FINAL REPORT
STRUCTURE FOUNDATION EXPLORATION
RETAINING WALL T
CUY-90-16.28 (CCG3A)
CUYAHOGA COUNTY, OHIO
PID#: 82382

Prepared For:

Michael Baker International
1111 Superior Avenue, Suite 2300
Cleveland, OH 44114

Prepared by:

NATIONAL ENGINEERING AND ARCHITECTURAL SERVICES INC.
2800 Corporate Exchange Drive, Suite 240
Columbus, Ohio 43231

NEAS PROJECT 21-0011

May 15, 2024

National Engineering & Architectural Services Inc.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF APPENDICES

1. INTRODUCTION

1.1. General

National Engineering & Architectural Services, Inc. (NEAS) presents our Structure Foundation Exploration Report for the proposed Retaining Wall T (RW-T) structure as part of the proposed Ohio Department of Transportation (ODOT) project CCG3A (CUY-90-16.28, PID 82380) in the City of Cleveland, Cuyahoga County, Ohio. The overall project objective is to reconstruct and improve the IR-77/IR-90 interchange, IR-90 and associated surface streets within the project limits. The referenced retaining wall is proposed along the west side of Ramp IH5 and Ramp H5 including the joint portion of Ramps IH5/IH6 and the east side of both Ramp IH4 and East 14th Street (St). As a part of the interchange improvement project, it is our understanding that ODOT is planning to realign both Ramps H5 and H6 to improve the overall IR-77 and IR-90 interchange. However, in order to allow for the proposed Ramp H5 and H6 realignment as part of the overall project, Ramp IH5 is required for CCG3A as is the additional embankment fill for the ramp. RW-T is planned to provide the necessary grade separation between the new fill placed for Ramp IH5 (Ramp H5) and both Ramp IH4 and East 14th St grades. This report presents a summary of the encountered surficial and subsurface conditions and our recommendations for retaining wall 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, 9th Edition* (BDS) (AASHTO, 2020) and *ODOT's 2021 LRFD Bridge Design Manual* (BDM) (ODOT, 2021).

The exploration was conducted in general accordance with Barr Engineering, Inc. DBA National Engineering & Architectural Services, Inc.'s (formerly Barr & Prevost) proposal to Michael Baker International (Baker) dated June 11, 2014, subsequent Modification 7 (MOD 7) proposal to Baker dated October 12, 2020. The exploration was also conducted in general accordance with the provisions of the July 2014 (ODOT, 2014) and January 2021 (ODOT, 2021) revisions of ODOT's *Specifications for Geotechnical Explorations* (SGE).

The scope of work performed by NEAS as part of the CCG3A project included: 1) a review of published geotechnical information; 2) performing 182 total test soil borings (6 utilized within this report as a part of the indicated structure foundation exploration); 3) performing 30 total cone penetration test (CPT) soundings; 4) laboratory testing of soil samples in accordance with the SGE; 5) performing geotechnical engineering analysis to assess foundation design and construction considerations; and 6) development of this summary report.

1.2. Proposed Construction

The proposed realignment of Ramps H5 and H6 as part of the overall CCG3A project (CUY-90-16.28, PID 82380) will require the construction of Ramp IH5 as well as the associated placement of additional embankment fill for that ramp. This additional embankment fill will extend over the proposed grades for the adjacent Ramp IH4 and East 14th St without the grade separation that will be provided with the construction of RW-T. The existing topography slopes downward (from existing Ramp H5) at grades of about 2 Horizontal to 1 Vertical (2H:1V). RW-T is proposed along the west side of Ramp IH5 (Ramp H5) from approximate STA 1079+25 (Ramp IH5) to approximate STA 987+65 (Ramp H5).

Based on design information provided within the Retaining Wall T, Stage 2 plan dated January 12, 2024, the proposed RW-T will be a combination mechanically stabilized earth (MSE) retaining wall and cast-in-place (CIP) wall. It is our understanding that the MSE portion of the wall will be approximately 887 ft in length and have a maximum total height of approximately 19 ft at about RW-T Station 3+50. The CIP portion of the wall is approximately 57 ft in length and have a maximum height of 9.8 ft.

2. GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1. Geology and Physiography

The retaining wall site is located within the Erie Lake Plain, part of the Huron-Erie Lake Plains. This area is characterized as the edge of the very low-relief (10 ft), Ice-Age lake basin separated from the modern Lake Erie by shoreline cliffs with major streams in deep gorges being characteristic. The geology in this region is described as Pleistocene-age lacustrine sand, silt, clay and wave-planed glacial till over Devonian- and Mississippi-age shales and sandstones (ODGS, 1998).

The geology at the proposed retaining wall site is mapped as an average of 10 ft of Wisconsinan-age sand atop an average of 90 ft of Wisconsinan-age lacustrine silt and clay followed by an average of 80 ft of Wisconsinan-age till underlain by Wisconsinan-age sand all over Devonian-age Ohio Shale (ODGS, 2002). The Wisconsinan-age sand mapped at the site is characterized as well to moderately sorted, moderately to well rounded, finely stratified to massive and contains minor amounts of disseminated gravel or thin lenses of silt or clay. The lacustrine soils at the site is described as laminated silts and clays that may contain fine sand or gravel layers. The till is described as an unsorted mix of clay, silt, sand, gravel and boulders which may contain silt, sand and gravel lenses. Till in buried valleys and thicker areas are noted as potentially being older than Wisconsinan.

Bedrock beneath the proposed retaining wall has been mapped as sedimentary Devonian-age Ohio shale with carbonate and/or siderite concretions in the lowermost 50 ft. This brownish black to greenish gray shale is carbonaceous to clayey, laminated to thin bedded, and can have a petroliferous odor (USGS & ODGS, 2006). Based on the ODNR bedrock topography map of Ohio, bedrock elevations near the proposed retaining wall can be expected to be between elevations of 450 and 400 ft above mean sea level (amsl), putting bedrock at a depth ranging from about 235 to 295 ft below ground surface (bgs).

The soils at the retaining wall site have been mapped (Web Soil Survey) by the Natural Resources Conservation Service as Udorthents, loamy (Ua) and Urban Land (Ub). These are soils that have been disturbed by cutting or filling and are not rated for local roads (USDA, 2015).

2.2. Hydrology/Hydrogeology

The local hydro-geologic system is dominated by the valley of the Cuyahoga River, located approximately a quarter to a half mile to the southwest and flows northwest discharging into Lake Erie. The elevation of the Cuyahoga River and Lake Erie is about 570 to 575 ft amsl and is likely to be representative of the regional groundwater table. As mentioned previously, the surficial geology consists of primarily granular soils underlain by a relatively impermeable lacustrine or glacial silt and clay layer. It is possible for groundwater to become trapped in granular soils above the regional groundwater level by an underlying impermeable layer forming a perched water table. The project site follows a similar geological model and therefore, could result in a groundwater elevation within the project limits that is likely above the regional groundwater table elevation.

The proposed RW-M site is not located within a special flood hazard area based on available mapping by the Federal Emergency Management Agency's (FEMA) National Flood Hazard mapping program (FEMA, 2019).

2.3. Mining and Oil/Gas Production

No abandoned mines are noted on ODNR's Abandoned Underground Mine Locator within the immediate vicinity of the proposed Ramp H5/IH5 location (ODNR [1], 2016).

No oil or gas wells are noted on ODNR's Ohio Oil & Gas Locator within the immediate vicinity of the proposed Ramp H5/IH5 location (ODNR [2], 2016).

2.4. Historical Records and Previous Phases of Project Exploration

A historic record search was performed through ODOT's Transportation Information Mapping System (TIMS). However, no geotechnical data or information was available for review within the immediate vicinity of the proposed retaining wall site. Therefore, historic borings are not referenced within this report nor pictured within the associated developed Structure Foundation Exploration Sheets.

2.5. Site Reconnaissance

A field reconnaissance visit for the proposed RW-T site was conducted on May 20, 2015. During the site visit, site conditions were noted and photographed along Ramp H5 and H6 within the limits of the referenced wall site. No geohazards were observed within the immediate vicinity of the referenced wall site.

The proposed RW-T alignment extends from the eastern edge of the existing Ramp H5, across Ramp H5, down the north Ramp H5 embankment, across the southbound East 14th Street (St) lane, and ending within the grass median between northbound and southbound East 14th St. The existing Ramp H5 embankment slope at the beginning of the wall (Photograph 1) and at the point where the proposed wall extends down the slope to East 14th St (Photograph 2), appeared to have an estimated average slope of about 2 Horizontal to 1 Vertical (2H:1V) with grades ranging from 2H:1V to 3H:1V. The slopes are grass covered with a few bushes and/or shrubs. The median area between northbound and southbound East 14th St consists of an existing embankment for northbound East 14th St which slopes downward from northbound to southbound at grades ranging from 2H:1V to 3H:1V. This slope is vegetated with grasses, bushes, and the occasional mature tree. Each of the embankment slopes appeared to be in good condition with no visible slope instability.

The pavement condition Ramp H5 and East 14th St near the wall site appeared to be in fair condition with minor signs of distress. The roadways appeared to be well drained with no observable signs of standing water. Nearby signs and light poles appeared to be in fair to good condition without apparent signs of distress related to the underlying soil conditions.

Photograph 1: Existing Ramp H5 Slope Near Beginning of RW-T

Photograph 2: Existing Ramp H5 Slope Near East 14th St

3. GEOTECHNICAL EXPLORATION

3.1. Field Exploration Program

The exploration for this retaining wall was conducted by NEAS between November 17, 2014, and May 19, 2021, and included 6 borings drilled to depths between of 30.5 ft and 62.5 ft bgs. The boring locations were selected by NEAS in general accordance with the guidelines contained in the SGE at the time of the exploration with the intent to evaluate subsurface soil and groundwater conditions. Borings were typically located at/near proposed wall location that were not restricted by maintenance of traffic, underground utilities or dictated by terrain (i.e., steep embankment slopes). Project boring locations were located and surveyed in the field by NEAS after the completion of drilling. Each individual project boring log (included within Appendix B) includes the recorded boring latitude and longitude location (based on the surveyed Ohio State Plane North, NAD83, location) and the corresponding ground surface elevation. A summary of the borings including stationing, offsets, location information and elevations of the RW-T structure borings are shown in Table 1 below, while the boring locations are depicted on the Soil Profile Sheets provided within Appendix A

Table 1: Project Boring Summary

Boring Number	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Structure
B-102-0-14	41.495491	-81.677640	679.0	61.5	RW-T
B-118-0-14	41.492970	-81.676930	691.8	61.5	RW-T
B-119-0-14	41.493451	-81.677288	684.5	62.5	RW-T
B-120-0-14	41.493986	-81.677293	670.8	61.5	RW-T
B-120-1-20	41.494520	-81.677262	668.6	35.0	RW-T
B-120-2-20	41.494953	-81.677411	678.9	30.5	RW-T
Notes: *2. As-drilled boring location and corresponding ground surface elevation was surveyed in the field by NEAS Inc.*					

The borings were drilled using a either a CME 55 track mounted or CME 55, CME 75, or Mobile B-58 truck mounted drilling rig with each utilizing 3.25-inch diameter hollow stem augers. Soil samples were generally recovered at 2.5-ft intervals to a depth of 30 ft bgs and at 5.0-ft intervals thereafter using a split spoon sampler (AASHTO T-206 “Standard Method for Penetration Test and Split Barrel Sampling of Soils”). The soil samples obtained from the exploration program were visually observed in the field by the NEAS field representative and preserved for review by a Geologist and possible laboratory testing. Standard penetration tests (SPT) were conducted using auto hammers that had been calibrated to be between 78.8% and 92.2% efficient as indicated on the boring log. 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 level observations were recorded both during and after the completion of drilling. These groundwater level observations are included on the individual boring log. After completing the borings, the boreholes were backfilled with either auger cuttings, bentonite chips, or a combination of these materials.

3.2. Laboratory Testing Program

The laboratory testing program consisted of classification testing and moisture content determinations. The individual laboratory data sheets and results are included in Appendix B. Additionally, data from the laboratory testing program was incorporated onto the final borings logs. 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 33% of the samples. At each boring location, samples were selected for testing with the intent of identification and classification of all significant soil units. Soils not selected for testing were compared to laboratory tested samples/strata and classified visually. Moisture content testing was conducted on all samples. The laboratory testing was performed in general accordance with applicable AASHTO specifications.

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

3.2.2. Standard Penetration Test Results

Standard Penetration Tests (SPT) and split-barrel (commonly known as split-spoon) sampling of soils were performed at varying intervals (i.e., 2.5-ft and 5.0-ft) 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 each boring log presented in Appendix B. The boring logs represent NEAS's interpretation of the subsurface conditions encountered at each boring location based on our site observations, field logs, visual review of the soil samples by NEAS's geologist, and laboratory test results. The lines designating the interfaces between various soil strata on the boring logs represent the approximate interface location; the actual transition between strata may be gradual and indistinct. The subsurface soil and groundwater characterizations included herein, including summary test data, are based on the subsurface findings from the geotechnical 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

The general subsurface profile is relatively uniform and consistent with the geological model for the project. The subsurface profile at the RW-T site generally consists of surficial materials (i.e., pavement section) underlain by existing embankment fill soils followed by natural sands and gravels underlain by natural lacustrine soils. The embankment fill at the site can generally be described as very loose to very dense non-cohesive, granular soils. The natural sands and gravels encountered at the site were comprised of granular material that can be described as very loose to medium dense in the upper portion of the strata and medium dense to dense in the lower portion of the strata. The natural lacustrine soils at the site were variable, though predominantly cohesive, fine-grained soils that can be described as having a consistency of very stiff to hard. Bedrock was not encountered within the depths of the explorations performed.

4.1.1. Overburden Soil

At the site of proposed RW-T, three different materials were encountered below the surficial material. In general, the three different overburden materials consisted of embankment "man-made" fill soils, natural sands and gravels, and natural lacustrine soils. These materials and the general profile underlying the site is further described below.

Fill soils were encountered in three of the five borings performed for the proposed retaining wall. These fill soils were encountered immediately below the pavement section and extended to depths ranging from 9.5 to 9.8 ft bgs (approximate elevations 669.4 ft to 674.7 ft amsl). Based on laboratory testing results and a visual review of the soil samples obtained in the referenced borings, the fill at the RW-T site consisted of non-cohesive, granular material within borings B-102-0-14 and B-120-2-20 which was comprised of Gravel with Sand and Silt (A-2-4), Fine Sand (A-3) and Coarse and Fine Sand (A-3a). With respect to the soil strength, the granular fill soils can be described having a relative compactness of very loose to very dense correlating to converted SPT N values (N_{60}) between 6 and 77 blows per foot (bpf). Cohesive fill material was encountered in boring B-119-0-14, this material was classified as Silt and Clay (A-6a) and Silty Clay (A-6b) on the boring logs. The more cohesive fill soils can be described as stiff to hard in consistency. Based on an Atterberg Limits test performed on a representative sample of the fill material, the liquid and plastic limits were 38 percent and 22 percent, respectively. Natural moisture contents of the fill ranged from 6 to 25 percent.

The stratum encountered immediately beneath the fill or immediately below the surficial material consisted of a natural sand layer extending to depths between 37.5 and 53.8 ft bgs (approximate elevations 620.7 and 640.7 ft amsl). The natural sand layer extended to boring termination depth in borings B-120-1-20 and B-120-2-20. The soils in this stratum are generally classified on the boring logs as Gravel with Sand (A-1-b), Coarse and Fine Sand (A-3a), Coarse and Fine Sand (A-3), and Silt (A-4b). With respect to the relative compactness of the natural sand, the descriptions varied with an upper portion of the strata being less compact than the lower portion of the strata. The upper portion of the natural sand strata can be described as very loose to medium dense, correlating to N_{60} values between 3 and 16 bpf. The lower portion of the strata can generally be described as medium dense to dense, correlating to N_{60} values between 12 and 45 bpf. Natural moisture contents of the granular material ranged from 4 to 28 percent. Within the natural sand layer, a 2.5 to 5 ft thick layer of cohesive material was encountered in borings B-119-0-14 and B-120-0-14 which was medium stiff to stiff in consistency and had moisture contents ranging from 19 to 23 percent.

The soils encountered directly underlying the natural sand layer encountered at the site consisted of variable lacustrine soils which was comprised of predominantly cohesive, fine-grained soils. The lacustrine stratum extended to termination depths between 61.5 and 62.5 ft bgs (approximate elevations 609.3 and 622.0 ft amsl) and are classified on the boring logs as Silt (A-4b), Silt and Clay (A-6a), and Sandy Silt (A-4a). With respect to the soil strength, the lacustrine soils can be described having a consistency of very stiff to hard correlating to converted N_{60} between 18 and 46 bpf. Natural moisture contents of the lacustrine soils ranged from 19 to 28 percent. Based on Atterberg Limits test performed on representative samples of the lower lacustrine material, the liquid and plastic limits ranged from 23 to 29 percent and from 15 to 18 percent, respectively.

4.1.2. Groundwater

Groundwater measurements were taken during the boring drilling procedures and immediately following the completion of the borings performed. Groundwater was observed during drilling in each of the borings performed at the retaining wall site at depths ranging from 20 to 35.5 ft bgs (elevations 643.6 to 653.0 ft amsl). It should be noted that groundwater is affected by many hydrologic characteristics in the area and may vary from those measured at the time of the exploration. The specific groundwater readings are included on the logs located within Appendix B.

5. ANALYSES AND RECOMMENDATIONS

We understand that the construction of a retaining wall (RW-T) is planned to provide grade separation between Ramp IH4 and East 14th St grades and newly proposed fill grades associated with the construction of Ramp IH5 as part of the proposed CCG3A (CUY-90-16.28, PID 82380) project in Cleveland, Cuyahoga

County, Ohio. The proposed retaining wall will approximately parallel the proposed Ramp IH5 alignment, and will be approximately 887 ft in length.

Based on design information provided within the Retaining Wall T Stage 2 plan dated January 12, 2024 developed by MBI, it is our understanding that a combination MSE and CIP wall type has been selected for RW-T. Furthermore, it is also our understanding that the proposed retaining wall is planned to vary in height. Based on the referenced plan set, the top of wall elevation ranges from 674.2 ft to 688.6 ft while the bottom of footing elevation range is between 664.0 ft and 683.0 ft amsl. Therefore, RW-T's total wall height ranges between 5.59 ft and 19.6 ft.

A foundation review was completed for the foundations of the proposed retaining wall. The analyses performed are based on the information presented in Section 5.1 of this report in addition to: 1) the soil characteristics gathered during the subsurface exploration (i.e., SPT results, laboratory test results, etc.); 2) the proposed design files for the referenced retaining wall produced by MBI; and, 3) other design assumptions presented in subsequent sections of this report.

The geotechnical engineering analyses were performed in accordance with AASHTO's Publication LRFD BDS (AASHTO, 2020) and ODOT's 2021 BDM (ODOT, 2021). Based on the results of the analysis, it is our opinion that the subsurface conditions encountered are generally satisfactory and will provide adequate resistance to bearing, sliding and overturning assuming the proposed RW-T is constructed in accordance with the recommendations provided within this report, as well as all applicable standards and specifications (i.e., ODOT, manufacture, etc.) for MSE wall construction.

5.1. Retaining Wall Design Assumptions

5.1.1. Mechanically Stabilized Earth Wall Design Assumptions

As a large portion of the proposed RW-T is to be designed as a MSE type wall, ODOT's BDM and AASHTO's LRFD BDS dictate analysis parameters and design minimums/constraints 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:

- Minimum reinforcement strap lengths of proposed MSE walls are to be 70% of the total wall height (as measured from top of the coping to the top of the leveling pad) or 8 ft, whichever is greater, at the particular section of wall being analyzed (BDM Section 307.4);
- Minimum MSE wall embedment depths (as measured from top of the leveling pad to the proposed ground surface) are to conform to Figure 201-5 presented in ODOT's BDM and be the larger of 3 ft or the local frost depth;
- Soils below the bottom of leveling pad will be undercut a minimum of 1 ft and replaced Granular Material Type C according to the requirements of ODOT Construction & Materials Specifications Section 204.07 (CMS 204.07);
- Maximum allowable differential settlement in the longitudinal direction is 1% (BDM Section 307.1.6); and,
- Reinforced Zone and Retained Fill soils will meet the minimum design soil parameters per Table 840.04-1 of ODOT Supplemental Specification 840 (SS-840) as shown in Table 2 below.

Table 2: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Reinforced Zone	Select Granular Embankment (Backfill) Material	120	34	0
Retained Soil	On-site soil varying from sandy lean clay to silty sand	120	30	0
Notes: 1. *Table reproduced from Section 204.6.2.1 of 2007 ODOT Bridge Design Manual.*				

With respect to RW-T specific design constraints and assumptions, the geometry of the proposed wall (i.e., exposed wall heights, existing ground elevations, proposed final grade behind/at the toe of the wall, etc.) is assumed to be consistent with that shown in the proposed Stage 2 plan developed by MBI dated January 12, 2024.

