FINAL REPORT
STRUCTURE FOUNDATION EXPLORATION
PROJECT RETAINING WALLS
CUY-14-6.93
CUYAHOGA COUNTY, OHIO
PID#: 104132

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NEAS PROJECT 18-0023

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1. INTRODUCTION

1.1. General

National Engineering & Architectural Services, Inc. (NEAS) presents our Structure Foundation Exploration Report for the proposed project retaining walls as part of the proposed Ohio Department of Transportation (ODOT) bridge replacement and roadway realignment project CUY-14-6.93 (PID 104132) within the City of Garfield Heights, Cuyahoga County, Ohio. As part of the referenced project, it is our understanding that ODOT is planning to: 1) replace the existing continuous reinforced concrete beam bridge (CUY-14-0693) carrying Broadway Avenue (Ave) / State Route 14 (SR-14) over Chaincraft Road (Rd), Norfolk Southern Railway (Rwy) and Wheeling & Lake Erie Rwy with a new shortened structure on a new alignment; 2) remove the existing continuous reinforced concrete beam and steel stringer bridge (CUY-CR24-0062) carrying County Road (CR) 24 / Henry Street (St) over the existing culvert CUY-CR24-0061; and, 3) replace a segment of existing cast-in-place 4-sided box culvert directing Mill Creek under the existing bridge CUY-CR24-0062 and Chaincraft Rd. To facilitate the proposed improvements, five (5) permanent and two (2) temporary retaining walls are required. 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, 8th Edition* (BDS) (AASHTO, 2017) and the 2021 revision of *ODOT's Bridge Design Manual 2020 Edition* (BDM) (ODOT [1], 2021).

The exploration for the referenced retaining walls was conducted in general accordance with Barr Engineering, Inc. DBA National Engineering & Architectural Services, Inc.'s (NEAS) proposal to AECOM, dated June 7, 2021 and with the provisions of ODOT's *Specifications for Geotechnical Explorations* (SGE) (ODOT, 2021).

The scope of work performed by NEAS as part of the referenced project included: a review of published geotechnical information; performing 22 total test soil borings (18 utilized within this report as a part of the indicated structure foundation exploration); laboratory testing of soil samples in accordance with the SGE; performing geotechnical engineering analysis to assess foundation design and construction considerations; and, development of this summary report.

1.2. Proposed Construction

It is our understanding that ODOT plans to replace the existing bridge CUY-14-0693 with a new shortened structure on a new alignment as well as remove the existing bridge CUY-CR24-0062. To facilitate the proposed bridge replacement, bridge removal, and realignment the construction of five (5) permanent and two (2) temporary retaining walls are required.

Two (2) permanent retaining walls, designated as Retaining Walls 1 and 5 (RW-1 & RW-5), are proposed at the western end of the existing CUY-14-0693 bridge structure (Bent No. 1) and extend east to the rear abutment of the newly realigned bridge CUY-14-0693. RW-1 and RW-5 will replace the indicated portion of the existing CUY-14-0693 by supporting the proposed SR-14 embankment soils and providing grade separation between SR-14 and both Chaincraft Rd (RW-1) and Garfield Parkway (RW-5). Temporary RW-2 is also proposed at this location to facilitate the construction phasing and maintenance of traffic (MOT) scheme by temporarily supporting the proposed SR-14 embankment soils in order to maintain at least one lane of SR-14 during construction. RW-1 and RW-5 will consist of mechanically stabilized earth (MSE) walls and will be back-to-back for the majority of their lengths. Each wall is proposed to be supported on either varying heights of proposed embankment fill or the existing fill/possible fill soils encountered at the site. RW-1 will be approximately 382 ft in length with a maximum wall height of approximately 34 ft, while RW-5 will be approximately 276 ft in length with a maximum wall height of approximately 32 ft. Temporary RW-2 will be a temporary wire-faced MSE wall that will likely be a back-to-back wall with RW-1 for the entirety of its length and will be approximately 470 ft in length with a maximum wall height of approximately 42 ft.

Two (2) permanent retaining walls, designated as RW-3 and RW-6, are proposed following the forward abutment of the realigned bridge CUY-14-0693 and extending north/east tying into the existing SR-14 grades beyond the existing bridge. Each wall will facilitate the removal of the existing bridge at this location by supporting the proposed SR-14 embankment soils and providing grade separation between SR-14 and both Old Broadway Ave (RW-3) and the adjacent industrial property (RW-6). Temporary RW-4 is also proposed at this location to facilitate the construction phasing and MOT scheme by supporting the proposed SR-14 embankment soils in order to maintain at least one lane of SR-14 during construction. RW-3 and RW-6 will consist of MSE walls and will be back-to-back for the majority of their lengths. Each wall is proposed to be supported on either varying heights of proposed embankment fill or the existing fill/possible fill soils encountered at the site. RW-3 will be approximately 399 ft in length with a maximum wall height of approximately 39 ft, while RW-6 will be approximately 369 ft in length with a maximum wall height of approximately 36 ft. Temporary RW-4 will be a temporary wire-faced MSE wall that will likely be a back-to-back wall with RW-3 for the entirety of its length and will be approximately 475 ft in length with a maximum wall height of approximately 40 ft.

One (1) permanent retaining wall, designated as RW-7, is proposed along the east side of Henry St to facilitate the removal of the existing bridge CUY-CR24-0061. The proposed walls will retain the proposed embankment fill supporting Henry St and provide grade separation from Chaincraft Rd. The proposed RW-7 will consist of an MSE type wall bearing on either varying heights of proposed embankment fill or the existing fill/possible fill soils encountered at the site. The proposed wall will be approximately 187 ft in length with a maximum wall height of approximately 29 ft.

2. GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1. Geology and Physiography

The project site is located within the Galion Glaciated Low Plateau (ODGS, 1998). This area is characterized as rolling upland mantled with thin to thick drift and is transitional between the gently rolling Till Plain and the hilly Glaciated Allegheny Plateau with the overall area ranging in elevation from 800 ft to 1400 ft, with moderate relief (100 ft). The geology is described as medium- to low-lime Wisconsinan-age till over Mississippian-age shales and sandstone.

The geology underlying the majority of the project site is mapped as up to 70 ft of Wisconsinan-age sand and gravel thinning to an average thickness of 40 ft near the eastern limits of the project site, all over Mississippian-age sandstone and shale bedrock (ODGS, 2002). A portion of the eastern part of the project site is mapped as an average of 40 ft of Wisconsinan-age till overlying the natural sand and gravel followed by about 10 ft of till then bedrock. On the southwestern part of the project (underlying Henry St), the geology is mapped as solely till, with an average thickness of 30 ft, overlying the bedrock. The sand and gravel soils mapped at the project site are generally described as interbedded, well to moderately sorted sand and gravel commonly containing thin, discontinuous layers of silt and clay. The sand and gravel are characterized as finely stratified to massive, may be cross-bedded and locally may contain organics. The till at the project site is generally described as an unsorted mix of clay, silt, sand, gravel and boulders that may contain silt, sand and gravel lenses.

Bedrock underlying the project site has been mapped as Berea Sandstone and Bedford Shale, undivided, based on the Geologic Units Map of Ohio (USGS & ODGS, 2006). The sandstone at the site is described as brown, weathering light brown to reddish brown, thin to thick bedded with planar to lenticular bedding. The shale at the site is described as gray to brown in color, locally reddish brown, thin to medium bedded with planar to lenticular bedding as well. Based on the ODNR bedrock topography map of Ohio, the bedrock elevation at the project site can be expected at an approximate elevation of 800 ft above mean sea level (amsl), putting bedrock at depths between 15 ft and 50 ft below ground surface (bgs).

The soils underlying the project site have been mapped (Web Soil Survey) by the Natural Resources Conservation Service as being a combination of Urban land, Loudonville-Urban land complex and pits/quarry. Urban land is mapped underlying the existing Henry St as well as SR-14 east of Chaincraft Rd. The Loudonville-Urban land complex is mapped underlying the majority of the project area west of Chaincraft Rd as well as the area underlying the proposed bridge location, while pits/quarry are mapped underlying the northern most portion of the project encompassing the majority of the proposed RW-G site. Urban land is land that has been altered or obscured by urban work and structures. Soils within these areas can be non-native human-transported material, human-altered material, or minimally altered or intact native soils. Urban land soils are not rated for local roads. The Loudonville series is described as moderately deep, well drained soils with moderate permeability formed in loamy till and underlain by sandstone or siltstone. Soils in the Loudonville series classify as both cohesive and non-cohesive A-4 soils and cohesive A-6 and A-7 soils according to the AASHTO method of soil classification (USDA, 2019).

2.2. Hydrology/Hydrogeology

Groundwater elevations at the project site are anticipated to be near elevations consistent with that of the immediately adjacent Mill Creek (between approximate elevations 805 and 807 ft amsl) as it is the most dominant hydraulic influence in the vicinity of the project site. The water level of Mill Creek may be representative of the local groundwater table although perched groundwater systems may exist with the presence of fine-grained soils making it difficult for groundwater to permeate to the natural phreatic surface.

Areas in the eastern portion of the project are located within a 1% Annual Chance Flood Hazard area. Based on available mapping by the Federal Emergency Management Agency's (FEMA) National Flood Hazard mapping program (FEMA, 2016) the 1% Annual Chance Flood elevation is about 822 to 823 ft amsl within the flood hazard area.

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 project site (ODNR [1], 2016).

No oil or gas wells are noted on ODNR's Ohio Oil & Gas Locator within the immediate vicinity of the project site (ODNR [2], 2016).

2.4. Historical Records and Previous Phases of Project Exploration

The following plans were available for review and evaluation for this report:

- Bridge Foundation Investigation sheets and boring logs as part of ODOT bridge rehabilitation project CUY-14-06.99 Broadway Avenue Bridge No. 123, prepared by the Mason, Sandefur & de Verteuil, Inc., dated August 23, 1983;

Historical soil borings associated with the above referenced plans were reviewed, however, were not utilized for our analysis, and therefore, are not referenced or presented within this report or structure foundation exploration sheets.

2.5. Site Reconnaissance

A field reconnaissance visit for the proposed CUY-14-0693 bridge replacement project was conducted on August 9, 2021, during which site conditions were noted and photographed. During our field reconnaissance, no apparent geohazards were observed within the immediate vicinity of the project site. Land use of the area surrounding the proposed project site can be described as a mix of parks, industrial properties and railroad right-of-way. A summary of our observations at the different project wall locations is provided below.

2.5.1. Retaining Walls 1 and 5 & Temporary Wall 2

The location of the proposed MSE walls RW-1, RW-5 and temporary RW-2 encompasses the area beginning from the western end of the existing CUY-14-0693 bridge structure (Bent No. 1) and extending east to the rear abutment of the newly realigned bridge CUY-14-0693. A majority of this area is located underneath and closely surrounding the existing bridge and was observed to be a relatively flat grassy area that contained a few smaller trees as well as overhead light and utility poles. The slope near Bent No. 1 of the existing bridge was observed to be at about 2 Horizontal to 1 Vertical (2H:1V) with no signs of instability observed at the time of our visit. In general, the area did not appear to have any drainage concerns with no apparent signs of ponding observed at the time of our site visit. It was noted that a sediment-filled concrete drainage swale, located between Bent No. 1 and Bent No. 2 of the existing bridge, appeared to direct bridge drainage to a small area beneath the bridge (Photograph 1).

Photograph 1: Drainage area under existing bridge near Bent No. 1

2.5.2. Retaining Walls 3 and 6 & Temporary Wall 4

The location of the proposed MSE walls RW-3, RW-6 and temporary RW-4 encompasses the area located immediately following the forward abutment of the realigned bridge CUY-14-0693 (the edge of the Wheeling & Lake Erie Rwy) and extending north/east to match into the existing SR-14 grades beyond the existing bridge. At the time of our site visit, the indicated area consisted of: 1) gravel and paved access roads to the adjacent industrial properties; and 2) heavily vegetated areas containing various debris such as piles of broken concrete, wood, tires, abandoned trailers, etc. (Photographs 2 and 3). At the end of the existing bridge (Bent No. 49), a small concrete retaining wall appeared to be acting as a wing wall and wood lagging was observed to be retaining soil between Bent No. 48 and Bent No. 49 (Photograph 4). Neither the retaining wall nor the lagging showed obvious signs of instability at the time of our site visit. The embankment slope adjacent to Bent No. 49 was observed to be heavily vegetated and sloping at approximately 2H:1V. The embankment appeared to be stable with no apparent signs of instability observed. In general, the area did not appear to have any drainage concerns with no apparent signs of ponding observed within the footprint of the proposed walls at the time of our site visit.

Photograph 2: Ground cover along wall alignments

Photograph 3: Debris piles along wall alignment

Photograph 4: Walls near existing Bent No. 48 and 49

2.5.3. Retaining Wall 7

The location of the proposed MSE wall RW-7 extends along eastern side of the existing Henry St bridge (CUY-CR24-0061) from the rear abutment of the proposed bridge CUY-14-0693 to Bent No. 56 of the existing Henry St bridge. This area encompasses portions of the existing bridge as well as the existing Henry St embankment slope at this location. The slope is partially supported by a retaining wall that is also retaining fill around the existing bridge piers (Photograph 5). A staircase also ascends the existing embankment slope in this location allowing for pedestrian access to and from Chaincraft Rd and Henry St (Photograph 5). The embankment at this location was observed to be heavily vegetated and slope upward from the existing wall to the Henry St elevation at approximately 2.5H:1V. The slope and the existing retaining wall appeared to be stable with no apparent signs of instability observed during our site visit. In general, the site appeared to be well-drained with no apparent signs of ponding observed at the time of our visit.

Photograph 5: Retaining wall and slope along proposed wall alignment

3. GEOTECHNICAL EXPLORATION

3.1. Field Exploration Program

The exploration for the proposed retaining walls was conducted by NEAS between August 2, 2021 and August 31, 2021. The exploration for the referenced walls included 17 borings drilled to depths ranging from 35 to 61.5 ft bgs. The exploration locations were selected by NEAS in general accordance with the guidelines contained in the SGE with the intent to evaluate subsurface soil and groundwater conditions. Borings were typically located along proposed wall alignments that were not restricted by maintenance of traffic, underground utilities or dictated by terrain (i.e. steep embankment slopes). Project exploration 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 exploration locations including stationing, offsets, location information and elevations of the indicated structure foundation explorations are shown in Table 1 below, while the locations are depicted on the Soil Profile Sheets provided within Appendix A.

Table 1: Project Boring Summary

Boring Number	Location (Sta/Offset)[(2)]	Latitude	Longitude	Elevation (NAVD 88) (ft)	Depth (ft)	Structure
B-001-0-21	368+69, 29' RT.	41.431969	-81.602477	831.3	61.5	RW-A
B-002-0-21	369+61, 36' LT.	41.431962	-81.602068	813.0	40.0	RW-F, Temp. RW-H
B-003-0-21	370+98, 14' RT.	41.431652	-81.602046	813.2	45.0	RW-A, Temp. RW-H
B-004-0-21	371+23, 32' LT.	41.431688	-81.601606	812.9	45.0	RW-F, Temp. RW-H
B-005-0-21	372+69, 18' RT.	41.431413	-81.601611	813.6	44.8	RW-A, Temp. RW-H
B-006-0-21	372+57, 41' LT.	41.431548	-81.601193	812.9	49.4	CUY-14-0693 Rear Abutment RW-F, Temp. RW-H
B-007-0-21	374+39, 46' RT.	41.431220	-81.600616	815.2	50.0	CUY-14-0693 Rear Abutment RW-D
B-010-0-21	378+05, 45' LT.	41.431345	-81.599251	821.6	50.0	CUY-14-0693 Forw. Abutment RW-G, Temp. RW-I
B-011-0-21	378+84, 31' RT.	41.431112	-81.598998	823.5	59.7	CUY-14-0693 Forw. Abutment RW-E, Temp. RW-I
B-012-0-21	379+12, 38' LT.	41.431290	-81.598864	821.4	50.0	RW-G, Temp. RW-I
B-013-0-21	380+32, 21' RT.	41.431063	-81.598479	826.7	50.0	RW-E, Temp. RW-I
B-014-0-21	380+40, 65' LT.	41.431281	-81.598355	827.2	50.0	RW-G, Temp. RW-I
B-015-0-21	381+46, 28' RT.	41.430932	-81.598114	829.0	45.0	RW-E, Temp. RW-I
B-016-0-21	382+01, 13' LT.	41.430972	-81.597870	831.0	35.0	RW-G, Temp. RW-I
B-017-0-21	383+04, 46' RT.	41.430711	-81.597615	845.8	41.5	RW-E, Temp. RW-I
B-021-0-21	374+43, 176' RT.	41.430865	-81.600658	816.6	48.8	RW-B, RW-C, RW-D
B-022-0-21	374+00, 292' RT.	41.430563	-81.600868	849.3	51.5	RW-B

Notes:
1. *As-drilled boring location and corresponding ground surface elevation was surveyed in the field by NEAS Inc.*
2. *STA/Offset in reference to centerline SR-14 alignment.*

The borings were drilled using a either a CME 55, CME 75 or CME 55X truck or track mounted drilling rig utilizing 3.25-inch diameter hollow stem augers. Soil samples were generally recovered at 2.5-ft intervals to depths between 20 and 40 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"). Samples in combined structure/subgrade borings were sampled continuously to depths between 7.5 and 11 ft bgs. 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 CME auto hammers that had been calibrated to be between 68.4% and 89% 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 boring, the borehole was backfilled with auger cuttings, bentonite chips, or a combination of these materials, and patched with cold patch asphalt and/or quickset concrete where necessary and appropriate.

3.2. Laboratory Testing Program

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

3.2.1. Classification Testing

Representative soil samples were selected for index properties (Atterberg Limits) and gradation testing for classification purposes on approximately 31% of the samples. At 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., continuous, 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.

3.2.3. Unconfined Compressive Strength of Cohesive Soil Test Results

Unconfined compressive strength testing was performed in accordance with AASHTO T-208 "Standard Method of Test for Unconfined Compressive Strength of Cohesive Soil" on two (2) relatively undisturbed (Shelby Tube), cohesive samples obtained during the exploration programs. The samples were obtained from borings B-016-0-21 and B-021-0-21 at depths ranging from 7.6 to 8.3 ft bgs (between elevations 808.5 and 823.2 ft amsl). The tested samples were classified as either Silt and Clay (A-6a) or Clay (A-7-6). A summary of the Unconfined Compressive Strength of Cohesive Soil test is shown in Table 2 below, while the laboratory testing reports are included within Appendix B.

Table 2: Unconfined Compressive Strength of Cohesive Soil Test Results

Boring Number	Depth of Specimen Tested (ft bgs)	Classification	Estimated Elevation (ft amsl)	Wet Density (psf)	Unconfined Compressive Strength (psf)	Undrained Shear Strength (psf)	Strain at Failure (%)
B-016-0-21	7.8 - 8.3	A-7-6	823.3 - 822.7	121.2	1409	705	13.5
B-021-0-21	7.6 - 8.1	A-6a	809.0 - 808.5	136.6	582	291	3.5

3.2.4. Direct Shear Testing

Direct Shear Testing was conducted in accordance with AASHTO T-236 "Standard Method of Test for Direct Shear Test of Soils under Consolidated Drained Conditions" on two (2) relatively undisturbed samples obtained during the exploration program. The samples tested were obtained from borings B-016-0-21 and B-021-0-21 at depths ranging from 8.4 to 9.3 ft bgs (between elevations 807.3 and 822.6 ft amsl). The soils from these samples were classified as Clay (A-7-6) and Coarse and Fine Sand (A-3a). The Direct Shear Test results are shown in Table 3 below. The lab testing report is provided in Appendix B.

Table 3: Direct Shear Test Results

Boring Number	Depth of Sample (ft)	Classification	Average Wet Density (1) (pcf)	Average Void Ratio (1)	Cohesion - Effective (psf)	Angle of Friction - Effective (°)
B-016-0-21	8.4 - 8.9	A-7-6	118.2	0.842	130	20.5
B-021-0-21	8.8 - 9.3	A-3a	121.1	0.743	29	33.1

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

3.2.5. Consolidation Testing

One (1) consolidation test was performed in accordance with ASTM D 2435-04 "Standard Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading" on a relatively undisturbed cohesive soil sample collected from boring B-016-0-21; the results of the consolidation test are summarized in Table 4 below, while the laboratory testing report is included with the associated boring log within Appendix B.

Table 4: Consolidation Test Results

Boring Number	Depth (ft)	Elevation (ft)	Compression Index (Cc)	Recompression Index (Cr)	Preconsolidation Pressure (psf)	Void Ratio
B-016-0-21	8.9 - 9.0	822.1 - 822.0	0.169	0.042	5,500	0.816

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 exploration 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 logs represent the approximate interface location; the actual transition between strata may be gradual and indistinct. The subsurface 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 subsurface profile at the project site is relatively uniform and consistent with the geological model for the project. The subsurface profile generally consists of an upper stratum of highly variable fill/possible fill soils ranging from coarse-grained, non-cohesive material to fine-grained, cohesive material atop natural sand and gravel soils. The highly variable fill possible fill soils can be described as loose to very dense or soft to hard, while the natural sand and gravel soils encountered underlying the fill/possible fill soils can be described as medium dense to very dense non-cohesive, granular material. Bedrock was not encountered within the depths of the borings performed at the project site.

4.1.1. Groundwater

Groundwater measurements were taken during the boring drilling procedures and immediately following the completion of the boring performed. Groundwater was observed during drilling in 11 of the 17 borings performed at the retaining wall sites at depths ranging from 9.5 to 38.2 ft bgs (elevations 793.1 to 816.5 ft amsl). Groundwater was not encountered within borings B-002-0-21, B-011-0-21, B-014-0-21, B-016-0-21, B-017-0-21 and B-021-0-21 performed as part of the referenced structure foundation explorations. It should be noted that groundwater is affected by many hydrologic characteristics in the area and may vary from those measured at the time of the exploration. The specific groundwater readings are included on the boring logs located within Appendix B.

5. ANALYSES AND RECOMMENDATIONS

We understand that the construction of five (5) permanent and two (2) temporary retaining walls are required to facilitate the shortening and replacement of bridge CUY-14-0693 as well as removal of bridge CUY-CR24-0061 as part of the proposed CUY-14-6.93 (PID 104132) project in Garfield Heights, Cuyahoga County, Ohio. Based on design information for each of the proposed retaining walls provided by AECOM via email on December 2, 2021 and December 7, 2021 it is our understanding that the permanent walls will consist of MSE wall type while the temporary walls will consist of temporary wire face MSE wall type. Furthermore, it is also our understanding that the proposed retaining walls are planned to vary in height and will bear on either newly placed fill or on the existing fill/possible fill soils encountered at the site.

Geotechnical analyses consisting of external stability (i.e., bearing resistance, eccentricity, and sliding resistance), global stability, and settlement were performed for each of the proposed retaining walls. 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 above indicated proposed design information for the referenced retaining walls provided by AECOM; 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 retaining walls are constructed in accordance with the recommendations provided within this report (including recommended undercut and increasing of MSE wall strap length in select areas), as well as all applicable standards and specifications (i.e., ODOT, manufacture, etc.) for MSE wall construction.

5.1. Retaining Walls Analysis and Recommendations

5.1.1. Retaining Wall Design Assumptions

As the proposed project retaining walls are planned as MSE type, 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 were 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 proposed profile grade at the face of the wall to the top of the leveling pad) or 8 ft, whichever is greater, at the section of wall being analyzed, per ODOT’s BDM section 307.4-A;
- Minimum MSE wall embedment depths (as measured from top of the leveling pad to the lowest point on the ground surface within 4-ft of the face of the wall) 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 the ODOT Supplemental Specification 840 (SS-840) as shown in Table 5 below.

Table 5: Design Soil Parameters for Fill Materials

Fill Zone	Type of Soil	Soil Unit Weight (pcf)	Friction Angle (°)	Cohesion (psf)
Reinforced Zone	Select Granular Backfill	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 840.04 - A-1 of ODOT's SS 840.

With respect to design constraints and assumptions specific to the proposed retaining walls, the geometry of the proposed walls (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 structure design information provided by AECOM via email on December 2, 2021 and December 7, 2021.

5.1.2. Soil Profile for Analysis

For external stability, settlement and global stability analyses purposes, each boring drilled for the proposed project retaining walls was reviewed, and a generalized material profile was developed. 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 test (i.e., Atterberg Limits, grain size, etc.) 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 of the borings along a particular retaining wall alignment 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 along the indicated proposed wall alignments are presented in Tables 6 through 22 below. Settlement parameters (with sited correlation/reference material) developed for each Soil Type for each of the indicated wall alignments are presented in Tables 23 through 25.

Retaining Walls 1, 5 and Temporary 2:

Table 6: Soil Profile and Estimated Engineering Properties - At Boring B-001-0-21

RW-1, Temp RW-2: Profile for Analysis, B-001-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 1 Depth (831.3 ft - 804.3 ft)	110	1550	150	23
Soil Type 3 Depth (804.3 ft - 799.3 ft)	135	-	-	41
Soil Type 4 Depth (799.3 ft - 794.3 ft)	130	5650	400	29
Soil Type 3 Depth (794.3 ft - 769.8 ft)	135	-	-	41

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-002-0-21

RW-1, Temp RW-2: Profile for Analysis, B-002-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (813 ft - 801 ft)	110	-	-	29
Soil Type 3 Depth (801 ft - 773 ft)	135	-	-	41

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-003-0-21

RW-5: Profile for Analysis, B-003-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (813.2 ft - 803.7 ft)	110	-	-	29
Soil Type 3 Depth (803.7 ft - 791.2 ft)	135	-	-	41
Soil Type 4 Depth (791.2 ft - 787.7 ft)	130	5650	400	29
Soil Type 3 Depth (787.7 ft - 768.2 ft)	135	-	-	41

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-004-0-21

RW-1, Temp RW-2: Profile for Analysis, B-004-0-21				
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Soil Type 2 Depth (812.9 ft - 803.4 ft)	110	-	-	29
Soil Type 3 Depth (803.4 ft - 767.9 ft)	135	-	-	41

tes:
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: Soil Profile and Estimated Engineering Properties - At Boring B-005-0-21

RW-5: Profile for Analysis, B-005-0-21				
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Soil Type 2 Depth (813.6 ft - 801.6 ft)	110	-	-	29
Soil Type 3 Depth (801.6 ft - 789.1 ft)	135	-	-	41
Soil Type 4 Depth (789.1 ft - 785.3 ft)	130	5650	400	29
Soil Type 3 Depth (785.3 ft - 768.8 ft)	135	-	-	41

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

Table 11: Soil Profile and Estimated Engineering Properties - At Boring B-006-0-21

RW-1, Temp RW-2: Profile for Analysis, B-006-0-21				
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Soil Type 2 Depth (812.9 ft - 803.4 ft)	110	-	-	29
Soil Type 3 Depth (803.4 ft - 763.5 ft)	135	-	-	41

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

<u>Retaining Walls 3, 6 and Temporary 4:</u>

Table 12: Soil Profile and Estimated Engineering Properties - At Boring B-010-0-21

RW-3 & Temp RW-4: Profile for Analysis, B-010-0-21				
Soil Description	**Unit Weight[(1)] (pcf)**	**Undrained Shear Strength[(2)] (psf)**	**Effective Cohesion[(3)] (psf)**	**Effective Friction Angle[(3)] (degrees)**
Soil Type 1[(4)] Depth (821.6 ft - 809.6 ft)	118	700	130	20.5
Soil Type 3 Depth (809.6 ft - 771.6 ft)	135	-	-	42

:
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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 13: Soil Profile and Estimated Engineering Properties - At Boring B-011-0-21

RW-6: Profile for Analysis, B-011-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (823.5 ft - 819 ft)	120	-	-	30
Soil Type 3 Depth (819 ft - 763.8 ft)	135	-	-	42

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 14: Soil Profile and Estimated Engineering Properties - At Boring B-012-0-21

RW-3 & Temp RW-4: Profile for Analysis, B-012-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (821.4 ft - 814.4 ft)	120	-	-	30
Soil Type 1(4) Depth (814.4 ft - 811.9 ft)	118	700	130	20.5
Soil Type 3 Depth (811.9 ft - 771.4 ft)	135	-	-	42

:
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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 15: Soil Profile and Estimated Engineering Properties - At Boring B-013-0-21

RW-6: Profile for Analysis, B-013-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (826.7 ft - 819.2 ft)	120	-	-	30
Soil Type 1(4) Depth (819.2 ft - 817.2 ft)	118	700	130	20.5
Soil Type 3 Depth (817.2 ft - 776.7 ft)	135	-	-	42

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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 16: Soil Profile and Estimated Engineering Properties - At Boring B-014-0-21

RW-3 & Temp RW-4: Profile for Analysis, B-014-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 2 Depth (827.2 ft - 816.7 ft)	120	-	-	30
Soil Type 1(4) Depth (816.7 ft - 813.6 ft)	118	700	130	20.5
Soil Type 3 Depth (813.6 ft - 777.2 ft)	135	-	-	42

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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 17: Soil Profile and Estimated Engineering Properties - At Boring B-015-0-21

RW-6: Profile for Analysis, B-015-0-21				
Soil Description	**Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Soil Type 2 Depth (829 ft - 822 ft)	120	-	-	30
Soil Type 1[4] Depth (822 ft - 817 ft)	118	700	130	20.5
Soil Type 3 Depth (817 ft - 784 ft)	135	-	-	42

es:
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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 18: Soil Profile and Estimated Engineering Properties - At Boring B-016-0-21

RW-3 & Temp RW-4: Profile for Analysis, B-016-0-21				
Soil Description	**Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Soil Type 2 Depth (831 ft - 829.5 ft)	120	-	-	30
Soil Type 1[4] Depth (829.5 ft - 816.5 ft)	118	700	130	20.5
Soil Type 3 Depth (816.5 ft - 796 ft)	135	-	-	42

es:
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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

Table 19: Soil Profile and Estimated Engineering Properties - At Boring B-017-0-21

RW-6: Profile for Analysis, B-016-0-21				
Soil Description	**Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Soil Type 1[4] Depth (845.8 ft - 833.8 ft)	118	700	130	20.5
Soil Type 2 Depth (833.8 ft - 826.3 ft)	120	-	-	30
Soil Type 1[4] Depth (826.3 ft - 817.8 ft)	118	700	130	20.5
Soil Type 3 Depth (817.8 ft - 804.3 ft)	135	-	-	42

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.*
4. *Based on laboratory test results from boring B-016-0-21. See Apendix B for test reports.*

<u>Retaining Wall 7:</u>

Table 20: Soil Profile and Estimated Engineering Properties - At Boring B-007-0-21

RW-7: Profile for Analysis, B-007-0-21				
Soil Description	**Unit Weight[1] (pcf)**	**Undrained Shear Strength[2] (psf)**	**Effective Cohesion[3] (psf)**	**Effective Friction Angle[3] (degrees)**
Soil Type 1 Depth (815.2 ft - 806.2 ft)	108	-	-	29
Soil Type 3 Depth (806.2 ft - 765.2 ft)	135	-	-	42

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

Table 21: Soil Profile and Estimated Engineering Properties - At Boring B-021-0-21

RW-7: Profile for Analysis, B-021-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 1 Depth (816.6 ft - 809.6 ft)	108	-	-	29
Soil Type 2(4) Depth (809.6 ft - 804.8 ft)	125	5500	30	33
Soil Type 3 Depth (804.8 ft - 767.8 ft)	135	-	-	42

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.*
4. *Based on laboratory test results from boring B-021-0-21. See Appendix B for test reports.*

Table 22: Soil Profile and Estimated Engineering Properties - At Boring B-022-0-21

RW-7: Profile for Analysis, B-022-0-21				
Soil Description	**Unit Weight(1) (pcf)**	**Undrained Shear Strength(2) (psf)**	**Effective Cohesion(3) (psf)**	**Effective Friction Angle(3) (degrees)**
Soil Type 3 Depth (849.3 ft - 797.8 ft)	135	-	-	42

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.*

<u>Settlement Parameters:</u>

Table 23: Settlement Parameters for Analysis - Retaining Walls 1, 5 and Temporary 2

Retaining Walls 1, 5 and Temporary 2: Settlement Analysis, B-001-0-21 to B-006-0-21								
Soil Description	**Unit Weight (pcf)**	**Elastic Modulus(1) (psf)**	**Poissons Ratio(1), v**	**Void Ratio e_o**	**Compression Index(2), C_c**	**Recompression Index(3), C_r**	**OCR(4)**	**Coeff. of Consol.(5), C_v**
Soil Type 1	110	824000	0.40	0.792	0.15	0.030	8.00	0.81
Soil Type 2	110	43000	0.20	-	-	-	-	-
Soil Type 3	135	562000	0.40	-	-	-	-	-
Soil Type 4(6)	122	2000000	0.50	0.816	0.169	0.042	5.0	0.16

es:
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. *Based on laboratory test results from borings B-016-0-21.*

Table 24: Settlement Parameters for Analysis - Retaining Walls 3, 6 and Temporary 4

Retaining Walls 3, 6 and Temporary 4: Settlement Analysis, B-010-0-21 to B-018-0-21								
Soil Description	**Unit Weight (pcf)**	**Elastic Modulus(1) (psf)**	**Poissons Ratio(1), v**	**Void Ratio e_o**	**Compression Index(2), C_c**	**Recompression Index(3), C_r**	**OCR(4)**	**Coeff. of Consol.(5), C_v**
Soil Type 1(6)	118	586000	0.40	0.816	0.169	0.042	5.00	0.16
Soil Type 2	120	106000	0.25	-	-	-	-	-
Soil Type 3	135	990000	0.40	-	-	-	-	-

s:
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. *Based on laboratory test results from borings B-016-0-21.*

Table 25: Settlement Parameters for Analysis - Retaining Wall 7

Retaining Wall 7: Settlement Analysis, B-007-0-21, B-021-0-21 & B-022-0-21								
Soil Description	Unit Weight (pcf)	Elastic Modulus[1] (psf)	Poissons Ratio[1], v	Void Ratio e_o	Compression Index[2], C_c	Recompression Index[3], C_r	OCR[4]	Coeff. of Consol.[5], C_v
Soil Type 1	108	74000	0.20	-	-	-	-	-
Soil Type 2[6]	125	2000000	0.50	0.816	0.169	0.042	5.0	0.16
Soil Type 3	135	1521000	0.40	-	-	-	-	-

s:

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. *Based on laboratory test results from borings B-016-0-21.*

In addition to the Soil Type parameters presented above, graphical depictions of the generalized subsurface profiles along each of the wall alignments are located within Appendix C. The generalized subsurface profiles includes: a color coded general interpretation of the Soil Types between borings, a graphical interpretation of the soil strata identified by the project soil borings along the referenced wall profiles, representative boring data (N_{60}-values, moisture contents, and groundwater levels) and current ground surface elevation.

5.1.3. Global Stability Analysis

For purposes of evaluating the stability of the proposed project retaining walls (including back to back walls as a unit), NEAS reviewed cross-sections along the length of each proposed wall to determine the subsurface conditions that posed the greatest potential for slope instability. In general, cross-sections along the proposed wall alignments were reviewed to determine the sections that would represent a combination of existing subsurface conditions and planned site grading that would be most critical to slope stability (i.e., maximum total wall height, maximum embankment height measured from toe of slope to top of wall, proposed/existing grades behind and in front of the wall, weak and/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 for RW-1, RW-5 and RW-7 were estimated to be most "critical" and were analyzed for global stability. For RW-3 and RW-6 (which are back to back MSE walls) the subsurface conditions dictated that multiple cross-sections needed to be analyzed for each. For RW-1, RW-5 and RW-7 the cross-sections analyzed for global stability consisted of the maximum wall height section. These sections evaluated for global stability included RW-1 at approximate STA. 13+83, RW-5 at approximate STA. 11+95 and RW-7 at approximate STA. 11+87. At RW-3 the sections evaluated included STA. 10+00, STA. 10+30, STA. 10+60, STA. 11+30, STA. 11+60, STA. 11+85, and STA. 12+10. At RW-6 the sections evaluated included STA. 10+00, STA. 10+80, STA. 11+20, STA. 12+00, and STA. 13+20.

For the indicated cross-sections, NEAS developed a representative cross-sectional model to use as the basis for global stability analysis. The models were developed from NEAS's interpretation of the available information which included: 1) the project Stage 2 plans prepared by AECOM dated January 16, 2023; 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 project. With respect to the soil's engineering properties, the provided generalized soil profile and estimated engineering properties presented in Section 5.1.2. of this report were used in our analysis.

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

Based on our slope stability analyses for the referenced retaining wall sections, the short-term and long-term slope stability FOS for RW-1 and RW-5, achieved or exceeded the desired value of 1.3. However, the analyses identified that the FOS for the maximum total wall height sections of RW-3, RW-6 and RW-7 was below the desired value of 1.3. Because the FOS calculated for RW-3, RW-6 and RW-7 was below the minimum desired FOS of 1.3, further slope stability analyses were performed to: 1) evaluate possible solutions that could be considered to achieve a FOS greater than 1.3 at these sections; and, 2) determine the extents along the length of the wall to which the recommended solution would be required. The evaluated solutions to increase the slope stability FOS included the increase of reinforcement strap lengths of the proposed MSE walls, undercutting soils underlying the wall and replacing with more suitable material, or deepening of the specific wall section. Once the desired FOS was achieved, the respective slope stability models were re-evaluated to confirm the FOS for circular and block type failure planes under both short-term and long-term soil strength conditions met the desired minimum. Graphical outputs of the slope stability program (cross-sectional model, calculated safety factor, and critical failure plane) are presented within Appendix E.

In our analysis of RW-3, a FOS of less than 1.3 was encountered in five of the analyzed sections (STA. 10+00, 10+30, 10+60, 11+30, 11+60) with each failing in block type failure under short-term soil strength conditions. During our additional analysis of RW-3, it was concluded that increasing the MSE wall strap length had little impact on the FOS for sections at STA. 10+00 and STA. 10+30 while performing an undercut beneath RW-3 and increasing the strap length of RW-6 increased the FOS for RW-3 at the referenced stations. The maximum height section of RW-3 at STA. 10+00 is located near boring B-010-0-21 which encountered a relatively thick upper layer of cohesive soil (Soil Type 1). These upper cohesive soils are not present in the upper portions of adjacent RW-3 borings B-012-0-21 and B-014-0-21 nor in adjacent RW-6 borings B-011-0-21 or B-013-0-21. Based on our analysis it is this upper cohesive material that is causing the global stability issues associated with RW-3 at STA. 10+00 and STA. 10+30. Therefore, an iterative analysis of different undercut depths and lengths was performed to determine the extent of the undercut that would increase the FOS to the desired 1.3. Following this analysis, it is recommended that an undercut depth of 9 ft below the RW-3 leveling pad be performed and replaced with Granular Material Type C according to the requirements of CMS 204.07. The undercut should extend 48 ft in front of the front face of the wall and extend the entire length of the MSE wall straps. As previously indicated, the referenced cohesive material was not encountered in adjacent borings and as such, the undercut should be performed to the recommended limits under the direction of a field engineer until the cohesive material is removed and granular material is encountered. With the referenced undercut performed, RW-3 at STA. 10+00 and STA. 10+30 generally exceeded the desired FOS value of 1.3. At STA. 10+60, STA. 11+30, and STA. 11+60, a minimum FOS of 1.0 in block type failure was obtained for short-term soil strength conditions. During our additional analysis of RW-3 at these station it was determined that an increased strap length equal to at least 100% of the total wall height is required. With the referenced increased strap length, the cross-section of RW-3 at STA. 10+60, 11+30, and 11+60 generally achieved the desired FOS value of 1.3. Therefore; based on our additional analyses at this location and our experience on similar projects, it is our opinion that the increased strap length equal to 100% of the total wall height will be sufficient at these locations. The recommended MSE wall design alterations and FOSs for RW-3 are presented in Table 27 located in Section 5.1.4 of this report.

In our analysis of RW-6, a FOS of less than 1.3 was encountered in two of the analyzed sections (STA. 10+80 and 11+20) with each failing in block type failure under short-term soil strength conditions. During our additional analysis of RW-6 it was determined that at the referenced failing locations, an increased strap length ranging from at least 120% to 130% of the total wall height is required. It should also be noted that an increased strap length of 100% of the total wall height was required at RW-6 STA. 10+00 to aid in the global stability of RW-3. With the referenced increased strap length, the cross-section of RW-6 generally achieved the desired FOS value of 1.3. Therefore; based on our additional analyses at RW-6 location and our experience on similar projects, it is our opinion that the increased strap length ranging from at least 100% to 130% of the total wall height will be sufficient at this location. The recommended MSE wall design alterations and FOSs for RW-6 are presented in Table 29 located in Section 5.1.4 of this report.

In our analysis of RW-7, a minimum FOS of 1.2 in block type failure was obtained for long-term soil strength conditions. During our additional analysis of RW-7 it was determined that at the location of the critical wall section (STA. 11+86 of RW-7 alignment), an increased strap length equal to at least 80% of the total wall height is required. With the referenced increased strap length, the cross-section of RW-7 at STA. 1+86 (RW-7 alignment) generally achieved the desired FOS value of 1.3. Therefore; based on our additional analyses at this location and our experience on similar projects, it is our opinion that the increased strap length equal to 80% of the total wall height will be sufficient at this location. The recommended MSE wall design alterations and FOSs for RW-7 are presented in Table 30 located in Section 5.1.4 of this report.

It should be noted, profile information of the proposed permanent and temporary retaining walls were not available for review at the time of this report. Therefore, additional global stability analysis will be required once final wall grades are established.

5.1.4. External Stability Analysis

Based on our estimated engineering soil properties, the developed generalized profile and the retaining wall design assumptions provided in Section 5.1.2. of this report and following the completion of our global stability analysis (Section 5.1.1), external stability analyses of the proposed project retaining walls were performed. External stability was evaluated along each of the proposed permanent retaining wall alignments. One (1) cross-section for RW-1, RW-5 and RW-7 were estimated to be most "critical" with the critical cross-section consisting of the cross-section with the maximum total wall height. For RW-3 and RW-6 (which are back to back MSE wall) the subsurface conditions dictated that multiple cross-sections needed to be analyzed for each. These cross-sections were 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. Bearing resistances were calculated in accordance with LRFD BDS Sections 10.6.3.1.2a and 10.6.3.1.2c. LRFD BDS Section 10.6.3.1.2a was generally utilized for bearing analysis with the exception of one wall section from RW-7 and three wall sections from RW-6 where LRFD BDS Section 10.6.3.1.2c (limit equilibrium method) was utilized. Limit equilibrium method was used for wall segments bearing within the proposed embankment slopes or where highly variable (multiple) strata was present.

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 Tables 26 through 30 below. (External Stability and Bearing Resistance Calculation Results can be found in Appendix D)

Table 26: Retaining Wall 1 External Stability Analysis

Dimensions	
Retaining Wall 1	
Design Wall Height (feet)	33.7
Exposed Wall Height (feet)	30.7
Length of Reinforcement (feet)	23.6
Length of Reinf. To Height Ratio	0.7
Approximate Station[(1)]	13+83
Capactiy Demand Ratio (CDR)	
Sliding	1.5
Overturning / Eccentricity	1.8
Bearing Capacity	1.3
Factored Bearing Resistance (ksf)[(2)]	9.9

Notes:

1. *Stationing in reference to baseline of proposed retaining wall.*
2. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of LRFD BDS.*
3. *Ratio determined to satisfy global stability requirements.*

Table 27: Retaining Wall 3 External Stability Analysis

Dimensions												
Retaining Wall 3												
Design Wall Height (feet)	38.8		36.3		34.2		31.1		29.2		26.4	24.0
Exposed Wall Height (feet)	35.8		33.3		31.2		28.1		26.2		23.4	21.0
Length of Reinforcement (feet)	27.2		25.4		23.9	34.2	21.8	31.1	20.4	29.2	18.5	16.8
Length of Reinf. To Height Ratio	0.7		0.7		0.7	1.0	0.7	1.0	0.7	1.0	0.7	0.7
Approximate Station[(1)]	10+00 to 10+30		10+30 to 10+60		10+60 to 11+30		11+30 to 11+60		11+60 to 11+85		11+85 to 12+10	12+10 to 13+99
Undercut Depth Below Wall (feet)	0.0	7.5	0.0	10.5	N/A		N/A		N/A		N/A	N/A
Boring Used in Analysis	B-010-0-21		B-010-0-21		B-012-0-21		B-012-0-21		B-012-0-21		B-012-0-21	B-014-0-21
Capactiy Demand Ratio (CDR)												
Sliding	-	1.9	-	1.9	-	2.3	-	2.2	-	2.2	1.5	1.5
Overturning / Eccentricity	-	1.9	-	1.8	-	3.7	-	3.6	-	3.6	1.7	1.7
Bearing Capacity	-	2.0	-	2.1	-	2.0	-	1.8	-	1.7	1.2	1.3
Factored Bearing Resistance (ksf)[(2)]	-	18.1	-	17.4	-	13.6	-	11.0	-	10.1	7.7	7.7
Minimum Global Stability FOS[(3)]	0.8	1.3	0.7	1.3	1.0	1.3	1.1	1.3	1.2	1.3	1.4	1.3

Notes:

1. *Stationing in reference to baseline of proposed RW-3.*
2. *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.*
3. *Minimum FOS of 1.3 required for proposed MSE walls.*
4. *An increased strap length to height ratio is required to meet stability*

Table 28: Retaining Wall 5 External Stability Analysis

Dimensions	
Retaining Wall 5	
Design Wall Height (feet)	32.0
Exposed Wall Height (feet)	29.0
Length of Reinforcement (feet)	22.4
Length of Reinf. To Height Ratio	0.7
Approximate Station[(1)]	11+95
Capactiy Demand Ratio (CDR)	
Sliding	1.5
Overturning / Eccentricity	1.8
Bearing Capacity	1.0
Factored Bearing Resistance (ksf)[(2)]	7.5

Notes:

1. *Stationing in reference to baseline of proposed retaining wall.*
2. *Bearing Resistance calculated in accordance to Section 11.10.5.4 of LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of LRFD BDS.*
3. *Ratio determined to satisfy global stability requirements.*

Table 29: Retaining Wall 6 External Stability Analysis

Dimensions							
Retaining Wall 6							
Design Wall Height (feet)	36.3		33.0		30.6		22.7
Exposed Wall Height (feet)	33.3		30.0		27.6		18.2
Length of Reinforecement (feet)	25.4	36.3	23.1	39.6	21.4	39.8	15.9
Length of Reinf. To Height Ratio	0.7	1.0	0.7	1.2	0.7	1.3	0.7
Approximate Station[1]	10+00 to 10+80		10+80 to 11+20		11+20 to 13+20		13+20 to 13+69
Undercut Depth Below Wall (feet)	N/A		N/A		N/A		N/A
Boring Used in Analysis	B-011-0-21		B-013-0-21		B-015-0-21		B-015-0-21
Capactiy Demand Ratio (CDR)							
Sliding	-	2.3	-	2.7	-	2.9	1.5
Overturning / Eccentricity	-	3.7	-	5.3	-	6.1	1.7
Bearing Capacity	-	2.0	-	1.6	-	1.0	1.0
Factored Bearing Resistance (ksf)	-	14.4[2]	-	9.9[3]	-	5.8[3]	5.6[3]
Minimum Global Stability FOS[3]	< 1.3[5] / 2.0	1.3[5] / > 2.0	1.1	1.3	1.1	1.3	1.3

Notes:

1. *Stationing in reference to baseline of proposed RW-6.*
2. *Calculated in accordance to Section 11.10.5.4 of LRFD BDS and factored using Resistance Factor provided in Table 11.5.7-1 of LRFD BDS.*
3. *Minimum FOS of 1.3 required for proposed MSE walls.*
4. *Bearing Resistance calculated in accordance with Limit Equilibrium method.*
5. *An increased strap length to height ratio is required to meet stability requirements for RW-3 stability.*
6. *Global Stability FOS less than 1.3 at Retaining Wall 3 when Length of Reinforcement to Height Ratio is less than 1.0H.*

Table 30: Retaining Wall 7 External Stability Analysis

Dimensions		
Retaining Wall 7		
Design Wall Height (feet)	29.4	29.4
Exposed Wall Height (feet)	26.4	26.4
Length of Reinforecement (feet)	20.6	23.5
Length of Reinf. To Height Ratio	0.7	0.8
Approximate Station[1]	11+87	
Capactiy Demand Ratio (CDR)		
Sliding	-	1.8
Overturning / Eccentricity	-	2.3
Bearing Capacity	-	1.0
Factored Bearing Resistance (ksf)[2]	-	6.5
Minimum Global Stability FOS[3]	1.2	1.3

Notes:

1. *Stationing in reference to baseline of proposed retaining wall.*
2. *Bearing Resistance calculated in accordance with Limit Equilibrium method for wall sections bearing within slopes.*
3. *Ratio determined to satisfy global stability requirements.*

5.1.5. Settlement Analysis

In order to estimate the maximum total and differential settlement that could result within the subsurface soils supporting the proposed MSE retaining walls, NEAS reviewed: 1) proposed retaining wall cross-sections provided by AECOM via email on December 2, 2021 and December 7, 2021; 2) Service Limit State loading conditions; and, 3) the generalized subsurface profile and Settlement Parameters for Analysis provided in Section 5.1.2. of this report. 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. For analysis purposes and in order to determine the location of maximum settlement as well as differential settlement along the proposed retaining wall alignments, the developed model for settlement analysis was evaluated along the length (estimated proposed profile) of each wall alignment. Outputs of the settlement analysis program are presented within Appendix F.

Based on our analysis, the estimated maximum total settlement that could occur along the length of proposed RW-5, RW-1 and temporary RW-2 alignments as a result of the induced embankment and MSE retaining wall loads is estimated to be about 8 to 12.5 inches. The maximum differential settlement along the length of the proposed retaining walls is estimated to be less than the allowable differential settlement of 1% per ODOT's BDM. The total settlement magnitudes are not anticipated to be a concern as about 6 to 12 inches of the total settlement is expected to be elastic (immediate) and take place during construction. Of the remaining 0.5 to 2 inches of expected long-term (consolidation) settlement, the majority (approximately 90 percent) is expected to be complete within the first 30 days. With respect to potential downdrag loading on the existing foundations during construction, it is not anticipated that downdrag loading will be an issue as the threshold of more than 0.4 inches of long-term settlement is not anticipated to be reached within soils below the elevation of the existing substructures. In areas where more than 0.4 inches of long-term settlement is estimated, the majority of that settlement is anticipated to occur within the embankment soils above the elevation of the existing substructures and therefore, will not impose downdrag forces on the existing foundations.

Along the length of proposed RW-6, RW-3 and temporary RW-4 alignments, the estimated maximum total settlement that could occur along as a result of the induced embankment and MSE retaining wall loads is estimated to be about 3 to 5 inches. The maximum differential settlement along the length of the referenced walls is estimated to be less than the allowable differential settlement of 1% per ODOT's BDM. This settlement magnitude is not anticipated to be a concern as about 1 to 4.5 inches of the total settlement is expected to be elastic (immediate) and take place during construction. Of the remaining 0.5 to 2 inches of expected long-term (consolidation) settlement, more than half is expected to be complete within the first 60 days.

With respect to settlement along the proposed RW-7 alignments, the estimated maximum total settlement that could occur along as a result of the induced embankment and MSE retaining wall loads is estimated to be about 5.6 inches. The maximum differential settlement along the length of the referenced walls is estimated to be less than the allowable differential settlement of 1% per ODOT's BDM. This settlement magnitude is not anticipated to be a concern as about 5 inches of the total settlement is expected to be elastic (immediate) and take place during construction. Of the remaining 0.6 inches of expected long-term (consolidation) settlement, the majority (approximately 90 percent) is expected to be complete within the first 7 days.

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 the proposed project retaining walls. This report has been prepared for AECOM, ODOT and their design consultants to be used solely in evaluating the soils underlying the referenced proposed structures and presenting geotechnical engineering recommendations specific to this project. The assessment of general site environmental conditions or the presence of pollutants in the soil, rock and groundwater of the site was beyond the scope of this geotechnical exploration. Our recommendations are based on the results of our field explorations, laboratory test results from representative soil samples, and geotechnical engineering analyses. The results of the field explorations and laboratory tests, which form the basis of our recommendations, are presented in the appendices as noted. This report does not reflect any variations that may occur between the borings or elsewhere on the site, or variations whose nature and extent may not become evident until a later stage of construction. In the event that any changes in the nature, design or location of the referenced proposed retaining wall structures 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 AECOM in performing this geotechnical exploration for the CUY-14-6.93 project. Please call if there are any questions, or if we can be of further service.

Respectfully Submitted,

Brendan P. Andrews, P.E.
Geotechnical Engineer

Kevin C. Arens, P.E.
Geotechnical Engineer

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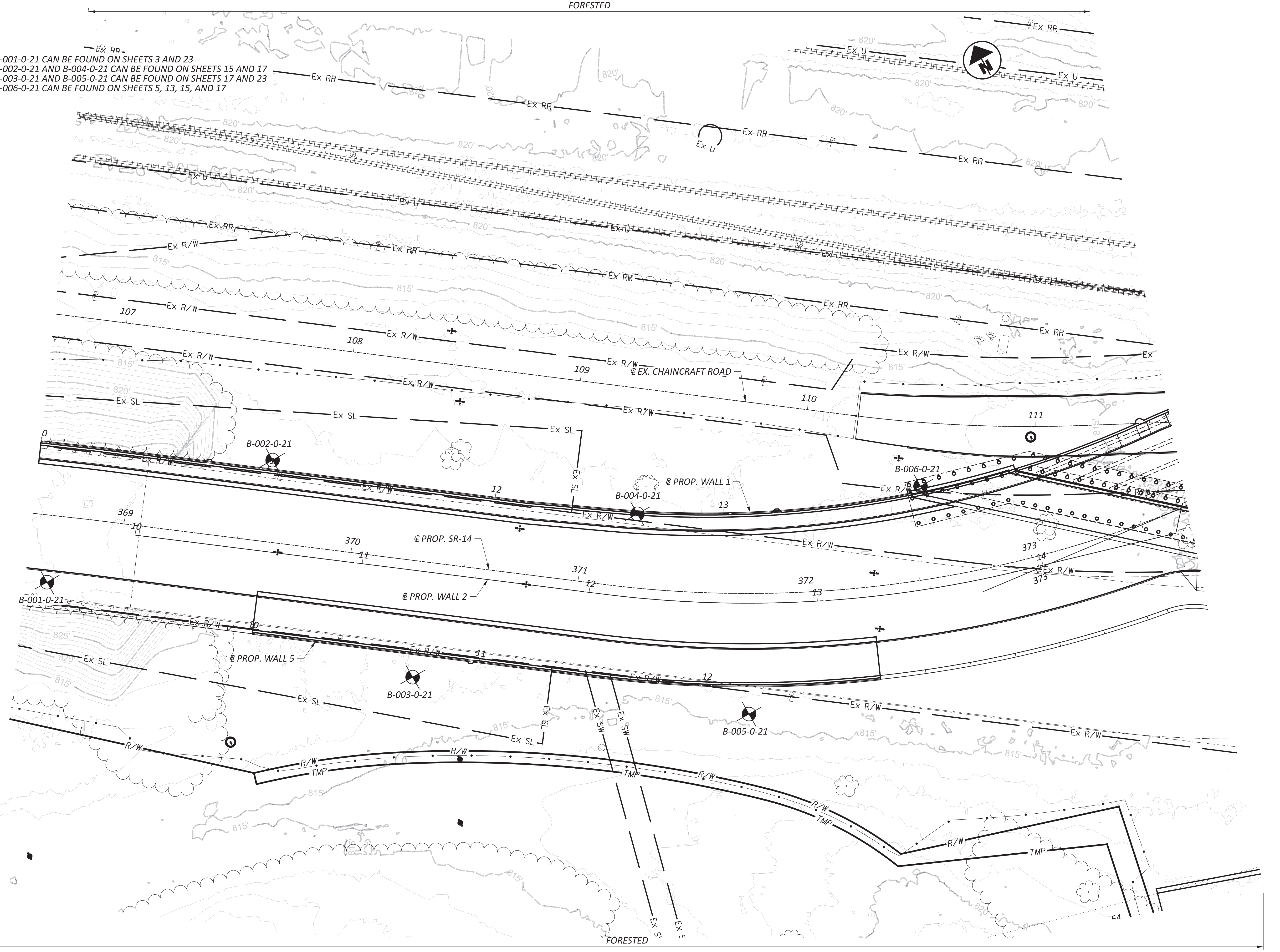
APPENDIX A

BORING LOCATION PLAN

INFORMATION FOR B-001-0-21 CAN BE FOUND ON SHEETS 3 AND 23
INFORMATION FOR B-002-0-21 AND B-004-0-21 CAN BE FOUND ON SHEETS 15 AND 17
INFORMATION FOR B-003-0-21 AND B-005-0-21 CAN BE FOUND ON SHEETS 17 AND 23
INFORMATION FOR B-006-0-21 CAN BE FOUND ON SHEETS 5, 13, 15, AND 17



GEOTECHNICAL PROFILE -ROADWAY BEGIN TO END WALL 1

CUY-14-6.93

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DESIGN AGENCY
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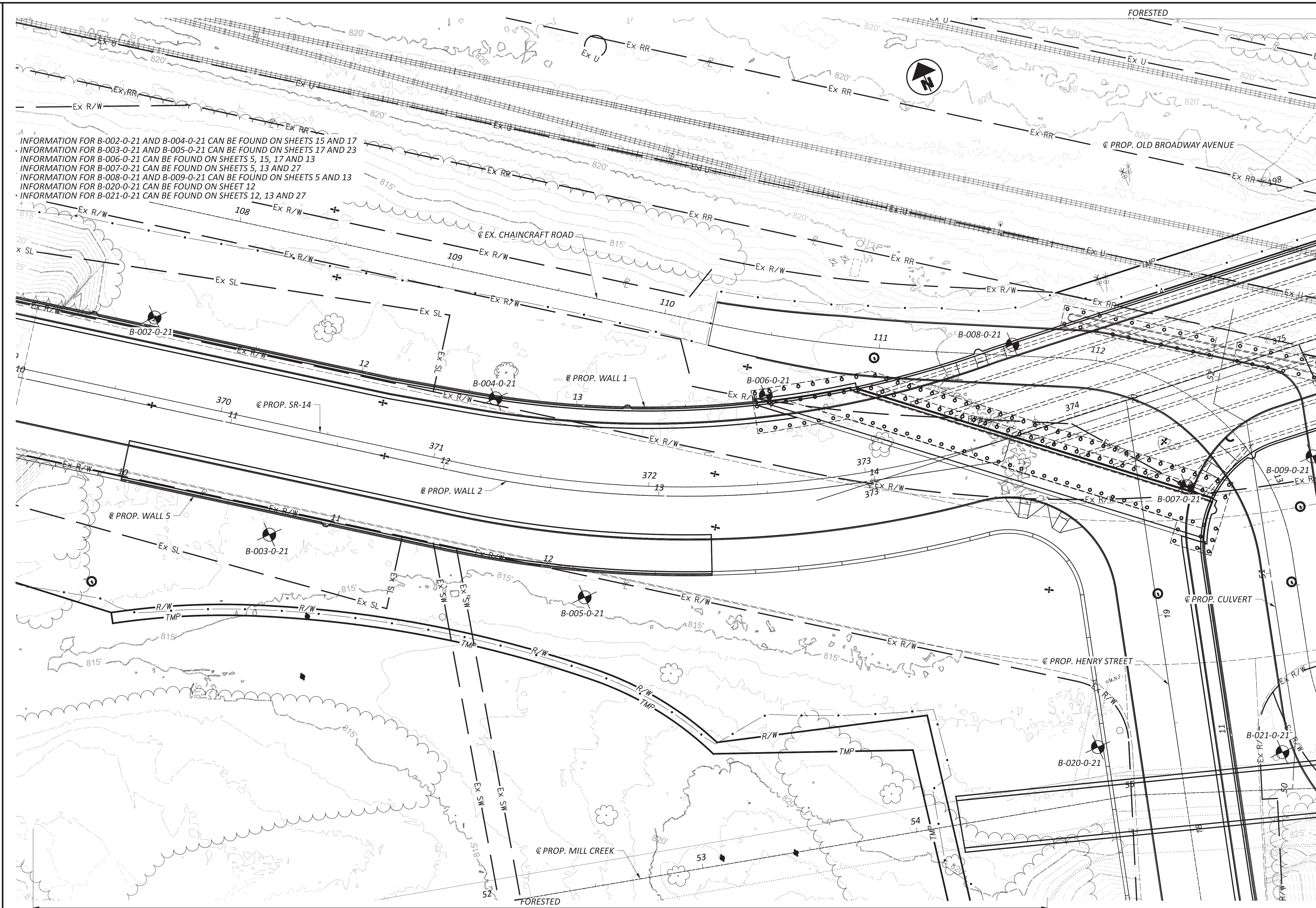
DESIGNER	MWJ/AI
REVIEWER	BPA 02/13/23
PROJECT ID	104132
SUBSET / TOTAL	14 / 51
SHEET / TOTAL	P.292 / 329

INFORMATION FOR B-002-0-21 AND B-004-0-21 CAN BE FOUND ON SHEETS 15 AND 17
INFORMATION FOR B-003-0-21 AND B-005-0-21 CAN BE FOUND ON SHEETS 17 AND 23
INFORMATION FOR B-006-0-21 CAN BE FOUND ON SHEETS 5, 15, 17 AND 13
INFORMATION FOR B-007-0-21 CAN BE FOUND ON SHEETS 5, 13 AND 27
INFORMATION FOR B-008-0-21 AND B-009-0-21 CAN BE FOUND ON SHEETS 5 AND 13
INFORMATION FOR B-020-0-21 CAN BE FOUND ON SHEET 12
INFORMATION FOR B-021-0-21 CAN BE FOUND ON SHEETS 12, 13 AND 27



GEOTECHNICAL PROFILE -ROADWAY
BEGIN TO END WALL 2

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PROJECT ID	104132
SUBSET 16	TOTAL 51
SHEET P.294	TOTAL 329

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INFORMATION FOR B-010-0-21 CAN BE FOUND ON SHEETS 7 AND 19
INFORMATION FOR B-011-0-21 AND B-013-0-21 CAN BE FOUND ON SHEETS 7, 21, AND 25
INFORMATION FOR B-012-0-21 AND B-014-0-21 CAN BE FOUND ON SHEETS 7, 19, AND 21
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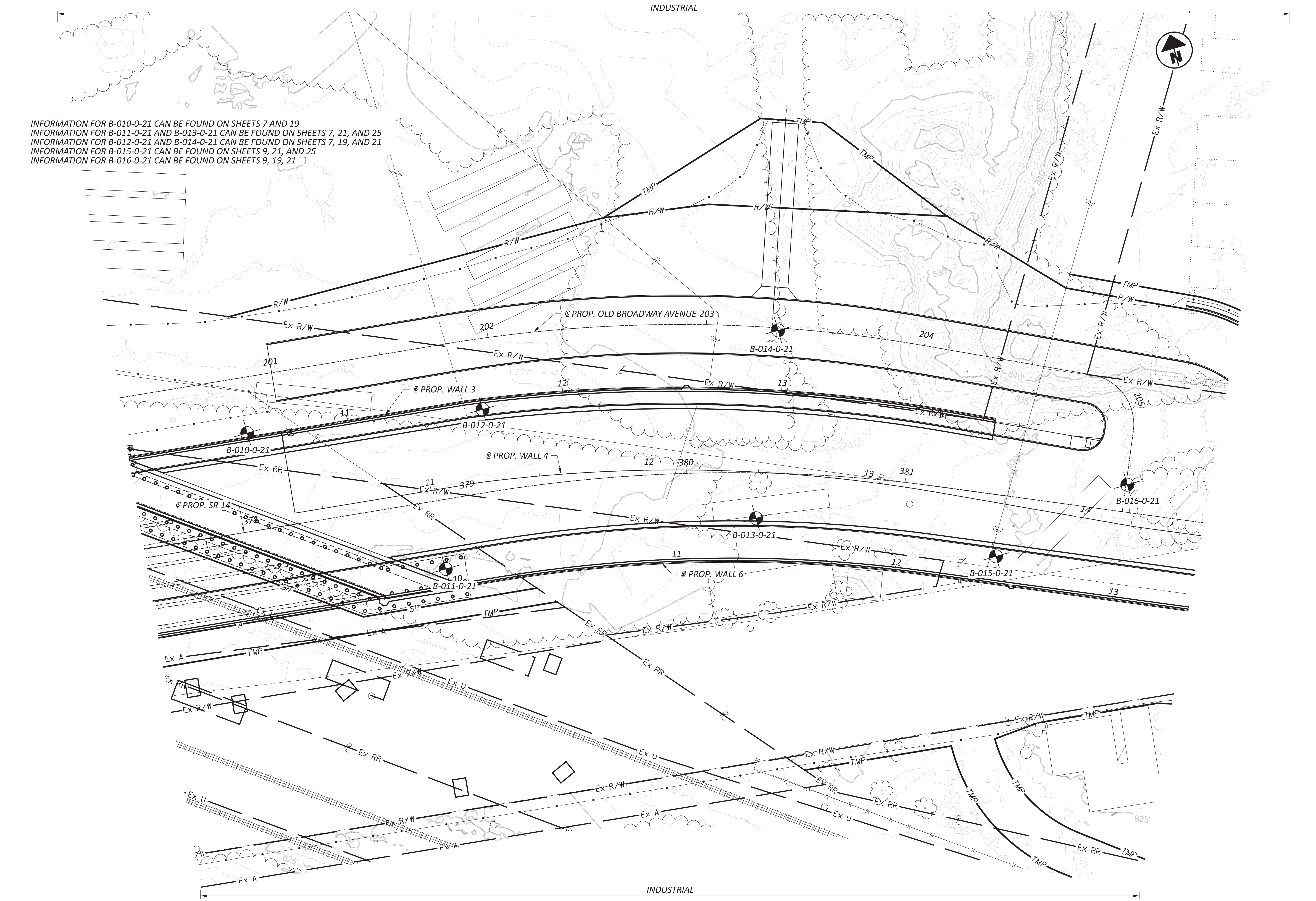
INFORMATION FOR B-016-0-21 CAN BE FOUND ON SHEETS 9, 19, 21



GEOTECHNICAL PROFILE -ROADWAY BEGIN TO END WALL 3

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PROJECT ID	104132
SUBSET 18	TOTAL 51
SHEET P.296	TOTAL 329

CUY-14-6.93

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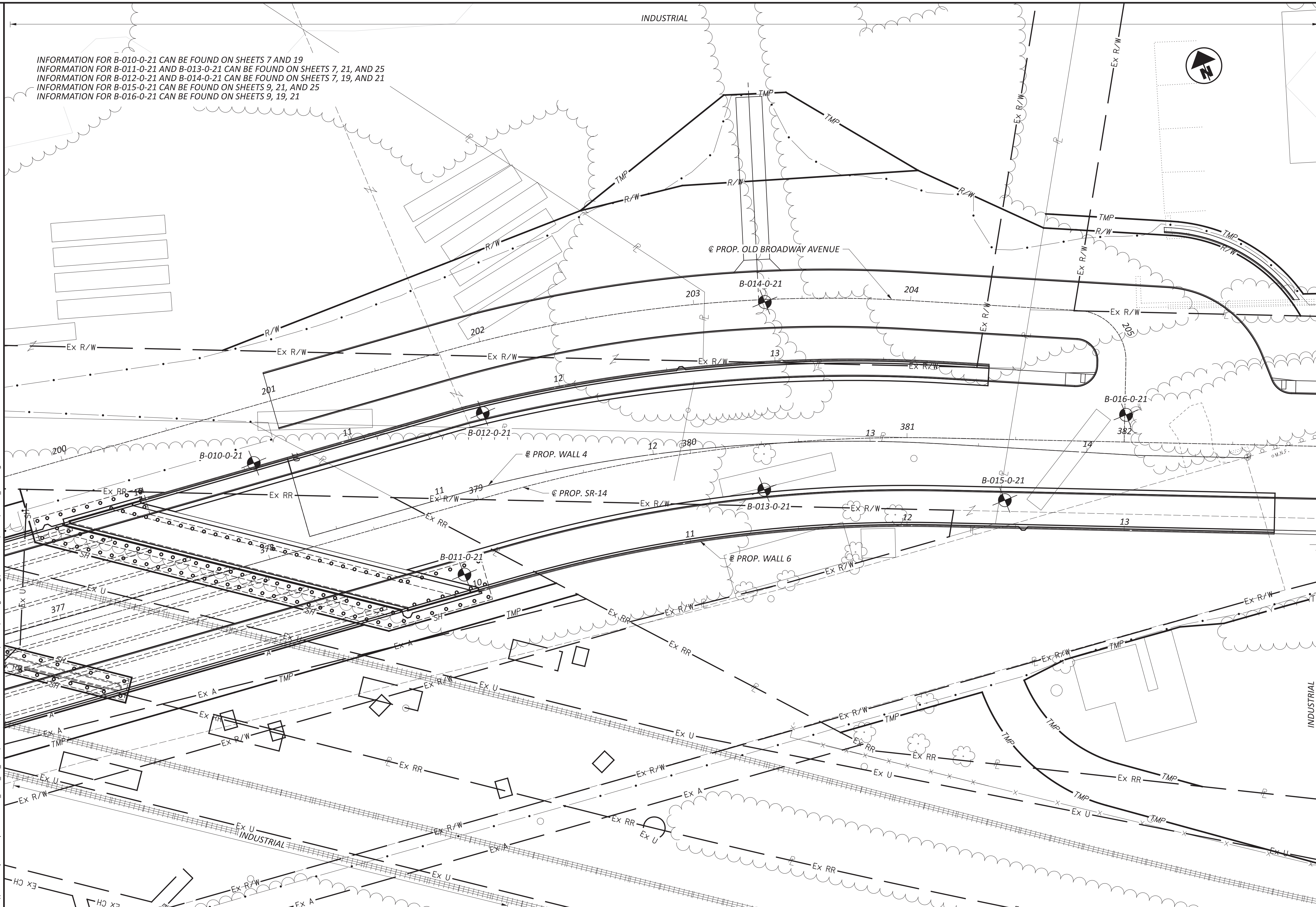
INFORMATION FOR B-010-0-21 CAN BE FOUND ON SHEETS 7 AND 19
INFORMATION FOR B-011-0-21 AND B-013-0-21 CAN BE FOUND ON SHEETS 7, 21, AND 25
INFORMATION FOR B-012-0-21 AND B-014-0-21 CAN BE FOUND ON SHEETS 7, 19, AND 21
INFORMATION FOR B-015-0-21 CAN BE FOUND ON SHEETS 9, 21, AND 25
INFORMATION FOR B-016-0-21 CAN BE FOUND ON SHEETS 9, 19, 21



