FRA-70-22.85
BRICE ROAD OVER I-70 WB-CD RAMP
(FRA-00070-23.919)
RETAINING WALLS 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B,5C AND 7
PID NO. 98232
FRANKLIN COUNTY, OHIO

STRUCTURE FOUNDATION EXPLORATION REPORT (REV. 1)

Prepared For:
EMH&T
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Columbus, OH 43054

Prepared By:
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Rii Project No. W-17-140

May 2023

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February 6, 2023 (Revised May 6, 2023)

Mr. Steve Beal, P.E.
Senior Transportation Engineer
EMH&T
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Columbus, Ohio 43054

Re: Structure Foundation Exploration (Rev. 1)
FRA-70-22.85 Far East Freeway
Brice Road over I-70 WB-CD Ramp (FRA-00070-23.919)
Retaining Walls 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B, 5C and 7
PID 98232
Franklin County, Ohio
Rii Project No. W-17-140

Mr. Beal:

Resource International, Inc. (Rii) is pleased to submit this revised Structure Foundation Exploration Report for the above referenced project. Engineering logs have been prepared and are attached to this report along with the results of laboratory testing. This report includes recommendations for the design and construction of the proposed FRA-00070-23.919 (SFN 2505742) Brice Road bridge structure over I-70 WB-CD Ramp as well as Retaining Walls 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B, 5C and 7, as part of the FRA-70-22.85 project within the City of Columbus, in Franklin County, Ohio.

We sincerely appreciate the opportunity to be of continued service to you on this project. If you have any questions regarding the structure foundation exploration, or this report, please do not hesitate to contact us.

Sincerely,

RESOURCE INTERNATIONAL, INC.

Brian Trenner

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

Brian R. Trenner, P.E.
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Enclosure: Structure Foundation Exploration Report (Rev. 1)

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EXECUTIVE SUMMARY

Based on the information received from EMH&T, it is understood that lane widening along I-70 westbound lanes will be performed and a new westbound CD ramp will be constructed, and will merge with Ramp F from I-70 westbound to I-270 northbound lanes. Therefore, a new bridge along Brice Road over the proposed WB-CD Ramp will be designed and constructed to accommodate the new configuration. As the existing grade of Brice Road will be maintained, the proposed I-70 WB-CD ramp will be cut through the existing embankment and soil to extend under Brice Road. The new ramp configuration will require a combination of graded slopes and retaining walls to accommodate the proposed configuration. In addition to the proposed I-70 WB-CD Ramp, new interchange ramps from I-70 westbound to Brice Road (Ramp N) and from Brice Road to I-70 WB (Ramp M) will be constructed along the north side of I-70 westbound, between the highway and the proposed I-70 WB-CD Ramp.

Retaining Walls 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B 5C and 7, will support proposed I-70 WB-CD Ramp and Ramps M and N to provide the required grade separation between the ramps as well as I-70 westbound. Retaining Walls 2A and Wall 2B will support the Chatford Drive along the south side of the roadway and I-70 WB-CD Ramp along the north side of the ramp, respectively, where the infield will grade down, towards east. Retaining Wall 3 will support Brice Road over the ramp in front of the forward abutment on the north side of the ramp. Retaining Walls 4A, 4B and 4C will align the south side of the I-70 WB-CD ramp and support Ramps M and N, including the embankment supporting the ramps. Retaining Walls 5A, 5B and 5C will align the south side of Ramps M and N and support the ramps. Design recommendations for the portion of Retaining Wall 5B where it crosses in front of the forward abutment of the bridge carrying Brice Road over I-70, between Sta. 15+85 to 17+96 (BL Wall 5B), as well as Retaining Wall 6 are presented under a separate cover. Retaining Wall 7 will support the I-70 WB-CD Ramp along the north side of the roadway in order to provide the required grade separation for the graded ditch that extends adjacent to the ramp.

Exploration and Findings

Between July 8 and November 12, 2020, and on November 22, 2021, a total of twenty-seven (27) borings were performed and analyzed for the proposed I-70 WB-CD Ramp and the associated retaining walls, ranging in depth from 20.0 to 75.0 feet beneath the existing ground surface.

Borings B-039-0-19 and B-040-1-21 were drilled through the existing Chatford Road and encountered 8.0 and 6.0 inches of asphalt, respectively, overlying 10.0 inches of aggregate base in boring B-039-0-19. Borings B-071-0-19 through B-078-0-19 were performed for the proposed new Brice Road Bridge over I-70 WB-CD Ramp. Borings B-071-0-19, B-072-0-19 and B-074-0-19 were drilled through the existing pavement along Brice Road and encountered 11.5 to 13.0 inches of asphalt overlying 4.5 to 6.0 inches of aggregate base. Boring B-043-0-19 was drilled through the existing berm along the ramp from Brice Road to I-70 westbound and encountered fill material identified as gravel with sand and silt to a depth of 2.5 feet at the ground surface. The remaining borings were drilled within the infields between the north interchange ramps and I-70 and encountered 2.0 to 9.0 inches of topsoil.

Beneath the surficial topsoil, existing embankment fill was encountered in borings B-044-0-19, B-046-0-19, B-047-0-19, B-073-0-19 through B-078-0-19 and B-086-0-19 through B-089-0-19 extending to depths ranging from approximately 5.5 to 27.0 feet below existing grade. In general, the existing embankment fill material was described as dark brown to brown sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b). Isolated zones of granular fill were also encountered within the existing embankment, which consisted of brown, gray and dark gray gravel, gravel with sand, gravel with sand and silt and coarse and fine sand (ODOT A-1-a, A-1-b, A-2-4, A-3a). Construction debris materials consisting of rock fragments and concrete fragments were encountered within the fill material.

Underlying the surficial and existing fill materials, the natural soils encountered generally consisted of cohesive soils with intermittent layers of and granular deposits. The native cohesive soils were generally described as brownish gray sandy silt, silt, silt and clay, silty clay and clay (ODOT A-4a, A-4b, A-6a, A-6b, A-7-6). The granular soils consisted of gravel with sand, gravel with sand and silt, gravel with sand, silt and clay and coarse and fine sand (ODOT A-1-b, A-2-4, A-2-6, A-3a).

Bedrock was not encountered in any of the borings performed for this investigation.

Analyses and Recommendations

Based on design information provided by EMH&T, the proposed bridge along Brice Road over WB-CD Ramp (FRA-00070-23.919, SFN 2505742) will consist of a single span, steel girder with composite reinforced concrete deck structure with reinforced concrete semi-integral abutments behind MSE walls. The span length between the rear and forward abutments is approximately 67 feet, measured center-to-center between the substructures.

It is understood that a combination of Cast-in-Place (CIP) and Mechanically Stabilized Earth (MSE) walls are being utilized for construction of the proposed retaining walls. As previously noted, design recommendations for the portion of Retaining Wall 5B where it crosses in front of the forward abutment of the bridge carrying Brice Road over I-70, between Sta. 15+85 to 17+96 (BL Wall 5B), as well as Retaining Wall 6 are presented under a separate cover. Retaining Wall 7 will support the I-70 WB-CD Ramp along the north side of the roadway in order to provide the required grade separation for the graded ditch that extends adjacent to the ramp.

Pile Foundation Recommendations

As per the 2020 ODOT Bridge Design Manual, cast-in-place (CIP) friction piles should be considered to support the superstructure units since bedrock was not encountered in any of the borings. Additionally, the CIP reinforced concrete pipe piles should consist of ASTM A252, Grade 2 steel (F_y = 35 ksi) or Grade 3 steel (F_y = 45 ksi) with a minimum wall thickness as indicated in the following table and outlined in Section 5.1.2 of the full report. Since bedrock was not encountered at the site, it is recommended that steel CIP pipe piles (ODOT Item 507.06) be driven to the frictional capacity provided in the following table, which summarizes recommended pile lengths of CIP piles and corresponding to ultimate bearing values (UBV).

CIP-Pile Recommendations

Substructure Reference	Bottom of Footing [1] (feet msl)	Pile Size (inch)	Min. Req. Pile Wall Thickness [2] (inch)	Sleeve Length [3] (feet)	Pile Elevation (feet msl)		Est. Pile Length [5] (feet)	Required UBV [6] (kips/pile)	φ_{dyn} [7]
					Top [4]	Tip			
Rear Abutment (B-073-0-19)	809.5	12” CIP	0.4375 (7/16) Grade 2 or 0.3125 (5/16) Grade 3	18.5	810.5	758.7	55.0	186	0.7
Rear Abutment (B-074-0-19)						755.4	60.0		
Rear Abutment (B-075-0-19)						762.0	50.0		
Forward Abutment (B-076-0-19)	809.0		0.4375 (7/16) Grade 2 or 0.3125 (5/16) Grade 3	17.0	810.0	764.2	50.0	189	
Forward Abutment (B-077-0-19)						763.6	50.0		
Forward Abutment (B-078-0-19)						762.1	50.0		

1. *Bottom of footing elevation determined from design plans provided by EMH&T.*
2. *See Section 5.1.2 of the full report for pile drivability discussion and results.*
3. *Sleeve length represents the required length of pile that should be sleeved within the MSE wall backfill, including the foundation preparation*
4. *The top of pile elevation corresponds to the pile cutoff elevation, which is considered to be 1.0-foot above the proposed bottom of footing elevation per Section 305.3.5.1 of the 2020 ODOT BDM.*
5. *Per Section 305.3.5.2 of the 2020 ODOT BDM, the estimated pile length was determined as the pile cutoff elevation (top) minus the pile tip elevation, rounded up to the nearest 5.0 feet.*
6. *Ultimate bearing value is the final maximum unfactored resistance that an individual pile is expected to supply. Values are based on design maximum factored structural loads provided by EMH&T.*
7. *The resistance factor listed assumes dynamic testing of the pile elements per Section 305.7.1 of the 2020 ODOT BDM.*

Given that the proposed I-70 WB-CD Ramp will be cut under the existing Brice Road, the proposed configuration and profile grade at the abutments will match the existing grade, resulting in no net loading or stress increase within the underlying soils. Therefore, settlement at the abutments will be negligible, and downdrag loads will not be imparted on CIP pipe piles.

MSE Retaining Wall Recommendations (Walls 3, 4B and 5B)

Borings B-041-0-19 through B-047-0-19, B-070-19 through B-078-0-19 and B-086-0-19 through B-089-0-19 were performed along the alignments of the I-70 WB CD Ramp and Ramps M and N. Based on the subsurface conditions encountered, the anticipated soils at the proposed bearing elevation along Retaining Walls 3, 4B and 5B will generally consist of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) with interbedded layers of medium dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4) extending to an approximate elevation 785 to 790 feet msl. Below this elevation, the subsurface soils generally consist of interbedded layers of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a) and medium dense to very dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4). More isolated pockets of stiff to hard silty clay and clay (ODOT A-6b, A-7-6) are also present within the lower portion of the subsurface soils. In general, the soils encountered at the proposed bearing elevation along Retaining Walls 4B and 5B are suitable for support of the proposed MSE wall in their current condition.

The upper medium stiff silty clay (ODOT A-6b) encountered in borings B-077-0-19 and B-078-0-19 along the I-70 WB CD Ramp in the vicinity of Retaining Wall 3, which extends to an elevation of 788.6 and 786.1 feet msl, respectively, is estimated to have an undrained shear strength ranging from 1,375 to 1,625 psf and will not be suitable for support of the proposed MSE wall. The bearing soils appear to be transitioning to non-plastic silt along the west end of the wall. Therefore, it is recommended that this material be completely over excavated to expose the underlying medium dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4) and replaced with ODOT Item 203 granular embankment. This stabilization measure should be performed for the entire length of the wall alignment where these unsuitable soils are present within the footprint of the MSE wall and select granular backfill

MSE wall foundations bearing these natural soils or granular embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a factored bearing resistance as indicated in in the following table. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state.

Retaining Walls 3, 4B and 5B MSE Wall Design Parameters

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Wall Height Analyzed (feet)	Backslope Behind Wall	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Equivalent Bearing Pressure [4] (ksf)	
	From [1]	To [1]					Nominal	Factored [3]	Strength Limit	Service Limit
3	10+00	12+70	B-076-0-19 to B-078-0-19	28.6	Level	20.0 (0.70H ≥ 8.0)	25.46	16.55	6.83	4.78
4B	10+00	10+75	B-043-0-19	11.3	4:1 Broken Back	8.0 (0.70H ≥ 8.0)	9.85	6.5	3.34	2.22
	10+75	11+50	B-044-0-19	12.9	3:1 Broken Back	11.0 (0.85H)	10.23	6.65	3.37	2.33
	11+50	13+52	B-046-0-19 & B-073-0-19	17.5	3:1 Broken Back	14.0 (0.80H)	14.02	9.11	4.72	3.26
	13+52	15+92	B-071-0-19 to B-075-0-19	30.3	Level	25.8 (0.85H)	15.27	9.93	6.46	4.59
	15+92	17+80	B-087-0-19 & B-088-0-19	17.0	3:1 Broken Back	14.5 (0.85H)	9.93	6.45	4.38	3.06
	17+80	18+60	B-087-0-19 & B-088-0-19	9.5	3:1 Broken Back	9.0 (0.95H ≥ 8.0)	8.14	5.29	2.33	1.62
5B	10+00	12+00	B-041-0-19	15.2	Level	10.6 (0.70H ≥ 8.0)	8.12	5.28	4.06	2.78
	12+00	14+25	B-045-0-19	22.1	Level	15.5 (0.70H)	15.69	10.20	5.46	3.80
	14+25	15+85 [5]	B-047-0-19 & B-007-0-65	27.9	Level	19.5 (0.70H)	12.75	8.29	6.69	4.68
	17+96 [5]	20+80	B-070-0-19, B-086-0-19, & B-088-0-19	26.7	Level	21.4 (0.80H)	9.44	6.14	5.94	4.20
	20+80	21+95	B-089-0-19	15.0	Level	10.5 (0.70H ≥ 8.0)	8.13	5.28	3.99	2.74

1. *Stationing referenced to the baseline of the respective retaining wall alignment.*
2. *The minimum reinforcement length is based on the maximum wall height analyzed. The value in parentheses represent the required reinforcement length 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 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 and service limit states.*
5. *Recommendations for Retaining Wall 5B between Sta. 15+85 and 17+96 (BL Wall 5B) as well as Retaining Wall 6 are provided under a separate cover.*

Total settlements of up to 2.22 inches at the center of the reinforced soil mass and 1.64 inches at the facing of the wall are anticipated along the alignment of Retaining Wall 5B. Based on the results of the analysis, 90 percent of the total settlement at the facing of the wall is anticipated to occur within 3 to 180 days following the completion of construction of the wall.

Based on the results of the external and global stability analysis performed, the recommended controlling strap length is 0.70 times the respective height of the MSE walls (measured from the top of the leveling pad to the top of coping or proposed profile grade of the roadway) for Retaining Walls 3, 4B (from Sta. 10+00 to 10+75, BL Wall 4B) and 5B (from Sta. 10+00 to 15+85 and Sta. 20+80 to 21+95, BL Wall 5B). All external and global stability calculations indicate that adequate resistance is available for support of the MSE walls at these locations for a strap length equal to 70 percent of the respective wall heights. Note that the recommended strap length for Retaining Wall 3 considers that the upper medium stiff silty clay (ODOT A-6b) material will be over excavated and replaced with ODOT Item 203 granular embankment.

Based on the results of the external and global stability analysis performed, for the remainder of Retaining Walls 4B (from Sta. 10+75 to 18+60, BL Wall 4B) and 5B (from Sta. 17+96 to 20+80, BL Wall 5B), the recommended controlling strap length is 0.80 to 0.95 times respective height of the MSE wall (measured from the top of the leveling pad to the top of coping). Sliding resistance under drained conditions and bearing resistance under undrained conditions were the controlling factors in the determination of the required strap lengths of 0.80 to 0.95 times the respective wall height for these sections.

CIP Retaining Wall Recommendations (Walls 2B, 4A, 4C, 5A, 5C and 7)

Borings B-039-0-19 through B-041-0-19 and B-043-0-19 were performed along or within the vicinity of the alignments of Retaining Walls 2B, 4A and 5A; boring B-089-0-19 was performed along the alignment and in close proximity to the alignments of Retaining Walls 4C and 5C; and, borings B-090-0-19 through B-092-0-19 and B-094-0-19 were performed along or in close proximity to Retaining Wall 7. In general, the subsurface profile along the wall alignments consists of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) extending to the boring termination depths. Along Retaining Wall 4A between Sta. 11+40 to 12+55 (BL Wall 4A), the subsurface profile consists primarily of medium dense to dense gravel with sand and silt (ODOT A-2-4) overlying interbedded stiff to hard sandy silt (ODOT A-4a) and medium dense to very dense gravel with sand and coarse and fine sand (ODOT A-1-b, A-3a). Additionally, granular soil consisting of medium dense gravel with sand and silt (ODOT A-2-4) was present below the surficial cohesive soils along Retaining Wall 7. These soils are suitable for support of the proposed CIP walls in their current condition.

CIP wall foundations bearing on these natural soils or newly placed embankment fill may be proportioned for a factored bearing resistance as indicated in the following table. A geotechnical resistance factor of φ_b=0.55 was considered in calculating the factored bearing resistance at the strength limit state.

Retaining Walls 2A, 2B, 4A, 4C, 5A, 5C and 7 CIP Wall Design Parameters

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Wall Height Analyzed (feet)	Foundation Width Analyzed (feet)	Backslope Behind Wall	Bearing Resistance at Strength Limit (ksf)		Equivalent Bearing Pressure [3] (ksf)	
	From [1]	To [1]					Nominal	Factored [2]	Strength Limit	Service Limit
2A	10+00	11+30	B-039-0-19 & B-040-0-19	13.3	9.0	Level	15.00	8.25	2.91	2.04
2B	10+00	12+21	B-039-0-19, B-040-0-19 & B-040-1-21	15.0	11.8	Level	13.09	7.20	2.87	2.05
4A	10+00	11+40	B-041-0-19	9.4	10.3	Level	8.22	4.52	1.85	1.34
	11+40	12+55	B-043-0-19	9.8	10.3	4:1 Broken-Back	19.60	10.78	1.69	1.25
4C	10+00	11+40	B-089-0-19	9.5	10.0	3:1 Broken-Back	8.34	4.59	1.39	1.02
5A	10+60	12+40	B-040-0-19 to B-041-0-19	10.2	9.5	Level	5.63	3.10	1.89	1.37
5C	10+00	10+57	B-089-0-19	8.7	9.5	Level	8.74	4.81	1.70	1.22
7	10+33	14+34	B-090-0-14 to B-092-0-19 & B-094-0-19	9.4	7.0 (w/ 2.5-foot Shear Key)	Level	7.98	4.39	1.97	1.40

1. *Station limits are referenced to the proposed baseline of the respective wall alignment.*
2. *A geotechnical resistance factor of φ_b=0.55 was considered in calculating the factored bearing resistance at the strength limit state.*
3. *The 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 and service limit state*

Total settlements of up to 0.98 inches are anticipated along the alignments of the CIP walls. Based on the results of the analysis, 90 percent of the total settlement at the facing of the wall is anticipated to occur within 1 to 75 days following the completion of construction of the walls.

Based on the results of the external and global stability analysis performed, all of the CIP wall sections analyzed meet all of the external and global stability requirements.

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 Phase 2 and 3 of the FRA-70-22.85 project. The project's proposed improvements include reconfiguration of the north half of the Brice Road interchange of westbound ramps to Interstate 270 (I-270) interchange, replacement of the Brice Road Bridge over Interstate 70 (I-70), a proposed Brice Road Bridge over new WB-CD Ramp, three (3) noise barriers, twelve (12) retaining walls, and five (5) culvert extensions.

This report is a presentation of the structure foundation exploration performed for the proposed new Brice Road bridge over Interstate Route 70 (I-70) westbound Collector Distributor (WB-CD) ramp and associated retaining walls, as shown on the vicinity map and boring plan presented in Appendix I. Based on the information received from EMH&T, it is understood that lane widening along I-70 westbound lanes will be performed and a new westbound CD ramp will be constructed, and will merge with Ramp F from I-70 westbound to I-270 northbound lanes. Therefore, a new bridge along Brice Road over the proposed WB-CD Ramp will be designed and constructed to accommodate the new configuration. As the existing grade of Brice Road will be maintained, the proposed I-70 WB-CD Ramp will be cut through the existing embankment and soil to extend under Brice Road. The new ramp configuration will require a combination of graded slopes and retaining walls to accommodate the proposed configuration. In addition to the proposed I-70 WB-CD Ramp, new interchange ramps from I-70 westbound to Brice Road (Ramp N) and from Brice Road to I-70 WB (Ramp M) will be constructed along the north side of I-70 westbound, between the highway and the proposed I-70 WB-CD Ramp.

It is understood that the Brice Road bridge structure over the I-70 WB-CD Ramp (FRA-00070-23.90, SFN 2505742) is proposed to consist of a single span, steel girder with composite reinforced concrete deck structure with reinforced concrete semi-integral abutments behind MSE walls. The span length between the rear and forward abutments is approximately 67 feet, measured center-to-center between the substructures.

Retaining Walls 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B, 5C and 7 will support Chatford Drive, proposed I-70 WB-CD Ramp and Ramps M and N to provide the required grade separation between the ramps as well as I-70 westbound. Retaining Wall 2A supports Chatford Drive along the south side of the roadway to provide the required grade separation for the infield ditch between the roadway and I-70 WB-CD Ramp. Retaining Wall 2B will support I-70 WB-CD Ramp along the north side of the ramp. Retaining Wall 3 will support Brice Road over the ramp in front of the forward abutment on the north side of the ramp. Retaining Walls 4A, 4B and 4C will align the south side of the I-70 WB-CD ramp and support Ramps M and N, including the embankment supporting the ramps. Retaining Walls 5A, 5B and 5C will align the south side of Ramps M and N and support the ramps. Design recommendations for the portion of Retaining Wall 5B where it crosses in front of the forward abutment of the bridge carrying Brice Road over I-70 (FRA-00070-23.90, SFN 2505739), between Sta. 15+85 to 17+96 (BL Wall 5B), as well as Retaining Wall 6 are presented under a separate cover. Retaining Wall 7 will support the I-70 WB-CD Ramp along the north side of the roadway in order to provide the required grade separation for the graded ditch that extends adjacent to the ramp.

The exploration was performed in general accordance with the Ohio Department of Transportation's (ODOT) Specifications for Geotechnical Explorations (SGE), dated July 2020.

2.0 RECONNAISSANCE AND PLANNING

2.1 Site Geology

Physiographically, the site lies within the Columbus Lowland District of the Southern Ohio Loamy Till Plain Region. This region is characterized by relatively flat-lying silty loam till ground moraine, interspersed with end and recessional moraines, outwash and alluvial deposits. Ground moraines are deposited during the retreat of a glacier, resulting in an undifferentiated mixture of clay, silt, sand and gravel. End moraines are normally associated with ice melting that is neither advancing nor retreating for a period of time. Recessional moraines are deposited when the ice sheet is retreating. Both end and recessional moraines are commonly associated with boulder belts. 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 from silty clay to cobble sized deposits, usually deposited in present and former floodplain areas, such as the Big Walnut Creek and its tributaries.

Based on the Bedrock Geology and Bedrock Topography maps of the Columbus area, obtained from Ohio Department of Natural Resources (ODNR), the bedrock at the proposed project site consists of the Upper Devonian-aged Ohio Shale Formation. The Ohio Shale Formation is further subdivided into three primary members, in descending order: the Cleveland, Chagrin, and Huron Members. The Cleveland Member consists of black shale and is thickest in the north-central portion of the state but thins out to the south and east. The Huron Member consists of gray to greenish gray interbedded shale, siltstone, and very fine-grained sandstone, and is thickest in the northeastern portion of the state, thinning out to the southwest. The Chagrin Member grades into the overlying and underlying members and consists of black, carbonaceous shale. The entire Ohio Shale formation ranges from 250 to over 500 feet thick, with generally laminated to thin bedding and fissile partings, and is characterized by such features as having a petroliferous odor and carbonate/siderite concretions.

According to bedrock topography mapping from ODNR, the top of bedrock forms a ridge to the north of the site, generally lying just outside of the I-270 loop, and roughly underlying the cities of Gahanna and Reynoldsburg. The bedrock surface forms a narrow plateau that extends southwest from the south end of this ridge, which projects beneath the I-270 and I-70 interchange. The bedrock surface slopes down to the northwest and to the southeast from this plateau near the interchange, then generally slopes downward to the south and southeast. The bedrock near the interchange and northward along I-270 and eastward along I-70, lies at approximately elevation of 750 feet mean sea level (msl), or 27 to 33 feet below the ground surface. The bedrock surface gets only slightly deeper moving northward and approximately 50 feet deeper eastward from the interchange near the Brice Road overpass over I-70. The bedrock surface slopes upwards moving northward along Brice Road from the Brice Road overpass over I-70.

2.2 Observations of the Project

The site of the proposed FRA-70-22.85 project is located along the east side of Columbus, in Franklin County, Ohio, with the project limits stretching from the east side approximately 1,400 feet east of the existing I-70 exit ramp to Brice Road, and extending westward along I-70 to the I-270 northbound ramp. The north side the project extends along Brice Road to the first intersection north of the bridge and on the south side the project extends along Brice Road to the intersection of Chantry Drive and Brice Road. Land use surrounding the majority of the project vicinity is predominantly commercial and residential units.

The existing embankment on the north side of the Brice Road and I-70 at the time of the site reconnaissance was well maintained and mowed, with dense vegetation near the forward abutment of the Brice Road bridge structure over I-70. The existing embankment is approximately 20 feet in height. The existing slopes of the embankment and spill through slope beneath the bridge structure appeared to be stable with no signs of distress. The existing ditch was observed to be relatively dry.

3.0 EXPLORATION

Between July 7 and November 12, 2020, and on November 22, 2021, a total of twenty-seven (27) borings were performed and analyzed for the proposed I-70 WB-CD Ramp and the associated retaining walls, ranging in depth from 10.0 to 75.0 feet beneath the existing ground surface. A summary of the borings analyzed for the subject structures is presented in Table 1.

Table 1. Summary of FRA-70-22.85 Borings

Boring Number	Alignment	Station	Offset	Latitude	Longitude	Ground Elevation (feet) [1]	Boring Depth (feet)
B-039-0-21	BL I-70 WB-CD Road	1578+33.5	22.6’ Lt	39.933438	-82.833771	788.6	25.0
B-040-0-19	BL I-70 WB-CD Road	1578+85.2	32.8’ Rt	39.933285	-82.833587	788.6	25.0
B-040-1-21	BL I-70 WB-CD Road	1579+46.7	51.3’ Lt	39.933520	-82.833376	788.7	20.0
B-041-0-19	BL Ramp M	2580+72.4	19.9’ Lt	39.933271	-82.833009	789.5	30.0
B-042-0-19	BL I-70 WB-CD Road	1580+86.0	15.2’ Lt	39.933442	-82.832876	790.0	25.0
B-043-0-19	BL I-70 WB-CD Road	1581+94.7	25.3’ Rt	39.933347	-82.832481	793.2	30.0
B-044-0-19	BL I-70 WB-CD Road	1582+96.9	43.21’ Rt	39.933314	-82.832114	799.4	30.0
B-045-0-19	BL Ramp M	2583+59.8	28.9’ Rt	39.933112	-82.832016	793.7	30.0
B-046-0-19 [2]	BL I-70 WB-CD Road	1583+18.8	41.1’ Rt	39.933335	-82.831767	805.8	55.0
B-047-0-19	BL Ramp M	2584+66.5	6.6’ Lt	39.933193	-82.831629	794.9	30.0
B-070-0-19	CL Const. Brice Road	31+88.3	77.5’ Rt	39.933031	-82.830456	796.6	75.0
B-071-0-19	CL Const. Brice Road	1586+63.4	30.8 Lt.	39.933291	-82.830827	820.7	75.0
B-072-0-19	CL Const. Brice Road	32+61.9	42.7 Rt.	39.933239	-82.830560	820.8	75.0
B-073-0-19	BL I-70 WB-CD Road	1585+96.1	47.1’ Rt	39.933330	-82.831060	822.7	75.0
B-074-0-19	BL I-70 WB-CD Road	1586+38.2	59.5’ Rt	39.933292	-82.830915	820.4	75.0
B-075-0-19	BL I-70 WB-CD Road	1587+63.4	45.8’ Lt	39.933307	-82.830477	819.0	60.0
B-076-0-19	BL I-70 WB-CD Road	1585+96.5	8.4’ Rt	39.933436	-82.831055	823.2	75.0
B-077-0-19	CL Const. Brice Road	1586+84.1	14.0’ Lt	39.933413	-82.830745	820.6	75.0
B-078-0-19	BL I-70 WB-CD Road	1587+68.1	4.5’ Lt	39.933419	-82.830446	818.1	75.0
B-086-0-19	BL Ramp N	4588.38.3	13.8’ Rt	39.933103	-82.830232	800.0	30.0
B-087-0-19 [2]	BL I-70 WB-CD Road	1588+73.4	31.5’ Rt	39.933311	-82.830087	822.7	70.0
B-088-0-19 [2]	BL I-70 WB-CD Road	1590+16.4	35.9’ Rt	39.933232	-82.829596	817.4	55.0
B-089-0-19	BL I-70 WB-CD Road	1591+71.1	34.5’ Rt	39.933146	-82.829057	804.6	30.0
B-090-0-19	BL I-70 WB-CD Road	1594+39.0	22.4’ Rt	39.933022	-82.828113	800.5	10.0
B-091-0-19	BL I-70 WB-CD Road	1595+86.8	10.1’ Lt	39.933032	-82.827573	798.0	15.0
B-092-0-19	BL I-70 WB-CD Road	1596+40.1	8.1’ Lt	39.933001	-82.827387	797.7	15.5
B-094-0-19	BL I-70 WB-CD Road	1597+94.4	6.8’ Rt	39.932898	-82.826851	803.3	10.0

1. *Ground surface elevations were provided by EMH&T survey.*
2. *Borings B-046-0-19, B-087-0-19 and B-088-0-19 were re-drilled on later date to depths of 55.0, 70.0 and 55.0 feet, respectively, below the ground surface.*

The boring locations were determined and field located by Rii personnel prior to drilling operations. During the field locating and reconnaissance, Rii utilized a handheld GPS locate the boring locations. Coordinates and ground surface elevations of the as drilled boring locations were provided by the EMH&T survey team.

The borings were drilled with either an all-terrain vehicle (ATV) or truck-mounted rotary drilling machine, utilizing a 3.25-inch inside diameter hollow-stem to advance the holes between sampling attempts. In general, standard penetration testing (SPT) and split spoon sampling were performed at 2.5-foot intervals to approximately 25 feet below the existing ground surface and at 5.0-foot intervals thereafter.

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. Driving resistance is recorded on the boring logs in terms of blows per 6-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_m) values are corrected to an equivalent (60%) energy ratio, N_{60}, by the following equation. Both values are represented on boring logs presented in Appendix III.

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

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

The hammers for the CME-55, Mobile B53 and CME-750X drill rigs were calibrated on September 4, 2018 and have drill rod energy ratios of 91.2, 80.7, and 79.5 percent, respectively. For borings performed on or after August 31,2020, updated rig calibrations were utilized, with drill rod energy ratios of 84.2, 83.6 and 86.2 percent for the CME-55, Mobile B53, and the CME-750X drill rigs, respectively.

Hand penetrometer readings, which provide a rough estimate of the unconfined compression strength (UCS) 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.

Upon completion of drilling, the borings were backfilled with bentonite chips and soil cuttings. Where borings penetrated the existing pavement, an equivalent thickness of quickset concrete was used to repair the pavement surface.

During drilling, field personnel prepared field logs 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 recovered 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	246
Plastic and Liquid Limits	AASHTO T89, T90	83
Gradation – Sieve/Hydrometer	AASHTO T88	77
Gradation – Sieve Only	AASHTO T88	5

The tests performed are necessary to classify existing soil according to the 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.

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 SGE at the time the exploration borings were performed. The following is a summary of what was found in the test borings and what is represented on the boring logs.

4.1 Surface Materials

Borings B-039-0-19 and B-040-1-21 were drilled through the existing Chatford Road and encountered 8.0 and 6.0 inches of asphalt, respectively, overlying 10.0 inches of aggregate base in boring B-039-0-19. Borings B-071-0-19 through B-078-0-19 were performed for the proposed new Brice Road Bridge over I-70 WB-CD Ramp. Borings B-071-0-19, B-072-0-19 and B-074-0-19 were drilled through the existing pavement along Brice Road and encountered 11.5 to 13.0 inches of asphalt overlying 4.5 to 6.0 inches of aggregate base. Boring B-043-0-19 was drilled through the existing berm along the ramp from Brice Road to I-70 westbound and encountered fill material identified as gravel with sand and silt to a depth of 2.5 feet at the ground surface. The remaining borings were drilled within the infields between the north interchange ramps and I-70 and encountered 2.0 to 9.0 inches of topsoil.

4.2 Subsurface Soils

Beneath the surficial topsoil, existing embankment fill was encountered in borings B-044-0-19, B-046-0-19, B-047-0-19, B-073-0-19 through B-078-0-19 and B-086-0-19 through B-089-0-19 extending to depths ranging from approximately 5.5 to 27.0 feet below existing grade. In general, the existing embankment fill material was described as dark brown to brown sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b). Isolated zones of granular fill were also encountered within the existing embankment, which consisted of brown, gray and dark gray gravel, gravel with sand, gravel with sand and silt and coarse and fine sand (ODOT A-1-a, A-1-b, A-2-4, A-3a). Additionally, boring B-090-0-19, encountered approximately 16.0 inches of asphalt fragments below the surface material. Construction debris materials consisting of rock fragments and concrete fragments were encountered within the fill material.

Underlying the surficial and existing fill materials, the natural soils encountered generally consisted of cohesive soils with intermittent layers of and granular deposits. The native cohesive soils were generally described as brownish gray sandy silt, silt, silt and clay, silty clay and clay (ODOT A-4a, A-4b, A-6a, A-6b, A-7-6). The granular soils consisted of gravel with sand, gravel with sand and silt, gravel with sand, silt and clay and coarse and fine sand (ODOT A-1-b, A-2-4, A-2-6, A-3a).

The shear strength and consistency of the cohesive soils are primarily derived from the hand penetrometer values (HP). The cohesive soils encountered ranged from soft ($0.25 < HP \leq 0.5$ tsf) to hard ($HP > 4.0$ tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 0.5 to over 4.5 tsf (limit of instrument). The relative density of granular soils is primarily derived from SPT blow counts (N_{60}). Based on the SPT blow counts obtained, the granular soils encountered ranged from loose ($5 < N_{60} < 11$ blows per foot [bpf]) to very dense ($N_{60} \geq 50$ bpf). Blow counts recorded from the SPT sampling ranged from 8 bpf to split spoon sampler refusal. Split spoon sampler refusal is defined as exceeding 50 blows with less than 6.0 inches of penetration by the split spoon sampler.

Natural moisture contents of the soil samples tested ranged from 3 to 32 percent. The natural moisture contents of the cohesive soil samples tested for plasticity ranged from 14 percent below to 7 percent above their corresponding plastic limits. In general, the soil exhibited natural moisture contents considered to be significantly below to moderately above optimum moisture levels.

4.3 Historic Borings

Rii reviewed the historic borings available through ODOT Transportation Information Mappin System (TIMS). From the historical information available, boring B-007-0-65, performed in 1965 by the Department of Highways as part of the FRA-70-22.29, encountered brown and gray sandy gravel and silty sandy gravel (ODOT A-1-a, A-2-4) overlying gray gravelly clay and sandy gravelly silt (ODOT A-6b, A-4a).

4.4 Bedrock

Bedrock was not encountered in any of the borings performed for this exploration.

4.5 Groundwater

Groundwater encountered in the borings performed at the proposed Brice Road Bridge over WB-CD Ramp as presented in Table 3.

Table 3. Groundwater Levels

Boring Number	Ground Elevation (feet msl)	Initial Groundwater		At Completion		Cave-In Depth	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-039-0-21	788.6	N/A	--	N/A	--	22.4	766.2
B-040-0-19	788.6	9.0	779.6	13.0	775.6	16.4	772.2
B-040-1-21	788.7	8.7	780.0	6.6	782.1	7.0	781.7
B-041-0-19	789.5	15.0	774.5	13.7	775.8	16.0	773.5
B-042-0-19	790.0	5.6	784.4	N/A [1]	--	15.5	774.5
B-043-0-19	793.2	11.0	782.2	N/A	--	N/A	--
B-044-0-19	799.4	19.0	780.4	18.0	781.4	N/A	--
B-045-0-19	793.7	14.0	779.7	N/A	--	N/A	--
B-046-0-19 [2]	805.8	N/A	--	29.0	776.8	N/A	--
B-047-0-19	794.9	N/A	--	14.5	780.4	N/A	--
B-070-0-19	796.6	13.5	783.1	N/A [1]	--	N/A	--
B-071-0-19	820.7	37.0	783.7	34.0	786.7	N/A	
B-072-0-19	820.8	38.5	782.3	22.5	798.3	N/A	--
B-073-0-19	822.7	24.0	798.7	12.5	810.2	N/A	--
B-074-0-19	820.4	44.0	776.4	N/A [1]	--	N/A	--
B-075-0-19	819.0	36.5	782.5	33.1	785.9	N/A	--
B-076-0-19	823.2	29.0	794.2	37.0	786.2	N/A	--
B-077-0-19	820.6	36.5	784.1	N/A [1]	--	N/A	--
B-078-0-19	818.1	32.0	786.1	64.3	753.8	N/A	--
B-086-0-19	800.0	18.0	782.0	16.0	784	14.9	785.1
B-087-0-19	822.7	48.5	774.2	N/A	--	3.5	819.2
B-088-0-19	817.4	26.5	790.9	26.0	791.4	17.8	799.6

Boring Number	Ground Elevation (feet msl)	Initial Groundwater		At Completion		Cave-In Depth	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-089-0-19	804.6	N/A	--	N/A	--	N/A	--
B-090-0-19	800.5	N/A	--	N/A	--	8.3	
B-091-0-19	798.0	12.0	786.0	12.0	786.0	13.2	784.8
B-092-0-19	797.7	8.0	789.7	3.2	794.5	8.4	789.3
B-094-0-19	803.3	N/A	--	N/A	--	N/A	--

1. *Groundwater level during and/or at the completion of drilling was not measured due to the addition of water or mud to the borehole to counteract heaving sands*

Groundwater seepage was encountered initially during the drilling process in boring B-041-0-19, B-044-0-19, B-045-0-19, B-046-0-19, B-047-0-19, B-073-0-19, B-074-0-19, B-090-0-19, B-091-0-19 and B-094-0-19, at the depths ranging from 4.0 feet to 22.5 feet below the ground surface. Static groundwater was observed during drilling in all of the borings performed, with exception of borings B-039-0-21, B-046-0-19, B-047-0-19, B-089-0-19, B-090-0-19 and B-094-0-19. The groundwater during drilling where observed ranges at depths from 5.6 feet to 48.5 feet below existing grade, which corresponds to the elevations ranging from 775.6 to 784.4 feet msl. Upon completion of drilling and after removing the augers, groundwater was encountered in borings B-040-0-19, B-041-0-19, B-044-0-19, B-046-0-19, B-047-0-19, B-71-0-19 through B-0-73-0-19, B-075-0-19 through B-078-0-19, B-086-0-19, B-088-0-19, B-091-0-19 and B-092-0-19, at depths ranging from 3.2 feet to 64.3 feet below existing grade, which corresponds to the elevation ranging from 753.8 to 810.2 feet msl. Cave-in condition was observed in borings B-039-0-19 through B-042-0-19 and B-086-0-19 through B-089-0-19, at depths ranging from 3.5 to 22.4 feet, below the respective ground elevation.

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 in the boring logs in Appendix III.

5.0 ANALYSES AND RECOMMENDATIONS

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

Based on design information provided by EMH&T, the proposed bridge along Brice Road over WB-CD Ramp (FRA-00070-23.919, SFN 2505742) will consist of a single span, steel girder with composite reinforced concrete deck structure with reinforced concrete semi-integral abutments behind MSE walls. The span length between the rear and forward abutments is approximately 67 feet, measured center-to-center between the substructures. The bearing elevations and structural loading was obtained from the proposed design plans provided by EMH&T and is summarized in Table 4.

Table 4. Bridge Structure Design Elevations

Substructure Reference	**Substructure Type**	**Structure Component**	**Elevation (ft. msl) ^{1}**	**Design Maximum Factored Structure Load ^{2} (kips/pile)**
Rear Abutment / Retaining Wall 4B (Sta. 15+85 to 17+96) (B-073-0-19, B-074-0-19 and B-075-0-19)	Semi-Integral Abutment Behind MSE Wall	Profile Grade	821.3	130
		Bottom of Footing	809.5	
		Bottom of Wall (Top of Leveling Pad)	791.0	
Forward Abutment / Retaining Wall 3 (B-076-0-19, B-077-0-19 and B-078-0-19)	Semi-Integral Abutment Behind MSE Wall	Profile Grade	820.6	132
		Bottom of Footing	809.0	
		Bottom of Wall (Top of Leveling Pad)	792.0	

1. *Elevations based on the proposed structure information provided by EMH&T.*
2. *Design maximum factored structural load was provided by EMH&T*

Retaining Walls 2A, 2B, 3, 4A, 4B, 4C, 5A, 5B, 5C and 7, will support Chatford Drive, proposed I-70 WB-CD Ramp and Ramps M and N to provide the required grade separation between the ramps as well as I-70 westbound. Retaining Wall 2A supports Chatford Drive along the south side of the roadway to provide the required grade separation for the infield ditch between the roadway and I-70 WB-CD Ramp. Retaining Wall 2B will support the I-70 WB-CD Ramp along the north side of the ramp where the infield will grade down, and Retaining Wall 3 will support Brice Road over the ramp in front of the forward abutment on the north side of the ramp. Retaining Walls 4A, 4B and 4C will align the south side of the I-70 WB-CD ramp and support Ramps M and N, including the embankment supporting the ramps. Retaining Walls 5A, 5B and 5C will align the south side of Ramps M and N and support the ramps.

It is understood that a combination of Cast-in-Place (CIP) and Mechanically Stabilized Earth (MSE) walls are being utilized for construction of the proposed retaining walls. As previously noted, design recommendations for the portion of Retaining Wall 5B where it crosses in front of the forward abutment of the bridge carrying Brice Road over I-70, between Sta. 15+85 to 17+96 (BL Wall 5B), as well as Retaining Wall 6 at the rear abutment of the bridge carrying Brice Road over I-70 are presented under a separate cover. Retaining Wall 7 will support the I-70 WB-CD Ramp along the north side of the roadway in order to provide the required grade separation for the graded ditch that extends adjacent to the ramp.

5.1 Pile Foundation Recommendations (FRA-00070-23.919 Bridge)

Based upon an evaluation of the subsurface conditions encountered in the borings performed at the subject structure, it is recommended that a deep foundation system consisting of driven piles be employed for support of the proposed bridge abutment foundation elements.

As per the 2020 ODOT Bridge Design Manual, cast-in-place (CIP) friction piles should be considered to support the superstructure units since bedrock was not encountered in any of the borings. Additionally, the CIP reinforced concrete pipe piles should consist of ASTM A252, Grade 2 steel (F_y = 35 ksi) or Grade 3 steel (F_y = 45 ksi) with a minimum wall thickness as indicated in Table 5 and outlined in Section 5.1.2. Since bedrock was not encountered at the site, it is recommended that steel CIP pipe piles (ODOT Item 507.06) be driven to the frictional capacity provided in Table 5, which summarizes recommended pile lengths of CIP piles and corresponding to ultimate bearing values (UBV).

Table 5. CIP-Pile Recommendations

Substructure Reference	Bottom of Footing [1] (feet msl)	Pile Size (inch)	Req. Pile Wall Thickness [2] (inch)	Sleeve Length [3] (feet)	Pile Elevation (feet msl)		Est. Pile Length [5] (feet)	Required UBV [6] (kips/pile)	φ_{dyn} [7]
					Top [4]	Tip			
Rear Abutment (B-073-0-19)	809.5	12" CIP	0.4375 (7/16) Grade 2 or 0.3125 (5/16) Grade 3	18.5	810.5	758.7	55.0	186	0.7
Rear Abutment (B-074-0-19)						755.4	60.0		
Rear Abutment (B-075-0-19)						762.0	50.0		
Forward Abutment (B-076-0-19)	809.0		0.4375 (7/16) Grade 2 or 0.3125 (5/16) Grade 3	17.0	810.0	764.2	50.0	189	
Forward Abutment (B-077-0-19)						763.6	50.0		
Forward Abutment (B-078-0-19)						762.1	50.0		

1. *Bottom of footing elevation determined from design plans provided by EMH&T.*
2. *See Section 5.1.2 for pile drivability discussion and results.*
3. *Sleeve length represents the required length of pile that should be sleeved within the MSE wall backfill, including the foundation preparation*
4. *The top of pile elevation corresponds to the pile cutoff elevation, which is considered to be 1.0-foot above the proposed bottom of footing elevation per Section 305.3.5.1 of the 2020 ODOT BDM.*
5. *Per Section 305.3.5.2 of the 2020 ODOT BDM, the estimated pile length was determined as the pile cutoff elevation (top) minus the pile tip elevation, rounded up to the nearest 5.0 feet.*
6. *Ultimate bearing value is the final maximum unfactored resistance that an individual pile is expected to supply. Values are based on design maximum factored structural loads provided by EMH&T.*
7. *The resistance factor listed assumes dynamic testing of the pile elements per Section 305.7.1 of the 2020 ODOT BDM.*

The piles were analyzed using the DrivenPiles software program and the results are provided in Appendix VI. The ultimate bearing values listed in Table 5 are based on the maximum factored load per pile and were calculated in accordance with Section 305.3.2 and 305.3.4 of the 2020 ODOT BDM. Additionally, the ultimate bearing values listed in Table 5 represent the calculated values after soil setup has occurred, following a specified waiting period (at restrike). Based on the subsurface conditions encountered, it is recommended that a minimum hold period of five (5) days be specified between the end of driving the pile and the time of restrike to allow adequate soil setup to occur. However, if dynamic testing indicates that the required ultimate bearing value is achieved at the end of driving the pile, a restrike of the pile will not be required. A minimum of one (1) dynamic pile load test should be performed for each substructure unit for each phase of construction. Settlement is estimated to be less than 1.0 inch for CIP pipe piles driven to the resistances provided in Table 5. It is to be noted that as per Section 305.3.5.7 of ODOT BDM, a minimum of 15.0 feet embedment in to the subsurface soils will be required in case the estimated pile lengths are not able to be driven due to the larger resistance developed during pile driving.

It should be noted that the pile lengths and ultimate bearing values presented in Table 5 are estimates using empirical equations based on the derived characteristics of the soils encountered in the subject borings drilled. The actual pile capacities should be verified using static or dynamic pile load testing as detailed in Sections 305.7.1 and 305.7.2 of the 2020 ODOT BDM. The most accurate method for determining pile capacities and lengths is to drive test piling at the site and perform static load testing in accordance with ASTM D1143. Dynamic pile load testing should be performed in accordance with ASTM 4945. Further installation considerations are presented in Section 5.1.3.

5.1.1 Downdrag Considerations

Given that the proposed I-70 WB-CD Ramp will be cut under the existing Brice Road, the proposed configuration and profile grade at the abutments will match the existing grade, resulting in no net loading or stress increase within the underlying soils. Therefore, settlement at the abutments will be negligible, and downdrag loads will not be imparted on CIP pipe piles.

5.1.2 Drivability

A drivability analysis was performed in accordance with Section 10.7.8 of the 2020 American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications (BDS) using the GRLWEAP software program, and the results are provided in Appendix VII. In the drivability analysis, a Delmag 19-42 hammer with a rated energy of approximately 43,000 ft-lbs was used in conjunction with the CIP pipe pile sections. The minimum wall thickness for the drivability analysis for CIP pipe piles is 0.25 inches per ODOT Item 507.06. In the drivability analysis, the piles were modeled using the minimum pile wall thickness, and the pile wall thickness was increased in 1/8-inch increments until the driving stresses induced on the piles were below 90 percent of the yield stress of the steel. Additionally, the portion of the pile within the sleeve length through the MSE walls was modeled using a friction angle of 28 degrees to simulate a sand backfill within the pile sleeves.

Based on the results of this analysis it appears that the driving stresses induced on the CIP pipe piles **would not exceed** 90 percent of the yield stress for ASTM A252, Grade 2 steel (f_y = 35 ksi, 0.9f_y = 31.5 ksi) if driven to the depths and corresponding ultimate bearing values provided in Table 5 using a pile wall thickness of 0.4375 (7/16) inches at the rear and forward abutment. If ASTM A252, Grade 3 steel is utilized, then the pile wall thickness at the rear and forward abutment can be reduced to 0.3125 (5/16) inches.

Additionally, due to the presence of cobbles and boulders, per Section 305.3.5.6 of the 2020 ODOT BDM it is recommended that pile points be installed to improve penetration and protect the piles during driving.

5.1.3 Driven Pile Considerations

Proper pile installation is as important as pile design in order to obtain a cost effective and safe product. Driven piles must be installed to develop adequate soil resistance without structural damage. Because piles cannot be visually inspected after installation, direct quality control of the finished product is impossible. Consequently, substantial control must be exercised over peripheral operations leading to the pile placement within the foundation. Construction monitoring should be employed in (1) pile materials, (2) installation equipment, and (3) the estimation of the static load capacity.

It is recommended that the contractor submit a wave equation analysis (bearing graph) of his driving equipment, or the necessary pile driving and equipment data to perform the wave equation analysis, for hammer approval. A constant capacity wave equation analysis (inspector’s chart) should also be performed to assist field personnel during inspection in accordance with the 2007 ODOT BDM.

5.1.4 Lateral Design

If lateral loads or moments are expected to be applied on the foundation elements, they should be analyzed to verify the pile has enough lateral and bending resistance against these loads. A boring-by-boring tabulation of parameters that should be used for lateral loading design is provided in Appendix VIII. In order to evaluate the lateral capacity, it is recommended that a derivation of COM624, such as LPILE, be utilized to determine the embedment depth provided is adequate to resist the lateral loading for a given end condition and deflection. Table 6 lists the different soil types internal to the LPILE program. These strata were utilized to define the soil strata in the soil profile for each boring provided in Appendix VIII.

Table 6. Subsurface Strata Description

Strata	Description
1	Soft Clay
2	Stiff Clay with Water
3	Stiff Clay without Free Water
4	Sand (Reese)
5	User Defined
6	Vuggy Limestone (Strong Rock)
7	Silt (with cohesion and internal friction angle)
8	API Sand
9	Weak Rock
10	Liquefiable Sand (Rollins)
11	Stiff Clay without free water with a specified initial K (Brown)

5.2 MSE Wall Recommendations (Retaining Walls 3, 4B and 5B)

It is proposed to construct MSE walls along the I-70 WB CD Ramp and Ramps M and N at the locations noted below:

- Retaining Wall 3: Sta. 1585+54.75 to 1588+23.01 (BL I-70 WB-CD) on the north side of the I-70 WB CD Ramp. The wall will provide the required grade separation for the forward abutment of the Brice Road bridge structure over the I-70 WB CD Ramp (FRA-00070-23.919). The wall height along the alignment will range from 4.3 and 5.6 feet at the ends of the wall up to a maximum height of 28.6 feet where the wall crosses in front of the abutment.

- Retaining Wall 4B: Sta. 2582+47.34 (BL Ramp M) to Sta. 4590+79.32 (BL Ramp N) on the south side of the I-70 WB CD Ramp and north of Ramps M and N. The wall will provide the required grade separation between the I-70 WB CD Ramp and Ramps M and N, with embankments grading up from the top of the wall to Ramps M and N, except where the wall crosses in front of the rear abutment of the Brice Road bridge structure over the I-70 WB CD Ramp (FRA-00070-23.919). The wall height ranges from 9.5 and 11.3 feet at the ends of the wall up to a maximum height of 30.3 feet where the wall crosses in front of the abutment, with 3H:1V or 4H:1V graded backslopes and a paved gutter present at the top of the wall for sections adjacent to the bridge abutment. The wall will connect to Retaining Walls 4A and 4C at the west and east ends of the wall, respectively.

- Retaining Wall 5B: Sta. 2580+29.92 (BL Ramp M) to Sta. 4592+03.42 (BL Ramp N) on the south side of Ramps M and N and north of I-70. The wall will provide the required grade separation between Ramps M and N and I-70 westbound. As previously noted, the recommendations for the portion of Retaining Wall 5B that crosses in front of the forward abutment of the Brice Road bridge structure over I-70 (FRA-00070-23.920) between Sta. 15+85 to 17+96 (BL Wall 5B) are presented under a separate cover. The wall height ranges from 8.7 and 10.4 feet at the ends of the wall up to a maximum height of 26.7 and 27.9 feet immediately adjacent to the ends of the abutment. The wall will connect to Retaining Walls 5A and 5C at the west and east ends of the wall, respectively.

