Resource International, Inc.

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FRA-71-14.36 PHASE 6R
RETAINING WALL W5
PID NO. 105588
FRANKLIN COUNTY, OHIO

STRUCTURE FOUNDATION EXPLORATION REPORT (REV. 1)

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

July 2019

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June 19, 2015 (Revised July 19, 2019)

Mr. Gary Gardner, P.E., P.S.
ms consultants, inc.
2221 Schrock Road
Columbus, OH 43229-1547

Re: Structure Foundation Exploration Report (Rev. 1)
FRA-71-14.36 Phase 6R
Retaining Wall W5
PID No. 105588
Rii Project No. W-13-072

Mr. Gardner:

Resource International, Inc. (Rii) is pleased to submit this revised 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 W5 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.

Brian Trenner

Brian R. Trenner, P.E.
Director – Geotechnical Programming

Jonathan P. Sterenberg, P.E.
Director – Geotechnical Planning

Enclosure: Structure Foundation Exploration Report (Rev. 1)

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APPENDICES

EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for the design and construction of the proposed Retaining Wall W5. It is understood that this wall will be located along the east side of I-71 southbound and Ramp C3, providing the required grade separation between the I-71/Ramp C3 roadways and the adjacent SR-315 SB roadway. The subject wall begins at Sta. 221+10 (BL I-71 SB), and extends northward along the east side of I-71 southbound to Sta. 230+94 (BL I-71 SB), where it crosses under the rear abutment of the FRA-71-1503L bridge structure and continues north along the east side of Ramp C3 from Sta. 3015+50 to 3008+14 (BL Ramp C3). 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 W5. Wall heights along the proposed alignment are anticipated to range from 6.8 feet at the southern terminus to a maximum height of 49.2 feet near Sta. 509+81 (BL Wall W5). The total anticipated wall length is on the order of 1,777 lineal feet.

Exploration and Findings

Between June 4, 2014, and April 28, 2015 a total of eleven (11) structural borings, designated as B-099-4-14, B-100-2-14, B-100-4-14, B-102-3-14, B-102-5-14, B-104-1-13, B-105-3-14, B-105-5-14, B-107-2-14, B-108-7-14 and B-108-8-14, were advanced to completion depths ranging from 15.0 to 70.5 feet below the existing ground surface. The borings were drilled in the shoulder of SR-315 southbound and along the toe of the existing embankment supporting I-71 southbound and the ramp from I-70 eastbound to I-71 southbound along the west side of SR-315 southbound. In addition to the borings performed by Rii as part of the current exploration, two (2) historic borings, designated as B-100-0-09 and B-104-0-09, 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) with their findings published in a report dated March 18, 2010. The historic borings were advanced to completion depths of 15.0 and 30.0 feet below the existing ground surface, respectively.

All borings performed as part of the current exploration were located within the existing pavement of I-71 southbound, the existing shoulder pavement of SR-315 southbound, or along the toe of the supporting embankment of I-71 southbound. Borings located within the existing pavement generally encountered either 2.0 to 5.0 inches of asphalt overlying 6.0 to 10.0 inches of concrete, or 9.0 to 12.0 inches of concrete at the ground surface. Aggregate base material was encountered underlying the surficial pavement materials in three (3) of the borings, ranging in thickness from 5.0 to 6.0 inches. Borings located outside the limits of the existing pavement generally encountered 4.0 to 8.0 inches of topsoil at the existing ground surface, as identified by the significant presence of organics and vegetation.

Beneath the surficial materials detailed in the previous section, existing fill and/or possible fill materials were encountered in a total of six (6) of the thirteen (13) borings analyzed as part of this exploration. The fill materials extended to depths ranging from as shallow as 5.5 feet to as deep as 25.5 feet beneath the existing ground surface. In general, the existing and possible fill materials consisted of brown, dark brown, gray and dark gray gravel, gravel with sand, gravel with sand and silt, sandy silt, silt and clay, and silty clay (ODOT A-1-a, A-1-b, A-2-4, A-4a, A-6a, and A-6b). While a majority of the fill materials that were encountered in the borings is considered to be existing embankment fill and suitable for foundation support, it should be noted that asphalt and coal fragments were noted within the fill materials encountered in borings B-105-5-14, B-107-2-14, and B-108-7-14. The presence of organic and chemical odors was also noted within the fill materials encountered in boring B-105-5-14 between El. 703.4 and 698.4 feet msl.

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

Bedrock was encountered in boring B-104-1-13 at a depth of 60.5 feet beneath the ground surface. 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 attempted. 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 W5. Wall heights along the proposed alignment are anticipated to range from 6.8 feet at the southern terminus to a maximum height of 49.2 feet near Sta. 509+81 (BL Wall W5). The total anticipated wall length is on the order of 1,777 lineal feet.

MSE Wall Recommendations

Wall heights on the order of 6.8 to 49.2 feet 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 anticipated soils at the proposed bearing elevation along a majority of the proposed wall alignment are anticipated to consist of natural cohesive soils and existing embankment fill comprised of stiff to hard silty sand, silt and clay, silty clay and clay (ODOT A-4a, A-6a, A-6b, A-7-6) overlying medium dense to very dense granular soils comprised primarily of gravel and gravel and sand (ODOT A-1-a, A-1-b). MSE wall foundations bearing on these competent natural soils , 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 nominal bearing resistance at the strength limit state.

Retaining Wall W5 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]	
500+00	507+00	28.3	Level	19.8 (0.70H ≥ 8.0)	13.38	8.70	6.76
507+00	508+50	40.2	Level	32.2 (0.80H)	13.41	8.72	8.58
508+50	509+85	48.5	Level	38.8 (0.80H)	15.99	10.39	10.20
600+19	601+83	36.3	2:1 (Broken-Back)	47.1 (1.30H)	15.42	8.12 (5)	6.92
601+83	605+50	33.7	2:1 (Broken-Back)	47.2 (1.40H)	14.14	7.81 (5)	7.76
605+50	607+00	33.8	2:1 (Broken-Back)	23.7 (0.70H)	29.65	19.27	10.10
607+00	607+65	10.1	2:1 (Infinite)	13.0 (1.30H ≥ 8.0)	6.75	4.39	2.27

1. *Stationing is referenced to the baseline of Retaining Wall W5.*
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 2018 AASHTO LRFD BDM.*

Total settlements ranging from 0.97 to 9.02 inches at the center of the reinforced soil mass and 0.76 to 3.61 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W5 between Sta. 500+00 and 510+30. It should be noted that the high settlement values of 9.02 at the center of the reinforced soil mass and 3.61 inches at the facing of the wall were observed at boring B-102-5-14, which represents the segment of wall between Sta. 507+00 and 508+50. Total settlements ranging from

0.95 to 4.46 inches at the center of the reinforced soil mass and 0.69 to 2.41 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W5 between Sta. 600+19 and 607+65. Based on the results of the analysis, 90 percent of the total settlement is anticipated to occur over a period of approximately 1 to 70 days.

Based on the results of the external and global stability analysis performed for Retaining Wall W5, the recommended controlling strap length is 0.70 times the height of the MSE wall (measured from the top of the leveling pad to the top of wall) between Sta. 500+00 and 507+00, 0.80 times the height of the MSE wall between Sta. 507+00 and 509+85, and 1.3 times the height of the MSE wall between Sta. 600+19 and 607+65.

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 five (5) new retaining walls (Walls E4, E5, E7, W2 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 W5, as shown on the vicinity map and boring plan presented in Appendix I. Retaining Wall W5 will be located along the east side of I-71 southbound and Ramp C3, providing the required grade separation between the I-71/Ramp C3 roadways and the adjacent SR-315 SB roadway. The subject wall begins at Sta. 221+10 (BL I-71 SB), and extends northward along the east side of I-71 southbound to Sta. 230+94 (BL I-71 SB), where it crosses under the rear abutment of the FRA-71-1503L bridge structure and continues north along the east side of Ramp C3 from Sta. 3015+50 to 3008+14 (BL Ramp C3). 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 W5. Wall heights along the proposed alignment are anticipated to range from 6.8 feet at the southern terminus to a maximum height of 49.2 feet near Sta. 509+81 (BL Wall W5). The total anticipated wall length is on the order of 1,777 lineal feet. **Please note that the recommendations for the portion of the retaining wall where it crosses in front of the rear abutment of the FRA-71-1503L structure are provided in the bridge structure foundation exploration report for that structure, which are presented under a separate cover.**

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 W5 is situated between the southbound lanes of I-71 and SR-315 and crosses under I-71 southbound at the rear abutment of the proposed FRA-71-1503L bridge structure, and continues north along the east side of Ramp C3 where it terminates on the south side of the proposed Ramp C5. The existing I-70 eastbound and I-71 southbound ramps are single-lane, asphalt paved roadways with full width shoulders, and the existing SR-315 southbound roadway is a two-lane, asphalt paved 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 eleven (11) structural borings, designated as B-099-4-14, B-100-2-14, B-100-4-14, B-102-3-14, B-102-5-14, B-104-1-13, B-105-3-14, B-105-5-14, B-107-2-14, B-108-7-14 and B-108-8-14, were advanced to completion depths ranging from 15.0 to 70.5 feet below the existing ground surface. The borings were drilled in the shoulder of SR-315 southbound and along the toe of the existing embankment supporting I-71 southbound and the ramp from I-70 eastbound to I-71 southbound along the west side of SR-315 southbound. In addition to the borings performed by Rii as part of the current exploration, two (2) historic borings, designated as B-100-0-09 and B-104-0-09, 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) with their findings published in a report dated March 18, 2010. The historic borings were advanced to completion depths of 15.0 and 30.0 feet below the existing ground surface, respectively. The current 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-099-4-14	BL I-71 SB	221+70.29	44.7' Rt.	39.945765348	-83.014005413	717.0	15.0
B-100-0-09	BL I-71 SB	222+98.38	5.9' Rt.	39.946029204	-83.014337557	716.6	15.0
B-100-2-14	BL I-71 SB	224+29.33	45.6’ Rt.	39.946399914	-83.014429916	716.9	15.0
B-100-4-14	BL I-71 SB	225+81.07	46.9’ Rt.	39.946768298	-83.014696343	716.3	25.0
B-102-3-14	BL I-71 SB	227+13.65	54.8’ Rt.	39.947091789	-83.014919601	715.6	30.0
B-102-5-14	BL I-71 SB	228+75.36	46.6’ Rt.	39.947458593	-83.015245752	713.6	45.0
B-104-0-09	BL I-71 SB	230+19.87	52.9' Rt.	39.947804392	-83.015488523	710.2	30.0
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-105-5-14	BL Ramp C3	3012+82.16	42.1' Lt.	39.948475867	-83.016258220	723.9	50.0
B-107-2-14	BL Ramp C3	3011+35.50	67.0' Lt.	39.948851596	-83.016450128	727.5	45.0
B-108-7-14	BL Ramp C3	3009+74.31	79.9' Lt.	39.949258997	-83.016710746	703.6	30.0
B-108-8-14	BL Ramp C3	3008+52.04	89.6' Lt.	39.949572208	-83.016991873	703.4	15.0

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 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 hammers for the Mobile B-53 and CME 750X drill rigs operated by Rii were calibrated on April 26, 2013, and have drill rod energy ratios of 77.7 and 86.8 percent, respectively. The hammer for the CME 750X and the CME 55 drill rigs operated by Rii were also calibrated on October 20, 2014, with drill rod energy ratios of 85.7 and 92.0 percent, respectively. The updated energy ratio for the CME 750X drill rig utilized for borings performed as part of this project has been reported on the boring logs. The hammers for the two CME 75 drill rigs operated by DLZ have drill rod energy ratios of 61.2 and 62.0 percent. No calibration date is available for the DLZ rig calibrations

Additionally, a total of five (5) borings included in this investigation were performed by our subcontractor, Stock Drilling, to ensure that all of the subject borings were completed in a timely and efficient manner. Stock utilized a BK-81 HD truck mounted drill rig to advance the borings, for which the hammer system was calibrated on March 28, 2013 with a drill rod energy ratio of 72.3 percent. The hammers for the two CME 75 drill rigs operated by DLZ for the performance of the historic borings have drill rod energy ratios of 61.2 and 62.0 percent. No calibration date was available for these rig calibrations at the time of this report.

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.

In addition to the SPT samples, one (1) undisturbed (Shelby tube) sample was attempted within boring B-100-2-14. This sample was obtained by hydraulically pushing a 2.75-inch outer diameter thin-walled seamless steel tube into the soil at a constant rate of penetration. The recovered Shelby tube sample was cleaned of soil cuttings and preserved within the tube by sealing the ends with wax.

During drilling, heaving sands were encountered in six (6) of the eleven (11) borings performed by Rii for the current exploration. The heaving sand conditions were encountered in the borings at depths ranging from 23.5 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-104-0-09 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:

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

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	116
Plastic and Liquid Limits	AASHTO T89, T90	47
Gradation – Sieve/Hydrometer	AASHTO T88	47
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.

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.

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

All borings performed as part of the current exploration were located within the existing pavement of I-71 southbound, the existing shoulder pavement of SR-315 southbound, or along the toe of the supporting embankment of I-71 southbound. Borings located within the existing pavement generally encountered either 2.0 to 5.0 inches of asphalt overlying 6.0 to 10.0 inches of concrete, or 9.0 to 12.0 inches of concrete at the ground surface. Aggregate base material was encountered underlying the surficial pavement materials in three (3) of the borings, ranging in thickness from 5.0 to 6.0 inches. Borings located outside the limits of the existing pavement generally encountered 4.0 to 8.0 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 Pavement Materials

Boring Number	Asphalt Thickness (in)	Concrete Thickness (in)	Aggregate Base Thickness (in)	Gravel Thickness (in)	Topsoil Thickness (in)
B-099-4-14	3.0	9.0	-	-	-
B-100-0-09	5.0	-	5.0	-	-
B-100-2-14	2.0	10.0	-	-	-
B-100-4-14	-	12.0	-	-	-
B-102-3-14	-	9.0	6.0	-	-
B-102-5-14	-	-	-	-	6.0
B-104-0-09	-	-	-	-	4.0
B-104-1-13	-	-	-	-	4.0
B-105-3-14	4.0	9.5	-	-	6.0
B-105-5-14	3.0	6.0	6.0	-	-
B-107-2-14	3.0	9.0	-	-	-
B-108-7-14	-	-	-	-	8.0
B-108-8-14	-	-	-	-	6.0

4.2 Subsurface Soils

Beneath the surficial materials detailed in the previous section, existing fill and/or possible fill materials were encountered in a total of six (6) of the thirteen (13) borings analyzed as part of this exploration. The fill materials extended to depths ranging from as shallow as 5.5 feet to as deep as 25.5 feet beneath the existing ground surface. In general, the existing and possible fill materials consisted of brown, dark brown, gray and dark gray gravel, gravel with sand, gravel with sand and silt, sandy silt, silt and clay, and silty clay (ODOT A-1-a, A-1-b, A-2-4, A-4a, A-6a, and A-6b). While a majority of the fill materials that were encountered in the borings is considered to be existing embankment fill and suitable for foundation support, it should be noted that asphalt and coal fragments were noted within the fill materials encountered in borings B-105-5-14, B-107-2-14, and B-108-7-14. The presence of organic and chemical odors was also noted within the fill materials encountered in boring B-105-5-14 between El. 703.4 and 698.4 feet msl.

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

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 ($1.0 < HP \leq 2.0$ tsf) to hard ($HP > 4.0$ tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 1.0 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 2 to 32 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 9 percent below to 6 percent above the corresponding plastic limits. In general, the soil exhibited natural moisture contents considered to be significantly below to moderately above the 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. 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 attempted. 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. A summary of the depth and elevation at which bedrock was encountered is presented in Table 4. 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.

Table 4. Top of Bedrock Elevations

Boring Number	Ground Surface Elevation (feet msl)	Top of Bedrock		Top of Bedrock Core	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-104-1-13	714.5	60.5	654.0	60.5	654.0

The percent recovery and RQD values of the bedrock core runs in boring B-104-1-13 is summarized in Table 5, along with the results of the unconfined compressive strength testing that was performed.

Table 5. Rock Core Summary

Boring Number	Core No.	Elevation (feet msl)	Recovery (%)	RQD (%)	Unconfined Compressive Strength
B-104-1-13	RC-1	654.0 to 649.0	100	75	N/A
	RC-2	649.0 to 644.0	90	70	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 ten (10) of the thirteen (13) borings analyzed as part of this investigation. A summary of the depths where groundwater was encountered in provided in Table 6. Groundwater was initially encountered in the borings at depths ranging from 3.0 to 35.0 feet beneath the ground surface, corresponding to elevations ranging from 685.1 to 713.6 feet msl. At the completion of drilling, groundwater had accumulated within the historic borings B-100-0-09 and B-104-0-09 to depths of 13.4 and 19.4 feet beneath the ground surface, corresponding to elevations of 703.2 and 690.8 feet msl, respectively. The borings performed by Rii as part of the current investigation were either dry at the completion of drilling, or accurate groundwater levels could not be obtained due to the addition of drilling fluids during the drilling process to counteract the water pressure causing sands to heave into the augers.

Table 6. 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-099-4-14	717.0	Dry	N/A	Dry	N/A
B-100-0-09	716.6	3.0	713.6	13.4	703.2
B-100-2-14	716.9	Dry	N/A	Dry	N/A
B-100-4-14	716.3	Dry	N/A	Dry	N/A
B-102-3-14	715.6	28.5	687.1	Dry	N/A
B-102-5-14	713.6	28.5	685.1	N/A	N/A
B-104-0-09	710.2	22.5	687.7	19.4	690.8
B-104-1-13	714.5	21.0	693.5	N/A	N/A
B-105-3-14	719.4	28.5	690.9	N/A	N/A
B-105-5-14	723.9	33.5	690.4	N/A	N/A
B-107-2-14	727.5	35.0	692.5	N/A	N/A
B-108-7-14	703.6	16.0	687.6	N/A	N/A
B-108-8-14	703.4	13.5	689.9	Dry	N/A

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.*

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 W5. The Wall will be located along the east side of I-71 southbound and Ramp C3, providing the required grade separation between the I-71/Ramp C3 roadways and the adjacent SR-315 SB roadway. The subject wall begins at Sta. 221+10 (BL I-71 SB), and extends northward along the east side of I-71 southbound to Sta. 230+94.01 (BL I-71 SB), where it continues north along the east side of Ramp C3 between Sta. 3015+50 and 3008+13.61 (BL Ramp C3). Wall heights along the proposed alignment are anticipated to range from 6.8 feet at the southern terminus to a maximum height of 49.2 feet near Sta. 509+81 (BL Wall W5). The total anticipated wall length is on the order of 1,777 lineal feet.

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 204.6.2.1 of the 2019 ODOT BDM, 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 204.6.2.1 of the 2007 ODOT BDM and Supplemental Specification (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.

As stated, information available at the time of this report indicates wall heights on the order of 6.8 to 49.2 feet 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 a majority of the proposed wall alignment will consist of stiff to hard silty sand, silt and clay, silty clay and clay (ODOT A-4a, A-6a, A-6b, A-7-6) overlying medium dense to very dense granular soils comprised primarily of gravel and gravel and sand (ODOT A-1-a, A-1-b). Existing embankment fill comprised of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a) overlying gravel with sand and gravel with sand and silt (ODOT A 1 b, A-2-4) was encountered in borings B-104-1-13, B-105-3-14, B-105-5-14 and B-107-2-14 extending to depths ranging from 6.0 to 13.0 feet below the bearing elevation. Based on the SPT N-values and hand penetrometer values within the existing embankment fill, this material is considered suitable for foundation support.

Per 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 7.

Table 7. 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 Silt and Clay (ODOT A-6a)	120	27 to 28	0 to 50	2,750 to 8,000
Stiff to Hard Silty Clay (ODOT A-6b)	120 to 125	26	0	2,500 to 3,000
Very Stiff to Hard Clay (ODOT A-7-6)	120	25	0	2,500
Very Loose to Medium Dense Granular Soil (ODOT A-1-a, A-1-b, A-3a)	115 to 125	29 to 39	0	N/A
Dense to Very Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-4)	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 2018 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 ODOT SS 840. Per SS 840, the select granular backfill in the reinforced zone and the retained embankment must meet the shear strength requirements provided in Table 7. 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 anticipated soils at the proposed bearing elevation along a majority of the proposed wall alignment are anticipated to consist of natural cohesive soils and existing embankment fill comprised of stiff to hard silty sand, silt and clay, silty clay and clay (ODOT A-4a, A-6a, A-6b, A-7-6) overlying medium dense to very dense granular soils comprised primarily of gravel and gravel and sand (ODOT A-1-a, A-1-b). MSE wall foundations bearing on these competent natural soils, 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 8. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state. 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 8. Retaining Wall W5 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]	
500+00	507+00	28.3	Level	19.8 (0.70H ≥ 8.0)	13.38	8.70	6.76
507+00	508+50	40.2	Level	32.2 (0.80H)	13.41	8.72	8.58
508+50	509+85	48.5	Level	38.8 (0.80H)	15.99	10.39	10.20
600+19	601+83	36.3	2:1 (Broken-Back)	47.1 (1.30H)	15.42	8.12 (5)	6.92
601+83	605+50	33.7	2:1 (Broken-Back)	47.2 (1.40H)	14.14	7.81 (5)	7.76
605+50	607+00	33.8	2:1 (Broken-Back)	23.7 (0.70H)	29.65	19.27	10.10
607+00	607+65	10.1	2:1 (Infinite)	13.0 (1.30H ≥ 8.0)	6.75	4.39	2.27

1. *Stationing is referenced to the baseline of Retaining Wall W5.*
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 2018 AASHTO LRFD BDM.*

For analysis of the wall sections between Sta. 600+19 and 605+50, 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 2018 AASHTO LRFD BDM. The bearing resistance for the remainder of this portion of the wall alignment, between Sta. 605+50 and 607+65, was calculated assuming no embedment depth below grade since there is just a small wedge of soil that will be placed in front of the wall.

Rii performed a verification of the bearing pressure exerted on the subgrade material for the specified wall heights indicated in Table 8. 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.

5.1.3 Settlement Evaluation

The compressibility parameters utilized in the settlement analyses of the proposed MSE wall are provided in Table 9.

Table 9. 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)	120 to 125	22 to 25	0.108 to 0.144	0.011 to 0.014	0.444 to 0.475	1,000	N/A	N/A
Stiff to Hard Silt and Clay (ODOT A-6a)	120 to 125	25 to 34	0.135 to 0.216	0.014 to 0.022	0.467 to 0.538	600	N/A	N/A
Stiff to Hard Silty Clay (ODOT A-6b)	115 to 125	33 to 40	0.207 to 0.270	0.021 to 0.027	0.530 to 0.585	300	N/A	N/A
Very Stiff to Hard Clay (ODOT A-7-6)	120 to 125	43 to 56	0.297 to 0.414	0.030 to 0.041	0.608 to 0.710	150	N/A	N/A
Very Loose to Medium Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-6, A-3a)	115 to 130	N/A	N/A	N/A	N/A	N/A	3 to 28	47 to 105
Dense to Very Dense Granular Soil (ODOT A-1-a, A-1-b, A-2-4, A-3a, A-4a)	130 to 135	N/A	N/A	N/A	N/A	N/A	33 to 120	75 to 851

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 2018 AASHTO LRFD BDS.*

Results of the settlement analysis are tabulated in Table 10. Total settlements ranging from 0.97 to 9.02 inches at the center of the reinforced soil mass and 0.76 to 3.61 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W5 between Sta. 500+00 and 510+30. It should be noted that the high settlement values of 9.02 at the center of the reinforced soil mass and 3.61 inches at the facing of the wall were observed at boring B-102-5-14, which represents the segment of wall between Sta. 507+00 and 508+50. Total settlements ranging from 0.95 to 4.46 inches at the center of the reinforced soil mass and 0.69 to 2.41 inches at the facing of the wall are anticipated along the alignment of Retaining Wall W5 between Sta. 600+19 and 607+65.

Based on the results of the analysis, 90 percent of the total settlement is anticipated to occur over a period of approximately 1 to 70 days. Please note that the consolidation settlement and time rate of consolidation are based on estimates using correlated compressibility parameters provided in Table 9 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 10. Retaining Wall W5 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	
500+00	507+00	1.25 to 4.74	0.97 to 2.62	0.76 to 1.96	13 to 70
507+00	508+50	6.11	9.02	3.61	95
508+50	509+85	6.86 to 7.29	4.18 to 5.43	2.54 to 2.63	1 to 5
600+19	601+83	5.05 to 5.30	3.52 to 4.46	1.87 to 2.41	3 to 15
601+83	605+50	5.61 to 6.10	2.95 to 3.51	1.32 to 1.54	1 to 5
605+50	607+00	7.06	2.40	1.34	1
607+00	607+65	1.65	0.95	0.69	3

1. *Station referenced to the baseline of Retaining Wall W5.*
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 1/500, 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 are provided in Appendix IV.

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 2018 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 8. Based on the minimum length of reinforced soil mass presented in Table 8 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 2018 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 0.47 to 0.67 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 ranges from 2.5 to 4.0 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 8 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 the 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 7. 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 2018 manufactured by Rocscience Inc. was utilized to perform the analyses.

Per 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. For MSE walls designed with a minimum strap length listed in Table 8, the resulting factor of safety under drained conditions (long-term stability) was greater than or equal to 1.3. The wall was also evaluated under undrained conditions (short-term stability) to verify the stability of the wall during and immediately following construction. The resulting factor of safety under undrained conditions was also 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 W5, the recommended controlling strap length is 0.70 times the height of the MSE wall (measured from the top of the leveling pad to the top of wall) between Sta. 500+00 and 507+00, 0.80 times the height of the MSE wall between Sta. 507+00 and 509+85, and 1.3 times the height of the MSE wall between Sta. 600+19 and 607+65. Bearing resistance and global stability were the controlling factors in the determination of the recommended strap length in the areas where the recommended strap length was 80 to 130 percent of the wall height.

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 11 and Table 12.

Table 11. 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, $\gamma' = \gamma - 62.4$ pcf and add hydrostatic water pressure.*

Table 12. 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	0	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, $\gamma' = \gamma - 62.4$ 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. 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 considered). Earth pressures on excavation support systems will be dependent on the type of sheeting and method of bracing or anchorage.

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 13. 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
Rock to 3.0' +/- below Auger Refusal	0.75 : 1.0	Above Ground Water Table and No Seepage
Stable Rock	Vertical	Above Ground Water Table and No Seepage

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

BORINGS B-099-4-14, B-100-2-14, B-100-4-14, B-102-3-14, B-102-5-14, B-105-3-14, B-105-5-13, B-107-2-14, B-108-7-14 AND B-108-8-13 WERE PERFORMED FOR WALL W5.

BORINGS B-099-2-13, B-099-3-13, B-099-5-14, B-100-1-14, B-100-3-14, B-102-2-14, B-102-4-14, B-102-6-14, B-103-1-14, B-105-4-14, B-105-5-14, B-107-3-14 AND B-107-4-14 WERE PERFORMED FOR WALL W2.

BORINGS B-104-1-13, B-105-2-13, B-107-1-13, B-108-4-13 AND B-108-5-13 WERE PERFORMED FOR THE FRA-71-1503L STRUCTURE.

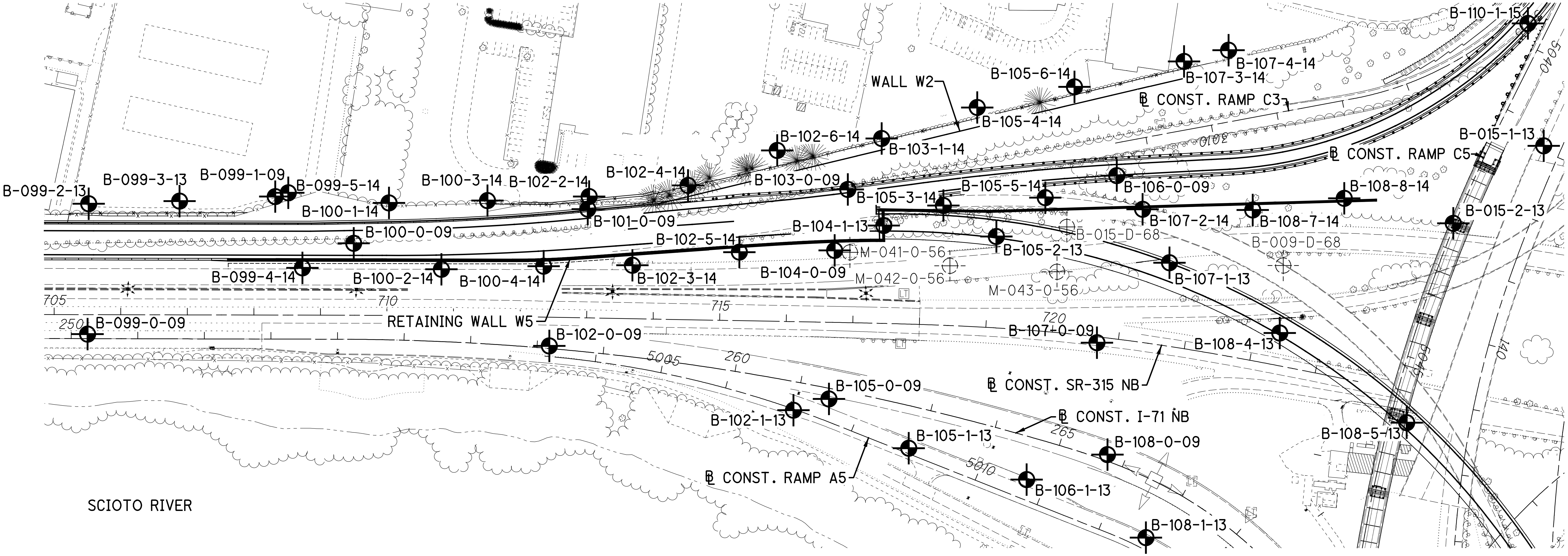
BORINGS B-015-1-13, B-015-2-13, B-102-1-13, B-105-1-13, B-106-1-13, B-108-1-13 AND B-110-1-15 WERE PERFORMED AS PART OF THE FRA-70-12.68 PROJECT 4A/4R.

BORINGS B-099-0-09, B-100-0-09, B-101-0-09, B-102-0-09, B-103-0-09, B-104-0-09, B-105-0-09, B-106-0-09, B-107-0-09 AND B-108-0-09 WERE DRILLED AS PART OF THE FRA-70-8.93 PRELIMINARY EXPLORATION.

LEGEND

⊕ PROJECT BORING

⌖ HISTORIC BORING



BORING PLAN

FRA-70-13.10 - RETAINING WALL W5

FRANKLIN COUNTY, OHIO

PROJECT NO.
Rii W-13-072

SCALE: 1"=150'
0 75 150

DRAWN
RRM

REVIEWED
BRT

DATE
7-17-19

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”		

DESCRIPTION OF ROCK TERMS

The following terminology was used to describe the rock throughout this report and is generally adapted from ASTM D5878.

Weathering – Describes the degree of weathering of the rock mass:

Description	Field Parameter
Unweathered	No evidence of any chemical or mechanical alteration of the rock mass. Mineral crystals have a right appearance with no discoloration. Fractures show little or not staining on surfaces.
Slightly Weathered	Slight discoloration of the rock surface with minor alterations along discontinuities. Less than 10% of the rock volume presents alteration.
Moderately Weathered	Portions of the rock mass are discolored as evident by a dull appearance. Surfaces may have a pitted appearance with weathering "halos" evident. Isolated zones of varying rock strengths due to alteration may be present. 10 to 15% of the rock volume presents alterations.
Highly Weathered	Entire rock mass appears discolored and dull. Some pockets of slightly to moderately weathered rock may be present and some areas of severely weathered materials may be present.
Severely Weathered	Majority of the rock mass reduced to a soil-like state with relic rock structure discernable. Zones of more resistant rock may be present but the material can generally be molded and crumbled by hand pressures.

Strength of Bedrock – The following terms are used to describe the relative strength of bedrock:

Description	Field Parameter
Very Weak	Can be carved with knife and scratched by fingernail. Pieces 1 in. thick can be broken by finger pressure.
Weak	Can be grooved or gouged with knife readily. Small, thin pieces can be broken by finger pressure.
Slightly Strong	Can be grooved or gouged 0.05 in deep with knife. 1 in. size pieces from hard blows of geologist hammer.
Moderately Strong	Can be scratched with knife or pick. 1/4 in. size grooves or gouges from blows of geologist hammer.
Strong	Can be scratched with knife or pick with difficulty. Hard hammer blows to detach hand specimen.
Very Strong	Cannot be scratched by knife or pick. Hard repeated blows of geologist hammer to detach hand specimen.
Extremely Strong	Cannot be scratched by knife or pick. Hard repeated blows of geologist hammer to chip hand specimen.

Bedding Thickness – Description of bedding thickness as the average perpendicular distances between bedding surfaces:

Description	Thickness
Very Thick	Greater than 36 inches
Thick	18 to 36 inches
Medium	10 to 18 inches
Thin	2 to 10 inches
Very Thin	0.4 to 2 inches
Laminated	0.1 to 0.4 inches
Thinly Laminated	Less than 0.1 inches

Fracturing – Describes the degree and condition of fracturing (fault, joint, or shear):

Degree of Fracturing

Description	Spacing
Unfractured	Greater than 10 feet
Intact	3 to 10 feet
Slightly Fractured	1 to 3 feet
Moderately Fractured	

Condition of Fractures

Aperature Width

Description	Width
Open	Greater than 0.2 inches
Narrow	0.05 to 0.2 inches
Tight	Less than 0.05 inches

Surface Roughness

Description	Criteria
Very Rough	Near vertical steps and ridges occur on surface
Slightly Rough	Asperities on the surfaces distinguishable
Slickensided	Surface has smooth, glassy finish, evidence of Striations

RQD – Rock Quality Designation:

RQD %	Rock Index Property Classification
0 – 25%	Very Poor
26 – 50%	Poor
51 – 70%	Fair
71 – 85%	Good
86 – 100%	Very Good

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		LL_O/LL x 100*	% Pass #40	% Pass #200	Liquid Limit (LL)	Plastic Index (PI)	Group Index Max.	REMARKS
		AASHTO	OHIO							
○	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.

APPENDIX III

PROJECT BORING LOGS

B-098-2-13 through B-107-4-14

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:

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

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
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 4/14/15 END: 4/14/15

DRILLING FIRM / OPERATOR: STOCK / T.B./B.Z.
SAMPLING FIRM / LOGGER: RII / D.M.
DRILLING METHOD: 4.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: BK 81 HD (SN 810792.111)
HAMMER: AUTOMATIC
CALIBRATION DATE: 3/28/13
ENERGY RATIO (%): 72.3

STATION / OFFSET: 221+70.29 / 44.7' RT
ALIGNMENT: BL I-71 SB
ELEVATION: 717.0 (MSL) EOB: 15.0 ft.
LAT / LONG: 39.945765, -83.014005

EXPLORATION ID
B-099-4-14

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 717.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.3' - ASPHALT (3.0")	716.7																	
0.7' - CONCRETE (9.0")	716.0																	
VERY STIFF, BROWN **CLAY**, SOME SILT, SOME FINE GRAVEL, LITTLE COARSE TO FINE SAND, DAMP.		1 2 3	9 7 5	14	44	SS-1	2.50	-	-	-	-	-	-	-	-	12	A-7-6 (V)	
		4 5	5 8 6	17	78	SS-2	2.50	36	12	6	25	21	43	18	25	17	A-7-6 (7)	
-ROCK FRAGMENTS PRESENT THROUGHOUT		6 7 8	20 24 24	58	78	SS-3	2.50	-	-	-	-	-	-	-	-	15	A-7-6 (V)	
	706.5	9 10	9 9 15	29	94	SS-4	3.00	-	-	-	-	-	-	-	-	13	A-7-6 (V)	
VERY STIFF, BROWN AND BLACK **SILT AND CLAY**, SOME COARSE TO FINE SAND, SOME FINE GRAVEL, DAMP.	704.0	11 12 13	7 8 9	20	50	SS-5	3.00	33	11	14	26	16	34	19	15	16	A-6a (3)	
MEDIUM DENSE, BROWN **GRAVEL**, LITTLE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-6	702.0	14 EOB 15	4 6 17	28	11	SS-6	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 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

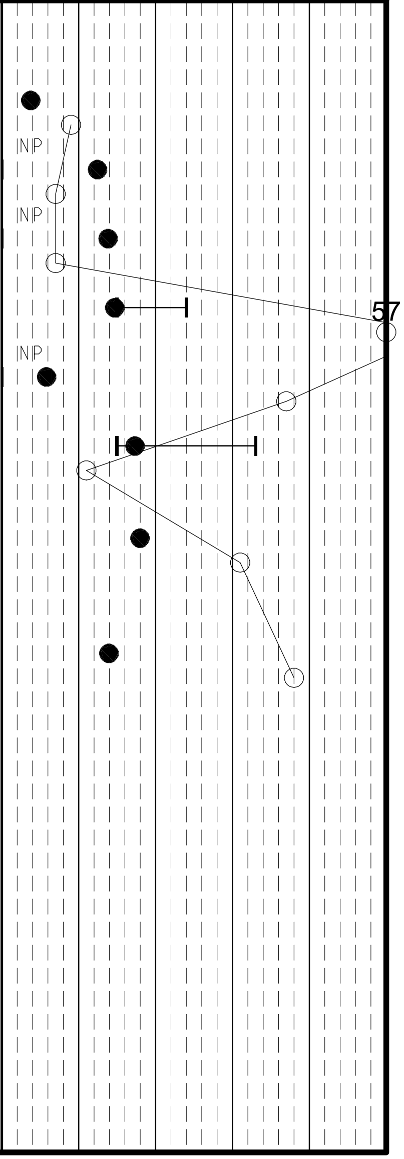
LOG OF: Boring B-100-0-09 | *Location:* Sta. 222+98.38, 5.9' RT., BL I-71 SB | *Date Drilled:* 9/1/2009

WATER OBSERVATIONS:
Water seepage at: 3.0'
Water level at completion: 13.4'

FIELD NOTES:

Depth (ft)	Elev. (ft) 716.6	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
0.8	715.8						Asphalt Concrete - 5" Aggregate Base - 5"							
		9 5 4	10	1			POSSIBLE FILL: Loose brown GRAVEL (A-1-a), some fine to coarse sand, trace to little silt; damp to moist.							
		5 2 5	4	2					68	17	---	6	--9--	
6.0	710.6	3 2 5	2	3					63	12	---	8	--17--	
7.5	709.1	4 23 32	12	4		1.0	Stiff gray SANDY SILT (A-4a), some fine to coarse sand, some gravel; moist.		21	11	---	15	30	23
9.0	707.6	17 28 8	12	5			Very dense gray GRAVEL WITH SAND (A-1-b), little silt; damp.		45	25	---	14	--16--	
		3 6 5	6	6		2.0	Stiff brown SILTY CLAY (A-6b), little to some fine to coarse sand, little gravel; contains rock fragments; damp to moist.		19	15	---	9	27	30
		6 18 12	10	7		1.0								
15.0	701.6	8 13 24	5	8		1.0								
							Bottom of Boring - 15.0'							

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



RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A TYPE: STRUCTURE PID: 89464 BR ID: N/A START: 4/13/15 END: 4/13/15	DRILLING FIRM / OPERATOR: STOCK / T.B./B.Z. SAMPLING FIRM / LOGGER: RII / D.M. DRILLING METHOD: 4.25" HSA SAMPLING METHOD: SPT	DRILL RIG: BK 81 HD (SN 810792.111) HAMMER: AUTOMATIC CALIBRATION DATE: 3/28/13 ENERGY RATIO (%): 72.3	STATION / OFFSET: 224+29.33 / 45.6' RT ALIGNMENT: BL I-71 SB ELEVATION: 716.9 (MSL) EOB: 15.0 ft. LAT / LONG: 39.946400, -83.014430	**EXPLORATION ID** **B-100-2-14** PAGE 1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 716.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.2' - ASPHALT (2.0")	716.7																	
0.8' - CONCRETE (10.0")	715.9	1																
VERY STIFF, BROWN **SILTY CLAY**, LITTLE COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST. -ROCK FRAGMENTS PRESENT IN SS-1		2	6 9 17	31	67	SS-1	2.50	-	-	-	-	-	-	-	-	20	A-6b (V)	
		3																
	711.4	4 5	5 5 10	18	78	SS-2	2.25	12	11	8	34	35	40	18	22	19	A-6b (12)	
VERY STIFF, BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -ROCK FRAGMENTS PRESENT IN SS-3	708.9	6 7	7 15 19	41	78	SS-3	2.50	-	-	-	-	-	-	-	-	12	A-6a (V)	
VERY STIFF, BROWN **SILTY CLAY**, SOME FINE GRAVEL, LITTLE COARSE TO FINE SAND, MOIST.		8 9 10																
-ROCK FRAGMENTS PRESENT THROUGHOUT		11			67	ST-4	3.25	25	9	6	30	30	35	17	18	20	A-6b (8)	
		12 13																
	701.9	14 EOB 15	5 11 18	35	83	SS-5	2.75	-	-	-	-	-	-	-	-	17	A-6b (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING

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

2014 ODOT BORING LOG-RII NE BRIDGE ID - OH DOT.GDT - 7/12/19 12:59 - U:\GI8\PROJECTS\2013W-13-072.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 4/14/15 END: 4/14/15

DRILLING FIRM / OPERATOR: STOCK / T.B./B.Z.
SAMPLING FIRM / LOGGER: RII / D.M.
DRILLING METHOD: 4.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: BK 81 HD (SN 810792.111)
HAMMER: AUTOMATIC
CALIBRATION DATE: 3/28/13
ENERGY RATIO (%): 72.3

STATION / OFFSET: 225+81.07 / 46.9' RT
ALIGNMENT: BL I-71 SB
ELEVATION: 716.3 (MSL) EOB: 25.0 ft.
LAT / LONG: 39.946768, -83.014696

EXPLORATION ID
B-100-4-14

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 716.3	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
1.0' - CONCRETE (12.0")	715.3																	
VERY STIFF, BROWN AND BLACK **SILTY CLAY**, SOME COARSE TO FINE SAND, LITTLE TO SOME FINE GRAVEL, DAMP TO MOIST.		1 2 3	3 6 8	17	56	SS-1	2.50	-	-	-	-	-	-	-	-	15	A-6b (V)	
		4 5	3 6 10	19	56	SS-2	2.50	20	12	8	31	29	39	18	21	16	A-6b (9)	
		6 7 8	4 16 10	31	78	SS-3	3.00	-	-	-	-	-	-	-	-	23	A-6b (V)	
		9 10	5 6 15	25	72	SS-4	3.00	28	14	8	29	21	38	19	19	16	A-6b (6)	
	703.3	11 12 13	9 9 19	34	89	SS-5	3.00	-	-	-	-	-	-	-	-	21	A-6b (V)	
DENSE TO VERY DENSE, GRAY TO BROWNISH GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT THROUGHOUT		14 15	11 12 15	33	94	SS-6	-	65	11	7	12	5	NP	NP	NP	10	A-1-b (0)	
	698.3	16 17 18	25 32 34	80	67	SS-7	-	-	-	-	-	-	-	-	-	6	A-1-b (V)	
MEDIUM DENSE, BROWNISH GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT THROUGHOUT		19 20 21 22 23	21 11 4	18	44	SS-8	-	37	34	9	16	4	NP	NP	NP	6	A-1-b (0)	
	691.3	24 EOB 25	6 6 9	18	50	SS-9	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING

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

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 2/26/15 END: 2/26/15

DRILLING FIRM / OPERATOR: RII / J.K.
SAMPLING FIRM / LOGGER: RII / C.D.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: MOBILE B-53 (SN 624400)
HAMMER: AUTOMATIC
CALIBRATION DATE: 4/26/13
ENERGY RATIO (%): 77.7

STATION / OFFSET: 227+13.65 / 54.8' RT
ALIGNMENT: BL I-71 SB
ELEVATION: 715.6 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.947092, -83.014920

EXPLORATION ID
B-102-3-14

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 715.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
0.8' - CONCRETE (9.0")	714.8																
0.5' - AGGREGATE BASE (6.0")	714.3	1															
STIFF TO VERY STIFF, BROWNISH GRAY **SILTY CLAY**, SOME FINE GRAVEL, SOME COARSE TO FINE SAND, DRY TO DAMP.		2 3	11 9 9	23	67	SS-1	3.00	-	-	-	-	-	-	-	-	5	A-6b (V)
-ROCK FRAGMENTS PRESENT IN SS-2	710.1	4 5	10 12 6	23	72	SS-2	1.50	27	14	9	46	4	34	17	17	16	A-6b (5)
DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, DAMP TO MOIST.		6 7 8	32 15 11	34	33	SS-3	-	-	-	-	-	-	-	-	-	2	A-1-a (V)
	705.1	9 10	8 15 14	38	56	SS-4	-	-	-	-	-	-	-	-	-	5	A-1-a (V)
VERY STIFF, DARK BROWNISH GRAY **SILTY CLAY**, SOME FINE GRAVEL, LITTLE COARSE TO FINE SAND, DAMP. -ROCK FRAGMENTS PRESENT IN SS-5	702.6	11 12	8 12 12	31	50	SS-5	3.50	34	14	6	24	22	40	18	22	12	A-6b (6)
VERY STIFF TO HARD, DARK GRAYISH BROWN **CLAY**, SOME COARSE TO FINE SAND, SOME FINE GRAVEL, LITTLE SILT, DAMP TO MOIST.		13 14 15	5 11 14	32	100	SS-6	4.50	-	-	-	-	-	-	-	-	32	A-7-6 (V)
	697.6	16 17 18	6 8 6	18	89	SS-7	4.00	23	15	9	19	34	56	23	33	20	A-7-6 (13)
MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.		19 20 21 22 23	5 8 4	16	50	SS-8	-	-	-	-	-	-	-	-	-	12	A-1-b (V)
		24 25	3 3 6	12	0	SS-9	-	-	-	-	-	-	-	-	-	-	
			24	-	0	3S-9A	-	-	-	-	-	-	-	-	-	-	
		26 27 28 W 29 EOB	7 10 11	27	100	SS-10	-	64	12	5	17	2	NP	NP	NP	15	A-1-b (0)

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 28.5'

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

2014 ODOT BORING LOG-RII NE BRIDGE ID - OH DOT.GDT - 7/12/19 12:59 - U:\GI8\PROJECTS\2013\W-13-072.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750X (SN 310218)	STATION / OFFSET: 228+75.36 / 46.6' RT	EXPLORATION ID **B-102-5-14**
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL I-71 SB	PAGE 1 OF 2
PID: 89464 BR ID: N/A	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 713.6 (MSL) EOB: 45.0 ft.	
START: 2/2/15 END: 2/3/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 85.7	LAT / LONG: 39.947459, -83.015246	

MATERIAL DESCRIPTION AND NOTES	ELEV. 713.6
0.5' - TOPSOIL (6.0")	713.1
MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST. -ROCK FRAGMENTS AND ROOT FIBERS PRESENT IN SS-1	710.6
VERY STIFF TO HARD, BROWNISH GRAY **SILTY CLAY**, SOME FINE GRAVEL, LITTLE COARSE TO FINE SAND, DRY TO DAMP. -ROCK FRAGMENTS PRESENT IN SS-2	705.6
VERY STIFF TO HARD, BROWN AND BLACK TO BROWNISH GRAY **CLAY**, "AND" SILT, TRACE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST. -ROCK FRAGMENTS IN SS-4 -ORGANICS PRESENT IN SS-5	691.6
MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.	686.6
MEDIUM DENSE, BLACK **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, TRACE SILT, TRACE CLAY, WET.	

