.      0.000
    11.700  9.784E-07   838.3512   -54.8432 -9.680E-07  9623.7546  6.529E+09
-0.6923   2547072.      0.000
    12.000 -1.674E-06   636.6711   -53.9380 -5.613E-07  9617.4841  6.529E+09
1.1951   2569752.      0.000
    12.300 -3.063E-06   450.3651   -47.8164 -2.616E-07  9611.6915  6.529E+09
2.2058   2592432.      0.000
    12.600 -3.558E-06   292.5648   -39.1938 -5.678E-08  9606.7853  6.529E+09
2.5845   2615112.      0.000
    12.900 -3.472E-06   168.2071   -29.9626  7.027E-08  9602.9188  6.529E+09
2.5439   2637792.      0.000
    13.200 -3.052E-06    76.7882   -21.3237  1.378E-07  9600.0764  6.529E+09
2.2555   2660472.      0.000
    13.500 -2.480E-06    14.5864   -13.9372  1.630E-07  9598.1425  6.529E+09
1.8481   2683152.      0.000
    13.800 -1.878E-06   -23.6664    -8.0884  1.605E-07  9598.4248  6.529E+09
1.4012   2685528.      0.000
    14.100 -1.324E-06   -43.7555    -3.7774  1.419E-07  9599.0494  6.529E+09
0.9938   2702273.      0.000
    14.400 -8.565E-07   -50.9564    -0.8240  1.158E-07  9599.2733  6.529E+09
0.6469   2719017.      0.000
    14.700 -4.902E-07   -49.7639     1.0111  8.803E-08  9599.2362  6.529E+09
0.3726   2735761.      0.000
    15.000 -2.227E-07   -43.7341     1.9882  6.225E-08  9599.0487  6.529E+09
0.1703   2752506.      0.000
    15.300 -4.203E-08   -35.4895     2.3529  4.041E-08  9598.7924  6.529E+09
0.0323   2769250.      0.000
    15.600  6.822E-08   -26.8194     2.3161  2.323E-08  9598.5228  6.529E+09
-0.0528   2785994.      0.000
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    15.900  1.252E-07   -18.8288     2.0456  1.064E-08  9598.2744  6.529E+09
-0.0975   2802738.      0.000
    16.200  1.449E-07   -12.0983     1.6659  2.117E-09  9598.0651  6.529E+09
-0.1135   2819483.      0.000
    16.500  1.405E-07    -6.8359     1.2625 -3.103E-09  9597.9015  6.529E+09
-0.1107   2836227.      0.000
    16.800  1.225E-07    -3.0066     0.8885 -5.817E-09  9597.7825  6.529E+09
-0.0971   2852971.      0.000
    17.100  9.859E-08    -0.4350     0.5723 -6.766E-09  9597.7025  6.529E+09
-0.0786   2869716.      0.000
    17.400  7.380E-08     1.1181     0.3243 -6.578E-09  9597.7237  6.529E+09
-0.0592   2886460.      0.000
    17.700  5.123E-08     1.9042     0.1434 -5.744E-09  9597.7482  6.529E+09
-0.0413   2903204.      0.000
    18.000  3.244E-08     2.1545     0.0217 -4.625E-09  9597.7560  6.529E+09
-0.0263   2919949.      0.000
    18.300  1.793E-08     2.0635    -0.0520 -3.462E-09  9597.7531  6.529E+09
-0.0146   2936693.      0.000
    18.600  7.509E-09     1.7826    -0.0894 -2.402E-09  9597.7444  6.529E+09
-0.006160   2953437.      0.000
    18.900  6.311E-10     1.4215    -0.1014 -1.519E-09  9597.7332  6.529E+09
-0.000521   2970182.      0.000
    19.200 -3.425E-09     1.0534    -0.0972 -8.362E-10  9597.7217  6.529E+09
0.002842   2986926.      0.000
    19.500 -5.390E-09     0.7220    -0.0840 -3.467E-10  9597.7114  6.529E+09
0.004497   3003670.      0.000
    19.800 -5.921E-09     0.4486    -0.0670 -2.397E-11  9597.7029  6.529E+09
0.004968   3020415.      0.000
    20.100 -5.562E-09     0.2396    -0.0496  1.658E-10  9597.6964  6.529E+09
0.004693   3037159.      0.000
    20.400 -4.727E-09     0.0914    -0.0339  2.571E-10  9597.6918  6.529E+09
0.004010   3053903.      0.000
    20.700 -3.711E-09  -0.004860    -0.0210  2.809E-10  9597.6891  6.529E+09
0.003165   3070648.      0.000
    21.000 -2.705E-09    -0.0601    -0.0111  2.630E-10  9597.6908  6.529E+09
0.002320   3087392.      0.000
    21.300 -1.817E-09    -0.0853  -0.004166  2.229E-10  9597.6916  6.529E+09
0.001558   3086698.      0.000
    21.600 -1.099E-09    -0.0902   0.000344  1.745E-10  9597.6918  6.529E+09
0.000947   3101680.      0.000
    21.900 -5.607E-10    -0.0829   0.002923  1.268E-10  9597.6916  6.529E+09
0.000485   3116661.      0.000
    22.200 -1.865E-10    -0.0693   0.004088  8.483E-11  9597.6911  6.529E+09
0.000162   3131643.      0.000
    22.500  5.015E-11    -0.0535   0.004301  5.097E-11  9597.6906  6.529E+09
-4.383E-05   3146625.      0.000
    22.800  1.805E-10    -0.0384   0.003937  2.563E-11  9597.6902  6.529E+09
-0.000159   3161607.      0.000
    23.100  2.347E-10    -0.0252   0.003279  8.106E-12  9597.6898  6.529E+09
-0.000207   3176588.      0.000
    23.400  2.388E-10    -0.0147   0.002525 -2.912E-12  9597.6894  6.529E+09
-0.000212   3191570.      0.000
    23.700  2.137E-10  -0.007028   0.001801 -8.916E-12  9597.6892  6.529E+09
-0.000190   3206552.      0.000
    24.000  1.747E-10  -0.001773   0.001177 -1.134E-11  9597.6890  6.529E+09
-0.000156   3221534.      0.000
    24.300  1.321E-10   0.001457   0.000682 -1.143E-11  9597.6890  6.529E+09
-0.000119   3236515.      0.000
    24.600  9.237E-11   0.003148   0.000318 -1.016E-11  9597.6891  6.529E+09
-8.343E-05   3251497.      0.000
    24.900  5.892E-11   0.003757  7.207E-05 -8.256E-12  9597.6891  6.529E+09
-5.346E-05   3266479.      0.000
    25.200  3.293E-11   0.003672 -7.818E-05 -6.207E-12  9597.6891  6.529E+09
```

-3.001E-05	3281461.	0.000				
25.500	1.423E-11	0.003198	-0.000156	-4.313E-12	9597.6891	6.529E+09
-1.303E-05	3296442.	0.000				
25.800	1.873E-12	0.002554	-0.000182	-2.727E-12	9597.6891	6.529E+09
-1.723E-06	3311424.	0.000				
26.100	-5.409E-12	0.001888	-0.000176	-1.502E-12	9597.6890	6.529E+09
4.998E-06	3326406.	0.000				
26.400	-8.944E-12	0.001286	-0.000152	0.000	9597.6890	6.529E+09
8.301E-06	3341388.	0.000				
26.700	-9.926E-12	0.000791	-0.000121	0.000	9597.6890	6.529E+09
9.254E-06	3356370.	0.000				
27.000	-9.336E-12	0.000416	-8.837E-05	0.000	9597.6890	6.529E+09
8.743E-06	3371351.	0.000				
27.300	-7.920E-12	0.000155	-5.922E-05	0.000	9597.6890	6.529E+09
7.450E-06	3386333.	0.000				
27.600	-6.197E-12	-1.018E-05	-3.527E-05	0.000	9597.6890	6.529E+09
5.855E-06	3401315.	0.000				
27.900	-4.494E-12	-9.937E-05	-1.705E-05	0.000	9597.6890	6.529E+09
4.265E-06	3416297.	0.000				
28.200	-2.988E-12	-0.000133	-4.251E-06	0.000	9597.6890	6.529E+09
2.848E-06	3431278.	0.000				
28.500	-1.747E-12	-0.000130	3.885E-06	0.000	9597.6890	6.529E+09
1.672E-06	3446260.	0.000				
28.800	0.000	-0.000105	8.217E-06	0.000	9597.6890	6.529E+09
7.344E-07	3461242.	0.000				
29.100	0.000	-7.123E-05	9.522E-06	0.000	9597.6890	6.529E+09
-9.252E-09	3476224.	0.000				
29.400	0.000	-3.706E-05	8.385E-06	0.000	9597.6890	6.529E+09
-6.222E-07	3491205.	0.000				
29.700	1.200E-12	-1.096E-05	5.162E-06	0.000	9597.6890	6.529E+09
-1.169E-06	3506187.	0.000				
30.000	1.737E-12	0.000	0.000	0.000	9597.6890	6.529E+09
-1.699E-06	1760584.	0.000				

* This analysis computed pile response using nonlinear moment-curvature relationships.
  Values of total stress due to combined axial and bending stresses are computed only
  for elastic sections only and do not equal the actual stresses in concrete and steel.
  Stresses in concrete and steel may be interpolated from the output for nonlinear
  bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.0953979 inches
Computed slope at pile head	=	-0.0035750 radians
Maximum bending moment	=	572040. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.1000000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	13
Number of zero deflection points	=	8

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

Boundary Condition Type 1, Shear and Moment

Shear = 23950. lb
Moment = 192000. in- lb
Axial Load = 91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
30.0000	0.0953977	572040.	23950.
28.5000	0.1037773	583577.	23950.
27.0000	0.0997303	578076.	23950.
25.5000	0.0956817	570814.	23950.
24.0000	0.1015542	579755.	23950.
22.5000	0.0968869	572947.	23950.
21.0000	0.1008988	578617.	23950.
19.5000	0.0956059	571721.	23950.
18.0000	0.0977753	574858.	23950.
16.5000	0.0986985	575858.	23950.
15.0000	0.0983757	575166.	23950.
13.5000	0.0968083	573254.	23950.
12.0000	0.0989723	576172.	23950.
10.5000	0.0986615	575835.	23950.
9.0000	0.0996440	576819.	23950.
7.5000	0.1000865	577142.	23950.
6.0000	0.1047912	572183.	23950.
4.5000	0.1996948	523270.	-29085.

Summary of Pile Response(s)

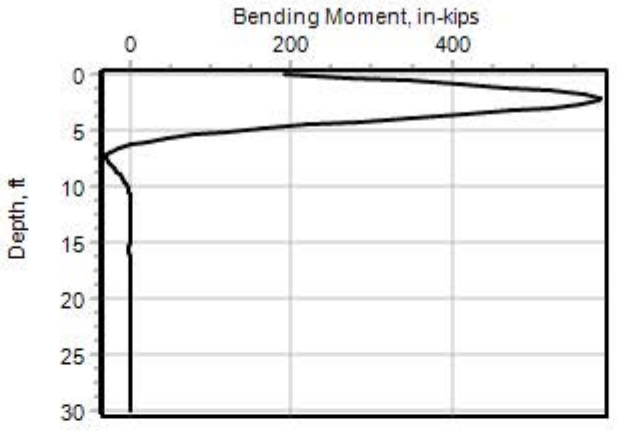
Definitions of Pile-head Loading Conditions:

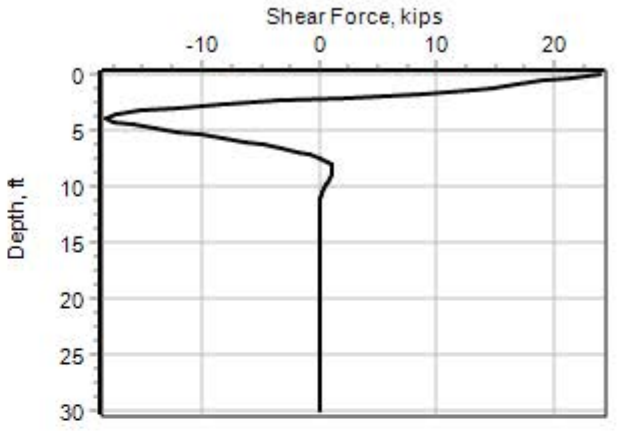
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

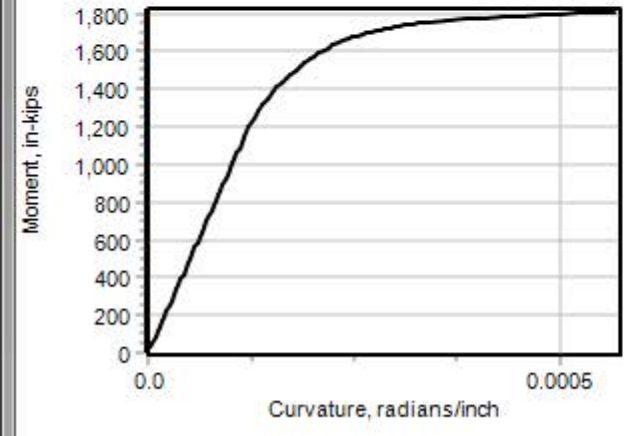
Load Case No.	Pile-head Load Type No.	Pile-head Condition 1 V(lbs) or y(inches)	Pile-head Condition 2 in-lb, rad., or Rotation in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Shear in Pile lbs	Maximum Pile-head Rotation radians
1	1	V = 23950.	M = 192000.	91000.	0.09539794	572040.	23950.	-0.00357503

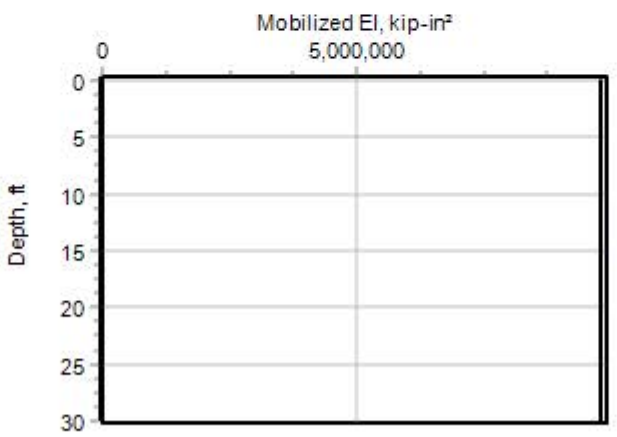
The analysis ended normally.

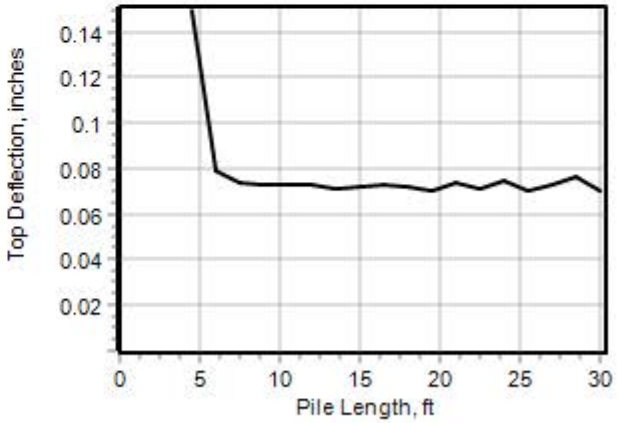
Results for Culvert#3_16inCIP_B-015s.lp7d











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LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_16inCIP_B-016s.lp7d
Name of output report file: Culvert#3_16inCIP_B-016s.lp7o
Name of plot output file: Culvert#3_16inCIP_B-016s.lp7p
Name of runtime messeage file: Culvert#3_16inCIP_B-016s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:53:12

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-016-0-14 & B-016-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	19.00 ft
Depth of ground surface below top of pile	=	-0.65 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	16.0000000
2	19.000000	16.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	19.00000 ft
Pile Diameter	=	16.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 2 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.65000 ft
Distance from top of pile to bottom of layer	=	3.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	2750.00000 psf
Undrained cohesion at bottom of layer	=	2750.00000 psf
Epsilon-50 at top of layer	=	0.00530
Epsilon-50 at bottom of layer	=	0.00530
Subgrade k at top of layer	=	917.00000 pci
Subgrade k at bottom of layer	=	917.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	3.75000 ft
Distance from top of pile to bottom of layer	=	19.85000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5050.00000 psf
Undrained cohesion at bottom of layer	=	5050.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1692.00000 pci
Subgrade k at bottom of layer	=	1692.00000 pci

(Depth of lowest soil layer extends 0.85 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-0.650	62.600	2750.000	0.00530	917.000
		3.750	62.600	2750.000	0.00530	917.000
2	Stiff Clay with Free Water	3.750	67.600	5050.000	0.00410	1692.000
		19.850	67.600	5050.000	0.00410	1692.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Compute Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section = 19.00000 ft
Outer Diameter of Pipe = 16.00000 in
Pipe Wall Thickness = 0.21900 in
Yield Stress of Pipe = 36.00000 ksi
Elastic Modulus = 29000. ksi
Cross-sectional Area = 10.85747 sq. in.
Moment of Inertia = 338.05798 in^4
Elastic Bending Stiffness = 9803681. kip-in^2
Plastic Modulus, Z = 54.54325 in^3
Plastic Moment Capacity = Fy Z = 1963.55709 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 390.869 kips
Nominal Axial Tensile Capacity = -390.869 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000002846	27.8945447	9801889.	109.5559504	9.0349600	
0.000005692	55.7890894	9801889.	58.7779752	9.6885910	
0.000008538	83.6836340	9801889.	41.8519835	10.3422222	
0.0000114	111.5781787	9801889.	33.3889876	10.9958533	
0.0000142	139.4727234	9801889.	28.3111901	11.6494843	
0.0000171	167.3672681	9801889.	24.9259917	12.3031154	
0.0000199	195.2618128	9801889.	22.5079929	12.9567465	
0.0000228	223.1563575	9801889.	20.6944938	13.6103776	
0.0000256	251.0509021	9801889.	19.2839945	14.2640087	
0.0000285	278.9454468	9801889.	18.1555950	14.9176397	
0.0000313	306.8399915	9801889.	17.2323591	15.5712708	
0.0000342	334.7345362	9801889.	16.4629959	16.2249019	
0.0000370	362.6290809	9801889.	15.8119962	16.8785330	
0.0000398	390.5236255	9801889.	15.2539965	17.5321641	
0.0000427	418.4181702	9801889.	14.7703967	18.1857952	
0.0000455	446.3127149	9801889.	14.3472469	18.8394263	
0.0000484	474.2072596	9801889.	13.9738794	19.4930574	
0.0000512	502.1018043	9801889.	13.6419972	20.1466884	
0.0000541	529.9963490	9801889.	13.3450500	20.8003195	
0.0000569	557.8908936	9801889.	13.0777975	21.4539506	
0.0000598	585.7854383	9801889.	12.8359976	22.1075817	
0.0000626	613.6799830	9801889.	12.6161796	22.7612128	
0.0000655	641.5745277	9801889.	12.4154761	23.4148439	

0.0000683	669.4690724	9801889.	12.2314979	24.0684749	
0.0000711	697.3636170	9801889.	12.0622380	24.7221060	
0.0000740	725.2581617	9801889.	11.9059981	25.3757371	
0.0000768	753.1527064	9801889.	11.7613315	26.0293682	
0.0000797	781.0472511	9801889.	11.6269982	26.6829993	
0.0000825	808.9417958	9801889.	11.5019293	27.3366304	
0.0000854	836.8363404	9801889.	11.3851983	27.9902614	
0.0000882	864.7308851	9801889.	11.2759984	28.6438925	
0.0000911	892.6254298	9801889.	11.1736234	29.2975236	
0.0000939	920.5199745	9801889.	11.0774530	29.9511547	
0.0000968	948.4145192	9801889.	10.9869397	30.6047858	
0.0000996	976.3090639	9801889.	10.9015986	31.2584169	
0.0001025	1004.2036085	9801889.	10.8209986	31.9120480	
0.0001053	1032.0981532	9801889.	10.7447554	32.5656790	
0.0001081	1059.9926979	9801889.	10.6725250	33.2193101	
0.0001110	1087.8872426	9801889.	10.6039987	33.8729412	
0.0001167	1143.6763319	9801889.	10.4769744	35.1802034	
0.0001224	1198.1090748	9790805.	10.3662110	36.0000000	Y
0.0001281	1243.6109150	9710967.	10.2938089	36.0000000	Y
0.0001338	1283.3508937	9594847.	10.2459050	36.0000000	Y
0.0001394	1319.0834079	9459467.	10.2147074	36.0000000	Y
0.0001451	1351.5945763	9312510.	10.1962604	36.0000000	Y
0.0001508	1381.4164312	9158814.	10.1878253	36.0000000	Y
0.0001565	1408.9517314	9001687.	10.1873471	36.0000000	Y
0.0001622	1434.5252101	8843493.	10.1932115	36.0000000	Y
0.0001679	1458.4093728	8685962.	10.2041103	36.0000000	Y
0.0001736	1480.6615391	8529360.	10.2195538	36.0000000	Y
0.0001793	1501.5977795	8375361.	10.2382681	36.0000000	Y
0.0001850	1521.2701184	8224007.	10.2599116	36.0000000	Y
0.0001907	1539.8782834	8076107.	10.2837034	36.0000000	Y
0.0001964	1557.3877960	7931187.	10.3096716	36.0000000	Y
0.0002021	1574.0275434	7790126.	10.3369970	36.0000000	Y
0.0002077	1589.8507759	7652864.	10.3654688	36.0000000	Y
0.0002134	1604.8447131	7519037.	10.3951112	36.0000000	Y
0.0002191	1619.1116034	7388845.	10.4255766	36.0000000	Y
0.0002248	1632.7293955	7262357.	10.4566111	36.0000000	Y
0.0002305	1645.2778322	7137477.	10.4856004	36.0000000	Y
0.0002362	1656.7404260	7014018.	10.5120844	36.0000000	Y
0.0002419	1666.4962254	6889313.	10.5320564	36.0000000	Y
0.0002476	1675.4900520	6767264.	10.5503623	36.0000000	Y
0.0002533	1683.6050104	6647230.	10.5663824	36.0000000	Y
0.0002590	1690.9507104	6529502.	10.5805613	36.0000000	Y
0.0002647	1697.8782759	6415257.	10.5941423	36.0000000	Y
0.0002704	1704.1280745	6303316.	10.6050739	36.0000000	Y
0.0002760	1710.0414337	6194773.	10.6165575	36.0000000	Y
0.0002817	1715.3820402	6088582.	10.6259222	36.0000000	Y
0.0002874	1720.5795793	5986099.	10.6353391	36.0000000	Y
0.0002931	1725.1763589	5885546.	10.6434922	36.0000000	Y
0.0002988	1729.7140234	5788626.	10.6516739	36.0000000	Y
0.0003045	1733.7598184	5693714.	10.6586115	36.0000000	Y
0.0003102	1737.7121426	5601984.	10.6655041	36.0000000	Y
0.0003159	1741.3402898	5512532.	10.6719068	36.0000000	Y
0.0003216	1744.8032643	5425734.	10.6775237	36.0000000	Y
0.0003273	1748.0944257	5341430.	10.6838703	36.0000000	Y
0.0003330	1751.1507726	5259303.	10.6881761	36.0000000	Y
0.0003387	1754.0194355	5179382.	10.6936149	36.0000000	Y
0.0003614	1764.2808887	4881514.	10.7106576	36.0000000	Y
0.0003842	1772.5149920	4613671.	10.7244801	36.0000000	Y
0.0004070	1779.3832122	4372441.	10.7357798	36.0000000	Y
0.0004297	1785.1557706	4154222.	10.7452183	36.0000000	Y
0.0004525	1790.0576895	3956037.	10.7533818	36.0000000	Y
0.0004753	1794.2422813	3775332.	10.7602677	36.0000000	Y
0.0004980	1797.8122768	3609913.	10.7653565	36.0000000	Y

0.0005208	1800.9570816	3458142.	10.7702091	36.0000000	Y
0.0005436	1803.6711664	3318291.	10.7752934	36.0000000	Y
0.0005663	1806.0555818	3189103.	10.7783424	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	1806.1

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. Distrib. p
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in
							Es*h Lat. Load lb/inch lb/inch
0.00	0.1164	192000.	23950.	-0.003402	12925.	9.802E+09	-400.6634 3925.5616 0.000
0.190	0.1086	246266.	22947.	-0.003351	14209.	9.802E+09	-479.1766 10056. 0.000
0.380	0.1011	298029.	21773.	-0.003288	15434.	9.802E+09	-550.3279 12414. 0.000
0.570	0.0937	346917.	20446.	-0.003213	16591.	9.802E+09	-614.3213 14956. 0.000
0.760	0.0864	392594.	18980.	-0.003127	17672.	9.802E+09	-671.2509 17709. 0.000
0.950	0.0794	434764.	17393.	-0.003031	18670.	9.802E+09	-721.1353 20709. 0.000
1.140	0.0726	473163.	15700.	-0.002925	19579.	9.802E+09	-763.9319 23991. 0.000
1.330	0.0661	507569.	13917.	-0.002811	20393.	9.802E+09	

-799.5332	27597.	0.000				
1.520	0.0598	537793.	12062.	-0.002690	21108.	9.802E+09
-827.7321	31569.	0.000				
1.710	0.0538	563689.	10152.	-0.002562	21721.	9.802E+09
-848.0979	35948.	0.000				
1.900	0.0481	585149.	8205.6285	-0.002428	22229.	9.802E+09
-859.1747	40726.	0.000				
2.090	0.0427	602114.	6252.2530	-0.002290	22630.	9.802E+09
-854.3126	45596.	0.000				
2.280	0.0377	614609.	4316.6166	-0.002148	22926.	9.802E+09
-843.6140	51076.	0.000				
2.470	0.0329	622689.	2411.4308	-0.002004	23117.	9.802E+09
-827.6016	57313.	0.000				
2.660	0.0285	626437.	548.7050	-0.001859	23206.	9.802E+09
-806.3685	64468.	0.000				
2.850	0.0244	625963.	-1259.7704	-0.001713	23194.	9.802E+09
-780.0134	72750.	0.000				
3.040	0.0207	621404.	-3002.4285	-0.001568	23087.	9.802E+09
-748.6341	82438.	0.000				
3.230	0.0173	612923.	-4667.9162	-0.001425	22886.	9.802E+09
-712.3200	93911.	0.000				
3.420	0.0142	600709.	-6205.3661	-0.001284	22597.	9.802E+09
-636.3203	102113.	0.000				
3.610	0.0114	585159.	-7542.1463	-0.001146	22229.	9.802E+09
-536.2939	106880.	0.000				
3.800	0.008983	566792.	-9455.5640	-0.001012	21794.	9.802E+09
-1142.1427	289881.	0.000				
3.990	0.006827	542461.	-11893.	-0.000883	21218.	9.802E+09
-995.6684	332535.	0.000				
4.180	0.004958	512928.	-13995.	-0.000760	20520.	9.802E+09
-848.5234	390216.	0.000				
4.370	0.003361	478959.	-15759.	-0.000645	19716.	9.802E+09
-698.6596	473946.	0.000				
4.560	0.002018	441335.	-17173.	-0.000538	18825.	9.802E+09
-541.4238	611657.	0.000				
4.750	0.000909	400876.	-18191.	-0.000440	17868.	9.802E+09
-351.5774	881418.	0.000				
4.940	1.328E-05	358569.	-18597.	-0.000351	16867.	9.802E+09
-5.1861	890213.	0.000				
5.130	-0.000693	316218.	-18292.	-0.000273	15864.	9.802E+09
273.1367	899009.	0.000				
5.320	-0.001231	275272.	-17499.	-0.000204	14896.	9.802E+09
422.7081	782923.	0.000				
5.510	-0.001623	236509.	-16463.	-0.000145	13978.	9.802E+09
485.4415	681828.	0.000				
5.700	-0.001890	200259.	-15313.	-9.376E-05	13120.	9.802E+09
523.8433	631885.	0.000				
5.890	-0.002051	166723.	-14093.	-5.107E-05	12327.	9.802E+09
545.6633	606643.	0.000				
6.080	-0.002123	136014.	-12838.	-1.586E-05	11600.	9.802E+09
555.1988	596242.	0.000				
6.270	-0.002123	108186.	-11573.	1.254E-05	10942.	9.802E+09
555.2192	596235.	0.000				
6.460	-0.002066	83238.	-10315.	3.480E-05	10351.	9.802E+09
547.6853	604450.	0.000				
6.650	-0.001964	61134.	-9082.0428	5.159E-05	9828.0350	9.802E+09
534.0779	619862.	0.000				
6.840	-0.001831	41803.	-7885.4462	6.356E-05	9370.5735	9.802E+09
515.5682	642128.	0.000				
7.030	-0.001675	25150.	-6735.5478	7.135E-05	8976.4885	9.802E+09
493.1146	671379.	0.000				
7.220	-0.001505	11059.	-5640.4232	7.556E-05	8643.0367	9.802E+09
467.5209	708146.	0.000				