MSE walls are constructed on earthen foundations at a minimum depth of 3.0 feet below grade, as defined by the top of the leveling pad to the ground surface located 4.0 feet from the face of the wall. Per Section 840.04.A of ODOT Supplemental Specification 840 (SS 840) and Section 3.11.5.8.1 of the 2020 AASHTO LRFD BDS, the height of the MSE wall is defined as the elevation difference between the top of coping and the top of the leveling pad. However, it is noted that the reinforced soil mass only extends from the foundation bearing elevation (top of leveling pad) to the roadway subgrade elevation. Where the walls cross in front of the bridge abutments, it is noted that the reinforced soil mass only extends from the foundation bearing elevation (top of leveling pad) to the bottom of footing elevation. Additionally, per Section 201.4.1.C.7 of the 2020 ODOT BDM, a minimum of one row of soil reinforcement straps should be attached to the backside of the abutment footing to resist horizontal forces from the bridge structure and lateral pressures along the back wall of the abutment footing, and prevent any load transfer from these forces to the coping and facing panels. 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.

The width of the MSE wall foundation (B) is defined by the length of the reinforced soil mass. Per the 307.4.A of the 2020 ODOT BDM and Section 840.04.A.2 of ODOT SS 840, the minimum length of the reinforced soil mass is equal to 70 percent of the height of the MSE wall or 8.0 feet, whichever is greater. For the analysis, the foundation width was set at 70 percent of the maximum wall height for the rear and forward abutments, respectively, and the foundation width was increased, if required, until external and global stability requirements were satisfied.

It is noted that the proposed I-70 WB CD Ramp will be constructed under the existing Brice Road, which will require up to approximately 30 feet of cut where the ramp crosses under the roadway. The existing embankment supporting Brice Road and the various interchange ramps consists primarily of stiff to very stiff silt and clay and silty clay (ODOT A-6a, A-6b). Based on the plans provided, the existing embankment will be removed to the proposed bottom of wall elevation along all of the wall alignments and reconstructed to support Ramps M and N as well as the abutments of the Brice Road bridges over I-70 and the proposed I-70 WB CD Ramp using a combination of retaining walls and new embankment.

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.

Borings B-041-0-19 through B-047-0-19, B-070-19 through B-078-0-19 and B-086-0-19 through B-089-0-19 were performed along the alignments of the I-70 WB CD Ramp and Ramps M and N. Based on the subsurface conditions encountered, the anticipated soils at the proposed bearing elevation along Retaining Walls 3, 4B and 5B will generally consist of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) with interbedded layers of medium dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4) extending to an approximate elevation 785 to 790 feet msl. Below this elevation, the subsurface soils generally consist of interbedded layers of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a) and medium dense to very dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4). More isolated pockets of stiff to hard silty clay and clay (ODOT A-6b, A-7-6) are also present within the lower portion of the subsurface soils. In general, the soils encountered at the proposed bearing elevation along Retaining Walls 4B and 5B are suitable for support of the proposed MSE wall in their current condition.

The upper medium stiff silty clay (ODOT A-6b) encountered in borings B-077-0-19 and B-078-0-19, which extends to an elevation of 788.6 and 786.1 feet msl, respectively, is estimated to have an undrained shear strength ranging from 1,375 to 1,625 psf and will not provide adequate bearing resistance for Retaining Wall 3. The bearing soils appear to be transitioning to non-plastic silt along the west end of the wall. Therefore, it is recommended that this material be completely over excavated to expose the underlying medium dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4) and replaced with ODOT Item 203 granular embankment. This stabilization measure should be performed for the entire length of the wall alignment where these unsuitable soils are present within the footprint of the MSE wall and select granular backfill.

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

5.2.1 Strength Parameters Utilized in External and Global Stability Analyses

The shear strength parameters utilized in the external and global stability analyses for the MSE walls are provided in Table 7.

Table 7. Shear Strength Parameters Utilized in MSE Wall Stability Analyses

Material Type	γ **(pcf)**	φ' (1) **(°)**	c' (2) **(psf)**	S_u (3) **(psf)**
MSE Wall Backfill (Select granular fill)	120	34	0	N/A
Item 203 Embankment (Retained soil)	120	30	0	2,000
Item 203 Granular Embankment (Over excavation backfill)	120	32	0	N/A
Existing Embankment Fill: Stiff to Very Stiff Silt and Clay and Silty Clay (ODOT A-6a, A-6b)	120	25 to 28	0	1,375 to 3,250
Medium Dense to Very Dense Granular Soils (ODOT A-1-a, A-1-b, A-2-4, A-2-6, A-3a, A-4a, A-4b)	120 to 135	30 to 38	0	N/A
Stiff to Hard Sandy Silt and Silt (ODOT A-4a, A-4b)	115 to 130	29 to 30	0 to 100	1,250 to 8,000
Stiff to Hard Silty and Clay (ODOT A-6a)	115 to 130	27 to 28	0 to 100	1,500 to 8,000
Very Stiff to Hard Silty Clay (ODOT A-6b)	115 to 130	26 to 27	0 to 100	1,375 to 6,825
Very Stiff Clay (ODOT A-7-6)	120	25	0	2,750

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

Shear strength parameters for the select granular backfill and retained embankment are provided in Table 307-1 of the 2020 ODOT BDM and Section 840.04.A.3 of ODOT SS 840. Per these specifications, the select granular backfill in the reinforced zone and the retained embankment must meet the shear strength requirements provided in Table 7.

The shear strength parameters for the natural soils were assigned using correlations provided in FHWA Geotechnical Engineering Circular (GEC) No. 5 (FHWA-NHI-16-072) Evaluation of Soil and Rock Properties, the 2020 AASHTO LRFD BDS and based on past experience in the vicinity of the site with projects performed in similar subsurface profiles. A tabulation of the correlated shear strength parameters for each boring is provided in Appendix VIII.

5.2.2 Bearing Stability

The anticipated bearing materials along the alignments of Retaining Walls 3, 4B and 5B generally consist of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) overlying interbedded layers of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a) and medium dense to very dense gravel with sand and gravel with sand and silt (ODOT A-1-b, A-2-4). As noted in Section 5.2, it is recommended to over excavate the upper medium stiff silty clay (ODOT A-6b) within the entire footprint of Retaining Wall 3 at the forward abutment of the Brice Road over I-70 WB CD Ramp bridge structure and replace with ODOT Item 203 granular embankment.

MSE wall foundations bearing these natural soils or granular embankment, placed and compacted in accordance with ODOT Item 203, may be proportioned for a factored bearing resistance as indicated in Table 8. A geotechnical resistance factor of φ_b=0.65 was considered in calculating the factored bearing resistance at the strength limit state. Given that the bearing soils along the majority of the wall alignments will consist of cohesive soils, the bearing resistance was evaluated under both drained and undrained conditions. The reinforcement lengths presented in Table 8 represent the minimum foundation widths required to satisfy external and global stability requirements, expressed as a percentage of the wall heights.

Table 8. Retaining Walls 3, 4B and 5B MSE Wall Design Parameters

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Wall Height Analyzed (feet)	Backslope Behind Wall	Minimum Required Reinforcement Length [2] (feet)	Bearing Resistance at Strength Limit (ksf)		Equivalent Bearing Pressure [4] (ksf)	
	From [1]	To [1]					Nominal	Factored [3]	Strength Limit	Service Limit
3	10+00	12+70	B-076-0-19 to B-078-0-19	28.6	Level	20.0 (0.70H ≥ 8.0)	25.46	16.55	6.83	4.78
4B	10+00	10+75	B-043-0-19	11.3	4:1 Broken Back	8.0 (0.70H ≥ 8.0)	9.85	6.5	3.34	2.22
	10+75	11+50	B-044-0-19	12.9	3:1 Broken Back	11.0 (0.85H)	10.23	6.65	3.37	2.33
	11+50	13+52	B-046-0-19 & B-073-0-19	17.5	3:1 Broken Back	14.0 (0.80H)	14.02	9.11	4.72	3.26
	13+52	15+92	B-071-0-19 to B-075-0-19	30.3	Level	25.8 (0.85H)	15.27	9.93	6.46	4.59
	15+92	17+80	B-087-0-19 & B-088-0-19	17.0	3:1 Broken Back	14.5 (0.85H)	9.93	6.45	4.38	3.06
	17+80	18+60	B-087-0-19 & B-088-0-19	9.5	3:1 Broken Back	9.0 (0.95H ≥ 8.0)	8.14	5.29	2.33	1.62
5B	10+00	12+00	B-041-0-19	15.2	Level	10.6 (0.70H ≥ 8.0)	8.12	5.28	4.06	2.78
	12+00	14+25	B-045-0-19	22.1	Level	15.5 (0.70H)	15.69	10.20	5.46	3.80
	14+25	15+85 [5]	B-047-0-19 & B-007-0-65	27.9	Level	19.5 (0.70H)	12.75	8.29	6.69	4.68
	17+96 [5]	20+80	B-070-0-19, B-086-0-19, & B-088-0-19	26.7	Level	21.4 (0.80H)	9.44	6.14	5.94	4.20
	20+80	21+95	B-089-0-19	15.0	Level	10.5 (0.70H ≥ 8.0)	8.13	5.28	3.99	2.74

1. *Stationing referenced to the baseline of the respective retaining wall alignment.*
2. *The minimum reinforcement length is based on the maximum wall height analyzed. The value in parentheses represent the required reinforcement length 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 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 and service limit states.*
5. *Recommendations for Retaining Wall 5B between Sta. 15+85 and 17+96 (BL Wall 5B) as well as Retaining Wall 6 are provided under a separate cover.*

Rii performed a verification of the bearing pressure exerted on the subgrade material for the specified wall heights indicated in Table 8. Based on the minimum length of reinforced soil mass presented, the factored equivalent bearing pressure exerted below the walls **<u>will not exceed</u>** the factored bearing resistance at the strength limit state.

5.2.3 Settlement Evaluation

Based on the plan and profile information provided, for Retaining Walls 3 and 4B, it is understood that the final top of wall elevation, or profile grade of the roadway where the walls cross in front of the abutments of the Brice Road bridge structure over the proposed I-70 WB CD Ramp, will approximately match the existing ground grade. This indicates that the proposed configuration should result in a net reduction or negligible change in the overburden pressure within the subsurface soils. As such, settlement along these two wall alignments will be negligible.

For Retaining Wall 5B, the wall will be supporting Ramps M and N for the full height from the adjacent grade of the I-70 berm or ditch line up to the proposed profile grade of the roadway. Therefore, settlement analysis was performed for this retaining wall. The compressibility parameters utilized in the settlement analyses for Retaining Wall 5B are provided in Table 9.

Table 9. Compressibility Parameters Utilized in Settlement Analysis For Wall 5B

Material Type	γ **(pcf)**	LL **(%)**	C_c (1)	C_r (2)	e_o (3)	C_v (4) **(ft^2/yr)**	N_{60}	C' (5)
Item 203 Embankment	120	30	0.180	0.009	0.507	300	N/A	N/A
Medium Dense to Very Dense Granular Soils (ODOT A-1-a, A-1-b, A-2-4, A-2-6, A-3a)	125 to 135	N/A	N/A	N/A	N/A	N/A	16 to 86	63 to 300
Stiff to Hard Sandy Silt and Silt (ODOT A-4a, A-4b)	115 to 130	20 to 27	0.090 to 0.153	0.009 to 0.015	0.428 to 0.483	400	N/A	N/A
Stiff to Hard Silty and Clay (ODOT A-6a)	115 to 125	28 to 38	0.162 to 0.252	0.016 to 0.025	0.491 to 0.569	300	N/A	N/A
Very Stiff to Hard Silty Clay (ODOT A-6b)	115 to 130	32 to 39	0.198 to 0.261	0.020 to 0.026	0.522 to 0.577	200	N/A	N/A

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

The settlement analysis was performed considering the unit weight and height (H) of the select granular backfill over the width of the wall (B) at the service limit state. Results of the settlement analysis are tabulated in Table 10. Total settlements of up to 2.22 inches at the center of the reinforced soil mass and 1.64 inches at the facing of the wall are anticipated along the alignment of Retaining Wall 5B. Based on the results of the analysis, 90 percent of the total settlement at the facing of the wall is anticipated to occur within 4 to 180 days following the completion of construction of the wall. Please note that the consolidation settlement and time rate of consolidation are based on estimates using correlated compressibility parameters provided in Table 9 for the underlying soils. Actual settlement and time rate of consolidation should be determined by monitoring the settlement of the wall using settlement platforms.

Table 10. Retaining Wall 5B Settlement Values

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Total Settlement Values (inches)		Differential Settlement Along Wall Facing (inches)	Time for 90% Consolidation (Days)
	From [1]	To [1]		Center of Wall Mass	Facing of Wall		
5B	10+00	15+85 [5]	B-041-0-19, B-045-0-19, B-047-0-19 & B-007-0-65	0.997 to 1.855	0.777 to 1.345	Less than 1 in. / 190 ft.	4 to 80
	17+96 [5]	21+95	B-070-0-19, B-086-0-19, B-088-0-19 & B-089-0-19	1.084 to 2.222	0.814 to 1.643	Less than 1 in. / 110 ft.	5 to 155

1. Stationing referenced to the baseline of Wall 5B.

Per Section 307.1.6 of the 2020 ODOT BDM, the maximum allowable differential settlement in the longitudinal direction (regardless of the size of panels) is one (1) percent (1 in. / 100 ft.). Based on the total anticipated settlement at the facing of Retaining Wall 5B, the maximum differential settlement in the longitudinal direction is anticipated to be less than 1 in. / 110 ft. (1/110), which is within the tolerable limit of 1/100. If the total or differential settlement values predicted for the proposed wall presents an issue with respect to the deformation tolerances that the wall can withstand, then measures should be taken to minimize the amount of settlement that will occur. This can be achieved by preloading the site using a surcharge and consolidating the underlying soils prior to constructing the walls.

5.2.4 Eccentricity (Overturning Stability)

The resistance of the MSE walls to overturning will be dependent on the on the location of the resultant force at the bottom of the wall due to the overturning and resisting moments acting on the wall. For MSE walls, overturning stability is determined by calculating the eccentricity of the resultant force from the midpoint of the base of the wall and comparing this value to a limiting eccentricity value. Per Section 11.10.5.5 of the 2020 AASHTO LRFD BDS, for foundations bearing on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds ($^{2}/_{3}$) of the base width. Therefore, the limiting eccentricity is one-third ($^{1}/_{3}$) of the base width of the wall. Rii performed a verification of the eccentricity of the resultant force for the specified wall height indicated in Table 8. Based on the minimum length of reinforced soil mass presented in Table 8 and utilizing the soil parameters listed in Section 5.2.1 for the retained embankment material, the calculated eccentricity of the resultant force **will not exceed** the limiting eccentricity at the strength limit state.

5.2.5 Sliding Stability

The resistance of the MSE walls to sliding was evaluated per Section 11.10.5.3 of the 2020 AASHTO LRFD BDS. Given that the bearing soils along majority of the wall alignments consist of cohesive material, the sliding resistance was evaluated under both drained and undrained conditions. For drained conditions, the sliding resistance is determined by multiplying a coefficient of sliding friction “f” times the total vertical force at the base of the wall. The coefficient of sliding friction is determined based on the limiting friction angle between the foundation soil and the reinforced soil backfill. Based on the soil parameters listed in Section 5.2.1 for the foundation soil and the reinforced soil backfill, a coefficient of sliding friction of 0.49 to 0.62 was utilized for design. For undrained conditions, the sliding resistance is taken as the limiting value between the undrained shear strength of the bearing soil and half of the vertical stress applied by the wall multiplied by the width of the MSE wall. Based on the soil parameters listed in Section 5.2.1, the undrained shear strength of the bearing material ranges from 1.50 to 4.25 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 for sliding. Based on the minimum length of reinforced soil mass presented in Table 8 and utilizing the soil parameters listed in Section 5.2.1 for the retained embankment material, the resultant horizontal forces on the back of the MSE walls **will not exceed** the factored shear resistance at the strength limit state under drained or undrained conditions.

5.2.6 Overall (Global) Stability

A slope stability analysis was performed to check the global stability of the MSE wall sections analyzed. As per Section 11.6.2.3 of the 2020 AASHTO LRFD BDS, safety against soil failure shall be evaluated at the service limit state by assuming the reinforced soil mass to be a rigid body. Soil parameters utilized in external stability analyses are presented in Section 5.2.1. For the global stability condition, it was considered that the failure plane will not cross through the reinforced soil masses. The computer software program Slide, manufactured by Rocscience Inc., was utilized to perform the analyses.

Per Section 307.1.2 of the 2020 ODOT BDM and Section 11.6.2.3 of the 2020 AASHTO LRFD BDS, overall (global) stability for MSE walls that are not integrated with or supporting structural foundations or elements, global stability is satisfied if the product of the factor of safety from the slope stability output multiplied by the resistance factor φ=0.75 is greater than 1.0. Therefore, global stability is satisfied when a minimum factor of safety of 1.3 is obtained. Overall (global) stability for MSE walls that are integrated with or supporting structural foundations or elements, for the walls or portions of walls that cross in front of the bridge abutments, is satisfied if the product of the factor of safety from the slope stability output multiplied by the resistance factor φ=0.65 is greater than 1.0. Therefore, global stability for these locations is satisfied when a minimum factor of safety of 1.5 is obtained.

For MSE walls designed with the minimum strap lengths listed in Table 8, the resulting factor of safety under drained conditions (long-term stability) was greater than 1.3 or 1.5 (as applicable). The walls were also evaluated under undrained conditions (short-term stability) to verify the stability of the walls during and immediately following construction. The resulting factor of safety under undrained conditions was also greater than 1.3 or 1.5 (as applicable).

5.2.7 Final MSE Wall Considerations

Based on the results of the external and global stability analysis performed, the recommended controlling strap length is 0.70 times the respective height of the MSE walls (measured from the top of the leveling pad to the top of coping or proposed profile grade of the roadway) for Retaining Walls 3, 4B (from Sta. 10+00 to 10+75, BL Wall 4B) and 5B (from Sta. 10+00 to 15+85 and Sta. 20+80 to 21+95, BL Wall 5B). All external and global stability calculations indicate that adequate resistance is available for support of the MSE walls at these locations for a strap length equal to 70 percent of the respective wall heights. Note that the recommended strap length for Retaining Wall 3 considers that the upper medium stiff silty clay (ODOT A-6b) material will be over excavated and replaced with ODOT Item 203 granular embankment.

Based on the results of the external and global stability analysis performed, for the remainder of Retaining Walls 4B (from Sta. 10+75 to 18+60, BL Wall 4B) and 5B (from Sta. 17+96 to 20+80, BL Wall 5B), the recommended controlling strap length is 0.80 to 0.95 times respective height of the MSE wall (measured from the top of the leveling pad to the top of coping). Sliding resistance under drained conditions and bearing resistance under undrained conditions were the controlling factors in the determination of the required strap lengths of 0.80 to 0.95 times the respective wall height for these sections.

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

5.3 CIP Wall Recommendations (Retaining Walls 2A, 2B, 4A, 4C, 5A, 5C and 7)

It is proposed to construct CIP walls along the I-70 WB CD Ramp and Ramps M and N at the locations noted below:

- Retaining Wall 2A: Sta. 65+08.19 to 66+30.19 (CL Chatford Dr) on the south of Chatford Drive. The wall will provide the required grade separation for the graded ditch that extends between Chatford Drive and the proposed I-70 WB-CD Ramp. The wall height along the alignment ranges from 12.3 to 13.3 feet and supports the graded berm and Chatford Drive roadway behind the wall.

- Retaining Wall 2B: Sta. 1578+22.43 to 1580+43.80 (BL I-70 WB-CD) on the north side of the I-70 WB CD Ramp. The wall will provide the required grade separation for the graded ditch that extend along the north side of the proposed I-70 WB CD Ramp between the ramp and the relocated Chatford Road. The wall height along the alignment ranges from 15.0 to 15.7 feet and supports the proposed I-70 WB CD Ramp behind the top of the wall.

- Retaining Wall 4A: Sta. 2579+92.95 to 2582+47.42 (BL Ramp M) on the south side of the I-70 WB CD Ramp and north of Ramps M and N. The wall will provide the required grade separation between the I-70 WB CD Ramp and Ramp M. The wall height between Sta. 10+00 and 11+40 (BL Wall 4A) ranges from 5.7 to 9.4 feet and supports the proposed Ramp M behind the top of the wall. The wall height between Sta. 11+40 and 12+56 (BL Wall 4A) ranges from 9.4 to 9.8 feet, with a paved gutter and 4H:1V graded backslope extending up from the top of the wall to Ramp M. The wall will connect to Retaining Wall 4B at the east end of the wall.

- Retaining Wall 4C: Sta. 4590+79.29 to 4592+17.82 (BL Ramp N) on the south side of the I-70 WB CD Ramp and north of Ramp N. The wall will provide the required grade separation between the I-70 WB CD Ramp and Ramp N. The wall height ranges from 7.0 to 9.5 feet, with a paved gutter and 3H:1V graded backslope extending up from the top of the wall to Ramp N. The wall will connect to Retaining Wall 4B at the west end of the wall.

- Retaining Wall 5A: Sta. 2578+50.20 to 2580+29.92 (BL Ramp M) on the south side of Ramp M and north of I-70. The wall will provide the required grade separation between Ramp M and I-70 westbound. The wall height along the alignment ranges from 6.7 to 10.2 feet and supports the proposed Ramp M behind the top of the wall. The wall will connect to Retaining Wall 5B at the east end of the wall.

- Retaining Wall 5C: Sta. 4592+3.42 to 4592+58.46 (BL Ramp N) on the south side of Ramp N and north of I-70. The wall will provide the required grade separation between Ramp N and I-70 westbound. The wall height along the alignment ranges from 7.7 to 8.7 feet and supports the proposed Ramp N behind the top of the wall. The wall will connect to Retaining Wall 5B at the west end of the wall.

- Retaining Wall 7: Sta. 1594+33.00 to 1598+35.0 (BL I-70 WB-CD) on the north side of the I-70 WB-CD Ramp and north of I-70. The wall will provide the required grade separation for the graded ditch on the north side of the ramp. The wall height along the alignment ranges from 6.4 to 9.4 feet.

For CIP walls bearing on earthen foundations, footings should be proportioned such that the factored equivalent bearing pressure exerted at the front of the wall will not exceed the factored bearing resistance at the strength limit state. Further, the footings should also be proportioned such that the entire footing width remains in compression (no tensile stresses form under the footing, pulling the footing up and away from the bearing surface) under service conditions. In general, the typical width of a CIP wall foundation (B) is equal to 50 to 70 percent the wall height.

Typical sections for the proposed CIP retaining walls were included in the design plans provided, which were used in the analysis of the proposed walls. Where analyses indicates that the base width needs modified to meet the external and global stability requirements, then the base width (toe and/or heel width) was increased or decreased to satisfy the stability requirements.

Borings B-039-0-19 through B-041-0-19 and B-043-0-19 were performed along or within the vicinity of the alignments of Retaining Walls 2B, 4A and 5A; boring B-089-0-19 was performed along the alignment and in close proximity to the alignments of Retaining Walls 4C and 5C; and, borings B-090-0-19 through B-092-0-19 and B-094-0-19 were performed along or in close proximity to Retaining Wall 7. In general, the subsurface profile along the wall alignments consists of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) extending to the boring termination depths. Along Retaining Wall 4A between Sta. 11+40 to 12+55 (BL Wall 4A), the subsurface profile consists primarily of medium dense to dense gravel with sand and silt (ODOT A-2-4) overlying interbedded stiff to hard sandy silt (ODOT A-4a) and medium dense to very dense gravel with sand and coarse and fine sand (ODOT A-1-b, A-3a). Additionally, granular soil consisting of medium dense gravel with sand and silt (ODOT A-2-4) was present below the surficial cohesive soils along Retaining Wall 7. These soils are suitable for support of the proposed CIP walls in their current condition.

5.3.1 *Strength Parameters Utilized in External and Global Stability Analyses*

The shear strength parameters utilized in the external and global stability analyses for the CIP walls are provided in Table 7.

Table 11. Shear Strength Parameters Utilized in CIP Wall Stability Analyses

Material Type	**γ (pcf)**	**φ' (1) (°)**	**c' (2) (psf)**	**S_u (3) (psf)**
Item 203 Embankment (Retained soil and backfill above heel)	120	30	0	2,000
Stiff to Hard Sandy Silt and Silt (ODOT A-4a, A-4b)	115 to 130	29 to 30	0 to 50	1,375 to 5,000
Stiff to Hard Silty and Clay (ODOT A-6a)	115 to 130	27 to 28	0 to 100	1,500 to 5,000
Stiff to Very Stiff Silty Clay and Clay (ODOT A-6b, A-7-6)	115	25 to 26	0	1,500 to 2,125
Medium Dense to Very Dense Granular Soils (ODOT A-1-b, A-2-4, A-3a)	125 to 135	30 to 37	0	N/A

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

Shear strength parameters for the retained embankment and backfill above the heel of the wall are provided in Table 307-1 of the 2020 ODOT BDM. Per this specification, the retained embankment must meet the shear strength requirements provided in Table 11.

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, the 2020 AASHTO LRFD BDS and based on past experience in the vicinity of the site with projects performed in similar subsurface profiles. A tabulation of the correlated shear strength parameters for each boring is provided in Appendix VIII.

5.3.1 *Bearing Stability*

The bearing materials along the retaining wall alignments are anticipated to consist of stiff to very stiff sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b) and medium dense to dense gravel with sand and silt (ODOT A-2-4). CIP wall foundations bearing on these natural soils or newly placed embankment fill may be proportioned for a factored bearing resistance as indicated in Table 12. A geotechnical resistance factor of φ_b=0.55 was considered in calculating the factored bearing resistance at the strength limit state. The foundation widths presented in the following table are based on the dimensions provided in the typical sections for the respective retaining wall, or the minimum width required to satisfy external and global stability requirements.

Table 12. Retaining Walls 2A, 2B, 4A, 4C, 5A, 5C and 7 CIP Wall Design Parameters

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Wall Height Analyzed (feet)	Foundation Width Analyzed (feet)	Backslope Behind Wall	Bearing Resistance at Strength Limit (ksf)		Equivalent Bearing Pressure[3] (ksf)	
	From[1]	To[1]					Nominal	Factored[2]	Strength Limit	Service Limit
2A	10+00	11+30	B-039-0-19 & B-040-0-19	13.3	9.0	Level	15.00	8.25	2.91	2.04
2B	10+00	12+21	B-039-0-19, B-040-0-19 & B-040-1-21	15.0	11.8	Level	13.09	7.20	2.87	2.05
4A	10+00	11+40	B-041-0-19	9.4	10.3	Level	8.22	4.52	1.85	1.34
	11+40	12+55	B-043-0-19	9.8	10.3	4:1 Broken-Back	19.60	10.78	1.69	1.25
4C	10+00	11+40	B-089-0-19	9.5	10.0	3:1 Broken-Back	8.34	4.59	1.39	1.02
5A	10+60	12+40	B-040-0-19 to B-041-0-19	10.2	9.5	Level	5.63	3.10	1.89	1.37
5C	10+00	10+57	B-089-0-19	8.7	9.5	Level	8.74	4.81	1.70	1.22
7	10+33	14+34	B-090-0-14 to B-092-0-19 & B-094-0-19	9.4	7.0 (w/ 2.5-foot Shear Key)	Level	7.98	4.39	1.97	1.40

1. *Station limits are referenced to the proposed baseline of the respective wall alignment.*
2. *A geotechnical resistance factor of φ_b=0.55 was considered in calculating the factored bearing resistance at the strength limit state.*
3. *The 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 and service limit state.*

Rii performed a verification of the bearing pressure exerted on the subgrade material for the maximum specified wall height indicated in Table 12. Based on the minimum footing width presented, the factored equivalent bearing pressure exerted below the wall **<u>will not exceed</u>** the factored bearing resistance at the strength limit state.

5.3.2 Settlement Evaluation

Based on the plan and profile information provided, for Retaining Walls 2A and 4C, it is understood that the final top of wall elevations will be at or below the existing ground grade. This indicates that the proposed configuration should result in a net reduction or negligible change in the overburden pressure within the subsurface soils. As such, settlement along these wall alignments will be negligible.

For Retaining Walls 2B, 4A, 5A, 5C and 7, the walls will be supporting the I-70 WB CD Ramp as well as Ramps M and N for the full height from the adjacent grade of the infield or I-70 berm or ditch line up to the proposed profile grade of the roadway. Therefore, settlement analysis was performed for these retaining walls. The compressibility parameters utilized in the settlement analyses for the CIP walls are provided in Table 13.

Table 13. Compressibility Parameters Utilized in Settlement Analysis for CIP Walls

Material Type	γ **(pcf)**	***LL*** **(%)**	C_c (1)	C_r (2)	e_o (3)	C_v (4) **(ft^2/yr)**	N_{60}	*C'* (5)
Item 203 Embankment	120	30	0.180	0.009	0.507	300	N/A	N/A
Stiff to Hard Sandy Silt and Silt (ODOT A-4a, A-4b)	115 to 130	18 to 27	0.072 to 0.153	0.007 to 0.015	0.413 to 0.483	400	N/A	N/A
Stiff to Hard Silty and Clay (ODOT A-6a)	115 to 130	25 to 31	0.135 to 0.189	0.014 to 0.019	0.467 to 0.514	300	N/A	N/A
Very Stiff to Hard Silty Clay (ODOT A-6b)	115	33 to 40	0.207 to 0.270	0.021 to 0.027	0.530 to 0.585	200	N/A	N/A
Stiff Clay (ODOT A-7-6	120	61	0.459	0.046	0.749	100	N/A	N/A
Medium Dense to Very Dense Granular Soils (ODOT A-1-b, A-2-4, A-3a)	125 to 135	N/A	N/A	N/A	N/A	N/A	16 to 64	70 to 240

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

The settlement analysis was performed considering that the bearing pressure is a 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. Total settlements of up to 0.99 inches are anticipated along the alignments of the CIP walls. Based on the results of the analysis, 90 percent of the total settlement at the facing of the wall is anticipated to occur within 1 to 75 days following the completion of construction of the walls.

Table 14. Retaining Wall 2B, 4A, 5A, 5C and 7 Settlement Values

Wall No.	Station Along Wall Alignment		Reference Boring(s)	Total Settlement (inches)	Differential Settlement Along Wall Facing (inches)	Time for 90% Consolidation (Days)
	From [1]	To [1]				
2B	10+00	12+21	B-039-0-19, B-040-0-19 & B-040-1-21	0.653 to 0.978	Less than 1 in. / 680 ft.	30 to 70
4A	10+00	12+55	B-041-0-19 & B-043-0-19	0.648 to 0.766	Less than 1 in. / 2,161 ft.	1 to 10
5A	10+60	12+40	B-040-0-19 to B-041-0-19	0.690 to 0.883	Less than 1 in. / 933 ft.	6 to 10
5C	10+00	10+57	B-089-0-19	0.796 to 0.838	Less than 1 in. / 1,357 ft.	75
7	10+33	14+34	B-090-0-14 to B-092-0-19 & B-094-0-19	0.428 to 0.980	Less than 1 in. / 726 ft.	3 to 32

1. *Stationing referenced to the baseline of the respective wall alignment.*

Per Section 307.1.6 of the 2020 ODOT BDM, the maximum allowable differential settlement in the longitudinal direction is 1 in. / 500 ft. Based on the total anticipated settlement along the wall alignments, the maximum differential settlement in the longitudinal direction is anticipated to be less than 1 in. / 680 ft., which is within the tolerable limit of 1 in. / 500 ft. If the total or differential settlement values predicted for the proposed wall presents an issue with respect to the deformation tolerances that the wall can withstand, then measures should be taken to minimize the amount of settlement that will occur. This can be achieved by preloading the site using a surcharge and consolidating the underlying soils prior to constructing the walls.

5.3.3 Eccentricity (Overturning Stability)

The resistance of the CIP walls to overturning will be dependent on the on the location of the resultant force at the bottom of the wall due to the overturning and resisting moments acting on the wall. For CIP 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 11.6.3.3 of the 2020 AASHTO LRFD BDS, for foundations bearing on soil, the location of the resultant of the reaction forces shall be within the middle two-thirds ($^2/_3$) of the base width. Therefore, the limiting eccentricity is one-third ($^1/_3$) of the base width of the wall. Based on the required foundation width presented in Table 12 and utilizing the soil parameters listed in Section 5.3.1 for the retained embankment material, the calculated eccentricity of the resultant force **will not exceed** the limiting eccentricity at the strength limit state.

5.3.4 Sliding Stability

The resistance of the CIP walls to sliding was evaluated per Section 11.6.3.6 of the 2020 AASHTO LRFD BDS. Given that the bearing soils along majority of the wall alignments consist of cohesive material, the sliding resistance was evaluated under both drained and undrained conditions. For drained conditions, the sliding resistance is determined by multiplying a coefficient of sliding friction "f" times the total vertical force at the base of the wall. The coefficient of sliding friction is determined based on the friction angle of the foundation soil. Based on the soil parameters listed in Section 5.3.1, a coefficient of sliding friction ranging from 0.47 to 0.58 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 wall. Based on the soil parameters listed in Section 5.3.1, the undrained shear strength of the bearing material is estimated to range from 1.00 to 3.13 ksf.

A geotechnical resistance factor of φ_τ=1.0 was considered in calculating the factored shear resistance along the base of the wall. Based on the foundation width presented in Table 12 and utilizing the soil parameters listed in Section 5.3.1 for the retained embankment material, the resultant horizontal forces on the back of the CIP wall **will not exceed** the factored shear resistance at the strength limit state under drained or undrained conditions for Retaining Walls 2A, 2B, 4A, 4C, 5A and 5C.

For Retaining Wall 7, if a shear key is incorporated into the wall design and the shear key is embedded a minimum of 2.5 feet below the bottom of the footing, then the resultant horizontal forces on the back of the CIP wall **will not exceed** the factored shear resistance at the strength limit state under drained or undrained conditions. For the analysis, passive pressure was only considered against the embedded shear key, and passive pressure was not considered for the embedment depth of the footing. A geotechnical resistance factor of φ_{ep}=0.50 was considered when calculating the factored passive resistance on the shear key for sliding.

5.3.5 Global (Overall) Stability

A slope stability analysis was performed to check the global stability of the CIP wall sections analyzed. As per 2020 AASHTO LRFD BDS, safety against soil failure shall be evaluated at the service limit state by assuming the concrete and soil backfill to be a rigid body. Soil parameters utilized in external stability analyses are presented Section 5.3.1. For the global stability condition, it was considered that the failure plane will not cross through any portion of the supported soil mass above the concrete or through the concrete footing itself. The computer software program Slide 2 manufactured by Rocscience Inc. was utilized to perform the analyses.

Per Section 11.6.2.3 of the 2020 AASHTO LRFD BDS, overall (global) stability for CIP walls that are not supporting structural foundations or elements 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. Based on the typical wall sections provided in the design plans as well as the footing widths listed in Table 12, the resulting factor of safety under drained conditions (long-term stability) and undrained (short-term stability) using the Spencer's analysis method was greater than 1.3 for all sections analyzed.

5.3.6 Final CIP Wall Considerations

Based on the results of the external and global stability analysis performed, all of the CIP wall sections analyzed meet all of the external and global stability requirements.

Calculations for external (bearing and sliding resistance and limiting eccentricity), overall (global) stability and settlement of the CIP wall are provided in Appendix X.

5.4 Lateral Earth Pressure Parameters

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 15 and Table 16.

Table 15. Estimated Undrained Soil Parameters for Design

Soil Type	γ (pcf) [1]	c (psf)	φ	k_a	k_o	k_p
Soft to Medium Stiff Cohesive Soil	115	750	0°	N/A	N/A	N/A
Stiff Cohesive Soil	120	1,500	0°	N/A	N/A	N/A
Very Stiff to Hard Cohesive Soil	125	3,000	0°	N/A	N/A	N/A
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	2,000	0°	N/A	N/A	N/A
Compacted Granular Engineered Fill	120	0	32°	0.27	0.47	6.82

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

Table 16. Estimated Drained Soil Parameters for Design

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

1. *When below groundwater table, use effective unit weight, $\gamma' = \gamma$ - 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. Active earth pressure is developed as the structure moves away from the backfill or retained soil, while passive pressure is developed as the structure moves towards the backfill. A relatively small amount of lateral movement is needed to reach the active condition (≥ 0.1 percent of the height), whereas the movements required to engage the passive condition are approximately ten times greater than those required to develop active earth pressure. The values in this table have been estimated from correlation charts based on minimum standards specified for compacted engineered fill materials.

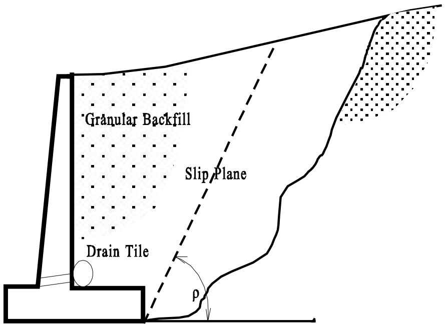
These recommendations do not take into consideration the effect of any surcharge loading or a sloped ground surface (a flat surface is assumed). Earth pressures on excavation support systems will be dependent on the type of sheeting and method of bracing or anchorage. Surcharge loads, such as that imposed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

Temporary retaining structures should be designed using the undrained soil parameters provided in Table 15, and the design should follow all applicable guidelines for the type of retaining structure utilized. Permanent retaining structures should be design using the drained soil parameters provided in Table 16. Regardless of whether the retaining structure is temporary or permanent, the effective unit weight ($\gamma' = \gamma$ - 62.4 pcf) plus the hydrostatic water pressure ($\gamma_w * h_w$, where h_w is the height of water behind the wall above the base of the wall) should be utilized below the design groundwater level. The lateral earth pressure coefficients should only be applied to the horizontal pressure resulting from the effective overburden pressure, and should not be applied to the hydrostatic water pressure.

In order to alleviate the build-up of hydrostatic pressure behind the walls, a minimum of 2.0 feet of clean free-draining granular fill (i.e., No. 57 gravel) should be placed full depth behind the walls. If granular fill other than No. 57 gravel is used, it should not have more than 8 percent (by weight) passing the No. 200 screen, and should be compacted to 95 percent of the maximum dry density as determined by the Standard Proctor Test (ASTM D698). A perforated, corrugated drain tile, wrapped with filter fabric, should be placed along the perimeter at the base of the wall for drainage purposes. A clay cap (minimum 1.0-foot thick) should be placed overtop the granular backfill to deter inflow of the surface water. The drainage system should properly outlet to a sewer or to a properly sized sump pump system.

The 2.0 feet of free draining material placed behind the wall prevents the formation of hydrostatic pressures as noted above. However, unless the free draining granular backfill is placed beyond the slip plane (see Figure 1), it has no influence on the equivalent fluid weight of the soil. If free-draining granular fill (meeting the requirements listed above) is to be placed beyond the slip plane (ρ=45° for at-rest conditions; ρ=45°+φ/2 for active conditions), the values presented for the compacted granular engineered fill can be employed, consequently lowering the pressures on the wall.

Figure 1. Slip Plane



Backfill Rankine Zone with Select Backfill

5.5 Construction Considerations

All site work shall conform to local codes, and to the latest ODOT CMS, including that all excavation and embankment preparation and construction should follow ODOT Item 200 (Earthwork).

5.5.1 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 17. 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

Temporary shoring can be design using the lateral earth pressures defined in Section 5.4 as well as the design parameters provided in Appendix VIII.

5.5.2 Groundwater Considerations

Based on the groundwater observations made during drilling, groundwater seepage is anticipated during construction. Where 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 inches below the deepest excavation. Any seepage or groundwater encountered at this site should be able to be controlled by pumping from temporary sumps. However, if any excavations extend in the underlying granular soil layer, additional dewatering measures such as point wells or deep well point may be required to maintain a dry, stable condition. Further, 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 our 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. 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.

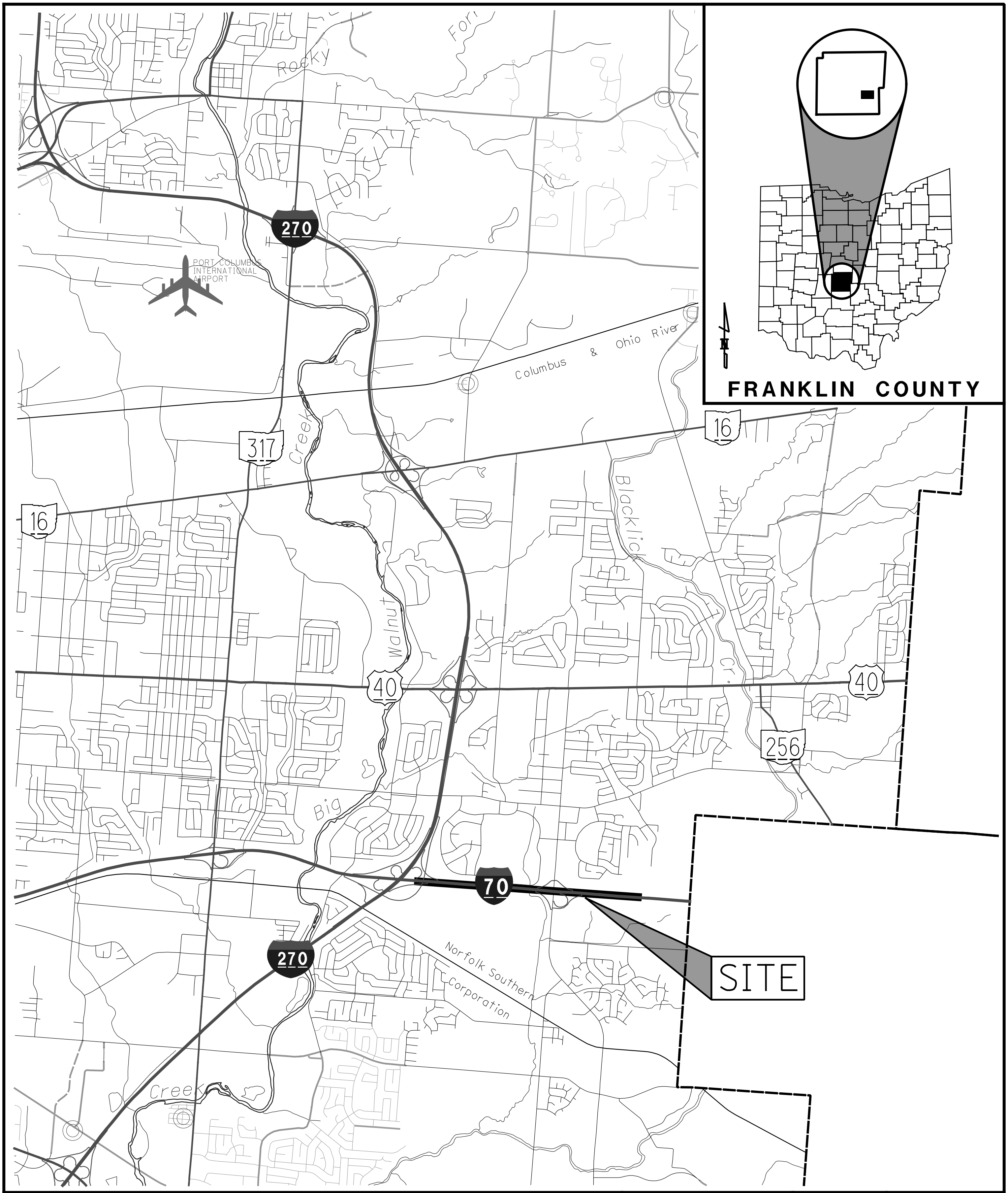
The conclusions and recommendations herein have been based upon the available soil information and the preliminary design details furnished by a representative of the owner of the proposed project. Any revision in the plans for the proposed construction from those anticipated in this report should be 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 or 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

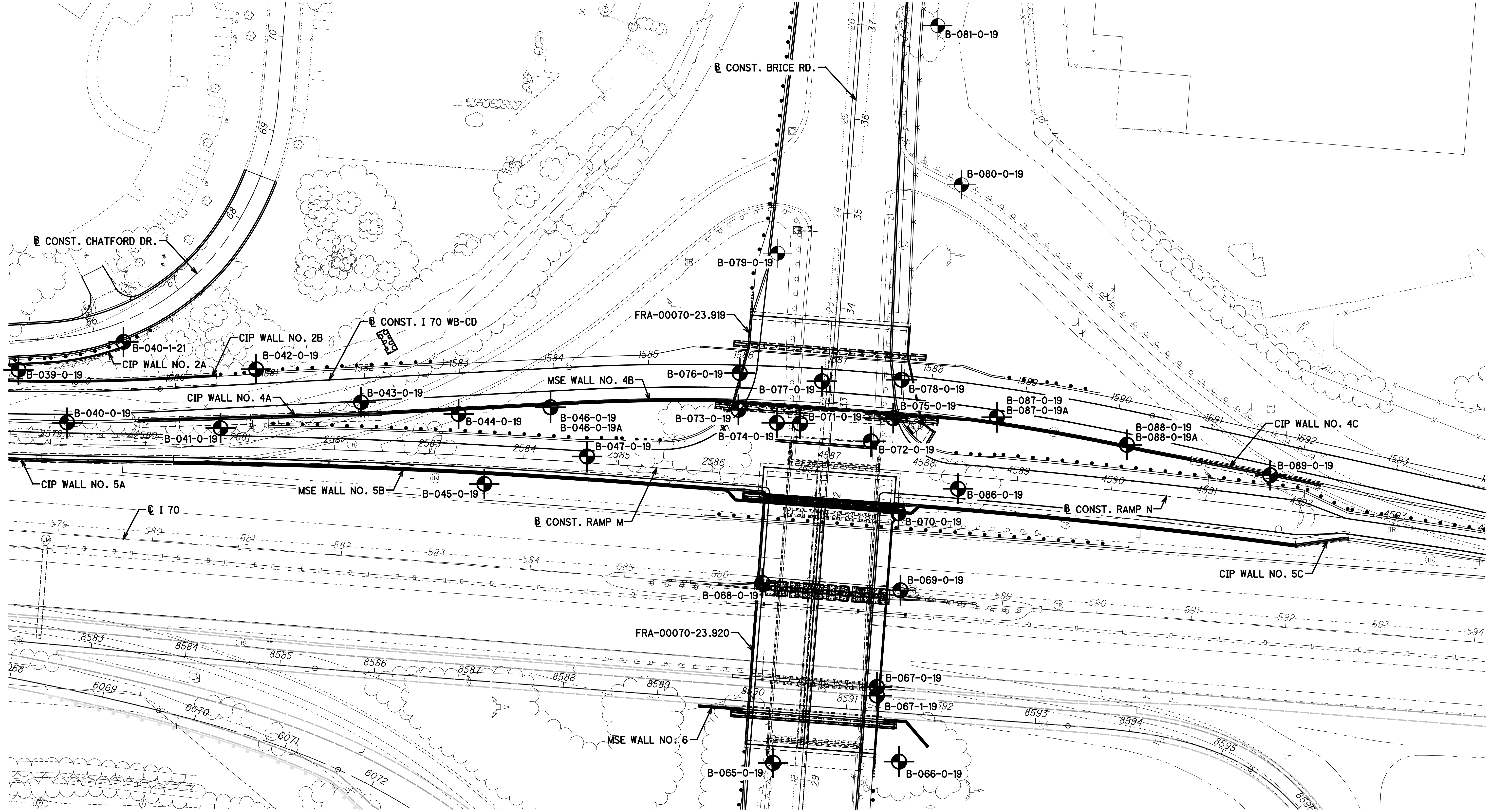


VICINITY MAP

FRA-70-22.85

COLUMBUS, OHIO

RII PROJECT NO. W-17-140	DRAWN JAS
	REVIEWED PPM
SCALE: 1″=5000′ 0 2500 5000	DATE 1/15/2021



BORING PLAN

BRICE ROAD OVER WB-CD RAMP (FRA-00070-23.919)
RETAINING WALLS 2B, 3, 4A, 4B, 4C, 5A, 5B AND 5C
FRANKLIN COUNTY, OHIO

RII PROJECT NO.
W-17-140

SCALE: 1"=100'
0 50 100

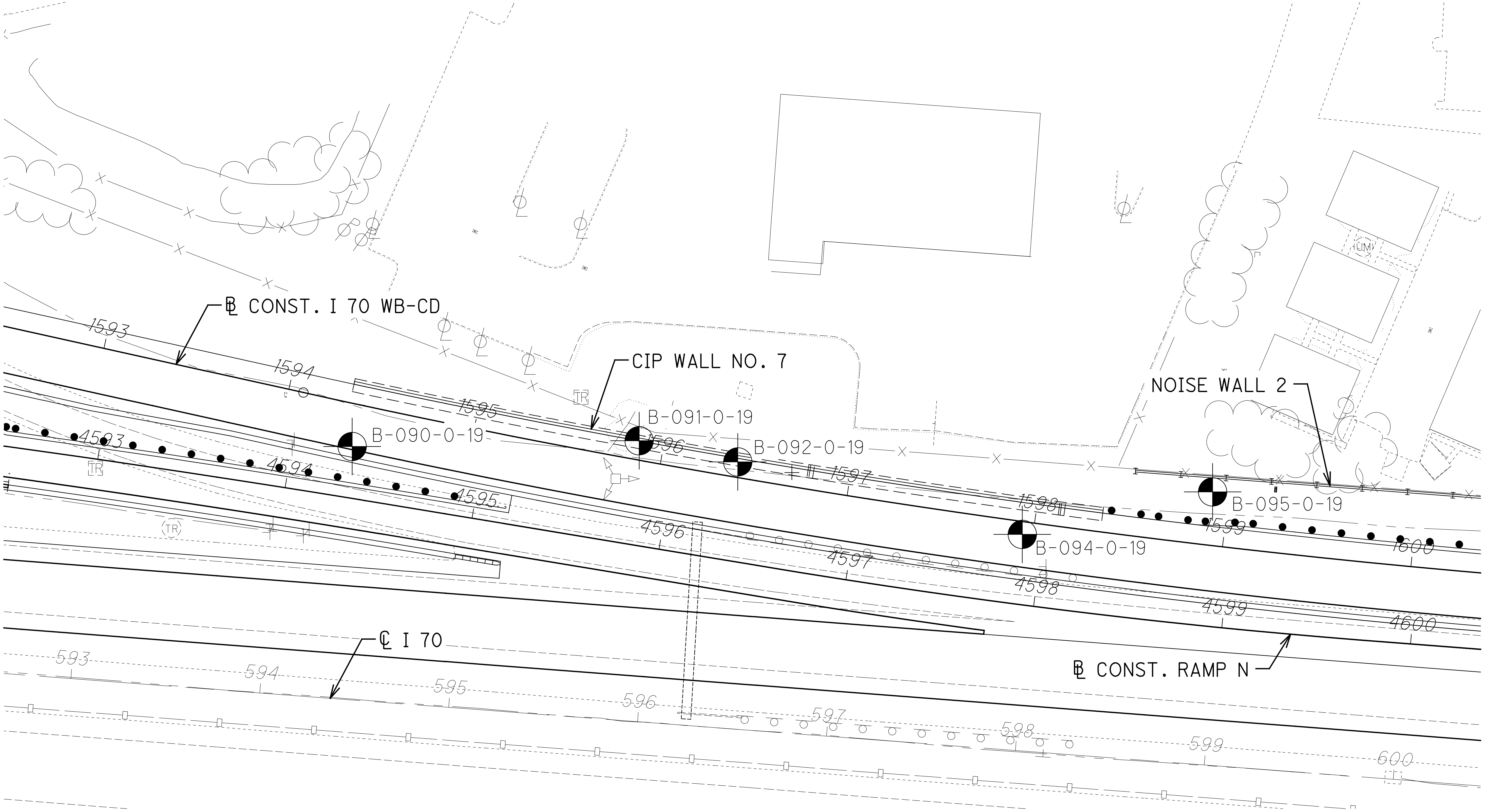
N

DRAWN
RRM

REVIEWED
BRT

DATE
4/02/22

RESOURCE INTERNATIONAL
Rii



BORING PLAN

CIP WALL NO. 7

FRANKLIN COUNTY, OHIO

RII PROJECT NO.
W-17-140

SCALE: 1"=50'
0 25 50

N

DRAWN
RRM

REVIEWED
BRT

DATE
4/02/22

RESOURCE INTERNATIONAL
Rii

APPENDIX II

DESCRIPTION OF SOIL AND ROCK TERMS

CLASSIFICATION OF SOILS

Ohio Department of Transportation

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

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

MATERIAL CLASSIFIED BY VISUAL INSPECTION

▧	Sod and Topsoil
▩	Pavement or Base
^	Uncontrolled Fill (Describe)
▪	Bouldery Zone
P	Peat

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

DESCRIPTION OF SOIL TERMS

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

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

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

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

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

Modifiers of Components - Modifiers of components are as follows:

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

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

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

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

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

Bedrock – The following terms are used to describe 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.