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

W

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
3 8 5	19	28	SS-1	-	-	-	-	-	-	-	-	-	10	A-2-6 (V)
5 21 9	43	56	SS-2	4.5+	26	9	6	29	30	39	21	18	13	A-6b (8)
3 3 5	11	56	SS-3	3.00	-	-	-	-	-	-	-	-	18	A-6b (V)
9 9 5	20	33	SS-4	2.50	-	-	-	-	-	-	-	-	28	A-7-6 (V)
4 4 5	13	67	SS-5	4.5+	0	1	4	47	48	46	26	20	29	A-7-6 (13)
3 3 7	14	89	SS-6	3.50	-	-	-	-	-	-	-	-	26	A-7-6 (V)
5 6 7	19	100	SS-7	3.00	-	-	-	-	-	-	-	-	26	A-7-6 (V)
2 5 5	14	100	SS-8	2.50	1	3	4	38	54	52	21	31	27	A-7-6 (18)
5 7 9	23	78	SS-9	-	-	-	-	-	-	-	-	-	10	A-1-b (V)
4 4 12	23	100	SS-10	-	15	28	44	8	5	NP	NP	NP	22	A-3a (0)

BACK FILL

2014 ODOT BORING LOG-RII NE BRIDGE ID - OH DOT.GDT - 7/12/19 13:00 - U:\GI8\PROJECTS\2013W-13-072.GPJ

PID: 89464 | BR ID: N/A | PROJECT: FRA-70-13.10 - PHASE 6A | STATION / OFFSET: 228+75.36 / 46.6 RT | START: 2/2/15 | END: 2/3/15 | PG 2 OF 2 | B-102-5-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 683.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE, BLACK **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, TRACE SILT, TRACE CLAY, WET. *(same as above)* -COBBLES PRESENT @ 31.0'	681.6	31 32																
DENSE, BROWN AND BLACK **GRAVEL**, "AND" COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 33.5' -INTRODUCED WATER @ 33.5'		33 34 35	17 12 13	36	39	SS-11	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		36 37 38 39 40	19 20 15	50	0	SS-12	-	-	-	-	-	-	-	-	-	-		
			39	-	100	3S-12A	-	50	30	9	8	3	NP	NP	NP	10	A-1-a (0)	
	671.6	41 42																
VERY DENSE, BLACK AND GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		43 44	21 17 29	66	100	SS-13	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
	668.6	EOB 45																

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 28.5'

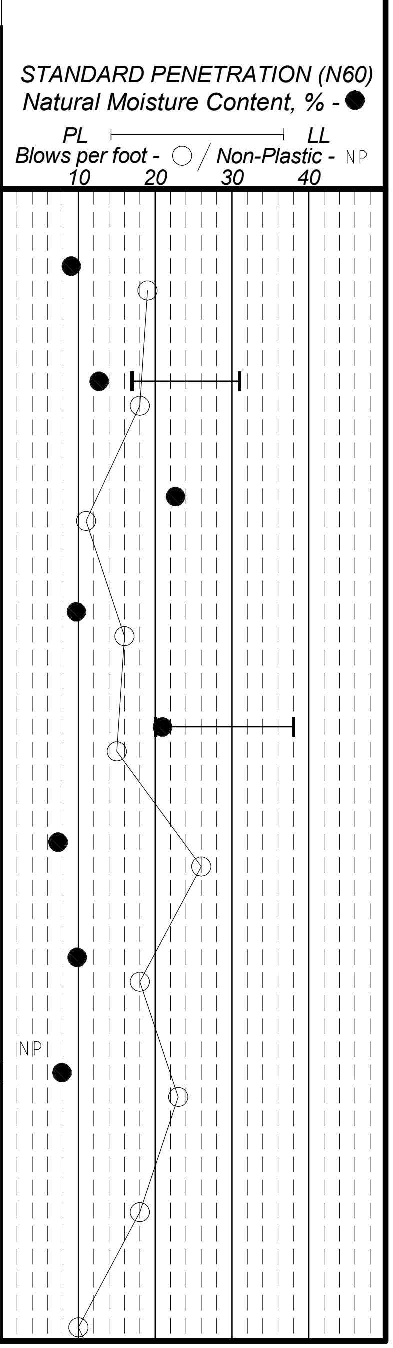
ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER SOIL CUTTINGS

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

LOG OF: Boring B-104-0-09 | *Location:* Sta. 222+98.38, 5.9' RT., BL I-71 SB | *Date Drilled:* 9/4/2009

WATER OBSERVATIONS:
Water seepage at: 22.5'
Water level at completion: 19.4'
FIELD NOTES:

Depth (ft)	Elev. (ft) 710.2	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	709.9						Topsoil - 4"						
		13 10 9	18	1			Medium dense gray SANDY SILT (A-4a), some fine to coarse sand, little gravel; damp.						
3.5	706.7												
5		11 10 8	12	2		3.0	Stiff to very stiff brown SILT AND CLAY (A-6a), some fine to coarse sand, little to some gravel; damp.	20	15	---	13	25	27
		3 4 7	12	3		2.0	@ 6.0'-7.5', dark brown, contains trace organic material.						
10		10 8 8	3	4		1.5							
11.0	699.2												
		6 7 8	13	5		4.0	Very stiff to hard brown SILTY CLAY (A-6b), little to some fine to coarse sand; damp.	0	2	---	18	37	43
13.5	696.7												
15		13 11 14	12	6			Medium dense brown GRAVEL (A-1-a). some fine to coarse sand, little silt; damp.						
		12 10 8	12	7									
20		15 11 12	12	8				57	18	---	10	--15--	
21.0	689.2												
		3 6 12	10	9			Medium dense brown COARSE AND FINE SAND (A-3a), little silt, little gravel; wet.						
23.5	686.7												
25	685.2	5 5 5	9	10			Medium dense to dense brown GRAVEL (A-1-a), little fine to coarse sand, trace silt; wet.						



Client: ms consultants

Project: FRA-70-8.93

Job No. 0221-1004.01

LOG OF: Boring B-104-0-09

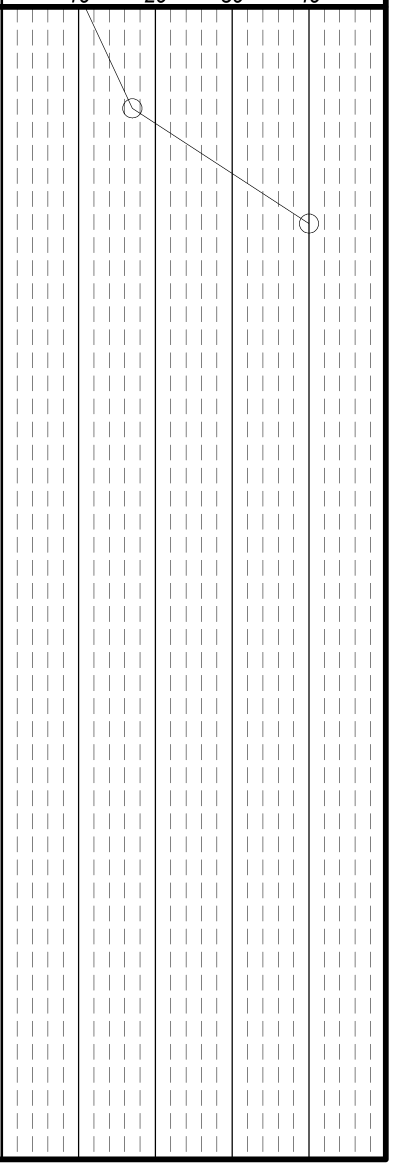
Location: Sta. 222+98.38, 5.9' RT., BL I-71 SB

Date Drilled: 9/4/2009

WATER OBSERVATIONS:
Water seepage at: 22.5'
Water level at completion: 19.4'

FIELD NOTES:

Depth (ft)	Elev. (ft)	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
	685.2													
		8 5 12	6	11			Medium dense to dense brown GRAVEL (A-1-a), little fine to coarse sand, trace silt; wet.							
30.0	680.2	18 20 19	8	12										
							Bottom of Boring - 30.0'							



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
START: 6/4/14 END: 6/26/14	SAMPLING METHOD: SPT / RC	ENERGY RATIO (%): 77.7	LAT / LONG: 39.947937, -83.015728	1 OF 3

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 3	5 9 13	28	67	SS-1	4.25	-	-	-	-	-	-	-	-	11	A-6a (V)	
		4 5 6	11 9 10	25	67	SS-2	4.25	16	12	14	29	29	25	14	11	15	A-6a (5)	
		7 8	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	13 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 18 W	14 21 17	49	67	SS-7	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		19 20 W	9 11 14	32	100	SS-8	-	97	1	1	1	0	NP	NP	NP	8	A-1-a (0)	
		21 22 23	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 28	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)	

2014 ODOT BORING LOG-RII NE BRIDGE ID - OH DOT.GDT - 7/12/19 13:00 - U:\GI8\PROJECTS\2013\W-13-072.GPJ

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 2 OF 3	B-104-1-13

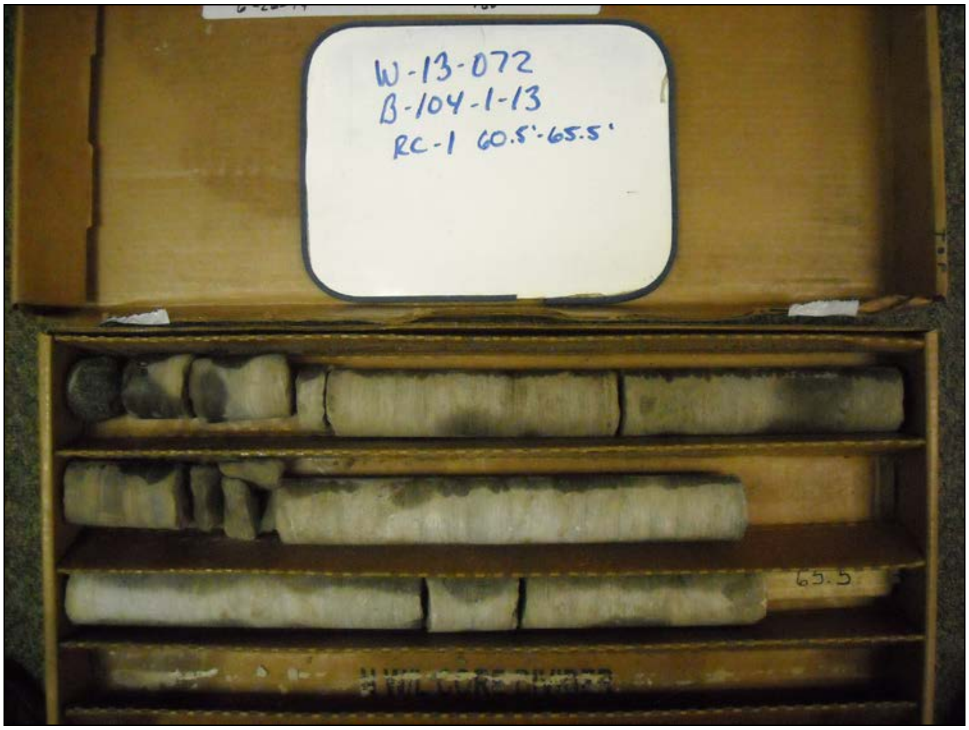
MATERIAL DESCRIPTION AND NOTES	ELEV. 684.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
MEDIUM DENSE TO VERY DENSE, BROWN TO BROWNISH GRAY **GRAVEL**, TRACE TO SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. *(same as above)*	682.5	31 32																
MEDIUM DENSE TO VERY DENSE, DARK BROWNISH GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		33																
		34 35	10 11 11	28	100	SS-13	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
-COBBLES PRESENT FROM 35.0' TO 38.5'		36 37 38																
		39	50/2"	-	0	SS-14	-	-	-	-	-	-	-	-	-	-		
	672.5	40 41																
VERY LOOSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		42 43																
		44 45	3 1 1	3	100	SS-15	-	39	43	6	2	10	NP	NP	NP	12	A-1-b (0)	
	667.5	46																
VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST.		47 48																
-HEAVING SANDS ENCOUNTERED @ 48.5' -INTRODUCED MUD @ 48.5'		49 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	52 53	0		25	RC-1											CORE	
HARD, BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP.		54 55 56 57																
-COBBLES PRESENT THROUGHOUT		58																
		59	50/3"	-	33	SS-17	-	-	-	-	-	-	-	-	-	-	A-6a (V)	
			50/4"	-	50	3S-17A	-	-	-	-	-	-	-	-	-	11	A-6a (V)	
	654.0	60																
		TR 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 (%)					ATTERBERG			WC	ODOT CLASS (GI)	HOLE SEALED
								GR	CS	FS	SI	CL	LL	PL	PI			
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 64 65	75		100	RC-2											CORE	
	644.0	66 67 68 69 70 EOB	70		90	RC-3											CORE	

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

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	EXPLORATION ID **B-105-3-14**
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.	PAGE 1 OF 2
START: 4/27/15 END: 4/28/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	LAT / LONG: 39.948118, -83.015970	

MATERIAL DESCRIPTION AND NOTES	ELEV. 719.4	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
0.3' - ASPHALT (4.0")	719.1																	
0.8' - CONCRETE (9.5")	718.3	1																
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.		2 3	3 6 8	21	33	SS-1	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)	
-ROCK FRAGMENTS PRESENT IN SS-2		4 5	3 5 14	29	89	SS-2	4.5+	20	10	15	33	22	26	16	10	13	A-4a (4)	
		6 7 8	4 7 7	21	100	SS-3	3.25	34	13	12	27	14	26	16	10	13	A-4a (1)	
	708.9	9 10	2 5 6	17	100	SS-4	2.25	-	-	-	-	-	-	-	-	15	A-4a (V)	
VERY DENSE, DARK GRAY **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, LITTLE SILT, DAMP. -ROCK FRAGMENTS PRESENT IN SS-5	706.4	11 12 13	13 23 21	66	100	SS-5	-	-	-	-	-	-	-	-	-	5	A-3a (V)	
VERY DENSE, DARK BROWN **GRAVEL WITH SAND AND SILT**, TRACE CLAY, DAMP.		14 15	4 24 29	80	100	SS-6	-	44	16	12	19	9	25	16	9	8	A-2-4 (0)	
	701.4	16 17 18	13 33 21	81	100	SS-7	-	-	-	-	-	-	-	-	-	5	A-2-4 (V)	
HARD, BROWN **CLAY**, "AND" SILT, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	697.4	19 20 21 22	4 8 10	27	89	SS-8	4.5+	3	4	9	36	48	43	22	21	22	A-7-6 (13)	
DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, DAMP.	694.7	23 24	7 9 11	30	100	SS-9	-	-	-	-	-	-	-	-	-	7	A-2-6 (V)	
HARD, BROWN **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, MOIST.	692.4	25 26 27					-	11	5	24	33	27	23	14	9	16	A-4a (5)	
MEDIUM DENSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST. -INTRODUCED MUD @ 28.5'		W 28 29	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.		33																
		34 35	14 19 27	69	72	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-a (V)	
		36 37 38																
		39 40	9 17 8	38	100	SS-12	-	55	25	6	10	4	22	18	4	10	A-1-a (0)	
		41 42 43																
		44 45	3 13 13	39	72	SS-13	-	-	-	-	-	-	-	-	-	13	A-1-a (V)	
-HEAVING SANDS ENCOUNTERED @ 48.5'		46 47 48																
		49 50	23 30 44	111	100	SS-14	-	63	21	9	5	2	NP	NP	NP	7	A-1-a (0)	
		51 52 53																
	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

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 4/17/15 END: 4/17/15

DRILLING FIRM / OPERATOR: STOCK / C/T
SAMPLING FIRM / LOGGER: RII / N.A.
DRILLING METHOD: 4.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: BK 81 HD (SN 810792.111)
HAMMER: AUTOMATIC
CALIBRATION DATE: 3/28/13
ENERGY RATIO (%): 72.3

STATION / OFFSET: 3012+82.16 / 42.1' LT
ALIGNMENT: BL RAMP C3
ELEVATION: 723.9 (MSL) EOB: 50.0 ft.
LAT / LONG: 39.948476, -83.016258

EXPLORATION ID
B-105-5-14

PAGE
1 OF 2

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)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)
					GR	CS	FS	SI	CL	LL	PL	PI		
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	- 4.5+	- -	- -	- -	- -	- -	- -	- -	- -	6 23	A-1-b (V) 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)

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

BACK FILL

PID: 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 | PG 2 OF 2 | B-105-5-14

MATERIAL DESCRIPTION AND NOTES	ELEV. 693.9	DEPTHS	SPT/ RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG 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 34 35	23 29 27	67	100	SS-11	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
		36 37 38																
-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		41 42 43																
		44 45	29 26 32	70	100	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-a (V)	
	676.9	46 47																
DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.		48																
	673.9	49 EOB 50	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

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	
PID: 89464 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 3/28/13	ELEVATION: 727.5 (MSL) EOB: 45.0 ft.	PAGE 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
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	720.5
FILL: VERY STIFF, GRAY **SILTY CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -ASPHALT FRAGMENTS PRESENT IN SS-2	710.5
FILL: VERY STIFF, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP. -ROCK FRAGMENTS PRESENT IN SS-4	707.0
FILL: VERY DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, DAMP TO MOIST. -ASPHALT FRAGMENTS PRESENT IN SS-7	702.0
VERY STIFF, DARK BROWN **SILTY CLAY**, "AND" COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP.	699.5
MEDIUM DENSE, BROWNISH GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.	

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
4 5 5	12	72	SS-1	1.50	-	-	-	-	-	-	-	-	10	A-4a (V)
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)
7 11 17	34	83	SS-4	3.50	-	-	-	-	-	-	-	-	9	A-6a (V)
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)
29 46 4	60	50	SS-7	-	-	-	-	-	-	-	-	-	9	A-1-b (V)
3 4 3	8	61	SS-8	3.00	18	21	22	21	18	37	18	19	14	A-6b (3)
15 14 9	28	83	SS-9	-	-	-	-	-	-	-	-	-	7	A-1-b (V)

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)	
		33																
		34 – 35	5 13 20	40	67	SS-11	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
-HEAVING SANDS ENCOUNTERED @ 35.0' -INTRODUCED MUD @ 35.0'		W 35																
-ROCK FRAGMENTS PRESENT THROUGHOUT		36 – 37	8 21 36	69	61	SS-12	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
		38																
		39 – 40	4 13 20	40	44	SS-13	-	45	27	13	13	2	NP	NP	NP	9	A-1-b (0)	
	685.5	41																
DENSE, BROWN **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, TRACE SILT, MOIST.		42 – 43																
	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
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 1/30/15 END: 1/30/15

DRILLING FIRM / OPERATOR: RII / S.B.
SAMPLING FIRM / LOGGER: RII / N.A.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 10/20/14
ENERGY RATIO (%): 85.7

STATION / OFFSET: 3009+74.31 / 79.9' LT
ALIGNMENT: BL RAMP C3
ELEVATION: 703.6 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.949259, -83.016711

EXPLORATION ID
B-108-7-14

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 703.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.7' - TOPSOIL (8.0")	702.9																	
FILL: DENSE TO VERY DENSE, BROWNISH GRAY TO BROWN **GRAVEL**, LITTLE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -COAL FRAGMENTS PRESENT IN SS-1 -COBBLES ENCOUNTERED THROUGHOUT		1 2	3 13 14	39	61	SS-1	-	-	-	-	-	-	-	-	-	15	A-1-a (V)	
		3																
	698.1	4 5	7 19 19	54	78	SS-2	-	81	7	4	6	2	NP	NP	NP	10	A-1-a (0)	
DENSE TO VERY DENSE, BROWNISH GRAY **GRAVEL**, TRACE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		6 7	10 12 22	49	89	SS-3	-	-	-	-	-	-	-	-	-	6	A-1-a (V)	
		8																
		9 10	19 30 21	73	67	SS-4	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	
-COBBLES ENCOUNTERED THROUGHOUT		11 12	40 50/6"	-	83	SS-5	-	87	5	3	4	1	NP	NP	NP	10	A-1-a (0)	
		13																
-ROCK FRAGMENTS PRESENT IN SS-6	688.6	14 15	31 50/5"	-	100	SS-6	-	-	-	-	-	-	-	-	-	6	A-1-a (V)	
MEDIUM DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST.		W 16 17	33 10 5	21	100	SS-7	-	52	22	7	14	5	NP	NP	NP	14	A-1-b (0)	
		18																
		19 20	3 4 5	13	100	SS-8	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
	681.6	21																
VERY DENSE, BROWNISH GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 23.5'		22 23																
		24 25	22 34 41	107	100	SS-9	-	33	32	20	11	4	NP	NP	NP	12	A-1-b (0)	
		26 27 28																
		29 EOB	17 19 24	61	100	SS-10	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	

NOTES: SEEPAGE ENCOUNTERED @ 11.0'; GROUNDWATER ENCOUNTERED INITIALLY @ 16.0'

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

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-13.10 - PHASE 6A
TYPE: STRUCTURE
PID: 89464 BR ID: N/A
START: 1/30/15 END: 1/30/15

DRILLING FIRM / OPERATOR: RII / S.B.
SAMPLING FIRM / LOGGER: RII / N.A.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 10/20/14
ENERGY RATIO (%): 85.7

STATION / OFFSET: 3008+52.04 / 89.6' LT
ALIGNMENT: BL RAMP C3
ELEVATION: 703.4 (MSL) EOB: 15.0 ft.
LAT / LONG: 39.949572, -83.016992

EXPLORATION ID
B-108-8-14

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 703.4	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
0.5' - TOPSOIL (6.0")	702.9																	
HARD, DARK BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -ROCK FRAGMENTS PRESENT IN SS-1 -COBBLES PRESENT @ 1.0'	700.4		9 12 6	26	50	SS-1	4.25	-	-	-	-	-	-	-	-	12	A-6a (V)	
DENSE, BROWNISH GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP.	697.9		4 11 12	33	44	SS-2	-	32	16	11	30	11	NP	NP	NP	8	A-4a (1)	
DENSE TO VERY DENSE, BROWN **GRAVEL**, TRACE COARSE TO FINE SAND, TRACE SILT, MOIST.			3 13 17	43	56	SS-3	-	-	-	-	-	-	-	-	-	6	A-1-a (V)	
	691.4		11 19 20	56	100	SS-4	-	96	2	1	1	0	NP	NP	NP	6	A-1-a (0)	
MEDIUM DENSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-5	688.4	W EOB	10 9 10	27	39	SS-5	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 13.5'

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

APPENDIX IV

LABORATORY TEST RESULTS

RESOURCE INTERNATIONAL, INC.
Engineering Consultants

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

6350 Presidential Gatew.
Columbus, OH 43231
Phone (614) 823-4949

9885 Rockside Road
Cleveland, OH 44125
Phone (216) 573-0955

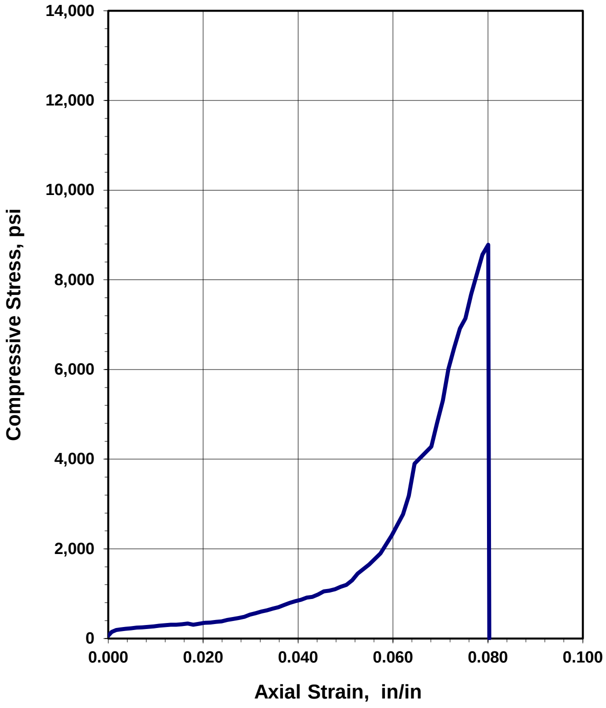
4480 Lake Forest Drive
Cincinnati, Ohio 45242
Phone (513) 769-6998

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.

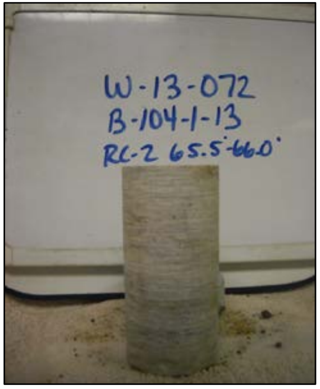
Rock Description: Dolomitic Limestone

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

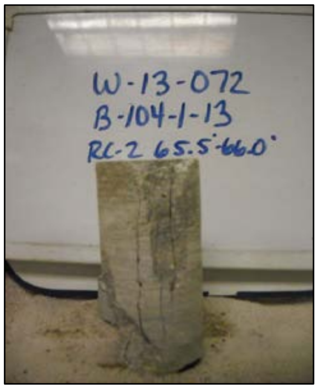
Unconfined Compression Test



Before Testing



After Failure

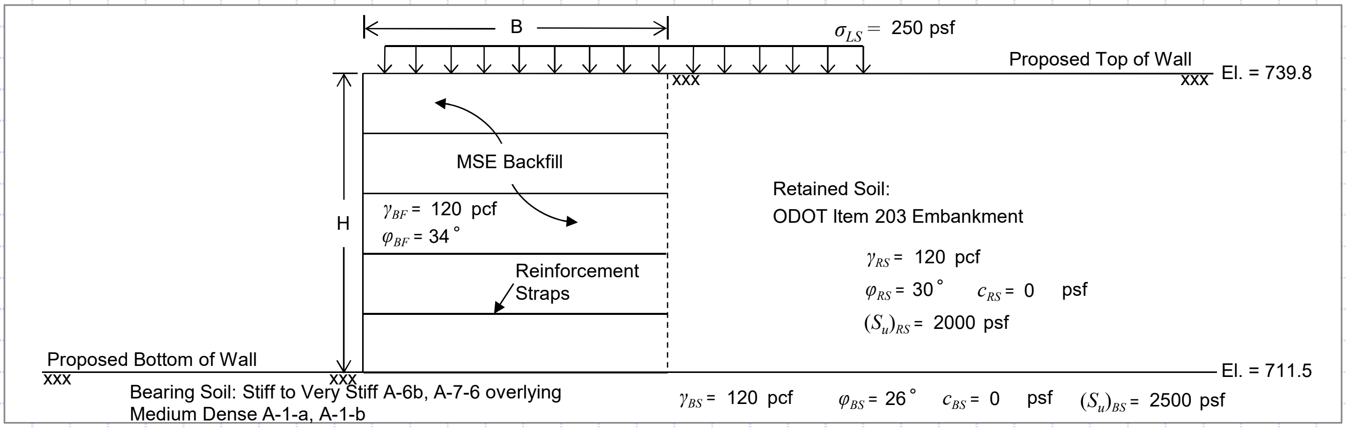


REMARKS:

APPENDIX V

MSE WALL CALCULATIONS

Retaining Wall W5 - Sta. 500+00 to 507+00 - B-099-4-14, B-100-0-09, B-100-2-14, B-100-4-14 and B-102-3-14 - 28.3 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.3	ft
MSE Wall Width (Reinforcement Length), (B) =	19.8	ft
MSE Wall Length, (L) =	1031	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}) =	26	°
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

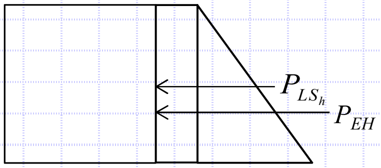
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:

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



$P_{EH} = ½ \gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(28.3 ft)²(0.297)(1.5) = 21.41 kip/ft

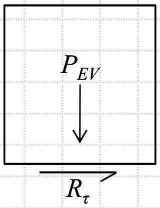
$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(28.3 ft)(0.297)(1.75) = 3.68 kip/ft

P_H = 21.41 kip/ft + 3.68 kip/ft = 25.09 kip/ft

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

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



$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(28.3 ft)(19.8 ft)(1.00) = 67.24 kip/ft

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

$\tan\delta =$ tan(26) ≤ tan(34) ⟶ 0.49 ≤ 0.67 ⟶ $\tan\delta =$ 0.49

R_τ = (67.24 kip/ft)(0.49) = 32.95 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 25.09 kip/ft ≤ (32.95 kip/ft)(1.0) = 32.95 kip/ft ⟶ 25.09 kip/ft ≤ 32.95 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) =	28.3	ft
MSE Wall Width (Reinforcement Length), (B) =	19.8	ft
MSE Wall Length, (L) =	1031	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}) =	26	°
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

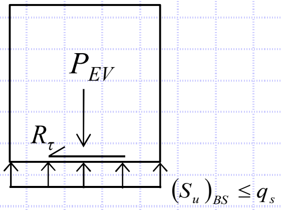
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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



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

$$q_s = \sigma_v / 2 = (3.40 \text{ ksf}) / 2 = 1.70 \text{ ksf}$$

$$\sigma_v = P_{EV} / B = (67.24 \text{ kip/ft}) / (19.8 \text{ ft}) = 3.40 \text{ ksf}$$

$$R_\tau = (2.50 \text{ ksf} \le 1.70 \text{ ksf})(19.8 \text{ ft}) = 33.66 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 25.09 kip/ft ≤ (33.66 kip/ft)(1.0) = 33.66 kip/ft ⟶ 25.09 kip/ft ≤ 33.66 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) = 28.3 ft
MSE Wall Width (Reinforcement Length), (B) = 19.8 ft
MSE Wall Length, (L) = 1031 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:

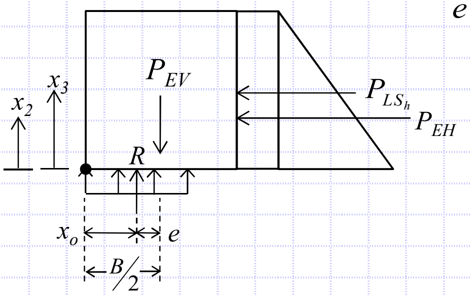
Bearing Soil Unit Weight, (γ_{BS}) = 120 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 26 °
Bearing Soil Drained Cohesion, (c_{BS}) = 0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ = 2500 psf
Embedment Depth, (D_f) = 4.0 ft
Depth to Grounwater (Below Bot. of Wall), (D_W) = 25.0 ft

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



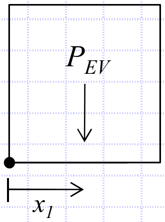
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(665.68 kip·ft/ft - 253.97 kip·ft/ft) / (67.24 kip/ft)} = 6.12 \text{ ft}$$

$$\left.\begin{array}{lcll} M_{EV} & = & 665.68 & \text{kip·ft/ft} \\ M_H & = & 253.97 & \text{kip·ft/ft} \\ P_{EV} & = & 67.24 & \text{kip/ft} \end{array}\right\} \text{Defined below}$$

$$e = \text{(19.8 ft)/2 - 6.12 ft} = 3.78 \text{ ft}$$

Resisting Moment, M_{EV}:



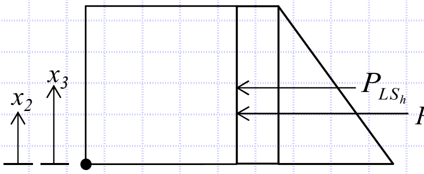
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(28.3 ft)(19.8 ft)(1.00)} = 67.24 \text{ kip/ft}$$

$$x_1 = B/2 = \text{(19.8 ft) / 2} = 9.90 \text{ ft}$$

$$M_{EV} = \text{(67.24 kip/ft)(9.90 ft)} = 665.68 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(28.3 ft)²(0.297)(1.5)} = 21.41 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(28.3 ft)(0.297)(1.75)} = 3.68 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(28.3 ft) / 3} = 9.43 \text{ ft}$$

$$x_3 = H/2 = \text{(28.3 ft) / 2} = 14.15 \text{ ft}$$

$$M_H = \text{(21.41 kip/ft)(9.43 ft) + (3.68 kip/ft)(14.15 ft)} = 253.97 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.78 ft < 6.60 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} = \text{(19.8 ft) / 3} = 6.60 \text{ ft}$

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.3	ft
MSE Wall Width (Reinforcement Length), (B) =	19.8	ft
MSE Wall Length, (L) =	1031	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:

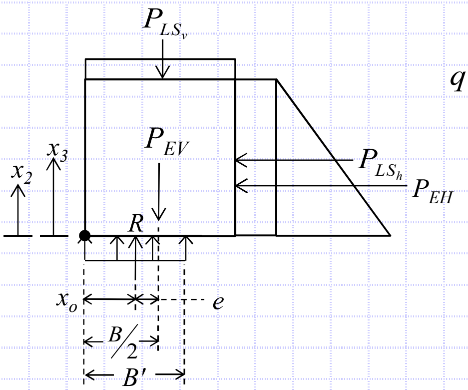
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	25.0	ft

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



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

$B' = B - 2e$ = 19.8 ft - 2(2.55 ft) = 14.70 ft

$e = B/2 - x_o$ = (19.8 ft) / 2 - 7.35 ft = 2.55 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (984.43 kip·ft/ft - 253.91 kip·ft/ft) / 99.44 kip/ft = 7.35 ft

q_{eq} = (99.44 kip/ft) / (14.7 ft) = 6.76 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)(28.3 ft)(19.8 ft)(1.35)](9.9 ft) + [(250 psf)(19.8 ft)(1.75)](9.9 ft) = 984.43 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)(28.3 ft)²(0.297)(1.5)](9.43 ft) + [(250 psf)(28.3 ft)(0.297)(1.75)](14.15 ft) = 253.91 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)(28.3 ft)(19.8 ft)(1.35) + (250 psf)(19.8 ft)(1.75) = 99.44 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 22.43

N_c = 22.25
s_c = 1+(14.7 ft/1031 ft)(11.85/22.25)
= 1.008
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 12.91

N_q = 11.85
s_q = 1.007
d_q = 1+2tan(26°)[1-sin(26°)]²tan⁻¹(4.0 ft/14.7 ft)
1.082
i_q = 1.000 (Assumed)
C_{wq} = 25.0 ft > 4.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 12.46

N_γ = 12.54
s_γ = 0.994
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 25.0 ft < 1.5(14.7 ft) + 4.0 ft = 1.067

q_n = (0 psf)(22.428) + (120 pcf)(4.0 ft)(12.911)(1.000) + ½(120 pcf)(14.7 ft)(12.465)(1.067) = 17.93 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 6.76 ksf ≤ (17.93 ksf)(0.65) = 11.65 ksf ⟶ 6.76 ksf ≤ 11.65 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.3	ft
MSE Wall Width (Reinforcement Length), (B) =	19.8	ft
MSE Wall Length, (L) =	1031	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}) =	26	°
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: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.160

N_c = 5.140

s_c = 1+(14.7 ft/[(5)(1031 ft)]) = 1.003

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/14.7 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(14.7 ft) + 4.0 ft = 1.067

$q_n =$ (2500 psf)(5.160) + (120 pcf)(4.0 ft)(1.000)(1.000) + ½(120 pcf)(14.7 ft)(0.000)(1.067) = 13.38 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b \longrightarrow$ 6.76 ksf ≤ (13.38 ksf)(0.65) = 8.70 ksf $\longrightarrow$ 6.76 ksf ≤ 8.70 ksf **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 28.3 ft
MSE Wall Width (Reinforcement Length), (B) = 19.8 ft
MSE Wall Length, (L) = 1031 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:

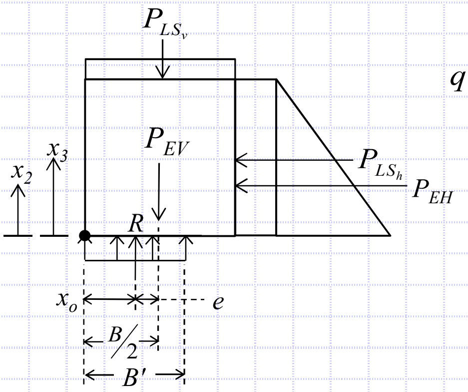
Bearing Soil Unit Weight, (γ_{BS}) = 120 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 26 °
Bearing Soil Drained Cohesion, (c_{BS}) = 0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ = 2500 psf
Embedment Depth, (D_f) = 4.0 ft
Depth to Grounwater (Below Bot. of Wall), (D_W) = 25.0 ft

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



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

$$B' = B - 2e \quad = \quad 19.8\text{ ft - 2(2.28 ft)} \quad = \quad 15.24 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad \text{(19.8 ft) / 2 - 7.62 ft} \quad = \quad 2.28 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(714.69 kip·ft/ft - 164.32 kip·ft/ft) / 72.19 kip/ft} \quad = \quad 7.62 \quad \text{ft}$$

$$q_{eq} = \quad \text{(72.19 kip/ft) / (15.24 ft)} \quad = \quad 4.74 \quad \text{ksf}$$

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

$$M_V = \quad \text{[(120 pcf)(28.3 ft)(19.8 ft)(1.00)](9.9 ft) + [(250 psf)(19.8 ft)(1.00)](9.9 ft)} \quad = \quad 714.69 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad \text{[½(120 pcf)(28.3 ft)²(0.297)(1.00)](9.43 ft) + [(250 psf)(28.3 ft)(0.297)(1.00)](14.15 ft)} \quad = \quad 164.32 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad \text{(120 pcf)(28.3 ft)(19.8 ft)(1.00) + (250 psf)(19.8 ft)(1.00)} \quad = \quad 72.19 \quad \text{kip/ft}$$

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-099-4-14	1.080 in	0.811 in	50 days		
B-100-0-09	0.967 in	0.758 in	13 days	120 ft	1/27170
B-100-2-14	1.108 in	0.872 in	70 days	125 ft	1/13160
B-100-4-14	1.884 in	1.496 in	14 days	140 ft	1/2690
B-102-3-14	2.617 in	1.957 in	22 days	130 ft	1/3380

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-099-4-14

H=	7.1	ft	Total wall height
B'=	7.1	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	1,250	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)		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-7-6	C	0.0	2.0	2.0	1.0	120	240	120	120	4,120	43	0.297	0.030	0.608				0.14	0.991	1,239	1,359	0.039	0.467	0.499	624	744	0.029	0.351
2	A-7-6	C	2.0	4.5	2.5	3.3	125	553	396	396	4,396	43	0.297	0.030	0.608				0.46	0.845	1,056	1,453	0.026	0.313	0.484	605	1,001	0.019	0.223
	A-7-6	C	4.5	7.0	2.5	5.8	125	865	709	709	4,709	43	0.297	0.030	0.608				0.81	0.637	796	1,505	0.015	0.181	0.439	549	1,257	0.011	0.138
3	A-6a	C	7.0	9.5	2.5	8.3	120	1,165	1,015	1,015	5,015	34	0.216	0.022	0.538				1.16	0.490	612	1,627	0.007	0.086	0.384	479	1,494	0.006	0.071
4	A-1-a	G	9.5	11.5	2.0	10.5	130	1,425	1,295	1,295	5,295					28	32	105	1.48	0.401	501	1,796	0.003	0.032	0.337	421	1,716	0.002	0.028
																				Total Settlement:			1.080 in		Total Settlement:			0.811 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5

MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019

Checked By: JPS Date: 7/1/2019

Boring B-099-4-14

H=	7.1	ft	Total wall height
B'=	7.1	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	1,250	psf	Equivalent bearing pressure at bottom of wall

	A-7-6	A-6a			
c_v =	150	600		ft^2/yr	Coefficient of consolidation
t =	50	50		days	Time following completion of construction
H_{dr} =	5	2.5		ft	Length of longest drainage path considered
T_v =	0.822	13.151			Time factor
U =	89	100		%	Degree of consolidation

$(S_c)_t$ = 0.733 in Settlement complete at 90% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-7-6	C	0.0	2.0	2.0	1.0	120	240	120	120	4,120	43	0.297	0.030	0.608				0.14	0.499	624	744	0.029	0.351	0.351	0.313	0.313
2	A-7-6	C	2.0	4.5	2.5	3.3	125	553	396	396	4,396	43	0.297	0.030	0.608				0.46	0.484	605	1,001	0.019	0.223	0.361	0.198	0.321
	A-7-6	C	4.5	7.0	2.5	5.8	125	865	709	709	4,709	43	0.297	0.030	0.608				0.81	0.439	549	1,257	0.011	0.138		0.123	
3	A-6a	C	7.0	9.5	2.5	8.3	120	1,165	1,015	1,015	5,015	34	0.216	0.022	0.538				1.16	0.384	479	1,494	0.006	0.071	0.071	0.071	0.071
4	A-1-a	G	9.5	11.5	2.0	10.5	130	1,425	1,295	1,295	5,295					28	32	105	1.48	0.337	421	1,716	0.002	0.028	0.028	0.028	0.028

Settlement Remaining After Hold Period: 0.078 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

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-0-09

H=	10.2	ft	Total wall height
B'=	6.3	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	1,880	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)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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-1-a	G	0.0	3.0	3.0	1.5	120	360	180	180	4,180					8	14	64	0.24	0.964	1,813	1,993	0.049	0.591	0.497	935	1,115	0.037	0.448
2	A-4a	C	3.0	4.5	1.5	3.8	125	548	454	454	4,454	24	0.126	0.013	0.460				0.60	0.758	1,426	1,879	0.008	0.096	0.469	882	1,335	0.006	0.073
3	A-1-b	G	4.5	6.0	1.5	5.3	130	743	645	645	4,645					37	51	174	0.83	0.625	1,175	1,820	0.004	0.047	0.435	819	1,464	0.003	0.037
4	A-6b	C	6.0	8.0	2.0	7.0	125	993	868	868	4,868	33	0.207	0.021	0.530				1.11	0.507	954	1,821	0.009	0.105	0.392	736	1,604	0.007	0.087
	A-6b	C	8.0	10.0	2.0	9.0	125	1,243	1,118	1,118	5,118	33	0.207	0.021	0.530				1.43	0.413	776	1,894	0.006	0.074	0.344	647	1,764	0.005	0.064
	A-6b	C	10.0	12.0	2.0	11.0	125	1,493	1,368	1,368	5,368	33	0.207	0.021	0.530				1.75	0.346	651	2,018	0.005	0.055	0.303	569	1,937	0.004	0.049
																				Total Settlement:			0.967 in		Total Settlement:			0.758 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-0-09

H=	10.2	ft	Total wall height
B'=	6.3	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	1,880	psf	Equivalent bearing pressure at bottom of wall

	A-6b				
c_v =	300			ft^2/yr	Coefficient of consolidation
t =	13			days	Time following completion of construction
H_{dr} =	6			ft	Length of longest drainage path considered
T_v =	0.297				Time factor
U =	61			%	Degree of consolidation

$(S_c)_t$ = 0.680 in Settlement complete at 90% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-1-a	G	0.0	3.0	3.0	1.5	120	360	180	180	4,180					8	14	64	0.24	0.497	935	1,115	0.037	0.448	0.448	0.448	0.448
2	A-4a	C	3.0	4.5	1.5	3.8	125	548	454	454	4,454	24	0.126	0.013	0.460				0.60	0.469	882	1,335	0.006	0.073	0.073	0.073	0.073
3	A-1-b	G	4.5	6.0	1.5	5.3	130	743	645	645	4,645					37	51	174	0.83	0.435	819	1,464	0.003	0.037	0.037	0.037	0.037
4	A-6b	C	6.0	8.0	2.0	7.0	125	993	868	868	4,868	33	0.207	0.021	0.530				1.11	0.392	736	1,604	0.007	0.087	0.200	0.053	0.122
	A-6b	C	8.0	10.0	2.0	9.0	125	1,243	1,118	1,118	5,118	33	0.207	0.021	0.530				1.43	0.344	647	1,764	0.005	0.064		0.039	
	A-6b	C	10.0	12.0	2.0	11.0	125	1,493	1,368	1,368	5,368	33	0.207	0.021	0.530				1.75	0.303	569	1,937	0.004	0.049		0.030	

Settlement Remaining After Hold Period: 0.078 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

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-2-14

H=	13.4	ft	Total wall height
B'=	7.0	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	2,500	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)		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	2.5	2.5	1.3	125	313	156	156	4,156	32	0.198	0.020	0.522				0.18	0.983	2,458	2,614	0.040	0.477	0.499	1,247	1,403	0.031	0.372
2	A-6b	C	2.5	4.5	2.0	3.5	125	563	438	438	4,438	35	0.225	0.023	0.546				0.50	0.818	2,046	2,483	0.022	0.263	0.480	1,199	1,637	0.017	0.200
	A-6b	C	4.5	7.0	2.5	5.8	125	875	719	719	4,719	35	0.225	0.023	0.546				0.82	0.631	1,577	2,296	0.018	0.220	0.437	1,093	1,812	0.015	0.175
	A-6b	C	7.0	9.5	2.5	8.3	125	1,188	1,031	1,031	5,031	35	0.225	0.023	0.546				1.18	0.484	1,211	2,242	0.012	0.147	0.381	952	1,984	0.010	0.124
																				Total Settlement:			1.108 in		Total Settlement:			0.872 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-2-14

H=	13.4	ft	Total wall height
B'=	7.0	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	2,500	psf	Equivalent bearing pressure at bottom of wall

	A-6a	A-6b			
c_v =	600	300		ft^2/yr	Coefficient of consolitation
t =	70	70		days	Time following completion of construction
H_{dr} =	2.5	9.5		ft	Length of longest drainage path considered
T_v =	18.411	0.637			Time factor
U =	100	83		%	Degree of consolidation

$(S_c)_t$ = 0.787 in Settlement complete at 90% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.5	2.5	1.3	125	313	156	156	4,156	32	0.198	0.020	0.522				0.18	0.499	1,247	1,403	0.031	0.372	0.372	0.372	0.372
2	A-6b	C	2.5	4.5	2.0	3.5	125	563	438	438	4,438	35	0.225	0.023	0.546				0.50	0.480	1,199	1,637	0.017	0.200	0.500	0.166	0.415
	A-6b	C	4.5	7.0	2.5	5.8	125	875	719	719	4,719	35	0.225	0.023	0.546				0.82	0.437	1,093	1,812	0.015	0.175		0.146	
	A-6b	C	7.0	9.5	2.5	8.3	125	1,188	1,031	1,031	5,031	35	0.225	0.023	0.546				1.18	0.381	952	1,984	0.010	0.124		0.103	

Settlement Remaining After Hold Period: 0.085 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. $(N1)_{60} = C_nN_{60}$, 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. $S_c = [C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$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

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-4-14

H=	19.5	ft	Total wall height
B'=	10.4	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	3,400	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)		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-6b	C	0.0	2.0	2.0	1.0	125	250	125	125	4,125	38	0.252	0.025	0.569				0.10	0.997	3,390	3,515	0.047	0.559	0.500	1,699	1,824	0.037	0.449
	A-6b	C	2.0	4.0	2.0	3.0	125	500	375	375	4,375	38	0.252	0.025	0.569				0.29	0.942	3,204	3,579	0.031	0.378	0.495	1,684	2,059	0.024	0.285
	A-6b	C	4.0	6.0	2.0	5.0	125	750	625	625	4,625	38	0.252	0.025	0.569				0.48	0.831	2,824	3,449	0.024	0.286	0.482	1,638	2,263	0.018	0.215
	A-6b	C	6.0	8.0	2.0	7.0	125	1,000	875	875	4,875	38	0.252	0.025	0.569				0.67	0.711	2,419	3,294	0.018	0.222	0.459	1,560	2,435	0.014	0.171
2	A-1-b	G	8.0	13.0	5.0	10.5	130	1,650	1,325	1,325	5,325					33	38	122	1.01	0.546	1,856	3,181	0.016	0.187	0.408	1,386	2,711	0.013	0.152
3	A-1-b	G	13.0	16.5	3.5	14.8	125	2,088	1,869	1,869	5,869					18	18	71	1.42	0.415	1,412	3,281	0.012	0.145	0.345	1,174	3,043	0.010	0.125
	A-1-b	G	16.5	20.0	3.5	18.3	125	2,525	2,306	2,306	6,306					18	17	69	1.75	0.344	1,171	3,477	0.009	0.109	0.302	1,026	3,332	0.008	0.098
																			Total Settlement:				1.884 in		Total Settlement:			1.496 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-100-4-14

H=	19.5	ft	Total wall height
B'=	10.4	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	3,400	psf	Equivalent bearing pressure at bottom of wall

	A-6b				
c_v =	300			ft^2/yr	Coefficient of consolidation
t =	14			days	Time following completion of construction
H_{dr} =	4			ft	Length of longest drainage path considered
T_v =	0.719				Time factor
U =	86			%	Degree of consolidation

$(S_c)_t$ = 1.339 in Settlement complete at 90% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6b	C	0.0	2.0	2.0	1.0	125	250	125	125	4,125	38	0.252	0.025	0.569				0.10	0.500	1,699	1,824	0.037	0.449	1.121	0.386	0.964
	A-6b	C	2.0	4.0	2.0	3.0	125	500	375	375	4,375	38	0.252	0.025	0.569				0.29	0.495	1,684	2,059	0.024	0.285		0.245	
	A-6b	C	4.0	6.0	2.0	5.0	125	750	625	625	4,625	38	0.252	0.025	0.569				0.48	0.482	1,638	2,263	0.018	0.215		0.185	
	A-6b	C	6.0	8.0	2.0	7.0	125	1,000	875	875	4,875	38	0.252	0.025	0.569				0.67	0.459	1,560	2,435	0.014	0.171		0.147	
2	A-1-b	G	8.0	13.0	5.0	10.5	130	1,650	1,325	1,325	5,325					33	38	122	1.01	0.408	1,386	2,711	0.013	0.152	0.152	0.152	0.152
3	A-1-b	G	13.0	16.5	3.5	14.8	125	2,088	1,869	1,869	5,869					18	18	71	1.42	0.345	1,174	3,043	0.010	0.125	0.223	0.125	0.223
	A-1-b	G	16.5	20.0	3.5	18.3	125	2,525	2,306	2,306	6,306					18	17	69	1.75	0.302	1,026	3,332	0.008	0.098		0.098	

Settlement Remaining After Hold Period: 0.157 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. $(N1)_{60} = C_nN_{60}$, 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

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT Date: 6/29/2019
Checked By: JPS Date: 7/1/2019

Boring B-102-3-14

H=	28.3	ft	Total wall height
B'=	15.2	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	4,740	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)		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-6b	C	0.0	1.5	1.5	0.8	120	180	90	90	4,090	34	0.216	0.022	0.538				0.05	1.000	4,738	4,828	0.050	0.601	0.500	2,370	2,460	0.030	0.363
2	A-1-a	G	1.5	4.0	2.5	2.8	130	505	343	343	4,343					36	57	202	0.18	0.983	4,658	5,000	0.014	0.173	0.499	2,364	2,707	0.011	0.133
	A-1-a	G	4.0	6.5	2.5	5.3	130	830	668	668	4,668					36	49	166	0.35	0.913	4,327	4,994	0.013	0.158	0.492	2,334	3,001	0.010	0.118
3	A-6b	C	6.5	9.0	2.5	7.8	125	1,143	986	986	4,986	40	0.270	0.027	0.585				0.51	0.812	3,849	4,835	0.029	0.353	0.479	2,269	3,255	0.022	0.265
4	A-7-6	C	9.0	11.5	2.5	10.3	120	1,443	1,293	1,293	5,293	56	0.414	0.041	0.710				0.67	0.711	3,369	4,661	0.034	0.405	0.459	2,174	3,467	0.026	0.311
	A-7-6	C	11.5	14.0	2.5	12.8	120	1,743	1,593	1,593	5,593	56	0.414	0.041	0.710				0.84	0.622	2,949	4,542	0.028	0.331	0.435	2,060	3,652	0.022	0.262
5	A-1-b	G	14.0	18.0	4.0	16.0	125	2,243	1,993	1,993	5,993					14	14	63	1.05	0.529	2,508	4,500	0.022	0.270	0.401	1,900	3,892	0.018	0.222
	A-1-b	G	18.0	22.0	4.0	20.0	125	2,743	2,493	2,493	6,493					14	13	61	1.32	0.443	2,098	4,590	0.017	0.208	0.360	1,707	4,200	0.015	0.178
6	A-1-b	G	22.0	26.0	4.0	24.0	130	3,263	3,003	3,003	7,003					27	23	82	1.58	0.378	1,794	4,796	0.010	0.119	0.324	1,534	4,536	0.009	0.105
																				Total Settlement:			2.617 in		Total Settlement:			1.957 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 500+00 to 507+00

Calculated By: BRT   Date: 6/29/2019
Checked By: JPS   Date: 7/1/2019

Boring B-102-3-14

H=	28.3	ft	Total wall height
B'=	15.2	ft	Effective footing width due to eccentricity
D_w =	25.0	ft	Depth below bottom of footing
q_e =	4,740	psf	Equivalent bearing pressure at bottom of wall

	A-6b	A-7-6			
c_v =	300	150		ft^2/yr	Coefficient of consolidation
t =	22	22		days	Time following completion of construction
H_{dr} =	1.5	5		ft	Length of longest drainage path considered
T_v =	8.037	0.362			Time factor
U =	100	67		%	Degree of consolidation

$(S_c)_t$ = 1.768 in   Settlement complete at 90% of primary consolidation

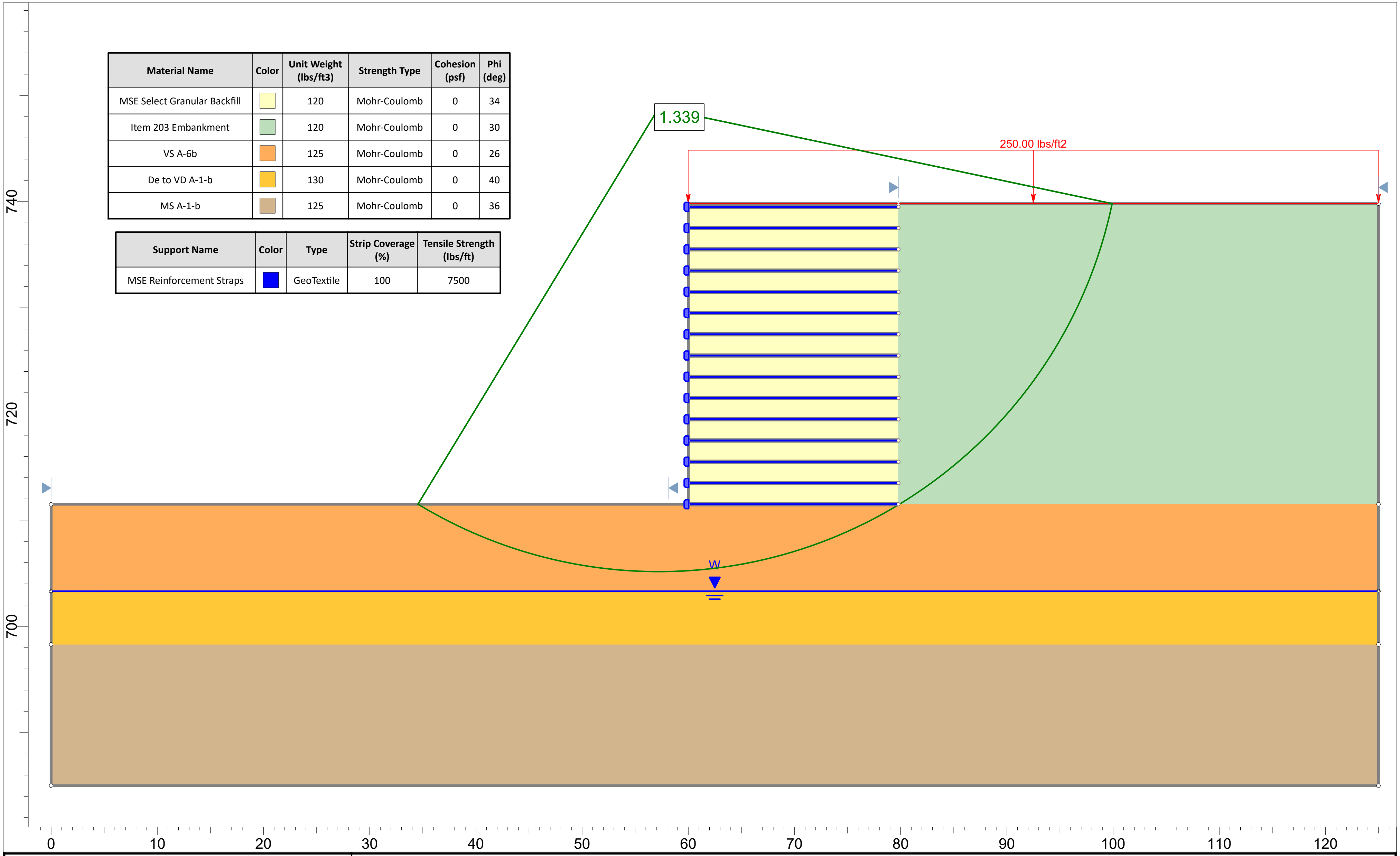
																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6b	C	0.0	1.5	1.5	0.8	120	180	90	90	4,090	34	0.216	0.022	0.538				0.05	0.500	2,370	2,460	0.030	0.363	0.363	0.363	0.363
2	A-1-a	G	1.5	4.0	2.5	2.8	130	505	343	343	4,343					36	57	202	0.18	0.499	2,364	2,707	0.011	0.133	0.251	0.133	0.251
	A-1-a	G	4.0	6.5	2.5	5.3	130	830	668	668	4,668					36	49	166	0.35	0.492	2,334	3,001	0.010	0.118		0.118	
3	A-6b	C	6.5	9.0	2.5	7.8	125	1,143	986	986	4,986	40	0.270	0.027	0.585				0.51	0.479	2,269	3,255	0.022	0.265	0.265	0.265	0.265
4	A-7-6	C	9.0	11.5	2.5	10.3	120	1,443	1,293	1,293	5,293	56	0.414	0.041	0.710				0.67	0.459	2,174	3,467	0.026	0.311	0.573	0.209	0.384
	A-7-6	C	11.5	14.0	2.5	12.8	120	1,743	1,593	1,593	5,593	56	0.414	0.041	0.710				0.84	0.435	2,060	3,652	0.022	0.262		0.175	
5	A-1-b	G	14.0	18.0	4.0	16.0	125	2,243	1,993	1,993	5,993					14	14	63	1.05	0.401	1,900	3,892	0.018	0.222	0.400	0.222	0.400
	A-1-b	G	18.0	22.0	4.0	20.0	125	2,743	2,493	2,493	6,493					14	13	61	1.32	0.360	1,707	4,200	0.015	0.178		0.178	
6	A-1-b	G	22.0	26.0	4.0	24.0	130	3,263	3,003	3,003	7,003					27	23	82	1.58	0.324	1,534	4,536	0.009	0.105	0.105	0.105	0.105

Settlement Remaining After Hold Period: 0.189 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. $S_c = [C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$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)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6b	🟧	125	Mohr-Coulomb	0	26
De to VD A-1-b	🟨	130	Mohr-Coulomb	0	40
MS A-1-b	🟫	125	Mohr-Coulomb	0	36

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



Resource International, Inc.
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SLIDEINTERPRET 8.020

Project Retaining Wall W5 - Sta. 500+00 to 507+00 - MSE Wall Global Stability

Analysis Description 28.3 ft Wall Height - B-100-4-14 - Drained - Circular - Spencer Method

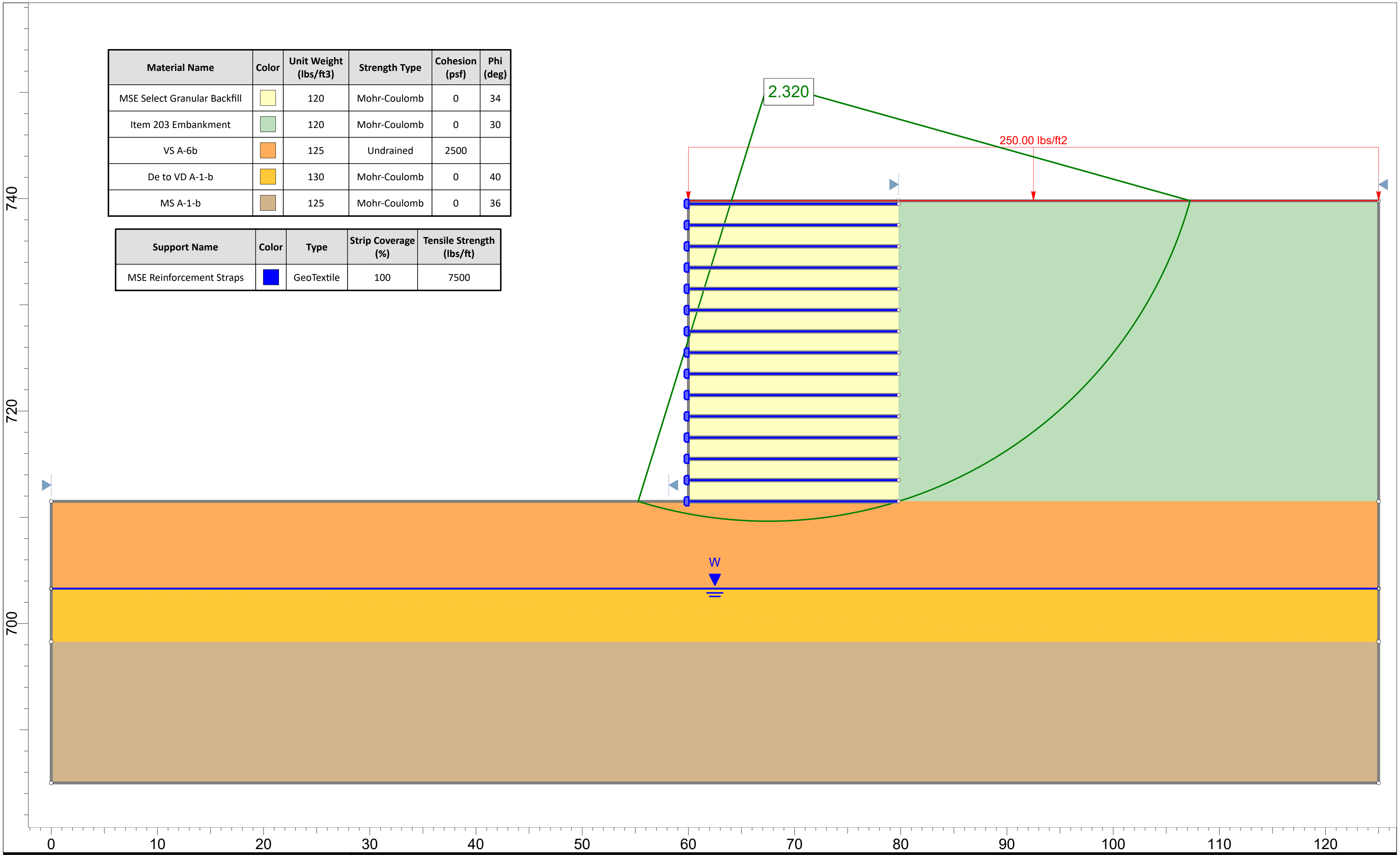
Drawn By BRT

Scale 1:150

Company Resource International, Inc.

Date 7/2/2019

File Name Retaining Wall W5 - Sta. 500+00 to 507+00 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6b	🟧	125	Undrained	2500	
De to VD A-1-b	🟨	130	Mohr-Coulomb	0	40
MS A-1-b	🟫	125	Mohr-Coulomb	0	36

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

Resource International, Inc.
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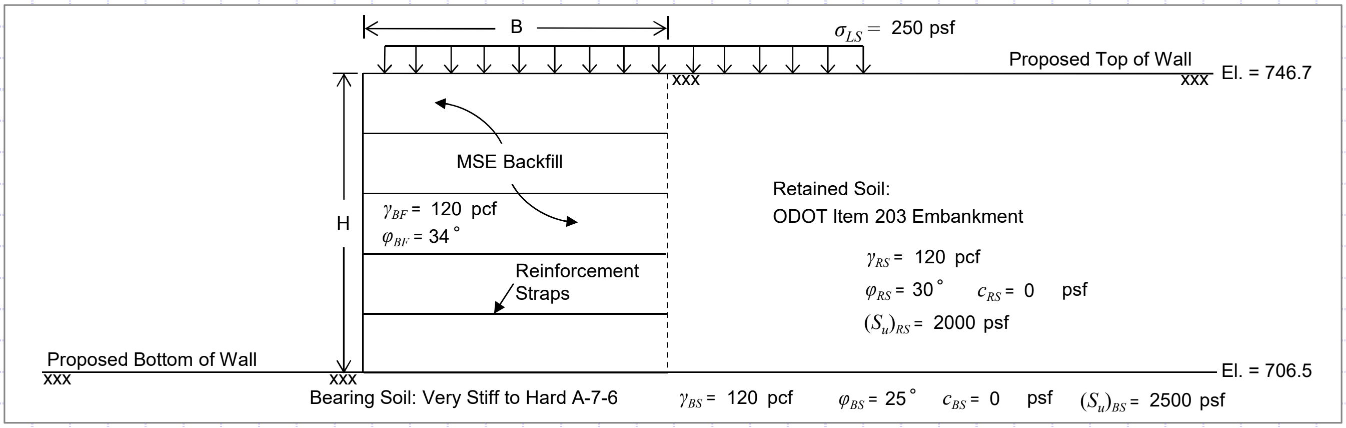
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 500+00 to 507+00 - MSE Wall Global Stability		
Analysis Description	28.3 ft Wall Height - B-100-4-14 - Undrained - Circular - Spencer Method		
Drawn By BRT	*Scale* 1:150	*Company*	Resource International, Inc.
Date 7/2/2019		*File Name*	Retaining Wall W5 - Sta. 500+00 to 507+00 - Global Stability.slim

Retaining Wall W5 - Sta. 507+00 to 508+50 - B-102-5-14 - 40.2 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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}) =	25	°
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) =	23.5	ft

LRFD Load Factors

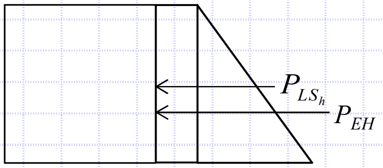
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(40.2 ft)²(0.297)(1.5) = 43.2 kip/ft

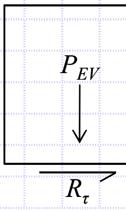
$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(40.2 ft)(0.297)(1.75) = 5.22 kip/ft

P_H = 43.2 kip/ft + 5.22 kip/ft = 48.42 kip/ft

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

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



$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(40.2 ft)(32.2 ft)(1.00) = 155.33 kip/ft

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

$\tan\delta =$ tan(25) ≤ tan(34) $\longrightarrow$ 0.47 ≤ 0.67 $\longrightarrow$ $\tan\delta =$ 0.47

R_τ = (155.33 kip/ft)(0.47) = 73.01 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ $\longrightarrow$ 48.42 kip/ft ≤ (73.01 kip/ft)(1.0) = 73.01 kip/ft $\longrightarrow$ 48.42 kip/ft ≤ 73.01 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) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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}) =	25	°
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) =	23.5	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

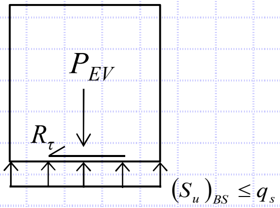
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting:

$$R_\tau = \left((S_u)_{BS} \leq q_s\right) \cdot B$$



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

$$q_s = \sigma_v / 2 = (4.82 \text{ ksf}) / 2 = 2.41 \text{ ksf}$$

$$\sigma_v = P_{EV} / B = (155.33 \text{ kip/ft}) / (32.2 \text{ ft}) = 4.82 \text{ ksf}$$

$$R_\tau = (2.50 \text{ ksf} \leq 2.41 \text{ ksf})(32.2 \text{ ft}) = 77.60 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \leq R_\tau \cdot \phi_\tau$ ⟶ 48.42 kip/ft ≤ (77.60 kip/ft)(1.0) = 77.60 kip/ft ⟶ 48.42 kip/ft ≤ 77.60 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) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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:

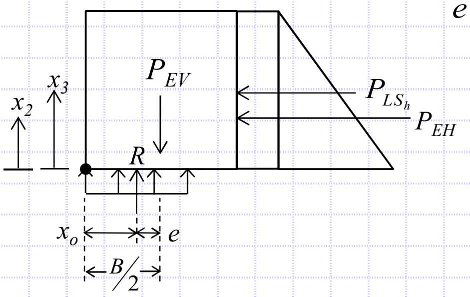
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	23.5	ft

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



$$e = B/2 - x_o$$

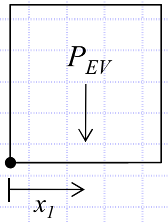
$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (2500.81 kip·ft/ft - 683.8 kip·ft/ft) / (155.33 kip/ft) = 11.70 ft

M_{EV} = 2500.81 kip·ft/ft
M_H = 683.8 kip·ft/ft
P_{EV} = 155.33 kip/ft
Defined below

$e =$ (32.2 ft)/2 - 11.7 ft = 4.40 ft

Resisting Moment, M_{EV}:

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



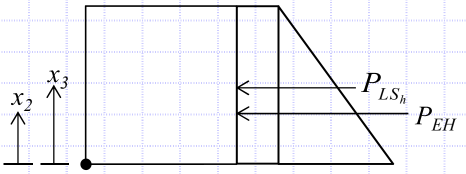
$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(40.2 ft)(32.2 ft)(1.00) = 155.33 kip/ft

$x_1 = B/2$ = (32.2 ft) / 2 = 16.10 ft

M_{EV} = (155.33 kip/ft)(16.10 ft) = 2500.81 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = ½\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(40.2 ft)²(0.297)(1.5) = 43.20 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(40.2 ft)(0.297)(1.75) = 5.22 kip/ft

$x_2 = H/3$ = (40.2 ft) / 3 = 13.40 ft

$x_3 = H/2$ = (40.2 ft) / 2 = 20.10 ft

M_H = (43.2 kip/ft)(13.4 ft) + (5.22 kip/ft)(20.10 ft) = 683.8 kip·ft/ft

Check Eccentricity

$e < e_{\max} \longrightarrow$ 4.40 ft < 10.73 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max}$ = (32.2 ft) / 3 = 10.73 ft

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	4	OF	6
CALCULATED BY	BRT	DATE	6/30/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 507+00 to 508+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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:

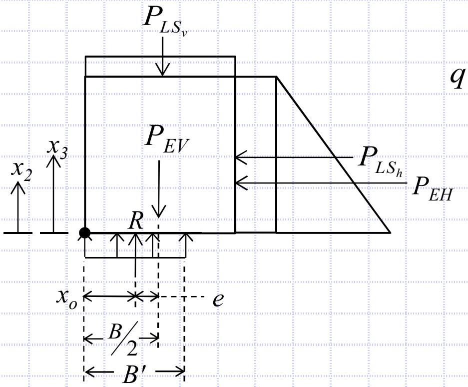
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	23.5	ft

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



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

$$B' = B - 2e \quad = \quad 32.2\text{ ft} - 2(3.06\text{ ft}) \quad = \quad 26.08 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (32.2\text{ ft}) / 2 - 13.04\text{ ft} \quad = \quad 3.06 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (3602.97\text{ kip·ft/ft} - 683.83\text{ kip·ft/ft}) / 223.79\text{ kip/ft} \quad = \quad 13.04 \quad \text{ft}$$

$$q_{eq} = \quad (223.79\text{ kip/ft}) / (26.08\text{ ft}) \quad = \quad 8.58 \quad \text{ksf}$$

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

$$M_V = \quad [(120\text{ pcf})(40.2\text{ ft})(32.2\text{ ft})(1.35)](16.1\text{ ft}) + [(250\text{ psf})(32.2\text{ ft})(1.75)](16.1\text{ ft}) \quad = \quad 3602.97 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad [\tfrac{1}{2}(120\text{ pcf})(40.2\text{ ft})^2(0.297)(1.5)](13.4\text{ ft}) + [(250\text{ psf})(40.2\text{ ft})(0.297)(1.75)](20.1\text{ ft}) \quad = \quad 683.83 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad (120\text{ pcf})(40.2\text{ ft})(32.2\text{ ft})(1.35) + (250\text{ psf})(32.2\text{ ft})(1.75) \quad = \quad 223.79 \quad \text{kip/ft}$$

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 20.99

N_c = 20.72
s_c = 1+(26.08 ft/1031 ft)(10.66/20.72)
= 1.013
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 11.29

N_q = 10.66
s_q = 1.012
d_q = 1+2tan(25°)[1-sin(25°)]²tan⁻¹(4.0 ft/26.08 ft)
1.047
i_q = 1.000 (Assumed)
C_{wq} = 23.5 ft > 4.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 10.77

N_γ = 10.88
s_γ = 0.990
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 23.5 ft < 1.5(26.08 ft) + 4.0 ft = 0.800

$$q_n = \quad (0\text{ psf})(20.989) + (120\text{ pcf})(4.0\text{ ft})(11.295)(1.000) + \tfrac{1}{2}(120\text{ pcf})(26.1\text{ ft})(10.771)(0.800) \quad = \quad 18.91 \quad \text{ksf}$$

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 8.58 ksf ≤ (18.91 ksf)(0.65) = 12.29 ksf ⟶ 8.58 ksf ≤ 12.29 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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}) =	25	°
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) =	23.5	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: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + ½\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.170

N_c = 5.140

s_c = 1+(26.08 ft/[(5)(1031 ft)]) = 1.005

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/26.08 ft)

1.000

i_q = 1.000 (Assumed)

C_{wq} = 23.5 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)

$C_{w\gamma}$ = 23.5 ft < 1.5(26.08 ft) + 4.0 ft = 0.800

$q_n =$ (2500 psf)(5.170) + (120 pcf)(4.0 ft)(1.000)(1.000) + ½(120 pcf)(26.1 ft)(0.000)(0.800) = 13.41 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 8.58 ksf ≤ (13.41 ksf)(0.65) = 8.72 ksf ⟶ 8.58 ksf ≤ 8.72 ksf **OK**

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

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	6/30/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 507+00 to 508+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	40.2	ft
MSE Wall Width (Reinforcement Length), (B) =	32.2	ft
MSE Wall Length, (L) =	1031	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:

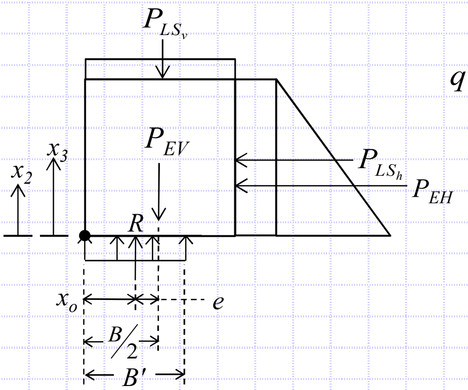
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2500	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	23.5	ft

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



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

$B' = B - 2e$ = 32.2 ft - 2(2.73 ft) = 26.74 ft

$e = B/2 - x_o$ = (32.2 ft) / 2 - 13.37 ft = 2.73 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (2630.46 kip·ft/ft - 445.89 kip·ft/ft) / 163.38 kip/ft = 13.37 ft

q_{eq} = (163.38 kip/ft) / (26.74 ft) = 6.11 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)(40.2 ft)(32.2 ft)(1.00)](16.1 ft) + [(250 psf)(32.2 ft)(1.00)](16.1 ft) = 2630.46 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)(40.2 ft)²(0.297)(1.00)](13.4 ft) + [(250 psf)(40.2 ft)(0.297)(1.00)](20.1 ft) = 445.89 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)(40.2 ft)(32.2 ft)(1.00) + (250 psf)(32.2 ft)(1.00) = 163.38 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-102-3-14	2.617 in	1.957 in	22 days		
B-102-5-14	9.024 in	3.611 in	95 days	150 ft	1/1090

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 507+00 to 508+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-102-5-14