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     7.410  -0.001330  -601.8799 -4606.4494  7.678E-05  8395.5722  9.802E+09
439.4737    753354.       0.000
     7.600  -0.001155 -9978.2198 -3638.5447  7.555E-05  8617.4593  9.802E+09
409.5655    808383.       0.000
     7.790  -0.000986    -17225. -2740.3666  7.238E-05  8788.9511  9.802E+09
378.3099    875189.       0.000
     7.980  -0.000825    -22504. -1914.4843  6.776E-05  8913.8844  9.802E+09
346.1483    956527.       0.000
     8.170  -0.000677    -25983. -1168.1545  6.212E-05  8996.2095  9.802E+09
308.5269   1039740.       0.000
     8.360  -0.000542    -27857.  -532.3840  5.586E-05  9040.5506  9.802E+09
249.1666   1048536.       0.000
     8.550  -0.000422    -28434.   -25.3299  4.932E-05  9054.2079  9.802E+09
195.6177   1057331.       0.000
     8.740  -0.000317    -27993.   366.6160  4.275E-05  9043.7682  9.802E+09
148.1945   1066127.       0.000
     8.930  -0.000227    -26780.   657.4936  3.638E-05  9015.0660  9.802E+09
106.9612   1074923.       0.000
     9.120  -0.000151    -25010.   861.2629  3.036E-05  8973.1750  9.802E+09
71.7838   1083719.       0.000
     9.310 -8.844E-05    -22865.   991.4062  2.479E-05  8922.4248  9.802E+09
42.3769   1092514.       0.000
     9.500 -3.798E-05    -20499.  1060.6288  1.975E-05  8866.4353  9.802E+09
18.3446   1101310.       0.000
     9.690  1.610E-06    -18037.  1080.6482  1.527E-05  8808.1657  9.802E+09
-0.7837   1110106.       0.000
     9.880  3.163E-05    -15578.  1062.0584  1.136E-05  8749.9720  9.802E+09
-15.5231   1118901.       0.000
    10.070  5.339E-05    -13199.  1014.2571  8.009E-06  8693.6700  9.802E+09
-26.4079   1127697.       0.000
    10.260  6.815E-05    -10956.   945.4249  5.200E-06  8640.6016  9.802E+09
-33.9713   1136493.       0.000
    10.450  7.710E-05 -8889.6947   862.5454  2.891E-06  8591.6998  9.802E+09
-38.7299   1145288.       0.000
    10.640  8.134E-05 -7024.1434   771.4581  1.041E-06  8547.5523  9.802E+09
-41.1712   1154084.       0.000
    10.830  8.185E-05 -5372.2774   676.9336 -4.011E-07  8508.4616  9.802E+09
-41.7451   1162880.       0.000
    11.020  7.951E-05 -3937.1597   582.7652 -1.484E-06  8474.5002  9.802E+09
-40.8588   1171675.       0.000
    11.210  7.508E-05 -2714.2521   491.8707 -2.257E-06  8445.5606  9.802E+09
-38.8733   1180471.       0.000
    11.400  6.921E-05 -1693.2925   406.3980 -2.770E-06  8421.4000  9.802E+09
-36.1028   1189267.       0.000
    11.590  6.245E-05  -859.9280   327.8314 -3.067E-06  8401.6788  9.802E+09
-32.8152   1198063.       0.000
    11.780  5.523E-05  -197.1084   257.0954 -3.190E-06  8385.9934  9.802E+09
-29.2340   1206858.       0.000
    11.970  4.790E-05   313.7509   194.6517 -3.176E-06  8388.7537  9.802E+09
-25.5413   1215654.       0.000
    12.160  4.074E-05   691.8212   140.5897 -3.059E-06  8397.7006  9.802E+09
-21.8815   1224450.       0.000
    12.350  3.395E-05   956.1096    94.7090 -2.868E-06  8403.9549  9.802E+09
-18.3648   1233245.       0.000
    12.540  2.767E-05  1124.8840    56.5909 -2.626E-06  8407.9488  9.802E+09
-15.0721   1242041.       0.000
    12.730  2.198E-05  1215.2536    25.6625 -2.354E-06  8410.0874  9.802E+09
-12.0581   1250837.       0.000
    12.920  1.694E-05  1242.8817     1.2502 -2.068E-06  8410.7412  9.802E+09
-9.3563   1259632.       0.000
    13.110  1.255E-05  1221.8123   -17.3758 -1.781E-06  8410.2426  9.802E+09
-6.9823   1268428.       0.000
    13.300  8.814E-06  1164.3873   -30.9642 -1.503E-06  8408.8837  9.802E+09
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-4.9374   1277224.      0.000
    13.490  5.695E-06  1081.2394   -40.2546 -1.242E-06  8406.9160  9.802E+09
-3.2120   1286019.      0.000
    13.680  3.149E-06   981.3418   -45.9549 -1.002E-06  8404.5520  9.802E+09
-1.7883   1294815.      0.000
    13.870  1.124E-06   872.1008   -48.7259 -7.869E-07  8401.9668  9.802E+09
-0.6424   1303611.      0.000
    14.060 -4.392E-07   759.4781   -49.1701 -5.971E-07  8399.3017  9.802E+09
0.2528   1312407.      0.000
    14.250 -1.599E-06   648.1331   -47.8254 -4.334E-07  8396.6667  9.802E+09
0.9267   1321202.      0.000
    14.440 -2.416E-06   541.5743   -45.1626 -2.950E-07  8394.1451  9.802E+09
1.4091   1329998.      0.000
    14.630 -2.945E-06   442.3142   -41.5851 -1.806E-07  8391.7961  9.802E+09
1.7290   1338794.      0.000
    14.820 -3.239E-06   352.0211   -37.4315 -8.822E-08  8389.6594  9.802E+09
1.9145   1347589.      0.000
    15.010 -3.347E-06   271.6630   -32.9792 -1.568E-08  8387.7577  9.802E+09
1.9911   1356385.      0.000
    15.200 -3.311E-06   201.6422   -28.4496  3.937E-08  8386.1007  9.802E+09
1.9823   1365181.      0.000
    15.390 -3.167E-06   141.9163   -24.0139  7.932E-08  8384.6873  9.802E+09
1.9087   1373976.      0.000
    15.580 -2.949E-06    92.1059   -19.7992  1.065E-07  8383.5086  9.802E+09
1.7884   1382772.      0.000
    15.770 -2.682E-06    51.5879   -15.8946  1.233E-07  8382.5497  9.802E+09
1.6366   1391568.      0.000
    15.960 -2.387E-06    19.5754   -12.3576  1.315E-07  8381.7922  9.802E+09
1.4660   1400363.      0.000
    16.150 -2.082E-06    -4.8172    -9.2196  1.332E-07  8381.4429  9.802E+09
1.2866   1409159.      0.000
    16.340 -1.779E-06   -22.5212    -6.4914  1.301E-07  8381.8619  9.802E+09
1.1065   1417955.      0.000
    16.530 -1.489E-06   -34.4719    -4.1680  1.234E-07  8382.1447  9.802E+09
0.9316   1426751.      0.000
    16.720 -1.216E-06   -41.5784    -2.2329  1.146E-07  8382.3129  9.802E+09
0.7658   1435546.      0.000
    16.910 -9.661E-07   -44.7017    -0.6622  1.046E-07  8382.3868  9.802E+09
0.6120   1444342.      0.000
    17.100 -7.396E-07   -44.6413     0.5729  9.417E-08  8382.3853  9.802E+09
0.4714   1453138.      0.000
    17.290 -5.367E-07   -42.1285     1.5025  8.408E-08  8382.3259  9.802E+09
0.3441   1461933.      0.000
    17.480 -3.562E-07   -37.8247     2.1568  7.478E-08  8382.2240  9.802E+09
0.2298   1470729.      0.000
    17.670 -1.957E-07   -32.3247     2.5635  6.662E-08  8382.0939  9.802E+09
0.1270   1479525.      0.000
    17.860 -5.240E-08   -26.1628     2.7473  5.982E-08  8381.9481  9.802E+09
0.0342   1488320.      0.000
    18.050  7.704E-08   -19.8219     2.7286  5.447E-08  8381.7980  9.802E+09
-0.0506   1497116.      0.000
    18.240  1.960E-07   -13.7430     2.5234  5.056E-08  8381.6541  9.802E+09
-0.1294   1505912.      0.000
    18.430  3.076E-07    -8.3363     2.1428  4.800E-08  8381.5262  9.802E+09
-0.2044   1514707.      0.000
    18.620  4.148E-07    -3.9916     1.5939  4.656E-08  8381.4234  9.802E+09
-0.2772   1523503.      0.000
    18.810  5.199E-07    -1.0876     0.8795  4.597E-08  8381.3547  9.802E+09
-0.3494   1532299.      0.000
    19.000  6.245E-07     0.000      0.000  4.585E-08  8381.3289  9.802E+09
-0.4221    770547.      0.000

* This analysis computed pile response using nonlinear moment-curvature
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relationships.
Values of total stress due to combined axial and bending stresses are computed only
for elastic sections only and do not equal the actual stresses in concrete and steel.
Stresses in concrete and steel may be interpolated from the output for nonlinear
bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.1163544 inches
Computed slope at pile head	=	-0.0034024 radians
Maximum bending moment	=	626437. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.6600000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	12
Number of zero deflection points	=	4

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950. lb
Moment	=	192000. in- lb
Axial Load	=	91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
19.0000	0.1163545	626437.	23950.
18.0500	0.1163053	626701.	23950.
17.1000	0.1160905	626901.	23950.
16.1500	0.1170260	625765.	23950.
15.2000	0.1164526	626375.	23950.
14.2500	0.1168557	625845.	23950.
13.3000	0.1169413	625471.	23950.
12.3500	0.1167537	625868.	23950.
11.4000	0.1162590	626378.	23950.
10.4500	0.1163502	626232.	23950.
9.5000	0.1167796	625720.	23950.
8.5500	0.1165146	626054.	23950.
7.6000	0.1185074	623904.	23950.
6.6500	0.1340152	612964.	23950.
5.7000	0.2296650	606612.	-28132.

Summary of Pile Response(s)

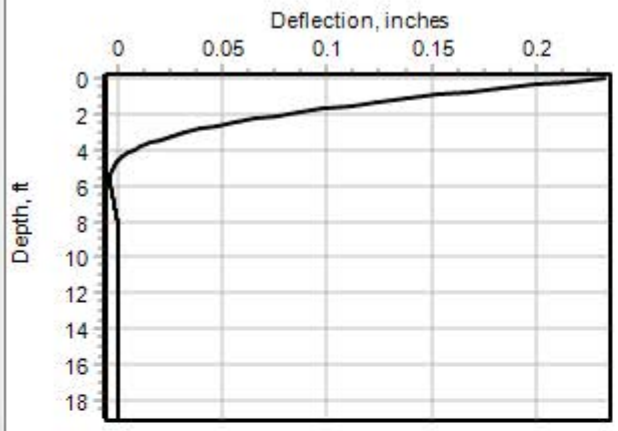
Definitions of Pile-head Loading Conditions:

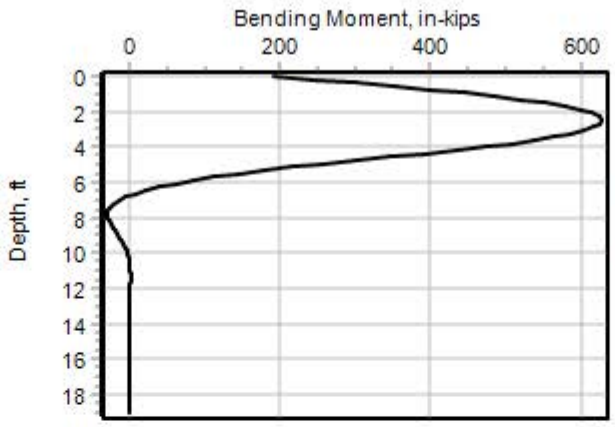
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

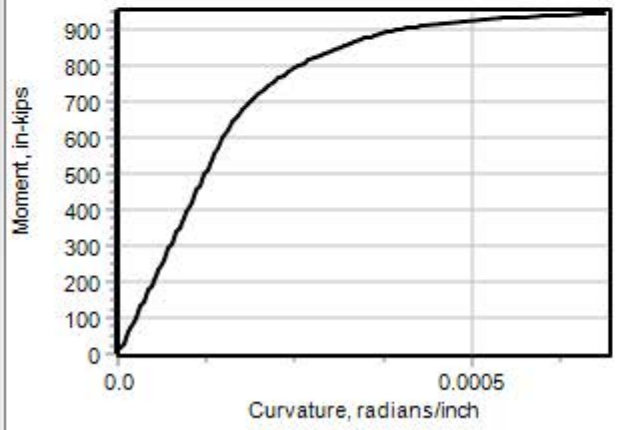
Load Case No.	Load Type No.	Pile-head Condition 1 Shear V(lbs) or y(inches)	Pile-head Condition 2 Moment in-lb, rad., or Rotation in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Load in Pile lbs	Maximum Shear in Pile radians
1	1	V = 23950.	M = 192000.	91000.	0.11635437	626437.	23950.	-0.00340237

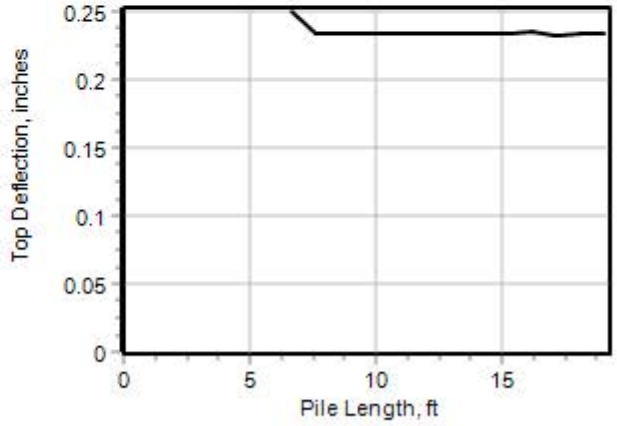
The analysis ended normally.

Results for Culvert#3_12inCIP_B-016s.lp7d









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LPile Plus for Windows, Version 2013-07.007

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

This copy of LPile is used by:

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_12inCIP_B-016s.lp7d
Name of output report file: Culvert#3_12inCIP_B-016s.lp7o
Name of plot output file: Culvert#3_12inCIP_B-016s.lp7p
Name of runtime messeage file: Culvert#3_12inCIP_B-016s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:48:30

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-016-0-14 & B-016-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	19.00 ft
Depth of ground surface below top of pile	=	-0.65 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	12.0000000
2	19.000000	12.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	19.00000 ft
Pile Diameter	=	12.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 2 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.65000 ft
Distance from top of pile to bottom of layer	=	3.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	2750.00000 psf
Undrained cohesion at bottom of layer	=	2750.00000 psf
Epsilon-50 at top of layer	=	0.00530
Epsilon-50 at bottom of layer	=	0.00530
Subgrade k at top of layer	=	917.00000 pci
Subgrade k at bottom of layer	=	917.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	3.75000 ft
Distance from top of pile to bottom of layer	=	19.85000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5050.00000 psf
Undrained cohesion at bottom of layer	=	5050.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1692.00000 pci
Subgrade k at bottom of layer	=	1692.00000 pci

(Depth of lowest soil layer extends 0.85 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor kpy Epsilon 50 pci
1	Stiff Clay with Free Water	-0.650	62.600	2750.000	917.000
		3.750	62.600	2750.000	917.000
2	Stiff Clay with Free Water	3.750	67.600	5050.000	1692.000
		19.850	67.600	5050.000	1692.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section = 19.00000 ft
Outer Diameter of Pipe = 12.00000 in
Pipe Wall Thickness = 0.21900 in
Yield Stress of Pipe = 36.00000 ksi
Elastic Modulus = 29000. ksi
Cross-sectional Area = 8.10543 sq. in.
Moment of Inertia = 140.66969 in^4
Elastic Bending Stiffness = 4079421. kip-in^2
Plastic Modulus, Z = 30.39894 in^3
Plastic Moment Capacity = Fy Z = 1094.36186 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 291.796 kips
Nominal Axial Tensile Capacity = -291.796 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003590	14.6460293	4079661.	113.8378926	11.8454549	
0.000007180	29.2920585	4079661.	59.9189463	12.4638702	
0.0000108	43.9380878	4079661.	41.9459642	13.0822859	
0.0000144	58.5841170	4079661.	32.9594731	13.7007012	
0.0000180	73.2301463	4079661.	27.5675785	14.3191164	
0.0000215	87.8761755	4079661.	23.9729821	14.9375320	
0.0000251	102.5222048	4079661.	21.4054132	15.5559474	
0.0000287	117.1682340	4079661.	19.4797366	16.1743628	
0.0000323	131.8142633	4079661.	17.9819881	16.7927782	
0.0000359	146.4602925	4079661.	16.7837893	17.4111937	
0.0000395	161.1063218	4079661.	15.8034448	18.0296091	
0.0000431	175.7523510	4079661.	14.9864910	18.6480245	
0.0000467	190.3983803	4079661.	14.2952225	19.2664399	
0.0000503	205.0444095	4079661.	13.7027066	19.8848553	
0.0000539	219.6904388	4079661.	13.1891928	20.5032707	
0.0000574	234.3364680	4079661.	12.7398683	21.1216861	
0.0000610	248.9824973	4079661.	12.3434054	21.7401015	
0.0000646	263.6285265	4079661.	11.9909940	22.3585170	
0.0000682	278.2745558	4079661.	11.6756786	22.9769324	
0.0000718	292.9205850	4079661.	11.3918946	23.5953478	
0.0000754	307.5666143	4079661.	11.1351377	24.2137632	
0.0000790	322.2126435	4079661.	10.9017224	24.8321787	
0.0000826	336.8586728	4079661.	10.6886040	25.4505941	

0.0000862	351.5047020	4079661.	10.4932455	26.0690095	
0.0000898	366.1507313	4079661.	10.3135157	26.6874249	
0.0000933	380.7967605	4079661.	10.1476113	27.3058403	
0.0000969	395.4427898	4079661.	9.9939960	27.9242558	
0.0001005	410.0888190	4079661.	9.8513533	28.5426712	
0.0001041	424.7348483	4079661.	9.7185480	29.1610866	
0.0001077	439.3808775	4079661.	9.5945964	29.7795020	
0.0001113	454.0269068	4079661.	9.4786417	30.3979174	
0.0001149	468.6729360	4079661.	9.3699341	31.0163328	
0.0001185	483.3189653	4079661.	9.2678149	31.6347483	
0.0001221	497.9649945	4079661.	9.1717027	32.2531637	
0.0001257	512.6110238	4079661.	9.0810826	32.8715791	
0.0001292	527.2570530	4079661.	8.9954970	33.4899945	
0.0001328	541.9030823	4079661.	8.9145376	34.1084099	
0.0001364	556.5491115	4079661.	8.8378393	34.7268254	
0.0001400	571.1951408	4079661.	8.7650742	35.3452408	
0.0001472	599.6344915	4073867.	8.6343588	36.0000000	Y
0.0001544	623.3530116	4038032.	8.5382521	36.0000000	Y
0.0001616	644.0460965	3986654.	8.4650284	36.0000000	Y
0.0001687	662.4878832	3926307.	8.4087481	36.0000000	Y
0.0001759	679.2447437	3861307.	8.3651071	36.0000000	Y
0.0001831	694.5892106	3793691.	8.3316408	36.0000000	Y
0.0001903	708.7299375	3724852.	8.3064628	36.0000000	Y
0.0001975	721.8361938	3655780.	8.2880733	36.0000000	Y
0.0002046	734.0244235	3587070.	8.2753779	36.0000000	Y
0.0002118	745.3737266	3519056.	8.2675803	36.0000000	Y
0.0002190	756.0452315	3452408.	8.2635576	36.0000000	Y
0.0002262	766.0342523	3386973.	8.2630781	36.0000000	Y
0.0002334	775.4849822	3323259.	8.2652247	36.0000000	Y
0.0002405	784.3549062	3260934.	8.2700477	36.0000000	Y
0.0002477	792.7762630	3200411.	8.2767617	36.0000000	Y
0.0002549	800.7765111	3141645.	8.2851318	36.0000000	Y
0.0002621	808.3405346	3084435.	8.2951545	36.0000000	Y
0.0002693	815.5356212	3028906.	8.3064327	36.0000000	Y
0.0002764	822.3962712	2975052.	8.3187484	36.0000000	Y
0.0002836	828.9444308	2922823.	8.3319577	36.0000000	Y
0.0002908	835.2011007	2872170.	8.3459303	36.0000000	Y
0.0002980	841.1864013	2823048.	8.3605481	36.0000000	Y
0.0003052	846.9196303	2775412.	8.3757035	36.0000000	Y
0.0003123	852.4193143	2729218.	8.3912976	36.0000000	Y
0.0003195	857.7032544	2684424.	8.4072394	36.0000000	Y
0.0003267	862.7885675	2640992.	8.4234443	36.0000000	Y
0.0003339	867.6492325	2598755.	8.4400462	36.0000000	Y
0.0003411	872.3273732	2557761.	8.4568425	36.0000000	Y
0.0003482	876.8469211	2518003.	8.4737218	36.0000000	Y
0.0003554	881.2229244	2479446.	8.4906174	36.0000000	Y
0.0003626	885.3840426	2441825.	8.5072690	36.0000000	Y
0.0003698	889.1600436	2404622.	8.5222170	36.0000000	Y
0.0003770	892.8414077	2368586.	8.5370928	36.0000000	Y
0.0003841	896.0296021	2332613.	8.5489267	36.0000000	Y
0.0003913	899.0077186	2297424.	8.5601198	36.0000000	Y
0.0003985	901.8403521	2263137.	8.5703638	36.0000000	Y
0.0004057	904.3215113	2229198.	8.5791569	36.0000000	Y
0.0004129	906.7900746	2196408.	8.5877275	36.0000000	Y
0.0004200	908.9791698	2164075.	8.5954938	36.0000000	Y
0.0004272	911.0928382	2132651.	8.6022827	36.0000000	Y
0.0004559	918.3846071	2014304.	8.6271859	36.0000000	Y
0.0004847	924.2341408	1907007.	8.6461098	36.0000000	Y
0.0005134	929.0046884	1809614.	8.6613777	36.0000000	Y
0.0005421	933.0001087	1721111.	8.6739223	36.0000000	Y
0.0005708	936.3786810	1640433.	8.6845929	36.0000000	Y
0.0005995	939.2026031	1566560.	8.6930479	36.0000000	Y
0.0006283	941.6355550	1498818.	8.7003694	36.0000000	Y

0.0006570	943.7786942	1436558.	8.7070009	36.0000000 Y
0.0006857	945.6523584	1379121.	8.7122537	36.0000000 Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	945.7

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. p	Distrib. Es*h Lat. Load
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in	lb/inch lb/inch
0.00	0.2329	192000.	23950.	-0.007433	19416.	4.080E+09	-246.1441	1204.7412 0.000
0.190	0.2161	247497.	23275.	-0.007310	21784.	4.080E+09	-345.7732	3648.2676 0.000
0.380	0.1996	301168.	22364.	-0.007157	24073.	4.080E+09	-453.1161	5176.3015 0.000
0.570	0.1835	352449.	21202.	-0.006974	26260.	4.080E+09	-566.1888	7036.5274 0.000
0.760	0.1678	400745.	19788.	-0.006763	28320.	4.080E+09	-674.6012	9167.1712 0.000
0.950	0.1526	445489.	18140.	-0.006527	30229.	4.080E+09	-771.0924	11520. 0.000
1.140	0.1380	486172.	16285.	-0.006267	31964.	4.080E+09	-855.8128	14138. 0.000
1.330	0.1240	522350.	14251.	-0.005985	33507.	4.080E+09	-928.8084	17072. 0.000

1.520	0.1107	553639.	12063.	-0.005684	34841.	4.080E+09
-990.0520	20386.	0.000				
1.710	0.0981	579717.	9749.5972	-0.005367	35954.	4.078E+09
-1039.4596	24153.	0.000				
1.900	0.0863	600324.	7336.9515	-0.005037	36833.	4.073E+09
-1076.8963	28466.	0.000				
2.090	0.0752	615263.	4852.8139	-0.004696	37470.	4.050E+09
-1102.1717	33439.	0.000				
2.280	0.0648	624402.	2325.2393	-0.004346	37860.	4.035E+09
-1114.9990	39208.	0.000				
2.470	0.0553	627670.	-216.2894	-0.003992	37999.	4.027E+09
-1114.4121	45921.	0.000				
2.660	0.0466	625072.	-2693.0518	-0.003638	37888.	4.034E+09
-1058.1865	51736.	0.000				
2.850	0.0387	616900.	-5020.0268	-0.003288	37540.	4.047E+09
-983.0196	57852.	0.000				
3.040	0.0316	603545.	-7154.2025	-0.002945	36970.	4.068E+09
-889.0643	64062.	0.000				
3.230	0.0253	585498.	-9074.2725	-0.002612	36200.	4.077E+09
-795.2076	71623.	0.000				
3.420	0.0197	563250.	-10781.	-0.002291	35251.	4.080E+09
-702.0858	81124.	0.000				
3.610	0.0149	537287.	-12276.	-0.001983	34144.	4.080E+09
-609.4437	93456.	0.000				
3.800	0.0107	508093.	-14201.	-0.001691	32899.	4.080E+09
-1078.8891	230134.	0.000				
3.990	0.007157	473232.	-16437.	-0.001417	31412.	4.080E+09
-882.8312	281248.	0.000				
4.180	0.004228	433726.	-18217.	-0.001163	29727.	4.080E+09
-678.5587	365930.	0.000				
4.370	0.001852	390643.	-19503.	-0.000933	27889.	4.080E+09
-449.0806	552989.	0.000				
4.560	-2.696E-05	345180.	-20003.	-0.000727	25950.	4.080E+09
10.0619	850798.	0.000				
4.750	-0.001466	299730.	-19537.	-0.000547	24011.	4.080E+09
399.4536	621390.	0.000				
4.940	-0.002522	256321.	-18484.	-0.000392	22160.	4.080E+09
524.0662	473693.	0.000				
5.130	-0.003253	215607.	-17208.	-0.000260	20423.	4.080E+09
595.1150	417158.	0.000				
5.320	-0.003708	177961.	-15805.	-0.000150	18818.	4.080E+09
635.4226	390705.	0.000				
5.510	-0.003937	143598.	-14334.	-6.017E-05	17352.	4.080E+09
654.7280	379190.	0.000				
5.700	-0.003982	112622.	-12837.	1.142E-05	16031.	4.080E+09
658.5213	377010.	0.000				
5.890	-0.003885	85056.	-11345.	6.666E-05	14855.	4.080E+09
650.3882	381728.	0.000				
6.080	-0.003678	60861.	-9882.0503	0.000107	13823.	4.080E+09
632.8956	392282.	0.000				
6.270	-0.003395	39949.	-8467.4295	0.000136	12931.	4.080E+09
607.9998	408348.	0.000				
6.460	-0.003060	22193.	-7116.2356	0.000153	12174.	4.080E+09
577.2581	430097.	0.000				
6.650	-0.002697	7435.6050	-5840.3380	0.000161	11544.	4.080E+09
541.9503	458121.	0.000				
6.840	-0.002325	-4505.6157	-4648.9222	0.000162	11419.	4.080E+09
503.1513	493452.	0.000				
7.030	-0.001958	-13831.	-3548.9054	0.000157	11817.	4.080E+09
461.7758	537670.	0.000				
7.220	-0.001609	-20754.	-2545.2697	0.000147	12112.	4.080E+09
418.6063	593123.	0.000				
7.410	-0.001287	-25498.	-1641.3498	0.000134	12315.	4.080E+09

