Resource International, Inc.

FRA-70-12.68 PROJECT 4R
RETAINING WALL 4W12
PID NO. 105523
FRANKLIN COUNTY, OHIO

STRUCTURE FOUNDATION EXPLORATION REPORT

Prepared For:
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Prepared By:

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Rii Project No. W-13-045

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RESOURCE INTERNATIONAL, INC.
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Planning

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May 27, 2015 (Revised July 17, 2018)

Mr. Christopher W. Luzier, P.E.
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Re: Structure Foundation Exploration Report
FRA-70-12.68 Project 4R
Retaining Wall 4W12
PID No. 105523
Rii Project No. W-13-045

Mr. Luzier:

Resource International, Inc. (Rii) is pleased to submit this 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 foundation recommendations for the design and construction of the proposed Retaining Wall 4W12 as part of the FRA-70-12.68 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 R. Trenner, P.E.
Director – Geotechnical Programming

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Enclosure: Structure Foundation Exploration Report

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EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for the design and construction of the proposed Retaining Wall 4W12. It is understood that this wall will be connected to the forward abutment of the proposed FRA-70-1282R I-70 eastbound over Souder Avenue bridge structure at the west end of the wall alignment and will extend east. It is understood that a mechanically stabilized earth (MSE) wall is being considered as the preferred wall type for the entire alignment of Retaining Wall 4W12. Wall heights along the alignment of the proposed structure are anticipated to range from roughly 6.9 feet to a maximum height of approximately 36.9 feet at Sta. 3003+06 (BL Ramp C3), and the total wall length is anticipated to be on the order of 935 lineal feet.

Exploration and Findings

On March 21 and 22, 2015, two (2) structure borings, designated as borings B-109-1-15 and B-110-1-15, were advanced to completion depths of 85.0 and 75.0 feet, respectively, below the existing ground surface. In addition to the borings performed by Rii as part of the current exploration, three (3) borings, designated as B-109-0-09, B-110-0-09, and B-111-0-09, were advanced to depths of 50.0, 49.4 and 30.0 feet below the existing ground surface, respectively, by DLZ as part of the FRA-70-8.93 preliminary exploration.

At the existing ground surface, boring B-109-1-15 encountered 6.0 inches of asphalt overlying 12.0 inches of aggregate base, while boring B-110-1-15 encountered 8.0 inches of asphalt underlain by 14.5 inches of concrete and 5.0 inches of aggregate base. Boring B-109-0-09 was located within the grass just south of the I-70 embankment and encountered 5.0 inches of topsoil at the ground surface. Boring B-110-0-09 was performed within the existing pavement of Mound Street/Harmon Avenue, encountering 5.0 inches of asphalt overlying 7.0 inches of concrete at the ground surface. Boring B-111-0-09 was performed within the ramp pavement connecting I-70 eastbound to I-71 southbound, and encountered 6.0 inches of concrete overlying 6.0 inches of aggregate base.

Beneath the surficial pavement materials encountered in borings B-109-1-15 and B-110-1-15, existing embankment fill consisting of gray gravel with sand and silt (ODOT A-2-4) and brown to gray silt and clay, and elastic clay (ODOT A-6a and A-7-5) were encountered extending to depths of 32.0 and 27.0 feet below existing grade, respectively. Brick, clay tile, and rock fragments were noted within the fill materials in boring B-109-1-15. Beneath the surficial topsoil and pavement materials encountered in borings B-109-0-09, B-110-0-09 and B-111-0-09, material identified as existing or possible existing fill was encountered extending to depths of 6.0, 10.5, and 3.5 feet below existing grades, respectively. The fill materials consisted of brown and dark brown gravel and sand, gravel with sand, silt and clay, coarse and fine sand, sandy silt, and silt and clay (ODOT A-1-b, A-2-6, A-4a, and A-6a). The uppermost fill material encountered at boring B-110-0-09 contained brick fragments and organic material to a depth of 8.0 feet below the ground surface; however, based on information provided by ODOT, it is anticipated that the brick fragments are likely from the demolition of an outbuilding associated with the former slaughter yards, and it is not uncommon for soils present during slaughter yard activities to be high in organic content.

Underlying the surficial materials and existing fill, the subsurface profile encountered in both the current and preliminary explorations primarily consisted of natural granular soils overlying deep, intermittent cohesive deposits. The natural granular soils were generally described as brown and gray gravel, gravel and sand, gravel with sand and silt, coarse and fine sand, and sandy silt (ODOT A-1-a, A-1-b, A-2-4, A-3a, and A-4a). The cohesive soils were generally described as brown, dark brown and gray sandy silt, silt and clay, and silty clay (ODOT A-4a, A-6a, and A-6b).

Analyses and Recommendations

Design details of the proposed retaining wall were provided by Dynotec. As stated, it is understood that a mechanically stabilized earth (MSE) wall type is currently being considered along the entire alignment of the proposed structure, which is to support the new alignment of Ramp C3. Based upon the proposed plan information, wall heights along the proposed alignment will range from a minimum height of 6.9 feet at the eastern termination point of the wall, to a maximum height of 36.9 feet at Sta. 3003+06 (BL Ramp C3), as measured from the top of the leveling pad to top of the coping.

Beginning at the forward abutment of the proposed FRA-70-1282R bridge structure, the wall will be located at the edge of the proposed Ramp C3, adjacent to Mound Street/Harmon Avenue, and will generally be aligned with the toe of the existing embankment supporting the I-70 eastbound ramp to I-71 southbound. The proposed wall will maintain this alignment as it extends eastward from approximately Sta. 5032+44 (BL Ramp C5) to Sta. 3003+06 (BL Ramp C3). At this location, the wall alignment will step up along the slope of the existing embankment and diverge from the edge of the proposed ramp alignment between approximately Sta. 3003+50 and 3007+34 (BL Ramp C3), where the wall terminates at the edge of Ramp C3. It is understood that 2:1 backslopes will be graded up to the proposed Ramp C3 roadway from the top of the wall between approximately Sta. 3003+50 and 3007+34 (BL Ramp C3), and that 4:1 slopes will be graded down from the bottom of the wall to the existing grade along Mound Street/Harmon Avenue where the wall will be aligned within the limits of the existing embankment. Additionally, it is understood that profile grade of Ramp C3 will be raised from the proposed profile grade for the current project as part of the FRA-70-13.10 Phase 6A project improvements from approximately Sta. 3005+00 to the end of the project alignment. Therefore, the geometry for both phases was considered in the analysis for the east end of the wall alignment.

The anticipated bearing materials along the proposed alignment of Retaining Wall 4W12 will likely consist of newly placed and compacted fill material, very stiff to hard cohesive soils (ODOT A-4a, A-6a or A-7-5), or loose to very dense granular soils (ODOT A-1-a, A-1-b, A-2-6, A-4a). MSE wall foundations bearing on these soils or ODOT Item 203 granular embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a nominal bearing resistance as indicated in the following table. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state. Given that the existing embankment material consists primarily of cohesive soil, the bearing resistance was evaluated under both drained and undrained conditions, where applicable. Calculations were based on generalization of the conditions encountered in borings B-109-1-15, B-110-0-09, B-110-1-15, and B-111-0-15. 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.

Retaining Wall 4W12 MSE Wall Design Parameters

Station Analyzed [1]	Wall Height Analyzed (feet)	Backslope Behind Wall	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Strength Limit Equivalent Bearing Pressure [4] (ksf)
				Nominal	Factored [3]	
3003+06	36.9	Level	25.8 (0.70H)	19.87	12.92	8.57
3004+50	25.2	2:1 (Broken-back)	19.2 (0.76H)	11.11	7.22	7.08
3005+50	18.2	2:1 (Broken-back)	16.0 (0.88H)	11.63	7.56	4.94
3006+24 (Phase 4A)	12.9	2:1 (Broken-back)	16.8 (1.30H)	13.15	8.55	3.00
3006+24 (Phase 6A)	12.9	2:1	16.8 (1.30H)	14.14	9.19	2.91

1. *Stationing is referenced to the baseline of Ramp C3.*
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.*

Total settlements of 1.17 to 2.76 inches at the center, and 0.83 to 2.01 inches at the face of the of the reinforced soil mass, respectively, are anticipated for the proposed MSE wall. Based on the total anticipated settlement at the facing of the wall, maximum differential settlement in the longitudinal direction is anticipated to be less than 1/1000, which is within the tolerable limit of 1/100. Due to the granular nature of the bearing soils, it is estimated that 90 percent of the settlement is to occur within 10 to 20 days of completion of the embankment.

Based on the results of the external and global stability analysis performed for the MSE walls, the recommended controlling strap length ranges from 0.70 to 1.30 times the height of the MSE wall (measured from the top of the leveling pad to top of the coping). Bearing resistance and global stability under drained conditions were the controlling factor in the determination of the recommended strap lengths greater than 0.70 times the height of the MSE Wall for the situations analyzed with a sloping backfill

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-70-12.68/13.11/14.05C (Project 4R/4H/4A) projects in Columbus, Ohio. The projects represent the central portion of FRA-70-8.93 (PID 77369) I-70/71 south innerbelt improvements project. The FRA-70-12.68 (Project 4R) phase will consist of all work associated with the construction of Ramp C5, starting at the bridge over Souder Avenue and extending east to Front Street. The proposed Ramp C5 will be a two-lane to four-lane ramp that will collect and direct traffic from I-71 northbound and SR-315 southbound as well as I-70 eastbound to exit in downtown at the intersection of Front Street and W. Fulton Avenue. This project includes the construction of six (6) new bridge structures for the proposed Ramp C5 alignment and replacement of three (3) bridge structures, two along I-70 and the Front Street Structure over I-70, as well as the construction of fourteen (14) new retaining walls and a culvert structure 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 4W12, as shown on the vicinity map and boring plan presented in Appendix I. It is understood that this wall will be connected to the forward abutment of the proposed FRA-70-1282R I-70 eastbound over Souder Avenue bridge structure at the west end of the wall alignment and will extend east. It is understood that a mechanically stabilized earth (MSE) wall is being considered as the preferred wall type for the entire alignment of Retaining Wall 4W12. Wall heights along the alignment of the proposed structure are anticipated to range from roughly 6.9 feet to a maximum height of approximately 36.9 feet at Sta. 3003+06 (BL Ramp C3), and the total wall length is anticipated to be on the order of 936 lineal feet.

2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1 Site Geology

Both the Illinoian and Wisconsinan glaciers advanced over two-thirds of the State of Ohio, leaving behind glacial features such as moraines, kame deposits, lacustrine deposits and outwash terraces. The glacial and non-glacial regions comprise five physiographic sections based on geological age, depositional process and geomorphic occurrence (physical features or landforms). The project area lies within the Columbus Lowland District of the Till Plains Section. This area is characterized by flat to gently rolling ground moraine deposits from the Late Wisconsinan age. The site topography exhibits moderate to high relief. The ground moraine deposits are composed primarily of silty loam till (Darby, Bellefontaine, Centerburg, Grand Lake, Arcanum, Knightstown Tills), with smaller alluvium and outwash deposits bordering the Scioto River, its tributaries and floodplain areas. A ground moraine is the sheet of debris left after the steady retreat of glacial ice. The debris left behind ranges in composition from clay size particles to boulders (including silt, sand, and gravel). Outwash deposits consist of undifferentiated sand and gravel deposited by meltwater in front of glacial ice, and often occurs as valley terraces or low plains. Alluvium and alluvial terrace deposits range in composition from silty clay size particles to cobbles, usually deposited in present and former floodplain areas.

According to the bedrock geology and topography maps obtained from the Ohio Department of Natural Resources (ODNR), the underlying bedrock consists predominantly of the Middle to Lower Devonian-aged Columbus Limestone Formation. 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 limy dolomite. Both of these members contain chert nodules. Just east of Scioto River, the Upper Devonian Ohio Shale Formation overlies the Columbus Limestone Formation. The Ohio Shale formation consists of brownish black to greenish gray, thinly bedded, fissile, carbonaceous shale. 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

It is understood that the proposed Retaining Wall 4W12 structure will connect to the forward abutment of the proposed FRA-70-1282R structure, which carries I-70 eastbound over Souder Avenue, at the west end of the wall alignment and will extend east a distance of roughly 960 lineal feet. Currently, an existing ramp begins just east of the Souder Avenue Bridge which connects I-70 eastbound to I-71 southbound. It is understood that I-70 eastbound is to be widened towards the south at the proposed FRA-70-1282R structure to accommodate the proposed reconfiguration of the existing ramp connecting I-70 eastbound to I-71 southbound (Proposed Ramp C3), and to allow for the addition of a new ramp which will parallel I-70 eastbound into downtown Columbus (Proposed Ramp C5). Plan information indicates that the proposed retaining wall will roughly parallel Ramp C3, beginning at the forward abutment of FRA-70-1282R and extending roughly 580 lineal feet to the east, at which point the proposed wall is proposed to turn southeast, at a sharper radius than Ramp C3, for a distance of approximately 380 lineal feet prior to terminating along Ramp C3.

Located approximately 2,500 feet west of the Scioto River, the existing I-70 eastbound roadway in the vicinity of the Souder Avenue structure is a four-lane, asphalt paved roadway aligned in a primarily west-to-east orientation. At the western end of the proposed retaining wall alignment, I-70 eastbound passes over Souder Avenue, which is also a four-lane, asphalt paved roadway, however it is primarily aligned in a south-to-north orientation. The existing I-70 roadway profile grade is elevated approximately 20 feet above the surrounding terrain on engineered embankments, which are grass covered with patches of dense vegetation. The proposed retaining wall is understood to be located within the existing embankment area, between I-70 eastbound and Mound Street/Harmon Avenue.

Within the project limits, Mound Street/Harmon Avenue roughly parallels the existing ramp connecting I-70 eastbound to I-71 southbound, along the south side of the existing embankment, intersecting with Souder Avenue just south of the FRA-70-1282R structure. A majority of Mound Street/Harmon Avenue maintains one lane of traffic in each direction, with the drive lane area widening near the intersection with Souder Avenue to accommodate both a left- and right-hand turn lane in the westbound direction. Along the eastern portion of the project limits, a concrete cast-in-place (CIP) retaining wall, Retaining Wall CB, borders the northern edge of the Mound Street/Harmon Avenue pavement, supporting the existing I-70 embankment. A chain link fence has been constructed along the top of the retaining wall, acting as the ODOT right-of-way fence along the alignment.

As stated, existing engineered embankments elevate I-70 roughly 20 feet above the surrounding terrain in this area. In general, the terrain along I-70 slopes gently downward towards the west, while the lower lying surrounding area is relatively flat. Land use along the south side of Mound Street/Harmon Avenue currently consists primarily of commercially developed properties, while the north side of I-70 is developed with primarily residential properties. It is understood that Sanborn maps of the area from 1922 and 1941 indicate that the area south of Mound Street/Harmon Avenue was once the site of slaughter yards associated with the A&E Maier Slaughter House and the David Davies Company. Furthermore, the area in the vicinity of the proposed retaining wall is understood to have been previously developed with residential properties.

3.0 EXPLORATION

On March 21 and 22, 2015, two (2) structure borings, designated as borings B-109-1-15 and B-110-1-15, were advanced to completion depths of 85.0 and 75.0 feet, respectively, below the existing ground surface. Both borings were performed within the shoulder of the existing ramp connecting I-70 eastbound to I-71 southbound to determine the subsurface conditions along the proposed alignment of Retaining Wall 4W12, and within the existing I-70 embankment fill. In addition to the borings performed by Rii as part of the current exploration, three (3) borings, designated as B-109-0-09, B-110-0-09, and B-111-0-09, were performed DLZ along the alignment of the proposed wall as part of the FRA-70-8.93 preliminary exploration and their findings were published in a report dated March 18, 2010. The borings were performed on September 1 and 11, 2009, and were advanced to completion depths of 50.0, 49.4 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 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-109-0-09	BL Ramp C5	5032+97.77	44.7' Rt.	39.949836696	-83.020667264	704.9	50.0
B-109-1-15	BL Ramp C3	3001+00.00	55.0' Lt.	39.950097038	-83.019715408	736.2	85.0
B-110-0-09	BL Ramp C3	3003+02.96	22.8' Rt.	39.949876643	-83.018993458	705.8	49.4
B-110-1-15	BL Ramp C3	3005+00.00	20.0' Lt.	39.949913094	-83.018276075	740.3	75.0
B-111-0-09	BL Ramp C3	3008+11.91	4.6’ Rt.	39.949346358	-83.017437998	734.9	30.0

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

The borings performed by Rii for the current exploration were drilled using truck-mounted rotary drilling machines, utilizing either a 3.25 or 4.25-inch inside diameter, hollow-stem auger to advance the holes. Standard penetration test (SPT) and split spoon sampling were performed in the borings at 5.0-foot increments to the proposed bottom of wall elevation at the respective boring location, at 2.5-foot increments to a depth of 20.0 feet below the proposed bottom of wall elevation, and at 5.0-foot increments thereafter to the boring termination depths. 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 blow per 6.0-inch interval of the driving distance. The second and third intervals are added to obtain the number of blows per foot (N). Standard penetration blow counts aid in determining soil properties applicable in foundation system design. Measured blow count (N) values are corrected to an equivalent (60%) energy ratio, N_{60}, by the following equation. Both values are represented on boring logs in Appendix III.

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

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

The hammer for the CME 55 drill rig used by Rii for boring B-109-1-15 was calibrated on October 20, 2014, and has a drill rod energy ratio of 92.0 percent. The hammer for the Mobile B-53 drill rig used by Rii for boring B-110-1-15 was calibrated on April 26, 2013, and has a drill rod energy ratio of 77.7 percent. The hammer for the CME 75 truck-mounted drill rig used by DLZ has a drill rod energy ratio of 62.0 percent.

Upon completion of drilling, the borings performed by Rii were backfilled in accordance with the ODOT policy for sealing boreholes, utilizing a cement-bentonite grout. Where borings penetrated the existing pavement, an equivalent thickness of quickset concrete was used to repair the pavement surface. Abandonment methods and quantities are not listed on the logs of the borings performed by DLZ.

During drilling for the borings performed by Rii, 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	40
Plastic and Liquid Limits	AASHTO T89, T90	14
Gradation – Sieve/Hydrometer	AASHTO T88	14

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. 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

As stated, borings B-109-1-15 and B-110-1-15 were performed Boring B-013-1-15 was performed within the shoulder of the existing ramp connecting I-70 eastbound to I-71 southbound. At the existing ground surface, boring B-109-1-15 encountered 6.0 inches of asphalt overlying 12.0 inches of aggregate base, while boring B-110-1-15 encountered 8.0 inches of asphalt underlain by 14.5 inches of concrete and 5.0 inches of aggregate base. Boring B-109-0-09 was located within the grass just south of the I-70 embankment and encountered 5.0 inches of topsoil at the ground surface, as identified by the significant presence of vegetation and organic material. Boring B-110-0-09 was performed within the existing pavement of Mound Street/Harmon Avenue, encountering 5.0 inches of asphalt overlying 7.0 inches of concrete at the ground surface. Boring B-111-0-09 was performed within the ramp connecting I-70 eastbound to I-71 southbound, and encountered 6.0 inches of concrete overlying 6.0 inches of aggregate base.

4.2 Subsurface Soils

Beneath the surficial pavement materials encountered in borings B-109-1-15 and B-110-1-15, existing embankment fill consisting of gray gravel with sand and silt (ODOT A-2-4) and brown to gray silt and clay, and elastic clay (ODOT A-6a and A-7-5) were encountered extending to depths of 32.0 and 27.0 feet below existing grade, respectively. Brick, clay tile, and rock fragments were noted within the fill materials in boring B-109-1-15. Beneath the surficial topsoil and pavement materials encountered in borings B-109-0-09, B-110-0-09 and B-111-0-09, material identified as existing or possible existing fill was encountered extending to depths of 6.0, 10.5, and 3.5 feet below existing grades, respectively. The fill materials consisted of brown and dark brown gravel and sand, gravel with sand, silt and clay, coarse and fine sand, sandy silt, and silt and clay (ODOT A-1-b, A-2-6, A-4a, and A-6a). The uppermost fill material encountered at boring B-110-0-09 contained brick fragments and organic material to a depth of 8.0 feet below the ground surface; however, based on information provided by ODOT, it is anticipated that the brick fragments are likely from the demolition of an outbuilding associated with the former slaughter yards, and it is not uncommon for soils present during slaughter yard activities to be high in organic content.

Underlying the surficial materials and existing fill, the subsurface profile encountered primarily consisted of natural granular soils overlying deep, intermittent cohesive deposits. The natural granular soils were generally described as brown and gray gravel, gravel and sand, gravel with sand and silt, coarse and fine sand, and sandy silt (ODOT A-1-a, A-1-b, A-2-4, A-3a, and A-4a). The cohesive soils were generally described as brown, dark brown and gray sandy silt, silt and clay, and silty clay (ODOT A-4a, A-6a, and A-6b).

The relative density of granular soils is primarily derived from SPT blow counts (N_{60}). Based on the SPT blow counts obtained, the granular soil encountered ranged from loose ($5 \leq N_{60} \leq 10$ blows per foot [bpf]) to very dense ($N_{60} > 50$ bpf). Overall blow counts recorded from the SPT sampling ranged from 5 bpf to split spoon sampler refusal. The shear strength and consistency of the cohesive soils are primarily derived from the hand penetrometer values (HP). The cohesive soils encountered ranged from stiff (1.0 < HP ≤ 2.0 tsf) to hard (HP > 4.0 tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 1.5 to over 4.5 tsf (limit of instrument).

