FRA-71-14.36 PHASE 6R
RETAINING WALL W3
PID NO. 105588
FRANKLIN COUNTY, OHIO

DRAFT STRUCTURE FOUNDATION EXPLORATION REPORT

Prepared For:
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Rii Project No. W-13-072

June 2021

RESOURCE INTERNATIONAL, INC.
ISO | ISO 9001:2015 Certified QMS
An ISO 9001:2015 QMS Certified Firm

Planning
Engineering
Construction Management
Technology

June 23, 2021

Ms. Leslie Montgomery, P.E.
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Columbus, OH 43229-1547

Re: Draft Structure Foundation Exploration Report
FRA-71-14.36 Phase 6R
Retaining Wall W3
PID No. 105588
Rii Project No. W-13-072

Mr. Montgomery:

Resource International, Inc. (Rii) is pleased to submit this draft structure foundation exploration report for the above referenced project. Engineering logs have been prepared and are attached to this report along with the results of laboratory testing. This report includes recommendations for the design and construction of the proposed Retaining Wall W3 as part of the FRA 71 14.36 Phase 6R project in Columbus, Ohio.

We sincerely appreciate the opportunity to be of service to you on this project. If you have any questions regarding the structure foundation exploration or this report, please contact us.

Sincerely,

RESOURCE INTERNATIONAL, INC.

Hanumanth S. Kulkarni, Ph.D., P.E.
Project Engineer – Geotechnical Services

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Enclosure: Draft Structure Foundation Exploration Report

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TABLE OF CONTENTS

APPENDICES

Appendix I	**Vicinity Map and Boring Plan**	
Appendix II	**Description of Soil Terms**	
Appendix III	**Project Boring Logs:**	**B-103-1-14, B-104-1-14, B-105-3-14 through B-105-6-14, B-106-0-09, B-107-2-14 through B-107-4-14 and B-111-0-09**
Appendix IV	**Laboratory Test Results**	
Appendix V	**MSE Wall Calculations**	

EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for the design and construction of the proposed Retaining Wall W3. Retaining Wall W3 will be located along the west side of Ramp C3, providing the required grade separation between the proposed Ramp C3 roadway and the adjacent lanes, which will be constructed for maintenance of traffic (MOT) in a previous phase of work. The subject wall begins at Sta. 300+00.00 (BL Wall W3) / Sta. 3006+50.00 (BL Ramp C3), and extends south along the west side of Ramp C3 to Sta. 308+69.19 (BL Wall W3) / Sta. 3015+29.65 (BL Ramp C3), where it will connect to Temporary Wall T3. It is understood that a mechanically stabilized earth (MSE) wall type is being considered as the preferred wall type for the entire alignment of Retaining Wall W3. Wall heights along the proposed alignment are anticipated to range from 12.8 feet at the northern terminus to a maximum height of 44.5 feet near Sta. 306+50 (BL Wall W3). The total wall length is 869 lineal feet.

Exploration and Findings

Between June 4, 2014, and April 28, 2015 a total of nine (9) structure borings, designated as B-103-1-14, B-104-1-13, B-105-3-14 through B-105-6-14 and B-107-2-14 through B-107-4-14, were advanced to completion depths ranging from 20.0 to 70.5 feet below the existing ground surface. The borings were drilled along the existing I-71 southbound ramp, the infield area between the I-70 eastbound and I-70 southbound ramps, the I-70 eastbound ramp and along the toe of the existing embankment supporting the ramp from I-70 eastbound to I-71/SR-315 southbound. In addition to the borings performed by Rii as part of the current exploration, two (2) borings, designated as B-106-0-09 and B-111-0-09, were performed by DLZ in the vicinity of the proposed structure as part of the FRA-70-8.93 Preliminary Engineering project (PID No. 77369) and their findings published in a report prepared by Burgess & Niple dated May 2010. The borings were advanced to completion depths of 21.8 and 30.0 feet below the existing ground surface, respectively.

Borings B-105-3-14, B-105-5-14 and B-107-2-14 were located within the existing I-71 southbound ramp and encountered 3.0 to 4.0 inches of asphalt overlying 6.0 to 9.5 inches of concrete followed by 6.0 inches of aggregate base in borings B-105-3-14 and B-105-5-14. Boring B-111-0-09 was located within the existing I-70 eastbound to I-71/SR-315 southbound ramp and encountered 6.0 inches of asphalt overlying 6.0 inches of aggregate base. Boring B-105-6-14 was performed within the existing parking lot of R.W. Setterlin Building Company and encountered 4.0 inches of asphalt overlying 8.0 inches of fill material. Borings located outside the limits of the existing pavement encountered 1.0 to 5.0 inches of topsoil at the existing ground surface, as identified by the significant presence of organics and vegetation.

Beneath the surficial materials, existing fill and/or possible fill materials were encountered in a total of seven (7) of the eleven (11) borings analyzed as part of this exploration. With the exception of boring B-107-3-14, the existing fill encountered in the remaining borings consisted of existing embankment fill comprised brown, dark brown, gray and brownish gray sandy silt, silt and clay and clay (ODOT A-4a, A-6a, A-6b) with intermittent seams of granular soils comprised of gravel with sand, gravel with sand and silt, and gravel with sand, silt and clay (ODOT A-1-b, A-2-4, A-2-6) which extended to depths ranging from 10.5 to 25.5 feet below the existing grade at along the I-70 eastbound to I-71/SR-315 southbound ramp. The presence of organic and chemical odors was also noted within the embankment fill material encountered in boring B-104-1-13 between El. 703.5 and 701.5 feet msl. The existing fill encountered in boring B-107-3-14 consisted of brown clay (ODOT A-7-6), which extended to a depth of 3.0 feet below grade.

Beneath the surficial and fill materials, where encountered, natural cohesive and granular soils were encountered extending to the boring termination depths or top of bedrock. In general, the borings primarily encountered natural cohesive soils overlying deep granular deposits. The cohesive soils were generally described as gray, brown, dark brown, dark gray, and black sandy silt, silt, silt and clay, silty clay, and clay (ODOT A-4a, A-4b, A-6a, A-6b, A-7-6). The granular soils were generally described as brown, gray, brownish gray and dark gray gravel, gravel with sand, gravel with sand and silt, gravel with sand, silt, silt and clay, coarse and fine sand and sandy silt (ODOT A-1-a, A-1-b, A-2-4, A-2-6, A-3a, A-4a).

Bedrock was encountered in boring B-104-1-13 at a depth of 60.5 feet beneath the ground surface, corresponding to an elevation of 654.0 feet msl. Upon encountering competent bedrock, as defined by auger refusal, a changeover to rock coring techniques was made and 10.0 feet of rock core was obtained. The cored bedrock consisted of gray limestone, described as being unweathered, very strong, very thickly bedded, calcareous, siliceous, cherty, dolomitic, crystalline, and slightly to moderately fractured, with open apertures and a slightly rough to very rough surface.

Analyses and Recommendations

Design details of the proposed retaining wall were provided by the Rii design team. It is understood that a mechanically stabilized earth (MSE) wall type is being considered as the preferred wall type for the entire alignment of Retaining Wall W3. Based on the proposed plan and profile information, wall heights along the proposed alignment are anticipated to range from 12.8 feet near the northern terminus to a maximum height of 44.5 feet near Sta. 306+50 (BL Wall W3).

MSE Wall Recommendations

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Based on the proposed plan and profile information, wall heights ranging from 12.8 feet at the northern terminus to 44.5 feet at Sta. 306+50 (BL Wall W3) are anticipated along the wall alignment, with the bottom of wall proposed to bear at a minimum depth of 4.0 feet beneath the proposed ground surface.

The bearing soils along the proposed wall alignment are anticipated to consist of existing embankment fill comprised of stiff to hard sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) with seams of medium dense to very dense gravel with sand and gravel with sand, silt and clay (ODOT A-1-b, A-2-6). MSE wall foundations bearing on existing embankment fill or new embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a factored bearing resistance as indicated in the following table. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state.

Retaining Wall W3 MSE Wall Design Parameters

From Station [1]	To Station [1]	Wall Height Analyzed (feet)	Backslope Behind Wall in Analysis	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Strength Limit Equivalent Bearing Pressure [4] (ksf)
					Nominal	Factored [3]	
300+00	303+50	14.2	2:1 (Broken-Back)	13.5 (0.95H)	12.90	8.39	3.93
303+50	305+00	25.1	2:1 (Broken-Back)	18.8 (0.75H)	13.33	8.66	7.90
305+00	307+00	42.9	Level	38.6 (0.90H)	13.43	8.73	8.69
307+00	308+69	43.5	Level Backfill with Front Slope	47.9 (1.1H)	12.98	8.35 (5)	8.31

1. *Stationing is referenced to the baseline of Wall W3.*
2. *The required foundation width is expressed as a percentage of the wall height, H.*
3. *A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state.*
4. *The strength limit equivalent bearing pressure is the uniformly distributed pressure asserted by the wall over an effective base width based on the eccentricity of the wall system at the strength limit state.*
5. *The factored bearing resistance includes a reduction factor applied to the nominal resistance to account for the fore slope in front of the wall per Section 10.6.3.1.2c of the 2020 AASHTO LRFD BDM.*

Total settlements ranging from 1.14 to 7.81 inches at the center of the reinforced soil mass and 0.90 to 2.44 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W3. Based on the results of the analysis, 90 percent of the total settlement is anticipated to occur over a period of approximately 3 to 22 days. Please note that the consolidation settlement and time rate of consolidation are based on estimates using correlated compressibility parameters provided in Table 8 for the underlying soils.

Overall stability analysis was performed considering the cross sections at Sta. 3008+50, 3010+50 and 3012+00 (BL Ramp C3), to represent the variable geometric dimensions of the MSE wall along the wall alignment. Based on the results of the external and global stability analysis performed for Retaining Wall W3, the recommended controlling strap length is 0.75 to 1.10 times the height of the MSE wall (measured from the top of the leveling pad to the top of wall) with statin limits as identified in Table 7 of this report. Sliding resistance under drained conditions and bearing resistance under undrained conditions were the controlling factors in the determination of the recommended strap lengths.

Please note that this executive summary does not contain all the information presented in the report. The unabridged subsurface exploration report should be read in its entirety to obtain a more complete understanding of the information presented.

1.0 INTRODUCTION

The overall purpose of this project is to provide detailed subsurface information and recommendations for the design and construction of the FRA-70/71-13.10/14.36 (Projects 6A/6R) project in Columbus, Ohio. The projects represent the central portion of FRA-70-8.93 (PID 77369) I-70/71 south innerbelt improvements project, which includes all improvements along I-70 westbound from the I-71/SR-315 interchange to Front Street and along I-71 southbound from I-70 to Greenlawn Avenue. The FRA-71-14.36 (Project 6R) phase will consist of all work associated with the reconfiguration and construction of I-71 southbound from downtown (Front Street) to Greenlawn Avenue, including Ramps C3, D6 and D7. This project includes the construction of two (2) new bridge structures, one (1) for I-71 southbound over Short Street, NS/CXS Railroad and the Scioto River (FRA-71-1503L) and one (1) for Ramp D7 over Short Street (FRA-70-1373B), as well as the construction of six (6) new retaining walls (Walls E4, E5, E7, W2, W3 and W5) to accommodate the new configuration.

This report is a presentation of the structure foundation exploration performed for the design and construction of the proposed Retaining Wall W3, as shown on the vicinity map and boring plan presented in Appendix I. Retaining Wall W3 will be located along the west side of Ramp C3, providing the required grade separation between the proposed Ramp C3 roadway and the adjacent lanes, which will be constructed for maintenance of traffic (MOT) in a previous phase of work. The subject wall begins at Sta. 300+00.00 (BL Wall W3) / Sta. 3006+50.00 (BL Ramp C3), and extends south along the west side of Ramp C3 to Sta. 308+69.19 (BL Wall W3) / Sta. 3015+29.65 (BL Ramp C3), where it will connect to Temporary Wall T3. It is understood that a mechanically stabilized earth (MSE) wall type is being considered as the preferred wall type for the entire alignment of Retaining Wall W3. Wall heights along the proposed alignment are anticipated to range from 12.8 feet at the northern terminus to a maximum height of 44.5 feet near Sta. 306+50 (BL Wall W3). The total wall length is 869 lineal feet.

2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1 Site Geology

Both the Illinoian and Wisconsinan glaciers advanced over two-thirds of the State of Ohio, leaving behind glacial features such as moraines, kame deposits, lacustrine deposits and outwash terraces. The glacial and non-glacial regions comprise five physiographic sections based on geological age, depositional process and geomorphic occurrence (physical features or landforms). The project area lies within the Columbus Lowland District of the Till Plains Section. This area is characterized by flat to gently rolling ground moraine deposits from the Late Wisconsinan age. The site topography exhibits moderate to high relief. The ground moraine deposits are composed primarily of silty loam till (Darby, Bellefontaine, Centerburg, Grand Lake, Arcanum, Knightstown

Tills), with smaller alluvium and outwash deposits bordering the Scioto River, its tributaries and floodplain areas. A ground moraine is the sheet of debris left after the steady retreat of glacial ice. The debris left behind ranges in composition from clay size particles to boulders (including silt, sand, and gravel). Outwash deposits consist of undifferentiated sand and gravel deposited by meltwater in front of glacial ice, and often occurs as valley terraces or low plains. Alluvium and alluvial terrace deposits range in composition from silty clay size particles to cobbles, usually deposited in present and former floodplain areas.

According to the bedrock geology and topography maps obtained from the Ohio Department of Natural Resources (ODNR), the underlying bedrock west of the Scioto River consists predominantly of the Middle to Lower Devonian-aged Columbus Limestone. This formation is further subdivided into two members in the central portion of the state, known as the Delhi and Bellepoint Members. The Delhi Member consists of light gray, finely to coarsely crystalline, irregularly bedded, fossiliferous limestone. The Bellepoint Member consists of variable brown, finely crystalline, massively bedded limey dolomite. Both of these members contain chert nodules. East of the Scioto River, the underlying bedrock consists of the Upper Devonian Ohio Shale Formation overlying the Middle Devonian-aged Delaware Limestone Formation. The Ohio Shale formation consists of brownish black to greenish gray, thinly bedded, fissile, carbonaceous shale. The Delaware Limestone consists of bluish gray, thin to medium bedded dolomitic limestone with nodules and layers of chert. Regionally, the bedrock surface forms a broad valley aligned roughly north-to-south beneath the Scioto River. According to bedrock topography mapping, the elevation of the bedrock surface ranges from approximately 600 feet mean sea level (msl) in the valley to approximately 625 feet msl near the project limits.

2.2 Existing Conditions

The proposed Retaining Wall W3 is situated within the infield area between the existing I-70 eastbound ramp to I-71/SR-315 southbound and I-71 southbound ramp. The existing I-70 eastbound and I-71 southbound ramps are single-lane, asphalt surfaced roadways with full width shoulders, and the existing SR-315 southbound roadway is a two-lane, asphalt surfaced roadway with full width inside and outside shoulders. The profile grade of the ramps and highway are elevated on engineered embankments ranging from 5 to 35 feet above the surrounding terrain. The existing embankments are covered with dense vegetation and show no visible signs of instability. Commercial properties are situated along the west side of the I-70 eastbound and I-71/SR-315 roadways, with the Scioto River situated along the west side of I-71/SR-315. The terrain along I-71/SR-315 southbound gently slopes downward to the south, and the surrounding area is relatively flat-lying.

3.0 EXPLORATION

Between June 4, 2014, and April 28, 2015 a total of nine (9) structure borings, designated as B-103-1-14, B-104-1-13, B-105-3-14 through B-105-6-14 and B-107-2-14 through B-107-4-14, were advanced to completion depths ranging from 20.0 to 70.5 feet below the existing ground surface. The borings were drilled along the existing I-71 southbound ramp, the infield area between the I-70 eastbound and I-70 southbound ramps, the I-70 eastbound ramp and along the toe of the existing embankment supporting the ramp from I-70 eastbound to I-71/SR-315 southbound. In addition to the borings performed by Rii as part of the current exploration, two (2) borings, designated as B-106-0-09 and B-111-0-09, were performed by DLZ in the vicinity of the proposed structure as part of the FRA-70-8.93 Preliminary Engineering project (PID No. 77369) and their findings published in a report prepared by Burgess & Niple dated May 2010. The borings were advanced to completion depths of 21.8 and 30.0 feet below the existing ground surface, respectively. The project boring locations are shown on the boring plan provided in Appendix I of this report and are summarized in Table 1 below.

Table 1. Test Boring Summary

Boring Number	Reference Alignment	Station	Offset	Latitude	Longitude	Ground Elevation (feet msl)	Boring Depth (feet)
B-103-1-14	BL Ramp C3	3015+16.32	74.2' Rt.	39.947764221	-83.016136629	703.3	54.3
B-104-1-13	BL I-71 SB	230+95.90	17.5' Rt.	39.947937268	-83.015727886	714.5	70.5
B-105-3-14	BL Ramp C3	3014+37.27	37.7' Lt.	39.948117531	-83.015969846	719.4	55.0
B-105-4-14	BL Ramp C3	3013+70.11	102.6' Rt.	39.948055710	-83.016519556	700.0	45.0
B-105-5-14	BL Ramp C3	3012+82.16	42.1' Lt.	39.948475867	-83.016258220	723.9	50.0
B-105-6-14	BL Ramp C3	3012+25.98	120.3' Rt.	39.948372985	-83.016857114	703.0	35.0
B-106-0-09	BL Ramp C3	3011+71.87	16.7' Lt.	39.948695780	-83.016539172	719.0	21.8
B-107-2-14	BL Ramp C3	3011+35.50	67.0' Lt.	39.948851596	-83.016450128	727.5	45.0
B-107-3-14	BL Ramp C3	3010+61.70	149.1' Rt.	39.948726068	-83.017248056	704.3	25.0
B-107-4-14	BL Ramp C3	3009+90.45	162.2' Rt.	39.948867841	-83.017410893	705.1	20.0
B-111-0-09	BL Ramp C3	3008+21.22	56.8' Rt.	39.949346000	-83.017438000	734.9	30.0

The locations for the current exploration borings performed by Rii were determined and located in the field by Rii representatives. Rii utilized a handheld GPS unit to obtain geographic latitude and longitude coordinates of the boring locations. Ground surface elevations at the boring locations were interpolated using topographic mapping information provided by ms consultants.

The borings performed by Rii for the current exploration were drilled with both truck and all-terrain vehicle (ATV) mounted rotary drilling machines, utilizing either a 3.25 or 4.25-inch inside diameter, hollow stem auger or a 4.5-inch outside diameter, continuous flight auger to advance the holes between sampling attempts. Standard penetration test (SPT) and split spoon sampling were generally performed in the borings at 2.5-foot increments to depths ranging from 20.0 to 40.0 feet beneath the existing ground surface, and at 5.0-foot increments thereafter to the boring termination depth or top of bedrock.

The SPT, per the American Society for Testing and Materials (ASTM) designation D1586, is conducted using a 140-pound hammer falling 30.0 inches to drive a 2.0-inch outside diameter split spoon sampler 18.0 inches. Rii utilized a calibrated automatic drop hammer to generate consistent energy transfer to the sampler. Driving resistance is recorded on the boring logs in terms of blows per 6.0-inch interval of the driving distance. The second and third intervals are added to obtain the number of blows per foot (N). Standard penetration blow counts aid in determining soil properties applicable in foundation system design. Measured blow count (N) values are corrected to an equivalent (60%) energy ratio, N_{60}, by the following equation. Both values are represented on boring logs in Appendix III.

$$N_{60} = N_m*(ER/60)$$

Where:
N_m = measured N value
ER = drill rod energy ratio, expressed as a percent, for the system used

The hammer for the Mobile B-53 drill rig operated by Rii was calibrated on April 26, 2013, and has a drill rod energy ratio of 77.7 percent. The hammers for the CME 750, CME 750X and CME 55 drill rigs operated by Rii were also calibrated on October 20, 2014, with drill rod energy ratios of 92.9, 85.7 and 92.0 percent, respectively. The hammers for the two CME 75 drill rigs operated by DLZ have drill rod energy ratios of 61.2 and 62.0 percent.

Additionally, borings B-105-5-14 and B-107-2-14 were performed by a subcontract drilling company, Stock Drilling, to ensure that all of the subject borings were completed in a timely and efficient manner. Stock Drilling utilized a BK-81 HD truck mounted drill rig to advance the borings, and the hammer system was calibrated on March 28, 2013, with a drill rod energy ratio of 72.3 percent.

For instances of little to no recovery from the standard split spoon interval, a 3.0-inch outside diameter split spoon was driven the full length of the standard split spoon interval plus an additional 6.0 inches to obtain a representative sample. Only the final 6.0 inches of sample was retained for classification. Blow counts from the 3S sampling are not correlated with N_{60} values.

Hand penetrometer readings, which provide a rough estimate of the unconfined compressive strength of the soil, were reported on the boring logs in units of tons per square foot (tsf) and were utilized to classify the consistency of the cohesive soil in each layer. An indirect estimate of the unconfined compressive strength of the cohesive split spoon samples can also be made from a correlation with the blow counts (N_{60}). Please note that split spoon samples are considered to be disturbed and the laboratory determination of their shear strengths may vary from undisturbed conditions.

During drilling, heaving sands were encountered in eight (8) of the nine (9) borings performed by Rii for the current exploration. The heaving sand conditions were encountered in the borings at depths ranging from 16.0 to 48.5 feet beneath the ground surface. Where these conditions were encountered, drilling fluid consisting of either water or a mixture of bentonite gel and water was introduced to the borings to counteract the water pressure and prevent the sands from heaving into the augers. Depths at which heaving sands were encountered and where drilling fluid was introduced to the boreholes is presented on the boring logs included in Appendix III.

The depth to bedrock in boring B-104-1-13 was determined by auger refusal on the bedrock surface. Auger refusal is defined as no or insignificant observable advancement of the augers with the weight of the drill rig driving the augers. An NQ-sized double-tube diamond bit core barrel (utilizing wire line equipment) was used to core the bedrock. Coring produced 1.85 inch diameter cores, from which the type of rock and its geological characteristics were determined.

Rock cores were logged in the field and visually classified in the laboratory. They were analyzed to identify the type of rock, color, mineral content, bedding planes and other geological and mechanical features of interest in this project. The Rock Quality Designation (RQD) for each rock core run was calculated according to the following equation:

$$RQD = \frac{\sum \text{segments equal to or longer than 4.0 inches}}{\text{core run length}} \times 100$$

The RQD value aids in estimating the general quality of the rock and is used in conjunction with other parameters to designate the quality of the rock mass.

Upon completion of drilling, the borings were backfilled in accordance with the ODOT policy for sealing boreholes, utilizing either a mixture of bentonite chips and soil cuttings or cement-bentonite grout. Where borings penetrated the existing pavement, an equivalent thickness of quickset concrete was used to repair the pavement surface.

During drilling for the borings performed as part of the current exploration, field logs were prepared by Rii personnel showing the encountered subsurface conditions. Soil samples obtained from the drilling operation were preserved and sealed in glass jars and delivered to the soil laboratory. In the laboratory, the soil samples were visually classified and select samples were tested, as noted in Table 2.

Table 2. Laboratory Test Schedule

Laboratory Test	Test Designation	Number of Tests Performed
Natural Moisture Content	ASTM D 2216	113
Plastic and Liquid Limits	AASHTO T89, T90	46
Gradation – Sieve/Hydrometer	AASHTO T88	46
Unconfined Compressive Strength of Intact Rock	ASTM D7012	1

The tests performed are necessary to classify existing soil according to the Ohio Department of Transportation (ODOT) classification system and to estimate engineering properties of importance in determining foundation design and construction recommendations. Results of the laboratory testing are presented on the boring logs in Appendix III and in Appendix IV. A description of the soil terms used throughout this report is presented in Appendix II.

4.0 FINDINGS

Interpreted engineering logs have been prepared based on the field logs, visual examination of samples and laboratory test results. Classification follows the respective version of the ODOT Specifications for Geotechnical Explorations (SGE) at the time the exploration borings were performed. The following is a summary of what was found in the test borings performed as part of the preliminary engineering phase and current exploration and what is represented on the boring logs.

4.1 Surface Materials

Borings B-105-3-14, B-105-5-14 and B-107-2-14 were located within the existing I-71 southbound ramp and encountered 3.0 to 4.0 inches of asphalt overlying 6.0 to 9.5 inches of concrete followed by 6.0 inches of aggregate base in borings B-105-3-14 and B-105-5-14. Boring B-111-0-09 was located within the existing I-70 eastbound to I-71/SR-315 southbound ramp and encountered 6.0 inches of asphalt overlying 6.0 inches of aggregate base. Boring B-105-6-14 was performed within the existing parking lot of R.W. Setterlin Building Company and encountered 4.0 inches of asphalt overlying 8.0 inches of fill material. Borings located outside the limits of the existing pavement encountered 1.0 to 5.0 inches of topsoil at the existing ground surface, as identified by the significant presence of organics and vegetation. A summary of the surficial materials encountered in the borings is provided in Table 3.

Table 3. Summary of Surficial Materials

Boring Number	Asphalt Thickness (in)	Concrete Thickness (in)	Aggregate Base Thickness (in)	Topsoil Thickness (in)
B-103-1-14	-	-	-	1.0
B-104-1-13	-	-	-	4.0
B-105-3-14	4.0	9.5	6.0	-
B-105-4-14	-	-	-	4.0
B-105-5-14	3.0	6.0	6.0	-
B-105-6-14	4.0	-	8.0	-
B-106-0-09	-	-	-	3.0
B-107-2-14	3.0	9.0	-	-
B-107-3-14	-	-	-	3.0
B-107-4-14	-	-	-	5.0
B-111-0-09	6.0	-	6.0	-

4.2 Subsurface Soils

Beneath the surficial materials, existing fill and/or possible fill materials were encountered in a total of seven (7) of the eleven (11) borings analyzed as part of this exploration. With the exception of boring B-107-3-14, the existing fill encountered in the remaining borings consisted of existing embankment fill comprised brown, dark brown, gray and brownish gray sandy silt, silt and clay and clay (ODOT A-4a, A-6a, A-6b) with intermittent seams of granular soils comprised of gravel with sand, gravel with sand and silt, and gravel with sand, silt and clay (ODOT A-1-b, A-2-4, A-2-6) which extended to depths ranging from 10.5 to 25.5 feet below the existing grade at along the I-70 eastbound to I-71/SR-315 southbound ramp. The presence of organic and chemical odors was also noted within the embankment fill material encountered in boring B-104-1-13 between El. 703.5 and 701.5 feet msl. The existing fill encountered in boring B-107-3-14 consisted of brown clay (ODOT A-7-6), which extended to a depth of 3.0 feet below grade.

Beneath the surficial and fill materials, where encountered, natural cohesive and granular soils were encountered extending to the boring termination depths or top of bedrock. In general, the borings primarily encountered natural cohesive soils overlying deep granular deposits. The cohesive soils were generally described as gray, brown, dark brown, dark gray, and black sandy silt, silt, silt and clay, silty clay, and clay (ODOT A-4a, A-4b, A-6a, A-6b, A-7-6). The granular soils were generally described as brown, gray, brownish gray and dark gray gravel, gravel with sand, gravel with sand and silt, gravel with sand, silt, silt and clay, coarse and fine sand and sandy silt (ODOT A-1-a, A-1-b, A-2-4, A-2-6, A-3a, A-4a).

It should be noted that auger refusal was initially encountered in boring B-104-1-13 at a depth of 51.0 feet beneath the ground surface. Upon encountering auger refusal, a changeover to rock coring techniques was made, and 3.0 feet of rock coring was performed. Upon inspection of the recovered sample, it was determined that auger refusal had been encountered on granite and limestone boulders. As a result, the boring was offset 5.0 feet north of its original location, and soil sampling was continued until competent bedrock was encountered.

The shear strength and consistency of the cohesive soils are primarily derived from the hand penetrometer values (HP). The cohesive soil encountered ranged from stiff (1.0 < HP ≤ 2.0 tsf) to hard (HP > 4.0 tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 1.5 to over 4.5 tsf (limit of instrument).The relative density of the granular soils is derived from the SPT blow counts (N_{60}). The relative density of the granular soil encountered ranged from very loose (N_{60} < 5 blows per foot [bpf]) to very dense (N_{60} > 50 bpf). Overall blow counts recorded from the SPT sampling ranged from 3 bpf to split spoon sampler refusal. Split spoon sampler refusal is defined as exceeding 50 blows from the hammer with less than 6.0 inches of penetration by the split spoon sampler.

Natural moisture contents of the soil samples tested ranged from 4 to 31 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 5 percent below to 5 percent above the corresponding plastic limits. In general, the soil exhibited natural moisture contents considered to be moderately below to moderately above optimum moisture levels.

4.3 Bedrock

Bedrock was encountered in boring B-104-1-13 at a depth of 60.5 feet beneath the ground surface, corresponding to an elevation of 654.0 feet msl. Upon encountering competent bedrock, as defined by auger refusal, a changeover to rock coring techniques was made and 10.0 feet of rock core was obtained. The cored bedrock consisted of gray limestone, described as being unweathered, very strong, very thickly bedded, calcareous, siliceous, cherty, dolomitic, crystalline, and slightly to moderately fractured, with open apertures and a slightly rough to very rough surface. The percent recovery, RQD values and unconfined compressive strength results of the bedrock core runs in boring B-104-1-13 is summarized in Table 4.

Table 4. Rock Core Summary

Boring Number	Core No.	Elevation (feet msl)	Recovery (%)	RQD (%)	Rock Type	Unconfined Compressive Strength
B-104-1-13	RC-1	654.0 to 649.0	100	75	Limestone	N/A
	RC-2	649.0 to 644.0	90	70	Limestone	q_u @ 65.5' = 8,783 psi

It should be noted that bedrock experiences mechanical breaks during the drilling and coring processes. Rii attempted to account for fresh, manmade breaks during tabulation of the RQD analysis. The quality of the cored bedrock, according to the RQD values, was good (70 < RQD ≤ 85%).

4.4 Groundwater

Groundwater was encountered in a total of nine (9) of the eleven (11) borings analyzed as part of this investigation. A summary of the depths where groundwater was encountered in provided in Table 5.