HORIZONTAL SCALE IN FEET
0 10 20 40

GEOTECHNICAL PROFILE -ROADWAY
BEGIN TO END WALL 4

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REVIEWER	BPA 02/13/23
PROJECT ID	104132
SUBSET / TOTAL	20 / 51
SHEET / TOTAL	P.298 / 329

CUY-14-6.93

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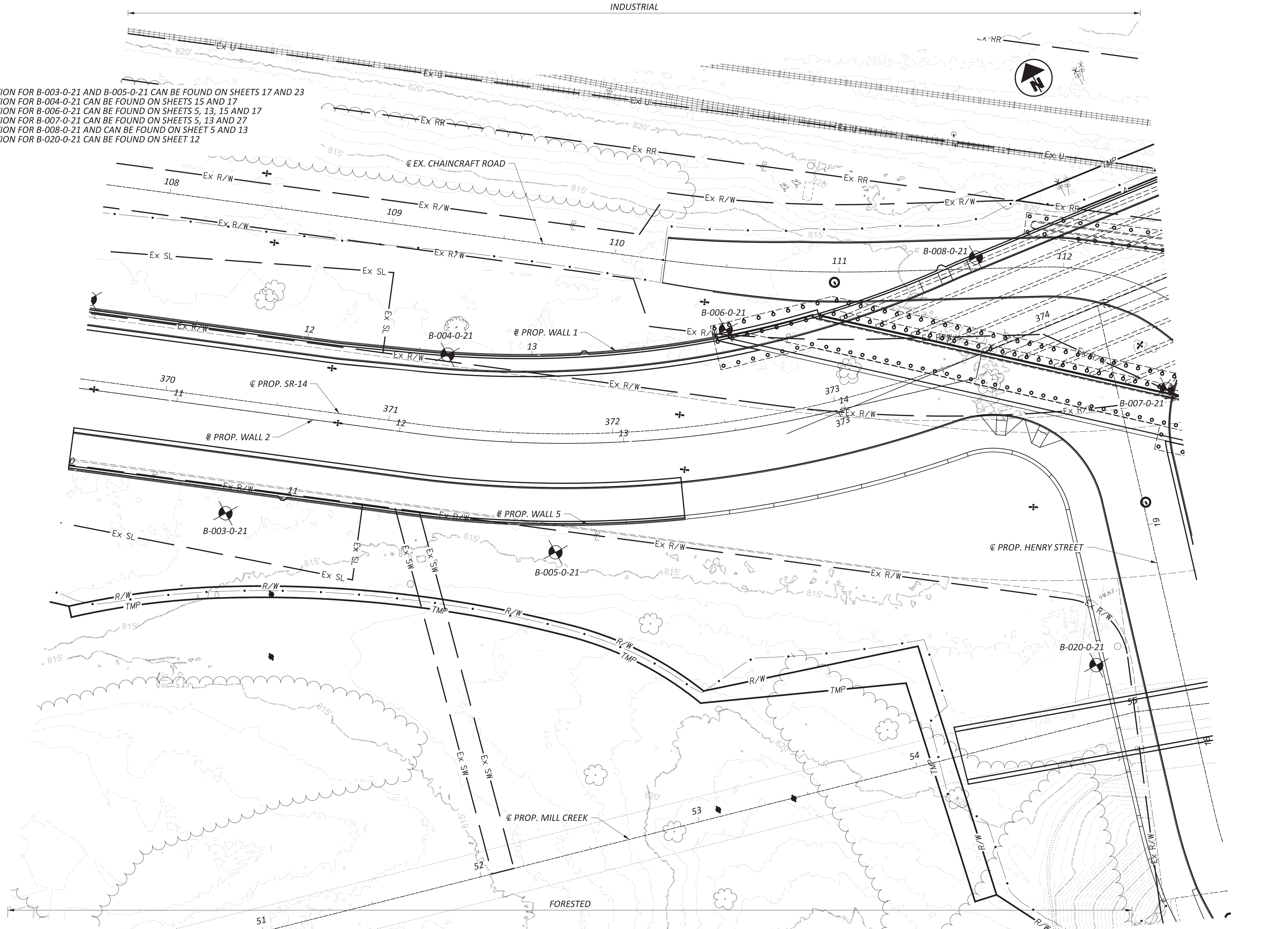
INFORMATION FOR B-003-0-21 AND B-005-0-21 CAN BE FOUND ON SHEETS 17 AND 23
INFORMATION FOR B-004-0-21 CAN BE FOUND ON SHEETS 15 AND 17
INFORMATION FOR B-006-0-21 CAN BE FOUND ON SHEETS 5, 13, 15 AND 17
INFORMATION FOR B-007-0-21 CAN BE FOUND ON SHEETS 5, 13 AND 27
INFORMATION FOR B-008-0-21 AND CAN BE FOUND ON SHEET 5 AND 13
INFORMATION FOR B-020-0-21 CAN BE FOUND ON SHEET 12



HORIZONTAL SCALE IN FEET
0 10 20 40

GEOTECHNICAL PROFILE -ROADWAY
BEGIN TO END WALL 5

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/AI
REVIEWER	BPA 02/13/23
PROJECT ID	104132
SUBSET / TOTAL	22 / 51
SHEET / TOTAL	P.300 / 329

CUY-14-6.93

MODEL: 104132_ZP701 PAPERSIZE: 34x22 (in.) DATE: 2/14/2023 TIME: 12:12:40 PM USER: mjasiewicz
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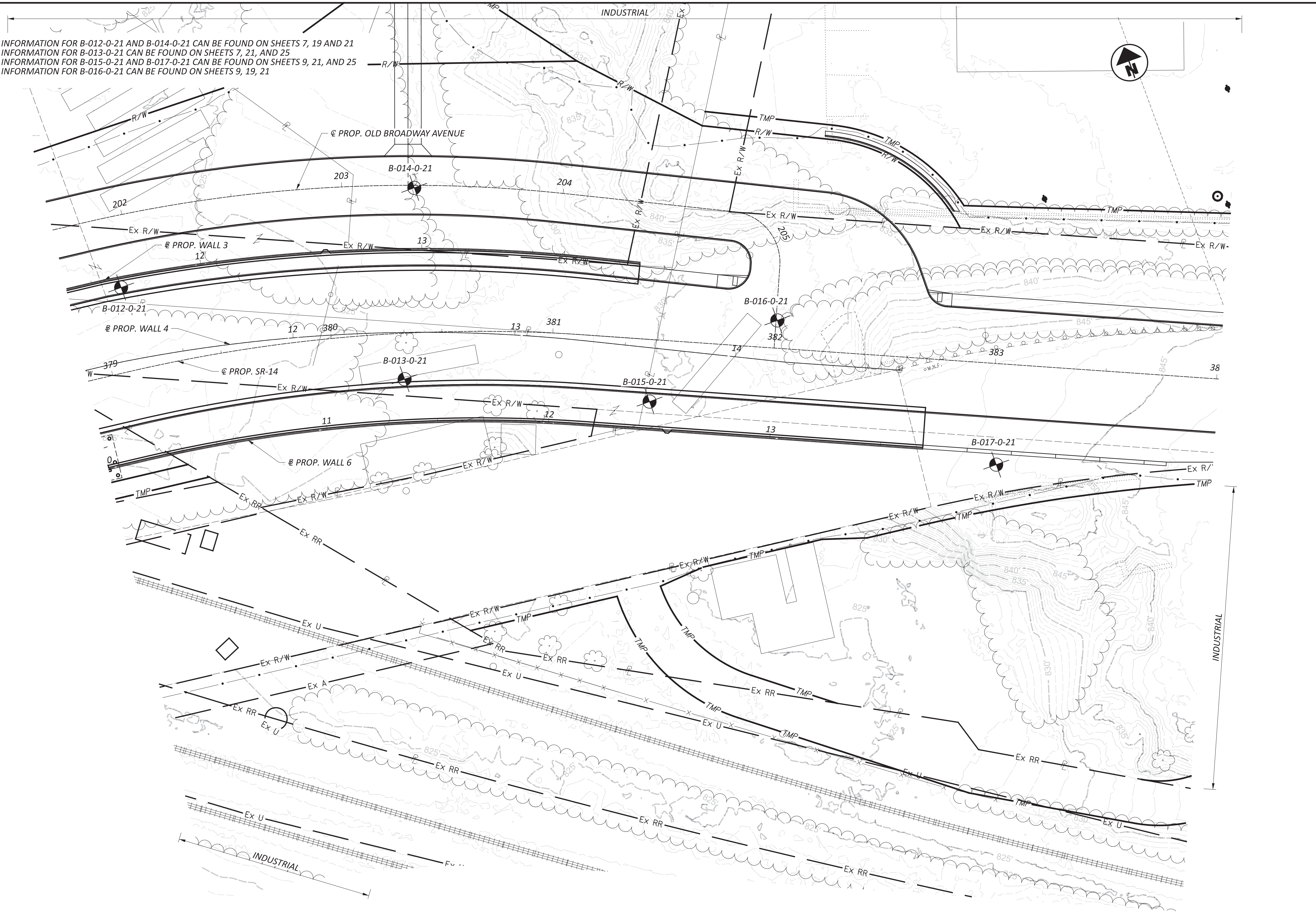
INFORMATION FOR B-012-0-21 AND B-014-0-21 CAN BE FOUND ON SHEETS 7, 19 AND 21
INFORMATION FOR B-013-0-21 CAN BE FOUND ON SHEETS 7, 21, AND 25
INFORMATION FOR B-015-0-21 AND B-017-0-21 CAN BE FOUND ON SHEETS 9, 21, AND 25
INFORMATION FOR B-016-0-21 CAN BE FOUND ON SHEETS 9, 19, 21



HORIZONTAL SCALE IN FEET
0 10 20 40

GEOTECHNICAL PROFILE -ROADWAY BEGIN TO END WALL 6

DESIGN AGENCY
NEAS
2800 CORPORATE EXCHANGE DR, SUITE 240 COLUMBUS, OH, 43231
TEL:614.714.0299
WWW.NEASINC.COM

DESIGNER
MWJ/AI
REVIEWER
BPA 02/13/23
PROJECT ID
104132
SUBSET 24 TOTAL 51
SHEET P.302 TOTAL 329

CUY-14-6.93

MODEL: 104132_ZP801 PAPERSIZE: 34x22 (in.) DATE: 2/14/2023 TIME: 12:13:17 PM USER: mjasiewicz
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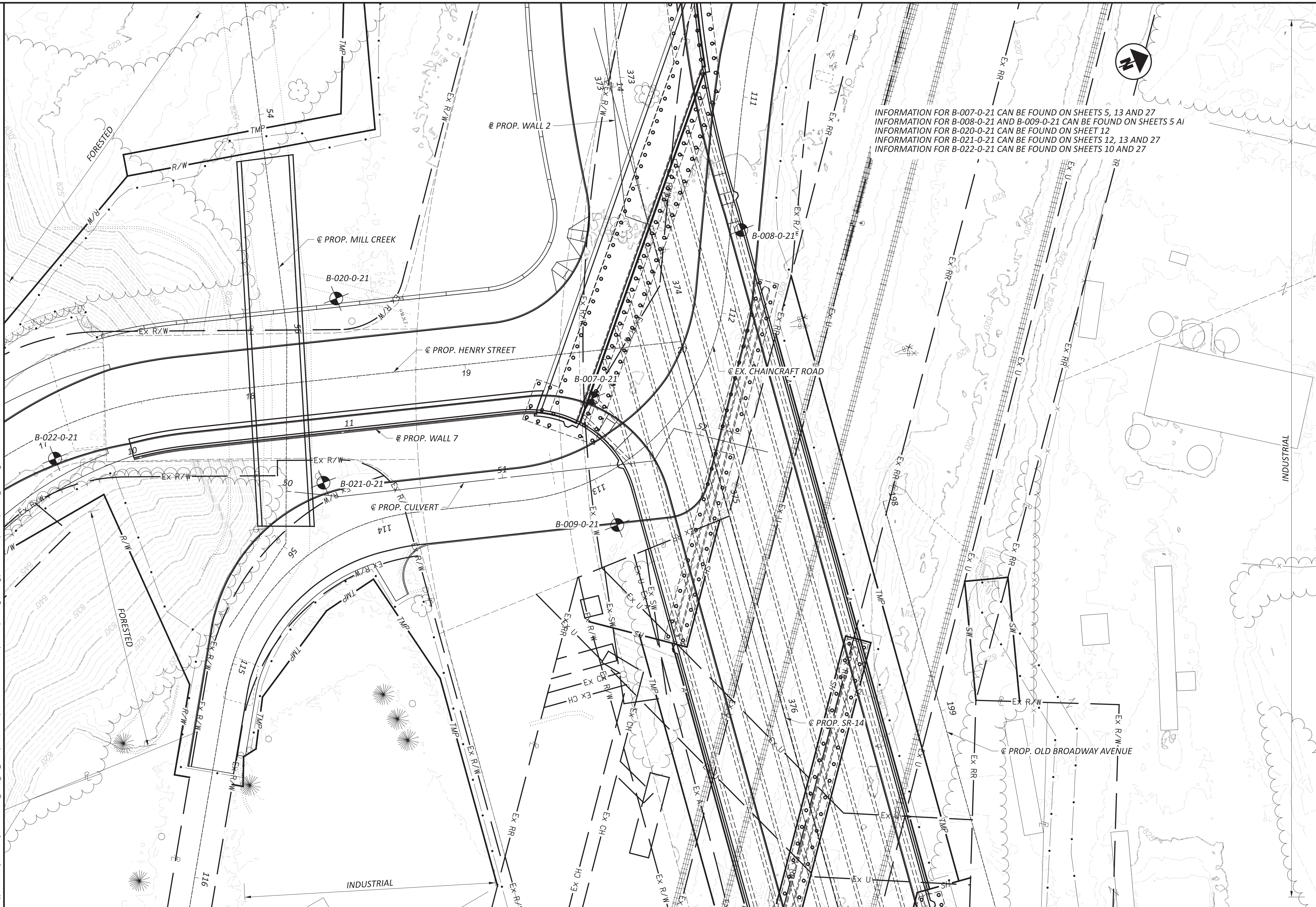

GEOTECHNICAL PROFILE -ROADWAY
BEGIN TO END WALL 7

DESIGN AGENCY
NEAS
2800 CORPORATE EXCHANGE DR, SUITE 240
COLUMBUS, OH, 43231
TEL:614.714.0299
WWW.NEASINC.COM

DESIGNER: MWJ/AI
REVIEWER: BPA 02/13/23
PROJECT ID: 104132
SUBSET 26 TOTAL 51
SHEET P.304 TOTAL 329

CUY-14-6.93

MODEL: 104132_ZP901 PAPERSIZE: 34x22 (in.) DATE: 2/14/2023 TIME: 12:13:40 PM USER: mjasiewicz
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APPENDIX B

BORING LOGS AND LABORATORY TESTING RESULTS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / ASHBAUGH	DRILL RIG: CME 55T	STATION / OFFSET: 368+69, 29' RT.	EXPLORATION ID B-001-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 831.3 (MSL) EOB: 61.5 ft.	PAGE 1 OF 2
START: 8/25/21 END: 8/25/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 68.4	LAT / LONG: 41.431969, -81.602477	

MATERIAL DESCRIPTION AND NOTES	ELEV. 831.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
7.0" ASPHALT AND 14.5" BASE (DRILLERS DESCRIPTION)	829.5																	
LOOSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, CONTAINS SLAG, DAMP **(FILL)**	827.4		4 4 5	10	100	SS-1	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
HARD, BROWN, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP	824.3		6 7 6	15	78	SS-2	4.25	4	8	21	46	21	23	16	7	15	A-4a (6)	
STIFF TO VERY STIFF, BROWN, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, DAMP TO MOIST			5 6 5	13	67	SS-3	3.50	-	-	-	-	-	-	-	-	17	A-6a (V)	
			4 5 6	13	67	SS-4	2.75	7	8	14	40	31	31	20	11	17	A-6a (8)	
			4 4 6	11	56	SS-5	2.75	-	-	-	-	-	-	-	-	18	A-6a (V)	
			4 3 4	8	44	SS-6	2.25	-	-	-	-	-	-	-	-	18	A-6a (V)	
			3 4 4	9	67	SS-7	2.25	6	10	17	38	29	30	19	11	17	A-6a (7)	
			3 5 5	11	78	SS-8	2.00	-	-	-	-	-	-	-	-	20	A-6a (V)	
@22.5' TO 26.5'; BECOMES GRAY MOTTLED WITH GRAY AND ORANGISH BROWN, CONTAINS IRON STAINING			6 8 7	17	78	SS-9	3.00	3	5	16	42	34	35	20	15	21	A-6a (10)	
	804.3		7 8 8	18	56	SS-10	2.50	-	-	-	-	-	-	-	-	22	A-6a (V)	
DENSE, DARK GRAY, **SANDY SILT**, LITTLE GRAVEL, TRACE CLAY, CONTAINS TRACE ROOTS AND HIGHLY WEATHERED WOOD FRAGMENTS, SLIGHTLY ORGANIC, WET	801.8		7 12 15	31	56	SS-11	-	19	9	33	31	8	NP	NP	NP	24	A-4a (1)	

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 368+69, 29' RT.	START: 8/25/21	END: 8/25/21	PG 2 OF 2	B-001-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 801.3	DEPTHS
DENSE, GRAY AND LIGHT BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, MOIST *(continued)*	799.3	
STIFF TO VERY STIFF, MAROONISH GRAY, **SANDY SILT**, "AND" CLAY, TRACE GRAVEL, CONTAINS 1.0" SILT SEAMS, MOIST TO DAMP	794.3	
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET TO MOIST		W 793.1
@42.5'; ENCOUNTERED A SILTSTONE COBBLE/BOULDER		
		EOB

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
10 19 21	46	56	SS-12	-	-	-	-	-	-	-	-	-	10	A-1-b (V)
12 20 26	52	56	SS-13	1.75	10	3	3	48	36	26	17	9	21	A-4a (8)
17 24 31	63	44	SS-14	2.00	-	-	-	-	-	-	-	-	12	A-4a (V)
17 20 27	54	50	SS-15	-	-	-	-	-	-	-	-	-	17	A-1-b (V)
15 21 24	51	61	SS-16	-	-	-	-	-	-	-	-	-	15	A-1-b (V)
50/4"	-	25	SS-17	-	-	-	-	-	-	-	-	-	3	
17 22 31	60	67	SS-18	-	11	67	14	6	2	NP	NP	NP	15	A-1-b (0)
21 27 50	88	33	SS-19	-	-	-	-	-	-	-	-	-	14	A-1-b (V)
15 27 30	65	89	SS-20	-	-	-	-	-	-	-	-	-	16	A-1-b (V)
16 20 36	64	78	SS-21	-	-	-	-	-	-	-	-	-	9	A-1-b (V)

Depth scale: 31 – 61

NOTES: GROUNDWATER ENCOUNTERED AT 38.2' DURING DRILLING. HOLE DID NOT CAVE.

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

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 369+61, 36' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 813.0 (MSL) EOB: 40.0 ft.
START: 8/5/21 END: 8/5/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431962, -81.602068

EXPLORATION ID B-002-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 813.0	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
VERY LOOSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, TRACE TO LITTLE GRAVEL, TRACE CLAY, CONTAINS ROOTS AND TRACE IRON STAINING, WET		2 1 1	3	100	SS-1	-	-	-	-	-	-	-	-	-	18	A-3a (V)
	806.0	1 1 1	3	100	SS-2	-	-	-	-	-	-	-	-	-	28	A-3a (V)
MEDIUM DENSE, BROWN, **GRAVEL WITH SAND AND SILT**, TRACE CLAY, CONTAINS ROOTS AND TRACE IRON STAINING, MOIST	803.5	4 5 4	13	100	SS-3	-	30	14	29	21	6	NP	NP	NP	17	A-2-4 (0)
LOOSE TO DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, MOIST TO WET		1 2 5	10	100	SS-4	-	-	-	-	-	-	-	-	-	20	A-1-b (V)
		4 9 12	31	100	SS-5	-	-	-	-	-	-	-	-	-	14	A-1-b (V)
		10 8 10	27	100	SS-6	-	27	37	26	8	2	NP	NP	NP	13	A-1-b (0)
		8 11 13	36	39	SS-7	-	-	-	-	-	-	-	-	-	13	A-1-b (V)
		5 11 20	46	28	SS-8	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
@22.5'; SS-9 BECOMES VERY DENSE		15 16 20	53	50	SS-9	-	-	-	-	-	-	-	-	-	10	A-1-b (V)
		17 19 20	58	56	SS-10	-	38	39	15	6	2	NP	NP	NP	10	A-1-b (0)

DEPTHS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

BACK FILL

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 369+61, 36' LT.	START: 8/5/21	END: 8/5/21	PG 2 OF 2	B-002-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 783.0	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
LOOSE TO DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, MOIST TO WET *(continued)*		31	18 20 23	64	50	SS-11	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
		32																
		33																
		34																
		35 / 36	21 25 30	82	39	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		37																
		38																
	773.0	39 / EOB 40	23 29 32	90	67	SS-13	-	42	41	10	6	1	NP	NP	NP	11	A-1-b (0)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 50 GAL. BENTONITE GROUT; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 370+98, 14' RT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 813.2 (MSL) EOB: 45.0 ft.
START: 8/2/21 END: 8/2/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431652, -81.602046

EXPLORATION ID B-003-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 813.2
VERY LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, LITTLE TO SOME GRAVEL, TRACE CLAY, MOIST TO WET	803.7
DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS**, LITTLE TO SOME SAND, TRACE SILT, TRACE CLAY, WET TO MOIST @11.0'; ENCOUNTERED POSSIBLE COBBLE	796.2
DENSE, BROWN AND MAROONISH GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND AND SILT**, LITTLE CLAY, DAMP	794.3
DENSE, BROWN AND MAROONISH GRAY, **SANDY SILT**, LITTLE CLAY, TRACE TO LITTLE GRAVEL, DAMP	788.7
STIFF, MAROONISH GRAY, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST @25.0'; ENCOUNTERED HEAVE	787.7
DENSE, GRAY, **COARSE AND FINE SAND**, TRACE GRAVEL, TRACE SILT, TRACE CLAY, WET	784.9
DENSE TO VERY DENSE, GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST	

DEPTHS: W 802.2 (at approx. 11 ft)

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
2 4 4	12	83	SS-1	-	-	-	-	-	-	-	-	-	11	A-3a (V)
1 2 1	4	67	SS-2	-	-	-	-	-	-	-	-	-	18	A-3a (V)
1 1 1	3	78	SS-3	-	21	17	34	23	5	NP	NP	NP	17	A-3a (0)
1 12 35	70	22	SS-4	-	-	-	-	-	-	-	-	-	14	A-1-a (V)
13 10 11	31	56	SS-5	-	-	-	-	-	-	-	-	-	12	A-1-a (V)
18 12 16	42	89	SS-6	-	-	-	-	-	-	-	-	-	8	A-1-a (V)
13 11 10	31	89	SS-7	-	32	15	18	19	16	21	13	8	12	A-2-4 (0)
23 12 19	46	100	SS-8	-	17	10	30	28	15	NP	NP	NP	12	A-4a (2)
13 14 14	42	100	SS-9	-	4	14	26	39	17	NP	NP	NP	14	A-4a (4)
10 9 16	37	100	SS-10A	1.50	-	-	-	-	-	-	-	-	21	A-7-6 (V)
			SS-10B	-	-	-	-	-	-	-	-	-	18	A-3a (V)

MATERIAL DESCRIPTION AND NOTES	ELEV. 783.2	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
DENSE TO VERY DENSE, GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST *(continued)* @30.0' TO 45.0'; DIFFICULT DRILLING DUE TO COBBLES AND/OR BOULDERS		30–31.5	10 17 15	47	100	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		35–36.5	24 20 25	67	100	SS-12	-	24	40	23	10	3	NP	NP	NP	13	A-1-b (0)	
@40.0'; SS-13 CONTAINS NO RECOVERY		40–41.5	11 21 26	70	0	SS-13	-	-	-	-	-	-	-	-	-	-		
		43.5–45	9 23 28	76	44	SS-14	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
		EOB 45																

NOTES: GROUNDWATER ENCOUNTERED AT 11.0' DURING DRILLING. HOLE DID NOT CAVE. ENCOUNTERED HEAVE AT 25.0', USED WATER AS CIRCULATION FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 50 GAL. BENTONITE GROUT; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 371+23, 32' LT.	EXPLORATION ID B-004-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 812.9 (MSL) EOB: 45.0 ft.	PAGE 1 OF 2
START: 8/5/21 END: 8/5/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431688, -81.601606	

MATERIAL DESCRIPTION AND NOTES	ELEV. 812.9	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
VERY LOOSE TO LOOSE, BROWN, **SANDY SILT**, LITTLE GRAVEL, TRACE CLAY, MOIST																		
		3 – 4.5	2 / 1 / 1	3	78	SS-1	-	16	9	36	30	9	NP	NP	NP	17	A-4a (1)	
		5 – 6.5	1 / 2 / 4	9	67	SS-2	-	-	-	-	-	-	-	-	-	16	A-4a (V)	
LOOSE, BROWN, **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST	805.9	7																
		8 – 9.5	2 / 2 / 2	6	33	SS-3	-	32	17	30	17	4	NP	NP	NP	14	A-2-4 (0)	
MEDIUM DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET TO MOIST	803.4	9.5 (W 802.9)																
		10 – 11.5	8 / 10 / 11	31	56	SS-4	-	-	-	-	-	-	-	-	-	16	A-1-b (V)	
		13 – 14.5	3 / 9 / 14	34	100	SS-5	-	-	-	-	-	-	-	-	-	21	A-1-b (V)	
		15.5 – 17	9 / 9 / 10	28	100	SS-6	-	29	43	18	8	2	NP	NP	NP	14	A-1-b (0)	
		18 – 19.5	7 / 12 / 12	36	44	SS-7	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		20.5 – 22	6 / 13 / 19	47	44	SS-8	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
		23 – 24.5	13 / 14 / 18	47	44	SS-9	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
@25.0'; DIFFICULT DRILLING DUE TO POSSIBLE ENCOUNTER WITH COBBLES AND/OR BOULDERS		25.5 – 27	12 / 16 / 21	55	33	SS-10	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 371+23, 32' LT.	START: 8/5/21	END: 8/5/21	PG 2 OF 2	B-004-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 782.9	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
MEDIUM DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET TO MOIST *(continued)*		31	15 16 19	52	39	SS-11	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
		32																
		33																
		34																
		35																
		36	19 22 29	76	44	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		37																
		38																
		39																
		40																
		41	25 31 38	102	89	SS-13	-	35	55	6	3	1	NP	NP	NP	13	A-1-b (0)	
		42																
		43																
		44	32 35 41	113	83	SS-14	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	767.9	EOB 45																

NOTES: GROUNDWATER ENCOUNTERED AT 10.0' DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 50 GAL. BENTONITE GROUT; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 372+69, 18' RT.	EXPLORATION ID B-005-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 813.6 (MSL) EOB: 44.8 ft.	PAGE
START: 8/3/21 END: 8/4/21	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 89	LAT / LONG: 41.431413, -81.601611	1 OF 2

MATERIAL DESCRIPTION AND NOTES	ELEV. 813.6	DEPTHS
MEDIUM DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, SS-1 CONTAINS A 1.5" LIMESTONE FRAGMENT, DAMP	806.6	
VERY LOOSE TO MEDIUM DENSE, BROWN, **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP TO MOIST	801.6	W 803.1
MEDIUM DENSE TO DENSE, GRAY, **FINE SAND**, "AND" COARSE SAND, TRACE SILT, TRACE GRAVEL, TRACE CLAY, MOIST TO WET @17.5'; ENCOUNTERED HEAVE. PULLED AUGERS AND REDRILLED WITH A SLURRY MIX TO COMBAT HEAVE.	794.1	
DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, MOIST	789.1	
STIFF, GRAY, **SANDY SILT**, "AND" CLAY, TRACE GRAVEL, CONTAINS A 2.0" SILT SEAM, MOIST	785.3	
VERY DENSE, GRAY, **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST		

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
5 6 5	16	44	SS-1	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
		75	ST-2	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
1 4 4	12	100	SS-3	-	29	13	28	19	11	NP	NP	NP	12	A-2-4 (0)	
1 1 2	4	17	SS-4	-	-	-	-	-	-	-	-	-	18	A-2-4 (V)	
6 13 14	40	67	SS-5	-	-	-	-	-	-	-	-	-	17	A-3 (V)	
3 4 7	16	100	SS-6	-	3	43	44	8	2	NP	NP	NP	21	A-3 (0)	
14 12 13	37	100	SS-7	-	-	-	-	-	-	-	-	-	12	A-3 (V)	
5 15 17	47	56	SS-8	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
7 16 20	53	100	SS-9	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
13 14 8	33	39	SS-10	1.75	8	6	12	38	36	26	17	9	21	A-4a (8)	

PID: 104132 | SFN: | PROJECT: CUY-14-6.93 | STATION / OFFSET: 372+69, 18' RT. | START: 8/3/21 | END: 8/4/21 | PG 2 OF 2 | B-005-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 783.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY DENSE, GRAY, **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST *(continued)* @30.0' TO 44.8'; DIFFICULT DRILLING DUE TO COBBLES AND/OR BOULDERS		31	11 23 25	71	100	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		32																
		33																
		34																
		35																
		36	22 34 42	113	100	SS-12	-	34	34	16	12	4	NP	NP	NP	9	A-1-b (0)	
		37																
		38																
		39																
		40																
		41	12 16 25	61	100	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	771.3	42																
VERY DENSE, GRAY, **STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, STONE FRAGMENTS ARE LIMESTONE. POSSIBLE LIMESTONE COBBLE, MOIST		43																
	768.8	44 EOB	33 47 50/4"	-	44	SS-14	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 10.5' DURING DRILLING. HOLE DID NOT CAVE. ENCOUNTERED HEAVE AT 17.5'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 75 GAL. BENTONITE GROUT; POURED 2 BAGS HOLE PLUG

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 372+57, 41' LT.	EXPLORATION ID B-006-0-21
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN: 1081085	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 812.9 (MSL) EOB: 49.4 ft.	PAGE 1 OF 2
START: 8/9/21 END: 8/9/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431548, -81.601193	

MATERIAL DESCRIPTION AND NOTES	ELEV. 812.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, LITTLE GRAVEL, TRACE CLAY, CONTAINS ROOTS, MOIST TO WET		3	3 5 3	12	22	SS-1	-	-	-	-	-	-	-	-	-	14	A-3a (V)	
		5	1 2 2	6	44	SS-2	-	-	-	-	-	-	-	-	-	19	A-3a (V)	
MEDIUM DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, CONTAINS 1.5" STONE FRAGMENTS, WET TO MOIST	805.9	7.5	1 4 5	13	39	SS-3	-	44	14	24	16	2	NP	NP	NP	14	A-1-b (0)	
@10.0' TO 49.4'; ENCOUNTERED COBBLES DURING DRILLING	803.2	W 802.9 / 10	6 16 35	76	100	SS-4	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		12.5	8 34 15	73	100	SS-5	-	21	45	17	14	3	NP	NP	NP	11	A-1-b (0)	
DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE GRAVEL, TRACE CLAY, WET	798.4	15	19 10 14	36	50	SS-6	-	-	-	-	-	-	-	-	-	18	A-3a (V)	
DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET TO MOIST	795.9	17.5	12 17 16	49	78	SS-7	-	-	-	-	-	-	-	-	-	16	A-1-b (V)	
		20	7 16 22	56	100	SS-8	-	30	38	20	9	3	NP	NP	NP	11	A-1-b (0)	
VERY DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE GRAVEL, TRACE SILT, TRACE CLAY, MOIST	790.9	22.5	9 17 20	55	89	SS-9	-	-	-	-	-	-	-	-	-	13	A-3a (V)	
	788.4	25	33 50	-	83	SS-10	-	58	14	10	15	3	NP	NP	NP	10	A-1-b (0)	

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 372+57, 41' LT.	START: 8/9/21	END: 8/9/21	PG 2 OF 2	B-006-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 782.9	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
@10.0' TO 49.4'; ENCOUNTERED COBBLES DURING DRILLING *(continued)*		31	2 8 50/3"	-	80	SS-11	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST *(continued)*	779.6	32–34																
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME TO "AND" SAND, LITTLE SILT, TRACE CLAY, DAMP TO MOIST		35–36	10 22 28	74	100	SS-12	-	51	23	13	11	2	NP	NP	NP	9	A-1-a (0)	
		37–39																
		40–41	18 23 31	80	89	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-a (V)	
		42–44																
		45–46	17 26 27	79	89	SS-14	-	-	-	-	-	-	-	-	-	12	A-1-a (V)	
		47–48																
	763.5	EOB 49	38 50/5"	-	82	SS-15	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 10.0' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 374+39, 46' RT.	EXPLORATION ID B-007-0-21
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN: 1081085	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 815.2 (MSL) EOB: 50.0 ft.	PAGE 1 OF 2
START: 8/10/21 END: 8/10/21	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 89	LAT / LONG: 41.431220, -81.600616	

MATERIAL DESCRIPTION AND NOTES	ELEV. 815.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY LOOSE, BROWN AND GRAY BECOMING GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, WET TO DAMP		3–4.5	4 1 2	4	17	SS-1	-	-	-	-	-	-	-	-	-	18	A-1-b (V)	
		5–6.5	1 1 1	3	28	SS-2	-	-	-	-	-	-	-	-	-	16	A-1-b (V)	
		7.5–9			83	ST-3	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
@9.0'; BECOMES VERY DENSE. DIFFICULT DRILLING DUE TO COBBLES AND/OR BOULDERS		W 805.7 (9–10.5)	8 21 29	74	33	SS-4	-	37	23	23	13	4	NP	NP	NP	16	A-1-b (0)	
		12.5–14	6 25 33	86	67	SS-5	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		15–16.5	27 24 29	79	100	SS-6	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
		17.5–19	20 21 26	70	100	SS-7	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		20–21.5	15 17 22	58	39	SS-8	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		22.5–24	18 24 25	73	44	SS-9	-	32	41	15	8	4	NP	NP	NP	10	A-1-b (0)	
		25–26.5	13 27 31	86	100	SS-10	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	786.9	28.3																

MATERIAL DESCRIPTION AND NOTES	ELEV. 785.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
@9.0'; BECOMES VERY DENSE. DIFFICULT DRILLING DUE TO COBBLES AND/OR BOULDERS *(continued)* VERY DENSE, GRAY AND DARK GRAY, **STONE FRAGMENTS**, LITTLE SAND, TRACE SILT, TRACE CLAY, STONE FRAGMENTS ARE LIMESTONE, POSSIBLE LIMESTONE COBBLE/BOULDER, MOIST *(continued)*		31	21 50	-	31	SS-11	-	-	-	-	-	-	-	-	-	13	A-1-a (V)
	781.9	32, 33															
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP TO MOIST		34, 35, 36	24 25 50	111	78	SS-12	-	35	37	15	9	4	NP	NP	NP	9	A-1-b (0)
		37, 38, 39, 40, 41	30 32 37	102	100	SS-13	-	29	38	17	10	6	NP	NP	NP	11	A-1-b (0)
		42, 43, 44, 45, 46	26 29 35	95	83	SS-14	-	-	-	-	-	-	-	-	-	12	A-1-b (V)
		47, 48, 49	21 32 35	99	100	SS-15	-	31	36	20	10	3	NP	NP	NP	9	A-1-b (0)
	765.2	EOB 50															

NOTES: GROUNDWATER ENCOUNTERED AT 9.5' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS BENTONITE CHIPS; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / JL	DRILL RIG: CME 55T	STATION / OFFSET: 378+05, 45' LT.
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / JL	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN: 1081085	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 821.6 (MSL) EOB: 50.0 ft.
START: 8/24/21 END: 8/24/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 68.4	LAT / LONG: 41.431345, -81.599251

EXPLORATION ID: B-010-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 821.6	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
5.0" LIMESTONE #57 GRAVEL (DRILLERS DESCRIPTION)	821.2																	
VERY STIFF, BROWN, **SILTY CLAY**, SOME SAND, SOME GRAVEL, CONTAINS BRICK FRAGMENTS, DAMP **(FILL)**	817.1		7-3-4	8	44	SS-1	2.25	25	14	13	18	30	39	21	18	18	A-6b (5)	
VERY STIFF, BROWN, **CLAY**, SOME SILT, LITTLE SAND, TRACE GRAVEL, MOIST	814.6		3-3-3	7	50	SS-2	2.75	10	9	5	22	54	48	23	25	25	A-7-6 (16)	
MEDIUM STIFF TO VERY STIFF, BROWN AND GRAY, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, CONTAINS IRON STAINING, MOIST			0-2-2	5	78	SS-3	0.75	6	7	28	39	20	30	18	12	24	A-6a (6)	
	809.6		0-2-4	7	72	SS-4	2.25	-	-	-	-	-	-	-	-	25	A-6a (V)	
DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL**, SOME SAND, LITTLE SILT, TRACE CLAY, MOIST TO WET		W 808.4	5-13-15	32	67	SS-5	-	-	-	-	-	-	-	-	-	17	A-1-a (V)	
			8-15-18	38	56	SS-6	-	55	19	11	12	3	NP	NP	NP	10	A-1-a (0)	
	802.1		9-21-26	54	61	SS-7	-	-	-	-	-	-	-	-	-	14	A-1-a (V)	
VERY DENSE, BROWN AND GRAY, **COARSE AND FINE SAND**, LITTLE GRAVEL, TRACE SILT, TRACE CLAY, MOIST	799.6		19-25-27	59	56	SS-8	-	-	-	-	-	-	-	-	-	14	A-3a (V)	
DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO WET			21-20-23	49	44	SS-9	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
			22-24-27	58	28	SS-10	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	

DEPTHS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 378+05, 45' LT.	START: 8/24/21	END: 8/24/21	PG 2 OF 2	B-010-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 791.6	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
DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO WET *(continued)*		31	10 22 25	54	33	SS-11	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
		32																
		33																
		34																
		35																
		36	15 28 33	70	39	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		37																
		38																
		39																
		40																
		41	15 26 32	66	72	SS-13	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		42																
		43																
		44																
		45																
		46	29 31 36	76	94	SS-14	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
		47																
		48																
		49	35 20 31	58	56	SS-15	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	771.6	EOB 50																

NOTES: GROUNDWATER ENCOUNTERED AT 13.2' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 55X	STATION / OFFSET: 378+84, 31' RT.
TYPE: BRIDGE	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN: 1081085	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 823.5 (MSL) EOB: 59.7 ft.
START: 8/30/21 END: 8/30/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 81.9	LAT / LONG: 41.431112, -81.598998

EXPLORATION ID B-011-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 823.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY LOOSE, WHITE, **SANDY SILT**, TRACE CLAY, TRACE GRAVEL, **UNTESTABLE MATERIAL. RESEMBLES LIME**, MOIST **(FILL)**		2.5–4	0 0 0	0	100	SS-1	-	-	-	-	-	-	-	-	-	-	A-4a (V)	
	819.0	4.5																
MEDIUM DENSE TO DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO MOIST		5–6.5	3 7 8	20	28	SS-2	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		7.5–9	5 10 12	30	22	SS-3	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		10–11.5	8 17 18	48	39	SS-4	-	18	33	31	14	4	NP	NP	NP	11	A-1-b (0)	
@12.5'; BECOMES VERY DENSE. DIFFICULT DRILLING DUE TO COBBLES AND/OR BOULDERS		12.5–14	8 20 28	66	22	SS-5	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		15–16.5	7 13 29	57	39	SS-6	-	44	27	11	13	5	NP	NP	NP	11	A-1-b (0)	
		17.5–19	20 29 33	85	28	SS-7	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		20–21.2	14 30 50/2"	-	64	SS-8	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		22.5–24	15 37 49	117	22	SS-9	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
@25.0'; SS-10 CONTAINS NO RECOVERY		25–26.2	35 47 50/2"	-	0	SS-10	-	-	-	-	-	-	-	-	-	-		

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 2/20/24 09:29 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2021 ARCHIVE\CUY-14-6.93\GINT FILES\CUY-14

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 378+84, 31' RT.	START: 8/30/21	END: 8/30/21	PG 2 OF 2	B-011-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 793.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
MEDIUM DENSE TO DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO MOIST *(continued)*		30-31	43 50/5"	-	45	SS-11	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		35-36.5	30 39 44	113	22	SS-12	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		40-41	40 50/4"	-	30	SS-13	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
		45-46	35 42 50/2"	-	21	SS-14	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
		50-51.5	20 37 44	111	44	SS-15	-	48	29	12	8	3	NP	NP	NP	9	A-1-b (0)	
		55-56	33 50/4"	-	70	SS-16	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
	763.8	58.8-59.7 EOB	32 39 50/2"	-	29	SS-17	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AT 10.0' TO COMBAT HEAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 100 GAL. BENTONITE GROUT; POURED 1 BAG HOLE PLUG; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 379+12, 38' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 821.4 (MSL) EOB: 50.0 ft.
START: 8/17/21 END: 8/17/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431290, -81.598864

EXPLORATION ID B-012-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 821.4
VERY DENSE, GRAY AND BROWN, **STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, CONTAINS 2.0" SLAG FRAGMENTS, WET TO MOIST **(FILL)** @5.0'; CHANGES TO VERY LOOSE	814.4
STIFF, BROWN, **SILT AND CLAY**, LITTLE SAND, TRACE GRAVEL, MOIST	811.9
VERY LOOSE, GRAY AND BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, LITTLE SILT, TRACE CLAY, WET	809.4
LOOSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, WET TO DAMP @12.0' TO 50.0'; ENCOUNTERED COBBLES DURING DRILLING @15.0' TO 29.0'; BECOMES DENSE TO VERY DENSE	791.9

DEPTHS: W 811.4 (at 10 ft)

DEPTH (ft)	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
2.5–4	6 11 24	52	83	SS-1	-	48	20	12	11	9	NP	NP	NP	14	A-1-b (0)
5–6.5	6 1 1	3	17	SS-2	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
7.5–9	1 2 2	6	11	SS-3	1.75	-	-	-	-	-	-	-	-	20	A-6a (V)
10–11.5	0 0 0	0	67	SS-4	-	-	-	-	-	-	-	-	-	25	A-3a (V)
12.5–14	1 3 4	10	44	SS-5	-	-	-	-	-	-	-	-	-	16	A-1-b (V)
15–16.5	4 15 15	45	28	SS-6	-	-	-	-	-	-	-	-	-	18	A-1-b (V)
17.5–19	12 14 15	43	100	SS-7	-	46	24	11	15	4	NP	NP	NP	10	A-1-b (0)
20–21.5	10 12 15	40	56	SS-8	-	-	-	-	-	-	-	-	-	12	A-1-b (V)
22.5–24	20 16 19	52	39	SS-9	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
25–26.5	20 21 26	70	33	SS-10	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
27.5–29	15 19 21	59	33	SS-11	-	-	-	-	-	-	-	-	-	7	A-1-b (V)

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

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 379+12, 38' LT.	START: 8/17/21	END: 8/17/21	PG 2 OF 2	B-012-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 791.4	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
@12.0' TO 50.0'; ENCOUNTERED COBBLES DURING DRILLING *(continued)* VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, DAMP *(continued)*		31	9 25 26	76	28	SS-12	-	67	17	9	6	1	NP	NP	NP	7	A-1-a (0)	
		35–36	11 32 35	99	56	SS-13	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	
	783.1	38																
VERY DENSE, GRAY, **SANDY SILT**, TRACE GRAVEL, TRACE CLAY, WET		40–41	19 25 30	82	89	SS-14	-	7	20	36	35	2	NP	NP	NP	18	A-4a (0)	
	778.1	43																
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, MOIST		45–46	33 34 32	98	50	SS-15	-	42	26	24	7	1	NP	NP	NP	11	A-1-b (0)	
	774.1	47																
VERY DENSE, GRAY, **STONE FRAGMENTS**, TRACE SAND, TRACE SILT, TRACE CLAY, MOIST		49	37 26 30	83	44	SS-16	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	
	771.4	EOB 50																

NOTES: GROUNDWATER ENCOUNTERED AT 10.0' DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 380+32, 21' RT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 826.7 (MSL) EOB: 50.0 ft.
START: 8/12/21 END: 8/12/21	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 89	LAT / LONG: 41.431063, -81.598479

EXPLORATION ID B-013-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 826.7	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 VERY DENSE, BROWN AND BLACK, **SANDY SILT**, LITTLE GRAVEL, LITTLE CLAY, CONTAINS BRICK FRAGMENTS AND TRACE IRON STAINING, DAMP **(FILL)**		1–2																
		3–4	9 17 22	58	72	SS-1	-	-	-	-	-	-	-	-	-	12	A-4a (V)	
	819.2	5–7	4 5 5	15	39	SS-2	-	20	19	20	21	20	23	16	7	14	A-4a (1)	
HARD, GRAYISH BROWN, **CLAY**, SOME SILT, TRACE GRAVEL, TRACE SAND, MOIST	817.2	8–9			79	ST-3	4.25	5	2	1	27	65	43	23	20	25	A-7-6 (13)	
VERY DENSE, BROWN, **STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, STONE FRAGMENTS ARE SANDSTONE, CONTAINS IRON STAINING, DAMP	814.9	10–11	11 24 22	68	44	SS-4	-	-	-	-	-	-	-	-	-	7	A-1-b (V)	
LOOSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, TRACE CLAY, TRACE GRAVEL, CONTAINS TRACE IRON STAINING, WET	812.2	12–14	3 2 2	6	78	SS-5	-	-	-	-	-	-	-	-	-	17	A-3a (V)	
MEDIUM DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, MOIST TO WET		W 811.7; 15–17	4 9 9	27	44	SS-6	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
@17.5' TO 50.0'; ENCOUNTERED COBBLES DURING DRILLING		18–19	7 15 21	53	100	SS-7	-	28	44	14	10	4	NP	NP	NP	12	A-1-b (0)	
		20–22	14 15 19	50	33	SS-8	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		23–24	10 13 20	49	44	SS-9	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		25–27	11 16 22	56	72	SS-10	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
		28–29	14 19 23	62	39	SS-11	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 380+32, 21' RT.	START: 8/12/21	END: 8/12/21	PG 2 OF 2	B-013-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 796.7	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 VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, MOIST TO WET *(continued)*		31	15 21 26	70	50	SS-12	-	36	44	10	9	1	NP	NP	NP	12	A-1-b (0)	
		32																
		33																
		34																
		35–36	17 28 29	85	33	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		37																
		38																
		39																
		40–41	13 15 20	52	39	SS-14	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		42																
		43																
		44																
		45–46	19 20 22	62	50	SS-15	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
	778.9	47																
VERY STIFF, GRAYISH BROWN AND MAROON, **SANDY SILT**, SOME CLAY, LITTLE GRAVEL, MOIST		48																
	776.7	49–50 EOB	14 15 33	71	50	SS-16	2.75	11	16	16	36	21	20	14	6	15	A-4a (4)	

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

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 380+40, 65' LT.	EXPLORATION ID B-014-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 827.2 (MSL) EOB: 50.0 ft.	PAGE 1 OF 2
START: 8/13/21 END: 8/13/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.431281, -81.598355	

MATERIAL DESCRIPTION AND NOTES	ELEV. 827.2	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 VERY DENSE, GRAY AND BROWN, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, WET TO MOIST			7 12 19	46	56	SS-1	-	41	21	27	8	3	NP	NP	NP	14	A-1-b (0)	
			6 10 14	36	44	SS-2	-	52	17	19	9	3	NP	NP	NP	12	A-1-b (0)	
			8 19 23	62	67	SS-3	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
	821.7		3 5 6	16	83	SS-4A	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
VERY STIFF, BROWN, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, MOIST						SS-4B	2.75	-	-	-	-	-	-	-	-	29	A-7-6 (V)	
	820.2		4 4 3	10	78	SS-5A	3.00	3	3	4	29	61	45	21	24	23	A-7-6 (15)	
LOOSE, BROWN, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, DAMP	819.2					SS-5B	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
VERY DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS**, TRACE SAND, TRACE SILT, TRACE CLAY, POSSIBLE ENCOUNTER WITH COBBLE, DAMP	816.7		10 18 20	56	56	SS-6	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
STIFF, BROWN AND ORANGISH BROWN, **SANDY SILT**, LITTLE CLAY, LITTLE GRAVEL, CONTAINS IRON STAINING, MOIST	813.6		5 6 6	18	56	SS-7	1.25	11	23	28	23	15	24	14	10	17	A-4a (1)	
MEDIUM DENSE, BROWN AND GRAY, **COARSE AND FINE SAND**, SOME SILT, LITTLE CLAY, LITTLE GRAVEL, MOIST	811.7		3 7 11	27	33	SS-8	-	-	-	-	-	-	-	-	-	10	A-3a (V)	
DENSE TO VERY DENSE, GRAY, **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST TO WET @15.5' TO 50.0'; DIFFICULT DRILLING/ENCOUNTERED COBBLES DURING DRILLING			9 15 20	52	78	SS-9	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
			16 21 21	62	22	SS-10	-	-	-	-	-	-	-	-	-	18	A-1-b (V)	
			11 12 21	49	50	SS-11	-	13	60	15	8	4	NP	NP	NP	14	A-1-b (0)	
	799.7		10 18 20	56	56	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
VERY DENSE, BROWN BECOMING GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, MOIST																		

DEPTHS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

MATERIAL DESCRIPTION AND NOTES	ELEV. 797.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY DENSE, BROWN BECOMING GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, MOIST *(continued)*		30–31.5	15 19 20	58	28	SS-13	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
		35–36.5	18 22 27	73	39	SS-14	-	64	20	7	7	2	NP	NP	NP	8	A-1-a (0)	
		40–41.5	14 20 21	61	28	SS-15	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	
	780.7	45–46.5	21 24 25	73	44	SS-16	-	-	-	-	-	-	-	-	-	10	A-1-a (V)	
VERY STIFF, MAROONISH GRAY, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, DAMP	778.4	48.5–49	17 20 30	74	44	SS-17A	2.25	-	-	-	-	-	-	-	-	12	A-7-6 (V)	
VERY DENSE, GRAY, **COARSE AND FINE SAND**, TRACE GRAVEL, TRACE SILT, TRACE CLAY, MOIST	777.2	49–50 EOB				SS-17B	-	-	-	-	-	-	-	-	-	11	A-3a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 2/20/24 09:29 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2021 ARCHIVE\CUY-14-6.93\GINT FILES\CUY-14

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 381+46, 28' RT.	EXPLORATION ID B-015-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 829.0 (MSL) EOB: 45.0 ft.	PAGE 1 OF 2
START: 8/11/21 END: 8/11/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 89	LAT / LONG: 41.430932, -81.598114	

MATERIAL DESCRIPTION AND NOTES	ELEV. 829.0	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
VERY LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, LITTLE SILT, TRACE CLAY, MOIST		3–4.5	3 5 4	13	100	SS-1	-	-	-	-	-	-	-	-	-	8	A-3a (V)	
		5–6.5	1 1 2	4	89	SS-2	-	18	22	34	16	10	NP	NP	NP	11	A-3a (0)	
VERY STIFF, BROWN, **CLAY**, "AND" SILT, LITTLE SAND, TRACE GRAVEL, MOIST	822.0	7.5–9	1 1 3	6	100	SS-3	3.50	-	-	-	-	-	-	-	-	27	A-7-6 (V)	
		10–11.5	1 2 3	7	100	SS-4	3.25	1	7	10	40	42	50	23	27	30	A-7-6 (17)	
MEDIUM DENSE TO VERY DENSE, BROWN BECOMING GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, WET TO DAMP	817.0	W 816.5; 12.5–14	14 19 20	58	44	SS-5	-	57	22	11	8	2	NP	NP	NP	8	A-1-a (0)	
@15.0' - 45.0'; ENCOUNTERED COBBLES DURING DRILLING		15–16.5	13 10 7	25	28	SS-6	-	-	-	-	-	-	-	-	-	17	A-1-a (V)	
		17.5–19	9 22 24	68	56	SS-7	-	-	-	-	-	-	-	-	-	16	A-1-a (V)	
		20–21.5	15 27 28	82	100	SS-8	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	
		25–26.5	18 20 25	67	100	SS-9	-	64	19	9	6	2	NP	NP	NP	8	A-1-a (0)	

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 2/20/24 09:29 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2021 ARCHIVE\CUY-14-6.93\GINT FILES\CUY-14

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 381+46, 28' RT.	START: 8/11/21	END: 8/11/21	PG 2 OF 2	B-015-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 799.0	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 TO VERY DENSE, BROWN BECOMING GRAY, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, WET TO DAMP *(continued)*		31	17 23 21	65	100	SS-10	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
		35	21 50/2"	-	25	SS-11	-	-	-	-	-	-	-	-	-	2	A-1-a (V)	
		40–41	23 24 27	76	22	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	
	784.0	44–45 EOB	22 26 31	85	17	SS-13	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 12.5' DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 3 BAGS HOLE PLUG; SHOVELED SOIL CUTTINGS

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 75T	STATION / OFFSET: 382+01, 13' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 5/1/19	ELEVATION: 831.0 (MSL) EOB: 35.0 ft.
START: 8/11/21 END: 8/11/21	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 89	LAT / LONG: 41.430972, -81.597870

EXPLORATION ID B-016-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 831.0	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
DENSE, BLACK AND BROWN, **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, SLIGHTLY ORGANIC, MOIST	829.5	6-14-11	37	83	SS-1	-	42	20	16	16	6	NP	NP	NP	11	A-1-b (0)
MEDIUM STIFF TO VERY STIFF, BROWN AND GRAY, **CLAY**, LITTLE TO "AND" SILT, TRACE TO LITTLE SAND, TRACE GRAVEL, CONTAINS IRON STAINING, MOIST TO DAMP		2-3-4	10	100	SS-2	2.75	5	8	7	37	43	49	22	27	24	A-7-6 (17)
		1-2-3	7	56	SS-3	2.00	-	-	-	-	-	-	-	-	28	A-7-6 (V)
		1-2-1	4	100	SS-4	0.75	3	2	2	21	72	52	24	28	29	A-7-6 (18)
		1-1-2	4	100	SS-5	1.00	-	-	-	-	-	-	-	-	31	A-7-6 (V)
@7.8' TO 8.3'; Qu = 1409 PSF @ 13.5%				77	ST-6	3.50	0	1	1	17	81	54	24	30	32	A-7-6 (19)
		2-2-1	4	100	SS-7	2.00	-	-	-	-	-	-	-	-	27	A-7-6 (V)
	816.5	3-5-6	16	100	SS-8	2.75	-	-	-	-	-	-	-	-	22	A-7-6 (V)
MEDIUM DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND AND SILT**, TRACE CLAY, CONTAINS IRON STAINING, DAMP	814.0	5-7-7	21	89	SS-9	-	51	18	10	13	8	26	18	8	11	A-2-4 (0)
DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS**, "AND" SAND, TRACE SILT, TRACE CLAY, DAMP TO MOIST		6-13-17	45	72	SS-10	-	-	-	-	-	-	-	-	-	11	A-1-a (V)
		5-19-21	59	83	SS-11	-	50	31	11	7	1	NP	NP	NP	9	A-1-a (0)
		22-39-43	122	100	SS-12	-	-	-	-	-	-	-	-	-	8	A-1-a (V)

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 2/20/24 09:29 - X:\ACTIVE PROJECTS\ACTIVE SOIL PROJECTS\1ARCHIVE\ARCHIVE BY YEAR\2021 ARCHIVE\CUY-14-6.93\GINT FILES\CUY-14

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 382+01, 13' LT.	START: 8/11/21	END: 8/11/21	PG 2 OF 2	B-016-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 801.0	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
DENSE TO VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS**, "AND" SAND, TRACE SILT, TRACE CLAY, DAMP TO MOIST *(continued)*		31	17 29 29	86	89	SS-13	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		32																
		33																
		34	20 27 33	89	44	SS-14	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
	796.0	EOB 35																

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AS CIRCULATING FLUID.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 2 BAGS BENTONITE CHIPS; SHOVELED SOIL CUTTINGS

National Engineering & Architectural Services Inc.

5710 Westbourne Avenue
Columbus, OH 43213
614.892.0162

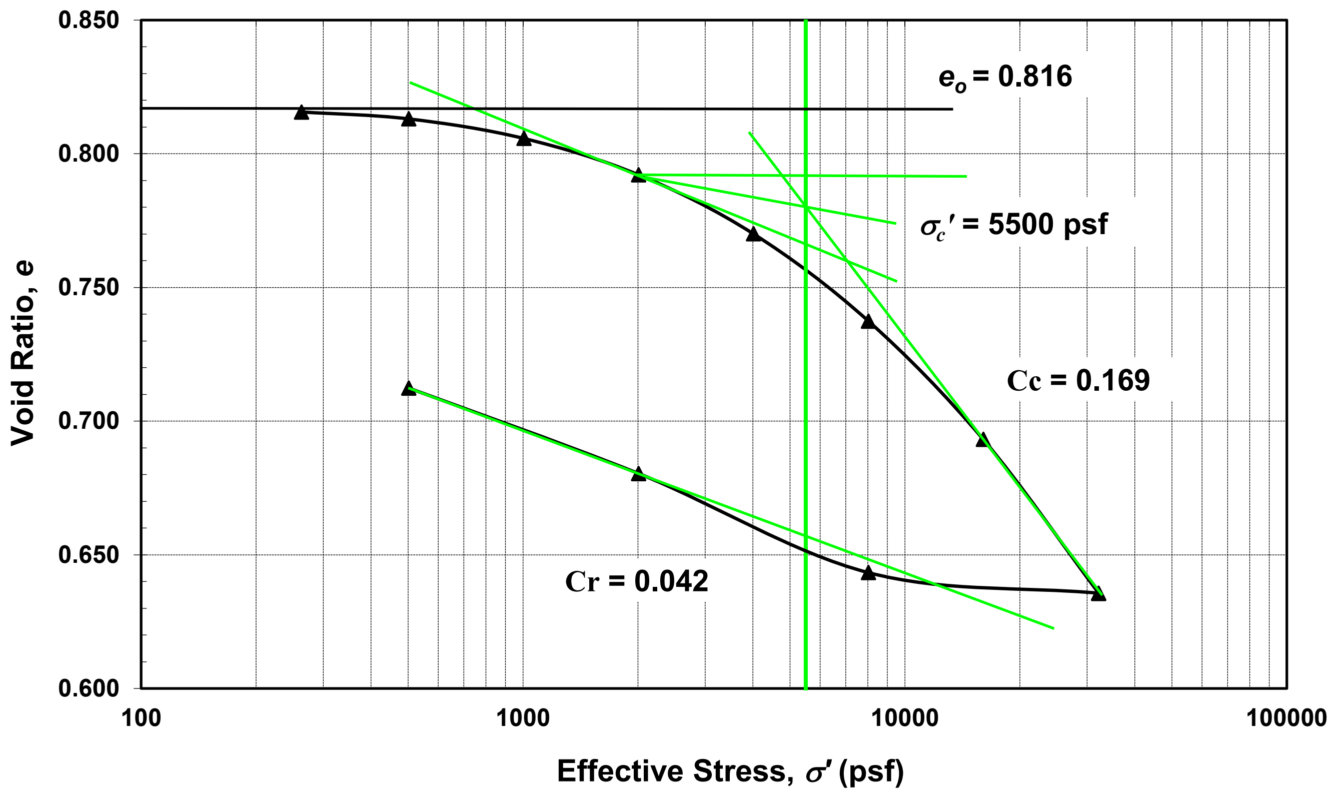
Consolidation Test

Project Name:	CUY-14-6.93	Prepared by:	LR
Source:	B-016-0-21 ST-6 (8.9'-9.0')	Checked by:	ZM
Description:	Medium stiff, grayish brown, CLAY, little silt, trace sand, trace gravel, moist. Please note that a 200g seating load was required to prevent swelling.	Date:	10/13/2021
Test Specification:	ASTM D 2435		
Initial Void Ratio:	0.816	Initial Bulk Unit Weight (lb/ft^3):	122
In-situ Vertical Effective Stress (psf):	1100	Dry Unit Weight (lb/ft^3):	93

Compression and Swelling Index

Compression Index (*Cc*):	0.169	Preconsolidation Pressure (σ_c') (psf):	**5500**
Recompression Index (*Cr*):	0.042	Over-Consolidation Ratio (*OCR*):	**5.00**

Consolidation Curve



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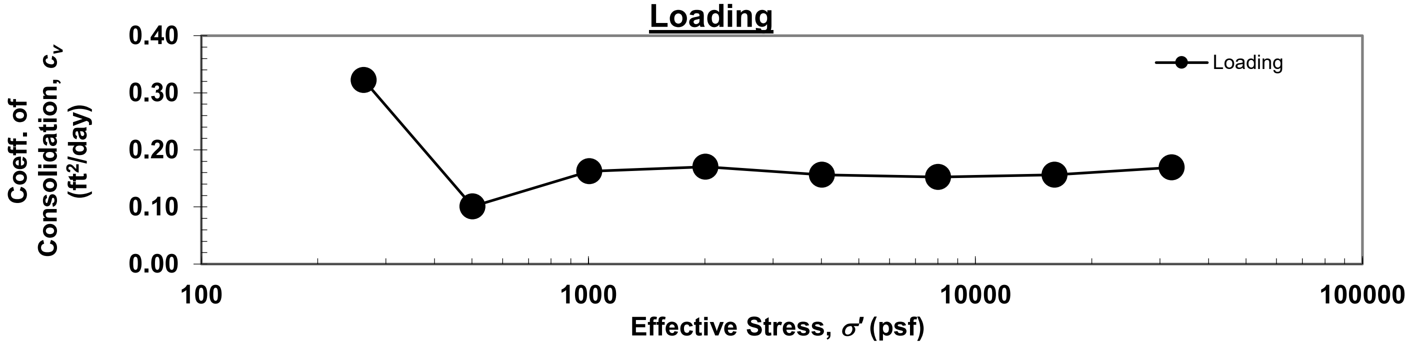

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Unconfined Compressive Strength of Cohesive Soil (ASTM D2166)

(Project: CUY-14-6.93, Boring Location: B-016-0-21, ST-6, Depth: 7.8 - 8.3ft)

Tested Date: 9/29/2021

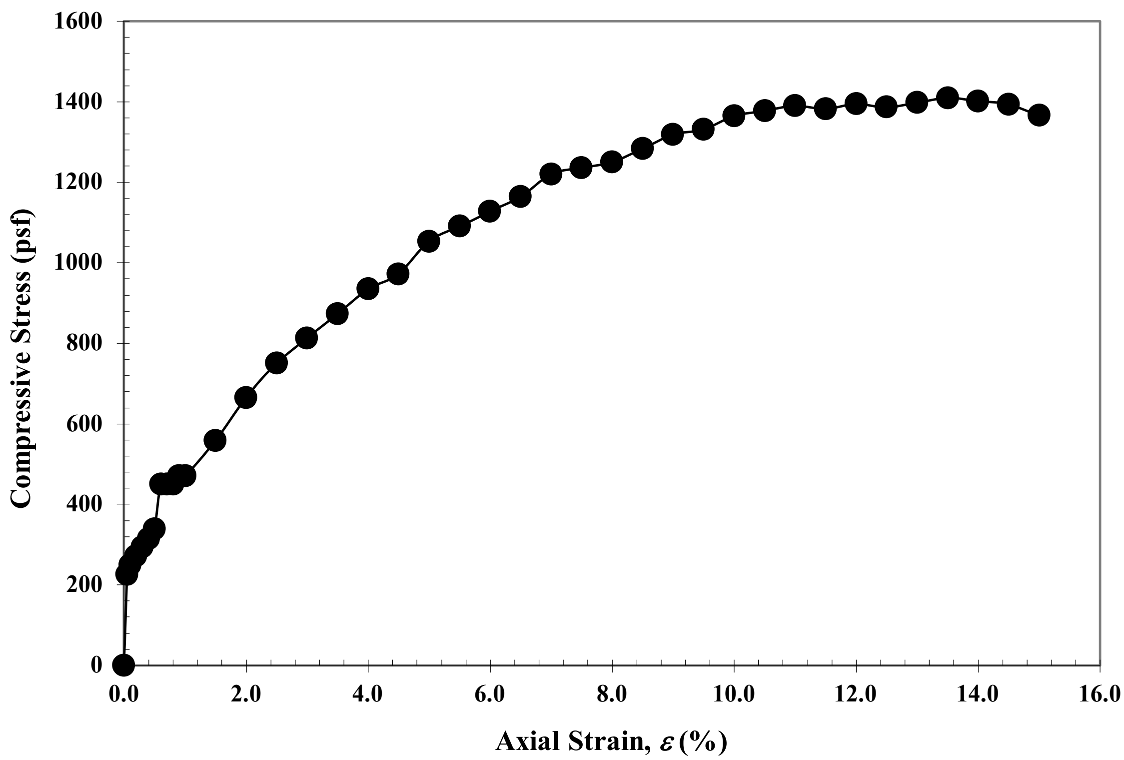
Specimen Properties

Average Dia., D_{avg} (in):	2.85
Average Height, H_{avg} (in):	5.73
Area, A (in^2):	6.36
Volume, V (in^3):	36.45
Wet Mass of Specimen (lb):	2.6
Moisture Content (%):	30.9
Dry Mass of Specimen (lb):	2.0
Wet Unit Weight, γ (lb/ft^3):	121.2
Dry Unit Weight, γ_d (lb/ft^3):	92.6

Final Specimen Figure

Results

Unconfined Compressive Strength (psf):	**1409**
Strain (%):	**13.5**

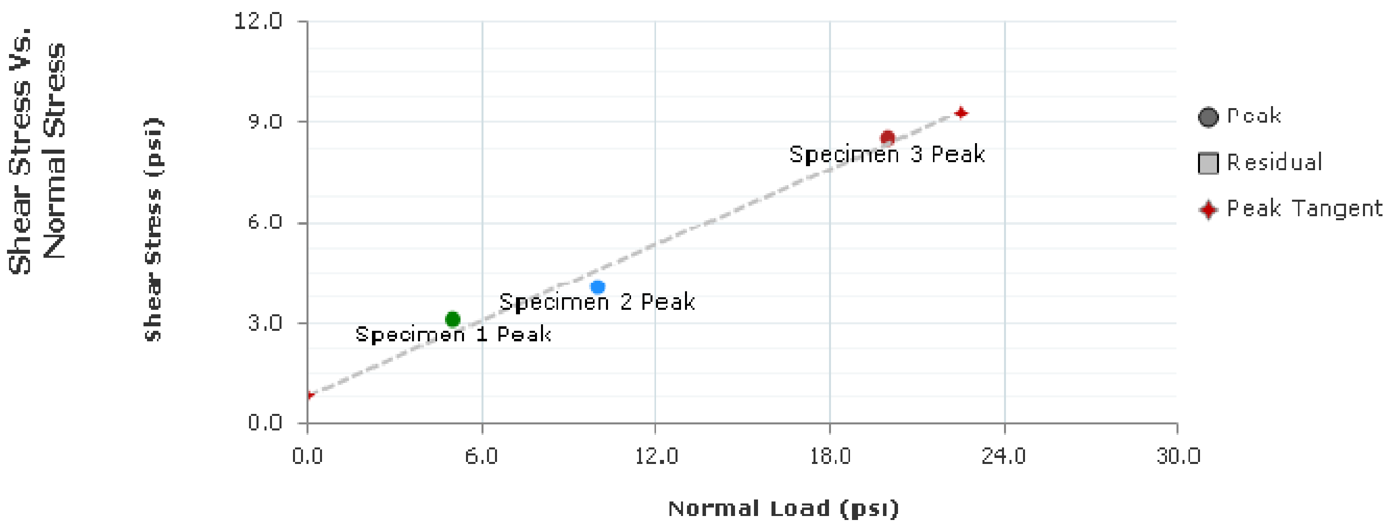


Notes: Medium stiff, grayish brown, CLAY, little silt, trace sand, trace gravel, moist.