Natural moisture contents of the soil samples tested ranged from 4 to 31 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 14 percent below to 2 percent above their corresponding plastic limits. In general, the soils exhibited natural moisture contents considered to be significantly below to slightly above their optimum moisture levels.

4.3 Bedrock

Bedrock was not encountered in the borings analyzed as part of this exploration.

4.4 Groundwater

Groundwater was encountered in the borings as presented in Table 3.

Table 3. Groundwater Levels

Boring Number	Ground Surface Elevation (feet msl)	Initial Groundwater		Upon Completion	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-109-0-09	704.9	13.5	691.4	12.5 [2]	692.4
B-109-1-15	736.2	Dry	Dry	N/A [1]	N/A [1]
B-110-0-09	705.8	10.5	695.3	10.6	695.2
B-110-1-15	740.3	53.5	686.8	N/A [1]	N/A [1]
B-111-0-09	734.9	Dry	Dry	Dry	Dry

1. *The groundwater level at completion could not be obtained due to the addition of drilling fluid.*
2. *The groundwater level at completion includes drilling water.*

Groundwater was encountered in boring B-109-0-09, B-110-0-09 and B-110-1-15 at depths ranging from 10.5 to 53.5 feet beneath the ground surface, corresponding to elevations ranging from 686.8 to 695.3 feet msl. At the completion of drilling, and prior to removing the augers, groundwater had accumulated in boring B-110-0-09 to a depth of 10.6 feet below the ground surface, corresponding to an elevation of 695.2 feet msl. Groundwater was not encountered during, or at the completion of, drilling in boring B-111-0-09. Groundwater was also not encountered in boring B-109-1-15 prior to the introduction of drilling fluid at a depth of 45.0 feet beneath the ground surface. As stated, drilling fluid was introduced to borings B-109-0-09, B-109-1-15, and B-110-1-15 to counteract the water pressure causing sands to heave into the augers. The introduction of drilling fluid to the borings prevents accurate measurements of the groundwater levels within the boreholes at the completion of drilling.

Please note that short-term water level readings, especially in cohesive soils, are not necessarily an accurate indication of the actual groundwater level. In addition, groundwater levels or 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 both the current and historic 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 Dynotec. As stated, it is understood that a mechanically stabilized earth (MSE) wall type is currently being considered along the entire alignment of the proposed structure, which is to support the new alignment of Ramp C3. Based on the information available at the time of this report, wall heights ranging from 4.4 to 36.9 feet are anticipated along the 936-foot long alignment, with the footings proposed to bear at a minimum depth of 3.0 feet beneath the proposed ground surface.

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 2007 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. 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.

Based upon the proposed plan information, wall heights along the proposed alignment will range from a minimum height of 6.9 feet at the eastern termination point of the wall, to a maximum height of 36.9 feet at Sta. 3003+06 (BL Ramp C3), as measured from the top of the leveling pad to top of the coping. Beginning at the forward abutment of the proposed FRA-70-1282R bridge structure, the wall will be located at the edge of the proposed Ramp C3, adjacent to Mound Street/Harmon Avenue, and will generally be aligned with the toe of the existing embankment supporting the I-70 eastbound ramp to I-71 southbound. The proposed wall will maintain this alignment as it extends eastward from approximately Sta. 5032+44 (BL Ramp C5) to Sta. 3003+06 (BL Ramp C3). At this location, the wall alignment will step up along the slope of the existing embankment and diverge from the edge of the proposed ramp alignment between approximately Sta. 3003+50 and 3007+34 (BL Ramp C3), where the wall terminates at the edge of Ramp C3. It is understood that 2:1 backslopes will be graded up to the proposed Ramp C3 roadway from the top of the wall between approximately Sta. 3003+50 and 3007+34 (BL Ramp C3), and that 4:1 slopes will be graded down from the bottom of the wall to the existing grade along Mound Street/Harmon Avenue where the wall will be aligned within the limits of the existing embankment.

Additionally, it is understood that profile grade of Ramp C3 will be raised from the proposed profile grade for the current project as part of the FRA-70-13.10 Phase 6A project improvements from approximately Sta. 3005+00 to the end of the project alignment. Therefore, the geometry for both phases was considered in the analysis for the east end of the wall alignment. For the analysis, the foundation width was set at 70 percent of the wall height and the foundation width was increased, if required, until external and global stability requirements were satisfied.

Materials identified as either existing or possible existing fill were encountered at the proposed bearing elevation in borings B-109-0-09 and B-110-0-09, extending to depths of 4.5 and 7.5 feet below the proposed bearing elevation, respectively. The fill materials, which are not associated with the embankment fill encountered in the remaining borings, consisted of both granular and cohesive soils identified as loose to very dense gravel with sand and coarse and fine sand (ODOT A-1-b, A-3a), and very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a). These fill materials were noted as containing brick fragments and organic material in boring B-110-0-09. Although debris was present and low blow counts were observed within these fill materials, it is anticipated that the limits of the fill will be localized and will not be present along the entirety of the proposed alignment. As previously stated, it is understood that this area was once the site of slaughter yards associated with the A&E Maier Slaughter House and the David Davies Company. The brick fragments encountered can likely be attributed to the demolition of the outbuildings associated with these operations, while soils high in organic content are not unusual in areas where such activities once occurred. Furthermore, it is anticipated that significant portions of this material would have been removed and replaced if encountered during the development and construction of the residential properties and existing Retaining Wall CB. If encountered during construction of Retaining Wall 4W12, it is recommended that any unsuitable foundation materials be remediated in accordance with ODOT SS840, Section 840.06.D.

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 bearing materials along the proposed alignment of Retaining Wall 4W12 will likely consist of newly placed and compacted fill material, very stiff to hard cohesive soils (ODOT A-4a, A-6a or A-7-5), or loose to very dense granular soils (ODOT A-1-a, A-1-b, A-2-6, A-4a).

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 4.

Table 4. 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
Ex. Embankment Fill: Very Stiff to Hard Sandy Silt (ODOT A-4a)	120	30	0	2,000
Ex. Fill: Loose to Medium Dense Gravel and Sand and Coarse and Fine Sand (ODOT A-1-b, A-3a)	120	28	0	N/A
Loose Sandy Silt (ODOT A-4a)	115	27	0	N/A
Medium Dense to Dense Granular Soils (ODOT A-1-a, A-3a)	130	30 to 40	0	N/A
Very Dense Granular Soils (ODOT A-1-a, A-1-b, A-3a)	135	40 to 42	0	N/A
Very Stiff Silty Clay (ODOT A-6b)	120	27	0	3,125
Hard Sandy Silt (ODOT A-4a)	130	32	50	8,000

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 4. 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 bearing materials along the proposed alignment of Retaining Wall 4W12 will likely consist of newly placed and compacted fill material, very stiff to hard cohesive soils (ODOT A-4a, A-6a or A-7-5), or loose to very dense granular soils (ODOT A-1-a, A-1-b, A-2-6, A-4a). MSE wall foundations bearing on these soils or ODOT Item 203 granular embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a nominal bearing resistance as indicated in Table 5. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state. Given that the existing embankment material consists primarily of cohesive soil, the bearing resistance was evaluated under both drained and undrained conditions, where applicable. Calculations were based on generalization of the conditions encountered in borings B-109-1-15, B-110-0-09, B-110-1-15, and B-111-0-15. 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 5. Retaining Wall 4W12 MSE Wall Design Parameters

Station Analyzed [1]	Wall Height Analyzed (feet)	Backslope Behind Wall	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Strength Limit Equivalent Bearing Pressure [4] (ksf)
				Nominal	Factored [3]	
3003+06	36.9	Level	25.8 (0.70H)	19.87	12.92	8.57
3004+50	25.2	2:1 (Broken-back)	19.2 (0.76H)	11.11	7.22	7.08
3005+50	18.2	2:1 (Broken-back)	16.0 (0.88H)	11.63	7.56	4.94
3006+24 (Phase 4A)	12.9	2:1 (Broken-back)	16.8 (1.30H)	13.15	8.55	3.00
3006+24 (Phase 6A)	12.9	2:1	16.8 (1.30H)	14.14	9.19	2.91

1. *Stationing is referenced to the baseline of Ramp C3.*
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.*

Rii performed a verification of the bearing pressure exerted on the subgrade material for the maximum specified wall heights indicated in Table 5. Based on the minimum length of reinforced soil mass presented, and utilizing the soil parameters listed in Table 4, the equivalent bearing pressure exerted below the wall **will not exceed** the factored bearing resistance at the strength limit state.

Total settlements of 1.17 to 2.76 inches at the center, and 0.83 to 2.01 inches at the face of the of the reinforced soil mass, respectively, are anticipated for the proposed MSE wall, as noted in Table 6. 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 wall, maximum differential settlement in the longitudinal direction is anticipated to be less than 1/1000, which is within the tolerable limit of 1/100. Due to the granular nature of the bearing soils and condition of the existing embankment, it is estimated that 90 percent of the settlement is to occur within 10 to 20 days of completion of the embankment. If either the total or differential settlement predicted presents 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. Settlement calculations are provided in Appendix IV.

Table 6. Retaining Wall 4W12 MSE Wall Settlement Values

Station [1]	**Wall Height Analyzed (feet)**	**Backslope Behind Wall**	**Service Limit Equivalent Bearing Pressure (ksf)**	**Total Anticipated Settlement (inches)**	
				Center of MSE	**Face of MSE**
3003+06	36.9	Level	6.03	2.76	2.01
3004+50	25.2	2:1 (Broken-back)	4.87	2.19	1.63
3005+50	18.2	2:1 (Broken-back)	3.43	1.40	1.04
3006+24 (Phase 4A)	12.9	2:1 (Broken-back)	2.14	1.17	0.83
3006+24 (Phase 6A)	12.9	2:1	2.11	1.19	0.83

1. *Stationing is referenced to the baseline of Ramp C3.*
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.*

5.1.3 Eccentricity (Overturning Stability)

The resistance of the MSE wall to overturning will be dependent 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 retaining wall configurations indicated in Table 5. Based on the minimum length of reinforced soil mass presented in Table 5 and utilizing the soil parameters listed in Table 4 for the retained embankment material, the calculated eccentricity of the resultant force **<u>will not exceed</u>** the limiting eccentricity at the strength limit state.

5.1.4 Sliding Stability

The resistance of the MSE wall to sliding was evaluated per Section 11.10.5.3 of the 2014 AASHTO LRFD BDS. Given that the existing embankment material consists primarily of cohesive soil, the sliding resistance was evaluated under both drained and undrained conditions where applicable. 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, a coefficient of sliding friction of 0.53 was utilized for design. For undrained conditions, the sliding resistance is taken as the limiting value between the undrained shear strength of the bearing soil and half of the vertical stress applied by the wall multiplied by the width of the MSE wall. Based on the soil parameters listed in Table 4, the undrained shear strength of the existing embankment material is estimated at 2.63 ksf. A geotechnical resistance factor of φ_τ=1.0 was considered in calculating the factored shear resistance between the reinforced soil mass and foundation soil for sliding. Based on the minimum length of reinforced soil mass presented in Table 5 and utilizing the soil parameters listed in Table 4 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 under drained or undrained conditions.

5.1.5 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 4. 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 6.0 manufactured by Rocscience Inc. was utilized to perform the analyses.

Per Section 11.6.2.3 of the 2014 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 5, the resulting factor of safety under drained conditions (long-term stability) was greater than or approximately equal to 1.3.

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

5.1.6 Final MSE Wall Considerations

Based on the results of the external and global stability analysis performed for the MSE walls, the recommended controlling strap length ranges from 0.70 to 1.30 times the height of the MSE wall (measured from the top of the leveling pad to top of the coping) as noted in Table 5. Bearing resistance and global stability under drained conditions were the controlling factor in the determination of the recommended strap lengths greater than 0.70 times the height of the MSE Wall for the situations analyzed with a sloping backfill.

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 7 and Table 8.

Table 7. 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	130	0	33°	0.26	0.46	7.41

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

Table 8. 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	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	130	0	33°	0.26	0.46	7.41

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 9. Excavation Back Slopes

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

5.3.2 Groundwater Considerations

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

6.0 LIMITATIONS OF STUDY

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

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

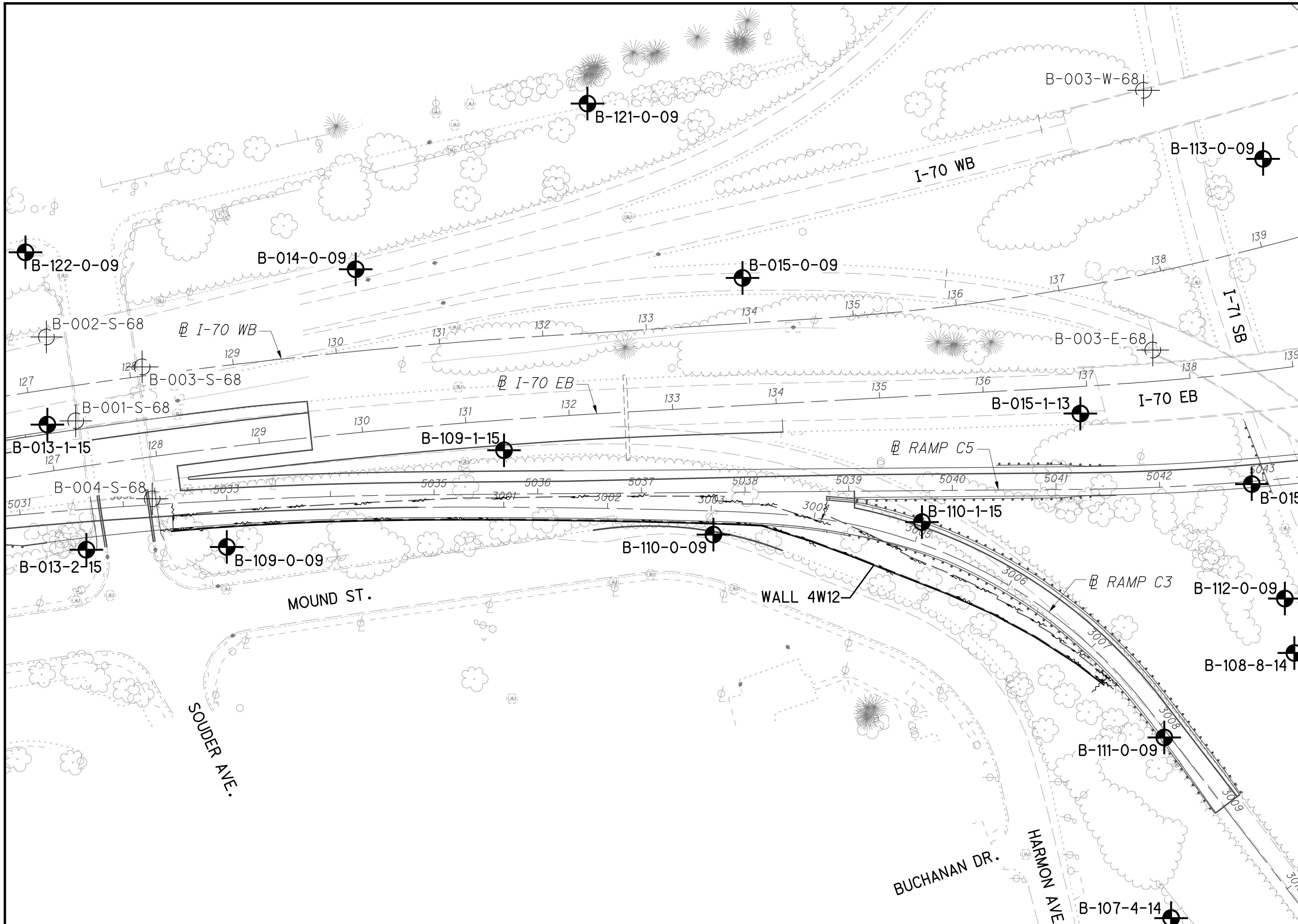
The conclusions and recommendations herein have been based upon the available soil and bedrock information and the design details furnished by a representative of the owner of the proposed project. Any revision in the plans for the proposed construction from those anticipated in this report should be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

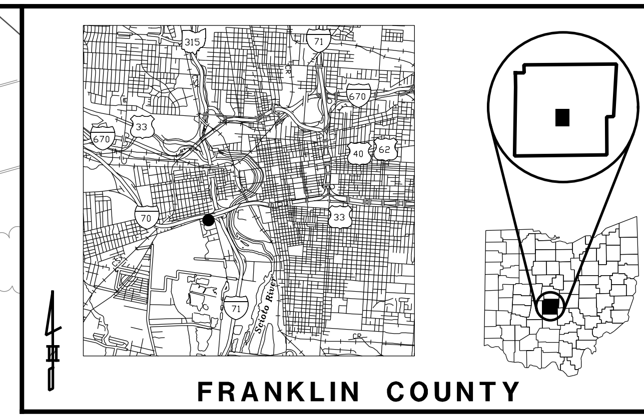
The scope of our services does not include any environmental assessment or investigation for the presence or absence of hazardous or toxic materials in the soil, groundwater or surface water within or beyond the site studied. Any statements in this report or on the test boring logs regarding odors, staining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

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

APPENDIX I

VICINITY MAP AND BORING PLAN





VICINITY MAP

BORING PLAN

FRA-70-12.68 - RETAINING WALL 4W12

FRANKLIN COUNTY, OHIO

RII PROJECT NO. W-13-045

SCALE: 1"=100'
0 50 100

DRAWN RRM
REVIEWED BRT
DATE 7-12-18

RESOURCE INTERNATIONAL, INC.

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 – ODOT A-1, A-2, A-3, A-4 (non-plastic)
The relative compactness of granular soils is described as:

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 – ODOT A-4, A-5, A-6, A-7, A-8
The relative consistency of cohesive soils is described as:

Description	Unconfined Compression (tsf)		
Very Soft	Less than		0.25
Soft	0.25	-	0.5
Medium Stiff	0.5	-	1.0
Stiff	1.0	-	2.0
Very Stiff	2.0	-	4.0
Hard	Over		4.0

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

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

Modifiers of Components - The following modifiers indicate the range of percentages of the minor soil components:

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 - ODOT
Dry	Well below Plastic Limit
Damp	Below Plastic Limit
Moist	Above PL to 3% below LL
Wet	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 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.

CLASSIFICATION OF SOILS

Ohio Department of Transportation

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

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

MATERIAL CLASSIFIED BY VISUAL INSPECTION

- Sod and Topsoil
- Pavement or Base
- Uncontrolled Fill (Describe)
- Bouldery Zone
- P Peat

* 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-109-0-09, B-109-1-15, B-110-0-09, B-110-1-15 and B-111-0-09

BORING LOGS

Definitions of Abbreviations

AS = Auger sample

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

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

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

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

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

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

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

RC = Rock core sample

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

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

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

S = Sulfate content (parts per million)

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

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

SS = Split spoon sample

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

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

TR = Top of rock

W = Initial water level measured during drilling

▼ = Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

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

Atterberg Limits:

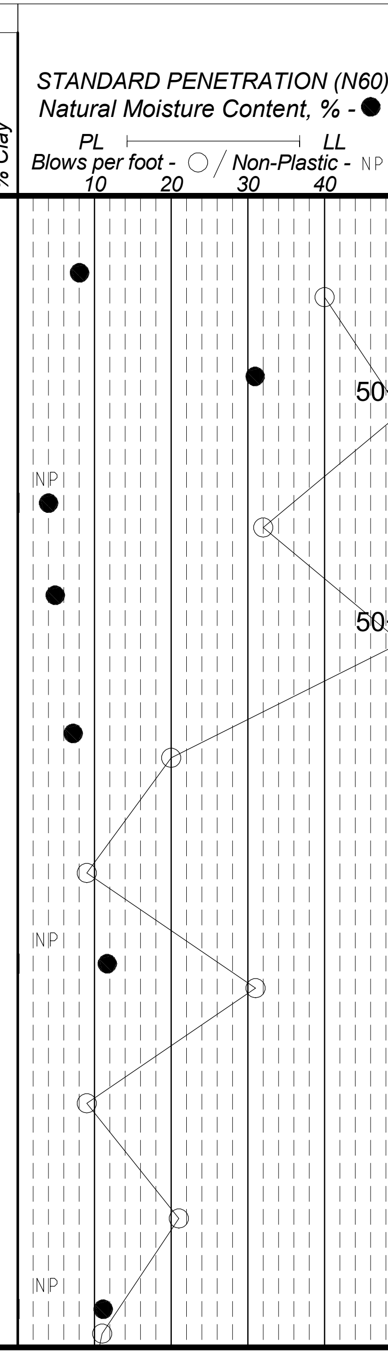
LL = Liquid limit
PL = Plastic limit
PI = Plasticity Index

WC = Water content (%)

Client: ms consultants	Project: FRA-70-8.93	Job No. 0221-1004.01
LOG OF: Boring B-109-0-09	Location: Sta. 5032+97.77, 44.7' RT., BL RAMP C5	Date Drilled: 9/11/2009

WATER OBSERVATIONS:
Water seepage at: 13.5', 42.0'
Water level at completion: 12.5' (includes drilling water)
FIELD NOTES:

Depth (ft)	Elev. (ft) 704.9	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
1.0	703.9						Topsoil - 5"						
3.5	701.4	6 18 21	6	1			FILL: Very dense brown SANDY SILT (A-4a), some fine to coarse sand, some gravel; damp.						
6.0	698.9	10 50/1	2	2		-	POSSIBLE FILL: Hard brown SANDY SILT (A-4a), little clay, trace to little fine to coarse gravel; damp.						
		15 15 16	12	3			Dense to very dense brown GRAVEL (A-1-a), little to some fine to coarse sand, trace silt; damp.	75	13	---	4	--8--	
		50/5	5	4									
		26 10 9	2	5			@ 11.0'-12.5'; contains sandstone fragments. @ 11.0'-15.0', loose to medium dense.						
		6 6 3	3	6			@ 13.5', becomes wet.						
		8 12 18	6	7				68	18	---	6	--8--	
		2 5 4	5	8			@ 18.5'-25.0', loose to medium dense.						
		5 8 12	2	9									
25	679.9	5 5 6	6	10			@ 23.5'-25.0', trace fine to coarse sand.	83	6	---	2	--9--	



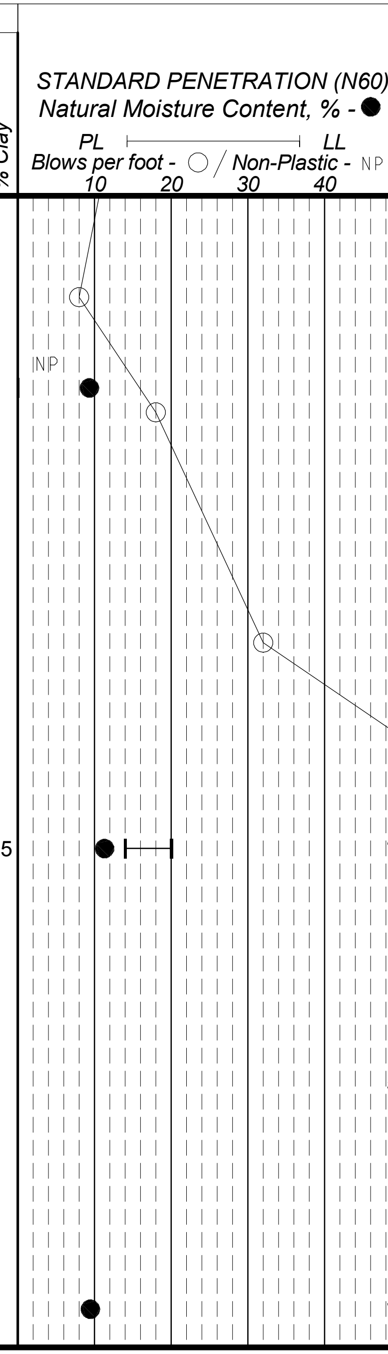
Client: ms consultants | *Project:* FRA-70-8.93 | *Job No.* 0221-1004.01

LOG OF: Boring B-109-0-09 | *Location:* Sta. 5032+97.77, 44.7' RT., BL RAMP C5 | *Date Drilled:* 9/11/2009

WATER OBSERVATIONS:
Water seepage at: 13.5', 42.0'
Water level at completion: 12.5' (includes drilling water)

FIELD NOTES:

Depth (ft)	Elev. (ft) 679.9	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Loose to medium dense brown GRAVEL WITH SAND (A-1-b), little fine to coarse sand, trace silt; damp.						
		3 3 5	3	11									
30		5 8 9	7	12				83	9	---	2	--6--	
35		15 14 17	1	13			@ 33.5'-35.0', dense.						
37.0	667.9						Hard gray SANDY SILT (A-4a), some fine to coarse sand, some gravel; damp.						
40		27 36 38	18	14		4.5+		21	16	---	17	31	15
42.0	662.9						Very dense gray COARSE AND FINE SAND (A-3a), little fine to coarse gravel, trace silt; wet.						
45		25 26 23	18	15									
47.0	657.9						Hard brown SANDY SILT (A-4a), trace to little gravel; moist.						
50.0	654.9	24 36 35	12	16		4.5+	Bottom of Boring - 50.0'						



RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-12.68 - PHASE 4A	DRILLING FIRM / OPERATOR: RII / J.K.	DRILL RIG: CME 55 (SN 386345)	STATION / OFFSET: 3001+00.00 / 55.0' LT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / M.M.	HAMMER: CME AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 77372 BR ID: N/A	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 736.2 (MSL) EOB: 85.0 ft.
START: 3/21/15 END: 3/22/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	LAT / LONG: 39.950097038, -83.019715408

EXPLORATION ID **B-109-1-15**

MATERIAL DESCRIPTION AND NOTES	ELEV. 736.2
0.5' - ASPHALT (6.0")	735.7
1.0' - AGGREGATE BASE (12.0")	734.7
FILL: DENSE, GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, DAMP.	733.2
FILL: VERY STIFF TO HARD, GRAY **SILT AND CLAY**, "AND" FINE GRAVEL, LITTLE COARSE TO FINE SAND, DAMP TO WET.	
-ROCK FRAGMENTS PRESENT IN SS-4	
-BRICK AND CLAY TILE FRAGMENTS PRESENT IN SS-7	

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
10 10 12	34	89	SS-1	-	18	31	17	24	10	NP	NP	NP	9	A-2-4 (0)
6 5 7	18	67	SS-2	3.50	-	-	-	-	-	-	-	-	14	A-6a (V)
7 7 11	28	89	SS-3	4.00	-	-	-	-	-	-	-	-	26	A-6a (V)
18 20 18	58	89	SS-4	4.50	37	10	10	23	20	29	17	12	16	A-6a (2)
7 9 8	26	89	SS-5	3.50	-	-	-	-	-	-	-	-	13	A-6a (V)
18 13 13	40	0	SS-6	-	-	-	-	-	-	-	-	-	-	
21 50/3"	-	100	SS-7	4.50	-	-	-	-	-	-	-	-	16	A-6a (V)

DEPTHS: 1 – 29

PID: 77372	BR ID: N/A	PROJECT: FRA-70-12.68 - PHASE 4A	STATION / OFFSET: 3001+00.00 / 55.0 LT	START: 3/21/15	END: 3/22/15	PG 2 OF 3	B-109-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 706.2	DEPTHS
FILL: VERY STIFF TO HARD, GRAY **SILT AND CLAY**, "AND" FINE GRAVEL, LITTLE COARSE TO FINE SAND, DAMP TO WET. *(same as above)*	704.2	31 – 32
DENSE, GRAY **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST.	700.7	32 – 35
HARD, BROWN **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DRY.	698.2	36 – 38
VERY DENSE, BROWN **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST.	695.7	39 – 40
VERY DENSE, BROWN **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT THROUGHOUT -INTORDUCED WATER @ 45.0'	690.7	41 – 45
VERY DENSE, BROWN **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST. -COBBLES PRESENT THROUGHOUT	685.7	46 – 50
VERY DENSE, GRAY **COARSE AND FINE SAND**, LITTLE FINE GRAVEL, TRACE SILT, MOIST. -ROCK FRAGMENTS PRESENT IN SS-16 -COBBLES PRESENT THROUGHOUT	683.2	51 – 53
VERY DENSE, GRAY **GRAVEL**, LITTLE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -COBBLES PRESENT THROUGHOUT	674.2	54 – 61

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
37 12 10	34	67	SS-8	-	-	-	-	-	-	-	-	-	7	A-1-b (V)	
7 8 9	26	89	SS-9	4.5+	27	25	12	19	17	36	29	7	15	A-4a (0)	
8 10 28	58	89	SS-10	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
33 50 50	153	89	SS-11	-	60	17	9	10	4	NP	NP	NP	5	A-1-a (0)	
18 44 22	101	67	SS-12	-	-	-	-	-	-	-	-	-	4	A-1-a (V)	
34 25 25	77	67	SS-13	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
18 32 37	106	67	SS-14	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
36 50/6"	-	25	SS-15	-	-	-	-	-	-	-	-	-	15	A-3a (V)	
22 23 18	63	89	SS-16	-	70	14	5	7	4	NP	NP	NP	8	A-1-a (0)	
18 19 19	58	44	SS-17	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	

PID: 77372	BR ID: N/A	PROJECT: FRA-70-12.68 - PHASE 4A	STATION / OFFSET: 3001+00.00 / 55.0 LT	START: 3/21/15	END: 3/22/15	PG 3 OF 3	B-109-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 674.1	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
DENSE, GRAY **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP. *(same as above)*		63																
		64–65	10 13 17	46	89	SS-18	-	30	22	13	16	19	21	14	7	10	A-2-4 (0)	
	669.2	66–67																
HARD, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		68																
		69–70	23 14 18	49	89	SS-19	4.5+	-	-	-	-	-	-	-	-	20	A-6b (V)	
	664.2	71–72																
HARD, GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, DAMP.		73																
		74–75	22 33 50/3"	-	100	SS-20	4.5+	17	22	15	27	19	22	14	8	9	A-4a (2)	
		76–78																
		79–80	26 50/6"	-	100	SS-21	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	
		81–83																
	651.2	84–85 (EOB)	22 35 43	120	89	SS-22	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED PRIOR TO INTRODUCTION OF WATER TO THE BOREHOLE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 376 LBS CEMENT / 100 LBS BENTONITE CHIPS / 80 GAL WATER

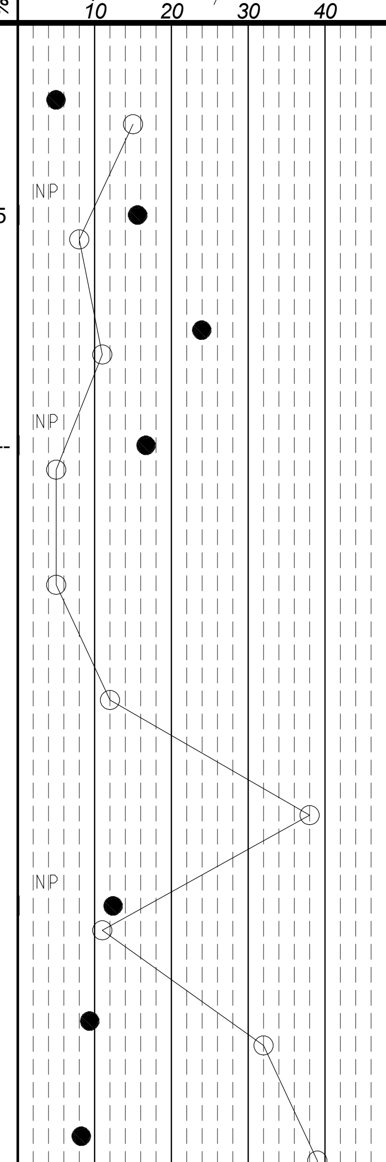
Client: ms consultants | *Project:* FRA-70-8.93 | *Job No.* 0221-1004.01

LOG OF: Boring B-110-0-09 | *Location:* Sta. 3003+02.96, 22.8' RT., BL RAMP C3 | *Date Drilled:* 9/11/2009

WATER OBSERVATIONS:
Water seepage at: 10.5', 46.0'
Water level at completion: 10.6'
FIELD NOTES:

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
	705.8						Asphalt Concrete - 5" Portland Cement Concrete - 7"						
1.0	704.8	5 9 6	6	1			FILL: Loose to medium dense dark brown GRAVEL WITH SAND (A-1-b), trace clay, trace silt; damp to moist.						
		2 4 4	18	2		1.5	@ 1.0'-2.5', contains trace brick fragments. @ 3.5'-5.0', organic; LOI @ 440 deg. C = 11.0%	47	32	---	7	9	5
6.0	699.8	4 5 6	12	3		3.0	FILL: Very stiff dark brown SILT AND CLAY (A-6a), little fine to coarse sand, slightly organic; damp.						
8.0	697.8	4 3 2	12	4			FILL: Loose brown COARSE AND FINE SAND (A-3a), little to some gravel, little silt; moist.	20	45	---	18	--17--	
10.5	695.3	1 1 4	7	5			Loose to medium dense brown SANDY SILT (A-4a), some fine to coarse sand, some gravel; wet.						
		2 8 4	3	6									
16.0	689.8	8 19 18	1	7			Medium dense to dense brown GRAVEL (A-1-a), little to some fine to coarse sand, trace silt; wet.						
		1 5 6	3	8				80	10	---	2	--8--	
		1 11 20	3	9									
25	680.8	7 22 16	8	10									

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

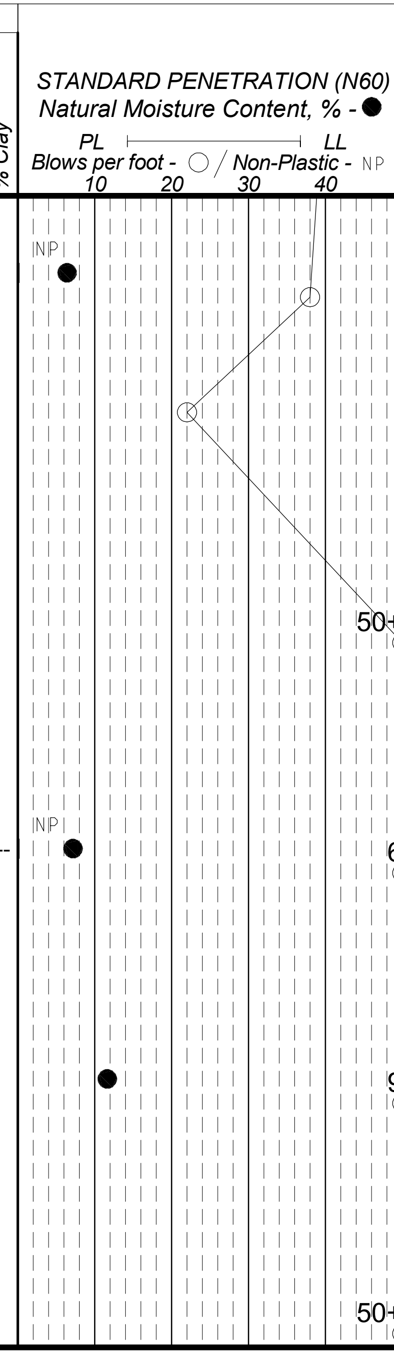


Client: ms consultants | *Project:* FRA-70-8.93 | *Job No.* 0221-1004.01

LOG OF: Boring B-110-0-09 | *Location:* Sta. 3003+02.96, 22.8' RT., BL RAMP C3 | *Date Drilled:* 9/11/2009

WATER OBSERVATIONS:
Water seepage at: 10.5', 46.0'
Water level at completion: 10.6'
FIELD NOTES:

Depth (ft)	Elev. (ft) 680.8	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Medium dense to dense brown GRAVEL (A-1-a), little to some fine to coarse sand, trace silt; wet.						
		10 18 19	6	11				82	11	---	4	--3--	
		12 11 10	4	12									
							@ 33.5'-34.4', very dense.						
		3 50/5	3	13									
37.0	668.8						Very dense gray GRAVEL WITH SAND (A-1-b), little silt; moist to wet.						
		30 34 30	12	14				49	20	---	13	--18--	
43.0	662.8						Hard gray SANDY SILT (A-4a), little fine to coarse gravel; damp to moist.						
		35 41 48	18	15		4.5+							
46.0	659.8						Very dense gray COARSE AND FINE SAND (A-3a), some silt, some gravel; wet.						
49.4	656.4	30 50/5	11	16									
							Bottom of Boring - 49.4'						



PROJECT: FRA-70-12.68 - PHASE 4A	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: MOBILE B-53 (SN 624400)	STATION / OFFSET: 3005+00.00 / 20.0' LT
TYPE: STRUCTURE	SAMPLING FIRM / LOGGER: RII / N.A.	HAMMER: AUTOMATIC	ALIGNMENT: BL RAMP C3
PID: 77372 BR ID: N/A	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 4/26/13	ELEVATION: 740.3 (MSL) EOB: 75.0 ft.
START: 3/21/15 END: 3/22/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 77.7	LAT / LONG: 39.949913094, -83.018276075

EXPLORATION ID B-110-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 740.3
0.7' - ASPHALT (8.0")	739.6
1.2' - CONCRETE (14.5")	738.4
0.4' - AGGREGATE BASE (5.0")	738.0
FILL: HARD, BROWNISH GRAY TO GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.	718.3
FILL: HARD, GRAY **ELASTIC CLAY**, SOME COARSE TO FINE SAND, SOME SILT, TRACE FINE GRAVEL, MOIST.	713.3
VERY DENSE, GRAY **GRAVEL**, LITTLE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-6	

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
6 9 9	23	100	SS-1	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)
4 9 10	25	50	SS-2	4.5+	8	12	9	36	35	30	17	13	13	A-6a (8)
2 10 17	35	100	SS-3	4.5+	-	-	-	-	-	-	-	-	22	A-6a (V)
4 5 11	21	100	SS-4	4.5+	-	-	-	-	-	-	-	-	10	A-6a (V)
21 34 18	67	0	SS-5	-	-	-	-	-	-	-	-	-	-	
17	-	100	2S-5A	4.5+	5	19	10	40	26	41	30	11	31	A-7-5 (7)
9 40 38	101	100	SS-6	-	-	-	-	-	-	-	-	-	4	A-1-a (V)

MATERIAL DESCRIPTION AND NOTES	ELEV. 710.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
	709.8	30																
MEDIUM DENSE, GRAY **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST.		31–32	7 8 12	26	100	SS-7	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
	707.3	33																
VERY DENSE, GRAY **GRAVEL**, LITTLE COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -ROCK FRAGMENTS PRESENT IN SS-8		34	10 50/2"	-	75	SS-8	-	67	14	4	9	6	NP	NP	NP	5	A-1-a (0)	
	704.8	35																
HARD, DARK BROWNISH GRAY TO BROWN **SILTY CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.		36–37	3 6 12	23	100	SS-9	4.00	-	-	-	-	-	-	-	-	27	A-6b (V)	
		38–40	5 9 12	27	100	SS-10	4.25	4	12	18	42	24	39	23	16	18	A-6b (9)	
	699.8	40																
VERY DENSE, BROWN TO GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.		41–42	13 19 34	69	100	SS-11	-	-	-	-	-	-	-	-	-	6	A-1-a (V)	
		43–45	9 24 23	61	100	SS-12	-	56	22	7	10	5	NP	NP	NP	8	A-1-a (0)	
		46–47	9 22 29	66	100	SS-13	-	-	-	-	-	-	-	-	-	8	A-1-a (V)	
		48–50	17 32 41	95	39	SS-14	-	-	-	-	-	-	-	-	-	5	A-1-a (V)	
		51–53 (W)																
		54–55	15 16 24	52	100	SS-15	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
		56–58																
		59–60	17 18 21	51	100	SS-16	-	65	21	6	5	3	NP	NP	NP	5	A-1-a (0)	
	678.3	61																

2014 ODOT BORING LOG-RII NE BRIDGE ID - OH DOT.GDT - 3/27/15 18:31 - U:\GI8\PROJECTS\2013\W-13-045.GPJ

PID: 77372	BR ID: N/A	PROJECT: FRA-70-12.68 - PHASE 4A	STATION / OFFSET: 3005+00.00 / 20.0 LT	START: 3/21/15	END: 3/22/15	PG 3 OF 3	B-110-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 678.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
MEDIUM DENSE TO DENSE, GRAY **COARSE AND FINE SAND**, LITTLE SILT, TRACE FINE GRAVEL, TRACE CLAY, MOIST TO WET. *(same as above)*		63																
		64	7 8 13	27	100	SS-17	-	-	-	-	-	-	-	-	-	17	A-3a (V)	
		65–68																
		69	16 17 19	47	56	SS-18	-	-	-	-	-	-	-	-	-	26	A-3a (V)	
		70–73																
	665.3	74	13 17 18	45	100	SS-19	-	8	40	30	16	6	NP	NP	NP	15	A-3a (0)	
		EOB 75																

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 53.5'

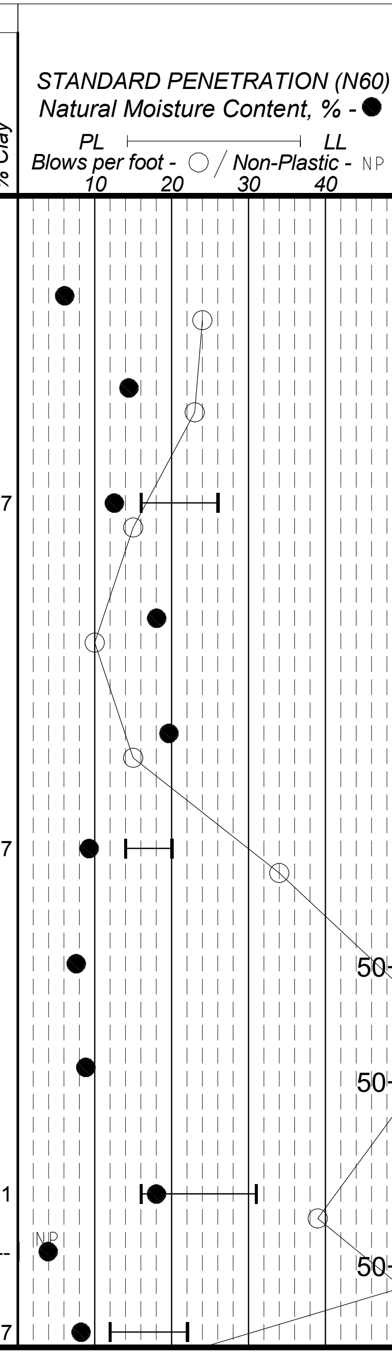
ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 188 LBS CEMENT / 50 LBS BENTONITE CHIPS / 40 GAL WATER

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

LOG OF: Boring B-111-0-09 | *Location:* Sta. 3008+11.91, 4.6' RT., BL RAMP C3 | *Date Drilled:* 9/1/2009