Table 5. Groundwater Level Readings in Borings

Boring Number	Ground Elevation (feet msl)	Initial Groundwater		Upon Completion	
		Depth (feet)	Elevation (feet msl)	Depth [1] (feet)	Elevation (feet msl)
B-103-1-14	703.3	15.5	687.8	N/A	-
B-104-1-13	714.5	21.0	693.5	N/A	-
B-105-3-14	719.4	28.5	690.9	N/A	-
B-105-4-14	700.0	11.0	689.0	N/A	-
B-105-5-14	723.9	33.5	690.4	N/A	-
B-105-6-14	703.0	13.5	689.5	N/A	-
B-106-0-09	719.0	Dry	Dry	Dry	Dry
B-107-2-14	727.5	35.0	692.5	N/A	-
B-107-3-14	704.3	16.0	688.3	N/A	-
B-107-4-14	705.1	13.5	691.6	15.0	690.1
B-111-0-09	734.9	Dry	Dry	Dry	Dry

1. *N/A indicates that the groundwater level at the completion of drilling could not be obtained due to the addition of water or mud to the boreholes to counteract heaving sands.*

Groundwater was not encountered during or at the completion of drilling in borings B-106-0-09 and B-111-0-09. Groundwater was encountered in the remaining borings initially during drilling at depths ranging from 11.0 to 35.0 feet beneath the ground surface, corresponding to elevations ranging from 687.8 to 693.5 feet msl. With the exception of boring B-107-4-14, the groundwater level at the completion of drilling could not be obtained in these borings due to the addition of water or mud to the boreholes to counteract heaving sands. At the completion of drilling in boring B-107-4-14, groundwater was encountered at a depth of 15.0 feet below grade, corresponding to an elevation of 690.1 feet msl.

Please note that short-term water level readings, especially in cohesive materials, are not necessarily an accurate indication of the actual groundwater level. In addition, groundwater levels and the presence of groundwater are considered to be dependent on seasonal fluctuations in precipitation.

A more comprehensive description of what was encountered during the drilling process may be found on the boring logs in Appendix III.

5.0 ANALYSES AND RECOMMENDATIONS

Data obtained from the drilling and testing programs have been used to determine the foundation support capabilities and the settlement potential for the soil encountered at the site. These parameters have been used to provide guidelines for the design of foundation systems for the subject retaining wall, as well as the construction specifications related to the placement of foundation systems and general earthwork recommendations, which are discussed in the following paragraphs.

Design details of the proposed retaining wall were provided by the Rii design team. It is understood that a mechanically stabilized earth (MSE) wall type is being considered as the preferred wall type for the entire alignment of Retaining Wall W3. Based on the proposed plan and profile information, wall heights along the proposed alignment are anticipated to range from 12.8 feet near the northern terminus to a maximum height of 44.5 feet near Sta. 306+50 (BL Wall W3).

5.1 MSE Wall Recommendations

MSE walls are constructed on earthen foundations at a minimum depth of 3.0 feet below grade, as defined by the top of the leveling pad to the ground surface located 4.0 feet from the face of the wall. Per Section 840.04.A of ODOT Supplemental Specification 840 (SS 840) and Section 3.11.5.8.1 of the 2020 AASHTO LRFD BDS, the height of the MSE wall is defined as the elevation difference between the top of coping and the top of the leveling pad. However, it is noted that the reinforced soil mass only extends from the foundation bearing elevation (top of leveling pad) to the roadway subgrade elevation where the roadway is supported on the top of the wall, and the reinforced soil mass extends to the top of the coping where the roadway is not supported on top of the wall. The width of the MSE wall foundation (B) is defined by the length of the reinforced soil mass. Per the Section 307.4.A of the 2020 ODOT BDM and 840.04.A.2 of ODOT SS 840, the minimum length of the reinforced soil mass is equal to 70 percent of the height of the MSE wall or 8.0 feet, whichever is greater. A non-structural bearing leveling pad consisting of a minimum of 6.0-inches of unreinforced concrete should be placed at the base of the wall facing for constructability purposes. Please note that the leveling pad is not a structural foundation.

Based on the proposed plan and profile information, wall heights ranging from 12.8 feet at the northern terminus to 44.5 feet at Sta. 306+50 (BL Wall W3) are anticipated along the wall alignment, with the bottom of wall proposed to bear at a minimum depth of 4.0 feet beneath the proposed ground surface. For the analysis, the foundation width was set at 70 percent of the wall height, or a minimum width of 8.0 feet, and the foundation width was increased, if required, until external and global stability requirements were satisfied.

Per Section 840.06.D of ODOT SS 840, the foundation subgrade should be inspected to verify that the subsurface conditions are the same as those anticipated in this report. The anticipated soils at the proposed bearing elevation along the proposed wall alignment will consist of existing embankment fill comprised of stiff to hard sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) with seams of medium dense to very dense gravel with sand and gravel with sand, silt and clay (ODOT A-1-b, A-2-6), overlying natural granular soils comprise primarily of medium dense to very dense gravel, gravel with sand and gravel with sand and silt (ODOT A-1-a, A-1-b, A-2-4). The existing embankment fill extends to approximately elevation 705 feet msl along the existing ramp alignment. Based on the SPT N-values and hand penetrometer values within the existing embankment fill, this material is considered suitable for foundation support.

Per 307.4.C of the 2020 AASHTO LRFD BDS and Section 840.06.D of ODOT SS 840, following foundation subgrade inspection and acceptance, a minimum of 12.0 inches of ODOT Item 703.16.C, Granular Material Type C, should be placed and compacted in accordance with ODOT Item 204.07.

5.1.1 Strength Parameters Utilized in External and Global Stability Analyses

The shear strength parameters utilized in the external and global stability analyses for the MSE wall are provided in Table 6.

Table 6. Shear Strength Parameters Utilized in MSE Wall Stability Analyses

Material Type	γ (pcf)	φ' (1) (°)	c' (2) (psf)	S_u (3) (psf)
MSE Wall Backfill (Select granular fill)	120	34	0	N/A
Item 203 Embankment Fill (Retained soil)	120	30	0	2,000
Very Stiff Silt (ODOT A-4b)	120	29	0	2,250
Stiff to Hard Sandy Silt (ODOT A-4a)	115 to 130	28 to 29	50 to 60	1,500 to 8,000
Very Stiff to Hard Silt and Clay (ODOT A-6a)	120 to 130	27 to 28	0 to 50	2,125 to 8,000
Medium Stiff to Very Stiff Silty Clay (ODOT A-6b)	120 to 130	26	0	1,000 to 3,125
Medium Stiff to Very Stiff Clay (ODOT A-7-6)	115 to 125	25	0	1,000 to 3,500
Very Loose to Medium Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-6, A-3a, A-4a)	120 to 130	29 to 42	0	N/A
Dense to Very Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-4, A-3a)	130 to 135	37 to 43	0	N/A

1. *Per Figure 7-45, Section 7.6.9 of FHWA GEC 5 for cohesive soils and Table 10.4.6.2.4-1 of the 2020 AASHTO LRFS BDS for granular soils.*
2. *Estimated based on overconsolidated nature of soil.*
3. *S_u = 125(N_{60}), Terzaghi and Peck (1967).*

Shear strength parameters for the reinforced soil backfill and retained embankment are provided in Table 307-1 of the 2020 ODOT BDM and Section 840.04.A.3 of ODOT SS 840. Per these specifications, the select granular backfill in the reinforced zone and the retained embankment must meet the shear strength requirements provided in Table 6. The shear strength parameters for the natural soils were assigned using correlations provided in FHWA Geotechnical Engineering Circular (GEC) No. 5 (FHWA-NHI-16-072) Evaluation of Soil and Rock Properties and based on past experience in the vicinity of the site with projects performed in similar subsurface profiles.

5.1.2 Bearing Stability

The bearing soils along the proposed wall alignment are anticipated to consist of existing embankment fill comprised of stiff to hard sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) with seams of medium dense to very dense gravel with sand and gravel with sand, silt and clay (ODOT A-1-b, A-2-6). MSE wall foundations bearing on existing embankment fill or new embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a factored bearing resistance as indicated in Table 7. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state. Given that the bearing soils consist existing cohesive embankment, the bearing resistance was evaluated under both drained and undrained conditions. The reinforcement lengths presented in the following table represent the minimum foundation widths required to satisfy external and global stability requirements, expressed as a percentage of the wall height.

Table 7. Retaining Wall W3 MSE Wall Design Parameters

From Station [1]	To Station [1]	Wall Height Analyzed (feet)	Backslope Behind Wall in Analysis	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Strength Limit Equivalent Bearing Pressure [4] (ksf)
					Nominal	Factored [3]	
300+00	303+50	14.2	2:1 (Broken-Back)	13.5 (0.95H)	12.90	8.39	3.93
303+50	305+00	25.1	2:1 (Broken-Back)	18.8 (0.75H)	13.33	8.66	7.90
305+00	307+00	42.9	Level	38.6 (0.90H)	13.43	8.73	8.69
307+00	308+69	43.5	Level Backfill with Front Slope	47.9 (1.1H)	12.98	8.35 [(5)]	8.31

1. *Stationing is referenced to the baseline of Wall W3.*
2. *The required foundation width is expressed as a percentage of the wall height, H.*
3. *A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state.*
4. *The strength limit equivalent bearing pressure is the uniformly distributed pressure asserted by the wall over an effective base width based on the eccentricity of the wall system at the strength limit state.*
5. *The factored bearing resistance includes a reduction factor applied to the nominal resistance to account for the fore slope in front of the wall per Section 10.6.3.1.2c of the 2020 AASHTO LRFD BDM.*

For analysis of the wall section from Sta. 307+00 to 308+69 (BL Wall W3), the calculated factored bearing resistance includes a reduction factor applied to the nominal resistance to account for the fore slope in front of the wall per Section 10.6.3.1.2c of the 2020 AASHTO LRFD BDM.

Rii performed a verification of the bearing pressure exerted on the subgrade material for the specified wall heights indicated in Table 7. Based on the minimum length of reinforced soil mass presented, the factored equivalent bearing pressure exerted below the wall **will not exceed** the factored bearing resistance at the strength limit state.

In addition to the bearing resistance calculations performed assuming a traditional MSW wall with embankment backfill behind the wall, a bearing resistance calculation was also performed at Sta. 3015+00 (BL Ramp C3) where the straps from Wall W3 will overlap with the straps from Wall W5. For this analysis, the bearing resistance was checked assuming a foundation width equal to the entire width of the reinforced soil mass from wall facing to wall facing, and the nominal bearing resistance was reduced to account for the fore slope in front of the wall per Section 10.6.3.1.2c of the 2020 AASHTO LRFD BDM. A wall height of 41.0 feet was considered in the analysis check, which results in a factored bearing pressure of 7.82 ksf at the bottom of the wall. The calculated factored bearing resistance is 7.90 ksf, which satisfies the bearing resistance requirement.

5.1.3 Settlement Evaluation

The compressibility parameters utilized in the settlement analyses of the proposed MSE wall are provided in Table 8.

Table 8. Compressibility Parameters Utilized in Settlement Analysis

Material Type	γ (pcf)	LL (%)	C_c (1)	C_r (2)	e_o (3)	C_v (4) (ft²/yr)	N_{60}	C' (5)
Very Stiff to Hard Sandy Silt and Silt (ODOT A-4a, A-4b)	115 to 130	22 to 26	0.108 to 0.144	0.011 to 0.014	0.444 to 0.475	1,000	N/A	N/A
Very Stiff to Hard Silt and Clay (ODOT A-6a)	120 to 130	28 to 32	0.162 to 0.198	0.016 to 0.019	0.491 to 0.499	600	N/A	N/A
Medium Stiff to Very Stiff Silty Clay (ODOT A-6b)	120 to 130	37 to 38	0.243 to 0.252	0.024 to 0.025	0.561 to 0.569	300	N/A	N/A
Medium Stiff to Very Stiff Clay (ODOT A-7-6)	115 to 125	43	0.297	0.030	0.608	150	N/A	N/A
Medium Dense to Very Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-4, A-2-6, A-3a, A-4a)	130 to 135	N/A	N/A	N/A	N/A	N/A	24 to 100	65 to 631

1. *Per Table 6-9, Section 6.14.1 of FHWA GEC 5.*
2. *Estimated at 10% of C_c per Section 8.11 of Holtz and Kovacs (1981).*
3. *Per Table 8-2 of Holtz and Kovacs (1981).*
4. *Per Figure 6-37, Section 6.14.2 of FHWA GEC 5.*
5. *Per Figure 10.6.2.4.2-1 of 2020 AASHTO LRFD BDS.*

Results of the settlement analysis are tabulated in Table 9. Total settlements ranging from 1.14 to 7.81 inches at the center of the reinforced soil mass and 0.90 to 2.44 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W3. Based on the results of the analysis, 90 percent of the total settlement is anticipated to occur over a period of approximately 3 to 22 days. Please note that the consolidation settlement and time rate of consolidation are based on estimates using correlated compressibility parameters provided in Table 8 for the underlying soils. Actual settlement and time rate of consolidation should be determined by monitoring the settlement of the wall using settlement platforms.

Table 9. Retaining Wall W3 MSE Wall Settlement Values

From Station [1]	To Station [1]	Service Limit Equivalent Bearing Pressure [3] (ksf)	Total Settlement Values (inches)		Time for 90% Consolidation (Days)
			Center of Wall Mass	Facing of Wall	
300+00	303+50	2.72	1.14	0.90	11
303+50	305+00	5.37	3.07	1.23	16
305+00	307+00	6.23	7.81	2.44	22
307+00	308+69	5.17 to 6.00	5.08 to 6.68	1.89 to 2.01	3 to 22

1. *Station referenced to the baseline of Wall W3.*
2. *The service limit equivalent bearing pressure is the uniformly distributed pressure asserted by the wall over an effective base width based on the eccentricity of the wall system at the service limit state.*

Per Section 204.6.2.1 of the ODOT BDM, "the maximum allowable differential settlement in the longitudinal direction (regardless of the size of panels) is one (1) percent." Based on the total anticipated settlement at the facing of the walls, maximum differential settlements in the longitudinal directions are anticipated to be less than 1/150, which is within the tolerable limit of 1/100.

If the total or differential settlement values predicted for the proposed walls present an issue with respect to the deformation tolerances that the walls can withstand, then measures should be taken to minimize the amount of settlement that will occur. This can be achieved by preloading the site and consolidating the underlying soils prior to constructing the walls. If preloading the site is not a desired option, then consideration could be given to ground improvement through the use of stone columns. Guidelines for the implementation of ground improvement, if utilized for any segment along this wall, are provided in the structure foundation exploration report for Retaining Wall E4. Settlement calculations for Wall W3 are provided in Appendix V of this report.

5.1.4 Eccentricity (Overturning Stability)

The resistance of the MSE wall to overturning will be dependent on the on the location of the resultant force at the bottom of the wall due to the overturning and resisting moments acting on the wall. For MSE walls, overturning stability is determined by calculating the eccentricity of the resultant force from the midpoint of the base of the wall and comparing this value to a limiting eccentricity value. Per Section 11.10.5.5 of the 2020 AASHTO LRFD BDS, for foundations bearing on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds ($^2/_3$) of the base width. Therefore, the limiting eccentricity is one-third ($^1/_3$) of the base width of the wall. Rii performed a verification of the eccentricity of the resultant force for the specified wall heights indicated in Table 7. Based on the minimum length of reinforced soil mass presented in Table 7 and utilizing the soil parameters listed in Section 5.1.1 for the retained embankment material, the calculated eccentricity of the resultant force **will not exceed** the limiting eccentricity at the strength limit state.

5.1.5 Sliding Stability

The resistance of the MSE wall to sliding was evaluated per Section 11.10.5.3 of the 2020 AASHTO LRFD BDS. Given that the bearing soils consist of both cohesive and granular materials, the sliding resistance was evaluated for both drained and undrained conditions. For drained conditions, the sliding resistance is determined by multiplying a coefficient of sliding friction "f" times the total vertical force at the base of the wall. The coefficient of sliding friction is determined based on the limiting friction angle between the foundation soil and the reinforced soil backfill. Based on the soil parameters listed in Section 5.1.1 for the foundation and reinforced soil backfill material, a coefficient of sliding friction of 0.53 was utilized for design. For undrained conditions, the sliding resistance is taken as the limiting value between the undrained shear strength of the bearing soil and half of the vertical stress applied by the wall multiplied by the width of the MSE wall. Based on the soil parameters listed in Section 5.1.1, the undrained shear strength of the cohesive bearing material was taken as 2.5 ksf.

A geotechnical resistance factor of φ_τ=1.0 was considered in calculating the factored shear resistance. Based on the minimum length of reinforced soil mass presented in Table 7 and utilizing the soil parameters listed in Section 5.1.1 for the retained embankment material, the resultant horizontal forces on the back of the MSE wall **will not exceed** the factored shear resistance at the strength limit state for drained or undrained conditions.

5.1.6 Overall (Global) Stability

A slope stability analysis was performed to check the global stability of the wall. As per Section 11.6.2.3 of the 2020 AASHTO LRFD BDS, safety against soil failure shall be evaluated at the service limit state by assuming the reinforced soil mass to be a rigid body. Soil parameters utilized in the global stability analyses are presented in Table 6. For the global stability condition, it was considered that the failure plane will not cross through the reinforced soil mass. The computer software program Slide, manufactured by Rocscience Inc., was utilized to perform the analyses.

Per Section 307.1.2 of the 2020 ODOT BDM and Section 11.6.2.3 of the 2018 AASHTO LRFD BDS, overall (global) stability for MSE walls that are not integrated with or supporting structural foundations or elements, global stability is satisfied if the product of the factor of safety from the slope stability output multiplied by the resistance factor φ=0.75 is greater than 1.0. Therefore, global stability is satisfied when a minimum factor of safety of 1.3 is obtained. Overall stability analysis was performed considering the cross sections at Sta. 3008+50, 3010+50 and 3012+00 (BL Ramp C3), to represent the variable geometric dimensions of the MSE wall along the wall alignment. For MSE walls designed with a minimum strap length listed in Table 7, the resulting factor of safety under drained conditions (long-term stability) was greater than 1.3.

5.1.7 Final MSE Wall Considerations

Based on the results of the external and global stability analysis performed for Retaining Wall W3, the recommended controlling strap length is 0.75 to 1.10 times the height of the MSE wall (measured from the top of the leveling pad to the top of wall) with statin limits as identified in Table 7. Sliding resistance under drained conditions and bearing resistance under undrained conditions were the controlling factors in the determination of the recommended strap lengths.

Calculations for external (bearing and sliding resistance and limiting eccentricity) and overall (global) stability of the MSE walls are provided in Appendix IV.

5.2 Lateral Earth Pressure

For the soil types encountered in the borings, the “in-situ” unit weight (γ), cohesion (c), effective angle of friction (φ'), and lateral earth pressure coefficients for at-rest conditions (k_o), active conditions (k_a), and passive conditions (k_p) have been estimated and are provided in Table 10 and Table 11.

Table 10. Estimated Undrained (Short-term) Soil Parameters for Design

Soil Type	γ (pcf) [1]	*c* (psf)	φ	k_a	k_o	k_p
Soft to Stiff Cohesive Soil	115	1,500	0°	N/A	N/A	N/A
Very Stiff to Hard Cohesive Soil	125	3,000	0°	N/A	N/A	N/A
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	2,000	0°	N/A	N/A	N/A
Compacted Granular Engineered Fill	120	0	32°	0.27	0.47	6.82

1. *When below groundwater table, use effective unit weight, γ' = γ - 62.4 pcf and add hydrostatic water pressure.*

Table 11. Estimated Drained (Long-term) Soil Parameters for Design

Soil Type	γ (pcf) [1]	*c* (psf)	φ'	k_a	k_o	k_p
Soft to Stiff Cohesive Soil	115	0	26°	0.35	0.56	4.53
Very Stiff to Hard Cohesive Soil	125	50	28°	0.32	0.53	5.07
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	0	30°	0.30	0.50	5.58
Compacted Granular Engineered Fill	120	0	32°	0.27	0.47	6.82

1. *When below groundwater table, use effective unit weight, γ' = γ - 62.4 pcf and add hydrostatic water pressure.*

These parameters are considered appropriate for the design of all subsurface structures and any excavation support systems. Subsurface structures (where the top of the structure is restrained from movement) should be designed based on at-rest conditions (k_o). For proposed temporary retaining structures (where the top of the structure is allowed to move), earth pressure distributions should be based on active (k_a) and passive (k_p) conditions. Active earth pressure is developed as the structure moves away from the backfill or retained soil, while passive pressure is developed as the structure moves towards the backfill. A relatively small amount of lateral movement is needed to reach the active condition (≥ 0.1 percent of the height), whereas the movements required to engage the passive condition are approximately ten times greater than those required to develop active earth pressure. The values in this table have been estimated from correlation charts based on minimum standards specified for compacted engineered fill materials.

These recommendations do not take into consideration the effect of any surcharge loading or a sloped ground surface (a flat surface is assumed). Earth pressures on excavation support systems will be dependent on the type of sheeting and method of bracing or anchorage. Surcharge loads, such as that imposed by traffic loading, will create additional lateral loading on the subsurface structures and excavation support systems. The resulting lateral earth pressure should be evaluated based on active (k_a) and at-rest (k_o) conditions and the anticipated magnitude of the loading.

5.3 Construction Considerations

All site work shall conform to local codes and to the latest ODOT Construction and Materials Specifications (CMS), including that all excavation and embankment preparation and construction should follow ODOT Item 200 (Earthwork) and MSE Wall Construction and foundation preparation follows Supplemental Specification 840.

5.3.1 Excavation Considerations

All excavations should be shored / braced or laid back at a safe angle in accordance to Occupational Safety and Health Administration (OSHA) guidelines. During excavation, if slopes cannot be laid back to OSHA Standards due to adjacent structures or other obstructions, temporary shoring may be required. The following table should be utilized as a general guide for implementing OSHA guidelines when estimating excavation back slopes at the various boring locations. Actual excavation back slopes must be field verified by qualified personnel at the time of excavation in strict accordance with OSHA guidelines.

Table 12. Excavation Back Slopes

Soil	Maximum Back Slope	Notes
Soft to Medium Stiff Cohesive	1.5 : 1.0	Above Ground Water Table and No Seepage
Stiff Cohesive	1.0 : 1.0	Above Ground Water Table and No Seepage
Very Stiff to Hard Cohesive	0.75 : 1.0	Above Ground Water Table and No Seepage
All Granular & Cohesive Soil Below Ground Water Table or with Seepage	1.5 : 1.0	None

5.3.2 Groundwater Considerations

Based on the groundwater observations made during drilling, little to no groundwater seepage is anticipated during construction. However, where/if groundwater is encountered, proper groundwater control should be employed and maintained to prevent disturbance to excavation bottoms consisting of cohesive soil, and to prevent the possible development of a quick or "boiling" condition where soft silts and/or fine sands are encountered. It is preferable that the groundwater level, if encountered, be maintained at least 36.0 inches below the deepest excavation. Any seepage or groundwater encountered at this site should be able to be controlled by pumping from temporary sumps. Additional measures may be required depending on seasonal fluctuations of the groundwater level. Note that determining and maintaining actual groundwater levels during construction is the responsibility of the contractor.

6.0 LIMITATIONS OF STUDY

The above recommendations are predicated upon construction inspection by a qualified soil technician under the direct supervision of a professional geotechnical engineer. Adequate testing and inspection during construction are considered necessary to assure an adequate foundation system and are part of these recommendations.

The recommendations for this project were developed utilizing soil and bedrock information obtained from the test borings that were made at the proposed site for the current investigation. Resource International is not responsible for the data, conclusions, opinions or recommendations made by others during previous investigations at this site. At this time we would like to point out that soil borings only depict the soil and bedrock conditions at the specific locations and time at which they were made. The conditions at other locations on the site may differ from those occurring at the boring locations.

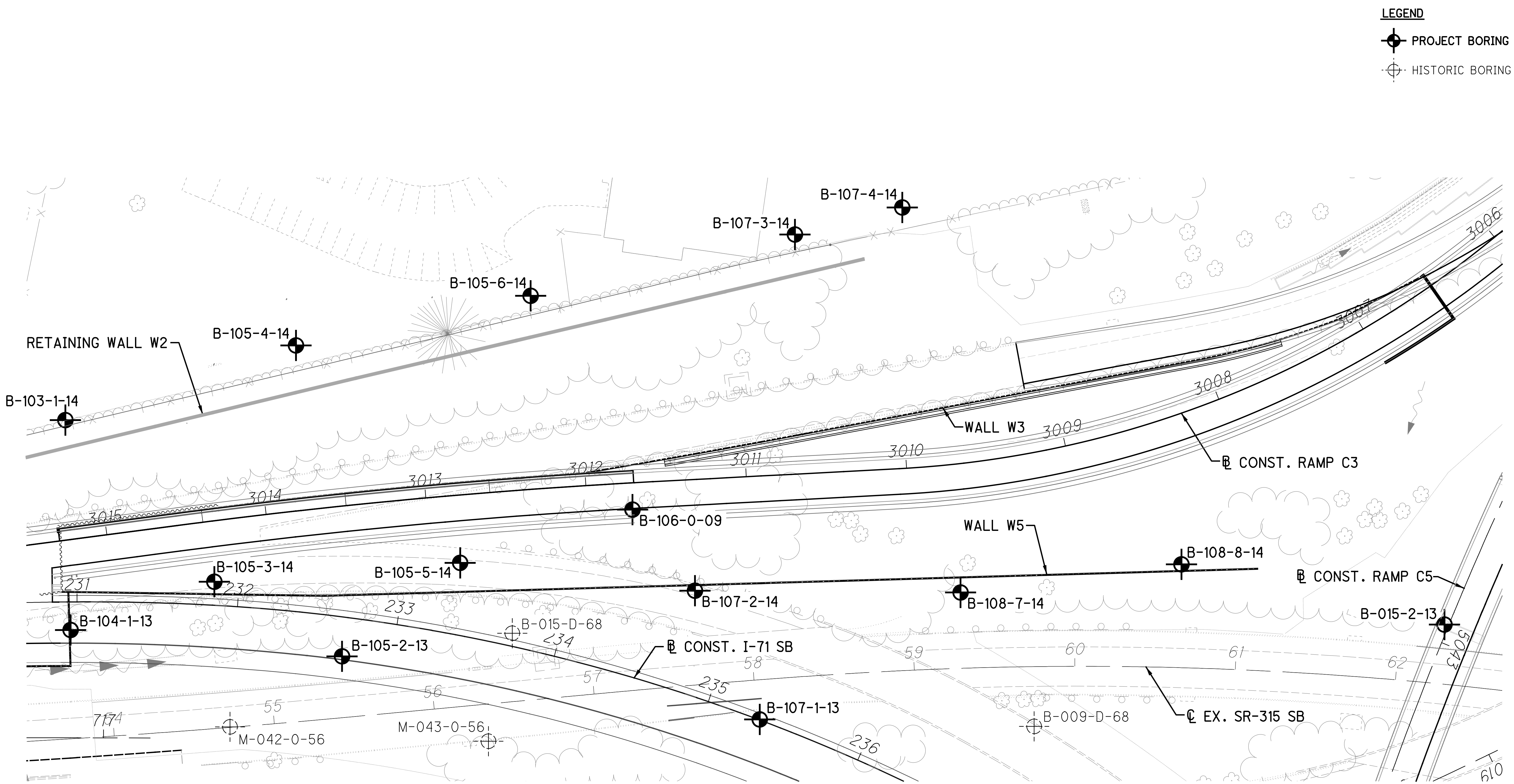
The conclusions and recommendations herein have been based upon the available soil and bedrock information and the design details furnished by a representative of the owner of the proposed project. Any revision in the plans for the proposed construction from those anticipated in this report should be brought to the attention of the geotechnical engineer to determine whether any changes in the foundation or earthwork recommendations are necessary. If deviations from the noted subsurface conditions are encountered during construction, they should also be brought to the attention of the geotechnical engineer.

The scope of our services does not include any environmental assessment or investigation for the presence or absence of hazardous or toxic materials in the soil, groundwater or surface water within or beyond the site studied. Any statements in this report or on the test boring logs regarding odors, staining of soils or other unusual conditions observed are strictly for the information of our client.

Our professional services have been performed, our findings obtained and our recommendations prepared in accordance with generally accepted geotechnical engineering principles and practices. Resource International is not responsible for the conclusions, opinions or recommendations made by others based upon the data included.

APPENDIX I

VICINITY MAP AND BORING PLAN



BORING PLAN **FRA-70-13.10 - WALL W3** **FRANKLIN COUNTY, OHIO**	PROJECT NO. Rii W-13-072	DRAWN RRM	RESOURCE INTERNATIONAL
	SCALE: 1"=60' 0 30 60	REVIEWED BRT	
		DATE 6/21/2021	

APPENDIX II

DESCRIPTION OF SOIL TERMS

DESCRIPTION OF SOIL TERMS

The following terminology was used to describe soils throughout this report and is generally adapted from ASTM 2487/2488 and ODOT Specifications for Geotechnical Explorations.