```
374.3059    663329.      0.000
     7.600  -0.000996    -28294.  -839.1047   0.000119     12434.  4.080E+09
329.4180    753726.      0.000
     7.790  -0.000742    -29374.  -139.4128   0.000103     12480.  4.080E+09
284.3469    873211.      0.000
     7.980  -0.000526    -28973.   450.0598  8.691E-05     12463.  4.080E+09
232.7343   1009120.      0.000
     8.170  -0.000346    -27358.   891.5527  7.117E-05     12394.  4.080E+09
154.5402   1017916.      0.000
     8.360  -0.000201    -24937.  1171.0781  5.655E-05     12291.  4.080E+09
90.6576   1026712.      0.000
     8.550 -8.827E-05    -22041.  1320.1288  4.343E-05     12167.  4.080E+09
40.0887   1035507.      0.000
     8.740 -3.300E-06    -18935.  1367.5531  3.198E-05     12035.  4.080E+09
1.5115   1044303.      0.000
     8.930  5.754E-05    -15818.  1338.9783  2.226E-05     11902.  4.080E+09
-26.5772   1053099.      0.000
     9.120  9.823E-05    -12838.  1256.5280  1.426E-05     11775.  4.080E+09
-45.7477   1061894.      0.000
     9.310   0.000123    -10095.  1138.7689  7.848E-06     11658.  4.080E+09
-57.5498   1070690.      0.000
     9.500   0.000134 -7648.8601  1000.8294  2.890E-06     11553.  4.080E+09
-63.4497   1079486.      0.000
     9.690   0.000136 -5532.0438   854.6408 -7.931E-07     11463.  4.080E+09
-64.7859   1088281.      0.000
     9.880   0.000130 -3751.3690   709.2572 -3.387E-06     11387.  4.080E+09
-62.7435   1097077.      0.000
    10.070   0.000120 -2296.4254   571.2202 -5.077E-06     11325.  4.080E+09
-58.3415   1105873.      0.000
    10.260   0.000107 -1144.4980   444.9396 -6.039E-06     11276.  4.080E+09
-52.4309   1114668.      0.000
    10.450  9.275E-05  -264.9948   333.0691 -6.433E-06     11238.  4.080E+09
-45.7011   1123464.      0.000
    10.640  7.791E-05   376.9664   236.8612 -6.401E-06     11243.  4.080E+09
-38.6918   1132260.      0.000
    10.830  6.356E-05   817.7486   156.4911 -6.067E-06     11262.  4.080E+09
-31.8084   1141056.      0.000
    11.020  5.025E-05  1093.0834    91.3423 -5.533E-06     11274.  4.080E+09
-25.3397   1149851.      0.000
    11.210  3.833E-05  1236.5657    40.2523 -4.882E-06     11280.  4.080E+09
-19.4761   1158647.      0.000
    11.400  2.798E-05  1278.6599     1.7163 -4.180E-06     11282.  4.080E+09
-14.3274   1167443.      0.000
    11.590  1.927E-05  1246.1265   -25.9477 -3.474E-06     11280.  4.080E+09
-9.9394   1176238.      0.000
    11.780  1.214E-05  1161.7799   -44.4713 -2.801E-06     11277.  4.080E+09
-6.3094   1185034.      0.000
    11.970  6.493E-06  1044.4998   -55.5395 -2.185E-06     11272.  4.080E+09
-3.3996   1193830.      0.000
    12.160  2.177E-06   909.4264   -60.7239 -1.639E-06     11266.  4.080E+09
-1.1482   1202625.      0.000
    12.350 -9.801E-07   768.2787   -61.4392 -1.170E-06     11260.  4.080E+09
0.5208   1211421.      0.000
    12.540 -3.158E-06   629.7491   -58.9187 -7.793E-07     11254.  4.080E+09
1.6902   1220217.      0.000
    12.730 -4.534E-06   499.9326   -54.2060 -4.636E-07     11248.  4.080E+09
2.4438   1229012.      0.000
    12.920 -5.272E-06   382.7620   -48.1571 -2.170E-07     11243.  4.080E+09
2.8622   1237808.      0.000
    13.110 -5.523E-06   280.4261   -41.4517 -3.163E-08     11239.  4.080E+09
3.0197   1246604.      0.000
    13.300 -5.416E-06   193.7554   -34.6094  1.009E-07     11235.  4.080E+09
2.9823   1255400.      0.000
```

13.490	-5.063E-06	122.5655	-28.0092	1.893E-07	11232.	4.080E+09	2.8073	1264195.	0.000
13.680	-4.553E-06	65.9547	-21.9108	2.419E-07	11230.	4.080E+09	2.5423	1272991.	0.000
13.870	-3.960E-06	22.5520	-16.4748	2.667E-07	11228.	4.080E+09	2.2261	1281787.	0.000
14.060	-3.337E-06	-9.2811	-11.7835	2.704E-07	11227.	4.080E+09	1.8891	1290582.	0.000
14.250	-2.727E-06	-31.2930	-7.8584	2.590E-07	11228.	4.080E+09	1.5540	1299378.	0.000
14.440	-2.156E-06	-45.2229	-4.6766	2.377E-07	11229.	4.080E+09	1.2371	1308174.	0.000
14.630	-1.643E-06	-52.7168	-2.1844	2.103E-07	11229.	4.080E+09	0.9490	1316969.	0.000
14.820	-1.197E-06	-55.2710	-0.3089	1.801E-07	11229.	4.080E+09	0.6961	1325765.	0.000
15.010	-8.217E-07	-54.2002	1.0330	1.495E-07	11229.	4.080E+09	0.4810	1334561.	0.000
15.200	-5.153E-07	-50.6228	1.9274	1.202E-07	11229.	4.080E+09	0.3036	1343356.	0.000
15.390	-2.734E-07	-45.4612	2.4583	9.339E-08	11229.	4.080E+09	0.1621	1352152.	0.000
15.580	-8.945E-08	-39.4515	2.7041	6.966E-08	11229.	4.080E+09	0.0534	1360948.	0.000
15.770	4.424E-08	-33.1597	2.7346	4.937E-08	11228.	4.080E+09	-0.0266	1369744.	0.000
15.960	1.357E-07	-27.0021	2.6108	3.256E-08	11228.	4.080E+09	-0.0820	1378539.	0.000
16.150	1.927E-07	-21.2679	2.3836	1.907E-08	11228.	4.080E+09	-0.1173	1387335.	0.000
16.340	2.226E-07	-16.1407	2.0945	8.617E-09	11228.	4.080E+09	-0.1363	1396131.	0.000
16.530	2.320E-07	-11.7204	1.7761	8.321E-10	11228.	4.080E+09	-0.1430	1404926.	0.000
16.720	2.264E-07	-8.0419	1.4531	-4.690E-09	11227.	4.080E+09	-0.1404	1413722.	0.000
16.910	2.106E-07	-5.0923	1.1432	-8.360E-09	11227.	4.080E+09	-0.1314	1422518.	0.000
17.100	1.883E-07	-2.8253	0.8587	-1.057E-08	11227.	4.080E+09	-0.1182	1431313.	0.000
17.290	1.624E-07	-1.1724	0.6070	-1.169E-08	11227.	4.080E+09	-0.1026	1440109.	0.000
17.480	1.350E-07	-0.0527	0.3922	-1.203E-08	11227.	4.080E+09	-0.0858	1448905.	0.000
17.670	1.075E-07	0.6211	0.2160	-1.187E-08	11227.	4.080E+09	-0.0688	1457700.	0.000
17.860	8.086E-08	0.9374	0.0784	-1.144E-08	11227.	4.080E+09	-0.0520	1466496.	0.000
18.050	5.538E-08	0.9832	-0.0218	-1.090E-08	11227.	4.080E+09	-0.0358	1475292.	0.000
18.240	3.115E-08	0.8426	-0.0858	-1.039E-08	11227.	4.080E+09	-0.0203	1484088.	0.000
18.430	7.998E-09	0.5964	-0.1148	-9.989E-09	11227.	4.080E+09	-0.005237	1492883.	0.000
18.620	-1.440E-08	0.3230	-0.1100	-9.732E-09	11227.	4.080E+09	0.009482	1501679.	0.000
18.810	-3.638E-08	0.0989	-0.0717	-9.614E-09	11227.	4.080E+09	0.0241	1510475.	0.000
19.000	-5.824E-08	0.000	0.000	-9.587E-09	11227.	4.080E+09	0.0388	759635.	0.000

* This analysis computed pile response using nonlinear moment-curvature relationships.

Values of total stress due to combined axial and bending stresses are computed only for elastic sections only and do not equal the actual stresses in concrete and steel.

Stresses in concrete and steel may be interpolated from the output for nonlinear bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.2329166 inches
Computed slope at pile head	=	-0.0074327 radians
Maximum bending moment	=	627670. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.4700000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	22
Number of zero deflection points	=	5

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950. lb
Moment	=	192000. in- lb
Axial Load	=	91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
19.0000	0.2329168	627670.	23950.
18.0500	0.2327893	627408.	23950.
17.1000	0.2323645	626859.	23950.
16.1500	0.2341252	627321.	23950.
15.2000	0.2330360	627165.	23950.
14.2500	0.2337624	627118.	23950.
13.3000	0.2338922	627132.	23950.
12.3500	0.2335262	627203.	23950.
11.4000	0.2325287	626955.	23950.
10.4500	0.2325931	626908.	23950.
9.5000	0.2334087	627031.	23950.
8.5500	0.2332244	626988.	23950.
7.6000	0.2338332	626966.	23950.
6.6500	0.2493332	629862.	23950.

Summary of Pile Response(s)

Definitions of Pile-head Loading Conditions:

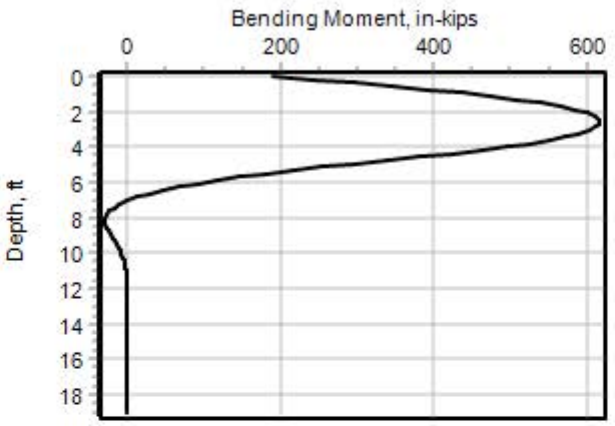
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians

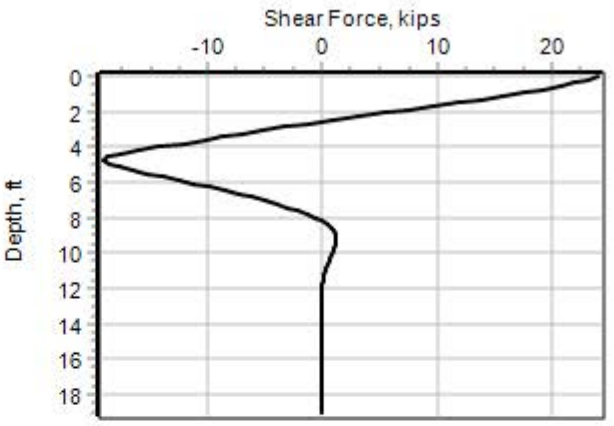
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

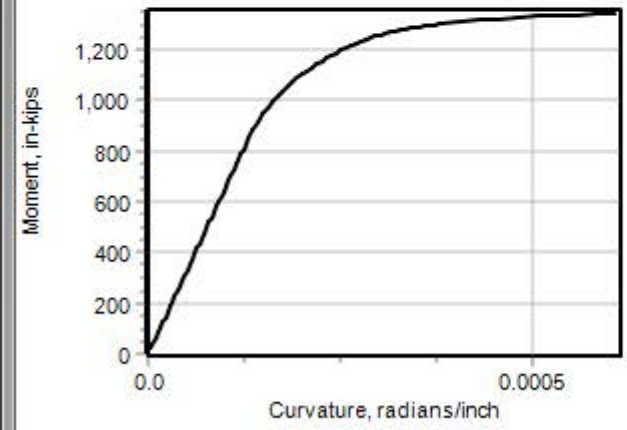
Load Case No.	Load Type No.	Pile-head Condition 1 Shear V(lbs) or y(inches)	Pile-head Condition 2 Pile-head Rotation or in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Load in Pile lbs	Maximum Shear in Pile radians
1	1	V = 23950.	M = 192000.	91000.	0.23291661	627670.	23950.	-0.00743269

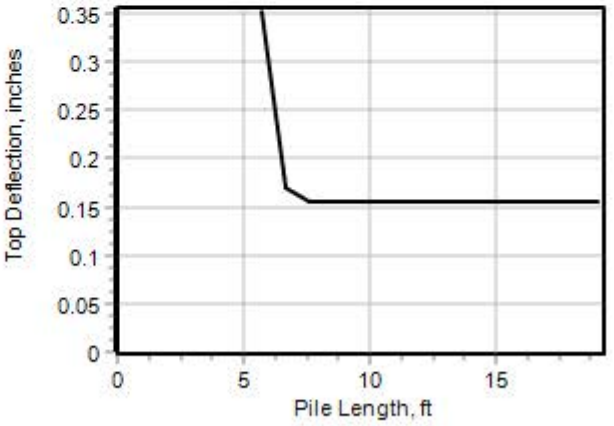
The analysis ended normally.

Results for Culvert#3_14inCIP_B-016s.lp7d









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LPile Plus for Windows, Version 2013-07.007

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

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_14inCIP_B-016s.lp7d
Name of output report file: Culvert#3_14inCIP_B-016s.lp7o
Name of plot output file: Culvert#3_14inCIP_B-016s.lp7p
Name of runtime messeage file: Culvert#3_14inCIP_B-016s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:50:56

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-016-0-14 & B-016-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections = 1

Total length of pile = 19.00 ft

Depth of ground surface below top of pile = -0.65 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	14.0000000
2	19.000000	14.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	19.00000 ft
Pile Diameter	=	14.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 2 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.65000 ft
Distance from top of pile to bottom of layer	=	3.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	2750.00000 psf
Undrained cohesion at bottom of layer	=	2750.00000 psf
Epsilon-50 at top of layer	=	0.00530
Epsilon-50 at bottom of layer	=	0.00530
Subgrade k at top of layer	=	917.00000 pci
Subgrade k at bottom of layer	=	917.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	3.75000 ft
Distance from top of pile to bottom of layer	=	19.85000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5050.00000 psf
Undrained cohesion at bottom of layer	=	5050.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1692.00000 pci
Subgrade k at bottom of layer	=	1692.00000 pci

(Depth of lowest soil layer extends 0.85 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor kpy Epsilon 50 pci
1	Stiff Clay with Free Water	-0.650	62.600	2750.000	917.000
		3.750	62.600	2750.000	917.000
2	Stiff Clay with Free Water	3.750	67.600	5050.000	1692.000
		19.850	67.600	5050.000	1692.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Compute Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section	=	19.00000 ft
Outer Diameter of Pipe	=	14.00000 in
Pipe Wall Thickness	=	0.21900 in
Yield Stress of Pipe	=	36.00000 ksi
Elastic Modulus	=	29000. ksi
Cross-sectional Area	=	9.48145 sq. in.
Moment of Inertia	=	225.14166 in^4
Elastic Bending Stiffness	=	6529108. kip-in^2
Plastic Modulus, Z	=	41.59510 in^3
Plastic Moment Capacity = Fy Z	=	1497.42348 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As	=	341.332 kips
Nominal Axial Tensile Capacity	=	-341.332 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000003177	20.7442314	6528512.	111.1562973	10.2362676	
0.000006355	41.4884628	6528512.	59.0781487	10.8748464	
0.000009532	62.2326942	6528512.	41.7187658	11.5134250	
0.0000127	82.9769257	6528512.	33.0390743	12.1520036	
0.0000159	103.7211571	6528512.	27.8312595	12.7905822	
0.0000191	124.4653885	6528512.	24.3593829	13.4291607	
0.0000222	145.2096199	6528512.	21.8794710	14.0677394	
0.0000254	165.9538513	6528512.	20.0195372	14.7063179	
0.0000286	186.6980827	6528512.	18.5729219	15.3448967	
0.0000318	207.4423142	6528512.	17.4156297	15.9834752	
0.0000350	228.1865456	6528512.	16.4687543	16.6220539	
0.0000381	248.9307770	6528512.	15.6796914	17.2606325	
0.0000413	269.6750084	6528512.	15.0120229	17.8992112	
0.0000445	290.4192398	6528512.	14.4397355	18.5377898	
0.0000477	311.1634712	6528512.	13.9437532	19.1763684	
0.0000508	331.9077026	6528512.	13.5097686	19.8149470	
0.0000540	352.6519341	6528512.	13.1268410	20.4535257	
0.0000572	373.3961655	6528512.	12.7864610	21.0921043	
0.0000604	394.1403969	6528512.	12.4819104	21.7306829	
0.0000635	414.8846283	6528512.	12.2078149	22.3692616	
0.0000667	435.6288597	6528512.	11.9598237	23.0078402	
0.0000699	456.3730911	6528512.	11.7343772	23.6464188	
0.0000731	477.1173226	6528512.	11.5285347	24.2849975	

0.0000763	497.8615540	6528512.	11.3398457	24.9235761	
0.0000794	518.6057854	6528512.	11.1662519	25.5621547	
0.0000826	539.3500168	6528512.	11.0060114	26.2007333	
0.0000858	560.0942482	6528512.	10.8576406	26.8393120	
0.0000890	580.8384796	6528512.	10.7198678	27.4778906	
0.0000921	601.5827111	6528512.	10.5915965	28.1164692	
0.0000953	622.3269425	6528512.	10.4718766	28.7550479	
0.0000985	643.0711739	6528512.	10.3598806	29.3936265	
0.0001017	663.8154053	6528512.	10.2548843	30.0322051	
0.0001049	684.5596367	6528512.	10.1562514	30.6707837	
0.0001080	705.3038681	6528512.	10.0634205	31.3093624	
0.0001112	726.0480995	6528512.	9.9758942	31.9479410	
0.0001144	746.7923310	6528512.	9.8932305	32.5865196	
0.0001176	767.5365624	6528512.	9.8150351	33.2250983	
0.0001207	788.2807938	6528512.	9.7409552	33.8636769	
0.0001239	809.0250252	6528512.	9.6706743	34.5022555	
0.0001303	850.5134880	6528512.	9.5403975	35.7794128	Y
0.0001366	888.4840391	6502765.	9.4358717	36.0000000	Y
0.0001430	920.1116790	6434946.	9.3647454	36.0000000	Y
0.0001493	948.2061189	6349240.	9.3131648	36.0000000	Y
0.0001557	973.5796758	6253055.	9.2761998	36.0000000	Y
0.0001621	996.7217948	6150645.	9.2506833	36.0000000	Y
0.0001684	1017.9829880	6044794.	9.2343152	36.0000000	Y
0.0001748	1037.6368196	5937444.	9.2253228	36.0000000	Y
0.0001811	1055.9080589	5829994.	9.2222894	36.0000000	Y
0.0001875	1072.9877235	5723472.	9.2240523	36.0000000	Y
0.0001938	1088.9145376	5617988.	9.2301495	36.0000000	Y
0.0002002	1103.9047270	5514522.	9.2394839	36.0000000	Y
0.0002065	1117.9907765	5413046.	9.2517411	36.0000000	Y
0.0002129	1131.3329838	5314134.	9.2661462	36.0000000	Y
0.0002192	1143.8756909	5217309.	9.2828157	36.0000000	Y
0.0002256	1155.7964593	5123183.	9.3009630	36.0000000	Y
0.0002320	1167.1335274	5031698.	9.3203812	36.0000000	Y
0.0002383	1177.9180972	4942773.	9.3409073	36.0000000	Y
0.0002447	1188.1476750	4856200.	9.3625254	36.0000000	Y
0.0002510	1197.9142415	4772165.	9.3848537	36.0000000	Y
0.0002574	1207.2484173	4690601.	9.4077648	36.0000000	Y
0.0002637	1216.1795120	4611439.	9.4311429	36.0000000	Y
0.0002701	1224.7356134	4534614.	9.4548828	36.0000000	Y
0.0002764	1232.9436671	4460061.	9.4788879	36.0000000	Y
0.0002828	1240.5526340	4386742.	9.5012324	36.0000000	Y
0.0002892	1247.5425917	4314504.	9.5221386	36.0000000	Y
0.0002955	1253.7132389	4242600.	9.5394456	36.0000000	Y
0.0003019	1259.3857384	4172074.	9.5549624	36.0000000	Y
0.0003082	1264.4962325	4102633.	9.5678278	36.0000000	Y
0.0003146	1269.2541211	4034876.	9.5804411	36.0000000	Y
0.0003209	1273.5749871	3968442.	9.5911348	36.0000000	Y
0.0003273	1277.7067624	3904009.	9.6011995	36.0000000	Y
0.0003336	1281.4341893	3840819.	9.6105721	36.0000000	Y
0.0003400	1284.9888204	3779483.	9.6189486	36.0000000	Y
0.0003463	1288.3094478	3719723.	9.6272544	36.0000000	Y
0.0003527	1291.3844866	3661419.	9.6341828	36.0000000	Y
0.0003591	1294.3438283	3604857.	9.6416218	36.0000000	Y
0.0003654	1297.0610132	3549600.	9.6475361	36.0000000	Y
0.0003718	1299.6293589	3495832.	9.6536994	36.0000000	Y
0.0003781	1302.1524425	3443751.	9.6595104	36.0000000	Y
0.0004035	1310.6043232	3247766.	9.6787469	36.0000000	Y
0.0004290	1317.5678936	3071539.	9.6940785	36.0000000	Y
0.0004544	1323.2738340	2912263.	9.7070292	36.0000000	Y
0.0004798	1328.0556807	2767937.	9.7175539	36.0000000	Y
0.0005052	1332.1017391	2636678.	9.7263358	36.0000000	Y
0.0005306	1335.5733438	2516913.	9.7339093	36.0000000	Y
0.0005561	1338.5986350	2407294.	9.7405798	36.0000000	Y

0.0005815	1341.1306317	2306412.	9.7455102	36.0000000	Y
0.0006069	1343.3708889	2213499.	9.7507176	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	1343.4

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. p	Distrib. Es*h Lat. Load
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in	lb/inch
0.00	0.1549	192000.	23950.	-0.004767	15567.	6.529E+09	-342.7713	2522.8054
0.190	0.1441	246697.	23052.	-0.004690	17268.	6.529E+09	-445.0821	7042.2910
0.380	0.1335	299063.	21931.	-0.004595	18896.	6.529E+09	-537.7221	9183.3172
0.570	0.1231	348611.	20610.	-0.004482	20437.	6.529E+09	-621.1127	11500.
0.760	0.1131	394906.	19109.	-0.004352	21876.	6.529E+09	-695.4842	14024.
0.950	0.1033	437556.	17449.	-0.004207	23202.	6.529E+09	-760.9488	16795.
1.140	0.0939	476219.	15650.	-0.004047	24404.	6.529E+09	-817.5413	19854.
1.330	0.0848	510598.	13731.	-0.003875	25473.	6.529E+09	-865.2394	23251.

1.520	0.0762	540442.	11714.	-0.003691	26401.	6.529E+09
-903.9716	27042.	0.000				
1.710	0.0680	565547.	9619.5347	-0.003498	27181.	6.529E+09
-933.6079	31296.	0.000				
1.900	0.0603	585758.	7467.7490	-0.003297	27810.	6.529E+09
-953.9234	36090.	0.000				
2.090	0.0530	600968.	5280.7674	-0.003090	28283.	6.529E+09
-964.4815	41506.	0.000				
2.280	0.0462	611121.	3082.2011	-0.002878	28598.	6.529E+09
-964.0855	47603.	0.000				
2.470	0.0399	616217.	906.4630	-0.002664	28757.	6.529E+09
-944.4567	54027.	0.000				
2.660	0.0340	616360.	-1213.0864	-0.002449	28761.	6.529E+09
-914.7973	61293.	0.000				
2.850	0.0287	611702.	-3257.6441	-0.002234	28616.	6.529E+09
-878.6744	69824.	0.000				
3.040	0.0238	602432.	-5209.6178	-0.002022	28328.	6.529E+09
-833.5832	79717.	0.000				
3.230	0.0195	588785.	-7018.6837	-0.001814	27904.	6.529E+09
-753.3166	88212.	0.000				
3.420	0.0156	571179.	-8645.3997	-0.001612	27357.	6.529E+09
-673.6273	98649.	0.000				
3.610	0.0121	550031.	-10061.	-0.001416	26699.	6.529E+09
-568.2511	106880.	0.000				
3.800	0.009113	525888.	-11936.	-0.001228	25948.	6.529E+09
-1076.0600	269216.	0.000				
3.990	0.006523	496114.	-14200.	-0.001049	25023.	6.529E+09
-910.3979	318215.	0.000				
4.180	0.004328	461571.	-16083.	-0.000882	23949.	6.529E+09
-741.5722	390682.	0.000				
4.370	0.002500	423139.	-17571.	-0.000728	22754.	6.529E+09
-563.6720	514045.	0.000				
4.560	0.001009	381747.	-18622.	-0.000587	21467.	6.529E+09
-358.2280	809163.	0.000				
4.750	-0.000177	338465.	-18954.	-0.000461	20121.	6.529E+09
67.7211	870512.	0.000				
4.940	-0.001095	295510.	-18451.	-0.000351	18786.	6.529E+09
372.8221	776553.	0.000				
5.130	-0.001777	254472.	-17485.	-0.000255	17510.	6.529E+09
475.0203	609626.	0.000				
5.320	-0.002256	215885.	-16333.	-0.000173	16310.	6.529E+09
535.3031	541022.	0.000				
5.510	-0.002563	180065.	-15072.	-0.000103	15196.	6.529E+09
570.6269	507556.	0.000				
5.700	-0.002727	147198.	-13751.	-4.625E-05	14174.	6.529E+09
588.6125	492063.	0.000				
5.890	-0.002774	117380.	-12403.	-4.580E-08	13247.	6.529E+09
593.6523	487897.	0.000				
6.080	-0.002728	90640.	-11055.	3.628E-05	12416.	6.529E+09
588.6478	492055.	0.000				
6.270	-0.002609	66954.	-9727.8146	6.380E-05	11679.	6.529E+09
575.6905	503138.	0.000				
6.460	-0.002437	46255.	-8437.2542	8.357E-05	11036.	6.529E+09
556.3801	520608.	0.000				
6.650	-0.002228	28445.	-7196.5072	9.661E-05	10482.	6.529E+09
531.9944	544480.	0.000				
6.840	-0.001996	13399.	-6015.9455	0.000104	10014.	6.529E+09
503.5861	575204.	0.000				
7.030	-0.001754	969.4845	-4903.7296	0.000106	9627.8317	6.529E+09
472.0419	613651.	0.000				
7.220	-0.001511	-9006.2041	-3866.1448	0.000105	9877.7057	6.529E+09
438.1202	661174.	0.000				
7.410	-0.001275	-16704.	-2907.8673	0.000101	10117.	6.529E+09

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402.4741    719745.      0.000
     7.600  -0.001052    -22308. -2032.1890  9.372E-05     10291.  6.529E+09
365.6647    792212.      0.000
     7.790  -0.000848    -26009. -1241.2236  8.528E-05     10406.  6.529E+09
328.1646    882759.      0.000
     7.980  -0.000663    -28003.  -536.1151  7.585E-05     10468.  6.529E+09
290.3516    997749.      0.000
     8.170  -0.000502    -28486.    52.9695  6.599E-05     10483.  6.529E+09
226.3893   1028835.      0.000
     8.360  -0.000363    -27789.   499.1702  5.616E-05     10462.  6.529E+09
165.0148   1037630.      0.000
     8.550  -0.000246    -26233.   815.7906  4.673E-05     10413.  6.529E+09
112.7224   1046426.      0.000
     8.740  -0.000150    -24088.  1023.1762  3.794E-05     10347.  6.529E+09
69.1948   1055222.      0.000
     8.930 -7.259E-05    -21583.  1140.6779  2.997E-05     10269.  6.529E+09
33.8769   1064017.      0.000
     9.120 -1.286E-05    -18899.  1186.1966  2.290E-05     10185.  6.529E+09
6.0518   1072813.      0.000
     9.310  3.182E-05    -16183.  1175.8872  1.677E-05     10101.  6.529E+09
-15.0951   1081609.      0.000
     9.500  6.362E-05    -13544.  1123.9953  1.158E-05     10019.  6.529E+09
-30.4241   1090404.      0.000
     9.690  8.463E-05    -11063.  1042.8009  7.284E-06  9941.6400  6.529E+09
-40.7990   1099200.      0.000
     9.880  9.683E-05 -8792.0992   942.6470  3.817E-06  9871.0488  6.529E+09
-47.0553   1107996.      0.000
    10.070   0.000102 -6765.6437   832.0305  1.100E-06  9808.0432  6.529E+09
-49.9767   1116792.      0.000
    10.260   0.000102 -4998.4967   717.7395 -9.543E-07  9753.0999  6.529E+09
-50.2786   1125587.      0.000
    10.450  9.768E-05 -3492.3557   605.0193 -2.437E-06  9706.2717  6.529E+09
-48.5988   1134383.      0.000
    10.640  9.073E-05 -2238.5976   497.7551 -3.438E-06  9667.2904  6.529E+09
-45.4926   1143179.      0.000
    10.830  8.200E-05 -1221.1661   398.6608 -4.042E-06  9635.6569  6.529E+09
-41.4322   1151974.      0.000
    11.020  7.230E-05  -419.0271   309.4654 -4.328E-06  9610.7172  6.529E+09
-36.8094   1160770.      0.000
    11.210  6.227E-05   191.7924   231.0905 -4.368E-06  9603.6521  6.529E+09
-31.9406   1169566.      0.000
    11.400  5.238E-05   636.5582   163.8148 -4.223E-06  9617.4805  6.529E+09
-27.0732   1178361.      0.000
    11.590  4.301E-05   940.5403   107.4226 -3.948E-06  9626.9318  6.529E+09
-22.3936   1187157.      0.000
    11.780  3.438E-05  1128.0434    61.3346 -3.587E-06  9632.7616  6.529E+09
-18.0344   1195953.      0.000
    11.970  2.665E-05  1221.7145    24.7203 -3.176E-06  9635.6740  6.529E+09
-14.0834   1204748.      0.000
    12.160  1.990E-05  1242.0861    -3.4078 -2.746E-06  9636.3073  6.529E+09
-10.5904   1213544.      0.000
    12.350  1.413E-05  1207.3145   -24.1170 -2.318E-06  9635.2262  6.529E+09
-7.5756   1222340.      0.000
    12.540  9.325E-06  1133.0744   -38.4935 -1.910E-06  9632.9180  6.529E+09
-5.0354   1231136.      0.000
    12.730  5.422E-06  1032.5765   -47.5953 -1.532E-06  9629.7934  6.529E+09
-2.9487   1239931.      0.000
    12.920  2.341E-06   916.6752   -52.4186 -1.191E-06  9626.1898  6.529E+09
-1.2822   1248727.      0.000
    13.110 -9.788E-09   794.0418   -53.8742 -8.925E-07  9622.3770  6.529E+09
0.005399   1257523.      0.000
    13.300 -1.729E-06   671.3790   -52.7737 -6.366E-07  9618.5632  6.529E+09
0.9600   1266318.      0.000
```