DESCRIPTION OF ROCK TERMS

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

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

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

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

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

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

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

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

Degree of Fracturing

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

Aperture Width

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

Surface Roughness

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

RQD – Rock Quality Designation (calculation shown in report) and Rock Quality (ODOT, GB 3, January 13, 2006):

RQD %	Rock Index Property Classification (based on RQD, not slake durability index)
0 – 25%	Very Poor
26 – 50%	Poor
51 – 70%	Fair
71 – 85%	Good
86 – 100%	Very Good

APPENDIX III

BORING LOGS:

B-039-0-19 through B-047-0-19,
B-070-0-19 through B-078-0-19,
B-086-0-19 through B-092-0-19 and B-094-0-19

BORING LOGS

Definitions of Abbreviations

AS = Auger sample

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

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

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

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

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

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

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

RC = Rock core sample

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

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

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

S = Sulfate content (parts per million)

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

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

SS = Split spoon sample

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

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

TR = Top of rock

W = Initial water level measured during drilling

▼ = Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

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

Atterberg Limits:

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

WC = Water content (%)

PROJECT: FRA-070-22.85
TYPE: ROADWAY
PID: 98232 SFN:
START: 8/31/20 END: 8/31/20

DRILLING FIRM / OPERATOR: RII / TG
SAMPLING FIRM / LOGGER: RII / JK
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1578+33.48 / 22.6' LT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 788.6 (MSL) EOB: 25.0 ft.
LAT / LONG: 39.933438, -82.833771

EXPLORATION ID
B-039-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 788.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.7' - ASPHALT (8.0")	787.9																	
0.8' - AGGREGATE BASE (10.0")	787.1	1																
STIFF TO VERY STIFF, GRAY, DARK BROWN AND DARK GRAY **SILTY CLAY**, LITTLE FINE GRAVEL, TRACE COARSE TO FINE SAND, MOIST.		2 3	3 5 5	14	89	SS-1	3.00	-	-	-	-	-	-	-	-	20	A-6b (V)	
		4 5	3 3 4	10	50	SS-2	3.50	19	3	3	36	39	51	29	22	32	A-6b (V)	
	780.6	6 7 8	3 4 3	10	53	SS-3	2.00	-	-	-	-	-	-	-	-	28	A-6b (V)	
HARD, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP TO MOIST.		9 10 11	3 8 9	24	61	SS-4	4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)	
		12 13	2 6 8	20	72	SS-5	4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)	
		14 15 16	6 8 10	25	42	SS-6	4.5+	25	15	11	31	18	23	15	8	10	A-4a (3)	
		17 18	6 9 10	27	89	SS-7	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
		19 20 21	5 8 10	25	72	SS-8	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
		22 23	4 8 10	25	89	SS-9	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	
	763.6	24 EOB 25	15 19 15	48	83	SS-10	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING; CAVE-IN DEPTH @ 22.4'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS. PAVEMENT PATCHED WITH ASPHALT COLD PATCH. .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: ROADWAY
PID: 98232 SFN:
START: 9/10/20 END: 9/10/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 1578+85.24 / 32.8' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 788.6 (MSL) EOB: 25.0 ft.
LAT / LONG: 39.933285, -82.833587

EXPLORATION ID
B-040-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 788.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.3' - TOPSOIL (3.0")	788.3		1 2 4	9	67	SS-1A	-	-	-	-	-	-	-	-	-	-		
STIFF TO VERY STIFF, DARK BROWNISH GRAY **SILTY CLAY**, SOME COARSE TO FINE SAND, TRACE TO LITTLE FINE GRAVEL, DAMP.						SS-1B	2.00	18	16	10	35	21	40	21	19	16	A-6b (8)	
	785.4		4 5 6	16	89	SS-2	3.75	8	11	10	45	26	38	20	18	19	A-6b (10)	
STIFF TO VERY STIFF, DARK BROWNISH GRAY **SILT**, SOME COARSE TO FINE SAND, LITTLE CLAY, TRACE FINE GRAVEL, MOIST. -COBBLES @ 5.0'			3 4 4	11	94	SS-3	3.25	-	-	-	-	-	-	-	-	21	A-4b (V)	
	780.6		1 2 2	6	44	SS-4	1.50	6	8	14	53	19	27	18	9	21	A-4b (7)	
DENSE, BROWN **GRAVEL WITH SAND**, TRACE SILT, WET. -COBBLES @ 9.5'	778.1	W 779.6	4 9 14	33	53	SS-5	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.			9 10 12	32	89	SS-6	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
		▽ 775.6	8 9 11	29	94	SS-7	4.5+	-	-	-	-	-	-	-	-	11	A-6a (V)	
			15 16 18	49	0	SS-8	-	-	-	-	-	-	-	-	-	-		
			19	-	67	2S-8A	4.5+	7	12	16	35	30	25	14	11	17	A-6a (6)	
			8 12 13	36	92	SS-9	4.5+	-	-	-	-	-	-	-	-	10	A-6a (V)	
			11 16 20	52	81	SS-10	4.5+	-	-	-	-	-	-	-	-	9	A-6a (V)	
	763.6	EOB	9 12 15	39	89	SS-11	4.25	-	-	-	-	-	-	-	-	13	A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 9.0' AND AT COMPLETION @ 13.0'; CAVE-IN DEPTH @ 16.4'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: ROADWAY
PID: 98232 SFN:
START: 11/22/21 END: 11/12/21

DRILLING FIRM / OPERATOR: RII / TG
SAMPLING FIRM / LOGGER: RII / JK
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: MOBILE B53 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 83.6

STATION / OFFSET: 1579+46.71 / 51.3' LT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 788.7 (MSL) EOB: 20.0 ft.
LAT / LONG: 39.933520, -82.833376

EXPLORATION ID
B-040-1-21

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 788.7	DEPTHS	SPT/ RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.5' - ASPHALT (6.0")	788.2																	
VERY STIFF, DARK BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	785.7		1 2 4	8	42	SS-1	2.50	-	-	-	-	-	-	-	-	21	A-6a (V)	
STIFF, MOTTLED BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.	783.2		6 3 3	8	39	SS-2	1.75	16	4	9	44	27	37	18	19	25	A-6b (11)	
MEDIUM DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE FINE GRAVEL, MOIST.		▽ 782.1	5 5 7	17	50	SS-3	-	-	-	-	-	-	-	-	-	11	A-1-b (V)	
	778.2	W 780.0	5 5 7	17	39	SS-4	-	45	24	11	14	6	22	16	6	11	A-1-b (0)	
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP TO MOIST.			6 8 9	24	0	SS-5	-	-	-	-	-	-	-	-	-	-		
			8	-	100	SS-5A	3.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
			11 14 18	45	92	SS-6	4.00	21	18	15	29	17	22	13	9	8	A-4a (2)	
			11 13 13/6"	-	103	SS-7	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
	768.7	EOB 20	9 10 14	33	86	SS-8	4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 8.7' AND AT COMPLETION @ 6.6'; CAVE-IN DEPTH @ 7.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 12.5 LBS BENTONITE CHIPS AND SOIL CUTTINGS. PAVEMENT PATCHED WITH ASPHALT COLD PATCH. .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 9/10/20 END: 9/10/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / TG
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 2580+72.37 / 19.9' LT
ALIGNMENT: BL RAMP M
ELEVATION: 789.5 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933271, -82.833009

EXPLORATION ID
B-041-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 789.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.3' - TOPSOIL (3.0") VERY STIFF, BROWNISH GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	789.2		2 3 4	10	56	SS-1	2.50	-	-	-	-	-	-	-	-	19	A-6a (V)	
			4 6 6	17	58	SS-2	2.25	-	-	-	-	-	-	-	-	25	A-6a (V)	
			2 4 5	13	33	SS-3A	2.50	-	-	-	-	-	-	-	-	27	A-6a (V)	
	784.0					SS-3B	2.25	-	-	-	-	-	-	-	-	26	A-6a (V)	
MEDIUM DENSE, BROWN TO DARK GRAY **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, MOIST.			4 6 8	20	58	SS-4	-	-	-	-	-	-	-	-	-	17	A-2-4 (V)	
	779.0		4 4 6	14	47	SS-5	-	36	14	19	12	19	19	17	2	15	A-2-4 (0)	
HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.	776.5		4 5 9	20	67	SS-6	4.5+	-	-	-	-	-	-	-	-	11	A-6a (V)	
VERY STIFF TO HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, MOIST.	774.0	▽ 775.8 W 774.5	3 4 4	11	67	SS-7	3.75	-	-	-	-	-	-	-	-	13	A-4a (V)	
HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	771.5		4 5 8	19	81	SS-8	4.25	12	14	19	22	33	28	16	12	15	A-6a (5)	
HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, MOIST.	769.0		5 9 10	27	83	SS-9	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
DENSE, GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, VERY MOIST.	766.5		9 12 20	46	61	SS-10	2.75	-	-	-	-	-	-	-	-	11	A-2-4 (V)	
HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, MOIST.			10 11 12	33	89	SS-11	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
	759.5	EOB	7 11 14	36	42	SS-12	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)	

NOTES: SEEPAGE @ 7.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 15.0' AND AT COMPLETION @ 13.7'; CAVE-IN DEPTH @ 16.0'.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85	DRILLING FIRM / OPERATOR: RII / TG	DRILL RIG: MOBILE B53 (SN 386345)	STATION / OFFSET: 1580+86.04 / 15.2' LT	EXPLORATION ID **B-042-0-19**
TYPE: CULVERT	SAMPLING FIRM / LOGGER: RII / JK	HAMMER: AUTOMATIC	ALIGNMENT: BL IR 70 WB-CD	
PID: 98232 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 9/14/20	ELEVATION: 790.0 (MSL) EOB: 25.0 ft.	PAGE 1 OF 1
START: 8/31/20 END: 8/31/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 83.6	LAT / LONG: 39.933442, -82.832876	

MATERIAL DESCRIPTION AND NOTES	ELEV. 790.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.5' - TOPSOIL (6.0")	789.5																	
HARD, DARK BROWN AND BROWN **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, DAMP.			2 5 5	14	78	SS-1	4.5+	-	-	-	-	-	-	-	-	-	A-4a (V)	
	786.7		7 8 10	25	72	SS-2	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)	
LOOSE TO MEDIUM DENSE, BROWN, TAN, AND GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, WET.			7 6 7	18	78	SS-3	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
		W 784.4																
	782.0		4 3 4	10	61	SS-4	-	43	46	4	6	1	NP	NP	NP	17	A-1-b (0)	
STIFF, GRAY **SILT**, LITTLE CLAY, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, WET.	780.8		4 5 5	14	75	SS-5A	-	-	-	-	-	-	-	-	-	25	A-4b (V)	
MEDIUM DENSE TO DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, WET. -COBBLES ENCOUNTERED @ 10.0' & 12.0'						SS-5B	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
			6 12 17	40	72	SS-6	-	-	-	-	-	-	-	-	-	7	A-1-b (V)	
	774.5		23 6 6	17	36	SS-7	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
VERY STIFF, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, MOIST.			2 2 3	7	36	SS-8	3.00	22	20	11	30	17	23	15	8	13	A-4a (2)	
-WATER ADDED TO BOREHOLE @ 18.0'			5 5 6	15	19	SS-9	2.50	-	-	-	-	-	-	-	-	13	A-4a (V)	
			5	-	0	2S-9A	-	-	-	-	-	-	-	-	-	-		
			3 5 7	17	72	SS-10	3.00	-	-	-	-	-	-	-	-	13	A-4a (V)	
	765.0	EOB 25	3 6 9	21	58	SS-11	3.00	-	-	-	-	-	-	-	-	13	A-4a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 5.6' AND NOT DETERMINED AT COMPLETION DUE TO THE USE OF WASH WATER; CAVE-IN DEPTH @ 15.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:29 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 9/9/20 END: 9/9/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 1581+94.71 / 25.3' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 793.2 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933347, -82.832481

EXPLORATION ID
B-043-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 793.2
FILL: MEDIUM DENSE, DARK GRAY/GRAY/ORANGISH BROWN **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP.	790.7
MEDIUM DENSE TO VERY DENSE, DARK GRAY/GRAY/ORANGISH BROWN **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, DAMP. -COBBLE ENCOUNTERED @ 6.5'	782.7
VERY STIFF TO HARD, DARK GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, DAMP TO MOIST.	775.2
DENSE, GRAY **COARSE AND FINE SAND**, TRACE SILT, WET. -COBBLE ENCOUNTERED @ 18.0'	772.7
MEDIUM DENSE TO VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, WET.	768.2
VERY STIFF TO HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, MOIST.	763.2

DEPTHS: W 782.2 (at 11.0); EOB (at 30.0)

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
5 6 6	17	56	SS-1	-	-	-	-	-	-	-	-	-	11	A-2-4 (V)
5 4 7	16	50	SS-2	3.50	-	-	-	-	-	-	-	-	13	A-2-4 (V)
13 18 21	56	67	SS-3	4.00	53	12	8	15	12	22	17	5	8	A-2-4 (0)
15 14 14	40	78	SS-4	-	-	-	-	-	-	-	-	-	9	A-2-4 (V)
5 5 6	16	72	SS-5	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)
7 11 10	30	72	SS-6	3.50	17	16	29	23	15	18	15	3	14	A-4a (1)
2 4 12	23	83	SS-7	-	-	-	-	-	-	-	-	-	16	A-4a (V)
22 22 15	53	72	SS-8	-	-	-	-	-	-	-	-	-	14	A-3a (V)
8 6 7	19	67	SS-9	-	-	-	-	-	-	-	-	-	13	A-1-b (V)
15 23 25	69	0	SS-10	-	-	-	-	-	-	-	-	-	-	
30	-	100	2S-10A	4.50	-	-	-	-	-	-	-	-	9	A-4a (V)
19 22 14	52	44	SS-11	4.00	-	-	-	-	-	-	-	-	13	A-4a (V)

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 11.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/13/20 END: 7/13/20

DRILLING FIRM / OPERATOR: RII / LH
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1582+96.90 / 43.2' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 799.4 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933314, -82.832114

EXPLORATION ID
B-044-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 799.4
0.6' - TOPSOIL (7.0")	798.8
FILL: VERY STIFF TO HARD, DARK BROWN TO BROWN AND DARK BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, SOME FINE GRAVEL, DAMP TO MOIST. -COBBLES @ 8.0'	788.9
MEDIUM DENSE, BROWN **COARSE AND FINE SAND**, TRACE SILT, DAMP TO MOIST.	786.4
MEDIUM DENSE TO DENSE, BROWN TO GRAY **GRAVEL WITH SAND**, TRACE SILT, MOIST TO WET.	778.9
MEDIUM DENSE TO VERY DENSE, GRAY **COARSE AND FINE SAND**, TRACE SILT, WET.	769.4

DEPTHS: W 780.4 — EOB

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
2 4 5	13	67	SS-1	4.5+	-	-	-	-	-	-	-	-	11	A-6a (V)
4 7 9	22	61	SS-2	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)
4 4 5	13	61	SS-3	4.00	-	-	-	-	-	-	-	-	20	A-6a (V)
3 3 4	10	44	SS-4	3.00	-	-	-	-	-	-	-	-	20	A-6a (V)
11 10 12	31	33	SS-5	4.5+	24	11	15	28	22	33	18	15	13	A-6a (5)
3 5 6	15	56	SS-6	-	-	-	-	-	-	-	-	-	9	A-3a (V)
5 9 21	42	56	SS-7	-	51	13	16	16	4	NP	NP	NP	11	A-1-b (0)
4 11 10	29	50	SS-8	-	-	-	-	-	-	-	-	-	10	A-1-b (V)
2 6 6	17	56	SS-9	-	-	-	-	-	-	-	-	-	16	A-1-b (V)
11 17 24	58	61	SS-10	-	-	-	-	-	-	-	-	-	17	A-3a (V)
10 7 9	22	100	SS-11	-	-	-	-	-	-	-	-	-	14	A-3a (V)
9 5 10	21	94	SS-12	-	-	-	-	-	-	-	-	-	13	A-3a (V)

NOTES: SEEPAGE @ 14.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 19.0' AND AT COMPLETION @ 18.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/16/20 END: 7/16/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 2583+59.84 / 28.9' RT
ALIGNMENT: BL RAMP M
ELEVATION: 793.7 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933112, -82.832016

EXPLORATION ID
B-045-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 793.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.6' - TOPSOIL (7.0")	793.1																	
POSSIBLE FILL: VERY STIFF TO HARD, DARK BROWN AND BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.			9 9 11	28	44	SS-1	3.50	-	-	-	-	-	-	-	-	13	A-6a (V)	
			3 5 11	22	56	SS-2	4.5+	-	-	-	-	-	-	-	-	17	A-6a (V)	
			4 7 9	22	28	SS-3	2.50	-	-	-	-	-	-	-	-	-	A-6a (V)	
-COBBLES @ 7.0'	785.7		7 14 19	46	39	SS-4	3.25	-	-	-	-	-	-	-	-	19	A-6a (V)	
DENSE, DARK BROWN AND BROWN **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST.	783.2		9 11 14	35	100	SS-5	-	-	-	-	-	-	-	-	-	11	A-2-4 (V)	
STIFF, BROWN **SILTY CLAY**, "AND" FINE GRAVEL, SOME FINE TO COARSE SAND, MOIST.			10 14 16	42	39	SS-6	1.25	41	13	8	20	18	35	17	18	15	A-6b (2)	
	778.2	W 779.7	6 12 13	35	67	SS-7	-	-	-	-	-	-	-	-	-	17	A-6b (V)	
MEDIUM DENSE, GRAY **COARSE AND FINE SAND**, TRACE SILT, WET.			7 6 7	18	78	SS-8	-	-	-	-	-	-	-	-	-	16	A-3a (V)	
	773.2		8 5 5	14	78	SS-9	-	-	-	-	-	-	-	-	-	21	A-3a (V)	
SOFT TO STIFF, GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, MOIST.			2 3 6	13	67	SS-10	1.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
			5 9 12	29	39	SS-11	0.50	20	14	16	29	21	22	13	9	14	A-4a (3)	
	763.7	EOB	6 7 14	29	78	SS-12	1.50	-	-	-	-	-	-	-	-	12	A-4a (V)	

NOTES: SEEPAGE @ 11.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 14.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/13/20 END: 7/13/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1583+94.29 / 41.1' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 805.8 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933335, -82.831767

EXPLORATION ID
B-046-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 805.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.7' - TOPSOIL (8.0")	805.1																	
FILL: HARD, DARK BROWN TO BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		1	1 3 4	10	61	SS-1	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	
		2 3	6 8 7	21	56	SS-2	4.5+	-	-	-	-	-	-	-	-	11	A-6a (V)	
	800.3	4 5	5 5 5	14	78	SS-3	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	
FILL: VERY STIFF, BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		6 7 8	5 5 4	13	72	SS-4	2.75	-	-	-	-	-	-	-	-	19	A-6b (V)	
		9 10	4 4 5	13	56	SS-5	3.75	-	-	-	-	-	-	-	-	15	A-6b (V)	
	793.8	11 12	11 7 8	21	83	SS-6	3.25	-	-	-	-	-	-	-	-	15	A-6b (V)	
MEDIUM DENSE, BROWN **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST.		13 14 15	10 9 11	28	89	SS-7	-	43	23	8	17	9	25	18	7	9	A-2-4 (0)	
	787.8	16 17	5 8 7	21	72	SS-8	-	-	-	-	-	-	-	-	-	9	A-2-4 (V)	
MEDIUM DENSE, BROWN AND DARK BROWN **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, MOIST.		18 19 20	8 6 9	21	72	SS-9	-	26	18	9	30	17	28	19	9	14	A-4a (2)	
	782.8	21 22	18 9 11	28	83	SS-10	-	-	-	-	-	-	-	-	-	12	A-4a (V)	
MEDIUM DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, MOIST TO WET.	778.8	23 24 25	7 9 10	27	61	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
MEDIUM DENSE, GRAY **COARSE AND FINE SAND**, TARCE SILT, WET.	775.8	26 27 28 ∇ 776.8 29 EOB	10 8 13	29	67	SS-12	-	-	-	-	-	-	-	-	-	21	A-3a (V)	

NOTES: SEEPAGE @ 22.5'; GROUNDWATER AT COMPLETION @ 29.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 11/12/20 END: 11/12/20

DRILLING FIRM / OPERATOR: RII / SB/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1583+94.29 / 41.1' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 805.8 (MSL) EOB: 55.0 ft.
LAT / LONG: 39.933335, -82.831767

EXPLORATION ID
B-046-0-19A

PAGE
1 OF 2

MATERIAL DESCRIPTION AND NOTES	ELEV. 805.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
SAME AS B-046-0-19		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:29 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158394.29, 41' RT.	START: 11/12/20	END: 11/12/20	PG 2 OF 2	B-046-0-19A

MATERIAL DESCRIPTION AND NOTES	ELEV. 775.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
SAME AS B-046-0-19 *(continued)*	774.8																	
MEDIUM DENSE, DARK BROWNISH GRAY **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST.	772.8	31 32	13 10 8	25	78	SS-13	0.25	52	19	8	13	8	28	17	11	11	A-2-6 (0)	
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP.		33 34 35	7 7 8	21	94	SS-14	4.00	-	-	-	-	-	-	-	-	12	A-4a (V)	
		36 37 38	8 8 10	25	78	SS-15	4.50	9	15	17	34	25	23	15	8	12	A-4a (5)	
		39 40	9 10 11	29	0	SS-16	-	-	-	-	-	-	-	-	-	-		
			17	-	100	2S-16A	4.50	-	-	-	-	-	-	-	-	10	A-4a (V)	
	763.8	41 42																
STIFF, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		43 44 45	8 10 16	36	33	SS-17	1.50	-	-	-	-	-	-	-	-	20	A-6b (V)	
	758.8	46 47																
HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP.		48 49 50	10 14 19	46	83	SS-18	4.50	-	-	-	-	-	-	-	-	13	A-4a (V)	
		51 52 53																
	750.8	54 EOB 55	7 13 15	39	89	SS-19	4.50	-	-	-	-	-	-	-	-	9	A-4a (V)	

NOTES: AUGERED WITHOUT SAMPLING TO 31 FEET

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:29 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/16/20 END: 7/16/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 2584+66.50 / 6.6' LT
ALIGNMENT: BL RAMP M
ELEVATION: 794.9 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933193, -82.831629

EXPLORATION ID
B-047-0-19

PAGE
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MATERIAL DESCRIPTION AND NOTES	ELEV. 794.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.7' - TOPSOIL (8.0")	794.2																	
FILL: MEDIUM DENSE, BROWN AND GRAY **GRAVEL WITH SAND**, TRACE SILT, DAMP.			4 5 8	18	33	SS-1	-	-	-	-	-	-	-	-	-	-	A-1-b (V)	
	789.4		4 6 7	18	50	SS-2	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
FILL: LOOSE TO MEDIUM DENSE, BROWN TO DARK BROWN/BLACK **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, MOIST.			6 4 2	8	56	SS-3	-	28	23	9	23	17	27	19	8	13	A-4a (1)	
	784.4		3 4 5	13	89	SS-4	-	-	-	-	-	-	-	-	-	15	A-4a (V)	
MEDIUM DENSE TO DENSE, GRAY **GRAVEL WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST TO WET.			5 9 5	20	72	SS-5	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
		W 780.4	2 4 6	14	94	SS-6	-	31	34	10	15	10	24	18	6	14	A-1-b (0)	
			8 6 7	18	100	SS-7	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
	774.4		13 14 17	44	100	SS-8	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
MEDIUM DENSE, GRAY AND BLACK **COARSE AND FINE SAND**, WET.	771.9		11 8 13	29	100	SS-9	4.5+	-	-	-	-	-	-	-	-	17	A-3a (V)	
VERY STIFF TO HARD, GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, MOIST.			4 8 12	28	78	SS-10	4.00	-	-	-	-	-	-	-	-	12	A-4a (V)	
	764.9	EOB	7 8 12	28	56	SS-11	2.75	-	-	-	-	-	-	-	-	15	A-4a (V)	

NOTES: SEEPAGE @ 13.0'; GROUNDWATER INITIALLY ENCOUNTERED @ 14.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN: 2505738
START: 8/25/20 END: 8/25/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 31+88.29 / 77.5' RT
ALIGNMENT: CL CONST. BRICE RD
ELEVATION: 796.6 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933031, -82.830456

EXPLORATION ID
B-070-0-19

PAGE
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MATERIAL DESCRIPTION AND NOTES	ELEV. 796.6	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG				ODOT CLASS (GI)	HOLE SEALED
									GR	CS	FS	SI	CL	LL	PL	PI	WC		
0.7' - TOPSOIL (8.0")	795.9																		
VERY STIFF TO HARD, BROWN **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP TO MOIST.			1 2	4 3 4	10	61	SS-1	4.50	-	-	-	-	-	-	-	-	10	A-4a (V)	
			3																
			4 5	5 4 5	13	44	SS-2	4.00	-	-	-	-	-	-	-	-	19	A-4a (V)	
			6 7	6 5 4	13	83	SS-3	4.50	21	18	10	32	19	25	17	8	13	A-4a (3)	
			8																
			9 10	8 7 6	19	67	SS-4	3.00	-	-	-	-	-	-	-	-	13	A-4a (V)	
MEDIUM DENSE, GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST. -COBBLES @ 13.0'	786.1	W	11 12	10 8 9	24	61	SS-5	-	-	-	-	-	-	-	-	-	8	A-2-4 (V)	
MEDIUM DENSE TO DENSE, GRAY **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST TO WET.	783.6	W 783.1	13 14 15	12 10 24	49	67	SS-6	-	-	-	-	-	-	-	-	-	11	A-2-6 (V)	
			16 17	8 9 6	22	50	SS-7	-	-	-	-	-	-	-	-	-	12	A-2-6 (V)	
			18																
			19 20	9 8 10	26	0	SS-8	-	-	-	-	-	-	-	-	-	-	A-2-6 (V)	
-SANDSTONE FRAGMENTS IN SS-8A				10	-	100	2S-8A	-	-	-	-	-	-	-	-	-	-		
MEDIUM DENSE, GRAY **COARSE AND FINE SAND**, TRACE FINE GRAVEL, TRACE SILT, WET.	775.6		21 22	17 9 8	24	44	SS-9	-	-	-	-	-	-	-	-	-	11	A-3a (V)	
MEDIUM DENSE TO VERY DENSE, GRAY **GRAVEL**, TRACE COARSE TO FINE SAND, TRACE SILT, WET.	773.6		23 24 25	33 22 25	68	44	SS-10	-	-	-	-	-	-	-	-	-	11	A-1-a (V)	
			26 27	3 14 8	32	61	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-a (V)	
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP TO MOIST.	768.6		28 29	6 7 10	24	94	SS-12	4.50	-	-	-	-	-	-	-	-	13	A-4a (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 3188.29, 78' RT.	START: 8/25/20	END: 8/25/20	PG 2 OF 3	B-070-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 766.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP TO MOIST. *(continued)*		31 32 33																
		34 35	6 9 12	30	89	SS-13	4.00	-	-	-	-	-	-	-	-	14	A-4a (V)	
		36 37 38																
		39 40	21 14 11	36	72	SS-14	4.50	23	13	14	31	19	22	15	7	12	A-4a (3)	
-COBBLES @ 42.5'	754.6	41 42																
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE TO LITTLE FINE GRAVEL, DAMP TO MOIST.		43																
		44 45	33 14 10	34	67	SS-15	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
		46 47 48																
		49 50	12 16 49	93	72	SS-16	4.50	6	13	15	38	28	23	15	8	10	A-4a (6)	
-COBBLES @ 51.0'		51 52 53																
		54 55	30 30 36	95	33	SS-17	2.00	-	-	-	-	-	-	-	-	15	A-4a (V)	
		56 57 58																
		59 60	47 38 35	105	78	SS-18	4.50	-	-	-	-	-	-	-	-	9	A-4a (V)	
		61																

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 3188.29, 78' RT.	START: 8/25/20	END: 8/25/20	PG 3 OF 3	B-070-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 734.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE TO LITTLE FINE GRAVEL, DAMP TO MOIST. *(continued)*	729.6	63 64 65 66	9 10 13	33	50	SS-19	3.50	13	12	16	31	28	24	14	10	17	A-4a (5)	
VERY STIFF TO HARD, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		67 68 69 70	6 9 11	29	83	SS-20	4.50	-	-	-	-	-	-	-	-	27	A-6b (V)	
	721.6	71 72 73 74 EOB 75	6 8 10	26	50	SS-21	2.50	-	-	-	-	-	-	-	-	19	A-6b (V)	

NOTES: SEEPAGE @ 11.0'; GROUNDWATER ENCOUNTERED INITIALLY @ 13.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 94 LBS CEMENT / 50 LBS BENTONITE POWDER / 20 GAL WATER .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN: 2505738
START: 9/21/20 END: 9/21/20

DRILLING FIRM / OPERATOR: RII / LARRY
SAMPLING FIRM / LOGGER: DHDC / GANESH
DRILLING METHOD: 4.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/4/18
ENERGY RATIO (%): 90

STATION / OFFSET: 1586+63.41 / 59' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 820.7 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933291, -82.830827

EXPLORATION ID
B-071-0-19

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MATERIAL DESCRIPTION AND NOTES	ELEV. 820.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
ASPHALT (13") & **GRANULAR BASE** (5")	819.2	1																
FILL: VERY STIFF, DARK BROWN OR BROWN, **SILTY CLAY**, LITTLE TO SOOME SAND, TRACE TO LITTLE GRAVEL, MOIST ---CONTAINS BLUISH GRAY STAINING--- ---CONTAINS ROCK FRAGMENTS--- @18.5'-22.5'; ROCK FRAGMENTS		2 3	6 5 8	20	58	SS-1	4.00	-	-	-	-	-	-	-	-	13	A-6b (V)	
		4 5	3 5 5	15	56	SS-2	4.00	-	-	-	-	-	-	-	-	13	A-6b (V)	
		6 7	5 6 9	23	22	SS-3A	4.00	-	-	-	-	-	-	-	-	14	A-6b (V)	
		8	10	-	100	SS-3B	4.00	-	-	-	-	-	-	-	-	15	A-6b (V)	
		9 10	9 10 13	35	67	SS-4	4.00	-	-	-	-	-	-	-	-	12	A-6b (V)	
		11 12 13	3 4 8	18	64	SS-5	4.00	11	10	15	32	32	35	19	16	13	A-6b (8)	
		14	12 10 10	30	0	SS-6A	-	-	-	-	-	-	-	-	-	-	A-6b (V)	
		15	7	-	58	SS-6B	4.00	-	-	-	-	-	-	-	-	16	A-6b (V)	
		16 17 18	7 7 11	27	33	SS-7	4.00	-	-	-	-	-	-	-	-	10	A-6b (V)	
		19 20 21	50/5"	-	100	SS-8	4.00	-	-	-	-	-	-	-	-	12	A-6b (V)	
		22	15 10 18	42	0	SS-9A	-	-	-	-	-	-	-	-	-	-	A-6b (V)	
	797.2	23	11	-	33	SS-9B	-	-	-	-	-	-	-	-	-	10	A-6b (V)	
FILL: VERY STIIFF, GRAY, **SILT AND CLAY**, SOME SAND, LITTLE GRAVEL, WET		24 25 26 27 28	11 18 18	54	78	SS-10	4.00	11	10	16	32	31	34	19	15	11	A-6a (8)	
		29	6 10 11	32	67	SS-11	4.00	-	-	-	-	-	-	-	-	12	A-6a (V)	

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:31 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158663.41, 59' RT.	START: 9/21/20	END: 9/21/20	PG 2 OF 3	B-071-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 790.7	DEPTHS		SPT/ RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
									GR	CS	FS	SI	CL	LL	PL	PI			
FILL: VERY STIIFF, GRAY, **SILT AND CLAY**, SOME SAND, LITTLE GRAVEL, WET *(continued)*	788.7		31																
STIFF, GRAY, **SILT AND CLAY**, LITTLE SAND, LITTLE GRAVEL, WET			32																
			33																
		W 786.7	34	10 13 11	36	72	SS-12	1.50	-	-	-	-	-	-	-	-	19	A-6a (V)	
			35																
	783.7	▼	36																
DENSE, GRAY, **GRAVEL AND/OR STONE FRAGMENTS** WITH SAND AND SILT, WET			37																
			38																
			39	11 13 12	38	89	SS-13	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)	
			40																
			41																
			42																
			43																
			44	14 10 12	33	89	SS-14	-	30	37	4	- 29 -		NP	NP	NP	14	A-2-4 (0)	
			45																
			46																
			47																
			48																
			49	14 15 15	45	72	SS-15	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)	
			50																
	768.7		51																
VERY STIFF, GREENISH GRAY TO GRAY, **SILTY CLAY**, AND SAND, LITTLE GRAVEL, DAMP			52																
			53																
			54	16 5 9	21	61	SS-16	3.50	-	-	-	-	-	-	-	-	17	A-6b (V)	
			55																
			56																
			57																
			58																
			59	4 9 9	27	44	SS-17	2.50	10	13	24	29	24	39	21	18	18	A-6b (7)	
			60																
			61																

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158663.41, 59' RT.	START: 9/21/20	END: 9/21/20	PG 3 OF 3	B-071-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 758.6	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
									GR	CS	FS	SI	CL	LL	PL	PI			
VERY STIFF, GREENISH GRAY TO GRAY, **SILTY CLAY**, AND SAND, LITTLE GRAVEL, DAMP *(continued)*			63																
			64 65	8 14 24	57	56	SS-18	4.00	-	-	-	-	-	-	-	-	13	A-6b (V)	
			66 67 68																
			69 70	15 13 16	44	67	SS-19	4.00	14	10	13	32	31	34	18	16	12	A-6b (8)	
			71 72 73																
	745.7	EOB	74 75	14 15 15	45	44	SS-20	4.00	-	-	-	-	-	-	-	-	17	A-6b (V)	

NOTES: BORING WAS RELOCATED 32.0 FEET NORTH AND 5.0 FEET EAST DUE TO OVERHEAD UTILITIES AND OBSTRUCTIONS.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: USED ASPHALT PATCH; POURED BENTONITE GROUT

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN: 2505738
START: 9/21/20 END: 9/22/20

DRILLING FIRM / OPERATOR: RII / LARRY
SAMPLING FIRM / LOGGER: DHDC / GANESH
DRILLING METHOD: 4.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/4/18
ENERGY RATIO (%): 90

STATION / OFFSET: 32+61.92 / 42.7' RT
ALIGNMENT: CL CONST. BRICE RD
ELEVATION: 820.8 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933239, -82.830560

EXPLORATION ID
B-072-0-19

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MATERIAL DESCRIPTION AND NOTES	ELEV. 820.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
ASPHALT (11.5") & **GRANULAR BASE** (4.5")	819.4	1																
FILL: VERY STIFF, DARK BROWN TO GRAYISH BROWN, **SILT AND CLAY**, LITTLE TO SOME SAND, TRACE TO LITTLE GRAVEL, MOIST ---ROCK FRAGMENTS IN SAMPLE---		2 3	6 7 9	24	86	SS-1	4.00	-	-	-	-	-	-	-	-	11	A-6a (V)	
		4 5	8 6 12	27	56	SS-2	4.00	-	-	-	-	-	-	-	-	14	A-6a (V)	
		6 7 8	10 4 7	17	64	SS-3	4.00	-	-	-	-	-	-	-	-	20	A-6a (V)	
		9 10	5 7 7	21	89	SS-4	4.00	-	-	-	-	-	-	-	-	10	A-6a (V)	
		11 12 13	5 6 8	21	100	SS-5	4.00	11	9	15	32	33	35	20	15	18	A-6a (8)	
		14 15	5 5 8	20	72	SS-6	4.00	-	-	-	-	-	-	-	-	14	A-6a (V)	
		16 17 18	7 7 10	26	72	SS-7	4.00	-	-	-	-	-	-	-	-	17	A-6a (V)	
		19 20	7 9 10	29	64	SS-8	4.00	-	-	-	-	-	-	-	-	11	A-6a (V)	
@22.0'; POSSIBLE ROCK FRAGMENTS		21 22 23	6 32 12	66	33	SS-9	4.00	11	12	16	31	30	36	23	13	17	A-6a (6)	
@23.5'-25.0'; BRICK FRAGMENTS IN SAMPLE		24 25	6 8 13	32	67	SS-10	4.00	-	-	-	-	-	-	-	-	21	A-6a (V)	
	793.3	26 27																
VERY STIFF, MOTTLED BROWN AND GRAY, **SILT AND CLAY**, AND SAND, TRACE GRAVEL, MOIST		28 29	10 8 11	29	72	SS-11	4.00	3	29	9	24	35	35	22	13	17	A-6a (6)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 3261.92, 43' RT.	START: 9/21/20	END: 9/22/20	PG 2 OF 3	B-072-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 790.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY STIFF, MOTTLED BROWN AND GRAY, **SILT AND CLAY**, AND SAND, TRACE GRAVEL, MOIST *(continued)*	789.3	31																
MEDIUM DENSE, MOTTLED BROWN AND GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SILT**, MOIST		32 33																
		34 35	3 4 8	18	56	SS-12	-	-	-	-	-	-	-	-	-	15	A-2-4 (V)	
	783.8	36 37																
DENSE, BROWN AND GRAY TO GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET ---SAMPLES ARE MOSTLY STONE FRAGMENTS---		38 W 782.1																
		39 40	5 12 10	33	56	SS-13	-	38	28	9	- 25 -		NP	NP	NP	18	A-1-b (0)	
		41 42 43																
		44 45	5 10 12	33	78	SS-14	-	-	-	-	-	-	-	-	-	10	A-1-b (V)	
	773.8	46 47																
VERY DENSE, BLACKISH GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SILT**, WET ---SHALE FRAGMENTS IN SAMPLE---		48																
		49 50	17 12 36	72	89	SS-15	-	-	-	-	-	-	-	-	-	13	A-2-4 (V)	
	768.8	51 52																
HARD, GRAY, **SILT AND CLAY**, SOME SAND, TRACE GRAVEL, WET		53																
		54 55	15 12 20	48	78	SS-16	4.00	10	8	20	39	23	31	18	13	12	A-6a (7)	
	763.8	56 57																
VERY STIFF, GRAY, **SANDY SILT**, TRACE GRAVEL, WET ---BLACK ORGANICS IN SAMPLE---		58																
		59 60	4 5 12	26	89	SS-17	4.00	-	-	-	-	-	-	-	-	20	A-4a (V)	
	758.8	61																

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 3261.92, 43' RT.	START: 9/21/20	END: 9/22/20	PG 3 OF 3	B-072-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 758.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY DENSE, GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SILT**, TRACE CLAY, WET CONTAIINS SANDY SILT SEAMS *(continued)* @63.0'; POSSIBLE BOULDER		63																
		64	15 47 24	107	72	SS-18	-	32	20	15	- 33 -		NP	NP	NP	15	A-2-4 (0)	
		65																
		66																
		67																
		68	50/5"	-	0	SS-19	-	-	-	-	-	-	-	-	-	-	A-2-4 (V)	
		69																
		70																
		71																
		72																
		73	50/4"	-	75	SS-20	-	-	-	-	-	-	-	-	-	16	A-2-4 (V)	
		74																
	745.8	EOB 75																

NOTES: BORING WAS RELOCATED 20.0 FEET NORTH, 1.0 FEET WEST DUE TO OVERHEAD UTILITIES.

ABANDONMENT METHODS, MATERIALS, QUANTITIES: USED ASPHALT PATCH; POURED BENTONITE GROUT

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN:
START: 7/14/20 END: 7/15/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1585+96.13 / 47.1' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 822.8 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933330, -82.831060

EXPLORATION ID
B-073-0-19

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 822.8	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
									GR	CS	FS	SI	CL	LL	PL	PI			
0.6' - TOPSOIL (7.0")	822.2																		
FILL: HARD, DARK BROWN **SILTY CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP.			1 2 3	4 6 8	20	28	SS-1	4.5+	-	-	-	-	-	-	-	-	11	A-6b (V)	
	817.3		4 5	6 5 4	13	67	SS-2	4.25	17	13	13	30	27	35	19	16	15	A-6b (7)	
FILL: VERY STIFF TO HARD, DARK BROWN **SILT AND CLAY**, "AND" FINE TO COARSE SAND, LITTLE FINE GRAVEL, DAMP TO MOIST.			6 7 8	6 8 10	25	61	SS-3	-	-	-	-	-	-	-	-	-	11	A-6a (V)	
			9 10	3 4 8	17	33	SS-4	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	
-BRICK TILE FRAGMENTS, ASPHALT PICES PRESENT THROUGHOUT			11 12 13	5 7 8	21	83	SS-5	3.50	-	-	-	-	-	-	-	-	14	A-6a (V)	
			14 15	7 8 11	27	61	SS-6	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
		W	16 17 18	3 4 5	13	67	SS-7	2.50	16	24	13	25	22	30	16	14	12	A-6a (4)	
			19 20	3 6 8	20	33	SS-8	3.00	-	-	-	-	-	-	-	-	-	A-6a (V)	
	799.8		21 22 23	2 3 2	7	22	SS-9	2.25	-	-	-	-	-	-	-	-	-	A-6a (V)	
LOOSE, BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, WET.	794.8	W 798.8	24 25 26 27 28	4 3 2	7	44	SS-10	-	-	-	-	-	-	-	-	-	21	A-2-6 (V)	
MEDIUM STIFF TO VERY STIFF, BROWN TO DARK GRAY AND BROWN **SILT AND CLAY**, SOME FINE TO COARSE SAND, SOME FINE GRAVEL, DAMP TO MOIST.			29	4 4 5	13	33	SS-11	-	-	-	-	-	-	-	-	-	20	A-6a (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158596.13, 47' RT.	START: 7/14/20	END: 7/15/20	PG 2 OF 3	B-073-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 792.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM STIFF TO VERY STIFF, BROWN TO DARK GRAY AND BROWN **SILT AND CLAY**, SOME FINE TO COARSE SAND, SOME FINE GRAVEL, DAMP TO MOIST. *(continued)*		31																
		32																
		33																
		34	9 12 15	38	67	SS-12	0.75	31	15	11	23	20	35	20	15	21	A-6a (3)	
		35																
		36																
		37																
		38																
		39	11 28 45	102	56	SS-13	2.50	-	-	-	-	-	-	-	-	22	A-6a (V)	
		40																
		41																
		42																
		43																
		44	26 45 43	123	67	SS-14	1.75	-	-	-	-	-	-	-	-	16	A-6a (V)	
		45																
-LARGE BOULDER @ 45.0'. BORING OFFSET 5' NW AND CONTINUED DRILLING.		46																
	775.8	47																
STIFF TO HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.		48																
		49	19 21 16	52	78	SS-15	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	
		50																
		51																
		52																
		53																
		54	4 15 19	48	50	SS-16	1.75	9	14	14	35	28	30	17	13	14	A-6a (7)	
		55																
		56																
		57																
		58																
		59	8 12 19	44	94	SS-17	4.5+	-	-	-	-	-	-	-	-	13	A-6a (V)	
		60																
		61																

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:31 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158596.13, 47' RT.	START: 7/14/20	END: 7/15/20	PG 3 OF 3	B-073-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 760.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
STIFF TO HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST. *(continued)*		63																
		64 65	8 10 16	36	89	SS-18	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
		66 67 68																
		69 70	9 14 18	45	94	SS-19	4.5+	-	-	-	-	-	-	-	-	9	A-6a (V)	
		71 72 73																
	747.8	74 EOB 75	26 37 25	87	67	SS-20	4.5+	-	-	-	-	-	-	-	-	11	A-6a (V)	

NOTES: SEEPAGE @ 17.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 24.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN:
START: 7/15/20 END: 7/17/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1586+38.19 / 59.5' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 820.4 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933292, -82.830915

EXPLORATION ID
B-074-0-19

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 820.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
FILL: HARD, DARK BROWN **SILT AND CLAY**, SOME FINE TO COARSE SAND, LITTLE FINE GRAVEL, DAMP.	817.4	1 2 3	5 6 8	20	100	SS-1	4.5+	18	19	12	28	23	29	16	13	12	A-6a (4)	
FILL: VERY DENSE, DARK BROWN **GRAVEL WITH SAND AND SILT**, DAMP.	814.9	4 5	12 24 20	62	67	SS-2	-	-	-	-	-	-	-	-	-	5	A-2-4 (V)	
FILL: MEDIUM DENSE, GRAYISH BROWN **GRAVEL WITH SAND, SILT, AND CLAY**, DAMP.	812.4	6 7 8	3 4 4	11	67	SS-3	-	-	-	-	-	-	-	-	-	9	A-2-6 (V)	
FILL: VERY STIFF, GRAYISH BROWN **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	809.9	9 10	5 3 6	13	56	SS-4	3.00	3	8	12	40	37	37	18	19	20	A-6b (12)	
FILL: STIFF TO HARD, GRAY TO BROWN **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP TO MOIST.		11 12 13	8 4 5	13	100	SS-5	2.00	-	-	-	-	-	-	-	-	17	A-4a (V)	
		14 15	7 20 12	45	100	SS-6	3.00	9	11	16	37	27	26	16	10	12	A-4a (6)	
		16 17 18	11 16 15	44	28	SS-7	3.25	-	-	-	-	-	-	-	-	-	A-4a (V)	
		19 20	7 9 12	29	83	SS-8	4.25	-	-	-	-	-	-	-	-	11	A-4a (V)	
		21 22 23	4 7 9	22	83	SS-9	4.5+	9	14	17	36	24	26	16	10	11	A-4a (5)	
	793.4	24 25 26	6 8 12	28	94	SS-10	4.5+	-	-	-	-	-	-	-	-	13	A-4a (V)	
VERY STIFF, BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST TO VERY MOIST.		27 28 29	4 4 8	17	89	SS-11	3.00	-	-	-	-	-	-	-	-	28	A-6b (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158638.19, 60' RT.	START: 7/15/20	END: 7/17/20	PG 2 OF 3	B-074-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 790.4	DEPTHS		SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY STIFF, BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST TO VERY MOIST. *(continued)*	788.4		31 32																
VERY STIFF, GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.			33 34 35	6 7 11	25	94	SS-12	3.00	-	-	-	-	-	-	-	-	19	A-6a (V)	
-COBBLES @ 35.5'	783.4		36 37																
STIFF, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.			38 39 40	4 16 22	53	33	SS-13	1.00	-	-	-	-	-	-	-	-	18	A-6b (V)	
-COBBLES @ 40.5'			41																
-HEAVING SANDS @ 41.5'	778.4		42																
MEDIUM DENSE TO VERY DENSE, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, MOIST.		W 776.4	43 44 45	6 8 13	29	78	SS-14	-	-	-	-	-	-	-	-	-	14	A-4a (V)	
			46 47 48 49 50	17 27 18	63	122	SS-15	-	-	-	-	-	-	-	-	-	18	A-4a (V)	
-HEAVING SANDS @ 53.5'			51 52 53 54 55	11 10 18	39	117	SS-16	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
	758.4		56 57 58 59 60 61	7 11 17	39	61	SS-17	-	-	-	-	-	-	-	-	-	20	A-4a (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158638.19, 60' RT.	START: 7/15/20	END: 7/17/20	PG 3 OF 3	B-074-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 758.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY STIFF, GRAY **SILT AND CLAY**, SOME FINE TO COARSE SAND, LITTLE FINE GRAVEL, MOIST. *(continued)*		63																
		64 65	10 25 18	60	67	SS-18	3.25	18	19	12	28	23	29	16	13	17	A-6a (4)	
	753.4	66 67																
HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, DAMP.		68																
		69 70	9 13 22	49	100	SS-19	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)	
		71 72 73																
	745.4	74 EOB 75	8 9 16	35	100	SS-20	4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)	

NOTES: SEEPAGE @ 19.0'; GROUNDWATER ENCOUNTERED INITIALLY @ 44.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN:
START: 7/8/20 END: 7/9/20

DRILLING FIRM / OPERATOR: RII / KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1587+63.37 / 45.8' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 819.0 (MSL) EOB: 60.0 ft.
LAT / LONG: 39.933307, -82.830477

EXPLORATION ID
B-075-0-19

PAGE
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MATERIAL DESCRIPTION AND NOTES	ELEV. 819.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	HOLE SEALED
								GR	CS	FS	SI	CL	LL	PL	PI			
0.5' - TOPSOIL (6.0")	818.5		2 3 4	10	72	SS-1A	-	-	-	-	-	-	-	-	-	20		
FILL: STIFF, DARK BROWN, BROWN, AND GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		1				SS-1B	2.00	-	-	-	-	-	-	-	-	19	A-6a (V)	
	815.8	2 3	3 4 5	13	61	SS-2	1.75	14	10	15	30	31	30	16	14	18	A-6a (7)	
FILL: STIFF TO VERY STIFF, DARK GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP TO MOIST.		4 5	3 3 3	8	72	SS-3	2.25	-	-	-	-	-	-	-	-	12	A-4a (V)	
		6 7 8	3 3 4	10	86	SS-4	2.00	-	-	-	-	-	-	-	-	13	A-4a (V)	
	808.5	9 10	4 5 5	14	78	SS-5	3.25	14	11	16	34	25	22	14	8	10	A-4a (5)	
FILL: VERY STIFF, BROWN AND GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP TO MOIST.		11 12 13	3 6 6	17	78	SS-6	3.50	-	-	-	-	-	-	-	-	20	A-6a (V)	
		14 15	6 7 7	20	56	SS-7	4.00	-	-	-	-	-	-	-	-	-	A-6a (V)	
	801.0	16 17	4 4 6	14	94	SS-8	3.75	11	11	16	35	27	26	15	11	12	A-6a (6)	
FILL: HARD, GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP.	798.5	18 19 20	6 8 6	20	89	SS-9	4.25	-	-	-	-	-	-	-	-	10	A-4a (V)	
VERY STIFF TO HARD, MOTTLED BROWN AND GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		21 22 23	8 10 8	25	100	SS-10	4.50	-	-	-	-	-	-	-	-	18	A-6a (V)	
		24 25 26 27 28	6 8 9	24	67	SS-11	4.5+	-	-	-	-	-	-	-	-	19	A-6a (V)	
		29	6 7 9	22	72	SS-12	-	-	-	-	-	-	-	-	-	13	A-6a (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158763.37, 46' RT.	START: 7/8/20	END: 7/9/20	PG 2 OF 2	B-075-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 789.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	HOLE SEALED
VERY STIFF TO HARD, MOTTLED BROWN AND GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST. *(continued)*	787.0	31 32																
MEDIUM DENSE TO VERY DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, MOIST TO WET.	772.0	∇ 785.9 33																
		34 35	5 8 11	27	56	SS-13	-	-	-	-	-	-	-	-	-	3	A-1-b (V)	
		36 W 782.5 37 38																
		39	16 50/5"	-	100	SS-14	-	-	-	-	-	-	-	-	-	-	A-1-b (V)	
		40 41 42 43																
		44 45	10 21 25	65	17	SS-15	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
		46 47																
VERY STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, MOIST.	762.0	48																
		49 50	4 6 8	20	67	SS-16	-	8	9	21	39	23	22	14	8	13	A-4a (5)	
		51 52 53																
		54 55	3 4 8	17	78	SS-17	2.75	-	-	-	-	-	-	-	-	12	A-4a (V)	
		56																
VERY DENSE, GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST.	759.0	57 58																
		59 EOB 60	15 21 41	87	100	SS-18	4.00	-	-	-	-	-	-	-	-	11	A-2-4 (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 36.5' AND AT COMPLETION @ 33.1'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 94 LBS CEMENT / 50 LBS BENTONITE POWDER / 20 GAL WATER .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: BRIDGE
PID: 98232 SFN:
START: 7/13/20 END: 7/14/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1585+96.52 / 8.4' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 823.2 (MSL) EOB: 75.0 ft.
LAT / LONG: 39.933436, -82.831055

EXPLORATION ID
B-076-0-19

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1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 823.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.8' - TOPSOIL (9.0")	822.4																	
FILL: VERY STIFF TO HARD, BROWN AND DARK BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP TO MOIST.		1	3 4 5	13	50	SS-1	3.50	-	-	-	-	-	-	-	-	14	A-6a (V)	
		2 3	4 5 11	22	44	SS-2	4.5+	-	-	-	-	-	-	-	-	17	A-6a (V)	
		4 5	3 7 5	17	89	SS-3	4.5+	13	13	16	35	23	28	17	11	12	A-6a (5)	
		6 7 8	2 4 10	20	78	SS-4	3.50	-	-	-	-	-	-	-	-	20	A-6a (V)	
		9 10	3 4 9	18	78	SS-5	3.50	-	-	-	-	-	-	-	-	12	A-6a (V)	
	810.2	11 12 13	4 4 5	13	72	SS-6	3.50	-	-	-	-	-	-	-	-	19	A-6a (V)	
FILL: VERY STIFF, DARK BROWN AND DARK GRAY **SILTY CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		14 15	1 1 2	4	50	SS-7	2.25	-	-	-	-	-	-	-	-	19	A-6b (V)	
	805.2	16 17 18	2 3 2	7	89	SS-8	2.75	13	13	13	34	27	34	18	16	19	A-6b (8)	
FILL: HARD, DARK BROWN AND DARK GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST. -COBBLES @ 20.0'		19 20	2 4 7	15	83	SS-9	4.25	-	-	-	-	-	-	-	-	14	A-6a (V)	
	800.2	21 22 23	24 48 21	97	72	SS-10	4.5+	-	-	-	-	-	-	-	-	16	A-6a (V)	
MEDIUM DENSE TO DENSE, DARK GRAY, BROWN AND BLACK **GRAVEL WITH SAND AND SILT**, TRACE CLAY, WET.		24 25 26 27 28	7 8 10	25	61	SS-11	-	-	-	-	-	-	-	-	-	16	A-2-4 (V)	
		W 794.2 29	8 5 19	34	83	SS-12	-	-	-	-	-	-	-	-	-	17	A-2-4 (V)	