Granular Soils - The relative compactness of granular soils is described as:
ODOT A-1, A-2, A-3, A-4 (non-plastic) or USCS GW, GP, GM, GC, SW, SP, SM, SC, ML (non-plastic)

Description	Blows per foot – SPT (N_{60})		
Very Loose	Below		5
Loose	5	-	10
Medium Dense	11	-	30
Dense	31	-	50
Very Dense	Over		50

Cohesive Soils - The relative consistency of cohesive soils is described as:
ODOT A-4, A-5, A-6, A-7, A-8 or USCS ML, CL, OL, MH, CH, OH, PT

Description	Blows per foot – SPT (N_{60})			Unconfined Compression (tsf)
Very Soft	Below		2	UCS ≤ 0.25
Soft	2	-	4	0.25 < UCS ≤ 0.5
Medium Stiff	5	-	8	0.5 < UCS ≤ 1.0
Stiff	9	-	15	1.0 < UCS ≤ 2.0
Very Stiff	16	-	30	2.0 < UCS ≤ 4.0
Hard	Over		30	UCS > 4.0

Gradation - The following size-related denominations are used to describe soils:

Soil Fraction		USCS Size	ODOT Size
Boulders		Larger than 12”	Larger than 12”
Cobbles		12” to 3”	12” to 3”
Gravel	coarse	3” to ¾”	3” to ¾“
	fine	¾” to 4.75 mm (¾” to #4 Sieve)	¾” to 2.0 mm (¾” to #10 Sieve)
Sand	coarse	4.75 mm to 2.0 mm (#4 to #10 Sieve)	2.0 mm to 0.42 mm (#10 to #40 Sieve)
	medium	2.0 mm to 0.42 mm (#10 to #40 Sieve)	-
	fine	0.42 mm to 0.074 mm (#40 to #200 Sieve)	0.42 mm to 0.074 mm (#40 to #200 Sieve)
Silt		0.074 mm to 0.005 mm (#200 to 0.005 mm)	0.074 mm to 0.005 mm (#200 to 0.005 mm)
Clay		Smaller than 0.005 mm	Smaller than 0.005 mm

Modifiers of Components - Modifiers of components are as follows:

Term	Range		
Trace	0%	-	10%
Little	10%	-	20%
Some	20%	-	35%
And	35%	-	50%

Moisture Table - The following moisture-related denominations are used to describe cohesive soils:

Term	Range - USCS	Range - ODOT
Dry	0% to 10%	Well below Plastic Limit
Damp	>2% below Plastic Limit	Below Plastic Limit
Moist	2% below to 2% above Plastic Limit	Above PL to 3% below LL
Very Moist	>2% above Plastic Limit	
Wet	³ Liquid Limit	3% below LL to above LL

Organic Content – The following terms are used to describe organic soils:

Term	Organic Content (%)
Slightly organic	2-4
Moderately organic	4-10
Highly organic	>10

Bedrock – The following terms are used to describe bedrock hardness:

Term	Blows per foot – SPT (N)		
Very Soft	Below		50
Soft	50/5”	–	50/6”
Medium Hard	50/3”	–	50/4”
Hard	50/1”	–	50/2”
Very Hard	50/0”		

CLASSIFICATION OF SOILS

Ohio Department of Transportation

(The classification of a soil is found by proceeding from top to bottom of the chart. The first classification that the test data fits is the correct classification.)

SYMBOL	DESCRIPTION	Classifcation AASHTO	OHIO	LL_O/LL x 100*	% Pass #40	% Pass #200	Liquid Limit (LL)	Plastic Index (PI)	Group Index Max.	REMARKS
	Gravel and/or Stone Fragments	A-1-a			30 Max.	15 Max.		6 Max.	0	Min. of 50% combined gravel, cobble and boulder sizes
	Gravel and/or Stone Fragments with Sand	A-1-b			50 Max.	25 Max.		6 Max.	0	
F.S.	Fine Sand	A-3			51 Min.	10 Max.	NON-PLASTIC		0	
	Coarse and Fine Sand	--	A-3a			35 Max.		6 Max.	0	Min. of 50% combined coarse and fine sand sizes
	Gravel and/or Stone Fragments with Sand and Silt	A-2-4				35 Max.	40 Max.	10 Max.	0	
		A-2-5					41 Min.			
	Gravel and/or Stone Fragments with Sand, Silt and Clay	A-2-6				35 Max.	40 Max.	11 Min.	4	
		A-2-7					41 Min.			
	Sandy Silt	A-4	A-4a	76 Min.		36 Min.	40 Max.	10 Max.	8	Less than 50% silt sizes
	Silt	A-4	A-4b	76 Min.		50 Min.	40 Max.	10 Max.	8	50% or more silt sizes
	Elastic Silt and Clay	A-5		76 Min.		36 Min.	41 Min.	10 Max.	12	
	Silt and Clay	A-6	A-6a	76 Min.		36 Min.	40 Max.	11 - 15	10	
	Silty Clay	A-6	A-6b	76 Min.		36 Min.	40 Max.	16 Min.	16	
	Elastic Clay	A-7-5		76 Min.		36 Min.	41 Min.	≤LL-30	20	
	Clay	A-7-6		76 Min.		36 Min.	41 Min.	>LL-30	20	
	Organic Silt	A-8	A-8a	75 Max.		36 Min.				W/o organics would classify as A-4a or A-4b
	Organic Clay	A-8	A-8b	75 Max.		36 Min.				W/o organics would classify as A-5, A-6a, A-6b, A-7-5 or A-7-6

MATERIAL CLASSIFIED BY VISUAL INSPECTION

- Sod and Topsoil
- Pavement or Base
- Uncontrolled Fill (Describe)
- Bouldery Zone
- Peat, S-Sedimentary W-Woody F-Fibrous L-Loamy & etc

* Only perform the oven-dried liquid limit test and this calculation if organic material is present in the sample.

BORING LOGS

Definitions of Abbreviations

AS = Auger sample

GI = Group index as determined from the Ohio Department of Transportation classification system

HP = Unconfined compressive strength as determined by a hand penetrometer (tons per square foot)

LL_o = Oven-dried liquid limit as determined by ASTM D4318. Per ASTM D2487, if LL_o/LL is less than 75 percent, soil is classified as “organic”.

LOI = Percent organic content (by weight) as determined by ASTM D2974 (loss on ignition test)

PID = Photo-ionization detector reading (parts per million)

QR = Unconfined compressive strength of intact rock core sample as determined by ASTM D2938 (pounds per square inch)

QU = Unconfined compressive strength of soil sample as determined by ASTM D2166 (pounds per square foot)

RC = Rock core sample

REC = Ratio of total length of recovered soil or rock to the total sample length, expressed as a percentage

RQD = Rock quality designation – estimate of the degree of jointing or fracture in a rock mass, expressed as a percentage:

$$\frac{\sum \text{segments equal to or longer than 4.0 inches}}{\text{core run length}} \times 100$$

S = Sulfate content (parts per million)

SPT = Standard penetration test blow counts, per ASTM D1586. Driving resistance recorded in terms of blows per 6-inch interval while letting a 140-pound hammer free fall 30 inches to drive a 2-inch outer diameter (O.D.) split spoon sampler a total of 18 inches. The second and third intervals are added to obtain the number of blows per foot (N_m).

N_{60} = Measured blow counts corrected to an equivalent (60 percent) energy ratio (ER) by the following equation: $N_{60} = N_m$*(ER/60)

SS = Split spoon sample

2S = For instances of no recovery from standard SS interval, a 2.5 inch O.D. split spoon is driven the full length of the standard SS interval plus an additional 6.0 inches to obtain a representative sample. Only the final 6.0 inches of sample is retained. Blow counts from 2S sampling are not correlated with N_{60} values.

3S = Same as 2S, but using a 3.0 inch O.D. split spoon sampler.

TR = Top of rock

W = Initial water level measured during drilling

▼ = Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

GR = % Gravel
SA = % Sand
SI = % Silt
CL = % Clay

Atterberg Limits:

LL = Liquid limit
PL = Plastic limit
PI = Plasticity Index

WC = Water content (%)

APPENDIX III

PROJECT BORING LOGS

B-103-1-14, B-104-1-14, B-105-3-14 through B-105-6-14, B-106-0-09, B 107-2-14 through B-107-4-14 and B-111-0-09

BORING LOGS

Definitions of Abbreviations

AS	=	Auger sample
GI	=	Group index as determined from the Ohio Department of Transportation classification system
HP	=	Unconfined compressive strength as determined by a hand penetrometer (tons per square foot)
LL_o	=	Oven-dried liquid limit as determined by ASTM D4318. Per ASTM D2487, if LL_o/LL is less than 75 percent, soil is classified as "organic".
LOI	=	Percent organic content (by weight) as determined by ASTM D2974 (loss on ignition test)
PID	=	Photo-ionization detector reading (parts per million)
QR	=	Unconfined compressive strength of intact rock core sample as determined by ASTM D2938 (pounds per square inch)
QU	=	Unconfined compressive strength of soil sample as determined by ASTM D2166 (pounds per square foot)
RC	=	Rock core sample
REC	=	Ratio of total length of recovered soil or rock to the total sample length, expressed as a percentage
RQD	=	Rock quality designation – estimate of the degree of jointing or fracture in a rock mass, expressed as a percentage: $$\frac{\sum \text{segments equal to or longer than 4.0 inches}}{\text{core run length}} \times 100$$
S	=	Sulfate content (parts per million)
SPT	=	Standard penetration test blow counts, per ASTM D1586. Driving resistance recorded in terms of blows per 6-inch interval while letting a 140-pound hammer free fall 30 inches to drive a 2-inch outer diameter (O.D.) split spoon sampler a total of 18 inches. The second and third intervals are added to obtain the number of blows per foot (N_m).
N_{60}	=	Measured blow counts corrected to an equivalent (60 percent) energy ratio (ER) by the following equation: $N_{60} = N_m*(ER/60)$
SS	=	Split spoon sample
2S	=	For instances of no recovery from standard SS interval, a 2.5 inch O.D. split spoon is driven the full length of the standard SS interval plus an additional 6.0 inches to obtain a representative sample. Only the final 6.0 inches of sample is retained. Blow counts from 2S sampling are not correlated with N_{60} values.
3S	=	Same as 2S, but using a 3.0 inch O.D. split spoon sampler.
TR	=	Top of rock
W	=	Initial water level measured during drilling
▼	=	Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

GR	=	% Gravel
SA	=	% Sand
SI	=	% Silt
CL	=	% Clay

Atterberg Limits:

LL	=	Liquid limit
PL	=	Plastic limit
PI	=	Plasticity Index

WC	=	Water content (%)

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750 (SN 98048)	STATION / OFFSET: 3015+16.32 / 74.2' RT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 703.3 (MSL) EOB: 54.3 ft.
START: 3/26/15 END: 3/27/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92.9	LAT / LONG: 39.947764, -83.016137

EXPLORATION ID **B-103-1-14**

MATERIAL DESCRIPTION AND NOTES	ELEV. 703.3	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
0.1' - TOPSOIL (1.0")	703.2																	
STIFF TO VERY STIFF, DARK GRAY TO DARK GRAYISH BROWN **CLAY**, LITTLE TO "AND" SILT, TRACE TO SOME COARSE TO FINE SAND, TRACE TO SOME FINE GRAVEL, DAMP TO MOIST.		1–2	5 4 3	11	33	SS-1	1.50	-	-	-	-	-	-	-	-	28	A-7-6 (V)	
		4–5	1 6 7	20	100	SS-2	3.50	5	3	3	58	31	54	25	29	23	A-7-6 (18)	
		6–7	2 4 6	15	100	SS-3	3.50	-	-	-	-	-	-	-	-	24	A-7-6 (V)	
-ROCK FRAGMENTS PRESENT IN SS-4	692.8	9–10	1 4 4	12	78	SS-4	1.50	33	21	7	15	24	43	21	22	18	A-7-6 (4)	
MEDIUM DENSE TO DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		11–12	5 8 7	23	33	SS-5	-	-	-	-	-	-	-	-	-	4	A-1-a (V)	
-COBBLES PRESENT @ 13.0'		14–15	7 14 10	36	0	SS-6	-	-	-	-	-	-	-	-	-	-		
		W 15	4	-	100	3S-6A	-	69	19	5	6	1	NP	NP	NP	14	A-1-a (0)	
		16–17	7 4 5	14	0	SS-7	-	-	-	-	-	-	-	-	-	-		
	685.3	18	6	-	100	3S-7A	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	
DENSE TO VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 18.5'		19–20	8 9 12	32	100	SS-8	-	-	-	-	-	-	-	-	-	17	A-1-b (V)	
-INTRODUCED MUD @ 20.0'		24–25	7 10 10	30	100	SS-9	-	37	51	4	5	3	NP	NP	NP	13	A-1-b (0)	
		29–30	6 18 16	51	100	SS-10	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	

PID: 89464	BR ID: N/A	PROJECT: FRA-70-13.10 - PHASE 6A	STATION / OFFSET: 3015+16.32 / 74.2 RT	START: 3/26/15	END: 3/27/15	PG 2 OF 2	B-103-1-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 673.3	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
DENSE TO VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST. *(same as above)*		31–33																
		34	7 16 16	48	100	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		35–38																
		39	21 10 12	33	67	SS-12	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	661.3	40–41																
HARD, GRAY **SANDY SILT**, SOME CLAY, SOME FINE GRAVEL, DAMP.		42–43																
		44	10 34 45	119	100	SS-13	4.5+	23	13	17	25	22	22	12	10	10	A-4a (2)	
	656.3	45–46																
VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		47–48																
		49	17 27 30	86	100	SS-14	-	-	-	-	-	-	-	-	-	16	A-1-b (V)	
		50–53																
-ROCK FRAGMENTS PRESENT IN SS-15	649.0	54 EOB	30 50/4"	-	100	SS-15	-	34	39	13	8	6	NP	NP	NP	13	A-1-b (0)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 15.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 250 LBS BENTONITE CHIPS AND SOIL CUTTINGS

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / J.K.	DRILL RIG: MOBILE B-53 (SN 624400)	STATION / OFFSET: 230+95.90 / 17.5' RT	EXPLORATION ID **B-104-1-13**
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / S.B./J.P.	HAMMER: AUTOMATIC	ALIGNMENT: BL I-71 SB	
PID: 89464 BR ID: FRA-71-1503L	DRILLING METHOD: 3.25" HSA / NQ	CALIBRATION DATE: 4/26/13	ELEVATION: 714.5 (MSL) EOB: 70.5 ft.	PAGE 1 OF 3
START: 6/4/14 END: 6/26/14	SAMPLING METHOD: SPT / RC	ENERGY RATIO (%): 77.7	LAT / LONG: 39.947937, -83.015728	

MATERIAL DESCRIPTION AND NOTES	ELEV. 714.5	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
0.3' - TOPSOIL (4.0")	714.2																	
FILL: VERY STIFF TO HARD, DARK BROWN TO GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE TO SOME FINE GRAVEL, DAMP TO MOIST.		1–2	5 9 13	28	67	SS-1	4.25	-	-	-	-	-	-	-	-	11	A-6a (V)	
		4–5	11 9 10	25	67	SS-2	4.25	16	12	14	29	29	25	14	11	15	A-6a (5)	
		6–7	3 5 25	39	78	SS-3	4.50	-	-	-	-	-	-	-	-	17	A-6a (V)	
-ROCK FRAGMENTS PRESENT IN SS-4		9–10	6 6 9	19	33	SS-4	3.00	-	-	-	-	-	-	-	-	18	A-6a (V)	
-ORGANIC ODOR PRESENT IN SS-5	701.5	11–12	4 3 5	10	44	SS-5	3.50	32	18	10	19	21	31	16	15	18	A-6a (2)	
MEDIUM DENSE, BROWN **COARSE AND FINE SAND**, SOME SILT, TRACE CLAY, MOIST.	699.0	14–15	3 4 5	12	67	SS-6	-	0	10	59	21	10	NP	NP	NP	14	A-3a (0)	
MEDIUM DENSE TO VERY DENSE, BROWN TO BROWNISH GRAY **GRAVEL**, TRACE TO SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		16–17	14 21 17	49	67	SS-7	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		W 18; 19–20	9 11 14	32	100	SS-8	-	97	1	1	1	0	NP	NP	NP	8	A-1-a (0)	
		W 21; 21–22	5 12 13	32	89	SS-9	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
		24–25	10 11 11	28	100	SS-10	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		26–27	15 25 21	60	78	SS-11	-	68	12	10	6	4	NP	NP	NP	8	A-1-a (0)	
		29	13 17 21	49	100	SS-12	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	

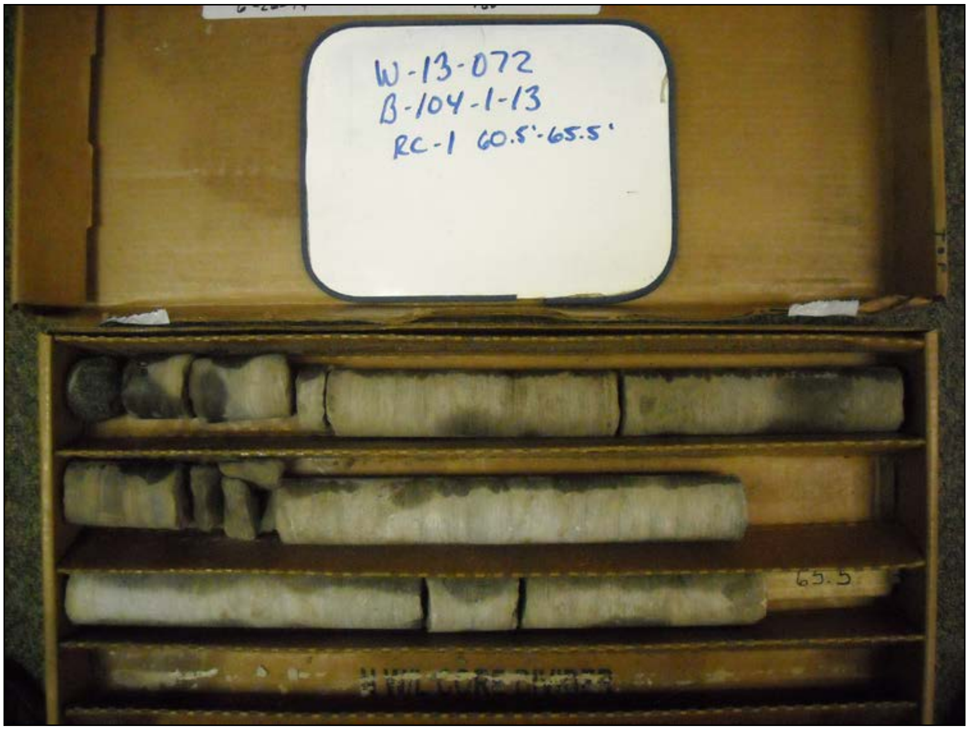
MATERIAL DESCRIPTION AND NOTES	ELEV. 684.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
MEDIUM DENSE TO VERY DENSE, BROWN TO BROWNISH GRAY **GRAVEL**, TRACE TO SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. *(same as above)*	682.5	31 – 32																
MEDIUM DENSE TO VERY DENSE, DARK BROWNISH GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		33 – 35	10 11 11	28	100	SS-13	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
-COBBLES PRESENT FROM 35.0' TO 38.5'		38 – 39	50/2"	-	0	SS-14	-	-	-	-	-	-	-	-	-	-		
	672.5	40 – 42																
VERY LOOSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		43 – 45	3 1 1	3	100	SS-15	-	39	43	6	2	10	NP	NP	NP	12	A-1-b (0)	
	667.5	46 – 47																
VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 48.5' -INTRODUCED MUD @ 48.5'		48 – 50	16 25 50/2"	-	100	SS-16	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
AUGER REFUSAL @ 51.0'	663.5	51																
GRANITE AND LIMESTONE BOULDERS. -BORING TERMINATED @ 54.0' ON 6-5-14. OFFSET BORING 5.0' NORTH AND CONTINUED SAMPLING @ 58.5' ON 6-26-14.	660.5	51 – 54	0		25	RC-1											CORE	
HARD, BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -COBBLES PRESENT THROUGHOUT		58.5 – 59	50/3"	-	33	SS-17	-	-	-	-	-	-	-	-	-	-	A-6a (V)	
	654.0	59 – 60 TR	50/4"	-	50	3S-17A	-	-	-	-	-	-	-	-	-	11	A-6a (V)	
		61																

PID: 89464	BR ID: FRA-71-1503L	PROJECT: FRA-70-13.10 - PHASE 6A	STATION / OFFSET: 230+95.90 / 17.5 RT	START: 6/4/14	END: 6/26/14	PG 3 OF 3	B-104-1-13

MATERIAL DESCRIPTION AND NOTES	ELEV. 652.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
LIMESTONE : GRAY, UNWEATHERED, VERY STRONG, VERY THICK BEDDED, CALCAREOUS, SILICEOUS, CHERTY, DOLOMITIC, CRYSTALLINE, SLIGHTLY TO MODERATELY FRACTURED, OPEN APERTURES, SLIGHTLY TO VERY ROUGH; RQD 73%, REC 95%. *(same as above)* -QU @ 65.5' = 8,783 PSI		63	75		100	RC-2											CORE	
		64																
		65																
		66																
		67																
		68	70		90	RC-3											CORE	
		69																
	644.0	70 EOB																

NOTES: SEEPAGE ENCOUNTERED @ 18.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 21.0'; CAVE-IN DEPTH @ 45.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 188 LBS CEMENT / 50 LBS BENTONITE POWDER / 40 GAL WATER



B-104-1-13 – RC-1 – Depth from 60.5 to 65.5 feet

B-104-1-13 – RC-2 – Depth from 65.5 to 70.5 feet

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME-55 (SN 386345)	STATION / OFFSET: 3014+37.27 / 37.7' LT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 719.4 (MSL) EOB: 55.0 ft.
START: 4/27/15 END: 4/28/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	LAT / LONG: 39.948118, -83.015970

EXPLORATION ID **B-105-3-14**

MATERIAL DESCRIPTION AND NOTES	ELEV. 719.4 (bottom of layer)
0.3' - ASPHALT (4.0")	719.1
0.8' - CONCRETE (9.5")	718.3
0.5' - AGGREGATE BASE (6.0")	717.8
FILL: VERY STIFF TO HARD, GRAYISH BROWN **SANDY SILT**, LITTLE TO SOME CLAY, LITTLE TO SOME FINE GRAVEL, DAMP. -ROCK FRAGMENTS PRESENT IN SS-2	708.9
VERY DENSE, DARK GRAY **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, LITTLE SILT, DAMP. -ROCK FRAGMENTS PRESENT IN SS-5	706.4
VERY DENSE, DARK BROWN **GRAVEL WITH SAND AND SILT**, TRACE CLAY, DAMP.	701.4
HARD, BROWN **CLAY**, "AND" SILT, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	697.4
DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, DAMP.	694.7
HARD, BROWN **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, MOIST.	692.4
MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST. -INTRODUCED MUD @ 28.5'	

Depths shown: 1 – 29 ft; W (water) noted at about 28.5 ft.

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
3, 6, 8	21	33	SS-1	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)
3, 5, 14	29	89	SS-2	4.5+	20	10	15	33	22	26	16	10	13	A-4a (4)
4, 7, 7	21	100	SS-3	3.25	34	13	12	27	14	26	16	10	13	A-4a (1)
2, 5, 6	17	100	SS-4	2.25	-	-	-	-	-	-	-	-	15	A-4a (V)
13, 23, 21	66	100	SS-5	-	-	-	-	-	-	-	-	-	5	A-3a (V)
4, 24, 29	80	100	SS-6	-	44	16	12	19	9	25	16	9	8	A-2-4 (0)
13, 33, 21	81	100	SS-7	-	-	-	-	-	-	-	-	-	5	A-2-4 (V)
4, 8, 10	27	89	SS-8	4.5+	3	4	9	36	48	43	22	21	22	A-7-6 (13)
7, 9, 11	30	100	SS-9	-	-	-	-	-	-	-	-	-	7	A-2-6 (V)
				-	11	5	24	33	27	23	14	9	16	A-4a (5)
3, 11, 5	24	67	SS-10	-	-	-	-	-	-	-	-	-	13	A-2-6 (V)

PID: 89464	BR ID: N/A	PROJECT: FRA-70-13.10 - PHASE 6A	STATION / OFFSET: 3014+37.27 / 37.7 LT	START: 4/27/15	END: 4/28/15	PG 2 OF 2	B-105-3-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 689.4	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
MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST. *(same as above)*	687.4	31–32																
DENSE TO VERY DENSE, BROWN TO GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		34	14 19 27	69	72	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-a (V)	
		39	9 17 8	38	100	SS-12	-	55	25	6	10	4	22	18	4	10	A-1-a (0)	
		44	3 13 13	39	72	SS-13	-	-	-	-	-	-	-	-	-	13	A-1-a (V)	
-HEAVING SANDS ENCOUNTERED @ 48.5'		49	23 30 44	111	100	SS-14	-	63	21	9	5	2	NP	NP	NP	7	A-1-a (0)	
	664.4	54 (EOB 55)	7 25 22	71	100	SS-15	-	-	-	-	-	-	-	-	-	5	A-1-a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 28.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER SOIL CUTTINGS

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750X (SN 310218)	STATION / OFFSET: 3013+70.11 / 102.6' RT	EXPLORATION ID **B-105-4-14**
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3	
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 700.0 (MSL) EOB: 45.0 ft.	PAGE
START: 2/17/15 END: 2/18/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 85.7	LAT / LONG: 39.948056, -83.016520	1 OF 2

MATERIAL DESCRIPTION AND NOTES	ELEV. 700.0	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
0.3' - TOPSOIL (4.0")	699.7																	
VERY STIFF TO HARD, BROWN **CLAY**, "AND" SILT, TRACE COARSE TO FINE SAND, DAMP TO MOIST. -ROOT FIBERS PRESENT IN SS-1		1 - 2	4 7 7	20	100	SS-1	4.25	0	1	5	40	54	54	22	32	24	A-7-6 (19)	
	694.5	3 - 5	2 3 3	9	33	SS-2	2.75	-	-	-	-	-	-	-	-	20	A-7-6 (V)	
LOOSE TO MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, DAMP TO MOIST. -IRON STAINING PRESENT IN SS-3		6 - 7	2 3 2	7	39	SS-3	-	-	-	-	-	-	-	-	-	9	A-2-6 (V)	
	689.5	8 (W) - 10	2 3 5	11	44	SS-4	-	-	-	-	-	-	-	-	-	13	A-2-6 (V)	
VERY DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		11 (W) - 12	9 20 30	71	100	SS-5	-	66	12	10	9	3	NP	NP	NP	14	A-1-a (0)	
-ROCK FRAGMENTS AND PETROLEUM ODOR PRESENT IN SS-6 -COBBLES ENCOUNTERED @ 14.0'	684.5	13 - 15	22 23 25	69	100	SS-6	-	-	-	-	-	-	-	-	-	10	A-1-a (V)	
MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, WET. -HEAVING SANDS ENCOUNTERED @ 16.0' -INTRODUCED MUD @ 16.0'		16 - 17	3 5 7	17	100	SS-7	-	22	37	25	12	4	NP	NP	NP	21	A-1-b (0)	
	678.0	18 - 20	5 6 7	19	100	SS-8	-	-	-	-	-	-	-	-	-	25	A-1-b (V)	
MEDIUM DENSE, BROWN **SANDY SILT**, LITTLE FINE GRAVEL, TRACE CLAY, MOIST. -IRON STAINING PRESENT IN SS-9		21 - 25	3 7 7	20	100	SS-9	-	20	11	30	33	6	NP	NP	NP	19	A-4a (1)	
	673.0	26																
DENSE TO VERY DENSE, GRAY **GRAVEL**, "AND" COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		27 - 29	13 15 12	39	100	SS-10	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	

PID: 89464	BR ID: N/A	PROJECT: FRA-70-13.10 - PHASE 6A	STATION / OFFSET: 3013+70.11 / 102.6 RT	START: 2/17/15	END: 2/18/15	PG 2 OF 2	B-105-4-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 670.0	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" COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. *(same as above)*		31–33																
		34–35	21 19 31	71	100	SS-11	-	55	29	7	6	3	NP	NP	NP	11	A-1-a (0)	
		36–38																
		39–40	19 28 29	81	78	SS-12	-	-	-	-	-	-	-	-	-	18	A-1-a (V)	
	658.0	41																
VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		42–43																
-ROCK FRAGMENTS PRESENT IN SS-13	655.0	44–45 EOB	20 28 31	84	100	SS-13	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	

NOTES: SEEPAGE ENCOUNTERED @ 8.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 11.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 200 LBS BENTONITE CHIPS AND SOIL CUTTINGS

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: STOCK / C/T	DRILL RIG: BK 81 HD (SN 810792.111)	STATION / OFFSET: 3012+82.16 / 42.1' LT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 3/28/13	ELEVATION: 723.9 (MSL) EOB: 50.0 ft.
START: 4/17/15 END: 4/17/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 72.3	LAT / LONG: 39.948476, -83.016258

EXPLORATION ID B-105-5-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 723.9
0.3' - ASPHALT (3.0")	723.6
0.5' - CONCRETE (6.0")	723.1
0.5' - AGGREGATE BASE (6.0")	722.6
FILL: VERY STIFF TO HARD, BROWNISH GRAY TO GRAY **SILT AND CLAY**, LITTLE TO SOME COARSE TO FINE SAND, LITTLE TO SOME FINE GRAVEL, DAMP TO MOIST. -ROCK FRAGMENTS PRESENT IN SS-1	708.4
FILL: VERY DENSE, DARK GRAY TO BROWN **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP. -ROCK FRAGMENTS PRESENT THROUGHOUT	703.4
FILL: MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, DAMP. -CHEMICAL ODOR PRESENT IN SS-7A	702.2
HARD, DARK GRAY AND BLACK TO BROWN **SILTY CLAY**, TRACE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST. -ORGANICS PRESENT THROUGHOUT	698.4
VERY STIFF, BROWN **SILT**, LITTLE COARSE TO FINE SAND, LITTLE CLAY, LITTLE FINE GRAVEL, MOIST. -ROCK FRAGMENTS PRESENT IN SS-9	695.9
MEDIUM DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.	