13.490	-2.913E-06	553.6581	-49.8223	-4.227E-07	9614.9031	6.529E+09	1.6289
1275114.	0.000						
13.680	-3.656E-06	444.3649	-45.6183	-2.484E-07	9611.5050	6.529E+09	2.0587
1283910.	0.000						
13.870	-4.045E-06	345.7416	-40.6566	-1.104E-07	9608.4386	6.529E+09	2.2936
1292705.	0.000						
14.060	-4.160E-06	259.0165	-35.3351	-4.837E-09	9605.7422	6.529E+09	2.3744
1301501.	0.000						
14.250	-4.067E-06	184.6157	-29.9635	7.263E-08	9603.4290	6.529E+09	2.3375
1310297.	0.000						
14.440	-3.828E-06	122.3529	-24.7737	1.262E-07	9601.4931	6.529E+09	2.2149
1319092.	0.000						
14.630	-3.492E-06	71.5952	-19.9304	1.601E-07	9599.9150	6.529E+09	2.0337
1327888.	0.000						
14.820	-3.098E-06	31.4040	-15.5413	1.781E-07	9598.6654	6.529E+09	1.8164
1336684.	0.000						
15.010	-2.680E-06	0.6530	-11.6678	1.837E-07	9597.7093	6.529E+09	1.5814
1345480.	0.000						
15.200	-2.261E-06	-21.8773	-8.3342	1.800E-07	9598.3692	6.529E+09	1.3428
1354275.	0.000						
15.390	-1.859E-06	-37.4256	-5.5364	1.696E-07	9598.8526	6.529E+09	1.1114
1363071.	0.000						
15.580	-1.487E-06	-47.1936	-3.2492	1.548E-07	9599.1563	6.529E+09	0.8949
1371867.	0.000						
15.770	-1.153E-06	-52.3064	-1.4332	1.375E-07	9599.3153	6.529E+09	0.6982
1380662.	0.000						
15.960	-8.604E-07	-53.7859	-0.0395	1.189E-07	9599.3613	6.529E+09	0.5243
1389458.	0.000						
16.150	-6.106E-07	-52.5359	0.9851	1.004E-07	9599.3224	6.529E+09	0.3745
1398254.	0.000						
16.340	-4.026E-07	-49.3356	1.6952	8.259E-08	9599.2229	6.529E+09	0.2485
1407049.	0.000						
16.530	-2.340E-07	-44.8400	2.1441	6.615E-08	9599.0831	6.529E+09	0.1453
1415845.	0.000						
16.720	-1.010E-07	-39.5859	2.3817	5.140E-08	9598.9198	6.529E+09	0.0631
1424641.	0.000						
16.910	4.301E-10	-34.0008	2.4533	3.855E-08	9598.7461	6.529E+09	-0.000270
1433436.	0.000						
17.100	7.480E-08	-28.4147	2.3991	2.765E-08	9598.5724	6.529E+09	-0.0473
1442232.	0.000						
17.290	1.265E-07	-23.0725	2.2533	1.866E-08	9598.4063	6.529E+09	-0.0805
1451028.	0.000						
17.480	1.599E-07	-18.1472	2.0448	1.147E-08	9598.2532	6.529E+09	-0.1024
1459824.	0.000						
17.670	1.788E-07	-13.7528	1.7968	5.896E-09	9598.1166	6.529E+09	-0.1152
1468619.	0.000						
17.860	1.868E-07	-9.9562	1.5275	1.756E-09	9597.9985	6.529E+09	-0.1210
1477415.	0.000						
18.050	1.868E-07	-6.7881	1.2507	-1.168E-09	9597.9000	6.529E+09	-0.1218
1486211.	0.000						
18.240	1.815E-07	-4.2526	0.9762	-3.096E-09	9597.8212	6.529E+09	-0.1190
1495006.	0.000						
18.430	1.727E-07	-2.3353	0.7107	-4.246E-09	9597.7616	6.529E+09	-0.1139
1503802.	0.000						
18.620	1.621E-07	-1.0100	0.4583	-4.830E-09	9597.7204	6.529E+09	-0.1075
1512598.	0.000						
18.810	1.507E-07	-0.2437	0.2210	-5.049E-09	9597.6966	6.529E+09	-0.1005
1521393.	0.000						
19.000	1.391E-07	0.000	0.000	-5.092E-09	9597.6890	6.529E+09	-0.0933
765095.	0.000						