H=	40.2	ft	Total wall height
B'=	26.7	ft	Effective footing width due to eccentricity
D_w =	23.5	ft	Depth below bottom of footing
q_e =	6,110	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)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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	1.0	1.0	0.5	120	120	60	60	4,060	39	0.261	0.026	0.577				0.02	1.000	6,110	6,170	0.060	0.725	0.500	3,055	3,115	0.028	0.341
2	A-7-6	C	1.0	2.5	1.5	1.8	120	300	210	210	4,210	49	0.351	0.035	0.655				0.07	0.999	6,104	6,314	0.097	1.169	0.500	3,055	3,265	0.038	0.455
	A-7-6	C	2.5	5.0	2.5	3.8	120	600	450	450	4,450	49	0.351	0.035	0.655				0.14	0.991	6,058	6,508	0.140	1.683	0.499	3,051	3,501	0.047	0.567
	A-7-6	C	5.0	7.5	2.5	6.3	120	900	750	750	4,750	49	0.351	0.035	0.655				0.23	0.966	5,901	6,651	0.120	1.440	0.497	3,039	3,789	0.037	0.448
	A-7-6	C	7.5	10.0	2.5	8.8	120	1,200	1,050	1,050	5,050	49	0.351	0.035	0.655				0.33	0.923	5,637	6,687	0.101	1.210	0.493	3,015	4,065	0.031	0.374
	A-7-6	C	10.0	12.5	2.5	11.3	120	1,500	1,350	1,350	5,350	49	0.351	0.035	0.655				0.42	0.868	5,303	6,653	0.082	0.983	0.487	2,975	4,325	0.027	0.322
	A-7-6	C	12.5	15.0	2.5	13.8	120	1,800	1,650	1,650	5,650	49	0.351	0.035	0.655				0.51	0.809	4,942	6,592	0.064	0.766	0.478	2,922	4,572	0.023	0.282
4	A-1-b	G	15.0	20.0	5.0	17.5	125	2,425	2,113	2,113	6,113					23	23	80	0.66	0.722	4,411	6,523	0.031	0.367	0.461	2,818	4,931	0.023	0.276
5	A-3a	G	20.0	25.0	5.0	22.5	125	3,050	2,738	2,738	6,738					23	21	68	0.84	0.620	3,790	6,527	0.028	0.332	0.434	2,651	5,389	0.022	0.259
6	A-1-a	G	25.0	30.0	5.0	27.5	130	3,700	3,375	3,125	7,125					36	31	101	1.03	0.538	3,286	6,412	0.015	0.186	0.404	2,471	5,596	0.013	0.150
7	A-1-a	G	30.0	35.0	5.0	32.5	135	4,375	4,038	3,476	7,476					50	41	134	1.22	0.472	2,883	6,359	0.010	0.118	0.375	2,292	5,767	0.008	0.099
8	A-1-b	G	35.0	38.0	3.0	36.5	135	4,780	4,578	3,766	7,766					66	52	179	1.37	0.429	2,619	6,385	0.004	0.046	0.353	2,155	5,921	0.003	0.040
																				Total Settlement:			9.024 in		Total Settlement:			3.611 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 507+00 to 508+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-102-5-14

H=	40.2	ft	Total wall height
B'=	26.7	ft	Effective footing width due to eccentricity
D_w =	23.5	ft	Depth below bottom of footing
q_e =	6,110	psf	Equivalent bearing pressure at bottom of wall

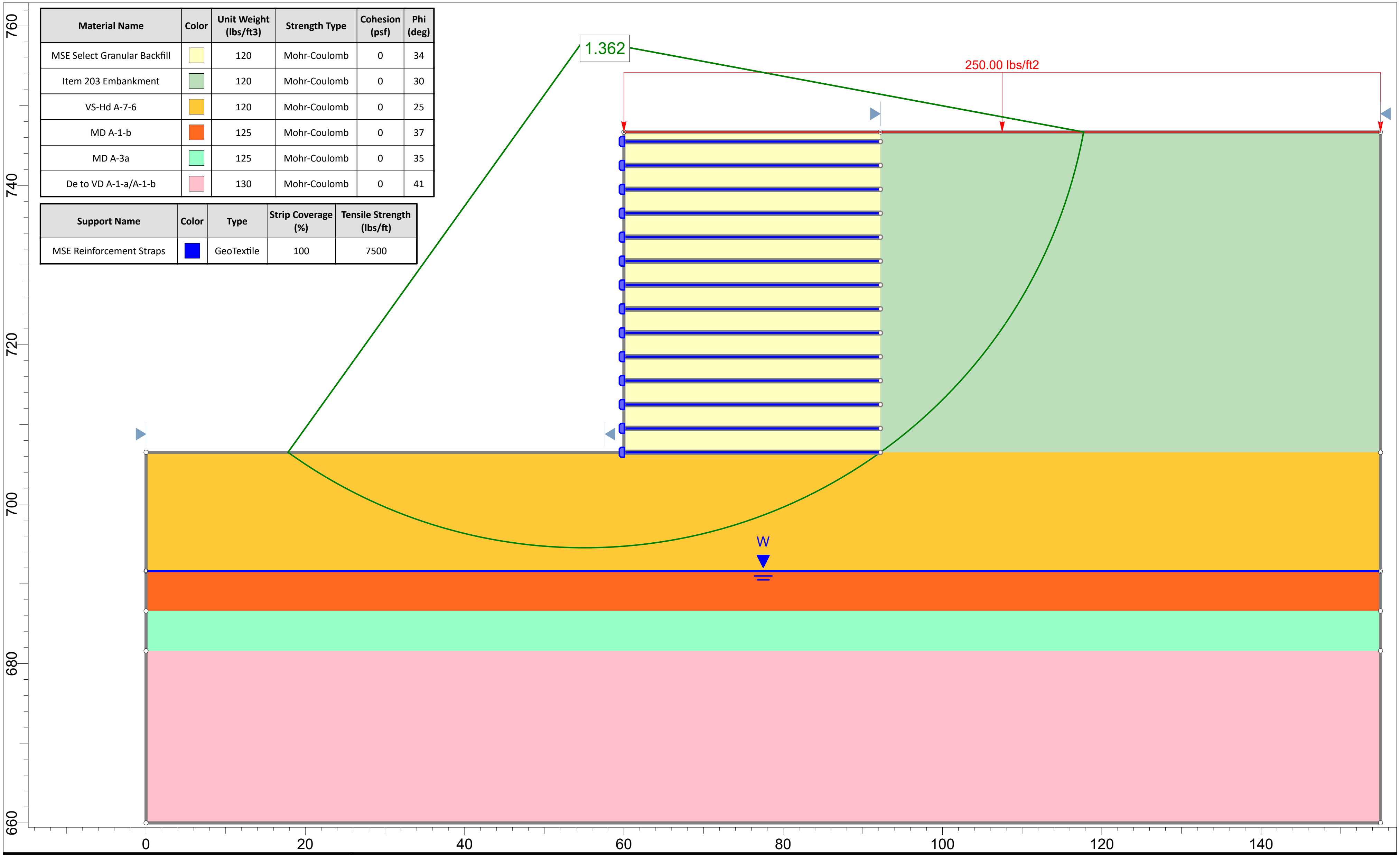
	A-6b	A-7-6			
c_v =	300	150		ft^2/yr	Coefficient of consolidation
t =	95	95		days	Time following completion of construction
H_{dr} =	1.0	7.5		ft	Length of longest drainage path considered
T_v =	78.082	0.694			Time factor
U =	100	85		%	Degree of consolidation

$(S_c)_t$ = 3.244 in Settlement complete at 90% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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)	Layer Settlement (in)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1	A-6a	C	0.0	1.0	1.0	0.5	120	120	60	60	4,060	39	0.261	0.026	0.577				0.02	0.500	3,055	3,115	0.028	0.341	0.341	0.341	0.341
2	A-7-6	C	1.0	2.5	1.5	1.8	120	300	210	210	4,210	49	0.351	0.035	0.655				0.07	0.500	3,055	3,265	0.038	0.455	2.446	0.387	2.080
	A-7-6	C	2.5	5.0	2.5	3.8	120	600	450	450	4,450	49	0.351	0.035	0.655				0.14	0.499	3,051	3,501	0.047	0.567		0.482	
	A-7-6	C	5.0	7.5	2.5	6.3	120	900	750	750	4,750	49	0.351	0.035	0.655				0.23	0.497	3,039	3,789	0.037	0.448		0.380	
	A-7-6	C	7.5	10.0	2.5	8.8	120	1,200	1,050	1,050	5,050	49	0.351	0.035	0.655				0.33	0.493	3,015	4,065	0.031	0.374		0.318	
	A-7-6	C	10.0	12.5	2.5	11.3	120	1,500	1,350	1,350	5,350	49	0.351	0.035	0.655				0.42	0.487	2,975	4,325	0.027	0.322		0.273	
	A-7-6	C	12.5	15.0	2.5	13.8	120	1,800	1,650	1,650	5,650	49	0.351	0.035	0.655				0.51	0.478	2,922	4,572	0.023	0.282		0.239	
4	A-1-b	G	15.0	20.0	5.0	17.5	125	2,425	2,113	2,113	6,113					23	23	80	0.66	0.461	2,818	4,931	0.023	0.276	0.276	0.276	0.276
5	A-3a	G	20.0	25.0	5.0	22.5	125	3,050	2,738	2,738	6,738					23	21	68	0.84	0.434	2,651	5,389	0.022	0.259	0.259	0.259	0.259
6	A-1-a	G	25.0	30.0	5.0	27.5	130	3,700	3,375	3,125	7,125					36	31	101	1.03	0.404	2,471	5,596	0.013	0.150	0.150	0.150	0.150
7	A-1-a	G	30.0	35.0	5.0	32.5	135	4,375	4,038	3,476	7,476					50	41	134	1.22	0.375	2,292	5,767	0.008	0.099	0.099	0.099	0.099
8	A-1-b	G	35.0	38.0	3.0	36.5	135	4,780	4,578	3,766	7,766					66	52	179	1.37	0.353	2,155	5,921	0.003	0.040	0.040	0.040	0.040

Settlement Remaining After Hold Period: 0.367 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



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS-Hd A-7-6	🟧	120	Mohr-Coulomb	0	25
MD A-1-b	🟥	125	Mohr-Coulomb	0	37
MD A-3a	🟩	125	Mohr-Coulomb	0	35
De to VD A-1-a/A-1-b	🟪	130	Mohr-Coulomb	0	41

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

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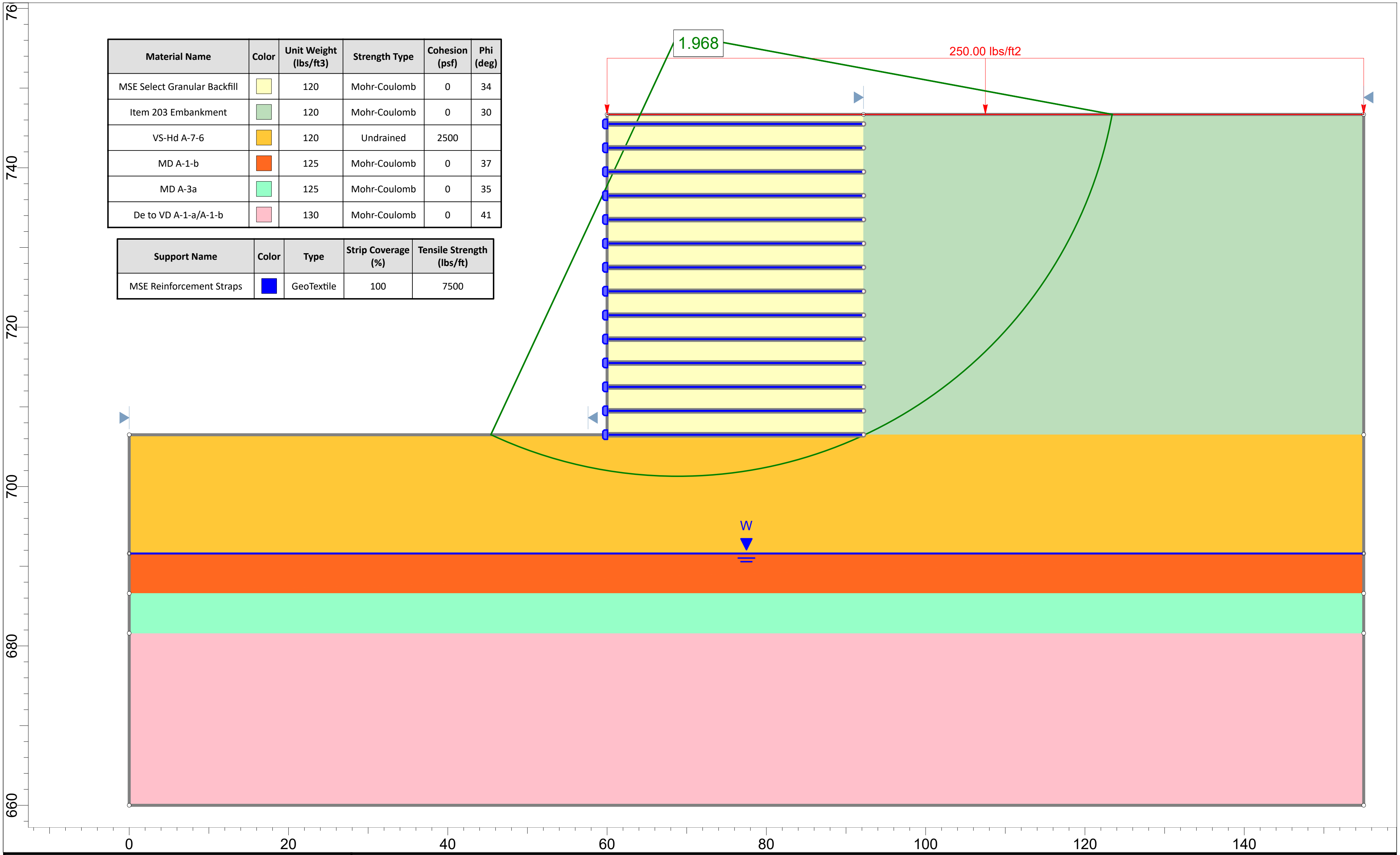
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 507+00 to 508+50 - MSE Wall Global Stability
Analysis Description	40.2 ft Wall Height - B-102-5-14 - Drained - Circular - Spencer Method

Drawn By	BRT	*Scale*	1:200	*Company*	Resource International, Inc.
Date	7/3/2019			*File Name*	Retaining Wall W5 - Sta. 507+00 to 508+50 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS-Hd A-7-6	🟨	120	Undrained	2500	
MD A-1-b	🟧	125	Mohr-Coulomb	0	37
MD A-3a	🟩	125	Mohr-Coulomb	0	35
De to VD A-1-a/A-1-b	🟥	130	Mohr-Coulomb	0	41

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

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SLIDEINTERPRET 8.020

Project Retaining Wall W5 - Sta. 507+00 to 508+50 - MSE Wall Global Stability

Analysis Description 40.2 ft Wall Height - B-102-5-14 - Undrained - Circular - Spencer Method

Drawn By BRT

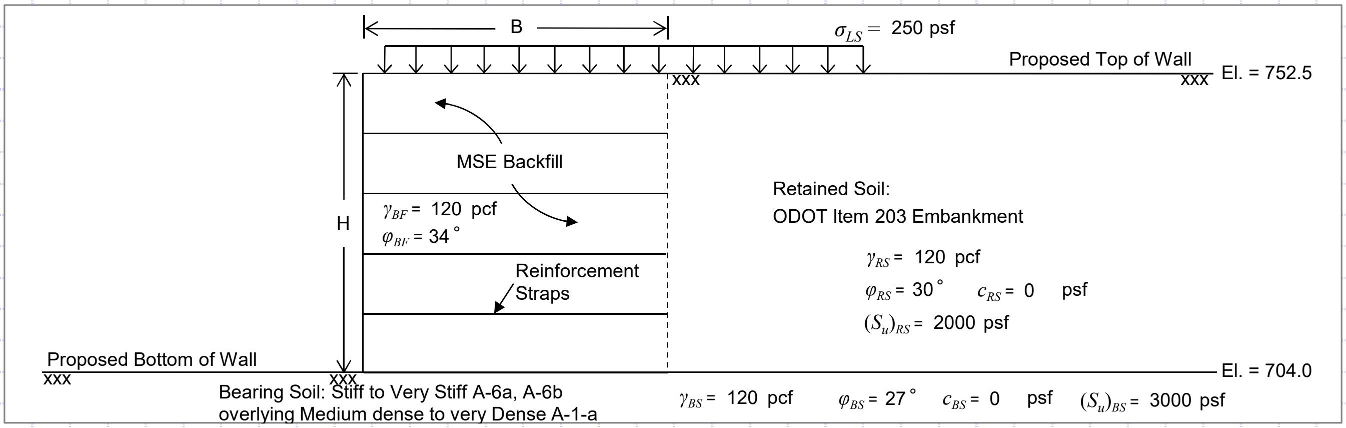
Scale 1:200

Company Resource International, Inc.

Date 7/3/2019

File Name Retaining Wall W5 - Sta. 507+00 to 508+50 - Global Stability.slim

Retaining Wall W5 - Sta. 508+50 to 509+85 - B-104-0-09 and B-104-1-13 - 48.5 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	48.5	ft
MSE Wall Width (Reinforcement Length), (B) =	38.8	ft
MSE Wall Length, (L) =	1031	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}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	3000	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.0	ft

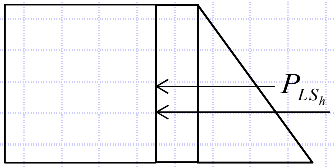
LRFD Load Factors

	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:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH} = \text{½(120 pcf)(48.5 ft)²(0.297)(1.5)} = 62.88 \text{ kip/ft}$$

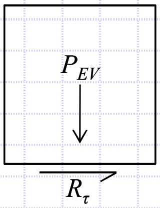
$$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS} = \text{(250 psf)(48.5 ft)(0.297)(1.75)} = 6.3 \text{ kip/ft}$$

$$P_H = \text{62.88 kip/ft + 6.3 kip/ft} = 69.18 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

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



$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(48.5 ft)(38.8 ft)(1.00)} = 225.82 \text{ kip/ft}$$

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

$$\tan\delta = \tan(27) \le \tan(34) \longrightarrow 0.51 \le 0.67 \longrightarrow \tan\delta = 0.51$$

$$R_\tau = \text{(225.82 kip/ft)(0.51)} = 115.17 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{69.18 kip/ft} \le \text{(115.17 kip/ft)(1.0) = 115.17 kip/ft} \longrightarrow \text{69.18 kip/ft} \le \text{115.17 kip/ft}$$

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) =	48.5	ft
MSE Wall Width (Reinforcement Length), (B) =	38.8	ft
MSE Wall Length, (L) =	1031	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}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3000	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.0	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

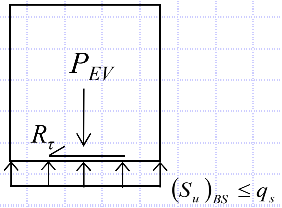
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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

Check Sliding Resistance - Undrained Condition

Nominal Sliding Resisting:

$$R_\tau = \left((S_u)_{BS} \leq q_s\right) \cdot B$$



$$(S_u)_{BS} = 3.00 \text{ ksf}$$

$$q_s = \sigma_v / 2 = (5.82 \text{ ksf}) / 2 = 2.91 \text{ ksf}$$

$$\sigma_v = P_{EV} / B = (225.82 \text{ kip/ft}) / (38.8 \text{ ft}) = 5.82 \text{ ksf}$$

$$R_\tau = (3.00 \text{ ksf} \leq 2.91 \text{ ksf})(38.8 \text{ ft}) = 112.91 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$$P_H \leq R_\tau \cdot \phi_\tau \longrightarrow 69.18 \text{ kip/ft} \leq (112.91 \text{ kip/ft})(1.0) = 112.91 \text{ kip/ft} \longrightarrow 69.18 \text{ kip/ft} \leq 112.91 \text{ kip/ft}$$

OK

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

JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 3 OF 6
CALCULATED BY BRT DATE 6/30/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 508+50 to 509+85

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 48.5 ft
MSE Wall Width (Reinforcement Length), (B) = 38.8 ft
MSE Wall Length, (L) = 1031 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:

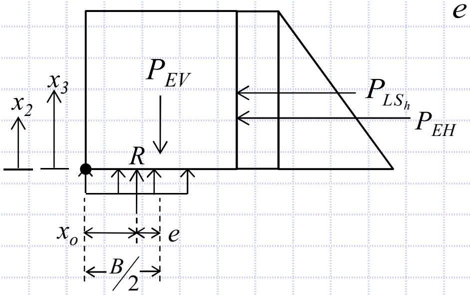
Bearing Soil Unit Weight, (γ_{BS}) = 120 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 27 °
Bearing Soil Drained Cohesion, (c_{BS}) = 0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ = 3000 psf
Embedment Depth, (D_f) = 4.0 ft
Depth to Grounwater (Below Bot. of Wall), (D_W) = 10.0 ft

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



$$e = B/2 - x_o$$

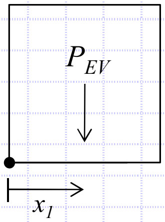
$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = 4380.91 kip·ft/ft - 1169.54 kip·ft/ft) / (225.82 kip/ft = 14.22 ft

M_{EV} = 4380.91 kip·ft/ft
M_H = 1169.54 kip·ft/ft
P_{EV} = 225.82 kip/ft
Defined below

$e =$ (38.8 ft)/2 - 14.22 ft = 5.18 ft

Resisting Moment, M_{EV}:

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



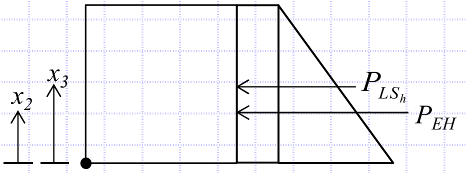
$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(48.5 ft)(38.8 ft)(1.00) = 225.82 kip/ft

$x_1 = B/2$ = (38.8 ft) / 2 = 19.40 ft

M_{EV} = (225.82 kip/ft)(19.40 ft) = 4380.91 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = ½\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(48.5 ft)²(0.297)(1.5) = 62.88 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(48.5 ft)(0.297)(1.75) = 6.3 kip/ft

$x_2 = H/3$ = (48.5 ft) / 3 = 16.17 ft

$x_3 = H/2$ = (48.5 ft) / 2 = 24.25 ft

M_H = (62.88 kip/ft)(16.17 ft) + (6.3 kip/ft)(24.25 ft) = 1169.54 kip·ft/ft

Check Eccentricity

$e < e_{\max} \longrightarrow$ 5.18 ft < 12.93 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max}$ = (38.8 ft) / 3 = 12.93 ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	48.5	ft
MSE Wall Width (Reinforcement Length), (B) =	38.8	ft
MSE Wall Length, (L) =	1031	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:

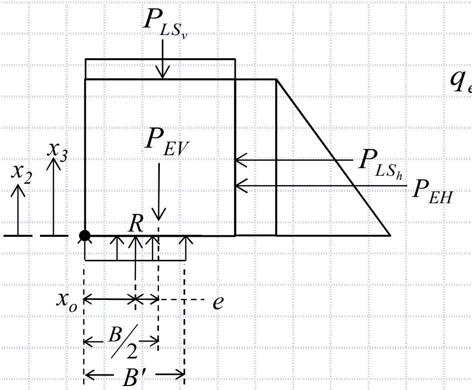
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3000	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.0	ft

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



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

$$B' = B - 2e \quad = \quad 38.8\text{ ft} - 2(3.63\text{ ft}) \quad = \quad 31.54 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (38.8\text{ ft}) / 2 - 15.77\text{ ft} \quad = \quad 3.63 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (6243.44\text{ kip·ft/ft} - 1169.52\text{ kip·ft/ft}) / 321.83\text{ kip/ft} \quad = \quad 15.77 \quad \text{ft}$$

$$q_{eq} \quad = \quad (321.83\text{ kip/ft}) / (31.54\text{ ft}) \quad = \quad 10.20 \quad \text{ksf}$$

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

$$M_V \quad = \quad [(120\text{ pcf})(48.5\text{ ft})(38.8\text{ ft})(1.35)](19.4\text{ ft}) + [(250\text{ psf})(38.8\text{ ft})(1.75)](19.4\text{ ft}) \quad = \quad 6243.44 \quad \text{kip·ft/ft}$$

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

$$M_H \quad = \quad [\tfrac{1}{2}(120\text{ pcf})(48.5\text{ ft})^2(0.297)(1.5)](16.17\text{ ft}) + [(250\text{ psf})(48.5\text{ ft})(0.297)(1.75)](24.25\text{ ft}) \quad = \quad 1{,}169.52 \quad \text{kip·ft/ft}$$

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

$$P_V \quad = \quad (120\text{ pcf})(48.5\text{ ft})(38.8\text{ ft})(1.35) + (250\text{ psf})(38.8\text{ ft})(1.75) \quad = \quad 321.83 \quad \text{kip/ft}$$

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 24.35

N_c = 23.94

s_c = 1+(31.54 ft/1031 ft)(13.2/23.94)

= 1.017

i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 13.92

N_q = 13.20

s_q = 1.016

d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(4.0 ft/31.54 ft)

1.038

i_q = 1.000 (Assumed)

C_{wq} = 10.0 ft > 4.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 14.30

N_γ = 14.47

s_γ = 0.988

i_γ = 1.000 (Assumed)

$C_{w\gamma}$ = 10.0 ft < 1.5(31.54 ft) + 4.0 ft = 0.606

$$q_n \quad = \quad (0\text{ psf})(24.347) + (120\text{ pcf})(4.0\text{ ft})(13.921)(1.000) + \tfrac{1}{2}(120\text{ pcf})(31.5\text{ ft})(14.296)(0.606) \quad = \quad 23.08 \quad \text{ksf}$$

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b \longrightarrow$ 10.20 ksf ≤ (23.08 ksf)(0.65) = 15.00 ksf $\longrightarrow$ 10.20 ksf ≤ 15.00 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	48.5	ft
MSE Wall Width (Reinforcement Length), (B) =	38.8	ft
MSE Wall Length, (L) =	1031	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}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3000	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.0	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: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.170

N_c = 5.140

s_c = 1+(31.54 ft/[(5)(1031 ft)]) = 1.006

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/31.54 ft)

1.000

i_q = 1.000 (Assumed)

C_{wq} = 10.0 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)

$C_{w\gamma}$ = 10.0 ft < 1.5(31.54 ft) + 4.0 ft = 0.606

$q_n =$ (3000 psf)(5.170) + (120 pcf)(4.0 ft)(1.000)(1.000) + ½(120 pcf)(31.5 ft)(0.000)(0.606) = 15.99 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b \longrightarrow$ 10.20 ksf ≤ (15.99 ksf)(0.65) = 10.39 ksf $\longrightarrow$ 10.20 ksf ≤ 10.39 ksf **OK**

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

JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 6 OF 6
CALCULATED BY BRT DATE 6/30/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 508+50 to 509+85

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	48.5	ft
MSE Wall Width (Reinforcement Length), (B) =	38.8	ft
MSE Wall Length, (L) =	1031	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:

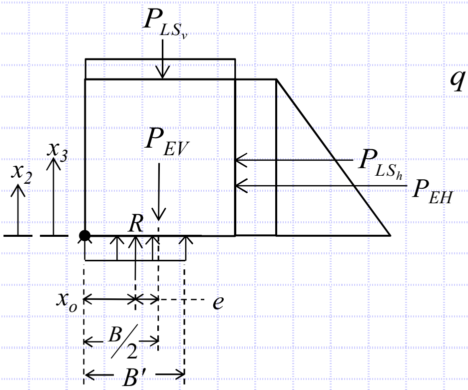
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3000	psf
Embedment Depth, (D_f) =	4.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.0	ft

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



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

$B' = B - 2e$ = 38.8 ft - 2(3.25 ft) = 32.30 ft

$e = B/2 - x_o$ = (38.8 ft) / 2 - 16.15 ft = 3.25 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (4569.01 kip·ft/ft - 765.13 kip·ft/ft) / 235.52 kip/ft = 16.15 ft

$q_{eq} =$ (235.52 kip/ft) / (32.3 ft) = 7.29 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)(48.5 ft)(38.8 ft)(1.00)](19.4 ft) + [(250 psf)(38.8 ft)(1.00)](19.4 ft) = 4569.01 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)(48.5 ft)²(0.297)(1.00)](16.17 ft) + [(250 psf)(48.5 ft)(0.297)(1.00)](24.25 ft) = 765.13 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)(48.5 ft)(38.8 ft)(1.00) + (250 psf)(38.8 ft)(1.00) = 235.52 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-102-5-14	9.024 in	3.611 in	105 days		
B-104-0-09	5.429 in	2.542 in	5 days	135 ft	1/1520
B-104-1-13	4.181 in	2.631 in	1 days	70 ft	1/9440

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 508+50 to 509+85

Calculated By: BRT   Date: 6/30/2019
Checked By: JPS   Date: 7/1/2019

Boring B-104-0-09

H=	45.5	ft	Total wall height
B'=	30.3	ft	Effective footing width due to eccentricity
D_w =	10.0	ft	Depth below bottom of footing
q_e =	6,860	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)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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	2.0	2.0	1.0	120	240	120	120	4,120	31	0.189	0.019	0.514				0.03	1.000	6,859	6,979	0.095	1.146	0.500	3,430	3,550	0.037	0.441
	A-6a	C	2.0	4.5	2.5	3.3	120	540	390	390	4,390	31	0.189	0.019	0.514				0.11	0.996	6,833	7,223	0.100	1.203	0.500	3,428	3,818	0.031	0.371
2	A-6b	C	4.5	7.0	2.5	5.8	120	840	690	690	4,690	39	0.261	0.026	0.577				0.19	0.980	6,725	7,415	0.117	1.401	0.499	3,420	4,110	0.032	0.385
3	A-1-a	G	7.0	9.5	2.5	8.3	125	1,153	996	996	4,996					23	28	94	0.27	0.950	6,517	7,513	0.023	0.279	0.496	3,403	4,399	0.017	0.205
	A-1-a	G	9.5	12.0	2.5	10.8	125	1,465	1,309	1,262	5,262					23	27	90	0.35	0.908	6,226	7,488	0.022	0.259	0.492	3,374	4,636	0.016	0.189
	A-1-a	G	12.0	14.5	2.5	13.3	125	1,778	1,621	1,418	5,418					23	26	87	0.44	0.858	5,886	7,304	0.020	0.244	0.486	3,331	4,750	0.015	0.180
4	A-3a	G	14.5	17.0	2.5	15.8	125	2,090	1,934	1,575	5,575					18	19	66	0.52	0.806	5,527	7,102	0.025	0.297	0.478	3,277	4,852	0.018	0.222
5	A-1-a	G	17.0	21.5	4.5	19.3	125	2,653	2,371	1,794	5,794					13	13	62	0.64	0.734	5,034	6,828	0.042	0.506	0.464	3,182	4,977	0.032	0.386
6	A-1-a	G	21.5	23.5	2.0	22.5	130	2,913	2,783	2,003	6,003					40	40	131	0.74	0.672	4,611	6,614	0.008	0.095	0.449	3,080	5,083	0.006	0.074
																				Total Settlement:			5.429 in		Total Settlement:			2.452 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 508+50 to 509+85

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-104-0-09

H=	45.5	ft	Total wall height
B'=	30.3	ft	Effective footing width due to eccentricity
D_w =	10.0	ft	Depth below bottom of footing
q_e =	6,860	psf	Equivalent bearing pressure at bottom of wall

	A-6a	A-6b			
c_v =	600	300		ft^2/yr	Coefficient of consolidation
t =	5	5		days	Time following completion of construction
H_{dr} =	3.5	2.5		ft	Length of longest drainage path considered
T_v =	0.671	0.658			Time factor
U =	85	84		%	Degree of consolidation

$(S_c)_t$ = 2.269 in Settlement complete at 93% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 93% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.0	2.0	1.0	120	240	120	120	4,120	31	0.189	0.019	0.514				0.03	0.500	3,430	3,550	0.037	0.441	0.812	0.375	0.690
	A-6a	C	2.0	4.5	2.5	3.3	120	540	390	390	4,390	31	0.189	0.019	0.514				0.11	0.500	3,428	3,818	0.031	0.371		0.315	
2	A-6b	C	4.5	7.0	2.5	5.8	120	840	690	690	4,690	39	0.261	0.026	0.577				0.19	0.499	3,420	4,110	0.032	0.385	0.385	0.323	0.323
3	A-1-a	G	7.0	9.5	2.5	8.3	125	1,153	996	996	4,996					23	28	94	0.27	0.496	3,403	4,399	0.017	0.205	0.574	0.205	0.574
	A-1-a	G	9.5	12.0	2.5	10.8	125	1,465	1,309	1,262	5,262					23	27	90	0.35	0.492	3,374	4,636	0.016	0.189		0.189	
	A-1-a	G	12.0	14.5	2.5	13.3	125	1,778	1,621	1,418	5,418					23	26	87	0.44	0.486	3,331	4,750	0.015	0.180		0.180	
4	A-3a	G	14.5	17.0	2.5	15.8	125	2,090	1,934	1,575	5,575					18	19	66	0.52	0.478	3,277	4,852	0.018	0.222	0.222	0.222	0.222
5	A-1-a	G	17.0	21.5	4.5	19.3	125	2,653	2,371	1,794	5,794					13	13	62	0.64	0.464	3,182	4,977	0.032	0.386	0.386	0.386	0.386
6	A-1-a	G	21.5	23.5	2.0	22.5	130	2,913	2,783	2,003	6,003					40	40	131	0.74	0.449	3,080	5,083	0.006	0.074	0.074	0.074	0.074

Settlement Remaining After Hold Period: 0.183 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

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 507+00 to 508+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-104-1-13

H= 48.5 ft Total wall height
B'= 32.3 ft Effective footing width due to eccentricity
D_w = 10.0 ft Depth below bottom of footing
q_e = 7,290 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)		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	2.5	2.5	1.3	120	300	150	150	4,150	31	0.189	0.019	0.514				0.04	1.000	7,289	7,439	0.124	1.489	0.500	3,645	3,795	0.044	0.525
2	A-3a	G	2.5	5.0	2.5	3.8	120	600	450	450	4,450					12	18	64	0.12	0.995	7,254	7,704	0.048	0.582	0.500	3,643	4,093	0.038	0.452
3	A-1-a	G	5.0	7.5	2.5	6.3	130	925	763	763	4,763					35	46	154	0.19	0.979	7,138	7,901	0.016	0.197	0.499	3,634	4,397	0.012	0.148
	A-1-a	G	7.5	10.0	2.5	8.8	130	1,250	1,088	1,088	5,088					35	42	138	0.27	0.951	6,930	8,017	0.016	0.188	0.496	3,617	4,704	0.011	0.138
	A-1-a	G	10.0	12.5	2.5	11.3	130	1,575	1,413	1,335	5,335					35	40	130	0.35	0.911	6,643	7,977	0.015	0.179	0.492	3,588	4,923	0.011	0.131
	A-1-a	G	12.5	15.0	2.5	13.8	130	1,900	1,738	1,504	5,504					35	38	125	0.43	0.865	6,307	7,811	0.014	0.172	0.487	3,547	5,051	0.011	0.126
4	A-1-a	G	15.0	18.0	3.0	16.5	135	2,305	2,103	1,697	5,697					54	57	201	0.51	0.811	5,915	7,612	0.010	0.117	0.479	3,489	5,186	0.007	0.087
	A-1-a	G	18.0	21.5	3.5	19.8	135	2,778	2,541	1,933	5,933					54	55	190	0.61	0.748	5,455	7,388	0.011	0.129	0.467	3,404	5,337	0.008	0.098
5	A-1-b	G	21.5	26.5	5.0	24.0	130	3,428	3,103	2,229	6,229					28	27	91	0.74	0.672	4,899	7,127	0.028	0.333	0.449	3,273	5,502	0.022	0.259
6	A-1-b	G	26.5	31.5	5.0	29.0	135	4,103	3,765	2,579	6,579					120	110	550	0.90	0.594	4,331	6,910	0.004	0.047	0.425	3,101	5,680	0.003	0.037
7	A-1-b	G	31.5	36.5	5.0	34.0	115	4,678	4,390	2,892	6,892					3	3	48	1.05	0.529	3,857	6,749	0.038	0.458	0.401	2,922	5,814	0.031	0.378
8	A-1-b	G	36.5	40.5	4.0	38.5	135	5,218	4,948	3,169	7,169					120	102	482	1.19	0.480	3,499	6,668	0.003	0.032	0.379	2,762	5,931	0.002	0.027
9	A-1-a	G	40.5	43.5	3.0	42.0	140	5,638	5,428	3,431	7,431					120	99	457	1.30	0.447	3,258	6,689	0.002	0.023	0.362	2,643	6,073	0.002	0.020
10	A-6a	C	43.5	50.0	6.5	46.8	130	6,483	6,060	3,767	7,767	30	0.180	0.018	0.507				1.45	0.408	2,976	6,743	0.020	0.236	0.341	2,488	6,255	0.017	0.205
																				Total Settlement:			4.181 in		Total Settlement:			2.631 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5

MSE Wall Settlement - Sta. 507+00 to 508+50

Calculated By: BRT   Date: 6/30/2019

Checked By: JPS   Date: 7/1/2019

Boring B-104-1-13

H=	48.5	ft	Total wall height
B'=	32.3	ft	Effective footing width due to eccentricity
D_w =	10.0	ft	Depth below bottom of footing
q_e =	7,290	psf	Equivalent bearing pressure at bottom of wall

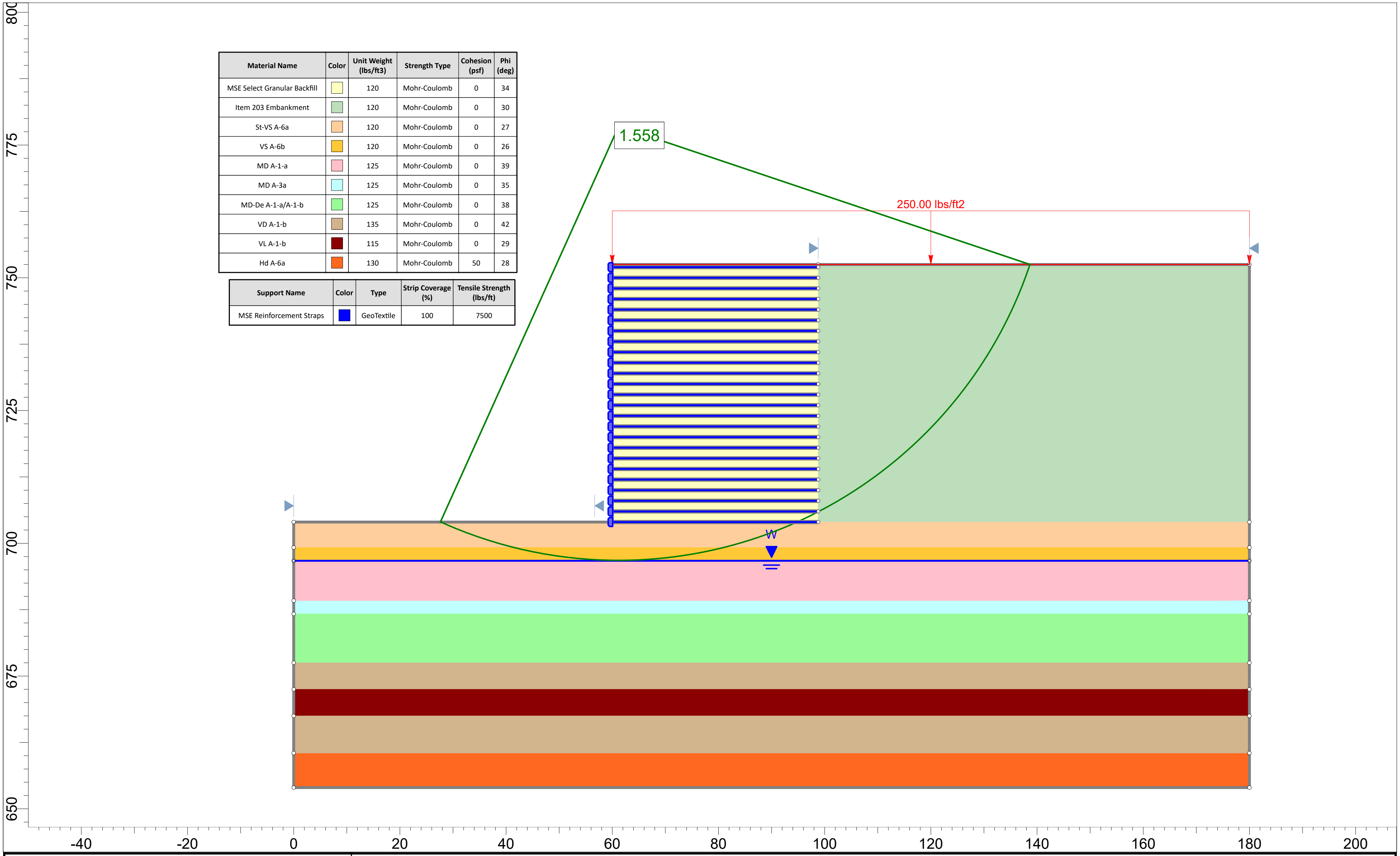
	A-6a (Upper)	A-6a (Lower)			
c_v =	600	600		ft^2/yr	Coefficient of consolidation
t =	1	1		days	Time following completion of construction
H_{dr} =	1.3	6.5		ft	Length of longest drainage path considered
T_v =	1.052	0.039			Time factor
U =	94	22		%	Degree of consolidation