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
3 6 7	16	50	SS-1	2.25	27	12	13	26	22	29	16	13	13	A-6a (4)
4 7 10	20	0	SS-2	-	-	-	-	-	-	-	-	-	-	
3 6 9	18	89	SS-3	4.50	-	-	-	-	-	-	-	-	20	A-6a (V)
4 9 12	25	100	SS-4	4.00	14	6	13	40	27	27	16	11	14	A-6a (7)
9 29 44	88	100	SS-5	-	25	22	25	17	11	NP	NP	NP	7	A-2-4 (0)
50/3"	-	100	SS-6	-	-	-	-	-	-	-	-	-	7	A-2-4 (V)
33 9 10	23	100	SS-7	-	-	-	-	-	-	-	-	-	6	A-1-b (V)
				4.5+	-	-	-	-	-	-	-	-	23	A-6b (V)
6 7 10	20	100	SS-8	4.5+	-	-	-	-	-	-	-	-	19	A-6b (V)
4 5 10	18	100	SS-9	2.50	11	3	13	56	17	22	17	5	20	A-4b (8)
4 11 12	28	67	SS-10	-	-	-	-	-	-	-	-	-	10	A-1-a (V)

PID: 89464 | BR ID: N/A | PROJECT: FRA-70-13.10 - PHASE 6A | STATION / OFFSET: 3012+82.16 / 42.1 LT | START: 4/17/15 | END: 4/17/15 | | B-105-5-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 693.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
-ROCK FRAGMENTS PRESENT IN SS-10 MEDIUM DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. *(same as above)*	691.9	31–32																
VERY DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 33.5' -INTRODUCED WATER @ 33.5'		W 33.5; 34–35	23 29 27	67	100	SS-11	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
-COBBLES AND BOULDERS ENCOUNTERED @ 38.0'		39–40	3 33 37	84	100	SS-12	-	60	18	7	9	6	20	17	3	10	A-1-a (0)	
-ROCK FRAGMENTS PRESENT THROUGHOUT		44–45	29 26 32	70	100	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-a (V)	
	676.9																	
DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.	673.9	49–50 EOB	2 14 17	37	100	SS-14	-	66	16	2	11	5	21	17	4	8	A-1-b (0)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 33.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER SOIL CUTTINGS

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750 (SN 98048)	STATION / OFFSET: 3012+25.98 / 120.3' RT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 703.0 (MSL) EOB: 35.0 ft.
START: 3/25/15 END: 3/25/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92.9	LAT / LONG: 39.948373, -83.016857

EXPLORATION ID B-105-6-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 703.0
0.3' - ASPHALT (4.0")	702.7
0.7' - FILL MATERIAL (8.0")	702.0
VERY STIFF, DARK GRAY TO DARK BROWNISH GRAY **CLAY**, "AND" SILT, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	697.5
MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST.	695.0
MEDIUM DENSE TO DENSE, BROWN TO GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -PETROLEUM ODOR PRESENT IN SS-6 AND SS-7 -HEAVING SANDS ENCOUNTERED @ 20.0'	676.0
VERY DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.	

DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
1–2.5	3 5 6	17	89	SS-1	2.75	2	7	3	62	26	43	26	17	31	A-7-6 (11)
3.5–5	3 3 6	14	50	SS-2	-	-	-	-	-	-	-	-	-	24	A-7-6 (V)
6–7.5	1 5 6	17	33	SS-3	-	-	-	-	-	-	-	-	-	15	A-2-6 (V)
8.5–10	2 6 6	18	39	SS-4	-	60	25	7	5	3	NP	NP	NP	12	A-1-a (0)
11–12.5	2 6 8	21	44	SS-5	-	-	-	-	-	-	-	-	-	17	A-1-a (V)
13.5–15	4 5 4	14	56	SS-6	-	-	-	-	-	-	-	-	-	12	A-1-a (V)
16–17.5	6 7 4	17	100	SS-7	-	-	-	-	-	-	-	-	-	11	A-1-a (V)
18.5–20	11 17 14	47	100	SS-8	-	65	26	0	7	2	NP	NP	NP	10	A-1-a (0)
23.5–25	10 17 14	47	56	SS-9	-	-	-	-	-	-	-	-	-	9	A-1-a (V)
28.5–30	7 14 21	53	100	SS-10	-	38	32	7	13	10	NP	NP	NP	11	A-1-b (0)

MATERIAL DESCRIPTION AND NOTES	ELEV. 673.0	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 DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST. *(same as above)*		31 32 33																
-ROCK FRAGMENTS PRESENT IN SS-11	668.0	34 EOB 35	12 22 17	59	56	SS-11	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	

NOTES: SEEPAGE ENCOUNTERED @ 8.5'; GROUNDWATER INITIALLY ENCOUNTERED @ 13.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 200 LBS BENTONITE CHIPS AND SOIL CUTTINGS

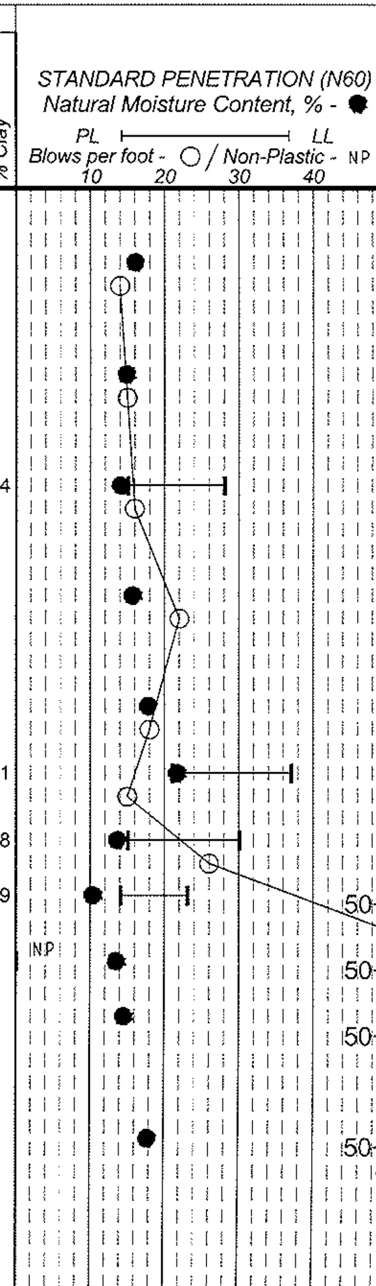
DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: ms consultants | Project: FRA-70-8.93 | Job No. 0221-1004.01

LOG OF: Boring B-106 | Location: Sta. 115+01.50, 8.44 ft Lt. of Ramp H3 BL | Date Drilled: 9/1/2009

WATER OBSERVATIONS:
Water seepage at: None
Water level at completion: None
FIELD NOTES:

Depth (ft)	Elev. (ft) 719.0	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.3	718.7						Topsoil - 3"						
		5 6 8	9	1		3.0	FILL: Very stiff brown SANDY SILT (A-4a), some fine to coarse sand, trace gravel; contains few brick fragments; damp.						
3.5	715.5	5 6 9	18	2		4.5+	Very stiff to hard gray SILT AND CLAY (A-6a), some fine to coarse sand, trace gravel; damp.						
		5 6 10	18	3		3.5		5	10	---	16	35	34
		4 9 13	18	4		4.25							
11.0	708.0	9 8 10	17	5		3.5	Very stiff gray SILTY CLAY (A-6b), some fine to coarse sand, trace to little gravel; moist.						
		11 9 6	3	6		2.5		10	9	---	16	34	31
14.0	705.0	4 7 18	12	7		4.5+	Hard gray SILT AND CLAY (A-6a), some fine to coarse sand, trace gravel; contains rock fragments; damp.	4	7	---	15	36	38
15.5	703.5	19 50/3	9	8		2.75	Very stiff gray SANDY SILT (A-4a), some gravel; damp.	22	18	---	19	22	19
17.0	702.0	49 50/3	7	9			Very dense gray GRAVEL WITH SAND (A-1-b), trace silt; contains rock fragments; damp.	38	41	---	15	--6--	
		50/4	4	10									
21.8	697.2	44 50/3	8	11									
							Bottom of Boring - 21.8'						



RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: STOCK / T.B./B.Z.	DRILL RIG: BK 81 HD (SN 810792.111)	STATION / OFFSET: 3011+35.50 / 67.0' LT	EXPLORATION ID **B-107-2-14**
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / D.M.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3	PAGE
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 3/28/13	ELEVATION: 727.5 (MSL) EOB: 45.0 ft.	1 OF 2
START: 4/13/15 END: 4/14/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 72.3	LAT / LONG: 39.948852, -83.016450	

MATERIAL DESCRIPTION AND NOTES	ELEV. 727.5	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
0.3' - ASPHALT (3.0")	727.2															
0.7' - CONCRETE (9.0")	726.5															
FILL: STIFF, GRAY **SANDY SILT**, LITTLE FINE GRAVEL, TRACE CLAY, DAMP. -ROCK FRAGMENTS PRESENT IN SS-1		4 5 5	12	72	SS-1	1.50	-	-	-	-	-	-	-	-	10	A-4a (V)
	720.5															
FILL: VERY STIFF, GRAY **SILTY CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -ASPHALT FRAGMENTS PRESENT IN SS-2		5 6 8	17	78	SS-2	3.50	-	-	-	-	-	-	-	-	13	A-6b (V)
		7 7 9	19	94	SS-3	3.00	10	12	15	33	30	33	16	17	14	A-6b (8)
	710.5															
FILL: VERY STIFF, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP. -ROCK FRAGMENTS PRESENT IN SS-4		7 11 17	34	83	SS-4	3.50	-	-	-	-	-	-	-	-	9	A-6a (V)
	707.0															
FILL: VERY DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST.		50/3"	-	0	SS-5	-	-	-	-	-	-	-	-	-	-	
		31 81 50/2"	-	100	SS-6	-	42	20	18	14	6	NP	NP	NP	5	A-1-b (0)
-ASPHALT FRAGMENTS PRESENT IN SS-7		29 46 4	60	50	SS-7	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
	702.0															
VERY STIFF, DARK BROWN **SILTY CLAY**, "AND" COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP.		3 4 3	8	61	SS-8	3.00	18	21	22	21	18	37	18	19	14	A-6b (3)
	699.5															
MEDIUM DENSE, BROWNISH GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.		15 14 9	28	83	SS-9	-	-	-	-	-	-	-	-	-	7	A-1-b (V)

DEPTHS: 1 – 29

PID: 89464	BR ID: N/A	PROJECT: FRA-70-13.10 - PHASE 6A	STATION / OFFSET: 3011+35.50 / 67.0 LT	START: 4/13/15	END: 4/14/15	PG 2 OF 2	B-107-2-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 697.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
DENSE TO VERY DENSE, BROWNISH GRAY TO BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST.	697.0	31–32	11 30 35	78	89	SS-10	-	45	21	14	13	7	NP	NP	NP	5	A-1-b (0)	
		34–35	5 13 20	40	67	SS-11	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
-HEAVING SANDS ENCOUNTERED @ 35.0' -INTRODUCED MUD @ 35.0' -ROCK FRAGMENTS PRESENT THROUGHOUT		W 35																
		36–37	8 21 36	69	61	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		39–40	4 13 20	40	44	SS-13	-	45	27	13	13	2	NP	NP	NP	9	A-1-b (0)	
DENSE, BROWN **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, TRACE SILT, MOIST.	685.5																	
	682.5	44–45 EOB	8 14 21	42	100	SS-14	-	-	-	-	-	-	-	-	-	15	A-3a (V)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 35.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER SOIL CUTTINGS

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750 (SN 98048)	STATION / OFFSET: 3010+61.70 / 149.1' RT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 704.3 (MSL) EOB: 25.0 ft.
START: 2/4/15 END: 2/4/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92.9	LAT / LONG: 39.948726, -83.017248

EXPLORATION ID **B-107-3-14**

PAGE 1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 704.3
0.3' - TOPSOIL (3.0")	704.0
FILL: HARD, BROWN **CLAY**, "AND" SILT, TRACE COARSE TO FINE SAND, DAMP. -BRICK AND ROCK FRAGMENTS PRESENT IN SS-1	701.3
VERY STIFF, BROWN **CLAY**, "AND" SILT, TRACE COARSE TO FINE SAND, DAMP TO MOIST. -ROOT FIBERS PRESENT IN SS-2 AND SS-3	696.3
MEDIUM DENSE, BROWN **GRAVEL WITH SAND AND SILT**, TRACE CLAY, DAMP.	693.8
DENSE TO VERY DENSE, BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST. -ROCK FRAGMENTS PRESENT THROUGHOUT -COBBLES PRESENT @ 15.0'	688.8
MEDIUM DENSE TO DENSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-7 -HEAVING SANDS ENCOUNTERED @ 20.0'	682.3
HARD, GRAY **SANDY SILT**, LITTLE FINE GRAVEL, LITTLE CLAY, DAMP.	679.3

DEPTHS: W (groundwater) at 16; EOB at 25

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
2 2 3	8	6	SS-1	4.5+	-	-	-	-	-	-	-	-	21	A-7-6 (V)
2 4 5	14	100	SS-2	3.75	0	1	3	48	48	55	24	31	27	A-7-6 (19)
3 3 8	17	100	SS-3	4.00	-	-	-	-	-	-	-	-	21	A-7-6 (V)
4 5 6	17	44	SS-4	-	44	14	9	24	9	26	18	8	7	A-2-4 (0)
14 19 23	63	67	SS-5	-	-	-	-	-	-	-	-	-	6	A-1-b (V)
6 15 16	47	67	SS-6	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
4 5 7	18	56	SS-7	-	72	16	4	6	2	NP	NP	NP	13	A-1-a (0)
14 13 16	44	100	SS-8	-	-	-	-	-	-	-	-	-	9	A-1-a (V)
21 27 29	84	39	SS-9	4.5+	16	15	21	34	14	20	13	7	8	A-4a (3)

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 16.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER SOIL CUTTINGS

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750 (SN 98048)	STATION / OFFSET: 3009+90.45 / 162.2' RT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.5" CFA	CALIBRATION DATE: 10/20/14	ELEVATION: 705.1 (MSL) EOB: 20.0 ft.
START: 2/4/15 END: 2/4/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92.9	LAT / LONG: 39.948868, -83.017411

EXPLORATION ID **B-107-4-14**

PAGE 1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 705.1	DEPTHS
0.4' - TOPSOIL (5.0")	704.7	0.4
VERY STIFF, BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -ROOT FIBERS PRESENT IN SS-1	702.1	3.0
VERY STIFF, DARK BROWN **CLAY**, "AND" SILT, TRACE FINE SAND, TRACE FINE GRAVEL, MOIST. -ROOT FIBERS PRESENT IN SS-2	699.6	5.5
MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST. -WOOD FRAGMENTS PRESENT IN SS-4 -ROCK FRAGMENTS PRESENT IN SS-5	688.1	17.0
VERY DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-6	685.1	20.0 (EOB)

Groundwater: W at 13.5'; ▼ at 15.0'

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
3 7 8	23	33	SS-1	-	-	-	-	-	-	-	-	-	12	A-6a (V)	
5 6 7	20	100	SS-2	3.50	1	0	10	45	44	47	22	25	24	A-7-6 (15)	
2 4 5	14	67	SS-3	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
3 6 11	26	100	SS-4	-	37	21	18	19	5	NP	NP	NP	6	A-1-b (0)	
7 4 3	11	50	SS-5	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
12 21 24	68	100	SS-6	-	66	16	6	10	2	NP	NP	NP	10	A-1-a (0)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 13.5' AND AT COMPLETION @ 15.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 100 LBS BENTONITE CHIPS AND SOIL CUTTINGS

DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

Client: ms consultants | Project: FRA-70-8.93 | Job No. 0221-1004.01

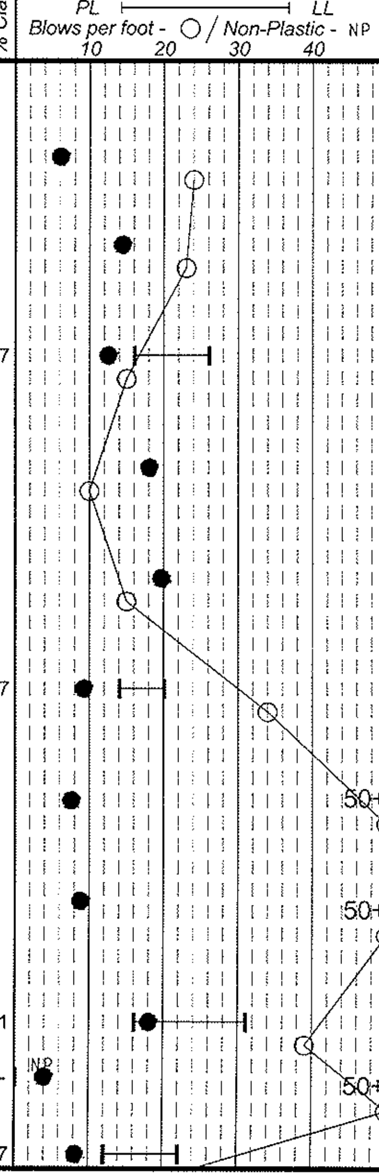
LOG OF: Boring B-111 | Location: Sta. 487+15.21, 19.28 ft Lt. of Ramp E1 BL | Date Drilled: 9/1/2009

WATER OBSERVATIONS:
Water seepage at: None
Water level at completion: None

FIELD NOTES:

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
	734.9						Asphalt Concrete - 6"						
1.0	733.9						Aggregate Base - 6"						
		9 11 12	8	1			POSSIBLE FILL: Medium dense brown GRAVEL WITH SAND, SILT, AND CLAY (A-2-6); damp.						
3.5	731.4												
5		8 11 11	12	2		4.5+	Very stiff to hard gray SANDY SILT (A-4a), some fine to coarse sand, trace to little gravel; damp.						
		2 7 8	18	3		1.5	@ 6.0'-7.5', stiff.	13	10	---	17	33	27
10		2 5 5	18	4		3.0							
		4 7 8	18	5		4.5+							
15		4 14 19	18	6		--	@ 13.5', becomes brown.	11	13	---	19	40	17
16.0	718.9												
		4 37 50/5	9	7			Very dense brown GRAVEL WITH SAND (A-1-b), little silt; damp.						
18.5	716.4												
20		12 50/5	5	8			Very dense brown SANDY SILT (A-4a), little to some gravel; damp.						
21.0	713.9												
		17 8 30	12	9		3.0	Very stiff brown SILTY AND CLAY (A-6a), some fine to coarse sand, trace gravel; moist.	8	8	---	26	27	31
22.5	712.4												
		48 50/5	10	10			Very dense gray GRAVEL WITH SAND (A-1-b), little silt; damp.	50	22	---	12	--16--	
24.0	710.9												
25	709.9	15 9		11		3.75	Stiff to very stiff gray SANDY SILT (A-4a); damp.	26	19	---	18	20	17

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL |———| LL
Blows per foot - ○ / Non-Plastic - NP



DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

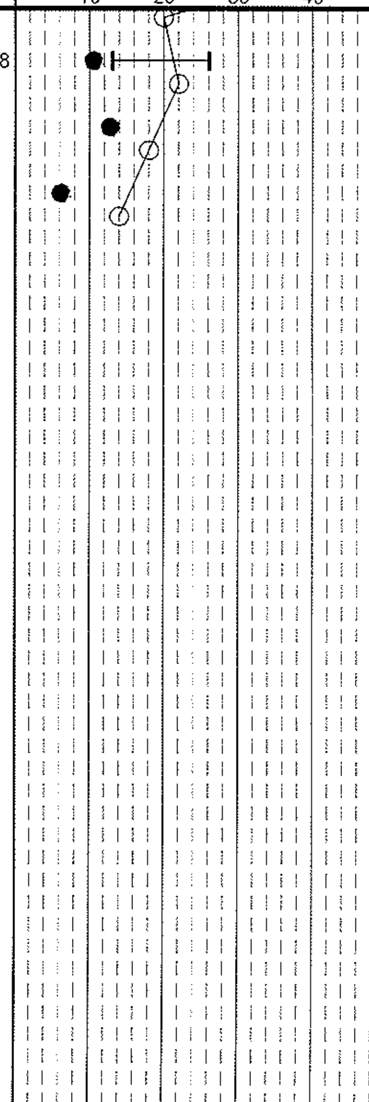
Client: ms consultants	Project: FRA-70-8.93	Job No. 0221-1004.01
LOG OF: Boring B-111	Location: Sta. 487+15.21, 19.28 ft Lt. of Ramp E1 BL	Date Drilled: 9/1/2009

WATER OBSERVATIONS:
Water seepage at: None
Water level at completion: None
FIELD NOTES:

Depth (ft)	Elev. (ft) 709.9	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		10	10											
		10 11 10	12	12		3.75	Stiff to very stiff gray SANDY SILT (A-4a), some fine to coarse sand, little gravel; damp.		13	12	---	17	30	28
		11 9 8	3	13		1.5	@ 25.5'-27.0', contains rock fragments.							
30.0	704.9	3 5 9	18	14		1.5								
							Bottom of Boring - 30.0'							

Depth scale: 30, 35, 40, 45, 50

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



APPENDIX IV

LABORATORY TEST RESULTS

RESOURCE INTERNATIONAL, INC.
Engineering Consultants

6350 Presidential Gatew. | 9885 Rockside Road | 4480 Lake Forest Drive
Columbus, OH 43231 | Cleveland, OH 44125 | Cincinnati, Ohio 45242
Phone (614) 823-4949 | Phone (216) 573-0955 | Phone (513) 769-6998

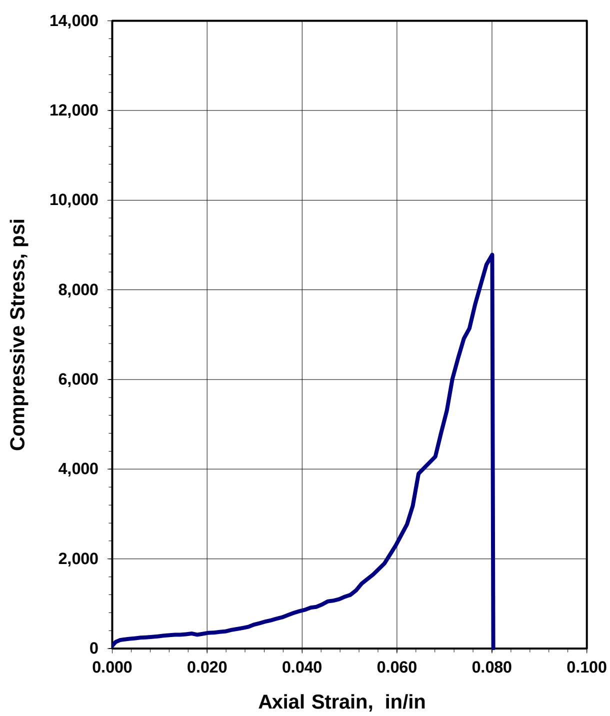
Unconfined Compressive Strength of Intact Rock Core Specimens (ASTM D 7012-04)

Project: FRA-70-13.10 - Project 6A
Project No.: W-13-072
Date of Testing: 7/3/2014
Test Performed by: K.R./T.K.

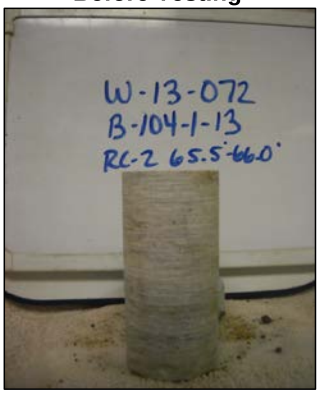
Rock Description: Dolomitic Limestone

Boring No.:	B-104-1-13	Average Length:	4.185 in
Sample No:	RC-2	Average Diameter:	1.858 in
Depth (ft):	65.5	Length to diameter ratio:	2.252
Moisture condition:	As received	Cross Sectional Area:	2.710 in^2
Rate of Loading:	55.1 lbs/sec	Failure Load:	23,820 lbs
Testing Time:	432 sec	Axial Strain at Failure:	0.0800 in/in
(Rate 2-15 minutes to failure)		Stress:	8,783 psi

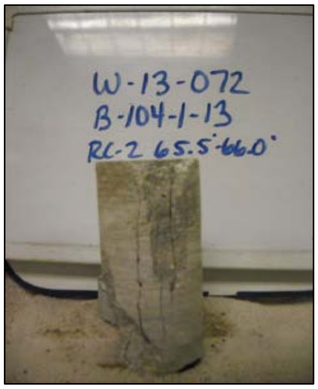
Unconfined Compression Test



Before Testing



After Failure



REMARKS:

APPENDIX V

MSE WALL CALCULATIONS

Boring No.	Elevation (feet msl)	Soil Class.	Soil Type	Strata	N_{60}	$N1_{60}$	γ (pcf)	γ' (pcf)	Strength Parameter	k (soil) k_{rm} (rock)	$ε_{50}$ (soil) E_r (rock)	RQD (rock)
B-103-1-14	703.3 to 692.8	A-7-6	C	3	14	14	115 psf	115 psf	Su = 1,750 psf	585 pci	0.0067	-
	692.8 to 685.3	A-1-a	G	4	24	25	125 psf	125 psf	φ = 39°	250 pci	-	-
	685.3 to 676.3	A-1-b	G	4	32	31	130 psf	67.6 psf	φ = 39°	140 pci	-	-
	676.3 to 666.3	A-1-b	G	4	51	44	135 psf	72.6 psf	φ = 41°	175 pci	-	-
	666.3 to 661.3	A-1-b	G	4	34	28	130 psf	67.6 psf	φ = 39°	140 pci	-	-
	661.3 to 656.3	A-4a	C	2	122	122	130 psf	67.6 psf	Su = 8,000 psf	2,665 pci	0.0033	-
	656.3 to 648.8	A-1-b	G	4	104	78	135 psf	72.6 psf	φ = 42°	195 pci	-	-
B-104-1-13	714.5 to 701.5	A-6a	C	3	24	24	120	120	Su = 3,000 psf	1,000 pci	0.0050	-
	701.5 to 699.0	A-3a	G	4	12	13	120	120	φ = 34°	115 pci	-	-
	699.0 to 682.5	A-1-a	G	4	42	38	130	67.6	φ = 41°	175 pci	-	-
	682.5 to 677.5	A-1-b	G	4	28	23	130	67.6	φ = 38°	125 pci	-	-
	677.5 to 672.5	A-1-b	G	4	120	94	135	72.6	φ = 42°	195 pci	-	-
	672.5 to 667.5	A-1-b	G	4	3	2	115	52.6	φ = 29°	25 pci	-	-
	667.5 to 663.5	A-1-b	G	4	120	88	135	72.6	φ = 42°	195 pci	-	-
	663.5 to 660.5	Boulders	G	4	120	86	140	77.6	φ = 45°	255 pci	-	-
	660.5 to 654.0	A-6a	C	2	120	120	130	67.6	Su = 8,000 psf	2,665 pci	0.0033	-
	654.0 to 644.0	Limestone	R	9	-	-	165	102.6	Qu = 10,000 psi	0.00005	1,000,000 psi	73
B-105-3-14	719.4 to 708.9	A-4a	C	3	22	22	120	120	Su = 2,750 psf	915 pci	0.0053	-
	708.9 to 706.4	A-3a	G	4	67	75	135	135	φ = 40°	280 pci	-	-
	706.4 to 701.4	A-2-4	G	4	82	83	135	135	φ = 41°	315 pci	-	-
	701.4 to 697.4	A-7-6	C	3	28	28	125	125	Su = 3,500 psf	1,165 pci	0.0048	-
	697.4 to 687.4	A-2-6	G	4	28	23	130	130	φ = 37°	190 pci	-	-
	687.4 to 682.4	A-1-a	G	4	71	54	135	72.6	φ = 43°	215 pci	-	-
	682.4 to 672.4	A-1-a	G	4	39	28	130	67.6	φ = 40°	155 pci	-	-
	672.4 to 664.4	A-1-a	G	4	92	63	135	72.6	φ = 43°	215 pci	-	-
B-105-4-14	700.0 to 694.5	A-7-6	C	3	14	14	115 psf	115 psf	Su = 1,750 psf	585 pci	0.0067	-
	694.5 to 689.5	A-2-6	G	4	9	11	120 psf	120 psf	φ = 34°	115 pci	-	-
	689.5 to 684.5	A-1-a	G	4	70	78	135 psf	72.6 psf	φ = 43°	215 pci	-	-
	684.5 to 678.0	A-1-b	G	4	18	19	125 psf	62.6 psf	φ = 37°	110 pci	-	-
	678.0 to 673.0	A-4a	G	4	20	19	125 psf	62.6 psf	φ = 33°	60 pci	-	-
	673.0 to 668.0	A-1-a	G	4	39	36	130 psf	67.6 psf	φ = 41°	175 pci	-	-
	668.0 to 658.0	A-1-a	G	4	76	65	135 psf	72.6 psf	φ = 43°	215 pci	-	-
	658.0 to 655.0	A-1-b	G	4	84	68	135 psf	72.6 psf	φ = 42°	195 pci	-	-
B-105-5-14	723.9 to 708.4	A-6a	C	3	20	20	120	120	Su = 2,500 psf	835 pci	0.0057	-
	708.4 to 702.4	A-2-4	G	4	104	100	135	135	φ = 41°	315 pci	-	-
	702.4 to 698.4	A-6b	C	3	21	21	120	120	Su = 2,625 psf	875 pci	0.0055	-
	698.4 to 695.9	A-4b	C	3	18	18	120	120	Su = 2,250 psf	750 pci	0.0060	-
	695.9 to 691.9	A-1-a	G	4	28	22	130	130	φ = 39°	250 pci	-	-
	691.9 to 676.9	A-1-a	G	4	74	53	135	72.6	φ = 43°	215 pci	-	-
	676.9 to 673.9	A-1-b	G	4	37	25	130	67.6	φ = 38°	125 pci	-	-
B-105-6-14	703.0 to 697.5	A-7-6	C	3	15	15	120 psf	120 psf	Su = 1,875 psf	625 pci	0.0065	-
	697.5 to 695.0	A-2-6	G	4	17	22	125 psf	125 psf	φ = 37°	190 pci	-	-
	695.0 to 685.0	A-1-a	G	4	18	19	125 psf	125 psf	φ = 38°	215 pci	-	-
	685.0 to 676.0	A-1-a	G	4	48	46	135 psf	72.6 psf	φ = 42°	195 pci	-	-
	676.0 to 668.0	A-1-b	G	4	57	50	135 psf	72.6 psf	φ = 42°	195 pci	-	-
B-106-0-09	719.0 to 715.5	A-4a	C	3	14	14	120	120	Su = 1,750 psf	585 pci	0.0067	-
	715.5 to 708.0	A-6a	C	3	17	17	125	125	Su = 2,125 psf	710 pci	0.0062	-
	708.0 to 705.0	A-6b	C	3	25	25	130	130	Su = 3,125 psf	1,040 pci	0.0050	-
	705.0 to 703.5	A-6a	C	3	25	25	130	130	Su = 3,125 psf	1,040 pci	0.0050	-
	703.5 to 702.0	A-4a	C	3	50	50	130	130	Su = 6,250 psf	2,085 pci	0.0039	-
	702.0 to 697.2	A-1-b	G	4	50	47	135	135	φ = 41°	315 pci	-	-
B-107-2-14	727.5 to 720.5	A-4a	C	3	12	12	115	115	Su = 1,500 psf	500 pci	0.0070	-
	720.5 to 710.5	A-6b	C	3	18	18	120	120	Su = 2,250 psf	750 pci	0.0060	-
	710.5 to 707.0	A-6a	C	3	34	34	125	125	Su = 4,250 psf	1,415 pci	0.0046	-
	707.0 to 702.0	A-1-b	G	4	90	80	135	135	φ = 42°	355 pci	-	-
	702.0 to 699.5	A-6b	C	3	8	8	115	115	Su = 1,000 psf	235 pci	0.0090	-
	699.5 to 697.0	A-1-b	G	4	28	23	130	130	φ = 38°	215 pci	-	-
	697.0 to 685.5	A-1-b	G	4	55	40	135	72.6	φ = 40°	155 pci	-	-
	685.5 to 682.5	A-3a	G	4	42	29	130	67.6	φ = 37°	110 pci	-	-
B-107-3-14	704.3 to 701.3	A-7-6	C	3	8	8	115 psf	115 psf	Su = 1,000 psf	235 pci	0.0090	-
	701.3 to 696.3	A-7-6	C	3	15	15	120 psf	120 psf	Su = 1,875 psf	625 pci	0.0065	-
	696.3 to 693.8	A-2-6	G	4	17	20	125 psf	125 psf	φ = 36°	160 pci	-	-
	693.8 to 688.8	A-1-b	G	4	56	60	135 psf	135 psf	φ = 42°	355 pci	-	-
	688.8 to 682.3	A-1-a	G	4	32	31	130 psf	67.6 psf	φ = 40°	155 pci	-	-
	682.3 to 679.3	A-4a	C	2	87	87	130 psf	67.6 psf	Su = 8,000 psf	2,665 pci	0.0033	-
B-107-4-14	705.1 to 702.1	A-6a	C	3	23	23	120 psf	120 psf	Su = 2,875 psf	960 pci	0.0052	-
	702.1 to 699.6	A-7-6	C	3	20	20	120 psf	120 psf	Su = 2,500 psf	835 pci	0.0057	-
	699.6 to 693.1	A-1-b	G	4	20	24	125 psf	125 psf	φ = 38°	215 pci	-	-
	693.1 to 688.1	A-1-b	G	4	11	12	120 psf	57.6 psf	φ = 35°	85 pci	-	-
	688.1 to 685.1	A-1-a	G	4	70	71	135 psf	72.6 psf	φ = 43°	215 pci	-	-
B-111-0-09	734.9 to 731.4	A-2-6	G	4	23	40	120	120	φ = 39°	250 pci	-	-
	731.4 to 723.4	A-4a	C	3	15	15	125	125	Su = 1,875 psf	625 pci	0.0065	-
	723.4 to 718.9	A-4a	C	3	33	33	125	125	Su = 4,125 psf	1,375 pci	0.0046	-
	718.9 to 716.4	A-1-b	G	4	28	50	135	135	φ = 42°	355 pci	-	-
	716.4 to 713.9	A-4a	C	3	50	50	130	130	Su = 6,250 psf	2,085 pci	0.0039	-
	713.9 to 712.4	A-6a	C	3	38	38	130	130	Su = 4,750 psf	1,585 pci	0.0044	-
	712.4 to 710.9	A-1-b	G	4	50	44	135	135	φ = 41°	315 pci	-	-
	710.9 to 704.9	A-4a	C	3	17	17	130	130	Su = 2,125 psf	710 pci	0.0062	-