* This analysis computed pile response using nonlinear moment-curvature relationships.

Values of total stress due to combined axial and bending stresses are computed only
for elastic sections only and do not equal the actual stresses in concrete and steel.
Stresses in concrete and steel may be interpolated from the output for nonlinear
bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.1548908 inches
Computed slope at pile head	=	-0.0047668 radians
Maximum bending moment	=	616360. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.6600000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	15
Number of zero deflection points	=	4

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950.	lb
Moment	=	192000.	in- lb
Axial Load	=	91000.	lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
19.0000	0.1548909	616360.	23950.
18.0500	0.1548382	616697.	23950.
17.1000	0.1545823	616842.	23950.
16.1500	0.1556504	616318.	23950.
15.2000	0.1549667	616514.	23950.
14.2500	0.1554337	616273.	23950.
13.3000	0.1555461	616059.	23950.
12.3500	0.1553082	616136.	23950.
11.4000	0.1547179	616179.	23950.
10.4500	0.1547772	616162.	23950.
9.5000	0.1553030	616048.	23950.
8.5500	0.1550871	616124.	23950.
7.6000	0.1560283	615703.	23950.
6.6500	0.1696888	612578.	23950.
5.7000	0.3521312	650879.	-31168.

Summary of Pile Response(s)

Definitions of Pile-head Loading Conditions:

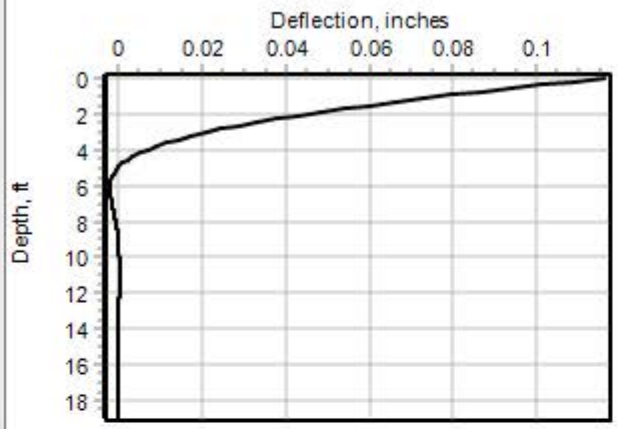
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs

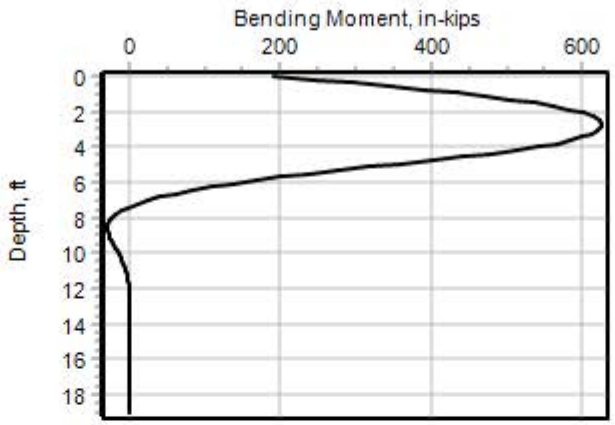
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

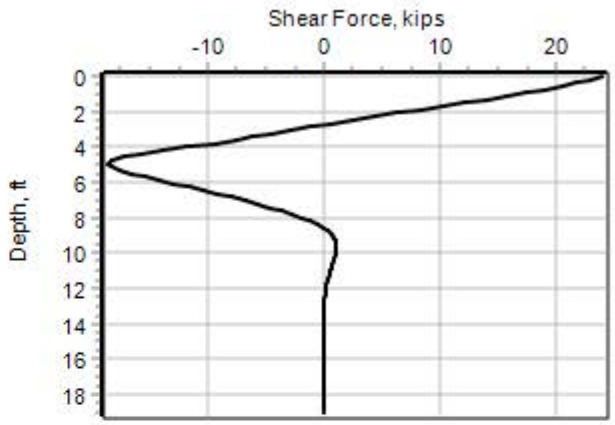
Load Case No.	Load Type No.	Pile-head Condition 1 Shear V(lbs) or y(inches)	Pile-head Condition 2 Pile-head Rotation or in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Load in Pile lbs	Maximum Shear in Pile radians
1	1	V = 23950.	M = 192000.	91000.	0.15489079	616360.	23950.	-0.00476676

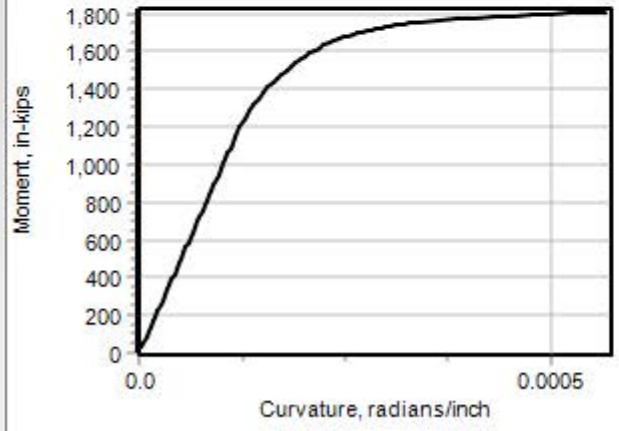
The analysis ended normally.

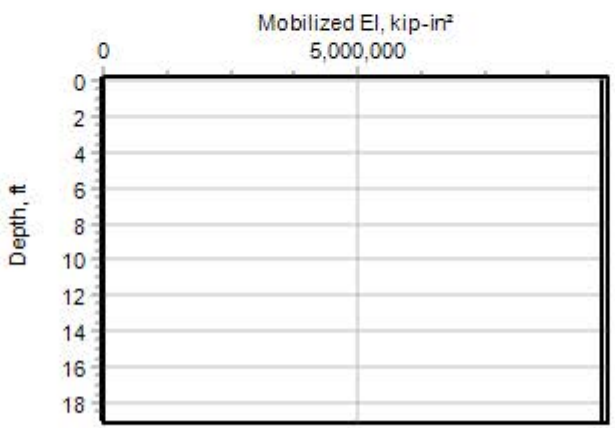
Results for Culvert#3_16inCIP_B-016s.lp7d

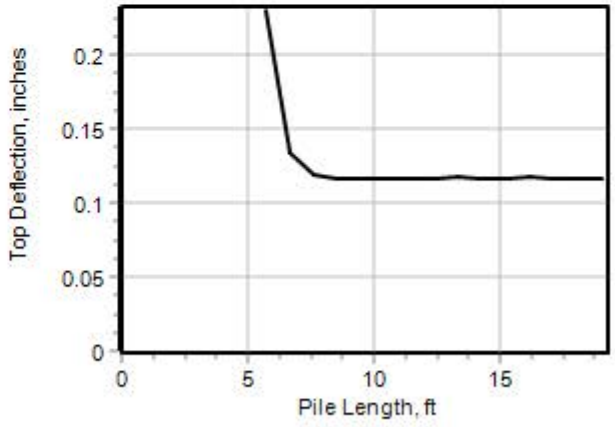












Show All Legends

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LPile Plus for Windows, Version 2013-07.007

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

This copy of LPile is used by:

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Files Used for Analysis

Path to file locations: P:\15-0091 (MED-18 92953)\92953\geotechnical\Culverts\Culvert #3\Lpile\File\
Name of input data file: Culvert#3_16inCIP_B-016s.lp7d
Name of output report file: Culvert#3_16inCIP_B-016s.lp7o
Name of plot output file: Culvert#3_16inCIP_B-016s.lp7p
Name of runtime messeage file: Culvert#3_16inCIP_B-016s.lp7r

Date and Time of Analysis

Date: April 3, 2018 Time: 13:53:12

Problem Title

Project Name: MED-18-Culvert #3

Job Number: 92953

Client: GPD Group

Engineer: ZM

Description: Lateral Load Analysis, B-016-0-14 & B-016-1-16

Program Options and Settings

Engineering Units of Input Data and Computations:
- Engineering units are US Customary 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

Computational Options:
- Use unfactored loads in computations (conventional analysis)
- Compute pile response under loading and nonlinear bending properties of pile (only if nonlinear pile properties are input)
- Use of p-y modification factors for p-y curves not selected
- 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:
- No p-y curves to be computed and reported for user-specified depths
- 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

Pile Structural Properties and Geometry

Total number of pile sections	=	1
Total length of pile	=	19.00 ft
Depth of ground surface below top of pile	=	-0.65 ft

Pile diameter values 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.

Point	Depth X ft	Pile Diameter in
1	0.00000	16.0000000
2	19.000000	16.0000000

Input Structural Properties:

Pile Section No. 1:

Section Type	=	Steel Pipe Pile
Section Length	=	19.00000 ft
Pile Diameter	=	16.00000 in

Ground Slope and Pile Batter Angles

Ground Slope Angle	=	0.000 degrees
	=	0.000 radians
Pile Batter Angle	=	0.000 degrees
	=	0.000 radians

Soil and Rock Layering Information

The soil profile is modelled using 2 layers

Layer 1 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	-0.65000 ft
Distance from top of pile to bottom of layer	=	3.75000 ft
Effective unit weight at top of layer	=	62.60000 pcf
Effective unit weight at bottom of layer	=	62.60000 pcf
Undrained cohesion at top of layer	=	2750.00000 psf
Undrained cohesion at bottom of layer	=	2750.00000 psf
Epsilon-50 at top of layer	=	0.00530
Epsilon-50 at bottom of layer	=	0.00530
Subgrade k at top of layer	=	917.00000 pci
Subgrade k at bottom of layer	=	917.00000 pci

Layer 2 is stiff clay with water-induced erosion

Distance from top of pile to top of layer	=	3.75000 ft
Distance from top of pile to bottom of layer	=	19.85000 ft
Effective unit weight at top of layer	=	67.60000 pcf
Effective unit weight at bottom of layer	=	67.60000 pcf
Undrained cohesion at top of layer	=	5050.00000 psf
Undrained cohesion at bottom of layer	=	5050.00000 psf
Epsilon-50 at top of layer	=	0.00410
Epsilon-50 at bottom of layer	=	0.00410
Subgrade k at top of layer	=	1692.00000 pci
Subgrade k at bottom of layer	=	1692.00000 pci

(Depth of lowest soil layer extends 0.85 ft below pile tip)

Summary of Soil Properties

Layer Num.	Soil Type (p-y Curve Criteria)	Layer Depth ft	Effective Unit Wt. pcf	Undrained Cohesion psf	Strain Factor Epsilon 50	kpy pci
1	Stiff Clay with Free Water	-0.650	62.600	2750.000	0.00530	917.000
		3.750	62.600	2750.000	0.00530	917.000
2	Stiff Clay with Free Water	3.750	67.600	5050.000	0.00410	1692.000
		19.850	67.600	5050.000	0.00410	1692.000

Loading Type

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

Pile-head Loading and Pile-head Fixity Conditions

Number of loads specified = 1

Load No.	Load Compute Type	Condition 1	Condition 2	Axial Thrust Force, lbs	Top y vs. Pile Length
1	1	V = 23950. lbs	M = 192000. in-lbs	91000.	Yes

V = perpendicular shear force applied to pile head
M = bending moment applied to pile head
y = lateral deflection relative to pile axis
S = pile slope relative to original pile batter angle
R = rotational stiffness applie to pile head
Axial thrust 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:

Dimensions and Properties of Steel Pipe Pile:

Length of Section = 19.00000 ft
Outer Diameter of Pipe = 16.00000 in
Pipe Wall Thickness = 0.21900 in
Yield Stress of Pipe = 36.00000 ksi
Elastic Modulus = 29000. ksi
Cross-sectional Area = 10.85747 sq. in.
Moment of Inertia = 338.05798 in^4
Elastic Bending Stiffness = 9803681. kip-in^2
Plastic Modulus, Z = 54.54325 in^3
Plastic Moment Capacity = Fy Z = 1963.55709 in-kip

Axial Structural Capacities:

Nom. Axial Structural Capacity = Fy As = 390.869 kips
Nominal Axial Tensile Capacity = -390.869 kips

Number of Axial Thrust Force Values Determined from Pile-head Loadings = 1

Number	Axial Thrust Force kips
1	91.000

Definition of Run Messages:

Y = part of pipe section has yielded.

Axial Thrust Force = 91.000 kips

Bending Curvature rad/in.	Bending Moment in-kip	Bending Stiffness kip-in2	Depth to N Axis in	Max Total Stress ksi	Run Msg
0.000002846	27.8945447	9801889.	109.5559504	9.0349600	
0.000005692	55.7890894	9801889.	58.7779752	9.6885910	
0.000008538	83.6836340	9801889.	41.8519835	10.3422222	
0.0000114	111.5781787	9801889.	33.3889876	10.9958533	
0.0000142	139.4727234	9801889.	28.3111901	11.6494843	
0.0000171	167.3672681	9801889.	24.9259917	12.3031154	
0.0000199	195.2618128	9801889.	22.5079929	12.9567465	
0.0000228	223.1563575	9801889.	20.6944938	13.6103776	
0.0000256	251.0509021	9801889.	19.2839945	14.2640087	
0.0000285	278.9454468	9801889.	18.1555950	14.9176397	
0.0000313	306.8399915	9801889.	17.2323591	15.5712708	
0.0000342	334.7345362	9801889.	16.4629959	16.2249019	
0.0000370	362.6290809	9801889.	15.8119962	16.8785330	
0.0000398	390.5236255	9801889.	15.2539965	17.5321641	
0.0000427	418.4181702	9801889.	14.7703967	18.1857952	
0.0000455	446.3127149	9801889.	14.3472469	18.8394263	
0.0000484	474.2072596	9801889.	13.9738794	19.4930574	
0.0000512	502.1018043	9801889.	13.6419972	20.1466884	
0.0000541	529.9963490	9801889.	13.3450500	20.8003195	
0.0000569	557.8908936	9801889.	13.0777975	21.4539506	
0.0000598	585.7854383	9801889.	12.8359976	22.1075817	
0.0000626	613.6799830	9801889.	12.6161796	22.7612128	
0.0000655	641.5745277	9801889.	12.4154761	23.4148439	

0.0000683	669.4690724	9801889.	12.2314979	24.0684749	
0.0000711	697.3636170	9801889.	12.0622380	24.7221060	
0.0000740	725.2581617	9801889.	11.9059981	25.3757371	
0.0000768	753.1527064	9801889.	11.7613315	26.0293682	
0.0000797	781.0472511	9801889.	11.6269982	26.6829993	
0.0000825	808.9417958	9801889.	11.5019293	27.3366304	
0.0000854	836.8363404	9801889.	11.3851983	27.9902614	
0.0000882	864.7308851	9801889.	11.2759984	28.6438925	
0.0000911	892.6254298	9801889.	11.1736234	29.2975236	
0.0000939	920.5199745	9801889.	11.0774530	29.9511547	
0.0000968	948.4145192	9801889.	10.9869397	30.6047858	
0.0000996	976.3090639	9801889.	10.9015986	31.2584169	
0.0001025	1004.2036085	9801889.	10.8209986	31.9120480	
0.0001053	1032.0981532	9801889.	10.7447554	32.5656790	
0.0001081	1059.9926979	9801889.	10.6725250	33.2193101	
0.0001110	1087.8872426	9801889.	10.6039987	33.8729412	
0.0001167	1143.6763319	9801889.	10.4769744	35.1802034	
0.0001224	1198.1090748	9790805.	10.3662110	36.0000000	Y
0.0001281	1243.6109150	9710967.	10.2938089	36.0000000	Y
0.0001338	1283.3508937	9594847.	10.2459050	36.0000000	Y
0.0001394	1319.0834079	9459467.	10.2147074	36.0000000	Y
0.0001451	1351.5945763	9312510.	10.1962604	36.0000000	Y
0.0001508	1381.4164312	9158814.	10.1878253	36.0000000	Y
0.0001565	1408.9517314	9001687.	10.1873471	36.0000000	Y
0.0001622	1434.5252101	8843493.	10.1932115	36.0000000	Y
0.0001679	1458.4093728	8685962.	10.2041103	36.0000000	Y
0.0001736	1480.6615391	8529360.	10.2195538	36.0000000	Y
0.0001793	1501.5977795	8375361.	10.2382681	36.0000000	Y
0.0001850	1521.2701184	8224007.	10.2599116	36.0000000	Y
0.0001907	1539.8782834	8076107.	10.2837034	36.0000000	Y
0.0001964	1557.3877960	7931187.	10.3096716	36.0000000	Y
0.0002021	1574.0275434	7790126.	10.3369970	36.0000000	Y
0.0002077	1589.8507759	7652864.	10.3654688	36.0000000	Y
0.0002134	1604.8447131	7519037.	10.3951112	36.0000000	Y
0.0002191	1619.1116034	7388845.	10.4255766	36.0000000	Y
0.0002248	1632.7293955	7262357.	10.4566111	36.0000000	Y
0.0002305	1645.2778322	7137477.	10.4856004	36.0000000	Y
0.0002362	1656.7404260	7014018.	10.5120844	36.0000000	Y
0.0002419	1666.4962254	6889313.	10.5320564	36.0000000	Y
0.0002476	1675.4900520	6767264.	10.5503623	36.0000000	Y
0.0002533	1683.6050104	6647230.	10.5663824	36.0000000	Y
0.0002590	1690.9507104	6529502.	10.5805613	36.0000000	Y
0.0002647	1697.8782759	6415257.	10.5941423	36.0000000	Y
0.0002704	1704.1280745	6303316.	10.6050739	36.0000000	Y
0.0002760	1710.0414337	6194773.	10.6165575	36.0000000	Y
0.0002817	1715.3820402	6088582.	10.6259222	36.0000000	Y
0.0002874	1720.5795793	5986099.	10.6353391	36.0000000	Y
0.0002931	1725.1763589	5885546.	10.6434922	36.0000000	Y
0.0002988	1729.7140234	5788626.	10.6516739	36.0000000	Y
0.0003045	1733.7598184	5693714.	10.6586115	36.0000000	Y
0.0003102	1737.7121426	5601984.	10.6655041	36.0000000	Y
0.0003159	1741.3402898	5512532.	10.6719068	36.0000000	Y
0.0003216	1744.8032643	5425734.	10.6775237	36.0000000	Y
0.0003273	1748.0944257	5341430.	10.6838703	36.0000000	Y
0.0003330	1751.1507726	5259303.	10.6881761	36.0000000	Y
0.0003387	1754.0194355	5179382.	10.6936149	36.0000000	Y
0.0003614	1764.2808887	4881514.	10.7106576	36.0000000	Y
0.0003842	1772.5149920	4613671.	10.7244801	36.0000000	Y
0.0004070	1779.3832122	4372441.	10.7357798	36.0000000	Y
0.0004297	1785.1557706	4154222.	10.7452183	36.0000000	Y
0.0004525	1790.0576895	3956037.	10.7533818	36.0000000	Y
0.0004753	1794.2422813	3775332.	10.7602677	36.0000000	Y
0.0004980	1797.8122768	3609913.	10.7653565	36.0000000	Y

0.0005208	1800.9570816	3458142.	10.7702091	36.0000000	Y
0.0005436	1803.6711664	3318291.	10.7752934	36.0000000	Y
0.0005663	1806.0555818	3189103.	10.7783424	36.0000000	Y

Summary of Results for Nominal (Unfactored) Moment Capacity for Section 1

Load No.	Axial Thrust kips	Nominal Mom. Cap. in-kip
1	91.000	1806.1

Note that the values in the above table are not factored by a strength reduction factor for LRFD.

The value of the strength reduction factor depends on the provisions of the LRFD code being followed.

The above values should be multiplied by the appropriate strength reduction factor to compute ultimate moment capacity according to the LRFD structural design standard being followed.

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 = 23950.0 lbs
Applied moment at pile head = 192000.0 in-lbs
Axial thrust load on pile head = 91000.0 lbs

Depth X	Deflect. y	Bending Moment	Shear Force	Slope S	Total Stress	Bending Stiffness	Soil Res. Spr. Distrib. p
feet	inches	in-lbs	lbs	radians	psi*	lb-in^2	lb/in
							Es*h Lat. Load lb/inch lb/inch
0.00	0.1164	192000.	23950.	-0.003402	12925.	9.802E+09	-400.6634 3925.5616 0.000
0.190	0.1086	246266.	22947.	-0.003351	14209.	9.802E+09	-479.1766 10056. 0.000
0.380	0.1011	298029.	21773.	-0.003288	15434.	9.802E+09	-550.3279 12414. 0.000
0.570	0.0937	346917.	20446.	-0.003213	16591.	9.802E+09	-614.3213 14956. 0.000
0.760	0.0864	392594.	18980.	-0.003127	17672.	9.802E+09	-671.2509 17709. 0.000
0.950	0.0794	434764.	17393.	-0.003031	18670.	9.802E+09	-721.1353 20709. 0.000
1.140	0.0726	473163.	15700.	-0.002925	19579.	9.802E+09	-763.9319 23991. 0.000
1.330	0.0661	507569.	13917.	-0.002811	20393.	9.802E+09	

-799.5332	27597.	0.000				
1.520	0.0598	537793.	12062.	-0.002690	21108.	9.802E+09
-827.7321	31569.	0.000				
1.710	0.0538	563689.	10152.	-0.002562	21721.	9.802E+09
-848.0979	35948.	0.000				
1.900	0.0481	585149.	8205.6285	-0.002428	22229.	9.802E+09
-859.1747	40726.	0.000				
2.090	0.0427	602114.	6252.2530	-0.002290	22630.	9.802E+09
-854.3126	45596.	0.000				
2.280	0.0377	614609.	4316.6166	-0.002148	22926.	9.802E+09
-843.6140	51076.	0.000				
2.470	0.0329	622689.	2411.4308	-0.002004	23117.	9.802E+09
-827.6016	57313.	0.000				
2.660	0.0285	626437.	548.7050	-0.001859	23206.	9.802E+09
-806.3685	64468.	0.000				
2.850	0.0244	625963.	-1259.7704	-0.001713	23194.	9.802E+09
-780.0134	72750.	0.000				
3.040	0.0207	621404.	-3002.4285	-0.001568	23087.	9.802E+09
-748.6341	82438.	0.000				
3.230	0.0173	612923.	-4667.9162	-0.001425	22886.	9.802E+09
-712.3200	93911.	0.000				
3.420	0.0142	600709.	-6205.3661	-0.001284	22597.	9.802E+09
-636.3203	102113.	0.000				
3.610	0.0114	585159.	-7542.1463	-0.001146	22229.	9.802E+09
-536.2939	106880.	0.000				
3.800	0.008983	566792.	-9455.5640	-0.001012	21794.	9.802E+09
-1142.1427	289881.	0.000				
3.990	0.006827	542461.	-11893.	-0.000883	21218.	9.802E+09
-995.6684	332535.	0.000				
4.180	0.004958	512928.	-13995.	-0.000760	20520.	9.802E+09
-848.5234	390216.	0.000				
4.370	0.003361	478959.	-15759.	-0.000645	19716.	9.802E+09
-698.6596	473946.	0.000				
4.560	0.002018	441335.	-17173.	-0.000538	18825.	9.802E+09
-541.4238	611657.	0.000				
4.750	0.000909	400876.	-18191.	-0.000440	17868.	9.802E+09
-351.5774	881418.	0.000				
4.940	1.328E-05	358569.	-18597.	-0.000351	16867.	9.802E+09
-5.1861	890213.	0.000				
5.130	-0.000693	316218.	-18292.	-0.000273	15864.	9.802E+09
273.1367	899009.	0.000				
5.320	-0.001231	275272.	-17499.	-0.000204	14896.	9.802E+09
422.7081	782923.	0.000				
5.510	-0.001623	236509.	-16463.	-0.000145	13978.	9.802E+09
485.4415	681828.	0.000				
5.700	-0.001890	200259.	-15313.	-9.376E-05	13120.	9.802E+09
523.8433	631885.	0.000				
5.890	-0.002051	166723.	-14093.	-5.107E-05	12327.	9.802E+09
545.6633	606643.	0.000				
6.080	-0.002123	136014.	-12838.	-1.586E-05	11600.	9.802E+09
555.1988	596242.	0.000				
6.270	-0.002123	108186.	-11573.	1.254E-05	10942.	9.802E+09
555.2192	596235.	0.000				
6.460	-0.002066	83238.	-10315.	3.480E-05	10351.	9.802E+09
547.6853	604450.	0.000				
6.650	-0.001964	61134.	-9082.0428	5.159E-05	9828.0350	9.802E+09
534.0779	619862.	0.000				
6.840	-0.001831	41803.	-7885.4462	6.356E-05	9370.5735	9.802E+09
515.5682	642128.	0.000				
7.030	-0.001675	25150.	-6735.5478	7.135E-05	8976.4885	9.802E+09
493.1146	671379.	0.000				
7.220	-0.001505	11059.	-5640.4232	7.556E-05	8643.0367	9.802E+09
467.5209	708146.	0.000				

```
     7.410  -0.001330  -601.8799 -4606.4494  7.678E-05  8395.5722  9.802E+09
439.4737    753354.       0.000
     7.600  -0.001155 -9978.2198 -3638.5447  7.555E-05  8617.4593  9.802E+09
409.5655    808383.       0.000
     7.790  -0.000986    -17225. -2740.3666  7.238E-05  8788.9511  9.802E+09
378.3099    875189.       0.000
     7.980  -0.000825    -22504. -1914.4843  6.776E-05  8913.8844  9.802E+09
346.1483    956527.       0.000
     8.170  -0.000677    -25983. -1168.1545  6.212E-05  8996.2095  9.802E+09
308.5269   1039740.       0.000
     8.360  -0.000542    -27857.  -532.3840  5.586E-05  9040.5506  9.802E+09
249.1666   1048536.       0.000
     8.550  -0.000422    -28434.   -25.3299  4.932E-05  9054.2079  9.802E+09
195.6177   1057331.       0.000
     8.740  -0.000317    -27993.   366.6160  4.275E-05  9043.7682  9.802E+09
148.1945   1066127.       0.000
     8.930  -0.000227    -26780.   657.4936  3.638E-05  9015.0660  9.802E+09
106.9612   1074923.       0.000
     9.120  -0.000151    -25010.   861.2629  3.036E-05  8973.1750  9.802E+09
71.7838   1083719.       0.000
     9.310 -8.844E-05    -22865.   991.4062  2.479E-05  8922.4248  9.802E+09
42.3769   1092514.       0.000
     9.500 -3.798E-05    -20499.  1060.6288  1.975E-05  8866.4353  9.802E+09
18.3446   1101310.       0.000
     9.690  1.610E-06    -18037.  1080.6482  1.527E-05  8808.1657  9.802E+09
-0.7837   1110106.       0.000
     9.880  3.163E-05    -15578.  1062.0584  1.136E-05  8749.9720  9.802E+09
-15.5231   1118901.       0.000
    10.070  5.339E-05    -13199.  1014.2571  8.009E-06  8693.6700  9.802E+09
-26.4079   1127697.       0.000
    10.260  6.815E-05    -10956.   945.4249  5.200E-06  8640.6016  9.802E+09
-33.9713   1136493.       0.000
    10.450  7.710E-05 -8889.6947   862.5454  2.891E-06  8591.6998  9.802E+09
-38.7299   1145288.       0.000
    10.640  8.134E-05 -7024.1434   771.4581  1.041E-06  8547.5523  9.802E+09
-41.1712   1154084.       0.000
    10.830  8.185E-05 -5372.2774   676.9336 -4.011E-07  8508.4616  9.802E+09
-41.7451   1162880.       0.000
    11.020  7.951E-05 -3937.1597   582.7652 -1.484E-06  8474.5002  9.802E+09
-40.8588   1171675.       0.000
    11.210  7.508E-05 -2714.2521   491.8707 -2.257E-06  8445.5606  9.802E+09
-38.8733   1180471.       0.000
    11.400  6.921E-05 -1693.2925   406.3980 -2.770E-06  8421.4000  9.802E+09
-36.1028   1189267.       0.000
    11.590  6.245E-05  -859.9280   327.8314 -3.067E-06  8401.6788  9.802E+09
-32.8152   1198063.       0.000
    11.780  5.523E-05  -197.1084   257.0954 -3.190E-06  8385.9934  9.802E+09
-29.2340   1206858.       0.000
    11.970  4.790E-05   313.7509   194.6517 -3.176E-06  8388.7537  9.802E+09
-25.5413   1215654.       0.000
    12.160  4.074E-05   691.8212   140.5897 -3.059E-06  8397.7006  9.802E+09
-21.8815   1224450.       0.000
    12.350  3.395E-05   956.1096    94.7090 -2.868E-06  8403.9549  9.802E+09
-18.3648   1233245.       0.000
    12.540  2.767E-05  1124.8840    56.5909 -2.626E-06  8407.9488  9.802E+09
-15.0721   1242041.       0.000
    12.730  2.198E-05  1215.2536    25.6625 -2.354E-06  8410.0874  9.802E+09
-12.0581   1250837.       0.000
    12.920  1.694E-05  1242.8817     1.2502 -2.068E-06  8410.7412  9.802E+09
-9.3563   1259632.       0.000
    13.110  1.255E-05  1221.8123   -17.3758 -1.781E-06  8410.2426  9.802E+09
-6.9823   1268428.       0.000
    13.300  8.814E-06  1164.3873   -30.9642 -1.503E-06  8408.8837  9.802E+09
```