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

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



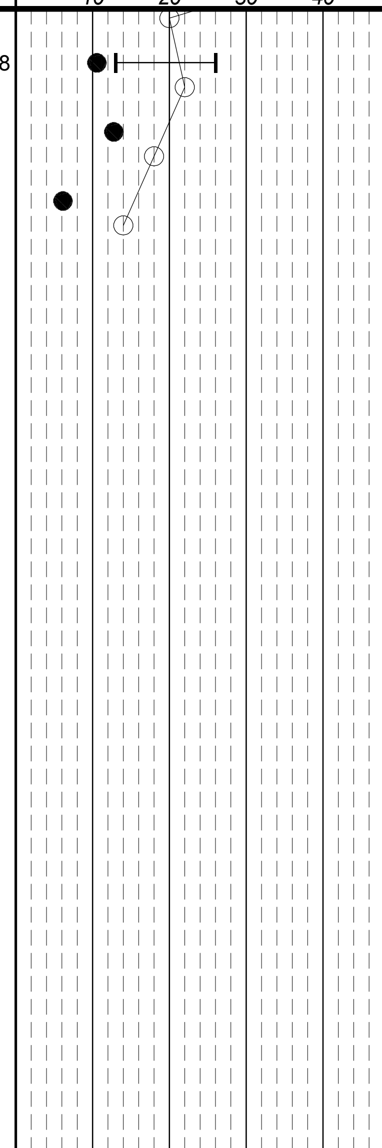
Client: ms consultants | **Project:** FRA-70-8.93 | **Job No.** 0221-1004.01

LOG OF: Boring B-111-0-09 | **Location:** Sta. 3008+11.91, 4.6' RT., BL RAMP C3 | **Date Drilled:** 9/1/2009

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

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

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

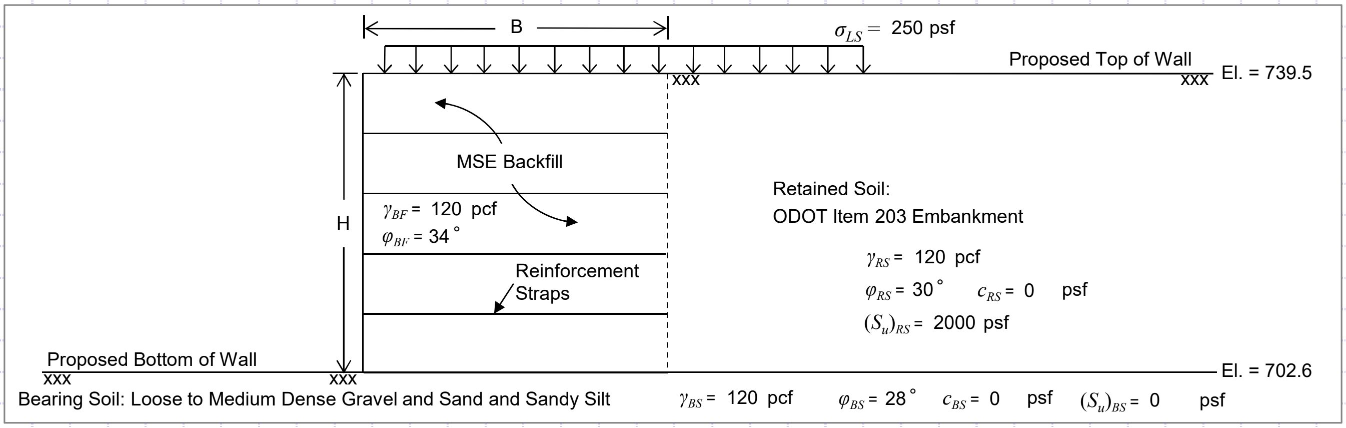


Depth scale: 30, 35, 40, 45, 50

APPENDIX IV

MSE Wall Calculations

FRA-70-12.68 - Retaining Wall 4W12 - Sta. 3003+06 - B-109-1-15 and B-110-0-15 - 30.9 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.9 ft
MSE Wall Width (Reinforcement Length), (B) =	25.8 ft
MSE Wall Length, (L) =	936 ft
Live Surcharge Load, (σ_{LS}) =	250 psf
Retained Soil Unit Weight, (γ_{RS}) =	120 pcf
Retained Soil Friction Angle, (φ_{RS}) =	30 °
Retained Soil Drained Cohesion [1], (c_{BS}) =	0 psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000 psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34 °

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0 psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	0 psf
Embedment Depth, (D_f) =	3.0 ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0 ft

LRFD Load Factors

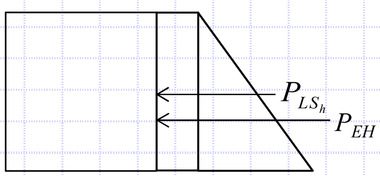
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

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

Sliding Force:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(36.9 ft)²(0.297)(1.5)} = 36.4 \text{ kip/ft}$$

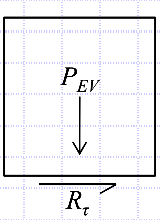
$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(36.9 ft)(0.297)(1.75)} = 4.79 \text{ kip/ft}$$

$$P_H = 36.4 \text{ kip/ft} + 4.79 \text{ kip/ft} = 41.19 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition

Nominal Sliding Resistance:

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



$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(36.9 ft)(25.8 ft)(1.00)} = 114.24 \text{ kip/ft}$$

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

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

$$R_\tau = \text{(114.24 kip/ft)(0.53)} = 60.55 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 41.19 kip/ft ≤ (60.55 kip/ft)(1.0) = 60.55 kip/ft ⟶ 41.19 kip/ft ≤ 60.55 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) =	36.9	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	936	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0	ft

LRFD Load Factors

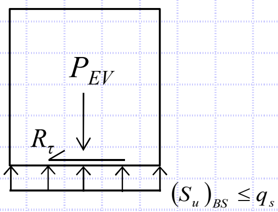
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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



$(S_u)_{BS} =$ N/A ksf

$q_s = \sigma_v / 2$ = (4.43 ksf) / 2 = 2.22 ksf

$\sigma_v = P_{EV} / B$ = (114.24 kip/ft) / (25.8 ft) = 4.43 ksf

R_τ = (N/A ksf ≤ 2.22 ksf)(25.8 ft) = N/A kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \leq R_\tau \cdot \phi_\tau$ ⟶ N/A ⟶ N/A

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) =	36.9	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	936	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

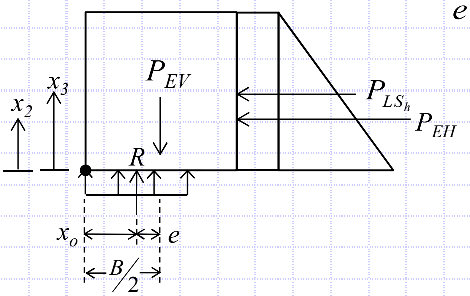
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0	ft

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



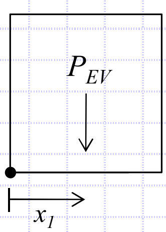
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (1473.7 kip·ft/ft - 536.1 kip·ft/ft) / (114.24 kip/ft) = 8.21 ft

M_{EV} = 1473.70 kip·ft/ft
M_H = 536.1 kip·ft/ft
P_{EV} = 114.24 kip/ft
(Defined below)

$e =$ (25.8 ft)/2 - 8.21 ft = 4.69 ft

Resisting Moment, M_{EV}:



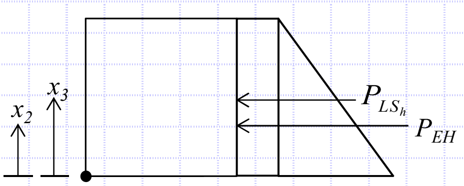
$$M_{EV} = P_{EV}(x_1)$$

$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(36.9 ft)(25.8 ft)(1.00) = 114.24 kip/ft

$x_1 = B/2$ = (25.8 ft) / 2 = 12.90 ft

$M_{EV} =$ (114.24 kip/ft)(12.90 ft) = 1473.70 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)(36.9 ft)²(0.297)(1.5) = 36.40 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(36.9 ft)(0.297)(1.75) = 4.79 kip/ft

$x_2 = H/3$ = (36.9 ft) / 3 = 12.30 ft

$x_3 = H/2$ = (36.9 ft) / 2 = 18.45 ft

$M_H =$ (36.4 kip/ft)(12.3 ft) + (4.79 kip/ft)(18.45 ft) = 536.1 kip·ft/ft

Check Eccentricity

$e < e_{max} \longrightarrow$ 4.69 ft < 8.60 ft **OK**

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (25.8 ft) / 3 = 8.60 ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.9	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	936	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

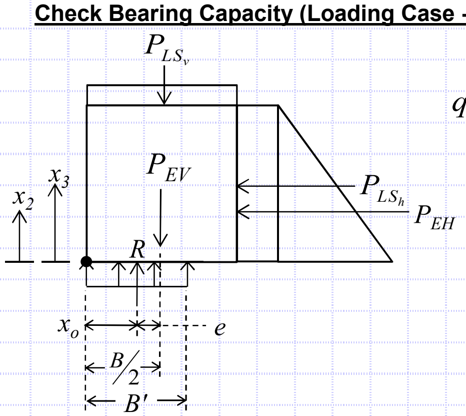
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0	ft

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



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

$B' = B - 2e$ = 25.8 ft - 2(3.24 ft) = 19.32 ft

$e = B/2 - x_o$ = (25.8 ft) / 2 - 9.66 ft = 3.24 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (2135.14 kip·ft/ft - 536.13 kip·ft/ft) / 165.51 kip/ft = 9.66 ft

q_{eq} = (165.51 kip/ft) / (19.32 ft) = 8.57 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)(36.9 ft)(25.8 ft)(1.35)](12.9 ft) + [(250 psf)(25.8 ft)(1.75)](12.9 ft) = 2135.14 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)(36.9 ft)²(0.297)(1.5)](12.3 ft) + [(250 psf)(36.9 ft)(0.297)(1.75)](18.45 ft) = 536.13 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)(36.9 ft)(25.8 ft)(1.35) + (250 psf)(25.8 ft)(1.75) = 165.51 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 26.11

N_c = 25.8
s_c = 1+(19.32 ft/936 ft)(14.72/25.8)
= 1.012
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 15.57

N_q = 14.72
s_q = 1.011
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/19.32 ft)
1.046
i_q = 1.000 (Assumed)
C_{wq} = 14.0 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.59

N_γ = 16.72
s_γ = 0.992
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 14.0 ft < 1.5(19.32 ft) + 3.0 ft = 0.742

q_n = (0 psf)(26.110) + (120 pcf)(3.0 ft)(15.566)(1.000) + ½(120 pcf)(19.3 ft)(16.586)(0.742) = 19.87 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 8.57 ksf ≤ (19.87 ksf)(0.65) = 12.92 ksf ⟶ 8.57 ksf ≤ 12.92 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.9	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	936	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, $[(S_u)_{RS}]$ =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	0	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0	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: $$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$

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

- N_c = 5.140
- s_c = 1+(19.32 ft/[(5)(936 ft)]) = 1.004
- 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(3.0 ft/19.32 ft) = 1.000
- i_q = 1.000 (Assumed)
- C_{wq} = 14.0 ft > 3.0 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)
- $C_{w\gamma}$ = 14.0 ft < 1.5(19.32 ft) + 3.0 ft = 0.742

$q_n =$ (0 psf)(5.160) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(19.3 ft)(0.000)(0.742) = N/A ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 8.57 ksf ≤ (N/A ksf)(0.65) = N/A ksf ⟶ N/A

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

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COLUMBUS, OHIO 43231
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FAX: (614) 823-4990
WWW.RESOURCEINTERATIONAL.COM

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	36.9	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	936	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Retained Soil Unit Weight, (γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Drained Cohesion, (c_{BS}) =	0	psf
Retained Soil Undrained Shear Strength, [$(S_u)_{RS}$] =	2000	psf
Retained Soil Active Earth Pressure Coeff., (K_a) =	0.297	
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°

Bearing Soil Properties:

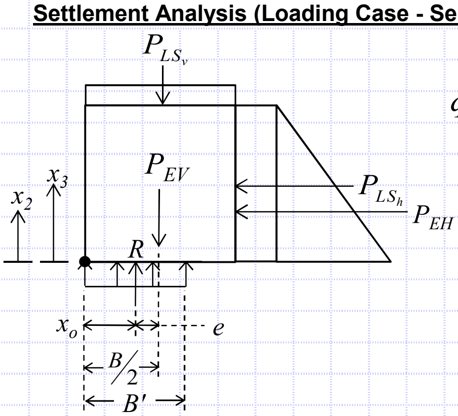
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	14.0	ft

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



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

$$B' = B - 2e \quad = \quad 25.8 \text{ ft} - 2(2.89 \text{ ft}) \quad = \quad 20.02 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (25.8 \text{ ft}) / 2 - 10.01 \text{ ft} \quad = \quad 2.89 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (1556.93 \text{ kip·ft/ft} - 349 \text{ kip·ft/ft}) / 120.69 \text{ kip/ft} \quad = \quad 10.01 \quad \text{ft}$$

$$q_{eq} = \quad (120.69 \text{ kip/ft}) / (20.02 \text{ ft}) \quad = \quad 6.03 \quad \text{ksf}$$

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

$$M_V = \quad [(120 \text{ pcf})(36.9 \text{ ft})(25.8 \text{ ft})(1.00)](12.9 \text{ ft}) + [(250 \text{ psf})(25.8 \text{ ft})(1.00)](12.9 \text{ ft}) \quad = \quad 1556.93 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad [\tfrac{1}{2}(120 \text{ pcf})(36.9 \text{ ft})^2(0.297)(1.00)](12.3 \text{ ft}) + [(250 \text{ psf})(36.9 \text{ ft})(0.297)(1.00)](18.45 \text{ ft}) \quad = \quad 349.00 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad (120 \text{ pcf})(36.9 \text{ ft})(25.8 \text{ ft})(1.00) + (250 \text{ psf})(25.8 \text{ ft})(1.00) \quad = \quad 120.69 \quad \text{kip/ft}$$

Settlement (See Attached Spreadsheet Calculations):

Total Settlement at Center of Reinforced Soil Mass: S_t = **2.764** in

Total Settlement at Wall Facing: S_t = **2.013** in

Time Rate of Consolidation Settlement at Wall Facing (See Attached Spreadsheet Calculations):

$(S_c)_{90}$ = in at days following completion of construction

W-13-045 - FRA-70-12.68 - Retaining Wall 4W12 | Calculated By: BRT | Date: 7/17/2018

MSE Wall Settlement - Sta. 3003+06 | Checked By: JPS | Date: 7/17/2018

Borings B-109-1-15 and B-110-0-15

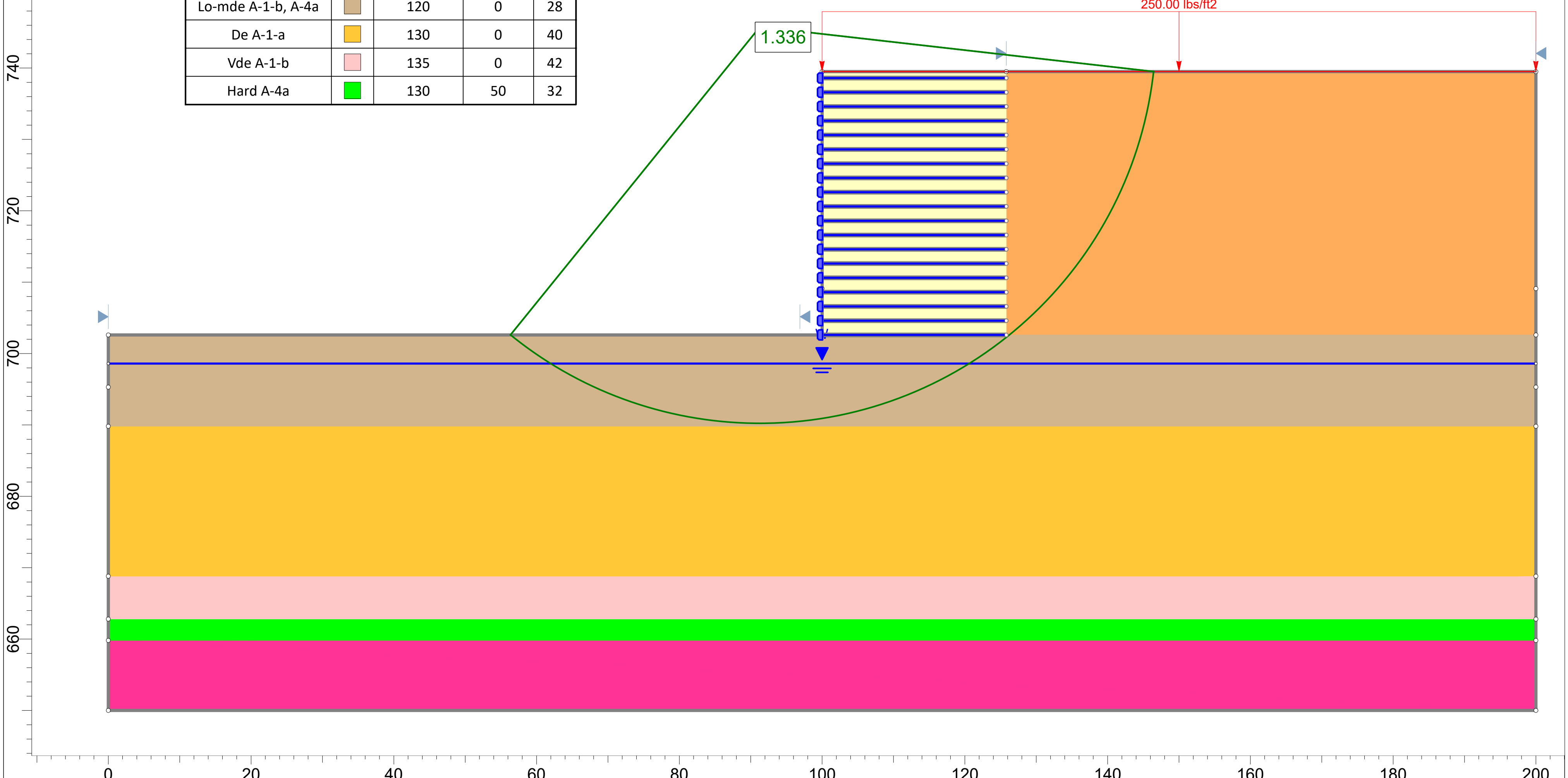
H=	36.9	ft	Total wall height
B'=	20.0	ft	Effective footing width due to eccentricity
D_w =	14.0	ft	Depth below bottom of footing
q_e =	6,030	psf	Equivalent bearing pressure at bottom of wall

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	Center: I (7)	Center: $\Delta\sigma_v$ (8) (psf)	Center: σ_{vf}' Midpoint (psf)	Center: S_c (9,10) (ft)	Center: S_c (in)	Facing: I (7)	Facing: $\Delta\sigma_v$ (8) (psf)	Facing: σ_{vf}' Midpoint (psf)	Facing: S_c (9,10) (ft)	Facing: S_c (in)
																				Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
1	A-1-b	G	0.0	1.5	1.5	0.8	120	180	90	90	4,090					29	58	205	0.04	0.994	5,995	6,085	0.013	0.160	0.500	3,015	3,105	0.011	0.135
	A-1-b	G	1.5	3.0	1.5	1.5	120	360	270	270	4,270					29	48	163	0.08	0.988	5,959	6,229	0.013	0.151	0.500	3,015	3,285	0.010	0.120
	A-1-b	G	3.0	4.5	1.5	2.3	120	540	450	450	4,450					29	44	143	0.11	0.976	5,888	6,338	0.012	0.144	0.500	3,015	3,465	0.009	0.111
	A-1-b	G	4.5	6.0	1.5	3.0	120	720	630	630	4,630					29	40	131	0.15	0.971	5,853	6,483	0.012	0.139	0.500	3,015	3,645	0.009	0.104
	A-1-b	G	6.0	7.3	1.3	3.7	120	876	798	798	4,798					29	38	124	0.18	0.965	5,817	6,615	0.010	0.116	0.500	3,015	3,813	0.007	0.086
2	A-4a	G	7.3	9.8	2.5	4.9	120	1,176	1,026	1,026	5,026					29	36	63	0.25	0.947	5,711	6,737	0.032	0.389	0.500	3,015	4,041	0.024	0.284
	A-4a	G	9.8	12.8	3.0	6.4	120	1,536	1,356	1,356	5,356					29	33	59	0.32	0.929	5,604	6,960	0.036	0.434	0.488	2,943	4,299	0.026	0.306
3	A-1-a	G	12.8	17.8	5.0	8.9	125	2,161	1,849	1,849	5,849					39	40	131	0.45	0.900	5,427	7,276	0.023	0.273	0.468	2,822	4,671	0.015	0.184
	A-1-a	G	17.8	22.8	5.0	11.4	125	2,786	2,474	2,474	6,474					39	36	118	0.57	0.800	4,824	7,298	0.020	0.239	0.448	2,701	5,175	0.014	0.163
	A-1-a	G	22.8	27.8	5.0	13.9	125	3,411	3,099	3,099	7,099					39	33	109	0.70	0.717	4,322	7,420	0.017	0.209	0.428	2,581	5,679	0.012	0.145
	A-1-a	G	27.8	33.8	6.0	16.9	125	4,161	3,786	3,605	7,605					39	31	103	0.85	0.644	3,886	7,491	0.019	0.222	0.404	2,436	6,041	0.013	0.157
4	A-1-b	G	33.8	39.8	6.0	19.9	130	4,941	4,551	4,183	8,183					64	48	162	1.00	0.578	3,484	7,667	0.010	0.117	0.386	2,326	6,509	0.007	0.085
5	A-4a	C	39.8	42.8	3.0	21.4	125	5,316	5,129	4,667	8,667	22	0.108	0.011	0.444				1.07	0.544	3,283	7,950	0.005	0.062	0.377	2,274	6,941	0.004	0.046
6	A-3a	G	42.8	52.8	10.0	26.4	130	6,616	5,966	5,192	9,192					100	68	204	1.32	0.457	2,757	7,949	0.009	0.109	0.349	2,102	7,294	0.007	0.087
																					Total Settlement:			2.764 in		Total Settlement:			2.013 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 26, FHWA GEC 5
3. C_r = 0.05(C_c) for embankment fill and 0.10(C_c) for natural cohesive soils; Ref. Section 5.4.2.5 of FHWA GEC 5
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. $S_c = [C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ 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 (Cohesiv 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)