5.1.2. Cast-in-Place Wall Design Assumptions

As a portion of RW-T is planned as a cast-in-place (CIP) wall founded on the existing soil at the site, ODOT's BDM, AASHTO's LRFD BDS, and the project conditions dictate analysis parameters and design minimums/constraints 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 Construction and Material Specifications (CMS);
- Retained fill soils will meet the minimum design soil parameters per Table 307-1 of ODOT's BDM as shown in Table 3 below;

Table 3: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Retained Soil (Soil behind the wall heel or behind the MSE Reinforced Soil Zone)	On-site soil varying from sandy lean clay to silty sand, per 703.16.A	120	30	0
CIP or Precast Semigravity Wall Infill	Granular Embankment, per 703.16.B	120	32	0
Notes: 1. *Table reproduced from Section 307.1 of ODOT's BDM.*				

With respect to RW-T specific design constraints and assumptions, the geometry of the proposed wall (i.e., exposed wall heights, existing ground elevations, proposed final grade behind/at the toe of the wall, etc.) is assumed to be consistent with that shown in the proposed Stage 2 plan developed by MBI dated January 12, 2024

5.1.3. Generalized Soil Profile for Analysis

For analysis purposes, each boring log was reviewed and a generalized material profile was developed for analysis. Utilizing the generalized soil profile, engineering properties for each soil strata was 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 from each boring 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 through 9 below. Settlement parameters (with sited correlation/reference material) developed for each Soil Type are presented in Table 10.

Table 4: Soil Profile and Estimated Engineering Properties - At Boring B-102-0-14

Wall T: Stability Analysis, B-102-0-14					
Soil Description	**Moist Unit Weight(1) (pcf)**	**Total Cohesion(2) (psf)**	**Total Friction Angle (degrees)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 1 Depth (679 ft - 669.5 ft)	120	-	36	-	36
Soil Type 2 Depth (669.5 ft - 662 ft)	115	-	30	-	30
Soil Type 4 Depth (662 ft - 620.7 ft)	125	-	33	-	33
Soil Type 5 Depth (620.7 ft - 617.5 ft)	125	3350	0	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 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 5: Soil Profile and Estimated Engineering Properties - At Boring B-118-0-14

Wall T: Stability Analysis, B-118-0-14					
Soil Description	**Moist Unit Weight(1) (pcf)**	**Total Cohesion(2) (psf)**	**Total Friction Angle (degrees)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Coarse and Fine Sand Depth (691.8 ft - 674.8 ft)	128	-	36	-	36
Coarse and Fine Sand Depth (674.8 ft - 669.8 ft)	118	-	31	-	31
Fine Sand Depth (669.8 ft - 662.3 ft)	118	-	31	-	31
Silt and Clay Depth (662.3 ft - 658.5 ft)	120	2100	0	200	24
Coarse and Fine Sand Depth (658.5 ft - 638.5 ft)	120	-	34	-	34
Sandy Silt Depth (638.5 ft - 630.3 ft)	130	-	34	-	34

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 6: Soil Profile and Estimated Engineering Properties - At Boring B-119-0-14

Wall T: Stability Analysis, B-119-0-14					
Soil Description	Moist Unit Weight(1) (pcf)	Total Cohesion(2) (psf)	Total Friction Angle (degrees)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)
Soil Type 1 Depth (684.5 ft - 674.7 ft)	115	1500	0	150	23
Soil Type 2 Depth (674.7 ft - 662 ft)	115	-	30	-	30
Soil Type 3 Depth (662 ft - 657 ft)	110	1650	0	150	24
Soil Type 4 Depth (657 ft - 640.7 ft)	125	-	33	-	33
Soil Type 5 Depth (640.7 ft - 622 ft)	125	3350	0	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 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 7: Soil Profile and Estimated Engineering Properties - At Boring B-120-0-14

Wall T: Stability Analysis, B-120-0-14					
Soil Description	Moist Unit Weight(1) (pcf)	Total Cohesion(2) (psf)	Total Friction Angle (degrees)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)
Soil Type 2 Depth (670.8 ft - 656.3 ft)	115	-	30	-	30
Soil Type 3 Depth (656.3 ft - 653.8 ft)	110	1650	0	150	24
Soil Type 4 Depth (653.8 ft - 633.3 ft)	125	-	33	-	33
Soil Type 5 Depth (633.3 ft - 609.3 ft)	125	3350	0	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 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 8: Soil Profile and Estimated Engineering Properties - At Boring B-120-1-20

Wall T: Stability Analysis, B-120-1-20					
Soil Description	Moist Unit Weight(1) (pcf)	Total Cohesion(2) (psf)	Total Friction Angle (degrees)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)
Soil Type 2 Depth (668.6 ft - 659.1 ft)	115	-	30	-	30
Soil Type 4 Depth (659.1 ft - 633.6 ft)	125	-	33	-	33

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 9: Soil Profile and Estimated Engineering Properties - At Boring B-120-2-20

Wall T: Stability Analysis, B-120-2-20					
Soil Description	Moist Unit Weight(1) (pcf)	Total Cohesion(2) (psf)	Total Friction Angle (degrees)	Effective Cohesion(3) (psf)	Effective Friction Angle(3) (degrees)
Soil Type 1 Depth (678.9 ft - 669.4 ft)	120	-	36	-	36
Soil Type 2 Depth (669.4 ft - 659.4 ft)	115	-	30	-	30
Soil Type 4 Depth (659.4 ft - 648.4 ft)	125	-	33	-	33

Notes:
1. *Values interpreted from Geotechnical Bulletin 7 Table 1.*
2. *Values calculated from Terzaghi and Peck (1967) if $N1_{60}$<52, else Stroud and Butler (1975) was used.*
3. *Values interpreted from Geotechnical Bulletin 7 Table 2 for cohesive soils and Kulhawy & Mayne (1990) for granular soils.*

Table 10: Settlement Parameters for Analysis - Retaining Wall T

Retaining Wall T: Settlement Analysis, B-119-0-14, B-120-0-14, B-120-1-20, B-120-2-20 and B-102-0-14								
Soil Description	**Unit Weight (pcf)**	**Elastic Modulus(1) (psf)**	**Poissons Ratio(1), v**	**Void Ratio e_o(6)**	**Compression Index(2), C_c**	**Recompression Index(3), C_r**	**OCR(4)**	**Coeff. of Consol.(5), C_v**
Soil Type 1 - Granular	120	1149000	0.30	-	-	-	-	-
Soil Type 2 - Granular	115	243000	0.25	-	-	-	-	-
Soil Type 3 - Cohesive	110	893000	0.40	0.838	0.11	0.022	2.5	0.14
Soil Type 4 - Granular	125	878000	0.25	-	-	-	-	-
Soil Type 5a - Cohesive(7)	125	2000000	0.40	0.573	0.06	0.008	1.3	0.29
Soil Type 5b - Cohesive(8)	125	2000000	0.45	0.784	0.10	0.020	1.2	0.23
Soil Type 5c - Cohesive	130	200000	0.50	0.534	0.12	0.024	1.1	0.21

Notes:

1. *Values interpreted from 2017 AASHTO LRFD BDS Table C10.4.6.3-1*
2. *Values calculated from Kulhawy and Mayne, 1990, Equation 6-6.*
3. *Values calculated from Kulhawy and Mayne, 1990, Equation 6-9.*
4. *Values interpreted from Mayne and Kemper, 1988, Figure 7.*
5. *Values interpreted from FHWA GEC No. 5, Boeckmann, et al., 2016, Figure 6-37.*
6. *Calculated based on assumed unit weight and a specific gravity value of 2.67.*
7. *Based on laboratory test results from B-134-2-14.*
8. *Based on laboratory test results from B-144-0-14.*

In addition to the Soil Type parameters presented above, a generalized subsurface profile is located within Appendix C which is based on a profile view of the proposed RW-T. The generalized subsurface profile included: a general interpretation of the Soil Types between borings, a graphical interpretation of the soil strata identified by the project soil borings along the referenced wall profile, representative boring data (N_{60}-values, moisture contents, and groundwater levels), current ground surface elevation, and proposed wall location (i.e., top of leveling pad and top of coping).

5.2. MSE Wall External Stability

Based on our estimated engineering soil properties, the developed generalized profile and the retaining wall design assumptions provided in Section 5.1 of this report, an external stability analysis of the proposed RW-T was performed. As the wall configuration is anticipated to change along the length of the wall, external stability was evaluated at two (2) separate cross-sections along the length of the proposed wall. The two cross-section locations include STA 3+50 and STA 05+00 in reference to the RW-T alignment. Each cross-section was evaluated for resistance to bearing pressure, sliding forces, and overturning at the Strength Limit State in accordance with Section 11.10.5 of the AASHTO's LRFD BDS. The capacity to demand ratios (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 11 below. (External Stability and Bearing Resistance Calculation Results can be found in Appendix D)

Table 11: MSE External Stability Analysis Summary

Dimensions		
Design Wall Height (feet)	19.0	15.8
Exposed Wall Height (feet)	16.0	12.8
Length of Reinforcement (feet)	13.3	11.1
Length of Reinf. To Height Ratio	0.7	0.7
Approximate Station[(1)]	03+50	05+00
Broken back slope above wall (°)	N/A	N/A
Capacity Demand Ratio (CDR)		
Bearing Capacity	2.46	2.55
Overturning / Eccentricity	1.42	1.34
Sliding	1.29	1.24
Factored Bearing Resistance (ksf)[(2)]	12.4	11.1

Notes:
1. *Stationing in reference to respective retaining wall alignment.*
2. *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*

5.3. CIP Wall External Stability

Based on our estimated engineering soil properties and the CIP retaining wall design assumptions provided in Sections 5.1.3. and 5.1.2. of this report, respectively, external stability analysis of the proposed CIP wall portion of RW-T was performed. External stability was evaluated at one (1) cross-section along the RW-T with the section evaluated consisting of the maximum total wall height section at approximate STA. 01+31.78. The referenced 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. The capacity to demand ratios (CDRs) calculated for the referenced cross-section with respect to bearing, sliding and overturning, as well as the calculated factored bearing resistance are presented in Table 12 below (External Stability Results can be found in Appendix G). A CDR ratio greater than 1.0 indicates an acceptable design per AASHTO's LRFD.

Table 12: CIP External Stability Analysis Summary

Dimensions	
Retaining Wall T	
Design Wall Height (feet)	9.8
Exposed Wall Height (feet)	5.2
Footing Width, B (feet)	9.25
Approximate Station[(1)]	1+31.78
Reference Boring	B-118-0-14
Slope in front of wall(°)	N/A
Capactiy Demand Ratio (CDR)	
Bearing Capacity	6.70
Overturning / Eccentricity	4.87
Sliding	3.10
Factored Bearing Resistance (ksf)[(2)]	15.7

Notes:
1. *Stationing in reference to respective retaining wall alignment.*
2. *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.*

5.4. Global Stability

For purposes of evaluating the stability of the proposed retaining wall (RW-T) site, NEAS reviewed multiple cross-sections within the project limits that were interpreted to represent conditions that posed the greatest potential for slope instability. In general, cross-sections along the proposed wall alignment were reviewed to determine if the section would represent a combination of existing subsurface conditions and planned site grading that would be most critical to slope stability (i.e., maximum total wall height, maximum embankment height measured from toe of slope to top of wall coping, proposed cut into existing embankment slopes, weak or thick soil layer, etc.). Based on our review of the available information at the referenced locations and the associated soil properties, one (1) cross-section was estimated to be most "critical" and was analyzed for global stability. The one cross-section analyzed for global stability was the maximum total wall height section at STA 03+50 in reference to the RW-T alignment.

For the cross-section, NEAS developed a representative cross-sectional model 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 proposed RW-T site plan developed by MBI and accessed on ProjectWise on September 26, 2021; 2) a live load surcharge of 250 pounds per square foot (psf), accounting for traffic induced loads; and, 3) test borings and laboratory data developed as part of this report. With respect to the soil's engineering properties, the provided Soil Profile and Estimated Engineering Properties presented in Section 5.1.1. of this report were used in our analyses.

The above referenced slope stability model was 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 Spencer analysis methods were used to calculate a factor of safety (FOS) for circular and block type slope failures, respectively. The FOS is the ratio of the resisting forces and the driving forces, with the desired safety factor being more than about 1.33 which equates to an AASHTO resistance factor less than 0.75 (per AASHTO's LRFD BDS the specified resistance factors are essentially the inverse of the FOS that should be targeted in slope stability programs). For this analysis, a resistance factor of 0.75 or lower is targeted as the slope does not contain or support a structural element.

Based on our slope stability analyses for the referenced retaining wall sections, the minimum slope stability safety factor is about 1.983 (0.50 resistance factor). The graphical output of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) is presented in Appendix E.

5.5. Settlement

In order to estimate the maximum total and differential settlement that could result within the subsurface soils supporting the proposed Ramp H5 and Ramp IH5 embankment soils at the proposed RW-T location, NEAS reviewed: 1) RW-T site plan profile views accessed via ProjectWise on September 25, 2021; 2) Service Limit State loading conditions; and, 3) the generalized subsurface profile and Settlement Parameters for Analysis provided in Section 5.1.1 of this report. Based on our review of the available information along the RW-T alignment, the section with the maximum total wall height and maximum amount of fill (STA 03+50) was developed for analysis as it is estimated to produce the greatest amount of settlement. Utilizing this information and the software entitled *FoSSA 2.0* by ADAMA Engineering, Inc., a settlement model was developed and analyzed for both elastic (immediate) and consolidation (long term) settlement at STA 03+50. Outputs of our *FoSSA 2.0* settlement analysis for RW-T STA 03+50 is included within Appendix F.

The estimated maximum total settlement associated with the loads induced by the proposed new embankment at the RW-T location is estimated to be between about 1.5 and 2.5 inches. This settlement magnitude is not anticipated to be a concern as about 0.5 to 1.7 inches of the total settlement is expected to be elastic (immediate) and take place during construction while the remaining long-term settlements is estimated to be less than 1 inch. Furthermore, based on these settlement magnitudes, the maximum differential settlement across the length of the proposed retaining wall is anticipated to be less than 1/100 (1%), the limiting amount of differential settlement for MSE walls per ODOT BDM Section 307.1.6.

5.6. MSE Wall Reinforced Backfill

For MSE wall reinforced backfill, we recommend the use of granular material meeting the requirements of ODOT's SS-840 Section 840.03.E "Select Granular Backfill" (SGB). Furthermore, it is recommended that, at a minimum, SGB be placed as backfill material within the limits shown in Figures 201-5 through 201-7 of ODOT's BDM. With respect to placement, it is recommended that SGB be place in accordance with SS-840 Section 840.06.I "Select Granular Backfill Placement".

5.7. Drainage Considerations

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

It is recommended that internal drainage of the retaining wall (reinforced fill) be designed as indicated in Section 307.4 and as shown in Figures 201-5 through 201-7 of the ODOT BDM. We recommend the wall drainage material conform to the requirements of SS-840, Section 840.03.F "Backfill Drainage Material" and wall drainage be constructed in accordance with SS-840 Section 840.06.F "Wall Drainage". Furthermore, it is recommended that the barrier or curb at the roadway extend at least 25 ft beyond the MSE wall limits, and outlet to a piped collection system (i.e., collection basin/inlet) located beyond the extents of the wall. Where a barrier or curb is not present, it is recommended that a paved channel (swale) be placed directly behind the top of the wall. The paved channel should be designed to intercept surface water and direct it to an outlet as well as reduce the potential for surface water from overtopping the wall. The designer should anticipate and address in design and detailing the possibility of water runoff from extreme events which will overtop the drainage swale and run down the wall face.

6. QUALIFICATIONS

This investigation was performed in accordance with accepted geotechnical engineering practice for the purpose of characterizing the subsurface conditions at the site of Retaining Wall T for the CCG3A (CUY-90-16.28, PID 82380) project. This report has been prepared for MBI, ODOT and their design consultants to be used solely in evaluating the soils underlying the retaining wall 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 retaining wall (RW-T) 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 Michael Baker International in performing this geotechnical exploration for the CUY-90-16.28 project. Please call if there are any questions, or if we can be of further service.

Respectfully Submitted,

Jawdat Siddiqi, P.E.
Principal

Brendan P. Andrews, P.E.
Geotechnical Engineer

REFERENCES

AASHTO. (2020). *LRFD Bridge Design Specifications; 9th Edition.* Washington, D.C.: American Association of State Highway and Transportation Officials.

FEMA. (2019). *National Flood Hazard Layer kmz v3.2.* Federal Emergency Management Agency.

ODGS. (1998). Physiographic regions of Ohio: Ohio Department of Natural Resources, Division of Geological Survey. page-size map with text, 2p., scale 1:2,100,00.

ODNR [1]. (2016). Ohio Abandoned Mine Locator Interactive Map. *Mines of Ohio*. Ohio Department of Natural Resources, Division of Geological Survey & Division of Mineral Resources. Retrieved from https://gis.ohiodnr.gov/MapViewer/?config= OhioMines

ODNR [2]. (2016). Ohio Oil & Gas Locator Interactive Map. *Ohio Oil & Gas Wells*. Ohio Department of Natural Resources, Division of Oil and Gas. Retrieved from https://gis.ohiodnr.gov/MapViewer/?config= oilgaswells

ODOT. (2014). *Specifications for Geotechnical Explorations.* Ohio Department of Transportation: Office of Geotechnical Engineering.

ODOT. (2021). *2021 Bridge Design Manual.* Columbus, OH: Ohio Department of Transportation: Office of Structural Engineering. Retrieved from http://www.dot.state.oh.us/Divisions/Engineering/Structures/standard/Bridges/Pages/BDM2004.aspx

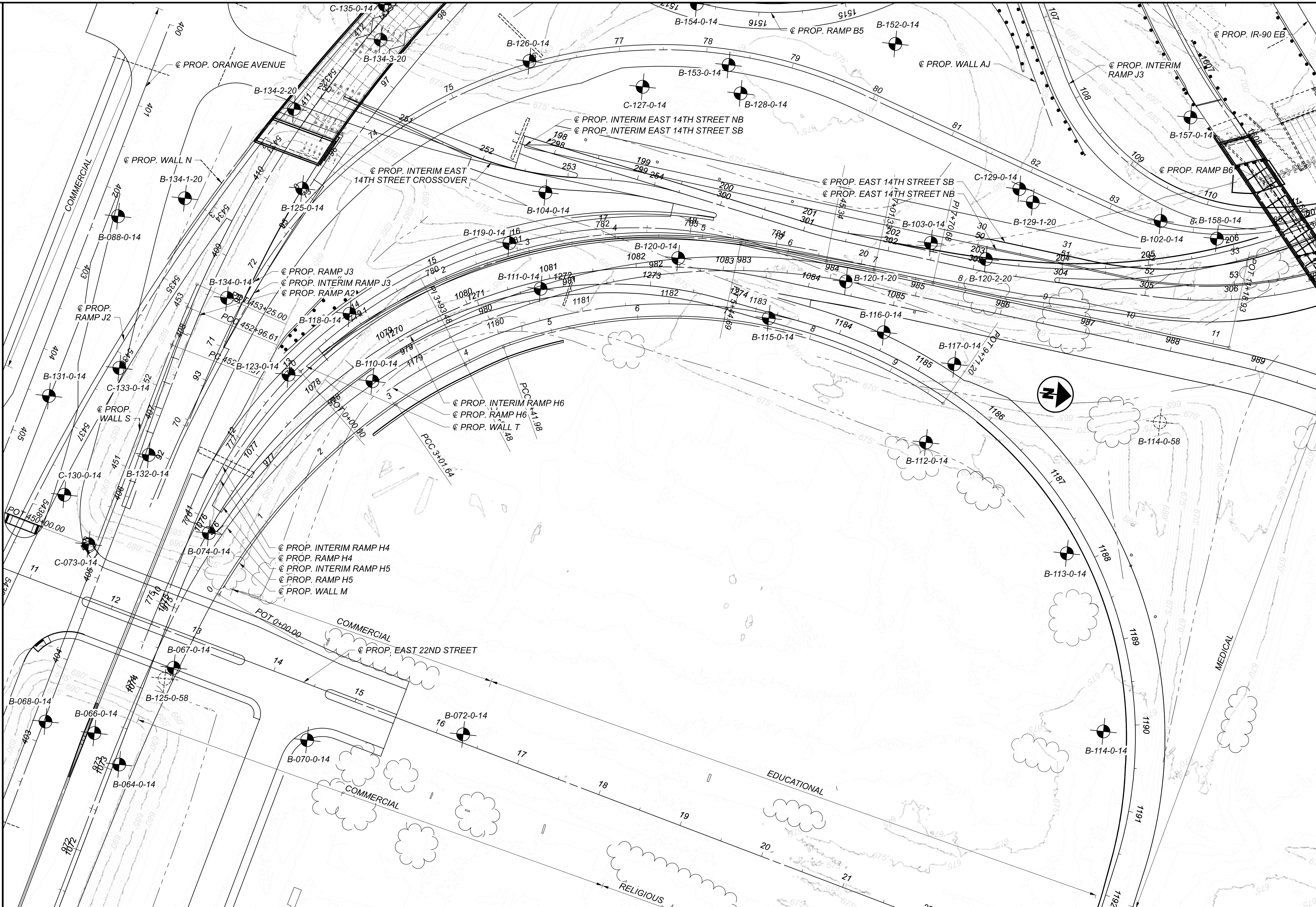
ODOT. (2021). *Specifications for Geotechnical Explorations.* Ohio Department of Transportation: Office of Geotechnical Engineering.

USDA. (2015, September). Web Soil Survey. Retrieved from http://websoilsurvey.nrcs.usda.gov

USGS & ODGS. (2006, June). Geologic Units of Ohio. *ohgeol.kmz*. United States Geologic Survey.