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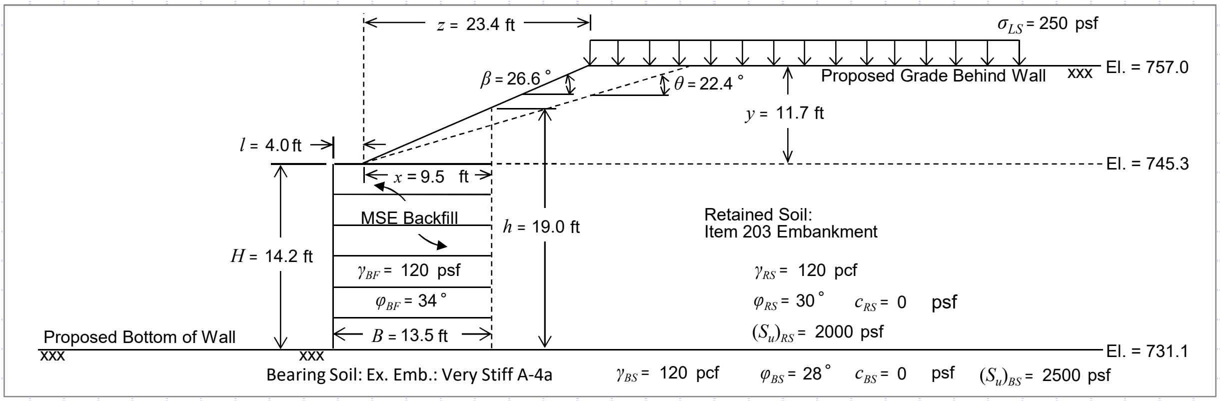
Retaining Wall W3 - Sta. 3008+50 (BL Ramp C3) - B-111-0-09 - 2:1 Broken Backslope - 14.2 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

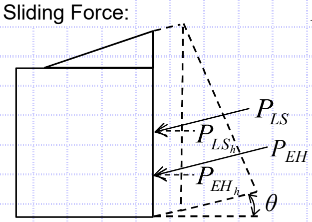
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Sections 11.6.3.6 and 11.10.5.3

Sliding Force:



$$P_H = (P_{EH} + P_{LS})\cos\theta$$

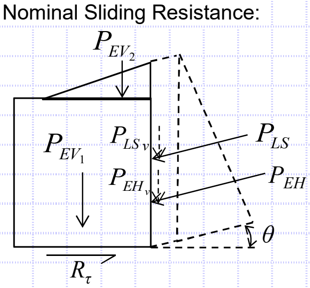
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(19.0 ft)(0.444)(1.75) = 3.29 kip/ft

P_H = (14.36 kip/ft + 3.29 kip/ft)cos(22.4°) = 16.32 kip/ft

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance: $R_\tau = (P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta)\tan\delta$ (Neglect P_{LS_v} for conservatism)



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(14.2 ft)(13.5 ft)(1.00) = 23 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.00) = 2.71 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF})$ ⟶ tan(28) ≤ tan(34) ⟶ 0.53 ≤ 0.67 = 0.53

R_τ = [23.00 kip/ft + 2.71 kip/ft + (14.36 kip/ft)sin(22.4°)](0.53) = 16.53 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 16.32 kip/ft ≤ (16.53 kip/ft)(1.0) = 16.53 kip/ft ⟶ 16.32 kip/ft ≤ 16.53 kip/ft **OK**

Use φ_τ = 1.0 *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

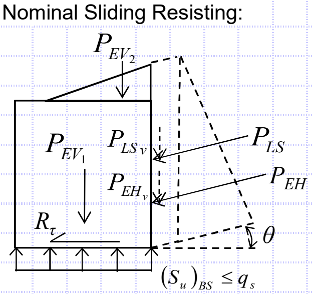
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3 *(Continued)*

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting: $R_\tau = \left((S_u)_{BS} \le q_s\right) \cdot B$



(Neglect P_{LS_V} for conservatism)

$(S_u)_{BS}$ = 2.50 ksf

$q_s = \sigma_v / 2$

$\sigma_v = P_V / B$

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(14.2 ft)(13.5 ft)(1.00) = 23 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$

P_{EV_2} = ½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.00) = 2.71 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

P_V = 23 kip/ft + 2.71 kip/ft + (14.36 kip/ft)sin(22.4°) = 31.18 kip/ft

σ_v = (31.18 kip/ft) / (13.5 ft) = 2.31 ksf

q_s = (2.31 ksf) / 2 = 1.16 ksf

R_τ = (2.50 ksf ≤ 1.16 ksf)(13.5 ft) = 33.75 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ $\longrightarrow$ 16.32 kip/ft ≤ (33.75 kip/ft)(1.0) = 33.75 kip/ft $\longrightarrow$ 16.32 kip/ft ≤ 33.75 kip/ft **OK**

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

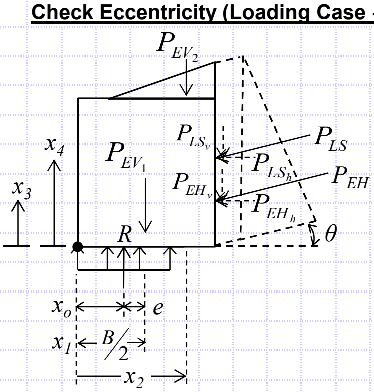
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Eccentricity (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.6.3.3



$$e = B/2 - x_o$$

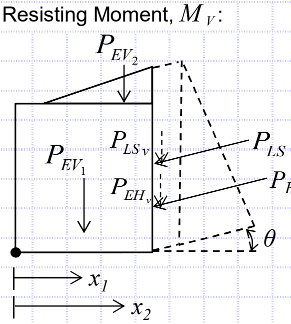
$$x_o = \frac{M_V - M_H}{P_V}$$ = (257.12 kip·ft/ft - 116.16 kip·ft/ft) / (31.18 kip/ft) = 4.52 ft

M_V = 257.12 kip·ft/ft
M_H = 116.16 kip·ft/ft
(Defined below)

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 23 kip/ft + 2.71 kip/ft + (14.36 kip/ft)sin(22.4°) = 31.18 kip/ft

$e =$ (13.5 ft/ 2) - 4.52 ft = 2.23 ft

Resisting Moment, M_V:



$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B)$$ (Neglect P_{LS_V} for conservatism)

$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV}$ = (120 pcf)(14.2 ft)(13.5 ft)(1.00) = 23.00 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.00) = 2.71 kip/ft

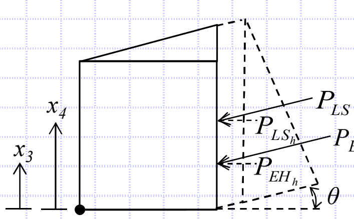
$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

$x_1 = B/2$ = (13.5 ft) / 2 = 6.75 ft

$x_2 = l + \tfrac{2}{3}(B-l)$ = 4.0 ft + ⅔(13.5 ft - 4.0 ft) = 10.33 ft

M_V = (23 kip/ft)(6.75 ft) + (2.71 kip/ft)(10.33 ft) + (14.36 kip/ft)sin(22.4°)(13.5 ft) = 257.12 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4)$$

$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(19.0 ft)(0.444)(1.75) = 3.68 kip/ft

$x_3 = h/3$ = (19.0 ft) / 3 = 6.32 ft

$x_4 = h/2$ = (19.0 ft) / 2 = 9.48 ft

M_H = (14.36 kip/ft)cos(22.4°)(6.32 ft) + (3.68 kip/ft)cos(22.4°)(9.48 ft) = 116.16 kip·ft/ft

Check Eccentricity Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (13.5 ft) / 3 = 4.50 ft

$e < e_{max} \longrightarrow$ 2.23 ft < 4.50 ft **OK**

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JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	4	OF	6
CALCULATED BY	HSK	DATE	5/28/2021
CHECKED BY	BRT	DATE	5/28/2021

Retaining Wall W3 - Sta. 3008+50 (BL Ramp C3)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

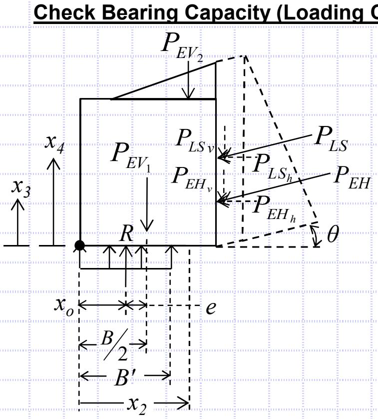
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.6.3.2



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 13.5 ft - 2(1.64 ft) = 10.22 ft

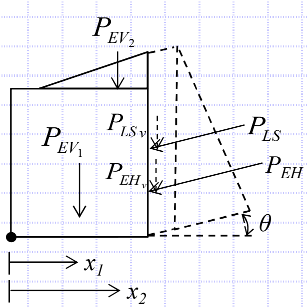
$e = B/2 - x_o$ = (13.5 ft / 2) - 5.11 ft = 1.64 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (321.34 kip·ft/ft - 116.16 kip·ft/ft) / 40.19 kip/ft = 5.11 ft

q_{eq} = (40.19 kip/ft) / (10.22 ft) = 3.93 ksf

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B)$$



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(14.2 ft)(13.5 ft)(1.35) = 31.06 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.35) = 3.66 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

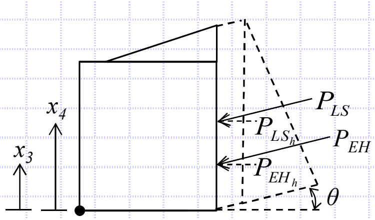
$x_1 = B/2$ = (13.5 ft) / 2 = 6.75 ft

$x_2 = l + \tfrac{2}{3}(B-l)$ = 4.0 ft + ⅔(13.5 ft - 4.0 ft) = 10.33 ft

M_V = (31.06 kip/ft)(6.75 ft) + (3.66 kip/ft)(10.3 ft) + (14.36 kip/ft)sin(22.4°)(13.5 ft) = 321.34 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4)$$



$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(19.0 ft)²(0.444)(1.50) = 14.36 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(19.0 ft)(0.444)(1.75) = 3.68 kip/ft

$x_3 = h/3$ = (19.0 ft) / 3 = 6.32 ft

$x_4 = h/2$ = (19.0 ft) / 2 = 9.48 ft

M_H = (14.36 kip/ft)cos(22.4°)(6.32 ft) + (3.68 kip/ft)cos(22.4°)(9.48 ft) = 116.16 kip·ft/ft

Vertical Forces, P_V:

$$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$$

P_V = 31.06 kip/ft + 3.66 kip/ft + (14.36 kip/ft)sin(22.4°) = 40.19 kip/ft

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4 *(Continued)*

Check Bearing Resistance - Drained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 25.8 $N_{qm} = N_q s_q d_q i_q$ = 16.2 $N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_c = 25.80
s_c = 1+(10.22 ft/869 ft)(14.72/25.8) = 1.000
i_c = 1.000 (Assumed)

N_q = 14.72
s_q = 1+(10.22 ft/869 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(4.0 ft/10.22 ft) = 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 4.0 ft = 1.000

N_γ = 16.72
s_γ = 1-0.4(10.22 ft/869 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(10.22 ft) + 4.0 ft = 0.500

q_n = (0 psf)(25.8) + (120 pcf)(4.0 ft)(16.2)(1.0) + ½(120 pcf)(10.2 ft)(16.7)(0.5) = 12.90 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.93 ksf ≤ (12.90 ksf)(0.65) = 8.39 ksf ⟶ 3.93 ksf ≤ 8.39 ksf **OK**

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

Check Bearing Resistance - Undrained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.140 $N_{qm} = N_q s_q d_q i_q$ = 1.000 $N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.000

N_c = 5.140
s_c = 1+(10.22 ft/[(5)(869 ft)] = 1.000
i_c = 1.000 (Assumed)

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(4.0 ft/10.22 ft) = 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 4.0 ft = 1.000

N_γ = 0.000
s_γ = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(10.22 ft) + 4.0 ft = 0.500

q_n = (2500 psf)(5.14) + (120 pcf)(4.0 ft)(1.0)(1.0) + ½(120 pcf)(10.2 ft)(0.0)(0.5) = 13.33 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.93 ksf ≤ (13.33 ksf)(0.65) = 8.66 ksf ⟶ 3.93 ksf ≤ 8.66 ksf **OK**

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	14.2	ft
MSE Wall Width (Reinforcement Length), (B) =	13.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	19.0	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	22.4	°
Distance from Toe to Top of Backslope, (z) =	23.4	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.444	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

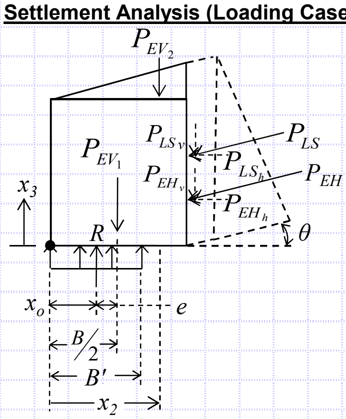
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Settlement Analysis (Loading Case - Service I) - AASHTO LRFD BDM Section 11.10.4.1



$$q_{eq} = \frac{P_V}{B'}$$

$$B' = B - 2e \quad = \quad 13.5\text{ ft} - 2(1.36\text{ ft}) \quad = \quad 10.78 \quad \text{ft}$$

$$e = \frac{B}{2} - x_o \quad = \quad (13.5\text{ ft} / 2) - 5.39\text{ ft} \quad = \quad 1.36 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (232.55\text{ kip·ft/ft} - 74.37\text{ kip·ft/ft}) / 29.36\text{ kip/ft} \quad = \quad 5.39 \quad \text{ft}$$

$$q_{eq} = \quad (29.36\text{ kip/ft}) / (10.78\text{ ft}) \quad = \quad 2.72 \quad \text{ksf}$$

$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B) = (\gamma_{BF}HB\gamma_{EV})(\tfrac{1}{2}B) + (\tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV})(l + \tfrac{2}{3}(B-l)) + (\tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}\sin\theta)(B)$$

M_V = [(120 pcf)(14.2 ft)(13.5 ft)(1.00)][½(13.5 ft)] + [½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(13.5 ft - 4.0 ft)] + [½(120 pcf)(19.0 ft)²(0.444)(1.00)sin(22.4°)](13.5 ft) = 232.55 kip·ft/ft

$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4) = (\tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}\cos\theta)(\tfrac{h}{3}) + (\sigma_{LS}hK_a\gamma_{LS}\cos\theta)(\tfrac{h}{2})$$

M_H = ½[(120 pcf)(19.0 ft)²(0.444)(1.00)cos(22.4°)](19.0 ft /3) + [(250 psf)(19.0 ft)(0.444)(1.00)cos(22.4°)](19.0 ft /2) = 74.37 kip·ft/ft

$$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta = (\gamma_{BF}HB\gamma_{EV}) + (\tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}) + (\tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}\sin\theta)$$

P_V = (120 pcf)(14.2 ft)(13.5 ft)(1.00) + ½(120 pcf)(19.0 ft - 14.2 ft)(13.5 ft - 4.0 ft)(1.00) + ½(120 pcf)(19.0 ft)²(0.444)(1.00)sin(22.4°) = 29.36 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Station Along Wall Alignment	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 100% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
3008+50	1.144 in	0.898 in	11 days		
3010+00	3.065 in	1.226 in	16 days	150 ft	1 in / 460 ft
3012+00	7.808 in	2.442 in	22 days	200 ft	1 in / 160 ft
3014+00	6.684 in	2.012 in	22 days	200 ft	1 in / 470 ft
3015+00	5.079 in	1.891 in	3 days	100 ft	1 in / 830 ft

W-13-072 - FRA-71-14.36- Retaining Wall W3
MSE Wall Settlement - Sta. 3008+50

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/20/2021

Boring B-111-0-09

H=	14.2	ft	Total wall height
B'=	10.8	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	2,720	psf	Equivalent bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		ELevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-4a	C	0.0	2.7	731.1	728.4	2.7	1.4	125	338	169	169	3,169	26	0.144	0.014	0.475				0.13	0.994	2,703	2,872	0.032	0.389	0.500	1,359	1,528	0.025	0.303
	A-4a	C	2.7	5.7	728.4	725.4	3.0	4.2	125	713	525	525	3,525	26	0.144	0.014	0.475				0.39	0.888	2,414	2,939	0.022	0.263	0.489	1,331	1,856	0.016	0.193
	A-4a	C	5.7	8.7	725.4	722.4	3.0	7.2	125	1,088	900	900	3,900	26	0.144	0.014	0.475				0.67	0.715	1,945	2,845	0.015	0.176	0.460	1,251	2,151	0.011	0.133
	A-4a	C	8.7	12.2	722.4	718.9	3.5	10.5	125	1,525	1,306	1,306	4,306	26	0.144	0.014	0.475				0.97	0.563	1,532	2,838	0.012	0.138	0.414	1,127	2,433	0.009	0.111
2	A-1-b	G	12.2	14.7	718.9	716.4	2.5	13.5	135	1,863	1,694	1,694	4,694					100	106	514	1.25	0.463	1,260	2,954	0.001	0.014	0.371	1,008	2,702	0.001	0.012
3	A-4a	G	14.7	17.2	716.4	713.9	2.5	16.0	130	2,188	2,025	2,025	5,025					100	100	159	1.48	0.401	1,091	3,116	0.003	0.035	0.337	917	2,942	0.003	0.031
4	A-6a	C	17.2	18.7	713.9	712.4	1.5	18.0	130	2,383	2,285	2,285	5,285	31	0.189	0.019	0.514				1.66	0.362	984	3,269	0.003	0.035	0.313	851	3,136	0.003	0.031
5	A-1-b	G	18.7	20.2	712.4	710.9	1.5	19.5	130	2,578	2,480	2,480	5,480					38	35	115	1.80	0.337	915	3,395	0.002	0.021	0.296	806	3,286	0.002	0.019
6	A-4a	C	20.2	21.7	710.9	709.4	1.5	21.0	130	2,773	2,675	2,675	5,675	26	0.144	0.014	0.475				1.94	0.314	855	3,530	0.002	0.021	0.281	765	3,440	0.002	0.019
	A-4a	C	21.7	23.2	709.4	707.9	1.5	22.5	130	2,968	2,870	2,870	5,870	26	0.144	0.014	0.475				2.08	0.295	802	3,672	0.002	0.019	0.267	726	3,596	0.001	0.017
	A-4a	C	23.2	24.7	707.9	706.4	1.5	24.0	130	3,163	3,065	3,065	6,065	26	0.144	0.014	0.475				2.22	0.278	756	3,821	0.001	0.017	0.254	691	3,756	0.001	0.016
	A-4a	C	24.7	25.7	706.4	705.4	1.0	25.2	130	3,293	3,228	3,215	6,215	26	0.144	0.014	0.475				2.33	0.265	720	3,935	0.001	0.010	0.244	664	3,879	0.001	0.010
	A-4a	C	25.7	26.2	705.4	704.9	0.5	26.0	130	3,358	3,325	3,266	6,266	26	0.144	0.014	0.475				2.40	0.258	701	3,966	0.000	0.005	0.238	649	3,914	0.000	0.005
																								Total Settlement:		1.144 in			Total Settlement:		0.898 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

W-13-072 - FRA-71-14.36- Retaining Wall W3
MSE Wall Settlement - Sta. 3008+50

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/20/2021

Boring B-111-0-09

H=	14.2	ft	Total wall height
B'=	10.8	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	2,720	psf	Equivalent bearing pressure at bottom of wall

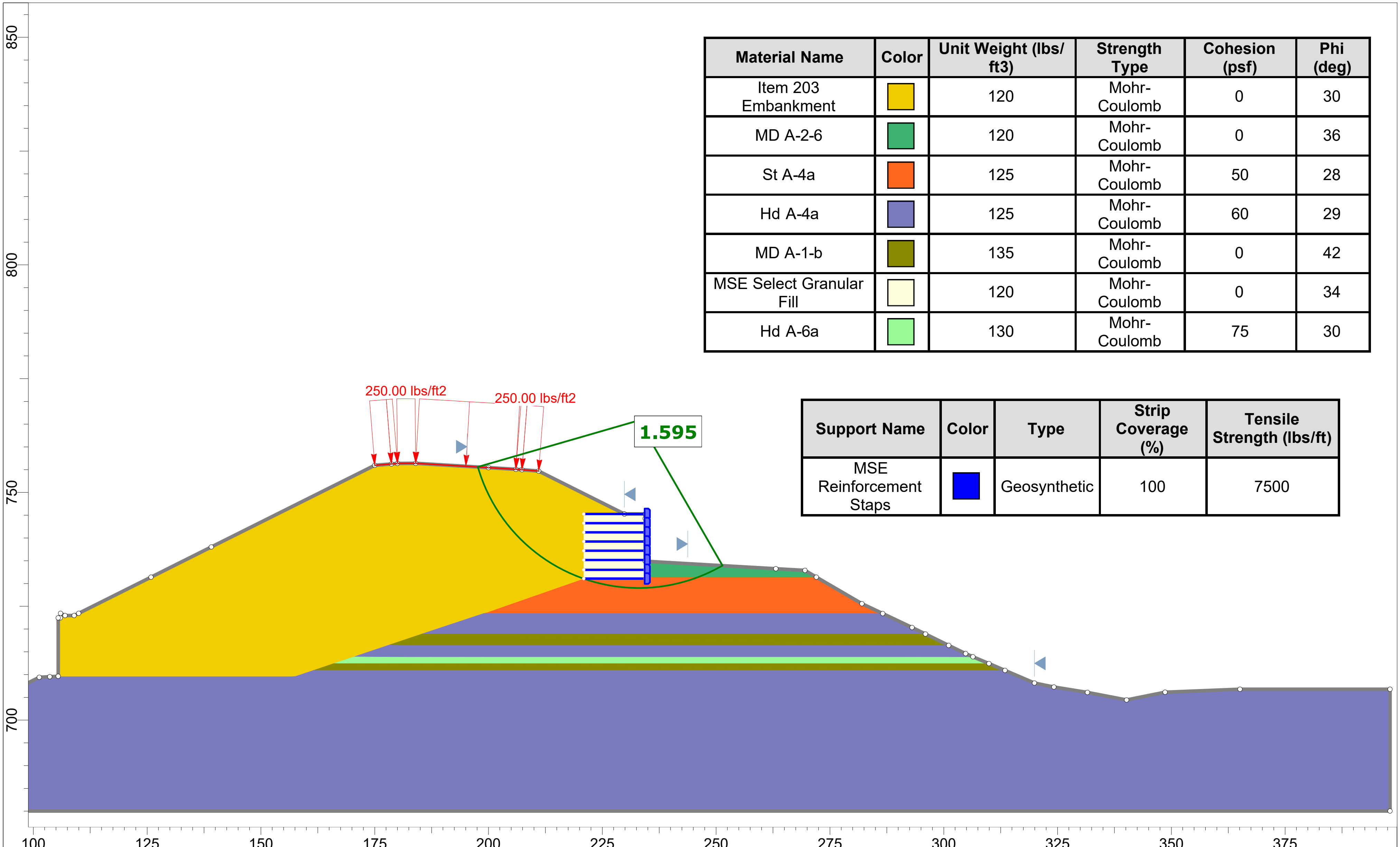
	A-4a (Upper)	A-6a	A-4a (Lower)		
c_v =	1,000	600	1000	ft^2/yr	Coefficient of consolidation
t =	11	11	11	days	Time following completion of construction
H_{dr} =	6.1	1.5	6.0	ft	Length of longest drainage path considered
T_v =	0.810	8.037	0.837		Time factor
U =	89	100	90	%	Degree of consolidation

$(S_c)_t$ = 0.810 in Settlement complete at 90% of primary consolidation

Layer	Soil Type	Soil Type	Layer Depth (ft)		ELevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	Total Settlement at Facing of Wall: S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	Settlement Complete at 90% of Primary Consolidation: $(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-4a	C	0.0	2.7	731.1	728.4	2.7	1.4	125	338	169	169	3,169	26	0.144	0.014	0.475				0.13	0.500	1,359	1,528	0.025	0.303	0.739	0.269	0.658
	A-4a	C	2.7	5.7	728.4	725.4	3.0	4.2	125	713	525	525	3,525	26	0.144	0.014	0.475				0.39	0.489	1,331	1,856	0.016	0.193		0.172	
	A-4a	C	5.7	8.7	725.4	722.4	3.0	7.2	125	1,088	900	900	3,900	26	0.144	0.014	0.475				0.67	0.460	1,251	2,151	0.011	0.133		0.118	
	A-4a	C	8.7	12.2	722.4	718.9	3.5	10.5	125	1,525	1,306	1,306	4,306	26	0.144	0.014	0.475				0.97	0.414	1,127	2,433	0.009	0.111		0.099	
2	A-1-b	G	12.2	14.7	718.9	716.4	2.5	13.5	135	1,863	1,694	1,694	4,694					100	106	514	1.25	0.371	1,008	2,702	0.001	0.012	0.012	0.012	0.012
3	A-4a	G	14.7	17.2	716.4	713.9	2.5	16.0	130	2,188	2,025	2,025	5,025					100	100	159	1.48	0.337	917	2,942	0.003	0.031	0.031	0.031	0.031
4	A-6a	C	17.2	18.7	713.9	712.4	1.5	18.0	130	2,383	2,285	2,285	5,285	31	0.189	0.019	0.514				1.66	0.313	851	3,136	0.003	0.031	0.031	0.031	0.031
5	A-1-b	G	18.7	20.2	712.4	710.9	1.5	19.5	130	2,578	2,480	2,480	5,480					38	35	115	1.80	0.296	806	3,286	0.002	0.019	0.019	0.019	0.019
6	A-4a	C	20.2	21.7	710.9	709.4	1.5	21.0	130	2,773	2,675	2,675	5,675	26	0.144	0.014	0.475				1.94	0.281	765	3,440	0.002	0.019	0.066	0.017	0.059
	A-4a	C	21.7	23.2	709.4	707.9	1.5	22.5	130	2,968	2,870	2,870	5,870	26	0.144	0.014	0.475				2.08	0.267	726	3,596	0.001	0.017		0.015	
	A-4a	C	23.2	24.7	707.9	706.4	1.5	24.0	130	3,163	3,065	3,065	6,065	26	0.144	0.014	0.475				2.22	0.254	691	3,756	0.001	0.016		0.014	
	A-4a	C	24.7	25.7	706.4	705.4	1.0	25.2	130	3,293	3,228	3,215	6,215	26	0.144	0.014	0.475				2.33	0.244	664	3,879	0.001	0.010		0.009	
	A-4a	C	25.7	26.2	705.4	704.9	0.5	26.0	130	3,358	3,325	3,266	6,266	26	0.144	0.014	0.475				2.40	0.238	649	3,914	0.000	0.005		0.004	