Direct Shear Test

T236

Project: CUY-14-6.93
Project Number: 104132
Location: B-016-0-21 ST-6
Client Name: AECOM



C (psi): 0.9 **Residual C (psi):** NA
Phi (°): 20.5 **Residual Phi (°):** NA

	Specimen Number							
Initial	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture (%):	33.3	30.7	27.4					
Dry Density (pcf):	86.5	92.0	93.3					
Void Ratio:	0.927	0.812	0.787					
Saturation (%):	96.0	101.1	93.2					
Diameter (in):	2.4975	2.4973	2.4973					
Height (in):	1.0028	1.0007	1.0018					
Final	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture (%):	40.6	33.8	33.8					
Dry Density (pcf):	86.1	93.1	93.1					
Void Ratio:	0.936	0.790	0.790					
Saturation (%):	115.9	114.2	114.1					
Height (in):	0.9958	0.9852	0.9814					
Normal Stress (psi):	5.0	10.0	20.0					
Peak Shear Stress (psi):	3.1	4.1	8.5					
Residual Stress (psi):	NA	NA	NA					
Horizontal Deformation (%):	3.1	2.4	3.5					
Rate (in/min):	0.010416	0.012816	0.004896					

Direct Shear Test

T236

Project: CUY-14-6.93
Project Number: 104132
Sampling Date: 10/6/2021
Sample Number: ST-6
Sample Depth: 7.5-9.5 ft
Location: B-016-0-21 ST-6
Client Name: AECOM
Remarks:

Information Parameters	Specimen Number							
	1	2	3	4	5	6	7	8
Liquid Limit:	54	54	54					
Plastic Limit:	24	24	24					
Specific Gravity:	2.67	2.67	2.67					
Specific Gravity Method:	ASSUMED	ASSUMED	ASSUMED					
Initial Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Test Temperature (°F):	72.0	72.0	72.0					
Sample Shape:	ROUND	ROUND	ROUND					
Height (in):	1.0028	1.0007	1.0018					
Diameter (in):	2.4975	2.4973	2.4973					
Area (in²):	4.899	4.898	4.898					
Volume (in³):	4.9128	4.9015	4.9073					
Moisture (%):	33.3	30.7	27.4					
Dry Density (pcf):	86.5	92.0	93.3					
Wet Density (pcf):	115.3	120.3	118.9					
Saturation (%):	96.0	101.1	93.2					
Void Ratio:	0.927	0.812	0.787					
Porosity (%):	48.1	44.8	44.0					
Consolidation Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Initial Reference Height (in):	1.0028	1.0007	1.0018					
Final Reference Height (in):	0.9958	0.9852	0.9814					
Height (in):	0.9958	0.9852	0.9814					
Final Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture Content (%)	40.6	33.8	33.8					
Dry Density (pcf):	86.1	93.1	93.1					
Wet Density (pcf):	121.1	124.6	124.5					
Saturation (%):	115.9	114.2	114.1					
Void Ratio:	0.936	0.790	0.790					
Porosity (%):	48.3	44.1	44.1					

Direct Shear Test

T236

Specimen 1

Test Description:	Direct Shear		
Other Associated Tests:			
Device Details:	HM-5760		
Test Specification:	Undisturbed		
Test Time:	10/7/2021		
Technician:	LR	Sampling Method:	Shelby Tube
Specimen Code:	8.4'-8.5'	Specimen Lab #:	1
Specimen Description:	Medium stiff, grayish brown, CLAY, little silt, trace sand, trace gravel, moist.		
Specific Gravity:	2.67		
Plastic Limit:	24	Liquid Limit:	54
Test Remarks:			

Specimen 2

Test Description:	Direct Shear		
Other Associated Tests:			
Device Details:	HM-5760		
Test Specification:	Undisturbed		
Test Time:	10/8/2021		
Technician:	LR	Sampling Method:	Shelby Tube
Specimen Code:	8.6'-8.7'	Specimen Lab #:	2
Specimen Description:	Medium stiff, grayish brown, CLAY, little silt, trace sand, trace gravel, moist.		
Specific Gravity:	2.67		
Plastic Limit:	24	Liquid Limit:	54
Test Remarks:			

Direct Shear Test

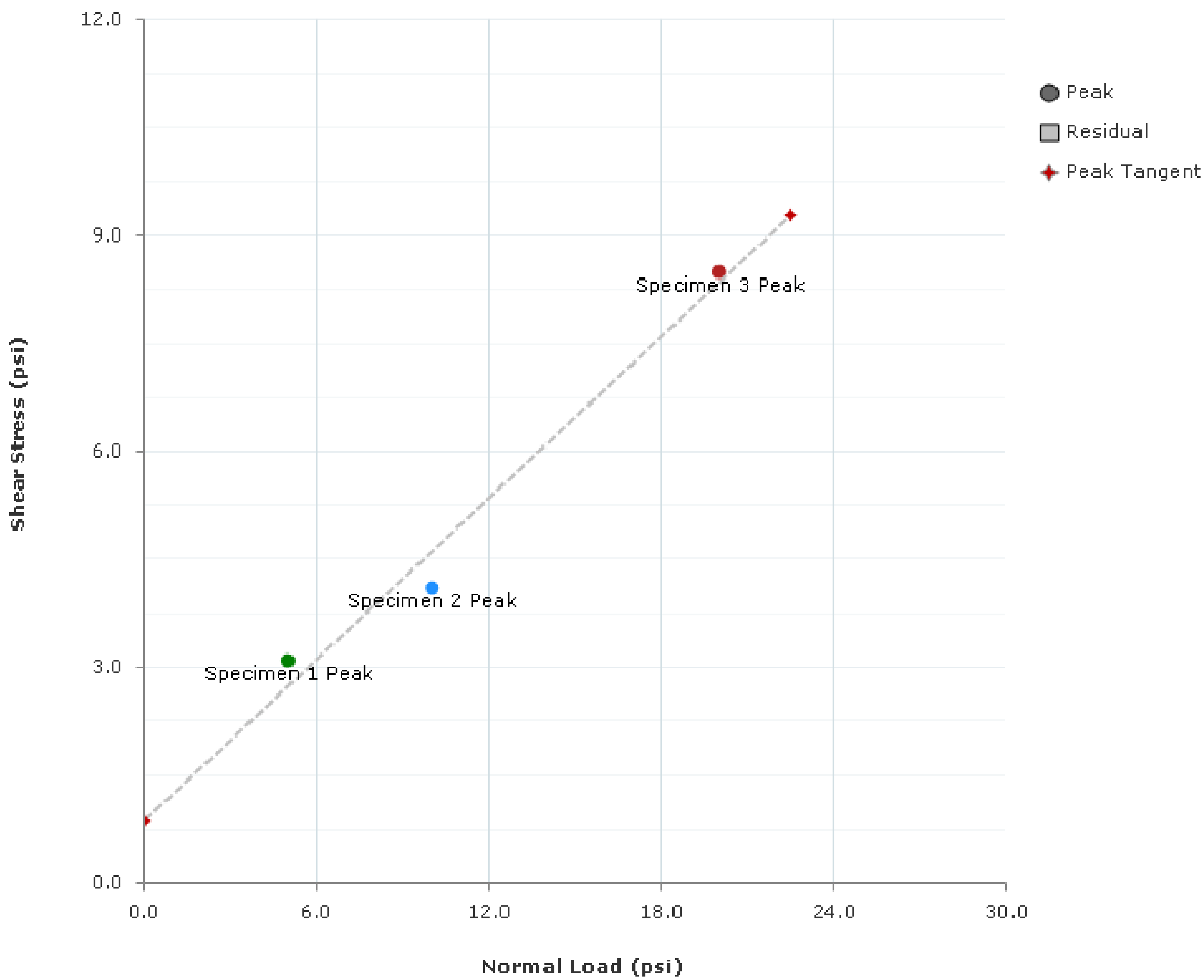
T236

Specimen 3

Test Description:	Direct Shear		
Other Associated Tests:			
Device Details:	HM-5760		
Test Specification:	Undisturbed		
Test Time:	10/12/2021		
Technician:	LR	Sampling Method:	Shelby Tube
Specimen Code:	8.8'-8.9'	Specimen Lab #:	3
Specimen Description:	Medium stiff, grayish brown, CLAY, little silt, trace sand, trace gravel, moist.		
Specific Gravity:	2.67		
Plastic Limit:	24	Liquid Limit:	54
Test Remarks:	Contains more silt than specimens 1 and 2.		

Direct Shear Test - Shear Stress Vs. Normal Stress

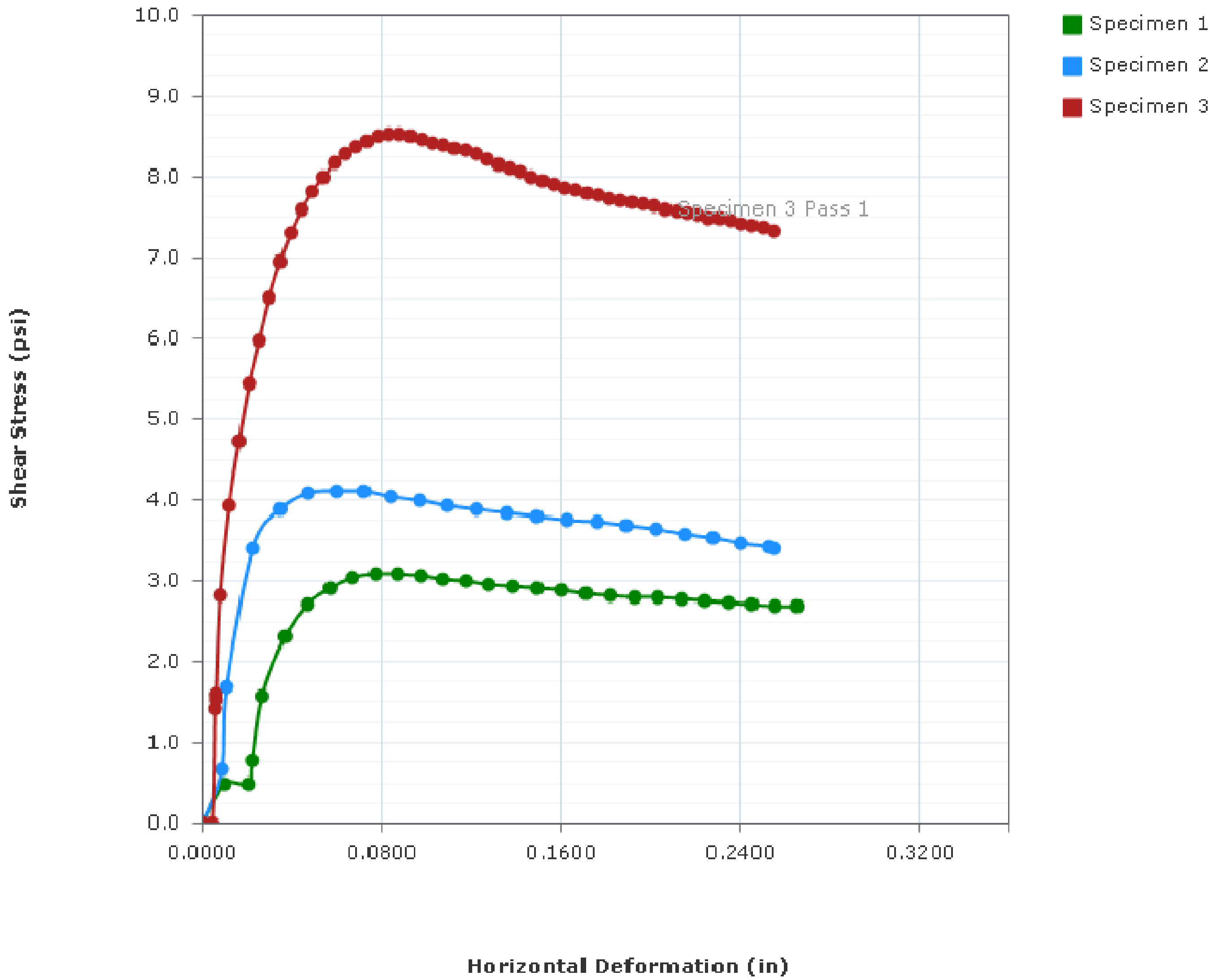
T236



Tangent Results	C (psi)	Phi (°)
Peak Tangent:	0.9	20.5
Residual Tangent:	NA	NA

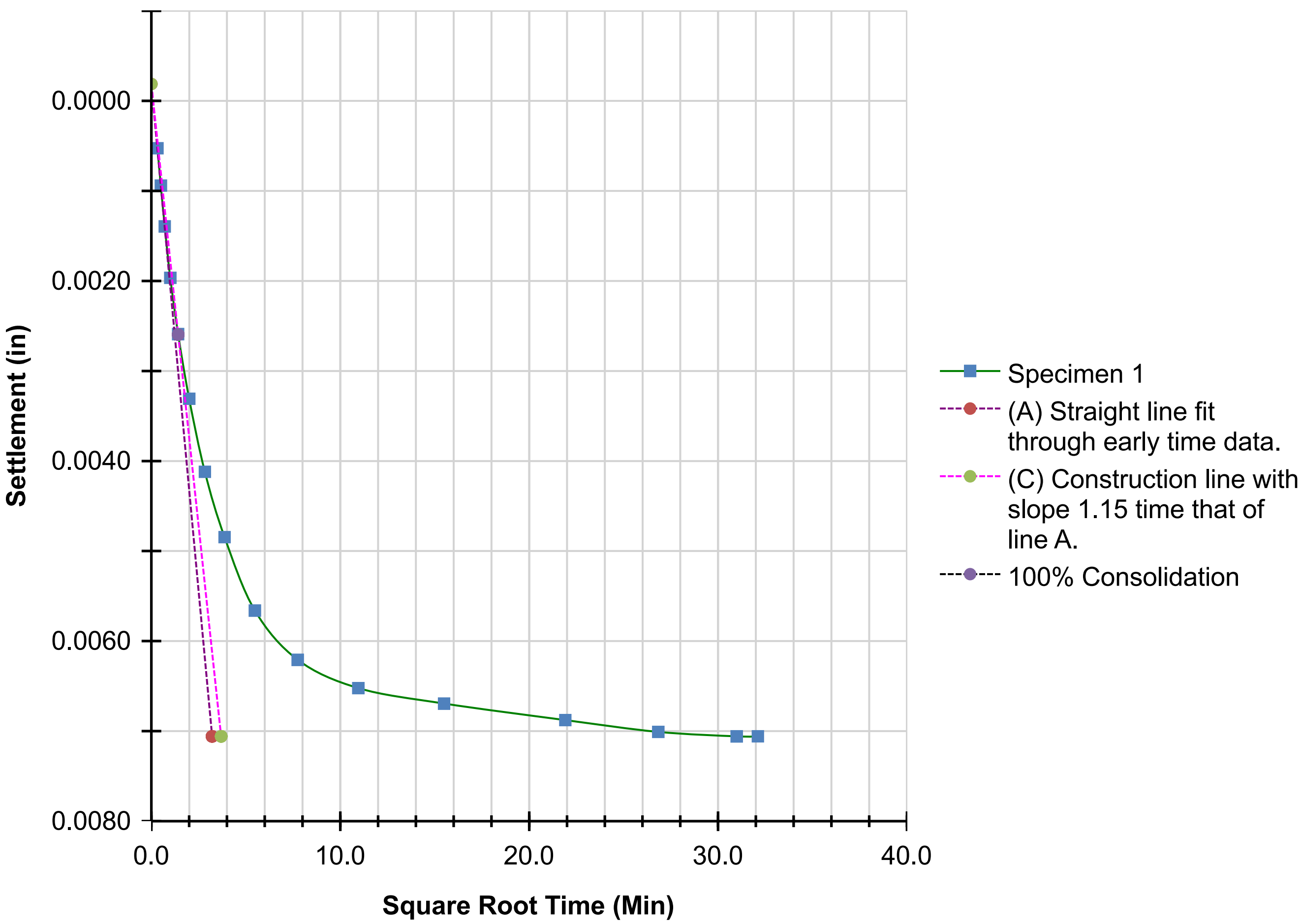
Graph - Stress Deformation

T236



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

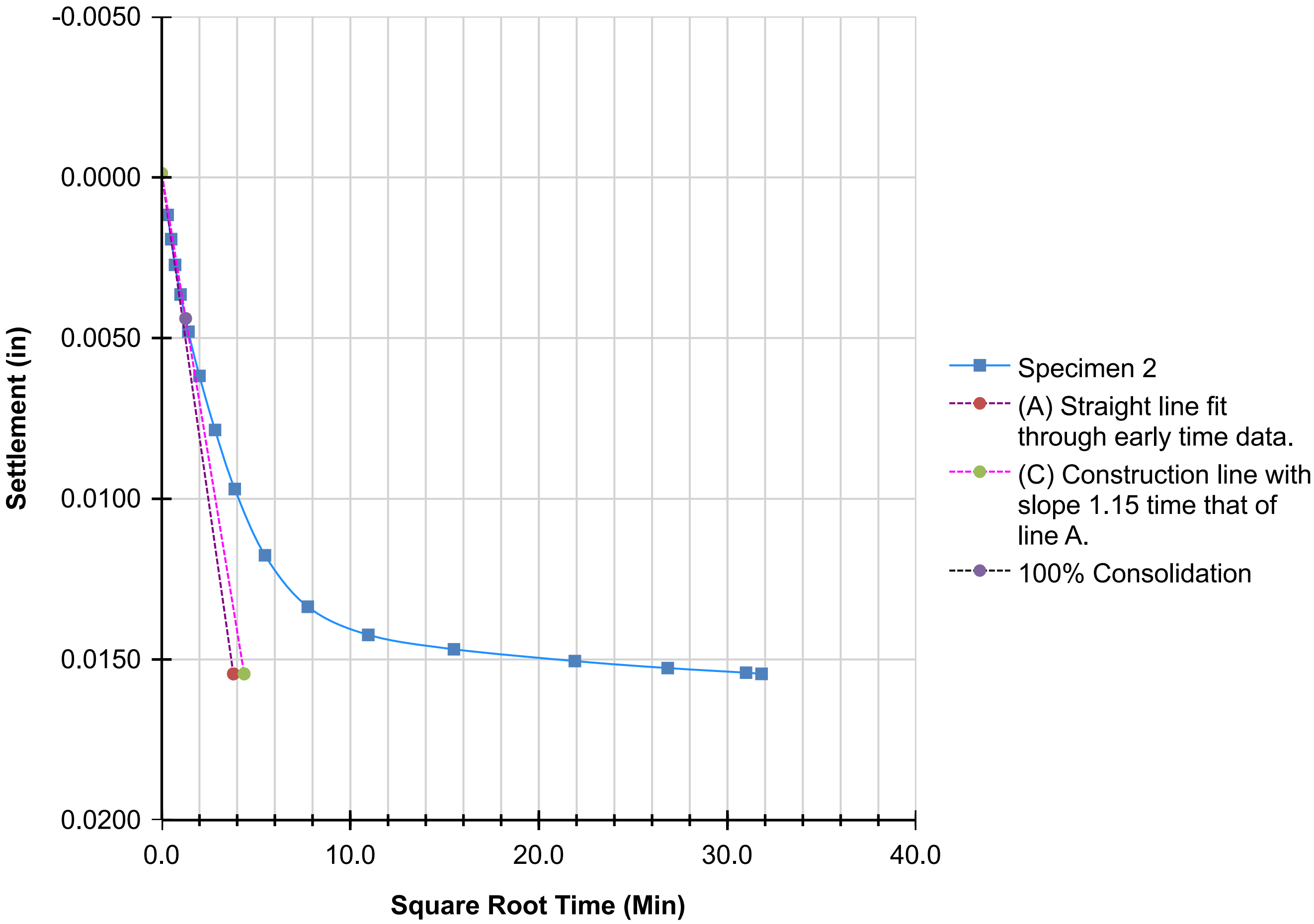
T236



Tangent Construction Results	
T90 (Min):	2.012
T50 (Min):	0.478
Cv (in²/Min):	0.42545

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

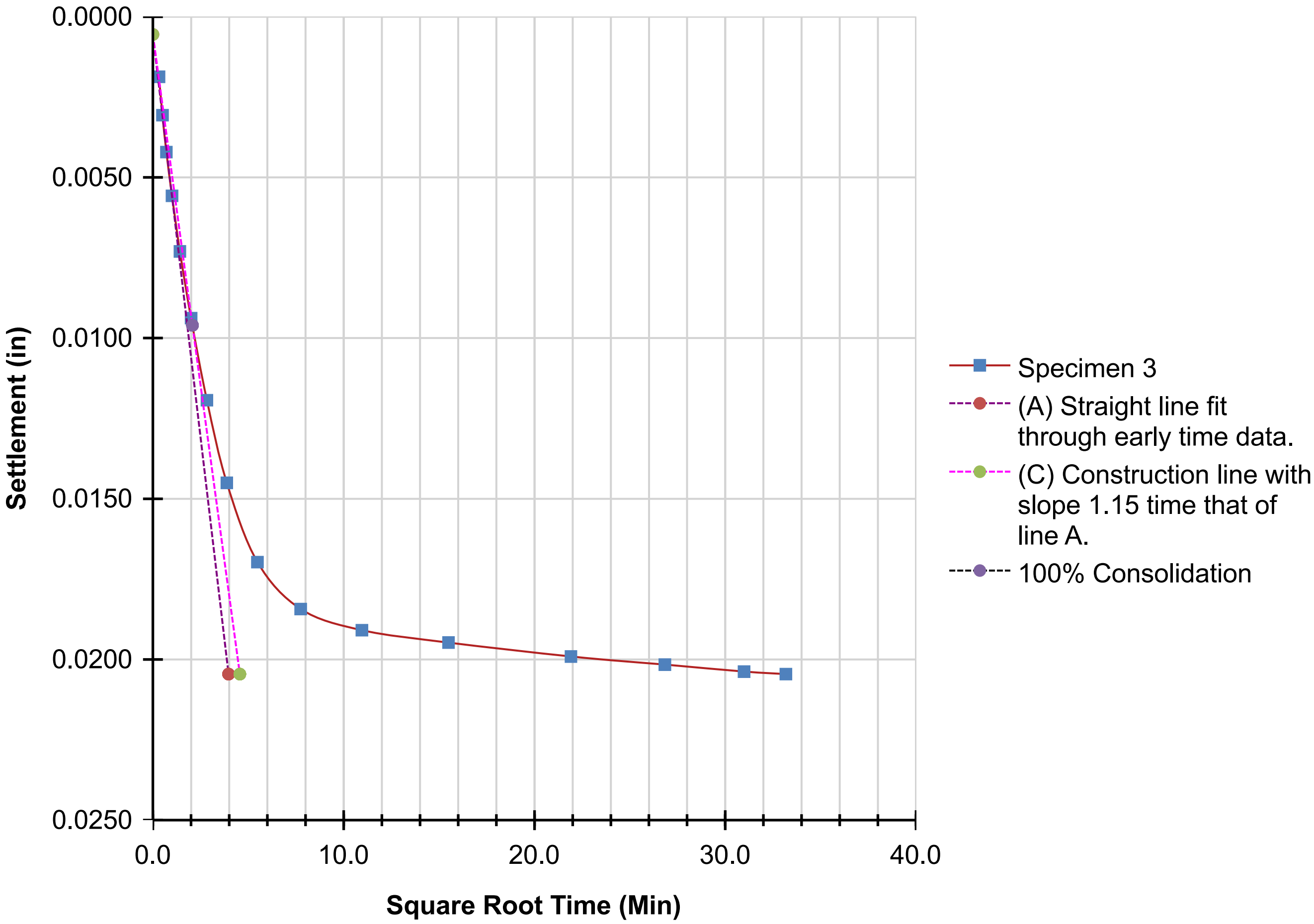
T236



Tangent Construction Results	
T90 (Min):	1.607
T50 (Min):	0.384
Cv (in²/Min):	0.50489

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

T236



Tangent Construction Results	
T90 (Min):	4.295
T50 (Min):	1.003
Cv (in²/Min):	0.17679

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / ASHBAUGH	DRILL RIG: CME 55T	STATION / OFFSET: 383+04, 46' RT.	EXPLORATION ID B-017-0-21
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: NEAS / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 845.8 (MSL) EOB: 41.5 ft.	PAGE 1 OF 2
START: 8/24/21 END: 8/24/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 68.4	LAT / LONG: 41.430711, -81.597615	

MATERIAL DESCRIPTION AND NOTES	ELEV. 845.8
7.0" ASPHALT AND 7.5" CONCRETE (DRILLERS DESCRIPTION)	844.6
STIFF TO VERY STIFF, BROWN AND GRAY, **CLAY**, SOME SILT, TRACE TO LITTLE GRAVEL, TRACE TO LITTLE SAND, CONTAINS TRACE IRON STAINING, MOIST @7.5'; SS-3 CONTAINS A 2.0" STONE FRAGMENT	833.8
MEDIUM DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP	831.3
VERY DENSE, GRAY, **STONE FRAGMENTS**, TRACE SAND, TRACE SILT, TRACE CLAY, POSSIBLE COBBLE(S), DAMP TO DRY	826.3
VERY STIFF TO HARD, GRAY AND BROWN, **CLAY**, SOME SILT, TRACE SAND, TRACE GRAVEL, DAMP TO MOIST	817.8

DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
2.5–4.0	3 3 4	8	44	SS-1	2.00	-	-	-	-	-	-	-	-	26	A-7-6 (V)
5.0–6.5	4 4 4	9	56	SS-2	2.25	-	-	-	-	-	-	-	-	27	A-7-6 (V)
7.5–9.0	3 3 3	7	50	SS-3	3.00	16	2	4	26	52	45	20	25	26	A-7-6 (15)
10.0–11.5	3 2 3	6	56	SS-4	1.75	-	-	-	-	-	-	-	-	25	A-7-6 (V)
12.5–14.0	4 5 8	15	28	SS-5	-	43	23	17	11	6	NP	NP	NP	9	A-1-b (0)
15.0	50/3"	-	67	SS-6	-	-	-	-	-	-	-	-	-	5	A-1-a (V)
17.5	50/3"	-	67	SS-7	-	-	-	-	-	-	-	-	-	2	A-1-a (V)
20.0–21.5	8 7 8	17	67	SS-8	2.50	-	-	-	-	-	-	-	-	22	A-7-6 (V)
22.5–24.0	8 9 12	24	72	SS-9	4.50	4	3	4	34	55	44	22	22	22	A-7-6 (14)
25.0–26.5	10 10 13	26	83	SS-10	4.50	-	-	-	-	-	-	-	-	20	A-7-6 (V)
27.5–29.0	9 11 14	29	56	SS-11A	2.50	-	-	-	-	-	-	-	-	23	A-7-6 (V)
				SS-11B	-	-	-	-	-	-	-	-	-	12	A-1-b (V)

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 383+04, 46' RT.	START: 8/24/21	END: 8/24/21	PG 2 OF 2	B-017-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 815.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, SS-11B CONTAINS TRACE IRON STAINING, DAMP TO MOIST *(continued)*		31	13 14 14	32	44	SS-12	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		32																
		33	17 21 27	55	78	SS-13	-	43	22	18	14	3	NP	NP	NP	8	A-1-b (0)	
		34																
		35–36	15 22 29	58	67	SS-14	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		37																
@37.5'; SS-15 CONTAINS NO RECOVERY		38	20 26 31	65	0	SS-15	-	-	-	-	-	-	-	-	-	-	A-1-b (V)	
		39																
	804.3	40–41 EOB	22 25 35	68	44	SS-16	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	

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

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

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / J. HODGES	DRILL RIG: CME 55X	STATION / OFFSET: 374+43, 176' RT.
TYPE: CULVERT	SAMPLING FIRM / LOGGER: NEAS / J. HODGES	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 816.6 (MSL) EOB: 48.8 ft.
START: 8/31/21 END: 8/31/21	SAMPLING METHOD: SPT / ST	ENERGY RATIO (%): 81.9	LAT / LONG: 41.430865, -81.600658

EXPLORATION ID B-021-0-21

MATERIAL DESCRIPTION AND NOTES (ELEV. 816.6)

VERY STIFF, BROWN, **SANDY SILT**, LITTLE GRAVEL, LITTLE CLAY, CONTAINS IRON STAINING, DAMP TO MOIST — 809.6

SOFT TO STIFF, BROWN, **SILT AND CLAY**, SOME SAND, SOME GRAVEL, DAMP
@7.6' TO 8.1'; Qu = 582 PSF @ 3.5%
@8.2'; CONTAINS A 3.0" BLACK ORGANIC SEAM CONTAINING WOOD FRAGMENTS — 808.2

BROWNISH GRAY WITH TRACE BLACK STREAKS, **COARSE AND FINE SAND**, LITTLE SILT, TRACE GRAVEL, TRACE CLAY, SLIGHTLY ORGANIC, WET — 807.2

SOFT, DARK GRAY, **CLAY**, SOME SILT, LITTLE SAND, TRACE GRAVEL, CONTAINS IRON STAINING, MOIST — 804.8

VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO WET
@11.8' TO 48.8'; ENCOUNTERED COBBLES AND/OR BOULDERS DURING DRILLING

DEPTHS: 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
7 4 4	11	100	SS-1	2.50	19	18	19	29	15	22	15	7	11	A-4a (2)	
3 2 2	5	100	SS-2	3.00	-	-	-	-	-	-	-	-	19	A-4a (V)	
		100	ST-3	1.25	23	18	16	22	21	28	17	11	15	A-6a (2)	
5 15 17	44	100	SS-4	0.25	-	-	-	-	-	-	-	-	29	A-7-6 (V)	
6 18 31	67	100	SS-5	-	39	24	15	16	6	NP	NP	NP	9	A-1-b (0)	
9 15 32	64	39	SS-6	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
25 36 34	96	44	SS-7	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
7 28 41	94	56	SS-8	-	41	28	16	12	3	NP	NP	NP	10	A-1-b (0)	
10 31 50/3"	-	20	SS-9	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
40 50/4"	-	40	SS-10	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
35 49 50/2"	-	29	SS-11	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 374+43, 176' RT.	START: 8/31/21	END: 8/31/21	PG 2 OF 2	B-021-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 786.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY DENSE, GRAY, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE TO LITTLE SILT, TRACE CLAY, DAMP TO WET *(continued)*		31	36 50	-	25	SS-12	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		32																
		33	33 40 50/2"	-	21	SS-13	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		34																
		35	37 50/3"	-	22	SS-14	-	-	-	-	-	-	-	-	-	18	A-1-b (V)	
		36																
		37																
		38																
		39																
		40	29 38 42	109	28	SS-15	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		41																
		42																
		43																
		44																
		45	39 50/4"	-	20	SS-16	-	-	-	-	-	-	-	-	-	17	A-1-b (V)	
		46																
	769.3	47																
VERY DENSE, GRAY, **STONE FRAGMENTS**, TRACE SAND, TRACE SILT, TRACE CLAY, DAMP		48																
	767.8	EOB	50/4"	-	50	SS-17	-	-	-	-	-	-	-	-	-	4	A-1-a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING. HOLE DID NOT CAVE. RAN A SLURRY MIX AT 10.0' TO COMBAT HEAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: POURED 1 BAG BENTONITE CHIPS; PUMPED 100 GAL. BENTONITE GROUT; SHOVELED SOIL CUTTINGS

National Engineering & Architectural Services Inc.

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

Unconfined Compressive Strength of Cohesive Soil (ASTM D2166)

(Project: CUY-14-6.93, Boring Location: B-021-0-21, ST-3, Depth: 7.6 - 8.1ft)

Tested Date: 9/14/2021

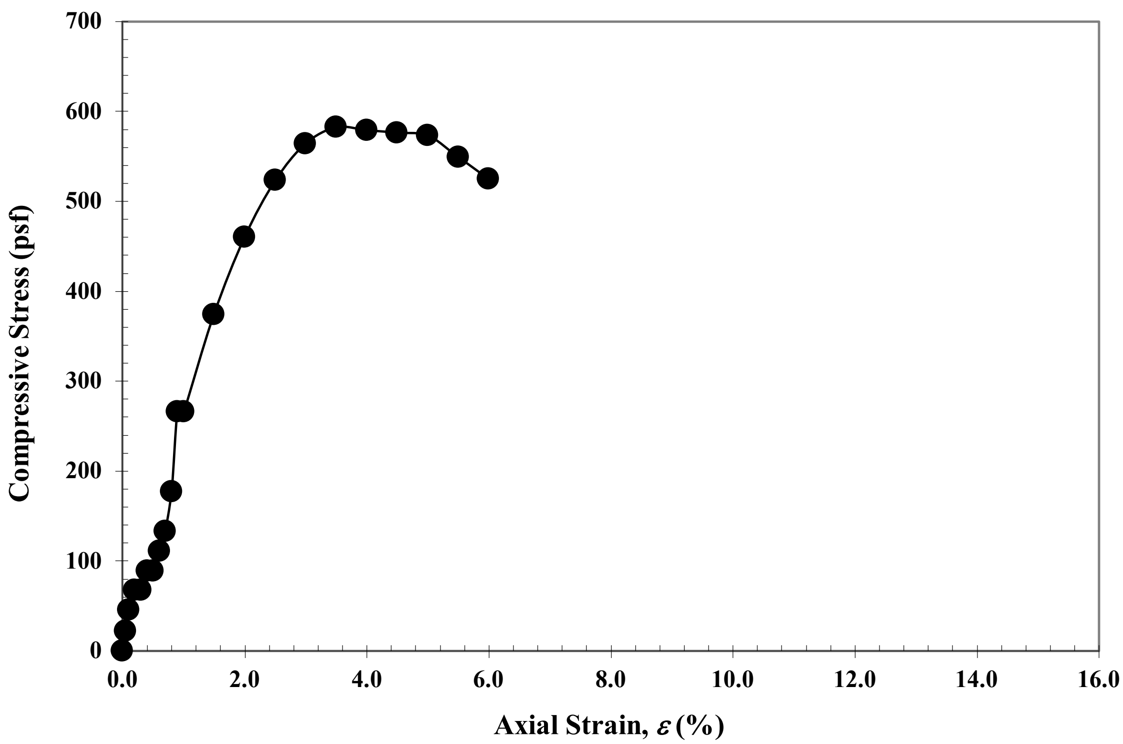
Specimen Properties

Average Dia., D_{avg} (in):	2.86
Average Height, H_{avg} (in):	5.72
Area, A (in^2):	6.44
Volume, V (in^3):	36.84
Wet Mass of Specimen (lb):	2.9
Moisture Content (%):	16.3
Dry Mass of Specimen (lb):	2.5
Wet Unit Weight, γ (lb/ft^3):	136.6
Dry Unit Weight, γ_d (lb/ft^3):	117.5

Final Specimen Figure

Results

Unconfined Compressive Strength (psf):	**582**
Strain (%):	**3.5**



Notes: Soft, brown and gray, SILT AND CLAY, some sand, some gravel, damp.

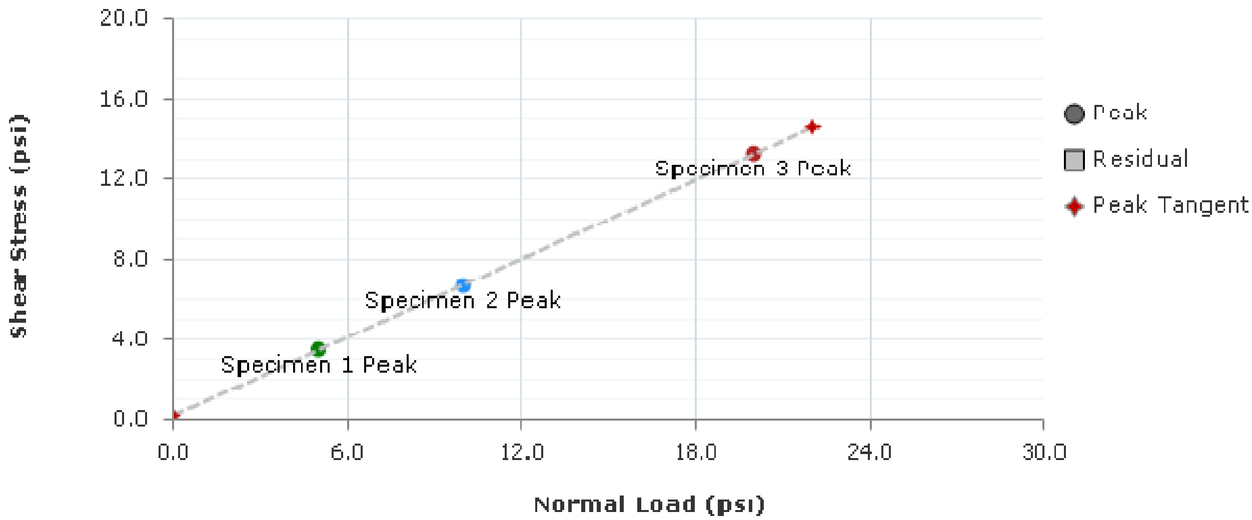
National Engineering & Architectural Services Inc.

Direct Shear Test

T236

Project: CUY-14-6.93
Project Number: 104132
Location: B-021-0-21 ST-3
Client Name: AECOM

Shear Stress Vs. Normal Stress



C (psi): 0.2
Phi (°): 33.1

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

	Specimen Number							
Initial	1	2	3	4	5	6	7	8
Moisture (%):	26.1	24.1	29.7					
Dry Density (pcf):	96.4	98.5	92.2					
Void Ratio:	0.729	0.692	0.807					
Saturation (%):	95.5	93.2	98.1					
Diameter (in):	2.4973	2.4973	2.4973					
Height (in):	1.0060	1.0000	1.0018					
Final	1	2	3	4	5	6	7	8
Moisture (%):	28.7	24.9	30.6					
Dry Density (pcf):	96.8	99.3	92.6					
Void Ratio:	0.723	0.678	0.801					
Saturation (%):	106.0	97.9	102.1					
Height (in):	1.0008	1.0000	1.0018					
Normal Stress (psi):	5.0	10.0	20.0					
Peak Shear Stress (psi):	3.5	6.7	13.3					
Residual Stress (psi):	NA	NA	NA					
Horizontal Deformation (%):	5.2	4.8	5.4					
Rate (in/min):	0.014869	0.007800	0.030816					

National Engineering & Architectural Services Inc.

Direct Shear Test

T236

Project:	CUY-14-6.93
Project Number:	104132
Sampling Date:	9/30/2021
Sample Number:	ST-3
Sample Depth:	7.5-9.5 ft
Location:	B-021-0-21 ST-3
Client Name:	AECOM
Remarks:	

Information Parameters	Specimen Number							
	1	2	3	4	5	6	7	8
Liquid Limit:	0	0	0					
Plastic Limit:	0	0	0					
Specific Gravity:	2.67	2.67	2.67					
Specific Gravity Method:	ASSUMED	ASSUMED	ASSUMED					
Initial Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Test Temperature (°C):	22.2	22.2	22.2					
Sample Shape:	ROUND	ROUND	ROUND					
Height (in):	1.0060	1.0000	1.0018					
Diameter (in):	2.4973	2.4973	2.4973					
Area (in^2):	4.898	4.898	4.898					
Volume (in^3):	4.9277	4.8983	4.9073					
Moisture (%):	26.1	24.1	29.7					
Dry Density (pcf):	96.4	98.5	92.2					
Wet Density (pcf):	121.5	122.3	119.6					
Saturation (%):	95.5	93.2	98.1					
Void Ratio:	0.729	0.692	0.807					
Porosity (%):	42.2	40.9	44.7					
Consolidation Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Initial Reference Height (in):	1.0060	1.0000	1.0018					
Final Reference Height (in):	1.0008	1.0000	1.0018					
Height (in):	1.0008	1.0000	1.0018					
Final Parameters	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**
Moisture Content (%)	28.7	24.9	30.6					
Dry Density (pcf):	96.8	99.3	92.6					
Wet Density (pcf):	124.5	124.0	120.9					
Saturation (%):	106.0	97.9	102.1					
Void Ratio:	0.723	0.678	0.801					
Porosity (%):	42.0	40.4	44.5					

Direct Shear Test

T236

Specimen 1

Test Description:	Direct Shear
Other Associated Tests:	
Device Details:	HM-5760
Test Specification:	Undisturbed
Test Time:	10/1/2021
Technician:	LR
Sampling Method:	Shelby Tube
Specimen Code:	8.8'-8.9'
Specimen Lab #:	1
Specimen Description:	Brownish gray, COARSE AND FINE SAND, little silt, trace clay, trace gravel, wet.
Specific Gravity:	2.67
Plastic Limit:	0
Liquid Limit:	0
Test Remarks:	

Specimen 2

Test Description:	Direct Shear
Other Associated Tests:	
Device Details:	HM-5760
Test Specification:	Undisturbed
Test Time:	10/5/2021
Technician:	LR
Sampling Method:	Shelby Tube
Specimen Code:	9.0'-9.1'
Specimen Lab #:	2
Specimen Description:	Brownish gray, COARSE AND FINE SAND, little silt, trace clay, trace gravel, wet.
Specific Gravity:	2.67
Plastic Limit:	0
Liquid Limit:	0
Test Remarks:	

National Engineering & Architectural Services Inc.

Direct Shear Test

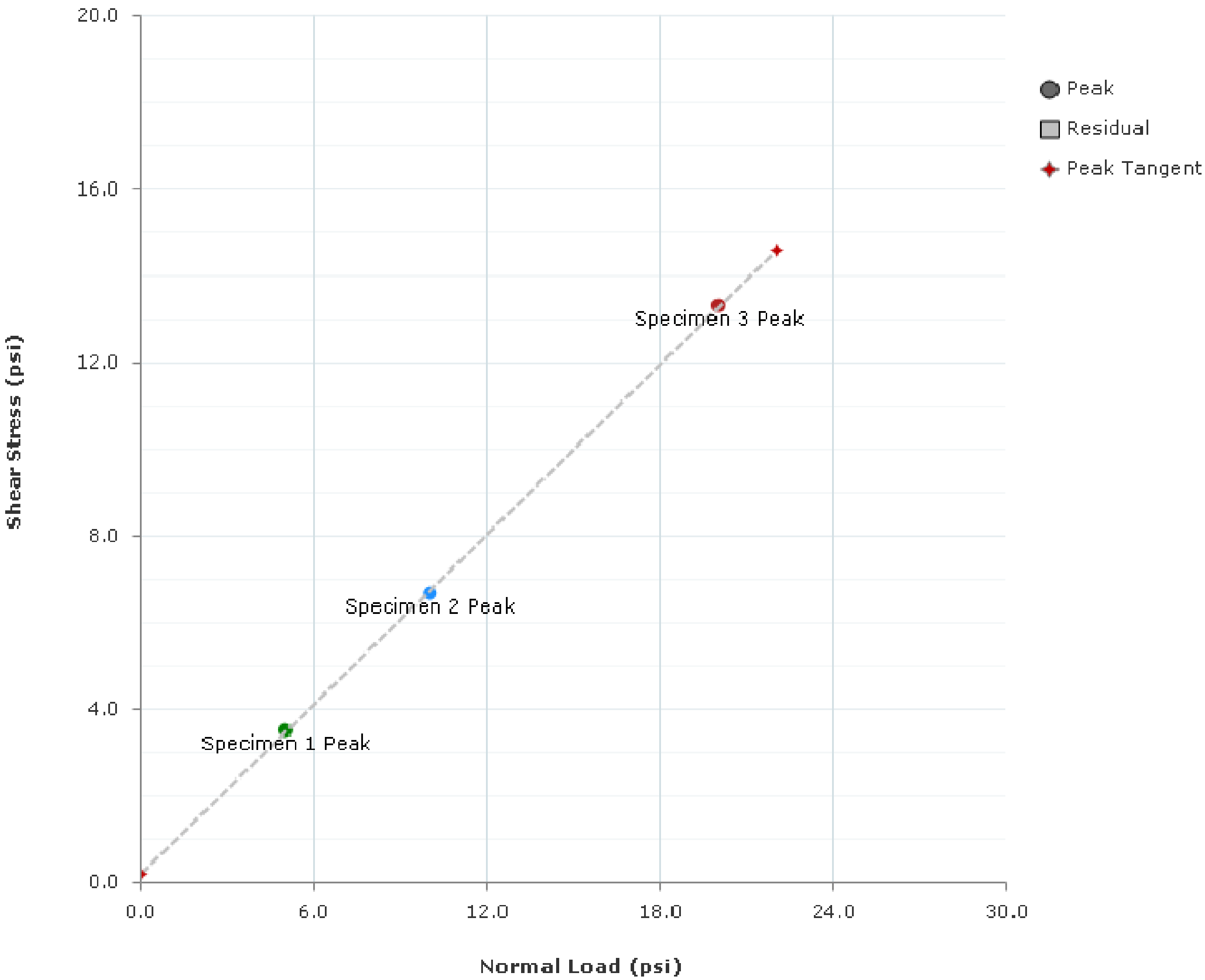
T236

Specimen 3

Test Description:	Direct Shear
Other Associated Tests:	
Device Details:	HM-5760
Test Specification:	Undisturbed
Test Time:	10/6/2021
Technician:	LR
Sampling Method:	Shelby Tube
Specimen Code:	9.2'-9.3'
Specimen Lab #:	3
Specimen Description:	Brownish gray, COARSE AND FINE SAND, some clay, little silt, trace gravel, wet.
Specific Gravity:	2.67
Plastic Limit:	0
Liquid Limit:	0
Test Remarks:	Specimen contains an 1/8" clay seam.

Direct Shear Test - Shear Stress Vs. Normal Stress

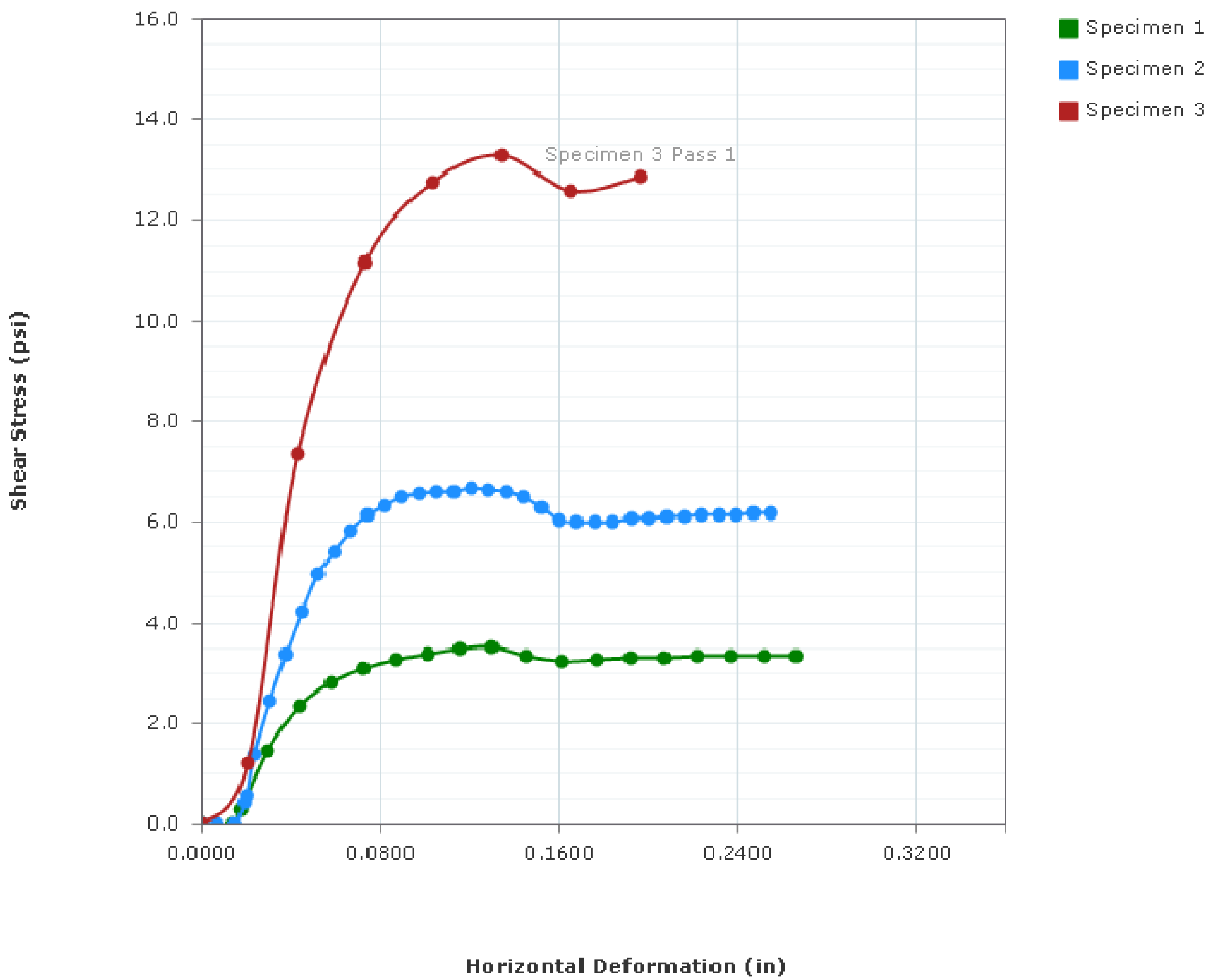
T236



Tangent Results	C (psi)	Phi (°)
Peak Tangent:	0.2	33.1
Residual Tangent:	NA	NA

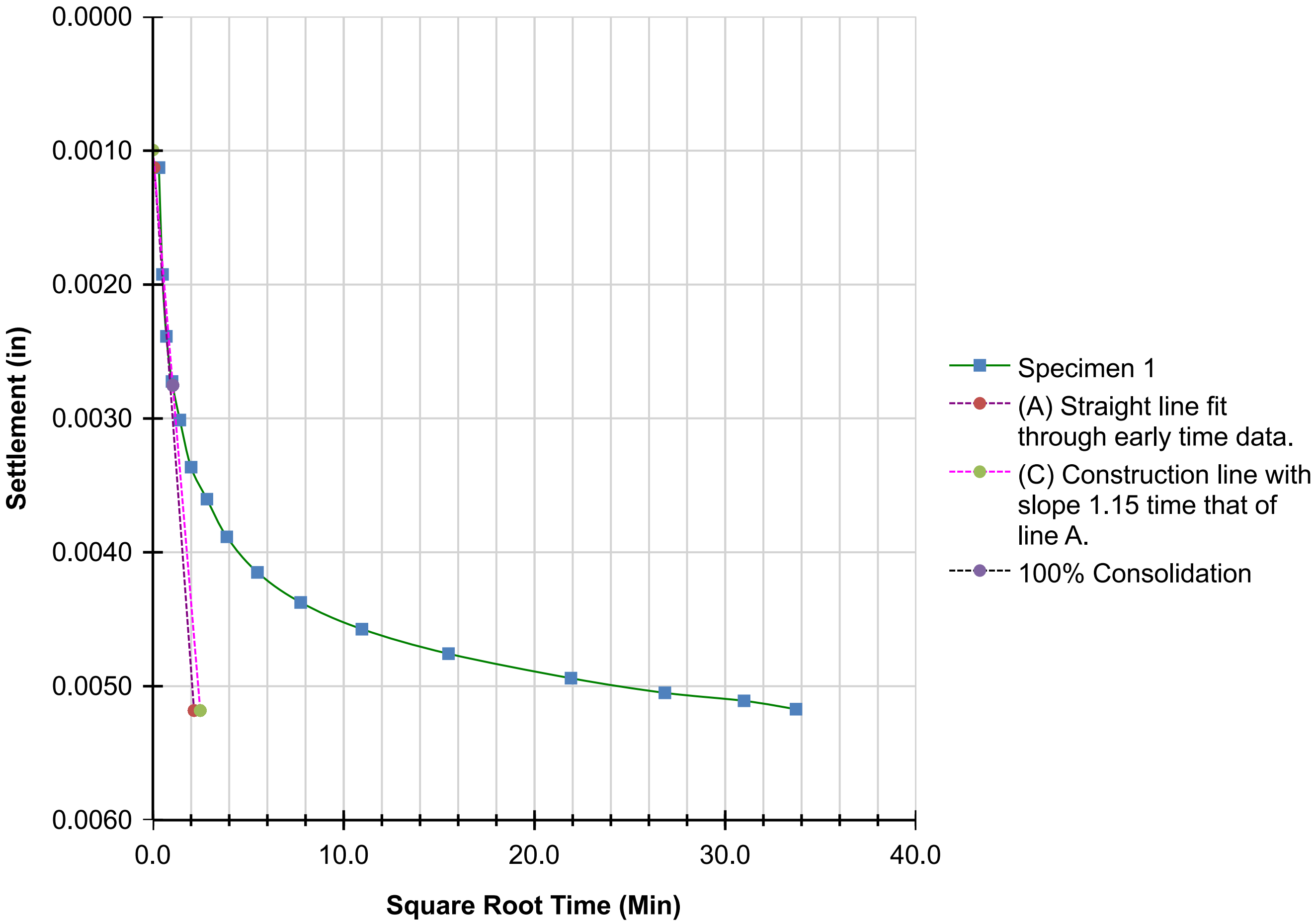
Graph - Stress Deformation

T236



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

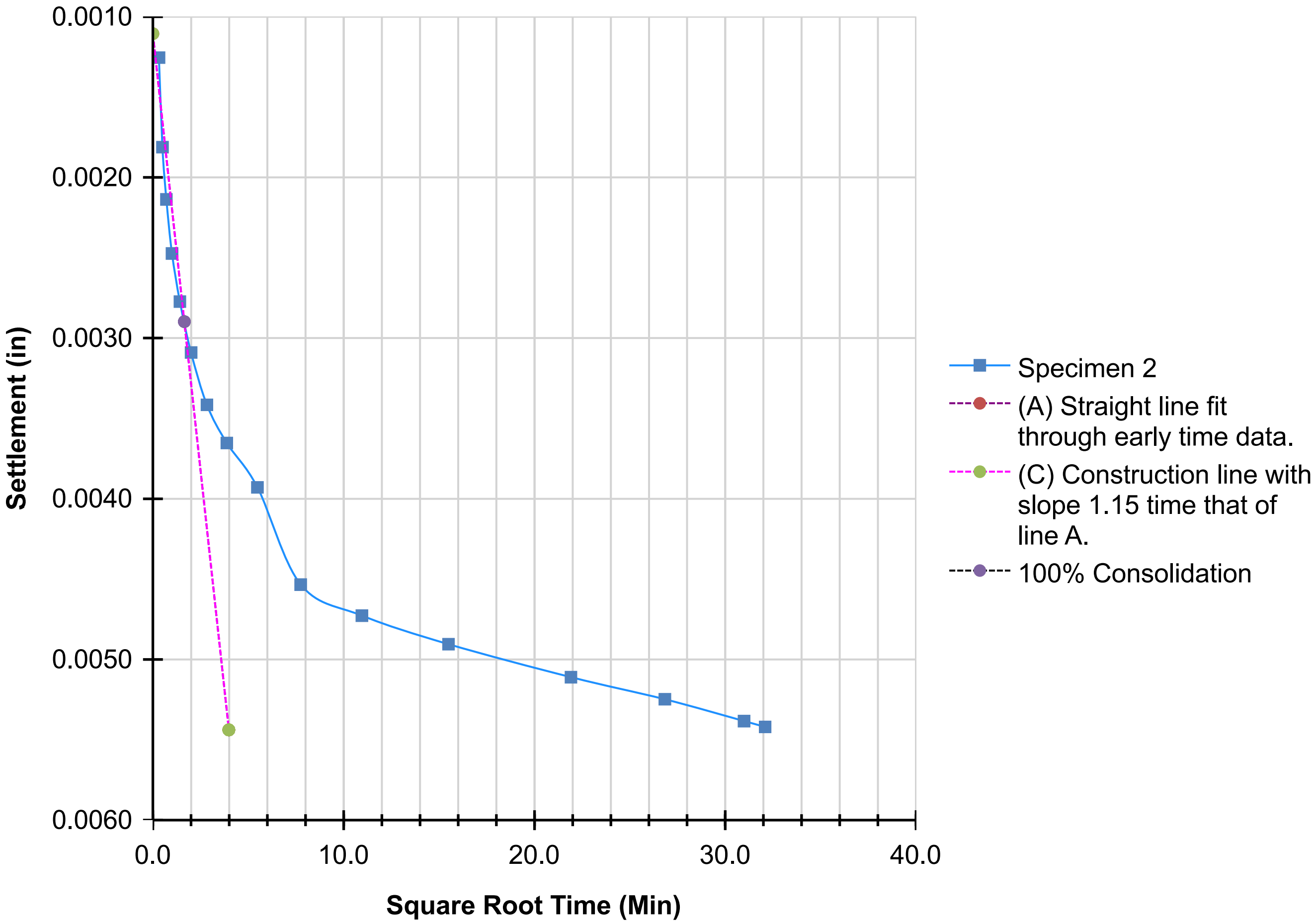
T236



Tangent Construction Results	
T90 (Min):	1.084
T50 (Min):	0.269
Cv (in²/Min):	0.75279

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

T236

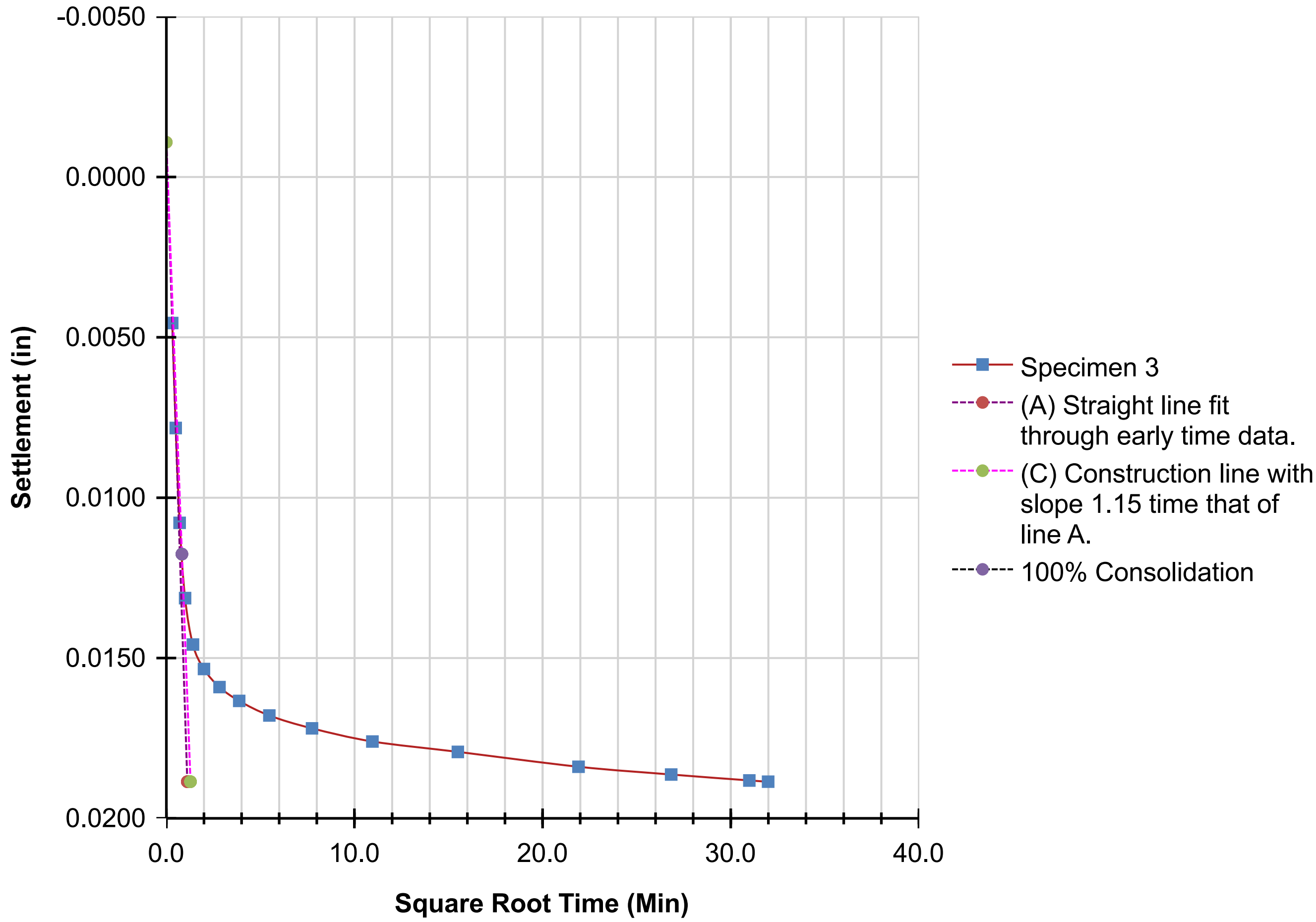


Tangent Construction Results	
T90 (Min):	2.707
T50 (Min):	0.466
Cv (in²/Min):	0.42770

National Engineering & Architectural Services Inc.