APPENDIX A

SOIL PROFILE SHEETS



HORIZONTAL SCALE IN FEET
0 25 50 100

SOIL PROFILE - ROADWAY
BEGIN TO END RETAINING WALL T

CUY-90-16.28 (CCG3A)

MODEL: 82382_ZP300I PAPERSIZE: 17x11 (in.) DATE: 6/23/2022 TIME: 1:36:36 PM USER: mjasiewicz
pw:\\mb-us-pw.bentley.com:mb-us-pw-03\Documents\ODOT\District12\82382\400-Engineering\Geotechnical\Sheets\82382_ZP300I.dgn

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

DESIGNER	MWJ
REVIEWER	BPA 06/23/22
PROJECT ID	82382
SUBSET 102	TOTAL 302
SHEET P.0	TOTAL 0

APPENDIX B

SOIL BORING LOGS AND LABORATORY TESTING RESULTS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:14 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PROJECT: CUY-CCG3	DRILLING FIRM / OPERATOR: BARR / P.STROUD	DRILL RIG: MOBILE B-58	STATION / OFFSET: 32+11, 55' LT.	EXPLORATION ID B-102-0-14
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / C. PIERCE	HAMMER: MOBILE AUTOMATIC	ALIGNMENT: SB E 14TH ST	
PID: 82380 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 679.0 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 12/3/14 END: 12/3/14	SAMPLING METHOD: SPT	ENERGY RATIO (%): 90*	LAT / LONG: 41.495491, -81.677640	

MATERIAL DESCRIPTION AND NOTES	ELEV. 679.0
4.0", **TOPSOIL**	678.7
LOOSE TO MEDIUM DENSE, DARK BROWN AND BROWN, **COARSE AND FINE SAND**, SOME GRAVEL, LITTLE SILT, TRACE CLAY, SS-1 AND SS-2 CONTAIN FEW ROOTS, WET **(FILL)** @3.0'; SS-2 CONTAINS CONCRETE FRAGMENTS	674.5
VERY DENSE, BROWN AND DARK GRAY, **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, CONTAINS GRANITE AND CONCRETE FRAGMENTS, WET **(FILL)**	672.0
DENSE, BROWN, **FINE SAND**, SOME COARSE SAND, TRACE SILT, TRACE GRAVEL, TRACE CLAY, DAMP @10.0'; SS-5 TO SS-7 BECOME LOOSE TO MEDIUM DENSE	662.0
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, TRACE SILT, TRACE CLAY, DAMP @22.5'; SS-10 TO SS-16 BECOME LITTLE SILT, TRACE GRAVEL, CONTAINS SILT LAYERS @27.5'; SS-12 TO SS-16 BECOME WET	

DEPTHS: 1–29 ft; W 652.5 (at approx. 26.5 ft)

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
3 2 2	6	100	SS-1	-	-	-	-	-	-	-	-	-	15	A-3a (V)
3 2 5	11	33	SS-2	-	23	14	37	17	9	NP	NP	NP	14	A-3a (0)
3 18 16	51	100	SS-3	-	-	-	-	-	-	-	-	-	20	A-2-4 (V)
16 13 12	38	100	SS-4	-	-	-	-	-	-	-	-	-	6	A-3 (V)
4 5 5	15	100	SS-5	-	-	-	-	-	-	-	-	-	6	A-3 (V)
3 2 2	6	100	SS-6	-	-	-	-	-	-	-	-	-	10	A-3 (V)
3 3 3	9	100	SS-7	-	3	27	65	4	1	NP	NP	NP	5	A-3 (0)
9 8 10	27	100	SS-8	-	-	-	-	-	-	-	-	-	5	A-3a (V)
7 7 10	26	100	SS-9	-	-	-	-	-	-	-	-	-	4	A-3a (V)
6 8 9	26	100	SS-10	-	-	-	-	-	-	-	-	-	5	A-3a (V)
7 7 6	20	67	SS-11	-	-	-	-	-	-	-	-	-	8	A-3a (V)
3 3 5	12	78	SS-12	-	-	-	-	-	-	-	-	-	20	A-3a (V)

GRADATION (%): GR, CS, FS, SI, CL; ATTERBERG: LL, PL, PI; BACK FILL

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:14 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PID: 82380	SFN:	PROJECT: CUY-CCG3	STATION / OFFSET: 32+11, 55' LT.	START: 12/3/14	END: 12/3/14	PG 2 OF 2	B-102-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 649.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, TRACE SILT, TRACE CLAY, DAMP *(continued)* @30.0'; SS-13 TO SS-16 BECOME GRAYISH BROWN		31	6 6 7	20	100	SS-13	-	1	5	82	11	1	NP	NP	NP	21	A-3a (0)	
		32–34																
@35.0'; SS-14 TO SS-16 BECOME DENSE		35–36	6 10 12	33	100	SS-14	-	-	-	-	-	-	-	-	-	20	A-3a (V)	
		37–39																
		40–41	6 9 12	32	100	SS-15	-	-	-	-	-	-	-	-	-	20	A-3a (V)	
		42–44																
		45–46	5 9 14	35	100	SS-16	-	-	-	-	-	-	-	-	-	22	A-3a (V)	
	630.7	47–48																
MEDIUM DENSE, GRAYISH BROWN, **SILT**, SOME SAND, LITTLE CLAY, TRACE GRAVEL, WET TO MOIST		49																
		50–51	4 6 6	18	100	SS-17	-	0	0	27	60	13	NP	NP	NP	23	A-4b (8)	
		52–54																
		55–56	6 7 12	29	100	SS-18	-	-	-	-	-	-	-	-	-	18	A-4b (V)	
	620.7	57–58																
STIFF, GRAY, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, INTERBEDDED, MOIST		59																
	617.5	60–61 EOB	6 5 7	18	100	SS-19	1.10	0	0	1	64	35	29	18	11	26	A-6a (8)	

NOTES: GROUNDWATER ENCOUNTERED AT 26.5' DURING DRILLING. CAVE DEPTH 25.1'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:15 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PROJECT: CUY-CCG3	DRILLING FIRM / OPERATOR: BARR / P.STROUD	DRILL RIG: MOBILE B-58	STATION / OFFSET: 1078+80, 53' LT.	EXPLORATION ID B-118-0-14
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / D.KLIMKOWICZ	HAMMER: MOBILE AUTOMATIC	ALIGNMENT: INTERIM RAMP H5	
PID: 82380 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 691.8 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 11/17/14 END: 11/17/14	SAMPLING METHOD: SPT	ENERGY RATIO (%): 90*	LAT / LONG: 41.492970, -81.676930	

MATERIAL DESCRIPTION AND NOTES	ELEV. 691.8
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE GRAVEL, TRACE CLAY, DAMP **(FILL)**	688.6
DENSE, BROWN, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, DAMP **(FILL)**	687.3
DENSE TO VERY DENSE, BROWN AND DARK GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE TO LITTLE GRAVEL, TRACE CLAY, SS-2 CONTAINS BRICK AND ASPHALT FRAGMENTS, DAMP TO MOIST **(FILL)** @7.5'; SS-3 TO SS-6 CHANGES TO BROWN, CONTAINS BRICK FRAGMENTS @15.0'; SS-6 CHANGES TO SOME GRAVEL	674.8
MEDIUM DENSE, ORANGISH BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, LITTLE SILT, TRACE CLAY, DAMP	669.8
MEDIUM DENSE, BROWN, **FINE SAND**, TRACE COARSE SAND, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DRY TO DAMP	662.3

DEPTHS: 1 – 29

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
6 8 12	30	94	SS-1A	-	-	-	-	-	-	-	-	-	7	A-3a (V)
			SS-1B	-	-	-	-	-	-	-	-	-	14	A-4a (V)
12 28 31	89	100	SS-2	-	19	13	40	19	9	NP	NP	NP	9	A-3a (0)
9 15 22	56	100	SS-3	-	-	-	-	-	-	-	-	-	11	A-3a (V)
9 11 12	35	100	SS-4	-	-	-	-	-	-	-	-	-	8	A-3a (V)
18 11 12	35	100	SS-5	-	10	25	50	11	4	NP	NP	NP	7	A-3a (0)
30 17 26	65	94	SS-6	-	-	-	-	-	-	-	-	-	7	A-3a (V)
3 4 6	15	100	SS-7	-	-	-	-	-	-	-	-	-	9	A-3a (V)
4 3 6	14	89	SS-8	-	-	-	-	-	-	-	-	-	5	A-3a (V)
4 4 6	15	100	SS-9	-	-	-	-	-	-	-	-	-	5	A-3 (V)
5 4 5	14	100	SS-10	-	1	7	87	3	2	NP	NP	NP	5	A-3 (0)
4 4 5	14	94	SS-11	-	-	-	-	-	-	-	-	-	8	A-3 (V)

BACK FILL

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:15 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PID: 82380	SFN:	PROJECT: CUY-CCG3	STATION / OFFSET: 1078+80, 53' LT.	START: 11/17/14	END: 11/17/14	PG 2 OF 2	B-118-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 661.8	DEPTHS	SPT/RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
STIFF, BROWN, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, MOIST *(continued)*		31	7 5 6	17	94	SS-12	1.25	0	0	2	67	31	33	20	13	27	A-6a (9)	
	658.5	32–33																
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, TRACE CLAY, TRACE GRAVEL, DAMP		34–36	5 5 7	18	100	SS-13	-	-	-	-	-	-	-	-	-	9	A-3a (V)	
@40.0'; SS-14 TO SS-16 BECOME DENSE, WET		37–41	8 14 12	39	100	SS-14	-	-	-	-	-	-	-	-	-	23	A-3a (V)	
@45.0'; SS-15 AND SS-16 BECOME GRAY		W 646.8; 42–46	7 12 14	39	94	SS-15	-	0	0	68	29	3	NP	NP	NP	22	A-3a (0)	
		47–51	7 12 14	39	100	SS-16	-	-	-	-	-	-	-	-	-	24	A-3a (V)	
	638.5	52–53																
DENSE, GRAY, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, WET		54–56	8 11 16	41	94	SS-17	-	0	1	56	35	8	NP	NP	NP	19	A-4a (2)	
	630.3	57–61; EOB	10 10 10	30	100	SS-18	-	-	-	-	-	-	-	-	-	21	A-4a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 45.0' DURING DRILLING. CAVE DEPTH 37.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:16 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PROJECT: CUY-CCG3	DRILLING FIRM / OPERATOR: BARR / J.GILBERT	DRILL RIG: CME 55X	STATION / OFFSET: 1080+66, 51' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / S.PENCE	HAMMER: CME AUTOMATIC	ALIGNMENT: INTERIM RAMP H5
PID: 82380 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 684.5 (MSL) EOB: 62.5 ft.
START: 4/8/15 END: 4/8/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.2	LAT / LONG: 41.493451, -81.677288

EXPLORATION ID B-119-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 684.5
STIFF TO VERY STIFF, BROWN, GRAY, AND GRAYISH BROWN, **SILTY CLAY**, SOME SAND, TRACE GRAVEL, CONTAINS MANY ROOTS, DAMP TO MOIST **(FILL)**	680.0
VERY STIFF, GRAYISH BROWN, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, SS-3 CONTAINS BRICK FRAGMENTS, DAMP **(FILL)** @7.5'; SS-4 CONTAINS GLASS	674.7
MEDIUM DENSE, BROWN, **FINE SAND**, TRACE COARSE SAND, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP (F.S.)	664.5
MEDIUM DENSE, GRAYISH BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, DAMP	662.0
MEDIUM DENSE, BROWN, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, WET	657.0
MEDIUM DENSE, BROWN AND GRAY, **COARSE AND FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP	

DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
0.0–1.5	2-2-2	5	83	SS-1	2.00	-	-	-	-	-	-	-	-	18	A-6b (V)
2.5–4.0	2-5-4	12	100	SS-2	1.25	7	9	18	35	31	38	22	16	25	A-6b (9)
5.0–6.5	3-6-8	19	100	SS-3	2.10	-	-	-	-	-	-	-	-	14	A-6a (V)
7.5–9.0	3-39-31	95	83	SS-4	2.20	-	-	-	-	-	-	-	-	15	A-6a (V)
10.5–12.0	3-5-6	15	100	SS-5	-	-	-	-	-	-	-	-	-	10	A-3 (V)
13.0–14.5	4-5-6	15	100	SS-6	-	4	2	84	5	5	NP	NP	NP	10	A-3 (0)
15.5–17.0	3-4-5	12	100	SS-7	-	-	-	-	-	-	-	-	-	8	A-3 (V)
18.0–19.5	4-4-5	12	100	SS-8	-	-	-	-	-	-	-	-	-	8	A-3 (V)
20.5–22.0	4-8-4	16	100	SS-9	-	-	-	-	-	-	-	-	-	8	A-3a (V)
23.0–24.5	3-3-5	11	100	SS-10	-	0	6	31	43	20	20	15	5	19	A-4a (6)
25.5–27.0	3-4-12	22	100	SS-11	-	-	-	-	-	-	-	-	-	22	A-4a (V)
28.0–29.5	4-8-13	28	100	SS-12	-	-	-	-	-	-	-	-	-	6	A-3a (V)

BACK FILL

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:16 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

MATERIAL DESCRIPTION AND NOTES	ELEV. 654.5	DEPTHS
MEDIUM DENSE, BROWN AND GRAY, **COARSE AND FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP *(continued)*	650.7	
MEDIUM DENSE, GRAY, **SANDY SILT**, LITTLE CLAY, TRACE GRAVEL, WET	645.7	W 649.0
DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, WET	640.7	
DENSE, GRAY, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, WET	625.7	
GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, WET		

DEPTH	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
31	6 11 9	27	100	SS-13	-	1	6	82	8	3	NP	NP	NP	8	A-3a (0)	
36	4 5 6	15	100	SS-14	-	-	-	-	-	-	-	-	-	25	A-4a (V)	
41	5 13 20	45	100	SS-15	-	-	-	-	-	-	-	-	-	17	A-3a (V)	
46	8 12 15	37	100	SS-16	-	0	1	48	46	5	NP	NP	NP	20	A-4a (3)	
51	7 10 16	35	100	SS-17	-	-	-	-	-	-	-	-	-	28	A-4a (V)	
56	11 9 14	31	100	SS-18	-	-	-	-	-	-	-	-	-	24	A-4a (V)	
61			83	SS-19	1.50	0	1	9	59	31	27	18	9	27	A-4b (8)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:16 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PID: 82380	SFN:	PROJECT: CUY-CCG3	STATION / OFFSET: 1080+66, 51' LT.	START: 4/8/15	END: 4/8/15	PG 3 OF 3	B-119-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 622.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
@62.0'; UNIT WEIGHT: 125.3 PCF @ 27.3% MC	622.0	EOB																

NOTES: GROUNDWATER ENCOUNTERED AT 35.5' DURING DRILLING. CAVE IN DEPTH 32.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:16 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PROJECT: CUY-CCG3	DRILLING FIRM / OPERATOR: BARR / T.GILBERT	DRILL RIG: CME 55	STATION / OFFSET: 49+47, 54' RT.	EXPLORATION ID B-120-0-14
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: BARR / D.KLIMKOWICZ	HAMMER: CME AUTOMATIC	ALIGNMENT: NB E 14TH ST	
PID: 82380 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 1/26/14	ELEVATION: 670.8 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 2/11/15 END: 2/11/15	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 78.8	LAT / LONG: 41.493986, -81.677293	

MATERIAL DESCRIPTION AND NOTES	ELEV. 670.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
6.0", **TOPSOIL**	670.3																	
VERY LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, TRACE TO SOME GRAVEL, LITTLE SILT, TRACE CLAY, SS-1 CONTAINS ROOTS, MOIST TO WET **(FILL)**		0 - 1.5	2 2 2	5	100	SS-1	-	21	18	41	11	9	NP	NP	NP	12	A-3a (0)	
		2.5 - 4	1 1 1	3	100	SS-2	-	10	13	58	11	8	NP	NP	NP	15	A-3a (0)	
		5 - 6.5	2 3 3	8	100	SS-3	-	-	-	-	-	-	-	-	-	13	A-3a (V)	
@7.5'; SS-4 AND SS-5 CHANGE TO DAMP		7.5 - 9	3 4 4	11	100	SS-4	-	-	-	-	-	-	-	-	-	9	A-3a (V)	
		10 - 11.5	2 3 3	8	100	SS-5	-	-	-	-	-	-	-	-	-	7	A-3a (V)	
@12.5'; SS-6 NO RECOVERY	656.3	12.5 - 14	2 1 1	3	0	SS-6	-	-	-	-	-	-	-	-	-	-		
VERY STIFF, BROWN, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, MOIST	653.8	15 - 16.5	1 2 3	7	100	SS-7	2.75	0	0	6	55	39	29	18	11	23	A-6a (8)	
MEDIUM DENSE TO DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, LITTLE CLAY, TRACE GRAVEL, MOIST TO WET		17.5 - 19	5 6 6	16	100	SS-8	-	-	-	-	-	-	-	-	-	11	A-3a (V)	
		W 650.8 (20); 20 - 21.5	5 6 9	20	100	SS-9	-	1	5	59	21	14	NP	NP	NP	23	A-3a (0)	
		22.5 - 24	6 8 10	24	100	SS-10	-	-	-	-	-	-	-	-	-	22	A-3a (V)	
		25 - 26.5	4 8 11	25	100	SS-11	-	-	-	-	-	-	-	-	-	26	A-3a (V)	
		27.5 - 29	6 8 10	24	100	SS-12	-	-	-	-	-	-	-	-	-	22	A-3a (V)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 14:16 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2017 ARCHIVE\CUY-CCG3 82380\GINT FILES

PID: 82380	SFN:	PROJECT: CUY-CCG3	STATION / OFFSET: 49+47, 54' RT.	START: 2/11/15	END: 2/11/15		B-120-0-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 640.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE TO DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, LITTLE CLAY, TRACE GRAVEL, MOIST TO WET *(continued)*		31	10 13 17	39	100	SS-13	-	-	-	-	-	-	-	-	-	22	A-3a (V)	
	637.5	32, 33																
DENSE, GRAY, **SILT**, "AND" SAND, TRACE CLAY, TRACE GRAVEL, WET		34, 35, 36	8 10 14	32	100	SS-14	-	0	0	40	52	8	NP	NP	NP	25	A-4b (5)	
	632.5	37, 38																
STIFF TO VERY STIFF, GRAY, **SILT**, SOME CLAY, LITTLE SAND, TRACE GRAVEL, WET		39, 40, 41	11 17 18	46	100	SS-15	2.10	-	-	-	-	-	-	-	-	24	A-4b (V)	
		42, 43, 44, 45, 46	3 4 5	12	100	SS-16	1.25	0	2	16	52	30	23	15	8	23	A-4b (8)	
	622.5	47, 48																
GRAY, **SILT**, LITTLE CLAY, TRACE SAND, TRACE GRAVEL, WET @51.2'; UNIT WEIGHT: 138.8 PCF @ 18.7% MC		49, 50, 51, 52			100	ST-17	-	0	0	8	79	13	NP	NP	NP	19	A-4b (8)	
	617.5	53																
VERY STIFF TO HARD, GRAY, **SILT**, SOME CLAY, TRACE SAND, TRACE GRAVEL, MOIST TO WET		54, 55, 56	3 5 7	16	100	SS-18	2.75	-	-	-	-	-	-	-	-	25	A-4b (V)	
	609.3	57, 58, 59, 60, 61 EOB	5 7 10	22	100	SS-19	4.50	0	1	2	68	29	26	18	8	19	A-4b (8)	

NOTES: GROUNDWATER ENCOUNTERED AT 20' DURING DRILLING. CAVE DEPTH 18.6'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PLACED 0.5 BAG ASPHALT PATCH; SHOVELED SOIL CUTTINGS

PROJECT: CUY-90-16.28 (CCG3A)	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 984+18, 0' RT.	EXPLORATION ID B-120-1-20
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: RAMP H5	
PID: 82382 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 668.6 (MSL) EOB: 35.0 ft.	PAGE 1 OF 2
START: 5/18/21 END: 5/18/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.494520, -81.677262	

MATERIAL DESCRIPTION AND NOTES	ELEV. 668.6	DEPTHS	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
LOOSE TO MEDIUM DENSE, BROWN, **FINE SAND**, TRACE TO LITTLE COARSE SAND, TRACE GRAVEL, TRACE SILT, TRACE CLAY, MOIST TO DAMP (F-S)		0–14.5																
@2.5'; SS-1 CONTAINS INTERBEDDED SILT SEAMS		2.5–4	6 4 5	13	100	SS-1	-	-	-	-	-	-	-	-	-	13	A-3 (V)	
		5–6.5	2 3 3	9	100	SS-2	-	10	14	66	8	2	NP	NP	NP	8	A-3 (0)	
		7.5–9	3 3 4	10	100	SS-3	-	-	-	-	-	-	-	-	-	6	A-3 (V)	
		10–11.5	6 8 10	27	100	SS-4	-	-	-	-	-	-	-	-	-	6	A-3 (V)	
	654.1	12.5–14	6 7 9	24	100	SS-5	-	0	2	92	5	1	NP	NP	NP	5	A-3 (0)	
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE TO SOME SILT, TRACE CLAY, TRACE GRAVEL, MOIST TO WET		15–16.5	3 4 5	13	100	SS-6	-	-	-	-	-	-	-	-	-	19	A-3a (V)	
		17.5–19	4 5 5	15	100	SS-7	-	-	-	-	-	-	-	-	-	28	A-3a (V)	
		20–21.5	2 2 3	7	100	SS-8	-	0	0	72	24	4	NP	NP	NP	25	A-3a (0)	
@22.5'; SS-9 CONTAINS INTERBEDDED SILT SEAMS		22.5–24	2 2 4	9	100	SS-9	-	-	-	-	-	-	-	-	-	31	A-3a (V)	
@25.0'; BECOMES GRAY	W 643.6	25–26.5	4 4 7	16	100	SS-10	-	-	-	-	-	-	-	-	-	27	A-3a (V)	
		27–29																

PID: 82382	SFN:	PROJECT: CUY-90-16.28 (CCG3A)	STATION / OFFSET: 984+18, 0' RT.	START: 5/18/21	END: 5/18/21	PG 2 OF 2	B-120-1-20