Settlement Remaining After Hold Period: 0.088 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment		120	Mohr-Coulomb	0	30
MD A-2-6		120	Mohr-Coulomb	0	36
St A-4a		125	Mohr-Coulomb	50	28
Hd A-4a		125	Mohr-Coulomb	60	29
MD A-1-b		135	Mohr-Coulomb	0	42
MSE Select Granular Fill		120	Mohr-Coulomb	0	34
Hd A-6a		130	Mohr-Coulomb	75	30

Support Name	Color	Type	Strip Coverage (%)	Tensile Strength (lbs/ft)
MSE Reinforcement Staps		Geosynthetic	100	7500

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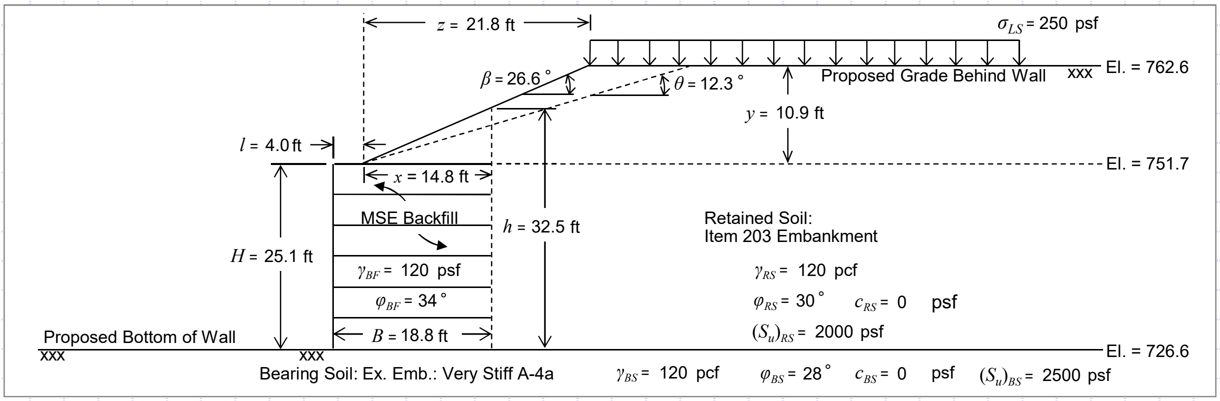
Project	FRA-71-14.36 - Retaining Wall W3 - Sta. 3008+50 (BL Ramp C3) - MSE Wall Global Stability		
Analysis Description	14.2 ft Wall Height - B-111-0-09 - Drained - Circular - Spencer Method		
Drawn By HSK/BRT	*Scale* 1:350	*Company*	Resource International Inc.
Date 6/4/2021, 3:24:21 PM		*File Name*	Sta 3008+50-Run1.slmd

SLIDEINTERPRET 9.010

Retaining Wall W3 - Sta. 3010+00 (BL Ramps C3) - B-111-0-09 - 2:1 Broken Backslope - 25.1 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.1	ft
MSE Wall Width (Reinforcement Length), (B) =	18.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	32.5	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	12.3	°
Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

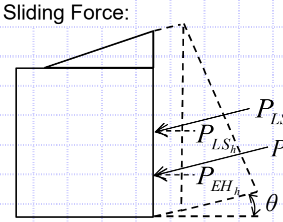
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Sections 11.6.3.6 and 11.10.5.3

Sliding Force: $P_H = (P_{EH} + P_{LS})\cos\theta$



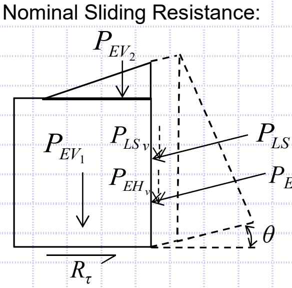
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(32.5 ft)(0.353)(1.75) = 4.49 kip/ft

P_H = (33.58 kip/ft + 4.49 kip/ft)cos(12.3°) = 37.20 kip/ft

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance: $R_\tau = (P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta)\tan\delta$ (Neglect P_{LS_v} for conservatism)



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.1 ft)(18.8 ft)(1.00) = 56.63 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.00) = 6.58 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF})$ ⟶ tan(28) ≤ tan(34) ⟶ 0.53 ≤ 0.67 = 0.53

R_τ = [56.63 kip/ft + 6.58 kip/ft + (33.58 kip/ft)sin(12.3°)](0.53) = 37.29 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 37.20 kip/ft ≤ (37.29 kip/ft)(1.0) = 37.29 kip/ft ⟶ 37.20 kip/ft ≤ 37.29 kip/ft **OK**

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.1	ft
MSE Wall Width (Reinforcement Length), (B) =	18.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	32.5	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	12.3	°
Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

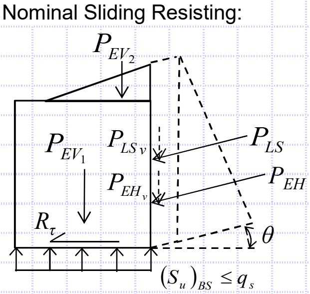
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3 *(Continued)*

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting: $R_\tau = ((S_u)_{BS} \le q_s) \cdot B$



(Neglect P_{LS_V} for conservatism)

$(S_u)_{BS}$ = 2.50 ksf

$q_s = \sigma_v / 2$

$\sigma_v = P_V / B$

$P_V = P_{EV_1} + P_{EV_2} + P_{EH} \sin\theta$

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.1 ft)(18.8 ft)(1.00) = 56.63 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$

P_{EV_2} = ½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.00) = 6.58 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

P_V = 56.63 kip/ft + 6.58 kip/ft + (33.58 kip/ft)sin(12.3°) = 70.36 kip/ft

σ_v = (70.36 kip/ft) / (18.8 ft) = 3.74 ksf

q_s = (3.74 ksf) / 2 = 1.87 ksf

R_τ = (2.50 ksf ≤ 1.87 ksf)(18.8 ft) = 47.00 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 37.20 kip/ft ≤ (47.00 kip/ft)(1.0) = 47.00 kip/ft ⟶ 37.20 kip/ft ≤ 47.00 kip/ft **OK**

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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MSE Wall Height, (H) =	25.1	ft
MSE Wall Width (Reinforcement Length), (B) =	18.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	32.5	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	12.3	°
Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, $[(S_u)_{RS}]$ =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

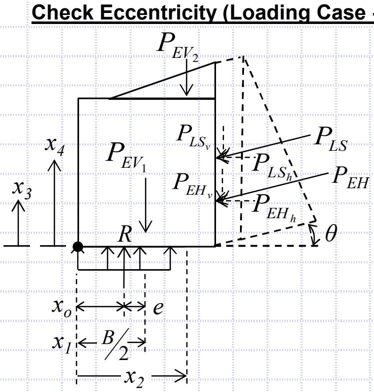
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Eccentricity (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.6.3.3



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (758.07 kip·ft/ft - 435.4 kip·ft/ft) / (70.36 kip/ft) = 4.59 ft

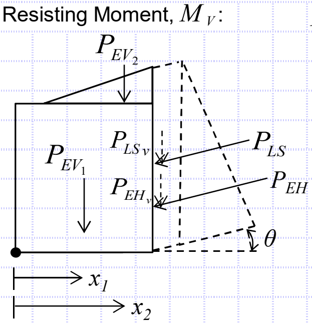
M_V = 758.07 kip·ft/ft
M_H = 435.40 kip·ft/ft
(Defined below)

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 56.63 kip/ft + 6.58 kip/ft + (33.58 kip/ft)sin(12.3°) = 70.36 kip/ft

$e =$ (18.8 ft/ 2) - 4.59 ft = 4.81 ft

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B)$$ (Neglect P_{LS_V} for conservatism)



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.1 ft)(18.8 ft)(1.00) = 56.63 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.00) = 6.58 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

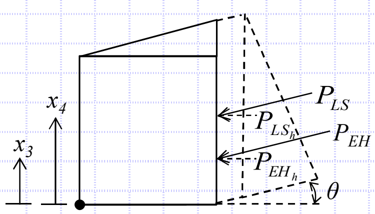
$x_1 = B/2$ = (18.8 ft) / 2 = 9.40 ft

$x_2 = l + \tfrac{2}{3}(B-l)$ = 4.0 ft + ⅔(18.8 ft - 4.0 ft) = 13.87 ft

M_V = (56.63 kip/ft)(9.40 ft) + (6.58 kip/ft)(13.87 ft) + (33.58 kip/ft)sin(12.3°)(18.8 ft) = 758.07 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4)$$



$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(32.5 ft)(0.353)(1.75) = 5.02 kip/ft

$x_3 = h/3$ = (32.5 ft) / 3 = 10.84 ft

$x_4 = h/2$ = (32.5 ft) / 2 = 16.26 ft

M_H = (33.58 kip/ft)cos(12.3°)(10.84 ft) + (5.02 kip/ft)cos(12.3°)(16.26 ft = 435.40 kip·ft/ft

Check Eccentricity Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (18.8 ft) / 3 = 6.27 ft

$e < e_{max} \longrightarrow$ 4.81 ft < 6.27 ft **OK**

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.1	ft
MSE Wall Width (Reinforcement Length), (B) =	18.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	32.5	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	12.3	°
Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Bearing Soil Properties:

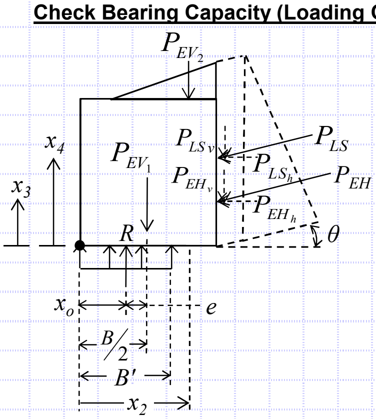
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.6.3.2



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 18.8 ft - 2(3.55 ft) = 11.70 ft

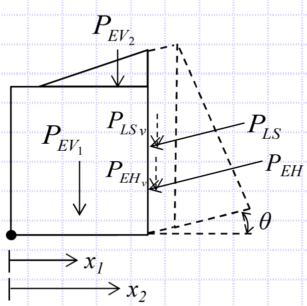
$e = B/2 - x_o$ = (18.8 ft / 2) - 5.85 ft = 3.55 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (976.19 kip·ft/ft - 435.40 kip·ft/ft) / 92.47 kip/ft = 5.85 ft

q_{eq} = (92.47 kip/ft) / (11.7 ft) = 7.90 ksf

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B)$$



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.1 ft)(18.8 ft)(1.35) = 76.44 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.35) = 8.88 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

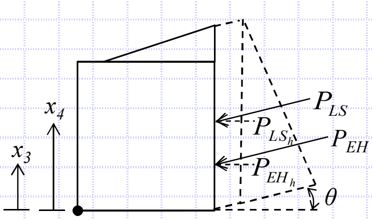
$x_1 = B/2$ = (18.8 ft) / 2 = 9.40 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 4.0 ft + ⅔(18.8 ft - 4.0 ft) = 13.87 ft

M_V = (76.44 kip/ft)(9.40 ft) + (8.88 kip/ft)(13.9 ft) + (33.58 kip/ft)sin(12.3°)(18.8 ft) = 976.19 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4)$$



$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(32.5 ft)²(0.353)(1.50) = 33.58 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(32.5 ft)(0.353)(1.75) = 5.02 kip/ft

$x_3 = h/3$ = (32.5 ft) / 3 = 10.84 ft

$x_4 = h/2$ = (32.5 ft) / 2 = 16.26 ft

M_H = (33.58 kip/ft)cos(12.3°)(10.84 ft) + (5.02 kip/ft)cos(12.3°)(16.26 ft = 435.40 kip·ft/ft

Vertical Forces, P_V:

$$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$$

P_V = 76.44 kip/ft + 8.88 kip/ft + (33.58 kip/ft)sin(12.3°) = 92.47 kip/ft

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Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4 ***(Continued)***

Check Bearing Resistance - Drained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 25.8 $N_{qm} = N_q s_q d_q i_q$ = 16.2 $N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_c = 25.80
s_c = 1+(11.7 ft/869 ft)(14.72/25.8) = 1.000
i_c = 1.000 (Assumed)

N_q = 14.72
s_q = 1+(11.7 ft/869 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(4.0 ft/11.7 ft) = 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 4.0 ft = 1.000

N_γ = 16.72
s_γ = 1-0.4(11.7 ft/869 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(11.7 ft) + 4.0 ft = 0.500

q_n = (0 psf)(25.8) + (120 pcf)(4.0 ft)(16.2)(1.0) + ½(120 pcf)(11.7 ft)(16.7)(0.5) = 13.64 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 7.90 ksf ≤ (13.64 ksf)(0.65) = 8.87 ksf ⟶ 7.90 ksf ≤ 8.87 ksf **OK**

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

Check Bearing Resistance - Undrained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.140 $N_{qm} = N_q s_q d_q i_q$ = 1.000 $N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.000

N_c = 5.140
s_c = 1+(11.7 ft/[(5)(869 ft)] = 1.000
i_c = 1.000 (Assumed)

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(4.0 ft/11.7 ft) = 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 4.0 ft = 1.000

N_γ = 0.000
s_γ = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(11.7 ft) + 4.0 ft = 0.500

q_n = (2500 psf)(5.14) + (120 pcf)(4.0 ft)(1.0)(1.0) + ½(120 pcf)(11.7 ft)(0.0)(0.5) = 13.33 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 7.90 ksf ≤ (13.33 ksf)(0.65) = 8.66 ksf ⟶ 7.90 ksf ≤ 8.66 ksf **OK**

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.1	ft
MSE Wall Width (Reinforcement Length), (B) =	18.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	869	ft
MSE Wall Effective Height, (h) =	32.5	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	12.3	°
Distance from Toe to Top of Backslope, (z) =	21.8	ft
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{RS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.353	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	25.0	ft

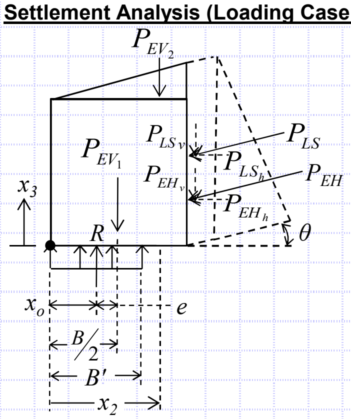
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Drained cohesion for retained soil not accounted for in external stability analyses. This parameter is utilized in global stability analysis.

Settlement Analysis (Loading Case - Service I) - AASHTO LRFD BDM Section 11.10.4.1



$$q_{eq} = P_V / B'$$

$$B' = B - 2e \quad = \quad 18.8\text{ ft} - 2(3.07\text{ ft}) \quad = \quad 12.66 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (18.8\text{ ft} / 2) - 6.33\text{ ft} \quad = \quad 3.07 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (713.20\text{ kip·ft/ft} - 282.61\text{ kip·ft/ft}) / 67.98\text{ kip/ft} \quad = \quad 6.33 \quad \text{ft}$$

$$q_{eq} \quad = \quad (67.98\text{ kip/ft}) / (12.66\text{ ft}) \quad = \quad 5.37 \quad \text{ksf}$$

$$M_V = P_{EV_1}(x_1) + P_{EV_2}(x_2) + P_{EH}\sin\theta(B) = (\gamma_{BF} H B \gamma_{EV})(\tfrac{1}{2}B) + (\tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV})(l + \tfrac{2}{3}(B-l)) + (\tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}\sin\theta)(B)$$

M_V = [(120 pcf)(25.1 ft)(18.8 ft)(1.00)][½(18.8 ft)] + [½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(18.8 ft - 4.0 ft)] + [½(120 pcf)(32.5 ft)²(0.353)(1.00)sin(12.3°)](18.8 ft) = 713.2 kip·ft/ft

$$M_H = P_{EH}\cos\theta(x_3) + P_{LS}\cos\theta(x_4) = (\tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}\cos\theta)(h/3) + (\sigma_{LS} h K_a \gamma_{LS}\cos\theta)(h/2)$$

M_H = ½[(120 pcf)(32.5 ft)²(0.353)(1.00)cos(12.3°)](32.5 ft /3) + [(250 psf)(32.5 ft)(0.353)(1.00)cos(12.3°)](32.5 ft /2) = 282.61 kip·ft/ft

$$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta = (\gamma_{BF} H B \gamma_{EV}) + (\tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}) + (\tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}\sin\theta)$$

P_V = (120 pcf)(25.1 ft)(18.8 ft)(1.00) + ½(120 pcf)(32.5 ft - 25.1 ft)(18.8 ft - 4.0 ft)(1.00) + ½(120 pcf)(32.5 ft)²(0.353)(1.00)sin(12.3°) = 67.98 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Station Along Wall Alignment	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 100% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
3008+50	1.144 in	0.898 in	11 days		
3010+00	3.065 in	1.226 in	16 days	150 ft	1 in / 460 ft
3012+00	7.808 in	2.442 in	22 days	200 ft	1 in / 160 ft
3014+00	6.684 in	2.012 in	22 days	200 ft	1 in / 470 ft
3015+00	5.079 in	1.891 in	3 days	100 ft	1 in / 830 ft

W-13-072 - FRA-71-14.36- Retaining Wall W3
MSE Wall Settlement - Sta. 3010+00

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/21/2021

Boring B-111-0-09

H=	25.1	ft	Total wall height
B'=	12.7	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	5,370	psf	Equivalent bearing pressure at bottom of wall

																				Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		ELevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
	A-4a	C	0.0	1.0	726.6	725.6	1.0	0.5	125	125	63	63	3,063	26	0.144	0.014	0.475				0.04	1.000	5,369	5,431	0.041	0.489	0.500	2,685	2,747	0.016	0.192
	A-4a	C	1.0	2.0	725.6	724.6	1.0	1.5	125	250	188	188	3,188	26	0.144	0.014	0.475				0.12	0.995	5,342	5,529	0.035	0.424	0.500	2,683	2,871	0.012	0.139
1	A-4a	C	2.0	4.0	724.6	722.6	2.0	3.0	125	500	375	375	3,375	26	0.144	0.014	0.475				0.24	0.965	5,182	5,557	0.061	0.731	0.497	2,671	3,046	0.018	0.213
	A-4a	C	4.0	6.0	722.6	720.6	2.0	5.0	125	750	625	625	3,625	26	0.144	0.014	0.475				0.39	0.885	4,751	5,376	0.048	0.580	0.489	2,627	3,252	0.014	0.168
	A-4a	C	6.0	7.7	720.6	718.9	1.7	6.9	125	963	856	856	3,856	26	0.144	0.014	0.475				0.54	0.793	4,260	5,116	0.031	0.375	0.476	2,554	3,410	0.010	0.120
2	A-1-b	G	7.7	10.2	718.9	716.4	2.5	9.0	135	1,300	1,131	1,131	4,131					100	119	631	0.70	0.693	3,723	4,854	0.003	0.030	0.454	2,441	3,572	0.002	0.024
3	A-4a	G	10.2	12.7	716.4	713.9	2.5	11.5	130	1,625	1,463	1,463	4,463					100	111	175	0.90	0.592	3,181	4,644	0.007	0.086	0.425	2,281	3,743	0.006	0.070
4	A-6a	C	12.7	14.2	713.9	712.4	1.5	13.5	130	1,820	1,723	1,723	4,723	32	0.198	0.020	0.522				1.06	0.527	2,828	4,550	0.008	0.099	0.400	2,147	3,869	0.007	0.082
5	A-1-b	G	14.2	15.7	712.4	710.9	1.5	15.0	130	2,015	1,918	1,918	4,918					38	39	126	1.18	0.485	2,603	4,521	0.004	0.053	0.381	2,047	3,965	0.004	0.045
	A-4a	C	15.7	17.2	710.9	709.4	1.5	16.5	130	2,210	2,113	2,113	5,113	26	0.144	0.014	0.475				1.30	0.448	2,408	4,520	0.005	0.058	0.363	1,951	4,063	0.004	0.050
	A-4a	C	17.2	18.7	709.4	707.9	1.5	18.0	130	2,405	2,308	2,308	5,308	26	0.144	0.014	0.475				1.41	0.417	2,237	4,545	0.004	0.052	0.346	1,858	4,166	0.004	0.045
6	A-4a	C	18.7	20.2	707.9	706.4	1.5	19.5	130	2,600	2,503	2,503	5,503	26	0.144	0.014	0.475				1.53	0.389	2,087	4,590	0.004	0.046	0.330	1,771	4,274	0.003	0.041
	A-4a	C	20.2	21.2	706.4	705.4	1.0	20.7	130	2,730	2,665	2,665	5,665	26	0.144	0.014	0.475				1.63	0.368	1,976	4,641	0.002	0.028	0.317	1,703	4,368	0.002	0.025
	A-4a	C	21.2	21.7	705.4	704.9	0.5	21.5	130	2,795	2,763	2,763	5,763	26	0.144	0.014	0.475				1.69	0.357	1,914	4,677	0.001	0.013	0.310	1,663	4,426	0.001	0.012
																								Total Settlement:		3.065 in			Total Settlement:		1.226 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(Cc)$ for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

W-13-072 - FRA-71-14.36- Retaining Wall W3 — Calculated By: HSK — Date: 6/8/2021

MSE Wall Settlement - Sta. 3010+00 — Checked By: BRT — Date: 6/21/2021

Boring B-111-0-09

H=	25.1	ft	Total wall height
B'=	12.7	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	5,370	psf	Equivalent bearing pressure at bottom of wall

	A-4a (Upper)	A-6a	A-4a (Lower)		
c_v =	1,000	600	1000	ft^2/yr	Coefficient of consolidation
t =	16	16	16	days	Time following completion of construction
H_{dr} =	7.7	1.5	6.0	ft	Length of longest drainage path considered
T_v =	0.739	11.689	1.218		Time factor
U =	87	100	96	%	Degree of consolidation

$(S_c)_t$ = 1.111 in — Settlement complete at 91% of primary consolidation

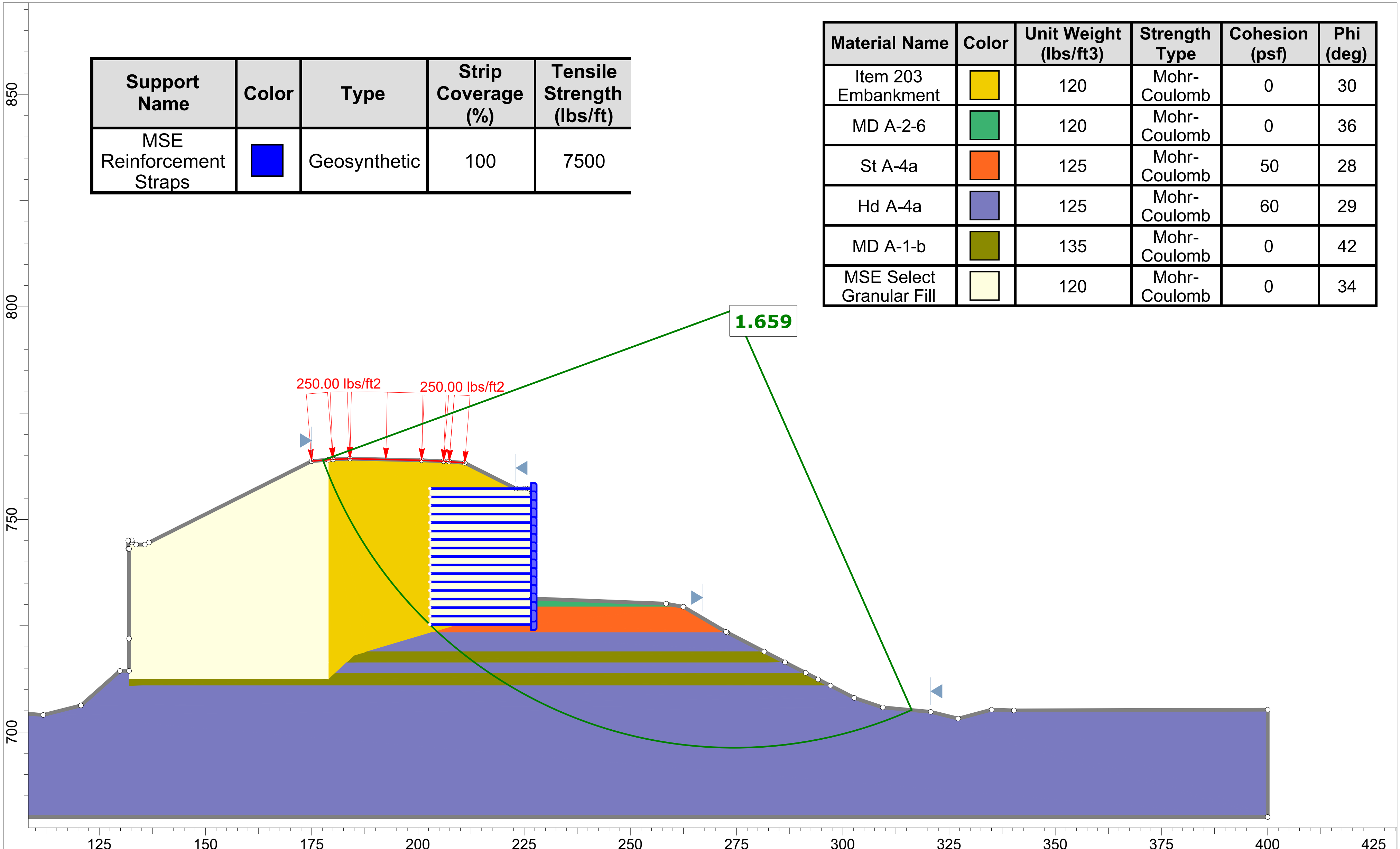
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' [1] (psf)	LL	C_c [2]	C_r [3]	e_o [4]	N_{60}	$(N1)_{60}$ [5]	C' [6]	Z_f/B	I [7]	$\Delta\sigma_v$ [8] (psf)	σ_{vf}' Midpoint (psf)	Total Settlement at Facing of Wall: S_c [9,10] (ft)	S_c (in)	Layer Settlement (in)	Settlement Complete at 91% of Primary Consolidation: $(S_c)_t$ [11] (in)	Layer Settlement (in)
1	A-4a	C	0.0	1.0	726.6	725.6	1.0	0.5	125	125	63	63	3,063	26	0.144	0.014	0.475				0.04	0.500	2,685	2,747	0.016	0.192	0.832	0.167	0.724
	A-4a	C	1.0	2.0	725.6	724.6	1.0	1.5	125	250	188	188	3,188	26	0.144	0.014	0.475				0.12	0.500	2,683	2,871	0.012	0.139		0.121	
	A-4a	C	2.0	4.0	724.6	722.6	2.0	3.0	125	500	375	375	3,375	26	0.144	0.014	0.475				0.24	0.497	2,671	3,046	0.018	0.213		0.185	
	A-4a	C	4.0	6.0	722.6	720.6	2.0	5.0	125	750	625	625	3,625	26	0.144	0.014	0.475				0.39	0.489	2,627	3,252	0.014	0.168		0.146	
	A-4a	C	6.0	7.7	720.6	718.9	1.7	6.9	125	963	856	856	3,856	26	0.144	0.014	0.475				0.54	0.476	2,554	3,410	0.010	0.120		0.104	
2	A-1-b	G	7.7	10.2	718.9	716.4	2.5	9.0	135	1,300	1,131	1,131	4,131					100	119	631	0.70	0.454	2,441	3,572	0.002	0.024	0.024	0.024	0.024
3	A-4a	G	10.2	12.7	716.4	713.9	2.5	11.5	130	1,625	1,463	1,463	4,463					100	111	175	0.90	0.425	2,281	3,743	0.006	0.070	0.070	0.070	0.070
4	A-6a	C	12.7	14.2	713.9	712.4	1.5	13.5	130	1,820	1,723	1,723	4,723	32	0.198	0.020	0.522				1.06	0.400	2,147	3,869	0.007	0.082	0.082	0.082	0.082
5	A-1-b	G	14.2	15.7	712.4	710.9	1.5	15.0	130	2,015	1,918	1,918	4,918					38	39	126	1.18	0.381	2,047	3,965	0.004	0.045	0.045	0.045	0.045
6	A-4a	C	15.7	17.2	710.9	709.4	1.5	16.5	130	2,210	2,113	2,113	5,113	26	0.144	0.014	0.475				1.30	0.363	1,951	4,063	0.004	0.050	0.173	0.048	0.166
	A-4a	C	17.2	18.7	709.4	707.9	1.5	18.0	130	2,405	2,308	2,308	5,308	26	0.144	0.014	0.475				1.41	0.346	1,858	4,166	0.004	0.045		0.043	
	A-4a	C	18.7	20.2	707.9	706.4	1.5	19.5	130	2,600	2,503	2,503	5,503	26	0.144	0.014	0.475				1.53	0.330	1,771	4,274	0.003	0.041		0.039	
	A-4a	C	20.2	21.2	706.4	705.4	1.0	20.7	130	2,730	2,665	2,665	5,665	26	0.144	0.014	0.475				1.63	0.317	1,703	4,368	0.002	0.025		0.024	
	A-4a	C	21.2	21.7	705.4	704.9	0.5	21.5	130	2,795	2,763	2,763	5,763	26	0.144	0.014	0.475				1.69	0.310	1,663	4,426	0.001	0.012		0.012	

Settlement Remaining After Hold Period: 0.115 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

Support Name	Color	Type	Strip Coverage (%)	Tensile Strength (lbs/ft)
MSE Reinforcement Straps		Geosynthetic	100	7500

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment		120	Mohr-Coulomb	0	30
MD A-2-6		120	Mohr-Coulomb	0	36
St A-4a		125	Mohr-Coulomb	50	28
Hd A-4a		125	Mohr-Coulomb	60	29
MD A-1-b		135	Mohr-Coulomb	0	42
MSE Select Granular Fill		120	Mohr-Coulomb	0	34