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Backfill		120	0	34
Existing Embankment		120	0	30
Lo-mde A-1-b, A-4a		120	0	28
De A-1-a		130	0	40
Vde A-1-b		135	0	42
Hard A-4a		130	50	32

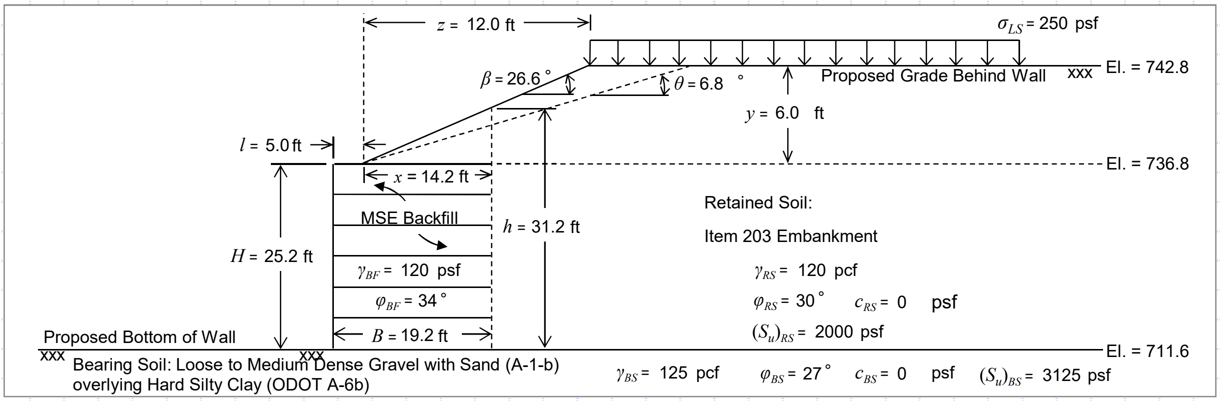
Support Name	Color	Type	Strip Coverage (%)	Tensile Strength (lbs/ft)
MSE Reinforcement Straps		GeoTextile	100	7500



Project	FRA-70-12.68 MSE Wall 4W12 - Sta. 3003+06		
Analysis Description	Spencer Method - Drained Conditions		
Drawn By: BRT	Scale: 1:250	Company	Resource International, Inc.
Date: 7/17/2018		File Name	Sta 3003+06 - Global Stability.slim

SLIDEINTERPRET 7.020

FRA-70-12.68 - Retaining Wall 4W12 - Sta. 3004+50 - B-110-0-15 and B-110-1-15 - 25.2 ft. Wall Height - Broken Backslope



MSE Wall Dimensions and Retained Soil Parameters		
MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	16.9	ft

LRFD Load Factors

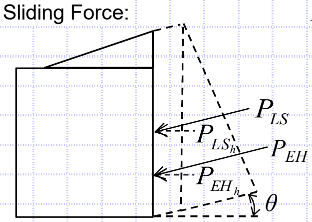
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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



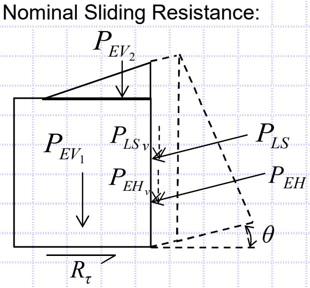
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(31.2 ft)²(0.324)(1.50) = 28.40 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(31.2 ft)(0.324)(1.75) = 3.96 kip/ft

P_H = (28.40 kip/ft + 3.96 kip/ft)cos(6.8°) = 32.13 kip/ft

Check Sliding Resistance - Drained Condition

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



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.2 ft)(19.2 ft)(1.00) = 58.06 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(31.2 ft - 25.2 ft)(19.2 ft - 5.0 ft)(1.00) = 5.12 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(31.2 ft)²(0.324)(1.50) = 28.40 kip/ft

$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF})$ ⟶ tan(27) ≤ tan(34) ⟶ 0.51 ≤ 0.67 = 0.51

R_τ = [58.06 kip/ft + 5.12 kip/ft + (28.40 kip/ft)sin(6.8°)](0.51) = 33.94 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 32.13 kip/ft ≤ (33.94 kip/ft)(1.0) = 33.94 kip/ft ⟶ 32.13 kip/ft ≤ 33.94 kip/ft **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	16.9	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

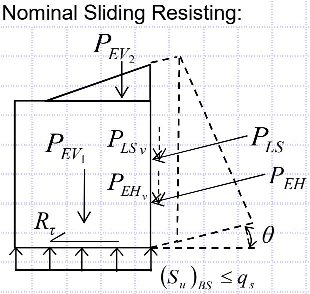
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



(Neglect P_{LSv} for conservatism)

$(S_u)_{BS}$ = 3.13 ksf

$q_s = \sigma_v / 2$

$\sigma_v = P_V / B$

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

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(25.2 ft)(19.2 ft)(1.00) = 58.06 kip/ft

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

P_{EV_2} = ½(120 pcf)(31.2 ft - 25.2 ft)(19.2 ft - 5.0 ft)(1.00) = 5.12 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(31.2 ft)²(0.324)(1.50) = 28.4 kip/ft

P_V = 58.06 kip/ft + 5.12 kip/ft + (28.4 kip/ft)sin(6.8°) = 66.54 kip/ft

σ_v = (66.54 kip/ft) / (19.2 ft) = 3.47 ksf

q_s = (3.47 ksf) / 2 = 1.74 ksf

R_τ = (3.13 ksf ≤ 1.74 ksf)(19.2 ft) = 60.00 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 32.13 kip/ft ≤ (60.00 kip/ft)(1.0) = 60.00 kip/ft ⟶ 32.13 kip/ft ≤ 60.00 kip/ft **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	16.9	ft

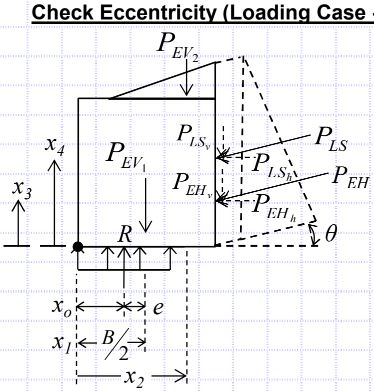
LRFD Load Factors

	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



$$e = B/2 - x_o$$

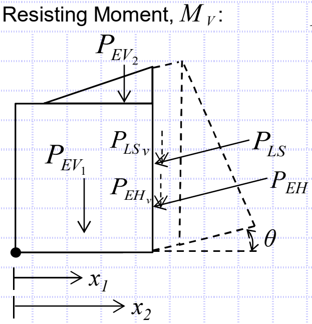
$$x_o = \frac{M_V - M_H}{P_V}$$ = (696.03 kip·ft/ft - 361.75 kip·ft/ft) / (66.54 kip/ft) = 5.02 ft

M_V = 696.03 kip·ft/ft
M_H = 361.75 kip·ft/ft } Defined below

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 58.06 kip/ft + 5.12 kip/ft + (28.4 kip/ft)sin(6.8°) = 66.54 kip/ft

$e =$ (19.2 ft/ 2) - 5.02 ft = 4.58 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)(25.2 ft)(19.2 ft)(1.00) = 58.06 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(31.2 ft - 25.2 ft)(19.2 ft - 5.0 ft)(1.00) = 5.12 kip/ft

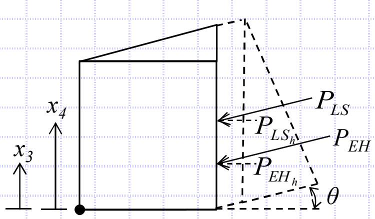
$P_{EH} = ½\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(31.2 ft)²(0.324)(1.50) = 28.4 kip/ft

$x_1 = B/2$ = (19.2 ft) / 2 = 9.60 ft

$x_2 = l + ⅔(B-l)$ = 5.0 ft + ⅔(19.2 ft - 5.0 ft) = 14.47 ft

M_V = (58.06 kip/ft)(9.60 ft) + (5.12 kip/ft)(14.47 ft) + (28.4 kip/ft)sin(6.8°)(19.2 ft) = 696.03 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)(31.2 ft)²(0.324)(1.50) = 28.40 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(31.2 ft)(0.324)(1.75) = 4.42 kip/ft

$x_3 = h/3$ = (31.2 ft) / 3 = 10.40 ft

$x_4 = h/2$ = (31.2 ft) / 2 = 15.6 ft

M_H = (28.4 kip/ft)cos(6.8°)(10.40 ft) + (4.42 kip/ft)cos(6.8°)(15.60 ft) = 361.75 kip·ft/ft

Check Eccentricity Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (19.2 ft) / 3 = 6.40 ft

$e < e_{max} \longrightarrow$ 4.58 ft < 6.40 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	16.9	ft

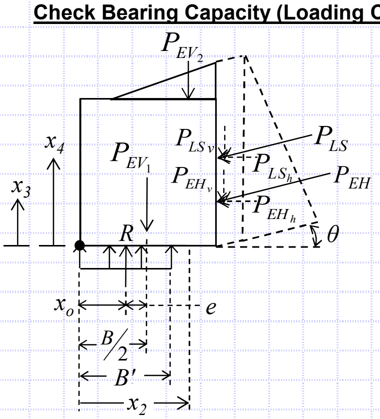
LRFD Load Factors

	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 11.6.3.2



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

$$B' = B - 2e \quad = \quad 19.2\text{ ft} - 2(3.34\text{ ft}) \quad = \quad 12.52 \quad \text{ft}$$

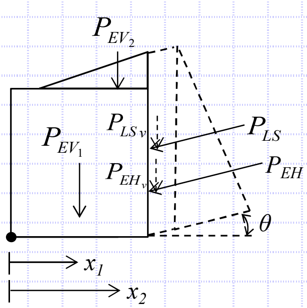
$$e = B/2 - x_o \quad = \quad (19.2\text{ ft} / 2) - 6.26\text{ ft} \quad = \quad 3.34 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (917.00\text{ kip·ft/ft} - 361.75\text{ kip·ft/ft}) / 88.65\text{ kip/ft} \quad = \quad 6.26 \quad \text{ft}$$

$$q_{eq} = \quad (88.65\text{ kip/ft}) / (12.52\text{ ft}) \quad = \quad 7.08 \quad \text{ksf}$$

Resisting Moment, M_V:

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad (120\text{ pcf})(25.2\text{ ft})(19.2\text{ ft})(1.35) \quad = \quad 78.38 \quad \text{kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV} = \tfrac{1}{2}(120\text{ pcf})(31.2\text{ ft} - 25.2\text{ ft})(19.2\text{ ft} - 5.0\text{ ft})(1.35) = \quad 6.91 \quad \text{kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad \tfrac{1}{2}(120\text{ pcf})(31.2\text{ ft})^2(0.324)(1.50) \quad = \quad 28.4 \quad \text{kip/ft}$$

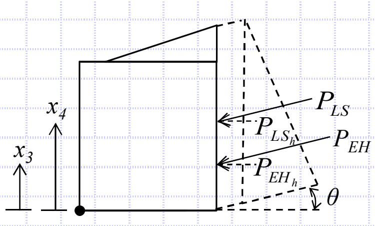
$$x_1 = B/2 \quad = \quad (19.2\text{ ft}) / 2 \quad = \quad 9.60 \quad \text{ft}$$

$$x_2 = l + \tfrac{2}{3}(B - l) \quad = \quad 5.0\text{ ft} + \tfrac{2}{3}(19.2\text{ ft} - 5.0\text{ ft}) \quad = \quad 14.47 \quad \text{ft}$$

$$M_V = \quad (78.38\text{ kip/ft})(9.60\text{ ft}) + (6.91\text{ kip/ft})(14.5\text{ ft}) + (28.4\text{ kip/ft})\sin(6.8°)(19.2\text{ ft}) \quad = \quad 917.00 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad \tfrac{1}{2}(120\text{ pcf})(31.2\text{ ft})^2(0.324)(1.50) \quad = \quad 28.40 \quad \text{kip/ft}$$

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \quad (250\text{ psf})(31.2\text{ ft})(0.324)(1.75) \quad = \quad 4.42 \quad \text{kip/ft}$$

$$x_3 = h/3 \quad = \quad (31.2\text{ ft}) / 3 \quad = \quad 10.40 \quad \text{ft}$$

$$x_4 = h/2 \quad = \quad (31.2\text{ ft}) / 2 \quad = \quad 15.6 \quad \text{ft}$$

$$M_H = \quad (28.4\text{ kip/ft})\cos(6.8°)(10.40\text{ ft}) + (4.42\text{ kip/ft})\cos(6.8°)(15.60\text{ ft}) \quad = \quad 361.75 \quad \text{kip·ft/ft}$$

Vertical Forces, P_V:

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

$$P_V = \quad 78.38\text{ kip/ft} + 6.91\text{ kip/ft} + (28.4\text{ kip/ft})\sin(6.8°) \quad = \quad 88.65 \quad \text{kip/ft}$$

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

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

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

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

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

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 23.94

N_c = 23.94
s_c = 1+(12.52 ft/935 ft)(13.2/23.94)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.5

N_q = 13.20
s_q = 1+(12.52 ft/935 ft)tan(27°) = 1.000
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/12.52 ft)
= 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 14.5

N_γ = 14.47
s_γ = 1-0.4(12.52 ft/935 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(12.52 ft) + 3.0 ft = 0.500

q_n = (0 psf)(23.94) + (125 pcf)(3.0 ft)(14.5)(1.0) + ½(125 pcf)(12.5 ft)(14.5)(0.5) = 11.11 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 7.08 ksf ≤ (11.11 ksf)(0.65) = 7.22 ksf ⟶ 7.08 ksf ≤ 7.22 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+(12.52 ft/[(5)(935 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(3.0 ft/12.52 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 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)
$C_{w\gamma}$ = 7.9 ft < 1.5(12.52 ft) + 3.0 ft = 0.500

q_n = (3125 psf)(5.14) + (125 pcf)(3.0 ft)(1.0)(1.0) + ½(125 pcf)(12.5 ft)(0.0)(0.5) = 16.44 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 7.08 ksf ≤ (16.44 ksf)(0.65) = 10.69 ksf ⟶ 7.08 ksf ≤ 10.69 ksf **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	25.2	ft
MSE Wall Width (Reinforcement Length), (B) =	19.2	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	31.2	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	6.8	°
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) =	0.324	
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}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	16.9	ft

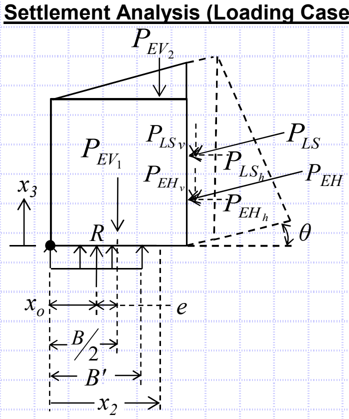
LRFD Load Factors

	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



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

$B' = B - 2e$ = 19.2 ft - 2(2.88 ft) = 13.44 ft

$e = B/2 - x_o$ = (19.2 ft / 2) - 6.72 ft = 2.88 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (674.50 kip·ft/ft - 234.76 kip·ft/ft) / 65.42 kip/ft = 6.72 ft

q_{eq} = (65.42 kip/ft) / (13.44 ft) = 4.87 ksf

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

M_V = [(120 pcf)(25.2 ft)(19.2 ft)(1.00)][½(19.2 ft)] + [½(120 pcf)(31.2 ft - 25.2 ft)(19.2 ft - 5.0 ft)(1.00)][5.0 ft + ⅔(19.2 ft - 5.0 ft)] + [½(120 pcf)(31.2 ft)²(0.324)(1.00)sin(6.8°)](19.2 ft) = 674.5 kip·ft/ft

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

M_H = ½[(120 pcf)(31.2 ft)²(0.324)(1.00)cos(6.8°)](31.2 ft /3) + [(250 psf)(31.2 ft)(0.324)(1.00)cos(6.8°)](31.2 ft /2) = 234.76 kip·ft/ft

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

P_V = (120 pcf)(25.2 ft)(19.2 ft)(1.00) + ½(120 pcf)(31.2 ft - 25.2 ft)(19.2 ft - 5.0 ft)(1.00) + ½(120 pcf)(31.2 ft)²(0.324)(1.00)sin(6.8°) = 65.42 kip/ft

Settlement (See Attached Spreadsheet Calculations):

Total Settlement at Center of Reinforced Soil Mass: S_t = **2.192** in

Total Settlement at Wall Facing: S_t = **1.634** in

Time Rate of Consolidation Settlement at Wall Facing (See Attached Spreadsheet Calculations):

$(S_c)_{100}$ = in at days following completion of construction

W-13-045 - FRA-70-12.68 - MSE Wall 4W12

MSE Wall Settlement - Sta. 3004+50

Calculated By: BRT Date: 7/17/2018

Checked By: JPS Date: 7/17/2018

Borings B-110-0-15 and B-110-1-15

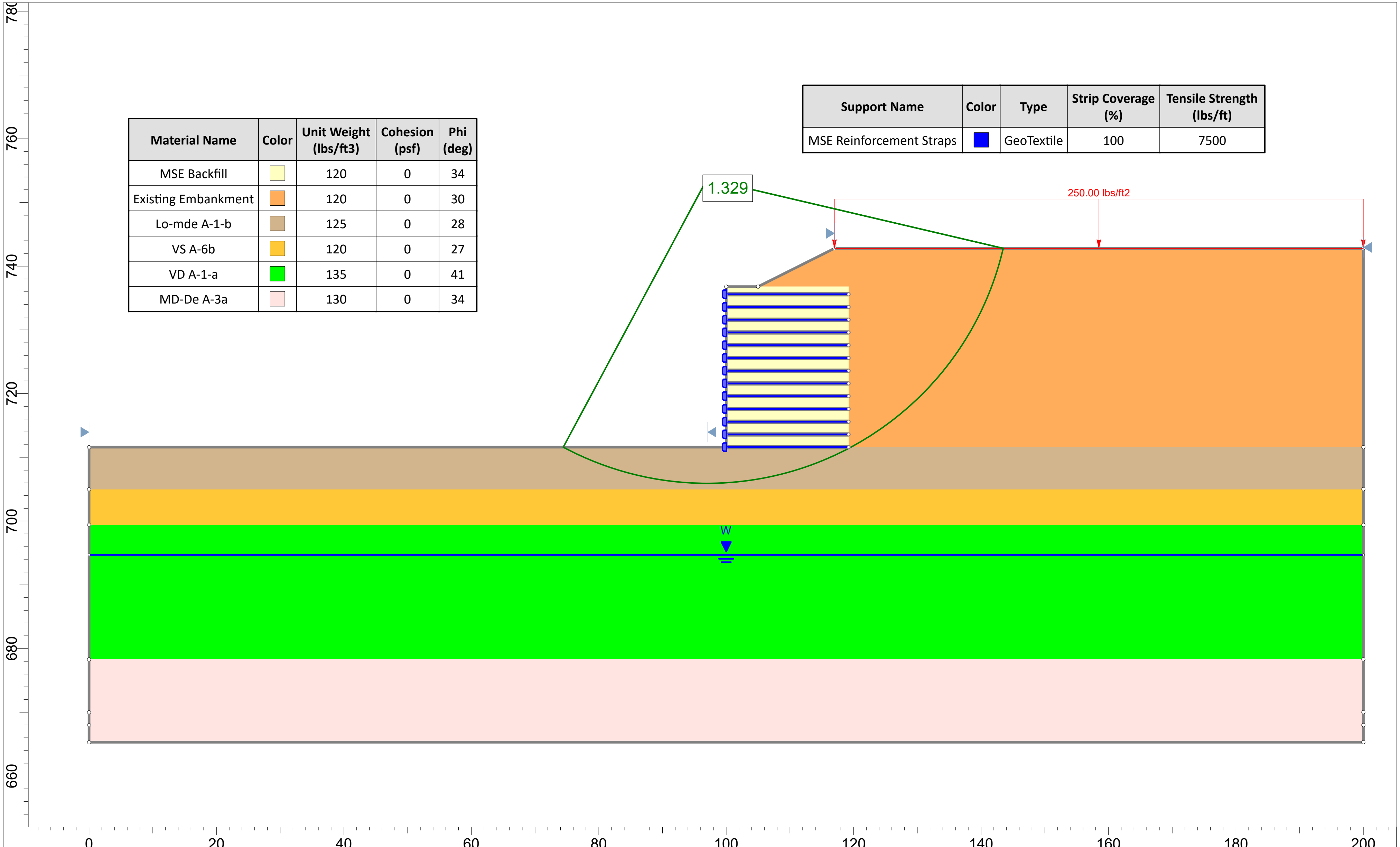
H=	25.2	ft	Total wall height
B'=	13.4	ft	Effective footing width due to eccentricity
D_w =	19.9	ft	Depth below bottom of footing
q_e =	4,870	psf	Equivalent bearing pressure at bottom of wall