MATERIAL DESCRIPTION AND NOTES	ELEV. 638.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE TO SOME SILT, TRACE CLAY, TRACE GRAVEL, MOIST TO WET *(continued)*		31	4 7 10	25	100	SS-11	-	0	0	74	23	3	NP	NP	NP	24	A-3a (0)	
		32																
		33																
		34	5 7 11	27	100	SS-12	-	-	-	-	-	-	-	-	-	25	A-3a (V)	
	633.6	EOB 35																

NOTES: GROUNDWATER ENCOUNTERED AT 17.5' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 1 BAG HOLE PLUG; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 13:25 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\CUY-90-16.28 (CCG3A - MOD#7)\GINT FILES\CUY-90-16.28 (CCG3/

PROJECT: CUY-90-16.28 (CCG3A)	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 203+11, 3' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SB E 14TH ST INTERIM
PID: 82382 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 678.9 (MSL) EOB: 30.5 ft.
START: 5/19/21 END: 5/19/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.494953, -81.677411

EXPLORATION ID B-120-2-20

MATERIAL DESCRIPTION AND NOTES	ELEV. 678.9	DEPTHS
VERY DENSE TO MEDIUM DENSE, BROWN AND YELLOWISH BROWN, **COARSE AND FINE SAND**, LITTLE TO SOME GRAVEL AND STONE FRAGMENTS, LITTLE SILT, TRACE TO LITTLE CLAY, CONTAINS RED BRICK FRAGMENTS, WET **(FILL)**	671.9	0–7
LOOSE TO DENSE, BROWN, **COARSE AND FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP	656.9	7–22
MEDIUM DENSE, BROWNISH GRAY, **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP	654.4	22–24.5
MEDIUM DENSE TO DENSE, BROWNISH GRAY, **FINE SAND**, TRACE SILT, TRACE COARSE SAND, TRACE CLAY, TRACE GRAVEL, MOIST TO WET		24.5–

W 651.9

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
8 23 29	77	100	SS-1	-	16	12	55	12	5	NP	NP	NP	14	A-3a (0)
2 8 12	30	100	SS-2	-	22	13	37	17	11	NP	NP	NP	14	A-3a (0)
4 10 11	31	100	SS-3	-	-	-	-	-	-	-	-	-	7	A-3a (V)
2 4 5	13	100	SS-4	-	-	-	-	-	-	-	-	-	6	A-3a (V)
4 3 4	10	100	SS-5	-	0	13	74	10	3	NP	NP	NP	8	A-3a (0)
4 5 6	16	100	SS-6	-	-	-	-	-	-	-	-	-	7	A-3a (V)
2 3 3	9	100	SS-7	-	-	-	-	-	-	-	-	-	8	A-3a (V)
2 4 8	18	100	SS-8	-	-	-	-	-	-	-	-	-	7	A-3a (V)
3 10 10	30	100	SS-9	-	25	44	18	11	2	NP	NP	NP	5	A-1-b (0)
8 12 12	36	100	SS-10	-	-	-	-	-	-	-	-	-	14	A-3 (V)
5 6 7	19	100	SS-11	-	0	4	86	8	2	NP	NP	NP	22	A-3 (0)
6 7	21	100	SS-12	-	-	-	-	-	-	-	-	-	26	A-3 (V)

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/22/22 13:25 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\CUY-90-16.28 (CCG3A - MOD#7)\GINT FILES\CUY-90-16.28 (CCG3A

PID: 82382	SFN:	PROJECT: CUY-90-16.28 (CCG3A)	STATION / OFFSET: 203+11, 3' LT.	START: 5/19/21	END: 5/19/21	PG 2 OF 2	B-120-2-20

MATERIAL DESCRIPTION AND NOTES	ELEV. 648.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
	648.4	EOB	7															

NOTES: GROUNDWATER ENCOUNTERED AT 27.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 1 BAG HOLE PLUG; SHOVELED SOIL CUTTINGS

NEAS
National Engineering & Architectural Services Inc.
5710 Westbourne Avenue
Columbus, OH 43213
614.892.0162

Consolidation Test

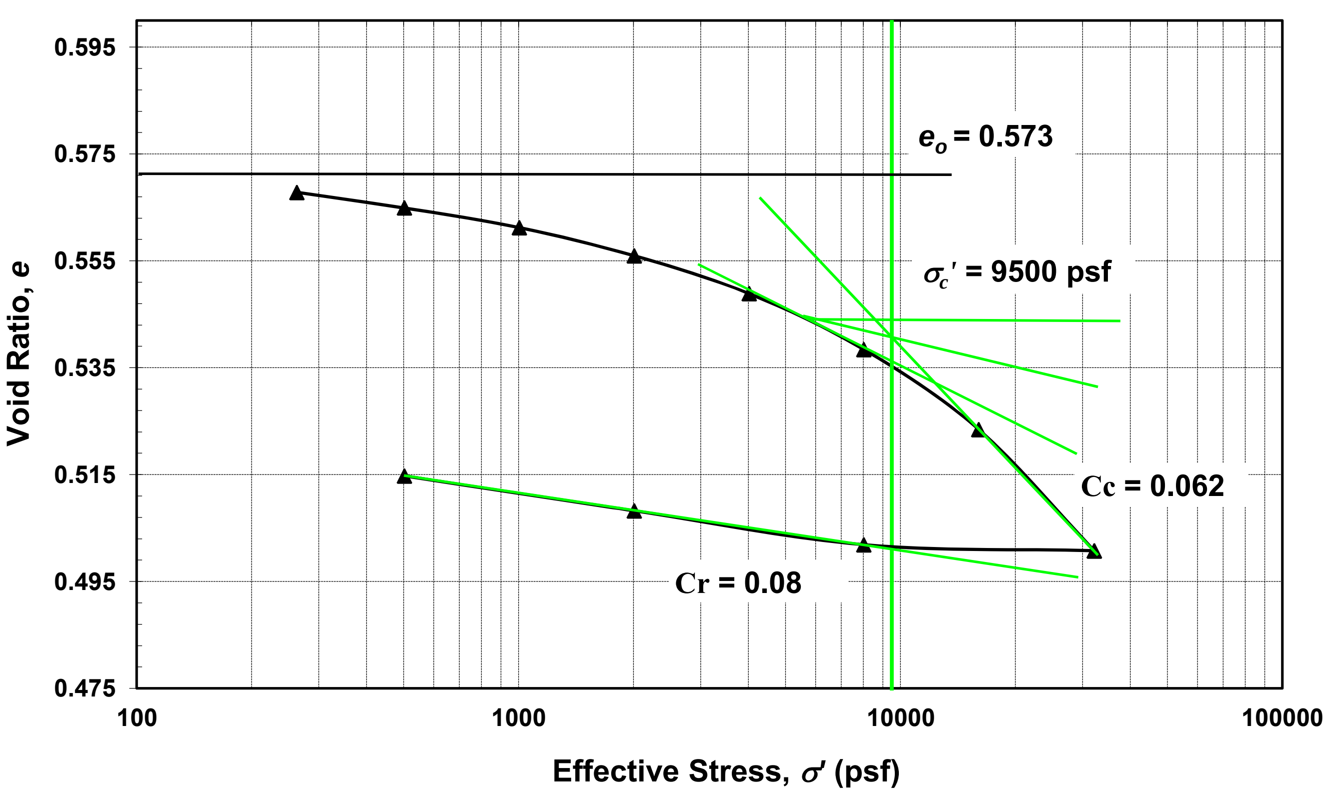
Project Name:	CUY-90-16.28 (CCG3A)	Prepared by:	LR
Source:	B-134-2-20 ST-1 (59.1' - 59.2')	Checked by:	ZM
Description:	Very stiff, gray, SILT, some clay, trace sand, trace gravel, damp.	Date:	4/26/2021

Test Specification:	ASTM D 2435		
Initial Void Ratio:	0.573	Initial Bulk Unit Weight (lb/ft^3):	129
In-situ Vertical Effective Stress (psf):	7100	Dry Unit Weight (lb/ft^3):	107

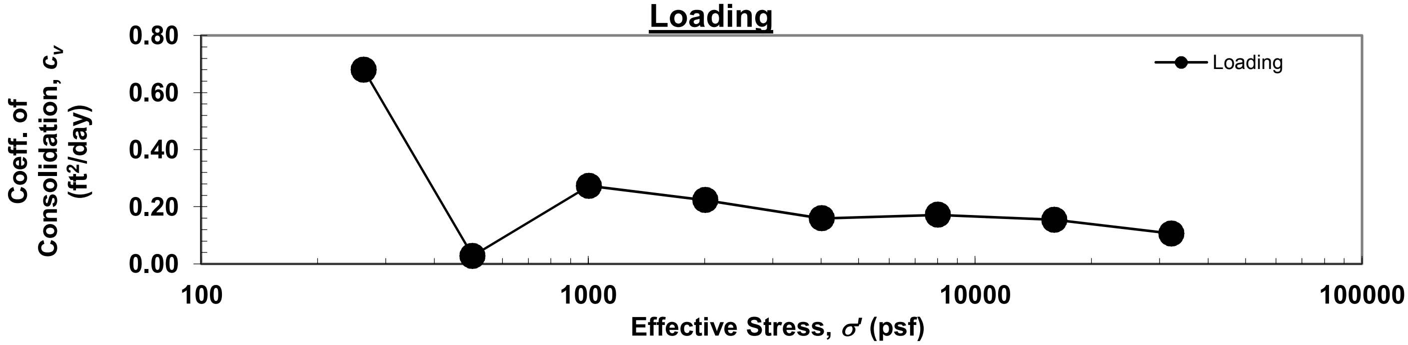
Compression and Swelling Index

Compression Index (*Cc*):	0.062	Preconsolidation Pressure (σ_c') (psf):	**9500**
Recompression Index (*Cr*):	0.008	Over-Consolidation Ratio (*OCR*):	**1.34**

Consolidation Curve



Loading



BARR & PREVOST
ENGINEERING | TESTING | SURVEYING

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

Consolidation Test

Project Name: CUY-77-13.80
Source: B-144-0-14, ST-21, 71.2' - 71.4'
Description: Very stiff, SILT, some clay, trace sand.

Prepared by: CH
Checked by:
Date: 12/9/2014

Test Specification: ASTM D 2435-04
Initial Void Ratio: 0.585
In-situ Vertical Effective Stress: 5900 psf

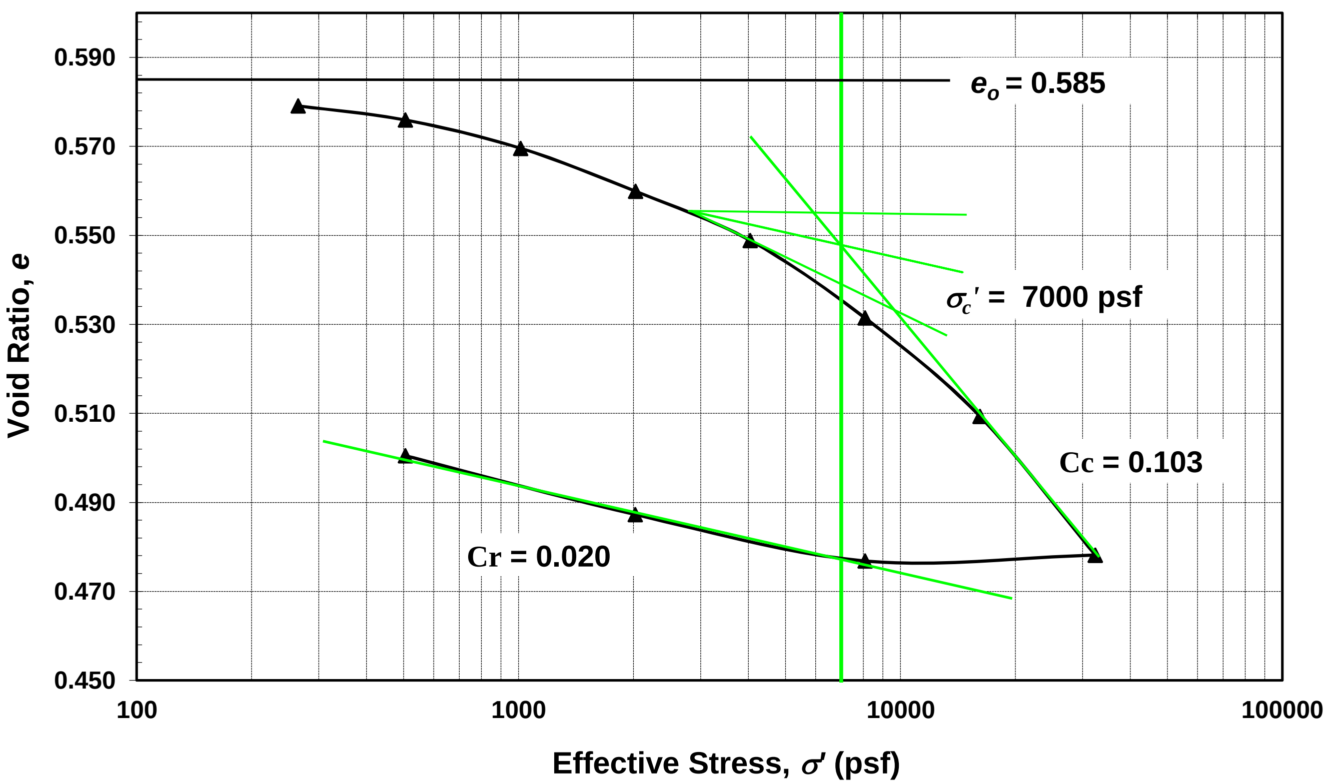
Initial Bulk Unit Weight (lb/ft^3): 128
Dry Unit Weight (lb/ft^3): 106

Compression and Swelling Index

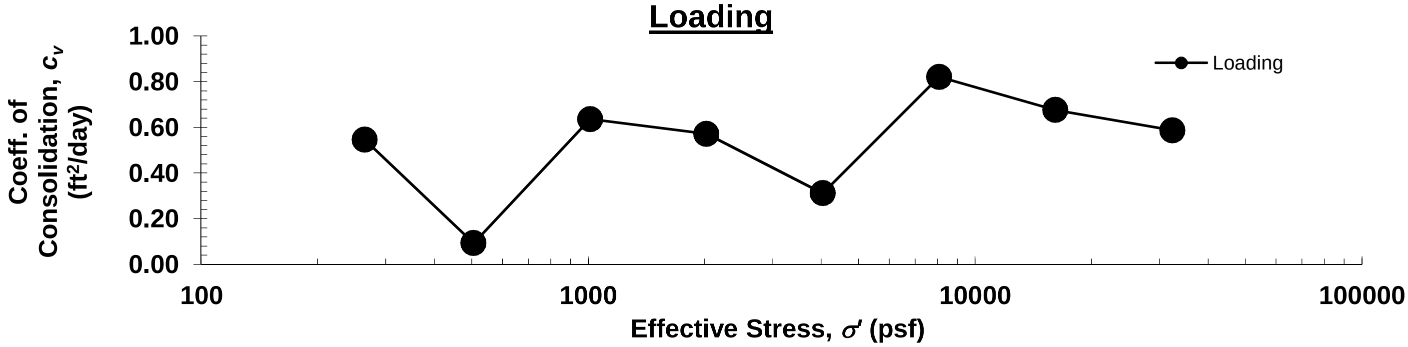
Compression Index (*Cc*): 0.103
Recompression Index (*Cr*): 0.020

Preconsolidation Pressure (σ_c'): **7000 psf**
Over-Consolidation Ratio (*OCR*): **1.2**

Consolidation Curve



Loading



APPENDIX C

GENERALIZED SUBSURFACE PROFILE

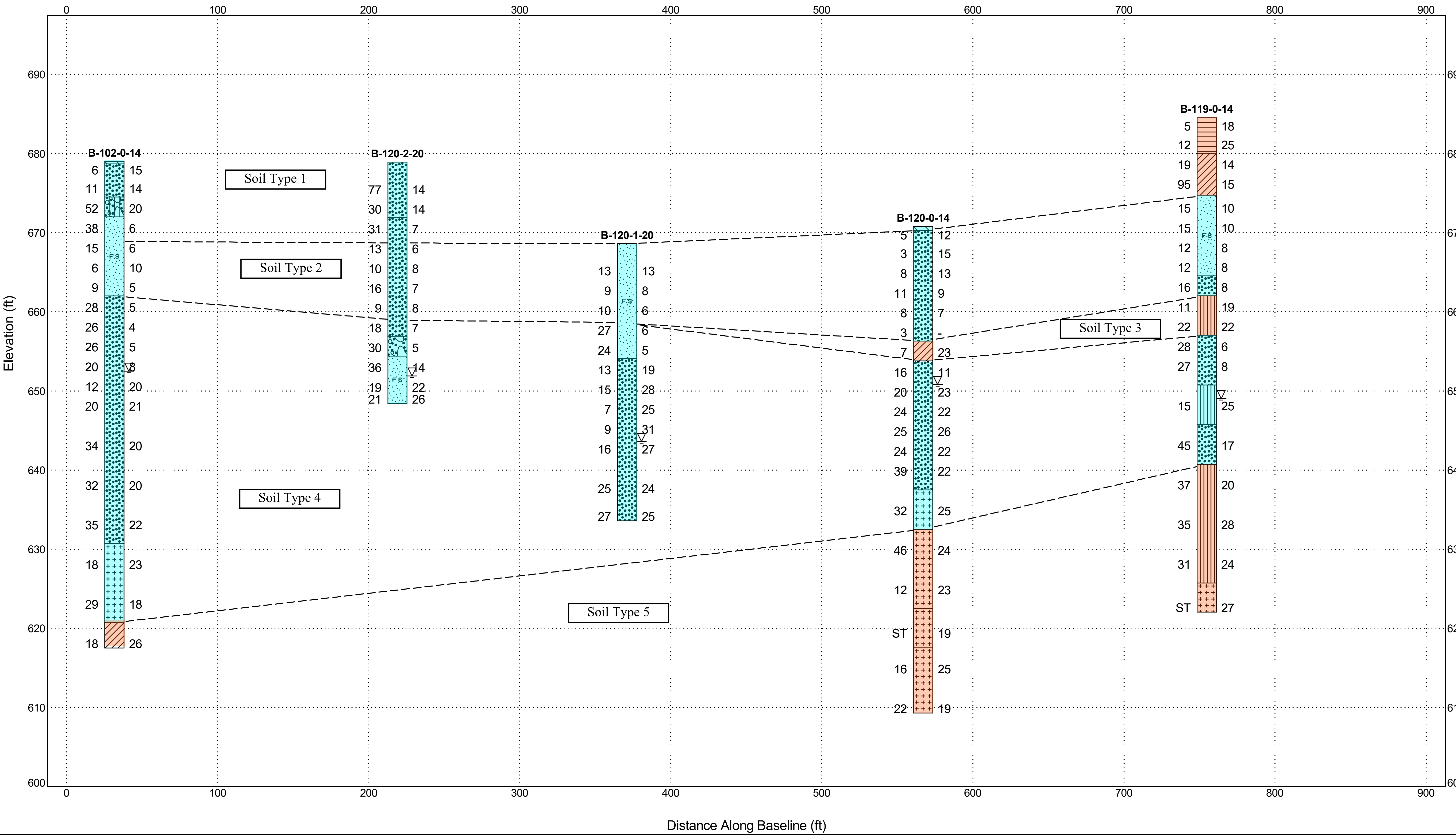
OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

Non-cohesive
Cohesive

SUBSURFACE DIAGRAM
RETAINING WALL T

Ohio DOT: Sod and Topsoil
Ohio DOT: A-3a, coarse and fine sand
Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt
Ohio DOT: A-3, fine sand
Ohio DOT: A-4b, silt
Ohio DOT: A-6a, silt and clay
Ohio DOT: A-6b, silty clay
Ohio DOT: A-4a, sandy silt

CLIENT Michael Baker International
PROJECT NUMBER 82380
PROJECT NAME CCG3A
PROJECT LOCATION Cuyahoga County, Ohio



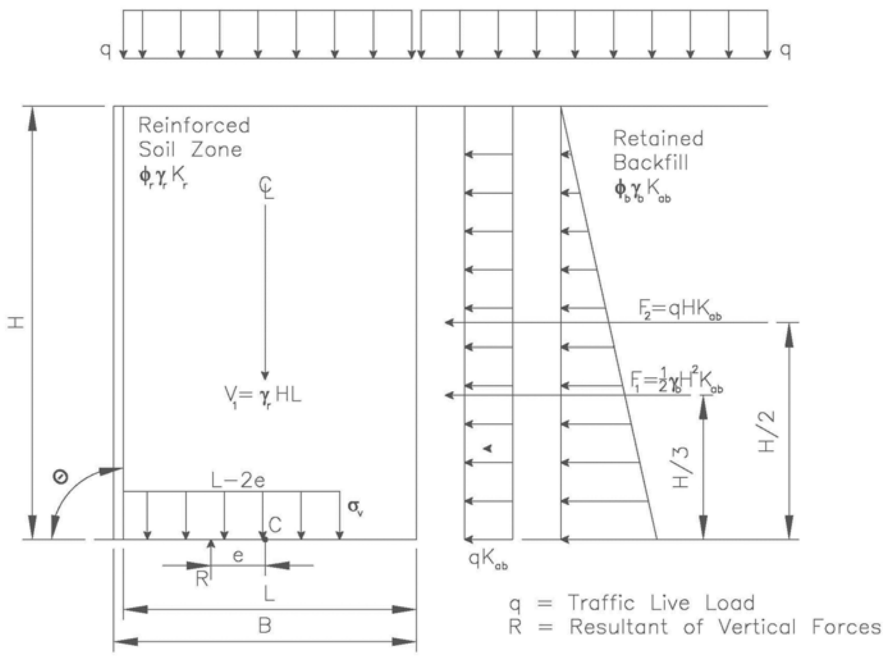
STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 9/27/21 15:56 - P:\21-0011 (82380 CCG3A MOD 7)\82380\GEOTECHNICAL\RETAINING WALLS\WALL T\ANALYSIS\GINT_PROFILE\CUY-CCG3 MASTER - LR UPDATED.GPJ