$(S_c)_t$ = 2.439 in   Settlement complete at 93% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 93% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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)	Layer Settlement (in)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	31	0.189	0.019	0.514				0.04	0.500	3,645	3,795	0.044	0.525	0.525	0.494	0.494
2	A-3a	G	2.5	5.0	2.5	3.8	120	600	450	450	4,450					12	18	64	0.12	0.500	3,643	4,093	0.038	0.452	1.082	0.452	1.082
3	A-1-a	G	5.0	7.5	2.5	6.3	130	925	763	763	4,763					35	46	154	0.19	0.499	3,634	4,397	0.012	0.148		0.148	
	A-1-a	G	7.5	10.0	2.5	8.8	130	1,250	1,088	1,088	5,088					35	42	138	0.27	0.496	3,617	4,704	0.011	0.138		0.138	
	A-1-a	G	10.0	12.5	2.5	11.3	130	1,575	1,413	1,335	5,335					35	40	130	0.35	0.492	3,588	4,923	0.011	0.131		0.131	
	A-1-a	G	12.5	15.0	2.5	13.8	130	1,900	1,738	1,504	5,504					35	38	125	0.43	0.487	3,547	5,051	0.011	0.126		0.126	
4	A-1-a	G	15.0	18.0	3.0	16.5	135	2,305	2,103	1,697	5,697					54	57	201	0.51	0.479	3,489	5,186	0.007	0.087		0.087	
	A-1-a	G	18.0	21.5	3.5	19.8	135	2,778	2,541	1,933	5,933					54	55	190	0.61	0.467	3,404	5,337	0.008	0.098	0.098	0.098	0.098
5	A-1-b	G	21.5	26.5	5.0	24.0	130	3,428	3,103	2,229	6,229					28	27	91	0.74	0.449	3,273	5,502	0.022	0.259	0.259	0.259	0.259
6	A-1-b	G	26.5	31.5	5.0	29.0	135	4,103	3,765	2,579	6,579					120	110	550	0.90	0.425	3,101	5,680	0.003	0.037	0.037	0.037	0.037
7	A-1-b	G	31.5	36.5	5.0	34.0	115	4,678	4,390	2,892	6,892					3	3	48	1.05	0.401	2,922	5,814	0.031	0.378	0.378	0.378	0.378
8	A-1-b	G	36.5	40.5	4.0	38.5	135	5,218	4,948	3,169	7,169					120	102	482	1.19	0.379	2,762	5,931	0.002	0.027	0.027	0.027	0.027
9	A-1-a	G	40.5	43.5	3.0	42.0	140	5,638	5,428	3,431	7,431					120	99	457	1.30	0.362	2,643	6,073	0.002	0.020	0.020	0.020	0.020
10	A-6a	C	43.5	50.0	6.5	46.8	130	6,483	6,060	3,767	7,767	30	0.180	0.018	0.507				1.45	0.341	2,488	6,255	0.017	0.205	0.205	0.045	0.045

Settlement Remaining After Hold Period: 0.192 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. $(N1)_{60} = C_nN_{60}$, 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)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St-VS A-6a	🟧	120	Mohr-Coulomb	0	27
VS A-6b	🟨	120	Mohr-Coulomb	0	26
MD A-1-a	🟪	125	Mohr-Coulomb	0	39
MD A-3a	🟦	125	Mohr-Coulomb	0	35
MD-De A-1-a/A-1-b	🟩	125	Mohr-Coulomb	0	38
VD A-1-b	🟫	135	Mohr-Coulomb	0	42
VL A-1-b	🟥	115	Mohr-Coulomb	0	29
Hd A-6a	🟧	130	Mohr-Coulomb	50	28

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

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SLIDEINTERPRET 8.020

Project
Retaining Wall W5 - Sta. 508+50 to 509+85 - MSE Wall Global Stability

Analysis Description
48.5 ft Wall Height - B-104-0-09 and B-104-1-13 - Drained - Circular - Spencer Method

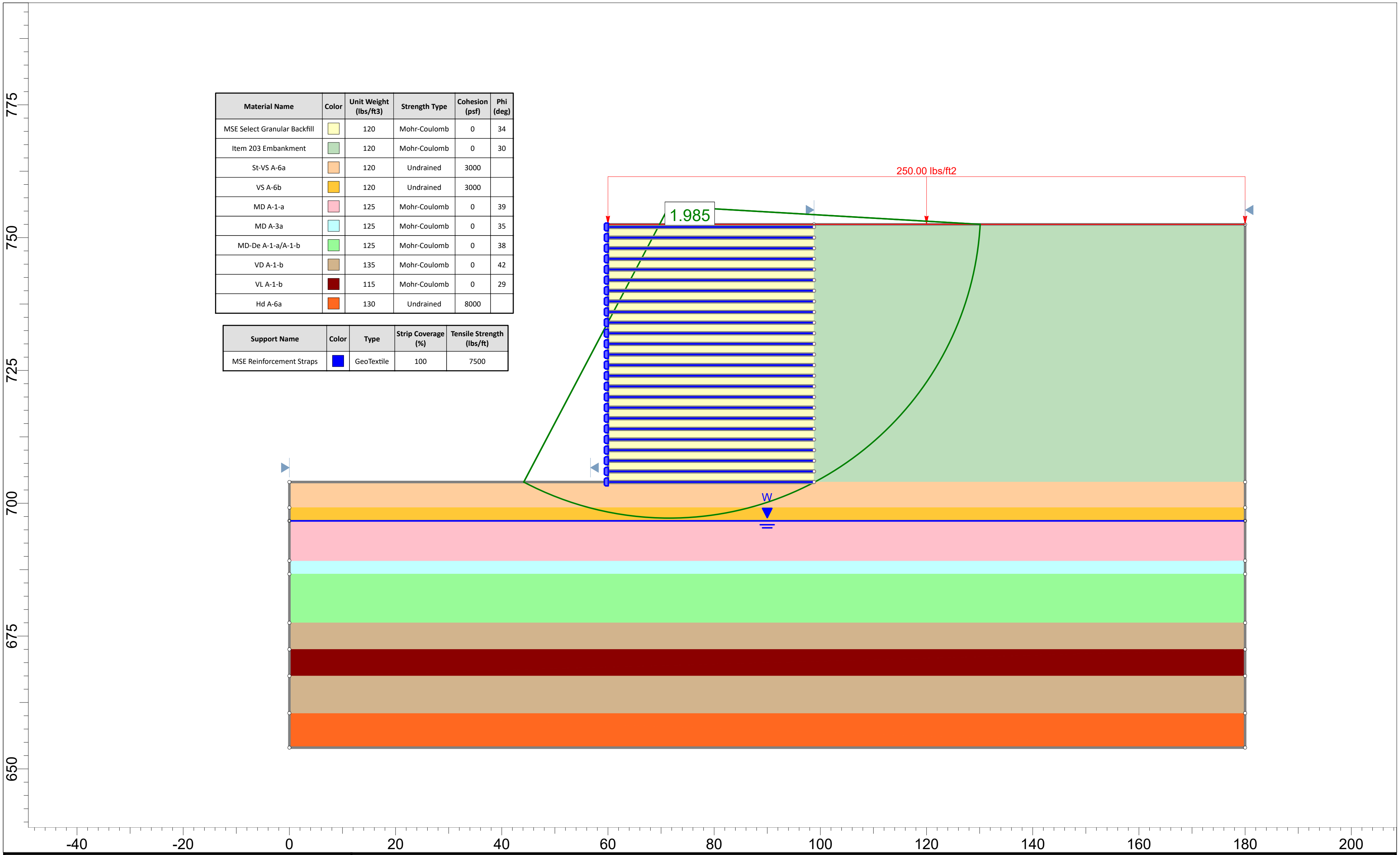
Drawn By BRT

Scale 1:300

Company Resource International, Inc.

Date 7/3/2019

File Name Retaining Wall W5 - Sta. 508+50 to 509+85 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	■	120	Mohr-Coulomb	0	34
Item 203 Embankment	■	120	Mohr-Coulomb	0	30
St-VS A-6a	■	120	Undrained	3000	
VS A-6b	■	120	Undrained	3000	
MD A-1-a	■	125	Mohr-Coulomb	0	39
MD A-3a	■	125	Mohr-Coulomb	0	35
MD-De A-1-a/A-1-b	■	125	Mohr-Coulomb	0	38
VD A-1-b	■	135	Mohr-Coulomb	0	42
VL A-1-b	■	115	Mohr-Coulomb	0	29
Hd A-6a	■	130	Undrained	8000	

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

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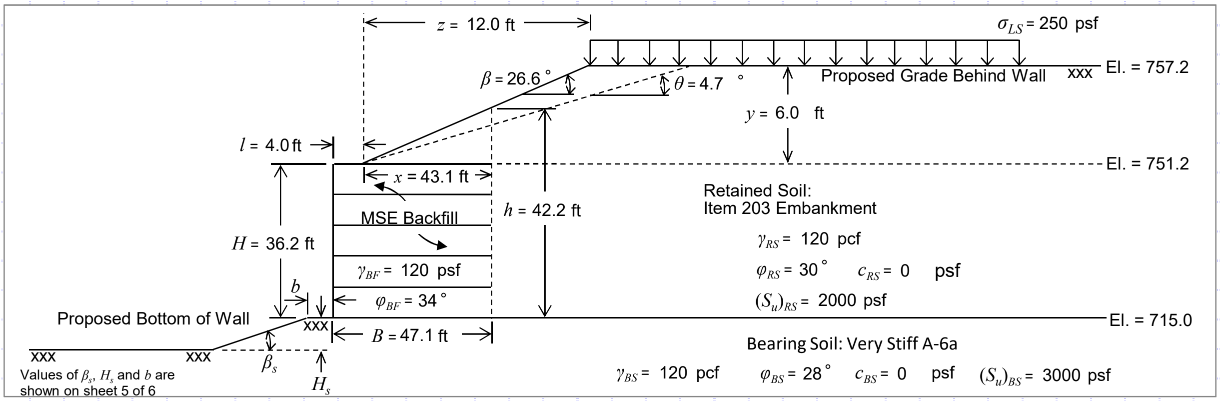
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 508+50 to 509+85 - MSE Wall Global Stability
Analysis Description	48.5 ft Wall Height - B-104-0-09 and B-104-1-13 - Undrained - Circular - Spencer Method
Drawn By	BRT
Scale	1:300
Company	Resource International, Inc.
Date	7/3/2019
File Name	Retaining Wall W5 - Sta. 508+50 to 509+85 - Global Stability.slim

Retaining Wall W5 - Sta. 600+19 to 600+75 - B-104-1-13 - 2:1 Broken Backslope - 36.2 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.2	ft
MSE Wall Width (Reinforcement Length), (B) =	47.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	42.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	4.7	°
Distance from Toe to Top of Backslope, (z) =	12.0	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) =	0.315	
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, $[(S_u)_{BS}]$ =	3000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	21.5	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

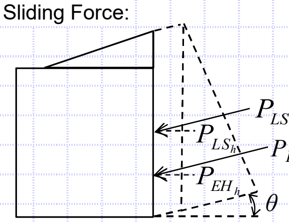
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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)(42.2 ft)²(0.315)(1.50) = 50.51 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(42.2 ft)(0.315)(1.75) = 5.20 kip/ft

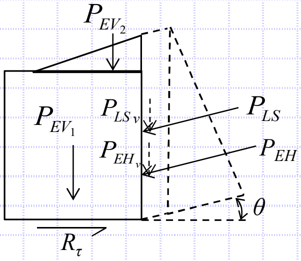
P_H = (50.51 kip/ft + 5.20 kip/ft)cos(4.7°) = 55.52 kip/ft

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)(36.2 ft)(47.1 ft)(1.00) = 204.6 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(42.2 ft - 36.2 ft)(47.1 ft - 4.0 ft)(1.00) = 15.54 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(42.2 ft)²(0.315)(1.50) = 50.51 kip/ft

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

R_τ = [204.60 kip/ft + 15.54 kip/ft + (50.51 kip/ft)sin(4.7°)](0.53) = 118.87 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 55.52 kip/ft ≤ (118.87 kip/ft)(1.0) = 118.87 kip/ft $\longrightarrow$ 55.52 kip/ft ≤ 118.87 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) =	36.2	ft
MSE Wall Width (Reinforcement Length), (B) =	47.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	42.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	4.7	°
Distance from Toe to Top of Backslope, (z) =	12.0	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) =	0.315	
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, [$(s_u)_{BS}$] =	3000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	21.5	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

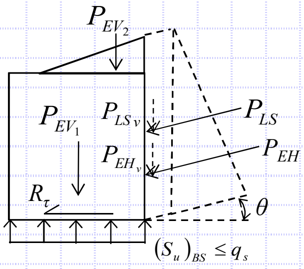
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



(Neglect P_{LS_V} for conservatism)

$(S_u)_{BS}$ = 3.00 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)(36.2 ft)(47.1 ft)(1.00) = 204.6 kip/ft

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

P_{EV_2}= ½(120 pcf)(42.2 ft - 36.2 ft)(47.1 ft - 4.0 ft)(1.00) = 15.54 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(42.2 ft)²(0.315)(1.50) = 50.51 kip/ft

P_V = 204.6 kip/ft + 15.54 kip/ft + (50.51 kip/ft)sin(4.7°) = 224.28 kip/ft

σ_v = (224.28 kip/ft) / (47.1 ft) = 4.76 ksf

q_s = (4.76 ksf) / 2 = 2.38 ksf

R_τ = (3.00 ksf ≤ 2.38 ksf)(47.1 ft) = 141.30 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 55.52 kip/ft ≤ (141.30 kip/ft)(1.0) = 141.30 kip/ft ⟶ 55.52 kip/ft ≤ 141.30 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) = 36.2 ft
MSE Wall Width (Reinforcement Length), (B) = 47.1 ft
Distance from Wall Face to Toe of Backslope, (l) = 4.0 ft
MSE Wall Length, (L) = 746 ft
MSE Wall Effective Height, (h) = 42.2 ft
Retained Soil Backslope, (β) = 26.6 °
Effective Retained Soil Backslope, (θ) = 4.7 °
Distance from Toe to Top of Backslope, (z) = 12.0 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) = 0.315
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, [$(s_u)_{BS}$] = 3000 psf
Embedment Depth, (D_f) = 0.0 ft
Depth to GW (Below Bot. of Wall), (D_W) = 21.5 ft

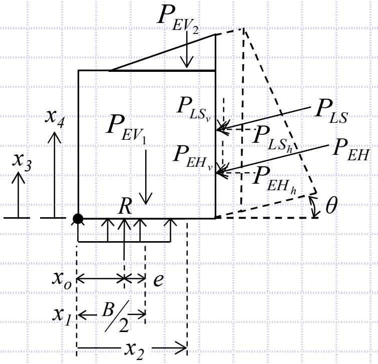
LRFD Load Factors

	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)

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



$$e = B/2 - x_o$$

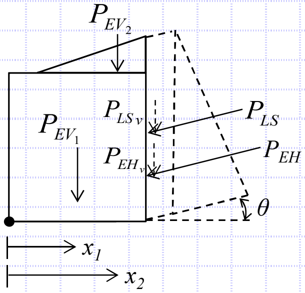
$$x_o = \frac{M_V - M_H}{P_V}$$ = (5521.89 kip·ft/ft - 830.68 kip·ft/ft) / (224.28 kip/ft = 20.92 ft

M_V = 5521.89 kip·ft/ft
M_H = 830.68 kip·ft/ft
Defined below

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 204.6 kip/ft + 15.54 kip/ft + (50.51 kip/ft)sin(4.7°) = 224.28 kip/ft

$e =$ (47.1 ft/ 2) - 20.92 ft = 2.63 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)(36.2 ft)(47.1 ft)(1.00) = 204.60 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(42.2 ft - 36.2 ft)(47.1 ft - 4.0 ft)(1.00) = 15.54 kip/ft

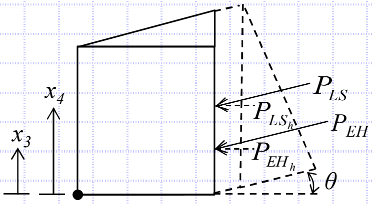
$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(42.2 ft)²(0.315)(1.50) = 50.51 kip/ft

$x_1 = B/2$ = (47.1 ft) / 2 = 23.55 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(47.1 ft - 4.0 ft) = 32.73 ft

M_V = (204.6 kip/ft)(23.55 ft) + (15.54 kip/ft)(32.73 ft) + (50.51 kip/ft)sin(4.7°)(47.1 ft) = 5521.89 kip·ft/ft

Overturning Moment, M_H:



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

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(42.2 ft)²(0.315)(1.50) = 50.51 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(42.2 ft)(0.315)(1.75) = 5.82 kip/ft

$x_3 = h/3$ = (42.2 ft) / 3 = 14.07 ft

$x_4 = h/2$ = (42.2 ft) / 2 = 21.1 ft

M_H = (50.51 kip/ft)cos(4.7°)(14.07 ft) + (5.82 kip/ft)cos(4.7°)(21.10 ft) = 830.68 kip·ft/ft

Check Eccentricity Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (47.1 ft) / 3 = 15.70 ft

$e < e_{\max} \longrightarrow$ 2.63 ft < 15.70 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.2	ft
MSE Wall Width (Reinforcement Length), (B) =	47.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	42.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	4.7	°
Distance from Toe to Top of Backslope, (z) =	12.0	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) =	0.315	
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)$_{BS}$] =	3000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	21.5	ft

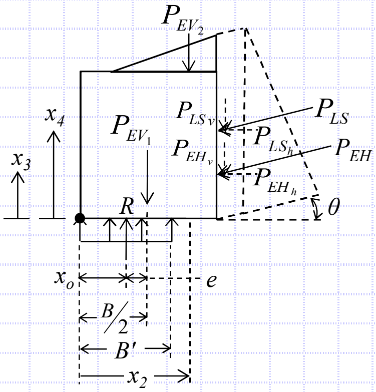
LRFD Load Factors

	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)

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



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

$$B' = B - 2e \quad = \quad 47.1 \text{ ft} - 2(1.79 \text{ ft}) \quad = \quad 43.52 \quad \text{ft}$$

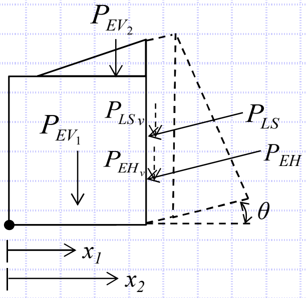
$$e = {B}/{2} - x_o \quad = \quad (47.1 \text{ ft} / 2) - 21.76 \text{ ft} \quad = \quad 1.79 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (7386.35 \text{ kip·ft/ft} - 830.68 \text{ kip·ft/ft}) / 301.33 \text{ kip/ft} \quad = \quad 21.76 \quad \text{ft}$$

$$q_{eq} \quad = \quad (301.33 \text{ kip/ft}) / (43.52 \text{ ft}) \quad = \quad 6.92 \quad \text{ksf}$$

Resisting Moment, M_V:

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad (120 \text{ pcf})(36.2 \text{ ft})(47.1 \text{ ft})(1.35) \quad = \quad 276.21 \quad \text{kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV} = \tfrac{1}{2}(120 \text{ pcf})(42.2 \text{ ft} - 36.2 \text{ ft})(47.1 \text{ ft} - 4.0 \text{ ft})(1.35) = \quad 20.98 \quad \text{kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad \tfrac{1}{2}(120 \text{ pcf})(42.2 \text{ ft})^2(0.315)(1.50) \quad = \quad 50.51 \quad \text{kip/ft}$$

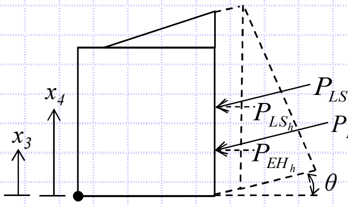
$$x_1 = {B}/{2} \quad = \quad (47.1 \text{ ft}) / 2 \quad = \quad 23.55 \quad \text{ft}$$

$$x_2 = l + \tfrac{2}{3}(B - l) \quad = \quad 4.0 \text{ ft} + \tfrac{2}{3}(47.1 \text{ ft} - 4.0 \text{ ft}) \quad = \quad 32.73 \quad \text{ft}$$

$$M_V = \quad (276.21 \text{ kip/ft})(23.55 \text{ ft}) + (20.98 \text{ kip/ft})(32.7 \text{ ft}) + (50.51 \text{ kip/ft})\sin(4.7°)(47.1 \text{ ft}) \quad = \quad 7386.35 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad \tfrac{1}{2}(120 \text{ pcf})(42.2 \text{ ft})^2(0.315)(1.50) \quad = \quad 50.51 \quad \text{kip/ft}$$

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} \quad = \quad (250 \text{ psf})(42.2 \text{ ft})(0.315)(1.75) \quad = \quad 5.82 \quad \text{kip/ft}$$

$$x_3 = {h}/{3} \quad = \quad (42.2 \text{ ft}) / 3 \quad = \quad 14.07 \quad \text{ft}$$

$$x_4 = {h}/{2} \quad = \quad (42.2 \text{ ft}) / 2 \quad = \quad 21.1 \quad \text{ft}$$

$$M_H = \quad (50.51 \text{ kip/ft})\cos(4.7°)(14.07 \text{ ft}) + (5.82 \text{ kip/ft})\cos(4.7°)(21.10 \text{ ft}) \quad = \quad 830.68 \quad \text{kip·ft/ft}$$

Vertical Forces, P_V:

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

$$P_V \quad = \quad 276.21 \text{ kip/ft} + 20.98 \text{ kip/ft} + (50.51 \text{ kip/ft})\sin(4.7°) \quad = \quad 301.33 \quad \text{kip/ft}$$

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	5	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 600+19 to 600+75

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.2	ft
MSE Wall Width (Reinforcement Length), (B) =	47.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	42.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	4.7	°
Distance from Toe to Top of Backslope, (z) =	12.0	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) =	0.315	
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, [$(s_u)_{BS}$] =	3000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	21.5	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)

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_c = 25.800
s_c = 1+(43.52 ft/746 ft)(14.72/25.8)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.7

N_q = 14.720
s_q = 1+(43.52 ft/746 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(0.0 ft/43.52 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 21.5 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_γ = 16.720
s_γ = 1-0.4(43.52 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 21.5 ft < 1.5(43.52 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (120 pcf)(0.0 ft)(14.7)(1.0) + ½(120 pcf)(43.5 ft)(16.7)(0.5) = 21.83 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 6.92 ksf ≤ (21.83 ksf)(0.51)(0.65) = 7.24 ksf → 6.92 ksf ≤ 7.24 ksf **OK**

RC_{BC} = **0.51** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* → Use β_s = 18.0 ° H_s = 10.0 ft b = 0.0 ft
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_c = 5.140
s_c = 1+(43.52 ft/[(5)(746 ft)] = 1.000
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/43.52 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 21.5 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)
$C_{w\gamma}$ = 21.5 ft < 1.5(43.52 ft) + 0.0 ft = 0.500

$q_n =$ (3000 psf)(5.14) + (120 pcf)(0.0 ft)(1.0)(1.0) + ½(120 pcf)(43.5 ft)(0.0)(0.5) = 15.42 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 6.92 ksf ≤ (15.42 ksf)(0.81)(0.65) = 8.12 ksf → 6.92 ksf ≤ 8.12 ksf **OK**

RC_{BC} = **0.81** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* → Use β_s = 18.0 ° H_s = 10.0 ft b = 0.0 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 600+19 to 600+75

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.2	ft
MSE Wall Width (Reinforcement Length), (B) =	47.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	42.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	4.7	°
Distance from Toe to Top of Backslope, (z) =	12.0	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) =	0.315	
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, $[(s_u)_{BS}]$ =	3000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	21.5	ft

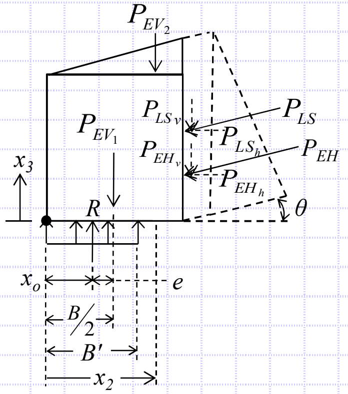
LRFD Load Factors

	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)

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



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

$$B' = B - 2e \quad = \quad 47.1\text{ ft} - 2(1.50\text{ ft}) \quad = \quad 44.10 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (47.1\text{ ft} / 2) - 22.05\text{ ft} \quad = \quad 1.50 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (5457.00\text{ kip·ft/ft} - 542.08\text{ kip·ft/ft}) / 222.90\text{ kip/ft} \quad = \quad 22.05 \quad \text{ft}$$

$$q_{eq} \quad = \quad (222.9\text{ kip/ft}) / (44.1\text{ ft}) \quad = \quad 5.05 \quad \text{ksf}$$

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

M_V = [(120 pcf)(36.2 ft)(47.1 ft)(1.00)][½(47.1 ft)] + [½(120 pcf)(42.2 ft - 36.2 ft)(47.1 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(47.1 ft - 4.0 ft)] = 5457 kip·ft/ft
+ [½(120 pcf)(42.2 ft)²(0.315)(1.00)sin(4.7°)](47.1 ft)

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

M_H = ½[(120 pcf)(42.2 ft)²(0.315)(1.00)cos(4.7°)](42.2 ft /3) = 542.08 kip·ft/ft
+ [(250 psf)(42.2 ft)(0.315)(1.00)cos(4.7°)](42.2 ft /2)

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

P_V = (120 pcf)(36.2 ft)(47.1 ft)(1.00) + ½(120 pcf)(42.2 ft - 36.2 ft)(47.1 ft - 4.0 ft)(1.00) = 222.9 kip/ft
+ ½(120 pcf)(42.2 ft)²(0.315)(1.00)sin(4.7°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5

MSE Wall Settlement - Sta. 600+19 to 600+75

Calculated By: BRT Date: 6/30/2019

Checked By: JPS Date: 7/1/2019

Boring B-104-1-13

H=	36.2	ft	Total wall height
B'=	44.1	ft	Effective footing width due to eccentricity
D_w =	21.5	ft	Depth below bottom of footing
q_e =	5,050	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)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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	2.5	2.5	1.3	120	300	150	150	4,150	25	0.135	0.014	0.467				0.03	1.000	5,050	5,200	0.056	0.668	0.500	2,525	2,675	0.029	0.345
	A-6a	C	2.5	5.5	3.0	4.0	120	660	480	480	4,480	25	0.135	0.014	0.467				0.09	0.998	5,038	5,518	0.052	0.621	0.500	2,524	3,004	0.022	0.264
	A-6a	C	5.5	8.5	3.0	7.0	120	1,020	840	840	4,840	25	0.135	0.014	0.467				0.16	0.988	4,989	5,829	0.043	0.519	0.499	2,521	3,361	0.017	0.199
2	A-6a	C	8.5	11.0	2.5	9.8	120	1,320	1,170	1,170	5,170	31	0.189	0.019	0.514				0.22	0.970	4,901	6,071	0.042	0.503	0.498	2,514	3,684	0.016	0.187
	A-6a	C	11.0	13.5	2.5	12.3	120	1,620	1,470	1,470	5,470	31	0.189	0.019	0.514				0.28	0.947	4,785	6,255	0.036	0.432	0.496	2,504	3,974	0.013	0.162
3	A-3	G	13.5	16.0	2.5	14.8	120	1,920	1,770	1,770	5,770					12	13	47	0.33	0.919	4,640	6,410	0.030	0.359	0.493	2,490	4,260	0.020	0.245
4	A-1-a	G	16.0	26.0	10.0	21.0	130	3,220	2,570	2,570	6,570					35	32	105	0.48	0.833	4,209	6,779	0.040	0.481	0.482	2,435	5,005	0.028	0.331
5	A-1-a	G	26.0	32.5	6.5	29.3	135	4,098	3,659	3,175	7,175					54	46	152	0.66	0.717	3,622	6,797	0.014	0.170	0.460	2,324	5,499	0.010	0.122
6	A-1-b	G	32.5	37.5	5.0	35.0	130	4,748	4,423	3,580	7,580					28	23	80	0.79	0.645	3,257	6,837	0.018	0.211	0.441	2,229	5,809	0.013	0.158
7	A-1-b	G	37.5	42.5	5.0	40.0	135	5,423	5,085	3,931	7,931					120	93	417	0.91	0.590	2,979	6,909	0.003	0.035	0.424	2,141	6,071	0.002	0.027
8	A-1-b	G	42.5	47.5	5.0	45.0	115	5,998	5,710	4,244	8,244					3	2	48	1.02	0.542	2,735	6,979	0.023	0.271	0.406	2,050	6,293	0.018	0.215
9	A-1-b	G	47.5	51.5	4.0	49.5	135	6,538	6,268	4,520	8,520					120	87	377	1.12	0.503	2,542	7,063	0.002	0.025	0.390	1,968	6,489	0.002	0.020
10	A-1-a	G	51.5	54.5	3.0	53.0	140	6,958	6,748	4,782	8,782					120	85	362	1.20	0.477	2,408	7,190	0.001	0.018	0.377	1,906	6,688	0.001	0.014
11	A-6a	C	54.5	61.0	6.5	57.8	130	7,803	7,380	5,118	9,118	30	0.180	0.018	0.507				1.31	0.444	2,244	7,362	0.012	0.147	0.361	1,824	6,942	0.010	0.123
																				Total Settlement:			4.459 in		Total Settlement:			2.412 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 600+19 to 600+75

Calculated By: BRT　Date: 6/30/2019
Checked By: JPS　Date: 7/1/2019

Boring B-104-1-13

H=	36.2	ft	Total wall height
B'=	44.1	ft	Effective footing width due to eccentricity
D_w =	21.5	ft	Depth below bottom of footing
q_e =	5,050	psf	Equivalent bearing pressure at bottom of wall

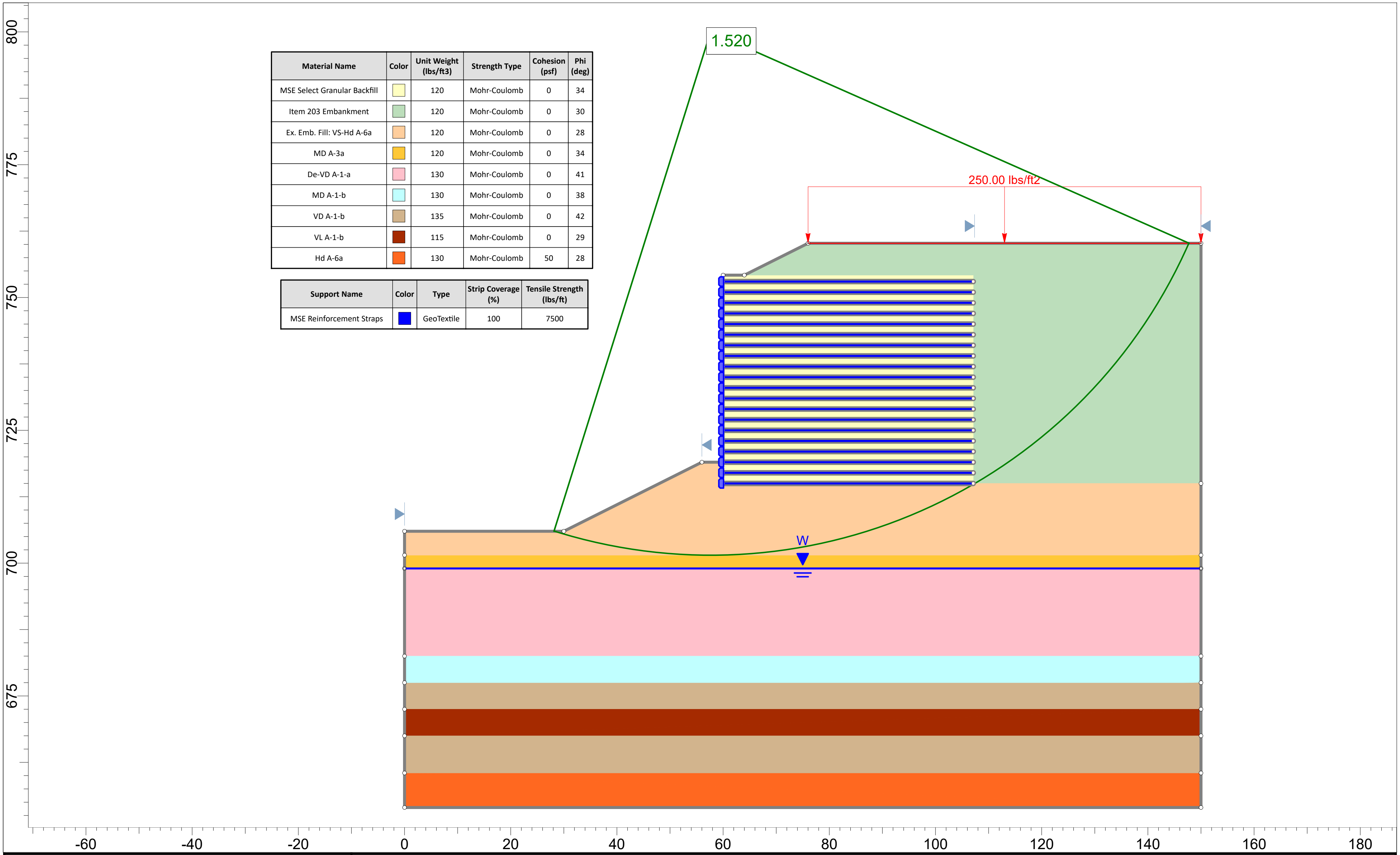
	A-6a				
c_v =	600			ft^2/yr	Coefficient of consolidation
t =	15			days	Time following completion of construction
H_{dr} =	6.5			ft	Length of longest drainage path considered
T_v =	0.584				Time factor
U =	81			%	Degree of consolidation

$(S_c)_t$ = 2.169 in　Settlement complete at 90% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	25	0.135	0.014	0.467				0.03	0.500	2,525	2,675	0.029	0.345	0.809	0.280	0.655
	A-6a	C	2.5	5.5	3.0	4.0	120	660	480	480	4,480	25	0.135	0.014	0.467				0.09	0.500	2,524	3,004	0.022	0.264		0.214	
	A-6a	C	5.5	8.5	3.0	7.0	120	1,020	840	840	4,840	25	0.135	0.014	0.467				0.16	0.499	2,521	3,361	0.017	0.199		0.162	
2	A-6a	C	8.5	11.0	2.5	9.8	120	1,320	1,170	1,170	5,170	31	0.189	0.019	0.514				0.22	0.498	2,514	3,684	0.016	0.187	0.348	0.151	0.282
	A-6a	C	11.0	13.5	2.5	12.3	120	1,620	1,470	1,470	5,470	31	0.189	0.019	0.514				0.28	0.496	2,504	3,974	0.013	0.162		0.131	
3	A-3	G	13.5	16.0	2.5	14.8	120	1,920	1,770	1,770	5,770					12	13	47	0.33	0.493	2,490	4,260	0.020	0.245	0.245	0.245	0.245
4	A-1-a	G	16.0	26.0	10.0	21.0	130	3,220	2,570	2,570	6,570					35	32	105	0.48	0.482	2,435	5,005	0.028	0.331	0.331	0.331	0.331
5	A-1-a	G	26.0	32.5	6.5	29.3	135	4,098	3,659	3,175	7,175					54	46	152	0.66	0.460	2,324	5,499	0.010	0.122	0.122	0.122	0.122
6	A-1-b	G	32.5	37.5	5.0	35.0	130	4,748	4,423	3,580	7,580					28	23	80	0.79	0.441	2,229	5,809	0.013	0.158	0.158	0.158	0.158
7	A-1-b	G	37.5	42.5	5.0	40.0	135	5,423	5,085	3,931	7,931					120	93	417	0.91	0.424	2,141	6,071	0.002	0.027	0.027	0.027	0.027
8	A-1-b	G	42.5	47.5	5.0	45.0	115	5,998	5,710	4,244	8,244					3	2	48	1.02	0.406	2,050	6,293	0.018	0.215	0.215	0.215	0.215
9	A-1-b	G	47.5	51.5	4.0	49.5	135	6,538	6,268	4,520	8,520					120	87	377	1.12	0.390	1,968	6,489	0.002	0.020	0.020	0.020	0.020
10	A-1-a	G	51.5	54.5	3.0	53.0	140	6,958	6,748	4,782	8,782					120	85	362	1.20	0.377	1,906	6,688	0.001	0.014	0.014	0.014	0.014
11	A-6a	C	54.5	61.0	6.5	57.8	130	7,803	7,380	5,118	9,118	30	0.180	0.018	0.507				1.31	0.361	1,824	6,942	0.010	0.123	0.123	0.100	0.100

Settlement Remaining After Hold Period: 0.243 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. $(N1)_{60} = C_nN_{60}$, 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)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Mohr-Coulomb	0	28
MD A-3a	🟨	120	Mohr-Coulomb	0	34
De-VD A-1-a	🟥	130	Mohr-Coulomb	0	41
MD A-1-b	🟦	130	Mohr-Coulomb	0	38
VD A-1-b	🟫	135	Mohr-Coulomb	0	42
VL A-1-b	🟥	115	Mohr-Coulomb	0	29
Hd A-6a	🟧	130	Mohr-Coulomb	50	28

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

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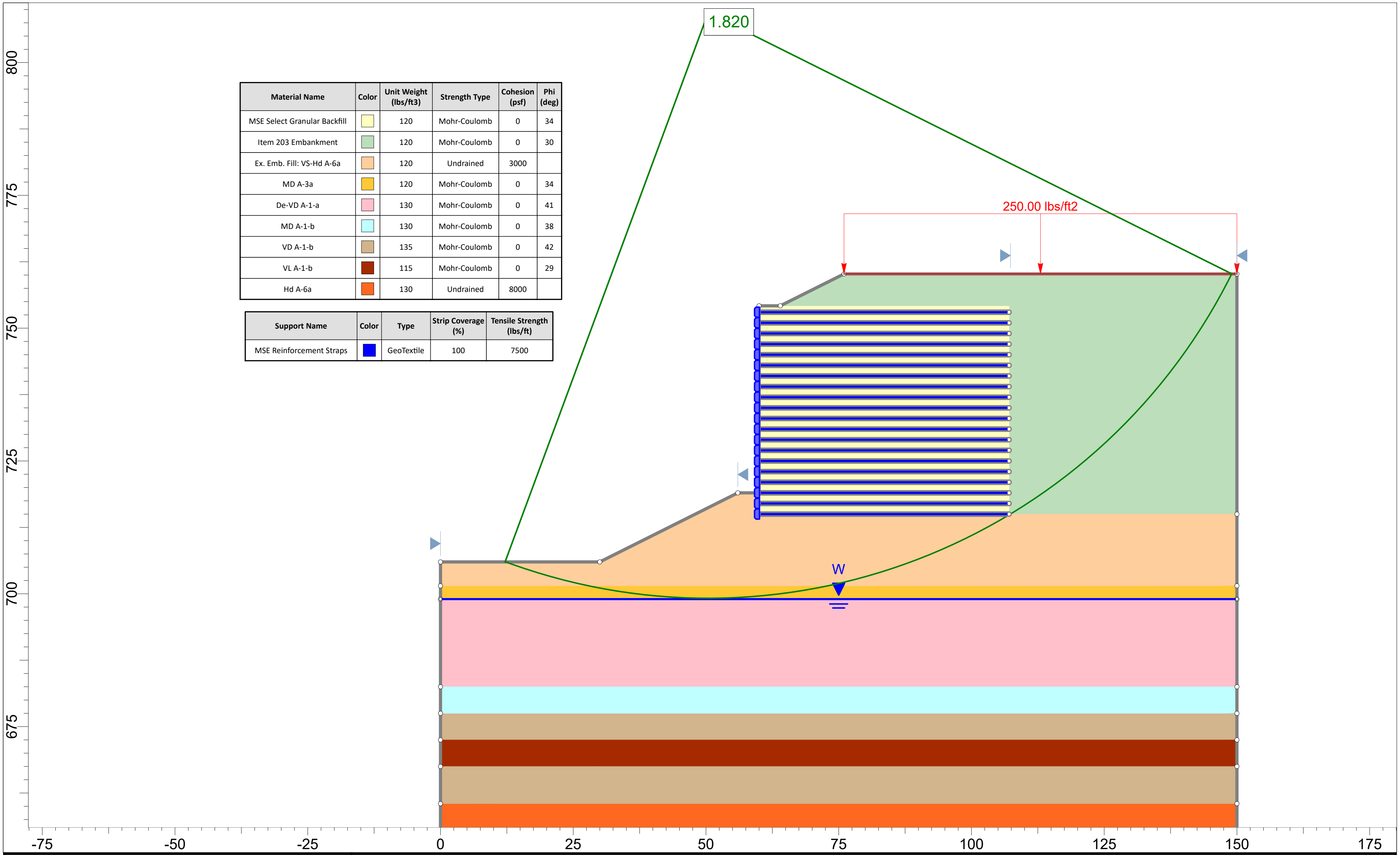
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 600+19 to 601+83 - MSE Wall Global Stability		
Analysis Description	36.2 ft Wall Height - B-104-1-13 - Drained - Circular - Spencer method		
Drawn By BRT	*Scale* 1:300	*Company*	Resource International, Inc
Date 7/3/2019		*File Name*	Retaining Wall W5 - Sta. 600+19 to 601+83 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Undrained	3000	
MD A-3a	🟨	120	Mohr-Coulomb	0	34
De-VD A-1-a	🟥	130	Mohr-Coulomb	0	41
MD A-1-b	🟦	130	Mohr-Coulomb	0	38
VD A-1-b	🟫	135	Mohr-Coulomb	0	42
VL A-1-b	🟥	115	Mohr-Coulomb	0	29
Hd A-6a	🟧	130	Undrained	8000	