PID: 98232 | SFN: | PROJECT: FRA-070-22.85 | STATION / OFFSET: 158596.52, 8' RT. | START: 7/13/20 | END: 7/14/20 | PG 2 OF 3 | B-076-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 793.2	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE TO DENSE, DARK GRAY, BROWN AND BLACK **GRAVEL WITH SAND AND SILT**, TRACE CLAY, WET. *(continued)*	791.2	31																
MEDIUM DENSE, BROWN **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, MOIST.		32 33																
		34 35	7 6 8	20	61	SS-13	-	-	-	-	-	-	-	-	-	27	A-4a (V)	
	786.2	36 37																
DENSE TO VERY DENSE, BROWNISH GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST TO WET.		38																
		39 40	10 14 50/5"	-	88	SS-14	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)	
		41 42 43																
		44 45	11 28 32	84	44	SS-15	-	-	-	-	-	-	-	-	-	17	A-2-4 (V)	
-COBBLES @ 45.5'		46 47 48																
		49 50	13 10 16	36	33	SS-16	-	-	-	-	-	-	-	-	-	17	A-2-4 (V)	
		51 52 53																
		54 55	16 12 17	41	39	SS-17	-	-	-	-	-	-	-	-	-	16	A-2-4 (V)	
	766.2	56 57																
STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP TO MOIST.		58																
		59 60	9 12 13	35	61	SS-18	4.25	-	-	-	-	-	-	-	-	12	A-4a (V)	
		61																

PID: 98232 | SFN: | PROJECT: FRA-070-22.85 | STATION / OFFSET: 158596.52, 8' RT. | START: 7/13/20 | END: 7/14/20 | PG 3 OF 3 | B-076-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 761.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
STIFF TO HARD, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP TO MOIST. *(continued)*		63																
		64–65	11 11 20	44	100	SS-19	4.5+	5	13	16	37	29	24	15	9	12	A-4a (6)	
		66–68																
		69–70	12 11 16	38	89	SS-20	4.5+	-	-	-	-	-	-	-	-	13	A-4a (V)	
		71–73																
	748.2	74–75 EOB	10 15 25	56	44	SS-21	1.00	-	-	-	-	-	-	-	-	19	A-4a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 29.0'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS. PUMPED CEMENT GROUT .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85	DRILLING FIRM / OPERATOR: RII / LARRY	DRILL RIG: CME 55 (386345)	STATION / OFFSET: 1586+84.13 / 13.1' RT
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: DHDC / GANESH	HAMMER: AUTOMATIC	ALIGNMENT: BL IR 70 WB-CD
PID: 98232 SFN:	DRILLING METHOD: 4.25" HSA	CALIBRATION DATE: 9/4/18	ELEVATION: 820.6 (MSL) EOB: 75.0 ft.
START: 9/10/20 END: 9/10/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 90	LAT / LONG: 39.933413, -82.830745

EXPLORATION ID
B-077-0-19

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 820.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
ASPHALT (13") & **GRANULAR BASE** (6")	819.0	1																
FILL: VERY STIFF, DARK BROWN WITH TRACE GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP	817.6	2 3	4 7 5	18	86	SS-1	-	-	-	-	-	-	-	-	-	14	A-6b (V)	
---SHALE AND ROCK FRAGMENTS IN SAMPLE--- **FILL**: STIFF TO VERY STIFF, DARK BROWN WITH TRACE GRAY, **SILTY CLAY**, LITTLE SAND, TRACE GRAVEL, DAMP		4 5	4 4 5	14	92	SS-2	-	-	-	-	-	-	-	-	-	13	A-6b (V)	
---ROCK FRAGMENTS IN SAMPLE #2--- ---TRACE BRICK FRAGMENTS IN SAMPLE #3---	812.6	6 7 8	4 4 7	17	78	SS-3	-	-	-	-	-	-	-	-	-	22	A-6b (V)	
FILL: VERY STIFF, GRAYISH BROWN, **SILT AND CLAY**, SOME SAND, LITTLE GRAVEL, DAMP @16.0'-17.5; ROCK FRAGMENTS		9 10	5 6 7	20	100	SS-4	-	14	11	17	33	25	36	22	14	10	A-6a (6)	
		11 12 13	4 5 8	20	100	SS-5	-	-	-	-	-	-	-	-	-	12	A-6a (V)	
		14 15	5 5 8	20	75	SS-6	-	-	-	-	-	-	-	-	-	13	A-6a (V)	
		16 17 18	7 8 12	30	97	SS-7	-	11	12	18	34	25	37	23	14	10	A-6a (6)	
		19	5 6 9	23	11	SS-8A	-	-	-	-	-	-	-	-	-	11	A-6a (V)	
		20	7	-	50	SS-8B	-	-	-	-	-	-	-	-	-	12	A-6a (V)	
		21 22 23	7 5 12	26	78	SS-9	-	-	-	-	-	-	-	-	-	18	A-6a (V)	
		24 25 26	7 12 11	35	36	SS-10	-	-	-	-	-	-	-	-	-	13	A-6a (V)	
	793.6	27																
STIFF, MOTTLED BROWN AND GRAY, **SILTY CLAY**, SOME SAND, TRACE GRAVEL, MOIST		28 29 30	2 4 5	14	89	SS-11	-	4	6	15	30	45	40	23	17	23	A-6b (11)	

PID: 98232 | SFN: | PROJECT: FRA-070-22.85 | STATION / OFFSET: 158684.13, 13' RT. | START: 9/10/20 | END: 9/10/20 | PG 2 OF 3 | B-077-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 789.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
	788.6																	
MEDIUM DENSE TO VERY DENSE, BROWN AND GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SIILT**, TRACE CLAY, MOIST TO WET @32.0'-42.0'; POSSIBLE COBBLE		32 33																
		34 35	4 7 8	23	61	SS-12	-	37	20	12	- 31 -		NP	NP	NP	13	A-2-4 (0)	
		36 37 38																
		39 40	24 32 50/3"	-	100	SS-13	-	-	-	-	-	-	-	-	-	10	A-2-4 (V)	
	778.6	41 42																
MEDIUM DENSE, GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, WET		43																
		44 45	7 5 12	26	44	SS-14	-	40	31	11	- 18 -		NP	NP	NP	12	A-1-b (0)	
		46 47 48																
		49 50	6 9 10	29	67	SS-15	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
	768.6	51 52																
VERY STIFF, BLUISH GRAY, **SANDY SILT**, LITTLE GRAVEL, MOIST ---LIGHT ORGANIC ODOR---		53																
		54 55	10 10 8	27	44	SS-16	-	-	-	-	-	-	-	-	-	13	A-4a (V)	
	763.6	56 57																
HARD, BROWN AND BLUISH GRAY, **SANDY SILT**, SOME GRAVEL, MOIST ---SHALE FRAGMENTS IN SAMPLE---		58																
		59 60	40 29 30	89	44	SS-17	-	-	-	-	-	-	-	-	-	15	A-4a (V)	
	758.6	61 62																
MEDIUM DENSE, BROWNISH GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SILT**, MOIST		63																
		64	9															

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158684.13, 13' RT.	START: 9/10/20	END: 9/10/20	PG 3 OF 3	B-077-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 756.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM DENSE, BROWNISH GRAY, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND AND SILT**, MOIST *(continued)*		65	7 13	30	22	SS-18A	-	-	-	-	-	-	-	-	-	15	A-2-4 (V)	
			11	-	100	SS-18B	-	-	-	-	-	-	-	-	-	16	A-2-4 (V)	
		66 67 68																
	752.6																	
HARD, GRAY, **SILTY CLAY**, SOME SAND, LITTLE GRAVEL, DAMP		69 70	9 11 14	38	78	SS-19	-	10	11	16	36	27	35	19	16	11	A-6b (8)	
		71 72 73																
		74	7 10 15	38	75	SS-20	-	-	-	-	-	-	-	-	-	11	A-6b (V)	
	745.6	EOB 75																

NOTES: WATER WAS INTRODUCED IN BOREHOLE AT ABOUT 36.5 FEET TO ADVANCE THE BOREHOLE. HAD NOT ENCOUNTERED WATER YET. BOULDER AT 37.0 FEET

ABANDONMENT METHODS, MATERIALS, QUANTITIES: USED ASPHALT PATCH; POURED BENTONITE GROUT

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:31 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT:	FRA-070-22.85	DRILLING FIRM / OPERATOR:	RII / TG/KC	DRILL RIG:	CME 55 (SN 386345)	STATION / OFFSET:	1587+68.09 / 4.5' RT
TYPE:	BRIDGE	SAMPLING FIRM / LOGGER:	RII / LH	HAMMER:	AUTOMATIC	ALIGNMENT:	BL IR 70 WB-CD
PID: 98232	SFN:	DRILLING METHOD:	3.25" HSA	CALIBRATION DATE:	9/14/20	ELEVATION:	818.1 (MSL) EOB: 75.0 ft.
START: 7/8/20	END: 7/8/20	SAMPLING METHOD:	SPT	ENERGY RATIO (%):	84.2	LAT / LONG:	39.933419, -82.830446

EXPLORATION ID
B-078-0-19

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MATERIAL DESCRIPTION AND NOTES	ELEV. 818.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.3' - TOPSOIL (3.0")	817.8																	
FILL: VERY STIFF, DARK BROWN AND GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		1	2 2 4	8	56	SS-1	2.75	-	-	-	-	-	-	-	-	9	A-6a (V)	
		2 3	4 5 8	18	72	SS-2	2.75	-	-	-	-	-	-	-	-	18	A-6a (V)	
		4 5	4 7 8	21	86	SS-3	3.00	-	-	-	-	-	-	-	-	10	A-4a (V)	
		6																
	810.1	7	3 2 3	7	67	SS-4	2.50	-	-	-	-	-	-	-	-	13	A-6a (V)	
FILL: VERY STIFF, BROWN AND DARK GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.		8																
	807.6	9 10	3 4 6	14	100	SS-5	2.25	-	-	-	-	-	-	-	-	26	A-6b (V)	
FILL: HARD, GRAY TO BROWN **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP.		11 12	4 7 7	20	94	SS-6	4.25	-	-	-	-	-	-	-	-	10	A-4a (V)	
-COBBLES @ 13.0'		13																
		14 15	7 8 9	24	44	SS-7	4.50	12	11	17	32	28	24	14	10	11	A-4a (5)	
		16 17	6 7 9	22	94	SS-8	4.25	-	-	-	-	-	-	-	-	11	A-4a (V)	
		18																
-COBBLES @ 20.0'	797.6	19 20	6 9 12	29	100	SS-9	4.25	-	-	-	-	-	-	-	-	11	A-6a (V)	
VERY STIFF TO HARD, MOTTLED BROWN AND GRAY **CLAY**, SOME SILT, TRACE COARSE TO FINE SAND, MOIST.		21 22	4 5 7	17	100	SS-10	2.25	0	2	7	34	57	57	19	38	23	A-7-6 (19)	
		23																
		24 25	5 8 10	25	78	SS-11	4.50	-	-	-	-	-	-	-	-	19	A-7-6 (V)	
	791.1	26 27																
MEDIUM STIFF, BROWN **SILTY CLAY**, LITTLE COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		28																
		29	3 3 4	10	56	SS-12	-	-	-	-	-	-	-	-	-	16	A-6b (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158768.09, 5' RT.	START: 7/8/20	END: 7/8/20	PG 2 OF 3	B-078-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 788.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
MEDIUM STIFF, BROWN **SILTY CLAY**, LITTLE COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST. *(continued)* -COBBLES @ 30.5'	786.1	W 786.1																
MEDIUM DENSE TO DENSE, GRAY **GRAVEL WITH SAND**, TRACE SILT, TRACE CLAY, WET. -HEAVING SANDS @ 33.5'			5 7 10	24	56	SS-13	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
			6 8 10	25	78	SS-14	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
	771.1		5 11 21	45	67	SS-15	-	29	44	14	7	6	NP	NP	NP	18	A-1-b (0)	
STIFF TO VERY STIFF, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP TO MOIST.			4 6 10	22	72	SS-16	3.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
			8 14 18	45	50	SS-17	1.75	-	-	-	-	-	-	-	-	14	A-4a (V)	
			5 8 14	31	86	SS-18	4.00	-	-	-	-	-	-	-	-	10	A-4a (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158768.09, 5' RT.	START: 7/8/20	END: 7/8/20	PG 3 OF 3	B-078-0-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 755.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
STIFF TO VERY STIFF, GRAY **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP TO MOIST. *(continued)*		63																
		▽ 753.8 64	10 14 20	48	50	SS-19	1.50	-	-	-	-	-	-	-	-	13	A-4a (V)	
	751.1	65 66																
VERY STIFF TO HARD, GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.		67 68																
		69	9 12 18	42	94	SS-20	4.25	8	7	10	32	43	29	17	12	12	A-6a (9)	
-COBBLES @ 72.5'		70 71 72 73																
	743.1	74 EOB 75	9 14 20	48	100	SS-21	4.00	-	-	-	-	-	-	-	-	18	A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 32.0' AND AT COMPLETION @ 64.3'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 94 LBS CEMENT / 50 LBS BENTONITE POWDER / 20 GAL WATER .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 9/25/20 END: 9/25/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / T.G.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 4588+38.26 / 13.8' RT
ALIGNMENT: BL RAMP N
ELEVATION: 800.0 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933103, -82.830232

EXPLORATION ID
B-086-0-19

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MATERIAL DESCRIPTION AND NOTES	ELEV. 800.0	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.5' - Topsoil (6.0")	799.5																	
FILL: HARD, BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DRY.		1 2	9 11 50/2"	-	57	SS-1	4.5+	-	-	-	-	-	-	-	-	8	A-6a (V)	
-GRANITE AND LIMESTONE FRAGMENTS IN SS-2	794.5	3 4 5	11 17 17	49	36	SS-2	4.5+	-	-	-	-	-	-	-	-	4	A-6a (V)	
VERY STIFF, BROWN **SILTY CLAY**, TRACE FINE TO COARSE SAND, TRACE FINE GRAVEL, DAMP.	792.0	6 7	8 9 11	29	61	SS-3	3.75	1	4	3	42	50	39	21	18	19	A-6b (11)	
STIFF, BROWN TO GRAYISH BROWN **SANDY SILT**, SOME CLAY, TRACE FINE GRAVEL, DAMP.		8 9 10	4 5 5	14	89	SS-4	1.75	6	12	11	44	27	25	18	7	16	A-4a (7)	
	787.0	11 12	7 9 14	33	81	SS-5	1.25	-	-	-	-	-	-	-	-	15	A-4a (V)	
DENSE TO VERY DENSE, BROWNISH GRAY **GRAVEL WITH SAND**, TRACE SILT, TARCE CLAY, MOIST TO WET.		13 14 15	15 21 35	80	75	SS-6	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
-COBBLES @ 15.5'		▽ 784.0 16 17 W 782.0	12 11 20	45	50	SS-7	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		18 19 20	8 12 12	34	56	SS-8	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
		21 22	10 13 10	33	61	SS-9	-	27	40	16	10	7	NP	NP	NP	15	A-1-b (0)	
		23 24 25	10 10 16	37	72	SS-10	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
	770.0	26 27 28 29 EOB	9 30 30	86	67	SS-11	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 18.0' AND AT COMPLETION @ 16.0'; CAVE-IN DEPTH @ 14.9'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/9/20 END: 7/9/20

DRILLING FIRM / OPERATOR: RII / TG/KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1588+73.65 / 31.5' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 822.7 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933311, -82.830087

EXPLORATION ID
B-087-0-19

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MATERIAL DESCRIPTION AND NOTES	ELEV. 822.7
0.3' - TOPSOIL (3.0")	822.4
FILL: HARD, DARK BROWN TO BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP.	819.5
FILL: VERY STIFF TO HARD, GRAY AND BROWN **SILTY CLAY**, SOME COARSE TO FINE SAND, SOME FINE GRAVEL, DAMP TO MOIST.	812.2
FILL: VERY STIFF, GRAYISH BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP. -COBBLES @ 12.0'	807.2
FILL: VERY STIFF, BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	804.7
FILL: VERY STIFF, BROWN **SANDY SILT**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	802.2
POSSIBLE FILL: MEDIUM DENSE TO VERY DENSE, BROWN, GRAY AND BLACK **GRAVEL WITH SAND**, LITTLE SILT, DAMP.	795.7
VERY DENSE, GRAY **GRAVEL**, TRACE SILT, DRY TO DAMP. -CONCRETE FRAGMENTS CONTAINED IN LAST SPLIT SPOON	792.7

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

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
3 5 6	15	50	SS-1A	-	-	-	-	-	-	-	-	-	14	
			SS-1B	4.25	-	-	-	-	-	-	-	-	-	A-6a (V)
10 10 8	25	72	SS-2	4.50	-	-	-	-	-	32	21	11	7	A-6a (V)
6 6 8	20	61	SS-3	4.50	-	-	-	-	-	-	-	-	18	A-6b (V)
3 4 4	11	78	SS-4	3.50	32	10	12	21	25	33	17	16	14	A-6b (4)
3 4 5	13	56	SS-5	3.75	-	-	-	-	-	-	-	-	16	A-6b (V)
3 8 5	18	83	SS-6	3.75	-	-	-	-	-	-	-	-	12	A-6a (V)
7 6 9	21	72	SS-7	2.75	35	17	12	19	17	31	19	12	12	A-6a (1)
5 5 5	14	100	SS-8	2.75	-	-	-	-	-	-	-	-	19	A-6b (V)
8 10 50/4"	-	75	SS-9	3.50	-	-	-	-	-	-	-	-	16	A-4a (V)
12 9 9	25	56	SS-10	-	-	-	-	-	-	-	-	-	-	A-1-b (V)
11 50/3"	-	100	SS-11	-	-	-	-	-	-	-	-	-	8	A-1-b (V)
50/5"	-	80	SS-12	-	-	-	-	-	-	-	-	-	7	A-1-a (V)

BACK FILL

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING'; CAVE-IN DEPTH @ 3.5'

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

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 11/10/20 END: 11/10/20

DRILLING FIRM / OPERATOR: RII / LH/KC
SAMPLING FIRM / LOGGER: RII / KS
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1588+73.65 / 31.5' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 822.7 (MSL) EOB: 70.0 ft.
LAT / LONG: 39.933311, -82.830087

EXPLORATION ID
B-087-0-19A

PAGE
1 OF 3

MATERIAL DESCRIPTION AND NOTES	ELEV. 822.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	HOLE SEALED
								GR	CS	FS	SI	CL	LL	PL	PI			
SAME AS B-087-0-19																		
		1																
		2																
		3																
		4																
		5																
		6																
		7																
		8																
		9																
		10																
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		21																
		22																
		23																
		24																
		25																
		26																
		27																
		28																
		29																

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158873.65, 32' RT.	START: 11/10/20	END: 11/10/20	PG 2 OF 3	B-087-0-19A

MATERIAL DESCRIPTION AND NOTES	ELEV. 792.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	HOLE SEALED
								GR	CS	FS	SI	CL	LL	PL	PI			
SAME AS B-087-0-19 *(continued)*	791.7																	
VERY STIFF, BROWNISH GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	789.7	31 32	12 5 7	17	78	SS-13	3.00	-	-	-	-	-	-	-	-	25	A-6a (V)	
MEDIUM DENSE, BROWN **SILT**, LITTLE CLAY, LITTLE COARSE TO FINE SAND, DAMP.	787.2	33 34 35	14 6 11	24	61	SS-14	-	-	-	-	-	-	-	-	-	11	A-4b (V)	
VERY STIFF TO HARD, GRAYISH BROWN **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP.		36 37 38	8 11 19	42	72	SS-15	4.50	-	-	-	-	-	-	-	-	10	A-4a (V)	
		39 40 41 42 43	6 9 15	34	67	SS-16	2.50	11	11	18	38	22	24	15	9	13	A-4a (5)	
	775.7	44 45 46	5 8 12	28	78	SS-17	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
VERY DENSE, GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, WET.		47 48 W 774.2 49 50 51 52 53	8 21 42	88	72	SS-18	-	45	13	13	22	7	20	16	4	11	A-2-4 (0)	
	765.7	54 55 56	12 12 28	56	61	SS-19	-	-	-	-	-	-	-	-	-	15	A-2-4 (V)	
SOFT, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	760.7	57 58 59 60 61	15 15 15	42	67	SS-20	0.50	-	-	-	-	-	-	-	-	20	A-6b (V)	

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 158873.65, 32' RT.	START: 11/10/20	END: 11/10/20	PG 3 OF 3	B-087-0-19A

MATERIAL DESCRIPTION AND NOTES	ELEV. 760.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG				ODOT CLASS (GI)	HOLE SEALED
								GR	CS	FS	SI	CL	LL	PL	PI	WC		
VERY DENSE, GRAY **GRAVEL WITH SAND, SILT, AND CLAY**, WET. *(continued)*	755.7	63 64 65 66 67	10 21 18	55	78	SS-21	-	-	-	-	-	-	-	-	-	16	A-2-6 (V)	
HARD, DARK GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP.	752.7	68 69 EOB 70	11 21 18	55	100	SS-22	4.50	-	-	-	-	-	-	-	-	13	A-6b (V)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 48.5'; AUGERED WITHOUT SAMPLING TO 31 FEET

ABANDONMENT METHODS, MATERIALS, QUANTITIES: PUMPED 94 LB. CEMENT / 50 LB. BENTONITE POWDER / 40 GAL WATER. .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 9/25/20 END: 9/25/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / T.G.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 1590+16.08 / 35.8' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 817.5 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933232, -82.829597

EXPLORATION ID
B-088-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 817.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.5' - TOPSOIL (6.0")	817.0																	
FILL: HARD, BROWN **SILT AND CLAY**, SOME FINE TO COARSE SAND, SOME FINE GRAVEL, DRY TO DAMP. -ROCK FRAGMENTS IN SS-2		1	5 50/5"	-	91	SS-1A	-	-	-	-	-	-	-	-	-	-		
						SS-1B	-	-	-	-	-	-	-	-	-	7	A-6a (V)	
		2 3	6 7 9	23	33	SS-2	4.5+	28	15	13	21	23	28	16	12	9	A-6a (2)	
		4 5	6 12 9	30	56	SS-3	4.5+	-	-	-	-	-	-	-	-	12	A-6a (V)	
	811.0	6	8 8 9	24	78	SS-4A	4.00	-	-	-	-	-	-	-	-	10	A-6a (V)	
FILL: MEDIUM DENSE, GRAY AND BLACK **COARSE AND FINE SAND**, SOME FINE GRAVEL, TRACE SILT, DAMP. -CONCRETE AND ASPHALT FRAGMENTS IN SS-4B	809.5	7 8				SS-4B	-	-	-	-	-	-	-	-	-	6	A-3a (V)	
FILL: STIFF TO VERY STIFF, BROWN TO BROWNISH GRAY **SANDY SILT**, SOME CLAY, LITTLE TO SOME FINE GRAVEL, DAMP. -CONCRETE FRAGMENTS IN SS-5		9 10	8 3 4	10	33	SS-5	3.50	-	-	-	-	-	-	-	-	14	A-4a (V)	
		11 12 13	2 3 3	9	44	SS-6	3.50	13	16	15	28	28	25	16	9	13	A-4a (4)	
		14 15	1 2 5	10	33	SS-7	2.00	-	-	-	-	-	-	-	-	14	A-4a (V)	
-COBBLES @ 15.0' -CONCRETE FRAGMENTS IN SS-8	799.5	16 17 18	5 8 50/4"	-	100	SS-8	4.00	32	13	16	19	20	26	16	10	12	A-4a (1)	
VERY DENSE, GRAY **GRAVEL WITH SAND (CONCRETE FRAGMENTS)**, DAMP.		19 20	40 14 50/5"	-	65	SS-9	-	-	-	-	-	-	-	-	-	6	A-1-b (V)	
	795.0	21 22	50/5"	-	100	SS-10	-	-	-	-	-	-	-	-	-	6	A-1-b (V)	
STIFF, BROWN **SILT AND CLAY**, SOME FINE TO COARSE SAND, SOME FINE GRAVEL, DAMP. -COBBLES @ 23.0'		23 24 25	5 5 7	17	0	SS-11	-	-	-	-	-	-	-	-	-	-		
-CONCRETE FRAGMENTS IN 2S-11A	▽ 791.5 W 791.0 790.5	26 27 28	11	-	100	2S-11A	1.75	28	14	11	24	23	38	23	15	22	A-6a (4)	
HARD, BROWN TO GRAY **SILT AND CLAY**, LITTLE FINE TO COARSE SAND, TRACE FINE GRAVEL, DAMP.	787.5	29 EOB	4 8 10	26	50	SS-12	4.5+	-	-	-	-	-	-	-	-	14	A-6a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 26.5' AND AT COMPLETION @ 26.0'; CAVE-IN DEPTH @ 17.8'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:32 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

PROJECT: FRA-070-22.85	DRILLING FIRM / OPERATOR: RII / SB/KC	DRILL RIG: CME 750X (SN 310218)	STATION / OFFSET: 1590+16.08 / 35.8' RT	**EXPLORATION ID** **B-088-0-19A**
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: RII / KS	HAMMER: AUTOMATIC	ALIGNMENT: BL IR 70 WB-CD	
PID: 98232 SFN:	DRILLING METHOD: 3.25" HSA	CALIBRATION DATE: 9/14/20	ELEVATION: 817.5 (MSL) EOB: 55.0 ft.	PAGE 1 OF 2
START: 11/11/20 END: 11/11/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 86.2	LAT / LONG: 39.933232, -82.829597	

MATERIAL DESCRIPTION AND NOTES	ELEV. 817.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
SAME AS B-088-0-19		1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29																▨

PID: 98232	SFN:	PROJECT: FRA-070-22.85	STATION / OFFSET: 159016.08, 36' RT.	START: 11/11/20	END: 11/11/20	PG 2 OF 2	B-088-0-19A

MATERIAL DESCRIPTION AND NOTES	ELEV. 787.5	DEPTHS	SPT/ RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
SAME AS B-088-0-19 *(continued)*	786.5																	
VERY STIFF TO HARD, BROWN TO GRAY **SILTY CLAY**, SOME COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP.	784.5	31 – 32	5 7 8	22	94	SS-13	2.50	8	12	19	37	24	34	14	20	17	A-6b (9)	
HARD, GRAY **SANDY SILT**, LITTLE CLAY, TRACE FINE GRAVEL, DAMP.		34 – 35	3 11 11	32	78	SS-14	4.50	-	-	-	-	-	-	-	-	11	A-4a (V)	
	779.5	36 – 37	4 6 8	20	89	SS-15	4.50	9	12	21	43	15	21	15	6	12	A-4a (5)	
DENSE TO VERY DENSE, GRAY **GRAVEL WITH SAND, SILT, AND CLAY**, WET.		39 – 40	21 16 15	45	67	SS-16	-	-	-	-	-	-	-	-	-	11	A-2-6 (V)	
	770.5	44 – 45	8 18 20	55	72	SS-17	-	-	-	-	-	-	-	-	-	10	A-2-6 (V)	
HARD, GRAY **SILT**, TRACE CLAY, TRACE COARSE TO FINE SAND, WET.	765.5	49 – 50	8 10 10	29	78	SS-18	4.50	-	-	-	-	-	-	-	-	17	A-4b (V)	
HARD, GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	762.5	54 – 55 EOB 55	3 9 13	32	72	SS-19	4.50	-	-	-	-	-	-	-	-	19	A-6b (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING; AUGERED WITHOUT SAMPLING TO 31 FEET

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

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN:
START: 7/10/20 END: 7/10/20

DRILLING FIRM / OPERATOR: RII / TG/KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1591+71.09 / 34.5' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 804.6 (MSL) EOB: 30.0 ft.
LAT / LONG: 39.933145, -82.829056

EXPLORATION ID
B-089-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 804.6	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.3' - TOPSOIL (4.0")	804.3		4 7 9	22	61	SS-1A	-	-	-	-	-	-	-	-	-	-		
FILL: VERY STIFF TO HARD, BROWN **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, DAMP.		1				SS-1B	4.50	-	-	-	-	-	-	-	-	8	A-6a (V)	
		2 3	9 24 17	58	78	SS-2	4.50	-	-	-	-	-	-	-	-	8	A-6a (V)	
		4 5	12 21 16	52	61	SS-3	4.50	13	10	14	34	29	28	15	13	9	A-6a (7)	
		6 7 8	14 14 9	32	100	SS-4	4.00	-	-	-	-	-	-	-	-	11	A-6a (V)	
		9 10	7 7 10	24	39	SS-5	3.75	-	-	-	-	-	-	-	-	-	A-6a (V)	
	791.6	11 12 13	10 11 8	27	72	SS-6	3.75	-	-	-	-	-	-	-	-	10	A-6a (V)	
STIFF TO VERY STIFF, MOTTLED DARK BROWN AND BROWN **SILTY CLAY**, SOME COARSE TO FINE SAND, LITTLE FINE GRAVEL, MOIST.		14 15	4 4 5	13	100	SS-7	2.50	-	-	-	-	-	-	-	-	21	A-6b (V)	
	786.6	16 17 18	3 4 4	11	83	SS-8	1.75	16	8	13	28	35	37	18	19	20	A-6b (9)	
VERY STIFF, GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, MOIST.		19 20	4 5 8	18	100	SS-9	2.50	-	-	-	-	-	-	-	-	13	A-4a (V)	
		21 22 23	5 5 5	14	83	SS-10	2.50	14	10	18	33	25	20	13	7	12	A-4a (5)	
		24 25 26 27 28	4 5 6	15	72	SS-11	3.00	-	-	-	-	-	-	-	-	10	A-4a (V)	
	774.6	29 EOB	10 11 14	35	56	SS-12	3.00	-	-	-	-	-	-	-	-	12	A-4a (V)	

NOTES: GROUNDWATER NOT ENCOUNTERED DURING DRILLING

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: ROADWAY
PID: 98232 SFN:
START: 7/7/20 END: 7/7/20

DRILLING FIRM / OPERATOR: RII / TG/KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 4.5" CFA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1594+39.02 / 22.4' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 800.5 (MSL) EOB: 10.0 ft.
LAT / LONG: 39.933022, -82.828113

EXPLORATION ID
B-090-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 800.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.3' - TOPSOIL (3.0")	800.2																	
FILL: DENSE, BLACK **ASPHALT FRAGMENTS**, DAMP.	799.0	1	9 22 10	45	78	SS-1	-	-	-	-	-	-	-	-	-	-		
VERY STIFF TO HARD, BROWN AND GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST.		2 3	5 6 9	21	81	SS-2	4.5+	-	-	-	-	-	-	-	-	10	A-6a (V)	
		4 5	2 3 6	13	78	SS-3	3.00	2	3	9	40	46	31	20	11	19	A-6a (8)	
		W 6 7 8	1 6 8	20	83	SS-4	3.50	-	-	-	-	-	-	-	-	17	A-6a (V)	
	790.5	9 EOB 10	6 6 7	18	94	SS-5	2.75	-	-	-	-	-	-	-	-	14	A-6a (V)	

NOTES: SEEPAGE @ 6.5'; CAVE-IN DEPTH @ 8.3'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 25 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

00-2021 NEW STA ODOT BORING LOG (8.5X11) - OH DOT.GDT - 4/4/22 11:32 - U:\GI8\PROJECTS\2017\W-17-140.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN: N/A
START: 9/25/20 END: 9/25/20

DRILLING FIRM / OPERATOR: RII / SB
SAMPLING FIRM / LOGGER: RII / T.G.
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 750X (SN 310218)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 86.2

STATION / OFFSET: 1595+86.79 / 10.1' LT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 798.0 (MSL) EOB: 15.0 ft.
LAT / LONG: 39.933032, -82.827573

EXPLORATION ID
B-091-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 798.0
0.3' - TOPSOIL (3.5")	797.7
VERY STIFF TO HARD, BROWN AND GRAY **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, DAMP TO MOIST. -ORGANICS IN SS-1B	794.8
VERY STIFF, REDDISH BROWN **SILTY CLAY**, SOME COARSE TO FINE SAND, DAMP TO MOIST.	790.0
MEDIUM DENSE, GRAY **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, MOIST.	783.0

DEPTHS: W (10.5); W 786.0 (12.0); EOB (15)

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
4 4 5	13	64	SS-SS-1A	-	-	-	-	-	-	-	-	-	-	
			SS-1B	4.5+	-	-	-	-	-	-	-	-	19	A-6a (V)
6 6 8	20	42	SS-2	4.00	-	-	-	-	-	-	-	-	17	A-6a (V)
8 5 7	17	83	SS-3	2.50	0	15	16	28	41	33	17	16	26	A-6b (9)
4 6 6	17	75	SS-4	2.50	-	-	-	-	-	-	-	-	16	A-6b (V)
5 8 7	22	53	SS-5	-	33	20	15	16	16	23	17	6	13	A-2-4 (0)
2 3 6	13	56	SS-6	-	-	-	-	-	-	-	-	-	14	A-2-4 (V)
5 7 10	24	81	SS-7	-	-	-	-	-	-	-	-	-	14	A-2-4 (V)

NOTES: SEEPAGE @ 10.5'; GROUNDWATER ENCOUNTERED INITIALLY @ 12.0' AND AT COMPLETION @ 12.0'; CAVE-IN DEPTH @ 13.2'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: RETAINING WALL
PID: 98232 SFN: N/A
START: 7/7/20 END: 7/7/20

DRILLING FIRM / OPERATOR: RII / TG/KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 3.25" HSA
SAMPLING METHOD: SPT

DRILL RIG: CME 55 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 84.2

STATION / OFFSET: 1596+40.12 / 8.1' LT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 797.7 (MSL) EOB: 15.5 ft.
LAT / LONG: 39.933001, -82.827387

EXPLORATION ID
B-092-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 797.7	DEPTHS
0.2' - TOPSOIL (2.0")	797.5	
VERY STIFF, BROWN **SILT AND CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST. -LIMESTONE FRAGMENTS AND ORGANICS IN SS-1B	794.2	▽ 794.5
VERY STIFF, BROWN AND GRAY **SILTY CLAY**, LITTLE COARSE TO FINE SAND, TRACE FINE GRAVEL, MOIST.	792.2	
VERY STIFF, BROWN AND DARK BROWN **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, MOIST.	789.7	W 789.7
MEDIUM DENSE, BROWN TO GRAY **GRAVEL WITH SAND AND SILT**, LITTLE CLAY, MOIST. -HEAVING SOILS @ 8.0'	782.2	EOB

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)
6 8 8	22	33	SS-1A	-	-	-	-	-	-	-	-	-	-	
			SS-1B	-	-	-	-	-	-	-	-	-	-	A-6a (V)
5 7 6	18	33	SS-2	-	-	-	-	-	-	-	-	-	-	A-6a (V)
12	-	100	2S-2A	3.75	-	-	-	-	-	-	-	-	18	A-6a (V)
3 5 6	15	100	SS-3	3.00	-	-	-	-	-	-	-	-	21	A-6b (V)
7 7 10	24	44	SS-4	3.75	26	13	15	30	16	24	16	8	13	A-4a (2)
10 10 7	24	72	SS-5	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)
4 4 4	11	67	SS-6	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)
5 6 7	18	83	SS-7	-	-	-	-	-	-	-	-	-	12	A-2-4 (V)

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 8.0' AND AT COMPLETION @ 3.2'; CAVE-IN DEPTH @ 8.4'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 50 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-070-22.85
TYPE: ROADWAY
PID: 98232 SFN:
START: 7/7/20 END: 7/7/20

DRILLING FIRM / OPERATOR: RII / TG/KC
SAMPLING FIRM / LOGGER: RII / LH
DRILLING METHOD: 4.5" CFA
SAMPLING METHOD: SPT

DRILL RIG: MOBILE B53 (SN 386345)
HAMMER: AUTOMATIC
CALIBRATION DATE: 9/14/20
ENERGY RATIO (%): 83.6

STATION / OFFSET: 1597+94.42 / 6.8' RT
ALIGNMENT: BL IR 70 WB-CD
ELEVATION: 803.3 (MSL) EOB: 10.0 ft.
LAT / LONG: 39.932898, -82.826851

EXPLORATION ID
B-094-0-19

PAGE
1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 803.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.3' - TOPSOIL (3.0")	803.0																	
VERY STIFF TO HARD, BROWN TO GRAY **SANDY SILT**, "AND" FINE GRAVEL, LITTLE CLAY, DRY TO MOIST.		1	9 17 18	49	81	SS-1	4.5+	-	-	-	-	-	-	-	-	5	A-4a (V)	
		2	1 9 10	26	44	SS-2	4.5+	36	15	10	26	13	26	18	8	7	A-4a (1)	
		3																
		W 4	2 3 2	7	72	SS-3	2.50	-	-	-	-	-	-	-	-	10	A-4a (V)	
	797.8	5																
VERY STIFF, GRAYISH BROWN WITH ORANGE **CLAY**, "AND" SILT, TRACE COARSE TO FINE SAND, MOIST.		6																
		7	4 4 4	11	100	SS-4	3.00	0	2	5	41	52	61	20	41	24	A-7-6 (20)	
		8																
		9	6 6 7	18	100	SS-5	2.50	-	-	-	-	-	-	-	-	22	A-7-6 (V)	
	793.3	EOB 10																

NOTES: SEEPAGE @ 4.0'; GROUNDWATER NOT ENCOUNTERED DURING DRILLING

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 25 LBS BENTONITE CHIPS AND SOIL CUTTINGS .

APPENDIX IV

HISTORIC BORING LOGS:

B-007-0-65

No. 10 sieve

LOG OF BORING

Date Started 4-27-65
Date Completed 4-28-65
Boring No. B-7

Sampler Type SS Dia. 1 3/8"
Casing: Length 25' Dia. 3 1/2"
Station & Offset 20+81, 48' Lt (FORWARD PIER)

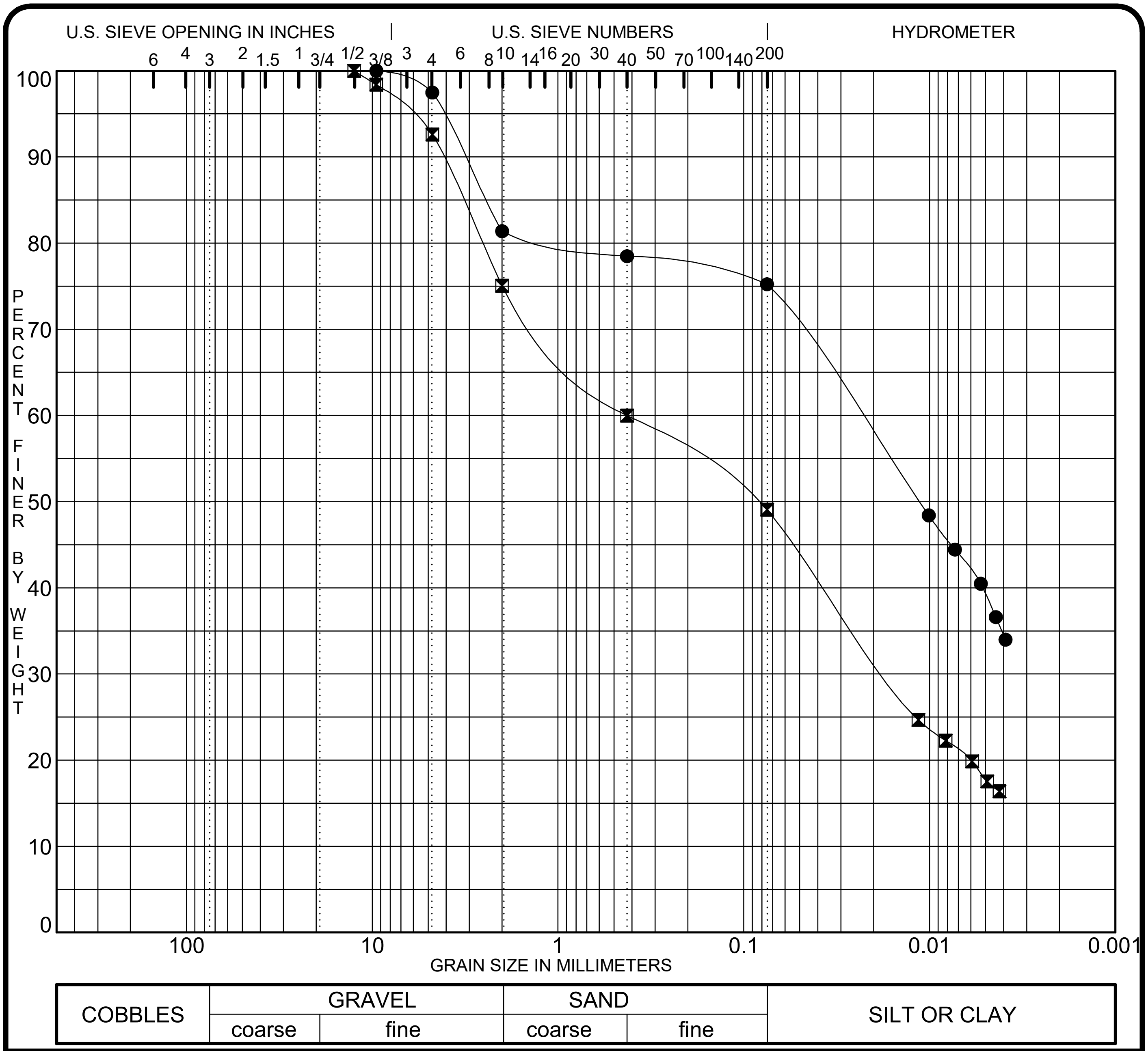
Water Elev.
Surface Elev. 793.4'

							Physical Characteristics								
Elev.	Depth	Std. Pen. (N)	Rec. ft.	Loss ft.	Description	Sample No.	% Agg.	% C.S.	% F.S.	% Silt	% Clay	L.L.	P.I.	W.C.	SHTL Class.
793.4	0														
	2														
	4														
788.4															
	6	23/20			Brown Silty Sandy Gravel	1	63	15	3	11	8	28	8	13	
785.9															
	8	13/18			Brown Sandy Gravel	2	79	15	3	-3-		NP	NP	9	
783.4	10														
		33/32			Brown Sandy Gravel	3	74	15	4	-7-		NP	NP	11	
780.9	12	50* (0.4')			Gray Sandy Gravel	4	68	18	6	-8-		NP	NP	3	
	14														
778.4															
	16	17/31			Gray Silty Sandy Gravel	5	64	18	5	-13-		NP	NP	9	
775.9	18				No Sample Recovered - Boulder.										
773.4	20														
		13/24			Gray Gravelly Clay	6	V	I S	U	A	L	31	16	7	
770.9	22														
	24	12/21			Brown Gravelly Clay	7	V	I S	U	A	L	32	16	10	
768.4															
	26	16/17			Brown Silty Sandy Gravel	8	V	I S	U	A	L			8	
	28														
763.4	30														
		22/31			Gray Sandy Gravelly Silt	9	27	9	14	31	19	22	8	11	
	32														
	34														
758.4															
	36	21/34			Gray Silty Sandy Gravel	10	47	8	9	17	19	22	6	10	
	38														
753.4	40				BOTTOM OF BORING										
752.4		13/26			Gray Gravelly Silt	11	30	9	5	30	26	23	9	11	

*Refusal

APPENDIX V

LABORATORY TEST RESULTS



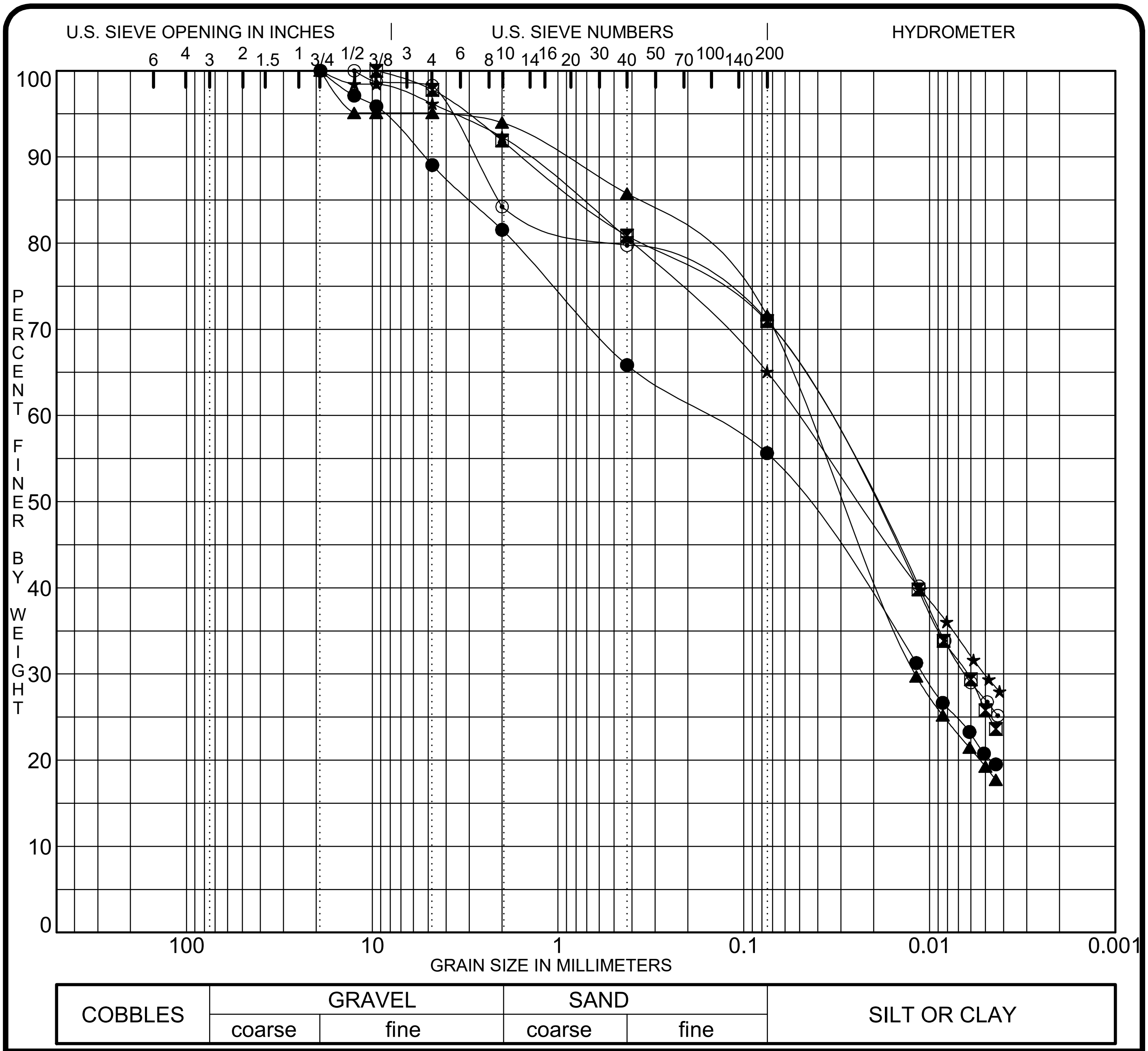
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-039-0-19**	**3.5**	**A-7-6**	**32**	**51**	**29**	**22**		
⧗	**B-039-0-19**	**14.0**	**A-4a**	**10**	**23**	**15**	**8**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-039-0-19**	**0.024**	**0.011**			**0.0**	**18.6**	**2.9**	**3.3**	**36.0**	**39.3**
⧗	**B-039-0-19**	**0.425**	**0.087**	**0.017**		**0.0**	**24.9**	**15.1**	**10.9**	**31.3**	**17.8**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



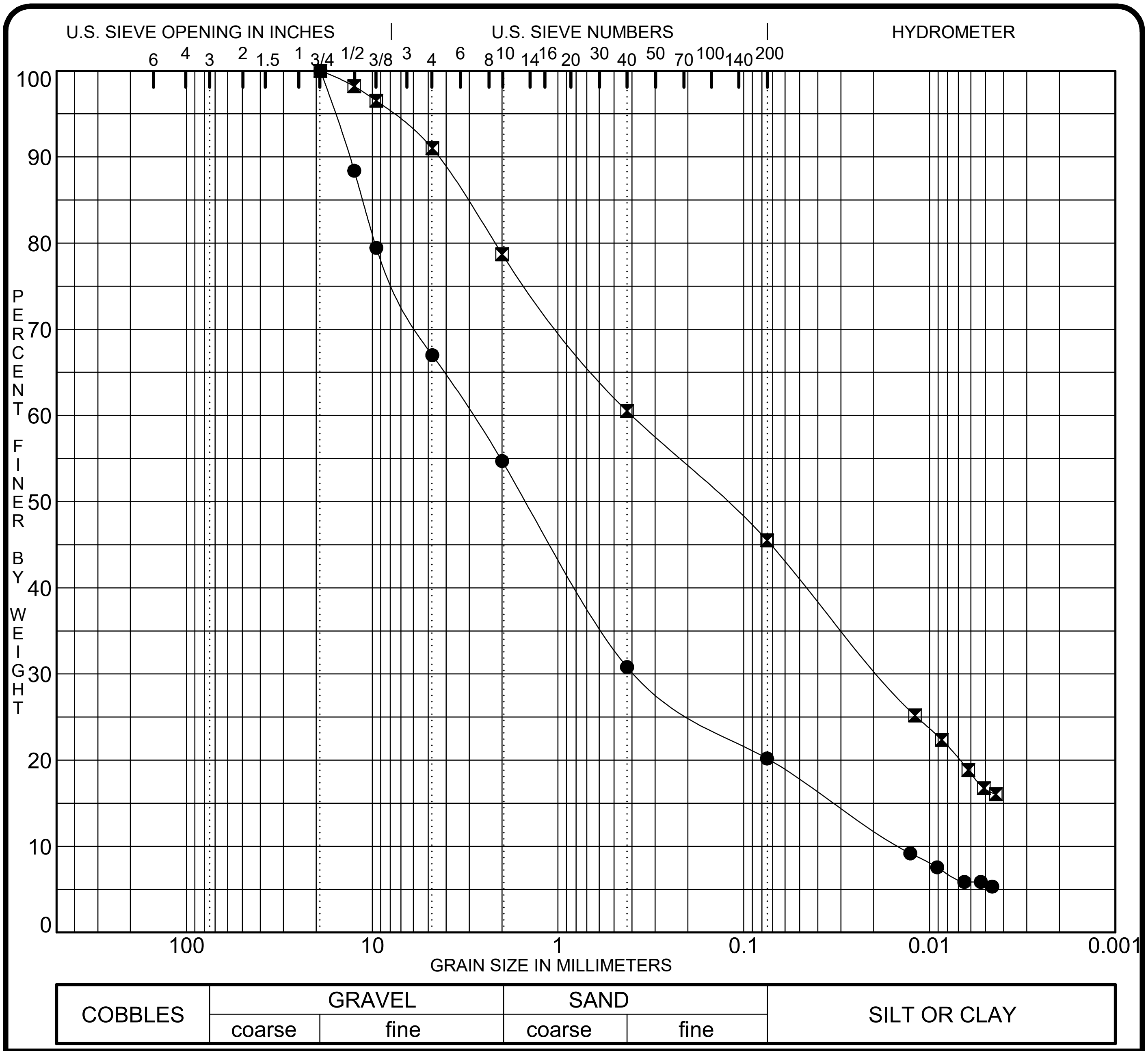
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-040-0-19**	**0.2**	**A-6b**	**16**	**40**	**21**	**19**		
⧗	**B-040-0-19**	**1.5**	**A-6b**	**19**	**38**	**20**	**18**		
▲	**B-040-0-19**	**6.0**	**A-4b**	**21**	**27**	**18**	**9**		
★	**B-040-0-19**	**17.5**	**A-6a**	**17**	**25**	**14**	**11**		
⊙	**B-040-1-21**	**3.5**	**A-6b**	**25**	**37**	**18**	**19**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-040-0-19**	**0.158**	**0.049**	**0.011**		**0.0**	**18.5**	**15.7**	**10.2**	**35.0**	**20.6**
⧗	**B-040-0-19**	**0.039**	**0.021**	**0.006**		**0.0**	**8.1**	**11.0**	**9.9**	**45.2**	**25.8**
▲	**B-040-0-19**	**0.045**	**0.029**	**0.012**		**0.0**	**6.0**	**8.2**	**14.2**	**52.4**	**19.2**
★	**B-040-0-19**	**0.051**	**0.024**	**0.005**		**0.0**	**7.7**	**11.7**	**15.5**	**35.2**	**29.9**
⊙	**B-040-1-21**	**0.038**	**0.021**	**0.006**		**0.0**	**15.8**	**4.5**	**8.6**	**44.2**	**27.0**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