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-4.9374   1277224.      0.000
    13.490  5.695E-06  1081.2394   -40.2546 -1.242E-06  8406.9160  9.802E+09
-3.2120   1286019.      0.000
    13.680  3.149E-06   981.3418   -45.9549 -1.002E-06  8404.5520  9.802E+09
-1.7883   1294815.      0.000
    13.870  1.124E-06   872.1008   -48.7259 -7.869E-07  8401.9668  9.802E+09
-0.6424   1303611.      0.000
    14.060 -4.392E-07   759.4781   -49.1701 -5.971E-07  8399.3017  9.802E+09
0.2528   1312407.      0.000
    14.250 -1.599E-06   648.1331   -47.8254 -4.334E-07  8396.6667  9.802E+09
0.9267   1321202.      0.000
    14.440 -2.416E-06   541.5743   -45.1626 -2.950E-07  8394.1451  9.802E+09
1.4091   1329998.      0.000
    14.630 -2.945E-06   442.3142   -41.5851 -1.806E-07  8391.7961  9.802E+09
1.7290   1338794.      0.000
    14.820 -3.239E-06   352.0211   -37.4315 -8.822E-08  8389.6594  9.802E+09
1.9145   1347589.      0.000
    15.010 -3.347E-06   271.6630   -32.9792 -1.568E-08  8387.7577  9.802E+09
1.9911   1356385.      0.000
    15.200 -3.311E-06   201.6422   -28.4496  3.937E-08  8386.1007  9.802E+09
1.9823   1365181.      0.000
    15.390 -3.167E-06   141.9163   -24.0139  7.932E-08  8384.6873  9.802E+09
1.9087   1373976.      0.000
    15.580 -2.949E-06    92.1059   -19.7992  1.065E-07  8383.5086  9.802E+09
1.7884   1382772.      0.000
    15.770 -2.682E-06    51.5879   -15.8946  1.233E-07  8382.5497  9.802E+09
1.6366   1391568.      0.000
    15.960 -2.387E-06    19.5754   -12.3576  1.315E-07  8381.7922  9.802E+09
1.4660   1400363.      0.000
    16.150 -2.082E-06    -4.8172    -9.2196  1.332E-07  8381.4429  9.802E+09
1.2866   1409159.      0.000
    16.340 -1.779E-06   -22.5212    -6.4914  1.301E-07  8381.8619  9.802E+09
1.1065   1417955.      0.000
    16.530 -1.489E-06   -34.4719    -4.1680  1.234E-07  8382.1447  9.802E+09
0.9316   1426751.      0.000
    16.720 -1.216E-06   -41.5784    -2.2329  1.146E-07  8382.3129  9.802E+09
0.7658   1435546.      0.000
    16.910 -9.661E-07   -44.7017    -0.6622  1.046E-07  8382.3868  9.802E+09
0.6120   1444342.      0.000
    17.100 -7.396E-07   -44.6413     0.5729  9.417E-08  8382.3853  9.802E+09
0.4714   1453138.      0.000
    17.290 -5.367E-07   -42.1285     1.5025  8.408E-08  8382.3259  9.802E+09
0.3441   1461933.      0.000
    17.480 -3.562E-07   -37.8247     2.1568  7.478E-08  8382.2240  9.802E+09
0.2298   1470729.      0.000
    17.670 -1.957E-07   -32.3247     2.5635  6.662E-08  8382.0939  9.802E+09
0.1270   1479525.      0.000
    17.860 -5.240E-08   -26.1628     2.7473  5.982E-08  8381.9481  9.802E+09
0.0342   1488320.      0.000
    18.050  7.704E-08   -19.8219     2.7286  5.447E-08  8381.7980  9.802E+09
-0.0506   1497116.      0.000
    18.240  1.960E-07   -13.7430     2.5234  5.056E-08  8381.6541  9.802E+09
-0.1294   1505912.      0.000
    18.430  3.076E-07    -8.3363     2.1428  4.800E-08  8381.5262  9.802E+09
-0.2044   1514707.      0.000
    18.620  4.148E-07    -3.9916     1.5939  4.656E-08  8381.4234  9.802E+09
-0.2772   1523503.      0.000
    18.810  5.199E-07    -1.0876     0.8795  4.597E-08  8381.3547  9.802E+09
-0.3494   1532299.      0.000
    19.000  6.245E-07     0.000      0.000  4.585E-08  8381.3289  9.802E+09
-0.4221    770547.      0.000