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

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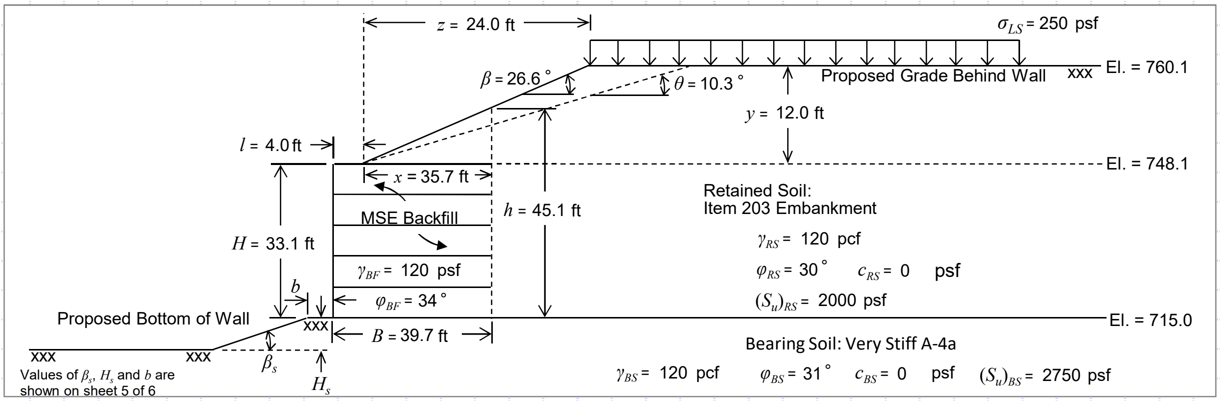
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 600+19 to 601+83 - MSE Wall Global Stability
Analysis Description	36.2 ft Wall Height - B-104-1-13 - Undrained - Circular - Spencer method
Drawn By	BRT
Scale	1:300
Company	Resource International, Inc
Date	7/3/2019
File Name	Retaining Wall W5 - Sta. 600+19 to 601+83 - Global Stability.slim

Retaining Wall W5 - Sta. 600+75 to 601+83 - B-105-3-14 - 2:1 Broken Backslope - 33.1 ft. Wall Height



Values of β_s, H_s and b are shown on sheet 5 of 6

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	ft

LRFD Load Factors

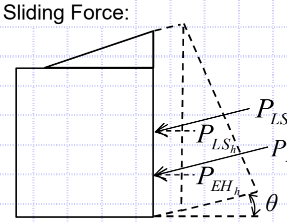
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(45.1 ft)²(0.342)(1.50)} = 62.66 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = \text{(250 psf)(45.1 ft)(0.342)(1.75)} = 6.04 \text{ kip/ft}$$

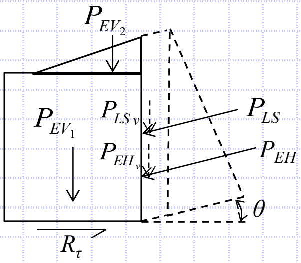
$$P_H = \text{(62.66 kip/ft + 6.04 kip/ft)cos(10.3°)} = 67.59 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

$$R_\tau = \left(P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta\right)\tan\delta$$

(Neglect P_{LS_v} for conservatism)



$$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV} = \text{(120 pcf)(33.1 ft)(39.7 ft)(1.00)} = 157.69 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.00)} = 25.74 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(45.1 ft)²(0.342)(1.50)} = 62.66 \text{ kip/ft}$$

$$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF}) \longrightarrow \tan(31) \le \tan(34) \longrightarrow 0.60 \le 0.67 = 0.60$$

$$R_\tau = \text{[157.69 kip/ft + 25.74 kip/ft + (62.66 kip/ft)sin(10.3°)](0.60)} = 116.78 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau\cdot\phi_\tau \longrightarrow \text{67.59 kip/ft} \le \text{(116.78 kip/ft)(1.0) = 116.78 kip/ft} \longrightarrow \text{67.59 kip/ft} \le \text{116.78 kip/ft}$$

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) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	ft

LRFD Load Factors

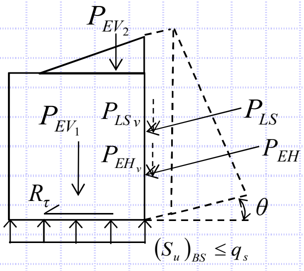
	EV	EH	LS	
Strength Ia	1.00	1.50	1.75	*(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)*
Strength Ib	1.35	1.50	1.75	
Service I	1.00	1.00	1.00	

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)

$$(S_u)_{BS} = 2.75 \text{ ksf}$$

$$q_s = {}^{\sigma_v}\!/_{2}$$

$$\sigma_v = {}^{P_V}\!/_{B}$$

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

$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(33.1 ft)(39.7 ft)(1.00)} = 157.7 \text{ kip/ft}$$

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

$$P_{EV_2} = \text{½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.00)} = 25.74 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(45.1 ft)²(0.342)(1.50)} = 62.66 \text{ kip/ft}$$

$$P_V = \text{157.69 kip/ft + 25.74 kip/ft + (62.66 kip/ft)sin(10.3°)} = 194.63 \text{ kip/ft}$$

$$\sigma_v = \text{(194.63 kip/ft) / (39.7 ft)} = 4.90 \text{ ksf}$$

$$q_s = \text{(4.90 ksf) / 2} = 2.45 \text{ ksf}$$

$$R_\tau = \text{(2.75 ksf ≤ 2.45 ksf)(39.7 ft)} = 109.18 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 67.59 kip/ft ≤ (109.18 kip/ft)(1.0) = 109.18 kip/ft ⟶ 67.59 kip/ft ≤ 109.18 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) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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:

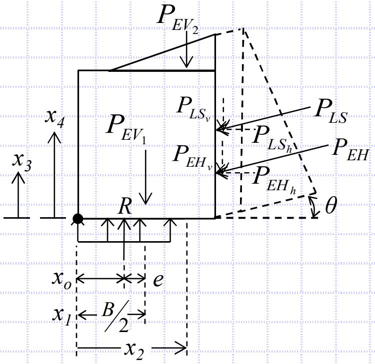
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	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 11.6.3.3



$$e = B/2 - x_o$$

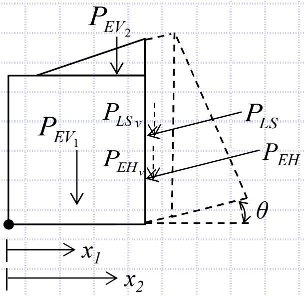
$$x_o = \frac{M_V - M_H}{P_V}$$ = 4290.51 kip·ft/ft - 1077.05 kip·ft/ft) / (194.63 kip/f = 16.51 ft

M_V = 4290.51 kip·ft/ft
M_H = 1077.05 kip·ft/ft } Defined below
P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 157.69 kip/ft + 25.74 kip/ft + (62.66 kip/ft)sin(10.3°) = 194.63 kip/ft

$e =$ (39.7 ft/ 2) - 16.51 ft = 3.34 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)(33.1 ft)(39.7 ft)(1.00) = 157.69 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.00) = 25.74 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(45.1 ft)²(0.342)(1.50) = 62.66 kip/ft

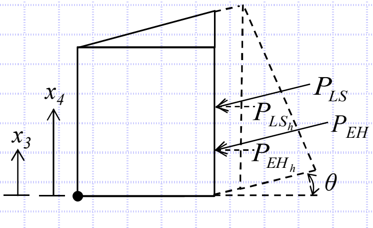
$x_1 = B/2$ = (39.7 ft) / 2 = 19.85 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(39.7 ft - 4.0 ft) = 27.80 ft

M_V = (157.69 kip/ft)(19.85 ft) + (25.74 kip/ft)(27.8 ft) + (62.66 kip/ft)sin(10.3°)(39.7 ft) = 4290.51 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(45.1 ft)²(0.342)(1.50) = 62.66 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(45.1 ft)(0.342)(1.75) = 6.75 kip/ft

$x_3 = h/3$ = (45.1 ft) / 3 = 15.04 ft

$x_4 = h/2$ = (45.1 ft) / 2 = 22.56 ft

M_H = (62.66 kip/ft)cos(10.3°)(15.04 ft) + (6.75 kip/ft)cos(10.3°)(22.56 ft = 1077.05 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (39.7 ft) / 3 = 13.23 ft

$e < e_{\max} \longrightarrow$ 3.34 ft < 13.23 ft **OK**

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	4	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 600+75 to 601+83

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	ft

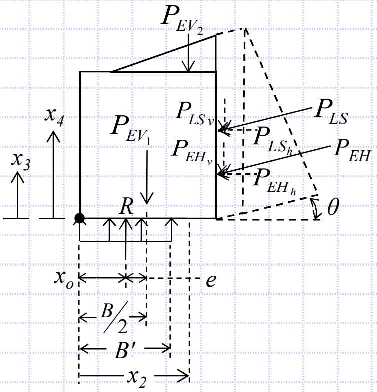
LRFD Load Factors

	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



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

$$B' = B - 2e \quad = \quad 39.7 \text{ ft - 2(2.23 ft)} \quad = \quad 35.24 \quad \text{ft}$$

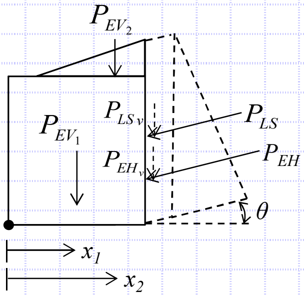
$$e = B/2 - x_o \quad = \quad \text{(39.7 ft / 2) - 17.62 ft} \quad = \quad 2.23 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \text{(5636.51 kip·ft/ft - 1077.05 kip·ft/ft) / 258.83 kip/f} \quad = \quad 17.62 \quad \text{ft}$$

$$q_{eq} = \quad \text{(258.83 kip/ft) / (35.24 ft)} \quad = \quad 7.34 \quad \text{ksf}$$

Resisting Moment, M_V:

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad \text{(120 pcf)(33.1 ft)(39.7 ft)(1.35)} \quad = \quad 212.88 \quad \text{kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.35)} = \quad 34.75 \quad \text{kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \quad \text{½(120 pcf)(45.1 ft)²(0.342)(1.50)} \quad = \quad 62.66 \quad \text{kip/ft}$$

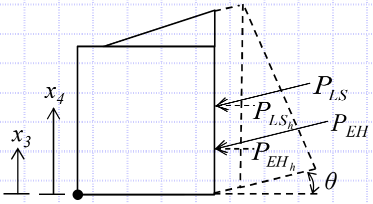
$$x_1 = B/2 \quad = \quad \text{(39.7 ft) / 2} \quad = \quad 19.85 \quad \text{ft}$$

$$x_2 = l + \tfrac{2}{3}(B-l) \quad = \quad \text{4.0 ft + ⅔(39.7 ft - 4.0 ft)} \quad = \quad 27.80 \quad \text{ft}$$

$$M_V = \text{(212.88 kip/ft)(19.85 ft) + (34.75 kip/ft)(27.8 ft) + (62.66 kip/ft)sin(10.3°)(39.7 ft)} \quad = \quad 5636.51 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \quad \text{½(120 pcf)(45.1 ft)²(0.342)(1.50)} \quad = \quad 62.66 \quad \text{kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} \quad = \quad \text{(250 psf)(45.1 ft)(0.342)(1.75)} \quad = \quad 6.75 \quad \text{kip/ft}$$

$$x_3 = h/3 \quad = \quad \text{(45.1 ft) / 3} \quad = \quad 15.04 \quad \text{ft}$$

$$x_4 = h/2 \quad = \quad \text{(45.1 ft) / 2} \quad = \quad 22.56 \quad \text{ft}$$

$$M_H = \text{(62.66 kip/ft)cos(10.3°)(15.04 ft) + (6.75 kip/ft)cos(10.3°)(22.56 ft} \quad = \quad 1077.05 \quad \text{kip·ft/ft}$$

Vertical Forces, P_V:

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

$$P_V \quad = \quad \text{212.88 kip/ft + 34.75 kip/ft + (62.66 kip/ft)sin(10.3°)} \quad = \quad 258.83 \quad \text{kip/ft}$$

JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 5 OF 6
CALCULATED BY BRT DATE 6/29/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 600+75 to 601+83

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	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 11.10.5.4 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 32.67

N_c = 32.670
s_c = 1+(35.24 ft/746 ft)(20.63/32.67)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 20.6

N_q = 20.630
s_q = 1+(35.24 ft/746 ft)tan(31°) = 1.000
d_q = 1+2tan(31°)[1-sin(31°)]²tan⁻¹(0.0 ft/35.24 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 24.0 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 26.0

N_γ = 25.990
s_γ = 1-0.4(35.24 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 24.0 ft < 1.5(35.24 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(32.67) + (120 pcf)(0.0 ft)(20.6)(1.0) + ½(120 pcf)(35.2 ft)(26.0)(0.5) = 27.48 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 7.34 ksf ≤ (27.48 ksf)(0.59)(0.65) = 10.54 ksf ⟶ 7.34 ksf ≤ 10.54 ksf **OK**

RC_{BC} = **0.59** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* ⟶ Use β_s = 15.0 ° H_s = 9.0 ft b = 0.0 ft
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_c = 5.140
s_c = 1+(35.24 ft/[(5)(746 ft)] = 1.000
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/35.24 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 24.0 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)
$C_{w\gamma}$ = 24.0 ft < 1.5(35.24 ft) + 0.0 ft = 0.500

$q_n =$ (2750 psf)(5.14) + (120 pcf)(0.0 ft)(1.0)(1.0) + ½(120 pcf)(35.2 ft)(0.0)(0.5) = 14.14 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 7.34 ksf ≤ (14.14 ksf)(0.81)(0.65) = 7.44 ksf ⟶ 7.34 ksf ≤ 7.44 ksf **OK**

RC_{BC} = **0.81** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* ⟶ Use β_s = 15.0 ° H_s = 9.0 ft b = 0.0 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

Retaining Wall W5 - Sta. 600+75 to 601+83

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.1	ft
MSE Wall Width (Reinforcement Length), (B) =	39.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	45.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	10.3	°
Distance from Toe to Top of Backslope, (z) =	24.0	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) =	0.342	
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}) =	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	24.0	ft

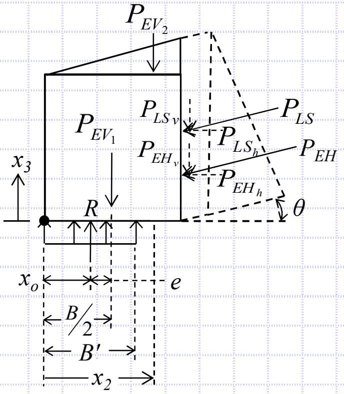
LRFD Load Factors

	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



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

$$B' = B - 2e \quad = \quad 39.7 \text{ ft - 2(1.84 ft)} \quad = \quad 36.02 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad \text{(39.7 ft / 2) - 18.01 ft} \quad = \quad 1.84 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(4142.29 kip·ft/ft - 703.72 kip·ft/ft) / 190.90 kip/ft} \quad = \quad 18.01 \quad \text{ft}$$

$$q_{eq} \quad = \quad \text{(190.9 kip/ft) / (36.02 ft)} \quad = \quad 5.30 \quad \text{ksf}$$

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

M_V = [(120 pcf)(33.1 ft)(39.7 ft)(1.00)][½(39.7 ft)] + [½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(39.7 ft - 4.0 ft)] = 4142.29 kip·ft/ft
+ [½(120 pcf)(45.1 ft)²(0.342)(1.00)sin(10.3°)](39.7 ft)

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

M_H = ½[(120 pcf)(45.1 ft)²(0.342)(1.00)cos(10.3°)](45.1 ft /3) = 703.72 kip·ft/ft
+ [(250 psf)(45.1 ft)(0.342)(1.00)cos(10.3°)](45.1 ft /2)

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

P_V = (120 pcf)(33.1 ft)(39.7 ft)(1.00) + ½(120 pcf)(45.1 ft - 33.1 ft)(39.7 ft - 4.0 ft)(1.00) = 190.9 kip/ft
+ ½(120 pcf)(45.1 ft)²(0.342)(1.00)sin(10.3°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5

MSE Wall Settlement - Sta. 600+75 to 601+83

Calculated By: BRT Date: 6/30/2019

Checked By: JPS Date: 7/1/2019

Boring B-105-3-14

H= 33.1 ft Total wall height

B'= 36.0 ft Effective footing width due to eccentricity

D_w = 24.0 ft Depth below bottom of footing

q_e = 5,300 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)		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	3.0	3.0	1.5	120	360	180	180	4,180	26	0.144	0.014	0.475				0.04	1.000	5,299	5,479	0.074	0.893	0.500	2,650	2,830	0.035	0.420
	A-4a	C	3.0	6.0	3.0	4.5	120	720	540	540	4,540	26	0.144	0.014	0.475				0.13	0.994	5,267	5,807	0.058	0.701	0.500	2,648	3,188	0.023	0.271
2	A-3a	G	6.0	8.5	2.5	7.3	135	1,058	889	889	4,889					67	85	278	0.20	0.977	5,177	6,066	0.007	0.090	0.498	2,641	3,530	0.005	0.065
3	A-2-4	G	8.5	11.0	2.5	9.8	135	1,395	1,226	1,226	5,226					85	99	461	0.27	0.951	5,038	6,264	0.004	0.046	0.496	2,629	3,856	0.003	0.032
	A-2-4	G	11.0	13.5	2.5	12.3	135	1,733	1,564	1,564	5,564					85	92	410	0.34	0.916	4,853	6,417	0.004	0.045	0.493	2,611	4,175	0.003	0.031
4	A-7-6	C	13.5	15.5	2.0	14.5	125	1,983	1,858	1,858	5,858	43	0.297	0.030	0.608				0.40	0.879	4,660	6,518	0.036	0.427	0.488	2,589	4,446	0.014	0.168
	A-7-6	C	15.5	17.5	2.0	16.5	125	2,233	2,108	2,108	6,108	43	0.297	0.030	0.608				0.46	0.845	4,477	6,585	0.029	0.350	0.484	2,564	4,671	0.013	0.153
5	A-2-6	G	17.5	22.5	5.0	20.0	130	2,883	2,558	2,558	6,558					28	26	88	0.56	0.783	4,150	6,708	0.024	0.287	0.474	2,511	5,068	0.017	0.204
	A-2-6	G	22.5	27.5	5.0	25.0	130	3,533	3,208	3,145	7,145					28	24	83	0.69	0.699	3,705	6,851	0.020	0.245	0.456	2,416	5,561	0.015	0.179
6	A-1-a	G	27.5	32.5	5.0	30.0	135	4,208	3,870	3,496	7,496					71	58	205	0.83	0.625	3,312	6,808	0.007	0.085	0.435	2,308	5,803	0.005	0.065
7	A-1-a	G	32.5	37.5	5.0	35.0	130	4,858	4,533	3,846	7,846					39	31	100	0.97	0.561	2,975	6,821	0.012	0.149	0.414	2,192	6,038	0.010	0.117
	A-1-a	G	37.5	42.5	5.0	40.0	130	5,508	5,183	4,184	8,184					39	29	97	1.11	0.507	2,689	6,873	0.011	0.133	0.392	2,075	6,259	0.009	0.108
8	A-1-a	G	42.5	50.5	8.0	46.5	135	6,588	6,048	4,644	8,644					92	66	247	1.29	0.449	2,382	7,026	0.006	0.070	0.364	1,928	6,572	0.005	0.059
																				Total Settlement:			3.519 in		Total Settlement:			1.872 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 600+75 to 601+83

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-105-3-14

H=	33.1	ft	Total wall height
B'=	36.0	ft	Effective footing width due to eccentricity
D_w =	24.0	ft	Depth below bottom of footing
q_e =	5,300	psf	Equivalent bearing pressure at bottom of wall

	A-4a	A-7-6			
c_v =	1,000	150		ft^2/yr	Coefficient of consolidation
t =	3	3		days	Time following completion of construction
H_{dr} =	2.5	2.5		ft	Length of longest drainage path considered
T_v =	1.315	0.197			Time factor
U =	97	50		%	Degree of consolidation

$(S_c)_t$ = 1.690 in Settlement complete at 90% of primary consolidation

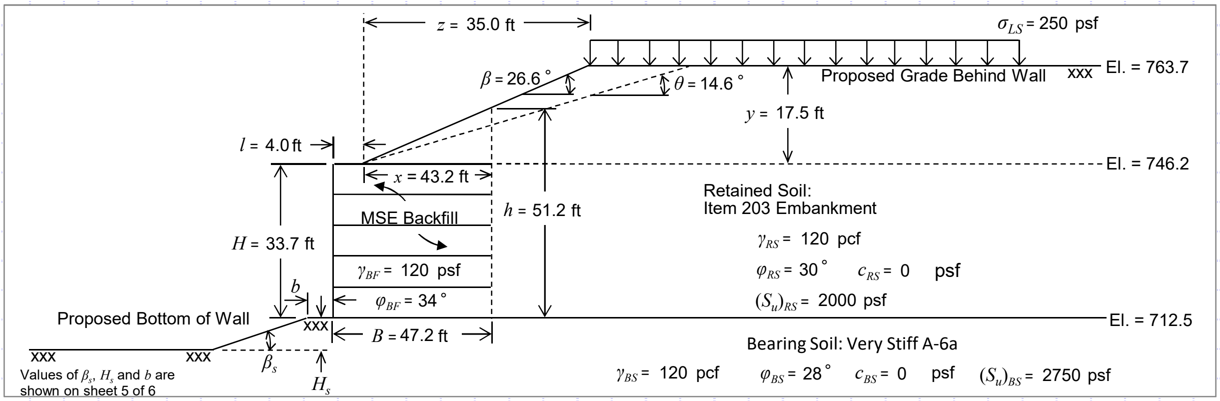
																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-4a	C	0.0	3.0	3.0	1.5	120	360	180	180	4,180	26	0.144	0.014	0.475				0.04	0.500	2,650	2,830	0.035	0.420	0.691	0.408	0.671
	A-4a	C	3.0	6.0	3.0	4.5	120	720	540	540	4,540	26	0.144	0.014	0.475				0.13	0.500	2,648	3,188	0.023	0.271		0.263	
2	A-3a	G	6.0	8.5	2.5	7.3	135	1,058	889	889	4,889					67	85	278	0.20	0.498	2,641	3,530	0.005	0.065	0.065	0.065	0.065
3	A-2-4	G	8.5	11.0	2.5	9.8	135	1,395	1,226	1,226	5,226					85	99	461	0.27	0.496	2,629	3,856	0.003	0.032	0.064	0.032	0.064
	A-2-4	G	11.0	13.5	2.5	12.3	135	1,733	1,564	1,564	5,564					85	92	410	0.34	0.493	2,611	4,175	0.003	0.031		0.031	
4	A-7-6	C	13.5	15.5	2.0	14.5	125	1,983	1,858	1,858	5,858	43	0.297	0.030	0.608				0.40	0.488	2,589	4,446	0.014	0.168	0.321	0.084	0.161
	A-7-6	C	15.5	17.5	2.0	16.5	125	2,233	2,108	2,108	6,108	43	0.297	0.030	0.608				0.46	0.484	2,564	4,671	0.013	0.153		0.077	
5	A-2-6	G	17.5	22.5	5.0	20.0	130	2,883	2,558	2,558	6,558					28	26	88	0.56	0.474	2,511	5,068	0.017	0.204	0.383	0.204	0.383
	A-2-6	G	22.5	27.5	5.0	25.0	130	3,533	3,208	3,145	7,145					28	24	83	0.69	0.456	2,416	5,561	0.015	0.179		0.179	
6	A-1-a	G	27.5	32.5	5.0	30.0	135	4,208	3,870	3,496	7,496					71	58	205	0.83	0.435	2,308	5,803	0.005	0.065	0.065	0.065	0.065
7	A-1-a	G	32.5	37.5	5.0	35.0	130	4,858	4,533	3,846	7,846					39	31	100	0.97	0.414	2,192	6,038	0.010	0.117	0.225	0.117	0.225
	A-1-a	G	37.5	42.5	5.0	40.0	130	5,508	5,183	4,184	8,184					39	29	97	1.11	0.392	2,075	6,259	0.009	0.108		0.108	
8	A-1-a	G	42.5	50.5	8.0	46.5	135	6,588	6,048	4,644	8,644					92	66	247	1.29	0.364	1,928	6,572	0.005	0.059	0.059	0.059	0.059

Settlement Remaining After Hold Period: 0.181 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. $(N1)_{60} = C_nN_{60}$, 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

JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 1 OF 6
CALCULATED BY BRT DATE 6/29/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 601+83 to 603+50

Retaining Wall W5 - Sta. 601+83 to 603+50 - B-105-5-14 - 2:1 Broken Backslope - 33.7 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.7	ft
MSE Wall Width (Reinforcement Length), (B) =	47.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	51.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	14.6	°
Distance from Toe to Top of Backslope, (z) =	35.0	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) =	0.368	
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, $[(S_u)_{BS}]$ =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	22.0	ft

LRFD Load Factors

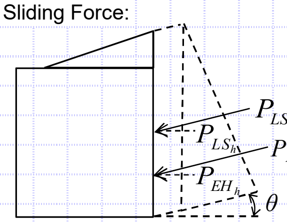
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(51.2 ft)²(0.368)(1.50)} = 86.91 \text{ kip/ft}$$

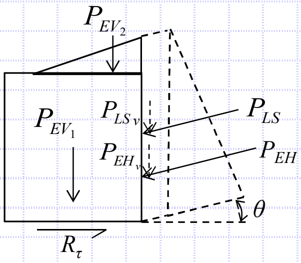
$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \text{(250 psf)(51.2 ft)(0.368)(1.75)} = 7.37 \text{ kip/ft}$$

$$P_H = \text{(86.91 kip/ft + 7.37 kip/ft)cos(14.6°)} = 91.24 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

$$R_\tau = \left(P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta\right)\tan\delta$$ (Neglect P_{LS_v} for conservatism)



$$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV} = \text{(120 pcf)(33.7 ft)(47.2 ft)(1.00)} = 190.88 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.00)} = 45.43 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(51.2 ft)²(0.368)(1.50)} = 86.91 \text{ kip/ft}$$

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

$$R_\tau = \text{[190.88 kip/ft + 45.43 kip/ft + (86.91 kip/ft)sin(14.6°)](0.53)} = 136.86 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{91.24 kip/ft} \le \text{(136.86 kip/ft)(1.0) = 136.86 kip/ft} \longrightarrow \text{91.24 kip/ft} \le \text{136.86 kip/ft}$$ **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) = 33.7 ft
MSE Wall Width (Reinforcement Length), (B) = 47.2 ft
Distance from Wall Face to Toe of Backslope, (l) = 4.0 ft
MSE Wall Length, (L) = 746 ft
MSE Wall Effective Height, (h) = 51.2 ft
Retained Soil Backslope, (β) = 26.6 °
Effective Retained Soil Backslope, (θ) = 14.6 °
Distance from Toe to Top of Backslope, (z) = 35.0 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) = 0.368
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, [$(s_u)_{BS}$] = 2750 psf
Embedment Depth, (D_f) = 0.0 ft
Depth to GW (Below Bot. of Wall), (D_W) = 22.0 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

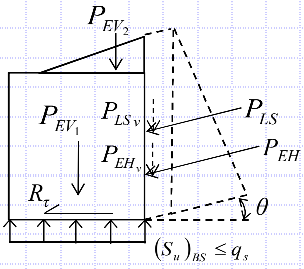
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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)

$(S_u)_{BS}$ = 2.75 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)(33.7 ft)(47.2 ft)(1.00) = 190.9 kip/ft

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

P_{EV_2}= ½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.00) = 45.43 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(51.2 ft)²(0.368)(1.50) = 86.91 kip/ft

P_V = 190.88 kip/ft + 45.43 kip/ft + (86.91 kip/ft)sin(14.6°) = 258.22 kip/ft

σ_v = (258.22 kip/ft) / (47.2 ft) = 5.47 ksf

q_s = (5.47 ksf) / 2 = 2.74 ksf

R_τ = (2.75 ksf ≤ 2.74 ksf)(47.2 ft) = 129.80 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 91.24 kip/ft ≤ (129.80 kip/ft)(1.0) = 129.80 kip/ft ⟶ 91.24 kip/ft ≤ 129.80 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) =	33.7	ft
MSE Wall Width (Reinforcement Length), (B) =	47.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	51.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	14.6	°
Distance from Toe to Top of Backslope, (z) =	35.0	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) =	0.368	
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, $[(s_u)_{BS}]$ =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	22.0	ft

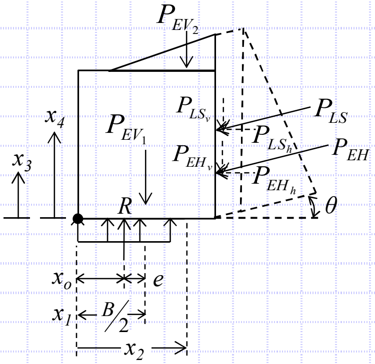
LRFD Load Factors

	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



$$e = B/2 - x_o$$

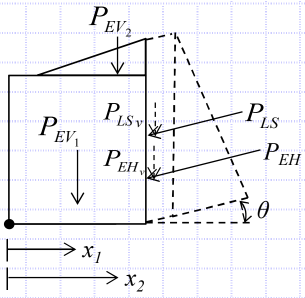
$$x_o = \frac{M_V - M_H}{P_V}$$ = (7028.9 kip·ft/ft - 1640.95 kip·ft/ft) / (258.22 kip/ft = 20.87 ft

M_V = 7028.90 kip·ft/ft
M_H = 1640.95 kip·ft/ft } Defined below

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 190.88 kip/ft + 45.43 kip/ft + (86.91 kip/ft)sin(14.6°) = 258.22 kip/ft

$e =$ (47.2 ft/ 2) - 20.87 ft = 2.73 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)(33.7 ft)(47.2 ft)(1.00) = 190.88 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.00) = 45.43 kip/ft

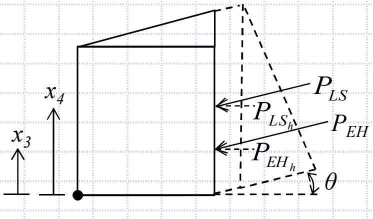
$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(51.2 ft)²(0.368)(1.50) = 86.91 kip/ft

$x_1 = B/2$ = (47.2 ft) / 2 = 23.60 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(47.2 ft - 4.0 ft) = 32.80 ft

M_V = (190.88 kip/ft)(23.60 ft) + (45.43 kip/ft)(32.8 ft) + (86.91 kip/ft)sin(14.6°)(47.2 ft) = 7028.90 kip·ft/ft

Overturning Moment, M_H:



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

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(51.2 ft)²(0.368)(1.50) = 86.91 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(51.2 ft)(0.368)(1.75) = 8.25 kip/ft

$x_3 = h/3$ = (51.2 ft) / 3 = 17.08 ft

$x_4 = h/2$ = (51.2 ft) / 2 = 25.61 ft

M_H = (86.91 kip/ft)cos(14.6°)(17.08 ft) + (8.25 kip/ft)cos(14.6°)(25.61 ft = 1640.95 kip·ft/ft

---

Check Eccentricity Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (47.2 ft) / 3 = 15.73 ft

$e < e_{\max} \longrightarrow$ 2.73 ft < 15.73 ft **OK**

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	4	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 601+83 to 603+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.7	ft
MSE Wall Width (Reinforcement Length), (B) =	47.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	51.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	14.6	°
Distance from Toe to Top of Backslope, (z) =	35.0	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) =	0.368	
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)$_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	22.0	ft

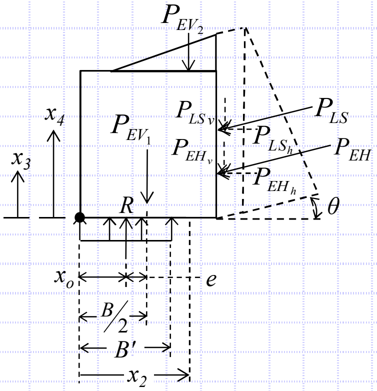
LRFD Load Factors

	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



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

$B' = B - 2e$ = 47.2 ft - 2(1.64 ft) = 43.92 ft

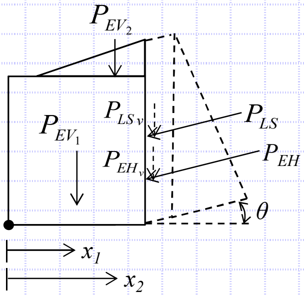
$e = {B}/{2} - x_o$ = (47.2 ft / 2) - 21.96 ft = 1.64 ft

$x_o = \frac{M_V - M_H}{P_V}$ = (9126.90 kip·ft/ft - 1640.95 kip·ft/ft) / 340.92 kip/f = 21.96 ft

q_{eq} = (340.92 kip/ft) / (43.92 ft) = 7.76 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)(33.7 ft)(47.2 ft)(1.35) = 257.68 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.35) = 61.33 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(51.2 ft)²(0.368)(1.50) = 86.91 kip/ft

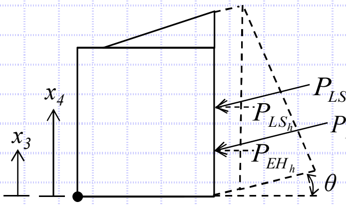
$x_1 = {B}/{2}$ = (47.2 ft) / 2 = 23.60 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 4.0 ft + ⅔(47.2 ft - 4.0 ft) = 32.80 ft

M_V = (257.68 kip/ft)(23.60 ft) + (61.33 kip/ft)(32.8 ft) + (86.91 kip/ft)sin(14.6°)(47.2 ft) = 9126.90 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(51.2 ft)²(0.368)(1.50) = 86.91 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(51.2 ft)(0.368)(1.75) = 8.25 kip/ft

$x_3 = {h}/{3}$ = (51.2 ft) / 3 = 17.08 ft

$x_4 = {h}/{2}$ = (51.2 ft) / 2 = 25.61 ft

M_H = (86.91 kip/ft)cos(14.6°)(17.08 ft) + (8.25 kip/ft)cos(14.6°)(25.61 ft = 1640.95 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 257.68 kip/ft + 61.33 kip/ft + (86.91 kip/ft)sin(14.6°) = 340.92 kip/ft

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	5	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 601+83 to 603+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.7	ft
MSE Wall Width (Reinforcement Length), (B) =	47.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	51.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	14.6	°
Distance from Toe to Top of Backslope, (z) =	35.0	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) =	0.368	
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, [$(s_u)_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	22.0	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 11.10.5.4 *(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_c = 25.800
s_c = 1+(43.92 ft/746 ft)(14.72/25.8)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.7

N_q = 14.720
s_q = 1+(43.92 ft/746 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(0.0 ft/43.92 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 22.0 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_γ = 16.720
s_γ = 1-0.4(43.92 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 22.0 ft < 1.5(43.92 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (120 pcf)(0.0 ft)(14.7)(1.0) + ½(120 pcf)(43.9 ft)(16.7)(0.5) = 22.03 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot RC_{BC} \cdot \Phi_b \longrightarrow$ 7.76 ksf ≤ (22.03 ksf)(0.55)(0.65) = 7.88 ksf ⟶ 7.76 ksf ≤ 7.88 ksf **OK**

RC_{BC} = **0.55** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* ⟶ Use β_s = 15.0 ° H_s = 7.0 ft b = 0.0 ft
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_c = 5.140
s_c = 1+(43.92 ft/[(5)(746 ft)] = 1.000
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/43.92 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 22.0 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)
$C_{w\gamma}$ = 22.0 ft < 1.5(43.92 ft) + 0.0 ft = 0.500

$q_n =$ (2750 psf)(5.14) + (120 pcf)(0.0 ft)(1.0)(1.0) + ½(120 pcf)(43.9 ft)(0.0)(0.5) = 14.14 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot RC_{BC} \cdot \Phi_b \longrightarrow$ 7.76 ksf ≤ (14.14 ksf)(0.85)(0.65) = 7.81 ksf ⟶ 7.76 ksf ≤ 7.81 ksf **OK**

RC_{BC} = **0.85** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* ⟶ Use β_s = 15.0 ° H_s = 7.0 ft b = 0.0 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 601+83 to 603+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.7	ft
MSE Wall Width (Reinforcement Length), (B) =	47.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	51.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	14.6	°
Distance from Toe to Top of Backslope, (z) =	35.0	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) =	0.368	
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:

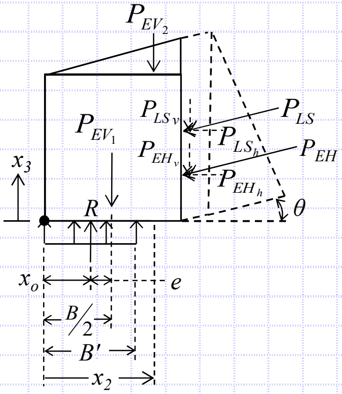
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2750	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	22.0	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



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

$$B' = B - 2e \quad = \quad 47.2\text{ ft} - 2(1.24\text{ ft}) \quad = \quad 44.72 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (47.2\text{ ft} / 2) - 22.36\text{ ft} \quad = \quad 1.24 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (6684.14\text{ kip·ft/ft} - 1074.25\text{ kip·ft/ft}) / 250.91\text{ kip/ft} \quad = \quad 22.36 \quad \text{ft}$$

$$q_{eq} \quad = \quad (250.91\text{ kip/ft}) / (44.72\text{ ft}) \quad = \quad 5.61 \quad \text{ksf}$$

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

M_V = [(120 pcf)(33.7 ft)(47.2 ft)(1.00)][½(47.2 ft)] + [½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(47.2 ft - 4.0 ft)] = 6684.14 kip·ft/ft
+ [½(120 pcf)(51.2 ft)²(0.368)(1.00)sin(14.6°)](47.2 ft)

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

M_H = ½[(120 pcf)(51.2 ft)²(0.368)(1.00)cos(14.6°)](51.2 ft /3) = 1,074.25 kip·ft/ft
+ [(250 psf)(51.2 ft)(0.368)(1.00)cos(14.6°)](51.2 ft /2)

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

P_V = (120 pcf)(33.7 ft)(47.2 ft)(1.00) + ½(120 pcf)(51.2 ft - 33.7 ft)(47.2 ft - 4.0 ft)(1.00) = 250.91 kip/ft
+ ½(120 pcf)(51.2 ft)²(0.368)(1.00)sin(14.6°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 601+83 to 603+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-105-5-14

H=	33.7	ft	Total wall height
B'=	44.7	ft	Effective footing width due to eccentricity
D_w =	22.0	ft	Depth below bottom of footing
q_e =	5,610	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)		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	2.0	2.0	1.0	120	240	120	120	4,120	27	0.153	0.015	0.483				0.02	1.000	5,610	5,730	0.061	0.735	0.500	2,805	2,925	0.029	0.343
	A-6a	C	2.0	4.0	2.0	3.0	120	480	360	360	4,360	27	0.153	0.015	0.483				0.07	0.999	5,604	5,964	0.050	0.605	0.500	2,805	3,165	0.019	0.234
2	A-2-4	G	4.0	7.0	3.0	5.5	135	885	683	683	4,683					104	142	851	0.12	0.994	5,577	6,259	0.003	0.041	0.500	2,803	3,485	0.002	0.030
	A-2-4	G	7.0	10.0	3.0	8.5	135	1,290	1,088	1,088	5,088					104	125	688	0.19	0.980	5,499	6,586	0.003	0.041	0.499	2,797	3,885	0.002	0.029
3	A-6b	C	10.0	12.0	2.0	11.0	120	1,530	1,410	1,410	5,410	38	0.252	0.025	0.569				0.25	0.961	5,392	6,802	0.051	0.608	0.497	2,788	4,198	0.015	0.183
	A-6b	C	12.0	14.0	2.0	13.0	120	1,770	1,650	1,650	5,650	38	0.252	0.025	0.569				0.29	0.941	5,281	6,931	0.046	0.548	0.495	2,778	4,428	0.014	0.165
4	A-4b	C	14.0	16.5	2.5	15.3	120	2,070	1,920	1,920	5,920	22	0.108	0.011	0.444				0.34	0.915	5,134	7,054	0.023	0.281	0.493	2,764	4,684	0.007	0.087
5	A-1-a	G	16.5	20.5	4.0	18.5	130	2,590	2,330	2,330	6,330					28	27	90	0.41	0.873	4,895	7,225	0.022	0.263	0.488	2,735	5,065	0.015	0.180
6	A-1-a	G	20.5	25.5	5.0	23.0	135	3,265	2,928	2,865	6,865					74	65	242	0.51	0.809	4,539	7,404	0.009	0.102	0.478	2,683	5,548	0.006	0.071
	A-1-a	G	25.5	30.5	5.0	28.0	135	3,940	3,603	3,228	7,228					74	62	227	0.63	0.739	4,147	7,375	0.008	0.095	0.465	2,609	5,837	0.006	0.068
	A-1-a	G	30.5	35.5	5.0	33.0	135	4,615	4,278	3,591	7,591					74	60	213	0.74	0.675	3,784	7,375	0.007	0.088	0.450	2,523	6,114	0.005	0.065
7	A-1-b	G	35.5	38.5	3.0	37.0	130	5,005	4,810	3,874	7,874					37	29	96	0.83	0.628	3,521	7,395	0.009	0.106	0.436	2,447	6,321	0.007	0.080
																				Total Settlement:			3.512 in		Total Settlement:			1.535 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 601+83 to 603+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-105-5-14

H=	33.7	ft	Total wall height
B'=	44.7	ft	Effective footing width due to eccentricity
D_w =	22.0	ft	Depth below bottom of footing
q_e =	5,610	psf	Equivalent bearing pressure at bottom of wall