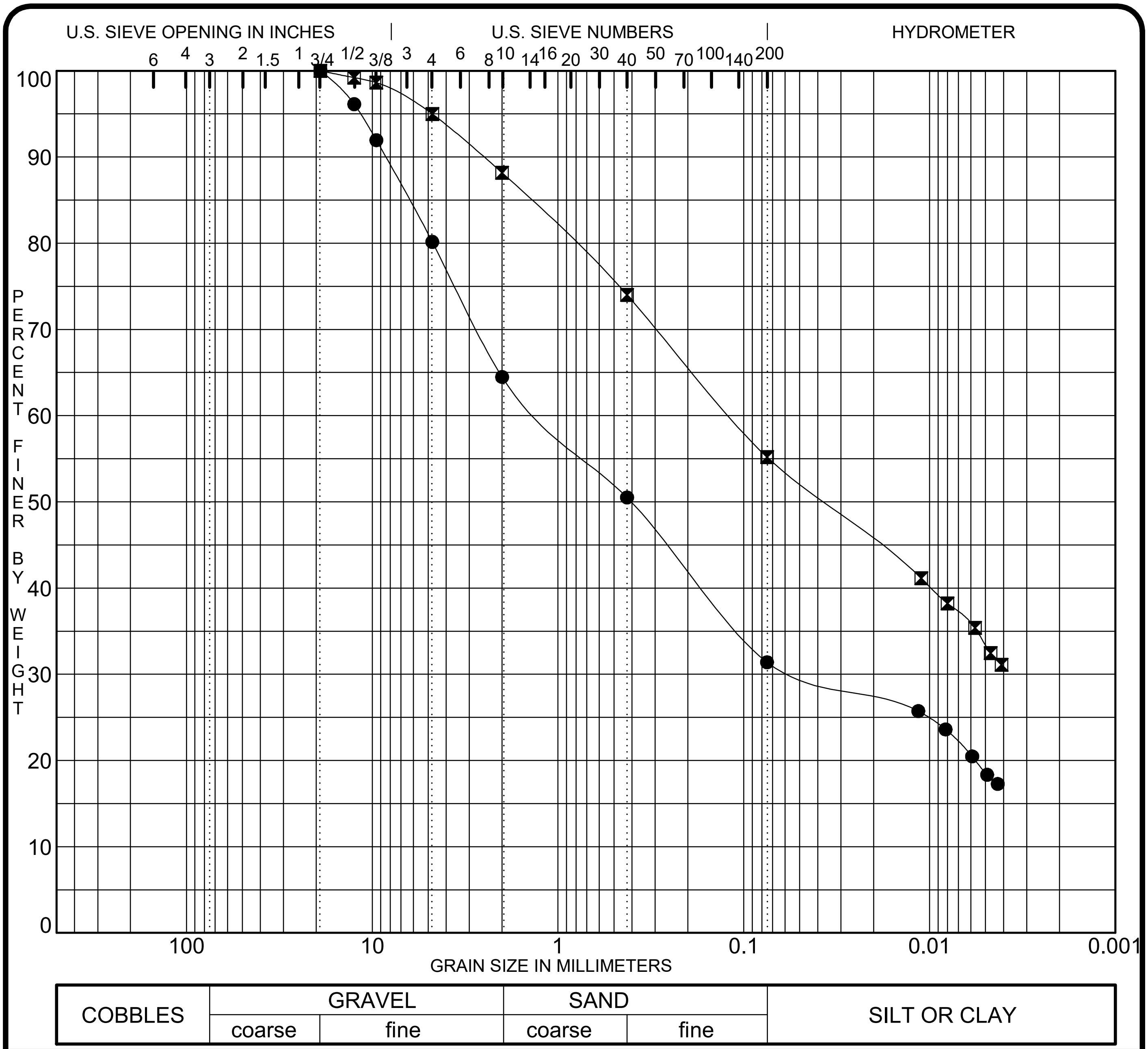
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-040-1-21**	**8.5**	**A-1-b**	**11**	**22**	**16**	**6**	**3.31**	**200.3**
☒	**B-040-1-21**	**13.5**	**A-4a**	**8**	**22**	**13**	**9**		

	Specimen Identification	D60	D50	D30	D10	%Gravel coarse	%Gravel fine	%Sand coarse	%Sand fine	%Silt	%Clay
●	**B-040-1-21**	**2.903**	**1.474**	**0.373**	**0.0145**	**0.0**	**45.3**	**23.9**	**10.6**	**14.5**	**5.6**
☒	**B-040-1-21**	**0.401**	**0.126**	**0.019**		**0.0**	**21.3**	**18.2**	**15.0**	**28.8**	**16.7**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



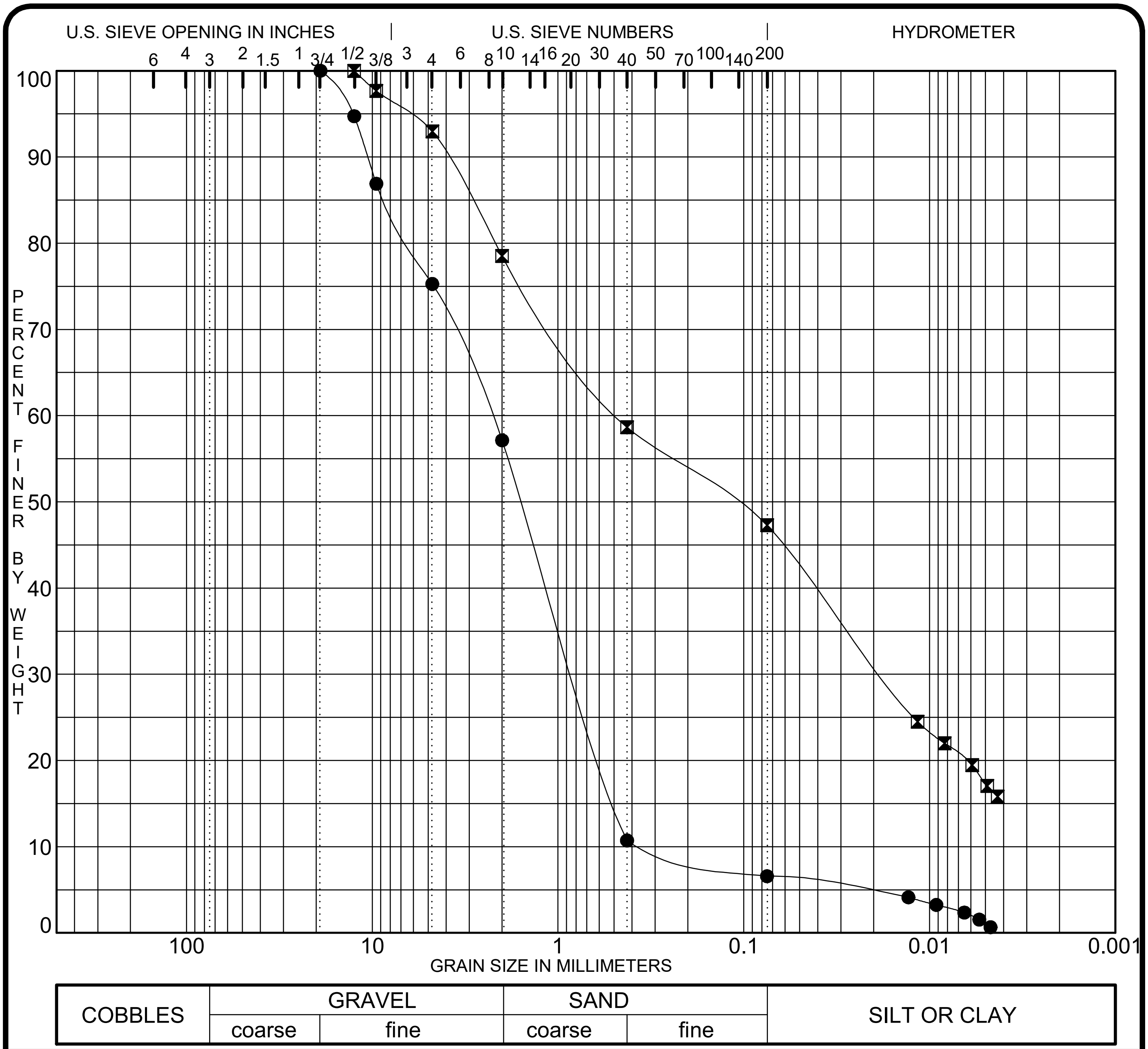
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-041-0-19**	**8.5**	**A-2-4**	**15**	**19**	**17**	**2**		
☒	**B-041-0-19**	**16.0**	**A-6a**	**15**	**28**	**16**	**12**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-041-0-19**	**1.217**	**0.406**	**0.047**		**0.0**	**35.5**	**14.0**	**19.1**	**12.8**	**18.6**
☒	**B-041-0-19**	**0.117**	**0.037**			**0.0**	**11.8**	**14.2**	**18.8**	**21.8**	**33.4**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



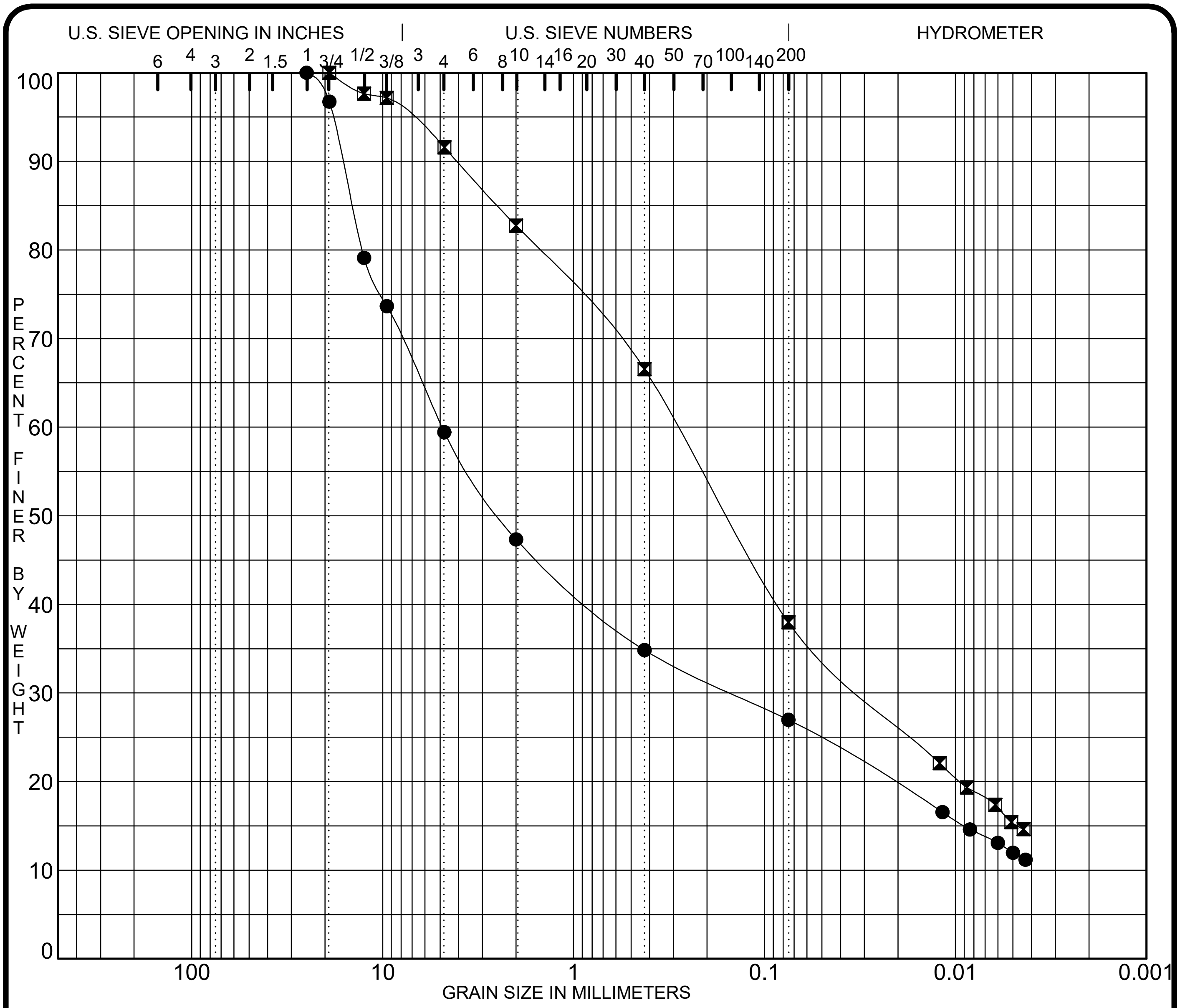
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-042-0-19**	**6.0**	**A-1-b**	**17**	**NP**	**NP**	**NP**	**0.91**	**7.3**
☒	**B-042-0-19**	**16.0**	**A-4a**	**13**	**23**	**15**	**8**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-042-0-19**	**2.293**	**1.576**	**0.809**	**0.3148**	**0.0**	**42.9**	**46.4**	**4.1**	**5.5**	**1.1**
☒	**B-042-0-19**	**0.472**	**0.114**	**0.018**		**0.0**	**21.5**	**19.9**	**11.4**	**30.0**	**17.3**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



COBBLES	GRAVEL		SAND		SILT OR CLAY
	coarse	fine	coarse	fine	

	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-043-0-19**	**6.0**	**A-2-4**	**8**	**22**	**17**	**5**		
☒	**B-043-0-19**	**13.5**	**A-4a**	**14**	**18**	**15**	**3**		

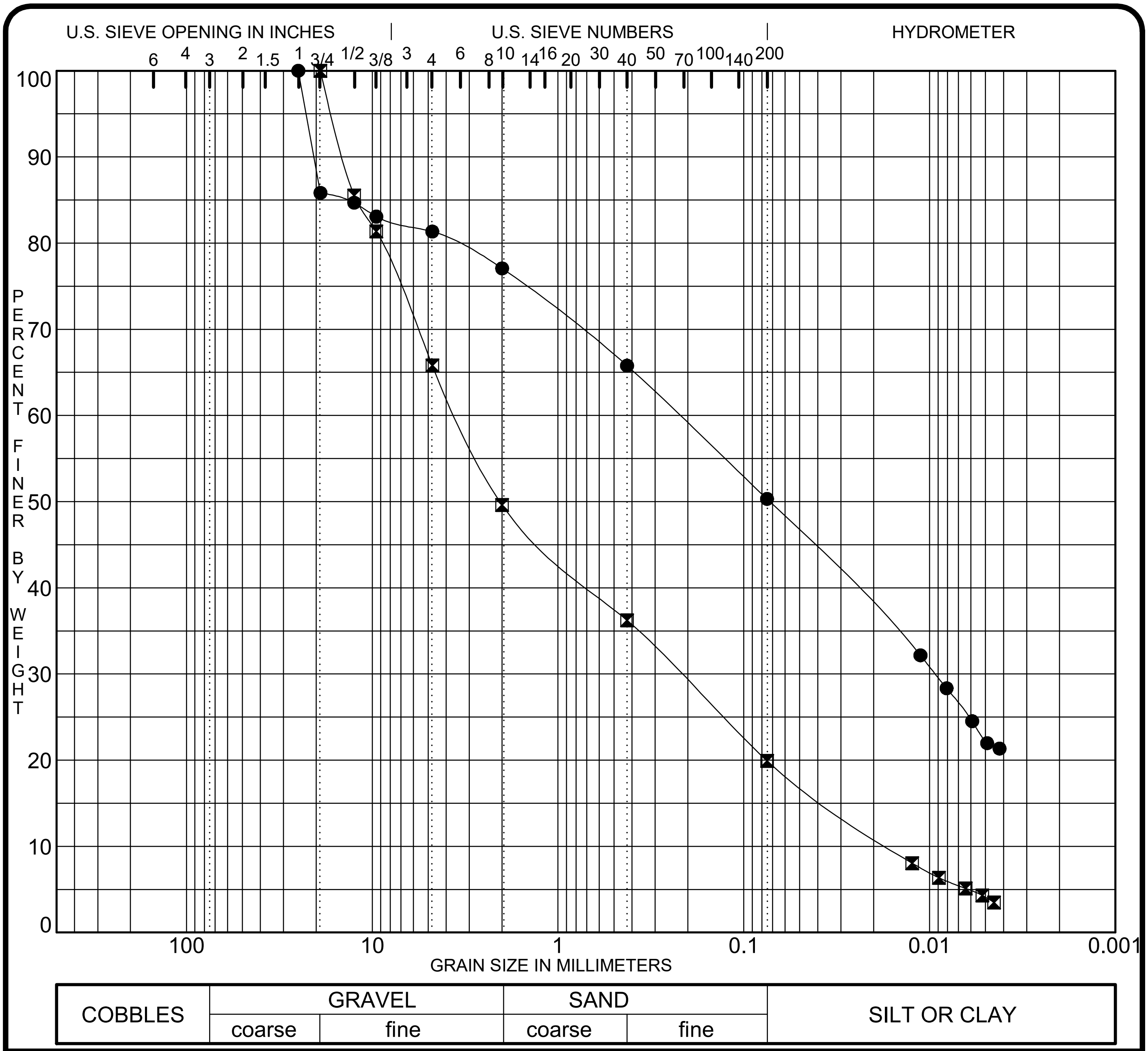
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-043-0-19**	**4.883**	**2.420**	**0.146**		**3.3**	**49.4**	**12.5**	**7.9**	**15.0**	**12.0**
☒	**B-043-0-19**	**0.286**	**0.156**	**0.030**		**0.0**	**17.3**	**16.2**	**28.6**	**22.7**	**15.3**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



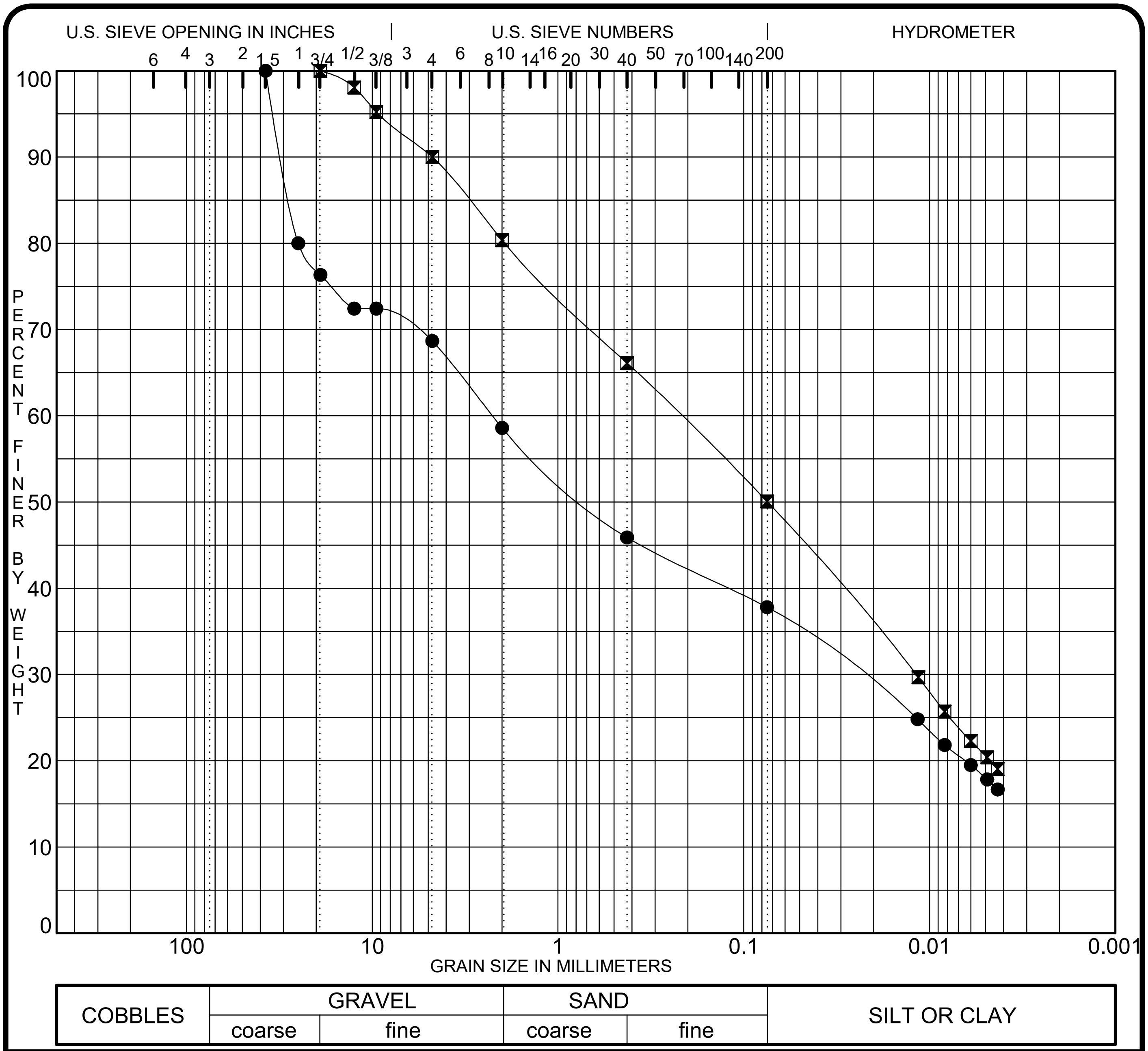
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-044-0-19**	**8.5**	**A-6a**	**13**	**33**	**18**	**15**		
⧗	**B-044-0-19**	**13.5**	**A-1-b**	**11**	**NP**	**NP**	**NP**	**0.83**	**208.8**

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-044-0-19**	**0.222**	**0.073**	**0.009**		**14.2**	**8.8**	**11.3**	**15.5**	**28.1**	**22.3**
⧗	**B-044-0-19**	**3.483**	**2.042**	**0.219**	**0.0167**	**0.0**	**50.4**	**13.4**	**16.3**	**15.8**	**4.1**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-045-0-19**	**11.0**	**A-6b**	**15**	**35**	**17**	**18**		
⧗	**B-045-0-19**	**23.5**	**A-4a**	**14**	**22**	**13**	**9**		

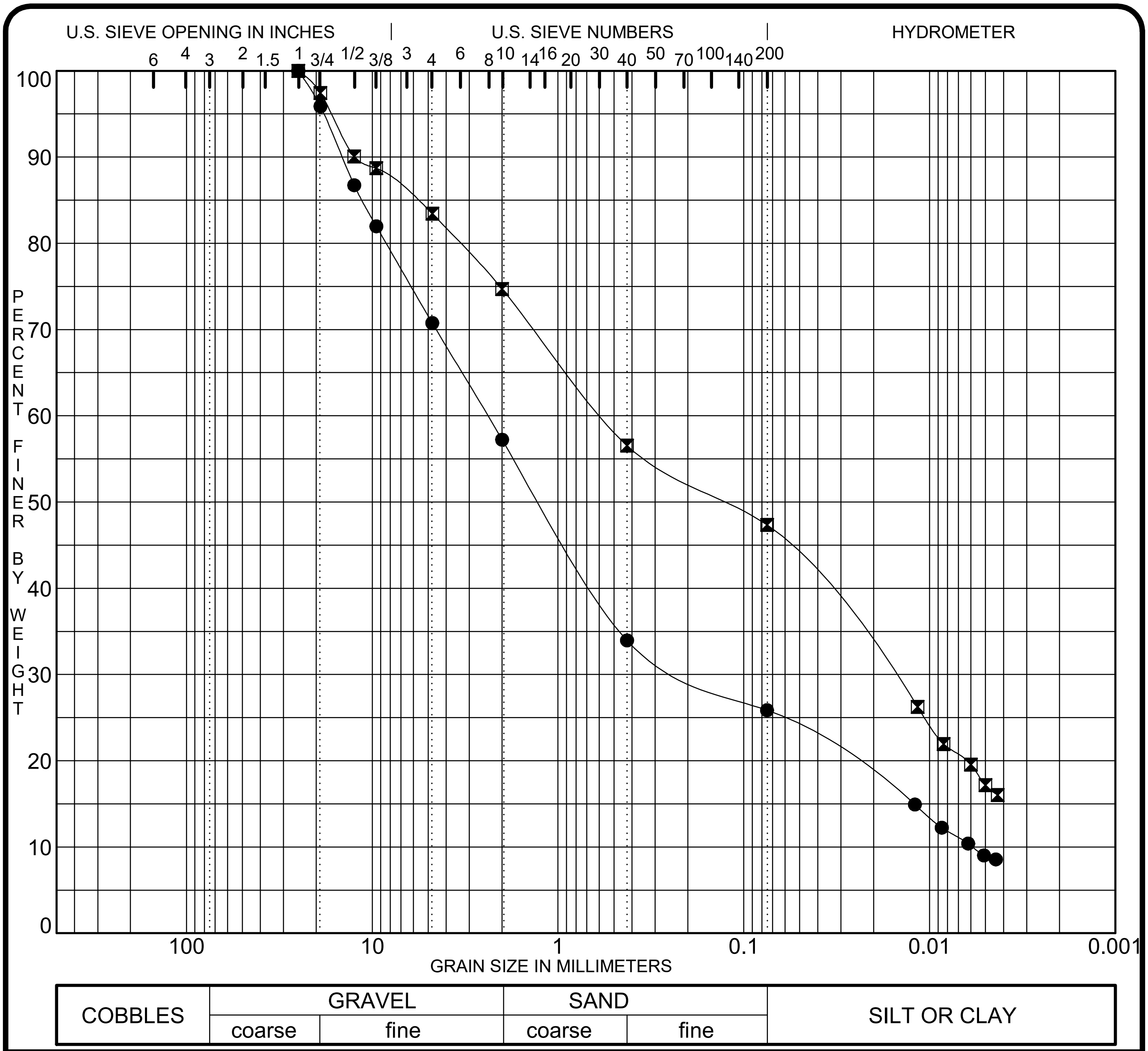
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-045-0-19**	**2.257**	**0.702**	**0.024**		**23.7**	**17.7**	**12.7**	**8.1**	**19.8**	**18.0**
⧗	**B-045-0-19**	**0.219**	**0.075**	**0.012**		**0.0**	**19.6**	**14.2**	**16.0**	**29.5**	**20.6**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



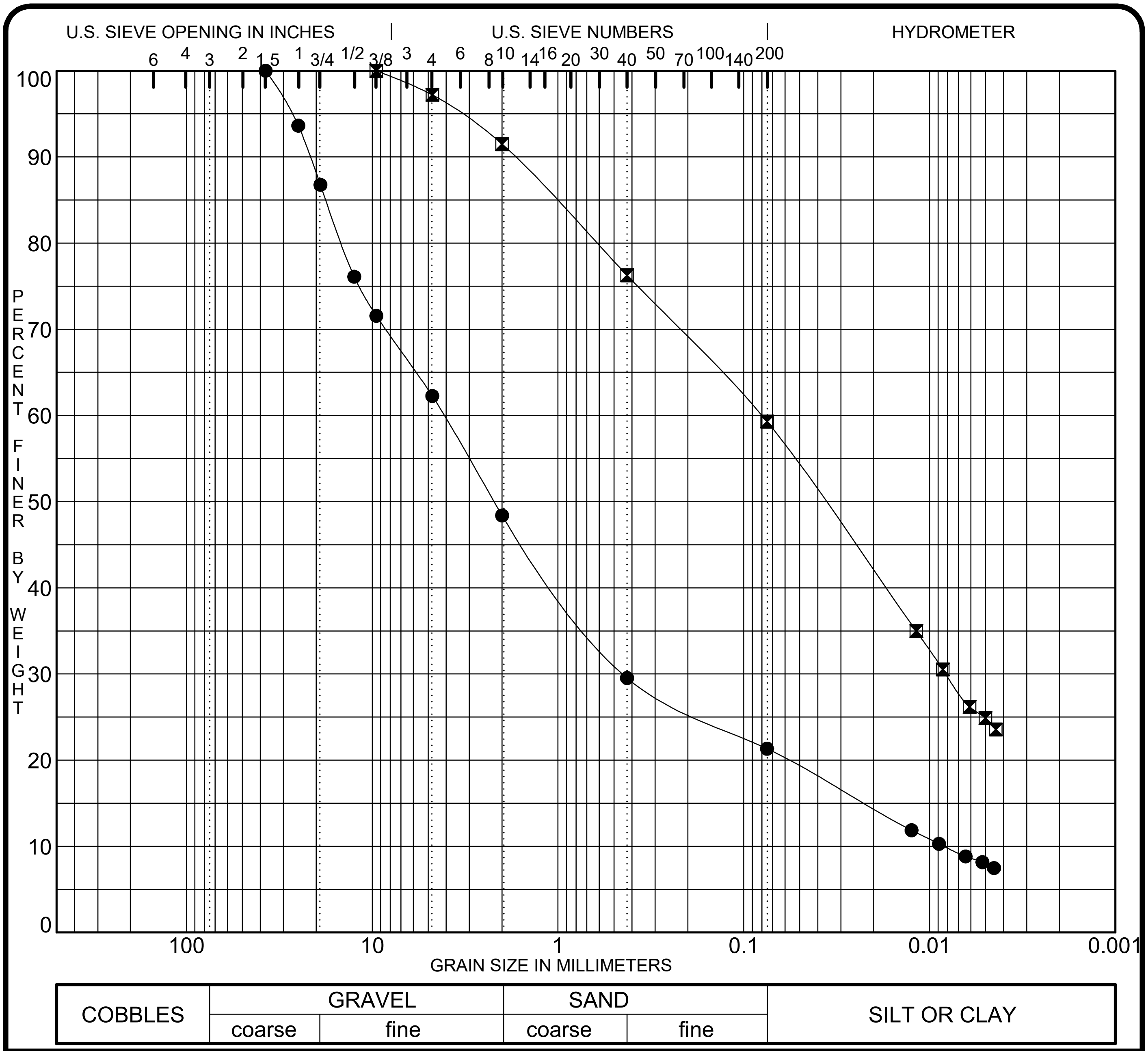
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-046-0-19**	**13.5**	**A-2-4**	**9**	**25**	**18**	**7**	**2.37**	**407.3**
☒	**B-046-0-19**	**18.5**	**A-4a**	**14**	**28**	**19**	**9**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-046-0-19**	**2.388**	**1.236**	**0.182**	**0.0059**	**4.1**	**38.7**	**23.3**	**8.1**	**16.9**	**9.0**
☒	**B-046-0-19**	**0.571**	**0.124**	**0.016**		**2.6**	**22.7**	**18.2**	**9.2**	**30.2**	**17.2**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



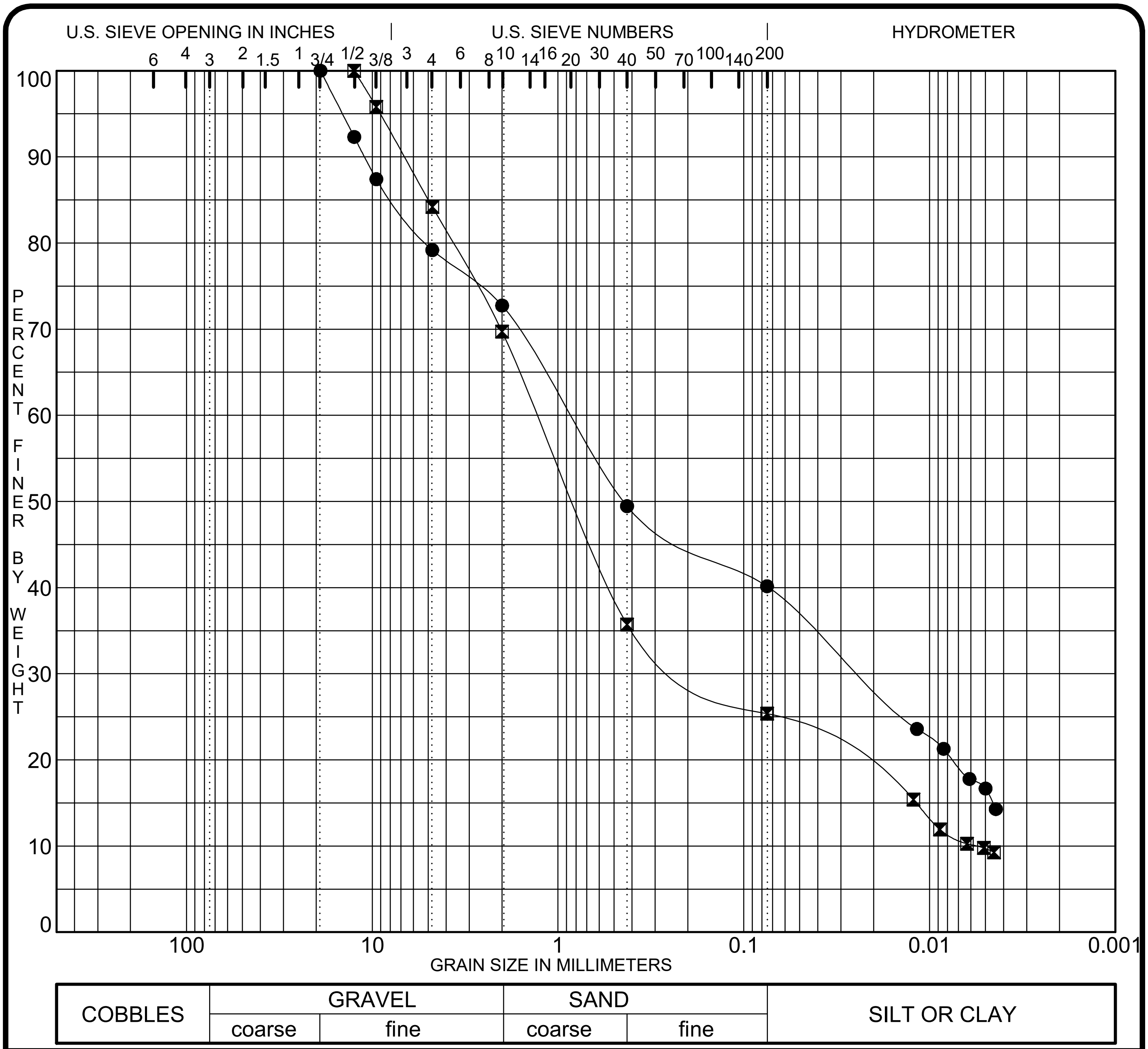
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-046-0-19A**	**31.0**	**A-2-6**	**11**	**28**	**17**	**11**	**5.68**	**494.9**
⧗	**B-046-0-19A**	**36.0**	**A-4a**	**12**	**23**	**15**	**8**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-046-0-19A**	**4.125**	**2.211**	**0.442**	**0.0083**	**13.2**	**38.4**	**18.9**	**8.2**	**13.4**	**8.0**
⧗	**B-046-0-19A**	**0.081**	**0.037**	**0.008**		**0.0**	**8.5**	**15.2**	**17.0**	**34.4**	**24.9**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



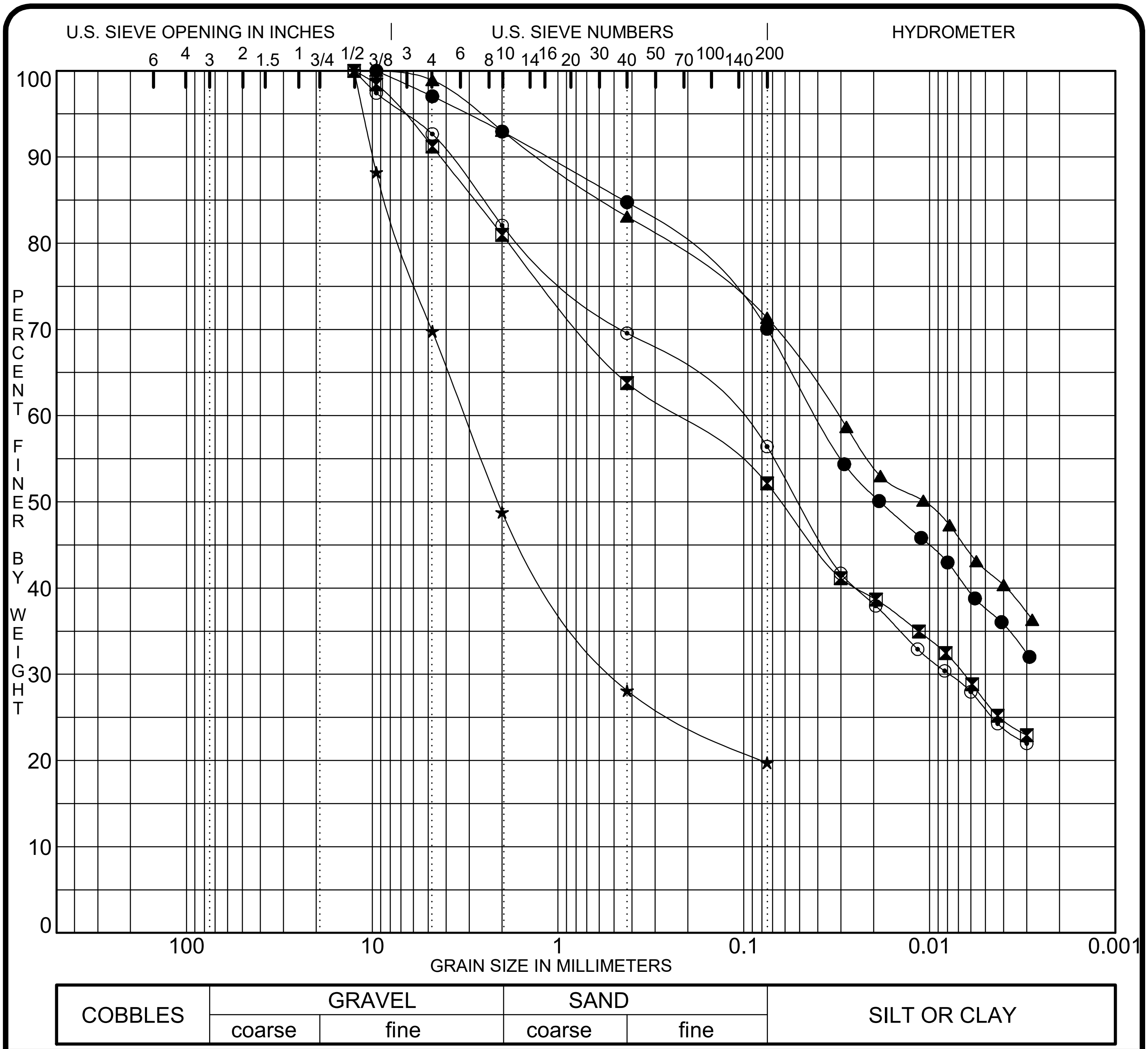
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-047-0-19**	**6.0**	**A-4a**	**13**	**27**	**19**	**8**		
⧗	**B-047-0-19**	**13.5**	**A-1-b**	**14**	**24**	**18**	**6**	**3.69**	**228.8**

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-047-0-19**	**0.857**	**0.441**	**0.024**		**0.0**	**27.3**	**23.3**	**9.3**	**23.5**	**16.7**
⧗	**B-047-0-19**	**1.286**	**0.815**	**0.163**	**0.0056**	**0.0**	**30.3**	**34.0**	**10.3**	**15.7**	**9.7**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-065-0-19**	**11.0**	**A-6b**	**20**	**34**	**18**	**16**		
⧗	**B-065-0-19**	**21.0**	**A-6a**	**12**	**35**	**24**	**11**		
▲	**B-065-0-19**	**33.5**	**A-6b**	**24**	**40**	**20**	**20**		
★	**B-065-0-19**	**48.5**	**A-1-b**	**13**	**NP**	**NP**	**NP**		
⊙	**B-065-0-19**	**63.5**	**A-6a**	**12**	**36**	**23**	**13**		

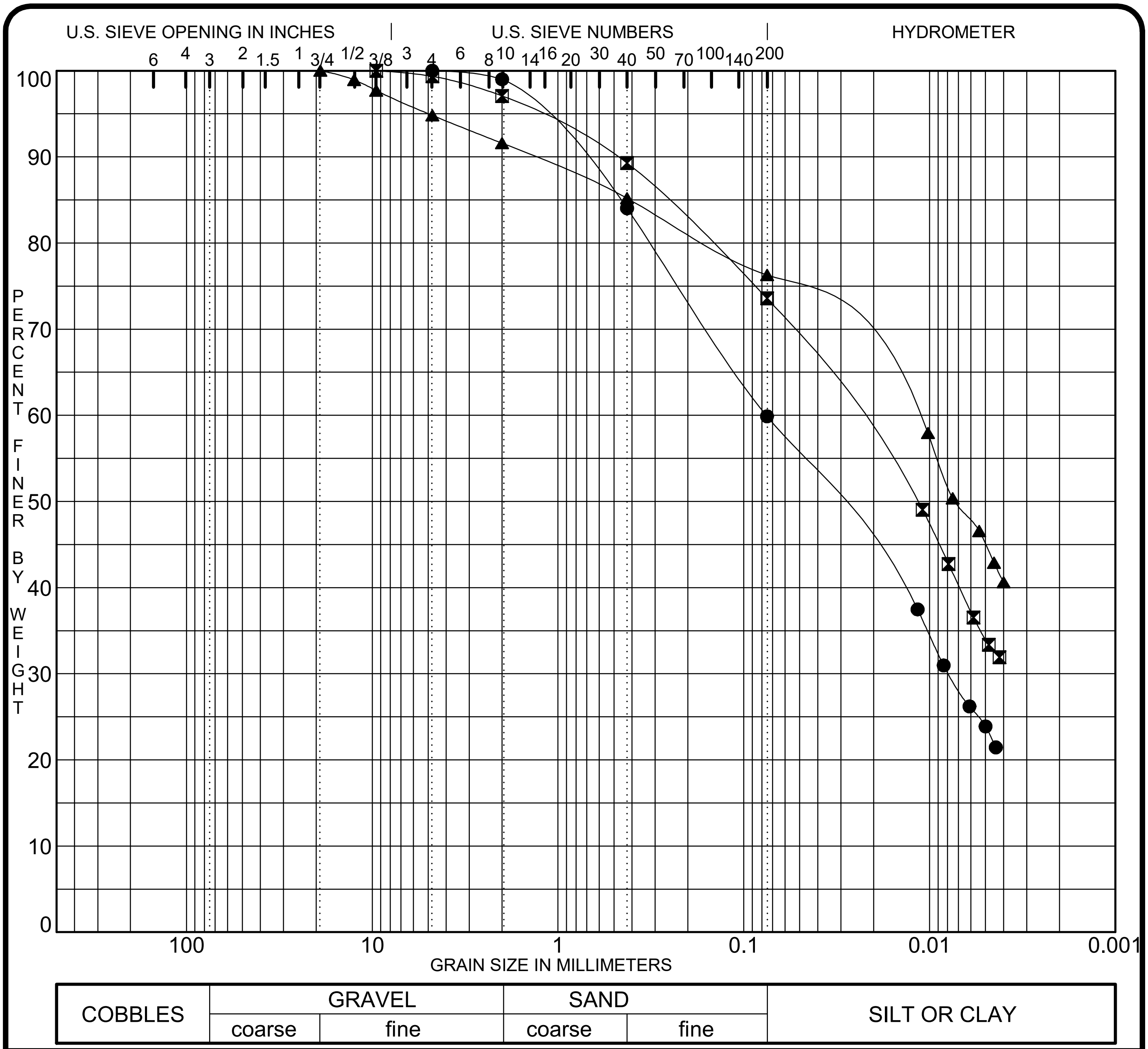
	Specimen Identification	D60	D50	D30	D10	%Gravel coarse	%Gravel fine	%Sand coarse	%Sand fine	%Silt	%Clay
●	**B-065-0-19**	**0.041**	**0.018**			**0.0**	**7.0**	**8.2**	**14.7**	**32.4**	**37.7**
⧗	**B-065-0-19**	**0.242**	**0.063**	**0.007**		**0.0**	**19.0**	**17.2**	**11.6**	**25.2**	**26.9**
▲	**B-065-0-19**	**0.031**	**0.011**			**0.0**	**7.0**	**9.9**	**11.8**	**29.2**	**42.2**
★	**B-065-0-19**	**3.174**	**2.102**	**0.490**		**0.0**	**51.2**	**20.7**	**8.4**	**19.7**	
⊙	**B-065-0-19**	**0.120**	**0.050**	**0.008**		**0.0**	**17.9**	**12.5**	**13.2**	**30.5**	**25.9**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



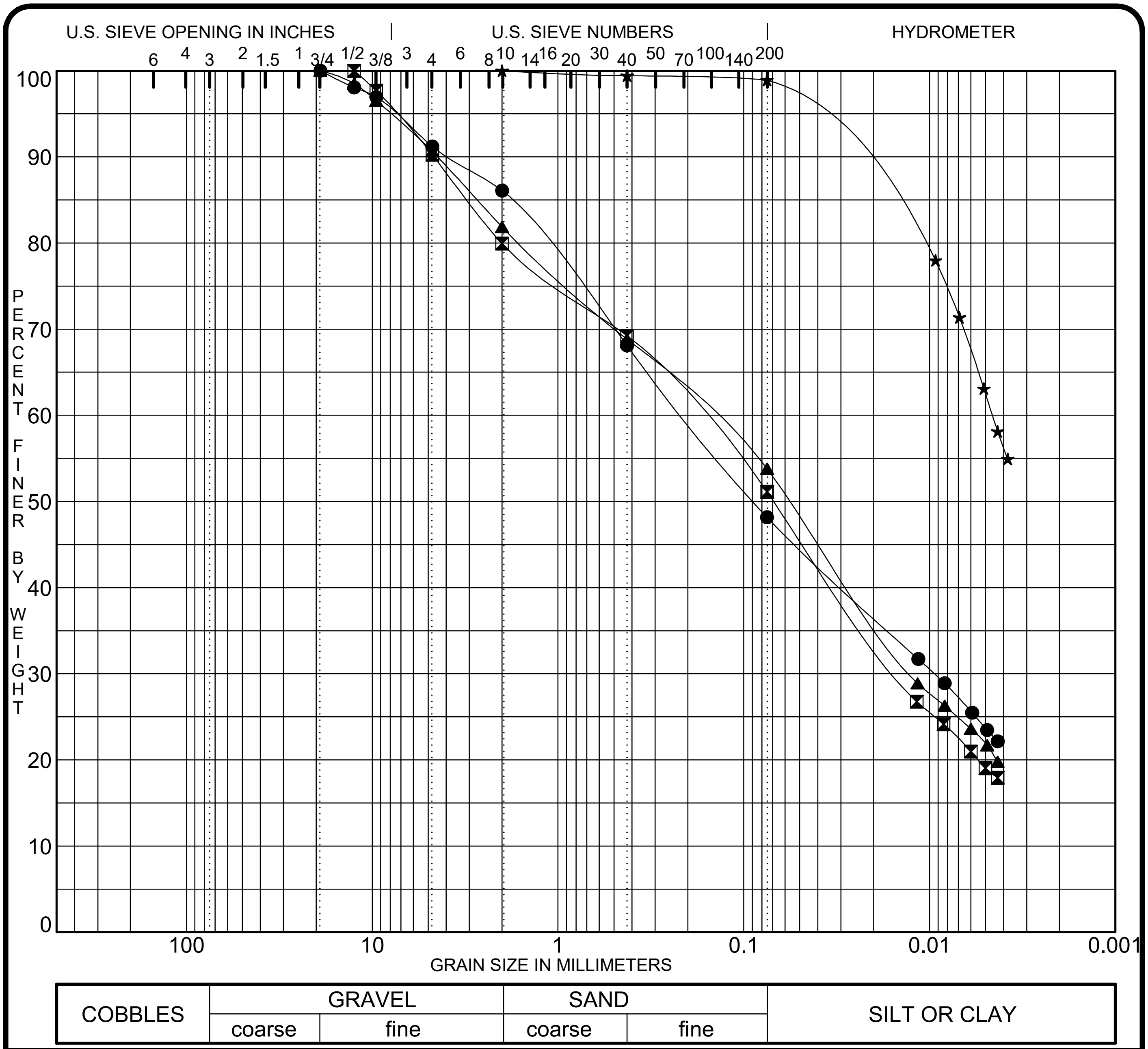
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-066-0-19**	**11.0**	**A-4a**	**29**	**24**	**18**	**6**		
☒	**B-066-0-19**	**33.5**	**A-4a**	**14**	**24**	**15**	**9**		
▲	**B-066-0-19**	**53.5**	**A-6a**	**16**	**29**	**17**	**12**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-066-0-19**	**0.076**	**0.033**	**0.008**		**0.0**	**1.0**	**15.0**	**24.2**	**36.0**	**23.9**
☒	**B-066-0-19**	**0.026**	**0.012**			**0.0**	**2.9**	**7.8**	**15.7**	**39.5**	**34.1**
▲	**B-066-0-19**	**0.013**	**0.007**			**0.0**	**8.4**	**6.4**	**8.9**	**31.3**	**45.0**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



Specimen Identification		Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-067-0-19**	**6.0**	**A-6b**	**23**	**37**	**20**	**17**		
⧗	**B-067-0-19**	**33.5**	**A-4a**	**14**	**25**	**16**	**9**		
▲	**B-067-0-19**	**48.5**	**A-4a**	**11**	**22**	**14**	**8**		
★	**B-067-0-19**	**68.5**	**A-6b**	**25**	**38**	**22**	**16**		

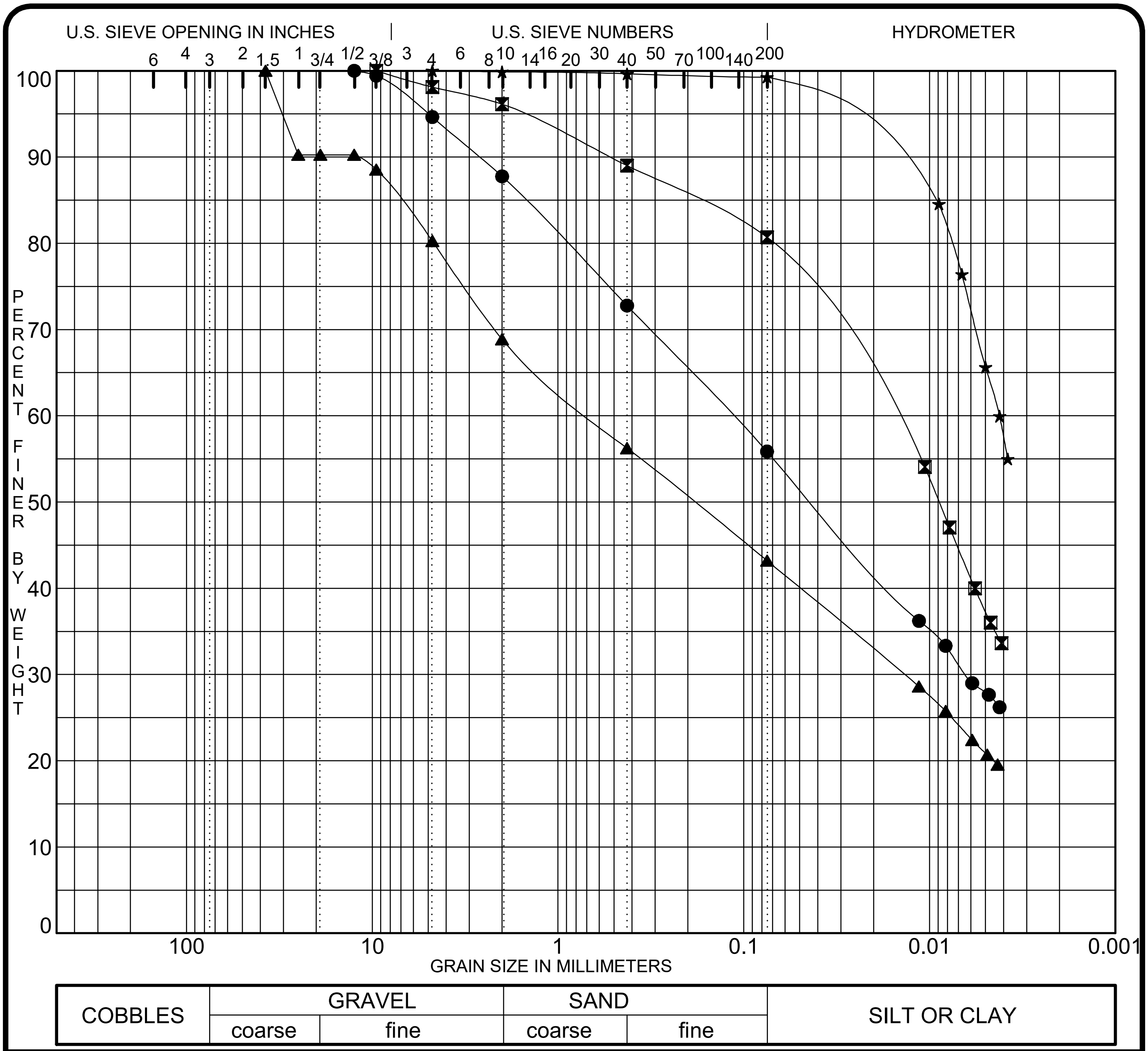
Specimen Identification		D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-067-0-19**	**0.210**	**0.088**	**0.009**		**0.0**	**13.9**	**18.0**	**19.9**	**24.5**	**23.7**
⧗	**B-067-0-19**	**0.176**	**0.069**	**0.015**		**0.0**	**20.1**	**10.7**	**18.1**	**32.1**	**19.0**
▲	**B-067-0-19**	**0.153**	**0.056**	**0.013**		**0.0**	**18.1**	**13.0**	**15.0**	**31.9**	**21.9**
★	**B-067-0-19**	**0.005**				**0.0**	**0.0**	**0.6**	**0.5**	**36.4**	**62.5**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



Specimen Identification		Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-068-0-19**	**3.5**	**A-6a**	**15**	**32**	**17**	**15**		
⧗	**B-068-0-19**	**8.5**	**A-7-6**	**29**	**43**	**25**	**18**		
▲	**B-068-0-19**	**33.5**	**A-4a**	**14**	**22**	**15**	**7**		
★	**B-068-0-19**	**58.5**	**A-6a**	**22**	**35**	**21**	**14**		