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SLIDEINTERPRET 9.010

Project	FRA-71-14.36 - Retaining Wall W3 - Sta. 3010+50 (BL Ramp C3) - MSE Wall Global Stability
Analysis Description	32.0 ft Wall Height - B-111-0-09 - Drained - Circular - Spencer Method
Drawn By	HSK/BRT
Scale	1:375
Company	Resource International Inc.
Date	6/6/2021, 10:52:27 PM
File Name	Sta 3010+50-Run1.slmd

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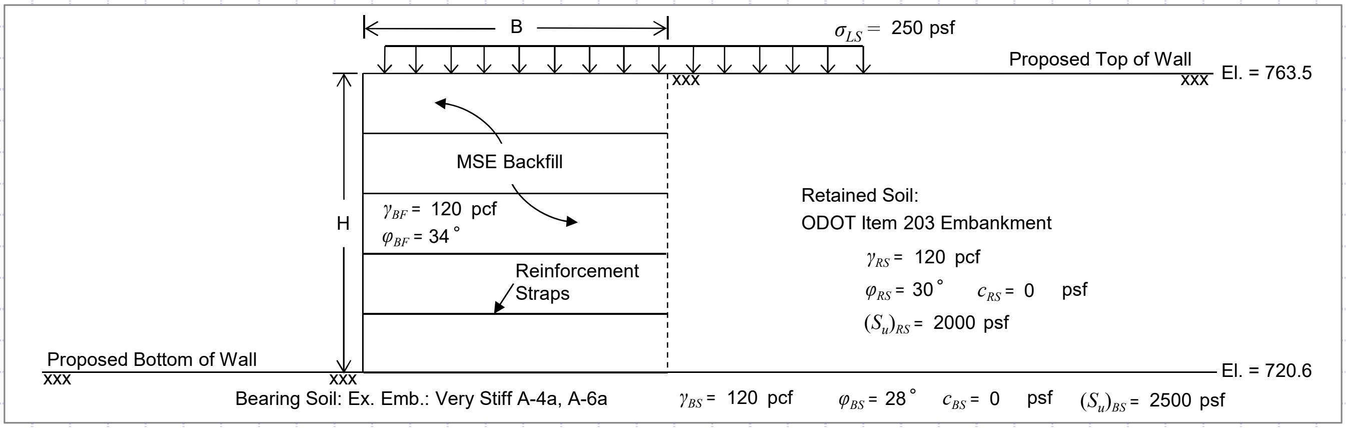
Retaining Wall W3 - Sta. 3012+00 (BL Ramp C3) - B-106-0-09 and B-111-0-09 - 42.9 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion [1], (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

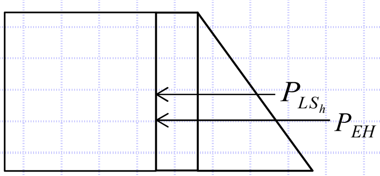
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3

Sliding Force:

$$P_H = P_{EH} + P_{LS_h}$$



$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(42.9 ft)²(0.297)(1.5)} = 49.19 \text{ kip/ft}$$

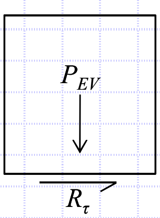
$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(42.9 ft)(0.297)(1.75)} = 5.57 \text{ kip/ft}$$

$$P_H = \text{49.19 kip/ft + 5.57 kip/ft} = 54.76 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

$$R_\tau = P_{EV} \cdot \tan\delta$$



$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(42.9 ft)(38.6 ft)(1.00)} = 198.71 \text{ kip/ft}$$

$$\tan\delta = \left(\tan\varphi_{BS} \le \tan\varphi_{BF}\right)$$

$$\tan\delta = \tan(28) \le \tan(34) \longrightarrow 0.53 \le 0.67 \longrightarrow \tan\delta = 0.53$$

$$R_\tau = \text{(198.71 kip/ft)(0.53)} = 105.32 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{54.76 kip/ft} \le \text{(105.32 kip/ft)(1.0) = 105.32 kip/ft} \longrightarrow \text{54.76 kip/ft} \le \text{105.32 kip/ft}$$

OK

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

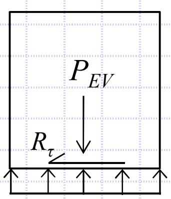
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3 *(Continued)*

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting: $$R_\tau = ((S_u)_{BS} \le q_s) \cdot B$$



$(S_u)_{BS}$ = 2.50 ksf

$q_s = \sigma_v / 2$ = (5.15 ksf) / 2 = 2.58 ksf

$\sigma_v = P_{EV} / B$ = (198.71 kip/ft) / (38.6 ft) = 5.15 ksf

R_τ = (2.50 ksf ≤ 2.58 ksf)(38.6 ft) = 96.50 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 54.76 kip/ft ≤ (96.50 kip/ft)(1.0) = 96.50 kip/ft ⟶ 54.76 kip/ft ≤ 96.50 kip/ft **OK**

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

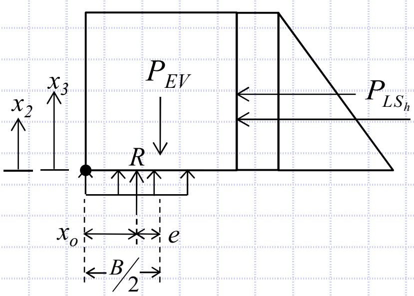
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Eccentricity (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.5



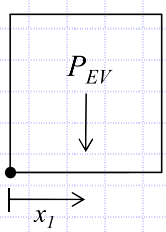
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (3835.1 kip·ft/ft - 822.89 kip·ft/ft) / (198.71 kip/ft) = 15.16 ft

M_{EV} = 3835.10 kip·ft/ft
M_H = 822.89 kip·ft/ft
P_{EV} = 198.71 kip/ft
} Defined below

$e =$ (38.6 ft)/2 - 15.16 ft = 4.14 ft

Resisting Moment, M_{EV}:



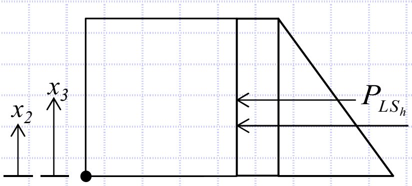
$$M_{EV} = P_{EV}(x_1)$$

$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(42.9 ft)(38.6 ft)(1.00) = 198.71 kip/ft

$x_1 = B/2$ = (38.6 ft) / 2 = 19.30 ft

$M_{EV} =$ (198.71 kip/ft)(19.30 ft) = 3835.10 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3)$$

$P_{EH} = ½\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(42.9 ft)²(0.297)(1.5) = 49.19 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(42.9 ft)(0.297)(1.75) = 5.57 kip/ft

$x_2 = H/3$ = (42.9 ft) / 3 = 14.30 ft

$x_3 = H/2$ = (42.9 ft) / 2 = 21.45 ft

$M_H =$ (49.19 kip/ft)(14.3 ft) + (5.57 kip/ft)(21.45 ft) = 822.89 kip·ft/ft

Check Eccentricity

$e < e_{max} \longrightarrow$ 4.14 ft < 12.87 ft **OK**

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (38.6 ft) / 3 = 12.87 ft

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

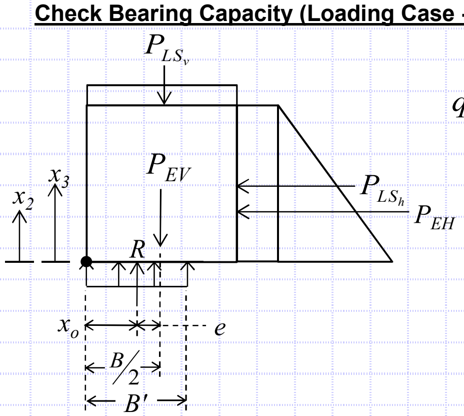
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 38.6 ft - 2(2.89 ft) = 32.82 ft

$e = B/2 - x_o$ = (38.6 ft) / 2 - 16.41 ft = 2.89 ft

$x_o = \frac{M_V - M_H}{P_V}$ = (5503.39 kip·ft/ft - 823.05 kip·ft/ft) / 285.15 kip/ft = 16.41 ft

q_{eq} = (285.15 kip/ft) / (32.82 ft) = 8.69 ksf

$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) = (\gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV})(x_1) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})(x_1)$$

M_V = [(120 pcf)(42.9 ft)(38.6 ft)(1.35)](19.3 ft) + [(250 psf)(38.6 ft)(1.75)](19.3 ft) = 5503.39 kip·ft/ft

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3) = (\tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH})(x_2) + (\sigma_{LS} H K_a \gamma_{LS})(x_3)$$

M_H = [½(120 pcf)(42.9 ft)²(0.297)(1.5)](14.3 ft) + [(250 psf)(42.9 ft)(0.297)(1.75)](21.45 ft) = 823.05 kip·ft/ft

$$P_V = P_{EV} + P_{LS} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} + \sigma_{LS} \cdot B \cdot \gamma_{LS}$$

P_V = (120 pcf)(42.9 ft)(38.6 ft)(1.35) + (250 psf)(38.6 ft)(1.75) = 285.15 kip/ft

Check Bearing Resistance - Drained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 26.37

N_c = 25.8

s_c = 1+(32.82 ft/869 ft)(14.72/25.8)

= 1.022

i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 15.55

N_q = 14.72

s_q = 1.020

d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(4.0 ft/32.82 ft)

1.036

i_q = 1.000 (Assumed)

C_{wq} = 25.0 ft > 4.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.47

N_γ = 16.72

s_γ = 0.985

i_γ = 1.000 (Assumed)

$C_{w\gamma}$ = 25.0 ft < 1.5(32.82 ft) + 4.0 ft = 0.754

q_n = (0 psf)(26.368) + (120 pcf)(4.0 ft)(15.555)(1.000) + ½(120 pcf)(32.8 ft)(16.469)(0.754) = 31.92 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 8.69 ksf ≤ (31.92 ksf)(0.65) = 20.75 ksf ⟶ 8.69 ksf ≤ 20.75 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4 ***(Continued)***

Check Bearing Resistance - Undrained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.180

N_c = 5.140

s_c = 1+(32.82 ft/[(5)(869 ft)]) = 1.008

i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 1.000

N_q = 1.000

s_q = 1.000

d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(4.0 ft/32.82 ft)

1.000

i_q = 1.000 (Assumed)

C_{wq} = 25.0 ft > 4.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.000

N_γ = 0.000

s_γ = 1.000

i_γ = 1.000 (Assumed)

$C_{w\gamma}$ = 25.0 ft < 1.5(32.82 ft) + 4.0 ft = 0.754

q_n = (2500 psf)(5.180) + (120 pcf)(4.0 ft)(1.000)(1.000) + ½(120 pcf)(32.8 ft)(0.000)(0.754) = 13.43 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 8.69 ksf ≤ (13.43 ksf)(0.65) = 8.73 ksf ⟶ 8.69 ksf ≤ 8.73 ksf **OK**

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	42.9	ft
MSE Wall Width (Reinforcement Length), (B) =	38.6	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

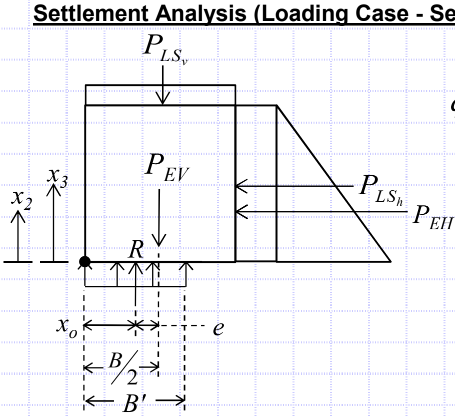
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Settlement Analysis (Loading Case - Service I) - AASHTO LRFD BDM Section 11.10.4.1



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 38.6 ft - 2(2.58 ft) = 33.44 ft

$e = B/2 - x_o$ = (38.6 ft) / 2 - 16.72 ft = 2.58 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (4021.40 kip·ft/ft - 537.31 kip·ft/ft) / 208.36 kip/ft = 16.72 ft

q_{eq} = (208.36 kip/ft) / (33.44 ft) = 6.23 ksf

$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) = (\gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV})(x_1) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})(x_1)$$

M_V = [(120 pcf)(42.9 ft)(38.6 ft)(1.00)](19.3 ft) + [(250 psf)(38.6 ft)(1.00)](19.3 ft) = 4021.40 kip·ft/ft

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3) = (\tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH})(x_2) + (\sigma_{LS} H K_a \gamma_{LS})(x_3)$$

M_H = [½(120 pcf)(42.9 ft)²(0.297)(1.00)](14.3 ft) + [(250 psf)(42.9 ft)(0.297)(1.00)](21.45 ft) = 537.31 kip·ft/ft

$$P_V = P_{EV} + P_{LS} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} + \sigma_{LS} \cdot B \cdot \gamma_{LS}$$

P_V = (120 pcf)(42.9 ft)(38.6 ft)(1.00) + (250 psf)(38.6 ft)(1.00) = 208.36 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Station Along Wall Alignment	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 100% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
3008+50	1.144 in	0.898 in	11 days		
3010+00	3.065 in	1.226 in	16 days	150 ft	1 in / 460 ft
3012+00	7.808 in	2.442 in	22 days	200 ft	1 in / 160 ft
3014+00	6.684 in	2.012 in	22 days	200 ft	1 in / 470 ft
3015+00	5.079 in	1.891 in	3 days	100 ft	1 in / 830 ft

W-13-072 - FRA-71-14.36- Retaining Wall W3

MSE Wall Settlement - Sta. 3012+00

Calculated By: HSK Date: 6/8/2021

Checked By: BRT Date: 6/21/2021

Boring B-105-6-14 and B-106-0-09

H=	42.9	ft	Total wall height
B'=	29.6	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	6,230	psf	Equivalent bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-4a	C	0.0	1.1	720.6	719.5	1.1	0.6	120	132	66	66	3,066	26	0.144	0.014	0.475				0.02	1.000	6,230	6,296	0.051	0.617	0.500	3,115	3,181	0.020	0.235
	A-4a	C	1.1	3.1	719.5	717.5	2.0	2.1	120	372	252	252	3,252	26	0.144	0.014	0.475				0.07	0.999	6,223	6,475	0.080	0.961	0.500	3,115	3,367	0.025	0.295
	A-4a	C	3.1	5.1	717.5	715.5	2.0	4.1	120	612	492	492	3,492	26	0.144	0.014	0.475				0.14	0.992	6,179	6,671	0.071	0.858	0.499	3,112	3,604	0.019	0.231
2	A-6a	C	5.1	7.6	715.5	713.0	2.5	6.4	125	925	768	768	3,768	28	0.162	0.016	0.491				0.21	0.973	6,060	6,828	0.089	1.067	0.498	3,103	3,871	0.022	0.263
	A-6a	C	7.6	10.1	713.0	710.5	2.5	8.9	125	1,237	1,081	1,081	4,081	28	0.162	0.016	0.491				0.30	0.937	5,840	6,921	0.078	0.936	0.495	3,083	4,164	0.018	0.217
	A-6a	C	10.1	12.6	710.5	708.0	2.5	11.4	125	1,550	1,393	1,393	4,393	28	0.162	0.016	0.491				0.38	0.891	5,551	6,945	0.068	0.811	0.490	3,052	4,445	0.015	0.179
3	A-6b	C	12.6	14.1	708.0	706.5	1.5	13.4	130	1,745	1,647	1,647	4,647	37	0.243	0.024	0.561				0.45	0.850	5,293	6,940	0.051	0.614	0.484	3,018	4,665	0.011	0.131
	A-6b	C	14.1	15.6	706.5	705.0	1.5	14.9	130	1,940	1,842	1,842	4,842	37	0.243	0.024	0.561				0.50	0.817	5,093	6,935	0.046	0.555	0.480	2,988	4,830	0.010	0.117
4	A-6a	C	15.6	17.1	705.0	703.5	1.5	16.4	130	2,135	2,037	2,037	5,037	30	0.180	0.018	0.507				0.55	0.785	4,893	6,930	0.032	0.382	0.474	2,954	4,991	0.007	0.084
5	A-4a	C	17.1	18.6	703.5	702.0	1.5	17.9	130	2,330	2,232	2,232	5,232	23	0.117	0.012	0.452				0.60	0.754	4,696	6,928	0.019	0.231	0.468	2,916	5,148	0.004	0.053
6	A-1-b	G	18.6	23.4	702.0	697.2	4.8	21.0	130	2,954	2,642	2,642	5,642					100	91	401	0.71	0.691	4,304	6,946	0.005	0.060	0.454	2,828	5,469	0.004	0.045
7	A-2-4	G	23.4	25.6	697.2	695.0	2.2	24.5	130	3,240	3,097	3,097	6,097					18	15	65	0.83	0.628	3,912	7,009	0.012	0.143	0.436	2,718	5,815	0.009	0.111
8	A-1-a	G	25.6	35.6	695.0	685.0	10.0	30.6	130	4,540	3,890	3,540	6,540					47	38	124	1.03	0.537	3,343	6,883	0.023	0.279	0.404	2,516	6,056	0.019	0.226
	A-1-a	G	35.6	44.6	685.0	676.0	9.0	40.1	130	5,710	5,125	4,182	7,182					56	42	139	1.35	0.432	2,692	6,874	0.014	0.168	0.355	2,209	6,392	0.012	0.143
9	A-1-b	G	44.6	52.6	676.0	668.0	8.0	48.6	131	6,758	6,234	4,761	7,761					56	40	130	1.64	0.366	2,279	7,040	0.010	0.125	0.316	1,967	6,728	0.009	0.111
																								Total Settlement:		7.808 in			Total Settlement:		2.442 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

W-13-072 - FRA-71-14.36- Retaining Wall W3
MSE Wall Settlement - Sta. 3012+00

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/21/2021

Boring B-105-6-14 and B-106-0-09

H=	42.9	ft	Total wall height
B'=	29.6	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	6,230	psf	Equivalent bearing pressure at bottom of wall

	A-4a (Upper)	A-6a (Upper)	A-6b	A-6a (Lower)	A-4a (Lower)		
c_v =	1,000	600	300	600	1,000	ft^2/yr	Coefficient of consolidation
t =	22	22	22	22	22	days	Time following completion of construction
H_{dr} =	5.1	9.3	6.0	3.0	1.5	ft	Length of longest drainage path considered
T_v =	2.317	0.418	0.502	4.018	26.788		Time factor
U =	100	71	77	100	100	%	Degree of consolidation

$(S_c)_t$ = 2.193 in Settlement complete at 90% of primary consolidation

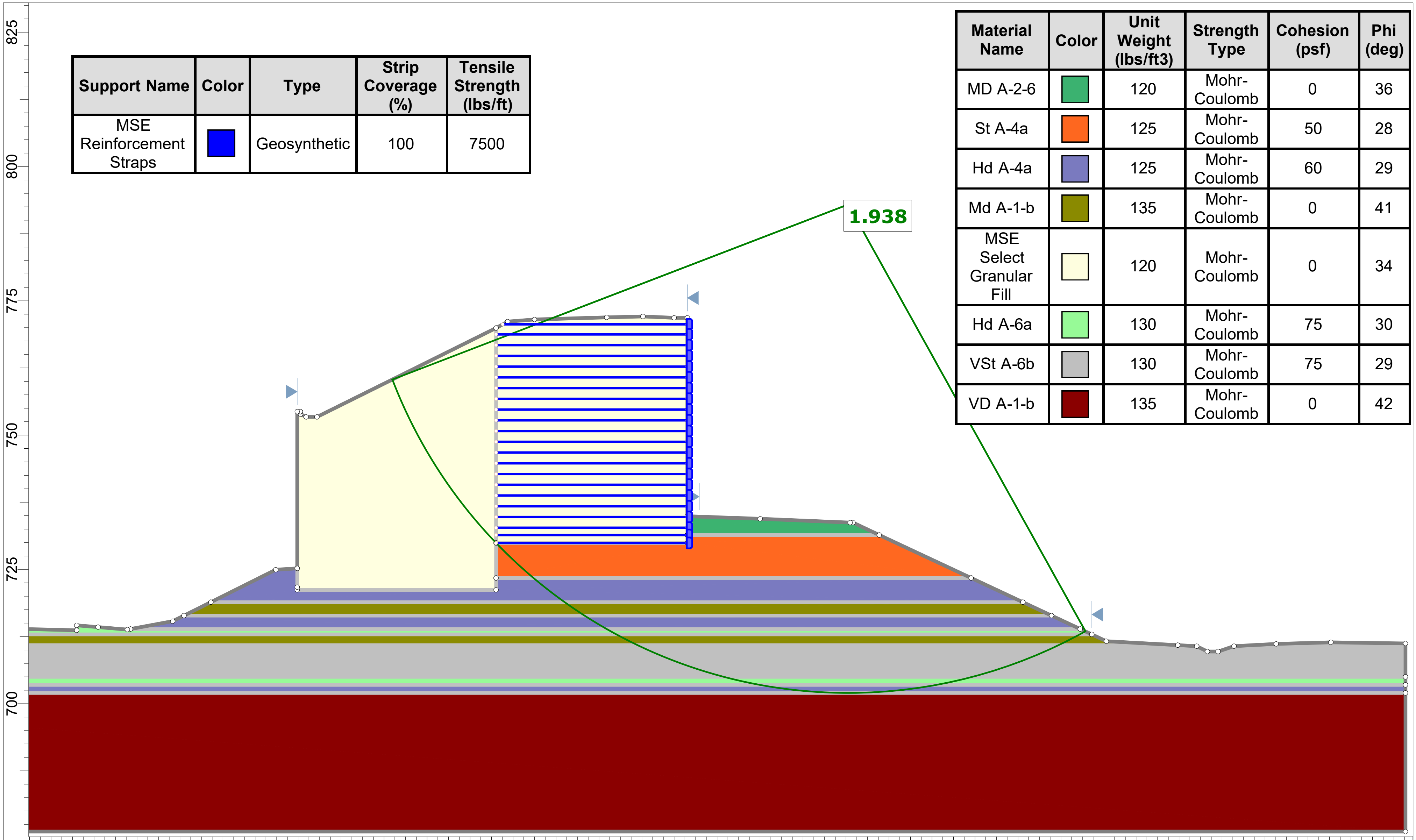
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	Total Settlement at Facing of Wall: S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	Settlement Complete at 90% of Primary Consolidation: $(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-4a	C	0.0	1.1	720.6	719.5	1.1	0.6	120	132	66	66	3,066	26	0.144	0.014	0.475				0.02	0.500	3,115	3,181	0.020	0.235	0.762	0.235	0.762
	A-4a	C	1.1	3.1	719.5	717.5	2.0	2.1	120	372	252	252	3,252	26	0.144	0.014	0.475				0.07	0.500	3,115	3,367	0.025	0.295		0.295	
	A-4a	C	3.1	5.1	717.5	715.5	2.0	4.1	120	612	492	492	3,492	26	0.144	0.014	0.475				0.14	0.499	3,112	3,604	0.019	0.231		0.231	
2	A-6a	C	5.1	7.6	715.5	713.0	2.5	6.4	125	925	768	768	3,768	28	0.162	0.016	0.491				0.21	0.498	3,103	3,871	0.022	0.263	0.659	0.187	0.468
	A-6a	C	7.6	10.1	713.0	710.5	2.5	8.9	125	1,237	1,081	1,081	4,081	28	0.162	0.016	0.491				0.30	0.495	3,083	4,164	0.018	0.217		0.154	
	A-6a	C	10.1	12.6	710.5	708.0	2.5	11.4	125	1,550	1,393	1,393	4,393	28	0.162	0.016	0.491				0.38	0.490	3,052	4,445	0.015	0.179		0.127	
3	A-6b	C	12.6	14.1	708.0	706.5	1.5	13.4	130	1,745	1,647	1,647	4,647	37	0.243	0.024	0.561				0.45	0.484	3,018	4,665	0.011	0.131	0.248	0.101	0.191
	A-6b	C	14.1	15.6	706.5	705.0	1.5	14.9	130	1,940	1,842	1,842	4,842	37	0.243	0.024	0.561				0.50	0.480	2,988	4,830	0.010	0.117		0.090	
4	A-6a	C	15.6	17.1	705.0	703.5	1.5	16.4	130	2,135	2,037	2,037	5,037	30	0.180	0.018	0.507				0.55	0.474	2,954	4,991	0.007	0.084	0.084	0.084	0.084
5	A-4a	C	17.1	18.6	703.5	702.0	1.5	17.9	130	2,330	2,232	2,232	5,232	23	0.117	0.012	0.452				0.60	0.468	2,916	5,148	0.004	0.053	0.053	0.053	0.053
6	A-1-b	G	18.6	23.4	702.0	697.2	4.8	21.0	130	2,954	2,642	2,642	5,642					100	91	401	0.71	0.454	2,828	5,469	0.004	0.045	0.045	0.045	0.045
7	A-2-4	G	23.4	25.6	697.2	695.0	2.2	24.5	130	3,240	3,097	3,097	6,097					18	15	65	0.83	0.436	2,718	5,815	0.009	0.111	0.111	0.111	0.111
8	A-1-a	G	25.6	35.6	695.0	685.0	10.0	30.6	130	4,540	3,890	3,540	6,540					47	38	124	1.03	0.404	2,516	6,056	0.019	0.226	0.369	0.226	0.369
	A-1-a	G	35.6	44.6	685.0	676.0	9.0	40.1	130	5,710	5,125	4,182	7,182					56	42	139	1.35	0.355	2,209	6,392	0.012	0.143		0.143	
9	A-1-b	G	44.6	52.6	676.0	668.0	8.0	48.6	131	6,758	6,234	4,761	7,761					56	40	130	1.64	0.316	1,967	6,728	0.009	0.111	0.111	0.111	0.111

Settlement Remaining After Hold Period: 0.248 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

Support Name	Color	Type	Strip Coverage (%)	Tensile Strength (lbs/ft)
MSE Reinforcement Straps		Geosynthetic	100	7500

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MD A-2-6		120	Mohr-Coulomb	0	36
St A-4a		125	Mohr-Coulomb	50	28
Hd A-4a		125	Mohr-Coulomb	60	29
Md A-1-b		135	Mohr-Coulomb	0	41
MSE Select Granular Fill		120	Mohr-Coulomb	0	34
Hd A-6a		130	Mohr-Coulomb	75	30
VSt A-6b		130	Mohr-Coulomb	75	29
VD A-1-b		135	Mohr-Coulomb	0	42

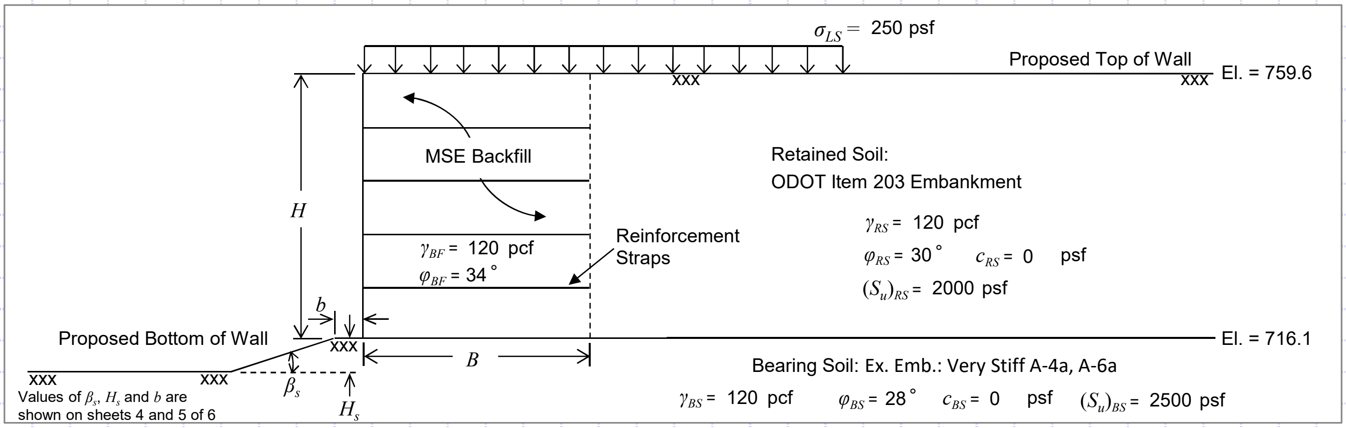


Resource International, Inc.
Planning | Engineering | Construction Management | Technology

Project	FRA-71-14.36 - Retaining Wall W3 - Sta. 3012+00 (BL Ramp C3) - MSE Wall Global Stability
Analysis Description	41.9 ft Wall Height - B-101-0-09 & B-106-0-09 - Drained - Circular - Spencer Method
Drawn By	HSK/BRT
Scale	1:300
Company	Resource International Inc.
Date	6/7/2021, 10:50:53 AM
File Name	Sta 3012+00-Run1.slmd

SLIDEINTERPRET 9.010

Retaining Wall W3 - Sta. 3014+00 (BL Ramp C3) - B-106-0-09 and B-105-5-14 - Level Backfill - 43.5 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion [1], (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, $[(S_u)_{RS}]$ =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

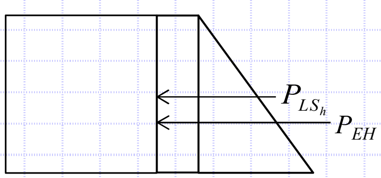
LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3

Sliding Force:



$$P_H = P_{EH} + P_{LS_h}$$

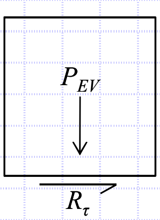
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(43.5 ft)²(0.297)(1.5)} = 50.58 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(43.5 ft)(0.297)(1.75)} = 5.65 \text{ kip/ft}$$

$$P_H = \text{50.58 kip/ft + 5.65 kip/ft} = 56.23 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:



$$R_\tau = P_{EV} \cdot \tan\delta$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(43.5 ft)(47.9 ft)(1.00)} = 250.04 \text{ kip/ft}$$

$$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF})$$

$$\tan\delta = \tan(28) \le \tan(34) \longrightarrow 0.53 \le 0.67 \longrightarrow \tan\delta = 0.53$$

$$R_\tau = \text{(250.04 kip/ft)(0.53)} = 132.52 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{56.23 kip/ft} \le \text{(132.52 kip/ft)(1.0) = 132.52 kip/ft} \longrightarrow \text{56.23 kip/ft} \le \text{132.52 kip/ft}$$