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

T236



Tangent Construction Results	
T90 (Min):	0.687
T50 (Min):	0.159
Cv (in²/Min):	1.10169

PROJECT: CUY-14-6.93	DRILLING FIRM / OPERATOR: NEAS / ASHBAUGH	DRILL RIG: CME 55T	STATION / OFFSET: 374+00, 292' RT.	EXPLORATION ID B-022-0-21
TYPE: CULVERT	SAMPLING FIRM / LOGGER: NEAS / ASHBAUGH	HAMMER: CME AUTOMATIC	ALIGNMENT: SR-14	
PID: 104132 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 12/5/19	ELEVATION: 849.3 (MSL) EOB: 51.5 ft.	PAGE 1 OF 2
START: 8/26/21 END: 8/26/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 68.4	LAT / LONG: 41.430563, -81.600868	

MATERIAL DESCRIPTION AND NOTES	ELEV. 849.3	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
4.0" TOPSOIL (DRILLERS DESCRIPTION)	849.0															
MEDIUM DENSE TO VERY DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, SS-1 CONTAINS ROOT HAIRS, DAMP TO MOIST		5 / 7 / 12	22	44	SS-1	-	39	26	21	11	3	NP	NP	NP	5	A-1-b (0)
		8 / 10 / 11	24	44	SS-2	-	-	-	-	-	-	-	-	-	10	A-1-b (V)
		12 / 14 / 11	29	28	SS-3	-	62	11	11	13	3	NP	NP	NP	4	A-1-b (0)
		10 / 19 / 21	46	50	SS-4	-	-	-	-	-	-	-	-	-	5	A-1-b (V)
		9 / 16 / 22	43	56	SS-5	-	-	-	-	-	-	-	-	-	5	A-1-b (V)
		10 / 17 / 24	47	67	SS-6	-	29	38	15	14	4	NP	NP	NP	5	A-1-b (0)
		18 / 22 / 26	55	56	SS-7	-	-	-	-	-	-	-	-	-	4	A-1-b (V)
		15 / 21 / 25	52	61	SS-8	-	-	-	-	-	-	-	-	-	4	A-1-b (V)
	834.8															
VERY DENSE, LIGHT BROWN, **COARSE AND FINE SAND**, TRACE GRAVEL, TRACE SILT, TRACE CLAY, DAMP		12 / 21 / 29	57	61	SS-9	-	-	-	-	-	-	-	-	-	5	A-3a (V)
	832.3															
DENSE TO VERY DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS**, SOME SAND, TRACE SILT, TRACE CLAY, DAMP		10 / 15 / 28	49	50	SS-10	-	52	18	16	10	4	NP	NP	NP	5	A-1-a (0)
		20 / 34 / 40	84	33	SS-11	-	-	-	-	-	-	-	-	-	6	A-1-a (V)
		20 / 29 / 40	79	22	SS-12	-	-	-	-	-	-	-	-	-	5	A-1-a (V)
	824.8															
VERY DENSE, BROWN, **COARSE AND FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP		12 / 21 / 30	58	50	SS-13	-	1	29	56	10	4	NP	NP	NP	6	A-3a (0)
		15 / 20 / 26	52	56	SS-14	-	-	-	-	-	-	-	-	-	7	A-3a (V)
	819.8															

DEPTHS: 1 – 29

PID: 104132	SFN:	PROJECT: CUY-14-6.93	STATION / OFFSET: 374+00, 292' RT.	START: 8/26/21	END: 8/26/21	PG 2 OF 2	B-022-0-21

MATERIAL DESCRIPTION AND NOTES	ELEV. 819.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP *(continued)*		30–31	12 50/2"	-	63	SS-15	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	
	817.3	32																
DENSE TO VERY DENSE, BROWN, **COARSE AND FINE SAND**, TRACE GRAVEL, TRACE SILT, TRACE CLAY, DAMP		33–34	12 17 26	49	67	SS-16	-	-	-	-	-	-	-	-	-	6	A-3a (V)	
		35–36	14 21 30	58	83	SS-17	-	-	-	-	-	-	-	-	-	7	A-3a (V)	
	811.0	W 811.1 — 38																
VERY DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST		40–41	16 24 31	63	50	SS-18	-	50	21	13	12	4	NP	NP	NP	9	A-1-b (0)	
	806.0	43																
VERY DENSE, BROWN, **GRAVEL**, "AND" SAND, TRACE SILT, TRACE CLAY, MOIST TO WET		45–46	14 23 30	60	67	SS-19	-	52	25	12	8	3	NP	NP	NP	9	A-1-a (0)	
	797.8	50–51, EOB	20 22 35	65	72	SS-20	-	-	-	-	-	-	-	-	-	13	A-1-a (V)	

NOTES: GROUNDWATER ENCOUNTERED AT 38.2' DURING DRILLING. HOLE DID NOT CAVE.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: SHOVELED SOIL CUTTINGS

APPENDIX C

GENERALIZED SOIL PROFILES

RETAINING WALL A

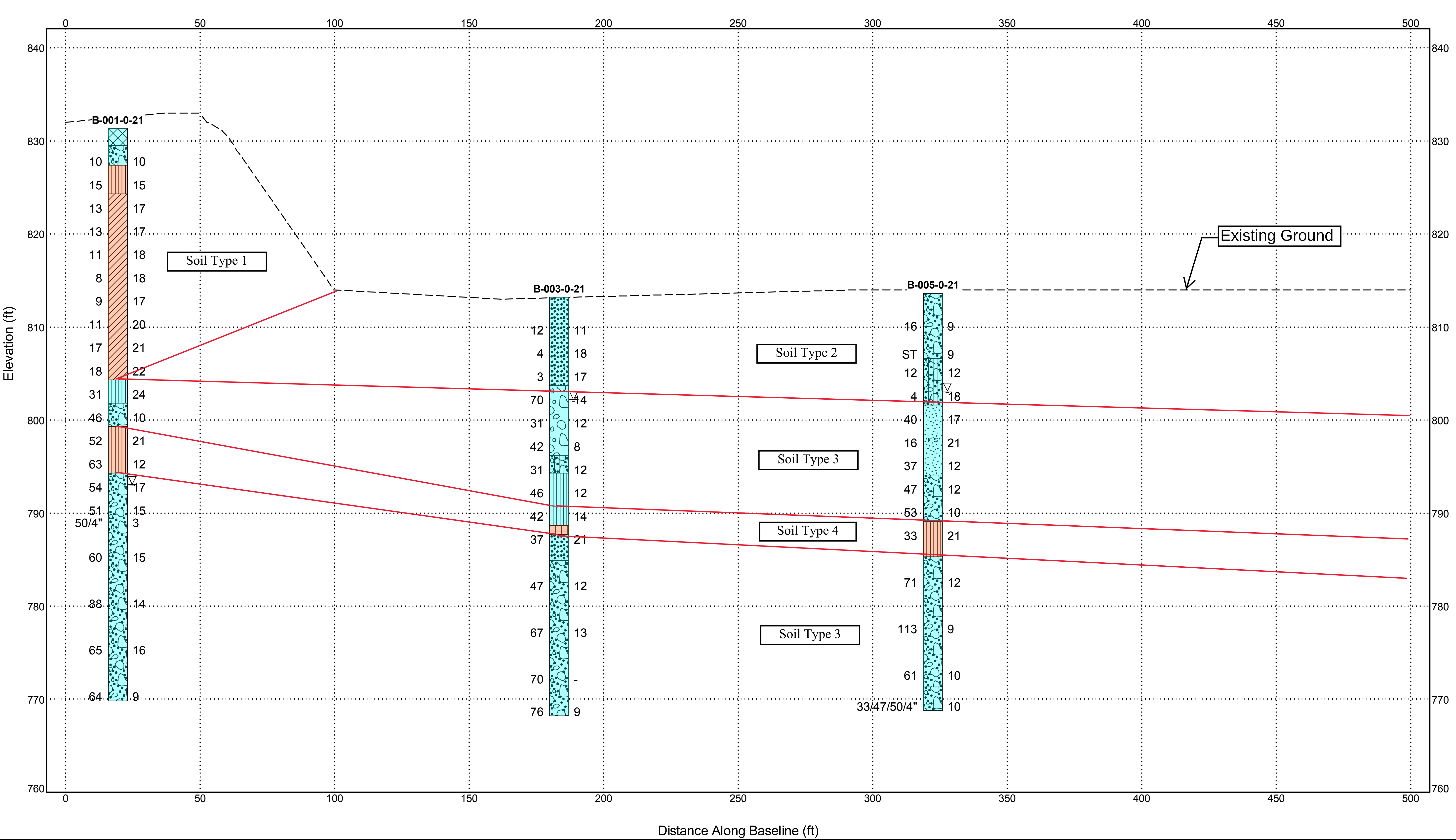
OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

Non-cohesive
Cohesive

SUBSURFACE DIAGRAM
RETAINING WALL A

Ohio DOT: Pavement or Aggregate base
Ohio DOT: A-6a, silt and clay
Ohio DOT: A-1-a, gravel and/or stone fragments
Ohio DOT: A-1-b, gravel and/or stone fragments with sand
Ohio DOT: A-3a, coarse and fine sand
Ohio DOT: A-7-6, clay
Ohio DOT: A-4a, sandy silt
Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt
Ohio DOT: A-3, fine sand

CLIENT AECOM
PROJECT NUMBER 104132
PROJECT NAME CUY-14-6.93
PROJECT LOCATION Garfield Heights, OH



STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 11/4/21 12:01 - C:\USERS\KARENS\DESKTOP\CUY-14-6.93\WALLS A-F-TEMP\GINT PROFILE\WORKING FILES\WALLA-F-H.GPJ

RETAINING WALL F AND TEMPORARY H

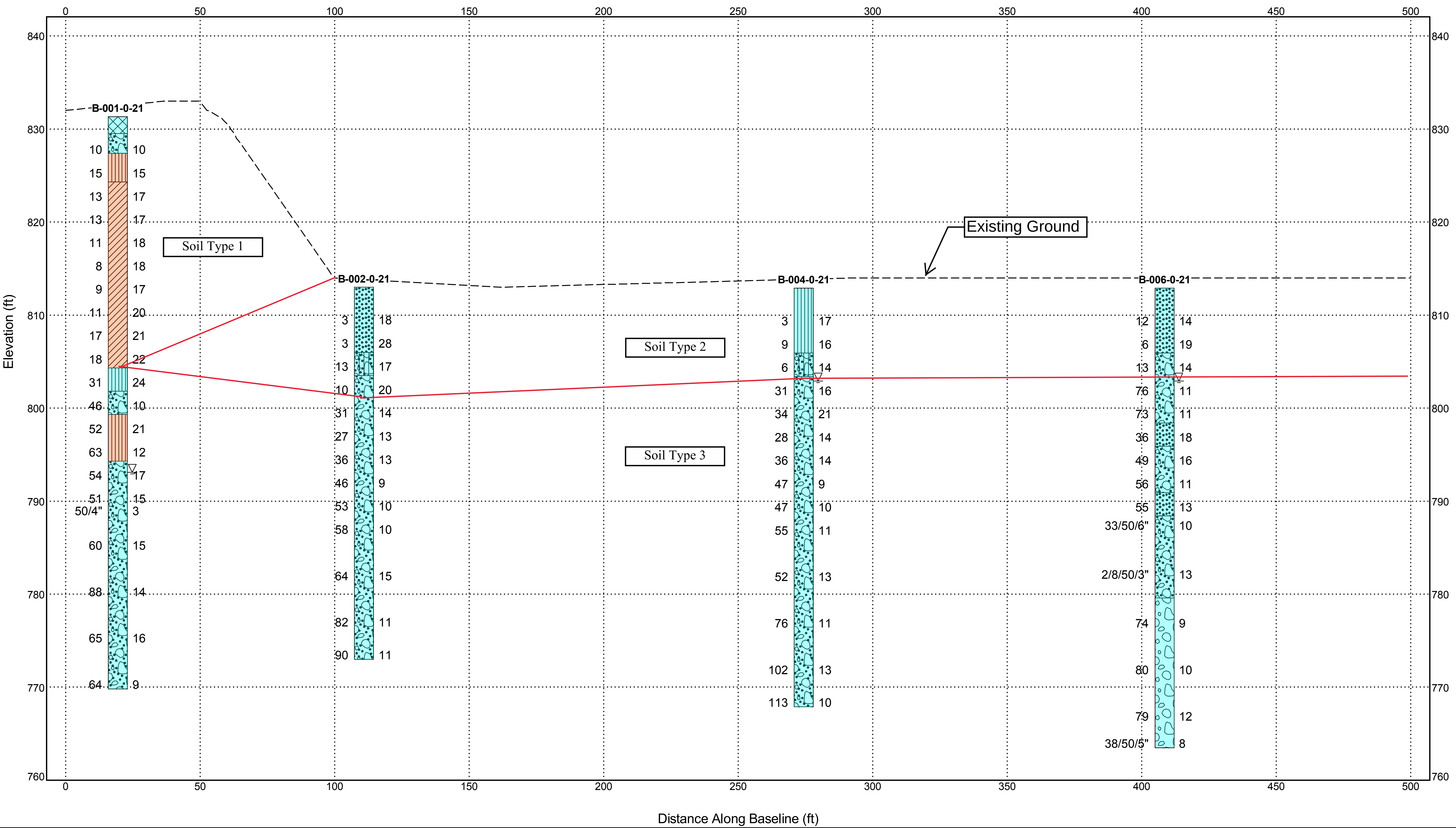
OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

Non-cohesive
Cohesive

SUBSURFACE DIAGRAM
RETAINING WALL F AND TEMPORARY WALL H

CLIENT AECOM
PROJECT NUMBER 104132
PROJECT NAME CUY-14-6.93
PROJECT LOCATION Garfield Heights, OH

- Ohio DOT: Pavement or Aggregate base
- Ohio DOT: A-6a, silt and clay
- Ohio DOT: A-1-a, gravel and/or stone fragments
- Ohio DOT: A-1-b, gravel and/or stone fragments with sand
- Ohio DOT: A-3a, coarse and fine sand
- Ohio DOT: A-7-6, clay
- Ohio DOT: A-4a, sandy silt
- Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt
- Ohio DOT: A-3, fine sand



RETAINING WALL E

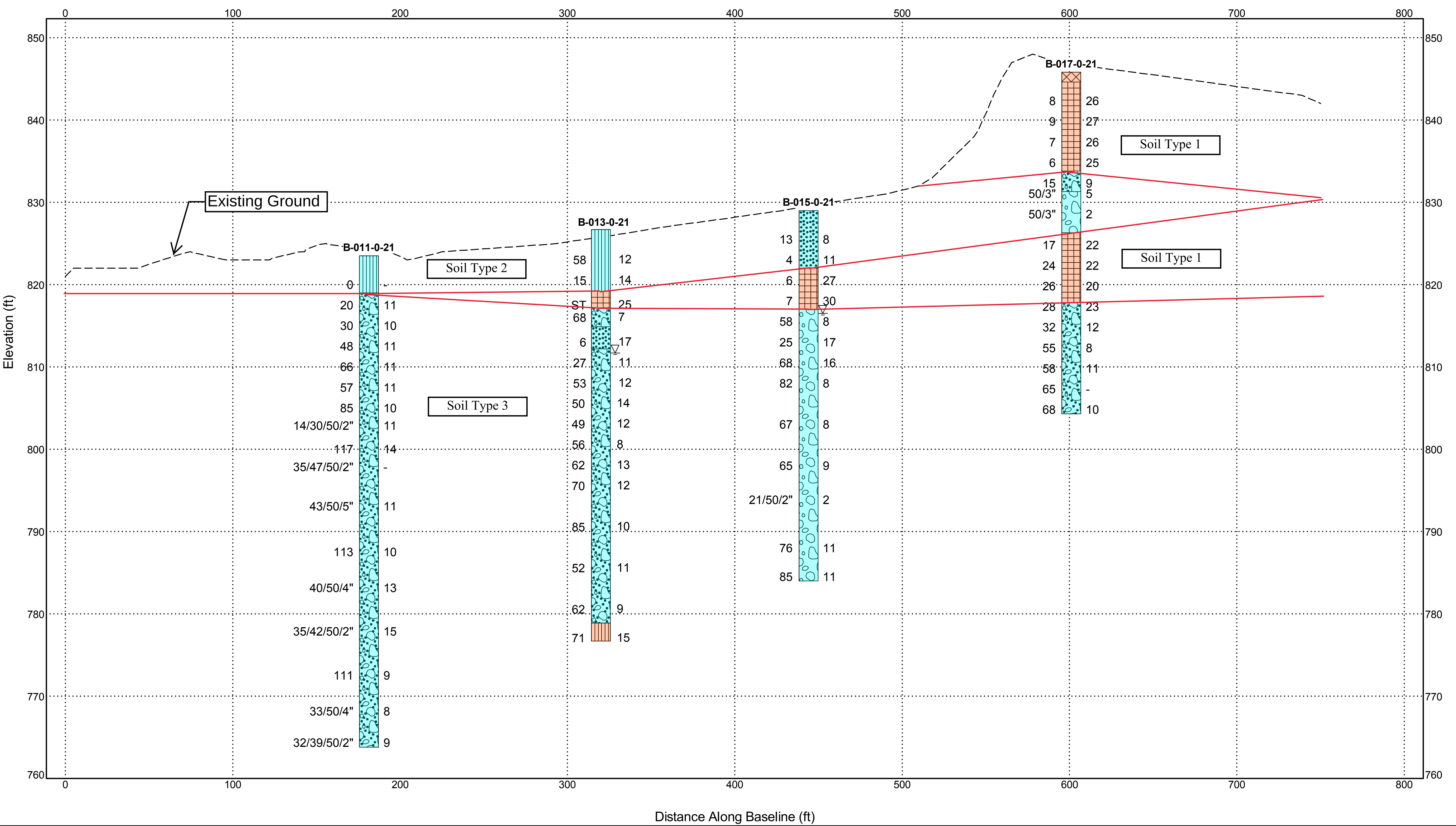
OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

Non-cohesive
Cohesive

SUBSURFACE DIAGRAM
RETAINING WALL E

Ohio DOT: Pavement or Aggregate base	Ohio DOT: A-6b, silty clay	Ohio DOT: A-7-6, clay
Ohio DOT: A-6a, silt and clay	Ohio DOT: A-1-a, gravel and/or stone fragments	Ohio DOT: A-3a, coarse and fine sand
Ohio DOT: A-1-b, gravel and/or stone fragments with sand	Ohio DOT: A-4a, sandy silt	Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt
Ohio DOT: A-4b, silt		

CLIENT AECOM
PROJECT NUMBER 104132
PROJECT NAME CUY-14-6.93
PROJECT LOCATION Garfield Heights, OH



STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 11/10/21 13:23 - C:\USERS\KAREN\S\DESKTOP\CUY-14-6.93\WALLSE-G-TEMP\GINT PROFILE\WORKING FILES\WALLE-G-I.GPJ

RETAINING WALL G AND TEMPORARY I

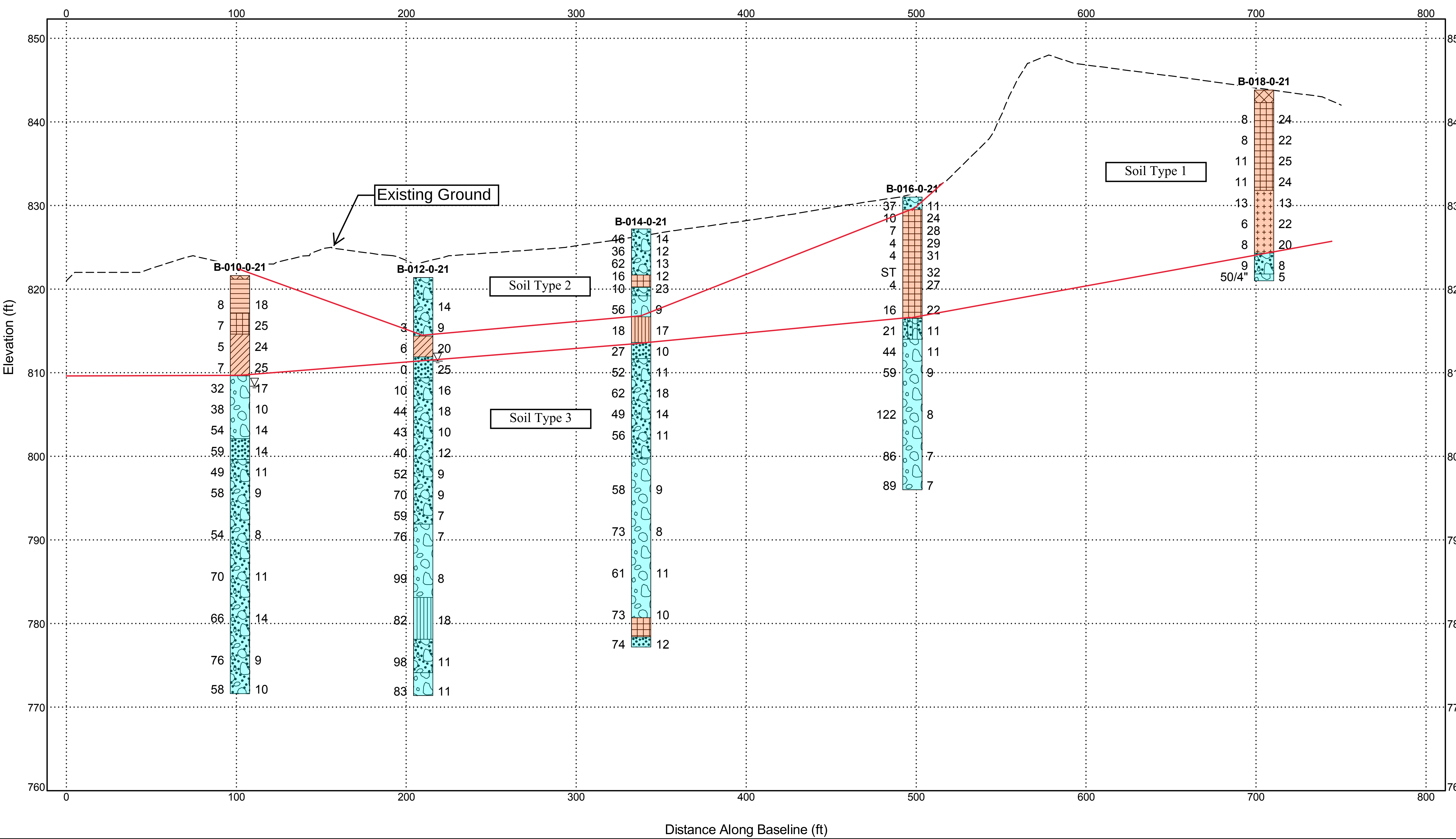
OHIO DEPARTMENT OF TRANSPORTION
OFFICE OF GEOTECHNICAL ENGINEERING

SUBSURFACE DIAGRAM
RETAINING WALL G AND TEMPORARY WALL I

CLIENT AECOM
PROJECT NUMBER 104132
PROJECT NAME CUY-14-6.93
PROJECT LOCATION Garfield Heights, OH

Non-cohesive
Cohesive

Ohio DOT: Pavement or Aggregate base
Ohio DOT: A-6a, silt and clay
Ohio DOT: A-1-b, gravel and/or stone fragments with sand
Ohio DOT: A-4b, silt
Ohio DOT: A-6b, silty clay
Ohio DOT: A-1-a, gravel and/or stone fragments
Ohio DOT: A-4a, sandy silt
Ohio DOT: A-7-6, clay
Ohio DOT: A-3a, coarse and fine sand
Ohio DOT: A-2-4, gravel and/or stone fragments with sand and silt



STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 11/10/21 13:23 - C:\USERS\KARENS\DESKTOP\CUY-14-6.93\WALLSE-G-TEMP\GINT PROFILE\WORKING FILES\WALLE-G-I.GPJ

RETAINING WALLS B, C AND D

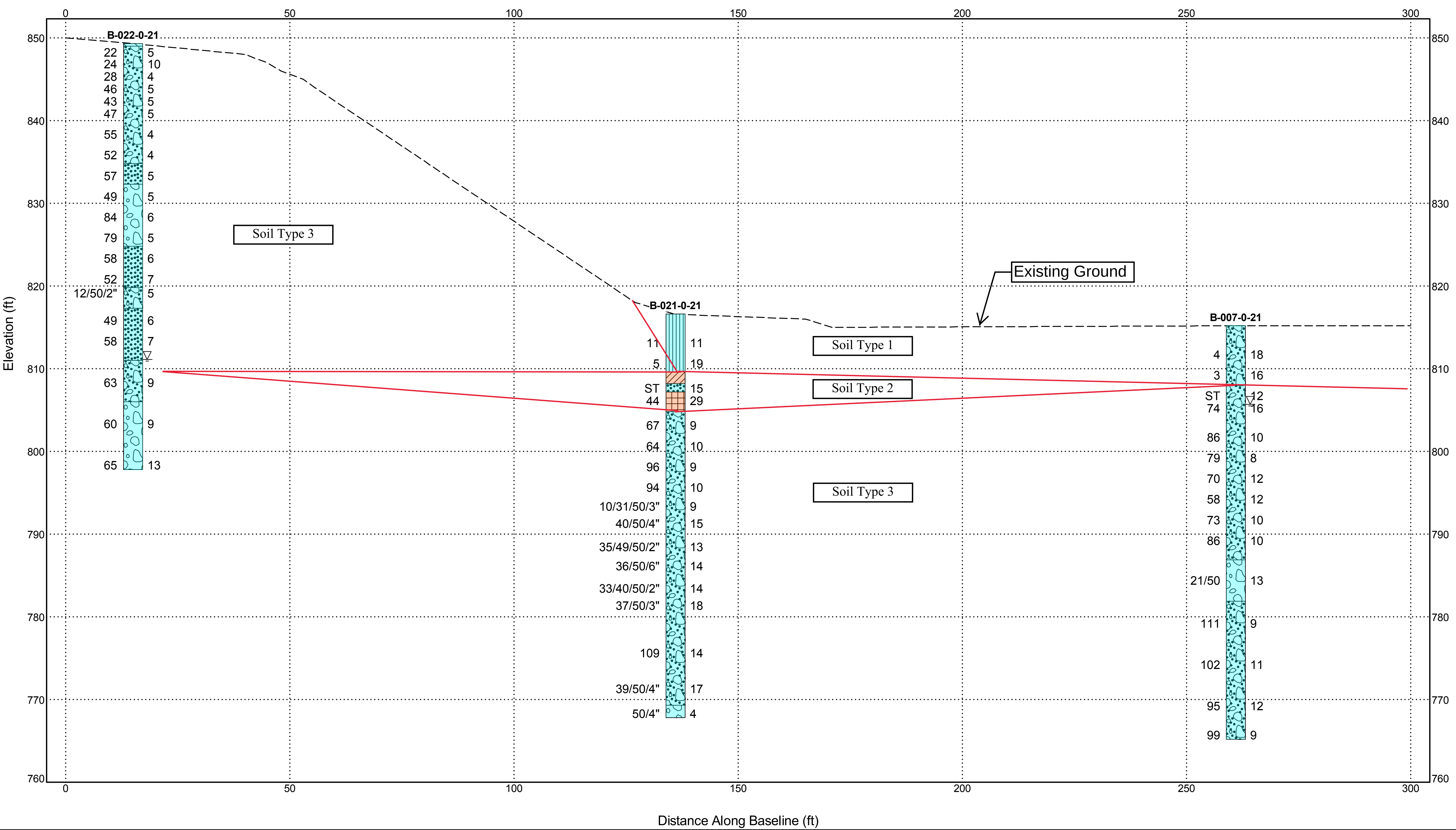
OHIO DEPARTMENT OF TRANSPORTATION
OFFICE OF GEOTECHNICAL ENGINEERING

Non-cohesive
Cohesive

SUBSURFACE DIAGRAM
RETAINING WALLS B, C AND D

Ohio DOT: A-1-b, gravel and/or stone fragments with sand
Ohio DOT: A-1-a, gravel and/or stone fragments
Ohio DOT: A-4a, sandy silt
Ohio DOT: A-6a, silt and clay
Ohio DOT: A-3a, coarse and fine sand
Ohio DOT: A-7-6, clay
Ohio DOT: Sod and Topsoil

CLIENT AECOM
PROJECT NUMBER 104132
PROJECT NAME CUY-14-6.93
PROJECT LOCATION Garfield Heights, OH



STRATIGRAPHY & GW - B SIZE - OH DOT.GDT - 12/10/21 15:32 - C:\USERS\KAREN5\DESKTOP\CUY-14-6.93\WALLSB-C-D\GINT PROFILE\WORKING FILES\WALLB-C-D.GPJ

APPENDIX D

EXTERNAL STABILITY ANALYSIS

RETAINING WALL 1 AND TEMPORARY 2

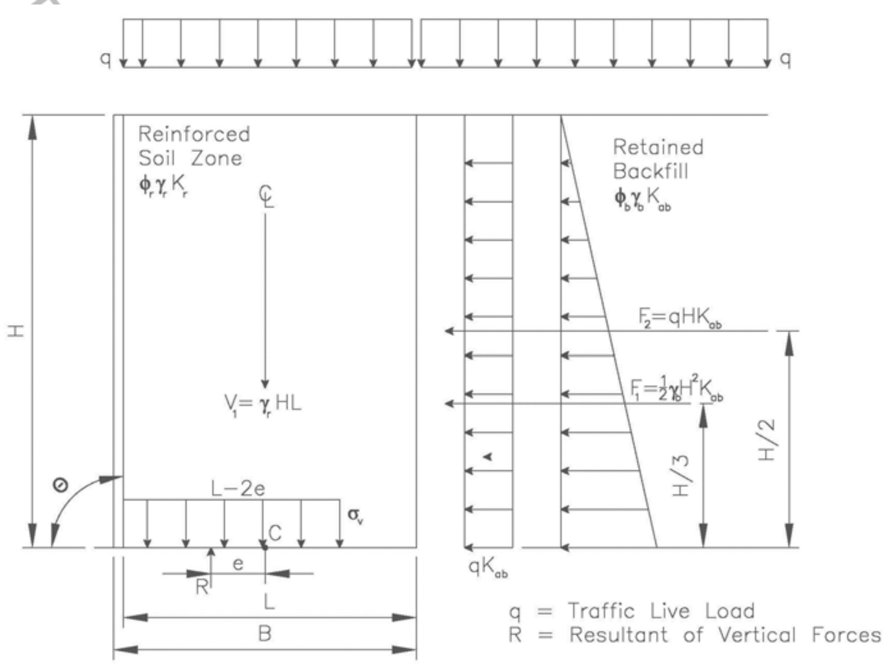
STA. 13+83

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:

<u>Wall Geometry:</u>

$H_e := 30.7 \cdot ft$	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)

<u>Reinforced Backfill Soil Design Parameters:</u>

$\phi'_r := 34 \cdot deg$	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

<u>Retained Backfill Soil Design Parameters</u>:

$\phi'_b := 30 \cdot deg$	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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 29 \cdot deg$ — Effective angle of internal friction

$\gamma_f := 110 \cdot \frac{lbf}{ft^3}$ — Unit weight

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

Undrained Conditions (Total Stress):

$\phi_f := 29 \cdot deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 110\ \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 33.7\ ft$

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

$d_{eSlope} = 1.7\ ft$ — 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.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 33.7\ ft$ — 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\quad L = 23.6\ ft$ — Length of Reinforcement

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:

$\beta := 0\ deg$ $\quad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\quad F_T = 20255.7\ \frac{lbf}{ft}$ $\quad$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\quad F_{SUR} = 2504.4\ \frac{lbf}{ft}$ $\quad$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 95398\ \frac{lbf}{ft}$ $\quad$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\quad V_2 = 5897.5\ \frac{lbf}{ft}$ $\quad$ 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:

$H_1 := F_T = 20255.7\ \frac{lbf}{ft}$ $\quad$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2504.4\ \frac{lbf}{ft}$ $\quad$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 11.2\ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 227539.2\ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 16.9\ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 42199.4\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\qquad V_{EV} = 95398\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\qquad V_{LS} = 5897.5\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\qquad H_{EH} = 20255.7\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\qquad H_{LS} = 2504.4\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 227539.2\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 42199.4\ \frac{lbf \cdot ft}{ft}$

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

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

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\qquad V_{Ia} = 95398\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\qquad V_{Ib} = 139107.9\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\qquad H_{Ia} = 34766.3\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\qquad H_{Ib} = 34766.3\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ia} = 415157.7\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ib} = 415157.7\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 415157.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 139107.9\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 3\ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 17.6\ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 12.9 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 34766.3\ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 139107.9\ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

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

$d_w := 0 \cdot ft$ — 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):

$$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right) \qquad N_q = 16.44$$

$$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right) \qquad N_c = 27.86$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f) \qquad N_\gamma = 19.3$$

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

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.806$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \frac{B'}{L_{Wall}} \cdot \tan(\phi'_f), 1\right) \qquad s_q = 1.757$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.454$$

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]**:

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

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

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

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

$d_q = 1.1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 50.322$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 28.894$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 8.772$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 15173.5 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 9.9 \ ksf$ $\quad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45\ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\quad N_q = 16.44$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\quad N_c = 27.86$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\quad N_\gamma = 19.3$

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

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.806$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.757$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.454$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 50.322$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 28.894$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 8.772$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 15173.5 \ \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 9.9 \ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 9.9 \ ksf$

Undrained Conditions: $q_{Ru} = 9.9 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 9.9 \ ksf$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

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

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

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 415157.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 139107.9\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 3\ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 17.6\ ft$ — Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\quad \sigma_v = 7894.4\ \frac{lbf}{ft^2}$ — Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ — Is the CDR > or = to 1.0? — $CDR_{Bearing} = 1.25$

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

$e_{max} := \frac{L}{3}$ $\quad e_{max} = 7.9\ ft$ — Maximum Eccentricity **LRFD [C11.6.3.3.]**

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

$\Sigma M_O := MH_{Ia}$ $\quad \Sigma M_O = 415157.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 95398\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 4.4\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ — Is the CDR > or = to 1.0? — $CDR_{Eccentricity} = 1.81$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_{\tau} := H_{Ia}$ $\qquad F_{\tau} = 34766.3 \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 95398 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 52880 \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 52.88 \frac{kip}{ft}$

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.**

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

$R_R = 52.9 \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_{\tau}}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.52$

RETAINING WALL 3 AND TEMPORARY 4

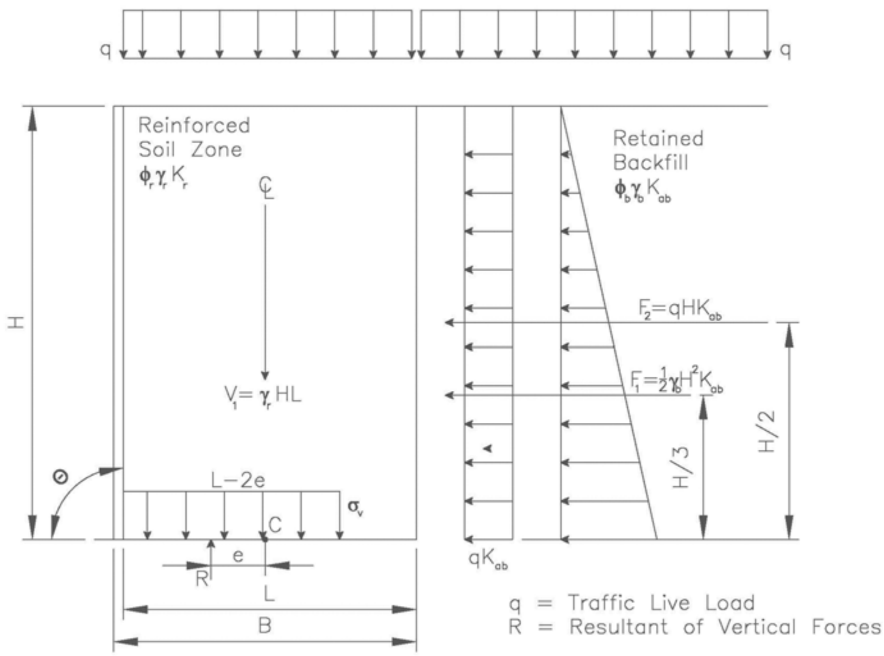
STA. 10+00

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 35.8 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 34 \cdot deg$ — Effective angle of internal friction

$\gamma_f := 130 \cdot \frac{lbf}{ft^3}$ — Unit weight

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

Undrained Conditions (Total Stress):

$\phi_f := 34 \cdot deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 130 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 38.8\ ft$

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

$d_{eSlope} = 1.9\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 38.8\ ft$ — 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 27.2\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 26850.4 \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 2883.4 \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 126457 \frac{lbf}{ft}$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 6790 \frac{lbf}{ft}$ 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:

$H_1 := F_T = 26850.4 \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2883.4 \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: / Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 12.9\ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 347265.5 \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 19.4\ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 55938.4 \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 126457 \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 6790 \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 26850.4 \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2883.4 \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 347265.5 \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 55938.4 \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 126457 \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 182599.4 \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 45321.6 \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 45321.6 \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 618790.4 \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 618790.4 \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 618790.4 \ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 182599.4 \ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 3.4 \ ft$ — Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ — $B' = 20.4 \ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 30 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 45321.6 \ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 182599.4 \ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ — 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):

$$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right) \qquad N_q = 29.44$$

$$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right) \qquad N_c = 42.16$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f) \qquad N_\gamma = 41.1$$

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

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.474$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \frac{B'}{L_{Wall}} \cdot \tan(\phi'_f), 1\right) \qquad s_q = 1.458$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.728$$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.04$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 62.166$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 42.931$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 29.904$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 27835.1\ \frac{lbf}{ft^2}$

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.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 18.1\ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45\ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\qquad N_q = 29.44$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\qquad N_c = 42.16$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\qquad N_\gamma = 41.1$

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

$$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.474$$

$$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right) \qquad s_q = 1.458$$

$$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.728$$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 62.166$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 42.931$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 29.904$

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

$$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma} \qquad q_{nu} = 27835.1 \ \frac{lbf}{ft^2}$$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $\qquad q_{Ru} = 18.1 \ ksf$ — Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 18.1 \ ksf$

Undrained Conditions: $q_{Ru} = 18.1 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 618790.4 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 182599.4 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.4 \; ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 20.4 \; ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 8958.7 \; \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 2.02$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 9.1 \; ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 618790.4 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 126457 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 4.9 \; ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.85$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 45321.6\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 126457\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad R_{\tau d} = 85296.3\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 85.296\ \frac{kip}{ft}$

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.**

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

$R_R = 85.3\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.88$

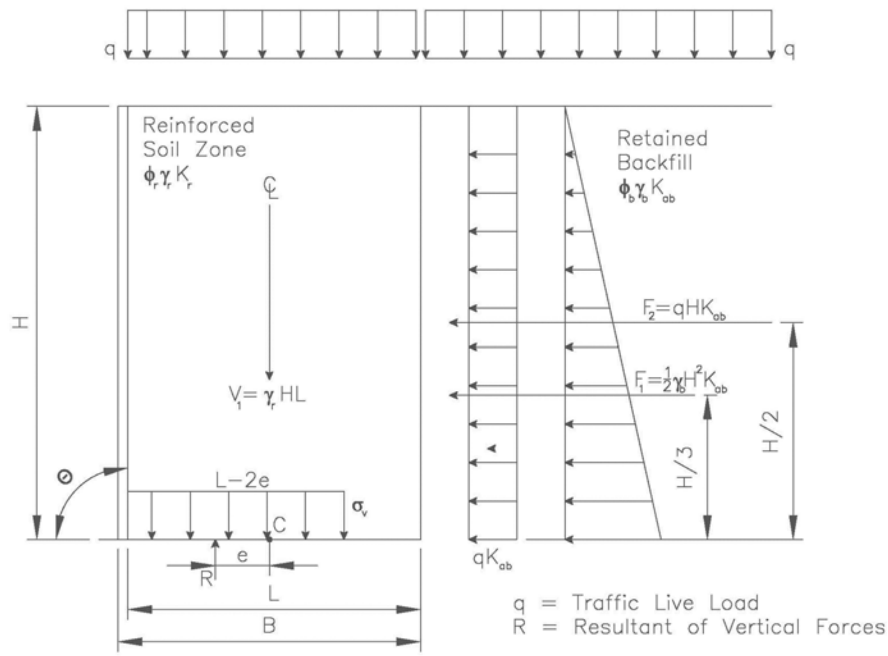
STA. 10+30

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 33.3 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 34 \cdot deg$ — Effective angle of internal friction

$\gamma_f := 130 \cdot \frac{lbf}{ft^3}$ — Unit weight

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

Undrained Conditions (Total Stress):

$\phi_f := 34 \cdot deg$ — Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 130 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H_{est} = 36.3\ ft$

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

$d_{eSlope} = 1.8\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H = 36.3\ ft$ — 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\qquad L = 25.4\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \quad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ — $F_T = 23501.8 \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ — $F_{SUR} = 2697.6 \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ — $V_1 = 110686 \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ — $V_2 = 6352.5 \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 23501.8 \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2697.6 \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 12.1\ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 284371.7 \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 18.2\ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 48962.1 \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 110686\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 6352.5\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 23501.8\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2697.6\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 284371.7\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 48962.1\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 110686\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 160542.9\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 39973.5\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 39973.5\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 512241.1\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 512241.1\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 512241.1\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 160542.9\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.2\ ft$ Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $B' = 19\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 30 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $H' = 39973.5\ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 160542.9\ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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):

$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right)$ $N_q = 29.44$

$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right)$ $N_c = 42.16$

$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f)$ $N_\gamma = 41.1$

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.443$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $s_q = 1.428$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.746$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.04$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 60.837$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 42.035$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 30.645$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 26831 \ \frac{lbf}{ft^2}$

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.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 17.4 \ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45\ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\qquad N_q = 29.44$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\qquad N_c = 42.16$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\qquad N_\gamma = 41.1$

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

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right)\cdot\left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5\cdot L_{Wall}}\right)\right)$ $s_c = 1.443$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\cdot\tan(\phi_f)\right), 1\right)$ $s_q = 1.428$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4\cdot\left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.746$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 60.837$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 42.035$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 30.645$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 26831 \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 17.4\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 17.4\ ksf$

Undrained Conditions: $q_{Ru} = 17.4\ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

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

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

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 512241.1 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 160542.9 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 3.2 \ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 19 \ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\quad \sigma_v = 8436.9 \ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 2.07$

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

$e_{max} := \frac{L}{3}$ $\quad e_{max} = 8.5 \ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

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

$\Sigma M_O := MH_{Ia}$ $\quad \Sigma M_O = 512241.1 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 110686 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 4.6 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.83$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 39973.5 \, \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 110686 \, \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 74658.6 \, \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 74.659 \, \frac{kip}{ft}$

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]**:

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

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

$R_R = 74.7 \, \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 1.87$

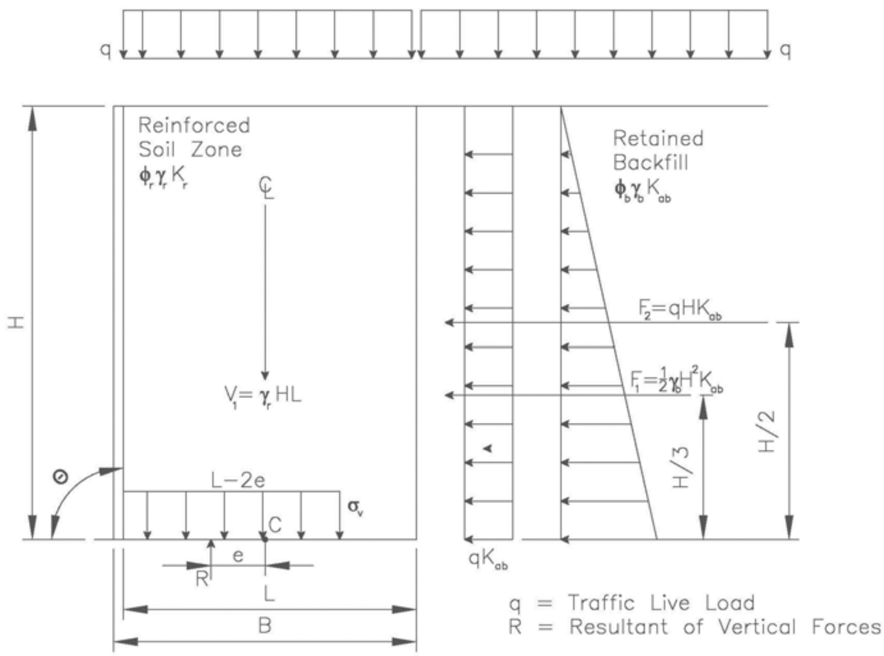
STA. 10+60 – 1.0H STRAP LENGTH

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 35.8 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ 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)

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

$d_{frost} := 3\ ft$ $d_{user} := 0\ ft$ 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 38.8\ ft$

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

$d_{eSlope} = 1.9\ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 38.8\ ft$ Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 34.2 \cdot ft$ User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 34.2\ ft$ Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 26850.4 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 2883.4 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 159235.2 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 8550 \ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 26850.4 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2883.4 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: / Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 12.9 \ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 347265.5 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 19.4 \ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 55938.4 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 159235.2\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 8550\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 26850.4\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2883.4\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 347265.5\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 55938.4\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 159235.2\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 229930\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 45321.6\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 45321.6\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 618790.4\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 618790.4\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 618790.4\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 229930\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

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

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 28.8\ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 70 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 45321.6\ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 229930\ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ — 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]**:

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.251$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right) \qquad s_q = 1.238$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.835$$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.03$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 37.715$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 22.775$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 18.713$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 20400.9 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 13.3 \ ksf$ $\quad$ 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]**:

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.251$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.238$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.835$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 37.715$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 22.775$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 18.713$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 20400.9 \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 13.3\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 13.3\ ksf$

Undrained Conditions: $q_{Ru} = 13.3\ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

Evaluate External Stability of Wall:

Bearing Resistance at Base of the Wall:

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

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

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 618790.4 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 229930 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

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

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 28.8 \ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\quad \sigma_v = 7978.8 \ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.66$

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

$e_{max} := \frac{L}{3}$ $\quad e_{max} = 11.4 \ ft$ Maximum Eccentricity **LRFD [C11.6.3.3.]**

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

$\Sigma M_O := MH_{Ia}$ $\quad \Sigma M_O = 618790.4 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 159235.2 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 3.9 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 2.93$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 45321.6\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 159235.2\ \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 91934.5\ \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 91.934\ \frac{kip}{ft}$

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]**:

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

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

$R_R = 91.9\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 2.03$

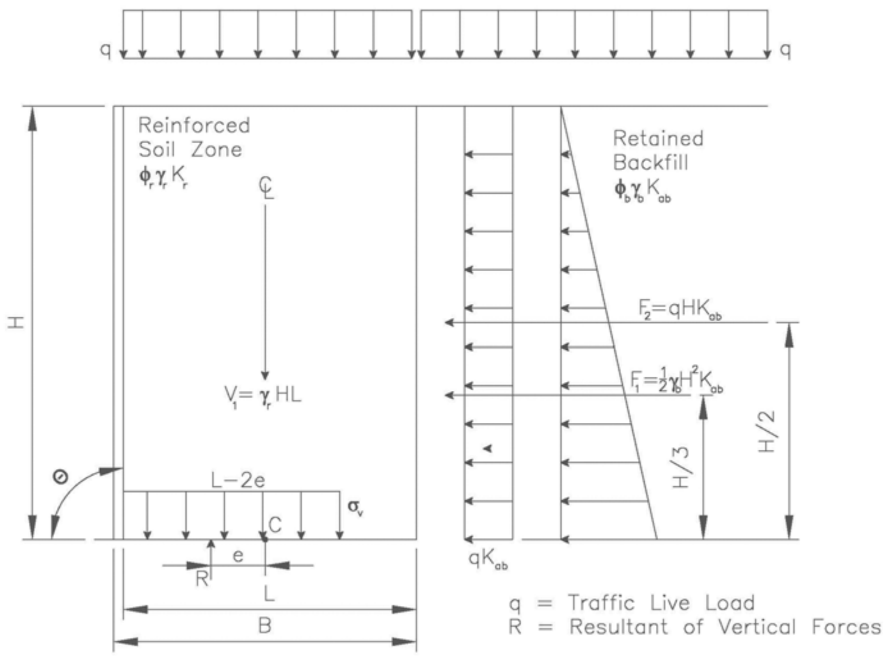
STA. 11+30 – 1.0H STRAP LENGTH

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 28.1 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ 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)

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

$d_{frost} := 3 \ ft$ $d_{user} := 0 \ ft$ 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**

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

$H_{est} := d_{est} + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 31.1 \ ft$

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

$d_{eSlope} = 1.6 \ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 31.1 \ ft$ Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 31.1 \cdot ft$ User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 31.1 \ ft$ Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 17250.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 2311.2 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 116065.2 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 7775 \ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 17250.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2311.2 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: / Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 10.4 \ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 178833 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 15.6 \ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 35939.1 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 116065.2\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 7775\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 17250.8\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2311.2\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 178833\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 35939.1\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot \left(Ia_{EV} \cdot V_{EV}\right)$ $\quad V_{Ia} = 116065.2\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot V_{EV}\right) + \left(Ib_{LS} \cdot V_{LS}\right)\right)$ $\quad V_{Ib} = 170294.3\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS}\right) + \left(Ia_{EH} \cdot H_{EH}\right)\right)$ $\quad H_{Ia} = 29920.8\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS}\right) + \left(Ib_{EH} \cdot H_{EH}\right)\right)$ $\quad H_{Ib} = 29920.8\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

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

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

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LS2}\right) + \left(Ia_{EH} \cdot M_{EH2}\right)\right)$ $\quad MH_{Ia} = 331142.9\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LS2}\right) + \left(Ib_{EH} \cdot M_{EH2}\right)\right)$ $\quad MH_{Ib} = 331142.9\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 331142.9 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 170294.3 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 1.9\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 27.2\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 30 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $\quad H' = 29920.8 \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $\quad V' = 170294.3 \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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]**:

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $\quad s_c = 1.554$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $\quad s_q = 1.524$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $\quad s_\gamma = 0.637$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.03$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad$ $N_{cm} = 46.83$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad$ $N_{qm} = 28.037$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad$ $N_{\gamma m} = 14.275$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad$ $q_{nd} = 16860.1 \ \frac{lbf}{ft^2}$

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.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad$ $q_{Rd} = 11 \ ksf$ $\qquad$ 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]**:

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.554$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.524$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.637$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 46.83$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 28.037$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 14.275$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 16860.1 \ \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 11 \ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 11 \ ksf$

Undrained Conditions: $q_{Ru} = 11 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ | $\Sigma M_O = 331142.9\ \frac{lbf \cdot ft}{ft}$ | Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ | $\Sigma V = 170294.3\ \frac{lbf}{ft}$ | Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ | $e_{wall} = 1.9\ ft$ | Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ | $B' = 27.2\ ft$ | Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ | $\sigma_v = 6258.3\ \frac{lbf}{ft^2}$ | Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ | Is the CDR > or = to 1.0? | $CDR_{Bearing} = 1.75$

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

$e_{max} := \frac{L}{3}$ | $e_{max} = 10.4\ ft$ | 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)

$\Sigma M_O := MH_{Ia}$ | $\Sigma M_O = 331142.9\ \frac{lbf \cdot ft}{ft}$ | Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ | $\Sigma V = 116065.2\ \frac{lbf}{ft}$ | Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ | $e_{wall} = 2.9\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ | Is the CDR > or = to 1.0? | $CDR_{Eccentricity} = 3.63$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 29920.8\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 116065.2\ \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 67010.3\ \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 67.01\ \frac{kip}{ft}$

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]**:

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

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

$R_R = 67\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 2.24$

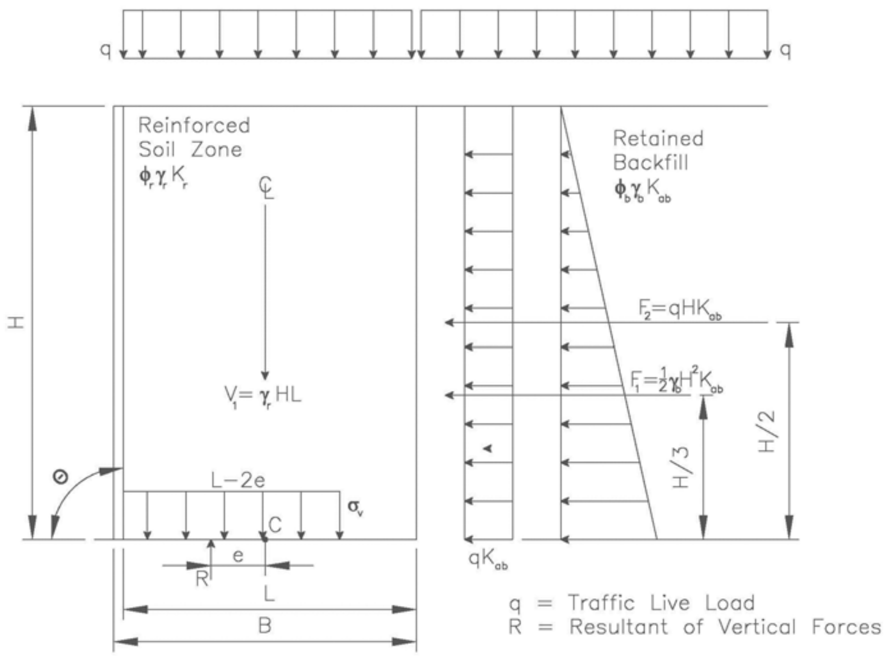
STA. 11+60 – 1.0H STRAP LENGTH

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 26.2 \cdot ft$ 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ 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)

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

$d_{frost} := 3 \ ft$ $d_{user} := 0 \ ft$ 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**

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

$H_{est} := d_{est} + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 29.2 \ ft$

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

$d_{eSlope} = 1.5 \ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 29.2 \ ft$ Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 29.2 \cdot ft$ User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 29.2 \ ft$ Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 15207.3 \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 2170 \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 102316.8 \frac{lbf}{ft}$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 7300 \frac{lbf}{ft}$ 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:

$H_1 := F_T = 15207.3 \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2170 \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: / Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 9.7\ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 148018.2 \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 14.6\ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 31682 \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 102316.8 \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 7300 \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 15207.3 \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2170 \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 148018.2 \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 31682 \frac{lbf \cdot ft}{ft}$

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

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

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 102316.8 \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 150902.7 \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 26608.5 \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 26608.5 \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 277470.7 \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 277470.7 \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 277470.7 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 150902.7 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 1.8 \ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 25.5 \ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 25 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $H' = 26608.5 \ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 150902.7 \ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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]**:

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.623$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right) \qquad s_q = 1.589$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.592$$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.03$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 48.925$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 29.247$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 13.254$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 15591.5 \ \frac{lbf}{ft^2}$

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.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 10.1 \ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained 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]**:

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.623$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.589$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.592$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 48.925$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 29.247$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 13.254$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 15591.5 \ \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 10.1 \ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 10.1 \ ksf$

Undrained Conditions: $q_{Ru} = 10.1 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 277470.7\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 150902.7\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 1.8\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 25.5\ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 5912.5\ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.71$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 9.7\ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 277470.7\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 102316.8\ \frac{lbf}{ft}$ 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? $CDR_{Eccentricity} = 3.59$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 26608.5 \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 102316.8 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad R_{\tau d} = 59072.6 \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 59.073 \frac{kip}{ft}$

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.**

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

$R_R = 59.1 \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 2.22$

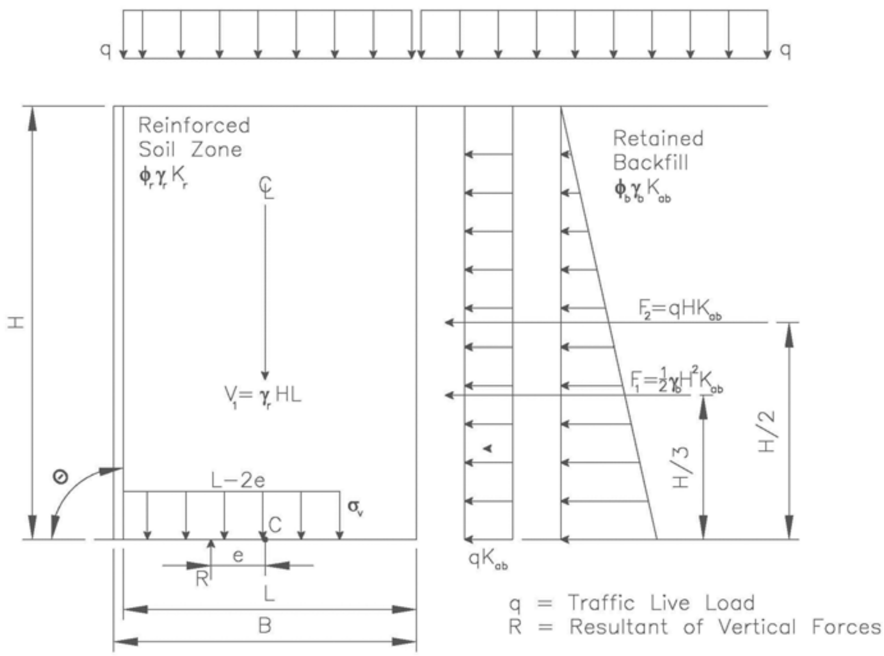
STA. 11+85

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 23.4 \cdot ft$	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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

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

$d_{frost} := 3\ ft$ $\quad d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 26.4\ ft$

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

$d_{eSlope} = 1.3\ ft$ — 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.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 26.4\ ft$ — 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\quad L = 18.5\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 12430.7 \ \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 1961.9 \ \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 58544.6 \ \frac{lbf}{ft}$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 4620 \ \frac{lbf}{ft}$ 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:

$H_1 := F_T = 12430.7 \ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1961.9 \ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: / Moment:

$d_{h1} := \frac{H}{3} \qquad d_{h1} = 8.8 \ ft \qquad MH_1 := H_1 \cdot d_{h1} \qquad MH_1 = 109390.2 \ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2} \qquad d_{h2} = 13.2 \ ft \qquad MH_2 := H_2 \cdot d_{h2} \qquad MH_2 = 25897.3 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\qquad V_{EV} = 58544.6\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\qquad V_{LS} = 4620\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\qquad H_{EH} = 12430.7\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\qquad H_{LS} = 1961.9\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 109390.2\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 25897.3\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\qquad V_{Ia} = 58544.6\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\qquad V_{Ib} = 87120.3\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\qquad H_{Ia} = 22079.4\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\qquad H_{Ib} = 22079.4\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ia} = 209405.5\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ib} = 209405.5\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 209405.5\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 87120.3\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.4\ ft$ Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $B' = 13.7\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 25 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $H' = 22079.4\ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 87120.3\ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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):

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

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

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

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.334$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $s_q = 1.316$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.781$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.06$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad$ $N_{cm} = 40.203$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad$ $N_{qm} = 24.211$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad$ $N_{\gamma m} = 17.502$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad$ $q_{nd} = 11812.9 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad$ $q_{Rd} = 7.7 \ ksf$ $\quad$ 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]**:

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.334$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.316$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.781$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 40.203$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 24.211$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 17.502$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 11812.9 \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 7.7\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 7.7\ ksf$

Undrained Conditions: $q_{Ru} = 7.7\ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 209405.5 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 87120.3 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.4 \; ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 13.7 \; ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 6371.8 \; \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.21$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 6.2 \; ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 209405.5 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 58544.6 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.6 \; ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.72$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 22079.4 \ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 58544.6 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\quad R_{\tau d} = 33800.8 \ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 33.801 \ \frac{kip}{ft}$

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.**

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

$R_R = 33.8 \ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.53$

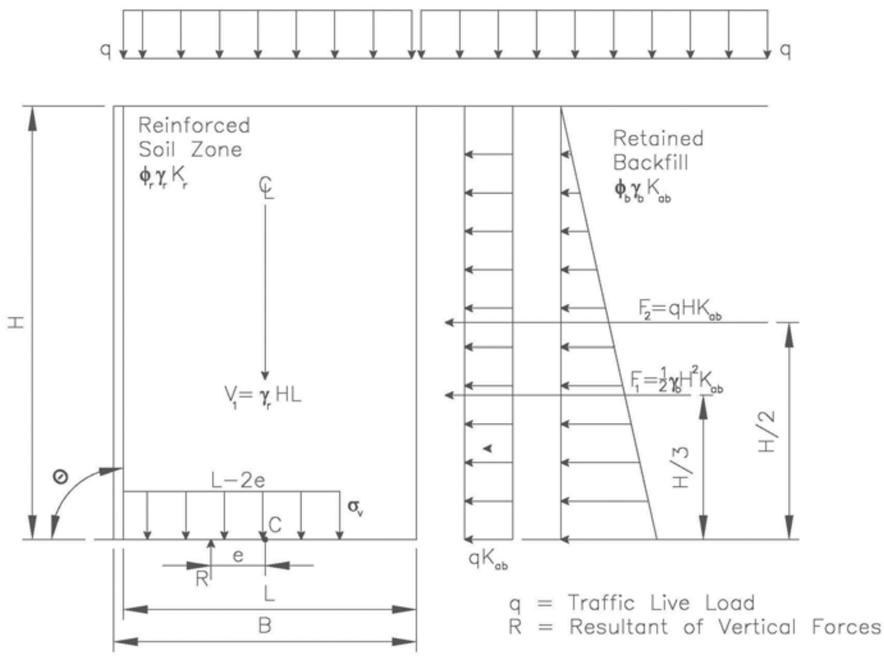
STA. 12+10

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 21 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

$\gamma_f = 120 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H_{est} = 24\ ft$

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

$d_{eSlope} = 1.2\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H = 24\ ft$ — 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\qquad L = 16.8\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

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

$k_{af} = 0.2973$ Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\qquad F_T = 10273.3 \; \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\qquad F_{SUR} = 1783.6 \; \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\qquad V_1 = 48384 \; \frac{lbf}{ft}$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\qquad V_2 = 4200 \; \frac{lbf}{ft}$ 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:

$H_1 := F_T = 10273.3 \; \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1783.6 \; \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 8 \; ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 82186.4 \; \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 12 \; ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 21402.7 \; \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\qquad V_{EV} = 48384\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\qquad V_{LS} = 4200\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\qquad H_{EH} = 10273.3\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\qquad H_{LS} = 1783.6\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 82186.4\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 21402.7\ \frac{lbf \cdot ft}{ft}$

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

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

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\qquad V_{Ia} = 48384\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\qquad V_{Ib} = 72668.4\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\qquad H_{Ia} = 18531.2\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\qquad H_{Ib} = 18531.2\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ia} = 160734.4\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ib} = 160734.4\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 160734.4\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 72668.4\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.2\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 12.4\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 189 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $H' = 18531.2\ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 72668.4\ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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):

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

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

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

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.04$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $s_q = 1.038$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.974$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.07$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\qquad N_{cm} = 31.345$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\qquad N_{qm} = 19.097$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\qquad N_{\gamma m} = 21.816$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\qquad q_{nd} = 11777.8 \ \frac{lbf}{ft^2}$

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.**

$q_{Rd} := \phi_b \cdot q_{nd}$ $\qquad q_{Rd} = 7.7 \ ksf$ $\qquad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

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

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

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

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

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.04$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.038$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.974$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 31.345$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 19.097$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 21.816$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 11777.8 \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 7.7\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 7.7\ ksf$

Undrained Conditions: $q_{Ru} = 7.7\ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 160734.4\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 72668.4\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.2\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 12.4\ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 5871.6\ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.30$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 5.6\ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 160734.4\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 48384\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.3\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.69$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 18531.2\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 48384\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad R_{\tau d} = 27934.5\ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 27.935\ \frac{kip}{ft}$

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.**

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

$R_R = 27.9\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.51$

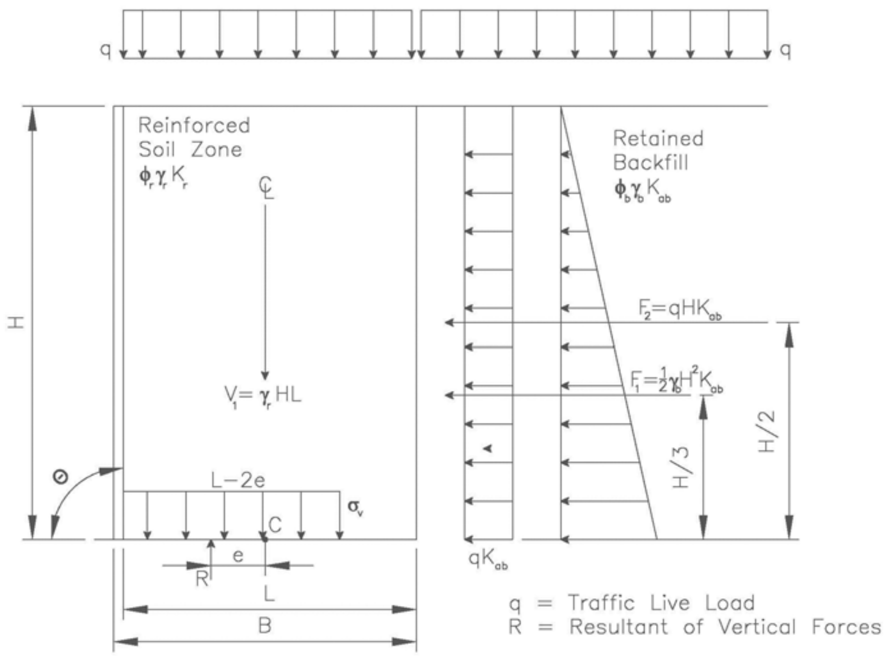
RETAINING WALL 5

STA. 11+95

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:

$H_e := 29 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

$\phi'_f := 29 \cdot deg$ Effective angle of internal friction

$\gamma_f := 110 \cdot \frac{lbf}{ft^3}$ Unit weight

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

Undrained Conditions (Total Stress):

$\phi_f := 29 \cdot deg$ Angle of internal friction (Same as Drained Conditions if Sand)

$\gamma_f = 110 \ \frac{lbf}{ft^3}$ 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:

$d_{frost} := 3 \ ft$ $d_{user} := 0 \ ft$ 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**

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

$H_{est} := d_{est} + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 32 \ ft$

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

$d_{eSlope} = 1.6 \ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4 \ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 32 \ ft$ 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 22.4 \ ft$ Length of Reinforcement

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:

$\beta := 0\ deg$ $\delta := 0.67 \cdot \phi'_b$

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

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

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

$k_{af} = 0.2973$ Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $F_T = 18263.7\ \frac{lbf}{ft}$ Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $F_{SUR} = 2378.1\ \frac{lbf}{ft}$ Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $V_1 = 86016\ \frac{lbf}{ft}$ Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $V_2 = 5600\ \frac{lbf}{ft}$ 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:

$H_1 := F_T = 18263.7\ \frac{lbf}{ft}$ Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2378.1\ \frac{lbf}{ft}$ Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: Moment:

$d_{h1} := \frac{H}{3}$ $d_{h1} = 10.7\ ft$ $MH_1 := H_1 \cdot d_{h1}$ $MH_1 = 194812.3\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2}$ $d_{h2} = 16\ ft$ $MH_2 := H_2 \cdot d_{h2}$ $MH_2 = 38049.3\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 86016 \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 5600 \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 18263.7 \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2378.1 \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 194812.3 \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 38049.3 \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 86016 \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 125921.6 \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 31557.1 \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 31557.1 \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 358804.7 \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 358804.7 \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 358804.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 125921.6\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2.8\ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 16.7\ ft$ — Effective Bearing Width

Foundation Layout:

$L_{Wall} := 70 \cdot ft$ — Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ — $H' = 31557.1\ \frac{lbf}{ft}$ — Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ — $V' = 125921.6\ \frac{lbf}{ft}$ — Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ — 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):

$$N_q := \text{if}\left(\phi'_f > 0, e^{\pi \cdot \tan(\phi'_f)} \cdot \tan\left(45\ deg + \frac{\phi'_f}{2}\right)^2, 1.0\right) \qquad N_q = 16.44$$

$$N_c := \text{if}\left(\phi'_f > 0, \frac{N_q - 1}{\tan(\phi'_f)}, 5.14\right) \qquad N_c = 27.86$$

$$N_\gamma := 2 \cdot (N_q + 1) \cdot \tan(\phi'_f) \qquad N_\gamma = 19.3$$

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

$$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right) \qquad s_c = 1.141$$

$$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right) \qquad s_q = 1.132$$

$$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right) \qquad s_\gamma = 0.905$$

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]**:

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

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

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

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

$d_q = 1.1$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 31.784$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 18.618$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 17.492$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 11562.3 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 7.5 \ ksf$ $\quad$ Factored bearing resistance Drained Conditions

Undrained Conditions (Effective Stress):

$N_q := \text{if}\left(\phi_f > 0, e^{\pi \cdot \tan\left(\phi_f\right)} \cdot \tan\left(45 \ deg + \frac{\phi_f}{2}\right)^2, 1.0\right)$ $\quad N_q = 16.44$

$N_c := \text{if}\left(\phi_f > 0, \frac{N_q - 1}{\tan\left(\phi_f\right)}, 5.14\right)$ $\quad N_c = 27.86$

$N_\gamma := 2 \cdot \left(N_q + 1\right) \cdot \tan\left(\phi_f\right)$ $\quad N_\gamma = 19.3$

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

$$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$$ $s_c = 1.141$

$$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan\left(\phi_f\right)\right), 1\right)$$ $s_q = 1.132$

$$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$$ $s_\gamma = 0.905$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 31.784$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 18.618$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 17.492$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 11562.3\ \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 7.5\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 7.5\ ksf$

Undrained Conditions: $q_{Ru} = 7.5\ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 7.5\ ksf$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 358804.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 125921.6\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2.8\ ft$ — Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ — $B' = 16.7\ ft$ — Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ — $\sigma_v = 7539.7\ \frac{lbf}{ft^2}$ — Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ — Is the CDR > or = to 1.0? — $CDR_{Bearing} = 1.00$

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

$e_{max} := \frac{L}{3}$ — $e_{max} = 7.5\ ft$ — 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)

$\Sigma M_O := MH_{Ia}$ — $\Sigma M_O = 358804.7\ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ — $\Sigma V = 86016\ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 4.2\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ — Is the CDR > or = to 1.0? — $CDR_{Eccentricity} = 1.79$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 31557.1 \, \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 86016 \, \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\qquad R_{\tau d} = 47679.4 \, \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 47.679 \, \frac{kip}{ft}$

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]**:

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

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

$R_R = 47.7 \, \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 1.51$

RETAINING WALL 6

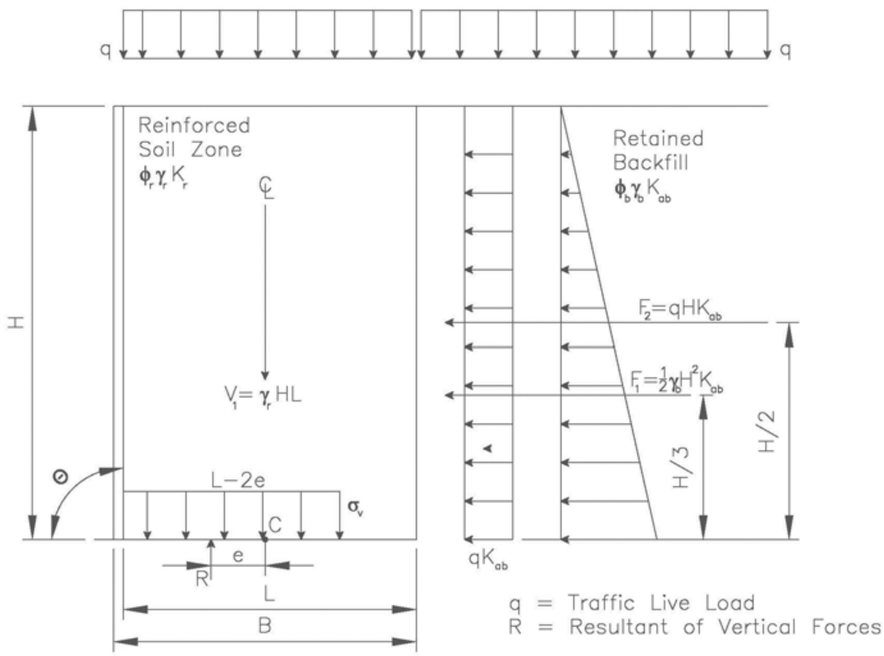
STA. 10+00 – 1.0H STRAP LENGTH

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. 204.6.2.1] LRFD Bridge Design Specifications, 9th Ed., 2014, [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:

$H_e := 33.3 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

$\gamma_f = 120 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 0\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H_{est} = 36.3\ ft$

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

$d_{eSlope} = 1.8\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H = 36.3\ ft$ — Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 36.3 \cdot ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\qquad L = 36.3\ ft$ — Length of Reinforcement

Live Load Surcharge Parameters:

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

Live load surcharge (per LRFD BDS [3.11.6.4])
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:

$\beta := 0 \cdot deg \qquad \delta := 0.67 \cdot \phi'_b$

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

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af} \qquad F_T = 23501.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af} \qquad F_{SUR} = 2697.6 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L \qquad V_1 = 158122.8 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L \qquad V_2 = 9075 \ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 23501.8 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2697.6 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 12.1 \ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 284371.7 \ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 18.2 \ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 48962.1 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $V_{EV} = 158122.8\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $V_{LS} = 9075\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $H_{EH} = 23501.8\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $H_{LS} = 2697.6\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $M_{EH2} = 284371.7\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $M_{LS2} = 48962.1\ \frac{lbf \cdot ft}{ft}$

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

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

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $V_{Ia} = 158122.8\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $V_{Ib} = 229347\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $H_{Ia} = 39973.5\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $H_{Ib} = 39973.5\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

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

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

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $MH_{Ia} = 512241.1\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $MH_{Ib} = 512241.1\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 512241.1\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 229347\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.2\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 31.8\ ft$ Effective Bearing Width

Foundation Layout:

$L_{Wall} := 80 \cdot ft$ Assumed Footing Length (Wall Section Length)

$H' := H_{Ib}$ $H' = 39973.5\ \frac{lbf}{ft}$ Summation of Horizontal Loads (Strength Ib)

$V' := V_{Ib}$ $V' = 229347\ \frac{lbf}{ft}$ Summation of Vertical Loads (Strength Ib)

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

$d_w := -0.5 \cdot ft$ 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):

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

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

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

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

$s_c := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.243$

$s_q := \text{if}\left(\phi'_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi'_f)\right), 1\right)$ $s_q = 1.23$

$s_\gamma := \text{if}\left(\phi'_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.841$

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]**:

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

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

Depth Correction Factor per Hanson (1970):

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

$d_q = 1.03$

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

$N_{cm} := N_c \cdot s_c \cdot i_c$ $\quad N_{cm} = 37.462$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $\quad N_{qm} = 22.629$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $\quad N_{\gamma m} = 18.837$

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

$q_{nd} := c'_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $\quad q_{nd} = 22172.9 \ \frac{lbf}{ft^2}$

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 14.4 \ ksf$ $\quad$ 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]**:

$s_c := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}}\right) \cdot \left(\frac{N_q}{N_c}\right), 1 + \left(\frac{B'}{5 \cdot L_{Wall}}\right)\right)$ $s_c = 1.243$

$s_q := \text{if}\left(\phi_f > 0, 1 + \left(\frac{B'}{L_{Wall}} \cdot \tan(\phi_f)\right), 1\right)$ $s_q = 1.23$

$s_\gamma := \text{if}\left(\phi_f > 0, 1 - 0.4 \cdot \left(\frac{B'}{L_{Wall}}\right), 1\right)$ $s_\gamma = 0.841$

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]:**

$N_{cm} := N_c \cdot s_c \cdot i_c$ $N_{cm} = 37.462$

$N_{qm} := N_q \cdot s_q \cdot i_q$ $N_{qm} = 22.629$

$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma$ $N_{\gamma m} = 18.837$

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

$q_{nu} := c_f \cdot N_{cm} + \gamma_q \cdot D_f \cdot N_{qm} \cdot d_q \cdot C_{wq} + 0.5 \cdot \gamma_f \cdot B' \cdot N_{\gamma m} \cdot C_{w\gamma}$ $q_{nu} = 22172.9 \ \frac{lbf}{ft^2}$

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 14.4 \ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 14.4 \ ksf$

Undrained Conditions: $q_{Ru} = 14.4 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations: $q_R := q_{Rd}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 512241.1\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 229347\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.2\ ft$ Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $B' = 31.8\ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 7204.7\ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 2.00$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 12.1\ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 512241.1\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 158122.8\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.2\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 3.74$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 39973.5 \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 158122.8 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad R_{\tau d} = 91292.2 \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained vs. Undrained Conditions:

Drained Conditions: $R_{\tau d} = 91.292 \frac{kip}{ft}$

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.**

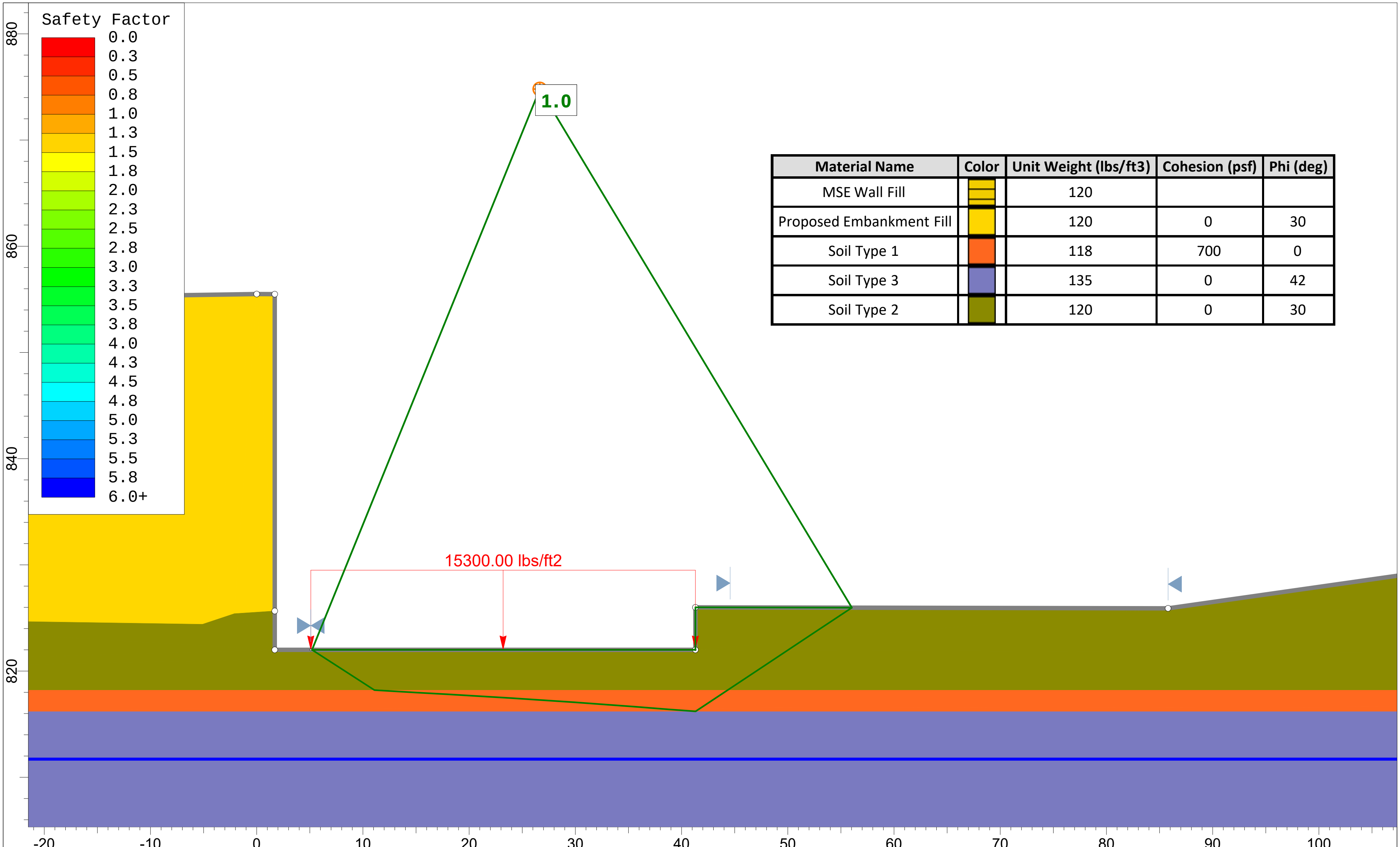
$\phi R_n := \phi_\tau \cdot R_\tau$ $\quad R_R := \phi R_n$