* This analysis computed pile response using nonlinear moment-curvature
```

relationships.
Values of total stress due to combined axial and bending stresses are computed only
for elastic sections only and do not equal the actual stresses in concrete and steel.
Stresses in concrete and steel may be interpolated from the output for nonlinear
bending properties relative to the magnitude of bending moment developed in the pile.

Output Summary for Load Case No. 1:

Pile-head deflection	=	0.1163544 inches
Computed slope at pile head	=	-0.0034024 radians
Maximum bending moment	=	626437. inch-lbs
Maximum shear force	=	23950. lbs
Depth of maximum bending moment	=	2.6600000 feet below pile head
Depth of maximum shear force	=	0.000000 feet below pile head
Number of iterations	=	12
Number of zero deflection points	=	4

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

Boundary Condition Type 1, Shear and Moment

Shear	=	23950. lb
Moment	=	192000. in- lb
Axial Load	=	91000. lb

Pile Length feet	Pile Head Deflection inches	Maximum Moment ln-lbs	Maximum Shear lbs
19.0000	0.1163545	626437.	23950.
18.0500	0.1163053	626701.	23950.
17.1000	0.1160905	626901.	23950.
16.1500	0.1170260	625765.	23950.
15.2000	0.1164526	626375.	23950.
14.2500	0.1168557	625845.	23950.
13.3000	0.1169413	625471.	23950.
12.3500	0.1167537	625868.	23950.
11.4000	0.1162590	626378.	23950.
10.4500	0.1163502	626232.	23950.
9.5000	0.1167796	625720.	23950.
8.5500	0.1165146	626054.	23950.
7.6000	0.1185074	623904.	23950.
6.6500	0.1340152	612964.	23950.
5.7000	0.2296650	606612.	-28132.

Summary of Pile Response(s)

Definitions of Pile-head Loading Conditions:

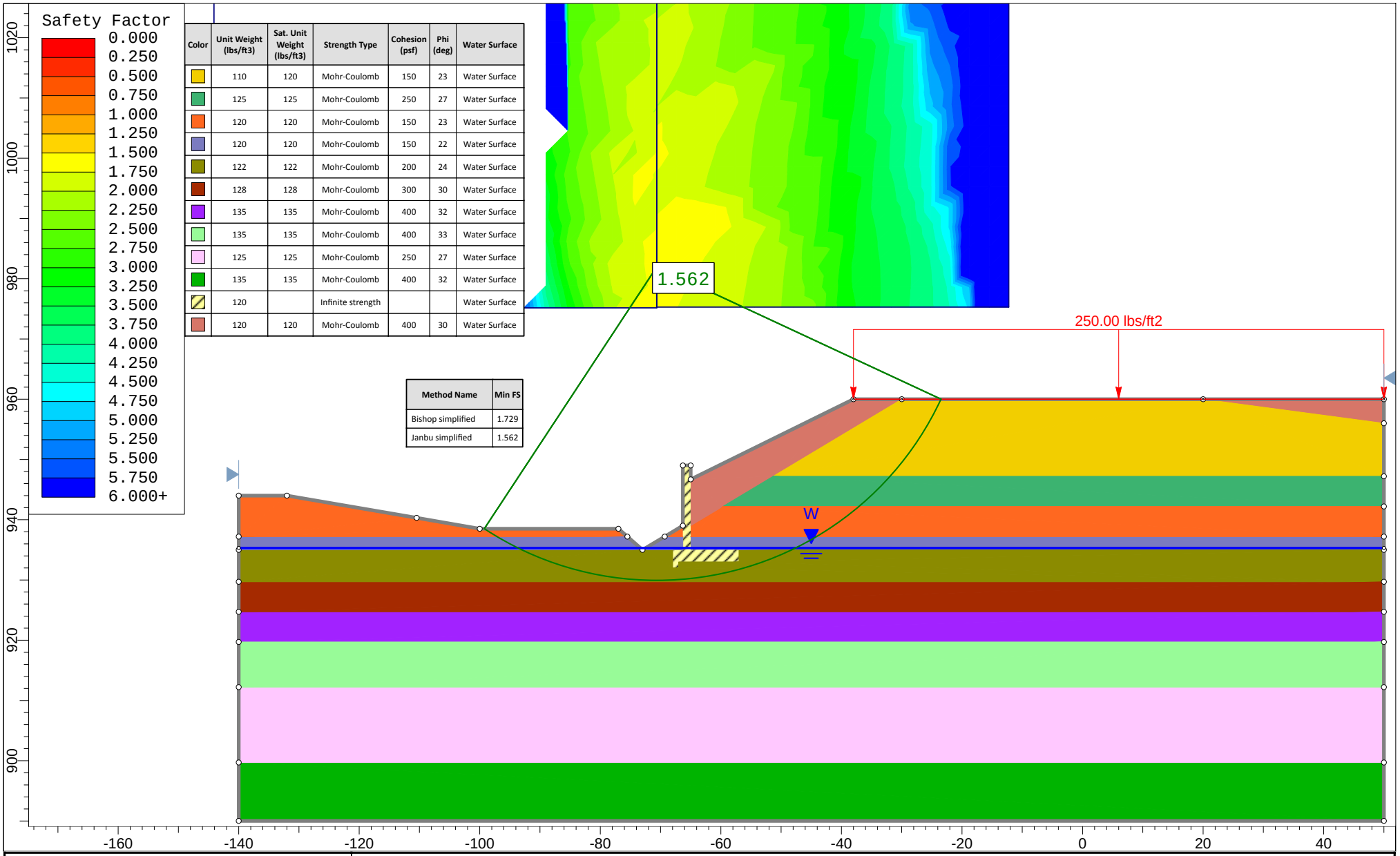
Load Type 1: Load 1 = Shear, lbs, and Load 2 = Moment, in-lbs
Load Type 2: Load 1 = Shear, lbs, and Load 2 = Slope, radians
Load Type 3: Load 1 = Shear, lbs, and Load 2 = Rotational Stiffness, in-lbs/radian
Load Type 4: Load 1 = Top Deflection, inches, and Load 2 = Moment, in-lbs
Load Type 5: Load 1 = Top Deflection, inches, and Load 2 = Slope, radians

Load Case No.	Load Type No.	Pile-head Condition 1 Shear V(lbs) or y(inches)	Pile-head Condition 2 Moment in-lb, rad., or Rotation in-lb/rad.	Axial Loading lbs	Pile-head Deflection inches	Maximum Moment in Pile in-lbs	Maximum Load in Pile lbs	Maximum Shear in Pile radians
1	1	V = 23950.	M = 192000.	91000.	0.11635437	626437.	23950.	-0.00340237

The analysis ended normally.

CULVERT #3

GLOBAL STABILITY ANALYSIS

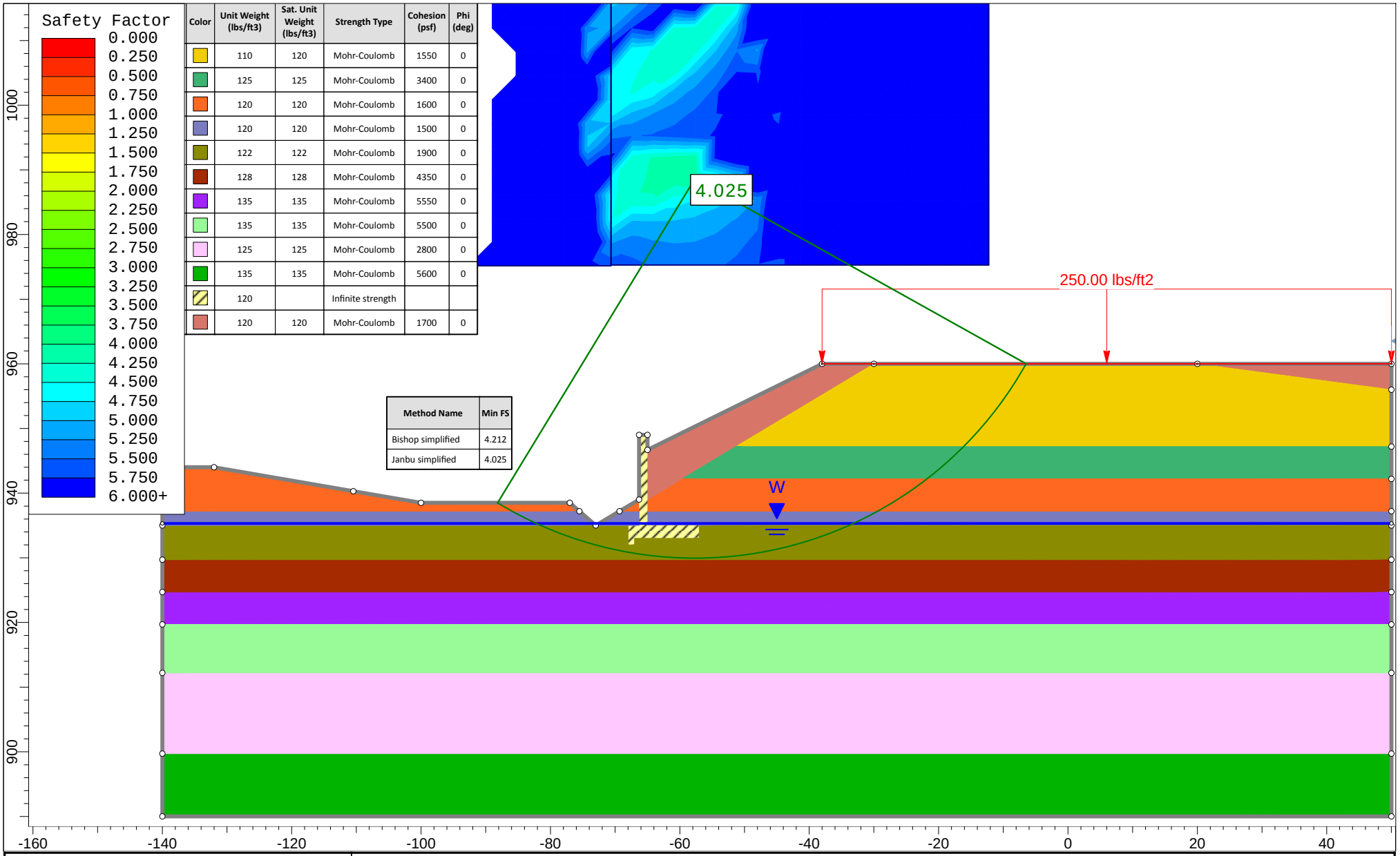


Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
	110	120	Mohr-Coulomb	150	23	Water Surface
	125	125	Mohr-Coulomb	250	27	Water Surface
	120	120	Mohr-Coulomb	150	23	Water Surface
	120	120	Mohr-Coulomb	150	22	Water Surface
	122	122	Mohr-Coulomb	200	24	Water Surface
	128	128	Mohr-Coulomb	300	30	Water Surface
	135	135	Mohr-Coulomb	400	32	Water Surface
	135	135	Mohr-Coulomb	400	33	Water Surface
	125	125	Mohr-Coulomb	250	27	Water Surface
	135	135	Mohr-Coulomb	400	32	Water Surface
	120		Infinite strength			Water Surface
	120	120	Mohr-Coulomb	400	30	Water Surface

Method Name	Min FS
Bishop simplified	1.729
Janbu simplified	1.562

SLIDEINTERPRET 7.022

Project	Med-18 Culvert #3		
Analysis Description	Circular_Effective Stress Analysis		
Drawn By	ZM	*Scale* 1:264	*Company* National Engineering & Architectural Services, Inc
Date	1/26/2017, 4:13:49 PM		*File Name* Circular_Effective_1ft_withHeadwall_B_014.slim

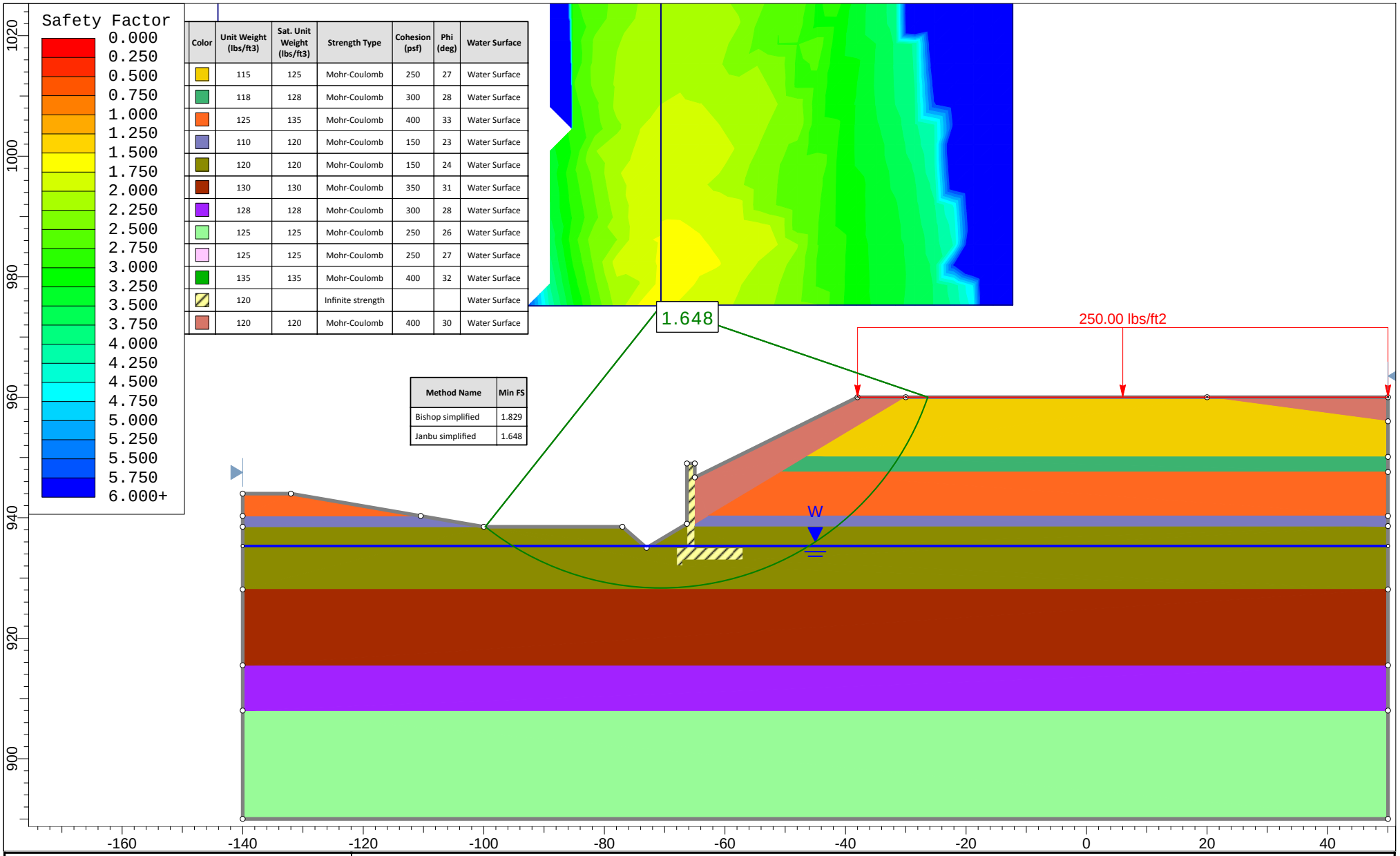


Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
	110	120	Mohr-Coulomb	1550	0
	125	125	Mohr-Coulomb	3400	0
	120	120	Mohr-Coulomb	1600	0
	120	120	Mohr-Coulomb	1500	0
	122	122	Mohr-Coulomb	1900	0
	128	128	Mohr-Coulomb	4350	0
	135	135	Mohr-Coulomb	5550	0
	135	135	Mohr-Coulomb	5500	0
	125	125	Mohr-Coulomb	2800	0
	135	135	Mohr-Coulomb	5600	0
	120		Infinite strength		
	120	120	Mohr-Coulomb	1700	0

Method Name	Min FS
Bishop simplified	4.212
Janbu simplified	4.025

SLIDEINTERPRET 7.022

Project	Med-18 Culvert #3		
Analysis Description	Circular_Total Stress Analysis		
Drawn By	ZM	*Scale* 1:246	*Company* National Engineering & Architectural Services, Inc
Date	1/26/2017, 4:13:49 PM		*File Name* Circular_Total_1ft_withHeadwall_B_014.slim

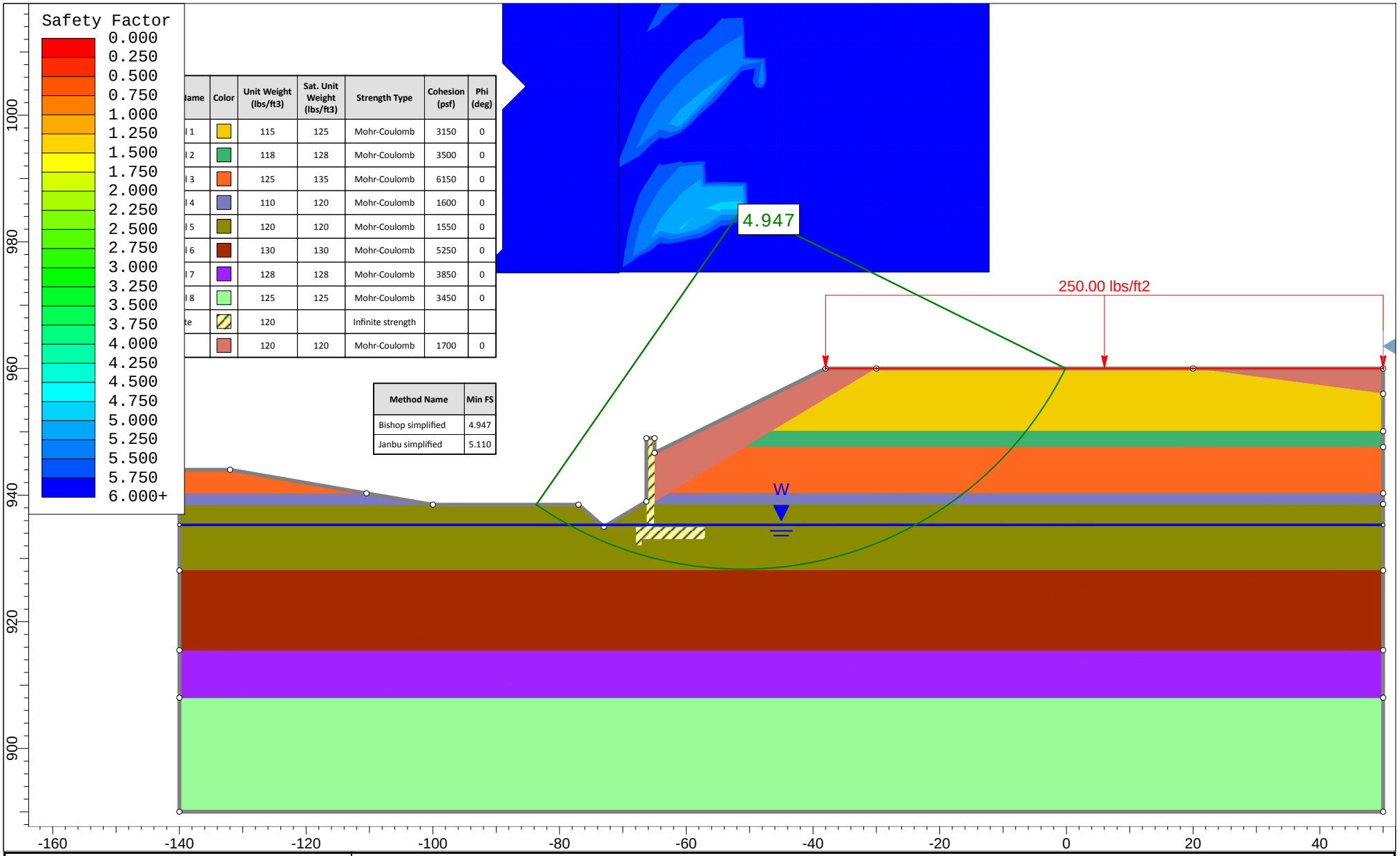


Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
	115	125	Mohr-Coulomb	250	27	Water Surface
	118	128	Mohr-Coulomb	300	28	Water Surface
	125	135	Mohr-Coulomb	400	33	Water Surface
	110	120	Mohr-Coulomb	150	23	Water Surface
	120	120	Mohr-Coulomb	150	24	Water Surface
	130	130	Mohr-Coulomb	350	31	Water Surface
	128	128	Mohr-Coulomb	300	28	Water Surface
	125	125	Mohr-Coulomb	250	26	Water Surface
	125	125	Mohr-Coulomb	250	27	Water Surface
	135	135	Mohr-Coulomb	400	32	Water Surface
	120		Infinite strength			Water Surface
	120	120	Mohr-Coulomb	400	30	Water Surface

Method Name	Min FS
Bishop simplified	1.829
Janbu simplified	1.648

SLIDEINTERPRET 7.022

Project	Med-18 Culvert #3		
Analysis Description	Circular_Effective Stress Analysis		
Drawn By	ZM	*Scale* 1:264	*Company* National Engineering & Architectural Services, Inc
Date	1/26/2017, 4:13:49 PM		*File Name* Circular_Effective_1ft_withHeadwall_B_015.slim



Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
l 1		115	125	Mohr-Coulomb	3150	0
l 2		118	128	Mohr-Coulomb	3500	0
l 3		125	135	Mohr-Coulomb	6150	0
l 4		110	120	Mohr-Coulomb	1600	0
l 5		120	120	Mohr-Coulomb	1550	0
l 6		130	130	Mohr-Coulomb	5250	0
l 7		128	128	Mohr-Coulomb	3850	0
l 8		125	125	Mohr-Coulomb	3450	0
te		120		Infinite strength		
		120	120	Mohr-Coulomb	1700	0

Method Name	Min FS
Bishop simplified	4.947
Janbu simplified	5.110

rocscience

SLIDEINTERPRET 7.022

Project	Med-18 Culvert #3		
Analysis Description	Circular_Total Stress Analysis		
Drawn By	ZM	*Scale* 1:251	*Company* National Engineering & Architectural Services, Inc
Date	1/26/2017, 4:13:49 PM		*File Name* Circular_Total_1ft_withHeadwall_B_015.slim

CULVERT #3

SETTLEMENT ANALYSIS

MED-18-13.54

PROJECT IDENTIFICATION

Title: MED-18-13.54
Project Number: -
Client: GPD/ODOT
Designer: ZM
Station Number:

Description:
Culvert #3

Company's information:

Name: NEAS, Inc.
Street:
Columbus, OH 43231
Telephone #:
Fax #:
E-Mail:

Original file path and name: P:\15-0091 ..... hnical\Culverts\Culvert #3\Fossa\MED18-B15-B15.2ST
Original date and time of creating this file: Sun Apr 8 11:27:50 2018

GEOMETRY: Analysis of a 3D-Approximate geometry

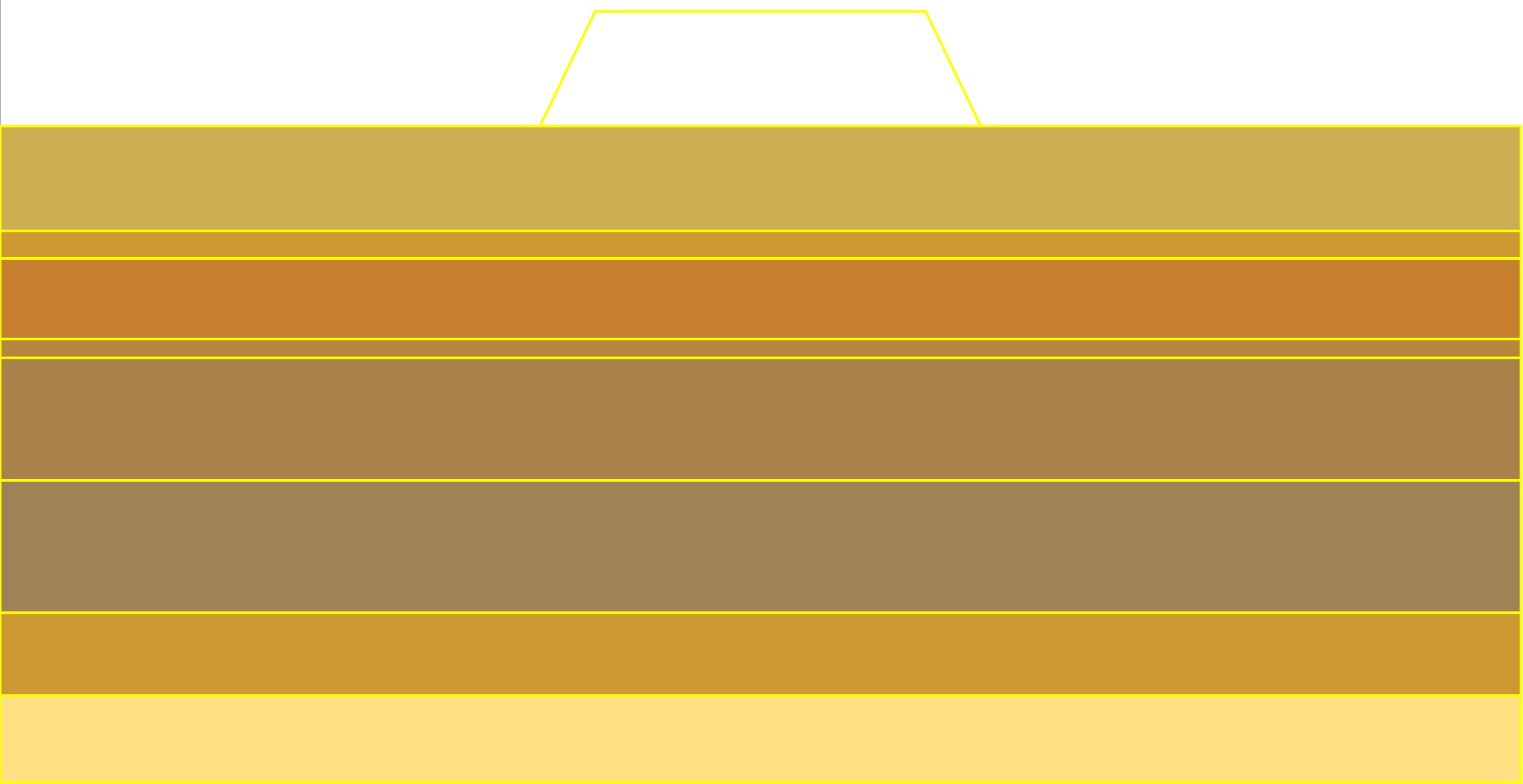
INPUT DATA -- FOUNDATION LAYERS -- 9 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	115.00	0.30	A-6b
2	118.00	0.30	Soft to very stiff, Silty Clay, A-6b
3	125.00	0.30	A-6a
4	110.00	0.30	A-6b
5	120.00	0.30	A-4a
6	130.00	0.30	Soft to Medium Stiff, Sandy Silt, A-4a
7	128.00	0.30	A-6a
8	125.00	0.30	A-4a
9	130.00	0.30	Granular Materials

INPUT DATA -- EMBANKMENT LAYERS -- 1 layers

	Wet Unit Weight, γ [lb/ft³]	Description of Soil
1	120.00	Embankment Fills

DRAWING OF SPECIFIED GEOMETRY



INPUT DATA FOR CONSOLIDATION -- α = 1/2

Layer # Undergoing Consolidation [Yes/No]		OCR = Pc / Po	Cc	Cr	e0	Cv [ft ²/day]	Drains at :
1	Yes	5.00	0.10	0.02	0.61	0.2000	Top & Bot.
2	Yes	4.00	0.10	0.02	0.54	0.2000	Top & Bot.
3	Yes	4.00	0.10	0.02	0.47	0.2000	Top & Bot.
4	Yes	3.00	0.10	0.02	0.67	0.2000	Top & Bot.
5	Yes	2.00	0.10	0.01	0.69	0.2153	Top & Bot.
6	Yes	3.00	0.10	0.01	0.47	0.2153	Top & Bot.
7	Yes	3.00	0.10	0.01	0.57	0.2153	Top & Bot.
8	Yes	2.00	0.10	0.01	0.58	0.2153	Top & Bot.
9	No	N/A	N/A	N/A	N/A	N/A	N/A

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	-20.00	0.00	1	600000	0.3000	0.0015	959.60	959.54	0.06
			2	700000	0.3000	0.0010			
			3	900000	0.3000	0.0029			
			4	300000	0.3000	0.0025			
			5	200000	0.3000	0.0215			
			6	300000	0.3000	0.0144			
			7	700000	0.3000	0.0033			
			8	500000	0.3000	0.0051			
			9	555400	0.3000	0.0035			
2	-15.00	0.00	1	600000	0.3000	0.0106	959.60	959.52	0.08
			2	700000	0.3000	0.0022			
			3	900000	0.3000	0.0048			
			4	300000	0.3000	0.0036			
			5	200000	0.3000	0.0288			
			6	300000	0.3000	0.0173			
			7	700000	0.3000	0.0038			
			8	500000	0.3000	0.0057			
			9	555400	0.3000	0.0038			
3	-10.00	0.00	1	600000	0.3000	0.0127	959.60	959.50	0.10
			2	700000	0.3000	0.0031			
			3	900000	0.3000	0.0064			
			4	300000	0.3000	0.0046			
			5	200000	0.3000	0.0350			
			6	300000	0.3000	0.0198			
			7	700000	0.3000	0.0042			
			8	500000	0.3000	0.0062			
			9	555400	0.3000	0.0041			
4	-5.00	0.00	1	600000	0.3000	0.0128	959.60	959.50	0.10
			2	700000	0.3000	0.0033			
			3	900000	0.3000	0.0072			
			4	300000	0.3000	0.0053			
			5	200000	0.3000	0.0391			
			6	300000	0.3000	0.0215			
			7	700000	0.3000	0.0045			
			8	500000	0.3000	0.0065			
			9	555400	0.3000	0.0042			
5	0.00	0.00	1	600000	0.3000	0.0128	959.60	959.49	0.11
			2	700000	0.3000	0.0034			
			3	900000	0.3000	0.0074			
			4	300000	0.3000	0.0055			
			5	200000	0.3000	0.0405			
			6	300000	0.3000	0.0221			
			7	700000	0.3000	0.0046			
			8	500000	0.3000	0.0066			
			9	555400	0.3000	0.0043			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
6	5.00	0.00	1	600000	0.3000	0.0128	959.60	959.50	0.10
			2	700000	0.3000	0.0033			
			3	900000	0.3000	0.0072			
			4	300000	0.3000	0.0053			
			5	200000	0.3000	0.0391			
			6	300000	0.3000	0.0215			
			7	700000	0.3000	0.0045			
			8	500000	0.3000	0.0065			
			9	555400	0.3000	0.0042			
7	10.00	0.00	1	600000	0.3000	0.0127	959.60	959.50	0.10
			2	700000	0.3000	0.0031			
			3	900000	0.3000	0.0064			
			4	300000	0.3000	0.0046			
			5	200000	0.3000	0.0350			
			6	300000	0.3000	0.0198			
			7	700000	0.3000	0.0042			
			8	500000	0.3000	0.0062			
			9	555400	0.3000	0.0041			
8	15.00	0.00	1	600000	0.3000	0.0106	959.60	959.52	0.08
			2	700000	0.3000	0.0022			
			3	900000	0.3000	0.0048			
			4	300000	0.3000	0.0036			
			5	200000	0.3000	0.0288			
			6	300000	0.3000	0.0174			
			7	700000	0.3000	0.0038			
			8	500000	0.3000	0.0057			
			9	555400	0.3000	0.0038			
9	20.00	0.00	1	600000	0.3000	0.0015	959.60	959.54	0.06
			2	700000	0.3000	0.0010			
			3	900000	0.3000	0.0029			
			4	300000	0.3000	0.0025			
			5	200000	0.3000	0.0216			
			6	300000	0.3000	0.0144			
			7	700000	0.3000	0.0033			
			8	500000	0.3000	0.0051			
			9	555400	0.3000	0.0035			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	-20.00	0.00	959.60	0.05	959.55
2	-15.00	0.00	959.60	0.12	959.48
3	-10.00	0.00	959.60	0.14	959.46
4	-5.00	0.00	959.60	0.15	959.45
5	0.00	0.00	959.60	0.15	959.45
6	5.00	0.00	959.60	0.15	959.45
7	10.00	0.00	959.60	0.14	959.46
8	15.00	0.00	959.60	0.12	959.48
9	20.00	0.00	959.60	0.05	959.55

*Note: Final Z is calculated assuming only 'Ultimate Settlement' exists.

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	D E S C R I P T I O N
1	1	-25.00	959.60	A-6b
	2	0.00	959.60	
	3	25.00	959.60	
2	1	-25.00	950.10	Soft to very stiff, Silty Clay, A-6b
	2	0.00	950.10	
	3	25.00	950.10	
3	1	-25.00	947.60	A-6a
	2	0.00	947.60	
	3	15.20	947.60	
4	1	-25.00	940.30	A-6b
	2	0.00	940.30	
	3	12.70	940.30	
5	1	-25.00	938.60	A-4a
	2	0.00	938.60	
	3	5.40	938.60	
6	1	-25.00	927.50	Soft to Medium Stiff, Sandy Silt, A-4a
	2	0.00	927.50	
	3	3.70	927.50	
7	1	-25.00	915.50	A-6a
	2	0.00	915.50	
	3	25.00	915.50	
8	1	-25.00	908.00	A-4a
	2	0.00	908.00	
	3	25.00	908.00	
9	1	-25.00	898.50	Granular Materials
	2	0.00	898.50	
	3	25.00	898.50	

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	D E S C R I P T I O N
1	X1 = -20.00 [ft]	1	-15.00	970.00	Embankment Fills
	X2 = 20.00 [ft]	2	15.00	970.00	

APPENDIX E

CULVERT #6 ANALYSES

CULVERT #6

BEARING RESISTANCE ANALYSIS

Objective: **To determine the nominal bearing capacity of foundation soil for shallow foundation design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**

Givens:

Footing Geometry:

$D_f := 3\ ft$ — Depth to base of footing below exterior grade

$L := 10.5\ ft$ — Assumed Footing Length

$B := 1\ ft$ — Width/Breadth of footing

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 25\ deg$ — Effective angle of internal friction

$\gamma_f := 122\ \frac{lbf}{ft^3}$ — Unit weight

$c'_f := 200\ \frac{lbf}{ft^2}$ — Cohesion

Undrained Conditions (Total Stress):

$\phi_f := 0\ deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 122\ \frac{lbf}{ft^3}$ — Unit weight

$c_f := 2100\ \frac{lbf}{ft^2}$ — Cohesion (Use Su if Angle of internal friction = 0 deg)

Foundation Surcharge Soil Parameters:

$\gamma_q := 120 \cdot \frac{lbf}{ft^3}$ — Unit weight of Soil above bearing depth (Used in Bearing Resistance of Soil Calculation LRFD 10.6.3.1.2a-1)

Groundwater Conditions:

$d_w := 0\ ft$ — Depth of Groundwater below Bearing Grade

Drained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi'_f > 0,\ e^{\pi \cdot \tan\langle\phi'_f\rangle} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2,\ 1.0\right) \qquad N_q = 10.66$$

$$N_c := \text{if}\left(\phi'_f > 0,\ \frac{N_q - 1}{\tan\langle\phi'_f\rangle},\ 5.14\right) \qquad N_c = 20.72$$

$$N_\gamma := 2 \cdot \langle N_q + 1\rangle \cdot \tan\langle\phi'_f\rangle \qquad N_\gamma = 10.9$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$$s_c := \text{if}\left(\phi'_f > 0\,,\ 1 + \left(\frac{B}{L}\right)\cdot\left(\frac{N_q}{N_c}\right),\ 1 + \left(\frac{B}{5\cdot L}\right)\right) \qquad s_c = 1.049$$

$$s_q := \text{if}\left(\phi'_f > 0\,,\ 1 + \left(\frac{B}{L}\cdot\tan\left(\phi'_f\right)\right),\ 1\right) \qquad s_q = 1.044$$

$$s_\gamma := \text{if}\left(\phi'_f > 0\,,\ 1 - 0.4\cdot\left(\frac{B}{L}\right),\ 1\right) \qquad s_\gamma = 0.962$$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$$i_q := 1 \qquad i_q = 1$$

$$i_\gamma := 1 \qquad i_\gamma = 1$$

$$i_c := 1 \qquad i_c = 1$$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$$C_{wq} := \text{if}\left(d_w > D_f,\ 1.0\,,\ \frac{(1.0 - 0.5)}{(D_f - 0)}\cdot\left(d_w - 0\right) + 0.5\right) \qquad C_{wq} = 0.5$$

$$C_{w\gamma} := \text{if}\left(d_w < D_f,\ 0.5\,,\ \text{if}\left(d_w > 1.5\cdot B + D_f,\ 1.0\,,\ \frac{(1.0 - 0.5)}{(1.5\cdot B + D_f - D_f)}\cdot\left(d_w - D_f\right) + 0.5\right)\right) \qquad C_{w\gamma} = 0.5$$

Depth Correction Factor Compute depth correction factor per **LRFD [Table 10.6.3.1.2a-4]**. It can be assumed that the soils above the footing are as competent as those beneath the footing. Therefore; the depth correction factor is taken as 1.0 if Df/B is less than 1.0.