OK

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

LRFD Load Factors

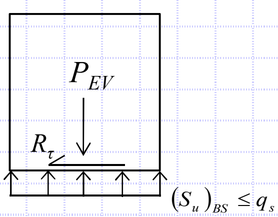
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Sliding (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.3 ***(Continued)***

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting: $R_\tau = ((S_u)_{BS} \leq q_s) \cdot B$



$(S_u)_{BS} =$ 2.50 ksf

$q_s = \sigma_v / 2$ = (5.22 ksf) / 2 = 2.61 ksf

$\sigma_v = P_{EV} / B$ = (250.04 kip/ft) / (47.9 ft) = 5.22 ksf

R_τ = (2.50 ksf ≤ 2.61 ksf)(47.9 ft) = 119.75 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \leq R_\tau \cdot \phi_\tau$ ⟶ 56.23 kip/ft ≤ (119.75 kip/ft)(1.0) = 119.75 kip/ft ⟶ 56.23 kip/ft ≤ 119.75 kip/ft **OK**

Use φ_τ = **1.0** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, $[(S_u)_{RS}]$ =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

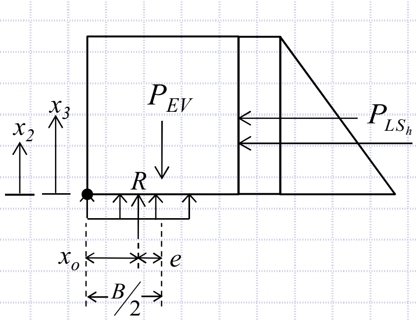
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Eccentricity (Loading Case - Strength Ia) - AASHTO LRFD BDM Section 11.10.5.5



$$e = B/2 - x_o$$

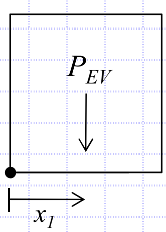
$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (5988.46 kip·ft/ft - 856.3 kip·ft/ft) / (250.04 kip/ft) = 20.53 ft

M_{EV} = 5988.46 kip·ft/ft
M_H = 856.3 kip·ft/ft
P_{EV} = 250.04 kip/ft
(Defined below)

$e =$ (47.9 ft)/2 - 20.53 ft = 3.42 ft

Resisting Moment, M_{EV}:

$$M_{EV} = P_{EV}(x_1)$$



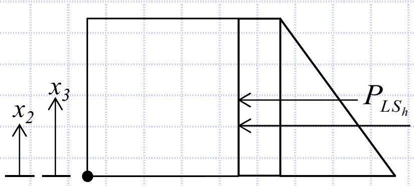
$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(43.5 ft)(47.9 ft)(1.00) = 250.04 kip/ft

$x_1 = B/2$ = (47.9 ft) / 2 = 23.95 ft

$M_{EV} =$ (250.04 kip/ft)(23.95 ft) = 5988.46 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3)$$



$P_{EH} = \frac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(43.5 ft)²(0.297)(1.5) = 50.58 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(43.5 ft)(0.297)(1.75) = 5.65 kip/ft

$x_2 = H/3$ = (43.5 ft) / 3 = 14.50 ft

$x_3 = H/2$ = (43.5 ft) / 2 = 21.75 ft

$M_H =$ (50.58 kip/ft)(14.5 ft) + (5.65 kip/ft)(21.75 ft) = 856.3 kip·ft/ft

Check Eccentricity

$e < e_{max} \longrightarrow$ 3.42 ft < 15.97 ft **OK**

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (47.9 ft) / 3 = 15.97 ft

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JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	4	OF	6
CALCULATED BY	HSK	DATE	5/27/2021
CHECKED BY	BRT	DATE	5/28/2021

Retaining Wall W3 - Sta. 3014+00 (BL Ramp C3)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

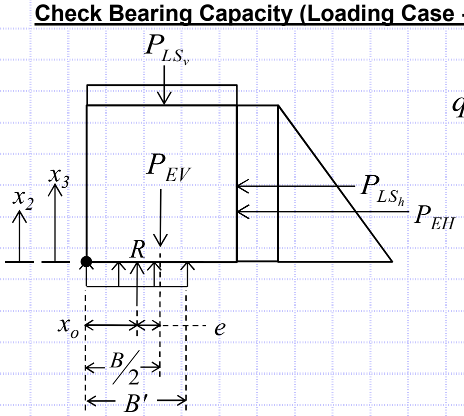
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 47.9 ft - 2(2.39 ft) = 43.12 ft

$e = B/2 - x_o$ = (47.9 ft) / 2 - 21.56 ft = 2.39 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (8586.26 kip·ft/ft - 856.34 kip·ft/ft) / 358.51 kip/ft = 21.56 ft

q_{eq} = (358.51 kip/ft) / (43.12 ft) = 8.31 ksf

$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) = (\gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV})(x_1) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})(x_1)$$

M_V = [(120 pcf)(43.5 ft)(47.9 ft)(1.35)](23.95 ft) + [(250 psf)(47.9 ft)(1.75)](23.95 ft) = 8586.26 kip·ft/ft

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3) = (\tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH})(x_2) + (\sigma_{LS} H K_a \gamma_{LS})(x_3)$$

M_H = [½(120 pcf)(43.5 ft)²(0.297)(1.5)](14.5 ft) + [(250 psf)(43.5 ft)(0.297)(1.75)](21.75 ft) = 856.34 kip·ft/ft

$$P_V = P_{EV} + P_{LS} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} + \sigma_{LS} \cdot B \cdot \gamma_{LS}$$

P_V = (120 pcf)(43.5 ft)(47.9 ft)(1.35) + (250 psf)(47.9 ft)(1.75) = 358.51 kip/ft

Check Bearing Resistance - Drained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 26.52

N_c = 25.8
s_c = 1+(43.12 ft/869 ft)(14.72/25.8)
= 1.028
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 15.10

N_q = 14.72
s_q = 1.026
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(0.0 ft/43.12 ft)
1.000
i_q = 1.000 (Assumed)
C_{wq} = 22.5 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.39

N_γ = 16.72
s_γ = 0.980
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 22.5 ft < 1.5(43.12 ft) + 0.0 ft = 0.674

q_n = (0 psf)(26.522) + (120 pcf)(0.0 ft)(15.103)(1.000) + ½(120 pcf)(43.1 ft)(16.386)(0.674) = 28.57 ksf

Use β_s = 21.0 ° H_s = 16.9 ft b = 12.4 ft

Verify Equivalent Pressure Less Than Factored Bearing Resistance

RC_{BC} = **0.98** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)*

Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

$q_{eq} \le q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 8.31 ksf ≤ (28.57 ksf)(0.98)(0.65) = 18.20 ksf $\longrightarrow$ 8.31 ksf ≤ 18.20 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Check Bearing Capacity (Loading Case - Strength Ib) - AASHTO LRFD BDM Section 11.10.5.4 ***(Continued)***

Check Bearing Resistance - Undrained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.190

N_c = 5.140
s_c = 1+(43.12 ft/[(5)(869 ft)]) = 1.010
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 1.000

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(0.0 ft/43.12 ft)
1.000
i_q = 1.000 (Assumed)
C_{wq} = 22.5 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.000

N_γ = 0.000
s_γ = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 22.5 ft < 1.5(43.12 ft) + 0.0 ft = 0.674

$q_n =$ (2500 psf)(5.190) + (120 pcf)(0.0 ft)(1.000)(1.000) + ½(120 pcf)(43.1 ft)(0.000)(0.674) = 12.98 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 8.31 ksf ≤ (12.98 ksf)(0.99)(0.65) = 8.35 ksf ⟶ 8.31 ksf ≤ 8.35 ksf **OK**

RC_{BC} = **0.99** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* ⟶ Use β_s = 21.0 ° H_s = 16.9 ft b = 12.4 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	43.5	ft
MSE Wall Width (Reinforcement Length), (B) =	47.9	ft
MSE Wall Length, (L) =	869	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

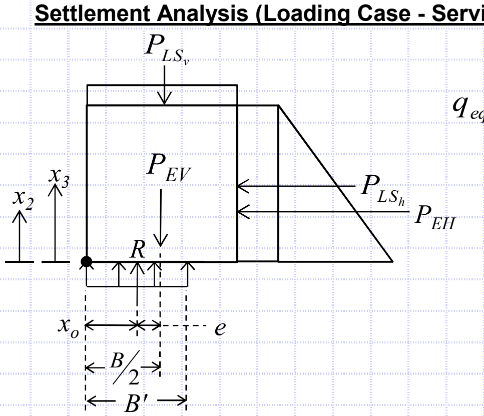
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2500	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	22.5	ft

LRFD Load Factors

	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

Settlement Analysis (Loading Case - Service I) - AASHTO LRFD BDM Section 11.10.4.1



$$q_{eq} = P_V / B'$$

$B' = B - 2e$ = 47.9 ft - 2(2.13 ft) = 43.64 ft

$e = B/2 - x_o$ = (47.9 ft) / 2 - 21.82 ft = 2.13 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (6275.21 kip·ft/ft - 559.19 kip·ft/ft) / 262.01 kip/ft = 21.82 ft

$q_{eq} =$ (262.01 kip/ft) / (43.64 ft) = 6.00 ksf

$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) = (\gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV})(x_1) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})(x_1)$$

$M_V =$ [(120 pcf)(43.5 ft)(47.9 ft)(1.00)](24.0 ft) + [(250 psf)(47.9 ft)(1.00)](24.0 ft) = 6275.21 kip·ft/ft

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3) = (\tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH})(x_2) + (\sigma_{LS} H K_a \gamma_{LS})(x_3)$$

$M_H =$ [½(120 pcf)(43.5 ft)²(0.297)(1.00)](14.5 ft) + [(250 psf)(43.5 ft)(0.297)(1.00)](21.75 ft) = 559.19 kip·ft/ft

$$P_V = P_{EV} + P_{LS} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} + \sigma_{LS} \cdot B \cdot \gamma_{LS}$$

$P_V =$ (120 pcf)(43.5 ft)(47.9 ft)(1.00) + (250 psf)(47.9 ft)(1.00) = 262.01 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Station Along Wall Alignment	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 100% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
3008+50	1.144 in	0.898 in	11 days		
3010+00	3.065 in	1.226 in	16 days	150 ft	1 in / 460 ft
3012+00	7.808 in	2.442 in	22 days	200 ft	1 in / 160 ft
3014+00	6.684 in	2.012 in	22 days	200 ft	1 in / 470 ft
3015+00	5.079 in	1.891 in	3 days	100 ft	1 in / 830 ft

W-13-072 - FRA-71-14.36 - Retaining Wall W3
MSE Wall Settlement - Sta. 3014+00

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/21/2021

Boring B-105-5-14

H=	43.5	ft	Total wall height
B'=	43.6	ft	Effective footing width due to eccentricity
D_w =	22.5	ft	Depth below bottom of footing
q_e =	6,000	psf	Equivalent bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6a	C	0.0	0.7	716.1	715.4	0.7	0.4	120	84	42	42	3,042	29	0.171	0.017	0.499				0.01	1.000	6,000	6,042	0.039	0.464	0.500	3,000	3,042	0.015	0.178
	A-6a	C	0.7	2.2	715.4	713.9	1.5	1.5	120	264	174	174	3,174	29	0.171	0.017	0.499				0.03	1.000	5,999	6,173	0.071	0.852	0.500	3,000	3,174	0.022	0.259
	A-6a	C	2.2	4.7	713.9	711.4	2.5	3.5	120	564	414	414	3,414	29	0.171	0.017	0.499				0.08	0.998	5,990	6,404	0.104	1.249	0.500	2,999	3,413	0.026	0.314
	A-6a	C	4.7	7.7	711.4	708.4	3.0	6.2	120	924	744	744	3,744	29	0.171	0.017	0.499				0.14	0.991	5,947	6,691	0.110	1.324	0.499	2,996	3,740	0.024	0.288
2	A-2-4	G	7.7	9.7	708.4	706.4	2.0	8.7	135	1,194	1,059	1,059	4,059					88	107	523	0.20	0.977	5,865	6,924	0.003	0.037	0.498	2,990	4,049	0.002	0.027
	A-2-4	G	9.7	12.7	706.4	703.4	3.0	11.2	135	1,599	1,397	1,397	4,397					88	99	459	0.26	0.957	5,740	7,136	0.005	0.056	0.497	2,980	4,377	0.003	0.039
3	A-1-b	G	12.7	13.9	703.4	702.2	1.2	13.3	135	1,761	1,680	1,680	4,680					23	24	84	0.31	0.934	5,606	7,286	0.009	0.109	0.495	2,968	4,648	0.006	0.076
4	A-6b	C	13.9	17.7	702.2	698.4	3.8	15.8	120	2,217	1,989	1,989	4,989	38	0.252	0.025	0.569				0.36	0.903	5,419	7,408	0.129	1.550	0.491	2,948	4,937	0.024	0.289
5	A-4b	C	17.7	20.2	698.4	695.9	2.5	19.0	120	2,517	2,367	2,367	5,367	22	0.108	0.011	0.444				0.43	0.860	5,158	7,525	0.034	0.409	0.486	2,915	5,282	0.007	0.078
6	A-1-a	G	20.2	22.7	695.9	693.4	2.5	21.5	130	2,842	2,680	2,680	5,680					28	25	86	0.49	0.823	4,941	7,620	0.013	0.157	0.481	2,883	5,563	0.009	0.110
	A-1-a	G	22.7	24.2	693.4	691.9	1.5	23.5	130	3,037	2,940	2,880	5,880					28	25	85	0.54	0.794	4,766	7,646	0.007	0.090	0.476	2,854	5,735	0.005	0.063
7	A-1-a	G	24.2	29.2	691.9	686.9	5.0	26.7	135	3,712	3,375	3,112	6,112					73	62	227	0.61	0.748	4,487	7,599	0.009	0.103	0.467	2,801	5,914	0.006	0.074
	A-1-a	G	29.2	39.2	686.9	676.9	10.0	34.2	135	5,062	4,387	3,657	6,657					73	58	207	0.78	0.650	3,899	7,556	0.015	0.182	0.443	2,657	6,314	0.011	0.137
8	A-1-b	G	39.2	42.2	676.9	673.9	3.0	40.7	130	5,452	5,257	4,121	7,121					37	28	94	0.93	0.578	3,468	7,589	0.008	0.102	0.420	2,518	6,640	0.007	0.080
																								Total Settlement:		6.684 in			Total Settlement:		2.012 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

W-13-072 - FRA-71-14.36 - Retaining Wall W3

MSE Wall Settlement - Sta. 3014+00

Calculated By: HSK Date: 6/8/2021

Checked By: BRT Date: 6/21/2021

Boring B-105-5-14

H=	43.5	ft	Total wall height
B'=	43.6	ft	Effective footing width due to eccentricity
D_w =	22.5	ft	Depth below bottom of footing
q_e =	6,000	psf	Equivalent bearing pressure at bottom of wall

	A-6a	A-6b	A-4a		
c_v =	600	300	1,000	ft^2/yr	Coefficient of consolidation
t =	22	22	22	days	Time following completion of construction
H_{dr} =	7.7	3.8	2.5	ft	Length of longest drainage path considered
T_v =	0.610	1.252	9.644		Time factor
U =	82	96	100	%	Degree of consolidation

$(S_c)_t$ = 1.813 in Settlement complete at 90% of primary consolidation

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	Total Settlement at Facing of Wall: S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	Settlement Complete at 90% of Primary Consolidation: $(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	0.7	716.1	715.4	0.7	0.4	120	84	42	42	3,042	29	0.171	0.017	0.499				0.01	0.500	3,000	3,042	0.015	0.178	1.039	0.146	0.852
	A-6a	C	0.7	2.2	715.4	713.9	1.5	1.5	120	264	174	174	3,174	29	0.171	0.017	0.499				0.03	0.500	3,000	3,174	0.022	0.259		0.212	
	A-6a	C	2.2	4.7	713.9	711.4	2.5	3.5	120	564	414	414	3,414	29	0.171	0.017	0.499				0.08	0.500	2,999	3,413	0.026	0.314		0.257	
	A-6a	C	4.7	7.7	711.4	708.4	3.0	6.2	120	924	744	744	3,744	29	0.171	0.017	0.499				0.14	0.499	2,996	3,740	0.024	0.288		0.236	
2	A-2-4	G	7.7	9.7	708.4	706.4	2.0	8.7	135	1,194	1,059	1,059	4,059					88	107	523	0.20	0.498	2,990	4,049	0.002	0.027	0.066	0.027	0.066
	A-2-4	G	9.7	12.7	706.4	703.4	3.0	11.2	135	1,599	1,397	1,397	4,397					88	99	459	0.26	0.497	2,980	4,377	0.003	0.039		0.039	
3	A-1-b	G	12.7	13.9	703.4	702.2	1.2	13.3	135	1,761	1,680	1,680	4,680					23	24	84	0.31	0.495	2,968	4,648	0.006	0.076	0.076	0.076	0.076
4	A-6b	C	13.9	17.7	702.2	698.4	3.8	15.8	120	2,217	1,989	1,989	4,989	38	0.252	0.025	0.569				0.36	0.491	2,948	4,937	0.024	0.289	0.289	0.278	0.278
5	A-4b	C	17.7	20.2	698.4	695.9	2.5	19.0	120	2,517	2,367	2,367	5,367	22	0.108	0.011	0.444				0.43	0.486	2,915	5,282	0.007	0.078	0.078	0.078	0.078
6	A-1-a	G	20.2	22.7	695.9	693.4	2.5	21.5	130	2,842	2,680	2,680	5,680					28	25	86	0.49	0.481	2,883	5,563	0.009	0.110	0.174	0.110	0.174
	A-1-a	G	22.7	24.2	693.4	691.9	1.5	23.5	130	3,037	2,940	2,880	5,880					28	25	85	0.54	0.476	2,854	5,735	0.005	0.063		0.063	
7	A-1-a	G	24.2	29.2	691.9	686.9	5.0	26.7	135	3,712	3,375	3,112	6,112					73	62	227	0.61	0.467	2,801	5,914	0.006	0.074	0.211	0.074	0.211
	A-1-a	G	29.2	39.2	686.9	676.9	10.0	34.2	135	5,062	4,387	3,657	6,657					73	58	207	0.78	0.443	2,657	6,314	0.011	0.137		0.137	
8	A-1-b	G	39.2	42.2	676.9	673.9	3.0	40.7	130	5,452	5,257	4,121	7,121					37	28	94	0.93	0.420	2,518	6,640	0.007	0.080	0.080	0.080	0.080

Settlement Remaining After Hold Period: 0.199 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 4,000 psf (moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \le 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \le \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

W-13-072 - FRA-71-14.36 - Retaining Wall W3 and W5	Calculated By:	HSK	Date:	5/28/2021
Shallow Foundation Bearing Resistance - Sta. 3015+00 (Back-to-Back Wall)	Checked By:	BRT	Date:	5/28/2021

Borings B-105-3-14 and B-105-5-14

B =	45.0	ft	
L =	100	ft	
c =	0	psf	
γ =	120	pcf	
D_f =	0.0	ft	
φ =	28	deg	
D_w =	20.0	ft	Below ground surface
q =	7.82	ksf	Factored bearing pressure at the bottom of the wall

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 23.99 ksf

$N_{cm} = N_c s_c i_c$ = 32.42

$N_{qm} = N_q s_q d_q i_q$ = 18.24

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 13.71

N_c =	25.80	s_c =	1+(45 ft/100 ft)(14.72/25.8) =	1.257	i_c =	1.000	d_q =	1+2tan(28°)[1-sin(28°)]²tan⁻¹(0 ft/45 ft) =	1.000
N_q =	14.72	s_q =	1+(45 ft/100 ft)tan(28°) =	1.239	i_q =	1.000	C_{wq} =	20.0 ft > 0.0 ft =	1.000
N_γ =	16.72	s_γ =	1-0.4(45 ft/100 ft) =	0.820	i_γ =	1.000	$C_{w\gamma}$ =	20.0 ft < 1.5(45 ft) + 0 ft =	0.648

$q_R = q_n \cdot \phi_b . RC_{BC}$ = 7.95 ksf ⟶ Check $q \le q_R$ **OK**

φ_b = 0.65

RC_{BC} =	0.51	β_s =	21.8	deg
		H_s =	8.2	ft
		b =	0.0	ft

W-13-072 - FRA-71-14.36 - Retaining Wall W3 and W5

Shallow Foundation Bearing Resistance - Sta. 3015+00 (Back-to-Back Wall)

Calculated By:	HSK
Date:	5/28/2021
Checked By:	BRT
Date:	5/28/2021

Borings B-105-3-14 and B-105-5-14

B =	45.0	ft	
L =	100	ft	
c =	2,500	psf	
γ =	120	pcf	
D_f =	0.0	ft	
φ =	0	deg	
D_w =	20.0	ft	Below ground surface
q =	7.82	ksf	Factored bearing pressure at the bottom of the wall

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 13.98 ksf

$N_{cm} = N_c s_c i_c$ = 5.59

$N_{qm} = N_q s_q d_q i_q$ = 1.00

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.00

N_c =	5.14	s_c =	1+(45 ft/100 ft)(1/5.14) =	1.088	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(0 ft/45 ft) =	1.000
N_q =	1.00	s_q =	1+(45 ft/100 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	20.0 ft > 0.0 ft =	1.000
N_γ =	0.00	s_γ =	1-0.4(45 ft/100 ft) =	0.820	i_γ =	1.000	$C_{w\gamma}$ =	20.0 ft < 1.5(45 ft) + 0 ft =	0.648

$q_R = q_n \cdot \phi_b . RC_{BC}$ = 7.90 ksf ⟶ Check $q \le q_R$ **OK**

φ_b = 0.65

RC_{BC} =	0.87	β_s =	21.8	deg
		H_s =	8.2	ft
		b =	0.0	ft

W-13-072 - FRA-71-14.36 - Retaining Wall W3
MSE Wall Settlement - Sta. 3015+00

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/21/2021

Boring B-105-3-14

H=	41.0	ft	Total wall height
B=	43.6	ft	Width of reinforced soil mass (wall facing to wall facing)
D_w =	20.0	ft	Depth below bottom of wall
q =	5,170	psf	Bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-4a	C	0.0	1.7	714.6	712.9	1.7	0.9	120	204	102	102	3,102	26	0.144	0.014	0.475				0.02	1.000	5,170	5,272	0.063	0.754	0.500	2,585	2,687	0.024	0.283
	A-4a	C	1.7	3.7	712.9	710.9	2.0	2.7	120	444	324	324	3,324	26	0.144	0.014	0.475				0.06	0.999	5,166	5,490	0.062	0.747	0.500	2,585	2,909	0.019	0.223
	A-4a	C	3.7	5.7	710.9	708.9	2.0	4.7	120	684	564	564	3,564	26	0.144	0.014	0.475				0.11	0.996	5,149	5,713	0.056	0.668	0.500	2,584	3,148	0.015	0.175
2	A-3a	G	5.7	8.2	708.9	706.4	2.5	7.0	135	1,022	853	853	3,853					66	85	277	0.16	0.988	5,107	5,959	0.008	0.092	0.499	2,581	3,433	0.005	0.066
3	A-2-4	G	8.2	10.7	706.4	703.9	2.5	9.5	135	1,359	1,190	1,190	4,190					80	94	424	0.22	0.972	5,025	6,215	0.004	0.051	0.498	2,574	3,765	0.003	0.035
	A-2-4	G	10.7	13.2	703.9	701.4	2.5	12.0	135	1,697	1,528	1,528	4,528					80	87	376	0.27	0.949	4,907	6,435	0.004	0.050	0.496	2,564	4,092	0.003	0.034
4	A-7-6	C	13.2	15.2	701.4	699.4	2.0	14.2	125	1,947	1,822	1,822	4,822	43	0.297	0.030	0.608				0.33	0.924	4,775	6,597	0.066	0.791	0.494	2,551	4,373	0.014	0.169
	A-7-6	C	15.2	17.2	699.4	697.4	2.0	16.2	125	2,197	2,072	2,072	5,072	43	0.297	0.030	0.608				0.37	0.898	4,642	6,714	0.059	0.712	0.491	2,537	4,608	0.013	0.154
5	A-2-6	G	17.2	19.9	697.4	694.7	2.7	18.6	130	2,548	2,372	2,372	5,372					30	28	94	0.43	0.865	4,474	6,846	0.013	0.158	0.487	2,516	4,888	0.009	0.108
6	A-4a	C	19.9	22.2	694.7	692.4	2.3	21.1	125	2,835	2,691	2,626	5,626	23	0.117	0.012	0.452				0.48	0.829	4,287	6,913	0.023	0.273	0.481	2,489	5,115	0.005	0.064
7	A-2-6	G	22.2	27.2	692.4	687.4	5.0	24.7	130	3,485	3,160	2,867	5,867					24	21	77	0.57	0.776	4,013	6,880	0.025	0.297	0.472	2,443	5,309	0.017	0.209
8	A-1-a	G	27.2	32.2	687.4	682.4	5.0	29.7	135	4,160	3,823	3,217	6,217					71	60	214	0.68	0.707	3,654	6,871	0.008	0.092	0.458	2,367	5,584	0.006	0.067
	A-1-a	G	32.2	42.2	682.4	672.4	10.0	37.2	130	5,460	4,810	3,737	6,737					39	31	102	0.85	0.615	3,180	6,917	0.026	0.316	0.432	2,235	5,972	0.020	0.241
	A-1-a	G	42.2	50.2	672.4	664.4	8.0	46.2	135	6,540	6,000	4,365	7,365					92	68	258	1.06	0.526	2,721	7,086	0.007	0.078	0.400	2,066	6,431	0.005	0.063
																						Total Settlement:				5.079 in	Total Settlement:				1.891 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 3,000 psf (slightly to moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

W-13-072 - FRA-71-14.36 - Retaining Wall W3
MSE Wall Settlement - Sta. 3015+00

Calculated By: HSK Date: 6/8/2021
Checked By: BRT Date: 6/21/2021

Boring B-105-3-14

H=	41.0	ft	Total wall height
B=	43.6	ft	Width of reinforced soil mass (wall facing to wall facing)
D_w =	20.0	ft	Depth below bottom of wall
q =	5,170	psf	Bearing pressure at bottom of wall

	A-4a (Upper)	A-7-6	A-4a (Lower)		
c_v =	1,000	150	1,000	ft^2/yr	Coefficient of consolidation
t =	3	3	3	days	Time following completion of construction
H_{dr} =	2.9	2	1.2	ft	Length of longest drainage path considered
T_v =	1.012	0.308	6.215		Time factor
U =	93	62	100	%	Degree of consolidation

$(S_c)_t$ = 1.721 in Settlement complete at 91% of primary consolidation

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	Total Settlement at Facing of Wall: S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	Settlement Complete at 91% of Primary Consolidation: $(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-4a	C	0.0	1.7	714.6	712.9	1.7	0.9	120	204	102	102	3,102	26	0.144	0.014	0.475				0.02	0.500	2,585	2,687	0.024	0.283	0.681	0.263	0.633
	A-4a	C	1.7	3.7	712.9	710.9	2.0	2.7	120	444	324	324	3,324	26	0.144	0.014	0.475				0.06	0.500	2,585	2,909	0.019	0.223		0.208	
	A-4a	C	3.7	5.7	710.9	708.9	2.0	4.7	120	684	564	564	3,564	26	0.144	0.014	0.475				0.11	0.500	2,584	3,148	0.015	0.175		0.163	
2	A-3a	G	5.7	8.2	708.9	706.4	2.5	7.0	135	1,022	853	853	3,853					66	85	277	0.16	0.499	2,581	3,433	0.005	0.066	0.066	0.066	0.066
3	A-2-4	G	8.2	10.7	706.4	703.9	2.5	9.5	135	1,359	1,190	1,190	4,190					80	94	424	0.22	0.498	2,574	3,765	0.003	0.035	0.070	0.035	0.070
	A-2-4	G	10.7	13.2	703.9	701.4	2.5	12.0	135	1,697	1,528	1,528	4,528					80	87	376	0.27	0.496	2,564	4,092	0.003	0.034		0.034	
4	A-7-6	C	13.2	15.2	701.4	699.4	2.0	14.2	125	1,947	1,822	1,822	4,822	43	0.297	0.030	0.608				0.33	0.494	2,551	4,373	0.014	0.169	0.322	0.105	0.200
	A-7-6	C	15.2	17.2	699.4	697.4	2.0	16.2	125	2,197	2,072	2,072	5,072	43	0.297	0.030	0.608				0.37	0.491	2,537	4,608	0.013	0.154		0.095	
5	A-2-6	G	17.2	19.9	697.4	694.7	2.7	18.6	130	2,548	2,372	2,372	5,372					30	28	94	0.43	0.487	2,516	4,888	0.009	0.108	0.108	0.108	0.108
6	A-4a	C	19.9	22.2	694.7	692.4	2.3	21.1	125	2,835	2,691	2,626	5,626	23	0.117	0.012	0.452				0.48	0.481	2,489	5,115	0.005	0.064	0.064	0.064	0.064
7	A-2-6	G	22.2	27.2	692.4	687.4	5.0	24.7	130	3,485	3,160	2,867	5,867					24	21	77	0.57	0.472	2,443	5,309	0.017	0.209	0.209	0.209	0.209
8	A-1-a	G	27.2	32.2	687.4	682.4	5.0	29.7	135	4,160	3,823	3,217	6,217					71	60	214	0.68	0.458	2,367	5,584	0.006	0.067	0.370	0.067	0.370
	A-1-a	G	32.2	42.2	682.4	672.4	10.0	37.2	130	5,460	4,810	3,737	6,737					39	31	102	0.85	0.432	2,235	5,972	0.020	0.241		0.241	
	A-1-a	G	42.2	50.2	672.4	664.4	8.0	46.2	135	6,540	6,000	4,365	7,365					92	68	258	1.06	0.400	2,066	6,431	0.005	0.063		0.063	

Settlement Remaining After Hold Period: 0.170 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 4,000 psf (moderately overconsolidated) for natural soil deposits; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(Cc) for natural soil deposits; Ref. Section 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0