$R_R = 91.3 \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 2.28$

STA. 10+80 – 1.2H STRAP LENGTH



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30

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SLIDEINTERPRET 9.025

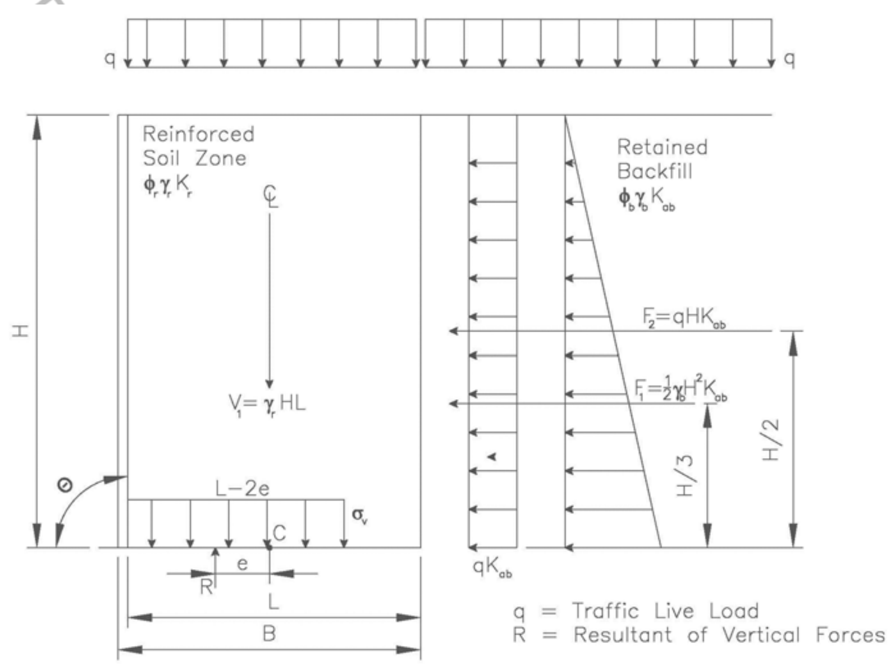
Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 10+80, Bearing Resistance - Limit Equilibrium		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA10+80_1.2H_B-013_TotalCircular021023.slim

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:

$H_e := 30 \cdot ft$ 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

$\gamma_f = 120 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 3\ ft$ — 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**

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

$H_{est} := d_{est} + (4\ ft \cdot \tan(Slope_{fw})) + H_e$ $\qquad H_{est} = 33\ ft$

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

$d_{eSlope} = 1.7\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + (4\ ft \cdot \tan(Slope_{fw})) + H_e$ $\qquad H = 33\ ft$ — Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 39.6 \cdot ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max(8 \cdot ft, 0.7 \cdot H, L_{user})$ $\qquad L = 39.6\ ft$ — Length of Reinforcement

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:

$\beta := 0 \ deg$ — Inclination of ground slope behind face of wall

$\delta := 0.67 \cdot \phi'_b$ — Interface angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\quad F_T = 19423 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\quad F_{SUR} = 2452.4 \ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 156816 \ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\quad V_2 = 9900 \ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 19423 \ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2452.4 \ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 11 \ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 213652.7 \ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 16.5 \ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 40464.5 \ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 156816\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 9900\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 19423\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2452.4\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 213652.7\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 40464.5\ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

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

Strength Limit State Ia: (Sliding and Eccentricity) $Ia_{EV} := 1$ $\quad Ia_{EH} := 1.5$ $\quad Ia_{LS} := 1.75$

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

Factored Vertical Loads by Limit State:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 156816\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 229026.6\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 33426.1\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 33426.1\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 391291.9\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 391291.9\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 391291.9 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 229026.6 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

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

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $B' = 36.2 \ ft$ Effective Bearing Width

Nominal bearing resistance (determined via limit equilibrium):

$q_{nd} := 15300 \ psf$ Nominal bearing resistance - Drained Conditions

$q_{nu} := 15300 \ psf$ Nominal bearing resistance - Undrained Conditions

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $q_{Rd} = 9.9 \ ksf$ Factored bearing resistance Drained Conditions

$q_{Ru} := \phi_b \cdot q_{nu}$ $q_{Ru} = 9.9 \ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 9.9 \ ksf$

Undrained Conditions: $q_{Ru} = 9.9 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 9.9 \ ksf$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 391291.9 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 229026.6 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

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

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 36.2 \; ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 6329.7 \; \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.57$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 13.2 \; ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 391291.9 \; \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 156816 \; \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.5 \; ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 5.29$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 33426.1 \ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 156816 \ \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 90537.8 \ \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 90.538 \ \frac{kip}{ft}$

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]**:

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

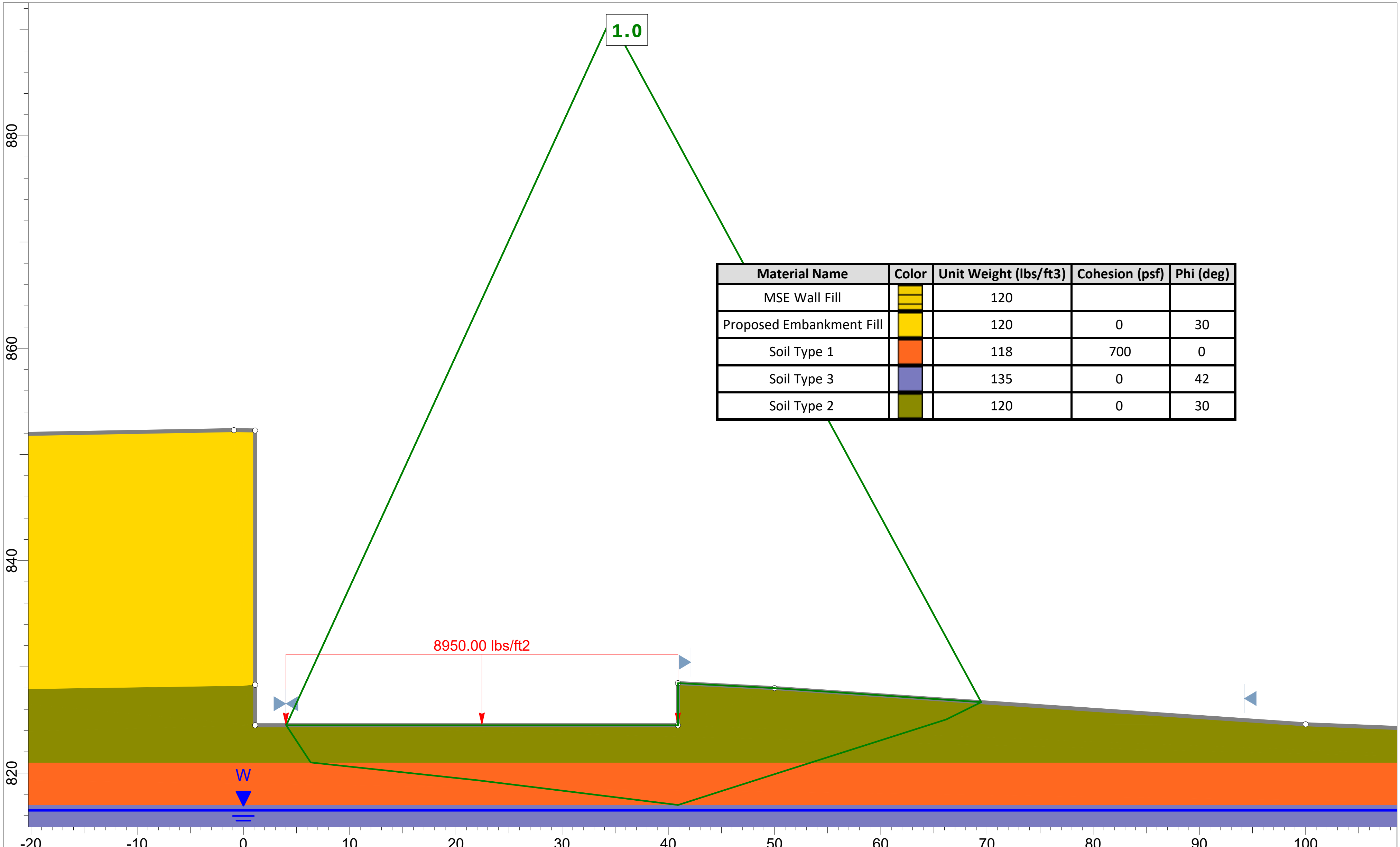
$\phi R_n := \phi_\tau \cdot R_\tau$ $\qquad R_R := \phi R_n$

$R_R = 90.5 \ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 2.71$

STA. 11+20 – 1.3H STRAP LENGTH



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30

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SLIDEINTERPRET 9.025

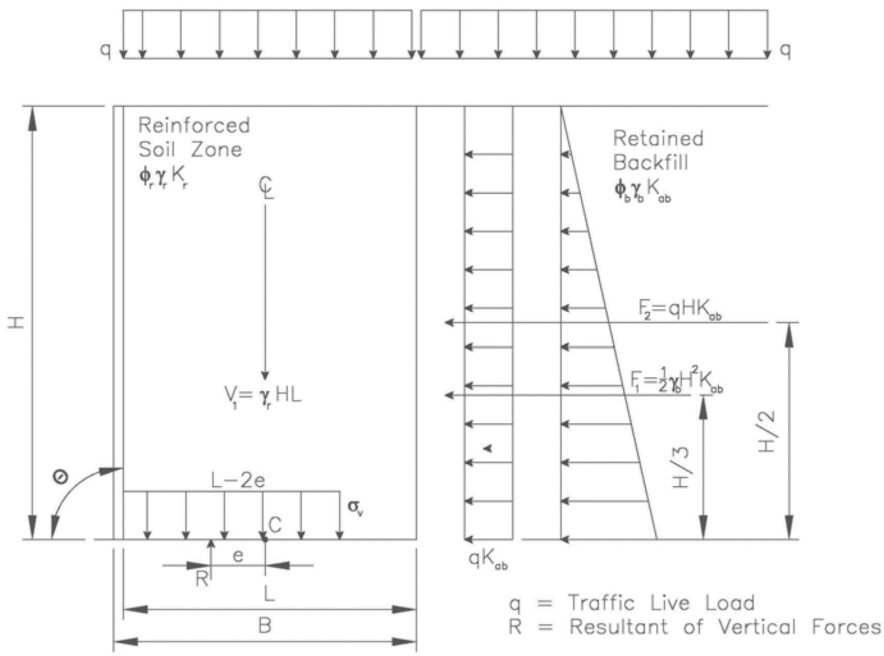
Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 12+00, Global Stability - Bearing Resistance - Limit Equilibrium
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA11+20_1.3H_B-015_LimitEquilibrium021023.slim

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:

$H_e := 27.6 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

$\gamma_f = 120 \frac{lbf}{ft^3}$ — 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:

$d_{frost} := 3\ ft$ $\quad d_{user} := 3\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H_{est} = 30.6\ ft$

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

$d_{eSlope} = 1.5\ ft$ — Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

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

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\qquad H = 30.6\ ft$ — Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 39.8 \cdot ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\qquad L = 39.8\ ft$ — Length of Reinforcement

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:

$\beta := 0\ deg$ — Inclination of ground slope behind face of wall

$\delta := 0.67 \cdot \phi'_b$ — Interface angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{\left(\sin\left(\theta + \phi'_b\right)\right)^2}{\left(\Gamma \cdot \left(\sin\left(\theta\right)\right)^2 \cdot \sin\left(\theta - \delta\right)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\qquad F_T = 16700.5\ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\qquad F_{SUR} = 2274\ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\qquad V_1 = 146145.6\ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\qquad V_2 = 9950\ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 16700.5\ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2274\ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 10.2\ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 170345.5\ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 15.3\ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 34792.8\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 146145.6\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 9950\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 16700.5\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2274\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 170345.5\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 34792.8\ \frac{lbf \cdot ft}{ft}$

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

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:

$V_{Ia} := \eta \cdot \left(Ia_{EV} \cdot V_{EV}\right)$ $\quad V_{Ia} = 146145.6\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot \left(\left(Ib_{EV} \cdot V_{EV}\right) + \left(Ib_{LS} \cdot V_{LS}\right)\right)$ $\quad V_{Ib} = 214709.1\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot H_{LS}\right) + \left(Ia_{EH} \cdot H_{EH}\right)\right)$ $\quad H_{Ia} = 29030.4\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot H_{LS}\right) + \left(Ib_{EH} \cdot H_{EH}\right)\right)$ $\quad H_{Ib} = 29030.4\ \frac{lbf}{ft}$

Factored Moments Produced by Vertical Loads by Limit State:

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

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

Factored Moments Produced by Horizontal Loads by Limit State:

$MH_{Ia} := \eta \cdot \left(\left(Ia_{LS} \cdot M_{LS2}\right) + \left(Ia_{EH} \cdot M_{EH2}\right)\right)$ $\quad MH_{Ia} = 316405.7\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot \left(\left(Ib_{LS} \cdot M_{LS2}\right) + \left(Ib_{EH} \cdot M_{EH2}\right)\right)$ $\quad MH_{Ib} = 316405.7\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 316405.7 \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 214709.1 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 1.5\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $\quad B' = 36.9\ ft$ Effective Bearing Width

Nominal bearing resistance (determined via limit equilibrium):

$q_{nd} := 8950\ psf$ Nominal bearing resistance - Drained Conditions

$q_{nu} := 8950\ psf$ Nominal bearing resistance - Undrained Conditions

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

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

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

$q_{Ru} := \phi_b \cdot q_{nu}$ $\quad q_{Ru} = 5.8\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

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

Undrained Conditions: $q_{Ru} = 5.8\ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 5.8\ ksf$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 316405.7 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 214709.1 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 1.5 \ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 36.9 \ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 5826.1 \ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.00$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 13.3 \ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 316405.7 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 146145.6 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.2 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 6.13$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\quad F_\tau = 29030.4 \ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\quad \Sigma V = 146145.6 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan(\phi'_f)$ $\quad R_{\tau d} = 84377.2 \ \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 84.377 \ \frac{kip}{ft}$

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.**

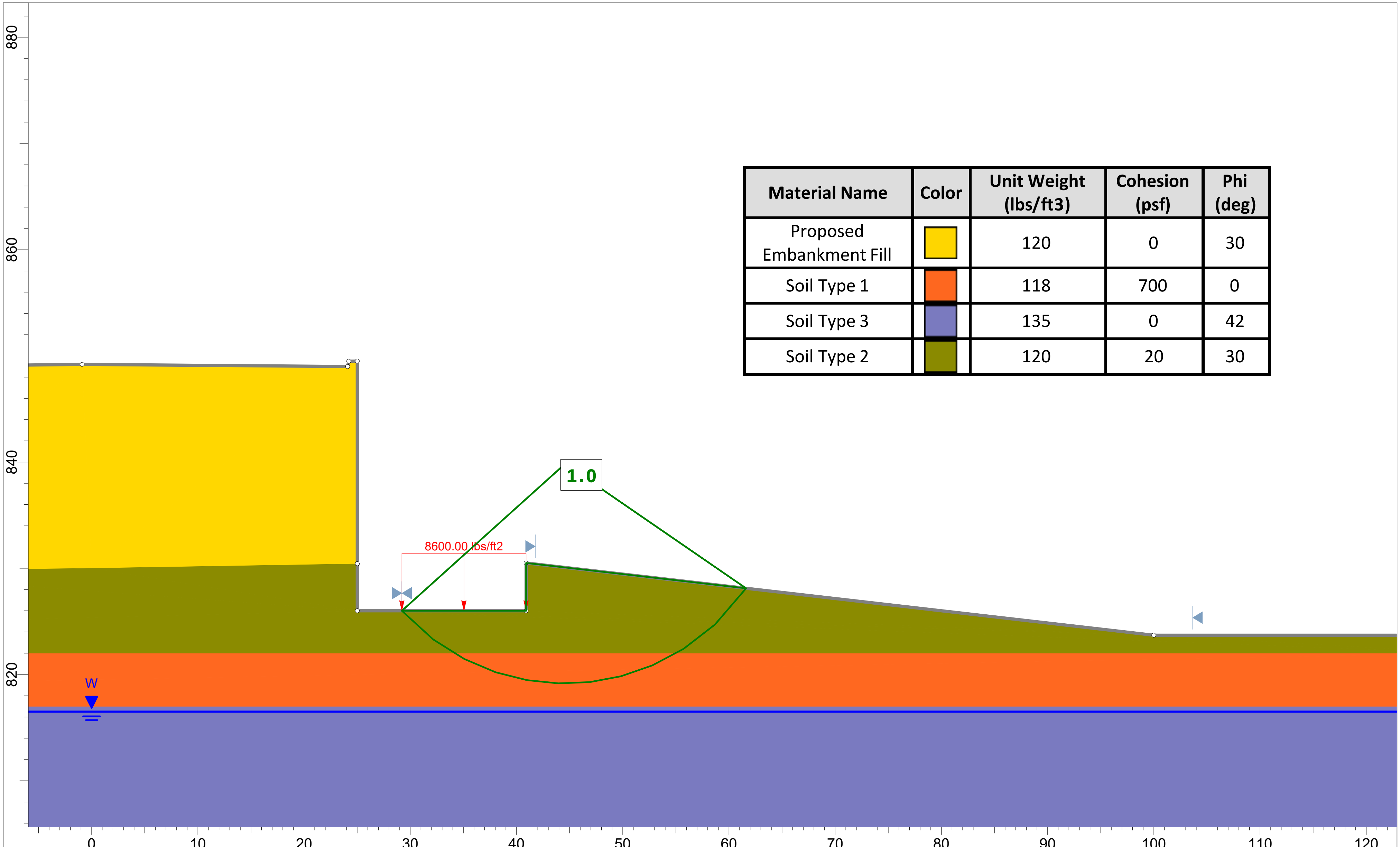
$\phi R_n := \phi_\tau \cdot R_\tau$ $\quad R_R := \phi R_n$

$R_R = 84.4 \ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 2.91$

STA. 13+20

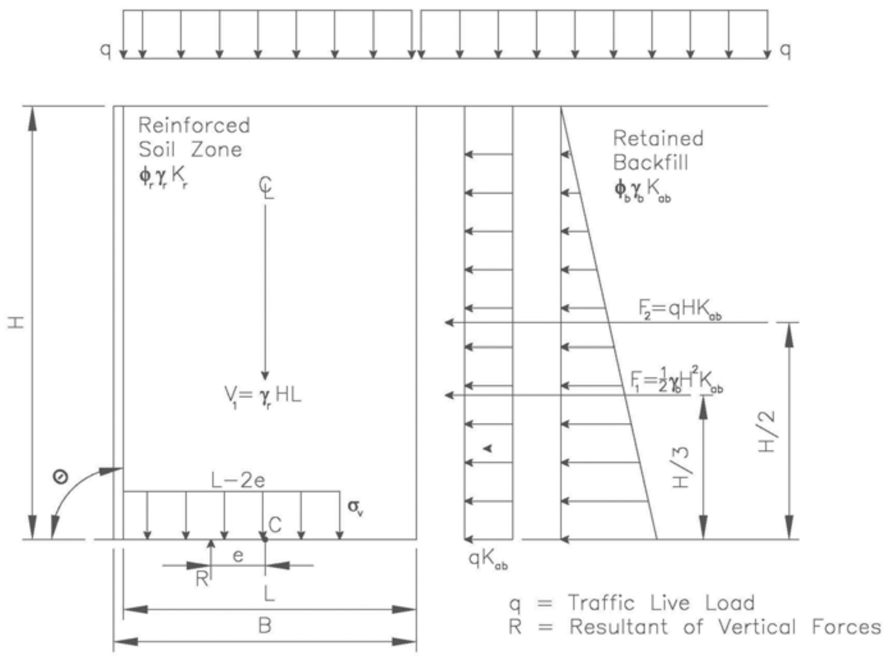


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
Proposed Embankment Fill	Yellow	120	0	30
Soil Type 1	Orange	118	700	0
Soil Type 3	Purple	135	0	42
Soil Type 2	Olive	120	20	30

rocscience	*Project*	CUY-14-6.93, PID 104132	
	Analysis Description	Retaining Wall 6 - STA. 13+20, Global Stability - Bearing Resistance - Limit Equilibrium	
	Drawn By KCA	*Company* NEAS Inc.	
SLIDEINTERPRET 9.025	*Date* 12/14/2021, 9:43:12 AM	*File Name* Wall6_STA13+20_0.7H_B-015_LimitEquilibrium021023.slim	

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:

$H_e := 18.2 \cdot ft$ — 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ 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)

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

$d_{frost} := 4.5\ ft$ $d_{user} := 3\ ft$ 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**

$d_{est} := \max\left(d_{frost}, 3\ ft, d_{user}\right)$ $d_{est} = 4.5\ ft$

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H_{est} = 22.7\ ft$

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

$d_{eSlope} = 1.1\ ft$ Minimum Embedment Depth per Table C11.10.2.2-1 of LRFD BDS

$d_e := \max\left(d_{est}, d_{eSlope}\right)$ $d_e = 4.5\ ft$ Minimum Required Embedment Depth used in analysis.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $H = 22.7\ ft$ 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)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $L = 15.9\ ft$ Length of Reinforcement

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:

$\beta := 0\ deg$ — Inclination of ground slope behind face of wall

$\delta := 0.67 \cdot \phi'_b$ — Interface angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.2973$$ Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\quad F_T = 9190.5\ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\quad F_{SUR} = 1687\ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 43284.4\ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\quad V_2 = 3972.5\ \frac{lbf}{ft}$ — Live Load Surcharge - (LS)

Moment Arm: | Moment:

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

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

Horizontal Loads:

$H_1 := F_T = 9190.5\ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 1687\ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm: | Moment:

$d_{h1} := \frac{H}{3}$ $\quad d_{h1} = 7.6\ ft$ $\quad MH_1 := H_1 \cdot d_{h1}$ $\quad MH_1 = 69541.5\ \frac{lbf \cdot ft}{ft}$

$d_{h2} := \frac{H}{2}$ $\quad d_{h2} = 11.4\ ft$ $\quad MH_2 := H_2 \cdot d_{h2}$ $\quad MH_2 = 19146.9\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\qquad V_{EV} = 43284.4\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\qquad V_{LS} = 3972.5\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\qquad H_{EH} = 9190.5\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\qquad H_{LS} = 1687\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\qquad M_{EH2} = 69541.5\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\qquad M_{LS2} = 19146.9\ \frac{lbf \cdot ft}{ft}$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\qquad V_{Ia} = 43284.4\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\qquad V_{Ib} = 65385.8\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\qquad H_{Ia} = 16737.9\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\qquad H_{Ib} = 16737.9\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ia} = 137819.3\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\qquad MH_{Ib} = 137819.3\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ $\quad \Sigma M_O = 137819.3\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\quad \Sigma V = 65385.8\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $\quad e_{wall} = 2.1\ ft$ Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ $\quad B' = 11.7\ ft$ Effective Bearing Width

Nominal bearing resistance (determined via limit equilibrium):

$q_{nd} := 8600\ psf$ Nominal bearing resistance - Drained Conditions

$q_{nu} := 8600\ psf$ Nominal bearing resistance - Undrained Conditions

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ $\quad q_{Rd} = 5.6\ ksf$ Factored bearing resistance Drained Conditions

$q_{Ru} := \phi_b \cdot q_{nu}$ $\quad q_{Ru} = 5.6\ ksf$ Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 5.6\ ksf$

Undrained Conditions: $q_{Ru} = 5.6\ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 5.6\ ksf$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 137819.3\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 65385.8\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.1\ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 11.7\ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 5600.8\ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.00$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 5.3\ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 137819.3\ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 43284.4\ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.2\ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 1.66$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $F_\tau = 16737.9 \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\Sigma V = 43284.4 \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $R_{\tau d} = 24990.2 \frac{lbf}{ft}$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 24.99 \frac{kip}{ft}$

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.**

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

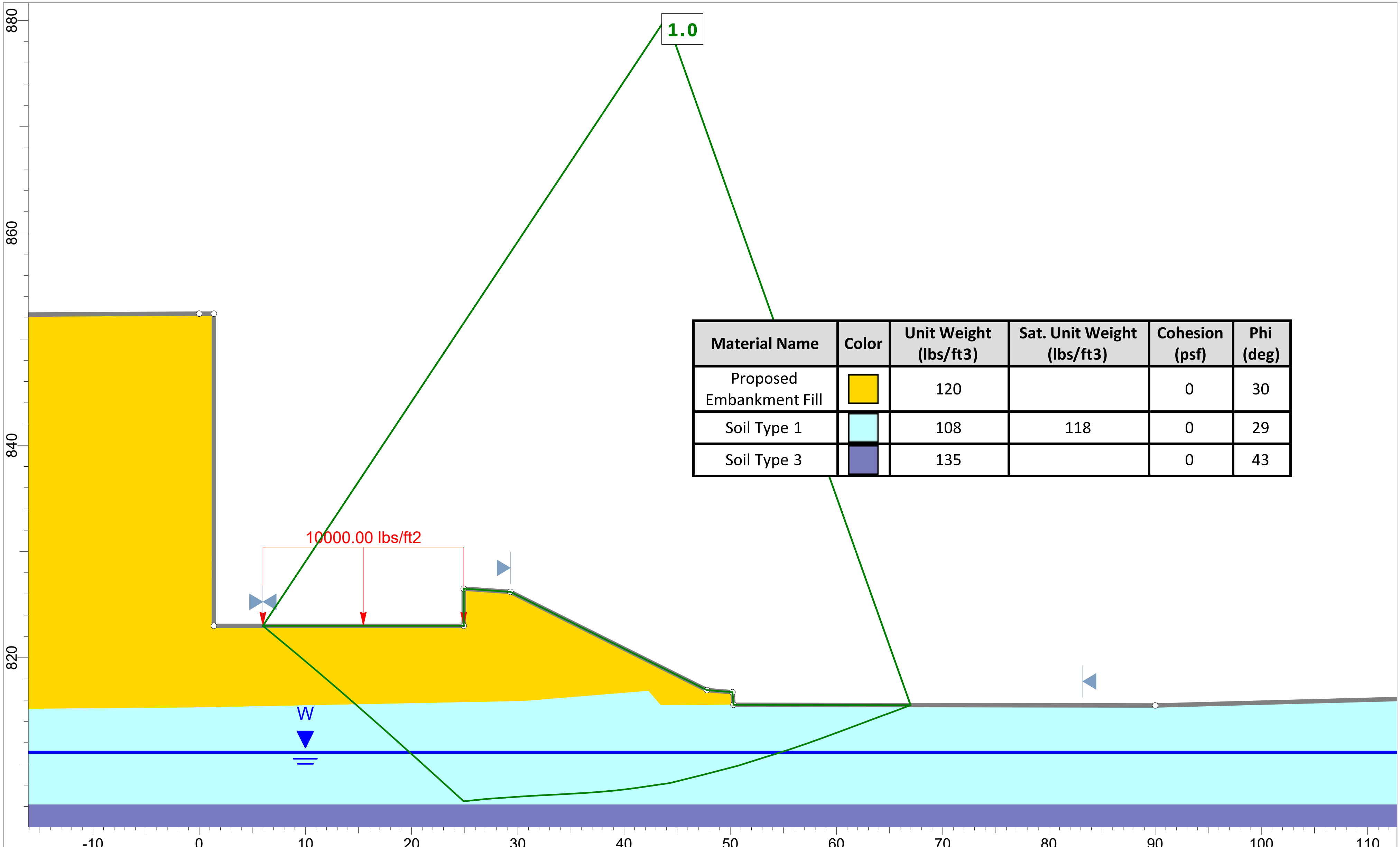
$R_R = 25 \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

$CDR_{Sliding} := \frac{R_R}{F_\tau}$ Is the CDR > or = to 1.0? $CDR_{Sliding} = 1.49$

RETAINING WALL 7

STA. 11+86 – 0.8H STRAP LENGTH



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
Proposed Embankment Fill		120		0	30
Soil Type 1		108	118	0	29
Soil Type 3		135		0	43

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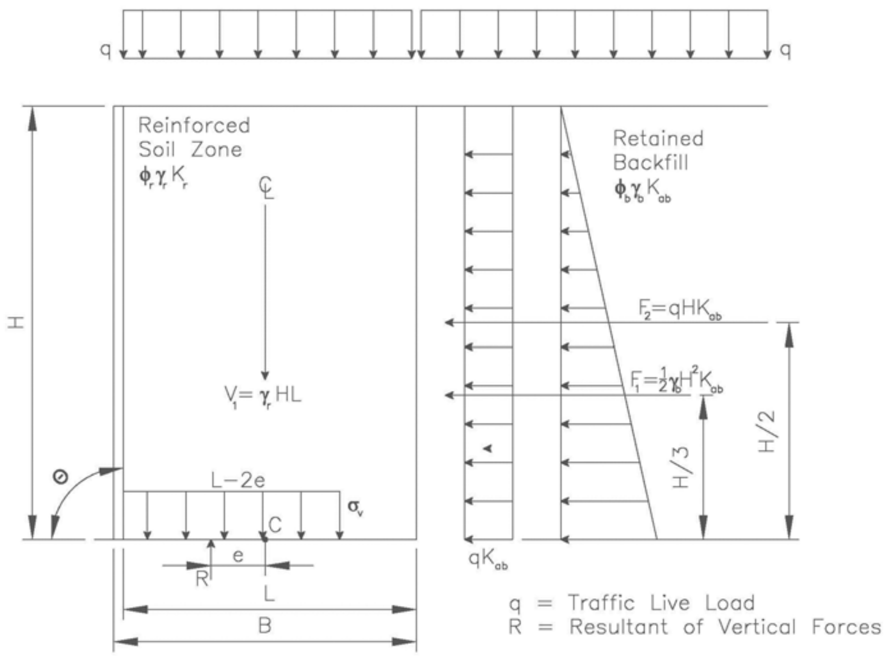
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 7 - STA. 11+86, Bearing Resistance - Limit Equilibrium		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall7_STA11+86_EffCirc-0.8Straps020923.slim

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:

$H_e := 26.4 \cdot ft$ 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

Foundation Soil Design Parameters:

Drained Conditions (Effective Stress):

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

$\gamma_f := 120 \cdot \frac{lbf}{ft^3}$ — 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)

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

$d_{frost} := 3\ ft$ $\quad d_{user} := 3\ ft$ — 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**

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

$H_{est} := d_{est} + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H_{est} = 29.4\ ft$

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

$d_{eSlope} = 1.5\ ft$ — 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.

$H := d_e + \left(4\ ft \cdot \tan\left(Slope_{fw}\right)\right) + H_e$ $\quad H = 29.4\ ft$ — Design Wall Height

Estimate Length of Reinforcement:

$L_{user} := 23.52 \cdot ft$ — User inputted value (if changes need to be made to satisfy other requirements)

$L := \max\left(8 \cdot ft, 0.7 \cdot H, L_{user}\right)$ $\quad L = 23.5\ ft$ — Length of Reinforcement

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:

$\beta := 0\ deg$ — Inclination of ground slope behind face of wall

$\delta := 0.67 \cdot \phi'_b$ — Interface angle of friction between retained backfill and reinforced soil

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

$$k_{af} := \left(\frac{(\sin(\theta + \phi'_b))^2}{\left(\Gamma \cdot (\sin(\theta))^2 \cdot \sin(\theta - \delta)\right)}\right) \qquad k_{af} = 0.2973$$

Active Earth Pressure Coefficient

$F_T := \frac{1}{2} \cdot \gamma_b \cdot H^2 \cdot k_{af}$ $\quad F_T = 15416.4\ \frac{lbf}{ft}$ — Active Earth Force Resultant (EH)

$F_{SUR} := SUR \cdot H \cdot k_{af}$ $\quad F_{SUR} = 2184.9\ \frac{lbf}{ft}$ — Live Load Surcharge (LS)

Vertical Loads:

$V_1 := \gamma_r \cdot H \cdot L$ $\quad V_1 = 82978.6\ \frac{lbf}{ft}$ — Soil backfill - reinforced soil (EV)

$V_2 := SUR \cdot L$ $\quad V_2 = 5880\ \frac{lbf}{ft}$ — 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:

$H_1 := F_T = 15416.4\ \frac{lbf}{ft}$ — Active Earth Force Resultant (horizontal comp. - EH)

$H_2 := F_{SUR} = 2184.9\ \frac{lbf}{ft}$ — Live Load Surcharge Resultant (horizontal comp. - LS)

Moment Arm:		Moment:	
$d_{h1} := \frac{H}{3}$	$d_{h1} = 9.8\ ft$	$MH_1 := H_1 \cdot d_{h1}$	$MH_1 = 151080.5\ \frac{lbf \cdot ft}{ft}$
$d_{h2} := \frac{H}{2}$	$d_{h2} = 14.7\ ft$	$MH_2 := H_2 \cdot d_{h2}$	$MH_2 = 32117.5\ \frac{lbf \cdot ft}{ft}$

Unfactored Loads by Load Type

$V_{EV} := V_1$ $\quad V_{EV} = 82978.6\ \frac{lbf}{ft}$

$V_{LS} := V_2$ $\quad V_{LS} = 5880\ \frac{lbf}{ft}$

$H_{EH} := H_1$ $\quad H_{EH} = 15416.4\ \frac{lbf}{ft}$

$H_{LS} := H_2$ $\quad H_{LS} = 2184.9\ \frac{lbf}{ft}$

Unfactored Moments by Load Type

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

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

$M_{EH2} := MH_1$ $\quad M_{EH2} = 151080.5\ \frac{lbf \cdot ft}{ft}$

$M_{LS2} := MH_2$ $\quad M_{LS2} = 32117.5\ \frac{lbf \cdot ft}{ft}$

Load Combination Limit States:

$\eta := 1$ LRFD Load Modifier

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

Strength Limit State Ia: (Sliding and Eccentricity) $\quad Ia_{EV} := 1 \quad Ia_{EH} := 1.5 \quad Ia_{LS} := 1.75$

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:

$V_{Ia} := \eta \cdot (Ia_{EV} \cdot V_{EV})$ $\quad V_{Ia} = 82978.6\ \frac{lbf}{ft}$

$V_{Ib} := \eta \cdot ((Ib_{EV} \cdot V_{EV}) + (Ib_{LS} \cdot V_{LS}))$ $\quad V_{Ib} = 122311.1\ \frac{lbf}{ft}$

Factored Horizontal Loads by Limit State:

$H_{Ia} := \eta \cdot ((Ia_{LS} \cdot H_{LS}) + (Ia_{EH} \cdot H_{EH}))$ $\quad H_{Ia} = 26948.1\ \frac{lbf}{ft}$

$H_{Ib} := \eta \cdot ((Ib_{LS} \cdot H_{LS}) + (Ib_{EH} \cdot H_{EH}))$ $\quad H_{Ib} = 26948.1\ \frac{lbf}{ft}$

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:

$MH_{Ia} := \eta \cdot ((Ia_{LS} \cdot M_{LS2}) + (Ia_{EH} \cdot M_{EH2}))$ $\quad MH_{Ia} = 282826.3\ \frac{lbf \cdot ft}{ft}$

$MH_{Ib} := \eta \cdot ((Ib_{LS} \cdot M_{LS2}) + (Ib_{EH} \cdot M_{EH2}))$ $\quad MH_{Ib} = 282826.3\ \frac{lbf \cdot ft}{ft}$

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)

$\Sigma M_O := MH_{Ib}$ — $\Sigma M_O = 282826.3 \ \frac{lbf \cdot ft}{ft}$ — Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ — $\Sigma V = 122311.1 \ \frac{lbf}{ft}$ — Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ — $e_{wall} = 2.3 \ ft$ — Wall Eccentricity

$B' := \text{if}\left(e_{wall} > 0, L - 2 \cdot e_{wall}, L\right)$ — $B' = 18.9 \ ft$ — Effective Bearing Width

Nominal bearing resistance (determined via limit equilibrium):

$q_{nd} := 10000 \ psf$ — Nominal bearing resistance - Drained Conditions

$q_{nu} := 10000 \ psf$ — Nominal bearing resistance - Undrained Conditions

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

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

$q_{Rd} := \phi_b \cdot q_{nd}$ — $q_{Rd} = 6.5 \ ksf$ — Factored bearing resistance Drained Conditions

$q_{Ru} := \phi_b \cdot q_{nu}$ — $q_{Ru} = 6.5 \ ksf$ — Factored bearing resistance Undrained Conditions

Factored Bearing Resistance Drained vs. Undrained Conditions:

Drained Conditions: $q_{Rd} = 6.5 \ ksf$

Undrained Conditions: $q_{Ru} = 6.5 \ ksf$

Factored Bearing Resistance to be used in CDR Calculations:

$q_R := q_{Rd}$

$q_R = 6.5 \ ksf$

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)

$\Sigma M_O := MH_{Ib}$ $\Sigma M_O = 282826.3 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ib)

$\Sigma V := V_{Ib}$ $\Sigma V = 122311.1 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ib)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 2.3 \ ft$ Wall Eccentricity

$B' := \text{if}(e_{wall} > 0, L - 2 \cdot e_{wall}, L)$ $B' = 18.9 \ ft$ Effective Bearing Width

Compute the ultimate bearing stress:

$\sigma_v := \frac{\Sigma V}{B'}$ $\sigma_v = 6473.1 \ \frac{lbf}{ft^2}$ Ultimate Bearing Stress

Bearing Capacity:Demand Ratio (CDR)

$CDR_{Bearing} := \frac{q_R}{\sigma_v}$ Is the CDR > or = to 1.0? $CDR_{Bearing} = 1.00$

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

$e_{max} := \frac{L}{3}$ $e_{max} = 7.8 \ ft$ 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)

$\Sigma M_O := MH_{Ia}$ $\Sigma M_O = 282826.3 \ \frac{lbf \cdot ft}{ft}$ Sum of Overturning Moments (Strength Ia)

$\Sigma V := V_{Ia}$ $\Sigma V = 82978.6 \ \frac{lbf}{ft}$ Sum of Vertical Loads (Strength Ia)

$e_{wall} := \frac{(\Sigma M_O - \Sigma M_R)}{\Sigma V}$ $e_{wall} = 3.4 \ ft$

Eccentricity Capacity:Demand Ratio (CDR)

$CDR_{Eccentricity} := \frac{e_{max}}{e_{wall}}$ Is the CDR > or = to 1.0? $CDR_{Eccentricity} = 2.30$

Sliding Resistance at Base of Wall LRFD [10.6.3.4]:

Factored Sliding Force (Strength Ia):

$F_\tau := H_{Ia}$ $\qquad F_\tau = 26948.1\ \frac{lbf}{ft}$

Compute sliding resistance between soil and foundation:

Drained Conditions:

$\Sigma V := V_{Ia}$ $\qquad \Sigma V = 82978.6\ \frac{lbf}{ft}$ $\qquad$ Sum of Vertical Loads (Strength Ia)

$R_{\tau d} := \Sigma V \cdot \tan\left(\phi'_f\right)$ $\qquad R_{\tau d} = 47907.7\ \frac{lbf}{ft}$ $\qquad$ Nominal sliding resistance Drained Conditions

Nominal Sliding Resistance Drained Conditions:

Drained Conditions: $R_{\tau d} = 47.908\ \frac{kip}{ft}$

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]**:

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

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

$R_R = 47.9\ \frac{kip}{ft}$

Sliding Capacity:Demand Ratio (CDR)

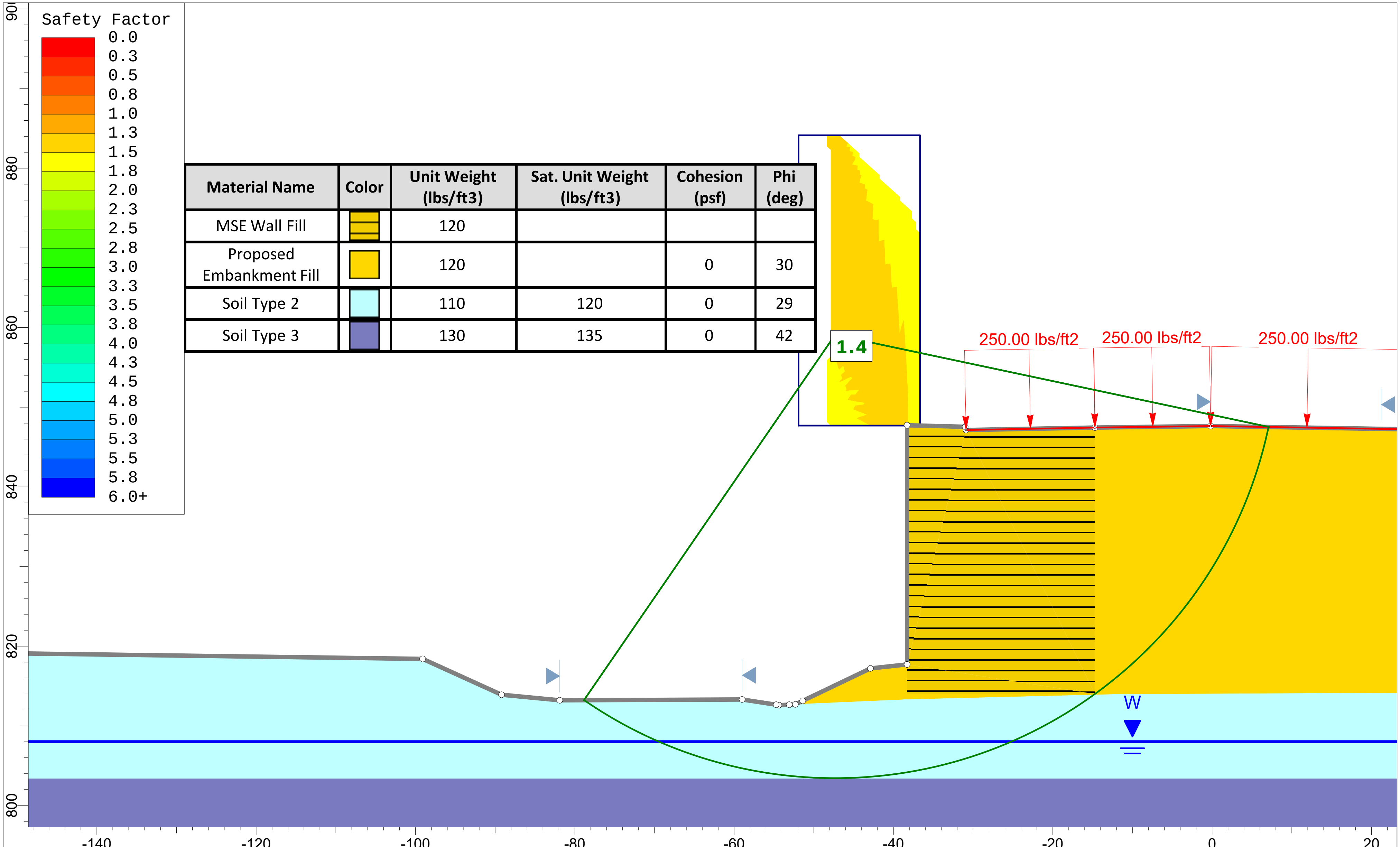
$CDR_{Sliding} := \frac{R_R}{F_\tau}$ $\qquad$ Is the CDR > or = to 1.0? $\qquad CDR_{Sliding} = 1.78$

APPENDIX E

GLOBAL STABILITY ANALYSIS

RETAINING WALL 1 AND TEMPORARY 2

STA. 13+83



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 2		110	120	0	29
Soil Type 3		130	135	0	42

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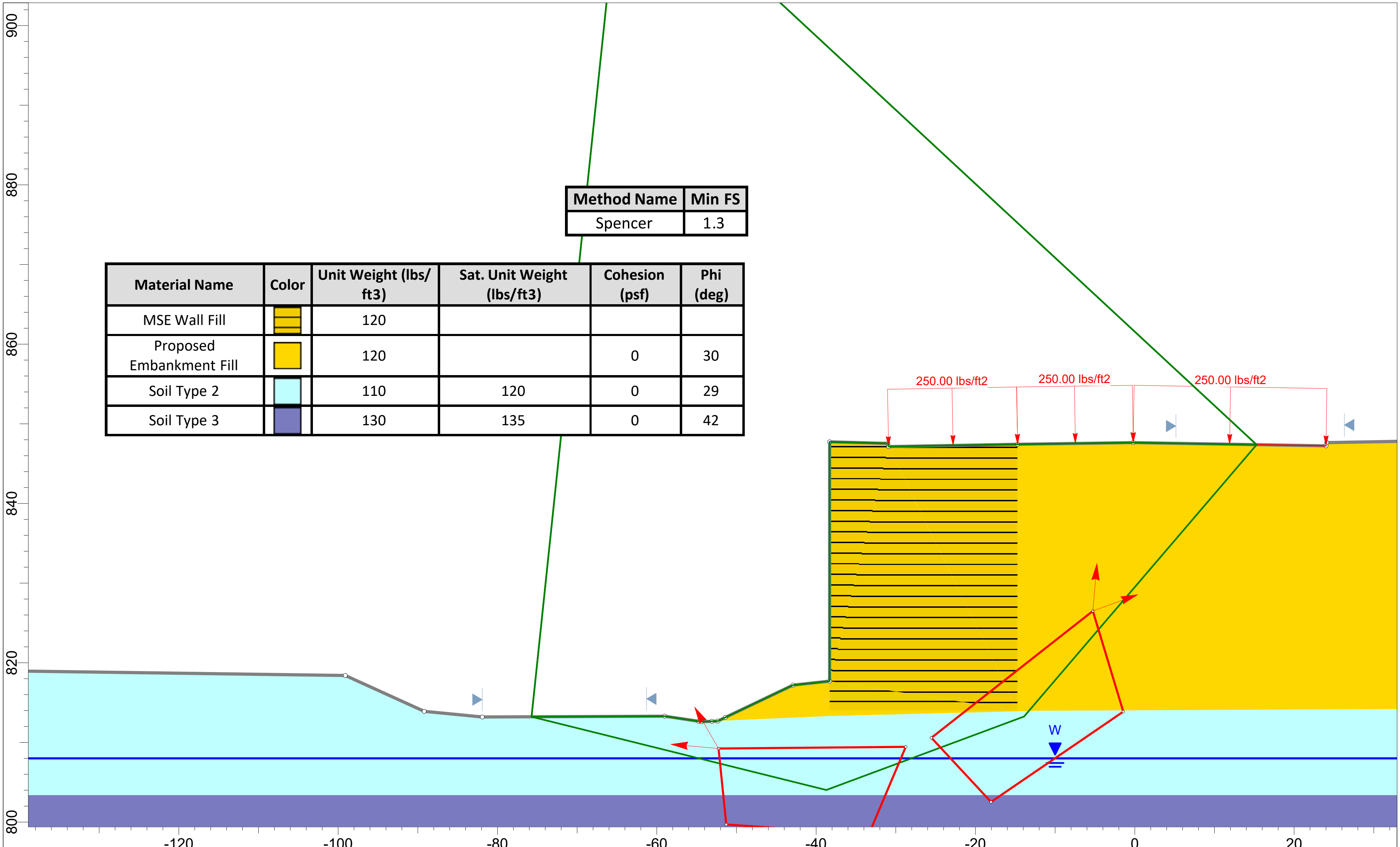
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 1 - STA. 13+83, Global Stability - Effective Stress, Circular Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall1_STA13+83_EffCirc020923.slim



Method Name	Min FS
Spencer	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 2		110	120	0	29
Soil Type 3		130	135	0	42

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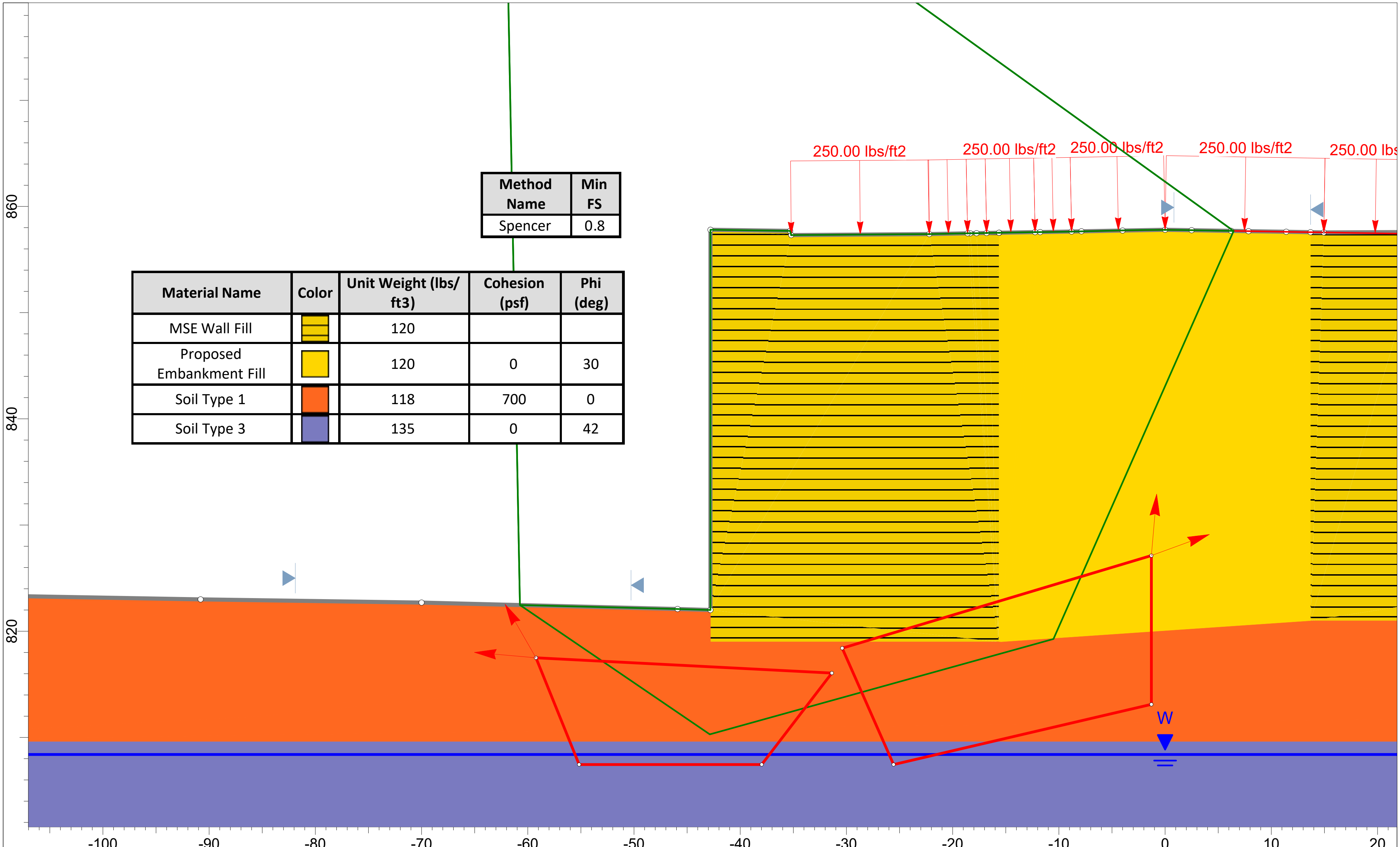
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 1 - STA. 13+83, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall1_STA13+83_EffBlock020923.slim

RETAINING WALL 3 AND TEMPORARY 4

STA. 10+00 – NO UNDERCUT



Method Name	Min FS
Spencer	0.8

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42

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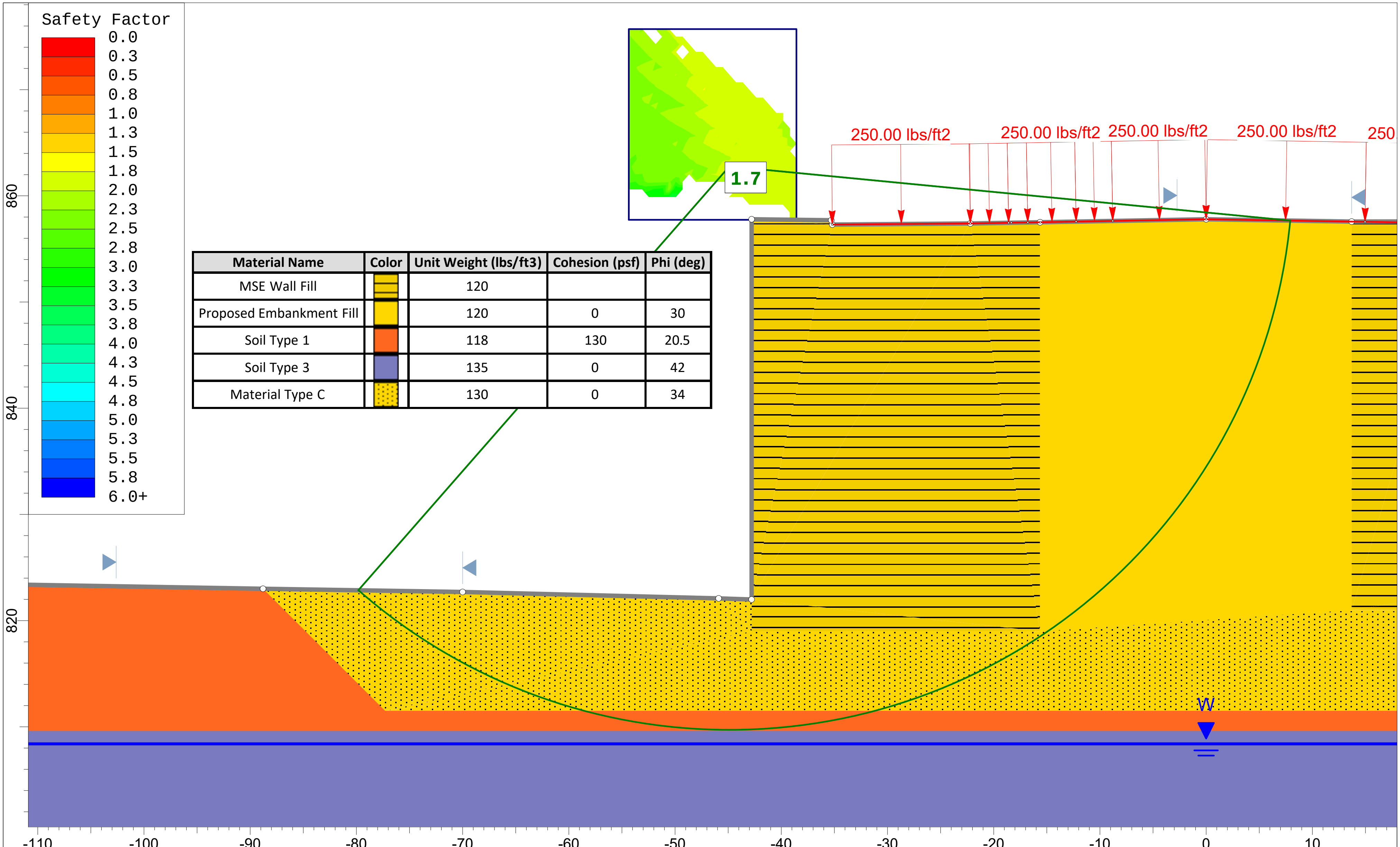
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+00, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+00_TotalBlock020923.slim

STA. 10+00 – WITH UNDERCUT



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Material Type C		130	0	34

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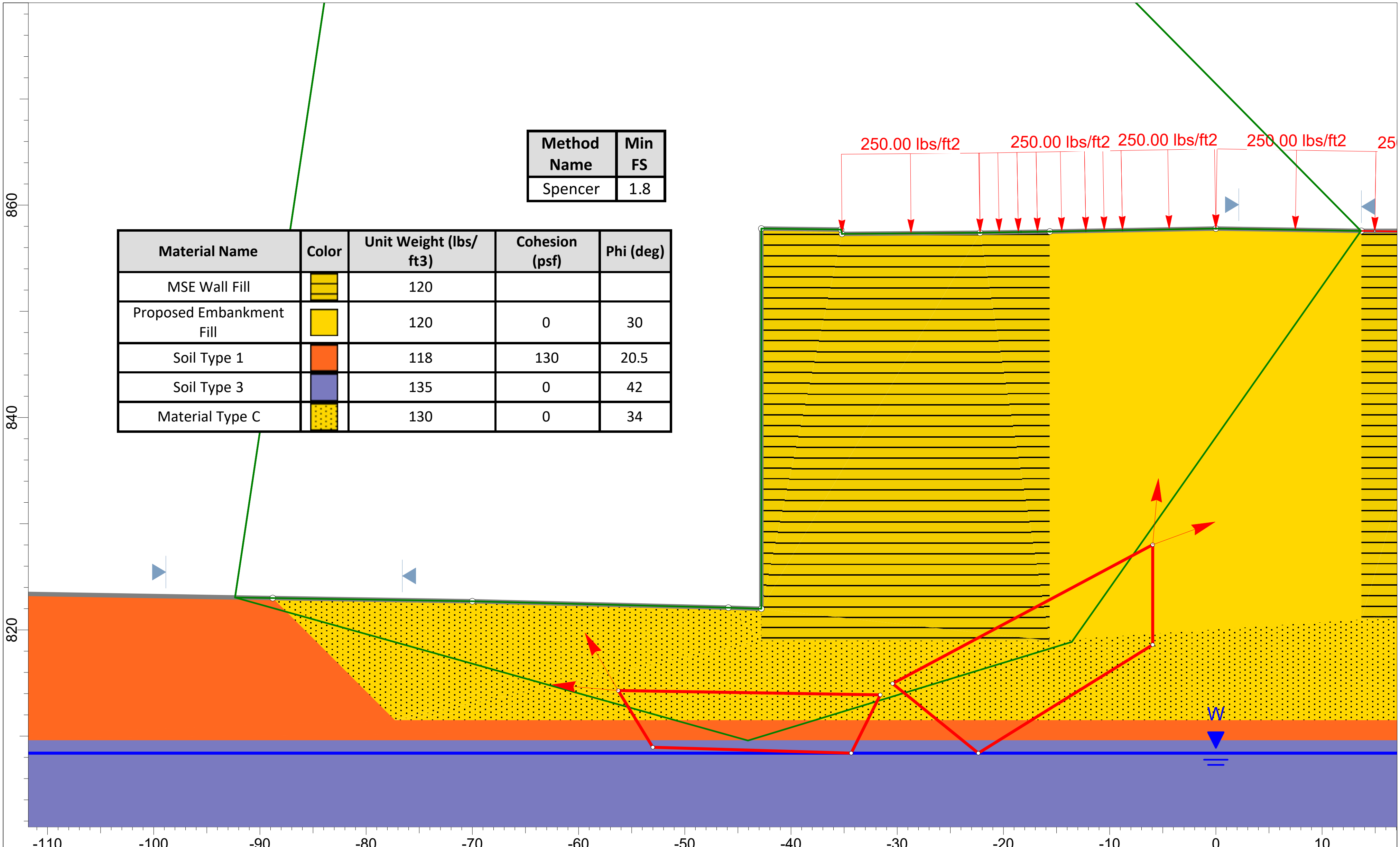
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+00, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+00_EffCircular020923.slim



Method Name	Min FS
Spencer	1.8

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Material Type C		130	0	34

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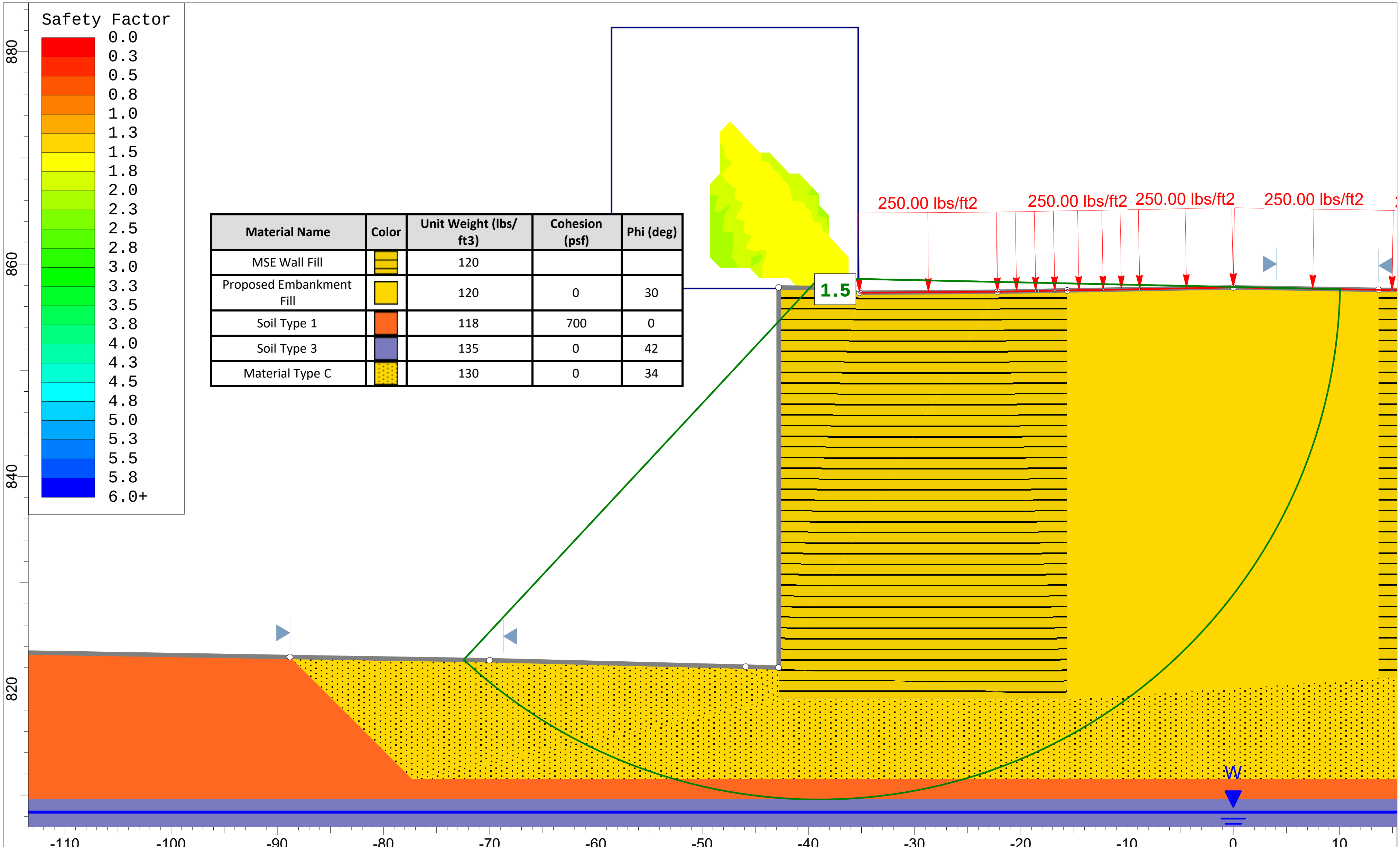
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+00, Global Stability - Effective Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+00_EffBlock020923.slim



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Material Type C		130	0	34

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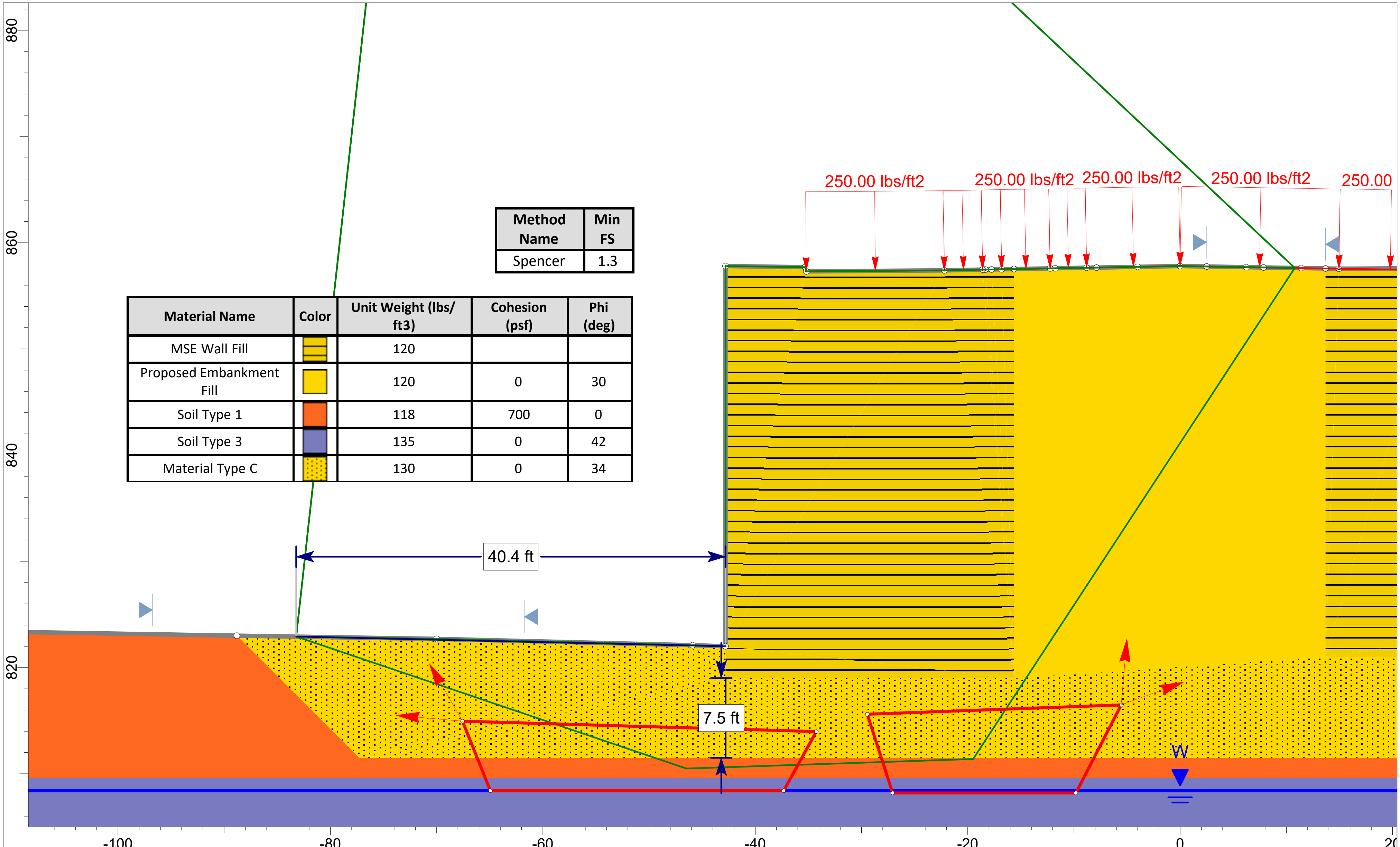
SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+00, Global Stability - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+00_TotalCircular020923.slim



Method Name	Min FS
Spencer	1.3

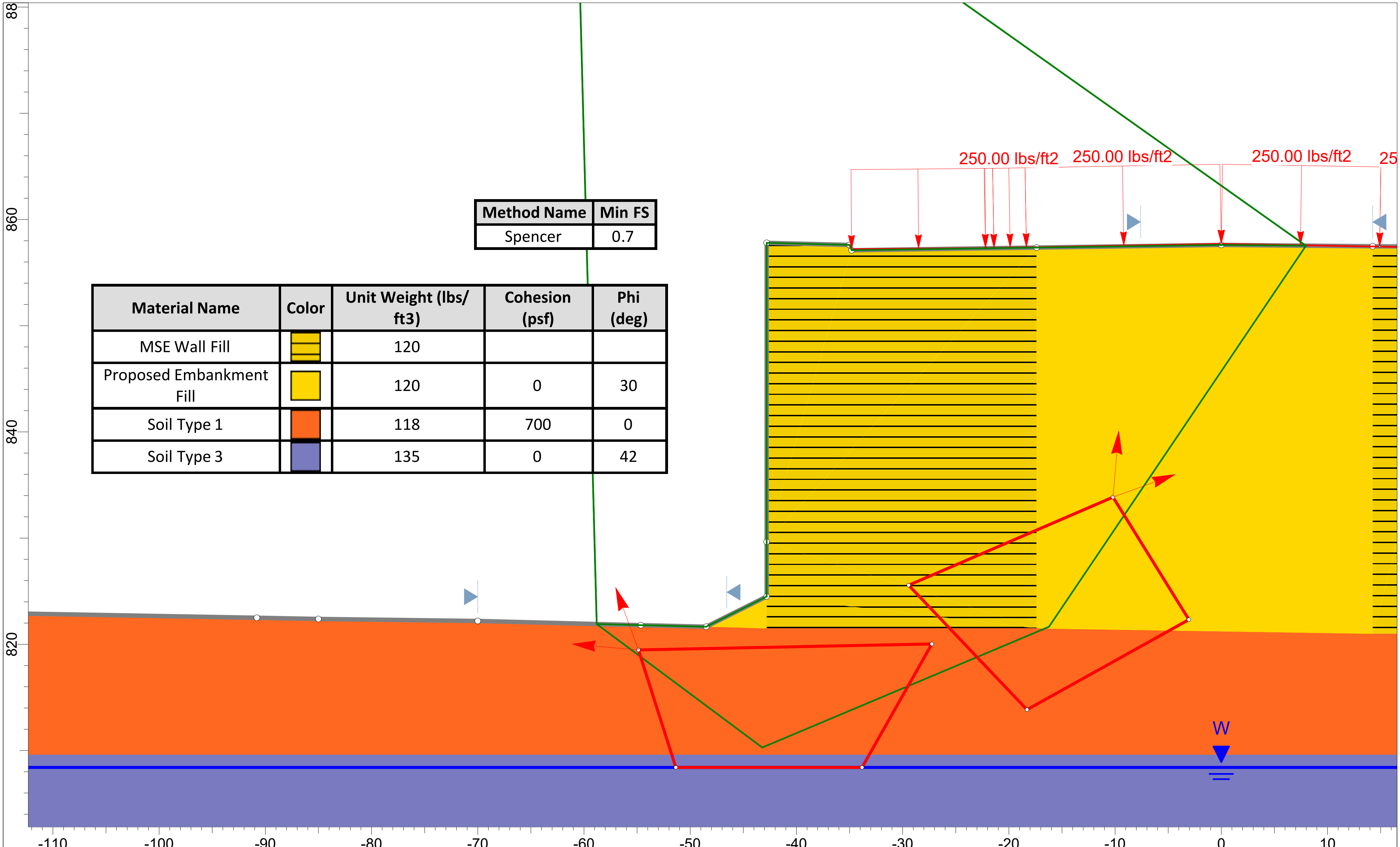
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+00, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+00_TotalBlock020923.slim