$\frac{D_f}{B} = 3$ **<---- CHECK** **The depth correction factor is taken as 1.0 if Df/B is less than 1.0. Otherwise check [Table 10.6.3.1.2a-4].**

$$d_q := 1.0$$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$$N_{cm} := N_c\cdot s_c\cdot i_c \qquad N_{cm} = 21.736$$

$$N_{qm} := N_q\cdot s_q\cdot i_q \qquad N_{qm} = 11.136$$

$$N_{\gamma m} := N_\gamma\cdot s_\gamma\cdot i_\gamma \qquad N_{\gamma m} = 10.462$$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$$q_{nd} := c'_f\cdot N_{cm} + \gamma_q\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq} + 0.5\cdot\gamma_f\cdot B\cdot N_{\gamma m}\cdot C_{w\gamma} \qquad q_{nd} = 6670.7\ \frac{lbf}{ft^2}$$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$$\phi_b := 0.5$$

Bearing resistance factor **LRFD 10.5.5.2.2-1**

$$q_{Rd} := \phi_b\cdot q_{nd} \qquad q_{Rd} = 3.3\ ksf$$

Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0\,,\, e^{\pi \cdot \tan\langle\phi_f\rangle} \cdot \tan\left(45\ \textit{deg} + \frac{\phi_f}{2}\right)^2\,,\, 1.0\right)$ $N_q = 1$

$N_c := \text{if}\left(\phi_f > 0\,,\, \frac{N_q - 1}{\tan\langle\phi_f\rangle}\,,\, 5.14\right)$ $N_c = 5.14$

$N_\gamma := 2 \cdot \langle N_q + 1\rangle \cdot \tan\langle\phi_f\rangle$ $N_\gamma = 0$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi_f > 0\,,\, 1 + \left(\frac{B}{L}\right) \cdot \left(\frac{N_q}{N_c}\right)\,,\, 1 + \left(\frac{B}{5 \cdot L}\right)\right)$ $s_c = 1.019$

$s_q := \text{if}\left(\phi_f > 0\,,\, 1 + \left(\frac{B}{L} \cdot \tan\langle\phi_f\rangle\right)\,,\, 1\right)$ $s_q = 1$

$s_\gamma := \text{if}\left(\phi_f > 0\,,\, 1 - 0.4 \cdot \left(\frac{B}{L}\right)\,,\, 1\right)$ $s_\gamma = 1$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $i_q = 1$

$i_\gamma := 1$ $i_\gamma = 1$

$i_c := 1$ $i_c = 1$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 5.238$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 1$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 0$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 11179.6\ \frac{\textit{lbf}}{\textit{ft}^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.5$ Bearing resistance factor **LRFD 10.5.5.2.2-1**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 5.6\ \textit{ksf}$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 3.3\ \textit{ksf}$

Undrained Conditions: $q_{Ru} = 5.6\ \textit{ksf}$

Objective: **To determine the nominal bearing capacity of foundation soil for shallow foundation design.**
Method: **In accordance with LRFD Bridge Design Specifications, 7th Ed., 2014, [Sect. 10.6.3.1.2].**

Givens:

Footing Geometry:

$D_f := 3\ ft$ Depth to base of footing below exterior grade

$L := 10.5\ ft$ Assumed Footing Length

$B := 1\ ft$ Width/Breadth of footing

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 34\ deg$ Effective angle of internal friction

$\gamma_f := 125 \cdot \frac{lbf}{ft^3}$ Unit weight

$c'_f := 0\ \frac{lbf}{ft^2}$ Cohesion

Undrained Conditions (Total Stress):

$\phi_f := 34 \cdot deg$ Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 125\ \frac{lbf}{ft^3}$ Unit weight

$c_f := 0\ \frac{lbf}{ft^2}$ Cohesion (Use Su if Angle of internal friction = 0 deg)

Foundation Surcharge Soil Parameters:

$\gamma_q := 120 \cdot \frac{lbf}{ft^3}$ Unit weight of Soil above bearing depth (Used in Bearing Resistance of Soil Calculation LRFD 10.6.3.1.2a-1)

Groundwater Conditions:

$d_w := 0\ ft$ Depth of Groundwater below Bearing Grade

Drained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi'_f > 0,\ e^{\pi \cdot \tan\left(\phi'_f\right)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2,\ 1.0\right) \qquad N_q = 29.44$$

$$N_c := \text{if}\left(\phi'_f > 0,\ \frac{N_q - 1}{\tan\left(\phi'_f\right)},\ 5.14\right) \qquad N_c = 42.16$$

$$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi'_f\right) \qquad N_\gamma = 41.1$$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi'_f > 0\,,\ 1 + \left(\frac{B}{L}\right)\cdot\left(\frac{N_q}{N_c}\right),\ 1 + \left(\frac{B}{5\cdot L}\right)\right)$ $s_c = 1.066$

$s_q := \text{if}\left(\phi'_f > 0\,,\ 1 + \left(\frac{B}{L}\cdot\tan\left(\phi'_f\right)\right),\ 1\right)$ $s_q = 1.064$

$s_\gamma := \text{if}\left(\phi'_f > 0\,,\ 1 - 0.4\cdot\left(\frac{B}{L}\right),\ 1\right)$ $s_\gamma = 0.962$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $i_q = 1$

$i_\gamma := 1$ $i_\gamma = 1$

$i_c := 1$ $i_c = 1$

Compute groundwater depth correction factors per **LRFD [Table 10.6.3.1.2a-2]**:

$C_{wq} := \text{if}\left(d_w > D_f,\ 1.0\,,\ \frac{(1.0 - 0.5)}{(D_f - 0)}\cdot\left\langle d_w - 0\right\rangle + 0.5\right)$ $C_{wq} = 0.5$

$C_{w\gamma} := \text{if}\left(d_w < D_f,\ 0.5\,,\ \text{if}\left(d_w > 1.5\cdot B + D_f,\ 1.0\,,\ \frac{(1.0 - 0.5)}{(1.5\cdot B + D_f - D_f)}\cdot\left\langle d_w - D_f\right\rangle + 0.5\right)\right)$ $C_{w\gamma} = 0.5$

Depth Correction Factor Compute depth correction factor per **LRFD [Table 10.6.3.1.2a-4]**. It can be assumed that the soils above the footing are as competent as those beneath the footing. Therefore; the depth correction factor is taken as 1.0 if Df/B is less than 1.0.

$\frac{D_f}{B} = 3$ **<---- CHECK** **The depth correction factor is taken as 1.0 if Df/B is less than 1.0. Otherwise check [Table 10.6.3.1.2a-4].**

$d_q := 1.0$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c\cdot s_c\cdot i_c$ $N_{cm} = 44.968$

$N_{qm} := N_q\cdot s_q\cdot i_q$ $N_{qm} = 31.331$

$N_{\gamma m} := N_\gamma\cdot s_\gamma\cdot i_\gamma$ $N_{\gamma m} = 39.499$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1]:**

$q_{nd} := c'_f\cdot N_{cm} + \gamma_q\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq} + 0.5\cdot\gamma_f\cdot B\cdot N_{\gamma m}\cdot C_{w\gamma}$ $q_{nd} = 6873.9\ \frac{lbf}{ft^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.5$ Bearing resistance factor **LRFD 10.5.5.2.2-1**

$q_{Rd} := \phi_b\cdot q_{nd}$ $q_{Rd} = 3.4\ ksf$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0\,,\ e^{\pi \cdot \tan\langle\phi_f\rangle} \cdot \tan\left(45\ \textit{deg} + \frac{\phi_f}{2}\right)^2\,,\ 1.0\right)$ $N_q = 29.44$

$N_c := \text{if}\left(\phi_f > 0\,,\ \frac{N_q - 1}{\tan\langle\phi_f\rangle}\,,\ 5.14\right)$ $N_c = 42.16$

$N_\gamma := 2 \cdot \langle N_q + 1\rangle \cdot \tan\langle\phi_f\rangle$ $N_\gamma = 41.1$

Compute shape correction factors per **LRFD [Table 10.6.3.1.2a-3]**:

$s_c := \text{if}\left(\phi_f > 0\,,\ 1 + \left(\frac{B}{L}\right) \cdot \left(\frac{N_q}{N_c}\right)\,,\ 1 + \left(\frac{B}{5 \cdot L}\right)\right)$ $s_c = 1.066$

$s_q := \text{if}\left(\phi_f > 0\,,\ 1 + \left(\frac{B}{L} \cdot \tan\langle\phi_f\rangle\right)\,,\ 1\right)$ $s_q = 1.064$

$s_\gamma := \text{if}\left(\phi_f > 0\,,\ 1 - 0.4 \cdot \left(\frac{B}{L}\right)\,,\ 1\right)$ $s_\gamma = 0.962$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $i_q = 1$

$i_\gamma := 1$ $i_\gamma = 1$

$i_c := 1$ $i_c = 1$

Compute modified bearing capacity factors **LRFD [Equation 10.6.3.1.2a-2 to 10.6.3.1.2a-4]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 44.968$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 31.331$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 39.499$

Compute nominal bearing resistance, **LRFD [Eq 10.6.3.1.2a-1:**

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 6873.9\ \frac{\textit{lbf}}{\textit{ft}^2}$

Compute factored bearing resistance, **LRFD [Eq 10.6.3.1.1]:**

$\phi_b := 0.5$ Bearing resistance factor **LRFD 10.5.5.2.2-1**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 3.4\ \textit{ksf}$ Factored bearing resistance Undrained Conditions

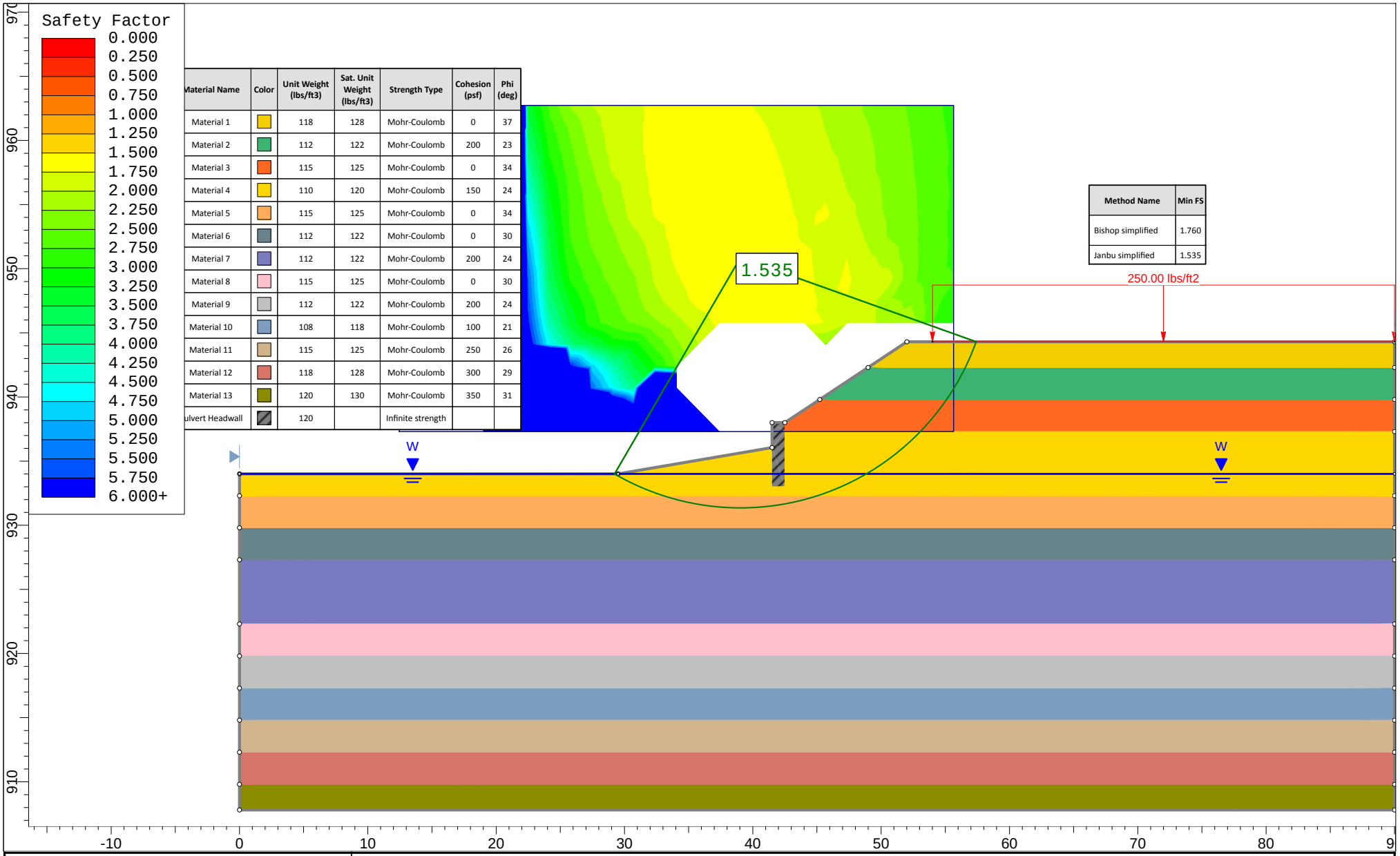
Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 3.4\ \textit{ksf}$

Undrained Conditions: $q_{Ru} = 3.4\ \textit{ksf}$

CULVERT #6

GLOBAL STABILITY ANALYSIS



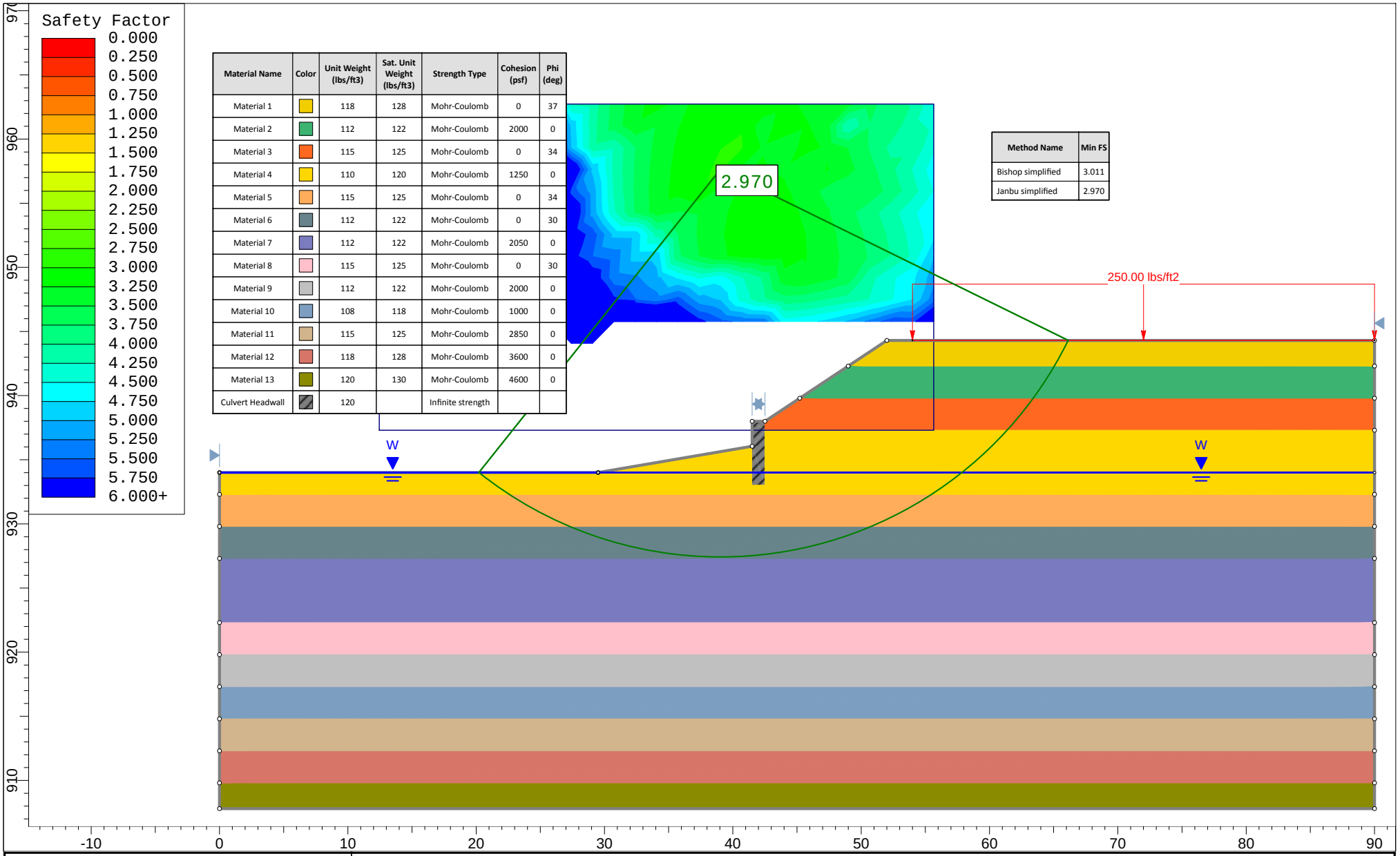
Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Material 1		118	128	Mohr-Coulomb	0	37
Material 2		112	122	Mohr-Coulomb	200	23
Material 3		115	125	Mohr-Coulomb	0	34
Material 4		110	120	Mohr-Coulomb	150	24
Material 5		115	125	Mohr-Coulomb	0	34
Material 6		112	122	Mohr-Coulomb	0	30
Material 7		112	122	Mohr-Coulomb	200	24
Material 8		115	125	Mohr-Coulomb	0	30
Material 9		112	122	Mohr-Coulomb	200	24
Material 10		108	118	Mohr-Coulomb	100	21
Material 11		115	125	Mohr-Coulomb	250	26
Material 12		118	128	Mohr-Coulomb	300	29
Material 13		120	130	Mohr-Coulomb	350	31
ulvert Headwall		120		Infinite strength		

Method Name	Min FS
Bishop simplified	1.760
Janbu simplified	1.535

rocscience

SLIDEINTERPRET 7.031

Project	MED-18 Culvert #6		
Analysis Description	Global Stability Analysis		
Drawn By	ZM	*Scale* 1:124	*Company* National Engineering & Architectural Services, Inc
Date	4/6/2016, 4:13:49 PM		*File Name* Culvert#6_Effective_1ft.slim



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Material 1		118	128	Mohr-Coulomb	0	37
Material 2		112	122	Mohr-Coulomb	2000	0
Material 3		115	125	Mohr-Coulomb	0	34
Material 4		110	120	Mohr-Coulomb	1250	0
Material 5		115	125	Mohr-Coulomb	0	34
Material 6		112	122	Mohr-Coulomb	0	30
Material 7		112	122	Mohr-Coulomb	2050	0
Material 8		115	125	Mohr-Coulomb	0	30
Material 9		112	122	Mohr-Coulomb	2000	0
Material 10		108	118	Mohr-Coulomb	1000	0
Material 11		115	125	Mohr-Coulomb	2850	0
Material 12		118	128	Mohr-Coulomb	3600	0
Material 13		120	130	Mohr-Coulomb	4600	0
Culvert Headwall		120		Infinite strength		

Method Name	Min FS
Bishop simplified	3.011
Janbu simplified	2.970

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SLIDEINTERPRET 7.031

Project	MED-18 Culvert #6		
Analysis Description	Global Stability Analysis		
Drawn By	ZM	*Scale* 1:124	*Company* National Engineering & Architectural Services, Inc
Date	4/6/2016, 4:13:49 PM		*File Name* Culvert#6_Total_1ft.slim

APPENDIX F

SEISMIC ANALYSIS

Design Maps Detailed Report

2009 AASHTO Guide Specifications for LRFD Seismic Bridge Design (41.13641°N, 81.81163°W)

Site Class D – "Stiff Soil"

Article 3.4.1 — Design Spectra Based on General Procedure

Note: Maps in the 2009 AASHTO Specifications are provided by AASHTO for Site Class B. Adjustments for other Site Classes are made, as needed, in Article 3.4.2.3.

From Figure 3.4.1-2 [1]	PGA = 0.042 g
From Figure 3.4.1-3 [2]	S_S = 0.090 g
From Figure 3.4.1-4 [3]	S_1 = 0.032 g

Article 3.4.2.1 — Site Class Definitions

The authority having jurisdiction (not the USGS), site-specific geotechnical data, and/or the default has classified the site as Site Class D, based on the site soil properties in accordance with Article 3.4.2.

Table 3.4.2.1–1 Site Class Definitions

SITE CLASS	SOIL PROFILE NAME	Soil shear wave velocity, $\overline{v}_s$, (ft/s)	Standard penetration resistance, $\overline{N}$	Soil undrained shear strength, $\overline{s}_u$, (psf)
A	Hard rock	$\overline{v}_s > 5{,}000$	N/A	N/A
B	Rock	$2{,}500 < \overline{v}_s \leq 5{,}000$	N/A	N/A
C	Very dense soil and soft rock	$1{,}200 < \overline{v}_s \leq 2{,}500$	$\overline{N} > 50$	>2,000 psf
D	Stiff soil profile	$600 \leq \overline{v}_s < 1{,}200$	$15 \leq \overline{N} \leq 50$	1,000 to 2,000 psf
E	Stiff soil profile	$\overline{v}_s < 600$	$\overline{N} < 15$	<1,000 psf
E	—	Any profile with more than 10 ft of soil having the characteristics: 1. Plasticity index $PI > 20$, 2. Moisture content $w \geq 40\%$, and 3. Undrained shear strength $\overline{s}_u < 500$ psf		
F	—	Any profile containing soils having one or more of the following characteristics: 1. Soils vulnerable to potential failure or collapse under seismic loading such as liquefiable soils, quick and highly sensitive clays, collapsible weakly cemented soils. 2. Peats and/or highly organic clays ($H > 10$ feet of peat and/or highly organic clay where H = thickness of soil) 3. Very high plasticity clays ($H > 25$ feet with plasticity index $PI > 75$) 4. Very thick soft/medium stiff clays ($H > 120$ feet)		

For SI: 1ft/s = 0.3048 m/s 1lb/ft² = 0.0479 kN/m²

Article 3.4.2.3 — Site Coefficients

Table 3.4.2.3-1 (for F_{pga})—Values of F_{pga} as a Function of Site Class and Mapped Peak Ground Acceleration Coefficient

Site Class	Mapped Peak Ground Acceleration				
	PGA ≤ 0.10	PGA = 0.20	PGA = 0.30	PGA = 0.40	PGA ≥ 0.50
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See AASHTO Article 3.4.3				

Note: Use straight–line interpolation for intermediate values of PGA

For Site Class = D and PGA = 0.042 g, F_{PGA} = 1.600

Table 3.4.2.3-1 (for F_a)—Values of F_a as a Function of Site Class and Mapped Short-Period Spectral Acceleration Coefficient

Site Class	Spectral Response Acceleration Parameter at Short Periods				
	$S_S \leq 0.25$	$S_S = 0.50$	$S_S = 0.75$	$S_S = 1.00$	$S_S \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	See AASHTO Article 3.4.3				

Note: Use straight–line interpolation for intermediate values of S_S

For Site Class = D and S_S = 0.090 g, F_a = 1.600

Table 3.4.2.3-2—Values of F_v as a Function of Site Class and Mapped 1-sec Period Spectral Acceleration Coefficient

Site Class	Mapped Spectral Response Acceleration Coefficient at 1-sec Periods				
	$S_1 \le 0.10$	$S_1 = 0.20$	$S_1 = 0.30$	$S_1 = 0.40$	$S_1 \ge 0.50$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	See AASHTO Article 3.4.3				

Note: Use straight–line interpolation for intermediate values of S_1

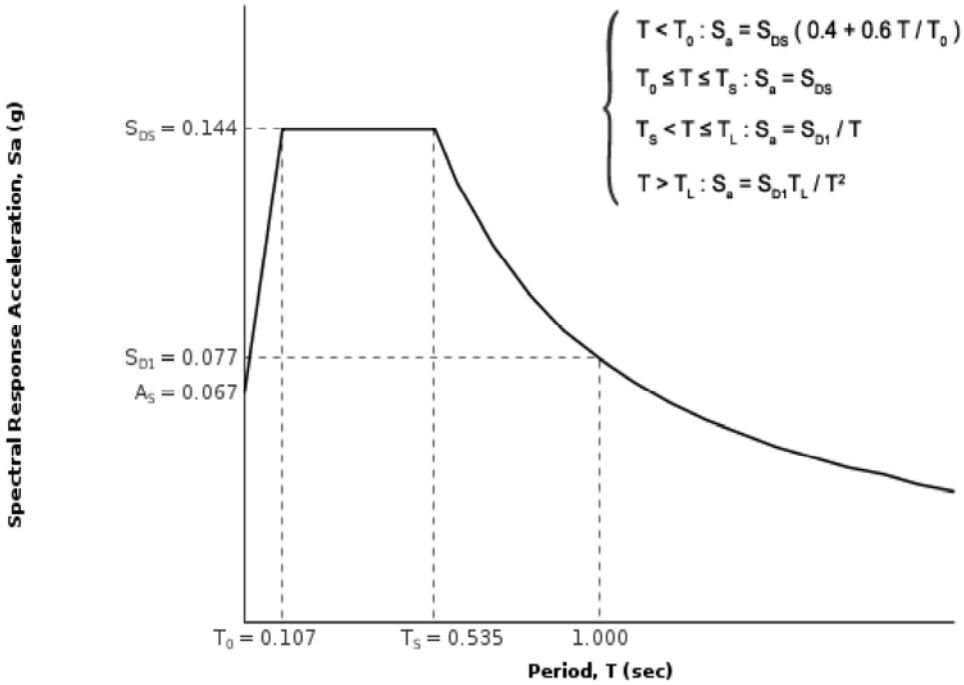
For Site Class = D and S_1 = 0.032 g, F_v = 2.400

Equation (3.4.1-1): $A_S = F_{PGA}\ PGA = 1.600 \times 0.042 = 0.067$ g

Equation (3.4.1-2): $S_{DS} = F_a\ S_S = 1.600 \times 0.090 = 0.144$ g

Equation (3.4.1-3): $S_{D1} = F_v\ S_1 = 2.400 \times 0.032 = 0.077$ g

Figure 3.4.1-1: Design Response Spectrum



Article 3.5 - Selection of Seismic Design Category (SDC)

Table 3.5-1—Partitions for Seismic Design Categories A, B, C, and D

VALUE OF S_{D1}	SDC
S_{D1} < 0.15g	A
0.15g ≤ S_{D1} < 0.30g	B
0.30g ≤ S_{D1} < 0.50g	C
0.50g ≤ S_{D1}	D

For S_{D1} = 0.077 g, Seismic Design Category = A

Seismic Design Category ≡ "the design category in accordance with Table 3.5-1" = A

References

1. *Figure 3.4.1-2*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/AASHTO-2009-Figure-3.4.1-2.pdf
2. *Figure 3.4.1-3*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/AASHTO-2009-Figure-3.4.1-3.pdf
3. *Figure 3.4.1-4*: http://earthquake.usgs.gov/hazards/designmaps/downloads/pdfs/AASHTO-2009-Figure-3.4.1-4.pdf