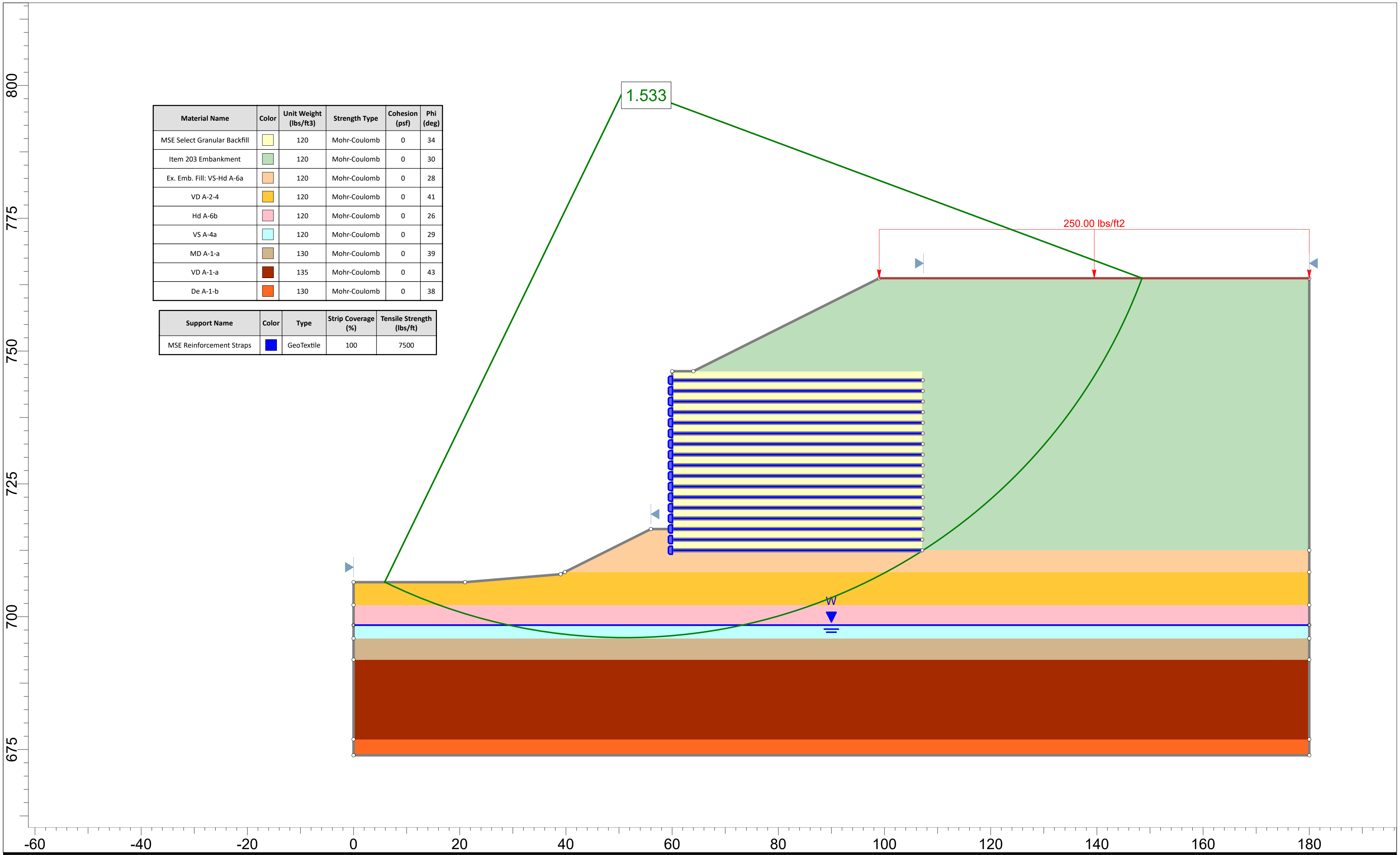
	A-6a	A-6b	A-4b		
c_v =	600	300	1000	ft^2/yr	Coefficient of consolidation
t =	5	5	5	days	Time following completion of construction
H_{dr} =	2.0	4	2.5	ft	Length of longest drainage path considered
T_v =	2.055	0.257	2.192		Time factor
U =	99	57	100	%	Degree of consolidation

$(S_c)_t$ = 1.380 in Settlement complete at 90% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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)	Layer Settlement (in)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.0	2.0	1.0	120	240	120	120	4,120	27	0.153	0.015	0.483				0.02	0.500	2,805	2,925	0.029	0.343	0.577	0.340	0.571
	A-6a	C	2.0	4.0	2.0	3.0	120	480	360	360	4,360	27	0.153	0.015	0.483				0.07	0.500	2,805	3,165	0.019	0.234		0.231	
2	A-2-4	G	4.0	7.0	3.0	5.5	135	885	683	683	4,683					104	142	851	0.12	0.500	2,803	3,485	0.002	0.030	0.059	0.030	0.059
	A-2-4	G	7.0	10.0	3.0	8.5	135	1,290	1,088	1,088	5,088					104	125	688	0.19	0.499	2,797	3,885	0.002	0.029		0.029	
3	A-6b	C	10.0	12.0	2.0	11.0	120	1,530	1,410	1,410	5,410	38	0.252	0.025	0.569				0.25	0.497	2,788	4,198	0.015	0.183	0.348	0.104	0.198
	A-6b	C	12.0	14.0	2.0	13.0	120	1,770	1,650	1,650	5,650	38	0.252	0.025	0.569				0.29	0.495	2,778	4,428	0.014	0.165		0.094	
4	A-4b	C	14.0	16.5	2.5	15.3	120	2,070	1,920	1,920	5,920	22	0.108	0.011	0.444				0.34	0.493	2,764	4,684	0.007	0.087	0.087	0.087	0.087
5	A-1-a	G	16.5	20.5	4.0	18.5	130	2,590	2,330	2,330	6,330					28	27	90	0.41	0.488	2,735	5,065	0.015	0.180	0.180	0.180	0.180
6	A-1-a	G	20.5	25.5	5.0	23.0	135	3,265	2,928	2,865	6,865					74	65	242	0.51	0.478	2,683	5,548	0.006	0.071	0.204	0.071	0.204
	A-1-a	G	25.5	30.5	5.0	28.0	135	3,940	3,603	3,228	7,228					74	62	227	0.63	0.465	2,609	5,837	0.006	0.068		0.068	
	A-1-a	G	30.5	35.5	5.0	33.0	135	4,615	4,278	3,591	7,591					74	60	213	0.74	0.450	2,523	6,114	0.005	0.065		0.065	
7	A-1-b	G	35.5	38.5	3.0	37.0	130	5,005	4,810	3,874	7,874					37	29	96	0.83	0.436	2,447	6,321	0.007	0.080	0.080	0.080	0.080

Settlement Remaining After Hold Period: 0.155 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. $(N1)_{60} = C_nN_{60}$, 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)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Mohr-Coulomb	0	28
VD A-2-4	🟨	120	Mohr-Coulomb	0	41
Hd A-6b	🟪	120	Mohr-Coulomb	0	26
VS A-4a	🟦	120	Mohr-Coulomb	0	29
MD A-1-a	🟫	130	Mohr-Coulomb	0	39
VD A-1-a	🟥	135	Mohr-Coulomb	0	43
De A-1-b	🟧	130	Mohr-Coulomb	0	38

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

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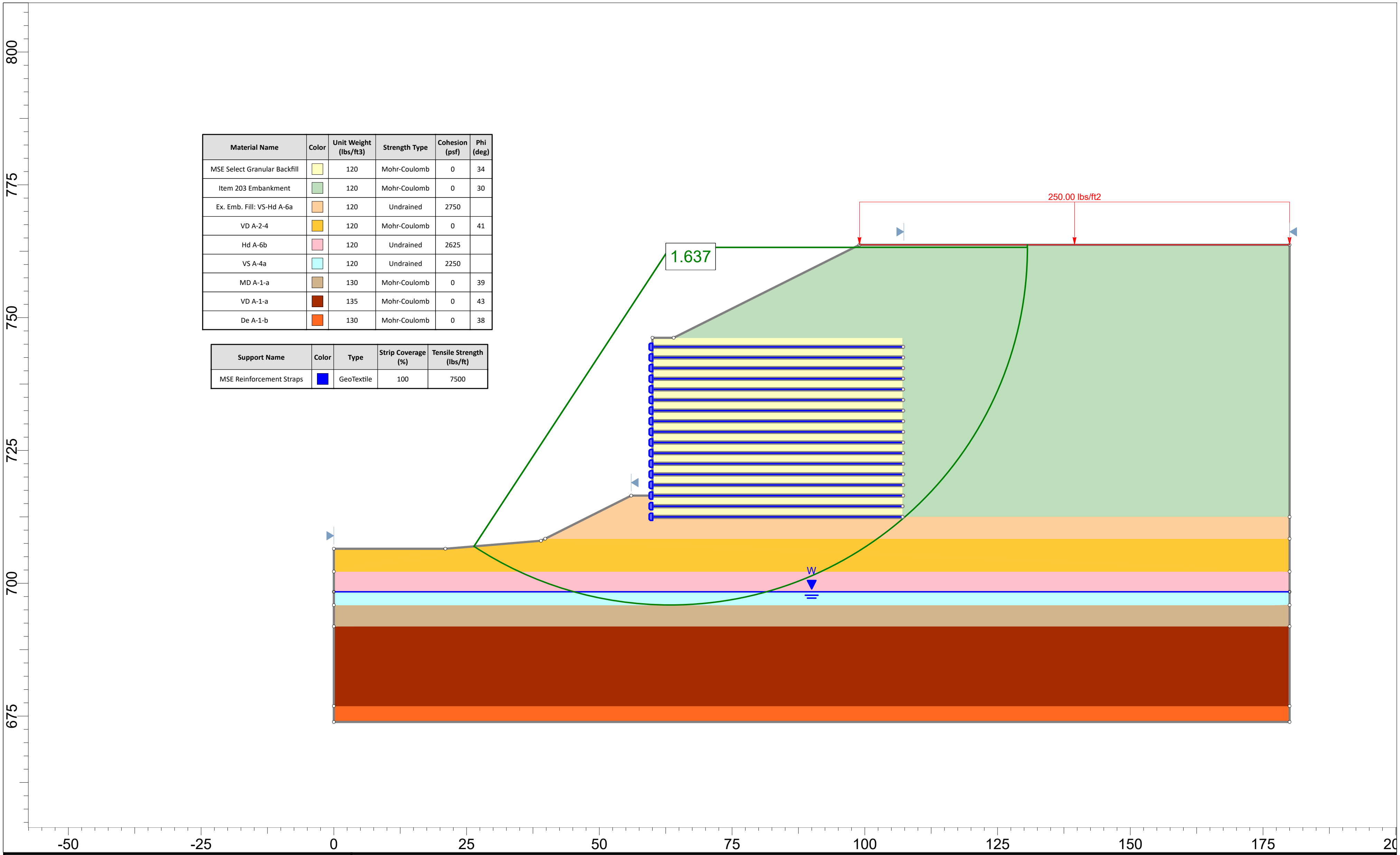
Project	Retaining Wall W5 - Sta. 601+83 to 605+50 - MSE Wall Global Stability
Analysis Description	33.7 ft Wall Height - B-105-5-14 - Drained - Circular - Spencer method

Drawn By	BRT	*Scale*	1:300	*Company*	Resource International, Inc
Date	7/3/2019			*File Name*	Retaining Wall W5 - Sta. 601+83 to 605+50 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Undrained	2750	
VD A-2-4	🟨	120	Mohr-Coulomb	0	41
Hd A-6b	🟪	120	Undrained	2625	
VS A-4a	🟦	120	Undrained	2250	
MD A-1-a	🟫	130	Mohr-Coulomb	0	39
VD A-1-a	🟥	135	Mohr-Coulomb	0	43
De A-1-b	🟧	130	Mohr-Coulomb	0	38

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

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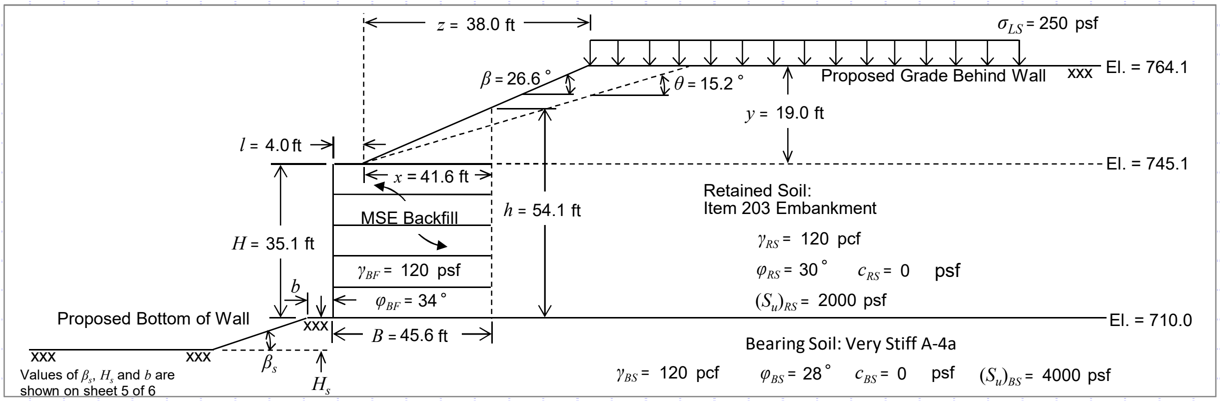
SLIDEINTERPRET 8.020

Project	Retaining Wall W5 - Sta. 601+83 to 605+50 - MSE Wall Global Stability
Analysis Description	33.7 ft Wall Height - B-105-5-14 - Undrained - Circular - Spencer method
Drawn By	BRT
Scale	1:300
Company	Resource International, Inc
Date	7/3/2019
File Name	Retaining Wall W5 - Sta. 601+83 to 605+50 - Global Stability.slim

Retaining Wall W5 - Sta. 603+50 to 605+50 - B-107-2-14 - 2:1 Broken Backslope - 35.1 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
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, $[(S_u)_{BS}]$ =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	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

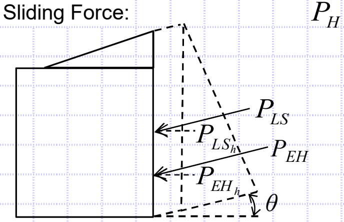
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \tfrac{1}{2}(120\text{ pcf})(54.1\text{ ft})^2(0.372)(1.50) = 98.09\text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = (250\text{ psf})(54.1\text{ ft})(0.372)(1.75) = 7.88\text{ kip/ft}$$

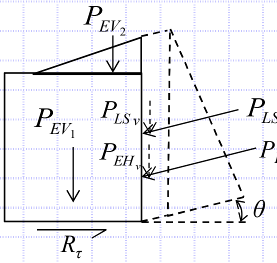
$$P_H = (98.09\text{ kip/ft} + 7.88\text{ kip/ft})\cos(15.2°) = 102.26\text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

$$R_\tau = \left(P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta\right)\tan\delta$$

(Neglect P_{LS_v} for conservatism)



$$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV} = (120\text{ pcf})(35.1\text{ ft})(45.6\text{ ft})(1.00) = 192.07\text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \tfrac{1}{2}(120\text{ pcf})(54.1\text{ ft} - 35.1\text{ ft})(45.6\text{ ft} - 4.0\text{ ft})(1.00) = 47.5\text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \tfrac{1}{2}(120\text{ pcf})(54.1\text{ ft})^2(0.372)(1.50) = 98.09\text{ kip/ft}$$

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

$$R_\tau = [192.07\text{ kip/ft} + 47.50\text{ kip/ft} + (98.09\text{ kip/ft})\sin(15.2°)](0.53) = 140.60\text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau\cdot\phi_\tau \longrightarrow 102.26\text{ kip/ft} \le (140.60\text{ kip/ft})(1.0) = 140.60\text{ kip/ft} \longrightarrow 102.26\text{ kip/ft} \le 140.60\text{ kip/ft}$$

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) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
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, [$(s_u)_{BS}$] =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	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

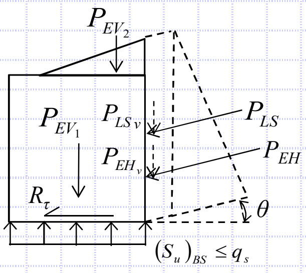
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



(Neglect P_{LS_V} for conservatism)

$(S_u)_{BS}$ = 4.00 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)(35.1 ft)(45.6 ft)(1.00) = 192.1 kip/ft

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

P_{EV_2}= ½(120 pcf)(54.1 ft - 35.1 ft)(45.6 ft - 4.0 ft)(1.00) = 47.5 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2 K_a \gamma_{EH}$ = ½(120 pcf)(54.1 ft)²(0.372)(1.50) = 98.09 kip/ft

P_V = 192.07 kip/ft + 47.5 kip/ft + (98.09 kip/ft)sin(15.2°) = 265.29 kip/ft

σ_v = (265.29 kip/ft) / (45.6 ft) = 5.82 ksf

q_s = (5.82 ksf) / 2 = 2.91 ksf

R_τ = (4.00 ksf ≤ 2.91 ksf)(45.6 ft) = 182.40 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 102.26 kip/ft ≤ (182.40 kip/ft)(1.0) = 182.40 kip/ft ⟶ 102.26 kip/ft ≤ 182.40 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) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing Soil Properties:

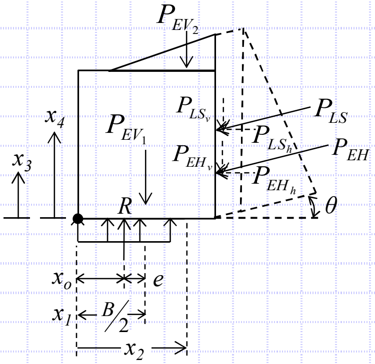
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	ft

LRFD Load Factors

	EV	EH	LS	
Strength Ia	1.00	1.50	1.75	*(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)*
Strength Ib	1.35	1.50	1.75	
Service I	1.00	1.00	1.00	

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (7059.12 kip·ft/ft - 1937.7 kip·ft/ft) / (265.29 kip/ft = 19.30 ft

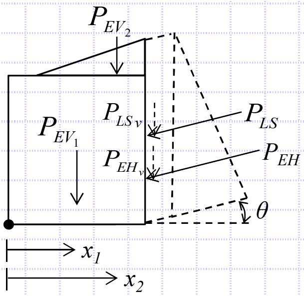
M_V = 7059.12 kip·ft/ft
M_H = 1937.70 kip·ft/ft
Defined below

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 192.07 kip/ft + 47.5 kip/ft + (98.09 kip/ft)sin(15.2°) = 265.29 kip/ft

$e =$ (45.6 ft/ 2) - 19.3 ft = 3.50 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)(35.1 ft)(45.6 ft)(1.00) = 192.07 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(54.1 ft - 35.1 ft)(45.6 ft - 4.0 ft)(1.00) = 47.5 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(54.1 ft)²(0.372)(1.50) = 98.09 kip/ft

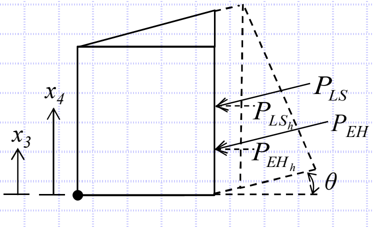
$x_1 = B/2$ = (45.6 ft) / 2 = 22.80 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 4.0 ft + ⅔(45.6 ft - 4.0 ft) = 31.73 ft

M_V = (192.07 kip/ft)(22.80 ft) + (47.5 kip/ft)(31.73 ft) + (98.09 kip/ft)sin(15.2°)(45.6 ft) = 7059.12 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(54.1 ft)²(0.372)(1.50) = 98.09 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(54.1 ft)(0.372)(1.75) = 8.81 kip/ft

$x_3 = h/3$ = (54.1 ft) / 3 = 18.04 ft

$x_4 = h/2$ = (54.1 ft) / 2 = 27.06 ft

M_H = (98.09 kip/ft)cos(15.2°)(18.04 ft) + (8.81 kip/ft)cos(15.2°)(27.06 ft = 1937.70 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (45.6 ft) / 3 = 15.20 ft

$e < e_{\max} \longrightarrow$ 3.50 ft < 15.20 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
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, [$(s_u)_{BS}$] =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	ft

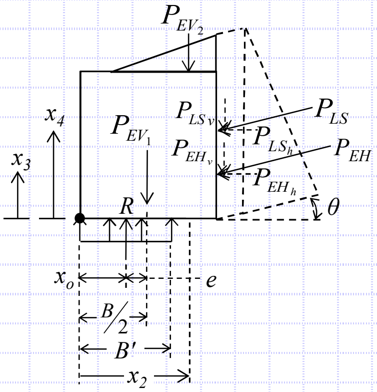
LRFD Load Factors

	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)

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



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

$B' = B - 2e$ = 45.6 ft - 2(2.23 ft) = 41.14 ft

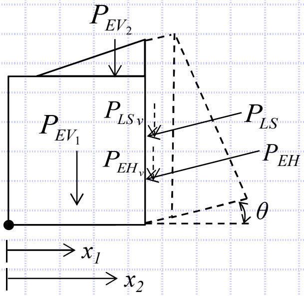
$e = B/2 - x_o$ = (45.6 ft / 2) - 20.57 ft = 2.23 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (9119.09 kip·ft/ft - 1937.70 kip·ft/ft) / 349.13 kip/f = 20.57 ft

q_{eq} = (349.13 kip/ft) / (41.14 ft) = 8.49 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)(35.1 ft)(45.6 ft)(1.35) = 259.29 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(54.1 ft - 35.1 ft)(45.6 ft - 4.0 ft)(1.35) = 64.12 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(54.1 ft)²(0.372)(1.50) = 98.09 kip/ft

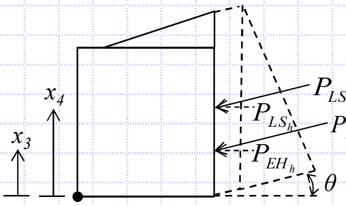
$x_1 = B/2$ = (45.6 ft) / 2 = 22.80 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(45.6 ft - 4.0 ft) = 31.73 ft

M_V = (259.29 kip/ft)(22.80 ft) + (64.12 kip/ft)(31.7 ft) + (98.09 kip/ft)sin(15.2°)(45.6 ft) = 9119.09 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(54.1 ft)²(0.372)(1.50) = 98.09 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(54.1 ft)(0.372)(1.75) = 8.81 kip/ft

$x_3 = h/3$ = (54.1 ft) / 3 = 18.04 ft

$x_4 = h/2$ = (54.1 ft) / 2 = 27.06 ft

M_H = (98.09 kip/ft)cos(15.2°)(18.04 ft) + (8.81 kip/ft)cos(15.2°)(27.06 ft = 1937.70 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 259.29 kip/ft + 64.12 kip/ft + (98.09 kip/ft)sin(15.2°) = 349.13 kip/ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
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, [$(s_u)_{BS}$] =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	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)

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

$N_{cm} = N_c s_c i_c$ = 25.8

N_c = 25.800
s_c = 1+(41.14 ft/746 ft)(14.72/25.8)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.7

N_q = 14.720
s_q = 1+(41.14 ft/746 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(0.0 ft/41.14 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 17.5 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_γ = 16.720
s_γ = 1-0.4(41.14 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 17.5 ft < 1.5(41.14 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (120 pcf)(0.0 ft)(14.7)(1.0) + ½(120 pcf)(41.1 ft)(16.7)(0.5) = 20.64 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 8.49 ksf ≤ (20.64 ksf)(0.64)(0.65) = 8.59 ksf $\longrightarrow$ 8.49 ksf ≤ 8.59 ksf **OK**

RC_{BC} = **0.64** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* $\longrightarrow$ Use β_s = 10.0 ° H_s = 4.0 ft b = 0.0 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.140

N_c = 5.140
s_c = 1+(41.14 ft/[(5)(746 ft)] = 1.000
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/41.14 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 17.5 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)
$C_{w\gamma}$ = 17.5 ft < 1.5(41.14 ft) + 0.0 ft = 0.500

$q_n =$ (4000 psf)(5.14) + (120 pcf)(0.0 ft)(1.0)(1.0) + ½(120 pcf)(41.1 ft)(0.0)(0.5) = 20.56 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot RC_{BC} \cdot \phi_b \longrightarrow$ 8.49 ksf ≤ (20.56 ksf)(0.86)(0.65) = 11.49 ksf $\longrightarrow$ 8.49 ksf ≤ 11.49 ksf **OK**

RC_{BC} = **0.86** *(Per AASHTO LRFD BDM Section 10.6.3.1.2c)* $\longrightarrow$ Use β_s = 10.0 ° H_s = 4.0 ft b = 0.0 ft
Use φ_b = **0.65** *(Per AASHTO LRFD BDM Table 11.5.6-1)*

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JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	6/29/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 603+50 to 605+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	35.1	ft
MSE Wall Width (Reinforcement Length), (B) =	45.6	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	54.1	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	38.0	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) =	0.372	
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, [$(s_u)_{BS}$] =	4000	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.5	ft

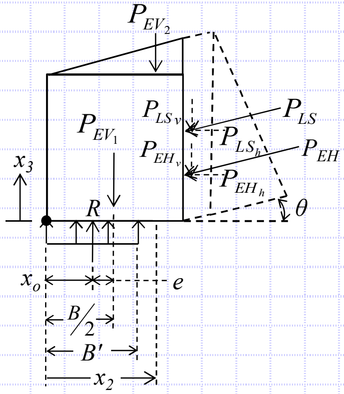
LRFD Load Factors

	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)

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



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

$$B' = B - 2e$$ = 45.6 ft - 2(1.77 ft) = 42.06 ft

$$e = B/2 - x_o$$ = (45.6 ft / 2) - 21.03 ft = 1.77 ft

$$x_o = \frac{M_V - M_H}{P_V}$$ = (6668.22 kip·ft/ft - 1270.14 kip·ft/ft) / 256.71 kip/ft = 21.03 ft

q_{eq} = (256.71 kip/ft) / (42.06 ft) = 6.10 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)(35.1 ft)(45.6 ft)(1.00)][½(45.6 ft)] + [½(120 pcf)(54.1 ft - 35.1 ft)(45.6 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(45.6 ft - 4.0 ft)] = 6668.22 kip·ft/ft
+ [½(120 pcf)(54.1 ft)²(0.372)(1.00)sin(15.2°)](45.6 ft)

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

M_H = ½[(120 pcf)(54.1 ft)²(0.372)(1.00)cos(15.2°)](54.1 ft /3) = 1,270.14 kip·ft/ft
+ [(250 psf)(54.1 ft)(0.372)(1.00)cos(15.2°)](54.1 ft /2)

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

P_V = (120 pcf)(35.1 ft)(45.6 ft)(1.00) + ½(120 pcf)(54.1 ft - 35.1 ft)(45.6 ft - 4.0 ft)(1.00) = 256.71 kip/ft
+ ½(120 pcf)(54.1 ft)²(0.372)(1.00)sin(15.2°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 603+50 to 605+50

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-107-2-14

H=	35.1	ft	Total wall height
B'=	42.1	ft	Effective footing width due to eccentricity
D_w =	17.5	ft	Depth below bottom of footing
q_e =	6,100	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)		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	3.0	3.0	1.5	125	375	188	188	4,188	27	0.153	0.015	0.483				0.04	1.000	6,099	6,287	0.096	1.156	0.500	3,050	3,237	0.038	0.459
2	A-1-b	G	3.0	5.5	2.5	4.3	135	713	544	544	4,544					90	129	726	0.10	0.997	6,080	6,623	0.004	0.045	0.500	3,049	3,592	0.003	0.034
	A-1-b	G	5.5	8.0	2.5	6.8	135	1,050	881	881	4,881					90	115	591	0.16	0.988	6,024	6,905	0.004	0.045	0.499	3,045	3,926	0.003	0.033
3	A-6b	C	8.0	10.5	2.5	9.3	115	1,338	1,194	1,194	5,194	37	0.243	0.024	0.561				0.22	0.971	5,922	7,116	0.078	0.937	0.498	3,037	4,231	0.021	0.257
4	A-1-b	G	10.5	13.0	2.5	11.8	130	1,663	1,500	1,500	5,500					28	31	101	0.28	0.947	5,776	7,276	0.017	0.204	0.496	3,024	4,524	0.012	0.142
5	A-1-b	G	13.0	15.5	2.5	14.3	135	2,000	1,831	1,831	5,831					55	57	199	0.34	0.917	5,592	7,423	0.008	0.091	0.493	3,006	4,837	0.005	0.063
	A-1-b	G	15.5	18.5	3.0	17.0	135	2,405	2,203	2,203	6,203					55	53	184	0.40	0.879	5,360	7,562	0.009	0.105	0.488	2,979	5,181	0.006	0.073
	A-1-b	G	18.5	21.5	3.0	20.0	135	2,810	2,608	2,452	6,452					55	51	175	0.48	0.834	5,088	7,540	0.008	0.100	0.482	2,941	5,393	0.006	0.070
	A-1-b	G	21.5	24.5	3.0	23.0	135	3,215	3,013	2,669	6,669					55	50	168	0.55	0.789	4,812	7,482	0.008	0.096	0.475	2,896	5,565	0.006	0.068
6	A-3	G	24.5	27.5	3.0	26.0	130	3,605	3,410	2,880	6,880					42	37	89	0.62	0.745	4,542	7,422	0.014	0.167	0.466	2,844	5,723	0.010	0.121
																				Total Settlement:			2.946 in		Total Settlement:			1.321 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 $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 603+50 to 605+50

Calculated By:	BRT	Date:	6/30/2019
Checked By:	JPS	Date:	7/1/2019

Boring B-107-2-14

H=	35.1	ft	Total wall height
B'=	42.1	ft	Effective footing width due to eccentricity
D_w =	17.5	ft	Depth below bottom of footing
q_e =	6,100	psf	Equivalent bearing pressure at bottom of wall

	A-6a	A-6b			
c_v =	600	300		ft^2/yr	Coefficient of consolidation
t =	1	1		days	Time following completion of construction
H_{dr} =	1.5	1.25		ft	Length of longest drainage path considered
T_v =	0.731	0.526			Time factor
U =	87	78		%	Degree of consolidation

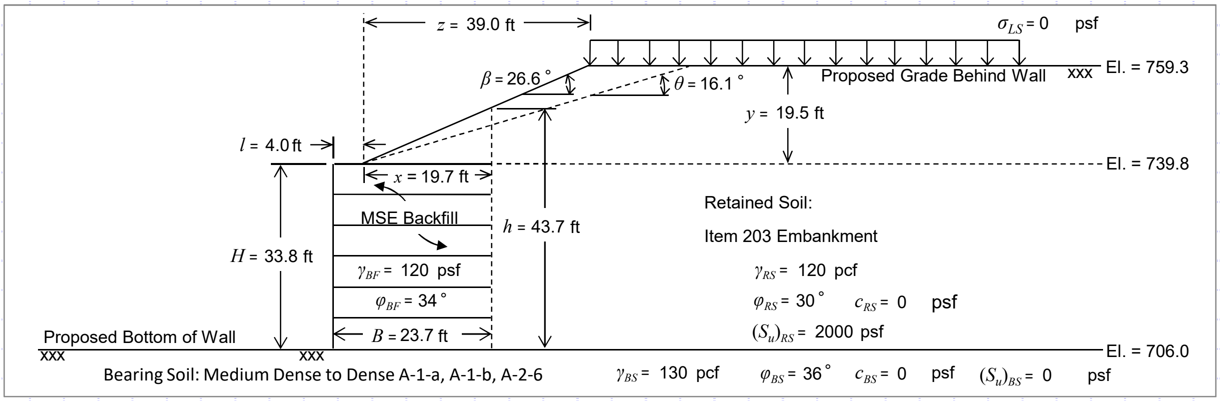
$(S_c)_t$ = 1.205 in Settlement complete at 91% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 91% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		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)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	3.0	3.0	1.5	125	375	188	188	4,188	27	0.153	0.015	0.483				0.04	0.500	3,050	3,237	0.038	0.459	0.459	0.400	0.400
2	A-1-b	G	3.0	5.5	2.5	4.3	135	713	544	544	4,544					90	129	726	0.10	0.500	3,049	3,592	0.003	0.034	0.067	0.034	0.067
	A-1-b	G	5.5	8.0	2.5	6.8	135	1,050	881	881	4,881					90	115	591	0.16	0.499	3,045	3,926	0.003	0.033		0.033	
3	A-6b	C	8.0	10.5	2.5	9.3	115	1,338	1,194	1,194	5,194	37	0.243	0.024	0.561				0.22	0.498	3,037	4,231	0.021	0.257	0.257	0.200	0.200
4	A-1-b	G	10.5	13.0	2.5	11.8	130	1,663	1,500	1,500	5,500					28	31	101	0.28	0.496	3,024	4,524	0.012	0.142	0.142	0.142	0.142
5	A-1-b	G	13.0	15.5	2.5	14.3	135	2,000	1,831	1,831	5,831					55	57	199	0.34	0.493	3,006	4,837	0.005	0.063	0.275	0.063	0.275
	A-1-b	G	15.5	18.5	3.0	17.0	135	2,405	2,203	2,203	6,203					55	53	184	0.40	0.488	2,979	5,181	0.006	0.073		0.073	
	A-1-b	G	18.5	21.5	3.0	20.0	135	2,810	2,608	2,452	6,452					55	51	175	0.48	0.482	2,941	5,393	0.006	0.070		0.070	
	A-1-b	G	21.5	24.5	3.0	23.0	135	3,215	3,013	2,669	6,669					55	50	168	0.55	0.475	2,896	5,565	0.006	0.068		0.068	
6	A-3	G	24.5	27.5	3.0	26.0	130	3,605	3,410	2,880	6,880					42	37	89	0.62	0.466	2,844	5,723	0.010	0.121	0.121	0.121	0.121

Settlement Remaining After Hold Period: 0.116 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. $(N1)_{60} = C_nN_{60}$, 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

Retaining Wall W5 - Sta. 605+50 to 607+00 - B-108-7-14 - 2:1 Broken Backslope - 33.8 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.8	ft
MSE Wall Width (Reinforcement Length), (B) =	23.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	43.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	16.1	°
Distance from Toe to Top of Backslope, (z) =	39.0	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) =	0.379	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	130	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	36	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.9	ft

LRFD Load Factors

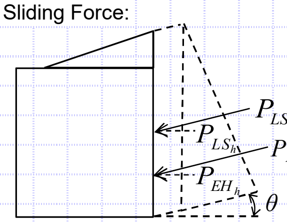
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

Sliding Force:



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

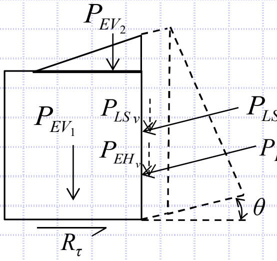
$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(43.7 ft)²(0.379)(1.50)} = 65.04 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = \text{(0 psf)(43.7 ft)(0.379)(1.75)} = 0.00 \text{ kip/ft}$$

$$P_H = \text{(65.04 kip/ft + 0.00 kip/ft)cos(16.1°)} = 62.49 \text{ kip/ft}$$

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)

$$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV} = \text{(120 pcf)(33.8 ft)(23.7 ft)(1.00)} = 96.13 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.00)} = 11.66 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(43.7 ft)²(0.379)(1.50)} = 65.04 \text{ kip/ft}$$

$$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF}) \longrightarrow \text{tan(36)} \le \text{tan(34)} \longrightarrow 0.73 \le 0.67 = 0.67$$

$$R_\tau = \text{[96.13 kip/ft + 11.66 kip/ft + (65.04 kip/ft)sin(16.1°)](0.67)} = 84.30 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau\cdot\phi_\tau \longrightarrow \text{62.49 kip/ft} \le \text{(84.30 kip/ft)(1.0) = 84.30 kip/ft} \longrightarrow \text{62.49 kip/ft} \le \text{84.30 kip/ft}$$ **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) =	33.8	ft
MSE Wall Width (Reinforcement Length), (B) =	23.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	43.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	16.1	°
Distance from Toe to Top of Backslope, (z) =	39.0	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) =	0.379	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	130	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	36	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.9	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

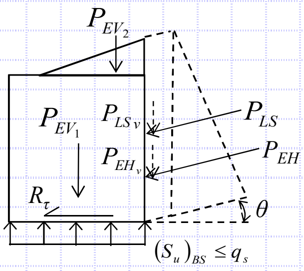
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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

Check 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)

$(S_u)_{BS}$ = N/A 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)(33.8 ft)(23.7 ft)(1.00) = 96.13 kip/ft

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

P_{EV_2} = ½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.00) = 11.66 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(43.7 ft)²(0.379)(1.50) = 65.04 kip/ft

P_V = 96.13 kip/ft + 11.66 kip/ft + (65.04 kip/ft)sin(16.1°) = 125.83 kip/ft

σ_v = (125.83 kip/ft) / (23.7 ft) = 5.31 ksf

q_s = (5.31 ksf) / 2 = 2.66 ksf

R_τ = (N/A ksf ≤ 2.66 ksf)(23.7 ft) = N/A kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ $\longrightarrow$ N/A $\longrightarrow$ N/A

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) =	33.8	ft
MSE Wall Width (Reinforcement Length), (B) =	23.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	43.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	16.1	°
Distance from Toe to Top of Backslope, (z) =	39.0	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) =	0.379	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	130	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	36	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.9	ft

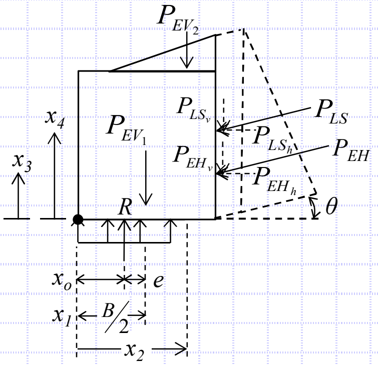
LRFD Load Factors

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



$$e = B/2 - x_o$$

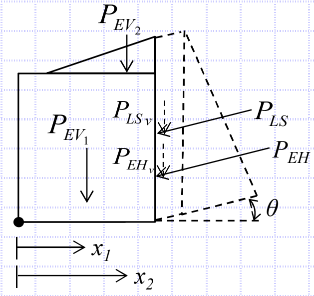
$$x_o = \frac{M_V - M_H}{P_V}$$ = (1766.34 kip·ft/ft - 909.84 kip·ft/ft) / (125.83 kip/ft = 6.81 ft

M_V = 1766.34 kip·ft/ft
M_H = 909.84 kip·ft/ft
} Defined below

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 96.13 kip/ft + 11.66 kip/ft + (65.04 kip/ft)sin(16.1°) = 125.83 kip/ft

$e =$ (23.7 ft/ 2) - 6.81 ft = 5.04 ft

Resisting Moment, M_V:



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

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(33.8 ft)(23.7 ft)(1.00) = 96.13 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.00) = 11.66 kip/ft

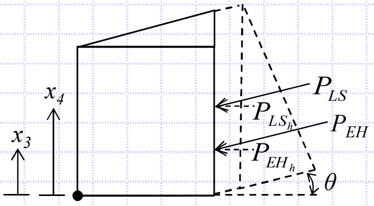
$P_{EH} = ½\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(43.7 ft)²(0.379)(1.50) = 65.04 kip/ft

$x_1 = B/2$ = (23.7 ft) / 2 = 11.85 ft

$x_2 = l + ⅔(B-l)$ = 4.0 ft + ⅔(23.7 ft - 4.0 ft) = 17.13 ft

M_V = (96.13 kip/ft)(11.85 ft) + (11.66 kip/ft)(17.13 ft) + (65.04 kip/ft)sin(16.1°)(23.7 ft) = 1766.34 kip·ft/ft

Overturning Moment, M_H:



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

$P_{EH} = ½\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(43.7 ft)²(0.379)(1.50) = 65.04 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (0 psf)(43.7 ft)(0.379)(1.75) = 0.00 kip/ft

$x_3 = h/3$ = (43.7 ft) / 3 = 14.56 ft

$x_4 = h/2$ = (43.7 ft) / 2 = 21.83 ft

M_H = (65.04 kip/ft)cos(16.1°)(14.56 ft) + (0 kip/ft)cos(16.1°)(21.83 ft) = 909.84 kip·ft/ft

---

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (23.7 ft) / 3 = 7.90 ft

$e < e_{\max} \longrightarrow$ 5.04 ft < 7.90 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.8	ft
MSE Wall Width (Reinforcement Length), (B) =	23.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	43.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	16.1	°
Distance from Toe to Top of Backslope, (z) =	39.0	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) =	0.379	
Live Surcharge Load, (σ_{LS}) =	0	psf

Bearing Soil Properties:

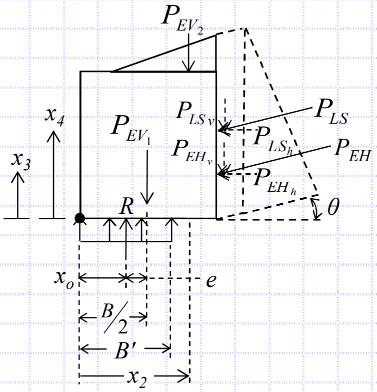
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	130	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	36	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.9	ft

LRFD Load Factors

	EV	EH	LS	
Strength Ia	1.00	1.50	1.75	*(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)*
Strength Ib	1.35	1.50	1.75	
Service I	1.00	1.00	1.00	

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



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

$B' = B - 2e$ = 23.7 ft - 2(3.75 ft) = 16.20 ft

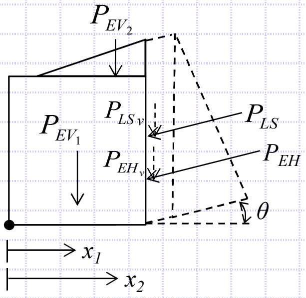
$e = B/2 - x_o$ = (23.7 ft / 2) - 8.1 ft = 3.75 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (2234.87 kip·ft/ft - 909.84 kip·ft/ft) / 163.55 kip/ft = 8.10 ft

$q_{eq} =$ (163.55 kip/ft) / (16.2 ft) = 10.10 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)(33.8 ft)(23.7 ft)(1.35) = 129.77 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.35) = 15.74 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(43.7 ft)²(0.379)(1.50) = 65.04 kip/ft

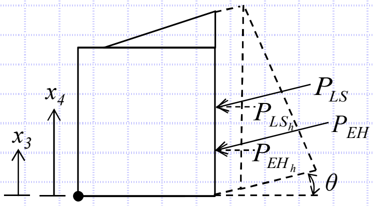
$x_1 = B/2$ = (23.7 ft) / 2 = 11.85 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(23.7 ft - 4.0 ft) = 17.13 ft

M_V = (129.77 kip/ft)(11.85 ft) + (15.74 kip/ft)(17.1 ft) + (65.04 kip/ft)sin(16.1°)(23.7 ft) = 2234.87 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(43.7 ft)²(0.379)(1.50) = 65.04 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (0 psf)(43.7 ft)(0.379)(1.75) = 0.00 kip/ft

$x_3 = h/3$ = (43.7 ft) / 3 = 14.56 ft

$x_4 = h/2$ = (43.7 ft) / 2 = 21.83 ft

M_H = (65.04 kip/ft)cos(16.1°)(14.56 ft) + (0 kip/ft)cos(16.1°)(21.83 ft) = 909.84 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 129.77 kip/ft + 15.74 kip/ft + (65.04 kip/ft)sin(16.1°) = 163.55 kip/ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	33.8	ft
MSE Wall Width (Reinforcement Length), (B) =	23.7	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	43.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	16.1	°
Distance from Toe to Top of Backslope, (z) =	39.0	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) =	0.379	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	130	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	36	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	17.9	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: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2}\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 50.59

N_c = 50.59
s_c = 1+(16.2 ft/746 ft)(37.75/50.59)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 37.8

N_q = 37.75
s_q = 1+(16.2 ft/746 ft)tan(36°) = 1.000
d_q = 1+2tan(36°)[1-sin(36°)]²tan⁻¹(0.0 ft/16.2 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 17.9 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 56.3

N_γ = 56.31
s_γ = 1-0.4(16.2 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 17.9 ft < 1.5(16.2 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(50.59) + (130 pcf)(0.0 ft)(37.8)(1.0) + ½(130 pcf)(16.2 ft)(56.3)(0.5) = 29.65 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ → 10.10 ksf ≤ (29.65 ksf)(0.65) = 19.27 ksf → 10.10 ksf ≤ 19.27 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_c = 5.140
s_c = 1+(16.2 ft/[(5)(746 ft)] = 1.000
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/16.2 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 17.9 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)
$C_{w\gamma}$ = 17.9 ft < 1.5(16.2 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(5.14) + (130 pcf)(0.0 ft)(1.0)(1.0) + ½(130 pcf)(16.2 ft)(0.0)(0.5) = N/A ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ → N/A → N/A

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

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JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 6 OF 6
CALCULATED BY BRT DATE 6/30/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 605+50 to 607+00

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 33.8 ft
MSE Wall Width (Reinforcement Length), (B) = 23.7 ft
Distance from Wall Face to Toe of Backslope, (l) = 4.0 ft
MSE Wall Length, (L) = 746 ft
MSE Wall Effective Height, (h) = 43.7 ft
Retained Soil Backslope, (β) = 26.6 °
Effective Retained Soil Backslope, (θ) = 16.1 °
Distance from Toe to Top of Backslope, (z) = 39.0 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) = 0.379
Live Surcharge Load, (σ_{LS}) = 0 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}) = 130 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 36 °
Bearing Soil Drained Cohesion, (c_{BS}) = 0 psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] = 0 psf
Embedment Depth, (D_f) = 0.0 ft
Depth to GW (Below Bot. of Wall), (D_W) = 17.9 ft

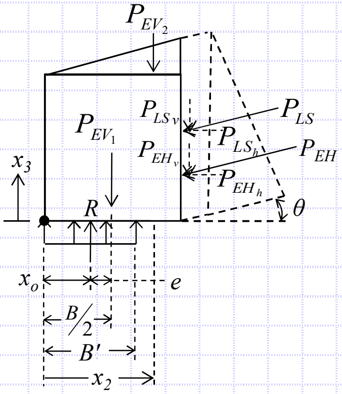
LRFD Load Factors

	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.