STA. 10+30 – NO UNDERCUT



Method Name	Min FS
Spencer	0.7

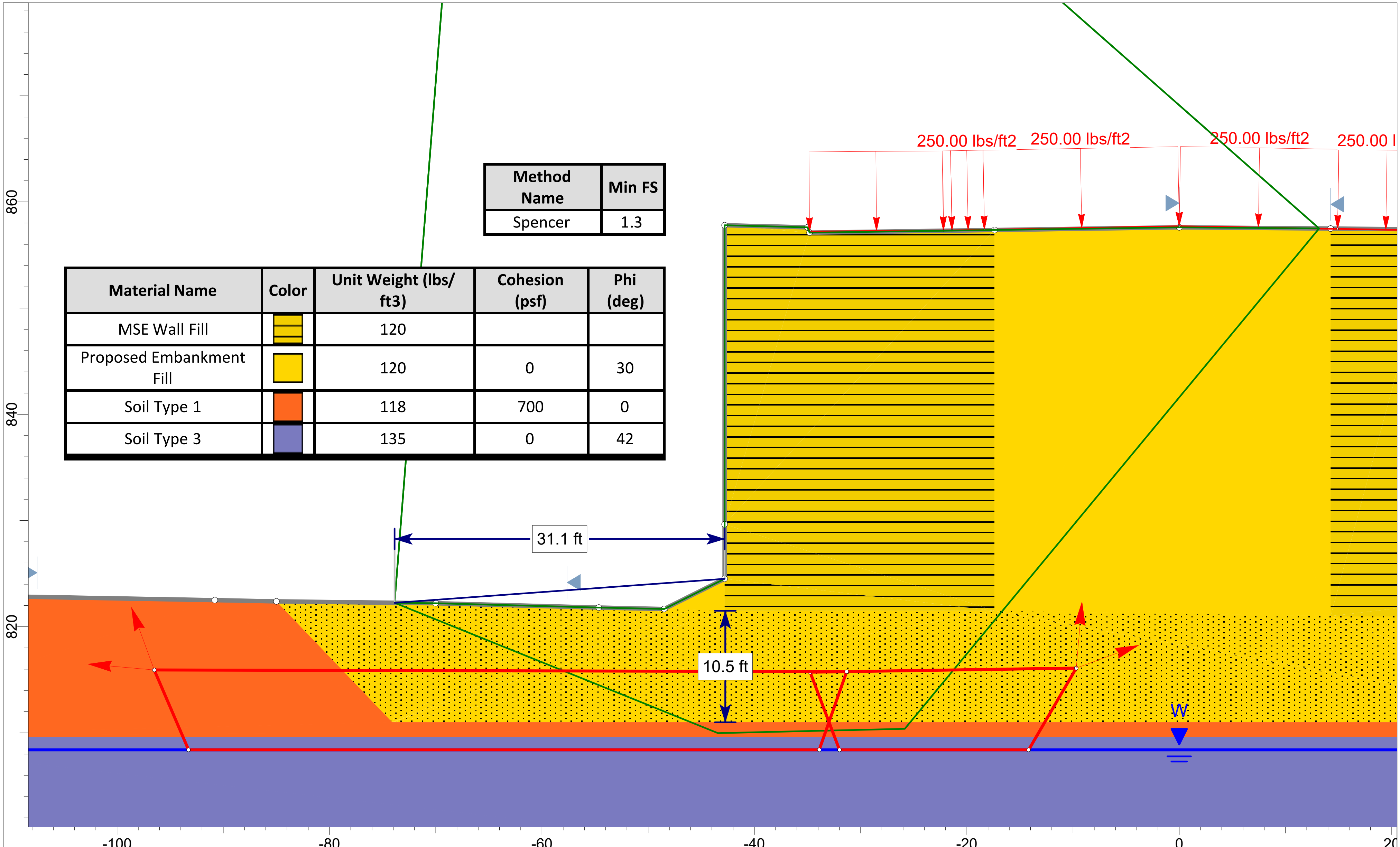
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 10+30, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA10+30_TotalBlock020923.slim

STA. 10+30 – WITH UNDERCUT



Method Name	Min FS
Spencer	1.3

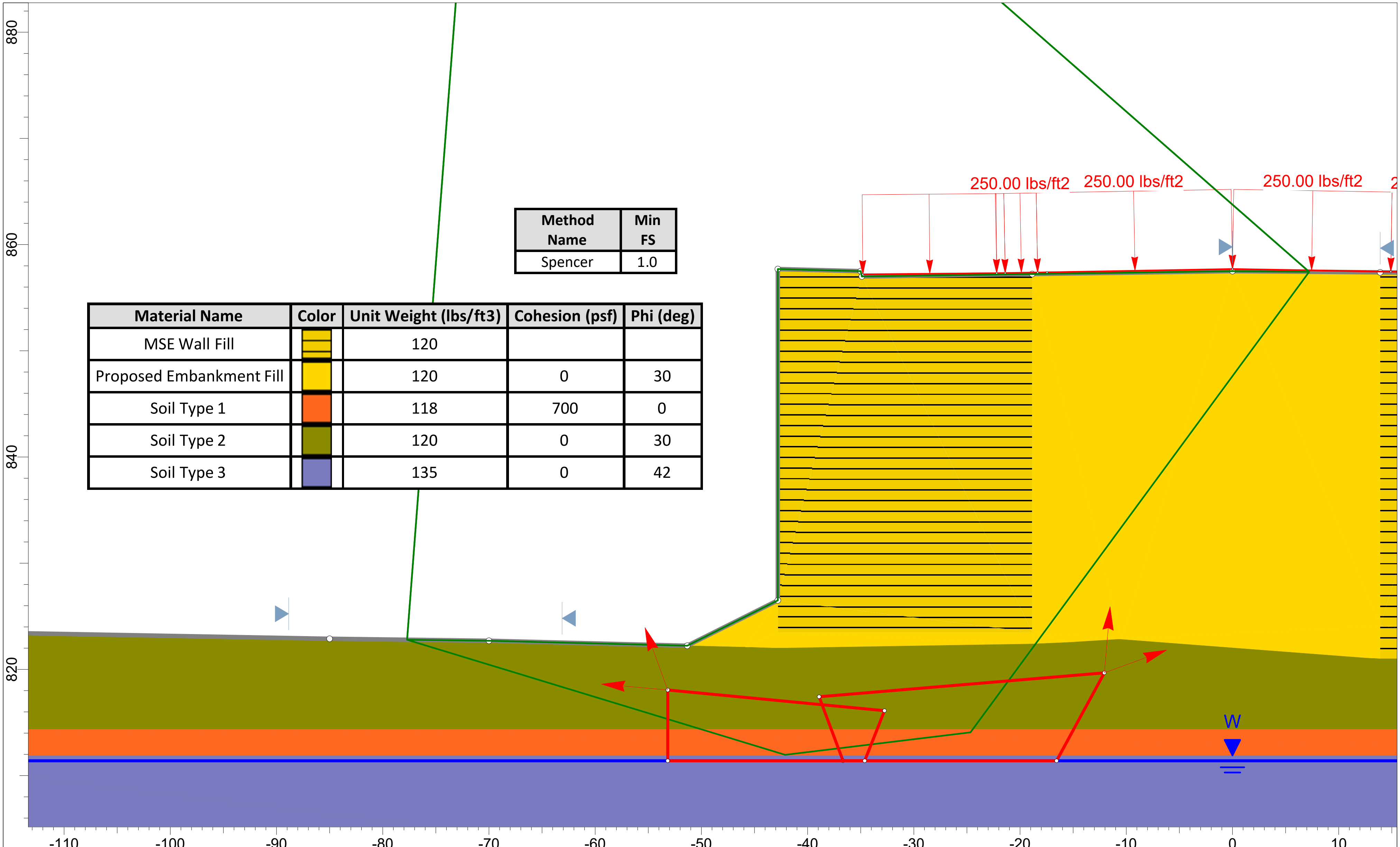
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 10+30, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA10+30_TotalBlock020923.slim

STA. 10+60 – 0.7H STRAP LENGTH



Method Name	Min FS
Spencer	1.0

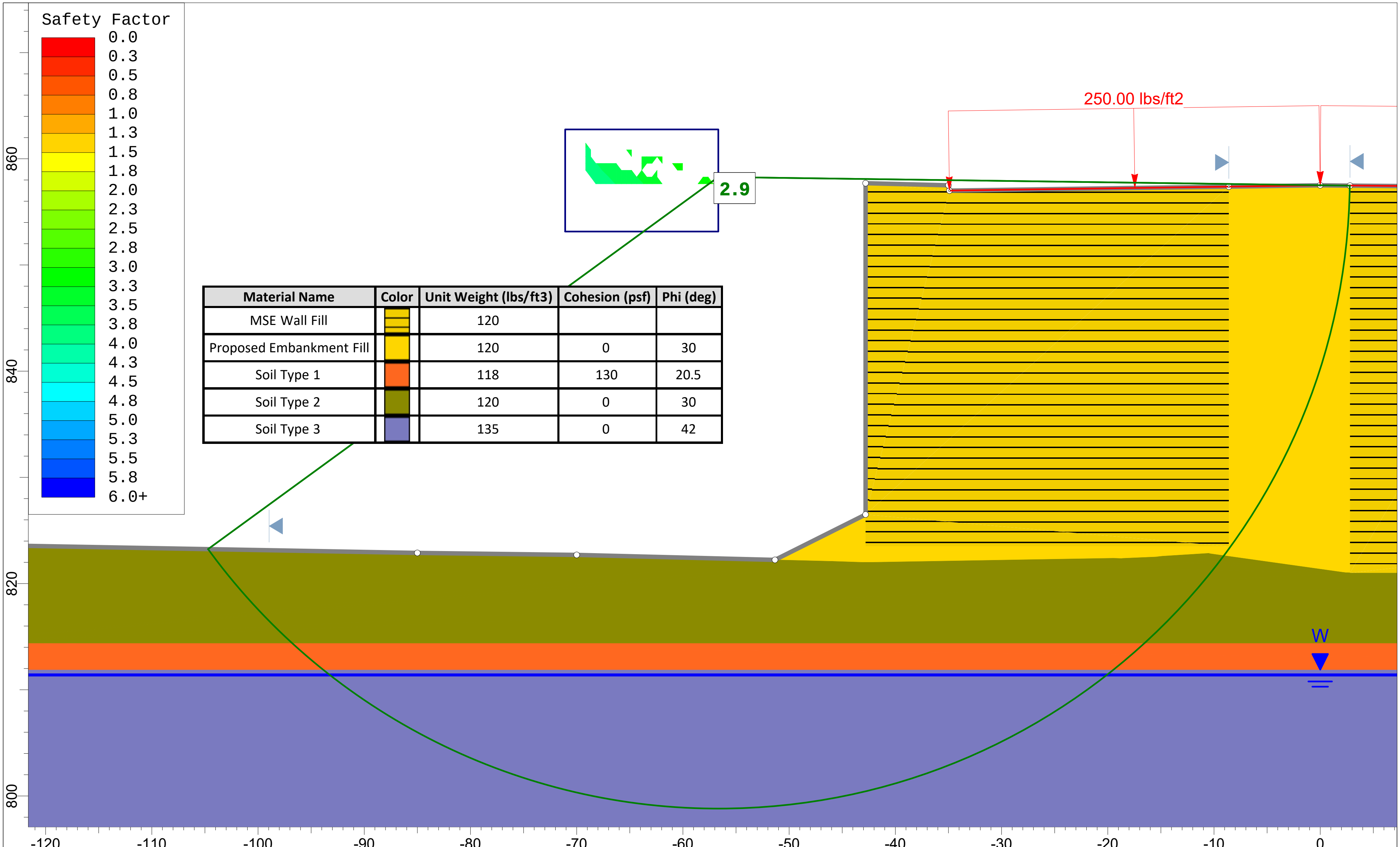
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 10+60, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA10+60_TotalBlock020923.slim

STA. 10+60 – 1.0H STRAP LENGTH



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project CUY-14-6.93, PID 104132

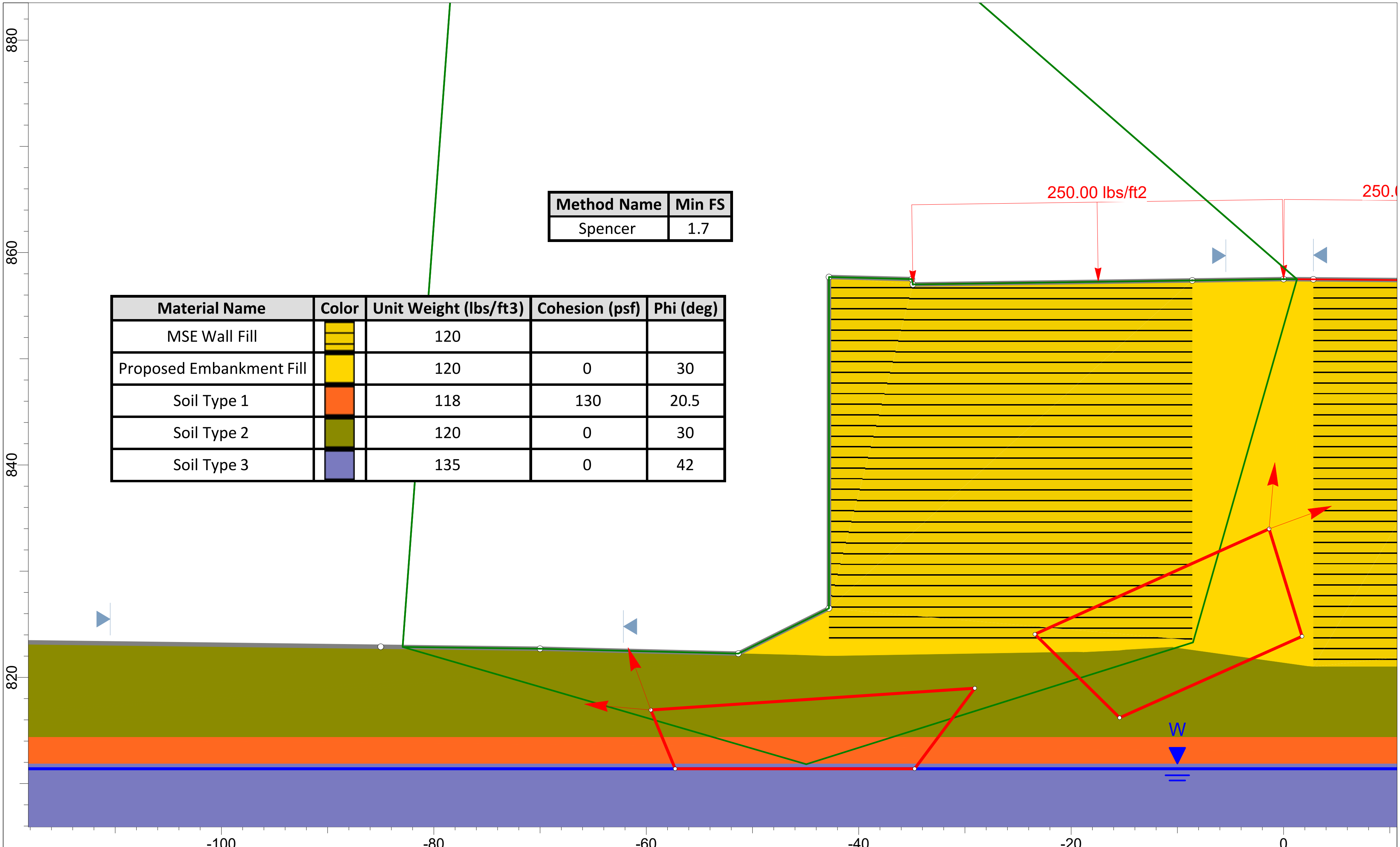
Analysis Description Retaining Wall 3 - STA. 10+60, Global Stability - Effective Stress, Circular Failure

Drawn By KCA

Company NEAS Inc.

Date 12/14/2021, 9:43:12 AM

File Name Wall3_STA10+60_1H_EffCircular020923.slim



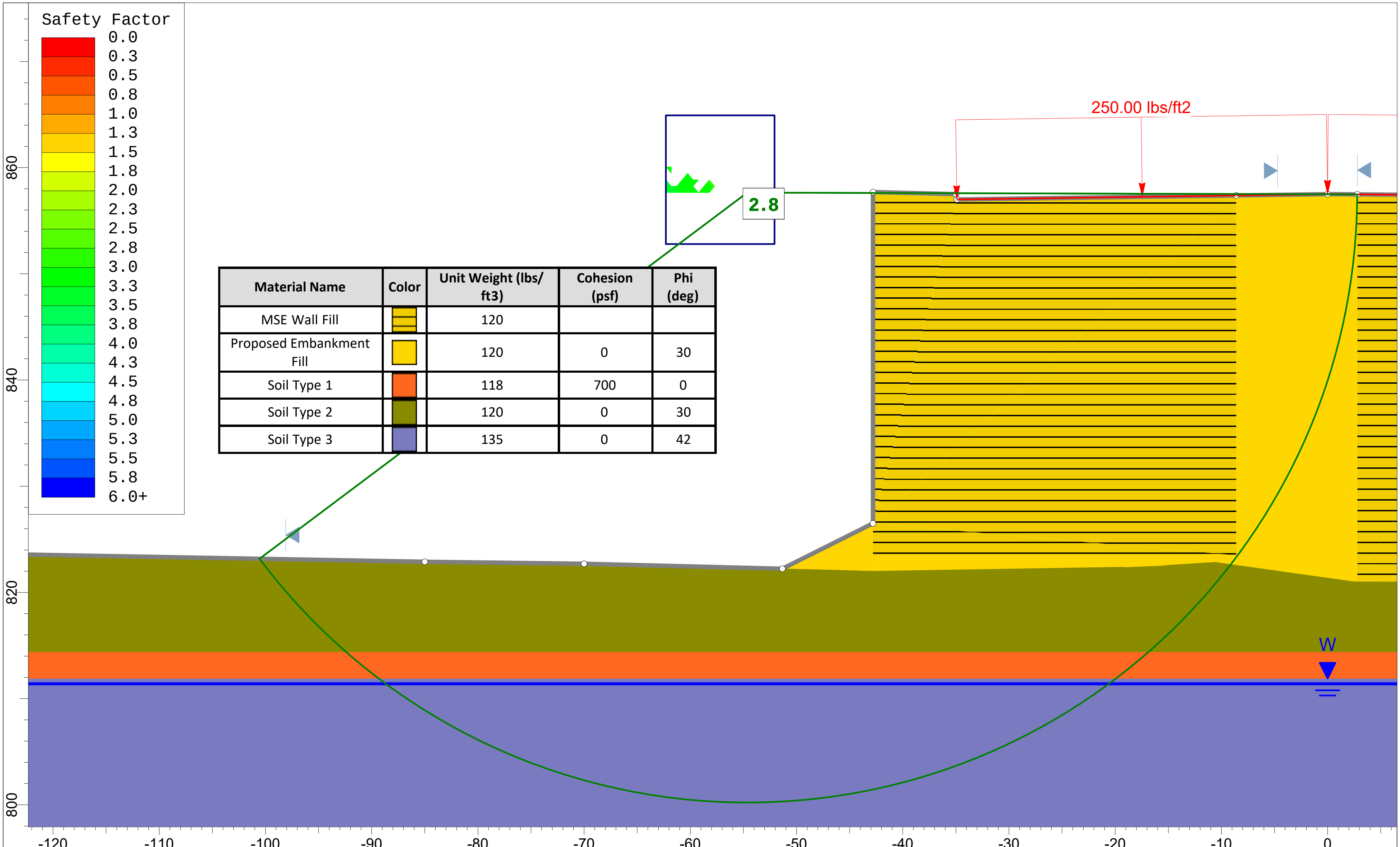
Method Name	Min FS
Spencer	1.7

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 10+60, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA10+60_1H_EffBlock020923.slim

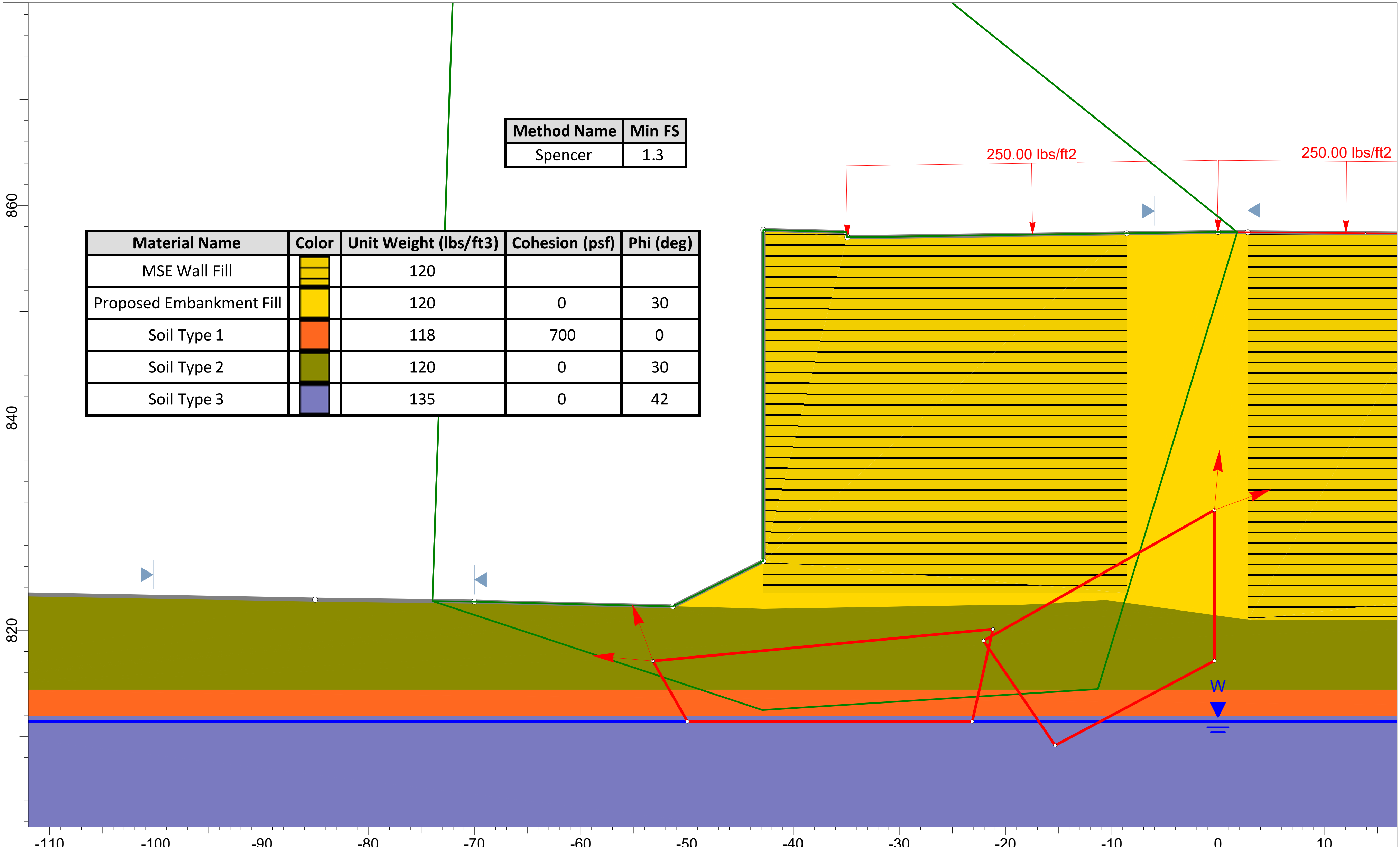


Material Name	Color	Unit Weight (lbs/ ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+60, Global Stability - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+60_1H_TotalCircular020923.slim



Method Name	Min FS
Spencer	1.3

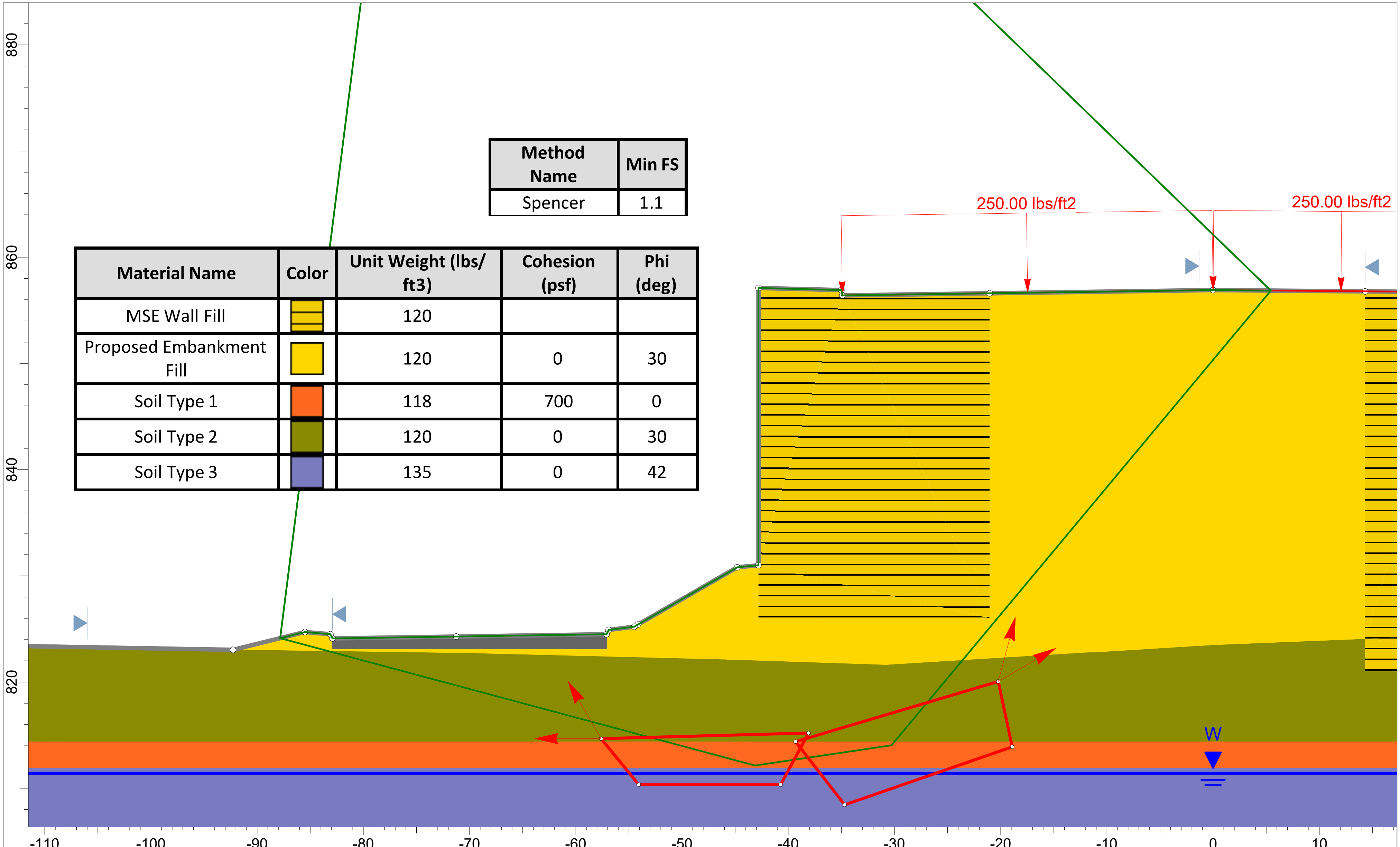
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 10+60, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA10+60_1H_TotalBlock020923.slim

STA. 11+30 – 0.7H STRAP LENGTH



Method Name	Min FS
Spencer	1.1

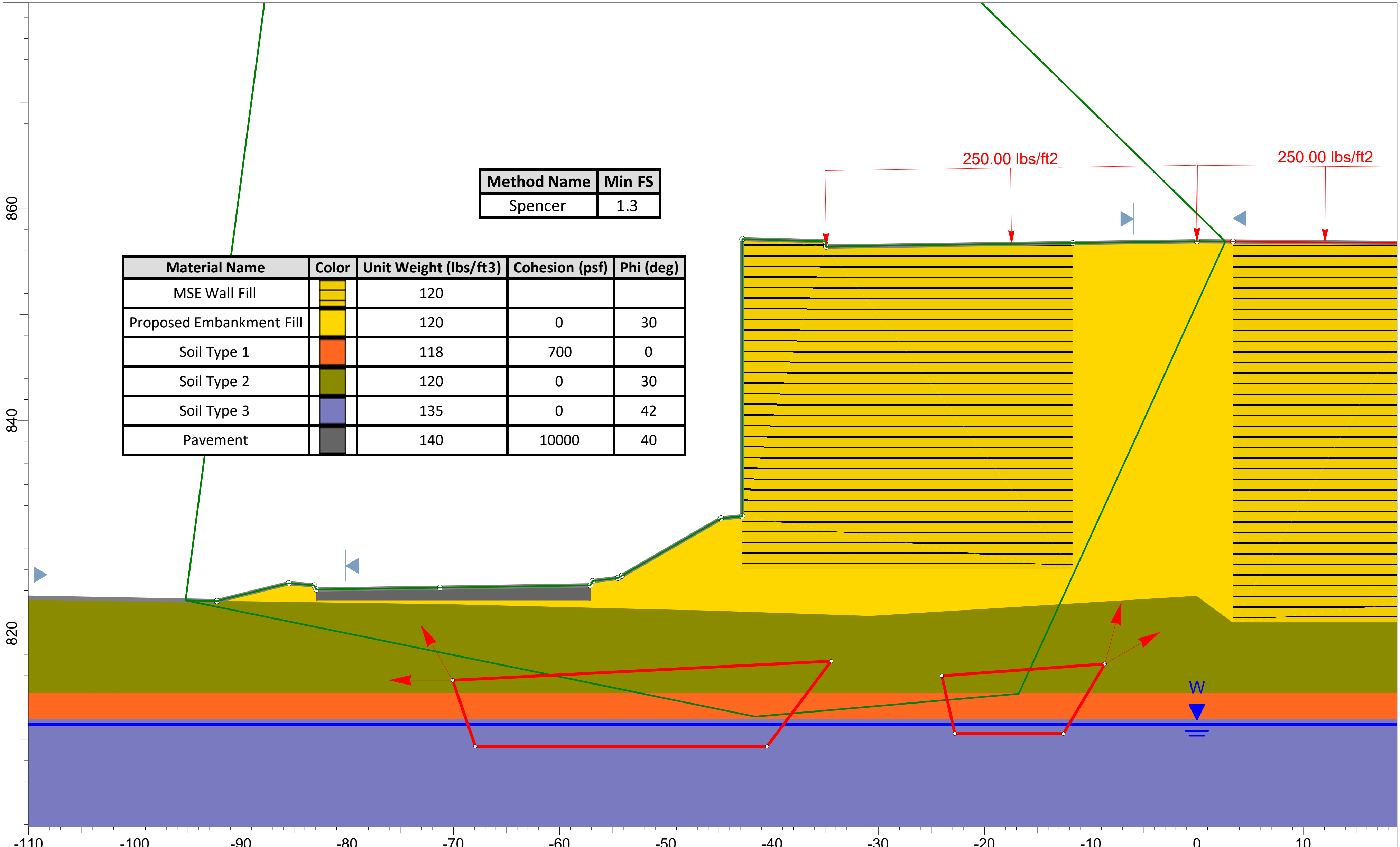
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 2		120	0	30
Soil Type 3		135	0	42

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+30, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+30_0.7H_TotalBlock021023.slim

STA. 11+30 – 1.0H STRAP LENGTH



Method Name	Min FS
Spencer	1.3

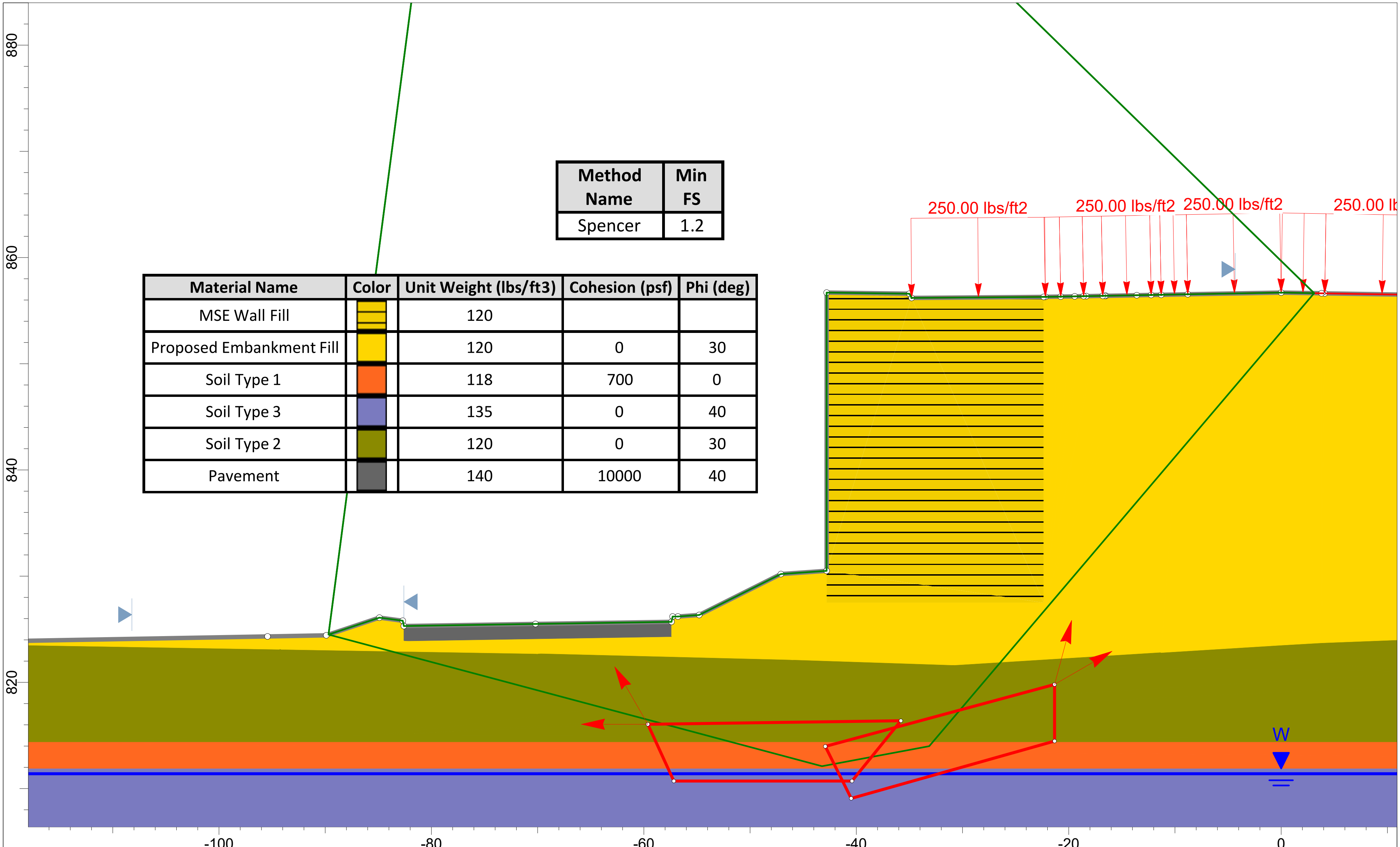
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 2		120	0	30
Soil Type 3		135	0	42
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+30, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+30_1H_TotalBlock021023.slim

STA. 11+60 – 0.7H STRAP LENGTH



Method Name	Min FS
Spencer	1.2

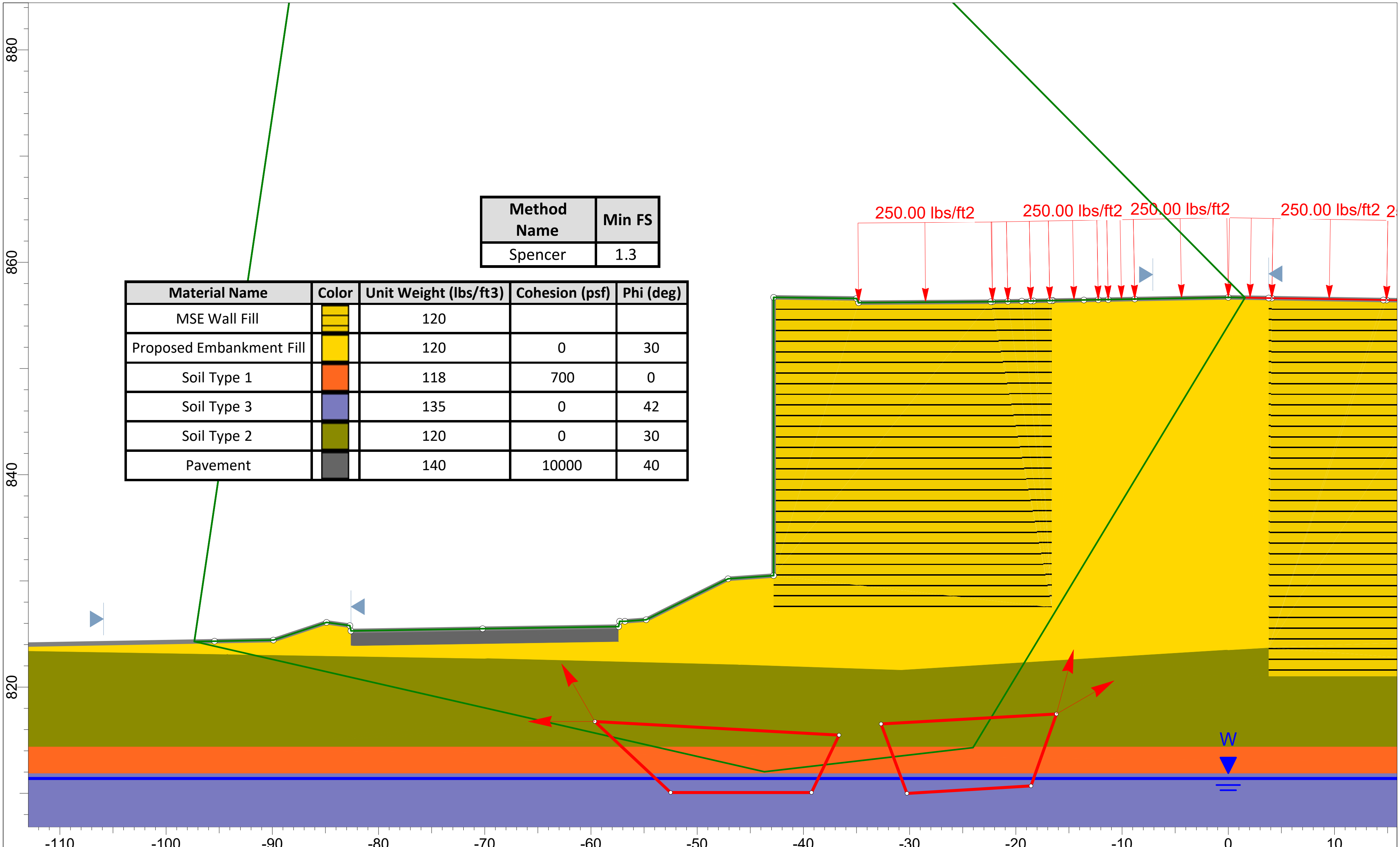
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	40
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 11+60, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA11+60_0.7H_TotalBlock021023.slim

STA. 11+60 – 1.0H STRAP LENGTH



Method Name	Min FS
Spencer	1.3

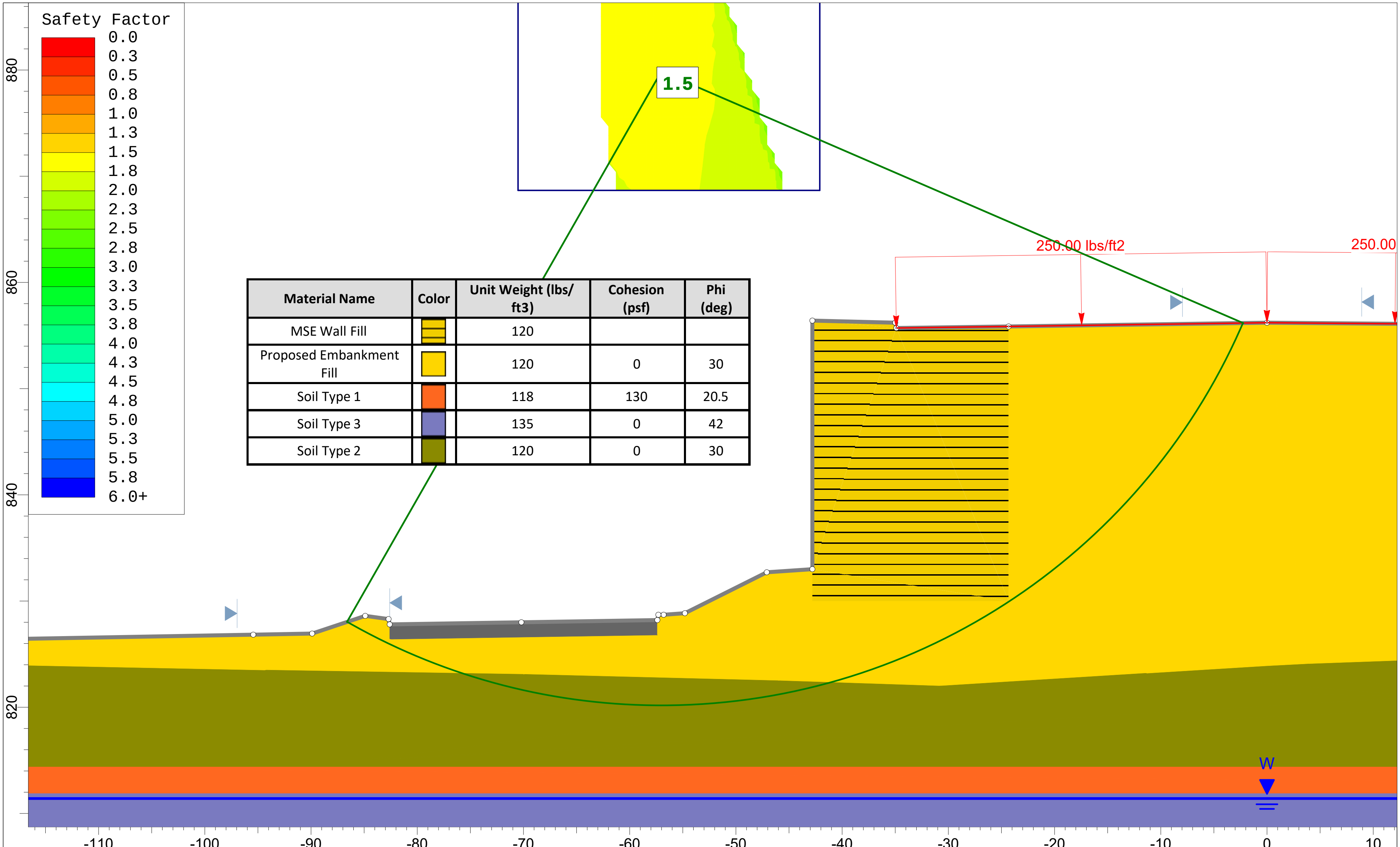
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+60, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+60_1H_TotalBlock021023.slim

STA. 11+85

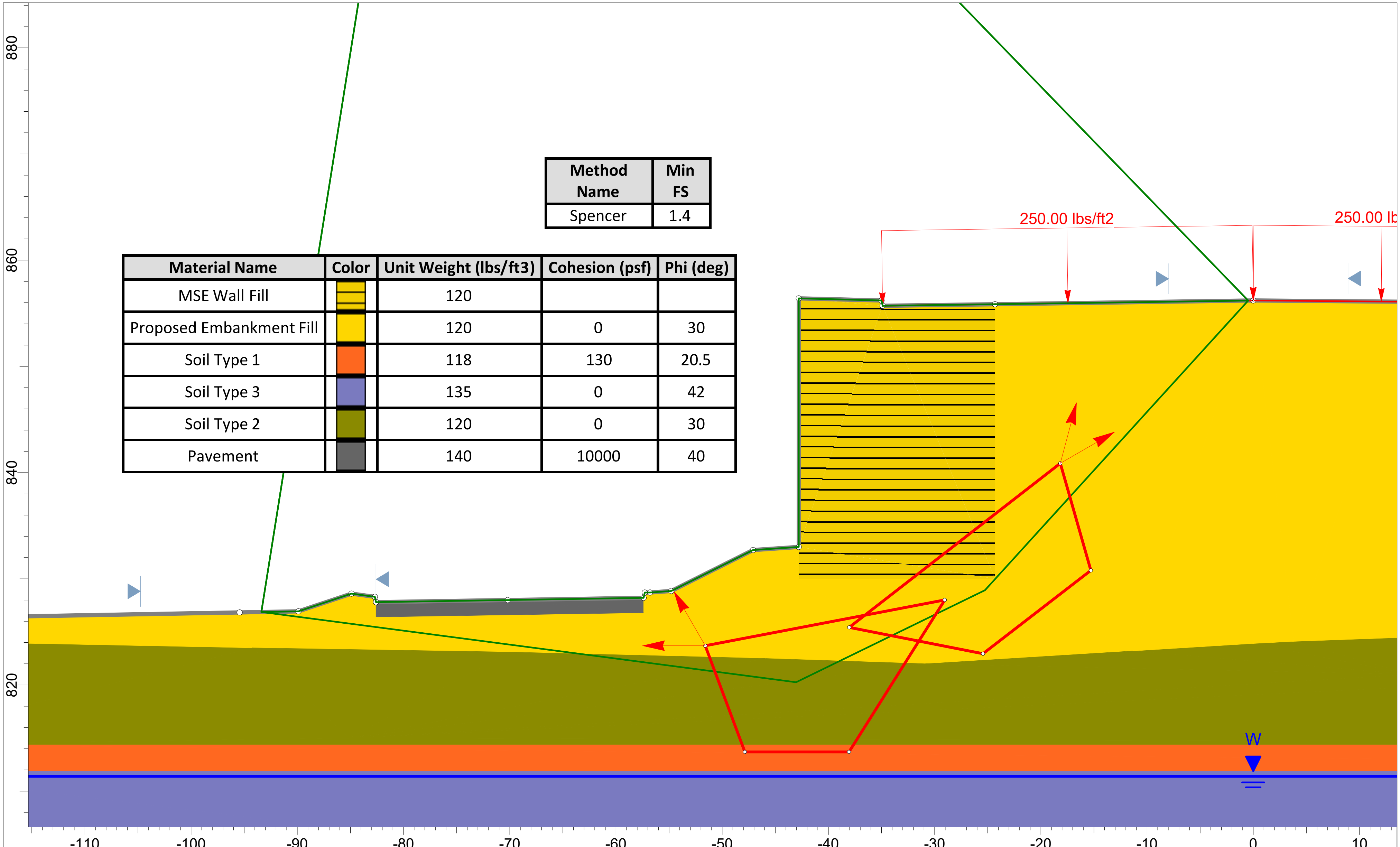


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+85, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+85_0.7H_EffCircular021023.slim



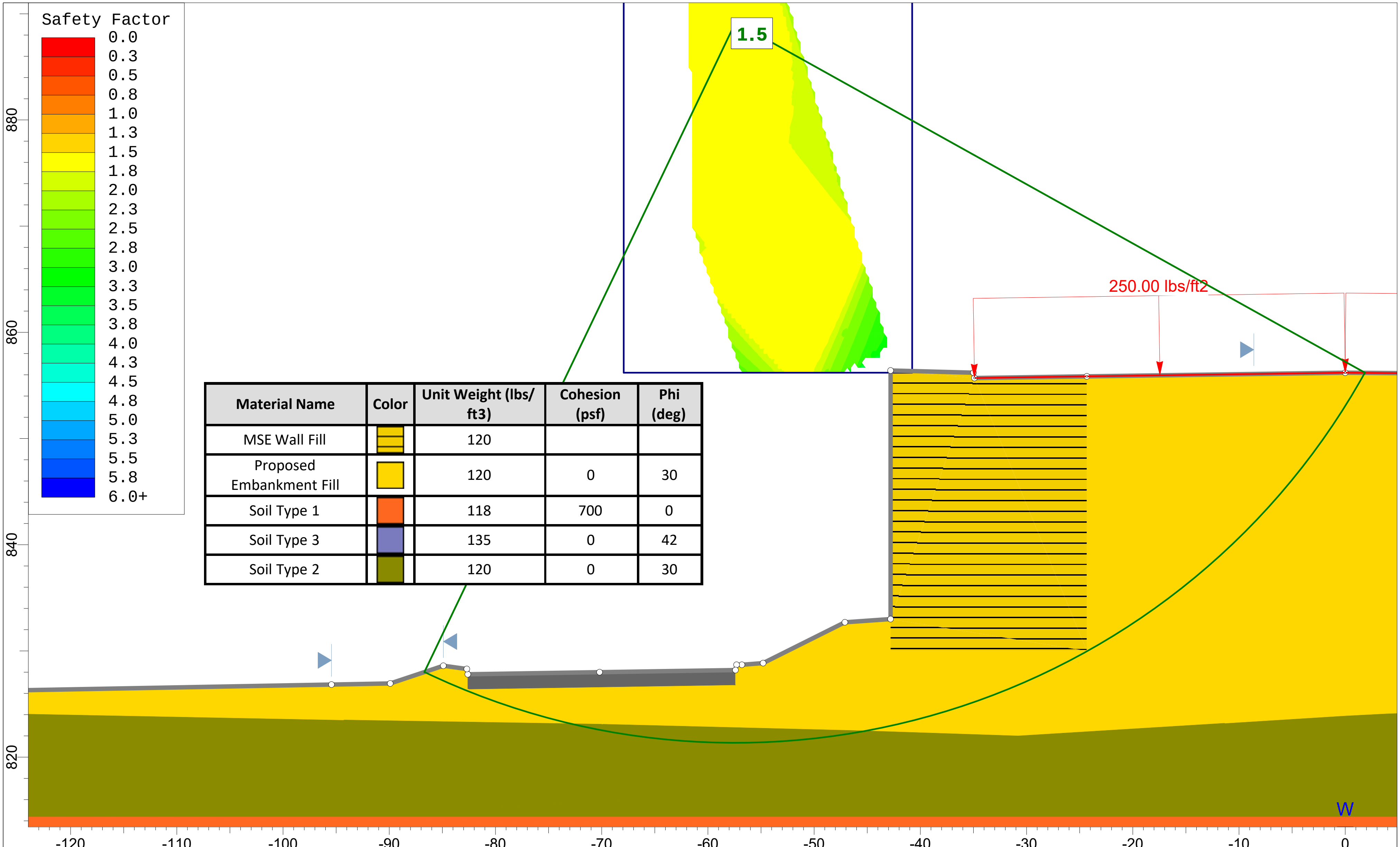
Method Name	Min FS
Spencer	1.4

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 11+85, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA11+85_0.7H_EffBlock021023.slim

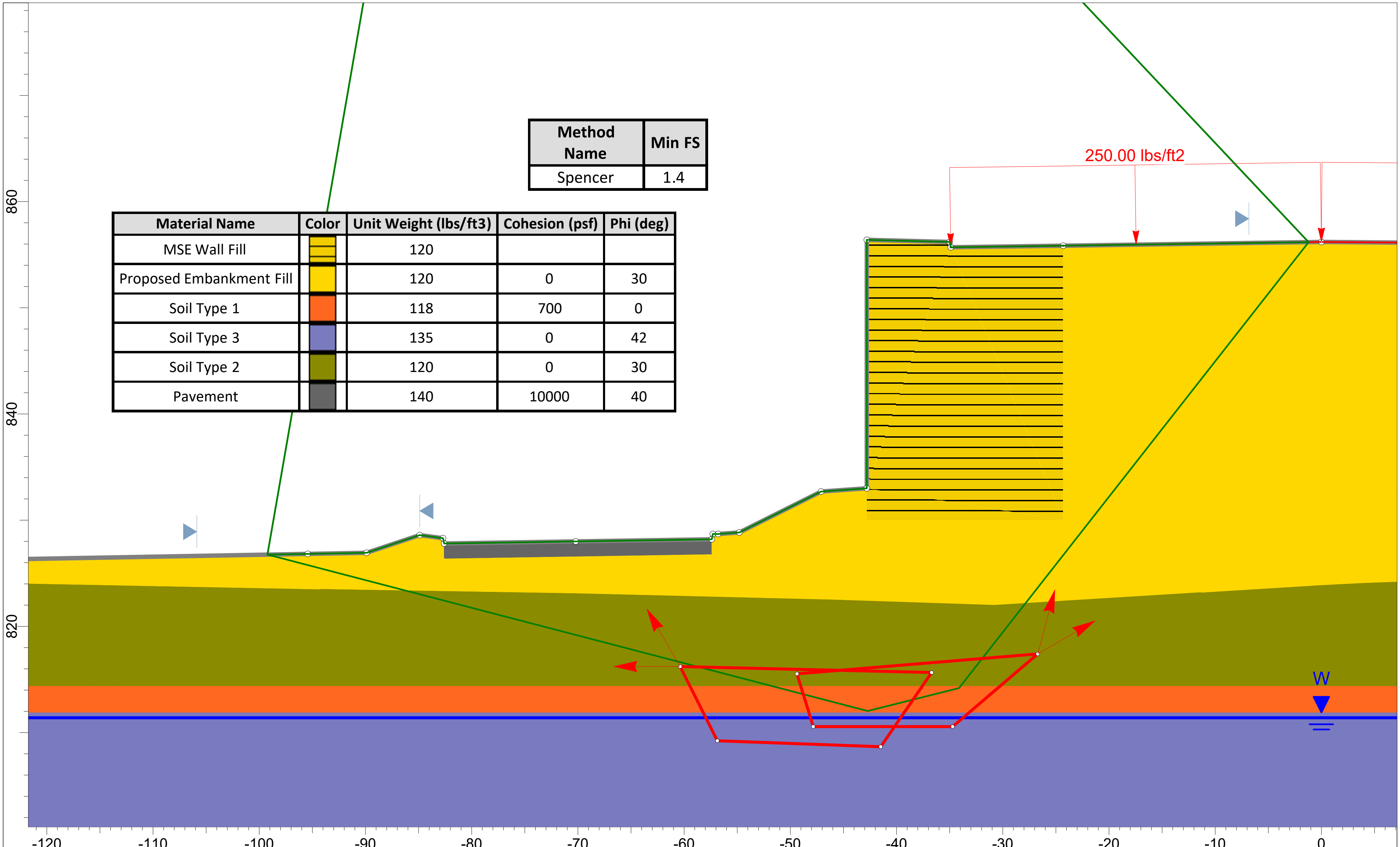


Material Name	Color	Unit Weight (lbs/ ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+85, Global Stability - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+85_0.7H_TotalCircular021023.slim



Method Name	Min FS
Spencer	1.4

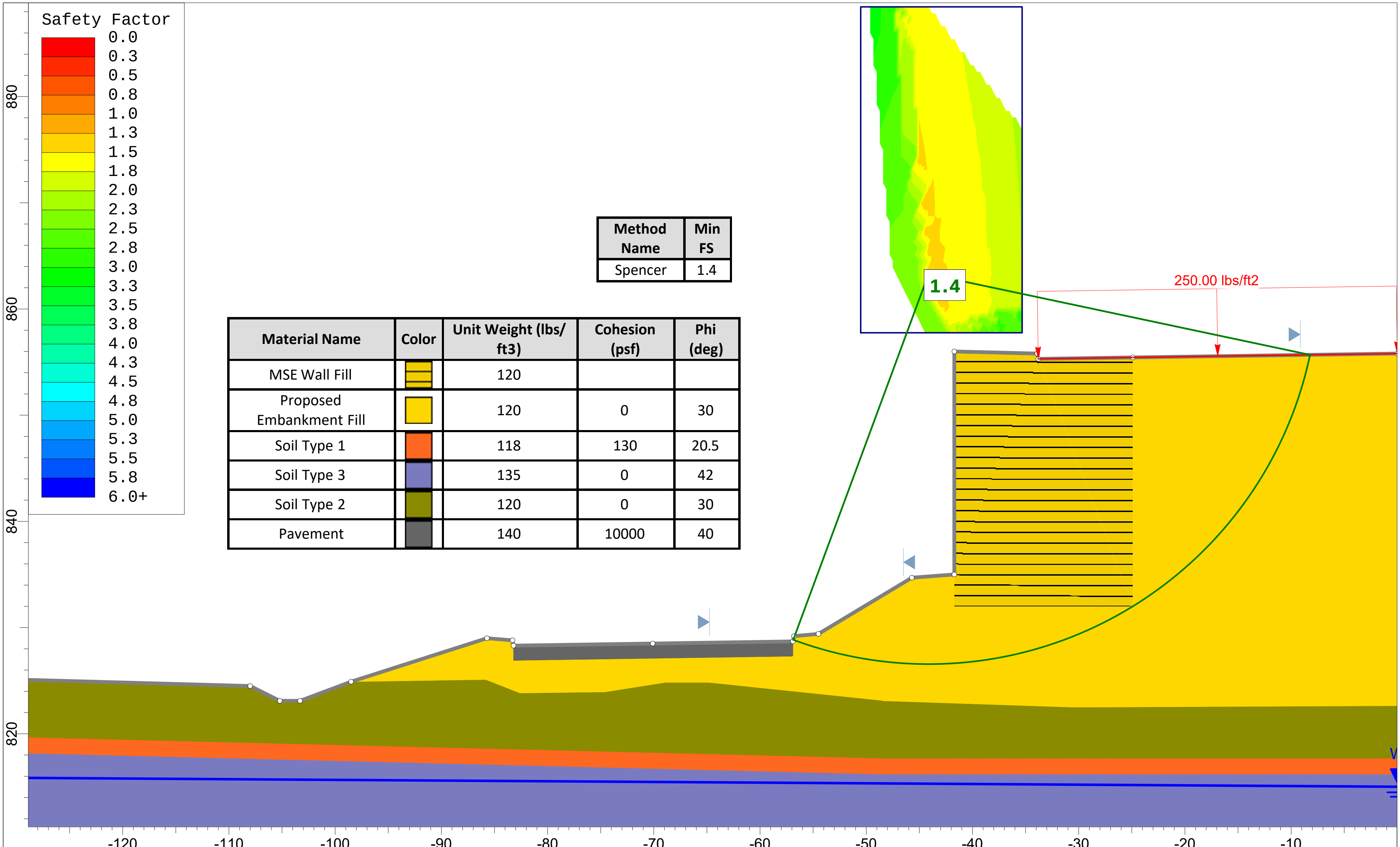
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 11+85, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA11+85_0.7H_TotalBlock021023.slim

STA. 12+10



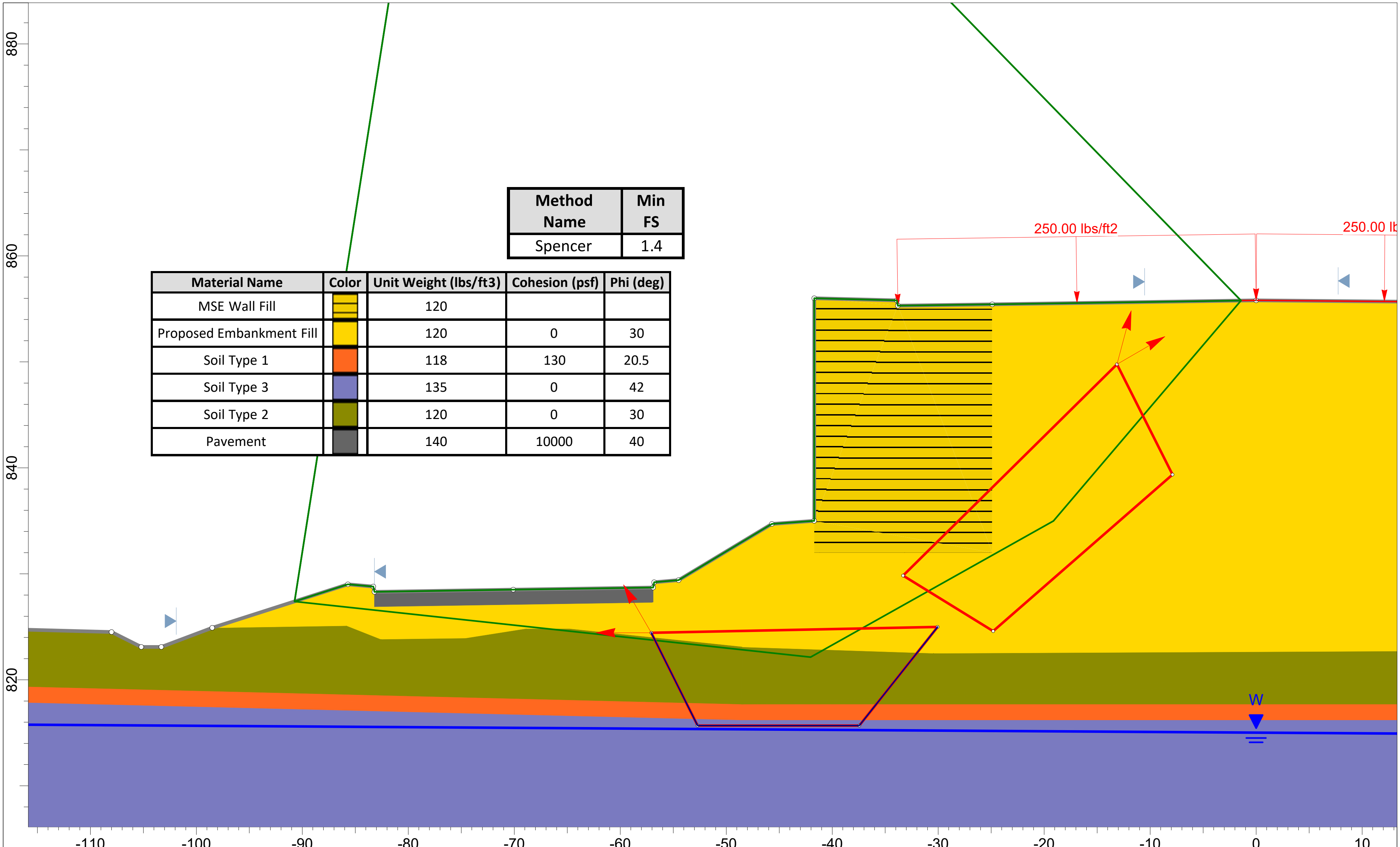
Method Name	Min FS
Spencer	1.4

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 12+10, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA12+10_0.7H_EffectiveCircular021023.slim



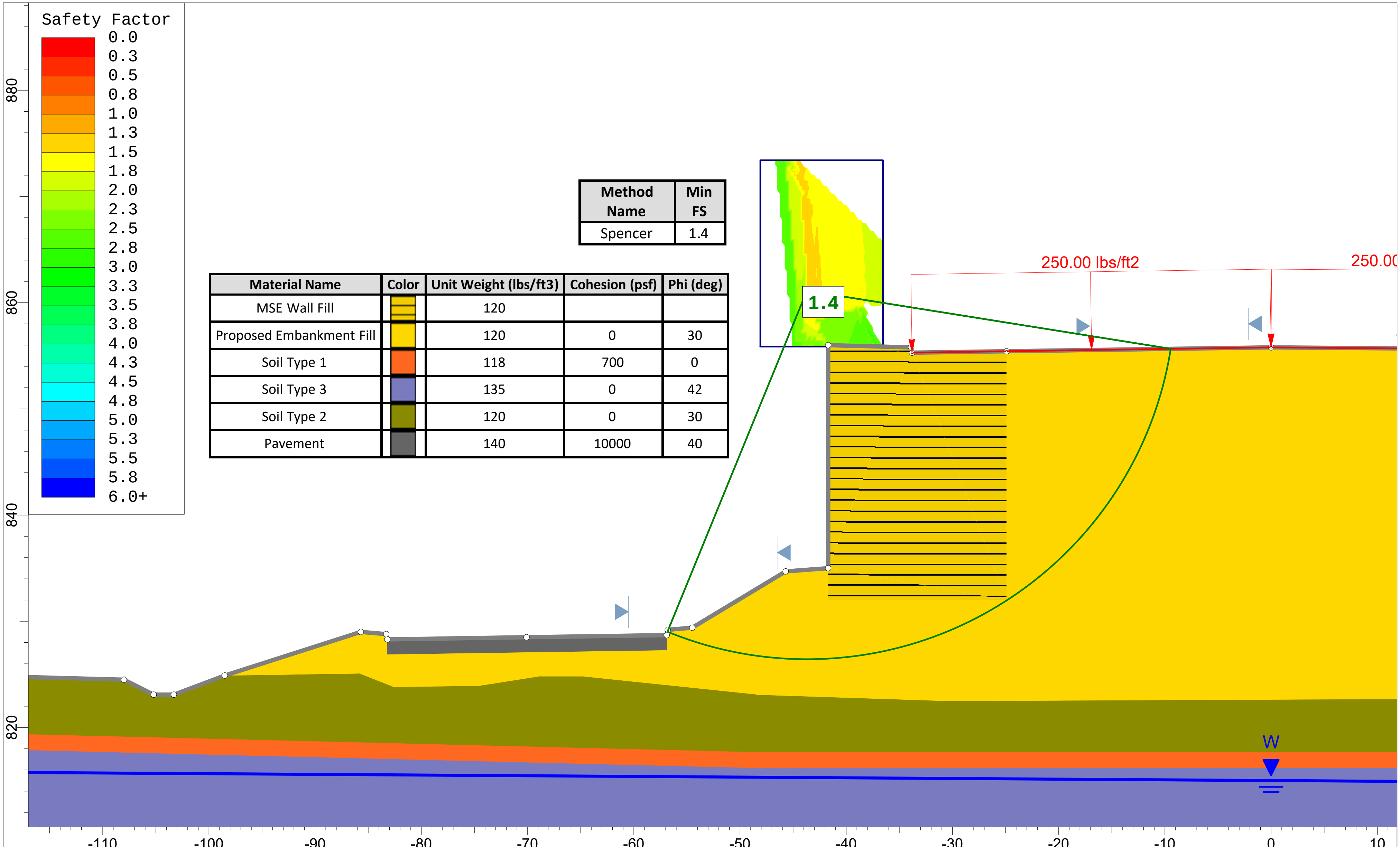
Method Name	Min FS
Spencer	1.4

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 12+10, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA12+10_0.7H_EffectiveBlock021023.slim



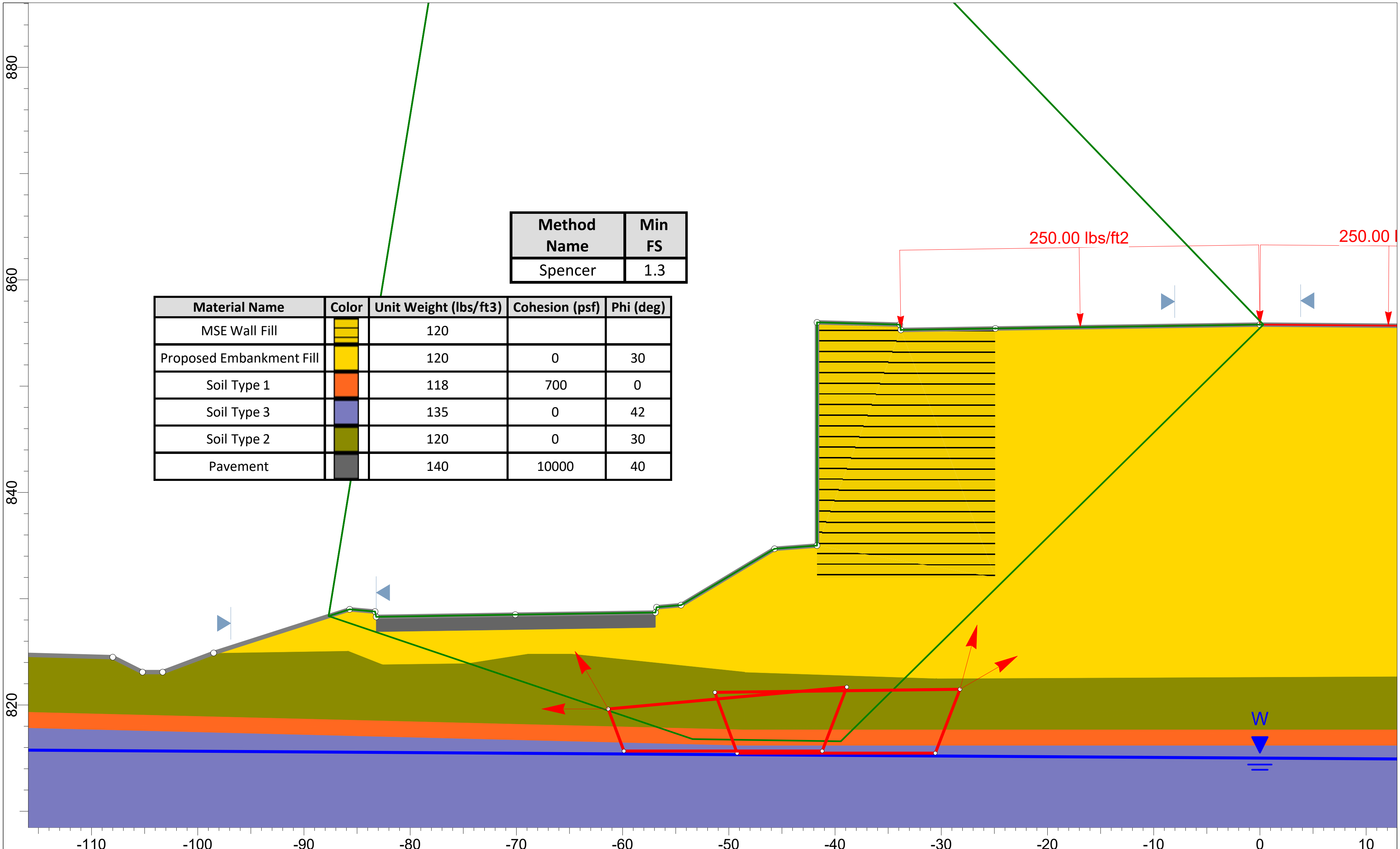
Method Name	Min FS
Spencer	1.4

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 3 - STA. 12+10, Global Stability - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall3_STA12+10_0.7H_TotalCircular021023.slim