																				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-1-b	G	0.0	1.5	1.5	0.8	125	188	94	94	4,094					29	58	205	0.06	0.994	4,841	4,935	0.013	0.151	0.500	2,435	2,529	0.010	0.125
	A-1-b	G	1.5	3.5	2.0	1.8	125	438	313	313	4,313					29	47	157	0.13	0.976	4,755	5,068	0.015	0.185	0.500	2,435	2,748	0.012	0.144
	A-1-b	G	3.5	6.5	3.0	3.3	125	813	625	625	4,625					29	40	132	0.24	0.947	4,612	5,237	0.021	0.252	0.500	2,435	3,060	0.016	0.188
2	A-4a	G	6.5	9.5	3.0	4.8	120	1,173	993	993	4,993					55	68	111	0.35	0.924	4,498	5,490	0.020	0.240	0.484	2,357	3,350	0.014	0.171
	A-4a	G	9.5	12.5	3.0	6.3	120	1,533	1,353	1,353	5,353					55	62	103	0.47	0.880	4,286	5,638	0.018	0.217	0.464	2,260	3,612	0.012	0.149
	A-4a	G	12.5	15.5	3.0	7.8	120	1,893	1,713	1,713	5,713					55	58	96	0.58	0.800	3,896	5,609	0.016	0.192	0.448	2,182	3,894	0.011	0.133
	A-4a	G	15.5	18.5	3.0	9.3	120	2,253	2,073	2,073	6,073					55	54	91	0.69	0.717	3,490	5,563	0.014	0.169	0.428	2,084	4,157	0.010	0.119
	A-4a	G	18.5	22.5	4.0	11.3	120	2,733	2,493	2,493	6,493					55	51	86	0.84	0.644	3,138	5,631	0.016	0.197	0.404	1,967	4,460	0.012	0.141
	A-4a	G	22.5	27.5	5.0	13.8	120	3,333	3,033	3,033	7,033					55	47	81	1.03	0.567	2,760	5,792	0.017	0.209	0.383	1,865	4,897	0.013	0.155
3	A-6b	C	27.5	30.5	3.0	15.3	125	3,708	3,520	3,520	7,520	39	0.261	0.026	0.577				1.14	0.511	2,489	6,009	0.012	0.138	0.369	1,795	5,315	0.009	0.107
4	A-1-b	G	30.5	35.5	5.0	17.8	130	4,358	4,033	4,033	8,033					61	47	156	1.32	0.457	2,226	6,259	0.006	0.073	0.349	1,698	5,730	0.005	0.059
	A-1-b	G	35.5	41.5	6.0	20.8	130	5,138	4,748	4,694	8,694					61	44	144	1.55	0.395	1,926	6,620	0.006	0.075	0.323	1,572	6,267	0.005	0.063
5	A-4a	C	41.5	43.5	2.0	21.8	125	5,388	5,263	5,147	9,147	22	0.108	0.011	0.444				1.62	0.382	1,859	7,007	0.002	0.024	0.314	1,531	6,678	0.002	0.020
6	A-3a	G	43.5	48.5	5.0	24.3	130	6,038	5,713	5,441	9,441					55	37	103	1.81	0.350	1,705	7,146	0.006	0.069	0.296	1,442	6,883	0.005	0.060
																						Total Settlement:		2.192 in			Total Settlement:		1.634 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 26, FHWA GEC 5
3. C_r = 0.05(C_c) for embankment fill and 0.10(C_c) for natural cohesive soils; Ref. Section 5.4.2.5 of FHWA GEC 5
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 (Cohesiv 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)

Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Backfill		120	0	34
Existing Embankment		120	0	30
Lo-mde A-1-b		125	0	28
VS A-6b		120	0	27
VD A-1-a		135	0	41
MD-De A-3a		130	0	34

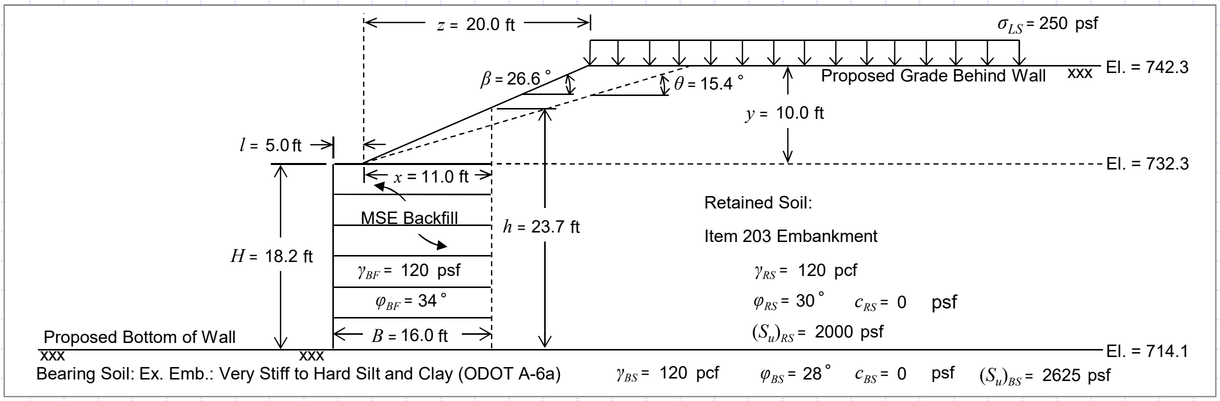
Support Name	Color	Type	Strip Coverage (%)	Tensile Strength (lbs/ft)
MSE Reinforcement Straps		GeoTextile	100	7500



Project	FRA-70-12.68 MSE Wall 4W12 - Sta. 3004+50		
Analysis Description	Broken Backslope - Spencer Method - Drained Condtions		
Drawn By BRT	*Scale* 1:250	*Company*	Resource International, Inc.
Date 07/18/2018		*File Name*	Sta 3004+50 - Global Stability.slim

SLIDEINTERPRET 7.020

FRA-70-12.68 - Retaining Wall 4W12 - Sta. 3005+50 - B-110-1-15 - 25.2 ft. Wall Height - Broken Backslope



MSE Wall Dimensions and Retained Soil Parameters		
MSE Wall Height, (H) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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, [$(S_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	19.1	ft

LRFD Load Factors

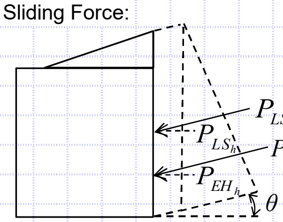
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

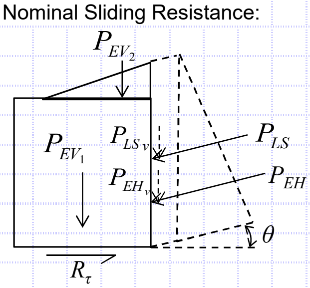
$P_{EH} = ½\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(23.7 ft)(0.374)(1.75) = 3.47 kip/ft

P_H = (18.92 kip/ft + 3.47 kip/ft)cos(15.4°) = 21.59 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)(18.2 ft)(16.0 ft)(1.00) = 34.94 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.00) = 3.64 kip/ft

$P_{EH} = ½\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

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

R_τ = [34.94 kip/ft + 3.64 kip/ft + (18.92 kip/ft)sin(15.4°)](0.53) = 23.11 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 21.59 kip/ft ≤ (23.11 kip/ft)(1.0) = 23.11 kip/ft ⟶ 21.59 kip/ft ≤ 23.11 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) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	19.1	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

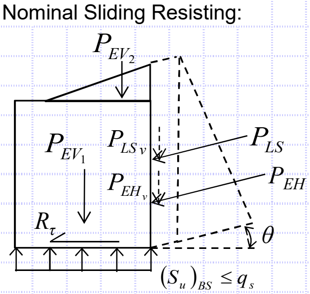
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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_{LSv} for conservatism)

$(S_u)_{BS}$ = 2.63 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)(18.2 ft)(16.0 ft)(1.00) = 34.94 kip/ft

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

P_{EV_2} = ½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.00) = 3.64 kip/ft

$P_{EH} = \frac{1}{2} \gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

P_V = 34.94 kip/ft + 3.64 kip/ft + (18.92 kip/ft)sin(15.4°) = 43.6 kip/ft

σ_v = (43.6 kip/ft) / (16.0 ft) = 2.73 ksf

q_s = (2.73 ksf) / 2 = 1.37 ksf

R_τ = (2.63 ksf ≤ 1.37 ksf)(16.0 ft) = 42.00 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 21.59 kip/ft ≤ (42.00 kip/ft)(1.0) = 42.00 kip/ft ⟶ 21.59 kip/ft ≤ 42.00 kip/ft **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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:

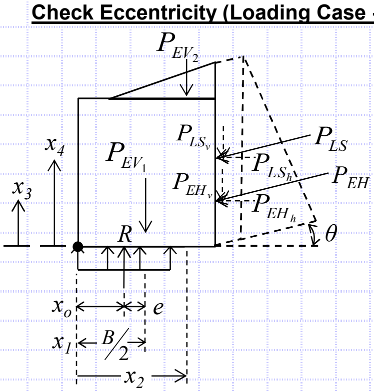
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	19.1	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



$$e = B/2 - x_o$$

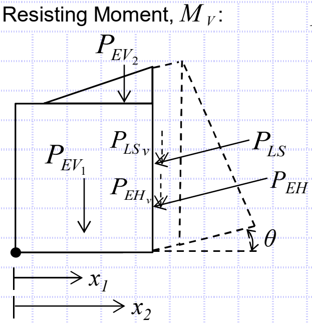
$$x_o = \frac{M_V - M_H}{P_V}$$ = (404.79 kip·ft/ft - 188.43 kip·ft/ft) / (43.6 kip/ft) = 4.96 ft

M_V = 404.79 kip·ft/ft
M_H = 188.43 kip·ft/ft — Defined below

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 34.94 kip/ft + 3.64 kip/ft + (18.92 kip/ft)sin(15.4°) = 43.60 kip/ft

$e =$ (16.0 ft/ 2) - 4.96 ft = 3.04 ft

Resisting Moment, M_V:



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

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(18.2 ft)(16.0 ft)(1.00) = 34.94 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.00) = 3.64 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

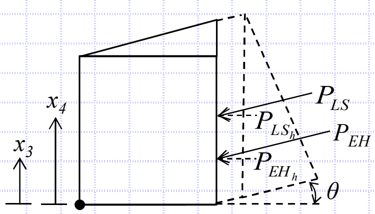
$x_1 = B/2$ = (16.0 ft) / 2 = 8.00 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 5.0 ft + ⅔(16.0 ft - 5.0 ft) = 12.33 ft

M_V = (34.94 kip/ft)(8.00 ft) + (3.64 kip/ft)(12.33 ft) + (18.92 kip/ft)sin(15.4°)(16 ft) = 404.79 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)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(23.7 ft)(0.374)(1.75) = 3.88 kip/ft

$x_3 = h/3$ = (23.7 ft) / 3 = 7.90 ft

$x_4 = h/2$ = (23.7 ft) / 2 = 11.85 ft

M_H = (18.92 kip/ft)cos(15.4°)(7.90 ft) + (3.88 kip/ft)cos(15.4°)(11.85 ft) = 188.43 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (16.0 ft) / 3 = 5.33 ft

$e < e_{max} \longrightarrow$ 3.04 ft < 5.33 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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:

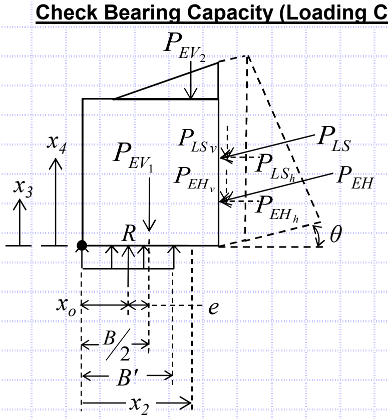
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	19.1	ft

LRFD Load Factors

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

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

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



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

$B' = B - 2e$ = 16.0 ft - 2(2.22 ft) = 11.56 ft

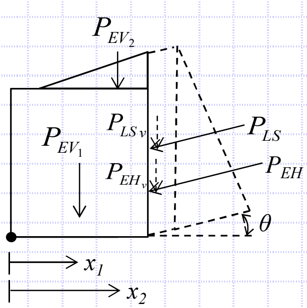
$e = B/2 - x_o$ = (16.0 ft / 2) - 5.78 ft = 2.22 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (518.29 kip·ft/ft - 188.43 kip·ft/ft) / 57.10 kip/ft = 5.78 ft

q_{eq} = (57.1 kip/ft) / (11.56 ft) = 4.94 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)(18.2 ft)(16.0 ft)(1.35) = 47.17 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.35) = 4.91 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

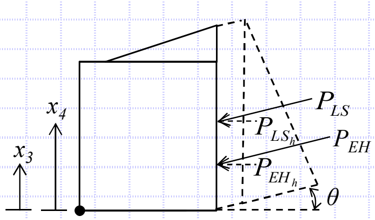
$x_1 = B/2$ = (16.0 ft) / 2 = 8.00 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 5.0 ft + ⅔(16.0 ft - 5.0 ft) = 12.33 ft

M_V = (47.17 kip/ft)(8.00 ft) + (4.91 kip/ft)(12.3 ft) + (18.92 kip/ft)sin(15.4°)(16 ft) = 518.29 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(23.7 ft)²(0.374)(1.50) = 18.92 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(23.7 ft)(0.374)(1.75) = 3.88 kip/ft

$x_3 = h/3$ = (23.7 ft) / 3 = 7.90 ft

$x_4 = h/2$ = (23.7 ft) / 2 = 11.85 ft

M_H = (18.92 kip/ft)cos(15.4°)(7.90 ft) + (3.88 kip/ft)cos(15.4°)(11.85 ft) = 188.43 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 47.17 kip/ft + 4.91 kip/ft + (18.92 kip/ft)sin(15.4°) = 57.1 kip/ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

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

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

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

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

Check Bearing Resistance - Drained Condition

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

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

N_c = 25.80
s_c = 1+(11.56 ft/935 ft)(14.72/25.8) = 1.000
i_c = 1.000 (Assumed)

N_q = 14.72
s_q = 1+(11.56 ft/935 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/11.56 ft) = 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

N_γ = 16.72
s_γ = 1-0.4(11.56 ft/935 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(11.56 ft) + 3.0 ft = 0.500

q_n = (0 psf)(25.8) + (120 pcf)(3.0 ft)(16.2)(1.0) + ½(120 pcf)(11.6 ft)(16.7)(0.5) = 11.63 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.94 ksf ≤ (11.63 ksf)(0.65) = 7.56 ksf ⟶ 4.94 ksf ≤ 7.56 ksf **OK**

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140
s_c = 1+(11.56 ft/[(5)(935 ft)] = 1.000
i_c = 1.000 (Assumed)

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(3.0 ft/11.56 ft) = 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

N_γ = 0.000
s_γ = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(11.56 ft) + 3.0 ft = 0.500

q_n = (2625 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(11.6 ft)(0.0)(0.5) = 13.85 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.94 ksf ≤ (13.85 ksf)(0.65) = 9.00 ksf ⟶ 4.94 ksf ≤ 9.00 ksf **OK**

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

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JOB	FRA-70-12.68	NO.	W-13-045
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	7/15/2018
CHECKED BY	JPS	DATE	7/15/2018

Retaining Wall 4W12 - Sta. 3005+50

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	18.2	ft
MSE Wall Width (Reinforcement Length), (B) =	16.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	23.7	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.4	°
Distance from Toe to Top of Backslope, (z) =	20.0	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) =	0.374	
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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	19.1	ft

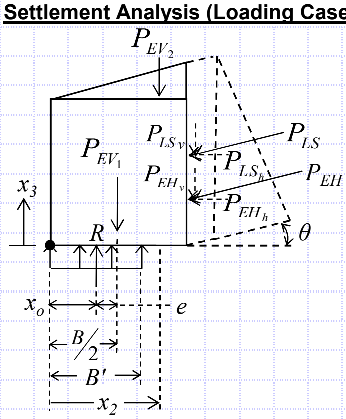
LRFD Load Factors

	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



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

$B' = B - 2e$ = 16.0 ft - 2(1.88 ft) = 12.24 ft

$e = B/2 - x_o$ = (16.0 ft / 2) - 6.12 ft = 1.88 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (377.98 kip·ft/ft - 121.44 kip·ft/ft) / 41.93 kip/ft = 6.12 ft

q_{eq} = (41.93 kip/ft) / (12.24 ft) = 3.43 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)(18.2 ft)(16.0 ft)(1.00)][½(16.0 ft)] + [½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.00)][5.0 ft + ⅔(16.0 ft - 5.0 ft)] = 377.98 kip·ft/ft
+ [½(120 pcf)(23.7 ft)²(0.374)(1.00)sin(15.4°)](16.0 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)(23.7 ft)²(0.374)(1.00)cos(15.4°)](23.7 ft /3) = 121.44 kip·ft/ft
+ [(250 psf)(23.7 ft)(0.374)(1.00)cos(15.4°)](23.7 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)(18.2 ft)(16.0 ft)(1.00) + ½(120 pcf)(23.7 ft - 18.2 ft)(16.0 ft - 5.0 ft)(1.00) = 41.93 kip/ft
+ ½(120 pcf)(23.7 ft)²(0.374)(1.00)sin(15.4°)

Settlement (See Attached Spreadsheet Calculations):

Total Settlement at Center of Reinforced Soil Mass: S_t = **1.396** in

Total Settlement at Wall Facing: S_t = **1.043** in

Time Rate of Consolidation Settlement at Wall Facing (See Attached Spreadsheet Calculations):

$(S_c)_{100}$ = in at days following completion of construction

W-13-045 - FRA-70-12.68 - MSE Wall 4W12
MSE Wall Settlement - Sta. 3005+50

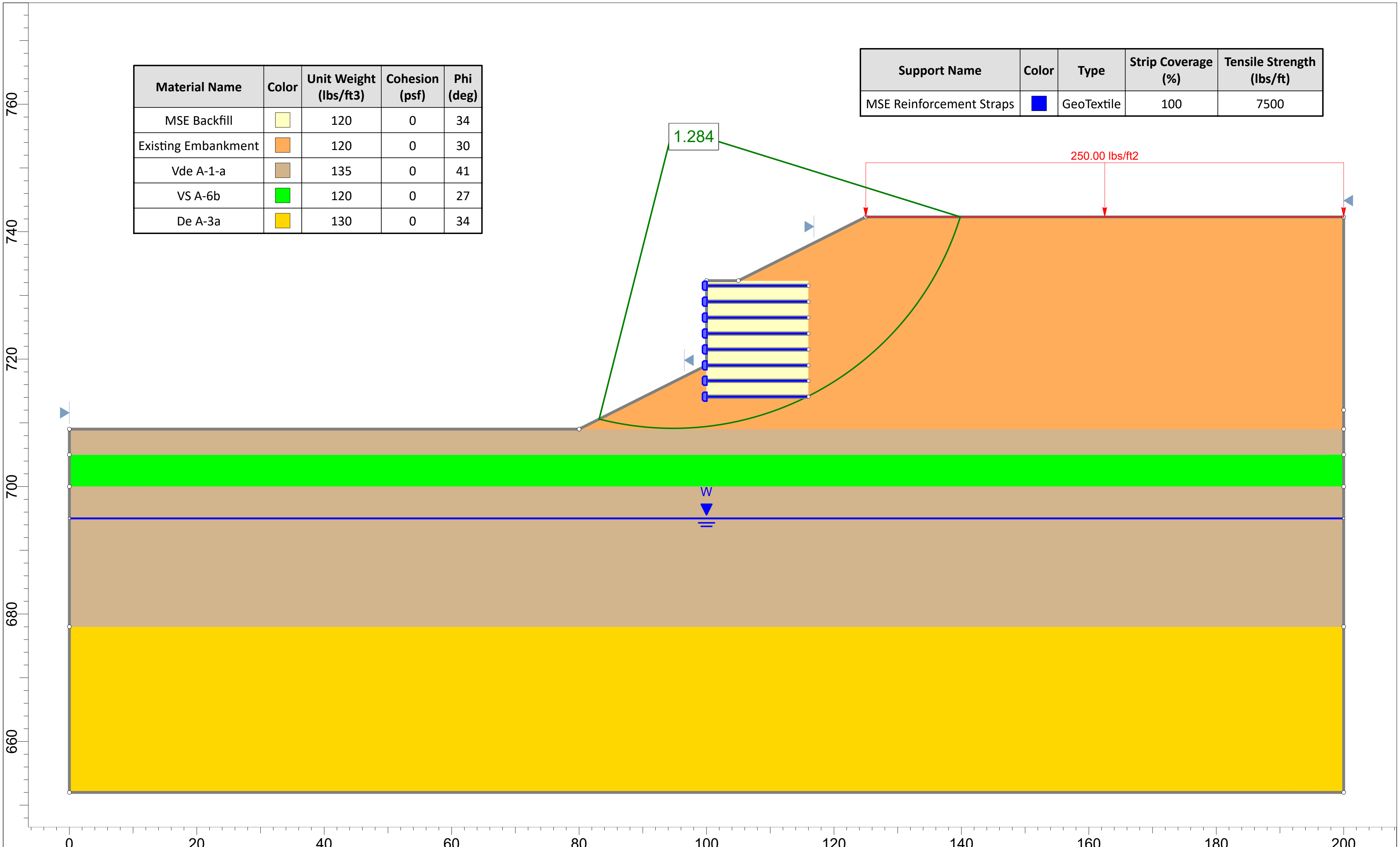
Calculated By: BRT Date: 7/17/2018
Checked By: JPS Date: 7/17/2018