APPENDIX D

EXTERNAL STABILITY ANALYSIS

Objective: To evaluate the external stability of MSE wall design with vertical wall face and horizontal backfill.
Method: In accordance with ODOT Bridge Design Manual, 2013 [Sect. 307] LRFD Bridge Design Specifications, 8th Ed., 2018, [Sect. 11.10.5].
Assumptions:

- **Horizontal backfill behind MSE wall on granular (drained) soils.**
- **For battered or vertical walls with a back face of wall angle of θ to horizontal.**
- **Not for sheet type reinforcement. If so, use different assessment for Sliding parameter ϕ_μ.**
- **MSE wall not acting as abutment, if so must meet minimum embedment depth of H/10 if no slope in front of wall**
- **Load combinations and wall configuration are as shown below:**



Givens:

Wall Geometry:

$H_e := 19 \cdot ft - 3 \cdot ft$ Exposed wall height

$\theta := 90 \cdot deg$ Angle of back face of wall to horizontal: 90 deg for vertical or near vertical walls (per Berg et al., 2009; near vertical = 80 deg < θ < 100 deg)

Reinforced Backfill Soil Design Parameters:

$\phi'_r := 34 \cdot deg$ Effective angle of internal friction (Per BDM [Table 307-1])

$\gamma_r := 120 \cdot \frac{lbf}{ft^3}$ Unit weight (Per BDM [Table 307-1])

$c'_r := 0 \cdot \frac{lbf}{ft^2}$ Effective Cohesion

Retained Backfill Soil Design Parameters:

$\phi'_b := 30 \cdot deg$ Effective angle of internal friction (Per BDM [Table 307-1])

$\gamma_b := 120 \cdot \frac{lbf}{ft^3}$ Unit weight (Per BDM [Table 307-1])

$c'_b := 0 \cdot \frac{lbf}{ft^2}$ Effective Cohesion

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 30 \cdot deg$ — Effective angle of internal friction

$\gamma_f := 115 \cdot \frac{lbf}{ft^3}$ — Unit weight

$c'_f := 0 \cdot \frac{lbf}{ft^2}$ — Cohesion

Undrained Conditions (Total Stress):

$\phi_f := 30 \cdot deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 115 \ \frac{lbf}{ft^3}$ — Unit weight

$c_f := 0 \cdot \frac{lbf}{ft^2}$ — 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)

Depth of Embedment Check:

$d_{frost} := 3.0 \ ft$ $\quad d_{user} := 0 \ ft$ — Local Frost Depth

$Slope_{fw} := 0 \ deg$

Inclination of ground slope in front of wall :

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

$d_{est} := \max\left(d_{frost}, 3 \ ft, d_{user}\right)$ $\quad d_{est} = 3 \ ft$

$H_{est} := d_{est} + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 19 \ ft$

$$d_{eSlope} := \text{if}\left(Slope_{fw} < 1 \ deg, \frac{H_{est}}{20}, \text{if}\left(Slope_{fw} < 26.565 \ deg, \frac{H_{est}}{10}, \text{if}\left(Slope_{fw} < 33.69 \ deg, \frac{H_{est}}{7}, \frac{H_{est}}{5}\right)\right)\right)$$

$d_{eSlope} = 1 \ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $\quad d_e = 3 \ ft$ — Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 19 \ ft$ — Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 0 \cdot ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\quad L = 13.3 \ ft$ — Length of Reinforcement

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Live Load Surcharge Parameters:

$SUR := 250 \cdot \frac{lbf}{ft^2}$

Live load surcharge (per **LRFD BDS [3.11.6.4]** & **BDM [307.1.1]**)
Note: If vehicular loading is within 1 ft of the backface of the wall and with a design height, H, less than 20 ft, see **LRFD BDS Section 3.11.6.4 and Table 3.11.6.4-2** for adjusted surcharge load calculation.
Note: When traffic vehicular live loads are not present within 0.5*H from the back of the reinforced zone let SUR equal 100 psf to account for construction loads.

Calculations:

Active Earth Pressure:

$\beta := 0 \qquad \delta := \beta$

Inclination of ground slope behind face of wall and angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.3333$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 7220 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 1583.3 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 30324 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 3325 \ \frac{lbf}{ft}$ — Live Load Surcharge - (LS)

Moment Arm: | Moment:

$d_{v1} := 0 \cdot ft \qquad d_{v1} = 0 \ ft \qquad MV_1 := V_1 \cdot d_{v1} \qquad MV_1 = 0 \ \frac{lbf \cdot ft}{ft}$

$d_{v2} := 0 \ ft \qquad d_{v2} = 0 \ ft \qquad MV_2 := V_2 \cdot d_{v2} \qquad MV_2 = 0 \ \frac{lbf \cdot ft}{ft}$

Horizontal Loads:

$H_1 := F_T = 7220 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1583.3 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: | Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 6.3 \ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 45726.7 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 9.5 \ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 15041.7 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\qquad V_{EV} = 30324\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\qquad V_{LS} = 3325\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\qquad H_{EH} = 7220\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\qquad H_{LS} = 1583.3\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{EV} := MV_1$ $\qquad M_{EV} = 0\ \frac{lbf \cdot ft}{ft}$

$M_{LS} := MV_2$ $\qquad M_{LS} = 0\ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 45726.7\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 15041.7\ \frac{lbf \cdot ft}{ft}$

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) $\quad Ia_{EV} := 1 \quad Ia_{EH} := 1.5 \quad Ia_{LS} := 1.75$

Strength Limit State Ib: (Bearing Capacity) $\quad Ib_{EV} := 1.35 \quad Ib_{EH} := 1.5 \quad Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\qquad V_{Ia} = 30324\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\qquad V_{Ib} = 46756.2\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\qquad H_{Ia} = 13600.8\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\qquad H_{Ib} = 13600.8\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot (Ia_{EV} \cdot M_{EV})$ $\qquad MV_{Ia} = 0\ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot ((Ib_{EV} \cdot M_{EV}) + (Ib_{LS} \cdot M_{LS}))$ $\qquad MV_{Ib} = 0\ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ia} = 94912.9\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ib} = 94912.9\ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

Compute the Effective Bearing Length (Strength Ib):

$\Sigma M_R := MV_{Ib}$ — $\Sigma M_R = 0\ \frac{lbf \cdot ft}{ft}$ — Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 94912.9\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 46756.2\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2\ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 9.2\ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 460 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 13600.8\ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 46756.2\ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

$D_f := d_e$ — $D_f = 3\ ft$ — Footing embedment

$d_w := 16.8 \cdot ft$ — Depth of Groundwater below Bearing Grade

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

Drained Conditions (Effective Stress):

$$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right) \qquad N_q = 18.4$$

$$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right) \qquad N_c = 30.14$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f) \qquad N_\gamma = 22.4$$

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

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.012$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \frac{B'}{L_{Wall}} \cdot \tan(\phi'_f), 1\right) \qquad s_q = 1.012$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.992$$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

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]**:

$C_{wq} := \text{if}\left(d_w \geq 0, 1, 0.5\right)$ $\qquad C_{wq} = 1$

$C_{w\gamma} := \text{if}\left(d_w > 1.5 \cdot B', 1, 0.5\right)$ $\qquad C_{w\gamma} = 1$

Depth Correction Factor per **Hanson (1970):**

$$d_q := \text{if}\left(\frac{D_f}{B'} \leq 1, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \frac{D_f}{B'}, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \text{atan}\left(\frac{D_f}{B'}\right)\right)$$

$d_q = 1.1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 30.509$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 18.615$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 22.222$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 19136.2\ \frac{lbf}{ft^2}$

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

$\phi_b := 0.65$ $\qquad$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 12.4\ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45\ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\qquad N_q = 18.4$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\qquad N_c = 30.14$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\qquad N_\gamma = 22.4$

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

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.012$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.012$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.992$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 30.509$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 18.615$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 22.222$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 19136.2 \frac{lbf}{ft^2}$

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

$\phi_b := 0.65$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 12.4\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 12.4\ ksf$

Undrained Conditions: $q_{Ru} = 12.4\ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 12.4\ ksf$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

Compute the resultant location (distance from Point 'O'):

$\Sigma M_R := MV_{Ib}$ $\quad \Sigma M_R = 0 \ \frac{lbf \cdot ft}{ft}$ $\quad$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 94912.9 \ \frac{lbf \cdot ft}{ft}$ $\quad$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 46756.2 \ \frac{lbf}{ft}$ $\quad$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 2 \ ft$ $\quad$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 9.2 \ ft$ $\quad$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\quad \sigma_v = 5060.1 \ \frac{lbf}{ft^2}$ $\quad$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ $\quad$ Is the CDR > or = to 1.0? $\quad CDR_{Bearing} = 2.46$

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

$e_{max} := \frac{L}{3}$ $\quad e_{max} = 4.4 \ ft$ $\quad$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\quad \Sigma M_R = 0 \ \frac{lbf \cdot ft}{ft}$ $\quad$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\quad \Sigma M_O = 94912.9 \ \frac{lbf \cdot ft}{ft}$ $\quad$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 30324 \ \frac{lbf}{ft}$ $\quad$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 3.1 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ $\quad$ Is the CDR > or = to 1.0? $\quad CDR_{Eccentricity} = 1.42$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 13600.8\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 30324\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\quad R_{\tau d} = 17507.6\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 17.508\ \frac{kip}{ft}$

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]**:

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

$\phi R_n := \phi_\tau \cdot R_\tau$ $\quad R_R := \phi R_n$

$R_R = 17.5\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

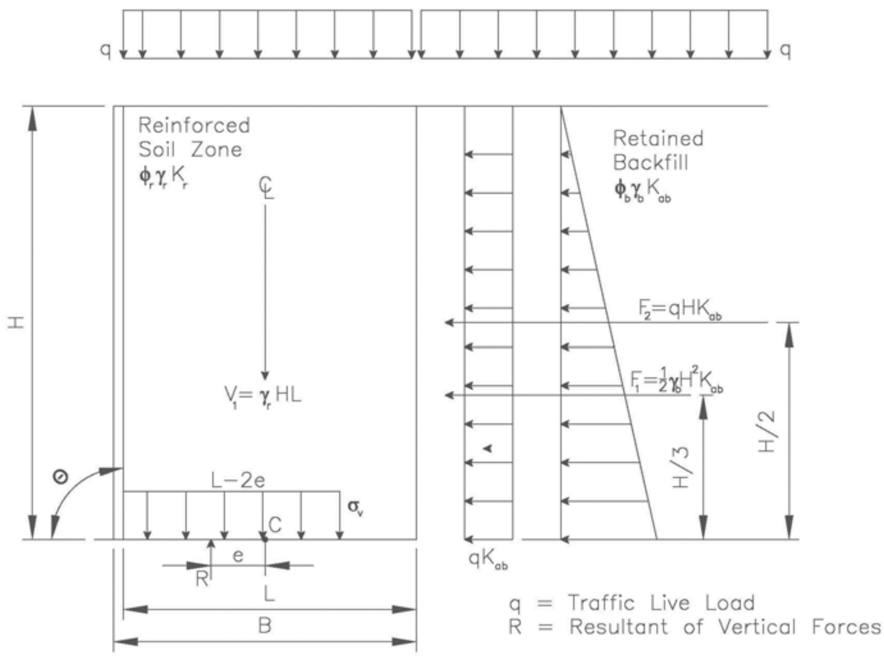
$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.29$

Objective: **To evaluate the external stability of MSE wall design with vertical wall face and horizontal backfill.**

Method: **In accordance with ODOT Bridge Design Manual, 2013 [Sect. 307] LRFD Bridge Design Specifications, 8th Ed., 2018, [Sect. 11.10.5].**

Assumptions:

- **Horizontal backfill behind MSE wall on granular (drained) soils.**
- **For battered or vertical walls with a back face of wall angle of θ to horizontal.**
- **Not for sheet type reinforcement. If so, use different assessment for Sliding parameter ϕ_μ.**
- **MSE wall not acting as abutment, if so must meet minimum embedment depth of H/10 if no slope in front of wall**
- **Load combinations and wall configuration are as shown below:**



Givens:

Wall Geometry:

$H_e := 15.8 \cdot ft - 3 \cdot ft$	Exposed wall height
$\theta := 90 \cdot deg$	Angle of back face of wall to horizontal: 90 deg for vertical or near vertical walls (per Berg et al., 2009; near vertical = 80 deg < θ < 100 deg)

Reinforced Backfill Soil Design Parameters:

$\phi'_r := 34 \cdot deg$	Effective angle of internal friction (Per BDM [Table 307-1])
$\gamma_r := 120 \cdot \frac{lbf}{ft^3}$	Unit weight (Per BDM [Table 307-1])
$c'_r := 0 \cdot \frac{lbf}{ft^2}$	Effective Cohesion

Retained Backfill Soil Design Parameters:

$\phi'_b := 30 \cdot deg$	Effective angle of internal friction (Per BDM [Table 307-1])
$\gamma_b := 120 \cdot \frac{lbf}{ft^3}$	Unit weight (Per BDM [Table 307-1])
$c'_b := 0 \cdot \frac{lbf}{ft^2}$	Effective Cohesion

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 30 \cdot deg$ Effective angle of internal friction

$\gamma_f := 115 \cdot \frac{lbf}{ft^3}$ Unit weight

$c'_f := 0 \cdot \frac{lbf}{ft^2}$ Cohesion

Undrained Conditions (Total Stress):

$\phi_f := 30 \cdot deg$ Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 115 \ \frac{lbf}{ft^3}$ Unit weight

$c_f := 0 \cdot \frac{lbf}{ft^2}$ 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)

Depth of Embedment Check:

$d_{frost} := 3.0 \ ft$ $\quad d_{user} := 0 \ ft$ Local Frost Depth

$Slope_{fw} := 0 \ deg$

Inclination of ground slope in front of wall :

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

$d_{est} := \max\left(d_{frost}, 3 \ ft, d_{user}\right)$ $\quad d_{est} = 3 \ ft$

$H_{est} := d_{est} + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 15.8 \ ft$

$$d_{eSlope} := \text{if}\left(Slope_{fw} < 1 \ deg, \frac{H_{est}}{20}, \text{if}\left(Slope_{fw} < 26.565 \ deg, \frac{H_{est}}{10}, \text{if}\left(Slope_{fw} < 33.69 \ deg, \frac{H_{est}}{7}, \frac{H_{est}}{5}\right)\right)\right)$$

$d_{eSlope} = 0.8 \ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $\quad d_e = 3 \ ft$ Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 15.8 \ ft$ Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 0 \cdot ft$ User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\quad L = 11.1 \ ft$ Length of Reinforcement

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Live Load Surcharge Parameters:

$SUR := 250 \cdot \frac{lbf}{ft^2}$

Live load surcharge (per **LRFD BDS [3.11.6.4]** & **BDM [307.1.1]**)
Note: If vehicular loading is within 1 ft of the backface of the wall and with a design height, H, less than 20 ft, see **LRFD BDS Section 3.11.6.4 and Table 3.11.6.4-2** for adjusted surcharge load calculation.
Note: When traffic vehicular live loads are not present within 0.5*H from the back of the reinforced zone let SUR equal 100 psf to account for construction loads.

Calculations:

Active Earth Pressure:

$\beta := 0 \qquad \delta := \beta$

Inclination of ground slope behind face of wall and angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.3333$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 4992.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 1316.7 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 20969.8 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 2765 \ \frac{lbf}{ft}$ — Live Load Surcharge - (LS)

Moment Arm:		Moment:	
$d_{v1} := 0 \cdot ft$	$d_{v1} = 0 \ ft$	$MV_1 := V_1 \cdot d_{v1}$	$MV_1 = 0 \ \frac{lbf \cdot ft}{ft}$
$d_{v2} := 0 \ ft$	$d_{v2} = 0 \ ft$	$MV_2 := V_2 \cdot d_{v2}$	$MV_2 = 0 \ \frac{lbf \cdot ft}{ft}$

Horizontal Loads:

$H_1 := F_T = 4992.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1316.7 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 5.3 \ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 26295.4 \ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 7.9 \ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 10401.7 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 20969.8 \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 2765 \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 4992.8 \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 1316.7 \frac{lbf}{ft}$

Unfactored Moments by Load Type

$M_{EV} := MV_1$ $\quad M_{EV} = 0 \frac{lbf \cdot ft}{ft}$

$M_{LS} := MV_2$ $\quad M_{LS} = 0 \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_1$ $\quad M_{EH2} = 26295.4 \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 10401.7 \frac{lbf \cdot ft}{ft}$

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) $\quad Ia_{EV} := 1$ $\quad Ia_{EH} := 1.5$ $\quad Ia_{LS} := 1.75$

Strength Limit State Ib: (Bearing Capacity) $\quad Ib_{EV} := 1.35$ $\quad Ib_{EH} := 1.5$ $\quad Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 20969.8 \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 33147.9 \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 9793.4 \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 9793.4 \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot (Ia_{EV} \cdot M_{EV})$ $\quad MV_{Ia} = 0 \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot ((Ib_{EV} \cdot M_{EV}) + (Ib_{LS} \cdot M_{LS}))$ $\quad MV_{Ib} = 0 \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 57646 \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 57646 \frac{lbf \cdot ft}{ft}$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Compute Bearing Resistance:

Compute the Effective Bearing Length (Strength Ib):

$\Sigma M_R := MV_{Ib}$ $\quad \Sigma M_R = 0\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 57646\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 33147.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 1.7\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 7.6\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 460 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $\quad H' = 9793.4\ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $\quad V' = 33147.9\ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

$D_f := d_e$ $\quad D_f = 3\ ft$ Footing embedment

$d_w := 16.8 \cdot ft$ Depth of Groundwater below Bearing Grade

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

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right)$ $\quad N_q = 18.4$

$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right)$ $\quad N_c = 30.14$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f)$ $\quad N_\gamma = 22.4$

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $\quad s_c = 1.01$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $\quad s_q = 1.01$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $\quad s_\gamma = 0.993$

Load inclination factors using **LRFD [10.6.3.1.2a-5] thru [10.6.3.1.2a-9]:**

$i_q := 1$ $\quad i_q = 1$

$i_\gamma := 1$ $\quad i_\gamma = 1$

$i_c := 1$ $\quad i_c = 1$

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

$C_{wq} := \text{if}\left(d_w \geq 0, 1, 0.5\right)$ $\quad C_{wq} = 1$

$C_{w\gamma} := \text{if}\left(d_w > 1.5 \cdot B', 1, 0.5\right)$ $\quad C_{w\gamma} = 1$

Depth Correction Factor per **Hanson (1970):**

$$d_q := \text{if}\left(\frac{D_f}{B'} \leq 1, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \frac{D_f}{B'}, 1 + 2 \cdot \tan\left(\phi'_f\right) \cdot \left(1 - \sin\left(\phi'_f\right)\right)^2 \cdot \text{atan}\left(\frac{D_f}{B'}\right)\right)$$

$d_q = 1.1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 30.443$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 18.576$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 22.255$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 17153.5 \ \frac{lbf}{ft^2}$

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

$\phi_b := 0.65$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 11.1 \ ksf$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45 \ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\quad N_q = 18.4$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\quad N_c = 30.14$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\quad N_\gamma = 22.4$

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

$$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.01$$

$$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right) \qquad s_q = 1.01$$

$$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.993$$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 30.443$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 18.576$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 22.255$

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

$$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 17153.5\ \frac{lbf}{ft^2}$$

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

$\phi_b := 0.65$ $\qquad$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $\qquad q_{Ru} = 11.1\ ksf$ $\qquad$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 11.1\ ksf$

Undrained Conditions: $q_{Ru} = 11.1\ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 11.1\ ksf$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

Compute the resultant location (distance from Point 'O'):

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 0\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 57646\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 33147.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 1.7\ ft$ Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $B' = 7.6\ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 4372\ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 2.55$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 3.7\ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 0\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 57646\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 20969.8\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.7\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.34$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad$ $F_\tau = 9793.4\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad$ $\Sigma V = 20969.8\ \frac{lbf}{ft}$ $\quad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad$ $R_{\tau d} = 12106.9\ \frac{lbf}{ft}$ $\quad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 12.107\ \frac{kip}{ft}$

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]**:

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

$\phi R_n := \phi_\tau \cdot R_\tau$ $\quad$ $R_R := \phi R_n$

$R_R = 12.1\ \frac{kip}{ft}$

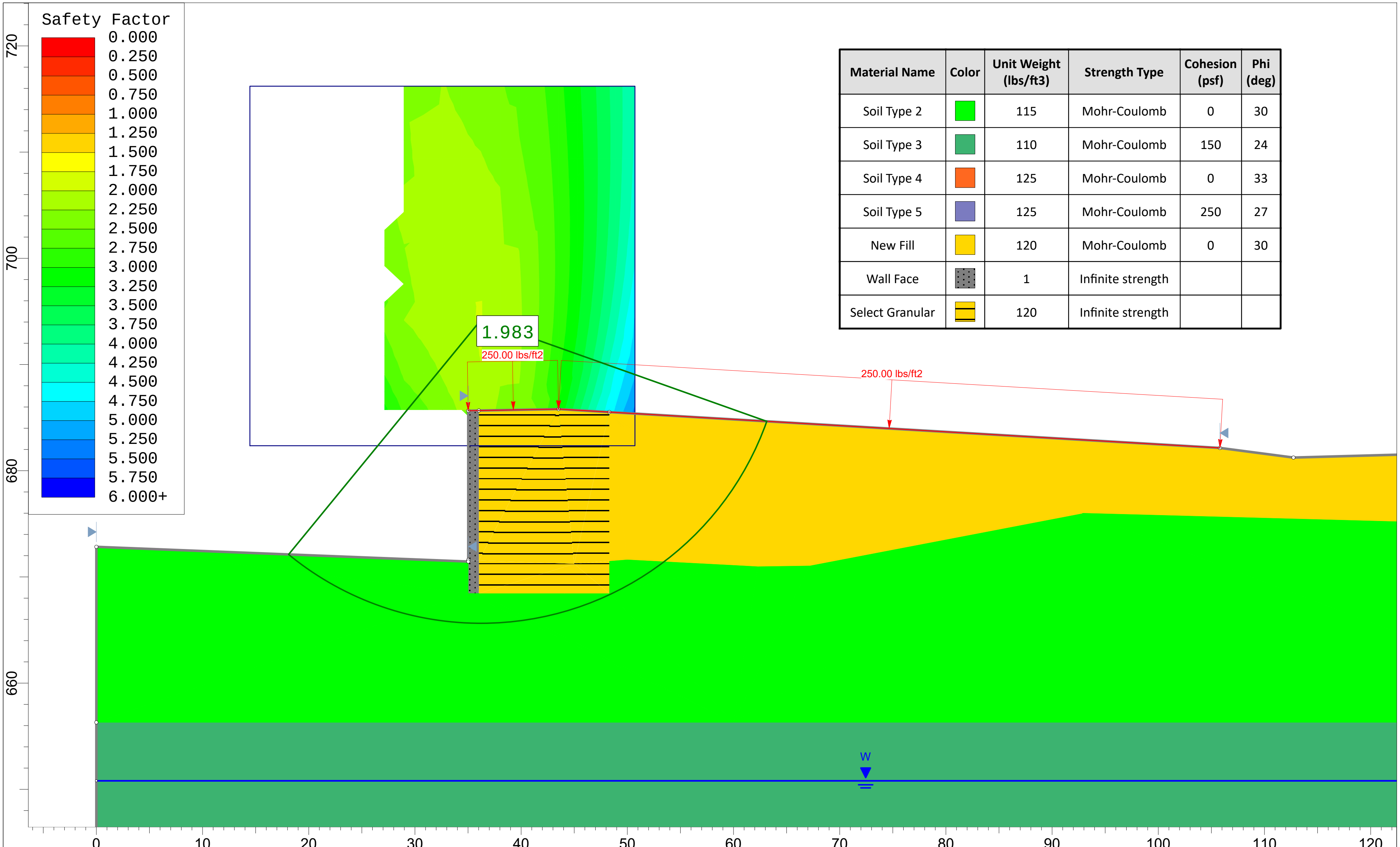
Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\quad$ Is the CDR > or = to 1.0? $\quad$ $CDR_{Sliding} = 1.24$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

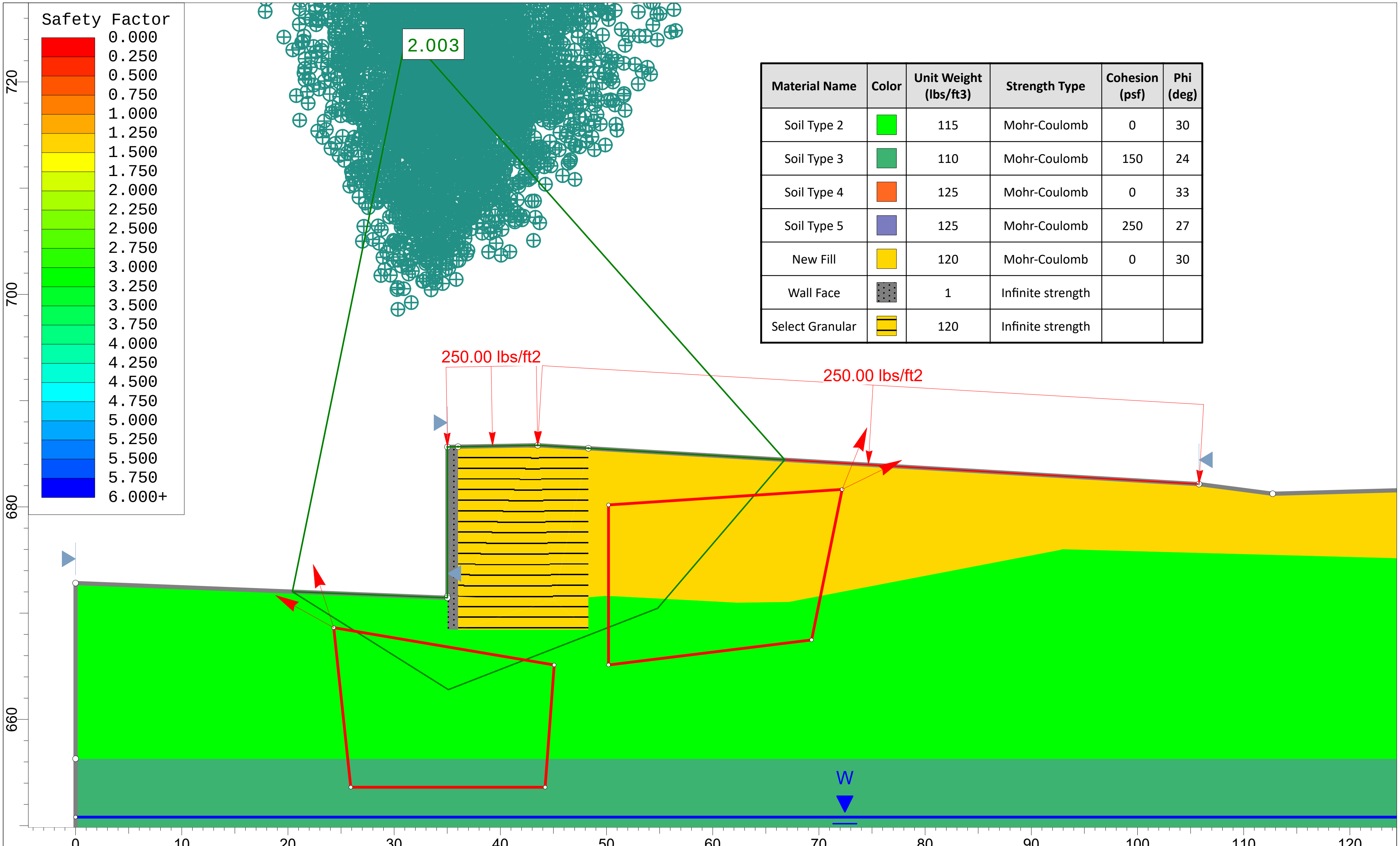
APPENDIX E

GLOBAL STABILITY ANALYSIS



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Soil Type 2		115	Mohr-Coulomb	0	30
Soil Type 3		110	Mohr-Coulomb	150	24
Soil Type 4		125	Mohr-Coulomb	0	33
Soil Type 5		125	Mohr-Coulomb	250	27
New Fill		120	Mohr-Coulomb	0	30
Wall Face		1	Infinite strength		
Select Granular		120	Infinite strength		

rocscience	*Project* CUY-90-16.28 (CCG3A)		
	Analysis Description Retaining Wall T - Effective - Circular		
	Drawn By BPA	*Scale* 1:150	*Company* NEAS Inc.
SLIDEINTERPRET 7.038	*Date* 9/29/21		*File Name* 3+50_WallT.slim

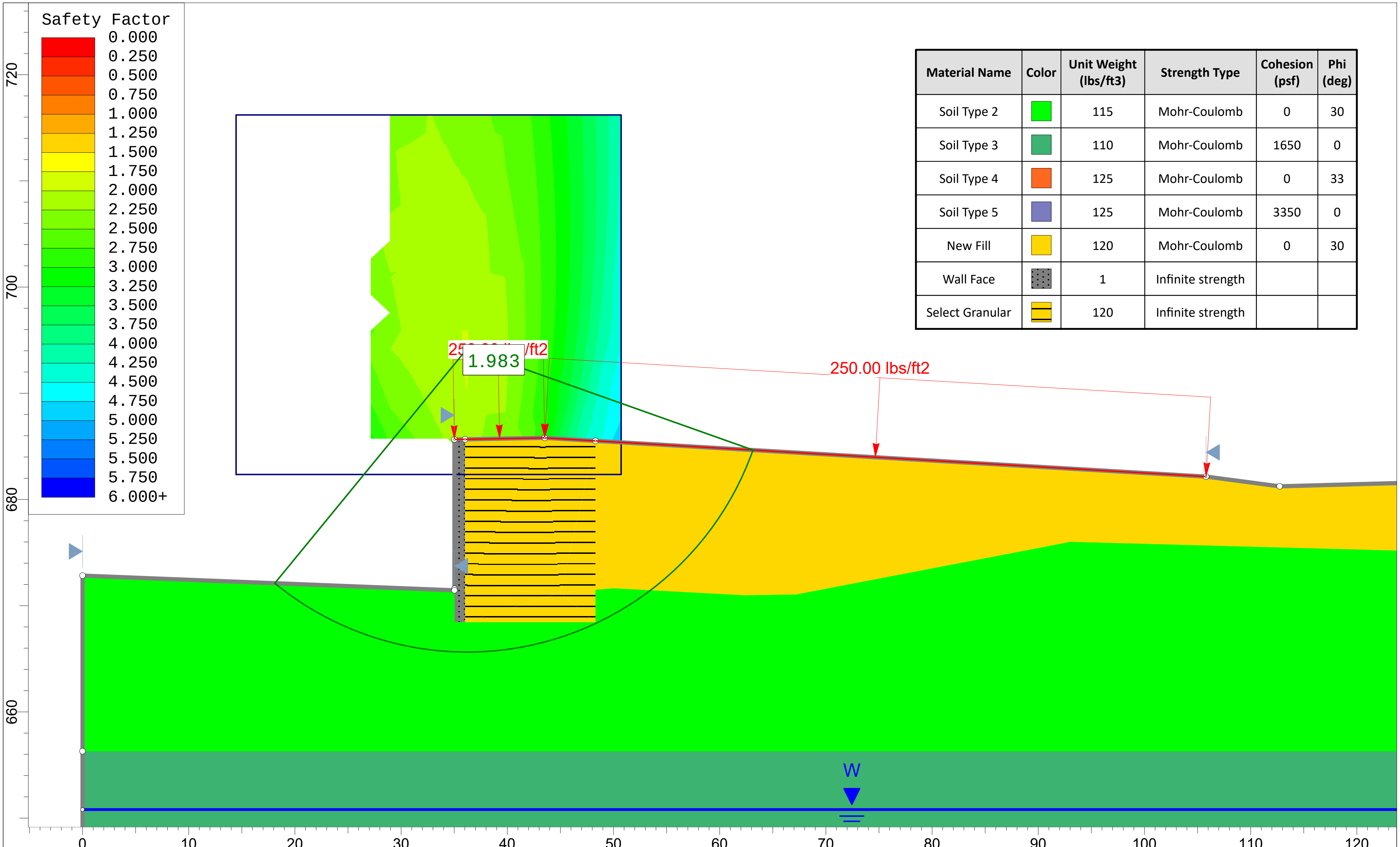


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Soil Type 2		115	Mohr-Coulomb	0	30
Soil Type 3		110	Mohr-Coulomb	150	24
Soil Type 4		125	Mohr-Coulomb	0	33
Soil Type 5		125	Mohr-Coulomb	250	27
New Fill		120	Mohr-Coulomb	0	30
Wall Face		1	Infinite strength		
Select Granular		120	Infinite strength		

rocscience

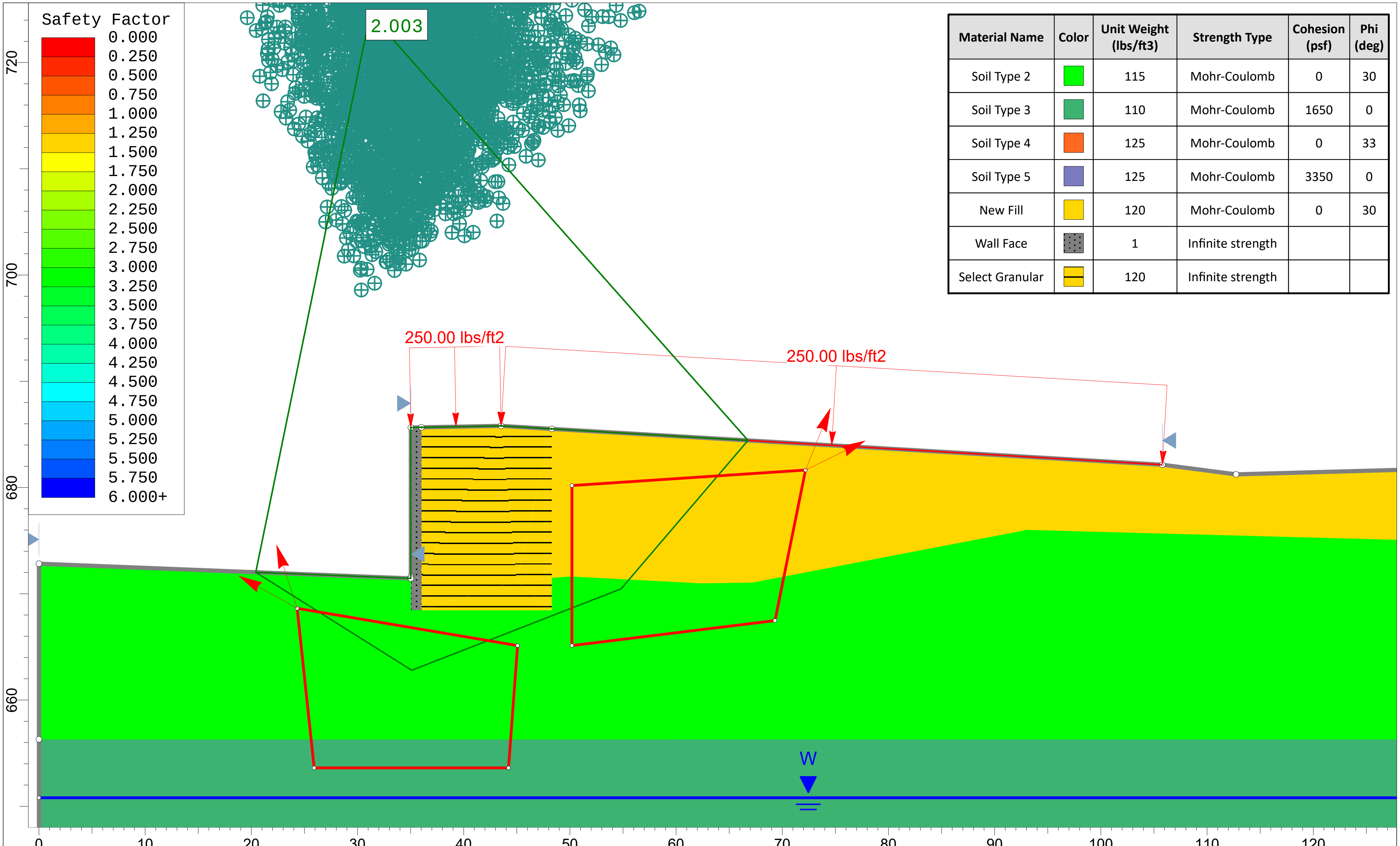
SLIDEINTERPRET 7.038

Project	CUY-90-16.28 (CCG3A)		
Analysis Description	Retaining Wall T - Effective - Block		
Drawn By BPA	*Scale* 1:150	*Company*	NEAS Inc.
Date	9/29/21	*File Name*	3+50_WallT_Eff_Block.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Soil Type 2		115	Mohr-Coulomb	0	30
Soil Type 3		110	Mohr-Coulomb	1650	0
Soil Type 4		125	Mohr-Coulomb	0	33
Soil Type 5		125	Mohr-Coulomb	3350	0
New Fill		120	Mohr-Coulomb	0	30
Wall Face		1	Infinite strength		
Select Granular		120	Infinite strength		

rocscience	*Project*	CUY-90-16.28 (CCG3A)	
	Analysis Description	Retaining Wall T - Total - Circular	
	Drawn By BPA	*Scale* 1:150	*Company* NEAS Inc.
SLIDEINTERPRET 7.038	*Date* 9/29/21		*File Name* 3+50_WallT_Tot_Circ.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Soil Type 2		115	Mohr-Coulomb	0	30
Soil Type 3		110	Mohr-Coulomb	1650	0
Soil Type 4		125	Mohr-Coulomb	0	33
Soil Type 5		125	Mohr-Coulomb	3350	0
New Fill		120	Mohr-Coulomb	0	30
Wall Face		1	Infinite strength		
Select Granular		120	Infinite strength		

rocscience

SLIDEINTERPRET 7.038

Project	CUY-90-16.28 (CCG3A)
Analysis Description	Retaining Wall T - Total - Block
Drawn By	BPA
Scale	1:150
Company	NEAS Inc.
Date	9/29/21
File Name	3+50_WallT_Tot_Block.slim

APPENDIX F

SETTLEMENT ANALYSIS

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

CUY-90-16.28 (CCG3A)

Report created by FoSSA(2.0): Copyright (c) 2003-2012, ADAMA Engineering, Inc.

PROJECT IDENTIFICATION

Title:	CUY-90-16.28 (CCG3A)
Project Number:	PID 92382 -
Client:	Michael Baker International
Designer:	KCA
Station Number:	

Description:

Company's information:

Name:	NEAS Inc.
Street:	2800 Coroporate Exchange Drive, Suite 240 Columbus, OH 43231
Telephone #:	614-714-0299
Fax #:	614-714-0251
E-Mail:	brendan.andrews@neasinc.com

Original file path and name: P:\21-0011 ..... alls\WallT\analysis\Settlement\RWT_FOSSA093021.2ST
Original date and time of creating this file: Thu Sep 30 08:19:59 2021

GEOMETRY: Analysis of a 2D geometry

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

INPUT DATA – FOUNDATION LAYERS – 8 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	120.00	0.30	Soil Type 1 - Granular
2	115.00	0.25	Soil Type 2 - Granular
3	110.00	0.40	Soil Type 3 - Cohesive
4	125.00	0.25	Soil Type 4 - Granular
5	125.00	0.40	Soil Type 5a - Cohesive
6	125.00	0.45	Soil Type 5b - Cohesive
7	130.00	0.50	Soil Type 5c - Cohesive
8	150.00	0.20	Termination Layer

INPUT DATA – EMBANKMENT LAYERS -- 1 layers

	Wet Unit Weight, γ [lb/ft³]	Description of Soil
1	120.00	Proposed Embankment

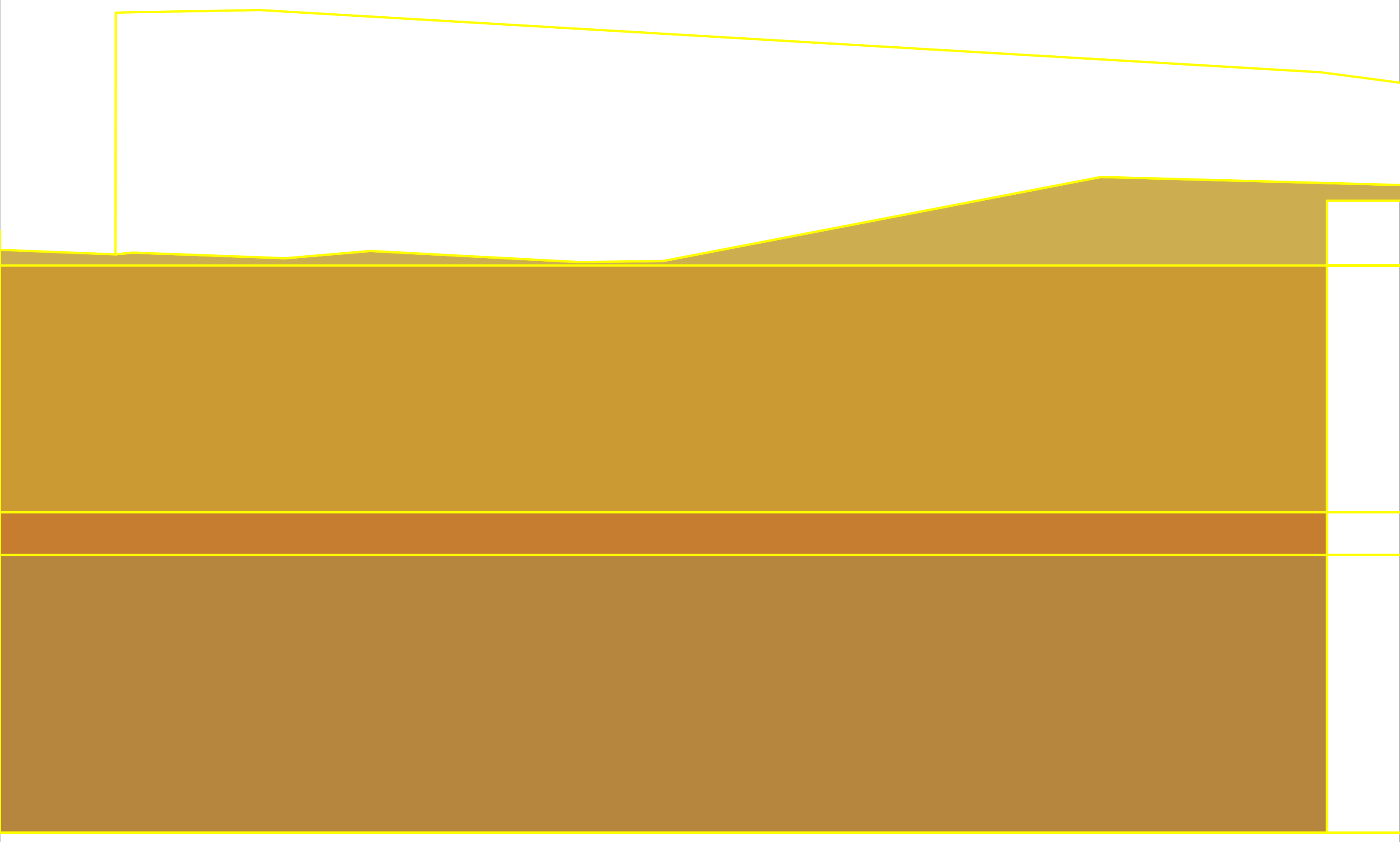
INPUT DATA OF WATER

Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]
1	0.00	650.80
2	150.00	650.80