Method Name	Min FS
Spencer	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Pavement		140	10000	40

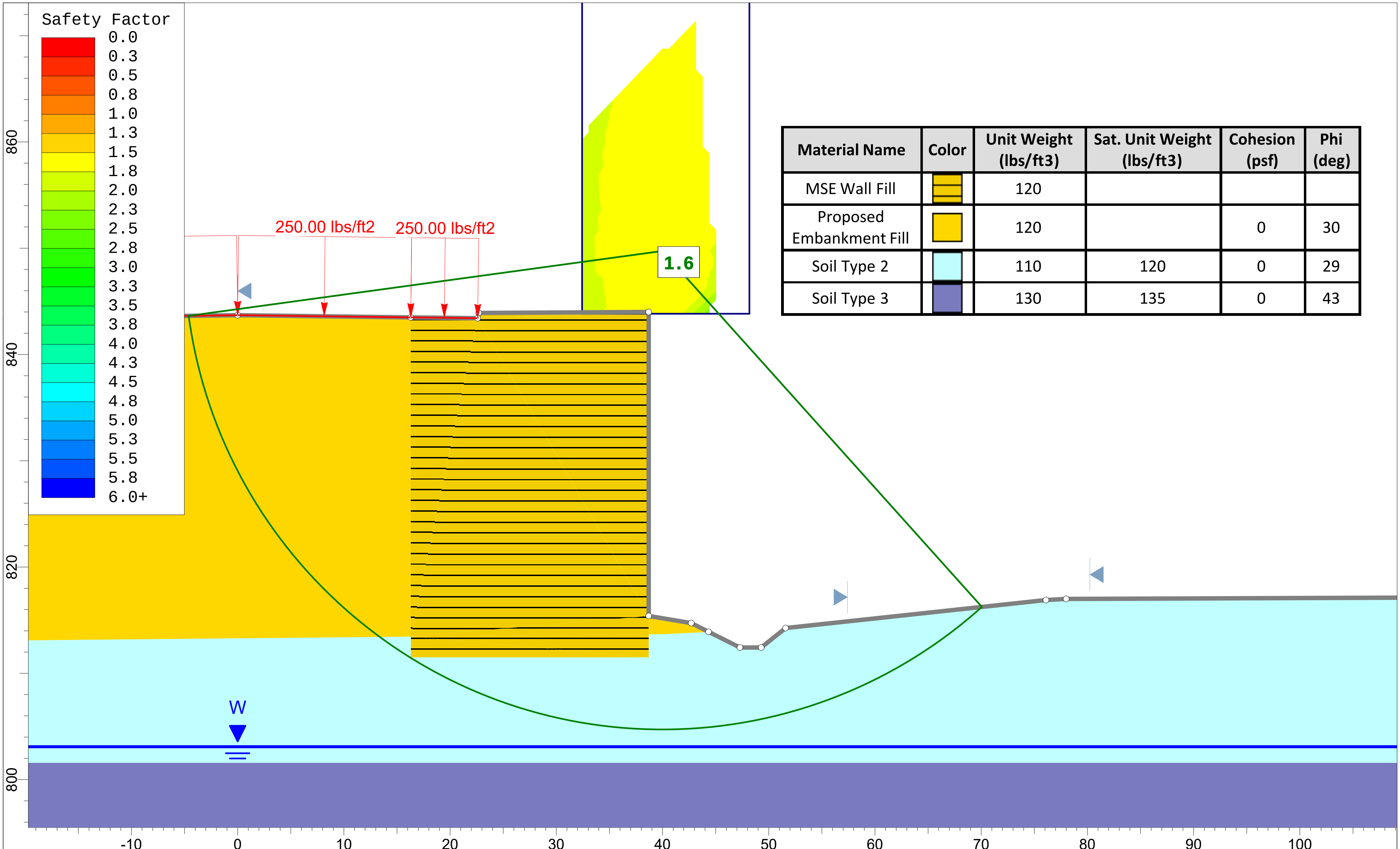
rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 3 - STA. 12+10, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall3_STA12+10_0.7H_TotalBlock021023.slim

RETAINING WALL 5

STA. 11+95

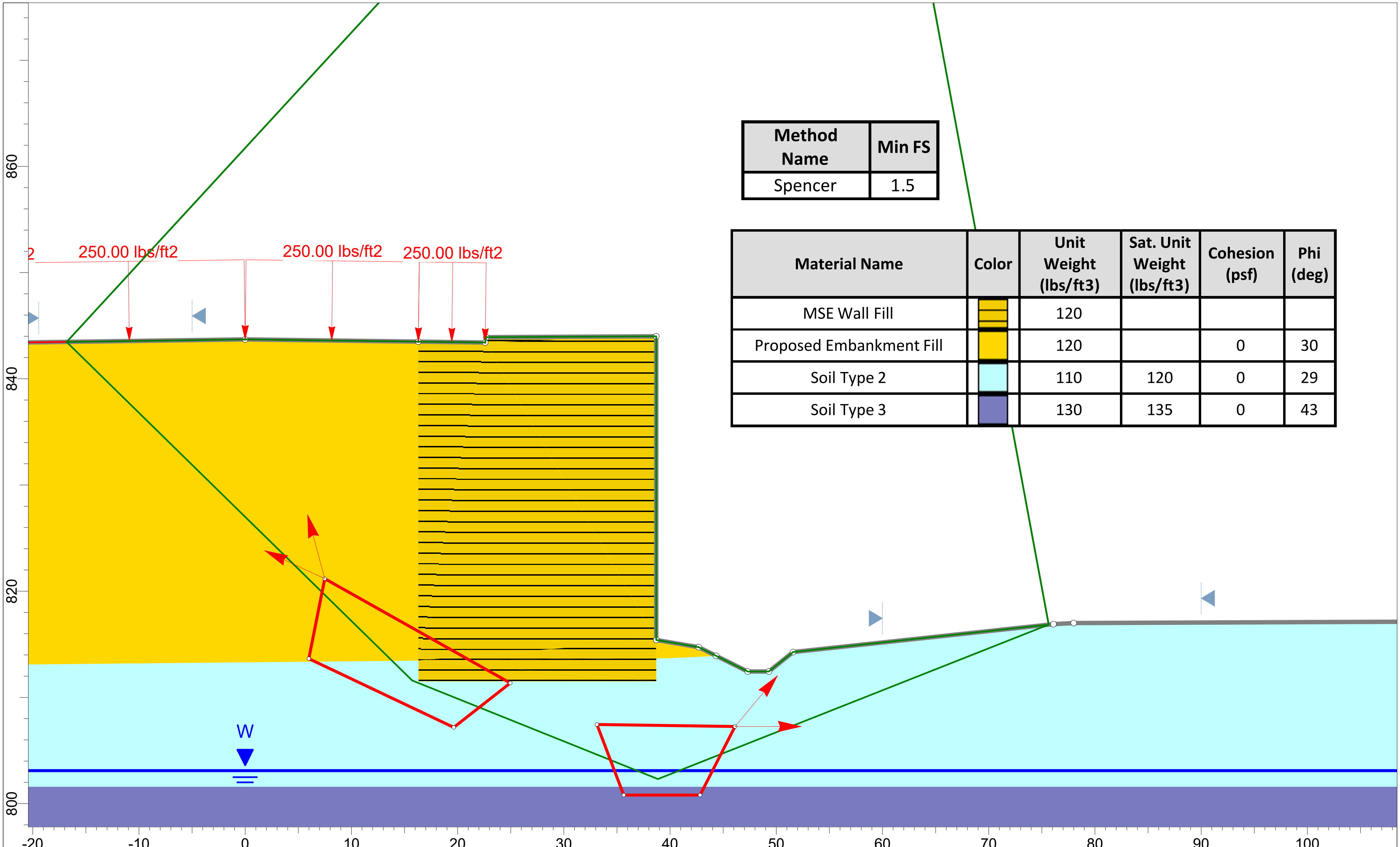


Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 2		110	120	0	29
Soil Type 3		130	135	0	43

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 5 - STA. 11+95, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall5_STA11+95_EffCircular020823.slim



Method Name	Min FS
Spencer	1.5

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 2		110	120	0	29
Soil Type 3		130	135	0	43

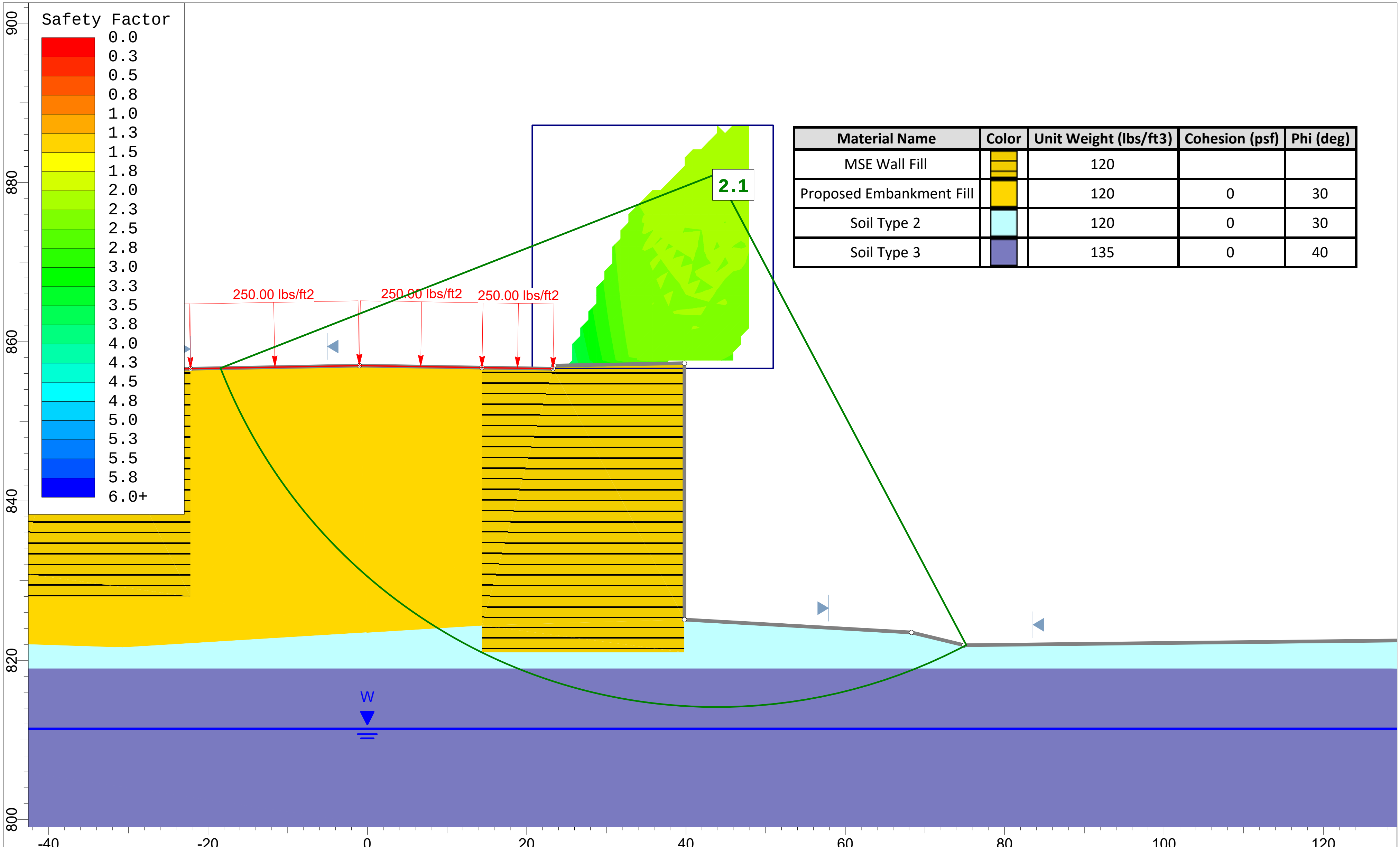
rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 5 - STA. 11+95, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall5_STA11+95_EffBlock020823.slim

RETAINING WALL 6

STA. 10+00

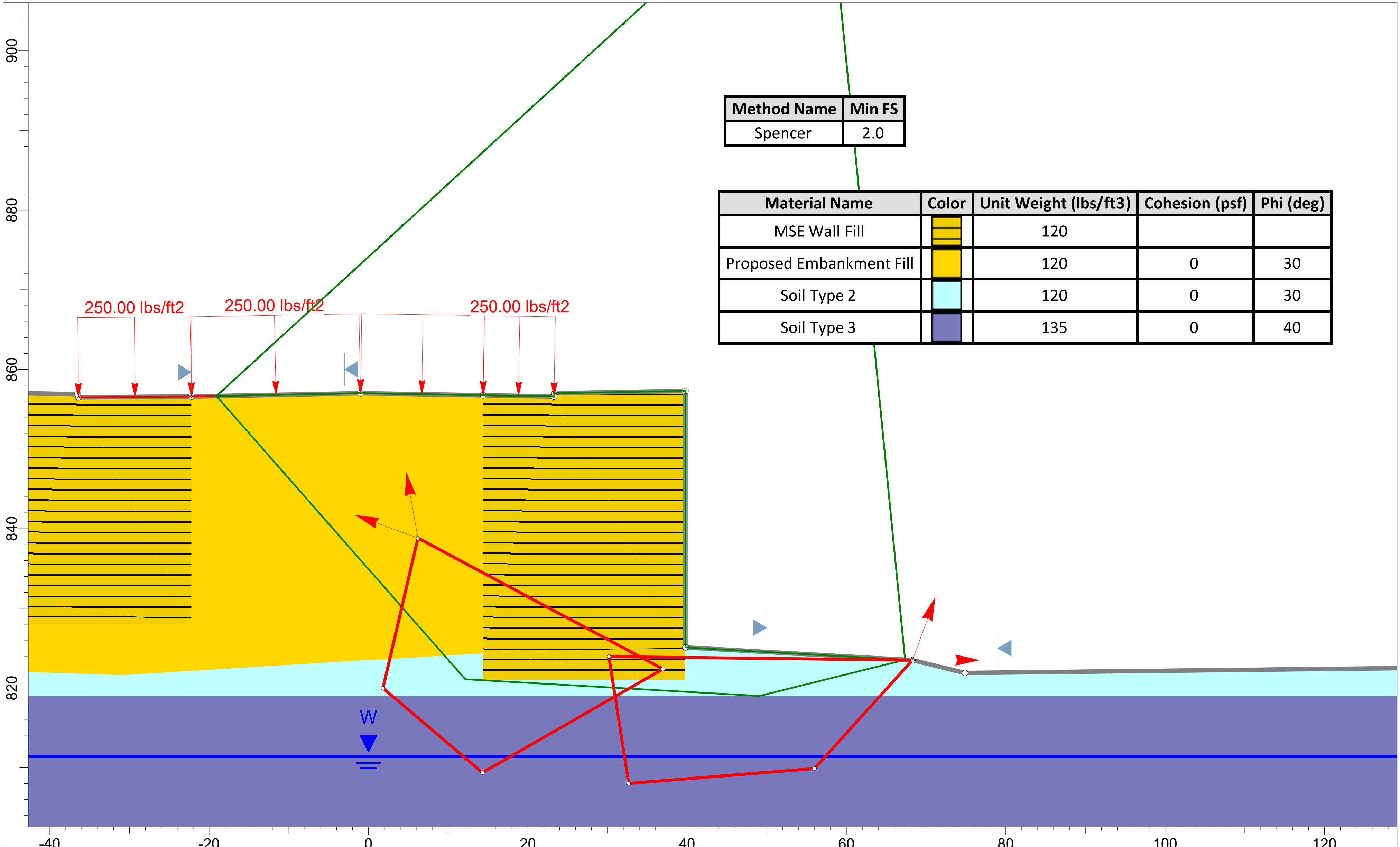


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 2		120	0	30
Soil Type 3		135	0	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 10+00, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA10+00_EffCircular020923.slim



Method Name	Min FS
Spencer	2.0

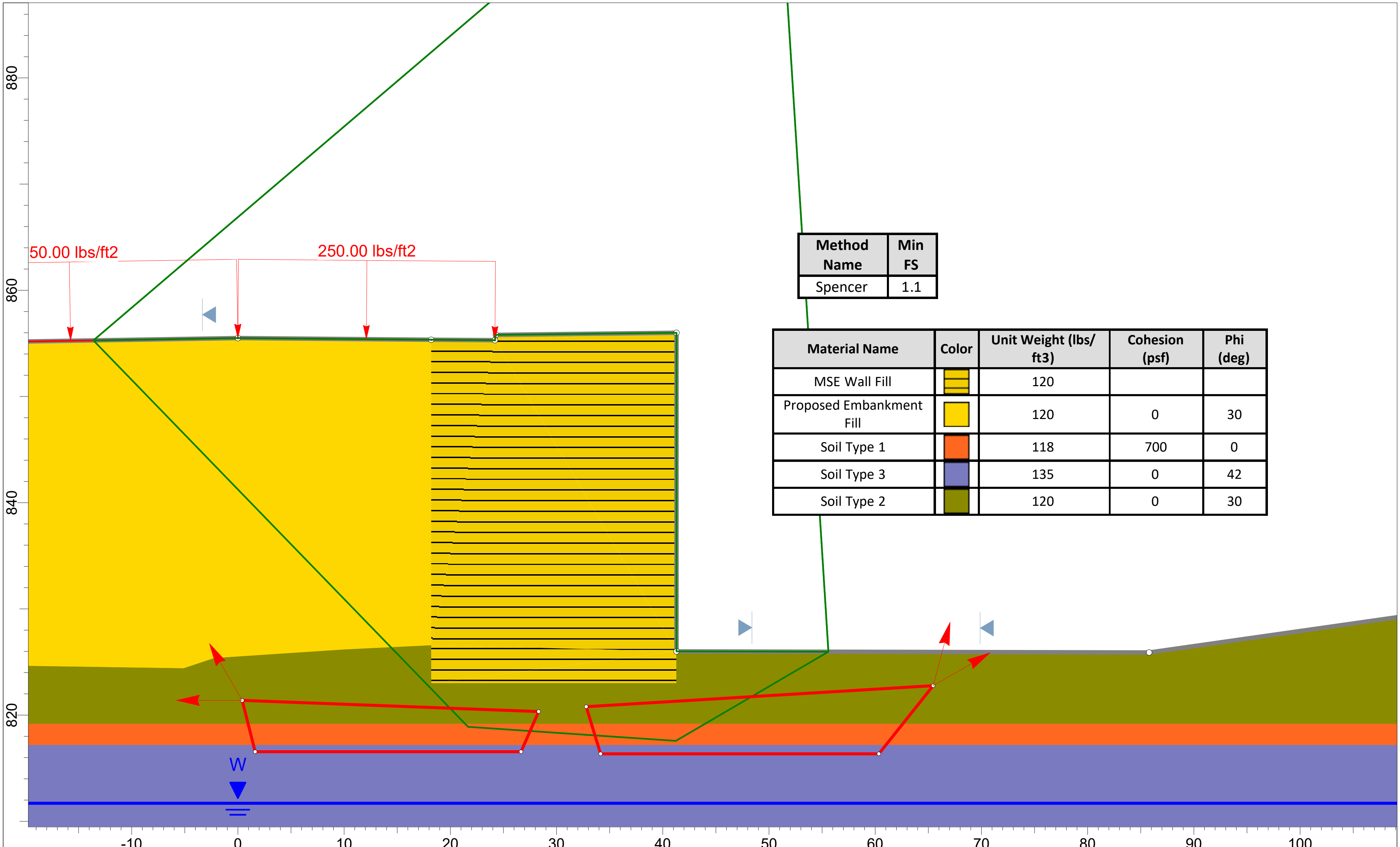
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 2		120	0	30
Soil Type 3		135	0	40

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 10+00, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA10+00_EffBlock020923.slim

STA. 10+80 – 0.7H STRAP LENGTH



Method Name	Min FS
Spencer	1.1

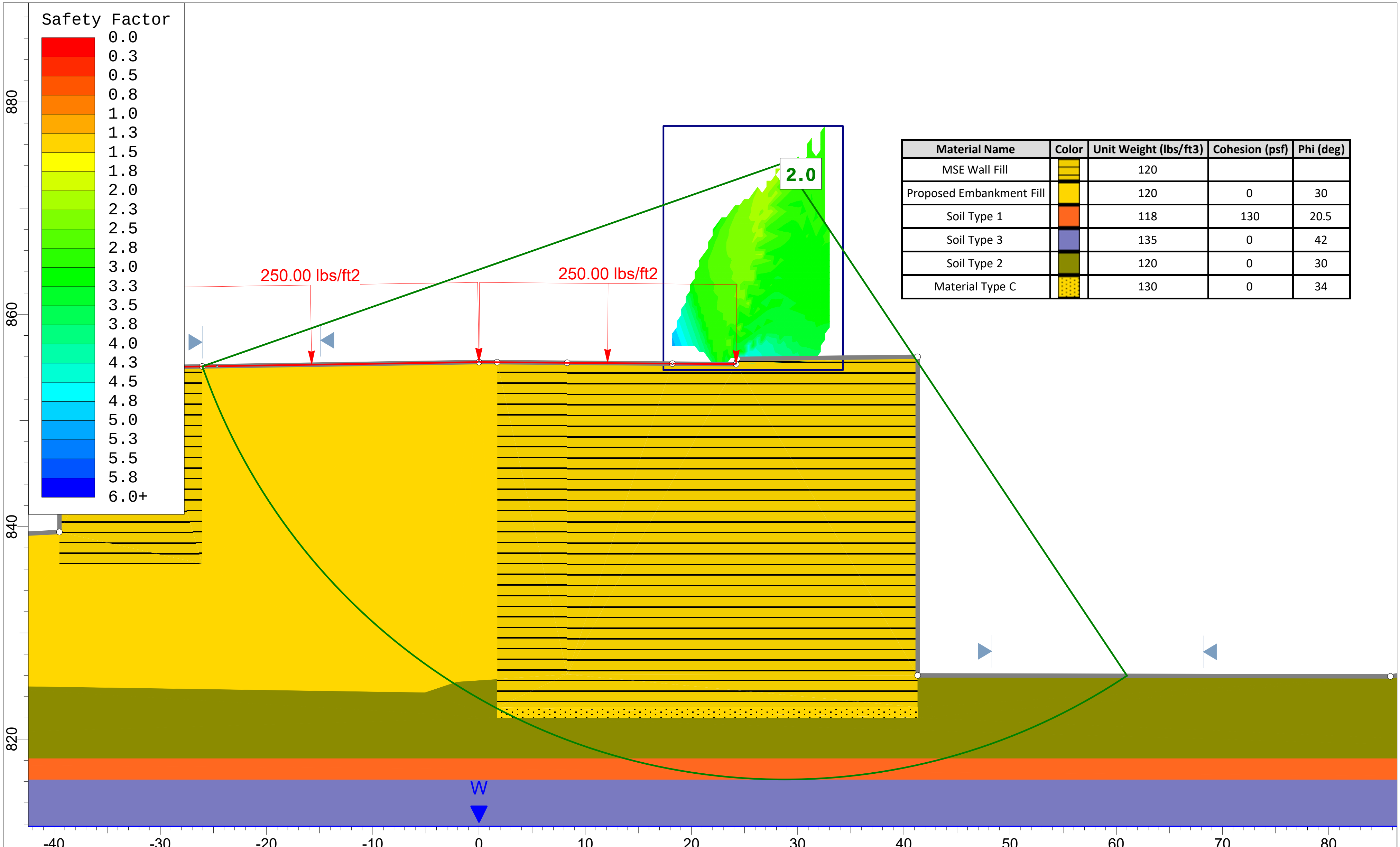
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 10+80, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA10+80__B-013_TotalBlock021023.slim

STA. 10+80 – 1.0H STRAP LENGTH

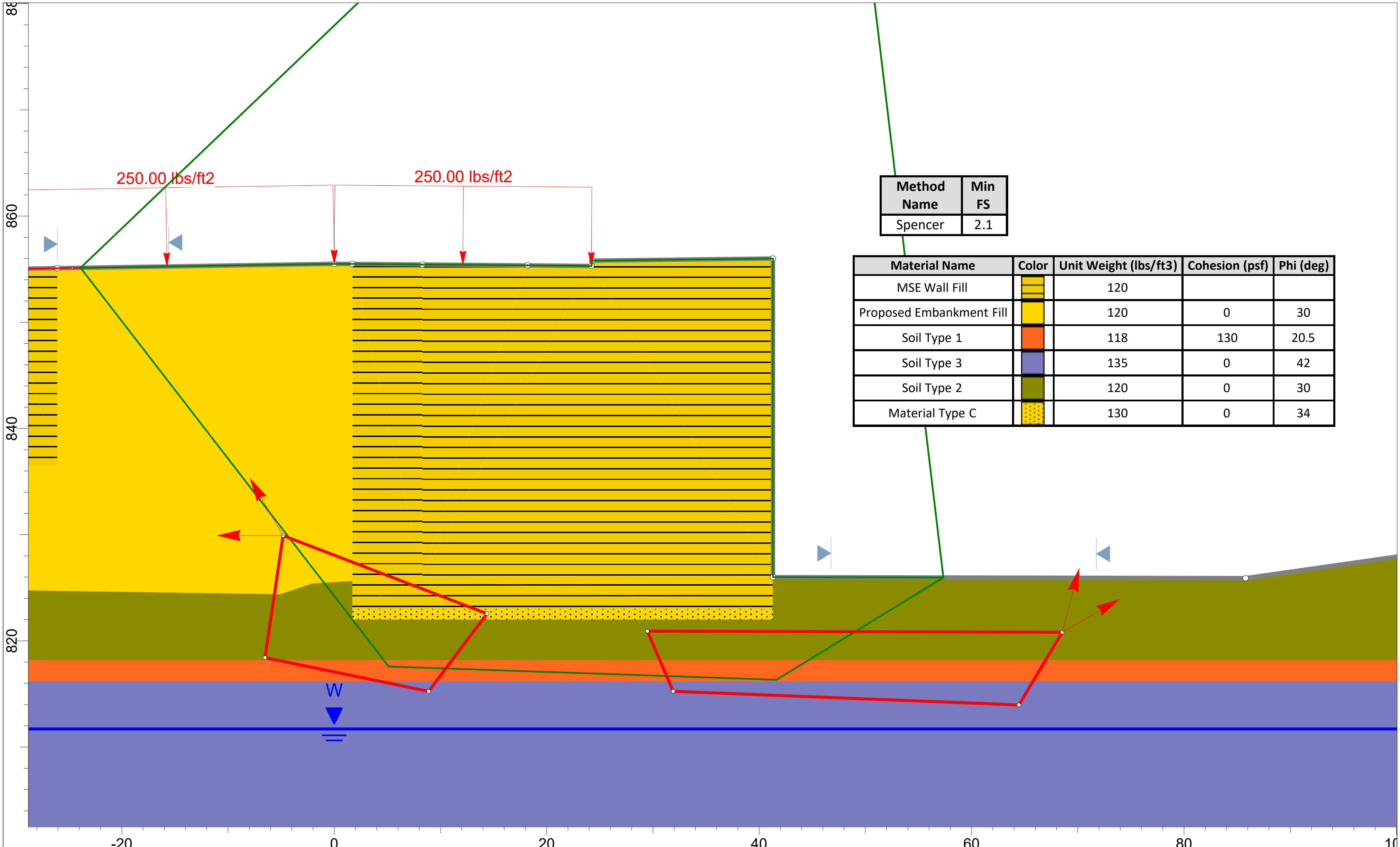


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

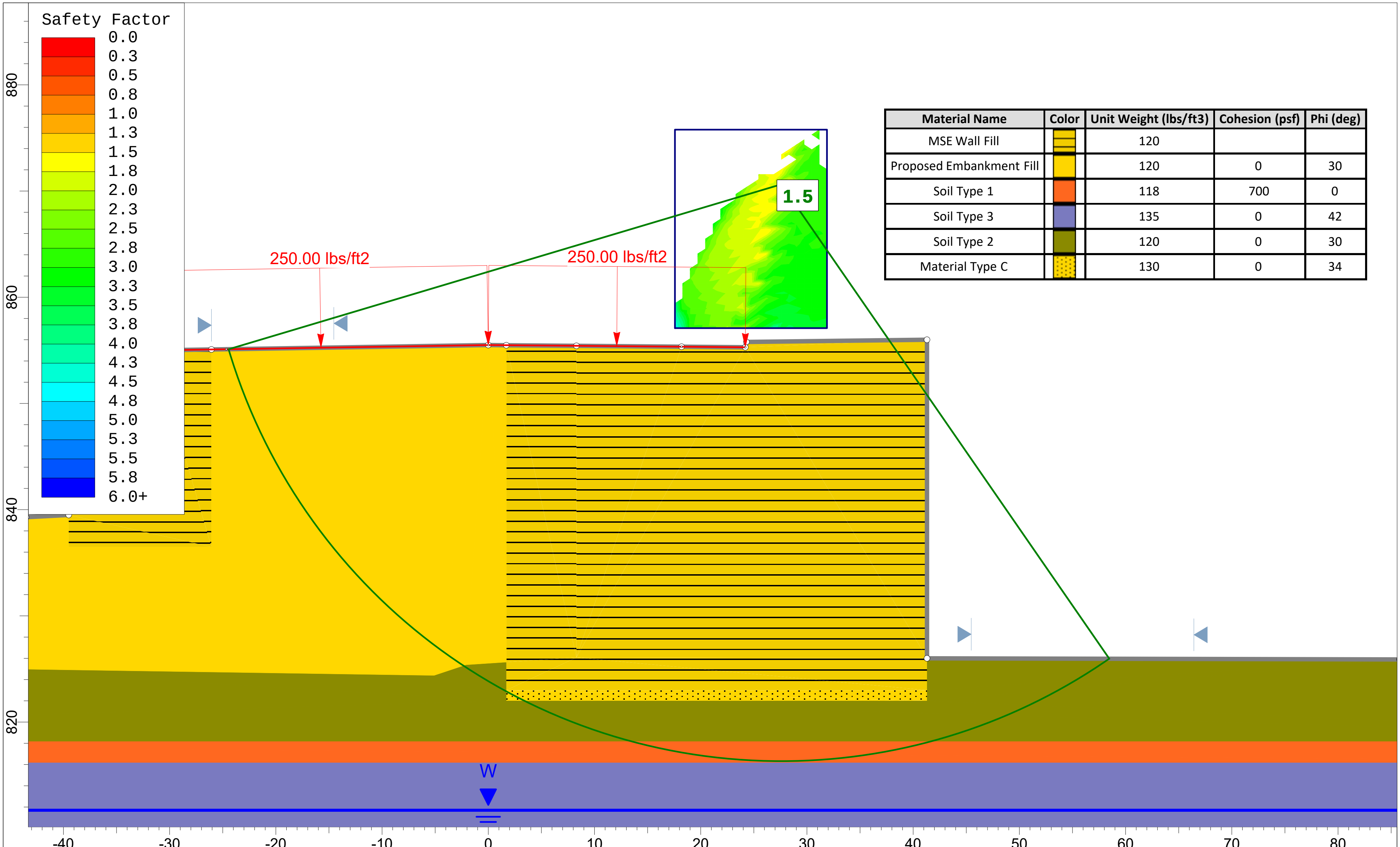
Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 10+80, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA10+80_1.2H_B-013_EffectiveCircular021023.slim



Method Name	Min FS
Spencer	2.1

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience	*Project* CUY-14-6.93, PID 104132		
	Analysis Description Retaining Wall 6 - STA. 10+80, Global Stability - Effective Stress, Block Failure		
	Drawn By KCA	*Company* NEAS Inc.	
SLIDEINTERPRET 9.025	*Date* 12/14/2021, 9:43:12 AM	*File Name* Wall6_STA10+80_1.2H_B-013_EffectiveBlock021023.slim	

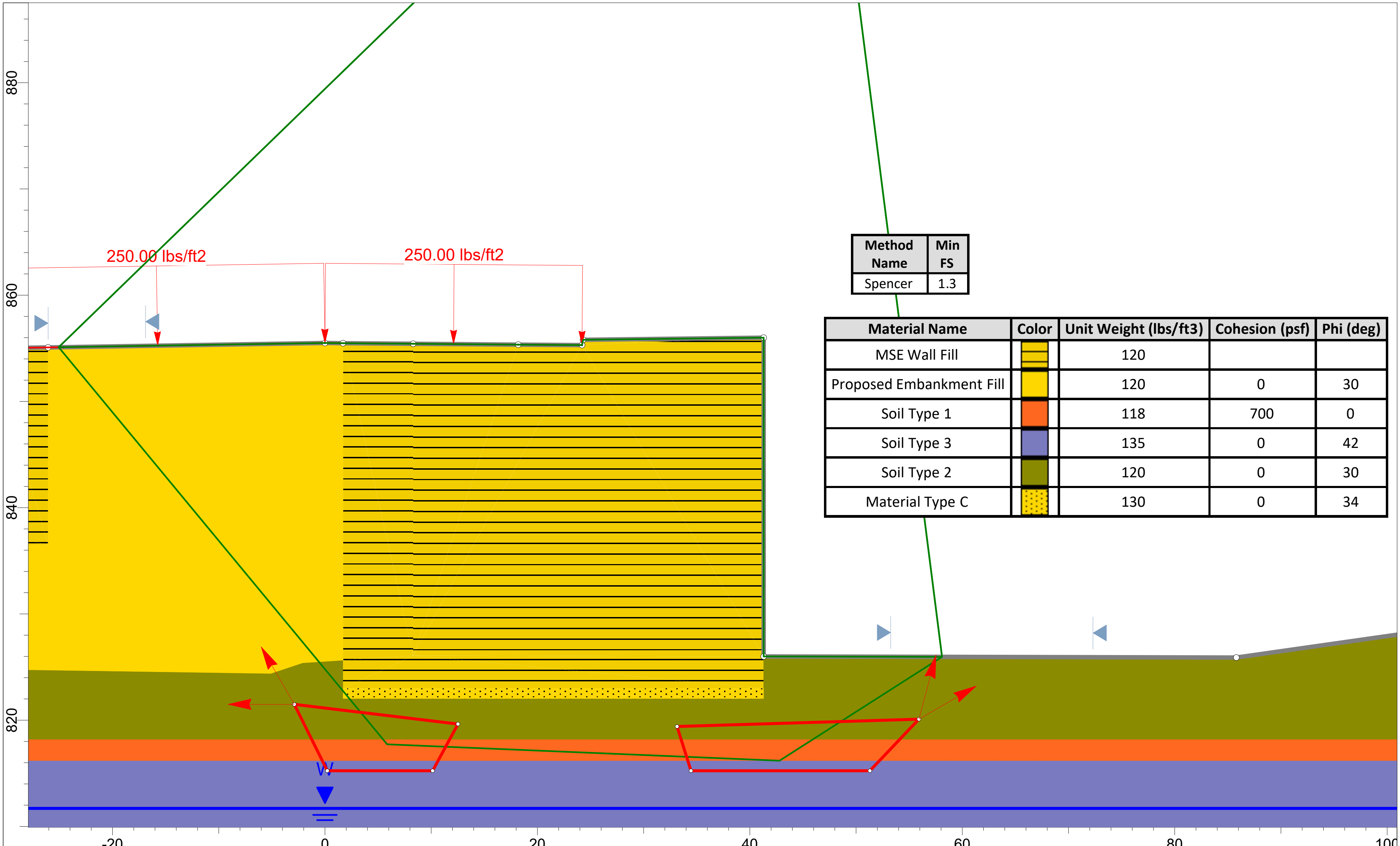


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 10+80, Global Stability - Total Stress, Circular Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA10+80_1.2H_B-013_TotalCircular021023.slim



Method Name	Min FS
Spencer	1.3

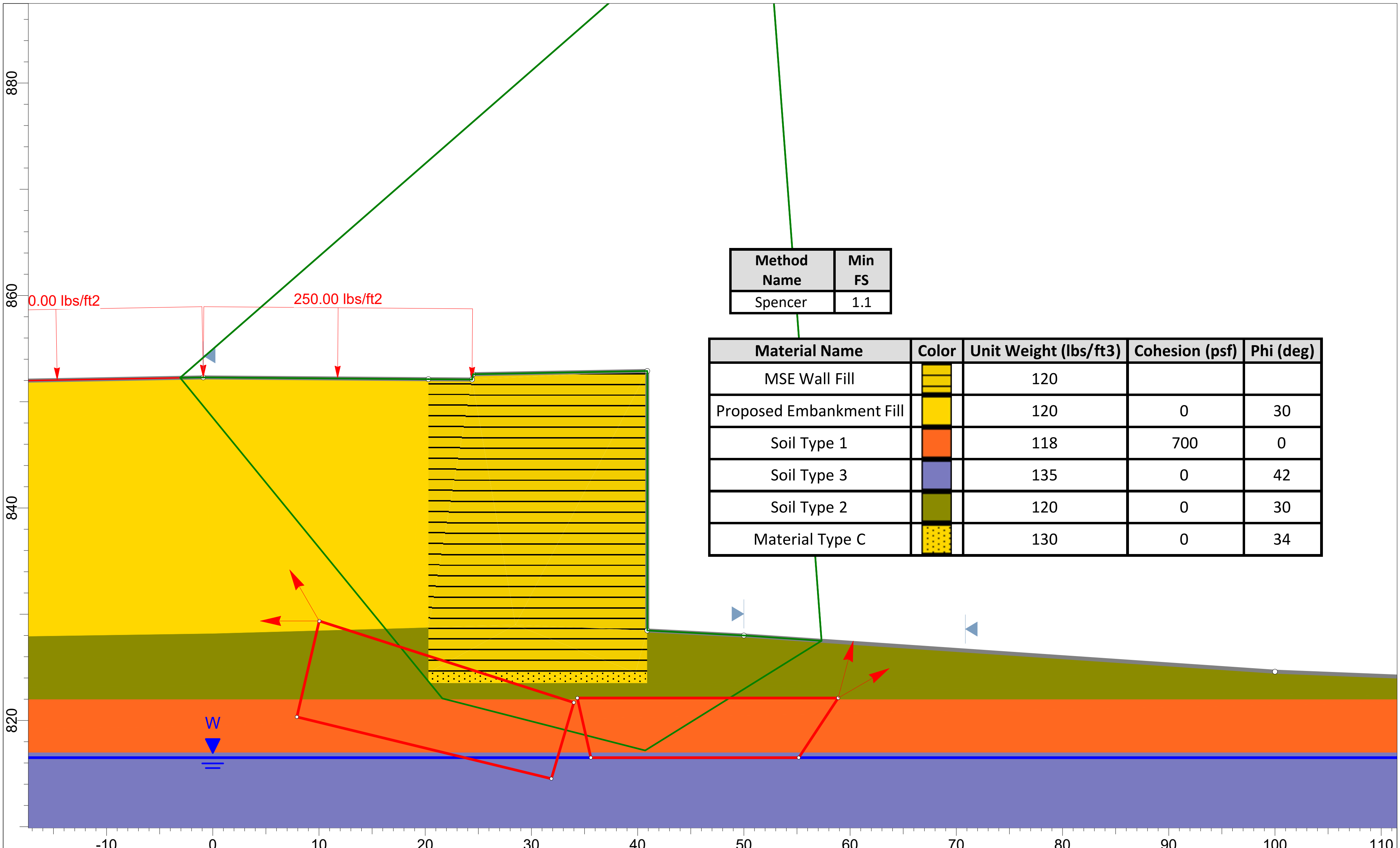
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 10+80, Global Stability - Total Stress, Block Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA10+80_1H_B-013_TotalBlock021023.slim

STA. 12+00 – 0.7H STRAP LENGTH



Method Name	Min FS
Spencer	1.1

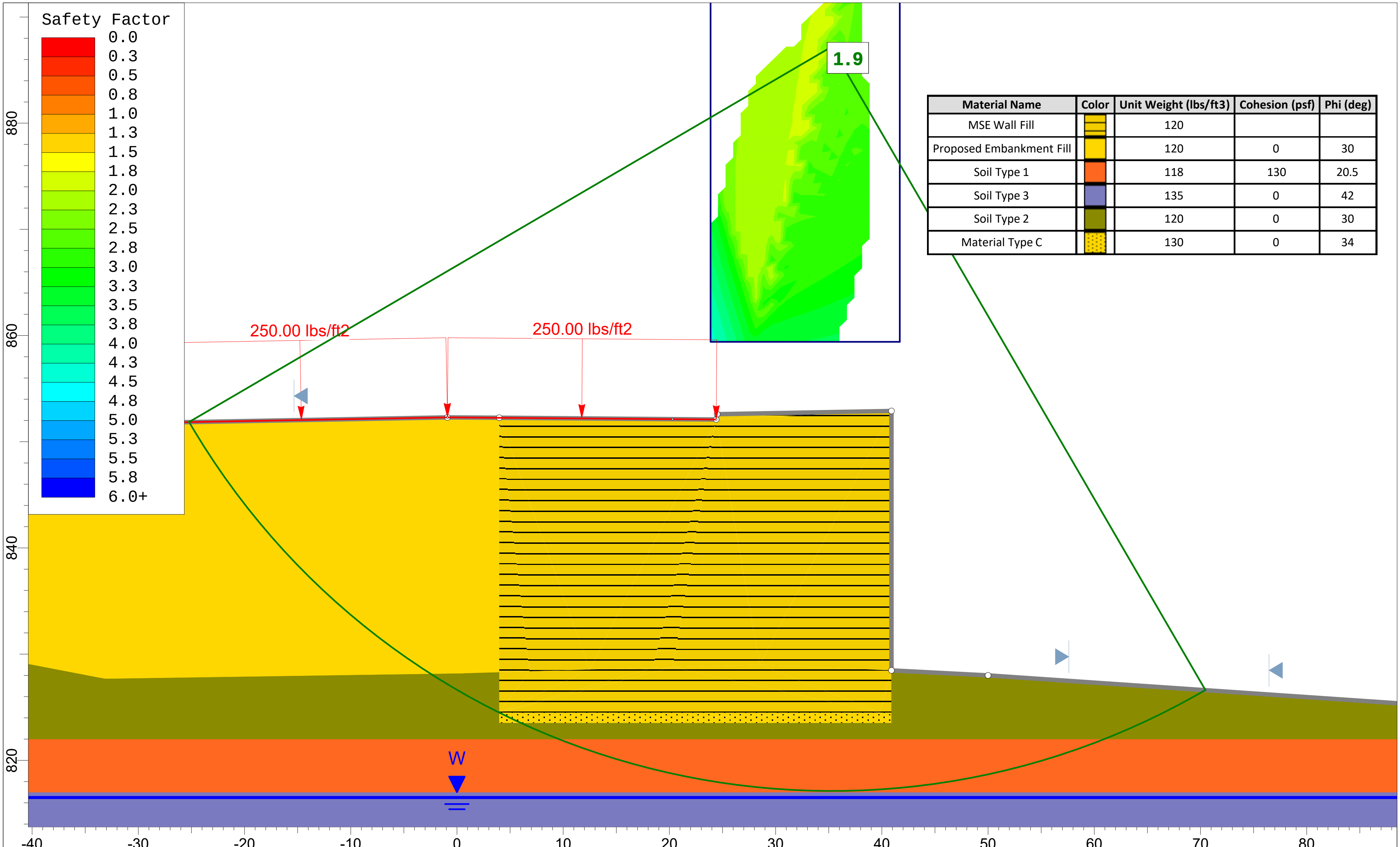
Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 11+20, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA11+20__B-015_TotalBlock021023.slim

STA. 12+00 – 1.3H STRAP LENGTH

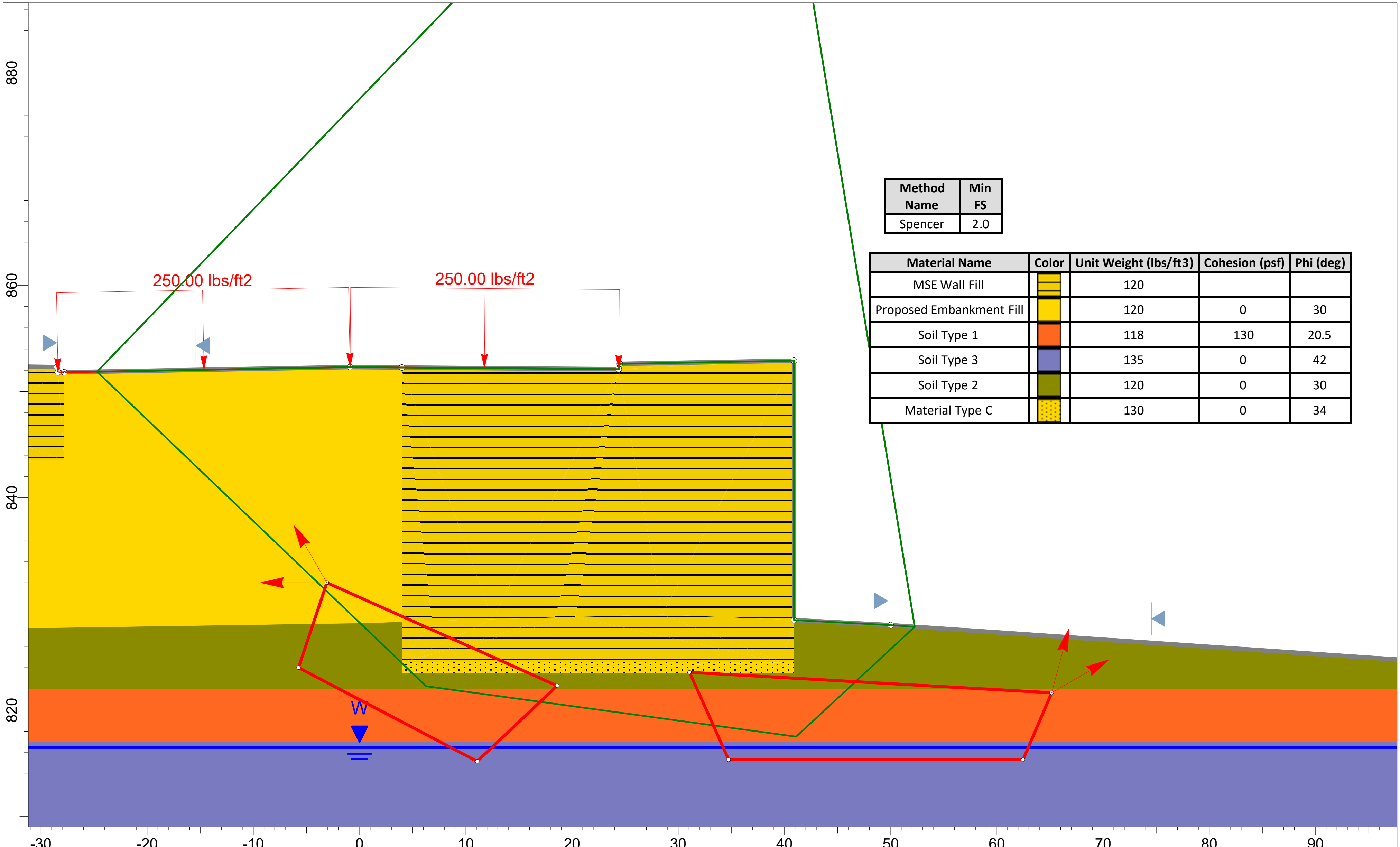


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 12+00, Global Stability - Effective Stress, Circular Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA12+00_1.3H_B-015_EffCircular021023.slim

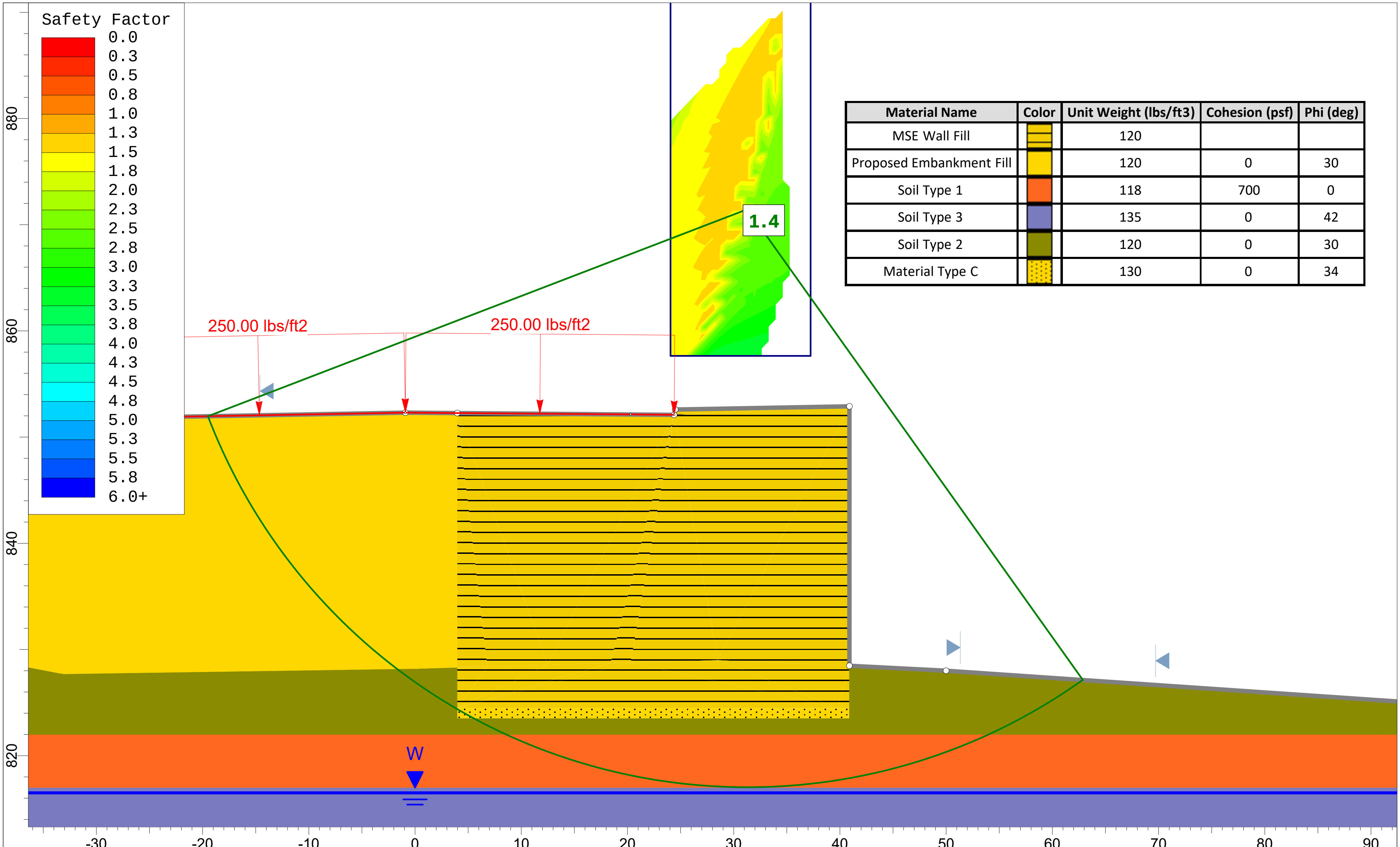


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 12+00, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA12+00_1.3H_B-015_EffBlock021023.slim

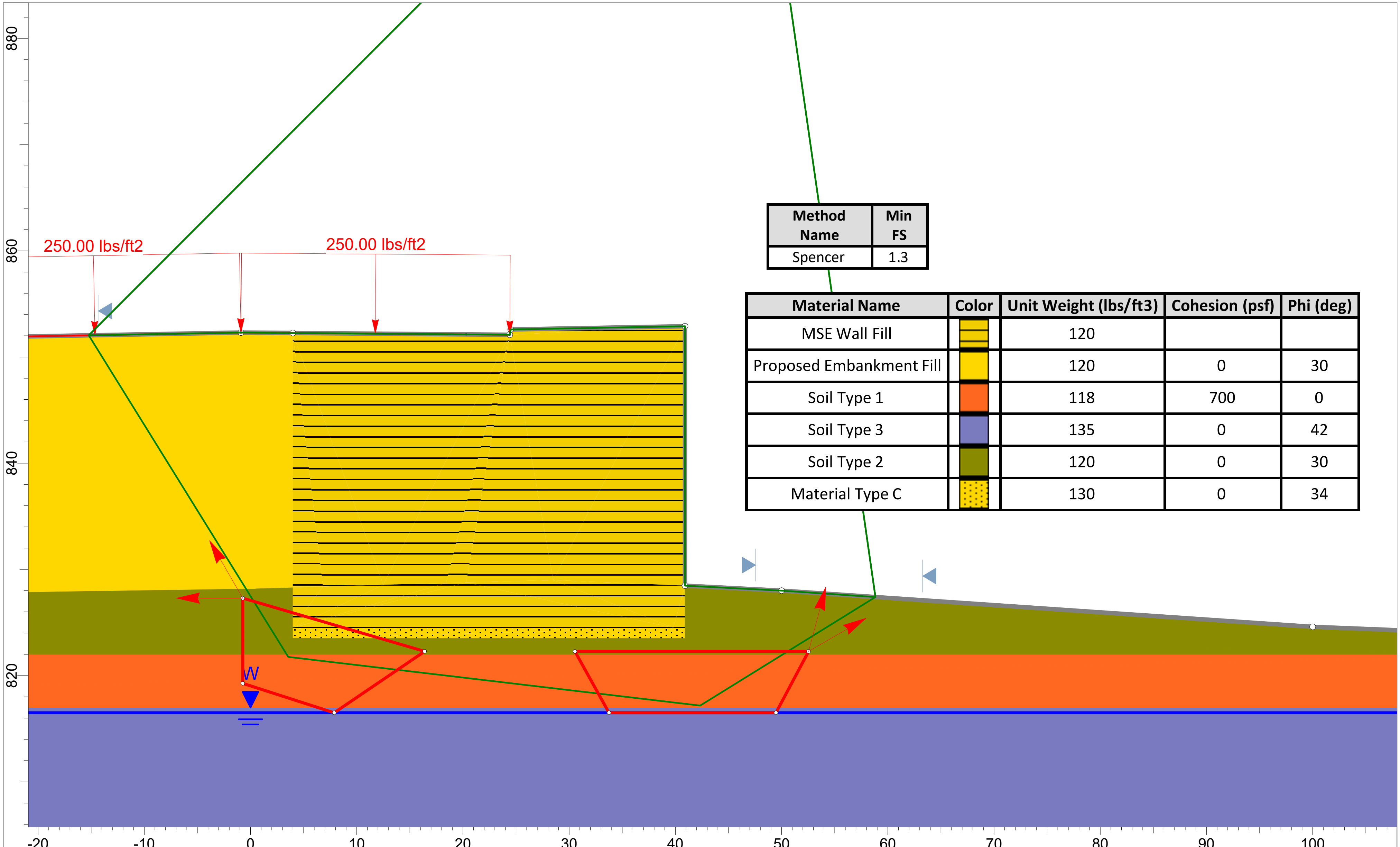


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 12+00, Global Stability - Total Stress, Circular Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA12+00_1.3H_B-015_TotalCircular021023.slim

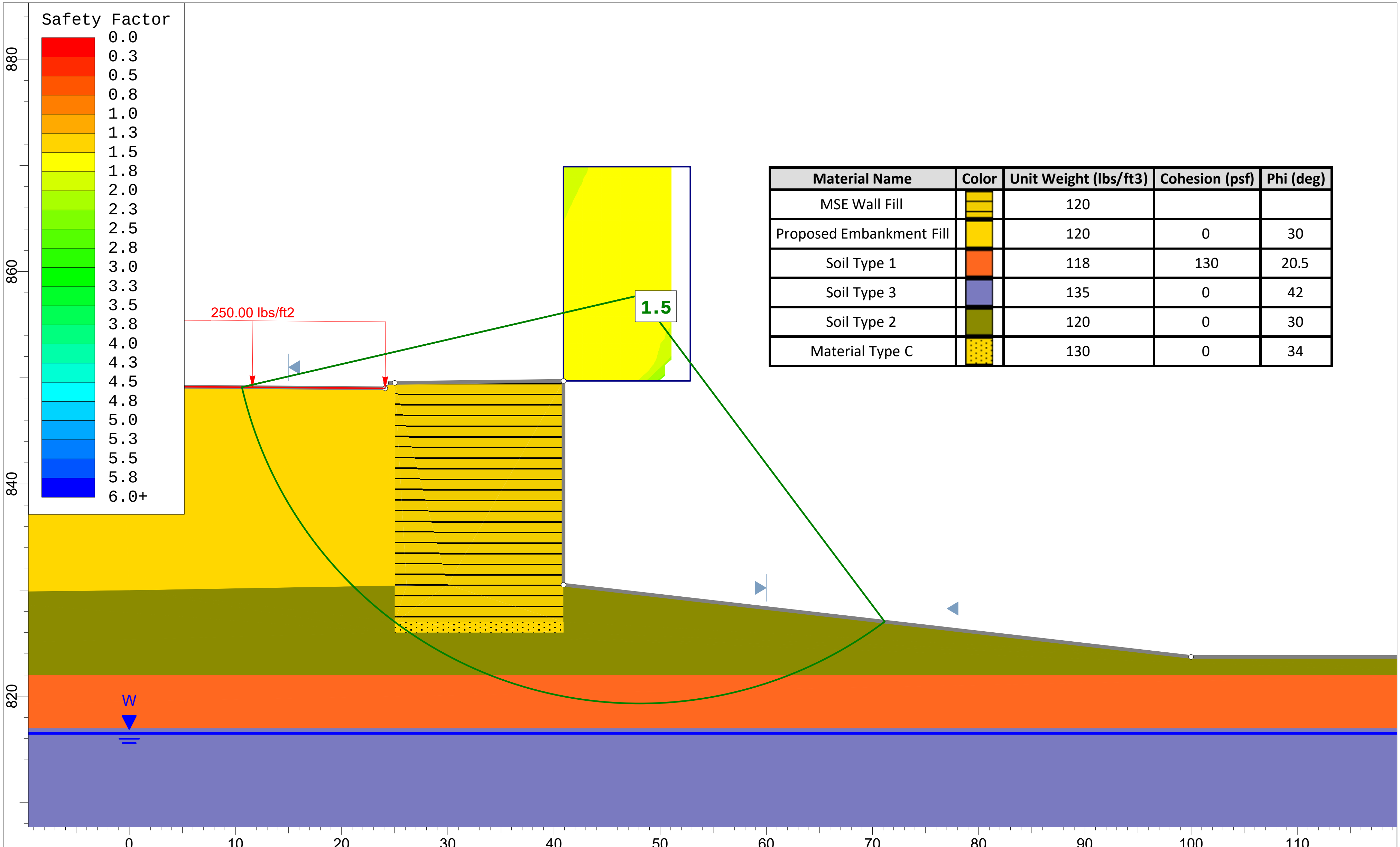


Method Name	Min FS
Spencer	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience	*Project*	CUY-14-6.93, PID 104132	
	Analysis Description	Retaining Wall 6 - STA. 12+00, Global Stability - Total Stress, Block Failure	
	Drawn By	KCA	*Company* NEAS Inc.
SLIDEINTERPRET 9.025	*Date*	12/14/2021, 9:43:12 AM	*File Name* Wall6_STA11+20__B-015_TotalBlock021023.slim

STA. 13+20

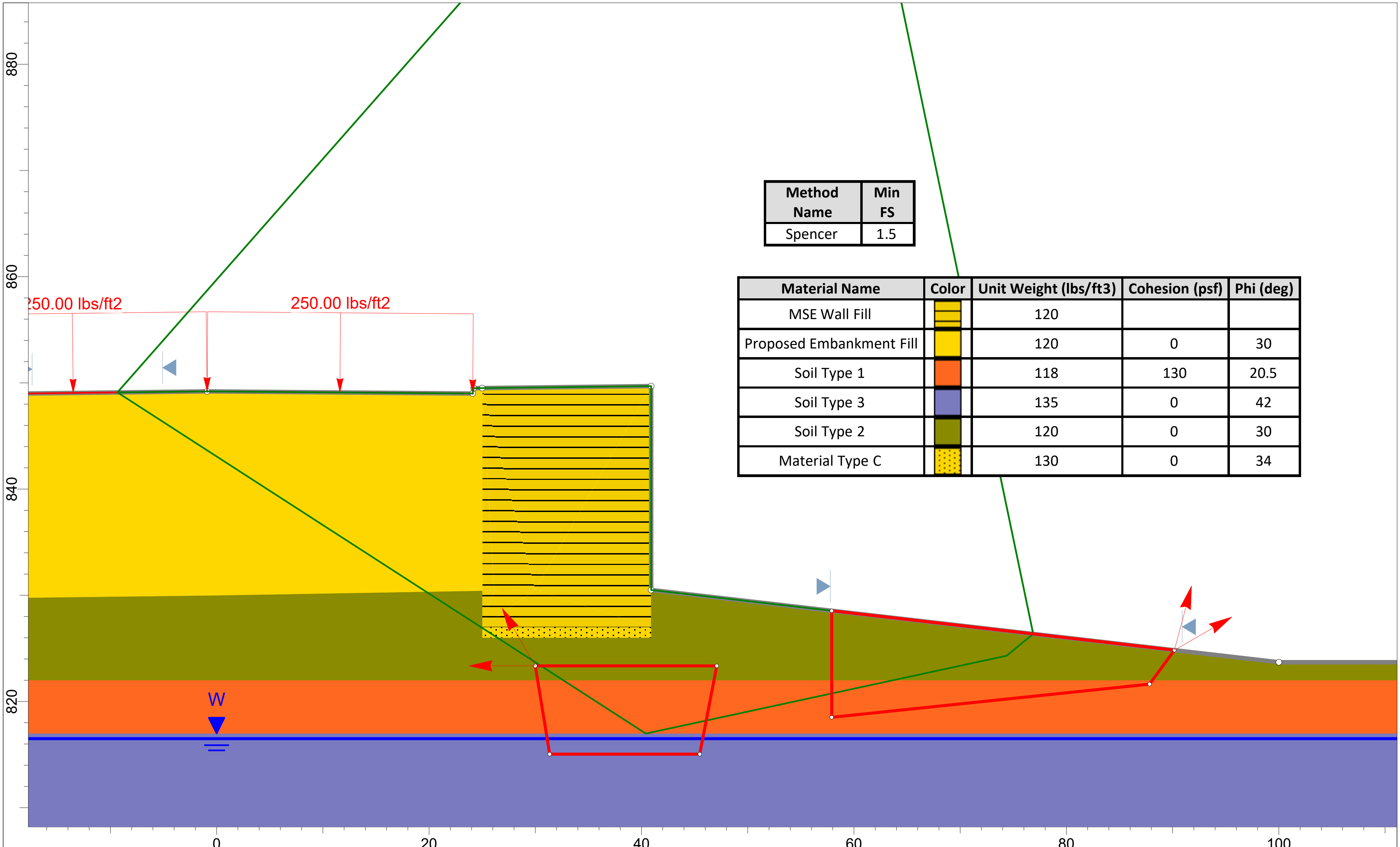


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 13+20, Global Stability - Effective Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA13+20_0.7H_B-015_EffectiveTotal021023.slim



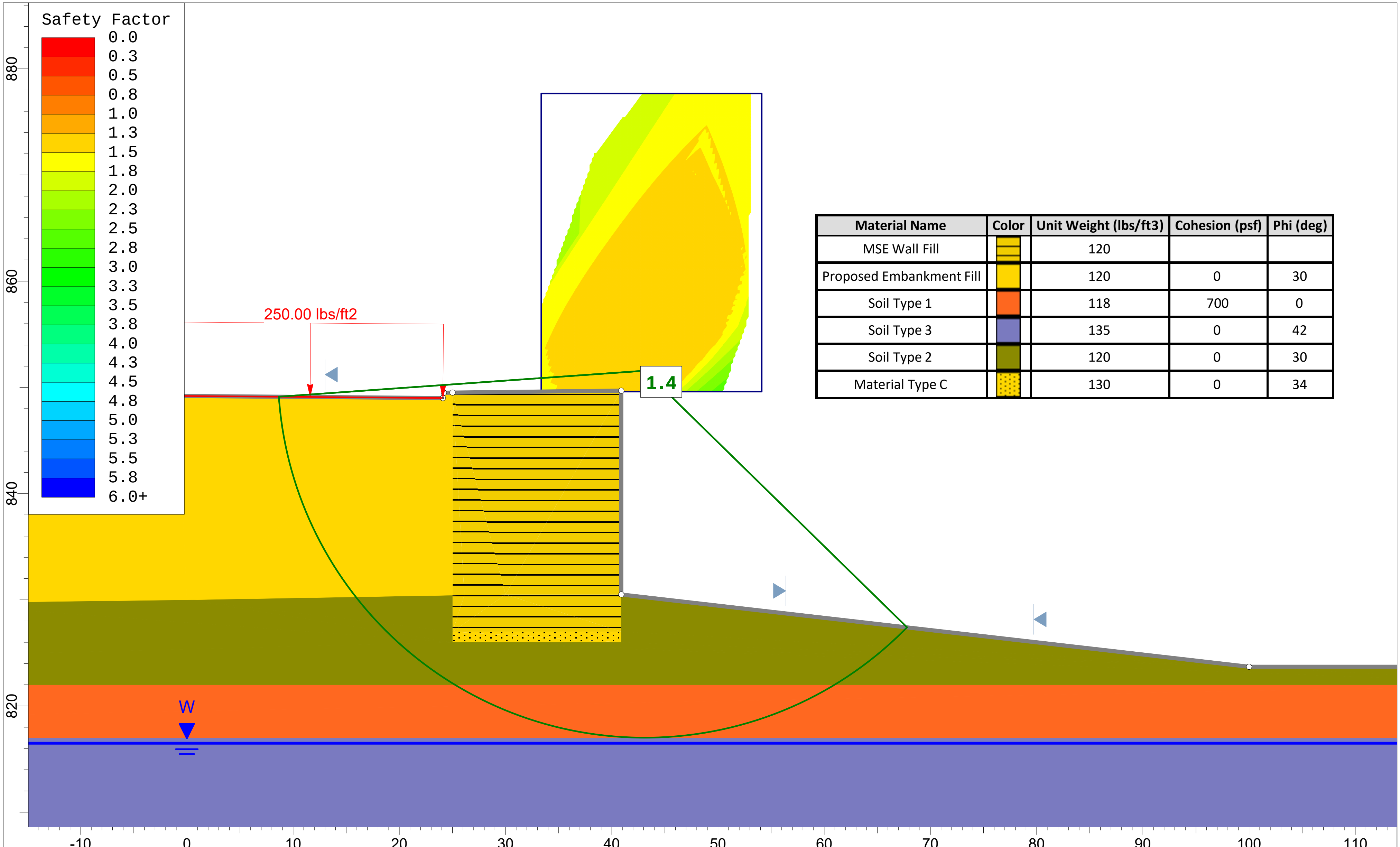
Method Name	Min FS
Spencer	1.5

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	130	20.5
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 13+20, Global Stability - Effective Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA13+20_0.7H_B-015_EffectiveBlock021023.slim

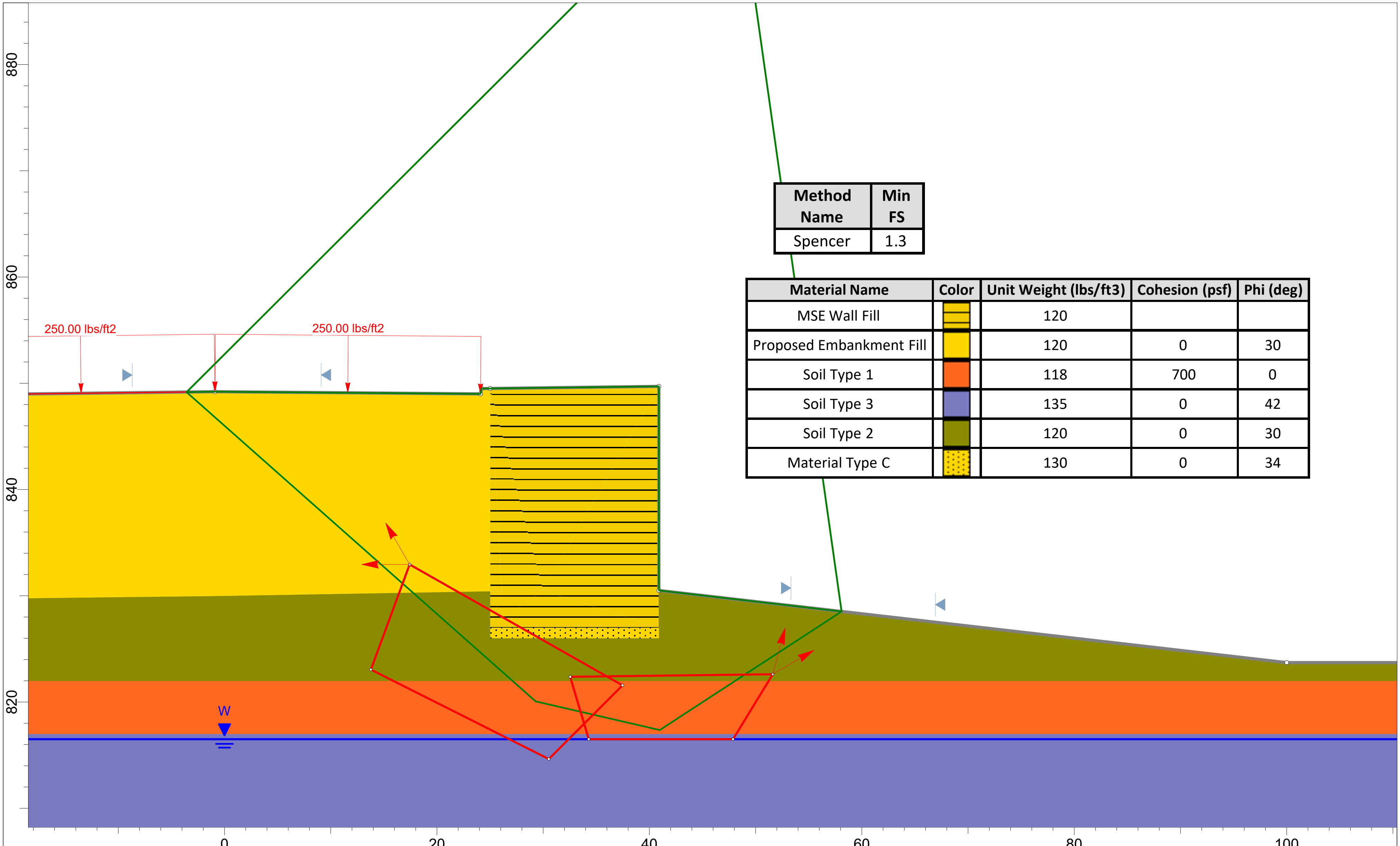


Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 6 - STA. 13+20, Global Stability - Total Stress, Circular Failure
Drawn By	KCA
Company	NEAS Inc.
Date	12/14/2021, 9:43:12 AM
File Name	Wall6_STA13+20_0.7H_B-015_TotalCircular021023.slim