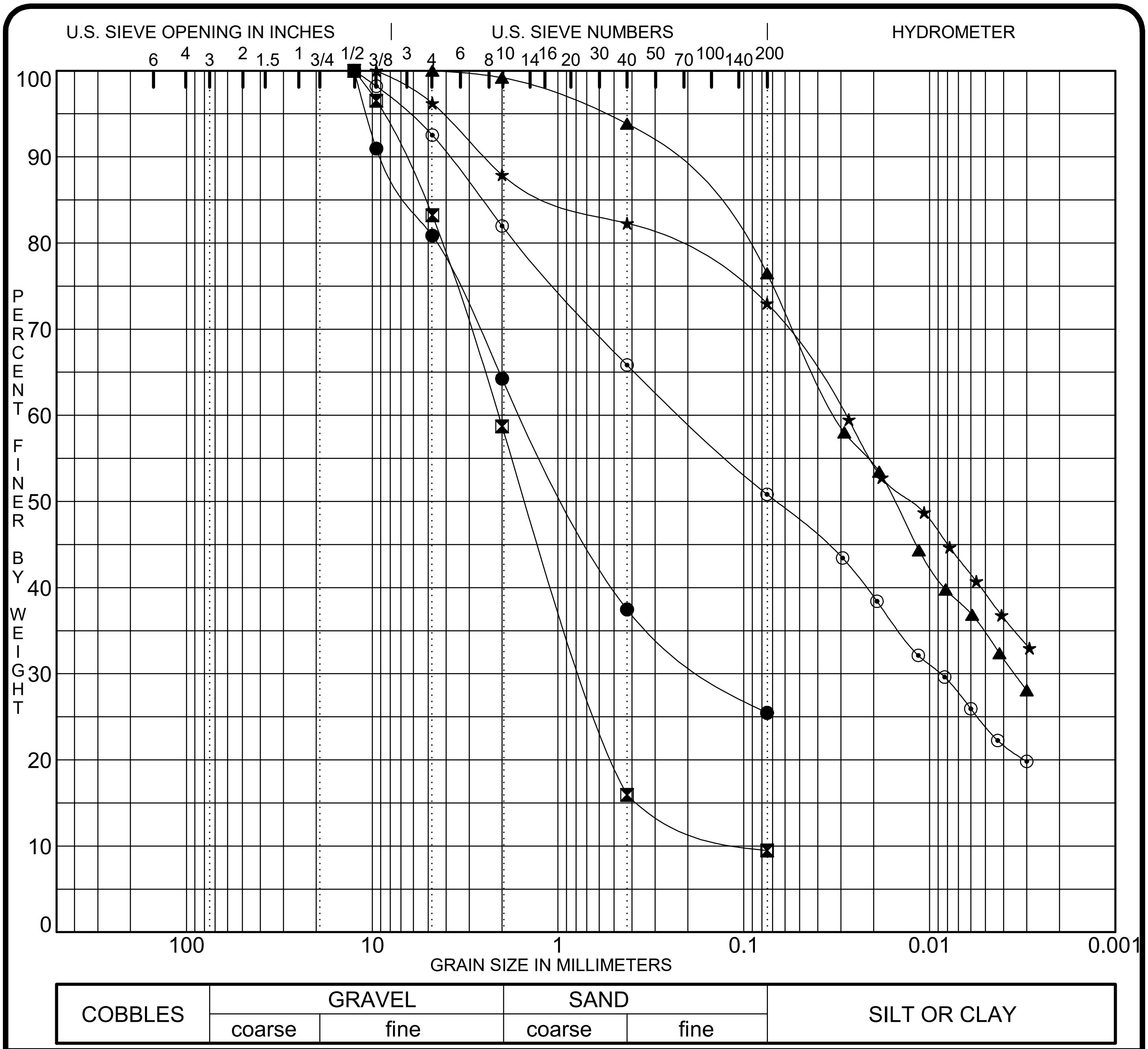
Specimen Identification		D60	D50	D30	D10	%Gravel coarse	%Gravel fine	%Sand coarse	%Sand fine	%Silt	%Clay
●	**B-068-0-19**	**0.115**	**0.043**	**0.006**		**0.0**	**12.2**	**15.0**	**16.9**	**27.9**	**27.9**
⧗	**B-068-0-19**	**0.016**	**0.009**			**0.0**	**3.9**	**7.1**	**8.3**	**43.4**	**37.3**
▲	**B-068-0-19**	**0.674**	**0.185**	**0.014**		**9.7**	**21.4**	**12.6**	**13.0**	**22.3**	**20.9**
★	**B-068-0-19**	**0.004**				**0.0**	**0.1**	**0.2**	**0.4**	**33.6**	**65.6**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



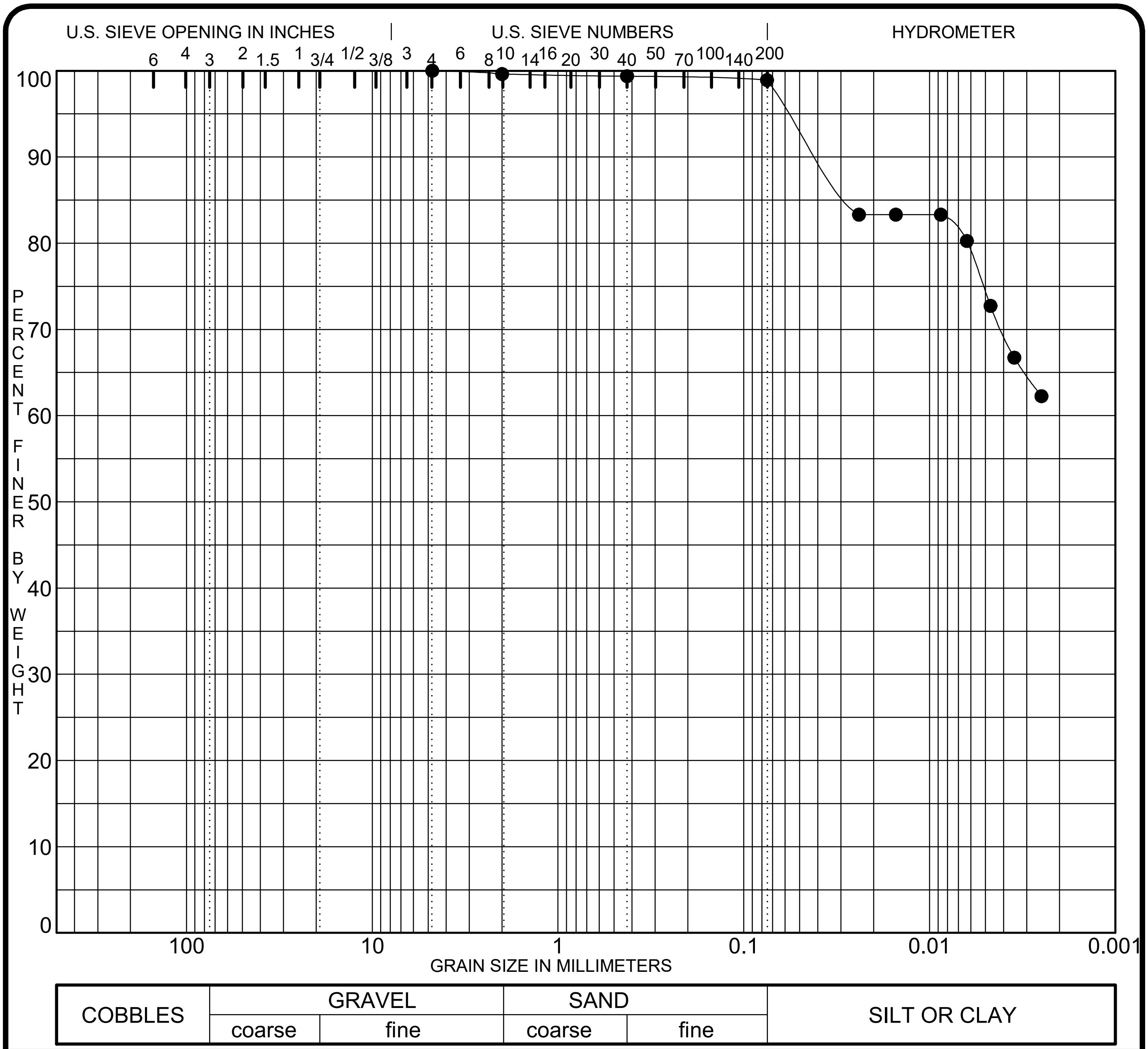
Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
● **B-069-0-19**	**3.5**	**A-1-b**	**13**	**NP**	**NP**	**NP**		
⧗ **B-069-0-19**	**18.5**	**A-1-b**	**13**	**NP**	**NP**	**NP**	**2.78**	**24.3**
▲ **B-069-0-19**	**28.5**	**A-6a**	**36**	**33**	**18**	**15**		
★ **B-069-0-19**	**33.5**	**A-6a**	**17**	**38**	**23**	**15**		
⊙ **B-069-0-19**	**48.5**	**A-6a**	**11**	**36**	**23**	**13**		

Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
					coarse	fine	coarse	fine		
● **B-069-0-19**	**1.564**	**0.877**	**0.145**		**0.0**	**35.7**	**26.8**	**12.0**	**25.5**	
⧗ **B-069-0-19**	**2.092**	**1.459**	**0.707**	**0.0861**	**0.0**	**41.3**	**42.8**	**6.4**	**9.5**	
▲ **B-069-0-19**	**0.032**	**0.016**	**0.003**		**0.0**	**0.8**	**5.3**	**17.4**	**41.8**	**34.7**
★ **B-069-0-19**	**0.028**	**0.013**			**0.0**	**12.1**	**5.6**	**9.3**	**33.7**	**39.3**
⊙ **B-069-0-19**	**0.217**	**0.068**	**0.009**		**0.0**	**18.0**	**16.1**	**15.0**	**26.9**	**23.9**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



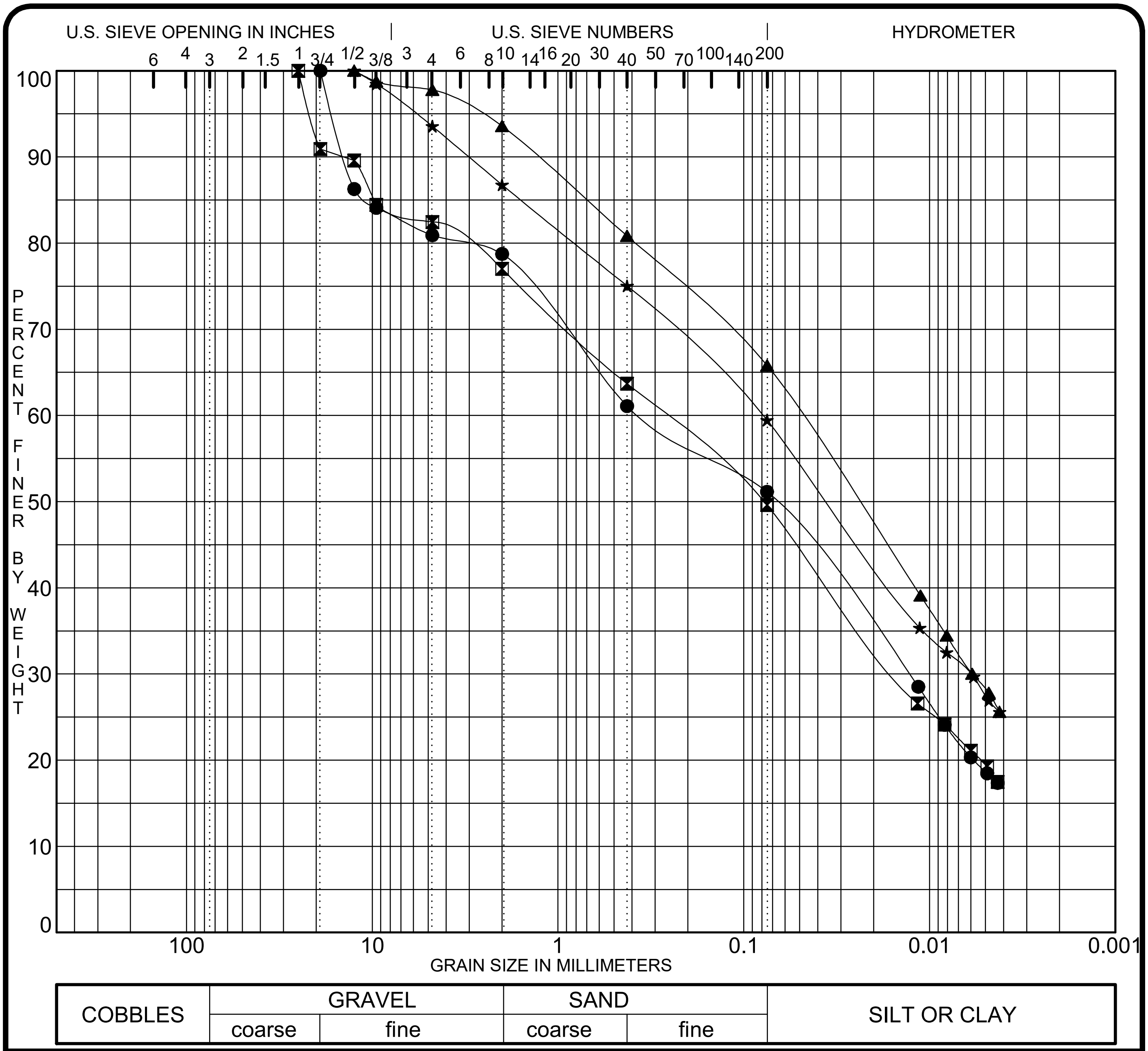
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-069-0-19**	**68.5**	**A-7-6**	**24**	**47**	**23**	**24**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-069-0-19**					**0.0**	**0.4**	**0.2**	**0.5**	**24.6**	**74.3**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



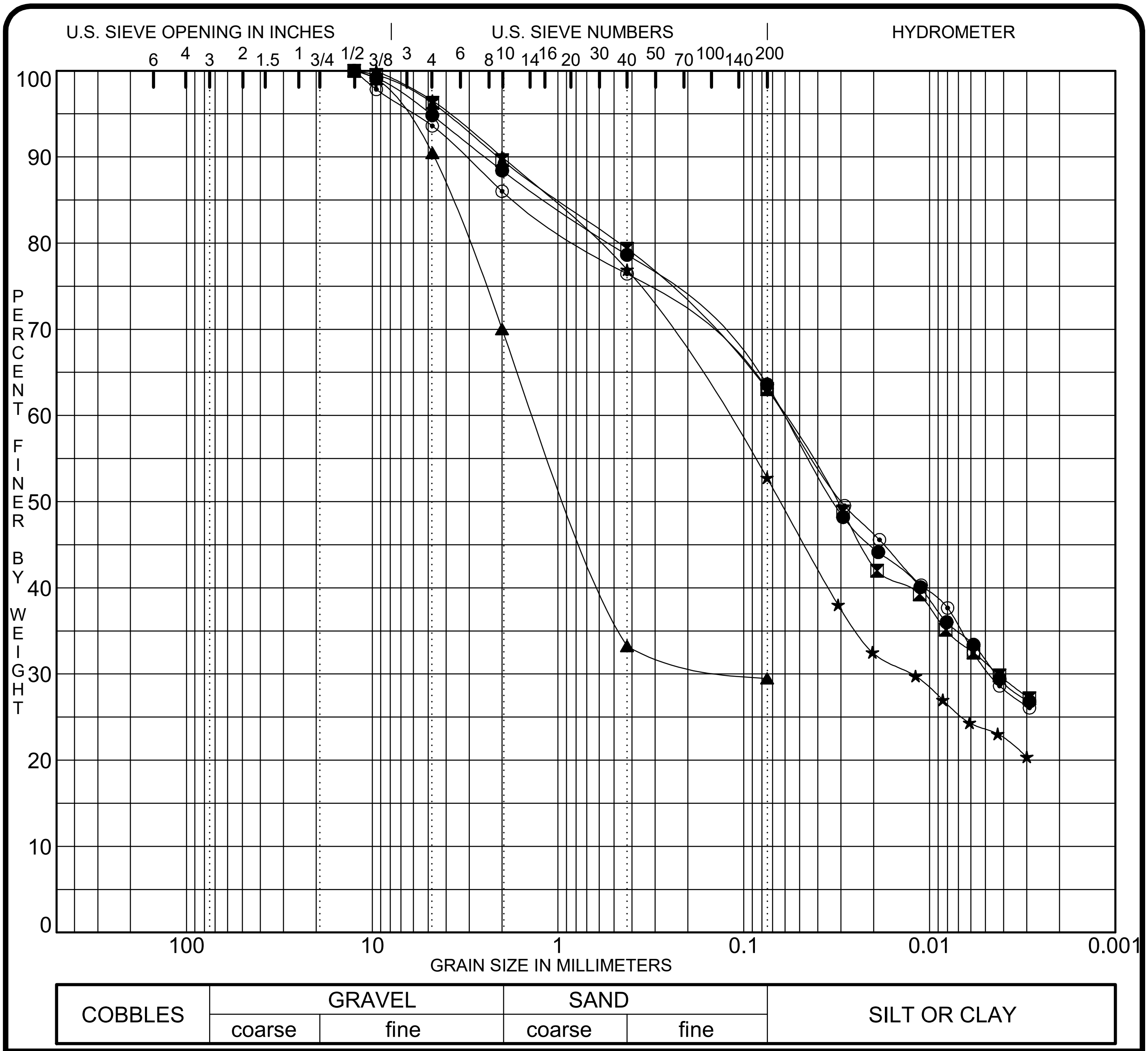
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-070-0-19**	**6.0**	**A-4a**	**13**	**25**	**17**	**8**		
⧗	**B-070-0-19**	**38.5**	**A-4a**	**12**	**22**	**15**	**7**		
▲	**B-070-0-19**	**48.5**	**A-4a**	**10**	**23**	**15**	**8**		
★	**B-070-0-19**	**63.5**	**A-4a**	**17**	**24**	**14**	**10**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-070-0-19**	**0.352**	**0.068**	**0.013**		**0.0**	**21.3**	**17.7**	**9.9**	**32.5**	**18.7**
⧗	**B-070-0-19**	**0.270**	**0.079**	**0.015**		**9.1**	**13.9**	**13.3**	**14.1**	**30.1**	**19.5**
▲	**B-070-0-19**	**0.050**	**0.024**	**0.006**		**0.0**	**6.4**	**12.7**	**15.0**	**37.6**	**28.2**
★	**B-070-0-19**	**0.080**	**0.036**	**0.006**		**0.0**	**13.2**	**11.7**	**15.6**	**32.0**	**27.5**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-071-0-19**	**11.0**	**A-6b**	**13**	**35**	**19**	**16**		
⊠	**B-071-0-19**	**23.5**	**A-6a**	**11**	**34**	**19**	**15**		
▲	**B-071-0-19**	**43.5**	**A-2-4**	**14**	**NP**	**NP**	**NP**		
★	**B-071-0-19**	**58.5**	**A-6b**	**18**	**39**	**21**	**18**		
⊙	**B-071-0-19**	**68.5**	**A-6b**	**12**	**34**	**18**	**16**		

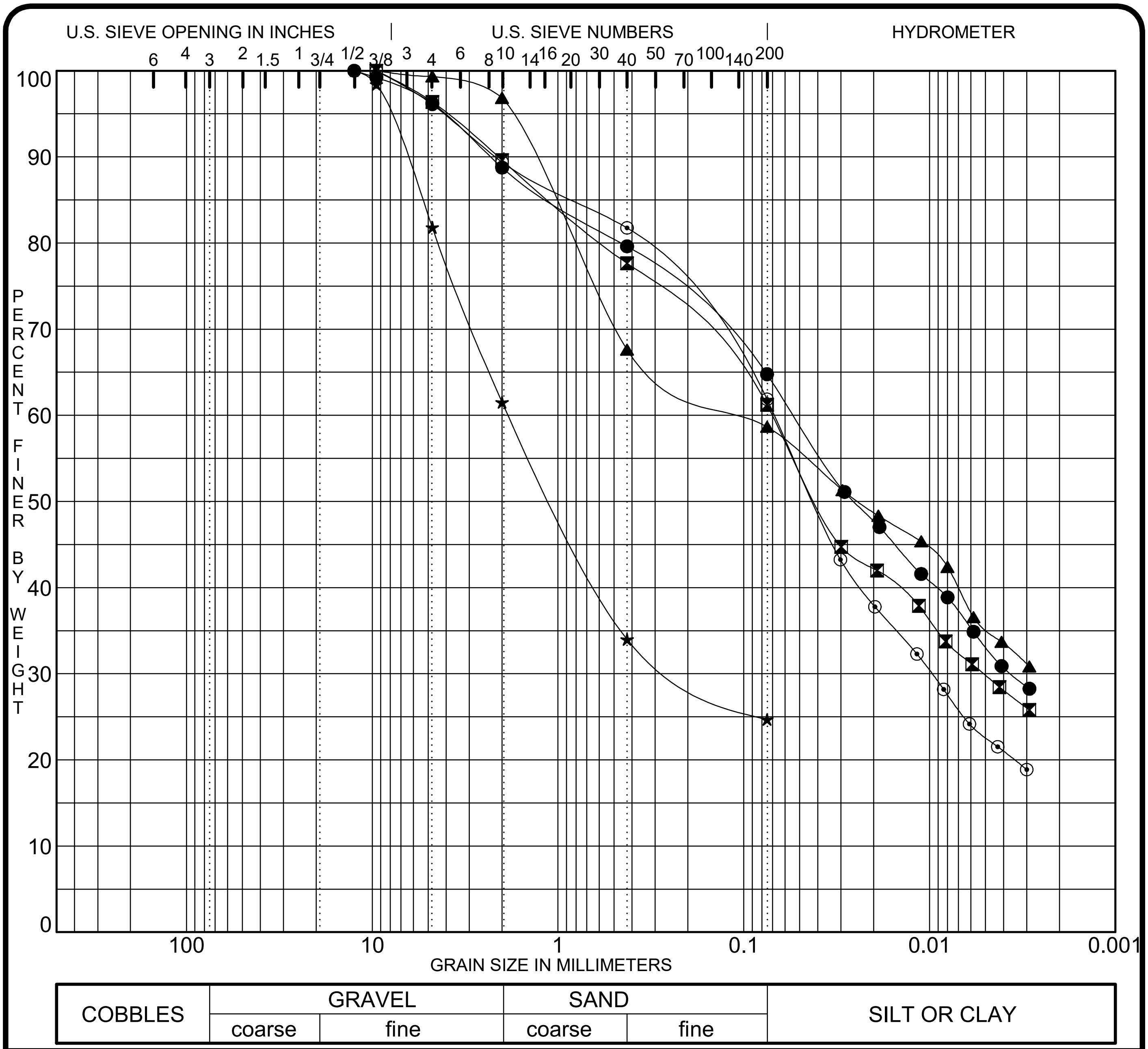
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-071-0-19**	**0.060**	**0.033**	**0.004**		**0.0**	**11.6**	**9.8**	**15.0**	**32.0**	**31.6**
⊠	**B-071-0-19**	**0.061**	**0.032**	**0.004**		**0.0**	**10.4**	**10.3**	**16.3**	**31.8**	**31.2**
▲	**B-071-0-19**	**1.312**	**0.861**	**0.095**		**0.0**	**30.0**	**36.8**	**3.8**	**29.5**	
★	**B-071-0-19**	**0.126**	**0.064**	**0.012**		**0.0**	**10.0**	**13.1**	**24.2**	**29.2**	**23.6**
⊙	**B-071-0-19**	**0.060**	**0.030**	**0.005**		**0.0**	**14.0**	**9.6**	**13.3**	**32.4**	**30.7**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



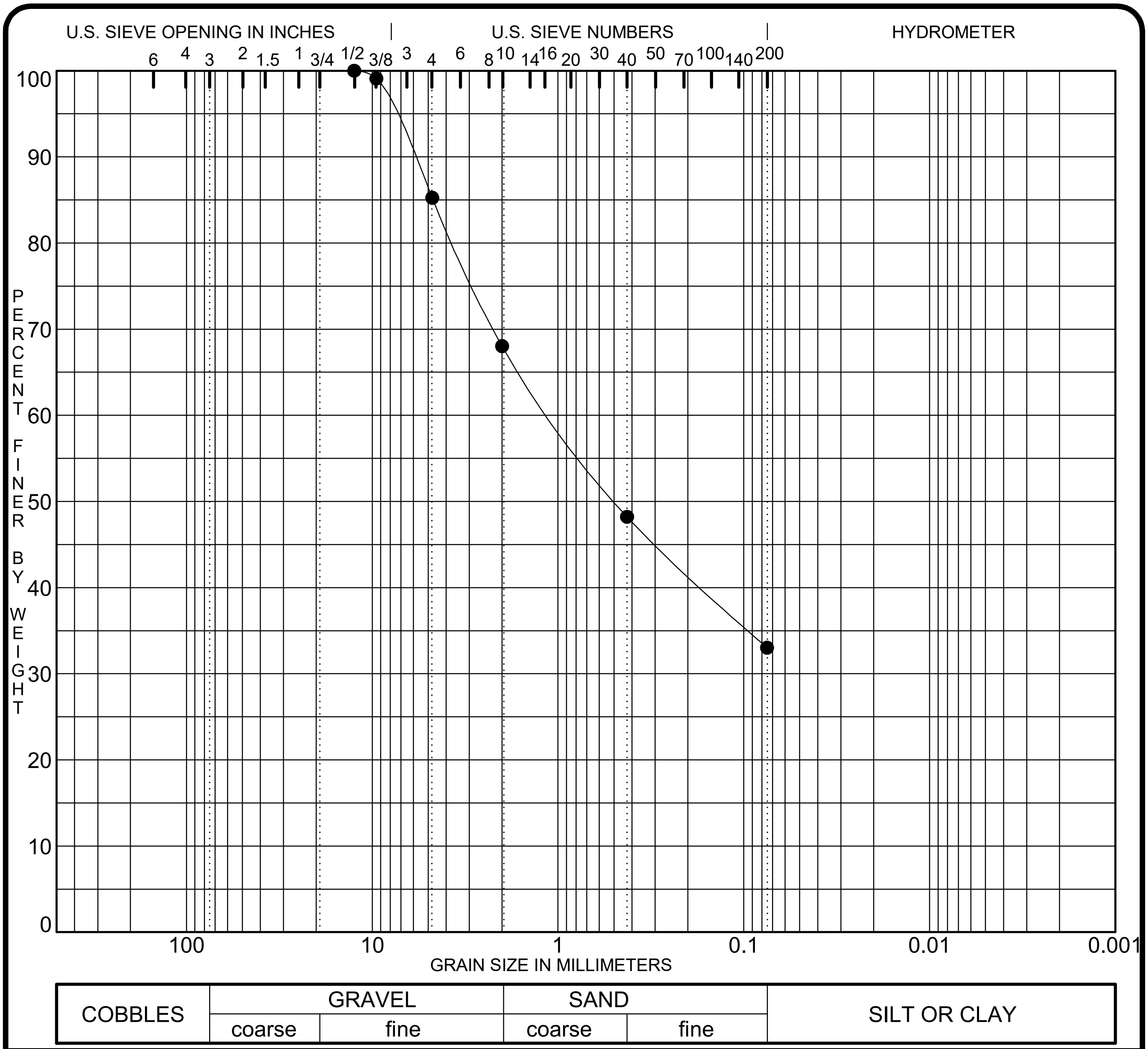
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-072-0-19**	**11.0**	**A-6a**	**18**	**35**	**20**	**15**		
⧗	**B-072-0-19**	**21.0**	**A-6a**	**17**	**36**	**23**	**13**		
▲	**B-072-0-19**	**28.5**	**A-6a**	**17**	**35**	**22**	**13**		
★	**B-072-0-19**	**38.5**	**A-1-b**	**18**	**NP**	**NP**	**NP**		
⊙	**B-072-0-19**	**53.5**	**A-6a**	**12**	**31**	**18**	**13**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-072-0-19**	**0.054**	**0.026**	**0.004**		**0.0**	**11.3**	**9.1**	**14.8**	**31.6**	**33.2**
⧗	**B-072-0-19**	**0.070**	**0.040**	**0.005**		**0.0**	**10.4**	**12.0**	**16.4**	**31.4**	**29.8**
▲	**B-072-0-19**	**0.097**	**0.024**			**0.0**	**3.1**	**29.2**	**9.0**	**23.3**	**35.3**
★	**B-072-0-19**	**1.837**	**1.046**	**0.202**		**0.0**	**38.5**	**27.5**	**9.3**	**24.7**	
⊙	**B-072-0-19**	**0.068**	**0.042**	**0.010**		**0.0**	**10.6**	**7.6**	**19.9**	**39.2**	**22.7**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



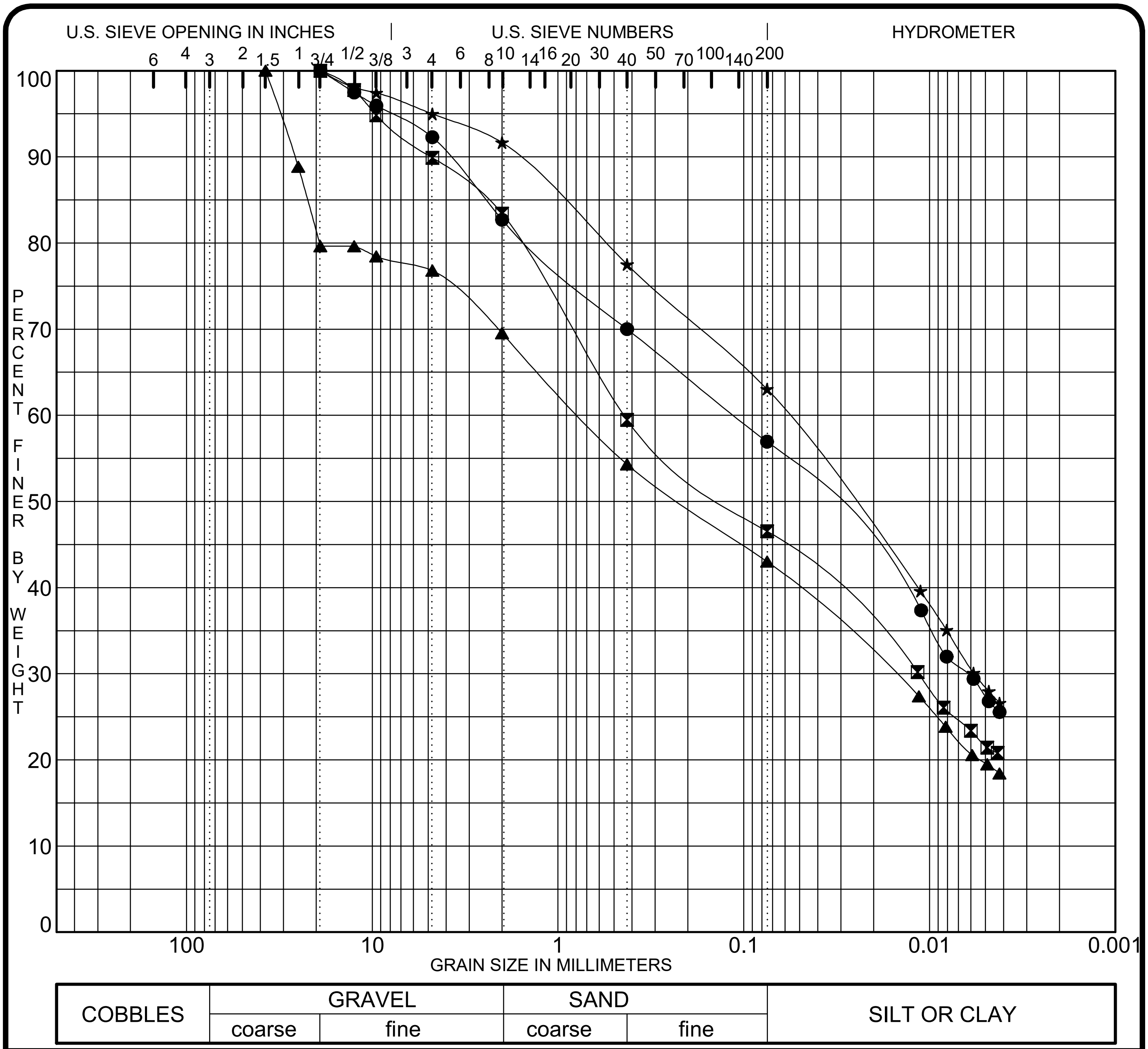
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-072-0-19**	**63.5**	**A-2-4**	**15**	**NP**	**NP**	**NP**		

	Specimen Identification	D60	D50	D30	D10	%Gravel coarse	%Gravel fine	%Sand coarse	%Sand fine	%Silt	%Clay
●	**B-072-0-19**	**1.068**	**0.489**			**0.0**	**32.0**	**19.8**	**15.2**	**33.0**	

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



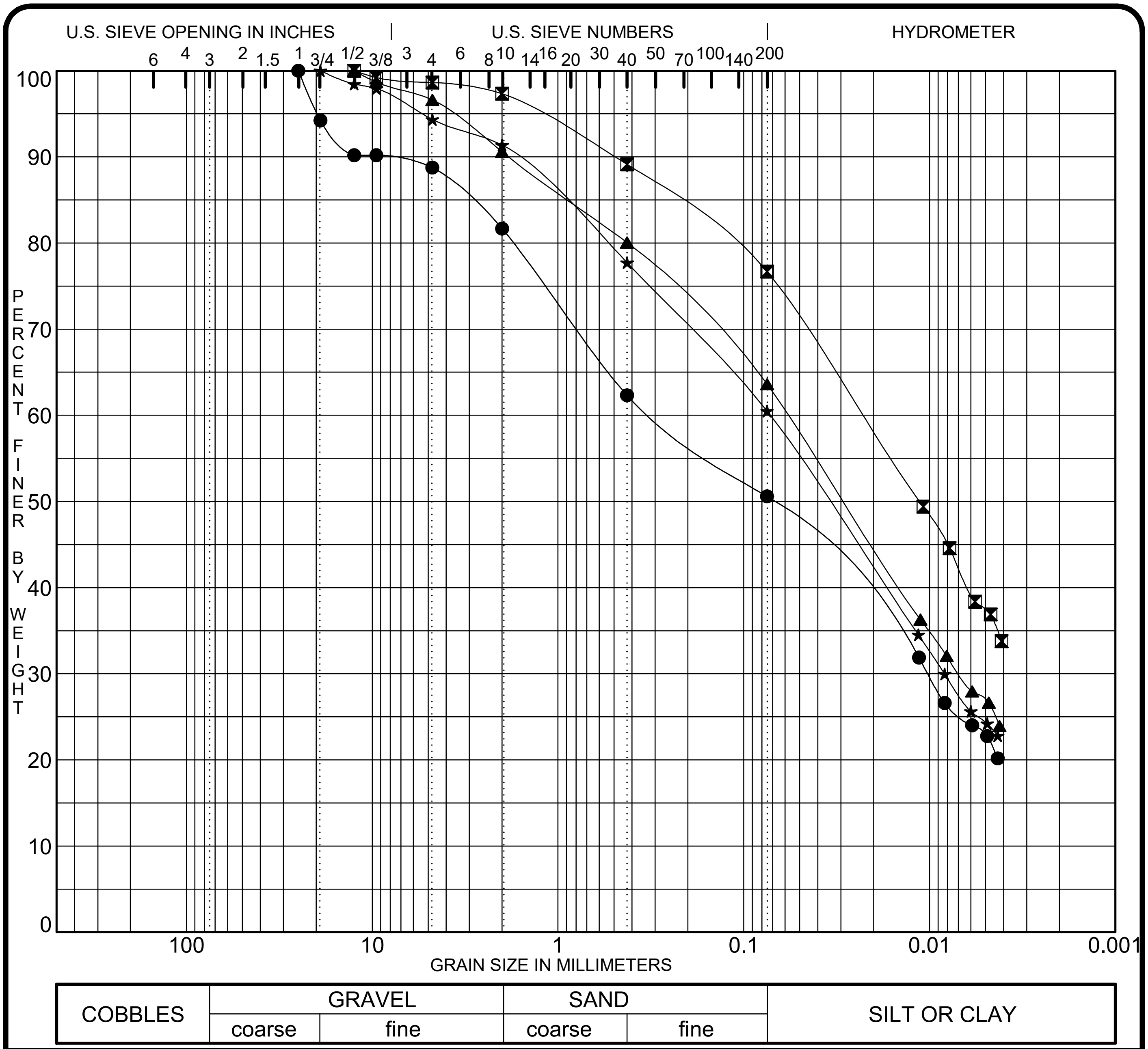
Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
● **B-073-0-19**	**3.5**	**A-6b**	**15**	**35**	**19**	**16**		
⧗ **B-073-0-19**	**16.0**	**A-6a**	**12**	**30**	**16**	**14**		
▲ **B-073-0-19**	**33.5**	**A-6a**	**21**	**35**	**20**	**15**		
★ **B-073-0-19**	**53.5**	**A-6a**	**14**	**30**	**17**	**13**		

Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
					coarse	fine	coarse	fine		
● **B-073-0-19**	**0.113**	**0.038**	**0.006**		**0.0**	**17.3**	**12.7**	**13.1**	**29.6**	**27.4**
⧗ **B-073-0-19**	**0.440**	**0.119**	**0.011**		**0.0**	**16.6**	**23.9**	**12.9**	**24.9**	**21.6**
▲ **B-073-0-19**	**0.758**	**0.219**	**0.016**		**20.4**	**10.1**	**15.2**	**11.3**	**23.4**	**19.6**
★ **B-073-0-19**	**0.059**	**0.026**	**0.006**		**0.0**	**8.3**	**14.2**	**14.5**	**34.6**	**28.4**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



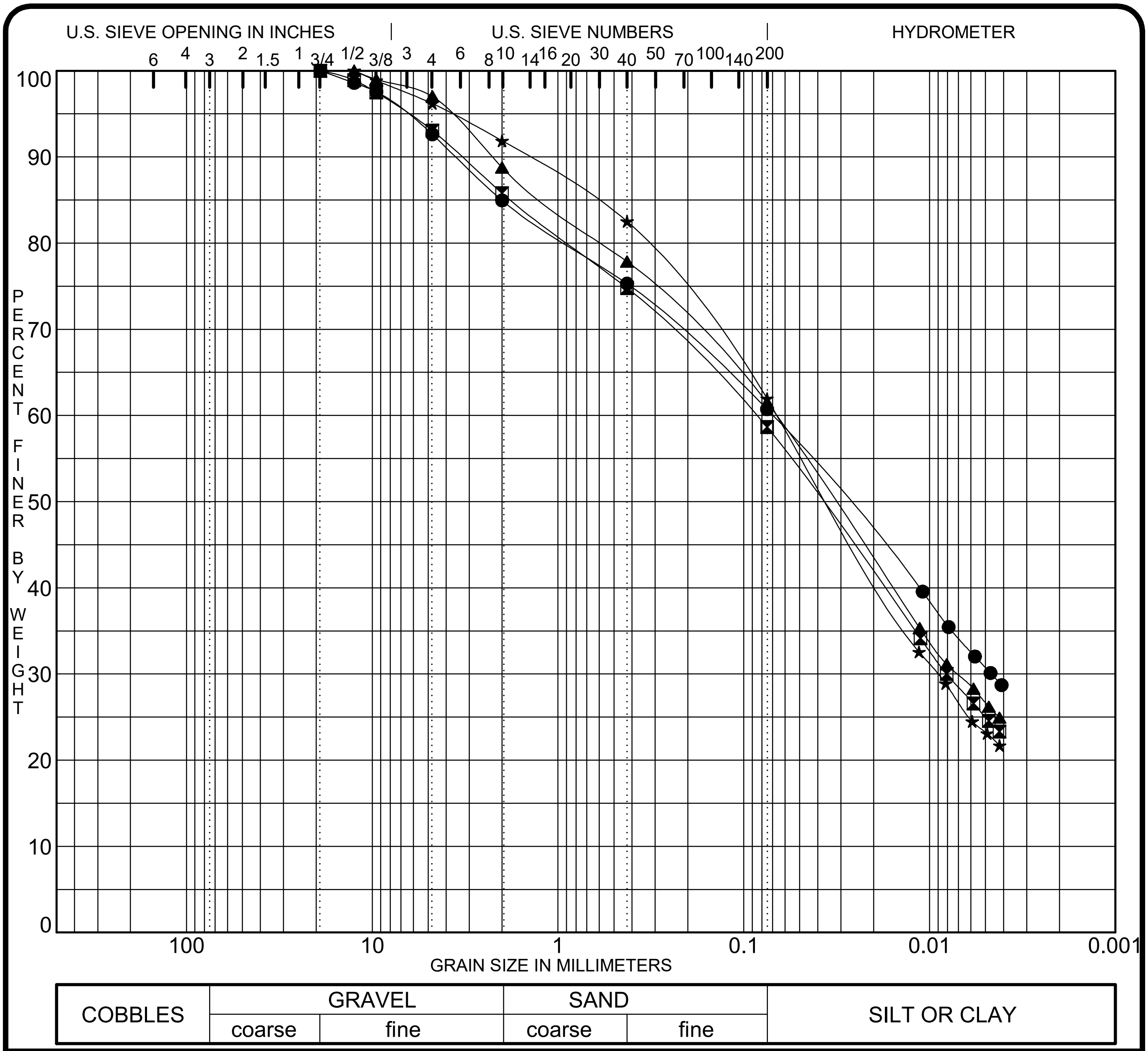
Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
● **B-074-0-19**	**1.0**	**A-6a**	**12**	**29**	**16**	**13**		
⧗ **B-074-0-19**	**8.5**	**A-6b**	**20**	**37**	**18**	**19**		
▲ **B-074-0-19**	**13.5**	**A-4a**	**12**	**26**	**16**	**10**		
★ **B-074-0-19**	**21.0**	**A-4a**	**11**	**26**	**16**	**10**		
⊙ **B-074-0-19**	**63.5**	**A-6a**	**17**	**29**	**16**	**13**		

Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
					coarse	fine	coarse	fine		
● **B-074-0-19**	**0.301**	**0.071**	**0.010**		**5.8**	**12.6**	**19.3**	**11.7**	**27.7**	**22.9**
⧗ **B-074-0-19**	**0.023**	**0.011**			**0.0**	**2.7**	**8.2**	**12.4**	**39.3**	**37.4**
▲ **B-074-0-19**	**0.058**	**0.029**	**0.007**		**0.0**	**9.4**	**10.5**	**16.4**	**36.7**	**26.9**
★ **B-074-0-19**	**0.072**	**0.035**	**0.008**		**0.0**	**8.6**	**13.7**	**17.2**	**36.1**	**24.4**
⊙ **B-074-0-19**	**0.301**	**0.071**	**0.010**		**5.8**	**12.6**	**19.3**	**11.7**	**27.7**	**22.9**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



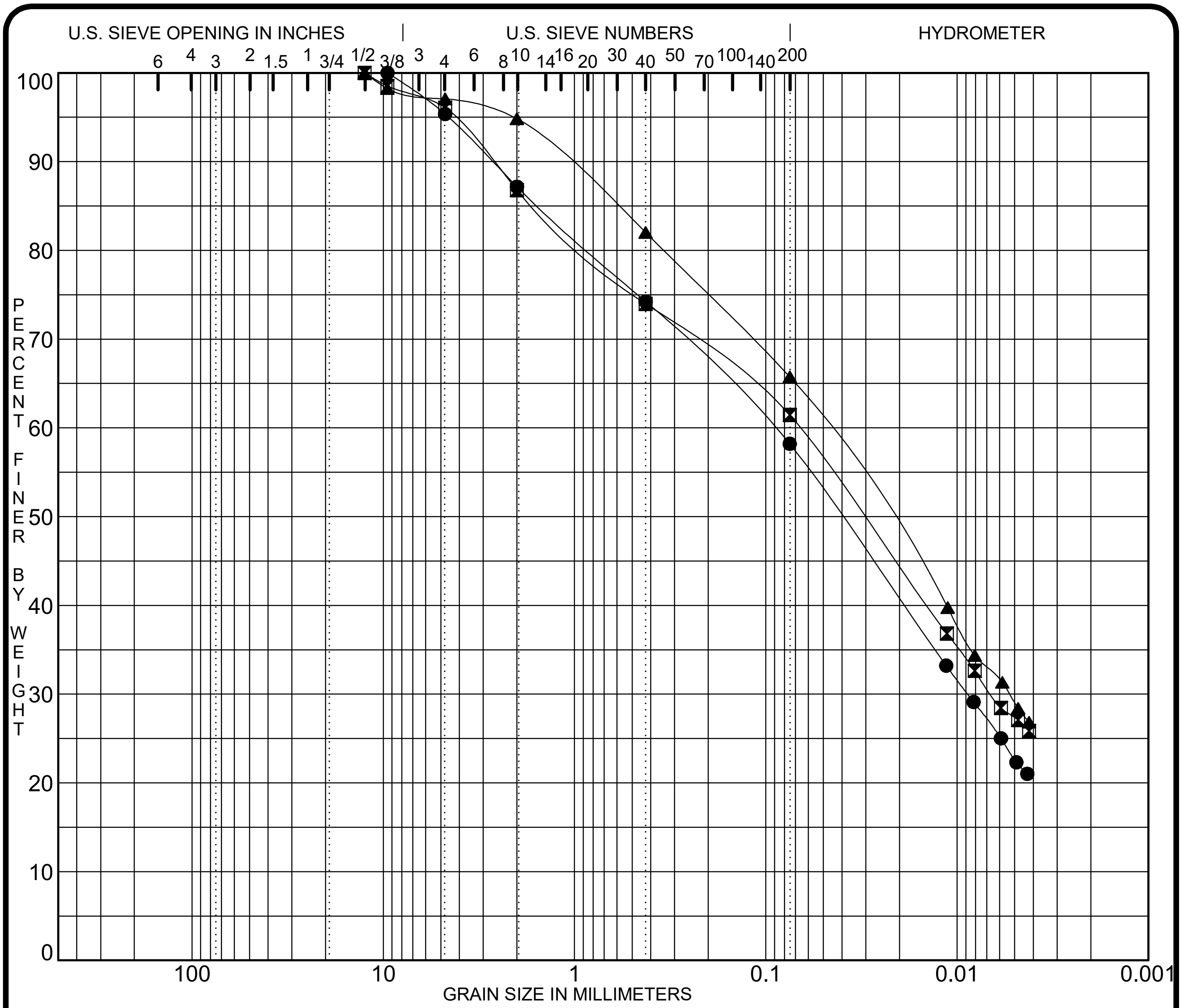
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-075-0-19**	**1.5**	**A-6a**	**18**	**30**	**16**	**14**		
⧗	**B-075-0-19**	**8.5**	**A-4a**	**10**	**22**	**14**	**8**		
▲	**B-075-0-19**	**16.0**	**A-6a**	**12**	**26**	**15**	**11**		
★	**B-075-0-19**	**48.5**	**A-4a**	**13**	**22**	**14**	**8**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-075-0-19**	**0.070**	**0.028**	**0.005**		**0.0**	**15.0**	**9.7**	**14.6**	**30.0**	**30.7**
⧗	**B-075-0-19**	**0.087**	**0.038**	**0.008**		**0.0**	**14.2**	**11.0**	**16.1**	**33.7**	**25.0**
▲	**B-075-0-19**	**0.067**	**0.033**	**0.007**		**0.0**	**11.2**	**10.9**	**16.3**	**34.9**	**26.6**
★	**B-075-0-19**	**0.066**	**0.035**	**0.009**		**0.0**	**8.1**	**9.4**	**20.6**	**38.7**	**23.2**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



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<tr><td>coarse</td><td>fine</td><td>coarse</td><td>fine</td></tr>
</table>

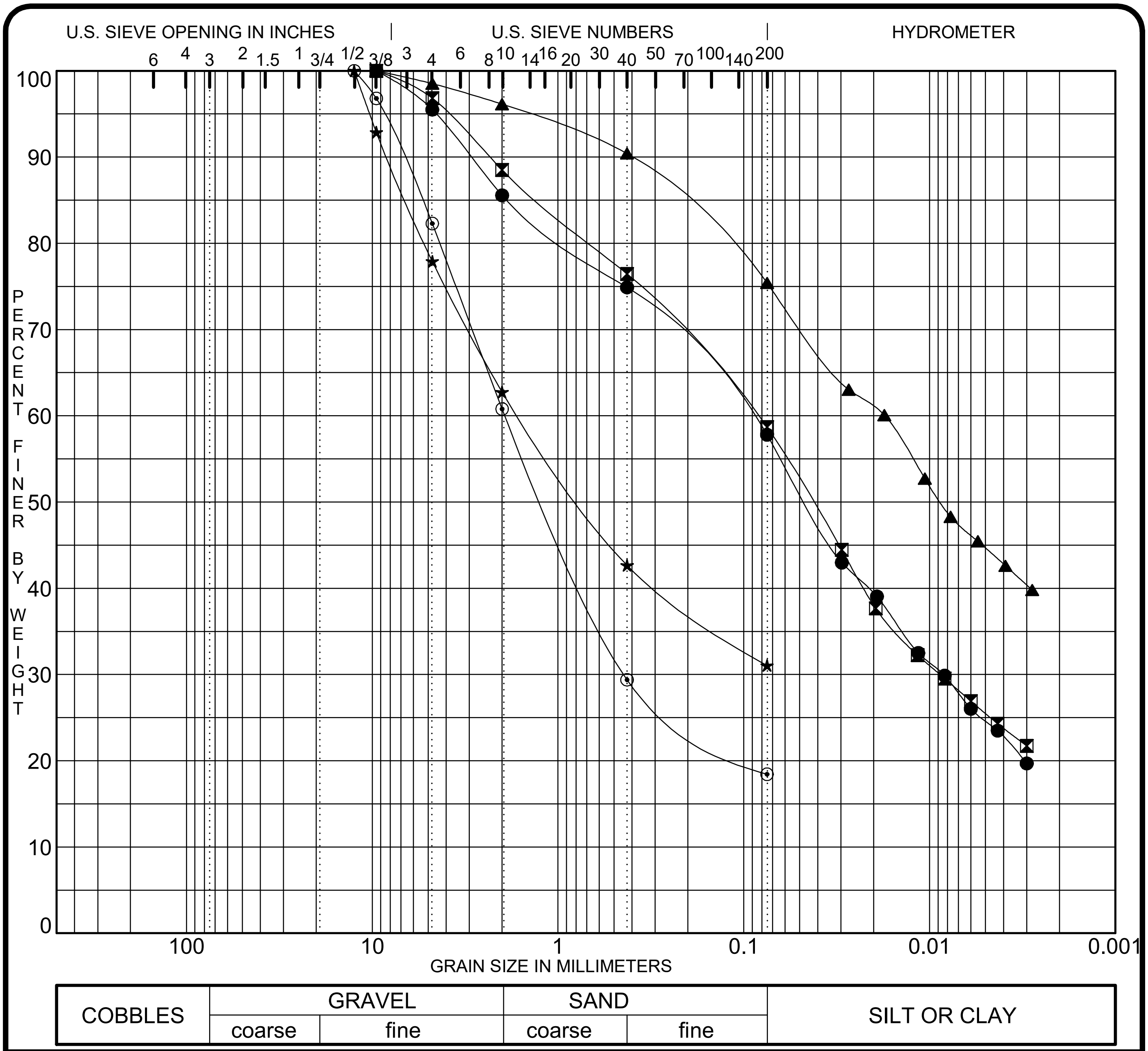
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-076-0-19**	**3.5**	**A-6a**	**12**	**28**	**17**	**11**		
⧗	**B-076-0-19**	**16.0**	**A-6b**	**19**	**34**	**18**	**16**		
▲	**B-076-0-19**	**63.5**	**A-4a**	**12**	**24**	**15**	**9**		

	Specimen Identification	D60	D50	D30	D10	%Gravel coarse	%Gravel fine	%Sand coarse	%Sand fine	%Silt	%Clay
●	**B-076-0-19**	**0.091**	**0.040**	**0.009**		**0.0**	**12.8**	**12.9**	**16.0**	**35.6**	**22.6**
⧗	**B-076-0-19**	**0.067**	**0.031**	**0.007**		**0.0**	**13.2**	**12.8**	**12.5**	**34.1**	**27.4**
▲	**B-076-0-19**	**0.049**	**0.024**	**0.005**		**0.0**	**5.2**	**12.8**	**16.3**	**36.7**	**29.0**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-077-0-19**	**8.5**	**A-6a**	**10**	**36**	**22**	**14**		
⧗	**B-077-0-19**	**16.0**	**A-6a**	**10**	**37**	**23**	**14**		
▲	**B-077-0-19**	**28.5**	**A-6b**	**23**	**40**	**23**	**17**		
★	**B-077-0-19**	**33.5**	**A-2-4**	**13**	**NP**	**NP**	**NP**		
⊙	**B-077-0-19**	**43.5**	**A-1-b**	**12**	**NP**	**NP**	**NP**		