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410

www.GeoPrograms.com

DRAWING OF SPECIFIED GEOMETRY



Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

INPUT DATA FOR CONSOLIDATION –– $\alpha = 1/2$

Layer #	Underging Consolidation [Yes/No]	OCR = Pc / Po	Cc	Cr	e0	Cv [ft ²/day]	Drains at :
1	No	N/A	N/A	N/A	N/A	N/A	N/A
2	No	N/A	N/A	N/A	N/A	N/A	N/A
3	Yes	2.50	0.110	0.022	0.838	0.1400	Top & Bot.
4	No	N/A	N/A	N/A	N/A	N/A	N/A
5	Yes	1.30	0.060	0.008	0.573	0.2900	Top
6	Yes	1.20	0.100	0.020	0.784	0.2300	Top
7	Yes	1.10	0.120	0.024	0.534	0.2100	Top
8	No	N/A	N/A	N/A	N/A	N/A	N/A

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

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	0.00	0.00	1	1149000	0.3000	-0.0000	672.83	672.82	0.01
			2	243000	0.2500	-0.0018			
			3	893000	0.4000	-0.0003			
			4	878000	0.2500	-0.0003			
			5	2000000	0.4000	0.0007			
			6	2000000	0.4500	0.0016			
			7	2000000	0.5000	0.0097			
			8	1000000000(	0.2000	0.0000			
2	5.00	0.00	1	1149000	0.3000	-0.0000	672.63	672.62	0.01
			2	243000	0.2500	-0.0021			
			3	893000	0.4000	-0.0004			
			4	878000	0.2500	0.0001			
			5	2000000	0.4000	0.0013			
			6	2000000	0.4500	0.0020			
			7	2000000	0.5000	0.0106			
			8	1000000000(	0.2000	0.0000			
3	10.00	0.00	1	1149000	0.3000	-0.0000	672.44	672.42	0.01
			2	243000	0.2500	-0.0024			
			3	893000	0.4000	-0.0004			
			4	878000	0.2500	0.0008			
			5	2000000	0.4000	0.0021			
			6	2000000	0.4500	0.0025			
			7	2000000	0.5000	0.0114			
			8	1000000000(	0.2000	0.0000			
4	15.00	0.00	1	1149000	0.3000	-0.0000	672.24	672.22	0.02
			2	243000	0.2500	-0.0027			
			3	893000	0.4000	-0.0004			
			4	878000	0.2500	0.0020			
			5	2000000	0.4000	0.0030			
			6	2000000	0.4500	0.0029			
			7	2000000	0.5000	0.0123			
			8	1000000000(	0.2000	0.0000			
5	20.00	0.00	1	1149000	0.3000	-0.0000	672.04	672.02	0.02
			2	243000	0.2500	-0.0027			
			3	893000	0.4000	-0.0003			
			4	878000	0.2500	0.0037			
			5	2000000	0.4000	0.0040			
			6	2000000	0.4500	0.0034			
			7	2000000	0.5000	0.0131			
			8	1000000000(	0.2000	0.0000			
6	25.00	0.00	1	1149000	0.3000	-0.0000	671.84	671.82	0.03
			2	243000	0.2500	-0.0013			
			3	893000	0.4000	-0.0001			
			4	878000	0.2500	0.0064			
			5	2000000	0.4000	0.0052			
			6	2000000	0.4500	0.0039			
			7	2000000	0.5000	0.0140			
			8	1000000000(	0.2000	0.0000			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

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.]
7	30.00	0.00	1	1149000	0.3000	-0.0000	671.65	671.61	0.04
			2	243000	0.2500	0.0049			
			3	893000	0.4000	0.0004			
			4	878000	0.2500	0.0099			
			5	2000000	0.4000	0.0065			
			6	2000000	0.4500	0.0044			
			7	2000000	0.5000	0.0148			
			8	1000000000(	0.2000	0.0000			
8	35.00	0.00	1	1149000	0.3000	0.0002	671.45	671.37	0.08
			2	243000	0.2500	0.0340			
			3	893000	0.4000	0.0012			
			4	878000	0.2500	0.0142			
			5	2000000	0.4000	0.0079			
			6	2000000	0.4500	0.0049			
			7	2000000	0.5000	0.0155			
			8	1000000000(	0.2000	0.0000			
9	40.00	0.00	1	1149000	0.3000	0.0006	671.41	671.30	0.12
			2	243000	0.2500	0.0657			
			3	893000	0.4000	0.0020			
			4	878000	0.2500	0.0184			
			5	2000000	0.4000	0.0092			
			6	2000000	0.4500	0.0054			
			7	2000000	0.5000	0.0162			
			8	1000000000(	0.2000	0.0000			
10	45.00	0.00	1	1149000	0.3000	0.0006	671.23	671.10	0.13
			2	243000	0.2500	0.0728			
			3	893000	0.4000	0.0025			
			4	878000	0.2500	0.0219			
			5	2000000	0.4000	0.0103			
			6	2000000	0.4500	0.0058			
			7	2000000	0.5000	0.0168			
			8	1000000000(	0.2000	0.0000			
11	50.00	0.00	1	1149000	0.3000	0.0008	671.65	671.51	0.14
			2	243000	0.2500	0.0728			
			3	893000	0.4000	0.0027			
			4	878000	0.2500	0.0243			
			5	2000000	0.4000	0.0113			
			6	2000000	0.4500	0.0062			
			7	2000000	0.5000	0.0173			
			8	1000000000(	0.2000	0.0000			
12	55.00	0.00	1	1149000	0.3000	0.0005	671.38	671.25	0.14
			2	243000	0.2500	0.0723			
			3	893000	0.4000	0.0028			
			4	878000	0.2500	0.0256			
			5	2000000	0.4000	0.0120			
			6	2000000	0.4500	0.0065			
			7	2000000	0.5000	0.0178			
			8	1000000000(	0.2000	0.0000			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

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.]
13	60.00	0.00	1	1149000	0.3000	0.0000	671.12	670.98	0.14
			2	243000	0.2500	0.0715			
			3	893000	0.4000	0.0027			
			4	878000	0.2500	0.0261			
			5	2000000	0.4000	0.0125			
			6	2000000	0.4500	0.0067			
			7	2000000	0.5000	0.0181			
			8	1000000000(	0.2000	0.0000			
14	65.00	0.00	1	1149000	0.3000	0.0000	671.04	670.90	0.14
			2	243000	0.2500	0.0695			
			3	893000	0.4000	0.0026			
			4	878000	0.2500	0.0257			
			5	2000000	0.4000	0.0126			
			6	2000000	0.4500	0.0068			
			7	2000000	0.5000	0.0183			
			8	1000000000(	0.2000	0.0000			
15	70.00	0.00	1	1149000	0.3000	0.0007	671.61	671.48	0.13
			2	243000	0.2500	0.0649			
			3	893000	0.4000	0.0024			
			4	878000	0.2500	0.0248			
			5	2000000	0.4000	0.0126			
			6	2000000	0.4500	0.0069			
			7	2000000	0.5000	0.0184			
			8	1000000000(	0.2000	0.0000			
16	75.00	0.00	1	1149000	0.3000	0.0013	672.57	672.44	0.12
			2	243000	0.2500	0.0585			
			3	893000	0.4000	0.0022			
			4	878000	0.2500	0.0234			
			5	2000000	0.4000	0.0123			
			6	2000000	0.4500	0.0068			
			7	2000000	0.5000	0.0184			
			8	1000000000(	0.2000	0.0000			
17	80.00	0.00	1	1149000	0.3000	0.0018	673.53	673.41	0.11
			2	243000	0.2500	0.0518			
			3	893000	0.4000	0.0019			
			4	878000	0.2500	0.0217			
			5	2000000	0.4000	0.0118			
			6	2000000	0.4500	0.0067			
			7	2000000	0.5000	0.0183			
			8	1000000000(	0.2000	0.0000			
18	85.00	0.00	1	1149000	0.3000	0.0021	674.48	674.38	0.10
			2	243000	0.2500	0.0451			
			3	893000	0.4000	0.0016			
			4	878000	0.2500	0.0199			
			5	2000000	0.4000	0.0112			
			6	2000000	0.4500	0.0065			
			7	2000000	0.5000	0.0181			
			8	1000000000(	0.2000	0.0000			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

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.]
19	90.00	0.00	1	1149000	0.3000	0.0022	675.44	675.35	0.10
			2	243000	0.2500	0.0390			
			3	893000	0.4000	0.0014			
			4	878000	0.2500	0.0181			
			5	2000000	0.4000	0.0105			
			6	2000000	0.4500	0.0063			
			7	2000000	0.5000	0.0178			
			8	1000000000(	0.2000	0.0000			
20	95.00	0.00	1	1149000	0.3000	0.0021	675.94	675.86	0.09
			2	243000	0.2500	0.0349			
			3	893000	0.4000	0.0012			
			4	878000	0.2500	0.0165			
			5	2000000	0.4000	0.0098			
			6	2000000	0.4500	0.0060			
			7	2000000	0.5000	0.0174			
			8	1000000000(	0.2000	0.0000			
21	100.00	0.00	1	1149000	0.3000	0.0021	675.81	675.73	0.08
			2	243000	0.2500	0.0334			
			3	893000	0.4000	0.0011			
			4	878000	0.2500	0.0151			
			5	2000000	0.4000	0.0089			
			6	2000000	0.4500	0.0056			
			7	2000000	0.5000	0.0169			
			8	1000000000(	0.2000	0.0000			

*Note: Final Z is calculated assuming only 'Immediate Settlement' exists.

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	0.00	0.00	672.83	0.03	672.80
2	5.00	0.00	672.63	0.03	672.60
3	10.00	0.00	672.44	0.04	672.40
4	15.00	0.00	672.24	0.04	672.20
5	20.00	0.00	672.04	0.04	672.00
6	25.00	0.00	671.84	0.05	671.80
7	30.00	0.00	671.65	0.05	671.60
8	35.00	0.00	671.45	0.05	671.40
9	40.00	0.00	671.41	0.06	671.36
10	45.00	0.00	671.23	0.06	671.17
11	50.00	0.00	671.65	0.06	671.59
12	55.00	0.00	671.38	0.07	671.32
13	60.00	0.00	671.12	0.07	671.05
14	65.00	0.00	671.04	0.07	670.97
15	70.00	0.00	671.61	0.07	671.54
16	75.00	0.00	672.57	0.06	672.50
17	80.00	0.00	673.53	0.06	673.46
18	85.00	0.00	674.48	0.06	674.42
19	90.00	0.00	675.44	0.06	675.39
20	95.00	0.00	675.94	0.06	675.89
21	100.00	0.00	675.81	0.05	675.76

*Note: Final Z is calculated assuming only 'Ultimate Settlement' exists.

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0 FoSSA Version 2.0

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	1	0.00	672.83	Soil Type 1 - Granular
	2	35.02	671.45	
	3	36.02	671.56	
	4	45.00	671.23	
	5	48.30	671.51	
	6	50.00	671.65	
	7	60.00	671.12	
	8	62.30	671.00	
	9	67.20	671.07	
	10	92.90	676.00	
	11	128.25	675.05	
	12	150.00	674.60	
2	1	0.00	670.80	Soil Type 2 - Granular
	2	150.00	670.80	
3	1	0.00	656.30	Soil Type 3 - Cohesive
	2	150.00	656.30	
4	1	0.00	653.80	Soil Type 4 - Granular
	2	150.00	653.80	
5	1	0.00	633.30	Soil Type 5a - Cohesive
	2	150.00	633.30	
6	1	0.00	598.50	Soil Type 5b - Cohesive
	2	150.00	598.50	
7	1	0.00	572.50	Soil Type 5c - Cohesive
	2	450.00	572.50	
8	1	0.00	450.00	Termination Layer
	2	150.00	450.00	

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	X1 = 35.02 [ft]	1	35.02	671.45	Proposed Embankment
	X2 = 128.26 [ft]	2	35.03	685.65	
		3	36.02	685.67	
		4	43.52	685.80	
		5	48.30	685.52	
		6	105.80	682.15	
		7	112.73	681.24	
		8	128.25	681.67	
		9	128.26	675.05	

Copyright © 2003-2012 ADAMA Engineering, Inc. www.GeoPrograms.com License number FoSSA-200410
www.GeoPrograms.com

APPENDIX G

CIP EXTERNAL STABILITY ANALYSIS

Objective: **To evaluate the external stability of CIP wall's with level backfill (no backslope).**
Method: **In accordance with ODOT Bridge Design Manual, 2019 [Sect. 204.6.2.2] LRFD Bridge Design Specifications, 8th Ed., Nov. 2017, [Sect. 11.6.1, Sect. 11.6.2, and Sect. 11.6.3].**

Givens:

Backfill Soil Design Parameters:

$\phi'_f := 30\ deg$ — Effective angle of internal friction

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

$c'_f := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta := 0.67 \cdot \phi'_f$ $\quad \delta = 20.1\ deg$ — Friction angle between backfill and wall taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_{fd} := 36\ deg$ — Effective angle of internal friction

$\gamma_{fd} := 128\ \frac{lbf}{ft^3}$ — Unit weight

$c'_{fd} := 0\ \frac{lbf}{ft^2}$ — Effective Cohesion

$\delta_{fd} := 0.67 \cdot \phi'_{fd}$ $\quad \delta_{fd} = 24.1\ deg$ — Friction angle between foundation soils and footing taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

Undrained Conditions (Total Stress):

$\phi_{fdu} := 36\ deg$ — Angle of internal friction (Same as Drained Conditions if granular soils)

$\gamma_{fd} = 128\ \frac{lbf}{ft^3}$ — Unit weight

$Su_{fdu} := 0\ \frac{lbf}{ft^2}$ — Undrained Shear Strength

$\delta_{fdu} := 0.67 \cdot \phi_{fdu}$ $\quad \delta_{fdu} = 24.1\ deg$ — Friction angle between foundation soils and footing taken as specified in **LRFD BDS C3.11.5.3 (degrees)**

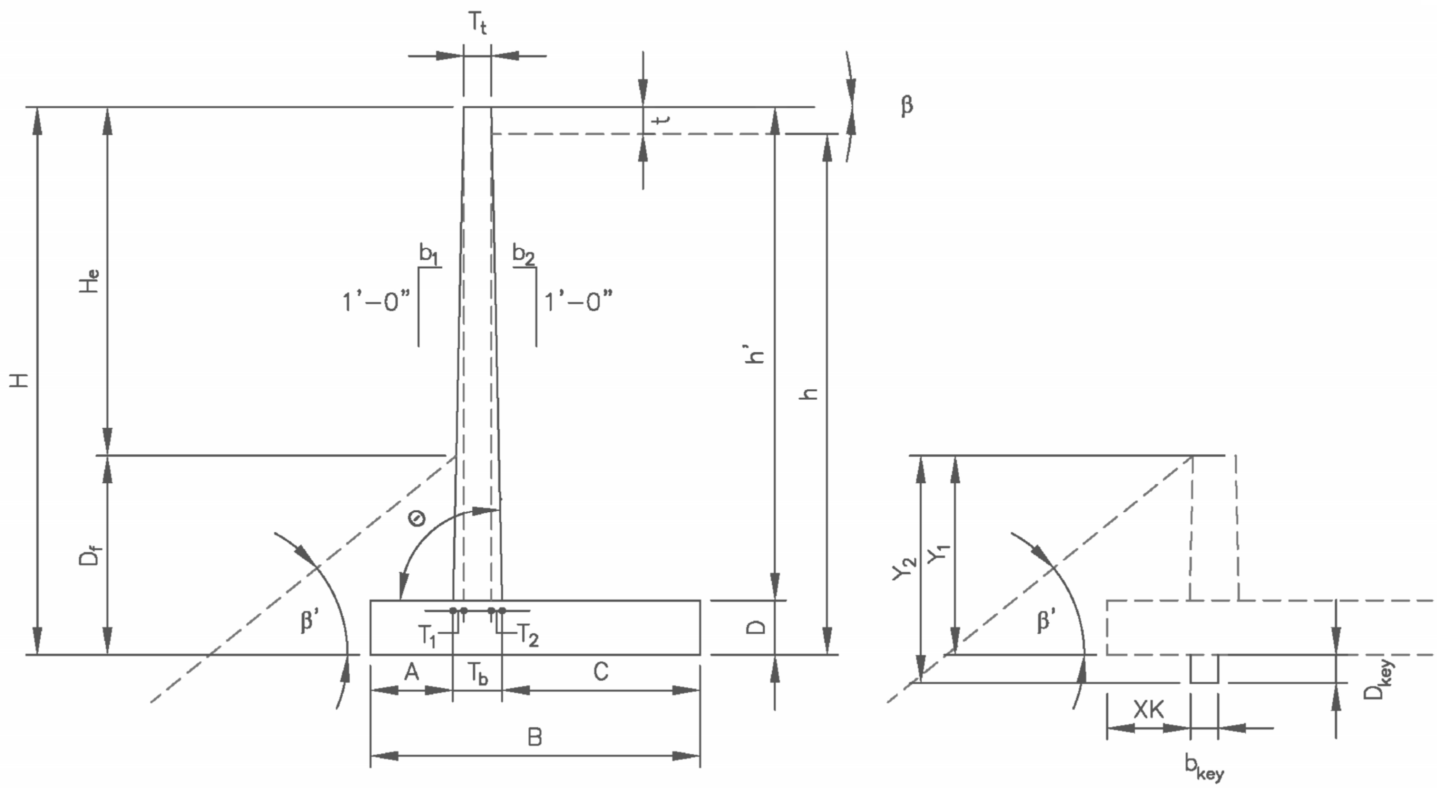
Foundation Surcharge Soil Parameters:

$\gamma_q := 120\ \frac{lbf}{ft^3}$ — Unit weight of Soil above bearing depth (Used in Bearing Resistance of Soil Calculation LRFD 10.6.3.1.2a-1)

Other Parameters:

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

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



Wall Geometry:

$H_e := 5.2\ ft$ — Exposed wall height

$D_f := 4.6\ ft$ — Footing cover at Toe

Note: Where the potential for scour, erosion of undermining exists, spread footings shall be located to bear below the maximum depth of scour or undermining. Spread footings shall be located below the depth of potential frost. **LRFD BDS 10.6.1.2.**

$H := H_e + D_f$ $\quad H = 9.8\ ft$ — Design Wall Height

$T_t := 18\ in$ — Stem thickness at top of wall

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

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

$\beta := 0\ deg$ — Inclination of ground slope behind face of wall. Horizontal backfill behind CIP wall, β = 0 deg

Inclination of ground slope:

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

$\beta' := 0\ deg$ — Inclination of ground slope in front of wall. If it is horizontal backfill in front of CIP wall, β' = 0 deg. A negative angle (-) indicates grades slope up from front of wall. Positive angle (+) indicates grade slope down from wall as shown in above figure.