Boring B-110-1-15

H=	18.2	ft	Total wall height
B'=	12.2	ft	Effective footing width due to eccentricity
D_w =	19.1	ft	Depth below bottom of footing
q_e =	3,430	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	29	0.171	0.009	0.499				0.10	0.982	3,369	3,519	0.020	0.235	0.500	1,715	1,865	0.016	0.187
	A-6a	C	2.5	5.0	2.5	2.5	120	600	450	450	4,450	29	0.171	0.009	0.499				0.20	0.959	3,289	3,739	0.013	0.157	0.500	1,715	2,165	0.010	0.117
2	A-1-a	G	5.0	7.5	2.5	3.8	120	900	750	750	4,750					75	100	466	0.31	0.935	3,208	3,958	0.004	0.046	0.492	1,688	2,438	0.003	0.033
	A-1-a	G	7.5	10.0	2.5	5.0	120	1,200	1,050	1,050	5,050					75	91	404	0.41	0.912	3,127	4,177	0.004	0.045	0.476	1,633	2,683	0.003	0.030
3	A-6b	C	10.0	12.5	2.5	6.3	125	1,513	1,356	1,356	5,356	39	0.261	0.026	0.577				0.51	0.860	2,950	4,306	0.021	0.249	0.460	1,578	2,934	0.014	0.166
	A-6b	C	12.5	15.0	2.5	7.5	125	1,825	1,669	1,669	5,669	39	0.261	0.026	0.577				0.61	0.767	2,630	4,298	0.017	0.204	0.440	1,509	3,178	0.012	0.139
4	A-1-b	G	15.0	17.0	2.0	8.5	130	2,085	1,955	1,955	5,955					65	66	244	0.70	0.717	2,458	4,413	0.003	0.035	0.428	1,468	3,423	0.002	0.024
	A-1-b	G	17.0	22.0	5.0	11.0	130	2,735	2,410	2,410	6,410					65	61	220	0.90	0.622	2,134	4,544	0.006	0.075	0.397	1,362	3,772	0.004	0.053
	A-1-b	G	22.0	27.0	5.0	13.5	130	3,385	3,060	3,060	7,060					65	56	195	1.11	0.533	1,829	4,889	0.005	0.063	0.374	1,284	4,344	0.004	0.047
	A-1-b	G	27.0	32.0	5.0	16.0	130	4,035	3,710	3,710	7,710					65	52	177	1.31	0.464	1,593	5,303	0.004	0.053	0.351	1,205	4,915	0.003	0.042
	A-1-b	G	32.0	37.0	5.0	18.5	130	4,685	4,360	4,360	8,360					65	48	162	1.52	0.400	1,372	5,732	0.004	0.044	0.326	1,117	5,477	0.003	0.037
5	A-3a	G	37.0	42.0	5.0	21.0	120	5,285	4,985	4,866	8,866					39	27	81	1.72	0.364	1,247	6,114	0.006	0.073	0.303	1,039	5,905	0.005	0.062
	A-3a	G	42.0	47.0	5.0	23.5	120	5,885	5,585	5,310	9,310					39	26	79	1.93	0.327	1,123	6,433	0.005	0.063	0.286	981	6,291	0.005	0.056
	A-3a	G	47.0	52.0	5.0	26.0	120	6,485	6,185	5,754	9,754					39	25	77	2.13	0.295	1,013	6,767	0.005	0.055	0.270	926	6,681	0.004	0.051
																					Total Settlement:			1.396 in		Total Settlement:			1.043 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 26, FHWA GEC 5
3. $C_r = 0.05(C_c)$ for embankment fill and $0.10(C_c)$ for natural cohesive soils; Ref. Section 5.4.2.5 of FHWA GEC 5
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 (Cohesiv 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)



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Backfill		120	0	34
Existing Embankment		120	0	30
Vde A-1-a		135	0	41
VS A-6b		120	0	27
De A-3a		130	0	34

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

Project	FRA-70-12.68 MSE Wall 4W12 - Sta. 3005+50		
Analysis Description	Spencer Method - Drained Conditons		
Drawn By BRT	*Scale* 1:250	*Company*	Resource International, Inc.
Date 07/17/2018		*File Name*	Sta 3005+50 - Global Stability.slim

SLIDEINTERPRET 7.020

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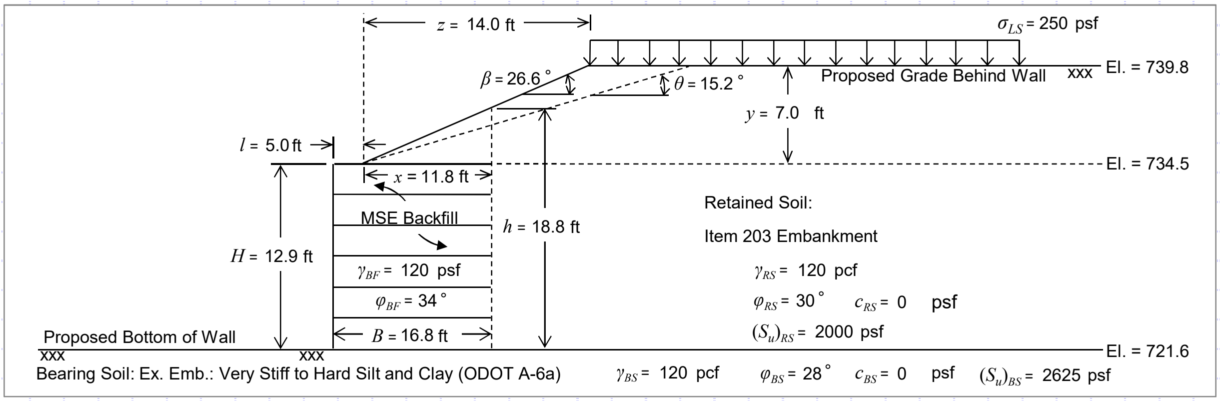
FRA-70-12.68 - Retaining Wall 4W12 - Sta. 3006+25 - B-110-1-15 and B-111-1-15 - 12.9 ft. Wall Height - Broken Backslope



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, [$(S_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	ft

LRFD Load Factors

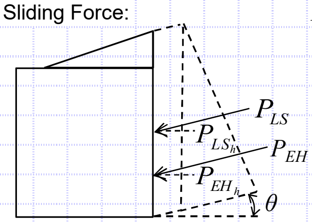
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

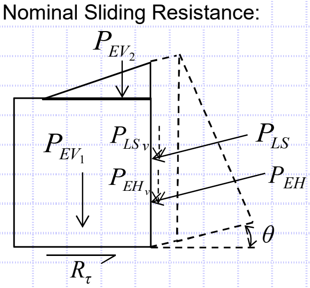
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(18.8 ft)(0.372)(1.75) = 2.74 kip/ft

P_H = (11.84 kip/ft + 2.74 kip/ft)cos(15.2°) = 14.07 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)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

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

R_τ = [26.01 kip/ft + 4.18 kip/ft + (11.84 kip/ft)sin(15.2°)](0.53) = 17.65 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 14.07 kip/ft ≤ (17.65 kip/ft)(1.0) = 17.65 kip/ft ⟶ 14.07 kip/ft ≤ 17.65 kip/ft **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	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

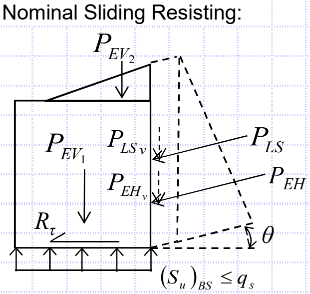
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



$(S_u)_{BS}$ = 2.63 ksf

$q_s = \sigma_v / 2$

$\sigma_v = P_V / B$

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

(Neglect P_{LSv} for conservatism)

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

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

P_{EV_2} = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

P_V = 26.01 kip/ft + 4.18 kip/ft + (11.84 kip/ft)sin(15.2°) = 33.29 kip/ft

σ_v = (33.29 kip/ft) / (16.8 ft) = 1.98 ksf

q_s = (1.98 ksf) / 2 = 0.99 ksf

R_τ = (2.63 ksf ≤ 0.99 ksf)(16.8 ft) = 44.10 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 14.07 kip/ft ≤ (44.10 kip/ft)(1.0) = 44.10 kip/ft ⟶ 14.07 kip/ft ≤ 44.10 kip/ft **OK**

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

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JOB	FRA-70-12.68	NO.	W-13-045
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	7/15/2018
CHECKED BY	JPS	DATE	7/15/2018

Retaining Wall 4W12 - Sta. 3006+25 - Phase 4R

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	ft

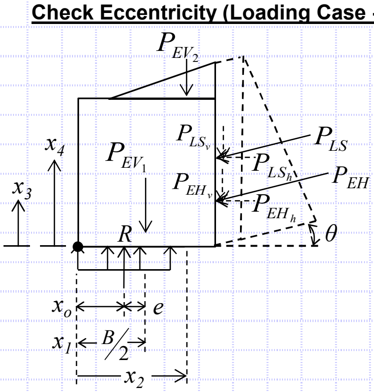
LRFD Load Factors

	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (324.43 kip·ft/ft - 99.4 kip·ft/ft) / (33.29 kip/ft) = 6.76 ft

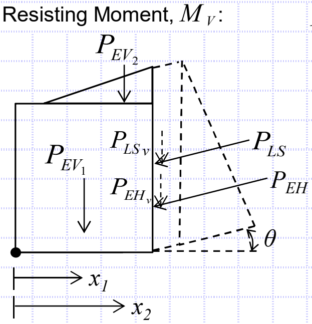
M_V = 324.43 kip·ft/ft
M_H = 99.40 kip·ft/ft
(Defined below)

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 26.01 kip/ft + 4.18 kip/ft + (11.84 kip/ft)sin(15.2°) = 33.29 kip/ft

$e =$ (16.8 ft/ 2) - 6.76 ft = 1.64 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)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

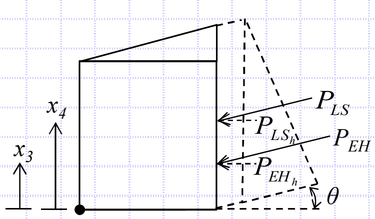
$x_1 = B/2$ = (16.8 ft) / 2 = 8.40 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 5.0 ft + ⅔(16.8 ft - 5.0 ft) = 12.87 ft

M_V = (26.01 kip/ft)(8.40 ft) + (4.18 kip/ft)(12.87 ft) + (11.84 kip/ft)sin(15.2°)(16.8 ft) = 324.43 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS}h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(18.8 ft)(0.372)(1.75) = 3.06 kip/ft

$x_3 = h/3$ = (18.8 ft) / 3 = 6.27 ft

$x_4 = h/2$ = (18.8 ft) / 2 = 9.4 ft

M_H = (11.84 kip/ft)cos(15.2°)(6.27 ft) + (3.06 kip/ft)cos(15.2°)(9.40 ft) = 99.40 kip·ft/ft

Check Eccentricity Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (16.8 ft) / 3 = 5.60 ft

$e < e_{max} \longrightarrow$ 1.64 ft < 5.60 ft **OK**

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	ft

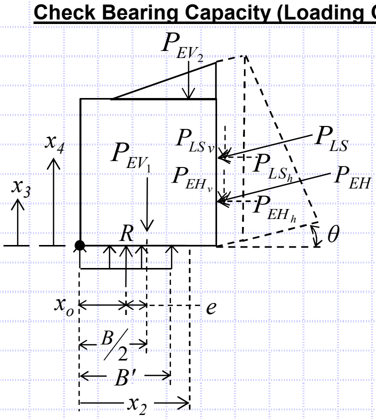
LRFD Load Factors

	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



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

$B' = B - 2e$ = 16.8 ft - 2(1.10 ft) = 14.60 ft

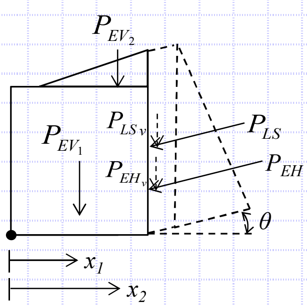
$e = B/2 - x_o$ = (16.8 ft / 2) - 7.3 ft = 1.10 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (419.79 kip·ft/ft - 99.40 kip·ft/ft) / 43.86 kip/ft = 7.30 ft

q_{eq} = (43.86 kip/ft) / (14.6 ft) = 3.00 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)(12.9 ft)(16.8 ft)(1.35) = 35.11 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.35) = 5.65 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

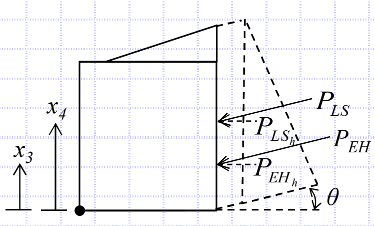
$x_1 = B/2$ = (16.8 ft) / 2 = 8.40 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 5.0 ft + ⅔(16.8 ft - 5.0 ft) = 12.87 ft

M_V = (35.11 kip/ft)(8.40 ft) + (5.65 kip/ft)(12.9 ft) + (11.84 kip/ft)sin(15.2°)(16.8 ft) = 419.79 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.372)(1.50) = 11.84 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(18.8 ft)(0.372)(1.75) = 3.06 kip/ft

$x_3 = h/3$ = (18.8 ft) / 3 = 6.27 ft

$x_4 = h/2$ = (18.8 ft) / 2 = 9.4 ft

M_H = (11.84 kip/ft)cos(15.2°)(6.27 ft) + (3.06 kip/ft)cos(15.2°)(9.40 ft) = 99.40 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 35.11 kip/ft + 5.65 kip/ft + (11.84 kip/ft)sin(15.2°) = 43.86 kip/ft

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

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

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

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

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

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 25.8

N_c = 25.80
s_c = 1+(14.6 ft/935 ft)(14.72/25.8) = 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 16.2

N_q = 14.72
s_q = 1+(14.6 ft/935 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/14.6 ft) = 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

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

N_γ = 16.72
s_γ = 1-0.4(14.6 ft/935 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(14.6 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (120 pcf)(3.0 ft)(16.2)(1.0) + ½(120 pcf)(14.6 ft)(16.7)(0.5) = 13.15 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.00 ksf ≤ (13.15 ksf)(0.65) = 8.55 ksf ⟶ 3.00 ksf ≤ 8.55 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+(14.6 ft/[(5)(935 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(3.0 ft/14.6 ft) = 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 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)
$C_{w\gamma}$ = 7.9 ft < 1.5(14.6 ft) + 3.0 ft = 0.500

$q_n =$ (2625 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(14.6 ft)(0.0)(0.5) = 13.85 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.00 ksf ≤ (13.85 ksf)(0.65) = 9.00 ksf ⟶ 3.00 ksf ≤ 9.00 ksf **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	15.2	°
Distance from Toe to Top of Backslope, (z) =	14.0	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, $[(s_u)_{BS}]$ =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	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.

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

= 16.8 ft - 2(0.85 ft) = 15.10 ft

= (16.8 ft / 2) - 7.55 ft = 0.85 ft

= (307.06 kip·ft/ft - 63.65 kip·ft/ft) / 32.26 kip/ft = 7.55 ft

(32.26 kip/ft) / (15.1 ft) = 2.14 ksf

= [(120 pcf)(12.9 ft)(16.8 ft)(1.00)][½(16.8 ft)] + [½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00)][5.0 ft + ⅔(16.8 ft - 5.0 ft)] + [½(120 pcf)(18.8 ft)²(0.372)(1.00)sin(15.2°)](16.8 ft) = 307.06 kip·ft/ft

= ½[(120 pcf)(18.8 ft)²(0.372)(1.00)cos(15.2°)](18.8 ft /3) + [(250 psf)(18.8 ft)(0.372)(1.00)cos(15.2°)](18.8 ft /2) = 63.65 kip·ft/ft

= (120 pcf)(12.9 ft)(16.8 ft)(1.00) + ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) + ½(120 pcf)(18.8 ft)²(0.372)(1.00)sin(15.2°) = 32.26 kip/ft

Settlement (See Attached Spreadsheet Calculations):

Total Settlement at Center of Reinforced Soil Mass: S_t = **1.168** in

Total Settlement at Wall Facing: S_t = **0.825** in

Time Rate of Consolidation Settlement at Wall Facing (See Attached Spreadsheet Calculations):

$(S_c)_{100}$ = in at days following completion of construction

W-13-045 - FRA-70-12.68 - MSE Wall 4W12
MSE Wall Settlement - Sta. 3006+24 (Phase 4A)

Calculated By: BRT Date: 7/17/2018
Checked By: JPS Date: 7/17/2018

Borings B-110-1-15 and B-111-0-09

H=	12.9	ft	Total wall height
B'=	15.1	ft	Effective footing width due to eccentricity
D_w =	26.6	ft	Depth below bottom of footing
q_e =	2,140	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	29	0.171	0.009	0.499				0.08	0.988	2,115	2,265	0.017	0.202	0.500	1,070	1,220	0.013	0.156
	A-6a	C	2.5	5.0	2.5	2.5	120	600	450	450	4,450	29	0.171	0.009	0.499				0.17	0.965	2,064	2,514	0.011	0.128	0.500	1,070	1,520	0.008	0.090
	A-6a	C	5.0	7.5	2.5	3.8	120	900	750	750	4,750	29	0.171	0.009	0.499				0.25	0.947	2,027	2,777	0.008	0.097	0.500	1,070	1,820	0.005	0.066
	A-6a	C	7.5	10.5	3.0	5.3	120	1,260	1,080	1,080	5,080	29	0.171	0.009	0.499				0.35	0.924	1,976	3,056	0.008	0.093	0.484	1,036	2,116	0.005	0.060
	A-6a	C	10.5	13.5	3.0	6.8	125	1,635	1,448	1,448	5,448	29	0.171	0.009	0.499				0.45	0.900	1,926	3,374	0.006	0.075	0.468	1,002	2,449	0.004	0.047
	A-6a	C	13.5	16.5	3.0	8.3	125	2,010	1,823	1,823	5,823	29	0.171	0.009	0.499				0.55	0.820	1,755	3,577	0.005	0.060	0.452	967	2,790	0.003	0.038
2	A-6b	C	16.5	19.0	2.5	9.5	130	2,335	2,173	2,173	6,173	39	0.261	0.026	0.577				0.63	0.767	1,641	3,813	0.010	0.121	0.440	942	3,114	0.006	0.078
	A-6b	C	19.0	21.5	2.5	10.8	130	2,660	2,498	2,498	6,498	39	0.261	0.026	0.577				0.71	0.717	1,534	4,031	0.009	0.103	0.428	916	3,413	0.006	0.067
3	A-1-b	G	21.5	27.0	5.5	13.5	130	3,375	3,018	3,018	7,018					60	52	177	0.89	0.622	1,332	4,349	0.005	0.059	0.397	850	3,867	0.003	0.040
	A-1-b	G	27.0	32.5	5.5	16.3	130	4,090	3,733	3,733	7,733					60	48	159	1.08	0.544	1,165	4,898	0.004	0.049	0.377	807	4,540	0.003	0.035
	A-1-b	G	32.5	38.0	5.5	19.0	130	4,805	4,448	4,448	8,448					60	44	146	1.26	0.479	1,024	5,472	0.003	0.041	0.357	764	5,212	0.003	0.031
	A-1-b	G	38.0	43.5	5.5	21.8	130	5,520	5,163	5,163	9,163					60	41	134	1.44	0.421	902	6,064	0.003	0.034	0.334	715	5,878	0.002	0.028
4	A-3a	G	43.5	50.0	6.5	25.0	120	6,300	5,910	5,910	9,910					39	25	76	1.66	0.377	807	6,717	0.005	0.057	0.311	666	6,576	0.004	0.048
	A-3a	G	50.0	56.5	6.5	28.3	120	7,080	6,690	6,587	10,587					39	24	73	1.87	0.336	720	7,307	0.004	0.048	0.290	621	7,208	0.003	0.042
																						Total Settlement:		1.168 in			Total Settlement:		0.825 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 26, FHWA GEC 5
3. C_r = 0.05(C_c) for embankment fill and 0.10(C_c) for natural cohesive soils; Ref. Section 5.4.2.5 of FHWA GEC 5
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 (Cohesiv 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)