Method Name	Min FS
Spencer	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120		
Proposed Embankment Fill		120	0	30
Soil Type 1		118	700	0
Soil Type 3		135	0	42
Soil Type 2		120	0	30
Material Type C		130	0	34

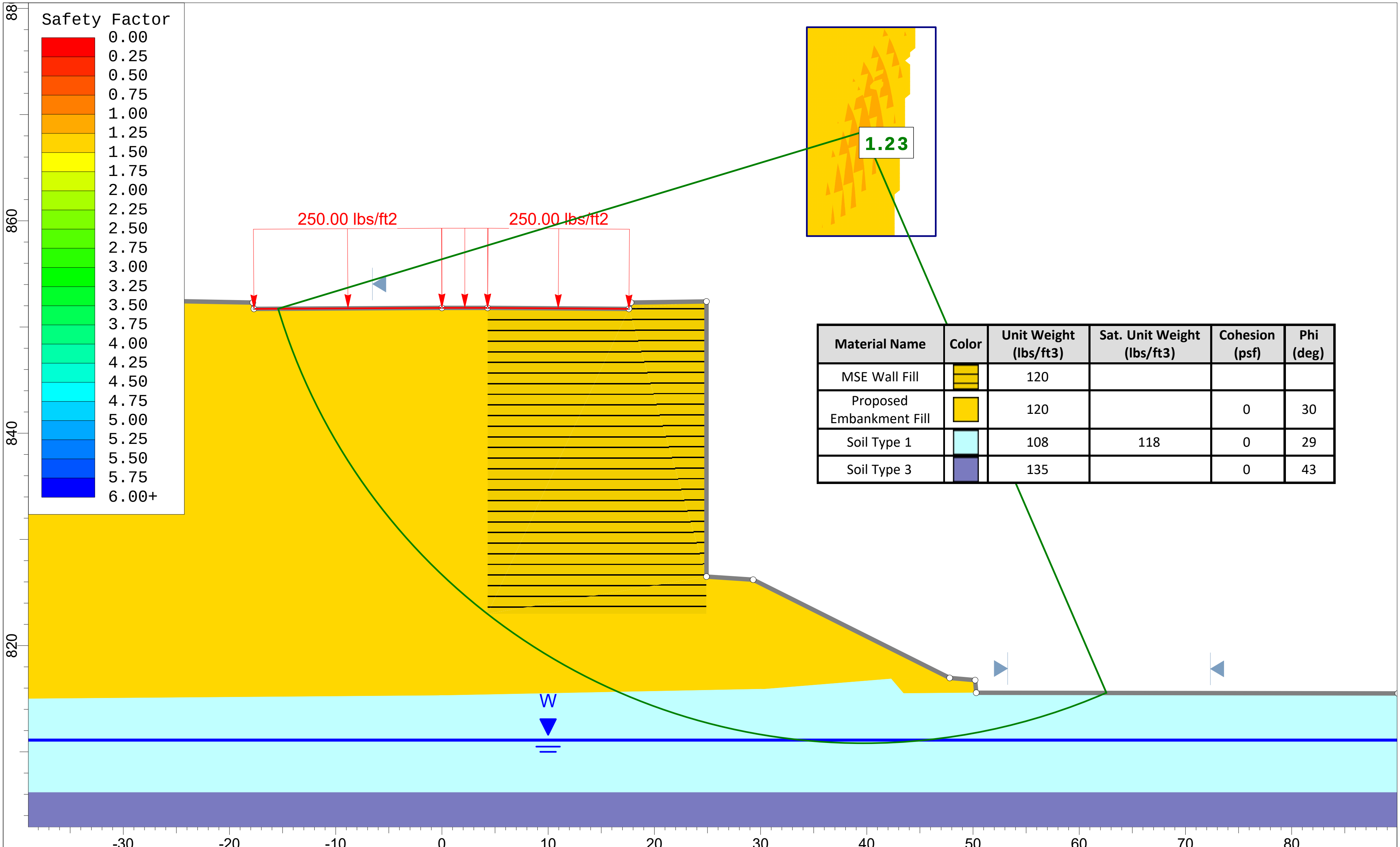
rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132		
Analysis Description	Retaining Wall 6 - STA. 13+20, Global Stability - Total Stress, Block Failure		
Drawn By	KCA	*Company*	NEAS Inc.
Date	12/14/2021, 9:43:12 AM	*File Name*	Wall6_STA13+20_0.7H_B-015_TotalBlock021023.slim

RETAINING WALL 7

STA. 11+86 – 0.7H STRAP LENGTH



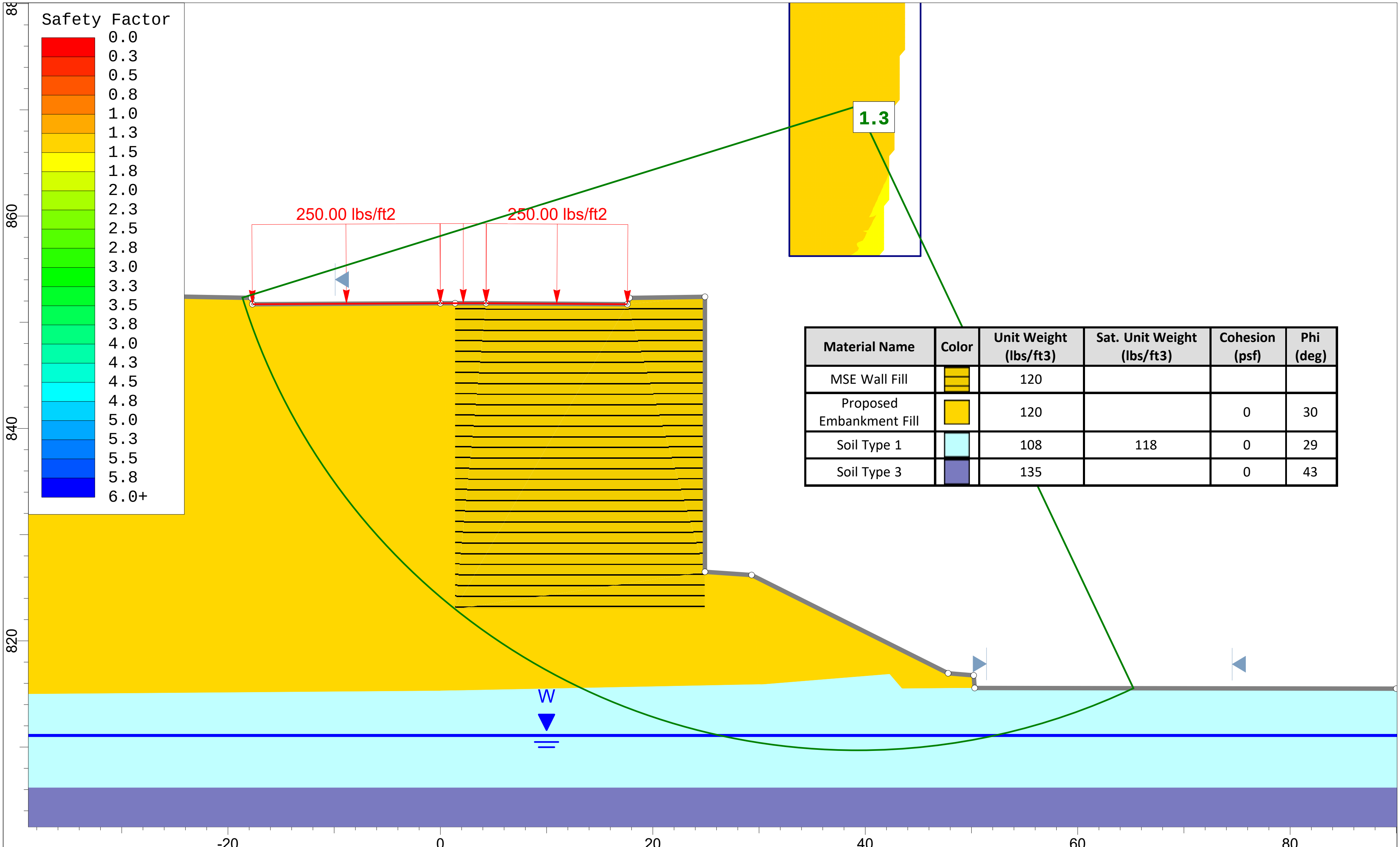
Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 1		108	118	0	29
Soil Type 3		135		0	43

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 7 - STA. 11+86, Global Stability - Effective Stress, Circular Failure (0.7H Strap Length)
Drawn By	KCA
Company	NEAS Inc.
Date	2/9/2023, 9:43:12 AM
File Name	Wall7_STA11+86_EffCircular-0.7Straps020923.slim

STA. 11+86 – 0.8H STRAP LENGTH



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 1		108	118	0	29
Soil Type 3		135		0	43

rocscience

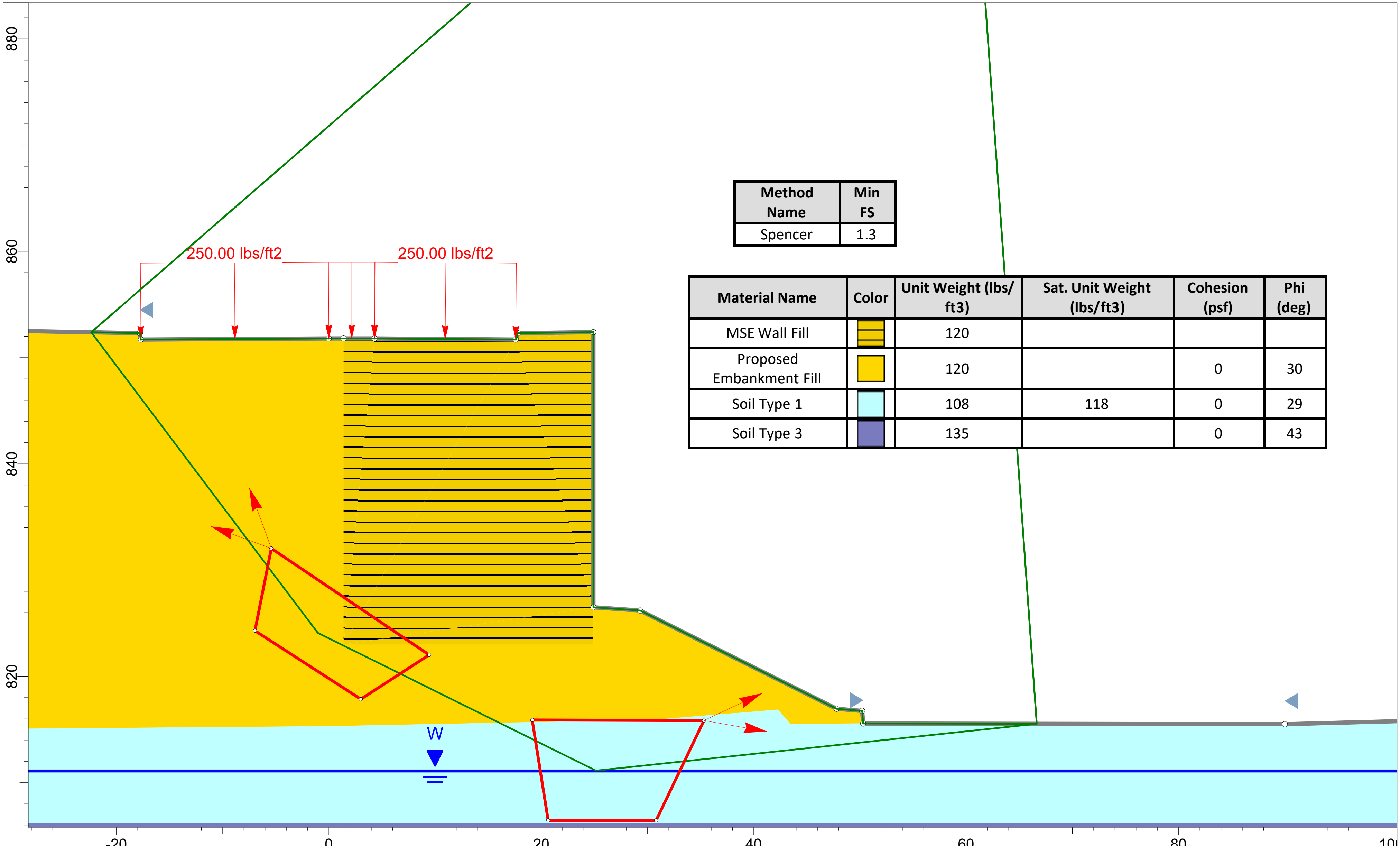
SLIDEINTERPRET 9.025

Project CUY-14-6.93, PID 104132

Analysis Description Retaining Wall 7 - STA. 11+86, Global Stability - Effective Stress, Circular Failure (0.7H Strap Length)

Drawn By KCA | *Company* NEAS Inc.

Date 2/9/2023, 9:43:12 AM | *File Name* Wall7_STA11+86_EffCircular-0.8HStraps020923.slim



Method Name	Min FS
Spencer	1.3

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Wall Fill		120			
Proposed Embankment Fill		120		0	30
Soil Type 1		108	118	0	29
Soil Type 3		135		0	43

rocscience

SLIDEINTERPRET 9.025

Project	CUY-14-6.93, PID 104132
Analysis Description	Retaining Wall 7 - STA. 11+86, Global Stability - Effective Stress, Block Failure (0.8H Strap Length)
Drawn By	KCA
Company	NEAS Inc.
Date	2/9/2023, 9:43:12 AM
File Name	Wall7_STA11+86_EffBlock-0.8HStraps020923.slim

APPENDIX F

SETTLEMENT ANALYSIS

RETAINING WALLS 1, 2 AND TEMPORARY 5

CUY-14-6.93

PROJECT IDENTIFICATION

Title:	CUY-14-6.93
Project Number:	PID 104132 -
Client:	AECOM
Designer:	KCA
Station Number:	

Description:

Settlement analysis for RW-A, RW-F, Temp RW-H

Company's information:

Name:	NEAS Inc.
Street:	2800 Corporate Exchange Drive Suite 240 Columbus, OH 43231
Telephone #:	614-714-0299
Fax #:	
E-Mail:	

Original file path and name:
Original date and time of creating this file: Thu Dec 16 16:17:56 2021

GEOMETRY: Analysis of a 2D geometry

INPUT DATA – FOUNDATION LAYERS – 5 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	110.00	0.40	Soil Type 1
2	110.00	0.20	Soil Type 2
3	135.00	0.40	Soil Type 3
4	122.00	0.50	Soil Type 4
5	135.00	0.40	Soil Type 3

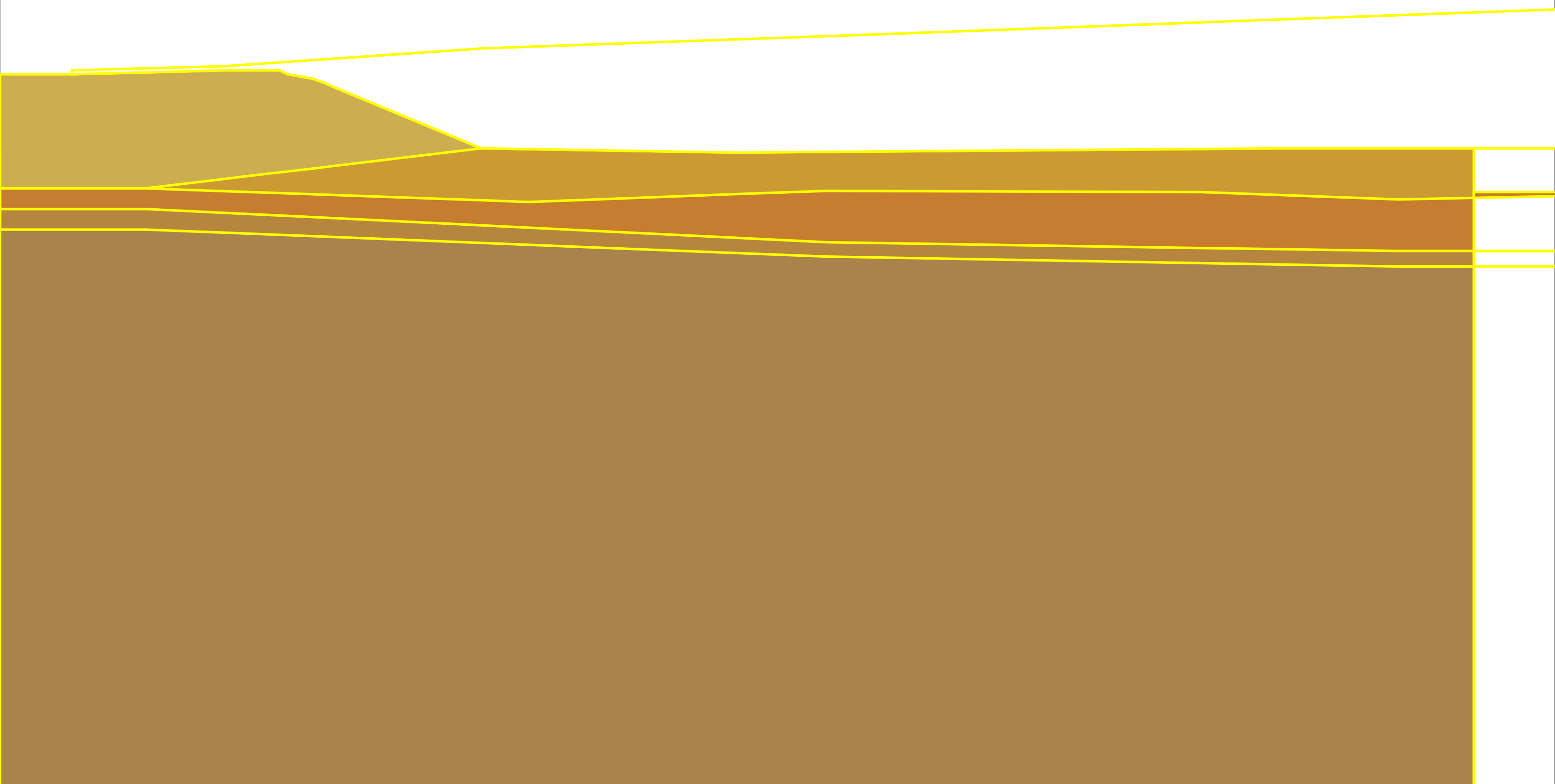
INPUT DATA – EMBANKMENT LAYERS -- 1 layers

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

INPUT DATA OF WATER

Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]
1	0.00	803.10
2	450.00	803.10

DRAWING OF SPECIFIED GEOMETRY



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	Yes	8.00	0.150	0.030	0.792	0.8100	Top & Bot.
2	No	N/A	N/A	N/A	N/A	N/A	N/A
3	No	N/A	N/A	N/A	N/A	N/A	N/A
4	Yes	5.00	0.169	0.042	0.816	0.1600	Top & Bot.
5	No	N/A	N/A	N/A	N/A	N/A	N/A

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	0.00	0.00	1	824000	0.4000	-0.0033	832.00	832.03	-0.03
			2	43000	0.2000	0.0000			
			3	562000	0.4000	-0.0024			
			4	2000000	0.5000	-0.0011			
			5	562000	0.4000	-0.0190			
2	10.00	0.00	1	824000	0.4000	-0.0031	832.27	832.30	-0.02
			2	43000	0.2000	0.0000			
			3	562000	0.4000	-0.0025			
			4	2000000	0.5000	-0.0012			
			5	562000	0.4000	-0.0180			
3	20.00	0.00	1	824000	0.4000	-0.0038	832.54	832.56	-0.02
			2	43000	0.2000	0.0000			
			3	562000	0.4000	-0.0026			
			4	2000000	0.5000	-0.0013			
			5	562000	0.4000	-0.0161			
4	30.00	0.00	1	824000	0.4000	-0.0044	832.81	832.83	-0.02
			2	43000	0.2000	0.0012			
			3	562000	0.4000	-0.0026			
			4	2000000	0.5000	-0.0012			
			5	562000	0.4000	-0.0124			
5	40.00	0.00	1	824000	0.4000	-0.0045	833.00	833.01	-0.01
			2	43000	0.2000	0.0090			
			3	562000	0.4000	-0.0024			
			4	2000000	0.5000	-0.0012			
			5	562000	0.4000	-0.0067			
6	50.00	0.00	1	824000	0.4000	-0.0029	833.00	832.97	0.03
			2	43000	0.2000	0.0329			
			3	562000	0.4000	-0.0013			
			4	2000000	0.5000	-0.0010			
			5	562000	0.4000	0.0014			
7	60.00	0.00	1	824000	0.4000	0.0015	830.45	830.35	0.10
			2	43000	0.2000	0.0820			
			3	562000	0.4000	0.0007			
			4	2000000	0.5000	-0.0006			
			5	562000	0.4000	0.0121			
8	70.00	0.00	1	824000	0.4000	0.0063	826.29	826.09	0.21
			2	43000	0.2000	0.1720			
			3	562000	0.4000	0.0036			
			4	2000000	0.5000	-0.0000			
			5	562000	0.4000	0.0246			
9	80.00	0.00	1	824000	0.4000	0.0081	822.13	821.78	0.35
			2	43000	0.2000	0.3007			
			3	562000	0.4000	0.0068			
			4	2000000	0.5000	0.0005			
			5	562000	0.4000	0.0378			
10	90.00	0.00	1	824000	0.4000	0.0061	817.97	817.45	0.51
			2	43000	0.2000	0.4441			
			3	562000	0.4000	0.0104			
			4	2000000	0.5000	0.0010			
			5	562000	0.4000	0.0497			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
11	100.00	0.00	1	824000	0.4000	0.0000	814.00	813.32	0.68
			2	43000	0.2000	0.6038			
			3	562000	0.4000	0.0129			
			4	2000000	0.5000	0.0013			
			5	562000	0.4000	0.0602			
12	110.00	0.00	1	824000	0.4000	0.0000	813.84	813.08	0.76
			2	43000	0.2000	0.6777			
			3	562000	0.4000	0.0152			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0683			
13	120.00	0.00	1	824000	0.4000	0.0000	813.68	812.91	0.77
			2	43000	0.2000	0.6749			
			3	562000	0.4000	0.0177			
			4	2000000	0.5000	0.0017			
			5	562000	0.4000	0.0741			
14	130.00	0.00	1	824000	0.4000	0.0000	813.52	812.76	0.76
			2	43000	0.2000	0.6573			
			3	562000	0.4000	0.0207			
			4	2000000	0.5000	0.0018			
			5	562000	0.4000	0.0770			
15	140.00	0.00	1	824000	0.4000	0.0000	813.36	812.60	0.76
			2	43000	0.2000	0.6523			
			3	562000	0.4000	0.0227			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0794			
16	150.00	0.00	1	824000	0.4000	0.0000	813.20	812.46	0.73
			2	43000	0.2000	0.6255			
			3	562000	0.4000	0.0254			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0808			
17	160.00	0.00	1	824000	0.4000	0.0000	813.04	812.31	0.73
			2	43000	0.2000	0.6154			
			3	562000	0.4000	0.0272			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0816			
18	170.00	0.00	1	824000	0.4000	0.0000	813.07	812.36	0.72
			2	43000	0.2000	0.6030			
			3	562000	0.4000	0.0298			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0819			
19	180.00	0.00	1	824000	0.4000	0.0000	813.15	812.45	0.70
			2	43000	0.2000	0.5889			
			3	562000	0.4000	0.0324			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0810			
20	190.00	0.00	1	824000	0.4000	0.0000	813.23	812.51	0.71
			2	43000	0.2000	0.5941			
			3	562000	0.4000	0.0333			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0818			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
21	200.00	0.00	1	824000	0.4000	0.0000	813.30	812.59	0.72
			2	43000	0.2000	0.5993			
			3	562000	0.4000	0.0334			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0816			
22	210.00	0.00	1	824000	0.4000	0.0000	813.38	812.65	0.72
			2	43000	0.2000	0.6047			
			3	562000	0.4000	0.0344			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0823			
23	220.00	0.00	1	824000	0.4000	0.0000	813.45	812.70	0.75
			2	43000	0.2000	0.6308			
			3	562000	0.4000	0.0346			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0820			
24	230.00	0.00	1	824000	0.4000	0.0000	813.53	812.77	0.75
			2	43000	0.2000	0.6366			
			3	562000	0.4000	0.0348			
			4	2000000	0.5000	0.0015			
			5	562000	0.4000	0.0818			
25	240.00	0.00	1	824000	0.4000	0.0000	813.60	812.84	0.76
			2	43000	0.2000	0.6427			
			3	562000	0.4000	0.0361			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0827			
26	250.00	0.00	1	824000	0.4000	0.0000	813.68	812.89	0.79
			2	43000	0.2000	0.6701			
			3	562000	0.4000	0.0364			
			4	2000000	0.5000	0.0016			
			5	562000	0.4000	0.0826			
27	260.00	0.00	1	824000	0.4000	0.0000	813.76	812.96	0.80
			2	43000	0.2000	0.6766			
			3	562000	0.4000	0.0368			
			4	2000000	0.5000	0.0017			
			5	562000	0.4000	0.0837			
28	270.00	0.00	1	824000	0.4000	0.0000	813.83	813.02	0.81
			2	43000	0.2000	0.6834			
			3	562000	0.4000	0.0382			
			4	2000000	0.5000	0.0017			
			5	562000	0.4000	0.0837			
29	280.00	0.00	1	824000	0.4000	0.0000	813.91	813.07	0.84
			2	43000	0.2000	0.7122			
			3	562000	0.4000	0.0378			
			4	2000000	0.5000	0.0017			
			5	562000	0.4000	0.0850			
30	290.00	0.00	1	824000	0.4000	0.0000	813.98	813.09	0.89
			2	43000	0.2000	0.7642			
			3	562000	0.4000	0.0386			
			4	2000000	0.5000	0.0018			
			5	562000	0.4000	0.0853			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
31	300.00	0.00	1	824000	0.4000	0.0000	814.01	813.09	0.92
			2	43000	0.2000	0.7956			
			3	562000	0.4000	0.0384			
			4	2000000	0.5000	0.0018			
			5	562000	0.4000	0.0869			
32	310.00	0.00	1	824000	0.4000	0.0000	814.01	813.05	0.96
			2	43000	0.2000	0.8283			
			3	562000	0.4000	0.0382			
			4	2000000	0.5000	0.0019			
			5	562000	0.4000	0.0873			
33	320.00	0.00	1	824000	0.4000	0.0000	814.01	813.02	0.99
			2	43000	0.2000	0.8620			
			3	562000	0.4000	0.0392			
			4	2000000	0.5000	0.0020			
			5	562000	0.4000	0.0891			
34	330.00	0.00	1	824000	0.4000	0.0000	814.01	813.00	1.01
			2	43000	0.2000	0.8735			
			3	562000	0.4000	0.0401			
			4	2000000	0.5000	0.0021			
			5	562000	0.4000	0.0909			
35	340.00	0.00	1	824000	0.4000	0.0000	814.01	813.01	1.00
			2	43000	0.2000	0.8617			
			3	562000	0.4000	0.0421			
			4	2000000	0.5000	0.0022			
			5	562000	0.4000	0.0927			
36	350.00	0.00	1	824000	0.4000	0.0000	814.01	813.00	1.01
			2	43000	0.2000	0.8735			
			3	562000	0.4000	0.0432			
			4	2000000	0.5000	0.0023			
			5	562000	0.4000	0.0944			
37	360.00	0.00	1	824000	0.4000	0.0000	814.01	813.00	1.01
			2	43000	0.2000	0.8615			
			3	562000	0.4000	0.0455			
			4	2000000	0.5000	0.0024			
			5	562000	0.4000	0.0960			
38	370.00	0.00	1	824000	0.4000	0.0000	814.01	813.01	1.00
			2	43000	0.2000	0.8492			
			3	562000	0.4000	0.0479			
			4	2000000	0.5000	0.0025			
			5	562000	0.4000	0.0975			
39	380.00	0.00	1	824000	0.4000	0.0000	814.01	813.00	1.01
			2	43000	0.2000	0.8614			
			3	562000	0.4000	0.0493			
			4	2000000	0.5000	0.0026			
			5	562000	0.4000	0.0983			
40	390.00	0.00	1	824000	0.4000	0.0000	814.01	813.01	1.00
			2	43000	0.2000	0.8483			
			3	562000	0.4000	0.0519			
			4	2000000	0.5000	0.0028			
			5	562000	0.4000	0.0983			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
41	400.00	0.00	1	824000	0.4000	0.0000	814.01	813.02	0.99
			2	43000	0.2000	0.8334			
			3	562000	0.4000	0.0543			
			4	2000000	0.5000	0.0028			
			5	562000	0.4000	0.0968			
42	410.00	0.00	1	824000	0.4000	0.0000	814.01	813.02	0.99
			2	43000	0.2000	0.8396			
			3	562000	0.4000	0.0547			
			4	2000000	0.5000	0.0028			
			5	562000	0.4000	0.0930			
43	420.00	0.00	1	824000	0.4000	0.0000	814.01	813.03	0.98
			2	43000	0.2000	0.8339			
			3	562000	0.4000	0.0534			
			4	2000000	0.5000	0.0027			
			5	562000	0.4000	0.0861			
44	430.00	0.00	1	824000	0.4000	0.0000	814.01	813.09	0.92
			2	43000	0.2000	0.7940			
			3	562000	0.4000	0.0486			
			4	2000000	0.5000	0.0023			
			5	562000	0.4000	0.0752			
45	440.00	0.00	1	824000	0.4000	0.0000	814.01	813.24	0.77
			2	43000	0.2000	0.6688			
			3	562000	0.4000	0.0381			
			4	2000000	0.5000	0.0017			
			5	562000	0.4000	0.0604			
46	450.00	0.00	1	824000	0.4000	0.0000	814.01	813.53	0.48
			2	43000	0.2000	0.4171			
			3	562000	0.4000	0.0223			
			4	2000000	0.5000	0.0008			
			5	562000	0.4000	0.0428			

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

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	0.00	0.00	832.00	0.02	831.98
2	10.00	0.00	832.27	0.03	832.24
3	20.00	0.00	832.54	0.03	832.51
4	30.00	0.00	832.81	0.04	832.78
5	40.00	0.00	833.00	0.04	832.96
6	50.00	0.00	833.00	0.07	832.93
7	60.00	0.00	830.45	0.11	830.34
8	70.00	0.00	826.29	0.14	826.15
9	80.00	0.00	822.13	0.17	821.96
10	90.00	0.00	817.97	0.16	817.80
11	100.00	0.00	814.00	0.04	813.97
12	110.00	0.00	813.84	0.04	813.80
13	120.00	0.00	813.68	0.04	813.64
14	130.00	0.00	813.52	0.04	813.48
15	140.00	0.00	813.36	0.04	813.32
16	150.00	0.00	813.20	0.04	813.16
17	160.00	0.00	813.04	0.04	813.00
18	170.00	0.00	813.07	0.04	813.04
19	180.00	0.00	813.15	0.03	813.11
20	190.00	0.00	813.23	0.03	813.19
21	200.00	0.00	813.30	0.04	813.27
22	210.00	0.00	813.38	0.04	813.34
23	220.00	0.00	813.45	0.04	813.42
24	230.00	0.00	813.53	0.04	813.49
25	240.00	0.00	813.60	0.04	813.57

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

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
26	250.00	0.00	813.68	0.04	813.64
27	260.00	0.00	813.76	0.04	813.72
28	270.00	0.00	813.83	0.04	813.79
29	280.00	0.00	813.91	0.04	813.87
30	290.00	0.00	813.98	0.04	813.95
31	300.00	0.00	814.01	0.04	813.97
32	310.00	0.00	814.01	0.04	813.97
33	320.00	0.00	814.01	0.04	813.97
34	330.00	0.00	814.01	0.04	813.97
35	340.00	0.00	814.01	0.04	813.97
36	350.00	0.00	814.01	0.04	813.97
37	360.00	0.00	814.01	0.04	813.97
38	370.00	0.00	814.01	0.04	813.97
39	380.00	0.00	814.01	0.04	813.97
40	390.00	0.00	814.01	0.04	813.97
41	400.00	0.00	814.01	0.04	813.97
42	410.00	0.00	814.01	0.04	813.97
43	420.00	0.00	814.01	0.04	813.97
44	430.00	0.00	814.01	0.03	813.98
45	440.00	0.00	814.01	0.03	813.98
46	450.00	0.00	814.01	0.03	813.98

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

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	1	0.00	832.00	Soil Type 1
	2	37.00	833.00	
	3	50.50	833.00	
	4	52.50	832.00	
	5	58.40	831.00	
	6	61.30	830.00	
	7	63.50	829.00	
	8	99.50	814.01	
	9	161.60	813.01	
	10	293.50	814.01	
	11	450.00	814.01	
2	1	0.00	804.31	Soil Type 2
	2	18.00	804.31	
	3	99.50	814.00	
	4	161.60	813.00	
	5	293.50	814.00	
	6	450.00	814.00	
3	1	0.00	804.30	Soil Type 3
	2	18.00	804.30	
	3	110.90	801.00	
	4	183.50	803.70	
	5	274.40	803.40	
	6	322.40	801.60	
	7	408.50	803.40	
	8	450.00	803.40	
4	1	0.00	799.30	Soil Type 4
	2	18.00	799.30	
	3	183.50	791.20	
	4	322.40	789.10	
	5	450.00	789.10	
5	1	0.00	794.30	Soil Type 3
	2	18.00	794.30	
	3	183.50	787.70	
	4	322.40	785.30	
	5	450.00	785.30	

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	X1 = 0.00 [ft]	1	0.00	833.00	Proposed Embankment and MSE Wall Fill
	X2 = 450.00 [ft]	2	37.00	834.00	
		3	100.00	838.30	
		4	200.00	841.90	
		5	300.00	845.60	
		6	400.00	849.20	
		7	450.00	851.00	

RETAINING WALLS 2, 3 AND TEMPORARY 6

CUY-14-6.93

PROJECT IDENTIFICATION

Title:	CUY-14-6.93
Project Number:	PID 104132 -
Client:	AECOM
Designer:	KCA
Station Number:	

Description:
Settlement analysis for RW-E, RW-G, Temp RW-I

Company's information:

Name:	NEAS Inc.
Street:	2800 Corporate Exchange Drive Suite 240 Columbus, OH 43231
Telephone #:	614-714-0299
Fax #:	
E-Mail:	

Original file path and name: C:\Users\karens\Desktop\CUY-14-6.93\RW-E-G-TempI_FoSSA2.2ST
Original date and time of creating this file: Thu Dec 16 16:17:56 2021

GEOMETRY: Analysis of a 2D geometry

INPUT DATA – FOUNDATION LAYERS – 4 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	118.00	0.40	Soil Type 1
2	120.00	0.25	Soil Type 2
3	118.00	0.50	Soil Type 1
4	135.00	0.40	Soil Type 3

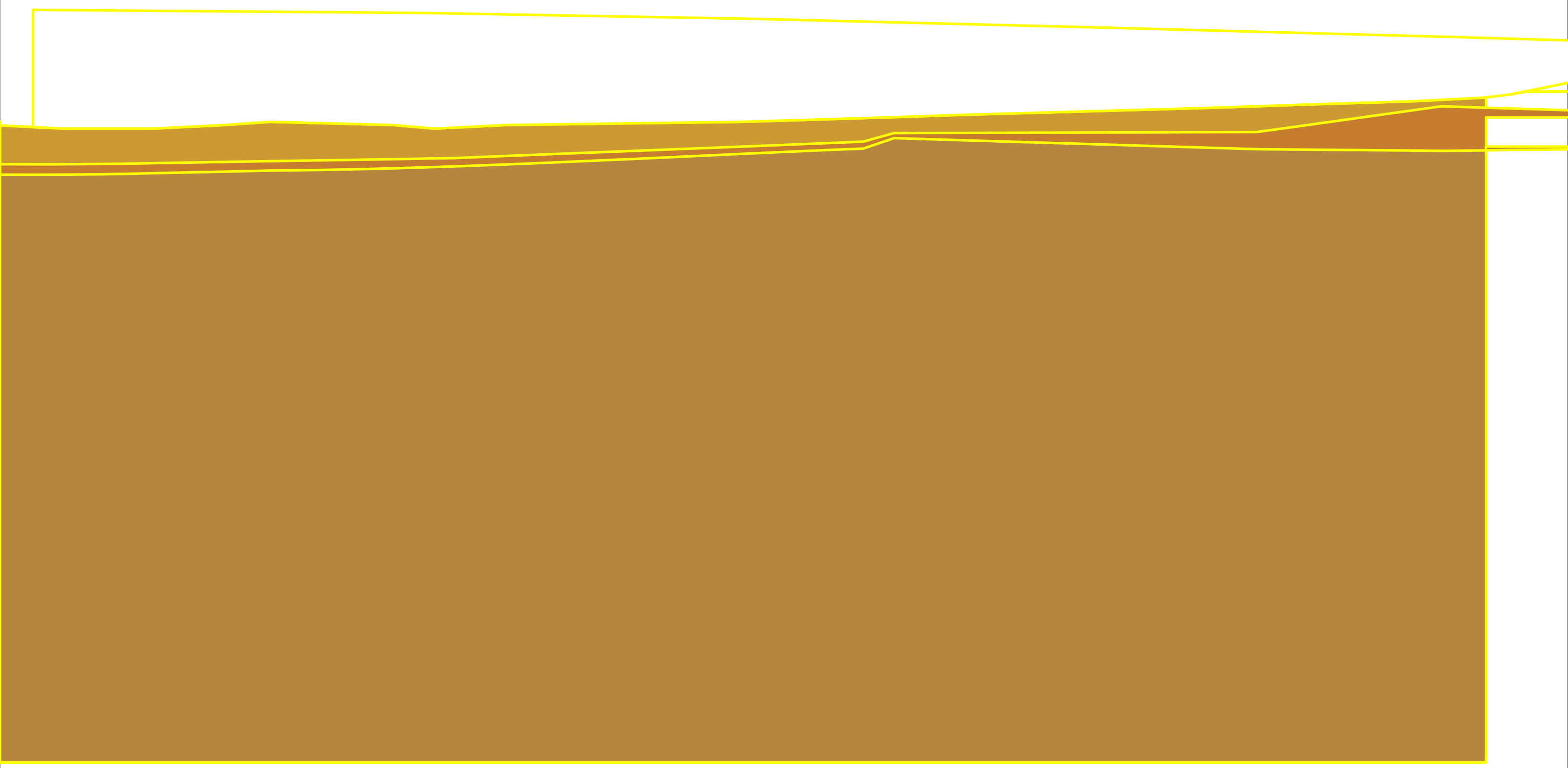
INPUT DATA – EMBANKMENT LAYERS -- 1 layers

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

INPUT DATA OF WATER

Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]
1	0.00	816.50
2	600.00	816.50

DRAWING OF SPECIFIED GEOMETRY



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	Yes	5.00	0.169	0.042	0.816	0.1600	Top & Bot.
2	No	N/A	N/A	N/A	N/A	N/A	N/A
3	Yes	5.00	0.169	0.042	0.816	0.1600	Top & Bot.
4	No	N/A	N/A	N/A	N/A	N/A	N/A

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	80.00	0.00	1	586000	0.4000	0.0000	823.75	823.75	0.00
			2	106000	0.2500	-0.0099			
			3	586000	0.5000	-0.0037			
			4	990000	0.4000	0.0170			
2	88.78	0.00	1	586000	0.4000	0.0000	823.35	823.06	0.28
			2	106000	0.2500	0.2320			
			3	586000	0.5000	0.0030			
			4	990000	0.4000	0.0461			
3	97.55	0.00	1	586000	0.4000	0.0000	823.01	822.65	0.36
			2	106000	0.2500	0.2848			
			3	586000	0.5000	0.0070			
			4	990000	0.4000	0.0720			
4	106.33	0.00	1	586000	0.4000	0.0000	823.01	822.63	0.38
			2	106000	0.2500	0.2817			
			3	586000	0.5000	0.0066			
			4	990000	0.4000	0.0871			
5	115.10	0.00	1	586000	0.4000	0.0000	823.01	822.63	0.38
			2	106000	0.2500	0.2776			
			3	586000	0.5000	0.0051			
			4	990000	0.4000	0.0950			
6	123.88	0.00	1	586000	0.4000	0.0000	823.10	822.73	0.37
			2	106000	0.2500	0.2649			
			3	586000	0.5000	0.0044			
			4	990000	0.4000	0.0977			
7	132.65	0.00	1	586000	0.4000	0.0000	823.52	823.15	0.37
			2	106000	0.2500	0.2678			
			3	586000	0.5000	0.0038			
			4	990000	0.4000	0.0983			
8	141.43	0.00	1	586000	0.4000	0.0000	823.94	823.56	0.37
			2	106000	0.2500	0.2706			
			3	586000	0.5000	0.0034			
			4	990000	0.4000	0.0968			
9	150.20	0.00	1	586000	0.4000	0.0000	824.56	824.19	0.38
			2	106000	0.2500	0.2799			
			3	586000	0.5000	0.0029			
			4	990000	0.4000	0.0954			
10	158.98	0.00	1	586000	0.4000	0.0000	824.93	824.56	0.37
			2	106000	0.2500	0.2754			
			3	586000	0.5000	0.0026			
			4	990000	0.4000	0.0935			
11	167.76	0.00	1	586000	0.4000	0.0000	824.68	824.32	0.36
			2	106000	0.2500	0.2688			
			3	586000	0.5000	0.0026			
			4	990000	0.4000	0.0928			
12	176.53	0.00	1	586000	0.4000	0.0000	824.44	824.08	0.36
			2	106000	0.2500	0.2623			
			3	586000	0.5000	0.0025			
			4	990000	0.4000	0.0926			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
13	185.31	0.00	1	586000	0.4000	0.0000	824.20	823.85	0.35
			2	106000	0.2500	0.2558			
			3	586000	0.5000	0.0023			
			4	990000	0.4000	0.0920			
14	194.08	0.00	1	586000	0.4000	0.0000	823.84	823.50	0.34
			2	106000	0.2500	0.2422			
			3	586000	0.5000	0.0024			
			4	990000	0.4000	0.0923			
15	202.86	0.00	1	586000	0.4000	0.0000	823.11	822.79	0.32
			2	106000	0.2500	0.2222			
			3	586000	0.5000	0.0025			
			4	990000	0.4000	0.0918			
16	211.63	0.00	1	586000	0.4000	0.0000	823.37	823.05	0.32
			2	106000	0.2500	0.2276			
			3	586000	0.5000	0.0024			
			4	990000	0.4000	0.0913			
17	220.41	0.00	1	586000	0.4000	0.0000	823.79	823.48	0.32
			2	106000	0.2500	0.2232			
			3	586000	0.5000	0.0022			
			4	990000	0.4000	0.0901			
18	229.18	0.00	1	586000	0.4000	0.0000	824.07	823.76	0.31
			2	106000	0.2500	0.2200			
			3	586000	0.5000	0.0021			
			4	990000	0.4000	0.0889			
19	237.96	0.00	1	586000	0.4000	0.0000	824.20	823.90	0.30
			2	106000	0.2500	0.2103			
			3	586000	0.5000	0.0020			
			4	990000	0.4000	0.0877			
20	246.73	0.00	1	586000	0.4000	0.0000	824.32	824.04	0.29
			2	106000	0.2500	0.1988			
			3	586000	0.5000	0.0020			
			4	990000	0.4000	0.0874			
21	255.51	0.00	1	586000	0.4000	0.0000	824.45	824.16	0.29
			2	106000	0.2500	0.1989			
			3	586000	0.5000	0.0019			
			4	990000	0.4000	0.0864			
22	264.29	0.00	1	586000	0.4000	0.0000	824.58	824.30	0.28
			2	106000	0.2500	0.1895			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0855			
23	273.06	0.00	1	586000	0.4000	0.0000	824.71	824.44	0.27
			2	106000	0.2500	0.1803			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0847			
24	281.84	0.00	1	586000	0.4000	0.0000	824.83	824.58	0.26
			2	106000	0.2500	0.1712			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0839			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
25	290.61	0.00	1	586000	0.4000	0.0000	824.96	824.71	0.25
			2	106000	0.2500	0.1697			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0836			
26	299.39	0.00	1	586000	0.4000	0.0000	825.17	824.92	0.24
			2	106000	0.2500	0.1603			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0826			
27	308.16	0.00	1	586000	0.4000	0.0000	825.43	825.19	0.24
			2	106000	0.2500	0.1578			
			3	586000	0.5000	0.0016			
			4	990000	0.4000	0.0815			
28	316.94	0.00	1	586000	0.4000	0.0000	825.68	825.45	0.24
			2	106000	0.2500	0.1552			
			3	586000	0.5000	0.0016			
			4	990000	0.4000	0.0803			
29	325.71	0.00	1	586000	0.4000	0.0000	825.94	825.72	0.23
			2	106000	0.2500	0.1457			
			3	586000	0.5000	0.0016			
			4	990000	0.4000	0.0790			
30	334.49	0.00	1	586000	0.4000	0.0000	826.23	826.03	0.20
			2	106000	0.2500	0.1159			
			3	586000	0.5000	0.0014			
			4	990000	0.4000	0.0797			
31	343.27	0.00	1	586000	0.4000	0.0000	826.52	826.34	0.18
			2	106000	0.2500	0.1004			
			3	586000	0.5000	0.0014			
			4	990000	0.4000	0.0796			
32	352.04	0.00	1	586000	0.4000	0.0000	826.81	826.63	0.18
			2	106000	0.2500	0.1051			
			3	586000	0.5000	0.0013			
			4	990000	0.4000	0.0775			
33	360.82	0.00	1	586000	0.4000	0.0000	827.09	826.90	0.19
			2	106000	0.2500	0.1096			
			3	586000	0.5000	0.0015			
			4	990000	0.4000	0.0756			
34	369.59	0.00	1	586000	0.4000	0.0000	827.33	827.15	0.18
			2	106000	0.2500	0.1077			
			3	586000	0.5000	0.0016			
			4	990000	0.4000	0.0737			
35	378.37	0.00	1	586000	0.4000	0.0000	827.58	827.39	0.19
			2	106000	0.2500	0.1120			
			3	586000	0.5000	0.0017			
			4	990000	0.4000	0.0720			
36	387.14	0.00	1	586000	0.4000	0.0000	827.82	827.63	0.19
			2	106000	0.2500	0.1161			
			3	586000	0.5000	0.0018			
			4	990000	0.4000	0.0703			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
37	395.92	0.00	1	586000	0.4000	0.0000	828.06	827.88	0.19
			2	106000	0.2500	0.1140			
			3	586000	0.5000	0.0020			
			4	990000	0.4000	0.0691			
38	404.69	0.00	1	586000	0.4000	0.0000	828.32	828.13	0.19
			2	106000	0.2500	0.1177			
			3	586000	0.5000	0.0021			
			4	990000	0.4000	0.0675			
39	413.47	0.00	1	586000	0.4000	0.0000	828.57	828.38	0.19
			2	106000	0.2500	0.1211			
			3	586000	0.5000	0.0022			
			4	990000	0.4000	0.0659			
40	422.24	0.00	1	586000	0.4000	0.0000	828.82	828.63	0.19
			2	106000	0.2500	0.1186			
			3	586000	0.5000	0.0023			
			4	990000	0.4000	0.0643			
41	431.02	0.00	1	586000	0.4000	0.0000	829.08	828.89	0.19
			2	106000	0.2500	0.1216			
			3	586000	0.5000	0.0022			
			4	990000	0.4000	0.0627			
42	439.80	0.00	1	586000	0.4000	0.0000	829.38	829.19	0.19
			2	106000	0.2500	0.1241			
			3	586000	0.5000	0.0023			
			4	990000	0.4000	0.0615			
43	448.57	0.00	1	586000	0.4000	0.0000	829.68	829.51	0.18
			2	106000	0.2500	0.1158			
			3	586000	0.5000	0.0027			
			4	990000	0.4000	0.0599			
44	457.35	0.00	1	586000	0.4000	0.0000	829.99	829.83	0.16
			2	106000	0.2500	0.0976			
			3	586000	0.5000	0.0031			
			4	990000	0.4000	0.0587			
45	466.12	0.00	1	586000	0.4000	0.0000	830.26	830.12	0.14
			2	106000	0.2500	0.0803			
			3	586000	0.5000	0.0036			
			4	990000	0.4000	0.0575			
46	474.90	0.00	1	586000	0.4000	0.0000	830.54	830.41	0.12
			2	106000	0.2500	0.0638			
			3	586000	0.5000	0.0040			
			4	990000	0.4000	0.0559			
47	483.67	0.00	1	586000	0.4000	0.0000	830.81	830.71	0.11
			2	106000	0.2500	0.0480			
			3	586000	0.5000	0.0045			
			4	990000	0.4000	0.0544			
48	492.45	0.00	1	586000	0.4000	0.0000	831.13	831.04	0.10
			2	106000	0.2500	0.0375			
			3	586000	0.5000	0.0051			
			4	990000	0.4000	0.0526			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
49	501.22	0.00	1	586000	0.4000	0.0000	831.57	831.48	0.09
			2	106000	0.2500	0.0319			
			3	586000	0.5000	0.0054			
			4	990000	0.4000	0.0501			
50	510.00	0.00	1	586000	0.4000	0.0000	832.01	831.92	0.09
			2	106000	0.2500	0.0393			
			3	586000	0.5000	0.0053			
			4	990000	0.4000	0.0466			

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

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	80.00	0.00	823.75	0.02	823.74
2	88.78	0.00	823.35	0.03	823.31
3	97.55	0.00	823.01	0.04	822.97
4	106.33	0.00	823.01	0.05	822.96
5	115.10	0.00	823.01	0.05	822.96
6	123.88	0.00	823.10	0.05	823.05
7	132.65	0.00	823.52	0.04	823.47
8	141.43	0.00	823.94	0.04	823.89
9	150.20	0.00	824.56	0.04	824.52
10	158.98	0.00	824.93	0.04	824.89
11	167.76	0.00	824.68	0.04	824.64
12	176.53	0.00	824.44	0.04	824.40
13	185.31	0.00	824.20	0.04	824.16
14	194.08	0.00	823.84	0.04	823.80
15	202.86	0.00	823.11	0.04	823.06
16	211.63	0.00	823.37	0.04	823.33
17	220.41	0.00	823.79	0.04	823.75
18	229.18	0.00	824.07	0.04	824.03
19	237.96	0.00	824.20	0.04	824.16
20	246.73	0.00	824.32	0.04	824.29
21	255.51	0.00	824.45	0.04	824.42
22	264.29	0.00	824.58	0.03	824.54
23	273.06	0.00	824.71	0.03	824.67
24	281.84	0.00	824.83	0.03	824.80
25	290.61	0.00	824.96	0.03	824.93

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

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
26	299.39	0.00	825.17	0.03	825.14
27	308.16	0.00	825.43	0.03	825.39
28	316.94	0.00	825.68	0.03	825.65
29	325.71	0.00	825.94	0.03	825.91
30	334.49	0.00	826.23	0.03	826.19
31	343.27	0.00	826.52	0.04	826.48
32	352.04	0.00	826.81	0.04	826.77
33	360.82	0.00	827.09	0.04	827.05
34	369.59	0.00	827.33	0.04	827.29
35	378.37	0.00	827.58	0.04	827.53
36	387.14	0.00	827.82	0.05	827.77
37	395.92	0.00	828.06	0.05	828.02
38	404.69	0.00	828.32	0.05	828.26
39	413.47	0.00	828.57	0.05	828.51
40	422.24	0.00	828.82	0.05	828.76
41	431.02	0.00	829.08	0.06	829.02
42	439.80	0.00	829.38	0.06	829.32
43	448.57	0.00	829.68	0.07	829.62
44	457.35	0.00	829.99	0.08	829.91
45	466.12	0.00	830.26	0.10	830.16
46	474.90	0.00	830.54	0.12	830.42
47	483.67	0.00	830.81	0.14	830.68
48	492.45	0.00	831.13	0.17	830.96
49	501.22	0.00	831.57	0.17	831.40
50	510.00	0.00	832.01	0.14	831.87

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

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	1	0.00	821.01	Soil Type 1
	2	5.00	822.01	
	3	44.00	822.01	
	4	58.50	823.01	
	5	74.50	824.01	
	6	96.00	823.01	
	7	122.00	823.01	
	8	143.00	824.01	
	9	156.00	825.01	
	10	192.00	824.01	
	11	204.00	823.01	
	12	225.00	824.01	
	13	294.00	825.01	
	14	328.00	826.01	
	15	358.00	827.01	
	16	394.00	828.01	
	17	429.00	829.01	
	18	458.00	830.01	
	19	490.00	831.01	
	20	510.00	832.01	
	21	518.00	833.01	
	22	523.00	834.01	
	23	528.00	835.01	
	24	533.00	836.01	
	25	538.00	837.01	
	26	543.00	838.01	
	27	546.00	839.01	
	28	548.00	840.01	
	29	550.50	841.01	
	30	552.50	842.01	
	31	554.50	843.01	
	32	557.00	844.01	
	33	559.50	845.01	
	34	562.50	846.01	
	35	565.50	847.01	
	36	578.00	848.01	
	37	593.00	847.01	
	38	600.00	846.81	

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
2	1	0.00	821.01	Soil Type 2
	2	5.00	822.01	
	3	44.00	822.01	
	4	58.50	823.01	
	5	74.50	824.01	
	6	96.00	823.01	
	7	122.00	823.01	
	8	143.00	824.01	
	9	156.00	825.01	
	10	192.00	824.01	
	11	204.00	823.01	
	12	225.00	824.01	
	13	294.00	825.01	
	14	328.00	826.01	
	15	358.00	827.01	
	16	394.00	828.01	
	17	429.00	829.01	
	18	458.00	830.01	
	19	490.00	831.01	
	20	510.00	832.01	
	21	518.00	833.01	
	22	522.50	833.80	
	23	600.00	833.80	
3	1	0.00	812.60	Soil Type 1
	2	102.20	812.60	
	3	209.90	814.40	
	4	329.10	819.20	
	5	338.10	821.70	
	6	444.00	822.00	
	7	497.70	829.50	
	8	600.00	826.30	
4	1	0.00	809.60	Soil Type 3
	2	102.20	809.60	
	3	209.90	811.90	
	4	329.10	817.20	
	5	338.10	820.20	
	6	444.00	817.00	
	7	497.70	816.50	
	8	600.00	817.80	

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	X1 = 87.00 [ft]	1	87.00	857.60	Proposed Embankment and MSE Wall Fill
	X2 = 593.00 [ft]	2	200.00	856.70	
		3	300.00	854.90	
		4	400.00	852.40	
		5	500.00	849.70	
		6	593.00	847.00	

RETAINING WALL 7

CUY-14-6.93

PROJECT IDENTIFICATION

Title:	CUY-14-6.93
Project Number:	PID 104132 -
Client:	AECOM
Designer:	KCA
Station Number:	

Description:

Settlement analysis for RW-A, RW-F, Temp RW-H

Company's information:

Name:	NEAS Inc.
Street:	2800 Corporate Exchange Drive Suite 240 Columbus, OH 43231
Telephone #:	614-714-0299
Fax #:	
E-Mail:	

Original file path and name: C:\Users\k ..... \Desktop\Projects\CUY-14-6.93\RW-7_FoSSA021223.2ST
Original date and time of creating this file: Thu Dec 16 16:17:56 2021

GEOMETRY: Analysis of a 2D geometry

INPUT DATA – FOUNDATION LAYERS – 4 layers

	Wet Unit Weight, γ [lb/ft³]	Poisson's Ratio μ	Description of Soil
1	135.00	0.40	Soil Type 3
2	108.00	0.20	Soil Type 1
3	125.00	0.50	Soil Type 2
4	135.00	0.40	Soil Type 3

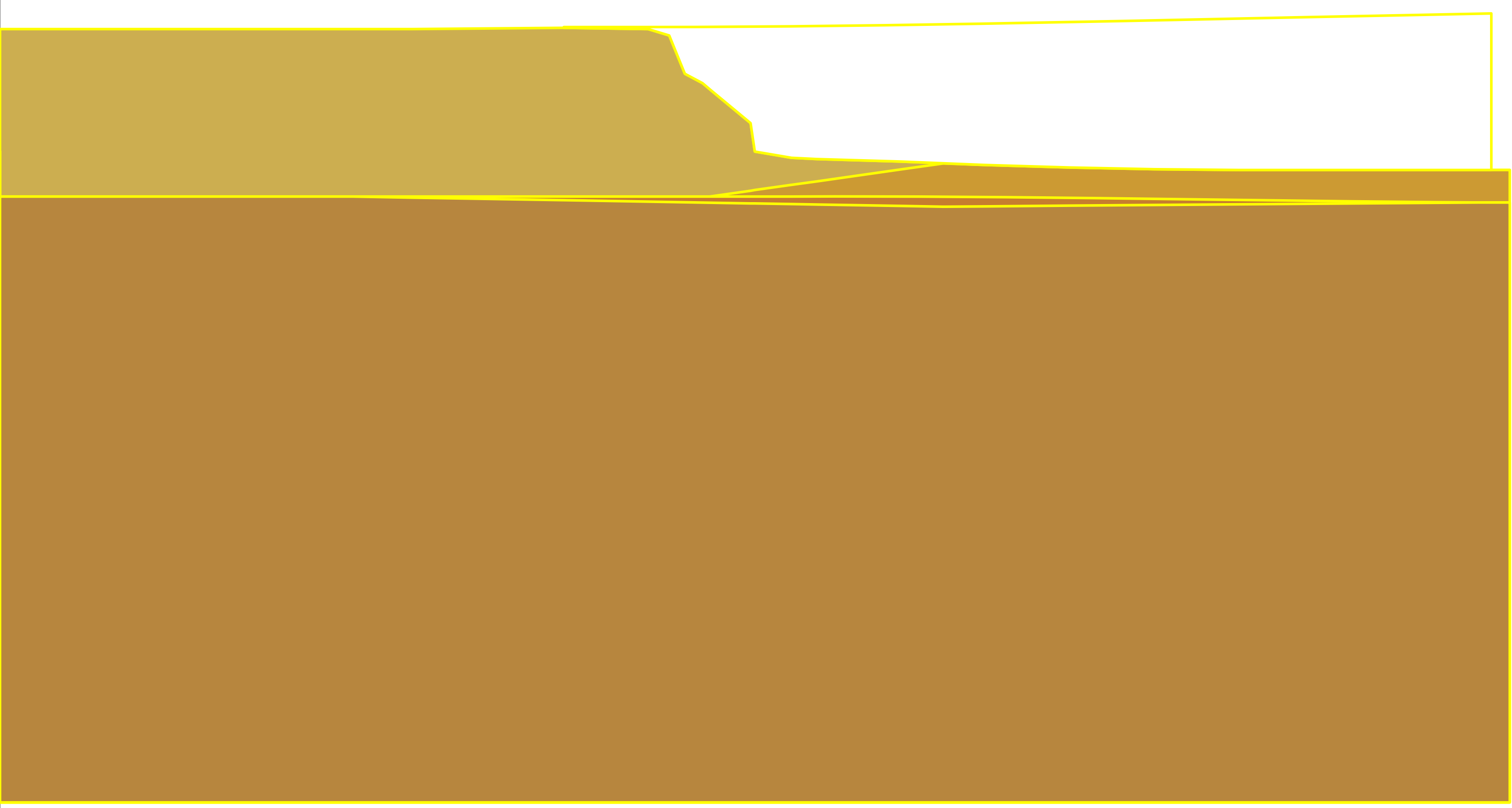
INPUT DATA – EMBANKMENT LAYERS -- 1 layers

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

INPUT DATA OF WATER

Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]
1	-50.00	811.10
2	220.00	811.10

DRAWING OF SPECIFIED GEOMETRY



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	5.00	0.169	0.042	0.816	0.1600	Top & Bot.
4	No	N/A	N/A	N/A	N/A	N/A	N/A

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
1	0.00	0.00	1	1521000	0.4000	-0.0078	849.60	849.61	-0.01
			2	74000	0.2000	0.0000			
			3	2000000	0.5000	-0.0002			
			4	1521000	0.4000	0.0004			
2	10.00	0.00	1	1521000	0.4000	-0.0072	849.45	849.45	-0.00
			2	74000	0.2000	0.0000			
			3	2000000	0.5000	-0.0002			
			4	1521000	0.4000	0.0065			
3	20.00	0.00	1	1521000	0.4000	-0.0037	849.30	849.29	0.01
			2	74000	0.2000	0.0000			
			3	2000000	0.5000	-0.0001			
			4	1521000	0.4000	0.0144			
4	30.00	0.00	1	1521000	0.4000	0.0070	838.02	837.99	0.03
			2	74000	0.2000	0.0000			
			3	2000000	0.5000	0.0002			
			4	1521000	0.4000	0.0239			
5	40.00	0.00	1	1521000	0.4000	0.0130	830.58	830.51	0.07
			2	74000	0.2000	0.0223			
			3	2000000	0.5000	0.0005			
			4	1521000	0.4000	0.0344			
6	50.00	0.00	1	1521000	0.4000	0.0074	819.49	819.37	0.12
			2	74000	0.2000	0.0681			
			3	2000000	0.5000	0.0010			
			4	1521000	0.4000	0.0441			
7	60.00	0.00	1	1521000	0.4000	0.0064	818.50	818.30	0.20
			2	74000	0.2000	0.1383			
			3	2000000	0.5000	0.0013			
			4	1521000	0.4000	0.0526			
8	70.00	0.00	1	1521000	0.4000	0.0045	818.20	817.93	0.27
			2	74000	0.2000	0.2036			
			3	2000000	0.5000	0.0016			
			4	1521000	0.4000	0.0592			
9	80.00	0.00	1	1521000	0.4000	0.0026	817.90	817.56	0.34
			2	74000	0.2000	0.2695			
			3	2000000	0.5000	0.0017			
			4	1521000	0.4000	0.0644			
10	90.00	0.00	1	1521000	0.4000	0.0000	817.50	817.08	0.42
			2	74000	0.2000	0.3485			
			3	2000000	0.5000	0.0020			
			4	1521000	0.4000	0.0679			
11	100.00	0.00	1	1521000	0.4000	0.0000	817.10	816.68	0.42
			2	74000	0.2000	0.3424			
			3	2000000	0.5000	0.0018			
			4	1521000	0.4000	0.0713			
12	110.00	0.00	1	1521000	0.4000	0.0000	816.80	816.39	0.41
			2	74000	0.2000	0.3343			
			3	2000000	0.5000	0.0018			
			4	1521000	0.4000	0.0734			

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

IMMEDIATE SETTLEMENT, Si

Node #	Settlement along section: X [ft.]	Y [ft.]	Layer (k)	Young's Modulus, E [lb/ft ²]	Poisson's Ratio, μ	Settlement of each layer, Si(k) [ft.]	Initial Z [ft.]	Final Z * [ft.]	Total Settlement Sum of Si(k), [ft.]
13	120.00	0.00	1	1521000	0.4000	0.0000	816.50	816.08	0.42
			2	74000	0.2000	0.3396			
			3	2000000	0.5000	0.0016			
			4	1521000	0.4000	0.0751			
14	130.00	0.00	1	1521000	0.4000	0.0000	816.30	815.89	0.41
			2	74000	0.2000	0.3291			
			3	2000000	0.5000	0.0016			
			4	1521000	0.4000	0.0761			
15	140.00	0.00	1	1521000	0.4000	0.0000	816.10	815.69	0.41
			2	74000	0.2000	0.3325			
			3	2000000	0.5000	0.0014			
			4	1521000	0.4000	0.0772			
16	150.00	0.00	1	1521000	0.4000	0.0000	816.00	815.59	0.41
			2	74000	0.2000	0.3350			
			3	2000000	0.5000	0.0012			
			4	1521000	0.4000	0.0773			
17	160.00	0.00	1	1521000	0.4000	0.0000	815.90	815.49	0.41
			2	74000	0.2000	0.3362			
			3	2000000	0.5000	0.0012			
			4	1521000	0.4000	0.0764			
18	170.00	0.00	1	1521000	0.4000	0.0000	815.90	815.49	0.41
			2	74000	0.2000	0.3347			
			3	2000000	0.5000	0.0010			
			4	1521000	0.4000	0.0745			
19	180.00	0.00	1	1521000	0.4000	0.0000	815.90	815.48	0.42
			2	74000	0.2000	0.3434			
			3	2000000	0.5000	0.0010			
			4	1521000	0.4000	0.0715			
20	190.00	0.00	1	1521000	0.4000	0.0000	815.90	815.50	0.40
			2	74000	0.2000	0.3284			
			3	2000000	0.5000	0.0007			
			4	1521000	0.4000	0.0660			
21	200.00	0.00	1	1521000	0.4000	0.0000	815.90	815.54	0.36
			2	74000	0.2000	0.2982			
			3	2000000	0.5000	0.0006			
			4	1521000	0.4000	0.0583			
22	210.00	0.00	1	1521000	0.4000	0.0000	815.90	815.60	0.30
			2	74000	0.2000	0.2568			
			3	2000000	0.5000	0.0000			
			4	1521000	0.4000	0.0479			
23	220.00	0.00	1	1521000	0.4000	0.0000	815.90	815.68	0.22
			2	74000	0.2000	0.1834			
			3	2000000	0.5000	0.0000			
			4	1521000	0.4000	0.0357			

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

ULTIMATE SETTLEMENT, Sc

Node #	X [ft.]	Y [ft.]	Original Z [ft.]	Settlement Sc [ft.]	Final Z * [ft.]
1	0.00	0.00	849.60	0.00	849.60
2	10.00	0.00	849.45	0.00	849.45
3	20.00	0.00	849.30	0.00	849.30
4	30.00	0.00	838.02	0.00	838.01
5	40.00	0.00	830.58	0.01	830.57
6	50.00	0.00	819.49	0.02	819.47
7	60.00	0.00	818.50	0.03	818.47
8	70.00	0.00	818.20	0.03	818.17
9	80.00	0.00	817.90	0.04	817.86
10	90.00	0.00	817.50	0.05	817.45
11	100.00	0.00	817.10	0.05	817.05
12	110.00	0.00	816.80	0.05	816.75
13	120.00	0.00	816.50	0.05	816.45
14	130.00	0.00	816.30	0.05	816.25
15	140.00	0.00	816.10	0.04	816.06
16	150.00	0.00	816.00	0.04	815.96
17	160.00	0.00	815.90	0.03	815.87
18	170.00	0.00	815.90	0.03	815.87
19	180.00	0.00	815.90	0.02	815.88
20	190.00	0.00	815.90	0.01	815.89
21	200.00	0.00	815.90	0.01	815.89
22	210.00	0.00	815.90	0.00	815.90
23	220.00	0.00	815.90	0.00	815.90

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

TABULATED GEOMETRY: INPUT OF FOUNDATION SOILS

Found. Soil #	Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	1	-50.00	849.30	Soil Type 3
	2	-36.00	849.30	
	3	0.00	849.60	
	4	20.00	849.30	
	5	25.00	847.80	
	6	28.70	838.70	
	7	32.90	836.50	
	8	44.30	827.00	
	9	45.30	820.30	
	10	54.00	818.80	
	11	60.00	818.50	
	12	80.00	817.90	
	13	90.00	817.50	
	14	100.00	817.10	
	15	120.00	816.50	
	16	140.00	816.10	
	17	160.00	815.90	
	18	220.00	815.90	
2	1	-50.00	809.61	Soil Type 1
	2	34.60	809.61	
	3	90.00	817.49	
	4	100.00	817.09	
	5	120.00	816.49	
	6	140.00	816.09	
	7	160.00	815.89	
	8	220.00	815.89	
3	1	-50.00	809.60	Soil Type 2
	2	90.00	809.60	
	3	217.00	808.20	
	4	220.00	808.20	
4	1	-50.00	809.59	Soil Type 3
	2	90.00	807.20	
	3	217.00	808.19	
	4	220.00	808.19	

TABULATED GEOMETRY: INPUT OF EMBANKMENT SOILS

Embank. Soil #		Point #	Coordinates (X, Z) : (X) [ft.]	(Z) [ft.]	DESCRIPTION
1	X1 = 0.00 [ft]	1	0.00	849.80	Proposed Embankment and MSE Wall Fill
	X2 = 220.00 [ft]	2	20.00	849.80	
		3	40.00	849.90	
		4	60.00	850.00	
		5	80.00	850.30	
		6	100.00	850.60	
		7	120.00	851.00	
		8	140.00	851.40	
		9	160.00	851.80	
		10	180.00	852.20	
		11	200.00	852.60	
		12	220.00	853.00	