$t := 1 \cdot ft$ — Pavement thickness

Preliminary Wall Dimensioning:

$B := 9.25\ ft$	$\frac{2}{5} \cdot H = 3.92\ ft$ to	$\frac{3}{5} \cdot H = 5.88\ ft$	Footing base width (2/5H to 3/5H)
$A := 0\ ft$	$\frac{H}{8} = 1.23\ ft$ to	$\frac{H}{5} = 1.96\ ft$	Toe projection (H/8 to H/5)
$D := 2\ ft$	$\frac{H}{8} = 1.23\ ft$ to	$\frac{H}{5} = 1.96\ ft$	Footing thickness (H/8 to H/5)

Shear Key Dimensioning:

$D_{key} := 0\ ft$ — Depth of shear key from bottom of footing
Note: Footings on rock typically require shear key

$b_{key} := 0\ ft$ — Width of shear key

$XK := A$ — Distance from toe to shear key

Other Wall Dimensions:

$h' := H - D$	$h' = 7.8\ ft$	Stem height
$T_1 := b_1 \cdot h'$	$T_1 = 0\ ft$	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
$C := B - A - T_b$	$C = 7.75\ ft$	Heel projection
$\theta := 90\ deg$		Angle of back face of wall to horizontal = *atan(12/b2)*
$b := 12\ in$	$b = 1\ ft$	Concrete strip width (for design)
$y_1 := 3 \cdot ft$	$y_1 = 3\ ft$	Depth to where passive pressure may begin to be utilized in front of wall. (Typically Df)
$y_2 := D_f + D_{key}$	$y_2 = 4.6\ ft$	Bottom of shear key/footing depth i.e. depth to where passive pressure may no longer be utilized.
$h := H - t$	$h = 8.8\ ft$	Height of retained fill at back of heel

Live Load Surcharge Parameters:

$\lambda := 1\ ft$ — Horizontal distance from the back of the wall to point of traffic surcharge load

$$SUR := \text{if}\left(\lambda < \frac{H}{2}, 240\ \frac{lbf}{ft^2}, 100\ \frac{lbf}{ft^2}\right) = 240\ \frac{lbf}{ft^2}$$

Live load surcharge (per LRFD BDS [3.11.6.4])
Note: If vehicular loading is within 1 ft of the backface of the wall and with a design height, H, less than 20 ft, see LRFD BDS Section 3.11.6.4 and Table 3.11.6.4-2 for adjusted surcharge load calculation.
Note: when $\lambda <$ H/2, SUR equal 100 psf to account for construction loads

Calculations:

Earth Pressure Coefficients:

Backfill Active Earth:

$$\Gamma := \left(1 + \sqrt{\frac{\left(\sin\left(\phi'_f + \delta\right) \cdot \sin\left(\phi'_f - \beta\right)\right)}{\left(\sin\left(\theta - \delta\right) \cdot \sin\left(\theta + \beta\right)\right)}}\right)^2 \qquad \Gamma = 2.687$$

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_f\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.297$$

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

Foundation Soil Passive Earth:

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

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

$$\frac{-\beta'}{\phi'_{fd}} = 0 \qquad \frac{-\delta_{fd}}{\phi'_{fd}} = -0.67$$

$k'_p := 6.44$ — Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

Determine Reduction Factor (R) by interpolation:

$R_d := 0.858$ — Reduction Factor

$k_{pd} := R_d \cdot k'_p \qquad k_{pd} = 5.526$ — Passive Earth Pressure Coefficient for Drained Conditions

Undrained Conditions ($\phi_{fdu} > 0$): **Note:** Expand window below to complete calculation

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

$$\frac{-\beta'}{\phi_{fdu}} = 0 \qquad \frac{-\delta_{fdu}}{\phi_{fdu}} = -0.67$$

$k'_p := 6.44$ — Passive Earth Pressure Coefficient from **LRFD Figure 3.11.5.4-2**

Determine Reduction Factor (R) by interpolation:

$R_{du} := 0.858$ — Reduction Factor

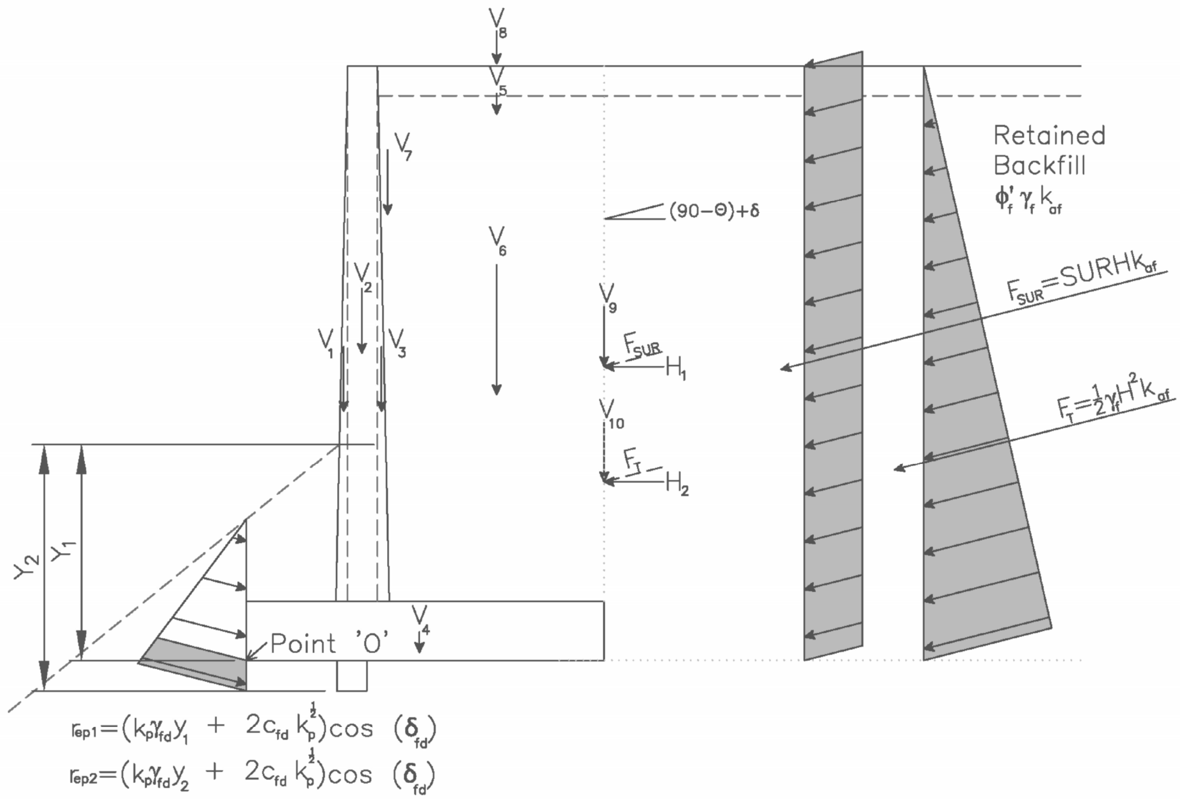
$k_{pu} := R_{du} \cdot k'_p \qquad k_{pu} = 5.526$ — Passive Earth Pressure Coefficient for Resistance Undrained Conditions

Undrained Conditions:

$k_{pu} := \text{if}\left(\phi_{fdu} > 0, k_{pu}, 1\right) \qquad k_{pu} = 5.526$ — Passive Earth Pressure Coefficient for Resistance Undrained Conditions

Created with PTC Mathcad Express. See www.mathcad.com for more information.

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



$F_T := \frac{1}{2} \cdot \gamma_f \cdot H^2 \cdot k_{af}$ | $F_T = 1712.9\ \frac{lbf}{ft}$ | Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ | $F_{SUR} = 699.2\ \frac{lbf}{ft}$ | 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)

$V_2 := T_t \cdot h' \cdot \gamma_c$ | $V_2 = 1755\ \frac{lbf}{ft}$ | 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)

$V_4 := D \cdot B \cdot \gamma_c$ | $V_4 = 2775\ \frac{lbf}{ft}$ | Wall Footing (DC)

$V_5 := t \cdot (T_2 + C) \cdot \gamma_p$ | $V_5 = 1162.5\ \frac{lbf}{ft}$ | Pavement (DC)

$V_6 := C \cdot (h' - t) \cdot \gamma_f$ | $V_6 = 6324\ \frac{lbf}{ft}$ | Soil Backfill - Heel (EV)

$V_7 := \frac{1}{2} \cdot b_2 \cdot (h' - t)^2 \cdot \gamma_f$ | $V_7 = 0\ \frac{lbf}{ft}$ | Soil Backfill - Batter (EV)

$V_8 := SUR \cdot (T_2 + C)$ | $V_8 = 1860\ \frac{lbf}{ft}$ | Live Load Surcharge above Heel- (LS) - Strength Ib

$V_9 := F_{SUR} \cdot \sin(90 \cdot deg - \theta + \delta)$ | $V_9 = 240.3\ \frac{lbf}{ft}$ | Live Load Surcharge Resultant (vertical comp. - LS) - Strength Ia

$V_{10} := F_T \cdot \sin(90 \cdot deg - \theta + \delta)$ | $V_{10} = 588.7\ \frac{lbf}{ft}$ | Active earth force resultant (vertical component - EH)

Moment Arm:

Moments produced from vertical loads about Point 'O'

Moment:

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

$d_{v2} := A + T_1 + \frac{T_t}{2} = 0.8\ ft$ $MV_2 := V_2 \cdot d_{v2} = 1316.3\ lbf$

$d_{v3} := A + T_1 + T_t + \frac{T_2}{3} = 1.5\ ft$ $MV_3 := V_3 \cdot d_{v3} = 0\ lbf$

$d_{v4} := \frac{B}{2} = 4.6\ ft$ $MV_4 := V_4 \cdot d_{v4} = 12834.4\ lbf$

$d_{v5} := B - \frac{T_2 + C}{2} = 5.4\ ft$ $MV_5 := V_5 \cdot d_{v5} = 6248.4\ lbf$

$d_{v6} := B - \frac{C}{2} = 5.4\ ft$ $MV_6 := V_6 \cdot d_{v6} = 33991.5\ lbf$

$d_{v7} := A + T_1 + T_t + \left(\frac{2}{3} \cdot b_2 \cdot (h' - t)\right) = 1.5\ ft$ $MV_7 := V_7 \cdot d_{v7} = 0\ lbf$

$d_{v8} := B - \frac{T_2 + C}{2} = 5.4\ ft$ $MV_8 := V_8 \cdot d_{v8} = 9997.5\ lbf$

$d_{v9} := B = 9.3\ ft$ $MV_9 := V_9 \cdot d_{v9} = 2222.5\ lbf$

$d_{v10} := B = 9.3\ ft$ $MV_{10} := V_{10} \cdot d_{v10} = 5445.2\ lbf$

Horizontal Loads:

$H_1 := F_{SUR} \cdot \cos(90 \cdot deg - \theta + \delta)$ $H_1 = 656.6\ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

$H_2 := F_T \cdot \cos(90 \cdot deg - \theta + \delta)$ $H_2 = 1608.6\ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

Moment Arm: Moment:

$d_{h1} := \frac{H}{2}$ $d_{h1} = 4.9\ ft$ $MH_1 := H_1 \cdot d_{h1}$ $MH_1 = 3217.2\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{3}$ $d_{h2} = 3.3\ ft$ $MH_2 := H_2 \cdot d_{h2}$ $MH_2 = 5254.8\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type:

$V_{DC} := V_1 + V_2 + V_3 + V_4 + V_5$ $V_{DC} = 5692.5\ \frac{lbf}{ft}$ $V_{EV} := V_6 + V_7$ $V_{EV} = 6324\ \frac{lbf}{ft}$

$V_{LS\_Ia} := V_9$ $V_{LS\_Ia} = 240.3\ \frac{lbf}{ft}$ $V_{LS\_Ib} := V_8 + V_9$ $V_{LS\_Ib} = 2100.3\ \frac{lbf}{ft}$

$V_{EH} := V_{10}$ $V_{EH} = 588.7\ \frac{lbf}{ft}$ $H_{LS} := H_1$ $H_{LS} = 656.6\ \frac{lbf}{ft}$

$H_{EH} := H_2$ $H_{EH} = 1608.6\ \frac{lbf}{ft}$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Unfactored Moments by Load Type

$M_{DC} := MV_1 + MV_2 + MV_3 + MV_4 + MV_5$ $\qquad M_{DC} = 20399.1\ \frac{lbf \cdot ft}{ft}$

$M_{EV} := MV_6 + MV_7$ $\qquad M_{EV} = 33991.5\ \frac{lbf \cdot ft}{ft}$

$M_{LSV\_Ia} := MV_9$ $\qquad M_{LSV\_Ia} = 2222.5\ \frac{lbf \cdot ft}{ft}$

$M_{LSV\_Ib} := MV_8 + MV_9$ $\qquad M_{LSV\_Ib} = 12220\ \frac{lbf \cdot ft}{ft}$

$M_{EH1} := MV_{10}$ $\qquad M_{EH1} = 5445.2\ \frac{lbf \cdot ft}{ft}$

$M_{LSH} := MH_1$ $\qquad M_{LSH} = 3217.2\ \frac{lbf \cdot ft}{ft}$

$M_{EH2} := MH_2$ $\qquad M_{EH2} = 5254.8\ \frac{lbf \cdot ft}{ft}$

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) $Ia_{DC} := 0.9$ $\quad Ia_{EV} := 1$ $\quad Ia_{EH} := 1.5$ $\quad Ia_{LS} := 1.75$

Strength Limit State Ib: (Bearing Capacity) $Ib_{DC} := 1.25$ $\quad Ib_{EV} := 1.35$ $\quad Ib_{EH} := 1.5$ $\quad Ib_{LS} := 1.75$

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot V_{DC} \right) + \left(Ia_{EV} \cdot V_{EV} \right) + \left(Ia_{EH} \cdot V_{EH} \right) + \left(Ia_{LS} \cdot V_{LS\_Ia} \right) \right)$ $\qquad V_{Ia} = 12750.7\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot V_{DC} \right) + \left(Ib_{EV} \cdot V_{EV} \right) + \left(Ib_{EH} \cdot V_{EH} \right) + \left(Ib_{LS} \cdot V_{LS\_Ib} \right) \right)$ $\qquad V_{Ib} = 20211.5\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS} \right) + \left(Ia_{EH} \cdot H_{EH} \right) \right)$ $\qquad H_{Ia} = 3561.9\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS} \right) + \left(Ib_{EH} \cdot H_{EH} \right) \right)$ $\qquad H_{Ib} = 3561.9\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

$MV_{Ia} := \eta \cdot \left(\left(Ia_{DC} \cdot M_{DC} \right) + \left(Ia_{EV} \cdot M_{EV} \right) + \left(Ia_{EH} \cdot M_{EH1} \right) + \left(Ia_{LS} \cdot M_{LSV\_Ia} \right) \right)$ $\qquad MV_{Ia} = 64407.8\ \frac{lbf \cdot ft}{ft}$

$MV_{Ib} := \eta \cdot \left(\left(Ib_{DC} \cdot M_{DC} \right) + \left(Ib_{EV} \cdot M_{EV} \right) + \left(Ib_{EH} \cdot M_{EH1} \right) + \left(Ib_{LS} \cdot M_{LSV\_Ib} \right) \right)$ $\qquad MV_{Ib} = 100940.1\ \frac{lbf \cdot ft}{ft}$

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LSH} \right) + \left(Ia_{EH} \cdot M_{EH2} \right) \right)$ $\qquad MH_{Ia} = 13512.3\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LSH} \right) + \left(Ib_{EH} \cdot M_{EH2} \right) \right)$ $\qquad MH_{Ib} = 13512.3\ \frac{lbf \cdot ft}{ft}$

Compute Bearing Resistance:

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

$\Sigma M_R := MV_{Ib}$ $\Sigma M_R = 100940.1 \ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ib)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 13512.3 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 20211.5 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 4.3 \ ft$ Distance from Point "O" the resultant intersects the base

$e := \left| \frac{B}{2} - x \right|$ $e = 0.3 \ ft$ 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 absolute value is used.

Foundation Layout:

$B' := B - 2 \cdot e$ $B' = 8.7 \ ft$ Effective Footing Width

$L' := 57 \ ft$ Effective Footing Length (Assumed)

$H' := H_{Ib}$ $H' = 3561.9 \ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 20211.5 \ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

$D_f = 4.6 \ ft$ Footing embedment

$d_w := 0 \ ft$ Depth of Groundwater below ground surface at front of wall.

Drained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi'_{fd} > 0, e^{\pi \cdot \tan(\phi'_{fd})} \cdot \tan\left(45 \ deg + \frac{\phi'_{fd}}{2}\right)^2, 1.0\right)$ $N_q = 37.75$

$N_c := \text{if}\left(\phi'_{fd} > 0, \frac{N_q - 1}{\tan(\phi'_{fd})}, 5.14\right)$ $N_c = 50.59$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_{fd})$ $N_\gamma = 56.3$

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

$s_c := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L'}\right)\right)$ $s_c = 1.113$

$s_q := \text{if}\left(\phi'_{fd} > 0, 1 + \left(\frac{B'}{L'} \cdot \tan(\phi'_{fd})\right), 1\right)$ $s_q = 1.11$

$s_\gamma := \text{if}\left(\phi'_{fd} > 0, 1 - 0.4 \cdot \left(\frac{B'}{L'}\right), 1\right)$ $s_\gamma = 0.939$

Load inclination factors:

$i_q := 1$

$i_\gamma := 1$

$i_c := 1$

Assumed to be 1.0, see **LRFD BDS C10.6.3.1.2a**. "Most geotechnical engineers do not used the load inclination factors". If desired, use LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9].

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

$C_{wq} := \text{if}\left(d_w \geq D_f, 1.0, 0.5\right)$ $\qquad C_{wq} = 0.5$

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

Depth Correction Factor per Hanson (1970):

$$d_q := \text{if}\left(\frac{D_f}{B} \leq 1, 1 + 2 \cdot \tan\left(\phi'_{fd}\right) \cdot \left(1 - \sin\left(\phi'_{fd}\right)\right)^2 \cdot \frac{D_f}{B}, 1 + 2 \cdot \tan\left(\phi'_{fd}\right) \cdot \left(1 - \sin\left(\phi'_{fd}\right)\right)^2 \cdot \text{atan}\left(\frac{D_f}{B}\right)\right)$$

$d_q = 1.12$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 56.315$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 41.916$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 52.892$

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

$q_{nd} := c'_{fd} \cdot N_{cm} + \gamma_{fd} \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_{fd} \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 28497.8 \ \frac{lbf}{ft^2}$

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

$\phi_b := .55$ $\qquad$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 15.7 \ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_{fdu} > 0, e^{\pi \cdot \tan\left(\phi_{fdu}\right)} \cdot \tan\left(45 \ deg + \frac{\phi_{fdu}}{2}\right)^2, 1.0\right)$ $\qquad N_q = 37.75$

$N_c := \text{if}\left(\phi_{fdu} > 0, \frac{N_q - 1}{\tan\left(\phi_{fdu}\right)}, 5.14\right)$ $\qquad N_c = 50.59$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_{fdu}\right)$ $\qquad N_\gamma = 56.3$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

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

$s_c := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L'}\right)\cdot\left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5\cdot L'}\right)\right)$ $s_c = 1.113$

$s_q := \text{if}\left(\phi_{fdu} > 0, 1 + \left(\frac{B'}{L'}\cdot\tan(\phi_{fdu})\right), 1\right)$ $s_q = 1.11$

$s_\gamma := \text{if}\left(\phi_{fdu} > 0, 1 - 0.4\cdot\left(\frac{B'}{L'}\right), 1\right)$ $s_\gamma = 0.939$

Load inclination factors:

$i_q := 1$

$i_\gamma := 1$

$i_c := 1$

Assumed to be 1.0, see **LRFD BDS C10.6.3.1.2a**. "Most geotechnical engineers do not used the load inclination factors". If desired, use LRFD Equations [10.6.3.1.2a-5] thru [10.6.3.1.2a-9].

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 56.315$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 41.916$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 52.892$

Depth Correction Factor per Hanson (1970):

$d_q := \text{if}\left(\frac{D_f}{B} \le 1, 1 + 2\cdot\tan(\phi_{fdu})\cdot(1 - \sin(\phi_{fdu}))^2\cdot\frac{D_f}{B}, 1 + 2\cdot\tan(\phi_{fdu})\cdot(1 - \sin(\phi_{fdu}))^2\cdot\text{atan}\left(\frac{D_f}{B}\right)\right)$

$d_q = 1.12$

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

$q_{nu} := Su_{fdu}\cdot N_{cm} + \gamma_{fd}\cdot D_f\cdot N_{qm}\cdot d_q\cdot C_{wq} + 0.5\cdot\gamma_{fd}\cdot B'\cdot N_{\gamma m}\cdot C_{w\gamma}$ $q_{nu} = 28497.8\ \frac{lbf}{ft^2}$

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

$\phi_b := .55$ Bearing resistance factor **LRFD Table 11.5.7-1.**

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 15.7\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 15.7\ ksf$

Undrained Conditions: $q_{Ru} = 15.7\ ksf$

Evaluate External Stability of Wall:

Compute the ultimate bearing stress :

$e = 0.3\ ft$

$\sigma_V := \frac{\Sigma V}{B - 2 \cdot e}$ $\sigma_V = 2.336\ ksf$

Bearing Capacity:Demand Ratio (CDR)

Drained Conditions: $CDR_{Bearing\_D} := \frac{q_{Rd}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_D} = 6.71$

Undrained Conditions: $CDR_{Bearing\_U} := \frac{q_{Ru}}{\sigma_V}$ Is the CDR > or = to 1.0? $CDR_{Bearing\_U} = 6.71$

Limiting Eccentricity at Base of Wall (Strength Ia):

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

$e_{max} := \frac{B}{3}$ $e_{max} = 3.1\ ft$ Maximum Eccentricity **LRFD [11.6.3.3.] Equals B/3 for soil.**

$\Sigma M_R := MV_{Ia}$ $\Sigma M_R = 64407.8\ \frac{lbf \cdot ft}{ft}$ Sum of Resisting Moments (Strength Ia)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 13512.3\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 12750.7\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$x := \frac{(\Sigma M_R - \Sigma M_O)}{\Sigma V}$ $x = 4\ ft$ Distance from Point "O" the resultant intersects the base

$e := \text{abs}\left(\frac{B}{2} - x\right)$ $e = 0.63\ ft$ 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. .

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 4.87$

Created with PTC Mathcad Express. See www.mathcad.com for more information.

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$R_u := H_{Ia}$ $\qquad R_u = 3561.9\ \frac{lbf}{ft}$

Drained Conditions (Effective Stress):

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

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

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

$R_{ep} := \frac{r_{ep1} + r_{ep2}}{2} \cdot \left(y_2 - y_1\right)$ $\qquad R_{ep} = 3924.7\ \frac{lbf}{ft}$ Nominal passive resistance Drained Conditions

416 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 embedment below the greater of these depths shall be considered effective **LRFD [11.6.3.5**].

Compute sliding resistance between soil and foundation:

$c := 1.0$ c = 1.0 for Cast-in-Place
c = 0.8 for Precast

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 12750.7\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_\tau := c \cdot \Sigma V \cdot \tan\left(\phi'_{fd}\right)$ $\qquad R_\tau = 9263.9\ \frac{lbf}{ft}$ Nominal sliding resistance Cohesionless Soils

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.**

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

Factored Sliding Resistance to be used in CDR Calculations: $R_R = 11226.312\ \frac{lbf}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{R_u}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 3.15$

Created with PTC Mathcad Express. See www.mathcad.com for more information.