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



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

$$B' = B - 2e \quad = \quad \text{23.7 ft - 2(3.36 ft)} \quad = \quad 16.98 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad \text{(23.7 ft / 2) - 8.49 ft} \quad = \quad 3.36 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(1623.85 kip·ft/ft - 606.31 kip·ft/ft) / 119.81 kip/ft} \quad = \quad 8.49 \quad \text{ft}$$

$$q_{eq} \quad = \quad \text{(119.81 kip/ft) / (16.98 ft)} \quad = \quad 7.06 \quad \text{ksf}$$

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

M_V = [(120 pcf)(33.8 ft)(23.7 ft)(1.00)][½(23.7 ft)] + [½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(23.7 ft - 4.0 ft)] = 1623.85 kip·ft/ft
+ [½(120 pcf)(43.7 ft)²(0.379)(1.00)sin(16.1°)](23.7 ft)

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

M_H = ½[(120 pcf)(43.7 ft)²(0.379)(1.00)cos(16.1°)](43.7 ft /3) = 606.31 kip·ft/ft
+ [(0 psf)(43.7 ft)(0.379)(1.00)cos(16.1°)](43.7 ft /2)

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

P_V = (120 pcf)(33.8 ft)(23.7 ft)(1.00) + ½(120 pcf)(43.7 ft - 33.8 ft)(23.7 ft - 4.0 ft)(1.00) = 119.81 kip/ft
+ ½(120 pcf)(43.7 ft)²(0.379)(1.00)sin(16.1°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 605+50 to 607+00

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-108-7-14

H=	33.8	ft	Total wall height
B'=	17.0	ft	Effective footing width due to eccentricity
D_w =	17.9	ft	Depth below bottom of footing
q_e =	7,060	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)		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 (Emb.)	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	30	0.180	0.018	0.507				0.07	0.999	7,051	7,201	0.115	1.375	0.500	3,529	3,679	0.042	0.498
2	A-1-a	G	2.5	5.0	2.5	3.8	135	638	469	469	4,469					47	70	267	0.22	0.971	6,852	7,321	0.011	0.134	0.498	3,515	3,984	0.009	0.104
	A-1-a	G	5.0	7.5	2.5	6.3	135	975	806	806	4,806					47	61	222	0.37	0.900	6,355	7,162	0.011	0.128	0.491	3,466	4,272	0.008	0.098
	A-1-a	G	7.5	10.0	2.5	8.8	135	1,313	1,144	1,144	5,144					47	56	195	0.51	0.809	5,711	6,855	0.010	0.119	0.478	3,376	4,520	0.008	0.092
3	A-1-a	G	10.0	13.5	3.5	11.8	135	1,785	1,549	1,549	5,549					104	113	576	0.69	0.701	4,949	6,498	0.004	0.045	0.456	3,222	4,771	0.003	0.036
	A-1-a	G	13.5	17.0	3.5	15.3	135	2,258	2,021	2,021	6,021					104	104	499	0.90	0.594	4,197	6,218	0.003	0.041	0.425	3,004	5,025	0.003	0.033
4	A-1-b	G	17.0	20.5	3.5	18.8	125	2,695	2,476	2,423	6,423					17	16	66	1.10	0.510	3,603	6,026	0.021	0.251	0.393	2,773	5,197	0.018	0.210
	A-1-b	G	20.5	24.0	3.5	22.3	125	3,133	2,914	2,642	6,642					17	15	65	1.31	0.445	3,138	5,781	0.018	0.218	0.361	2,550	5,193	0.016	0.189
5	A-1-b	G	24.0	28.0	4.0	26.0	135	3,673	3,403	2,897	6,897					84	74	289	1.53	0.389	2,748	5,645	0.004	0.048	0.330	2,331	5,228	0.004	0.043
	A-1-b	G	28.0	32.0	4.0	30.0	135	4,213	3,943	3,187	7,187					84	71	274	1.76	0.343	2,420	5,607	0.004	0.043	0.301	2,123	5,310	0.003	0.039
																			Total Settlement:			2.403 in			Total Settlement:			1.341 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)

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 605+50 to 607+00

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-108-7-14

H=	33.8	ft	Total wall height
B'=	17.0	ft	Effective footing width due to eccentricity
D_w =	17.9	ft	Depth below bottom of footing
q_e =	7,060	psf	Equivalent bearing pressure at bottom of wall

	A-6a				
c_v =	600			ft^2/yr	Coefficient of consolidation
t =	1			days	Time following completion of construction
H_{dr} =	1.3			ft	Length of longest drainage path considered
T_v =	1.052				Time factor
U =	94			%	Degree of consolidation

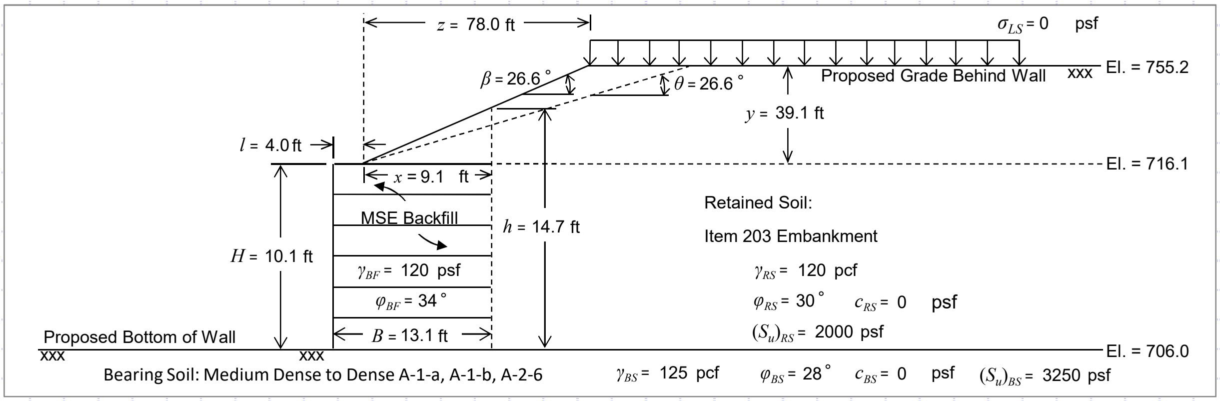
$(S_c)_t$ = 1.311 in Settlement complete at 98% of primary consolidation

																							Total Settlement at Facing of Wall			Settlement Complete at 98% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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)	Layer Settlement (in)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1 (Emb.)	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	30	0.180	0.018	0.507				0.07	0.500	3,529	3,679	0.042	0.498	0.498	0.468	0.468
2	A-1-a	G	2.5	5.0	2.5	3.8	135	638	469	469	4,469					47	70	267	0.22	0.498	3,515	3,984	0.009	0.104	0.294	0.104	0.294
	A-1-a	G	5.0	7.5	2.5	6.3	135	975	806	806	4,806					47	61	222	0.37	0.491	3,466	4,272	0.008	0.098		0.098	
	A-1-a	G	7.5	10.0	2.5	8.8	135	1,313	1,144	1,144	5,144					47	56	195	0.51	0.478	3,376	4,520	0.008	0.092		0.092	
3	A-1-a	G	10.0	13.5	3.5	11.8	135	1,785	1,549	1,549	5,549					104	113	576	0.69	0.456	3,222	4,771	0.003	0.036	0.069	0.036	0.069
	A-1-a	G	13.5	17.0	3.5	15.3	135	2,258	2,021	2,021	6,021					104	104	499	0.90	0.425	3,004	5,025	0.003	0.033		0.033	
4	A-1-b	G	17.0	20.5	3.5	18.8	125	2,695	2,476	2,423	6,423					17	16	66	1.10	0.393	2,773	5,197	0.018	0.210	0.399	0.210	0.399
	A-1-b	G	20.5	24.0	3.5	22.3	125	3,133	2,914	2,642	6,642					17	15	65	1.31	0.361	2,550	5,193	0.016	0.189		0.189	
5	A-1-b	G	24.0	28.0	4.0	26.0	135	3,673	3,403	2,897	6,897					84	74	289	1.53	0.330	2,331	5,228	0.004	0.043	0.081	0.043	0.081
	A-1-b	G	28.0	32.0	4.0	30.0	135	4,213	3,943	3,187	7,187					84	71	274	1.76	0.301	2,123	5,310	0.003	0.039		0.039	

Settlement Remaining After Hold Period: 0.030 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. $S_c = [C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$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

Retaining Wall W5 - Sta. 607+00 to 607+65 - B-108-8-14 - 2:1 Backslope - 10.1 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	10.1	ft
MSE Wall Width (Reinforcement Length), (B) =	13.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	14.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	78.0	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) =	0.526	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	3250	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	15.6	ft

LRFD Load Factors

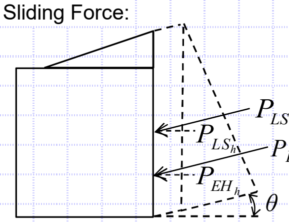
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(14.7 ft)²(0.526)(1.50)} = 10.17 \text{ kip/ft}$$

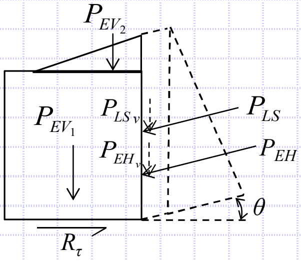
$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \text{(0 psf)(14.7 ft)(0.526)(1.75)} = 0.00 \text{ kip/ft}$$

$$P_H = \text{(10.17 kip/ft + 0.00 kip/ft)cos(26.6°)} = 9.09 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

$$R_\tau = (P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta)\tan\delta \qquad \text{(Neglect } P_{LS_v} \text{ for conservatism)}$$



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(10.1 ft)(13.1 ft)(1.00)} = 15.88 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(14.7 ft - 10.1 ft)(13.1 ft - 4.0 ft)(1.00)} = 2.49 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(14.7 ft)²(0.526)(1.50)} = 10.17 \text{ kip/ft}$$

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

$$R_\tau = \text{[15.88 kip/ft + 2.49 kip/ft + (10.17 kip/ft)sin(26.6°)](0.53)} = 12.15 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{9.09 kip/ft} \le \text{(12.15 kip/ft)(1.0) = 12.15 kip/ft} \longrightarrow \text{9.09 kip/ft} \le \text{12.15 kip/ft} \quad \textbf{OK}$$

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

JOB FRA-70-13.10 NO. W-13-072
SHEET NO. 2 OF 6
CALCULATED BY BRT DATE 6/30/2019
CHECKED BY JPS DATE 7/1/2019
Retaining Wall W5 - Sta. 607+00 to 607+65

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 10.1 ft
MSE Wall Width (Reinforcement Length), (B) = 13.1 ft
Distance from Wall Face to Toe of Backslope, (l) = 4.0 ft
MSE Wall Length, (L) = 746 ft
MSE Wall Effective Height, (h) = 14.7 ft
Retained Soil Backslope, (β) = 26.6 °
Effective Retained Soil Backslope, (θ) = 26.6 °
Distance from Toe to Top of Backslope, (z) = 78.0 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) = 0.526
Live Surcharge Load, (σ_{LS}) = 0 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}) = 125 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 28 °
Bearing Soil Drained Cohesion, (c_{BS}) = 0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ = 3250 psf
Embedment Depth, (D_f) = 0.0 ft
Depth to GW (Below Bot. of Wall), (D_W) = 15.6 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

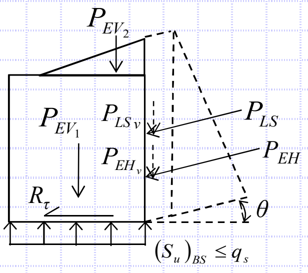
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



(Neglect $P_{LS\,v}$ for conservatism)

$$\left(S_u\right)_{BS} = 3.25 \text{ ksf}$$

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(10.1 ft)(13.1 ft)(1.00)} = 15.88 \text{ kip/ft}$$

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

$$P_{EV_2} = \text{½(120 pcf)(14.7 ft - 10.1 ft)(13.1 ft - 4.0 ft)(1.00)} = 2.49 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(14.7 ft)²(0.526)(1.50)} = 10.17 \text{ kip/ft}$$

$$P_V = \text{15.88 kip/ft + 2.49 kip/ft + (10.17 kip/ft)sin(26.6°)} = 22.92 \text{ kip/ft}$$

$$\sigma_v = \text{(22.92 kip/ft) / (13.1 ft)} = 1.75 \text{ ksf}$$

$$q_s = \text{(1.75 ksf) / 2} = 0.88 \text{ ksf}$$

$$R_\tau = \text{(3.25 ksf ≤ 0.88 ksf)(13.1 ft)} = 42.58 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 9.09 kip/ft ≤ (42.58 kip/ft)(1.0) = 42.58 kip/ft $\longrightarrow$ 9.09 kip/ft ≤ 42.58 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) =	10.1	ft
MSE Wall Width (Reinforcement Length), (B) =	13.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	14.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	78.0	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) =	0.526	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3250	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	15.6	ft

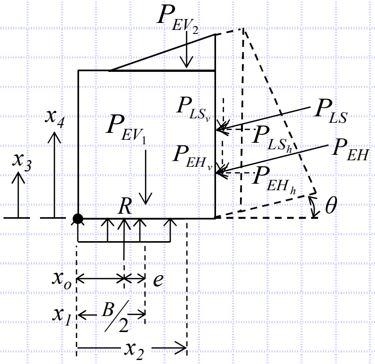
LRFD Load Factors

	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (188.74 kip·ft/ft - 44.47 kip·ft/ft) / (22.92 kip/ft) = 6.29 ft

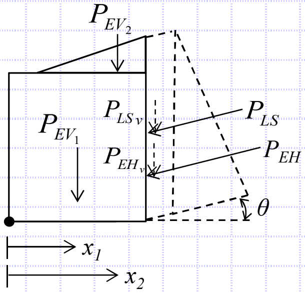
M_V = 188.74 kip·ft/ft
M_H = 44.47 kip·ft/ft
} Defined below

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 15.88 kip/ft + 2.49 kip/ft + (10.17 kip/ft)sin(26.6°) = 22.92 kip/ft

$e =$ (13.1 ft/ 2) - 6.29 ft = 0.26 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)(10.1 ft)(13.1 ft)(1.00) = 15.88 kip/ft

$P_{EV_2} = 1/2\,\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(14.7 ft - 10.1 ft)(13.1 ft - 4.0 ft)(1.00) = 2.49 kip/ft

$P_{EH} = 1/2\,\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(14.7 ft)²(0.526)(1.50) = 10.17 kip/ft

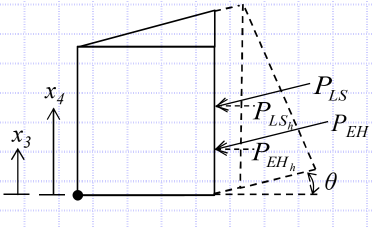
$x_1 = B/2$ = (13.1 ft) / 2 = 6.55 ft

$x_2 = l + 2/3(B-l)$ = 4.0 ft + ⅔(13.1 ft - 4.0 ft) = 10.07 ft

M_V = (15.88 kip/ft)(6.55 ft) + (2.49 kip/ft)(10.07 ft) + (10.17 kip/ft)sin(26.6°)(13.1 ft) = 188.74 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = 1/2\,\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(14.7 ft)²(0.526)(1.50) = 10.17 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (0 psf)(14.7 ft)(0.526)(1.75) = 0.00 kip/ft

$x_3 = h/3$ = (14.7 ft) / 3 = 4.89 ft

$x_4 = h/2$ = (14.7 ft) / 2 = 7.33 ft

M_H = (10.17 kip/ft)cos(26.6°)(4.89 ft) + (0 kip/ft)cos(26.6°)(7.33 ft) = 44.47 kip·ft/ft

---

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (13.1 ft) / 3 = 4.37 ft

$e < e_{\max} \longrightarrow$ 0.26 ft < 4.37 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	10.1	ft
MSE Wall Width (Reinforcement Length), (B) =	13.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	14.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	78.0	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) =	0.526	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3250	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	15.6	ft

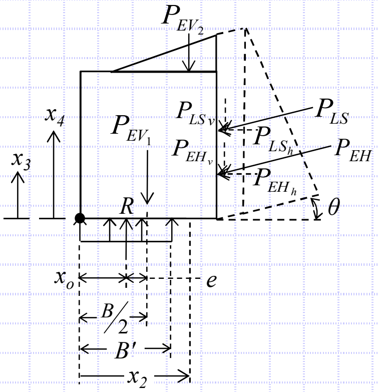
LRFD Load Factors

	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



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

$$B' = B - 2e \quad = \quad 13.1\text{ ft} - 2(0.09\text{ ft}) \quad = \quad 12.92 \quad \text{ft}$$

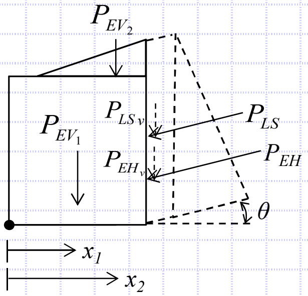
$$e = B/2 - x_o \quad = \quad (13.1\text{ ft} / 2) - 6.46\text{ ft} \quad = \quad 0.09 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (233.86\text{ kip·ft/ft} - 44.47\text{ kip·ft/ft}) / 29.34\text{ kip/ft} \quad = \quad 6.46 \quad \text{ft}$$

$$q_{eq} = \quad (29.34\text{ kip/ft}) / (12.92\text{ ft}) \quad = \quad 2.27 \quad \text{ksf}$$

Resisting Moment, M_V:

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad (120\text{ pcf})(10.1\text{ ft})(13.1\text{ ft})(1.35) \quad = \quad 21.43 \quad \text{kip/ft}$$

$$P_{EV_2} = ½\gamma_{RS}(h - H)(B - l)\gamma_{EV} = ½(120\text{ pcf})(14.7\text{ ft} - 10.1\text{ ft})(13.1\text{ ft} - 4.0\text{ ft})(1.35) = \quad 3.36 \quad \text{kip/ft}$$

$$P_{EH} = ½\gamma_{RS}h^2K_a\gamma_{EH} = \quad ½(120\text{ pcf})(14.7\text{ ft})^2(0.526)(1.50) \quad = \quad 10.17 \quad \text{kip/ft}$$

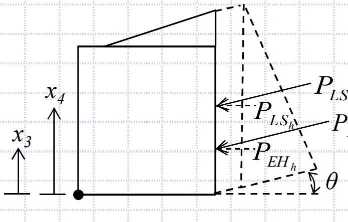
$$x_1 = B/2 \quad = \quad (13.1\text{ ft}) / 2 \quad = \quad 6.55 \quad \text{ft}$$

$$x_2 = l + ⅔(B - l) \quad = \quad 4.0\text{ ft} + ⅔(13.1\text{ ft} - 4.0\text{ ft}) \quad = \quad 10.07 \quad \text{ft}$$

$$M_V = \quad (21.43\text{ kip/ft})(6.55\text{ ft}) + (3.36\text{ kip/ft})(10.1\text{ ft}) + (10.17\text{ kip/ft})\sin(26.6°)(13.1\text{ ft}) \quad = \quad 233.86 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = ½\gamma_{RS}h^2K_a\gamma_{EH} = \quad ½(120\text{ pcf})(14.7\text{ ft})^2(0.526)(1.50) \quad = \quad 10.17 \quad \text{kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} \quad = \quad (0\text{ psf})(14.7\text{ ft})(0.526)(1.75) \quad = \quad 0.00 \quad \text{kip/ft}$$

$$x_3 = h/3 \quad = \quad (14.7\text{ ft}) / 3 \quad = \quad 4.89 \quad \text{ft}$$

$$x_4 = h/2 \quad = \quad (14.7\text{ ft}) / 2 \quad = \quad 7.33 \quad \text{ft}$$

$$M_H = \quad (10.17\text{ kip/ft})\cos(26.6°)(4.89\text{ ft}) + (0\text{ kip/ft})\cos(26.6°)(7.33\text{ ft}) \quad = \quad 44.47 \quad \text{kip·ft/ft}$$

Vertical Forces, P_V:

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

$$P_V \quad = \quad 21.43\text{ kip/ft} + 3.36\text{ kip/ft} + (10.17\text{ kip/ft})\sin(26.6°) \quad = \quad 29.34 \quad \text{kip/ft}$$

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	5	OF	6
CALCULATED BY	BRT	DATE	6/30/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 607+00 to 607+65

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	10.1	ft
MSE Wall Width (Reinforcement Length), (B) =	13.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	14.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	78.0	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) =	0.526	
Live Surcharge Load, (σ_{LS}) =	0	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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3250	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	15.6	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_c = 25.80
s_c = 1+(12.92 ft/746 ft)(14.72/25.8)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.7

N_q = 14.72
s_q = 1+(12.92 ft/746 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(0.0 ft/12.92 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 15.6 ft > 0.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.7

N_γ = 16.72
s_γ = 1-0.4(12.92 ft/746 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 15.6 ft < 1.5(12.92 ft) + 0.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (125 pcf)(0.0 ft)(14.7)(1.0) + ½(125 pcf)(12.9 ft)(16.7)(0.5) = 6.75 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.27 ksf ≤ (6.75 ksf)(0.65) = 4.39 ksf ⟶ 2.27 ksf ≤ 4.39 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_c = 5.140
s_c = 1+(12.92 ft/[(5)(746 ft)] = 1.000
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/12.92 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 15.6 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)
$C_{w\gamma}$ = 15.6 ft < 1.5(12.92 ft) + 0.0 ft = 0.500

$q_n =$ (3250 psf)(5.14) + (125 pcf)(0.0 ft)(1.0)(1.0) + ½(125 pcf)(12.9 ft)(0.0)(0.5) = 16.71 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.27 ksf ≤ (16.71 ksf)(0.65) = 10.86 ksf ⟶ 2.27 ksf ≤ 10.86 ksf **OK**

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

JOB	FRA-70-13.10	NO.	W-13-072
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	6/30/2019
CHECKED BY	JPS	DATE	7/1/2019

Retaining Wall W5 - Sta. 607+00 to 607+65

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	10.1	ft
MSE Wall Width (Reinforcement Length), (B) =	13.1	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	746	ft
MSE Wall Effective Height, (h) =	14.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	78.0	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) =	0.526	
Live Surcharge Load, (σ_{LS}) =	0	psf

Bearing Soil Properties:

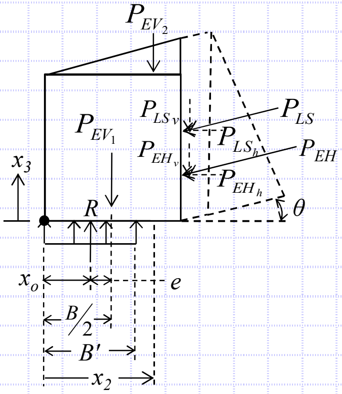
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3250	psf
Embedment Depth, (D_f) =	0.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	15.6	ft

LRFD Load Factors

	EV	EH	LS	
Strength Ia	1.00	1.50	1.75	(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)
Strength Ib	1.35	1.50	1.75	
Service I	1.00	1.00	1.00	

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



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

$$B' = B - 2e$$ = 13.1 ft - 2(0.05 ft) = 13.00 ft

$$e = B/2 - x_o$$ = (13.1 ft / 2) - 6.5 ft = 0.05 ft

$$x_o = \frac{M_V - M_H}{P_V}$$ = (168.81 kip·ft/ft - 29.62 kip·ft/ft) / 21.40 kip/ft = 6.50 ft

q_{eq} = (21.4 kip/ft) / (13 ft) = 1.65 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)(10.1 ft)(13.1 ft)(1.00)][½(13.1 ft)] + [½(120 pcf)(14.7 ft - 10.1 ft)(13.1 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(13.1 ft - 4.0 ft)] = 168.81 kip·ft/ft
+ [½(120 pcf)(14.7 ft)²(0.526)(1.00)sin(26.6°)](13.1 ft)

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

M_H = ½[(120 pcf)(14.7 ft)²(0.526)(1.00)cos(26.6°)](14.7 ft /3) = 29.62 kip·ft/ft
+ [(0 psf)(14.7 ft)(0.526)(1.00)cos(26.6°)](14.7 ft /2)

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

P_V = (120 pcf)(10.1 ft)(13.1 ft)(1.00) + ½(120 pcf)(14.7 ft - 10.1 ft)(13.1 ft - 4.0 ft)(1.00) = 21.4 kip/ft
+ ½(120 pcf)(14.7 ft)²(0.526)(1.00)sin(26.6°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Between Borings Along Wall Facing	Differential Settlement Along Wall Facing
B-104-1-13	4.459 in	2.412 in	15 days		
B-105-3-14	3.519 in	1.872 in	3 days	85 ft	1/1890
B-105-5-14	3.512 in	1.535 in	5 days	145 ft	1/5160
B-107-2-14	2.946 in	1.321 in	1 days	135 ft	1/7570
B-108-7-14	2.403 in	1.341 in	1 days	160 ft	1/96000
B-108-8-14	0.950 in	0.694 in	3 days	130 ft	1/2410

W-13-072 - FRA-70-13.10 - Retaining Wall W5
MSE Wall Settlement - Sta. 607+00 to 607+65

Calculated By: BRT Date: 6/30/2019
Checked By: JPS Date: 7/1/2019

Boring B-108-8-14

H=	10.1	ft	Total wall height
B'=	13.0	ft	Effective footing width due to eccentricity
D_w =	15.6	ft	Depth below bottom of footing
q_e =	1,650	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)		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 (Emb.)	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	30	0.180	0.018	0.507				0.10	0.997	1,645	1,795	0.032	0.386	0.500	825	975	0.024	0.291
2	A-6a	C	2.5	5.0	2.5	3.8	120	600	450	450	4,450	30	0.180	0.018	0.507				0.29	0.942	1,555	2,005	0.019	0.233	0.495	817	1,267	0.013	0.161
3	A-4a	G	5.0	7.5	2.5	6.3	130	925	763	763	4,763					33	44	75	0.48	0.831	1,370	2,133	0.015	0.178	0.482	795	1,557	0.010	0.124
4	A-1-a	G	7.5	10.5	3.0	9.0	135	1,330	1,128	1,128	5,128					51	61	219	0.69	0.700	1,156	2,283	0.004	0.050	0.456	753	1,880	0.003	0.036
	A-1-a	G	10.5	14.0	3.5	12.3	135	1,803	1,566	1,566	5,566					51	55	193	0.94	0.574	947	2,514	0.004	0.045	0.418	690	2,256	0.003	0.035
5	A-1-b	G	14.0	17.0	3.0	15.5	130	2,193	1,998	1,998	5,998					27	27	91	1.19	0.480	792	2,789	0.005	0.057	0.379	625	2,623	0.004	0.047
																				Total Settlement:			0.950 in		Total Settlement:			0.694 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. $(N1)_{60} = C_nN_{60}$, 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-70-13.10 - Retaining Wall W5

MSE Wall Settlement - Sta. 607+00 to 607+65

Calculated By: BRT   Date: 6/30/2019

Checked By: JPS   Date: 7/1/2019

Boring B-108-8-14

H=	10.1	ft	Total wall height
B'=	13.0	ft	Effective footing width due to eccentricity
D_w =	15.6	ft	Depth below bottom of footing
q_e =	1,650	psf	Equivalent bearing pressure at bottom of wall

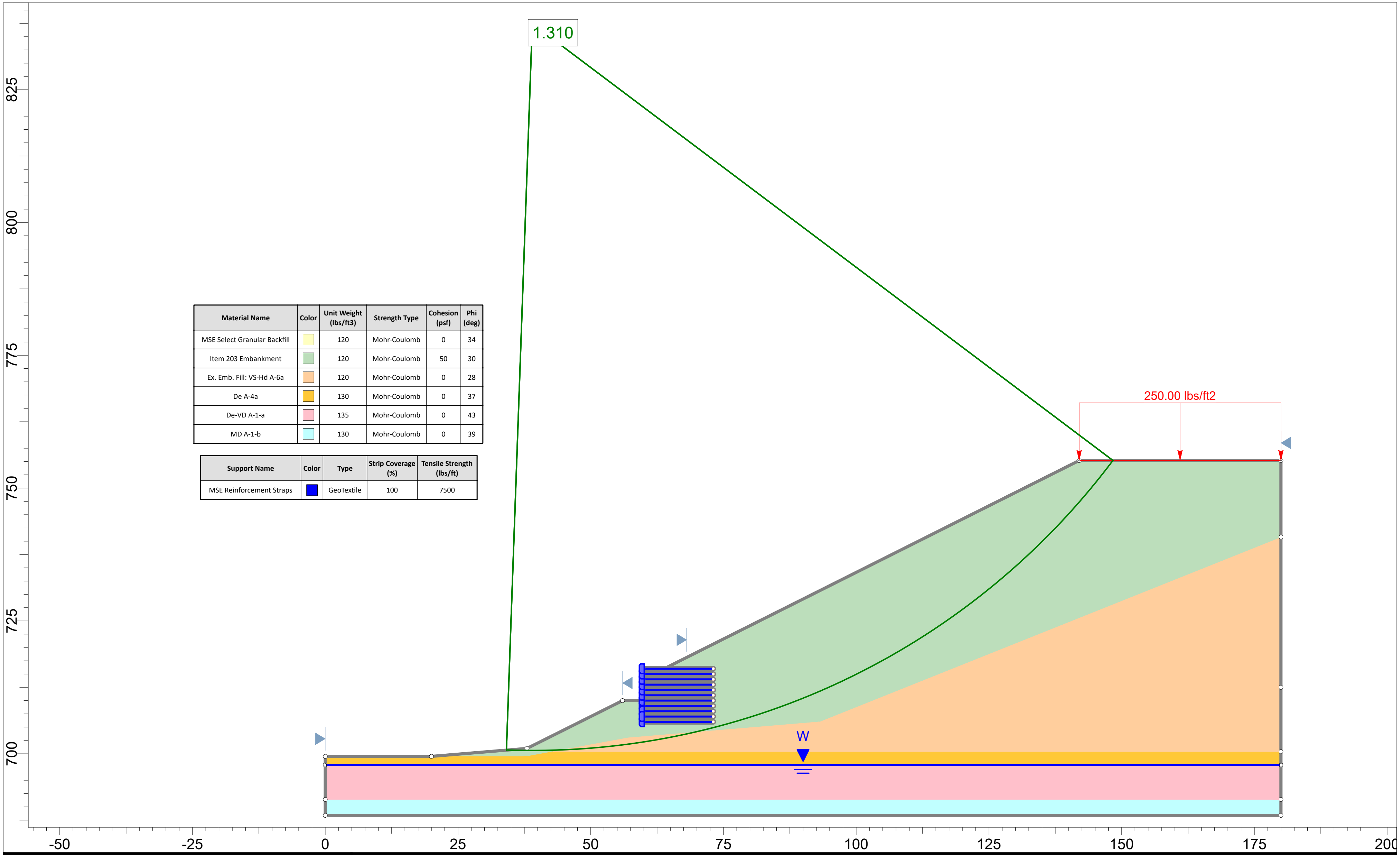
	A-6a					
c_v =	600				ft^2/yr	Coefficient of consolidation
t =	3				days	Time following completion of construction
H_{dr} =	2.5				ft	Length of longest drainage path considered
T_v =	0.789					Time factor
U =	88				%	Degree of consolidation

$(S_c)_t$ = 0.640 in Settlement complete at 92% of primary consolidation

																						Total Settlement at Facing of Wall			Settlement Complete at 92% of Primary Consolidation	
Layer	Soil Type	Soil Type	Layer Depth (ft)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (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)	Layer Settlement (in)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1 (Emb.)	A-6a	C	0.0	2.5	2.5	1.3	120	300	150	150	4,150	30	0.180	0.018	0.507				0.10	0.500	825	975	0.024	0.291	0.291	0.256	0.256
2	A-6a	C	2.5	5.0	2.5	3.8	120	600	450	450	4,450	30	0.180	0.018	0.507				0.29	0.495	817	1,267	0.013	0.161	0.161	0.142	0.142
3	A-4a	G	5.0	7.5	2.5	6.3	130	925	763	763	4,763					33	44	75	0.48	0.482	795	1,557	0.010	0.124	0.124	0.124	0.124
4	A-1-a	G	7.5	10.5	3.0	9.0	135	1,330	1,128	1,128	5,128					51	61	219	0.69	0.456	753	1,880	0.003	0.036	0.071	0.036	0.071
	A-1-a	G	10.5	14.0	3.5	12.3	135	1,803	1,566	1,566	5,566					51	55	193	0.94	0.418	690	2,256	0.003	0.035		0.035	
5	A-1-b	G	14.0	17.0	3.0	15.5	130	2,193	1,998	1,998	5,998					27	27	91	1.19	0.379	625	2,623	0.004	0.047	0.047	0.047	0.047

Settlement Remaining After Hold Period: 0.054 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



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	50	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Mohr-Coulomb	0	28
De A-4a	🟨	130	Mohr-Coulomb	0	37
De-VD A-1-a	🟥	135	Mohr-Coulomb	0	43
MD A-1-b	🟦	130	Mohr-Coulomb	0	39

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

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Project
Retaining Wall W5 - Sta. 605+50 to 607+65 - MSE Wall Global Stability

Analysis Description
10.1 ft Wall Height - B-108-8-14 - Drained - Circular - Spencer method

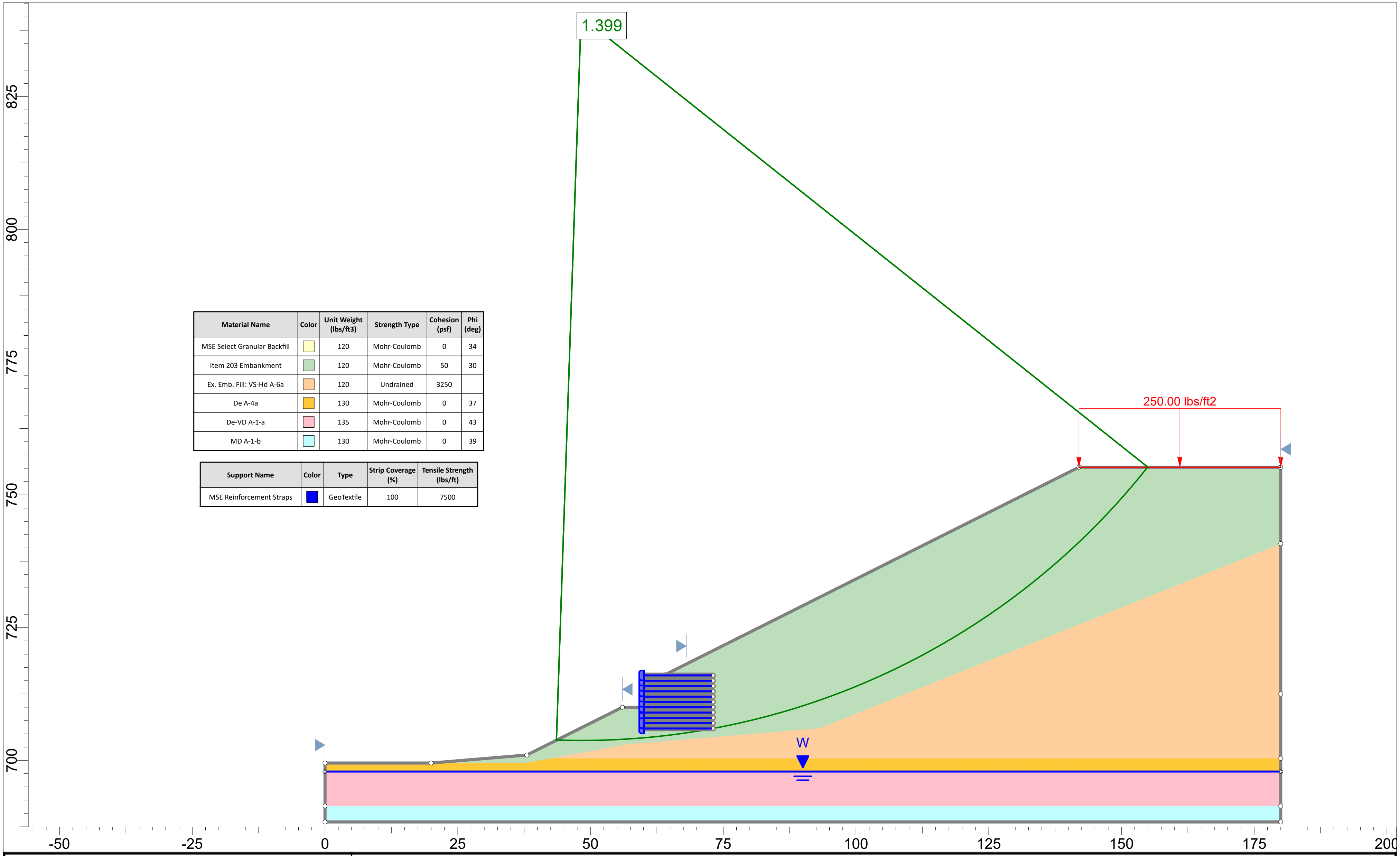
Drawn By BRT

Scale 1:300

Company Resource International, Inc

Date 7/3/2019

File Name Retaining Wall W5 - Sta. 605+50 to 607+65 - Global Stability.slim



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
MSE Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	50	30
Ex. Emb. Fill: VS-Hd A-6a	🟧	120	Undrained	3250	
De A-4a	🟨	130	Mohr-Coulomb	0	37
De-VD A-1-a	🟥	135	Mohr-Coulomb	0	43
MD A-1-b	🟦	130	Mohr-Coulomb	0	39

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

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Project	Retaining Wall W5 - Sta. 605+50 to 607+65 - MSE Wall Global Stability		
Analysis Description	10.1 ft Wall Height - B-108-8-14 - Undrained - Circular - Spencer method		
Drawn By BRT	*Scale* 1:300	*Company* Resource International, Inc	
Date 7/3/2019	*File Name* Retaining Wall W5 - Sta. 605+50 to 607+65 - Global Stability.slim		