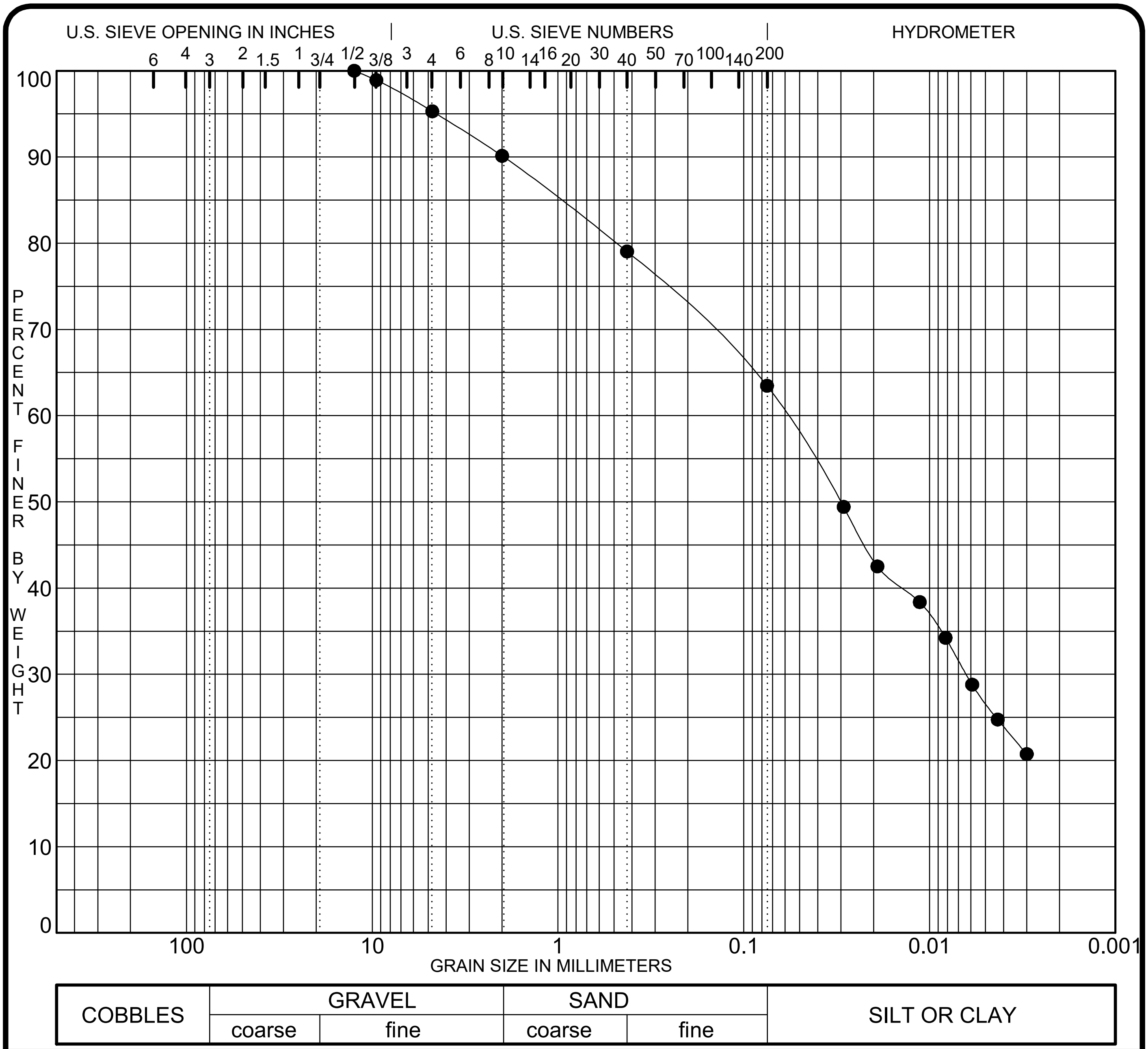
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-077-0-19**	**0.094**	**0.046**	**0.008**		**0.0**	**14.4**	**10.7**	**17.1**	**33.2**	**24.6**
⧗	**B-077-0-19**	**0.085**	**0.043**	**0.009**		**0.0**	**11.5**	**12.0**	**17.8**	**33.2**	**25.5**
▲	**B-077-0-19**	**0.017**	**0.009**			**0.0**	**3.9**	**5.7**	**15.0**	**30.7**	**44.7**
★	**B-077-0-19**	**1.618**	**0.748**			**0.0**	**37.2**	**20.1**	**11.6**	**31.0**	
⊙	**B-077-0-19**	**1.924**	**1.175**	**0.438**		**0.0**	**39.2**	**31.4**	**11.0**	**18.4**	

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



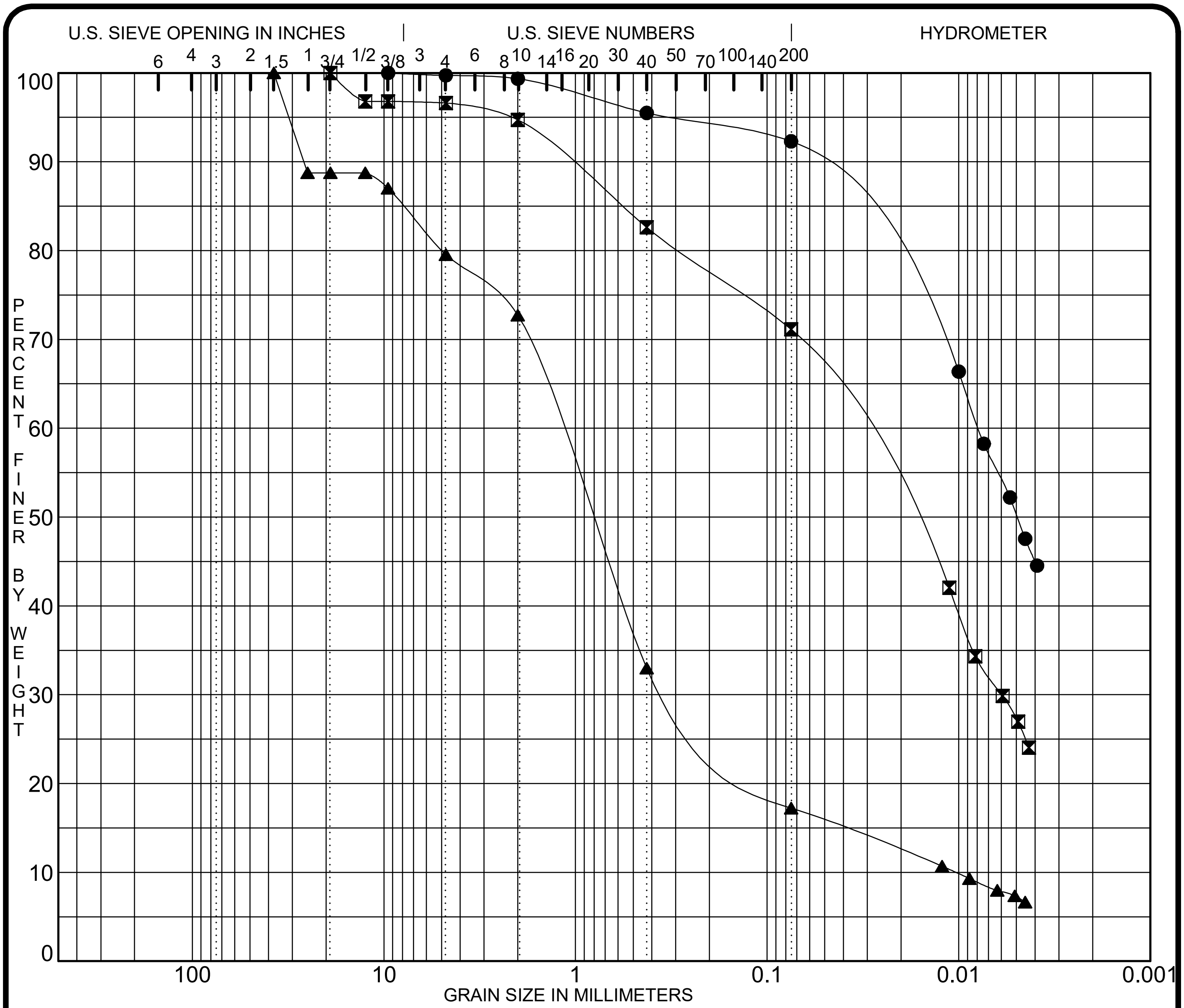
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-077-0-19**	**68.5**	**A-6b**	**11**	**35**	**19**	**16**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-077-0-19**	**0.059**	**0.030**	**0.006**		**0.0**	**9.9**	**11.1**	**15.6**	**36.8**	**26.7**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



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<tr><td>coarse</td><td>fine</td><td>coarse</td><td>fine</td></tr>
</table>

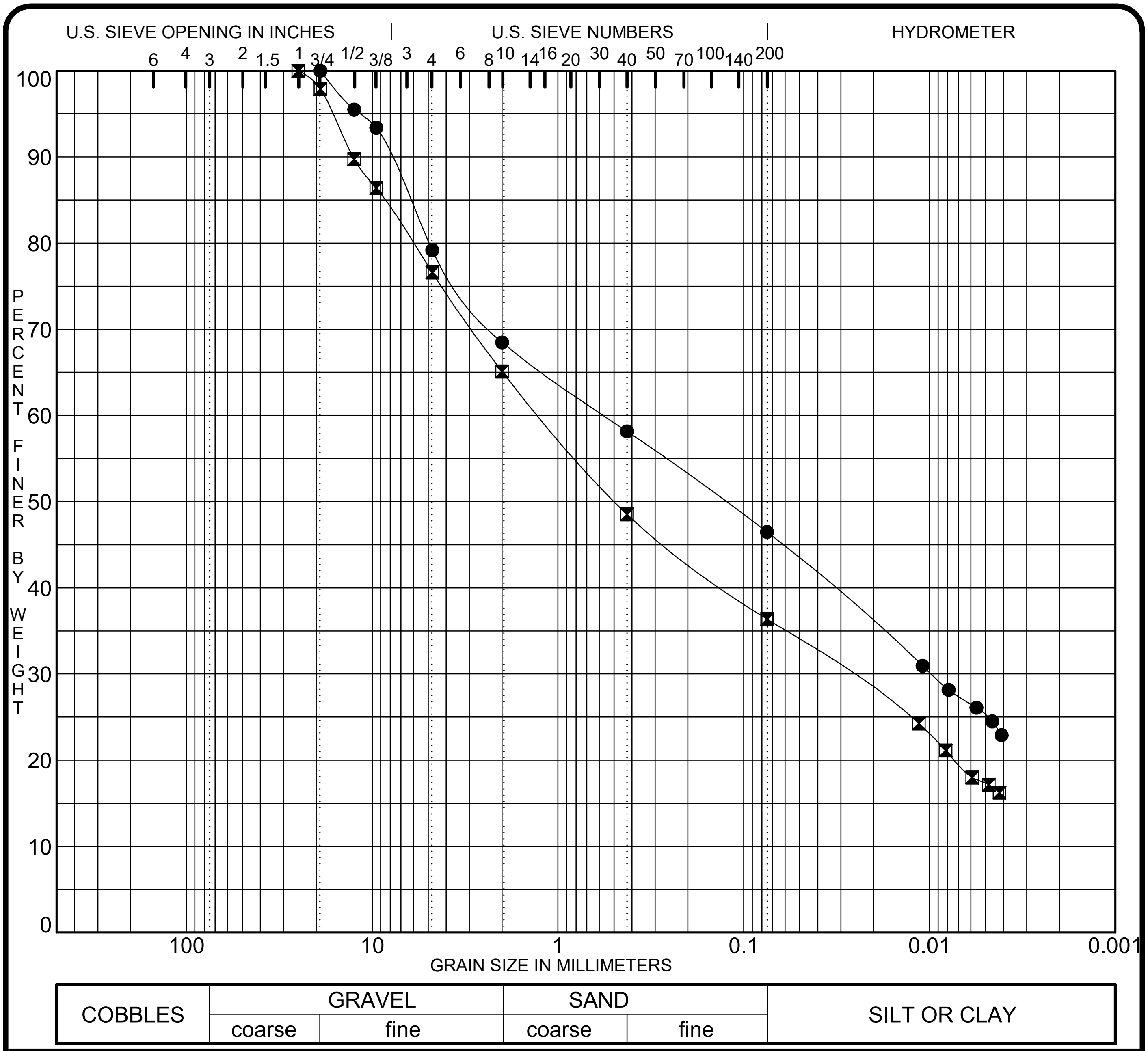
Specimen Identification		Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-086-0-19**	**6.0**	**A-6b**	**19**	**39**	**21**	**18**		
⧗	**B-086-0-19**	**8.5**	**A-4a**	**16**	**25**	**18**	**7**		
▲	**B-086-0-19**	**21.0**	**A-1-b**	**15**	**NP**	**NP**	**NP**	**7.40**	**117.4**

Specimen Identification		D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-086-0-19**	**0.008**	**0.005**			**0.0**	**0.7**	**3.8**	**3.2**	**42.1**	**50.2**
⧗	**B-086-0-19**	**0.036**	**0.019**	**0.006**		**0.0**	**5.3**	**12.1**	**11.5**	**43.9**	**27.3**
▲	**B-086-0-19**	**1.218**	**0.825**	**0.306**	**0.0104**	**11.2**	**16.0**	**39.7**	**15.7**	**10.0**	**7.2**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



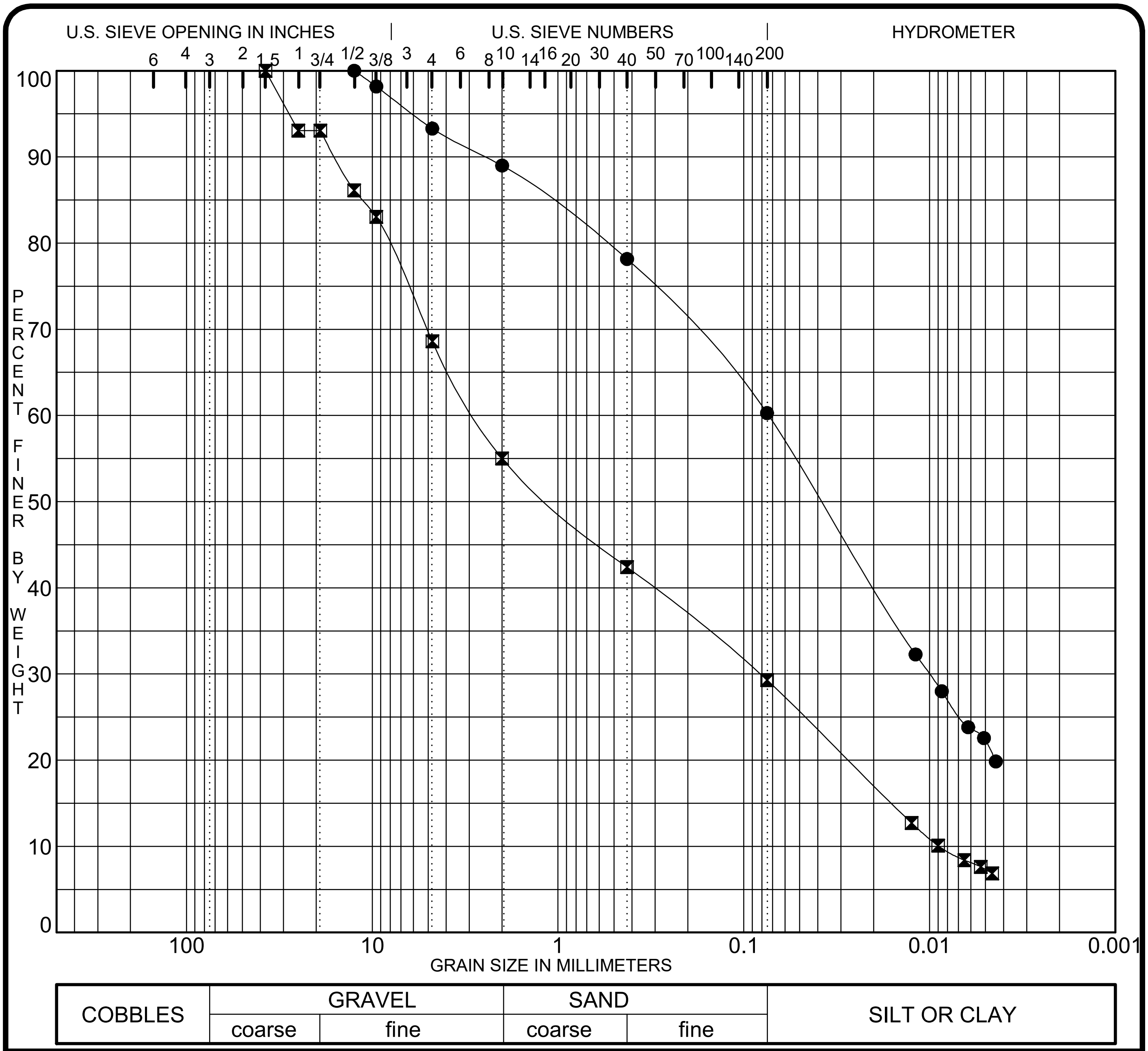
	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-087-0-19**	**6.0**	**A-6b**	**14**	**33**	**17**	**16**		
☒	**B-087-0-19**	**13.5**	**A-6a**	**12**	**31**	**19**	**12**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-087-0-19**	**0.561**	**0.127**	**0.010**		**0.0**	**31.5**	**10.3**	**11.7**	**21.3**	**25.2**
☒	**B-087-0-19**	**1.241**	**0.488**	**0.028**		**2.1**	**32.8**	**16.6**	**12.2**	**19.1**	**17.3**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-087-0-19A**	**38.5**	**A-4a**	**13**	**24**	**15**	**9**		
☒	**B-087-0-19A**	**48.5**	**A-2-4**	**11**	**20**	**16**	**4**	**0.28**	**309.4**

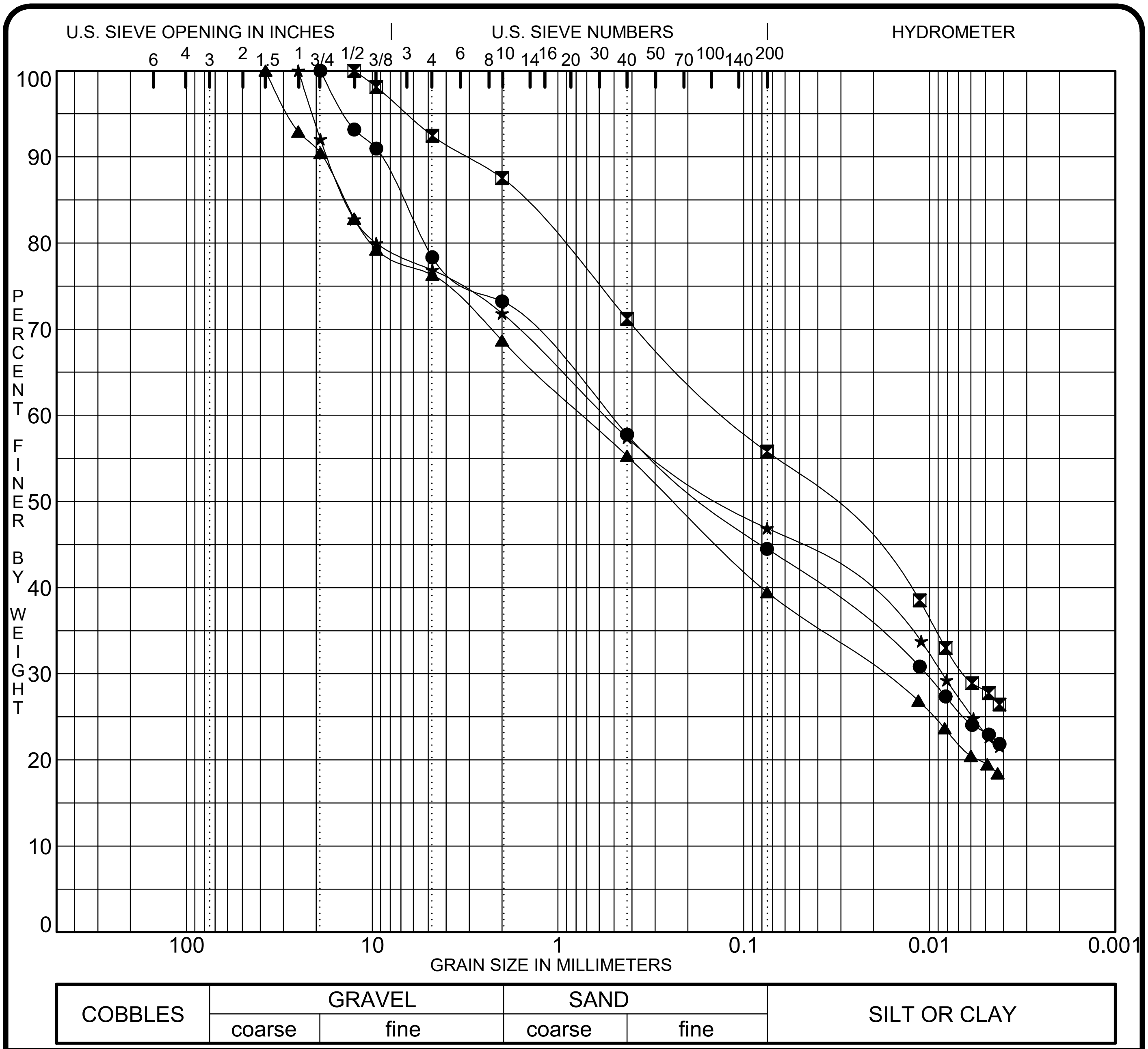
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-087-0-19A**	**0.074**	**0.038**	**0.010**		**0.0**	**11.0**	**10.8**	**17.9**	**38.1**	**22.2**
☒	**B-087-0-19A**	**2.748**	**1.081**	**0.082**	**0.0089**	**7.0**	**38.0**	**12.6**	**13.1**	**22.0**	**7.3**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



Specimen Identification		Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	B-088-0-19	1.5	A-6a	9	28	16	12		
⧗	B-088-0-19	11.0	A-4a	13	25	16	9		
▲	B-088-0-19	16.0	A-4a	12	26	16	10		
★	B-088-0-19	25.0	A-6a	22	38	23	15		

Specimen Identification		D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	B-088-0-19	0.532	0.154	0.010		0.0	26.8	15.5	13.3	21.3	23.2
⧗	B-088-0-19	0.121	0.040	0.006		0.0	12.4	16.3	15.4	27.8	28.0
▲	B-088-0-19	0.733	0.238	0.018		9.5	21.8	13.4	15.8	19.9	19.6
★	B-088-0-19	0.561	0.125	0.009		7.9	20.2	14.4	10.5	23.8	23.1

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

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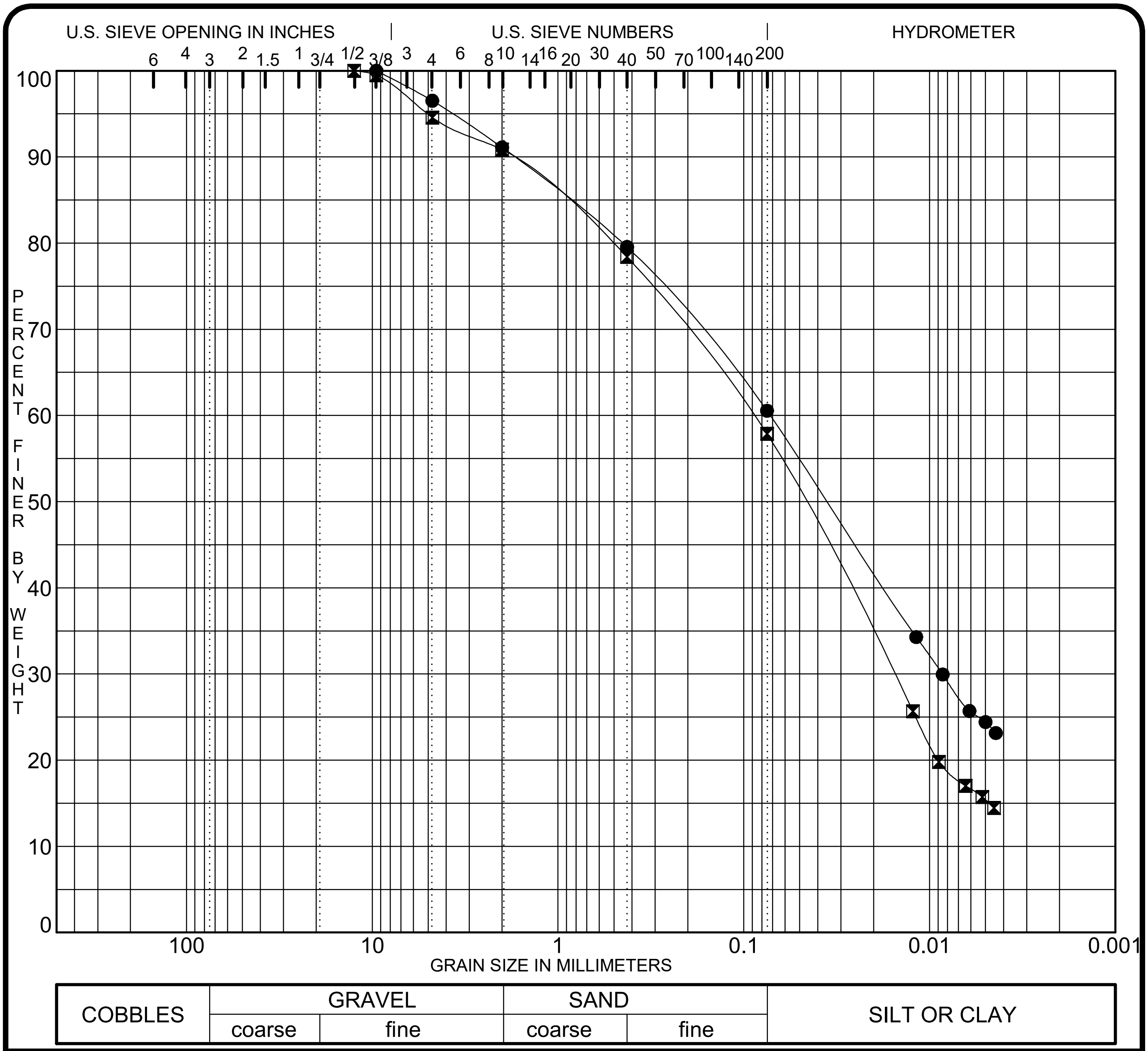


	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-088-0-19A**	**31.0**	**A-6b**	**17**	**34**	**14**	**20**		
☒	**B-088-0-19A**	**36.0**	**A-4a**	**12**	**21**	**15**	**6**		

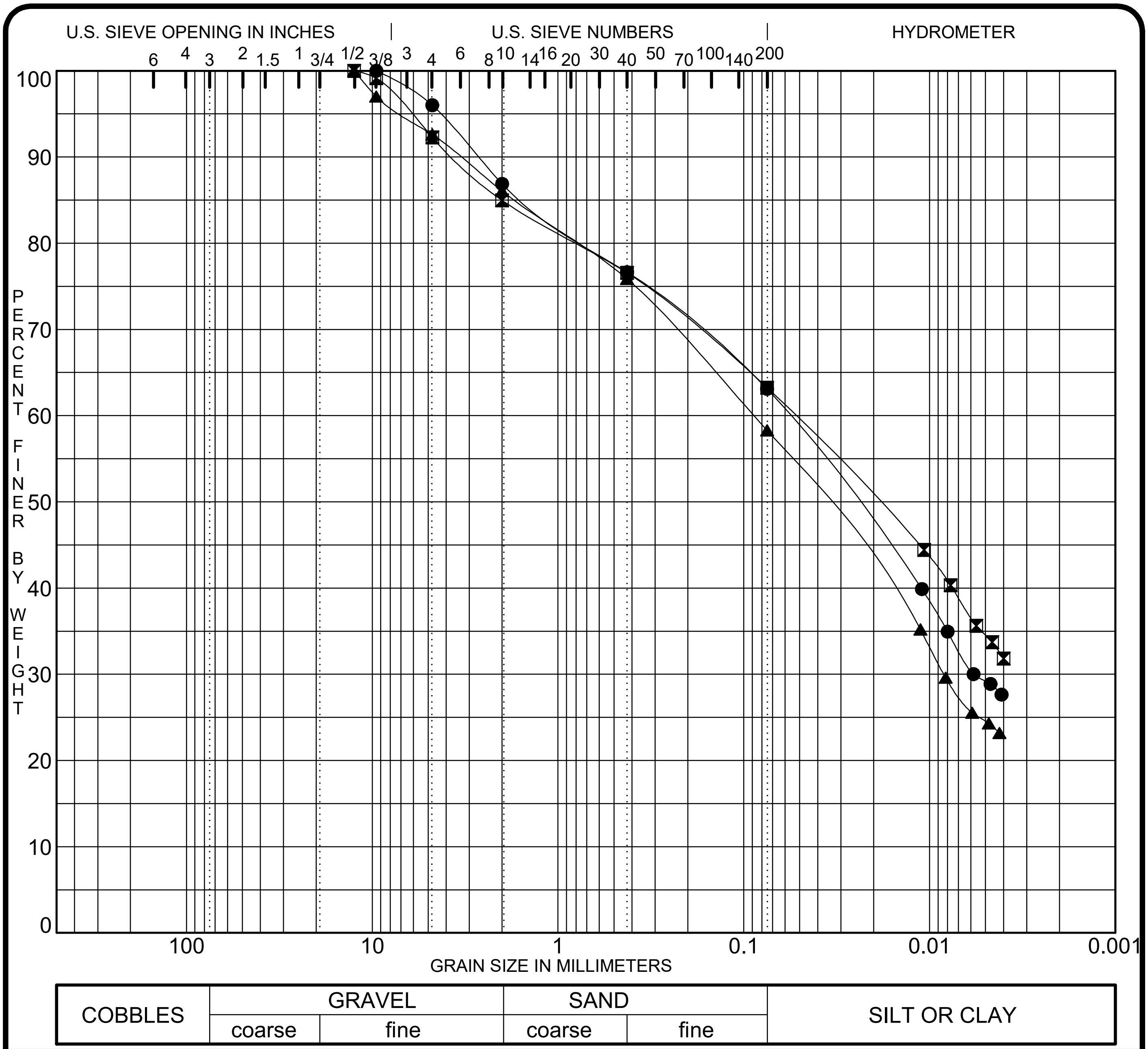
	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-088-0-19A**	**0.072**	**0.036**	**0.009**		**0.0**	**8.9**	**11.5**	**19.0**	**36.1**	**24.4**
☒	**B-088-0-19A**	**0.090**	**0.048**	**0.016**		**0.0**	**9.1**	**12.4**	**20.5**	**42.5**	**15.4**

PROJECT **FRA-070-22.85**

PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.



	Specimen Identification	Depth	Classification	MC%	LL	PL	PI	Cz	Cu
●	**B-089-0-19**	**3.5**	**A-6a**	**9**	**28**	**15**	**13**		
⧗	**B-089-0-19**	**16.0**	**A-6b**	**20**	**37**	**18**	**19**		
▲	**B-089-0-19**	**21.0**	**A-4a**	**12**	**20**	**13**	**7**		

	Specimen Identification	D60	D50	D30	D10	%Gravel		%Sand		%Silt	%Clay
						coarse	fine	coarse	fine		
●	**B-089-0-19**	**0.058**	**0.025**	**0.006**		**0.0**	**13.1**	**10.2**	**13.5**	**33.9**	**29.2**
⧗	**B-089-0-19**	**0.054**	**0.019**			**0.0**	**15.0**	**8.4**	**13.3**	**28.7**	**34.5**
▲	**B-089-0-19**	**0.089**	**0.038**	**0.008**		**0.0**	**14.0**	**10.2**	**17.6**	**33.8**	**24.5**

PROJECT **FRA-070-22.85** PROJECT NO. **W-17-140**

GRADATION CURVES

Resource International, Inc.

APPENDIX VI

DRIVENPILES ANALYSIS OUTPUTS

Rear Abutment
Boring B-073-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - RA (B-073-0-19).dvn
Project Name: FRA-00070-22.919 Brice Rd Bridge over WB-CD Ramp - Rear Abutment (B-073-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	23.50 ft
Driving/Restrike:	23.50 ft
Nominal:	23.50 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	18.50 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesive	5.30 ft	1.500	125.00 pcf	4750.00 psf	T-80 Same
3	Cohesive	10.00 ft	1.500	130.00 pcf	7625.00 psf	T-80 Same
4	Cohesive	15.00 ft	1.500	130.00 pcf	6000.00 psf	T-80 Same
5	Cohesive	8.00 ft	1.500	130.00 pcf	5000.00 psf	T-80 Same
6	Cohesive	5.00 ft	1.500	130.00 pcf	8000.00 psf	T-80 Same

Restrike: 188.8 kips
Driving: 137.7 kips

Estimated Ground Surface Elevation: 822.7 ft-msl
Bottom of Footing Elevation: 809.5 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 791.0 ft-msl

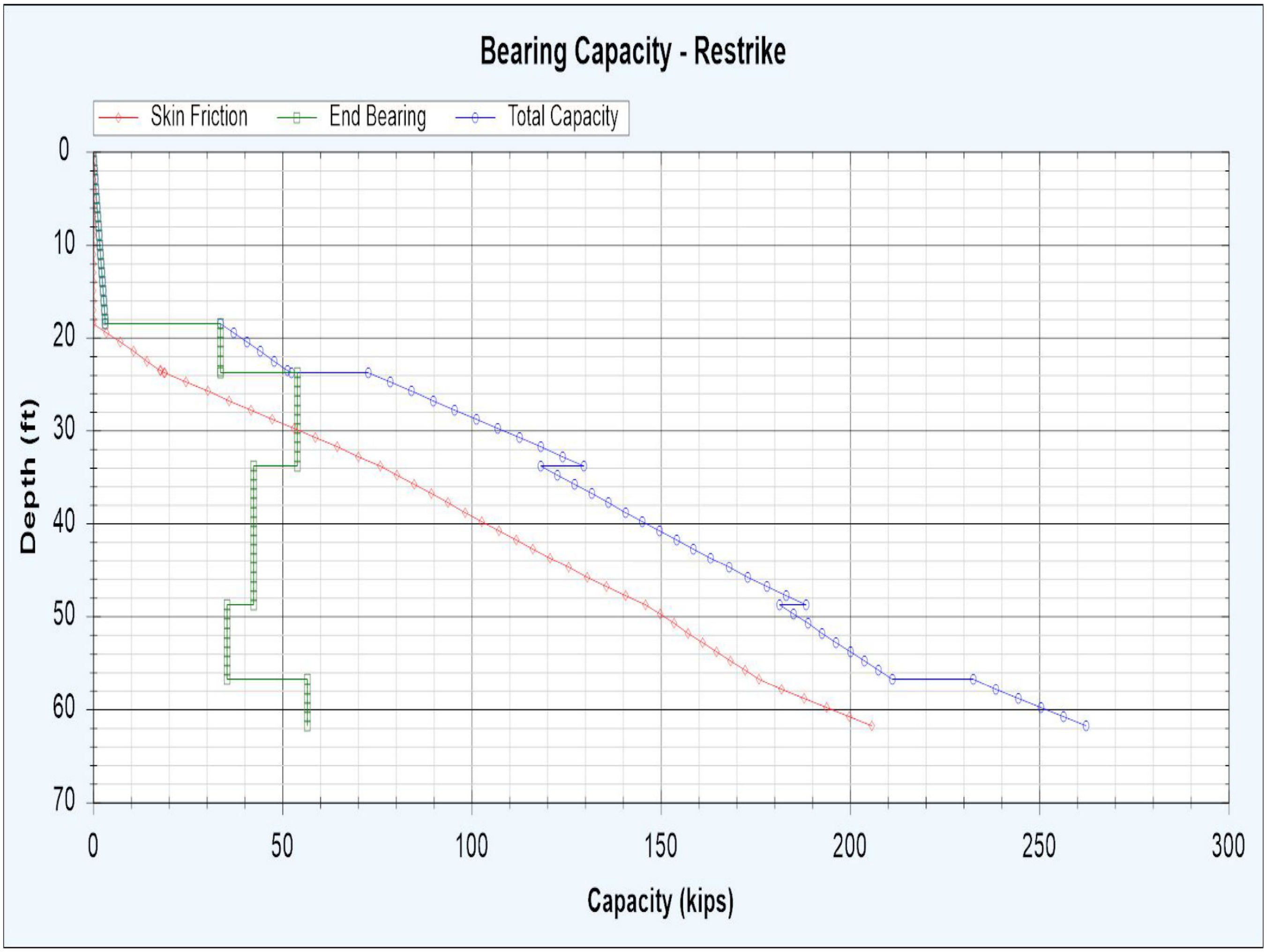
Estimated Pile Top Elevation: 810.5 ft-msl
Estimated Pile Tip Elevation: 758.7 ft-msl

Embedment Depth Below Bottom of Footing Elevation: 50.8 ft
Estimated Pile Length: 55.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.04 kips	33.58 kips	33.61 kips
19.50 ft	3.55 kips	33.58 kips	37.13 kips
20.50 ft	7.10 kips	33.58 kips	40.68 kips
21.50 ft	10.65 kips	33.58 kips	44.23 kips
22.50 ft	14.21 kips	33.58 kips	47.78 kips
23.49 ft	17.72 kips	33.58 kips	51.30 kips
23.51 ft	17.79 kips	33.58 kips	51.37 kips
23.79 ft	18.79 kips	33.58 kips	52.36 kips
23.81 ft	18.88 kips	53.90 kips	72.78 kips
24.80 ft	24.52 kips	53.90 kips	78.42 kips
25.80 ft	30.23 kips	53.90 kips	84.12 kips
26.80 ft	35.93 kips	53.90 kips	89.82 kips
27.80 ft	41.63 kips	53.90 kips	95.53 kips
28.80 ft	47.33 kips	53.90 kips	101.23 kips
29.80 ft	53.03 kips	53.90 kips	106.93 kips
30.80 ft	58.73 kips	53.90 kips	112.63 kips
31.80 ft	64.43 kips	53.90 kips	118.33 kips
32.80 ft	70.13 kips	53.90 kips	124.03 kips
33.79 ft	75.78 kips	53.90 kips	129.68 kips
33.81 ft	75.88 kips	42.41 kips	118.29 kips
34.80 ft	80.32 kips	42.41 kips	122.73 kips
35.80 ft	84.81 kips	42.41 kips	127.22 kips

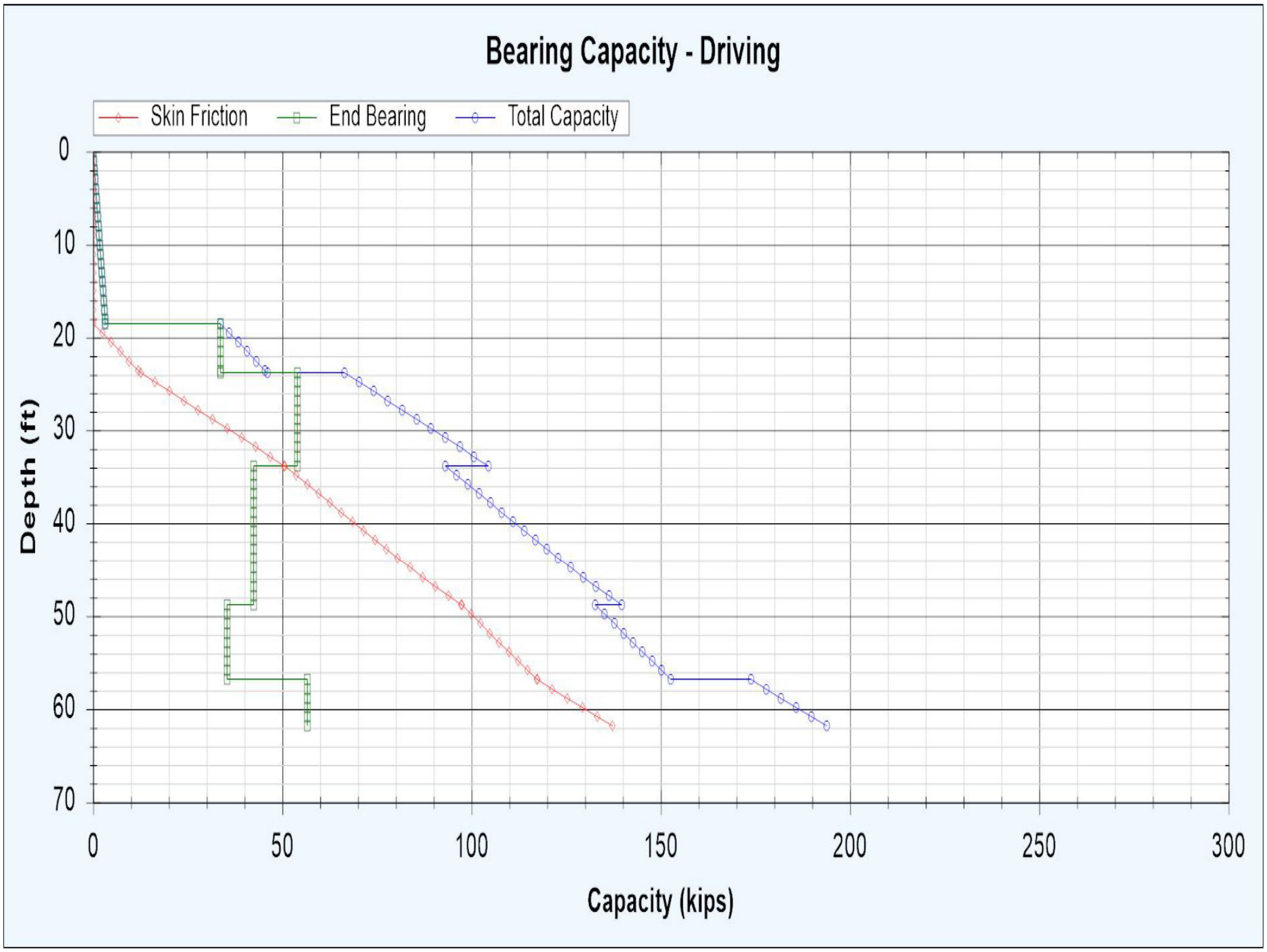
Depth	Skin Friction	End Bearing	Total Capacity
36.80 ft	89.29 kips	42.41 kips	131.71 kips
37.80 ft	93.78 kips	42.41 kips	136.19 kips
38.80 ft	98.27 kips	42.41 kips	140.68 kips
39.80 ft	102.75 kips	42.41 kips	145.16 kips
40.80 ft	107.24 kips	42.41 kips	149.65 kips
41.80 ft	111.72 kips	42.41 kips	154.14 kips
42.80 ft	116.21 kips	42.41 kips	158.62 kips
43.80 ft	120.70 kips	42.41 kips	163.11 kips
44.80 ft	125.61 kips	42.41 kips	168.02 kips
45.80 ft	130.59 kips	42.41 kips	173.00 kips
46.80 ft	135.65 kips	42.41 kips	178.06 kips
47.80 ft	140.79 kips	42.41 kips	183.20 kips
48.79 ft	145.95 kips	42.41 kips	188.36 kips
48.81 ft	146.04 kips	35.34 kips	181.38 kips
49.80 ft	149.74 kips	35.34 kips	185.08 kips
50.80 ft	153.48 kips	35.34 kips	188.82 kips
51.80 ft	157.22 kips	35.34 kips	192.56 kips
52.80 ft	160.96 kips	35.34 kips	196.30 kips
53.80 ft	164.70 kips	35.34 kips	200.04 kips
54.80 ft	168.43 kips	35.34 kips	203.78 kips
55.80 ft	172.17 kips	35.34 kips	207.52 kips
56.79 ft	175.87 kips	35.34 kips	211.22 kips
56.81 ft	175.97 kips	56.55 kips	232.52 kips
57.80 ft	181.89 kips	56.55 kips	238.44 kips
58.80 ft	187.87 kips	56.55 kips	244.42 kips
59.80 ft	193.86 kips	56.55 kips	250.40 kips
60.80 ft	199.84 kips	56.55 kips	256.39 kips
61.79 ft	205.76 kips	56.55 kips	262.31 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
50
100
150
200
250
300

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.02 kips	33.58 kips	33.60 kips
19.50 ft	2.37 kips	33.58 kips	35.94 kips
20.50 ft	4.74 kips	33.58 kips	38.31 kips
21.50 ft	7.10 kips	33.58 kips	40.68 kips
22.50 ft	9.47 kips	33.58 kips	43.05 kips
23.49 ft	11.82 kips	33.58 kips	45.39 kips
23.51 ft	11.86 kips	33.58 kips	45.44 kips
23.79 ft	12.53 kips	33.58 kips	46.10 kips
23.81 ft	12.59 kips	53.90 kips	66.49 kips
24.80 ft	16.35 kips	53.90 kips	70.25 kips
25.80 ft	20.15 kips	53.90 kips	74.05 kips
26.80 ft	23.95 kips	53.90 kips	77.85 kips
27.80 ft	27.75 kips	53.90 kips	81.65 kips
28.80 ft	31.55 kips	53.90 kips	85.45 kips
29.80 ft	35.36 kips	53.90 kips	89.25 kips
30.80 ft	39.16 kips	53.90 kips	93.05 kips
31.80 ft	42.96 kips	53.90 kips	96.86 kips
32.80 ft	46.76 kips	53.90 kips	100.66 kips
33.79 ft	50.52 kips	53.90 kips	104.42 kips
33.81 ft	50.59 kips	42.41 kips	93.00 kips
34.80 ft	53.55 kips	42.41 kips	95.96 kips
35.80 ft	56.54 kips	42.41 kips	98.95 kips

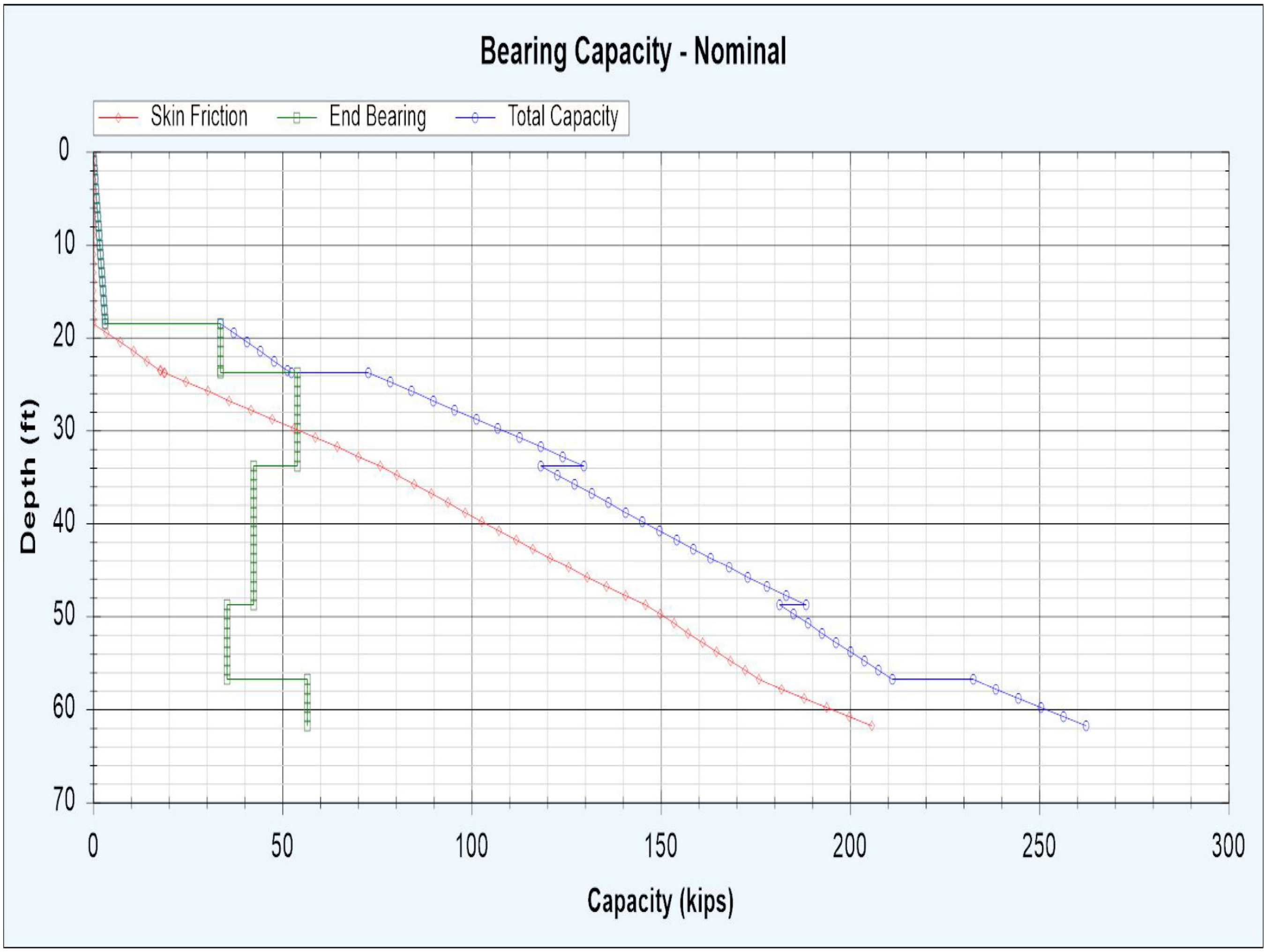
Depth	Skin Friction	End Bearing	Total Capacity
36.80 ft	59.53 kips	42.41 kips	101.94 kips
37.80 ft	62.52 kips	42.41 kips	104.93 kips
38.80 ft	65.51 kips	42.41 kips	107.93 kips
39.80 ft	68.51 kips	42.41 kips	110.92 kips
40.80 ft	71.50 kips	42.41 kips	113.91 kips
41.80 ft	74.49 kips	42.41 kips	116.90 kips
42.80 ft	77.48 kips	42.41 kips	119.89 kips
43.80 ft	80.47 kips	42.41 kips	122.88 kips
44.80 ft	83.74 kips	42.41 kips	126.15 kips
45.80 ft	87.06 kips	42.41 kips	129.48 kips
46.80 ft	90.44 kips	42.41 kips	132.85 kips
47.80 ft	93.86 kips	42.41 kips	136.28 kips
48.79 ft	97.31 kips	42.41 kips	139.72 kips
48.81 ft	97.37 kips	35.34 kips	132.71 kips
49.80 ft	99.83 kips	35.34 kips	135.18 kips
50.80 ft	102.33 kips	35.34 kips	137.67 kips
51.80 ft	104.82 kips	35.34 kips	140.16 kips
52.80 ft	107.31 kips	35.34 kips	142.65 kips
53.80 ft	109.80 kips	35.34 kips	145.15 kips
54.80 ft	112.29 kips	35.34 kips	147.64 kips
55.80 ft	114.79 kips	35.34 kips	150.13 kips
56.79 ft	117.25 kips	35.34 kips	152.60 kips
56.81 ft	117.32 kips	56.55 kips	173.87 kips
57.80 ft	121.27 kips	56.55 kips	177.82 kips
58.80 ft	125.26 kips	56.55 kips	181.80 kips
59.80 ft	129.24 kips	56.55 kips	185.79 kips
60.80 ft	133.23 kips	56.55 kips	189.78 kips
61.79 ft	137.18 kips	56.55 kips	193.73 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
Capacity (kips)

Nominal - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.04 kips	33.58 kips	33.61 kips
19.50 ft	3.55 kips	33.58 kips	37.13 kips
20.50 ft	7.10 kips	33.58 kips	40.68 kips
21.50 ft	10.65 kips	33.58 kips	44.23 kips
22.50 ft	14.21 kips	33.58 kips	47.78 kips
23.49 ft	17.72 kips	33.58 kips	51.30 kips
23.51 ft	17.79 kips	33.58 kips	51.37 kips
23.79 ft	18.79 kips	33.58 kips	52.36 kips
23.81 ft	18.88 kips	53.90 kips	72.78 kips
24.80 ft	24.52 kips	53.90 kips	78.42 kips
25.80 ft	30.23 kips	53.90 kips	84.12 kips
26.80 ft	35.93 kips	53.90 kips	89.82 kips
27.80 ft	41.63 kips	53.90 kips	95.53 kips
28.80 ft	47.33 kips	53.90 kips	101.23 kips
29.80 ft	53.03 kips	53.90 kips	106.93 kips
30.80 ft	58.73 kips	53.90 kips	112.63 kips
31.80 ft	64.43 kips	53.90 kips	118.33 kips
32.80 ft	70.13 kips	53.90 kips	124.03 kips
33.79 ft	75.78 kips	53.90 kips	129.68 kips
33.81 ft	75.88 kips	42.41 kips	118.29 kips
34.80 ft	80.32 kips	42.41 kips	122.73 kips
35.80 ft	84.81 kips	42.41 kips	127.22 kips