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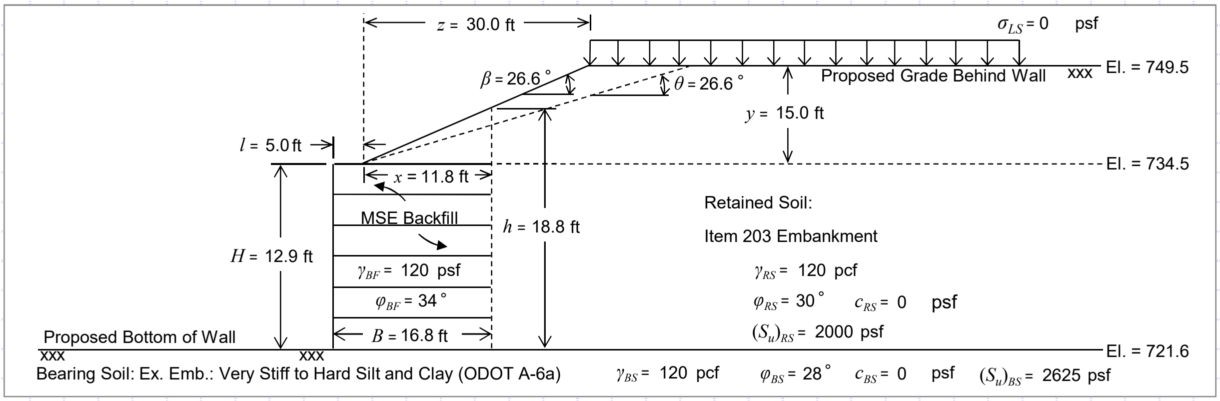
JOB	FRA-70-12.68	NO.	W-13-045
SHEET NO.	1	OF	6
CALCULATED BY	BRT	DATE	7/15/2018
CHECKED BY	JPS	DATE	7/15/2018

Retaining Wall 4W12 - Sta. 3006+25 - Phase 6A

FRA-70-12.68 - Retaining Wall 4W12 - Sta. 3006+25 - B-110-1-15 and B-111-0-09 - 12.9 ft. Wall Height - Broken Backslope



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	ft

LRFD Load Factors

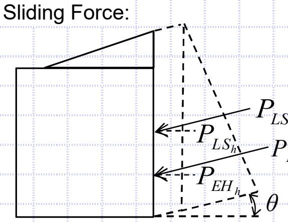
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

(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:



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

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (0 psf)(18.8 ft)(0.526)(1.75) = 0.00 kip/ft

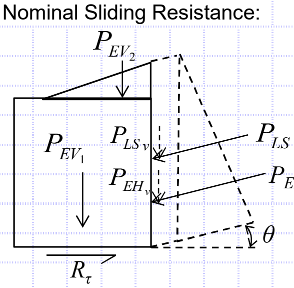
P_H = (16.75 kip/ft + 0.00 kip/ft)cos(26.6°) = 14.98 kip/ft

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)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 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 = [26.01 kip/ft + 4.18 kip/ft + (16.75 kip/ft)sin(26.6°)](0.53) = 19.98 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 14.98 kip/ft ≤ (19.98 kip/ft)(1.0) = 19.98 kip/ft $\longrightarrow$ 14.98 kip/ft ≤ 19.98 kip/ft **OK**

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

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JOB	FRA-70-12.68	NO.	W-13-045
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	7/15/2018
CHECKED BY	JPS	DATE	7/15/2018

Retaining Wall 4W12 - Sta. 3006+25 - Phase 6A

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	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

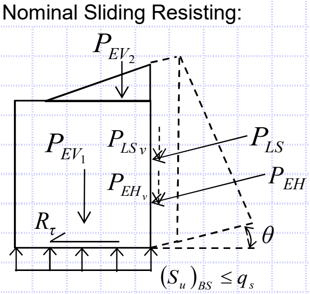
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

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



$(S_u)_{BS}$ = 2.63 ksf

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

(Neglect P_{LS_V} for conservatism)

$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

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

P_{EV_2} = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

P_V = 26.01 kip/ft + 4.18 kip/ft + (16.75 kip/ft)sin(26.6°) = 37.69 kip/ft

σ_v = (37.69 kip/ft) / (16.8 ft) = 2.24 ksf

q_s = (2.24 ksf) / 2 = 1.12 ksf

R_τ = (2.63 ksf ≤ 1.12 ksf)(16.8 ft) = 44.10 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 14.98 kip/ft ≤ (44.10 kip/ft)(1.0) = 44.10 kip/ft ⟶ 14.98 kip/ft ≤ 44.10 kip/ft **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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

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

Bearing Soil Properties:

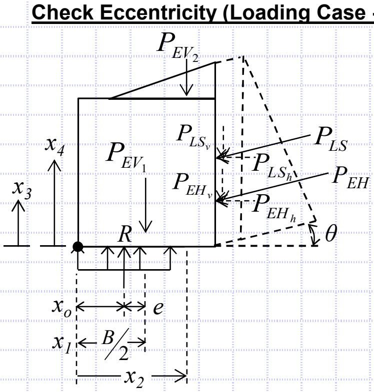
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	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)

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



$$e = B/2 - x_o$$

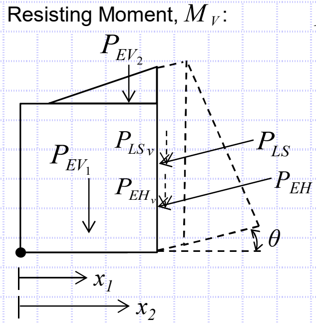
$$x_o = \frac{M_V - M_H}{P_V}$$ = (398.28 kip·ft/ft - 93.91 kip·ft/ft) / (37.69 kip/ft) = 8.08 ft

M_V = 398.28 kip·ft/ft
M_H = 93.91 kip·ft/ft
(Defined below)

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 26.01 kip/ft + 4.18 kip/ft + (16.75 kip/ft)sin(26.6°) = 37.69 kip/ft

$e =$ (16.8 ft/ 2) - 8.08 ft = 0.32 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)(12.9 ft)(16.8 ft)(1.00) = 26.01 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) = 4.18 kip/ft

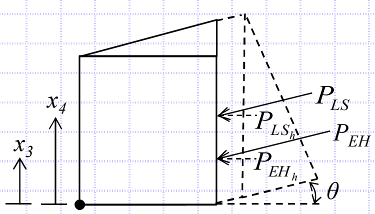
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

$x_1 = B/2$ = (16.8 ft) / 2 = 8.40 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 5.0 ft + ⅔(16.8 ft - 5.0 ft) = 12.87 ft

M_V = (26.01 kip/ft)(8.40 ft) + (4.18 kip/ft)(12.87 ft) + (16.75 kip/ft)sin(26.6°)(16.8 ft) = 398.28 kip·ft/ft

Overturning Moment, M_H:



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

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (0 psf)(18.8 ft)(0.526)(1.75) = 0.00 kip/ft

$x_3 = h/3$ = (18.8 ft) / 3 = 6.27 ft

$x_4 = h/2$ = (18.8 ft) / 2 = 9.4 ft

M_H = (16.75 kip/ft)cos(26.6°)(6.27 ft) + (0 kip/ft)cos(26.6°)(9.40 ft) = 93.91 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max} =$ (16.8 ft) / 3 = 5.60 ft

$e < e_{max} \longrightarrow$ 0.32 ft < 5.60 ft **OK**

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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

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

Bearing Soil Properties:

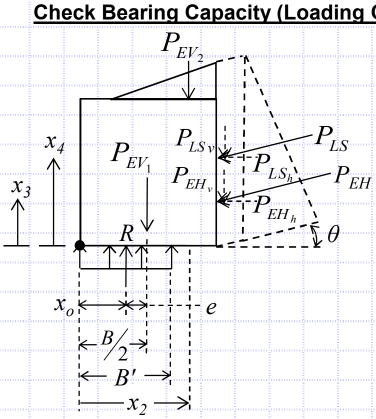
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34	°
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	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)

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



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

$B' = B - 2e$ = 16.8 ft - 2(0.12 ft) = 16.56 ft

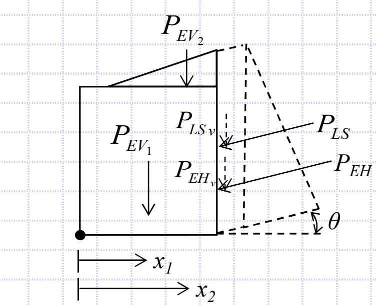
$e = B/2 - x_o$ = (16.8 ft / 2) - 8.28 ft = 0.12 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (493.64 kip·ft/ft - 93.91 kip·ft/ft) / 48.26 kip/ft = 8.28 ft

q_{eq} = (48.26 kip/ft) / (16.56 ft) = 2.91 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)(12.9 ft)(16.8 ft)(1.35) = 35.11 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.35) = 5.65 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

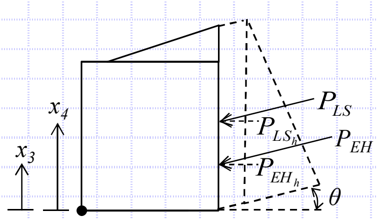
$x_1 = B/2$ = (16.8 ft) / 2 = 8.40 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 5.0 ft + ⅔(16.8 ft - 5.0 ft) = 12.87 ft

M_V = (35.11 kip/ft)(8.40 ft) + (5.65 kip/ft)(12.9 ft) + (16.75 kip/ft)sin(26.6°)(16.8 ft) = 493.64 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(18.8 ft)²(0.526)(1.50) = 16.75 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (0 psf)(18.8 ft)(0.526)(1.75) = 0.00 kip/ft

$x_3 = h/3$ = (18.8 ft) / 3 = 6.27 ft

$x_4 = h/2$ = (18.8 ft) / 2 = 9.4 ft

M_H = (16.75 kip/ft)cos(26.6°)(6.27 ft) + (0 kip/ft)cos(26.6°)(9.40 ft) = 93.91 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 35.11 kip/ft + 5.65 kip/ft + (16.75 kip/ft)sin(26.6°) = 48.26 kip/ft

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	7.9	ft

LRFD Load Factors

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

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

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

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

Check Bearing Resistance - Drained Condition

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

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

N_c = 25.80
s_c = 1+(16.56 ft/935 ft)(14.72/25.8) = 1.000
i_c = 1.000 (Assumed)

N_q = 14.72
s_q = 1+(16.56 ft/935 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/16.56 ft) = 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

N_γ = 16.72
s_γ = 1-0.4(16.56 ft/935 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(16.56 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (120 pcf)(3.0 ft)(16.2)(1.0) + ½(120 pcf)(16.6 ft)(16.7)(0.5) = 14.14 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.91 ksf ≤ (14.14 ksf)(0.65) = 9.19 ksf ⟶ 2.91 ksf ≤ 9.19 ksf **OK**

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140
s_c = 1+(16.56 ft/[(5)(935 ft)] = 1.000
i_c = 1.000 (Assumed)

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(3.0 ft/16.56 ft) = 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

N_γ = 0.000
s_γ = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(16.56 ft) + 3.0 ft = 0.500

$q_n =$ (2625 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(16.6 ft)(0.0)(0.5) = 13.85 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.91 ksf ≤ (13.85 ksf)(0.65) = 9.00 ksf ⟶ 2.91 ksf ≤ 9.00 ksf **OK**

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

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MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	16.8	ft
Distance from Wall Face to Toe of Backslope, (l) =	5.0	ft
MSE Wall Length, (L) =	935.0	ft
MSE Wall Effective Height, (h) =	18.8	ft
Retained Soil Backslope, (β) =	26.6	°
Effective Retained Soil Backslope, (θ) =	26.6	°
Distance from Toe to Top of Backslope, (z) =	30.0	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}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2625	psf
Embedment Depth, (D_f) =	3.0	ft
Depth to GW (Below Bot. of Wall), (D_W) =	26.6	ft

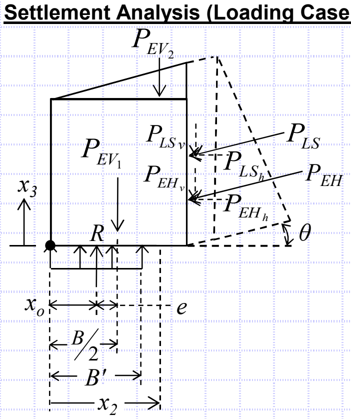
LRFD Load Factors

	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.

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



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

$B' = B - 2e$ = 16.8 ft - 2(0.05 ft) = 16.70 ft

$e = B/2 - x_o$ = (16.8 ft / 2) - 8.35 ft = 0.05 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (356.27 kip·ft/ft - 62.59 kip·ft/ft) / 35.19 kip/ft = 8.35 ft

q_{eq} = (35.19 kip/ft) / (16.7 ft) = 2.11 ksf

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

M_V = [(120 pcf)(12.9 ft)(16.8 ft)(1.00)][½(16.8 ft)] + [½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00)][5.0 ft + ⅔(16.8 ft - 5.0 ft)] + [½(120 pcf)(18.8 ft)²(0.526)(1.00)sin(26.6°)](16.8 ft) = 356.27 kip·ft/ft

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

M_H = ½[(120 pcf)(18.8 ft)²(0.526)(1.00)cos(26.6°)](18.8 ft /3) + [(0 psf)(18.8 ft)(0.526)(1.00)cos(26.6°)](18.8 ft /2) = 62.59 kip·ft/ft

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

P_V = (120 pcf)(12.9 ft)(16.8 ft)(1.00) + ½(120 pcf)(18.8 ft - 12.9 ft)(16.8 ft - 5.0 ft)(1.00) + ½(120 pcf)(18.8 ft)²(0.526)(1.00)sin(26.6°) = 35.19 kip/ft

Settlement (See Attached Spreadsheet Calculations):

Total Settlement at Center of Reinforced Soil Mass: S_t = **1.189** in

Total Settlement at Wall Facing: S_t = **0.830** in

Time Rate of Consolidation Settlement at Wall Facing (See Attached Spreadsheet Calculations):

$(S_c)_{100}$ = in at days following completion of construction

W-13-045 - FRA-70-12.68 - MSE Wall 4W12 Calculated By: BRT Date: 7/17/2018

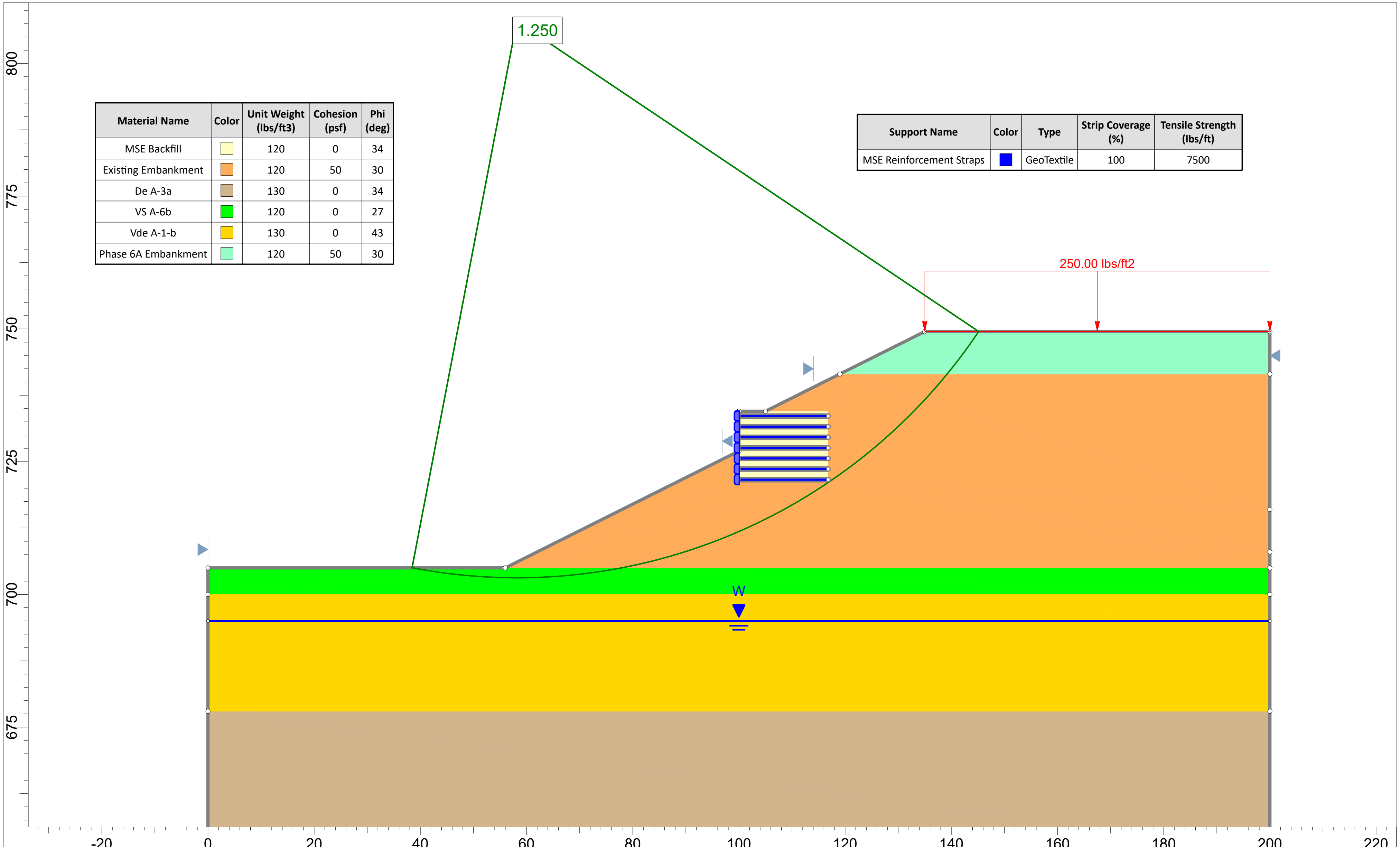
MSE Wall Settlement - Sta. 3006+24 (Phase 6A) Checked By: JPS Date: 7/17/2018

Borings B-110-1-15, and B-111-0-09

H=	12.9	ft	Total wall height
B'=	16.7	ft	Effective footing width due to eccentricity
D_w =	26.6	ft	Depth below bottom of footing
q_e =	2,110	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)	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	29	0.171	0.009	0.499				0.07	0.988	2,085	2,235	0.017	0.201	0.500	1,055	1,205	0.013	0.155
	A-6a	C	2.5	5.0	2.5	2.5	120	600	450	450	4,450	29	0.171	0.009	0.499				0.15	0.971	2,048	2,498	0.011	0.127	0.500	1,055	1,505	0.007	0.090
	A-6a	C	5.0	7.5	2.5	3.8	120	900	750	750	4,750	29	0.171	0.009	0.499				0.22	0.953	2,011	2,761	0.008	0.097	0.500	1,055	1,805	0.005	0.065
	A-6a	C	7.5	10.5	3.0	5.3	120	1,260	1,080	1,080	5,080	29	0.171	0.009	0.499				0.31	0.929	1,961	3,041	0.008	0.092	0.488	1,030	2,110	0.005	0.060
	A-6a	C	10.5	13.5	3.0	6.8	125	1,635	1,448	1,448	5,448	29	0.171	0.009	0.499				0.40	0.912	1,924	3,371	0.006	0.075	0.476	1,004	2,452	0.004	0.047
	A-6a	C	13.5	16.5	3.0	8.3	125	2,010	1,823	1,823	5,823	29	0.171	0.009	0.499				0.49	0.860	1,815	3,637	0.005	0.062	0.460	971	2,793	0.003	0.038
2	A-6b	C	16.5	19.0	2.5	9.5	130	2,335	2,173	2,173	6,173	39	0.261	0.026	0.577				0.57	0.800	1,688	3,861	0.010	0.124	0.448	945	3,118	0.006	0.078
	A-6b	C	19.0	21.5	2.5	10.8	130	2,660	2,498	2,498	6,498	39	0.261	0.026	0.577				0.64	0.750	1,583	4,080	0.009	0.106	0.436	920	3,417	0.006	0.068
3	A-1-b	G	21.5	27.0	5.5	13.5	130	3,375	3,018	3,018	7,018					60	52	177	0.81	0.667	1,407	4,424	0.005	0.062	0.412	869	3,887	0.003	0.041
	A-1-b	G	27.0	32.5	5.5	16.3	130	4,090	3,733	3,733	7,733					60	48	159	0.97	0.589	1,243	4,975	0.004	0.052	0.389	820	4,552	0.003	0.036
	A-1-b	G	32.5	38.0	5.5	19.0	130	4,805	4,448	4,448	8,448					60	44	146	1.14	0.511	1,078	5,526	0.004	0.043	0.369	778	5,225	0.003	0.032
	A-1-b	G	38.0	43.5	5.5	21.8	130	5,520	5,163	5,163	9,163					60	41	134	1.30	0.464	980	6,142	0.003	0.037	0.351	742	5,904	0.002	0.029
4	A-3a	G	43.5	50.0	6.5	25.0	120	6,300	5,910	5,910	9,910					39	25	76	1.50	0.407	859	6,769	0.005	0.060	0.329	693	6,603	0.004	0.049
	A-3a	G	50.0	56.5	6.5	28.3	120	7,080	6,690	6,587	10,587					39	24	73	1.69	0.368	777	7,364	0.004	0.051	0.306	645	7,232	0.004	0.043
																						Total Settlement:		1.189 in			Total Settlement:		0.830 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 26, FHWA GEC 5
3. C_r = 0.05(C_c) for embankment fill and 0.10(C_c) for natural cohesive soils; Ref. Section 5.4.2.5 of FHWA GEC 5
4. e_o = (C_c/1.15)+0.35; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesiv 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)



Material Name	Color	Unit Weight (lbs/ft3)	Cohesion (psf)	Phi (deg)
MSE Backfill		120	0	34
Existing Embankment		120	50	30
De A-3a		130	0	34
VS A-6b		120	0	27
Vde A-1-b		130	0	43
Phase 6A Embankment		120	50	30

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

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SLIDEINTERPRET 7.020

Project	FRA-70-12.68 MSE Wall 4W12 - Sta. 3006+24 - Phase 6A		
Analysis Description	Spencer Method - Drained Conditions		
Drawn By BRT	*Scale* 1:300	*Company*	Resource International, Inc.
Date	7/17/2018	*File Name*	3006+24 Global Stability - Phase 6A.slim