Depth	Skin Friction	End Bearing	Total Capacity
36.80 ft	89.29 kips	42.41 kips	131.71 kips
37.80 ft	93.78 kips	42.41 kips	136.19 kips
38.80 ft	98.27 kips	42.41 kips	140.68 kips
39.80 ft	102.75 kips	42.41 kips	145.16 kips
40.80 ft	107.24 kips	42.41 kips	149.65 kips
41.80 ft	111.72 kips	42.41 kips	154.14 kips
42.80 ft	116.21 kips	42.41 kips	158.62 kips
43.80 ft	120.70 kips	42.41 kips	163.11 kips
44.80 ft	125.61 kips	42.41 kips	168.02 kips
45.80 ft	130.59 kips	42.41 kips	173.00 kips
46.80 ft	135.65 kips	42.41 kips	178.06 kips
47.80 ft	140.79 kips	42.41 kips	183.20 kips
48.79 ft	145.95 kips	42.41 kips	188.36 kips
48.81 ft	146.04 kips	35.34 kips	181.38 kips
49.80 ft	149.74 kips	35.34 kips	185.08 kips
50.80 ft	153.48 kips	35.34 kips	188.82 kips
51.80 ft	157.22 kips	35.34 kips	192.56 kips
52.80 ft	160.96 kips	35.34 kips	196.30 kips
53.80 ft	164.70 kips	35.34 kips	200.04 kips
54.80 ft	168.43 kips	35.34 kips	203.78 kips
55.80 ft	172.17 kips	35.34 kips	207.52 kips
56.79 ft	175.87 kips	35.34 kips	211.22 kips
56.81 ft	175.97 kips	56.55 kips	232.52 kips
57.80 ft	181.89 kips	56.55 kips	238.44 kips
58.80 ft	187.87 kips	56.55 kips	244.42 kips
59.80 ft	193.86 kips	56.55 kips	250.40 kips
60.80 ft	199.84 kips	56.55 kips	256.39 kips
61.79 ft	205.76 kips	56.55 kips	262.31 kips


Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
50
100
150
200
250
300

Rear Abutment
Boring B-074-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - RA (B-074-0-19).dvn
Project Name: FRA-00070-22.919 Brice Rd Bridge over WB-CD Ramp - Rear Abutment (B-074-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	33.10 ft
Driving/Restrike:	33.10 ft
Nominal:	33.10 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	18.50 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesive	2.60 ft	1.750	120.00 pcf	2125.00 psf	T-80 Same
3	Cohesive	5.00 ft	1.500	120.00 pcf	3125.00 psf	T-80 Same
4	Cohesive	5.00 ft	1.750	130.00 pcf	6625.00 psf	T-80 Same
5	Cohesive	5.00 ft	1.500	125.00 pcf	3625.00 psf	T-80 Same
6	Cohesive	5.00 ft	1.500	130.00 pcf	7875.00 psf	T-80 Same
7	Cohesive	10.00 ft	1.500	125.00 pcf	3625.00 psf	T-80 Same
8	Cohesive	5.00 ft	1.500	130.00 pcf	7500.00 psf	T-80 Same
9	Cohesive	4.00 ft	1.500	130.00 pcf	6125.00 psf	T-80 Same
10	Cohesive	4.00 ft	1.500	125.00 pcf	4375.00 psf	T-80 Same

Restrike: 189.8 kips
Driving: 140.8 kips

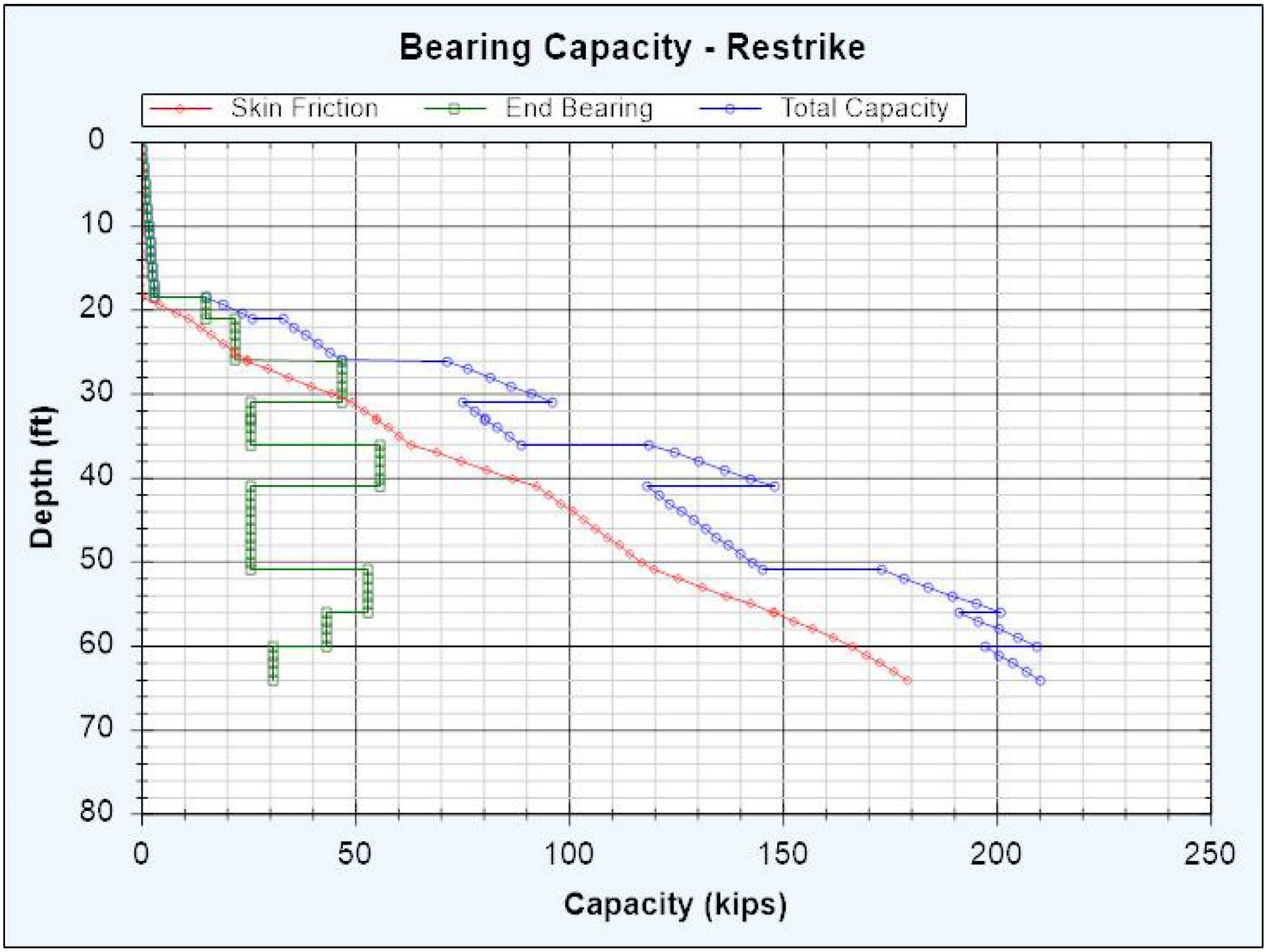
Estimated Ground Surface Elevation: 820.4 ft-msl
Bottom of Footing Elevation: 809.5 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 791.0 ft-msl

Estimated Pile Top Elevation: 810.5 ft-msl
Estimated Pile Tip Elevation: 755.4 ft-msl
Embedment Depth Below Bottom of Footing Elevation: 54.1 ft
Estimated Pile Length: 60.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.04 kips	15.02 kips	15.06 kips
19.50 ft	4.22 kips	15.02 kips	19.24 kips
20.50 ft	8.44 kips	15.02 kips	23.46 kips
21.09 ft	10.93 kips	15.02 kips	25.95 kips
21.11 ft	11.00 kips	22.09 kips	33.09 kips
22.10 ft	13.73 kips	22.09 kips	35.82 kips
23.10 ft	16.48 kips	22.09 kips	38.57 kips
24.10 ft	19.24 kips	22.09 kips	41.33 kips
25.10 ft	21.99 kips	22.09 kips	44.08 kips
26.09 ft	24.72 kips	22.09 kips	46.81 kips
26.11 ft	24.80 kips	46.83 kips	71.63 kips
27.10 ft	29.70 kips	46.83 kips	76.53 kips
28.10 ft	34.66 kips	46.83 kips	81.49 kips
29.10 ft	39.61 kips	46.83 kips	86.44 kips
30.10 ft	44.57 kips	46.83 kips	91.39 kips
31.09 ft	49.47 kips	46.83 kips	96.30 kips
31.11 ft	49.55 kips	25.62 kips	75.17 kips
32.10 ft	52.25 kips	25.62 kips	77.87 kips
33.09 ft	54.96 kips	25.62 kips	80.58 kips
33.11 ft	55.01 kips	25.62 kips	80.63 kips
34.10 ft	57.71 kips	25.62 kips	83.34 kips
35.10 ft	60.45 kips	25.62 kips	86.07 kips

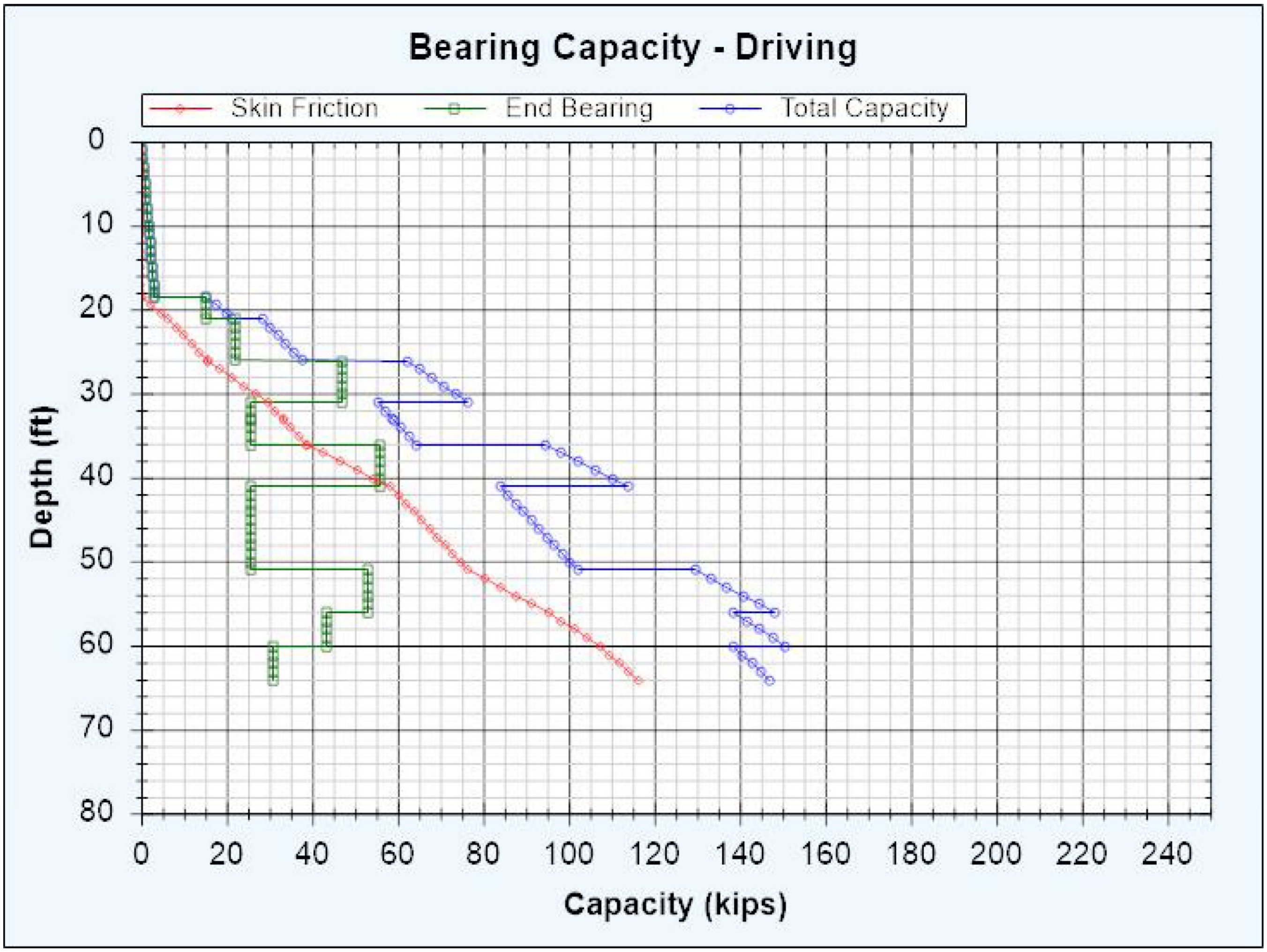
Depth	Skin Friction	End Bearing	Total Capacity
36.09 ft	63.15 kips	25.62 kips	88.78 kips
36.11 ft	63.24 kips	55.67 kips	118.90 kips
37.10 ft	69.07 kips	55.67 kips	124.73 kips
38.10 ft	74.96 kips	55.67 kips	130.62 kips
39.10 ft	80.84 kips	55.67 kips	136.51 kips
40.10 ft	86.73 kips	55.67 kips	142.40 kips
41.09 ft	92.56 kips	55.67 kips	148.23 kips
41.11 ft	92.65 kips	25.62 kips	118.27 kips
42.10 ft	95.35 kips	25.62 kips	120.98 kips
43.10 ft	98.08 kips	25.62 kips	123.71 kips
44.10 ft	100.82 kips	25.62 kips	126.44 kips
45.10 ft	103.55 kips	25.62 kips	129.17 kips
46.10 ft	106.28 kips	25.62 kips	131.90 kips
47.10 ft	109.01 kips	25.62 kips	134.64 kips
48.10 ft	111.74 kips	25.62 kips	137.37 kips
49.10 ft	114.48 kips	25.62 kips	140.10 kips
50.10 ft	117.21 kips	25.62 kips	142.83 kips
51.09 ft	119.91 kips	25.62 kips	145.54 kips
51.11 ft	120.00 kips	53.01 kips	173.01 kips
52.10 ft	125.55 kips	53.01 kips	178.56 kips
53.10 ft	131.16 kips	53.01 kips	184.17 kips
54.10 ft	136.76 kips	53.01 kips	189.78 kips
55.10 ft	142.37 kips	53.01 kips	195.39 kips
56.09 ft	147.92 kips	53.01 kips	200.94 kips
56.11 ft	148.02 kips	43.30 kips	191.32 kips
57.10 ft	152.56 kips	43.30 kips	195.85 kips
58.10 ft	157.14 kips	43.30 kips	200.43 kips
59.10 ft	161.72 kips	43.30 kips	205.01 kips
60.09 ft	166.25 kips	43.30 kips	209.55 kips
60.11 ft	166.33 kips	30.93 kips	197.25 kips
61.10 ft	169.57 kips	30.93 kips	200.49 kips
62.10 ft	172.84 kips	30.93 kips	203.76 kips
63.10 ft	176.11 kips	30.93 kips	207.04 kips
64.09 ft	179.35 kips	30.93 kips	210.27 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
Capacity (kips)
0
50
100
150
200
250

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.02 kips	15.02 kips	15.04 kips
19.50 ft	2.41 kips	15.02 kips	17.43 kips
20.50 ft	4.82 kips	15.02 kips	19.84 kips
21.09 ft	6.24 kips	15.02 kips	21.27 kips
21.11 ft	6.29 kips	22.09 kips	28.38 kips
22.10 ft	8.11 kips	22.09 kips	30.20 kips
23.10 ft	9.94 kips	22.09 kips	32.03 kips
24.10 ft	11.78 kips	22.09 kips	33.87 kips
25.10 ft	13.62 kips	22.09 kips	35.71 kips
26.09 ft	15.44 kips	22.09 kips	37.53 kips
26.11 ft	15.48 kips	46.83 kips	62.31 kips
27.10 ft	18.29 kips	46.83 kips	65.12 kips
28.10 ft	21.12 kips	46.83 kips	67.95 kips
29.10 ft	23.95 kips	46.83 kips	70.78 kips
30.10 ft	26.78 kips	46.83 kips	73.61 kips
31.09 ft	29.58 kips	46.83 kips	76.41 kips
31.11 ft	29.63 kips	25.62 kips	55.25 kips
32.10 ft	31.43 kips	25.62 kips	57.05 kips
33.09 ft	33.23 kips	25.62 kips	58.86 kips
33.11 ft	33.27 kips	25.62 kips	58.89 kips
34.10 ft	35.07 kips	25.62 kips	60.70 kips
35.10 ft	36.89 kips	25.62 kips	62.52 kips

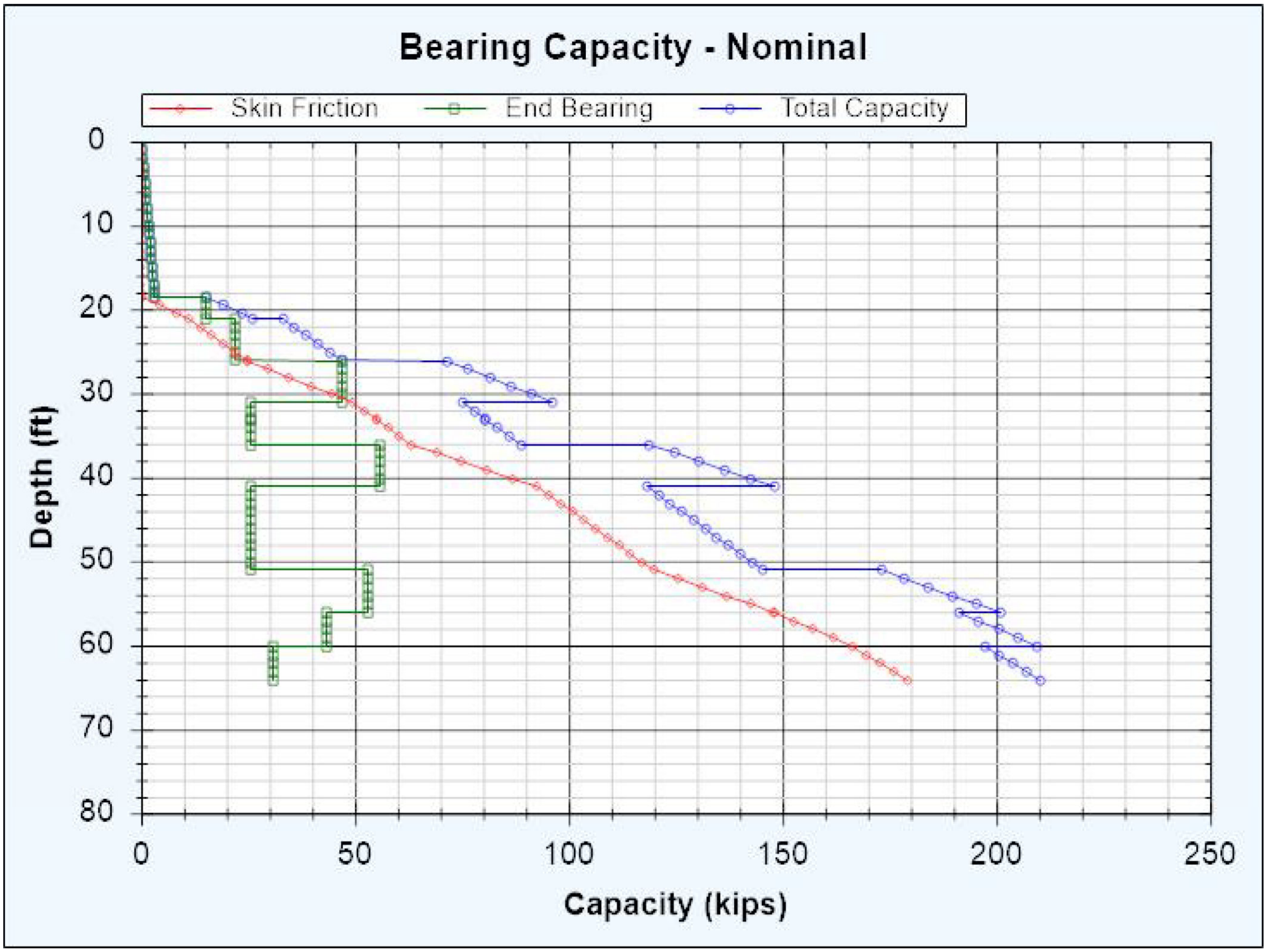
Depth	Skin Friction	End Bearing	Total Capacity
36.09 ft	38.70 kips	25.62 kips	64.32 kips
36.11 ft	38.75 kips	55.67 kips	94.42 kips
37.10 ft	42.64 kips	55.67 kips	98.31 kips
38.10 ft	46.57 kips	55.67 kips	102.23 kips
39.10 ft	50.49 kips	55.67 kips	106.16 kips
40.10 ft	54.42 kips	55.67 kips	110.08 kips
41.09 ft	58.30 kips	55.67 kips	113.97 kips
41.11 ft	58.36 kips	25.62 kips	83.99 kips
42.10 ft	60.16 kips	25.62 kips	85.79 kips
43.10 ft	61.99 kips	25.62 kips	87.61 kips
44.10 ft	63.81 kips	25.62 kips	89.43 kips
45.10 ft	65.63 kips	25.62 kips	91.25 kips
46.10 ft	67.45 kips	25.62 kips	93.07 kips
47.10 ft	69.27 kips	25.62 kips	94.90 kips
48.10 ft	71.09 kips	25.62 kips	96.72 kips
49.10 ft	72.92 kips	25.62 kips	98.54 kips
50.10 ft	74.74 kips	25.62 kips	100.36 kips
51.09 ft	76.54 kips	25.62 kips	102.16 kips
51.11 ft	76.60 kips	53.01 kips	129.61 kips
52.10 ft	80.30 kips	53.01 kips	133.31 kips
53.10 ft	84.04 kips	53.01 kips	137.05 kips
54.10 ft	87.77 kips	53.01 kips	140.79 kips
55.10 ft	91.51 kips	53.01 kips	144.53 kips
56.09 ft	95.21 kips	53.01 kips	148.23 kips
56.11 ft	95.28 kips	43.30 kips	138.58 kips
57.10 ft	98.30 kips	43.30 kips	141.60 kips
58.10 ft	101.36 kips	43.30 kips	144.65 kips
59.10 ft	104.41 kips	43.30 kips	147.71 kips
60.09 ft	107.43 kips	43.30 kips	150.73 kips
60.11 ft	107.49 kips	30.93 kips	138.41 kips
61.10 ft	109.65 kips	30.93 kips	140.57 kips
62.10 ft	111.83 kips	30.93 kips	142.75 kips
63.10 ft	114.01 kips	30.93 kips	144.93 kips
64.09 ft	116.17 kips	30.93 kips	147.09 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
0
20
40
60
80
100
120
140
160
180
200
220
240
Capacity (kips)

Nominal - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.04 kips	15.02 kips	15.06 kips
19.50 ft	4.22 kips	15.02 kips	19.24 kips
20.50 ft	8.44 kips	15.02 kips	23.46 kips
21.09 ft	10.93 kips	15.02 kips	25.95 kips
21.11 ft	11.00 kips	22.09 kips	33.09 kips
22.10 ft	13.73 kips	22.09 kips	35.82 kips
23.10 ft	16.48 kips	22.09 kips	38.57 kips
24.10 ft	19.24 kips	22.09 kips	41.33 kips
25.10 ft	21.99 kips	22.09 kips	44.08 kips
26.09 ft	24.72 kips	22.09 kips	46.81 kips
26.11 ft	24.80 kips	46.83 kips	71.63 kips
27.10 ft	29.70 kips	46.83 kips	76.53 kips
28.10 ft	34.66 kips	46.83 kips	81.49 kips
29.10 ft	39.61 kips	46.83 kips	86.44 kips
30.10 ft	44.57 kips	46.83 kips	91.39 kips
31.09 ft	49.47 kips	46.83 kips	96.30 kips
31.11 ft	49.55 kips	25.62 kips	75.17 kips
32.10 ft	52.25 kips	25.62 kips	77.87 kips
33.09 ft	54.96 kips	25.62 kips	80.58 kips
33.11 ft	55.01 kips	25.62 kips	80.63 kips
34.10 ft	57.71 kips	25.62 kips	83.34 kips
35.10 ft	60.45 kips	25.62 kips	86.07 kips

Depth	Skin Friction	End Bearing	Total Capacity
36.09 ft	63.15 kips	25.62 kips	88.78 kips
36.11 ft	63.24 kips	55.67 kips	118.90 kips
37.10 ft	69.07 kips	55.67 kips	124.73 kips
38.10 ft	74.96 kips	55.67 kips	130.62 kips
39.10 ft	80.84 kips	55.67 kips	136.51 kips
40.10 ft	86.73 kips	55.67 kips	142.40 kips
41.09 ft	92.56 kips	55.67 kips	148.23 kips
41.11 ft	92.65 kips	25.62 kips	118.27 kips
42.10 ft	95.35 kips	25.62 kips	120.98 kips
43.10 ft	98.08 kips	25.62 kips	123.71 kips
44.10 ft	100.82 kips	25.62 kips	126.44 kips
45.10 ft	103.55 kips	25.62 kips	129.17 kips
46.10 ft	106.28 kips	25.62 kips	131.90 kips
47.10 ft	109.01 kips	25.62 kips	134.64 kips
48.10 ft	111.74 kips	25.62 kips	137.37 kips
49.10 ft	114.48 kips	25.62 kips	140.10 kips
50.10 ft	117.21 kips	25.62 kips	142.83 kips
51.09 ft	119.91 kips	25.62 kips	145.54 kips
51.11 ft	120.00 kips	53.01 kips	173.01 kips
52.10 ft	125.55 kips	53.01 kips	178.56 kips
53.10 ft	131.16 kips	53.01 kips	184.17 kips
54.10 ft	136.76 kips	53.01 kips	189.78 kips
55.10 ft	142.37 kips	53.01 kips	195.39 kips
56.09 ft	147.92 kips	53.01 kips	200.94 kips
56.11 ft	148.02 kips	43.30 kips	191.32 kips
57.10 ft	152.56 kips	43.30 kips	195.85 kips
58.10 ft	157.14 kips	43.30 kips	200.43 kips
59.10 ft	161.72 kips	43.30 kips	205.01 kips
60.09 ft	166.25 kips	43.30 kips	209.55 kips
60.11 ft	166.33 kips	30.93 kips	197.25 kips
61.10 ft	169.57 kips	30.93 kips	200.49 kips
62.10 ft	172.84 kips	30.93 kips	203.76 kips
63.10 ft	176.11 kips	30.93 kips	207.04 kips
64.09 ft	179.35 kips	30.93 kips	210.27 kips


Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
Capacity (kips)
0
50
100
150
200
250

Rear Abutment
Boring B-075-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - RA (B-075-0-19).dvn
Project Name: FRA-00070-22.919 Brice Rd Bridge over WB-CD Ramp - Rear Abutment (B-075-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	27.00 ft
Driving/Restrike:	27.00 ft
Nominal:	27.00 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	18.50 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesive	4.00 ft	1.500	120.00 pcf	2875.00 psf	T-80 Same
3	Cohesionless	5.00 ft	1.000	130.00 pcf	32.0/32.0	Nordlund
4	Cohesionless	10.00 ft	1.000	135.00 pcf	37.0/37.0	Nordlund
5	Cohesive	10.00 ft	1.500	120.00 pcf	2250.00 psf	T-80 Sand
6	Cohesionless	3.00 ft	1.200	135.00 pcf	37.0/37.0	Nordlund

Restrike: 329.8 kips
Driving: 302.3 kips

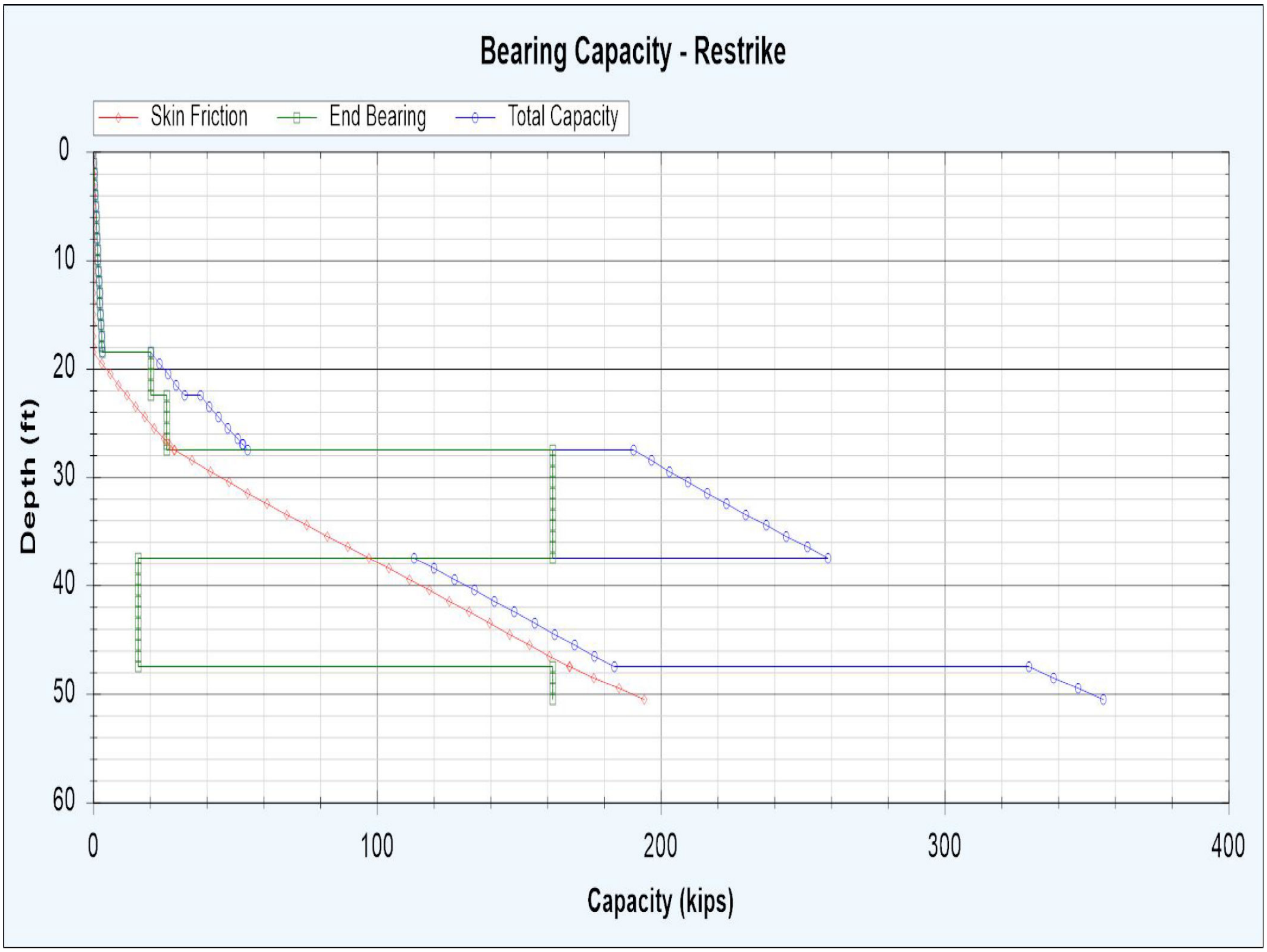
Estimated Ground Surface Elevation: 819.0 ft-msl
Bottom of Footing Elevation: 809.5 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 791.0 ft-msl

Estimated Pile Top Elevation: 810.5 ft-msl
Estimated Pile Tip Elevation: 762.0 ft-msl
Embedment Depth Below Bottom of Footing Elevation: 47.5 ft
Estimated Pile Length: 50.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.03 kips	20.32 kips	20.35 kips
19.50 ft	2.97 kips	20.32 kips	23.29 kips
20.50 ft	5.94 kips	20.32 kips	26.26 kips
21.50 ft	8.91 kips	20.32 kips	29.23 kips
22.49 ft	11.85 kips	20.32 kips	32.18 kips
22.51 ft	11.91 kips	25.92 kips	37.83 kips
23.50 ft	14.95 kips	25.92 kips	40.87 kips
24.50 ft	18.16 kips	25.92 kips	44.07 kips
25.50 ft	21.50 kips	25.92 kips	47.42 kips
26.50 ft	24.99 kips	25.92 kips	50.91 kips
26.99 ft	26.75 kips	25.92 kips	52.66 kips
27.01 ft	26.82 kips	25.92 kips	52.74 kips
27.49 ft	28.57 kips	25.92 kips	54.49 kips
27.51 ft	28.67 kips	161.82 kips	190.49 kips
28.50 ft	34.87 kips	161.82 kips	196.69 kips
29.50 ft	41.27 kips	161.82 kips	203.09 kips
30.50 ft	47.79 kips	161.82 kips	209.62 kips
31.50 ft	54.46 kips	161.82 kips	216.28 kips
32.50 ft	61.25 kips	161.82 kips	223.07 kips
33.50 ft	68.17 kips	161.82 kips	230.00 kips
34.50 ft	75.23 kips	161.82 kips	237.05 kips
35.50 ft	82.42 kips	161.82 kips	244.24 kips

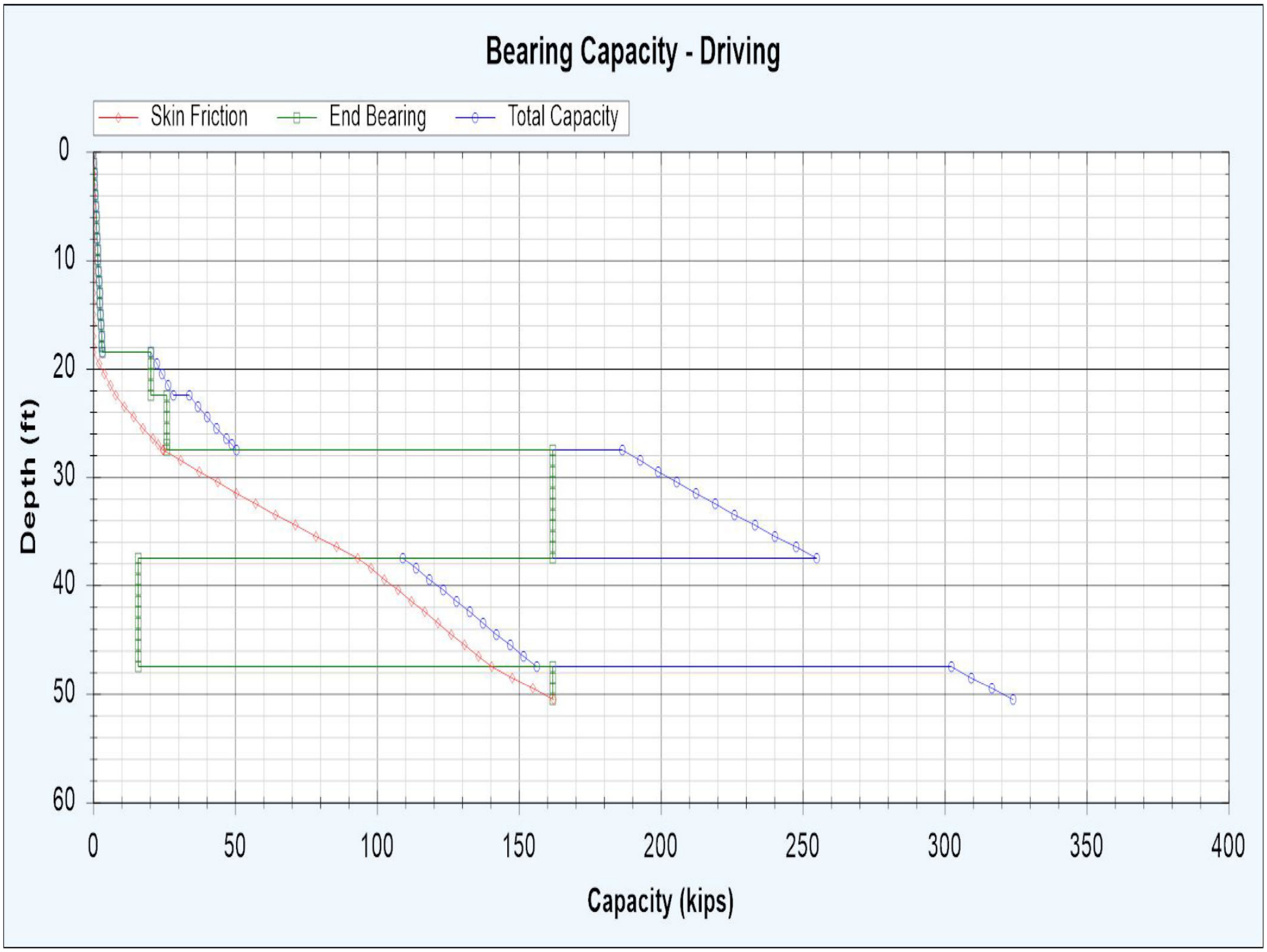
Depth	Skin Friction	End Bearing	Total Capacity
36.50 ft	89.74 kips	161.82 kips	251.56 kips
37.49 ft	97.12 kips	161.82 kips	258.94 kips
37.51 ft	97.26 kips	15.90 kips	113.17 kips
38.50 ft	104.26 kips	15.90 kips	120.16 kips
39.50 ft	111.33 kips	15.90 kips	127.23 kips
40.50 ft	118.40 kips	15.90 kips	134.30 kips
41.50 ft	125.47 kips	15.90 kips	141.37 kips
42.50 ft	132.53 kips	15.90 kips	148.44 kips
43.50 ft	139.60 kips	15.90 kips	155.51 kips
44.50 ft	146.67 kips	15.90 kips	162.58 kips
45.50 ft	153.74 kips	15.90 kips	169.64 kips
46.50 ft	160.81 kips	15.90 kips	176.71 kips
47.49 ft	167.81 kips	15.90 kips	183.71 kips
47.51 ft	167.96 kips	161.82 kips	329.79 kips
48.50 ft	176.51 kips	161.82 kips	338.33 kips
49.50 ft	185.27 kips	161.82 kips	347.09 kips
50.49 ft	194.08 kips	161.82 kips	355.90 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
0
100
200
300
400
Capacity (kips)

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.02 kips	20.32 kips	20.34 kips
19.50 ft	1.98 kips	20.32 kips	22.30 kips
20.50 ft	3.96 kips	20.32 kips	24.28 kips
21.50 ft	5.94 kips	20.32 kips	26.26 kips
22.49 ft	7.90 kips	20.32 kips	28.22 kips
22.51 ft	7.95 kips	25.92 kips	33.87 kips
23.50 ft	10.99 kips	25.92 kips	36.91 kips
24.50 ft	14.20 kips	25.92 kips	40.11 kips
25.50 ft	17.54 kips	25.92 kips	43.46 kips
26.50 ft	21.03 kips	25.92 kips	46.94 kips
26.99 ft	22.79 kips	25.92 kips	48.70 kips
27.01 ft	22.86 kips	25.92 kips	48.78 kips
27.49 ft	24.61 kips	25.92 kips	50.52 kips
27.51 ft	24.71 kips	161.82 kips	186.53 kips
28.50 ft	30.91 kips	161.82 kips	192.73 kips
29.50 ft	37.31 kips	161.82 kips	199.13 kips
30.50 ft	43.83 kips	161.82 kips	205.66 kips
31.50 ft	50.50 kips	161.82 kips	212.32 kips
32.50 ft	57.29 kips	161.82 kips	219.11 kips
33.50 ft	64.21 kips	161.82 kips	226.04 kips
34.50 ft	71.27 kips	161.82 kips	233.09 kips
35.50 ft	78.46 kips	161.82 kips	240.28 kips

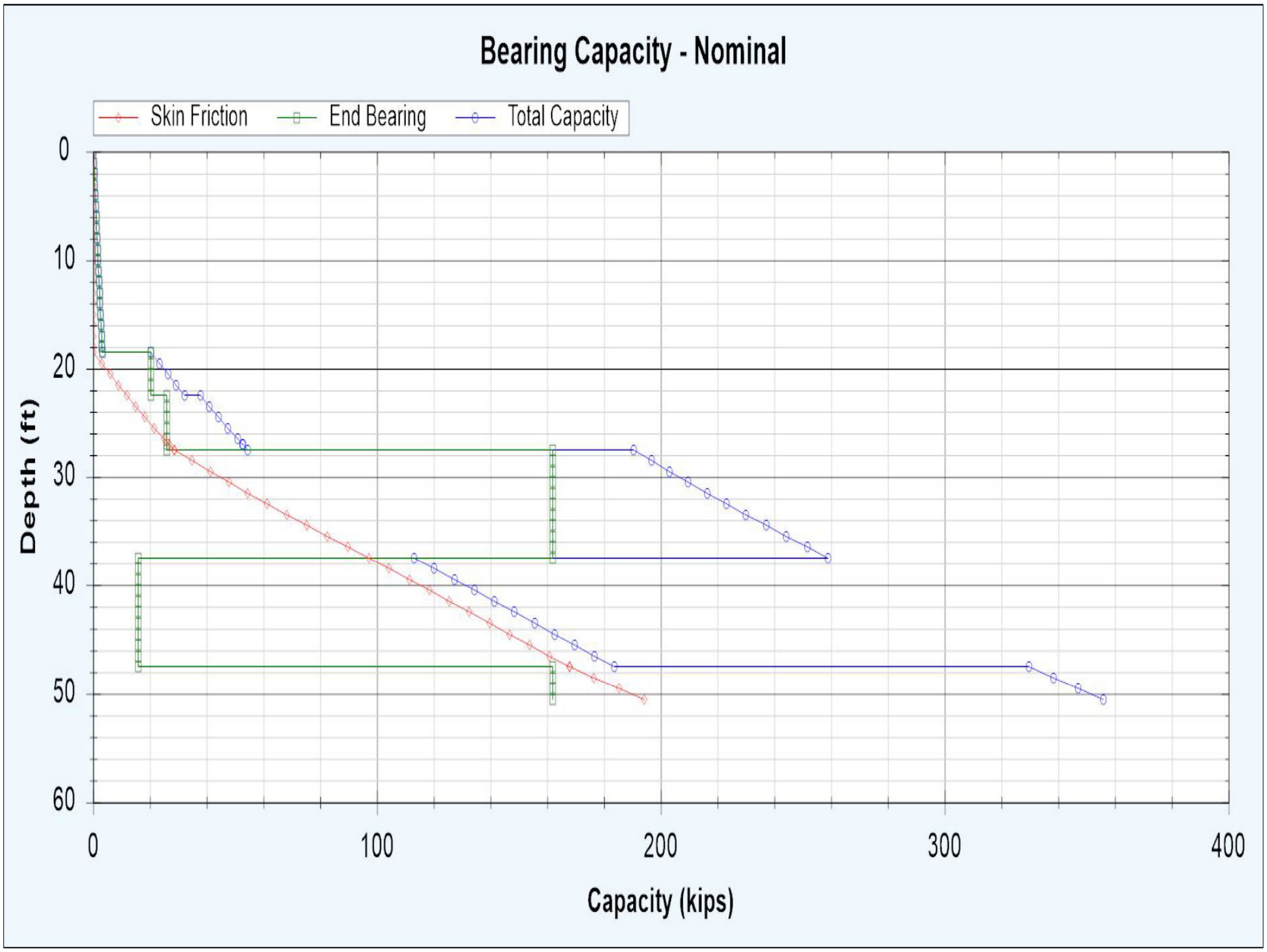
Depth	Skin Friction	End Bearing	Total Capacity
36.50 ft	85.78 kips	161.82 kips	247.60 kips
37.49 ft	93.16 kips	161.82 kips	254.98 kips
37.51 ft	93.28 kips	15.90 kips	109.18 kips
38.50 ft	97.94 kips	15.90 kips	113.85 kips
39.50 ft	102.66 kips	15.90 kips	118.56 kips
40.50 ft	107.37 kips	15.90 kips	123.27 kips
41.50 ft	112.08 kips	15.90 kips	127.99 kips
42.50 ft	116.79 kips	15.90 kips	132.70 kips
43.50 ft	121.51 kips	15.90 kips	137.41 kips
44.50 ft	126.22 kips	15.90 kips	142.12 kips
45.50 ft	130.93 kips	15.90 kips	146.84 kips
46.50 ft	135.64 kips	15.90 kips	151.55 kips
47.49 ft	140.31 kips	15.90 kips	156.21 kips
47.51 ft	140.43 kips	161.82 kips	302.25 kips
48.50 ft	147.55 kips	161.82 kips	309.37 kips
49.50 ft	154.85 kips	161.82 kips	316.67 kips
50.49 ft	162.19 kips	161.82 kips	324.01 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
0
50
100
150
200
250
300
350
400
Capacity (kips)

Nominal - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
17.00 ft	0.00 kips	2.92 kips	2.92 kips
18.00 ft	0.00 kips	3.10 kips	3.10 kips
18.49 ft	0.00 kips	3.18 kips	3.18 kips
18.51 ft	0.03 kips	20.32 kips	20.35 kips
19.50 ft	2.97 kips	20.32 kips	23.29 kips
20.50 ft	5.94 kips	20.32 kips	26.26 kips
21.50 ft	8.91 kips	20.32 kips	29.23 kips
22.49 ft	11.85 kips	20.32 kips	32.18 kips
22.51 ft	11.91 kips	25.92 kips	37.83 kips
23.50 ft	14.95 kips	25.92 kips	40.87 kips
24.50 ft	18.16 kips	25.92 kips	44.07 kips
25.50 ft	21.50 kips	25.92 kips	47.42 kips
26.50 ft	24.99 kips	25.92 kips	50.91 kips
26.99 ft	26.75 kips	25.92 kips	52.66 kips
27.01 ft	26.82 kips	25.92 kips	52.74 kips
27.49 ft	28.57 kips	25.92 kips	54.49 kips
27.51 ft	28.67 kips	161.82 kips	190.49 kips
28.50 ft	34.87 kips	161.82 kips	196.69 kips
29.50 ft	41.27 kips	161.82 kips	203.09 kips
30.50 ft	47.79 kips	161.82 kips	209.62 kips
31.50 ft	54.46 kips	161.82 kips	216.28 kips
32.50 ft	61.25 kips	161.82 kips	223.07 kips
33.50 ft	68.17 kips	161.82 kips	230.00 kips
34.50 ft	75.23 kips	161.82 kips	237.05 kips
35.50 ft	82.42 kips	161.82 kips	244.24 kips

Depth	Skin Friction	End Bearing	Total Capacity
36.50 ft	89.74 kips	161.82 kips	251.56 kips
37.49 ft	97.12 kips	161.82 kips	258.94 kips
37.51 ft	97.26 kips	15.90 kips	113.17 kips
38.50 ft	104.26 kips	15.90 kips	120.16 kips
39.50 ft	111.33 kips	15.90 kips	127.23 kips
40.50 ft	118.40 kips	15.90 kips	134.30 kips
41.50 ft	125.47 kips	15.90 kips	141.37 kips
42.50 ft	132.53 kips	15.90 kips	148.44 kips
43.50 ft	139.60 kips	15.90 kips	155.51 kips
44.50 ft	146.67 kips	15.90 kips	162.58 kips
45.50 ft	153.74 kips	15.90 kips	169.64 kips
46.50 ft	160.81 kips	15.90 kips	176.71 kips
47.49 ft	167.81 kips	15.90 kips	183.71 kips
47.51 ft	167.96 kips	161.82 kips	329.79 kips
48.50 ft	176.51 kips	161.82 kips	338.33 kips
49.50 ft	185.27 kips	161.82 kips	347.09 kips
50.49 ft	194.08 kips	161.82 kips	355.90 kips


Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
0
100
200
300
400
Capacity (kips)

Forward Abutment
Boring B-076-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - FA (B-076-0-19).dvn
Project Name: FRA-00070-22.919 Brice Rd Bridge over WB-CD Ramp - Forward Abutment (B-076-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	22.00 ft
Driving/Restrike:	22.00 ft
Nominal:	22.00 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	17.00 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesionless	0.80 ft	1.200	130.00 pcf	34.0/34.0	Nordlund
3	Cohesionless	5.00 ft	1.200	125.00 pcf	29.0/29.0	Nordlund
4	Cohesionless	10.00 ft	1.200	135.00 pcf	37.0/37.0	Nordlund
5	Cohesionless	10.00 ft	1.200	130.00 pcf	35.0/35.0	Nordlund
6	Cohesive	18.00 ft	1.500	130.00 pcf	5375.00 psf	T-80 Sand

Restrike: 195.7 kips
Driving: 163.8 kips

Estimated Ground Surface Elevation: 823.2 ft-msl
Bottom of Footing Elevation: 809.0 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 792.0 ft-msl

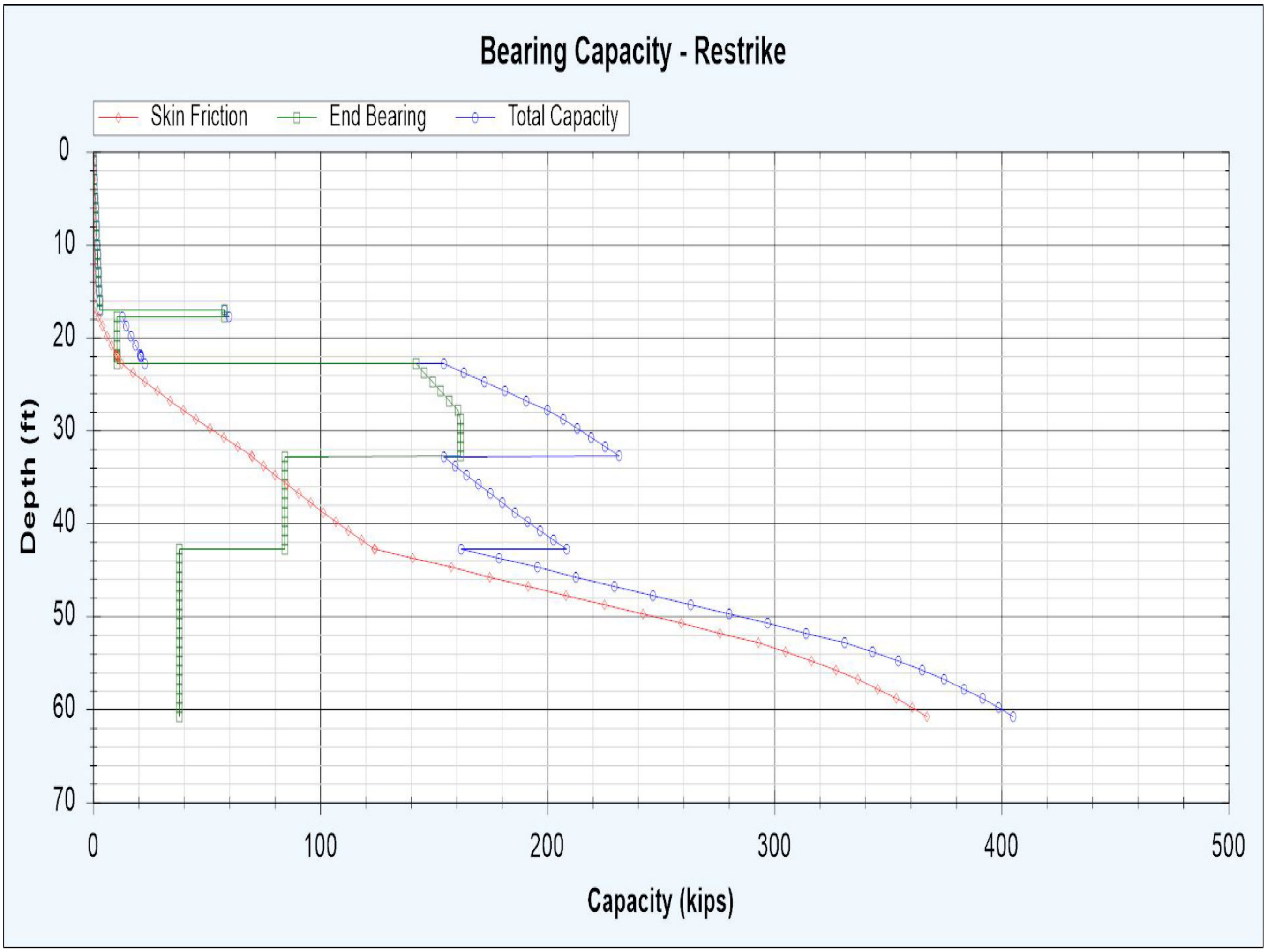
Estimated Pile Top Elevation: 810.0 ft-msl
Estimated Pile Tip Elevation: 764.2 ft-msl

Embedment Depth Below Bottom of Footing Elevation: 44.8 ft
Estimated Pile Length: 50.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.03 kips	57.74 kips	57.77 kips
17.79 ft	2.21 kips	57.74 kips	59.96 kips
17.81 ft	2.26 kips	10.46 kips	12.72 kips
18.80 ft	4.08 kips	10.46 kips	14.54 kips
19.80 ft	6.02 kips	10.46 kips	16.48 kips
20.80 ft	8.06 kips	10.46 kips	18.52 kips
21.80 ft	10.20 kips	10.46 kips	20.66 kips
21.99 ft	10.61 kips	10.46 kips	21.07 kips
22.01 ft	10.66 kips	10.46 kips	21.12 kips
22.79 ft	12.40 kips	10.46 kips	22.86 kips
22.81 ft	12.47 kips	142.14 kips	154.61 kips
23.80 ft	17.58 kips	145.78 kips	163.36 kips
24.80 ft	22.87 kips	149.46 kips	172.33 kips
25.80 ft	28.30 kips	153.14 kips	181.44 kips
26.80 ft	33.86 kips	156.82 kips	190.67 kips
27.80 ft	39.55 kips	160.50 kips	200.04 kips
28.80 ft	45.37 kips	161.82 kips	207.19 kips
29.80 ft	51.32 kips	161.82 kips	213.14 kips
30.80 ft	57.40 kips	161.82 kips	219.23 kips
31.80 ft	63.62 kips	161.82 kips	225.45 kips
32.79 ft	69.91 kips	161.82 kips	231.73 kips
32.81 ft	70.02 kips	84.51 kips	154.53 kips
33.80 ft	74.94 kips	84.51 kips	159.45 kips
34.80 ft	80.01 kips	84.51 kips	164.52 kips

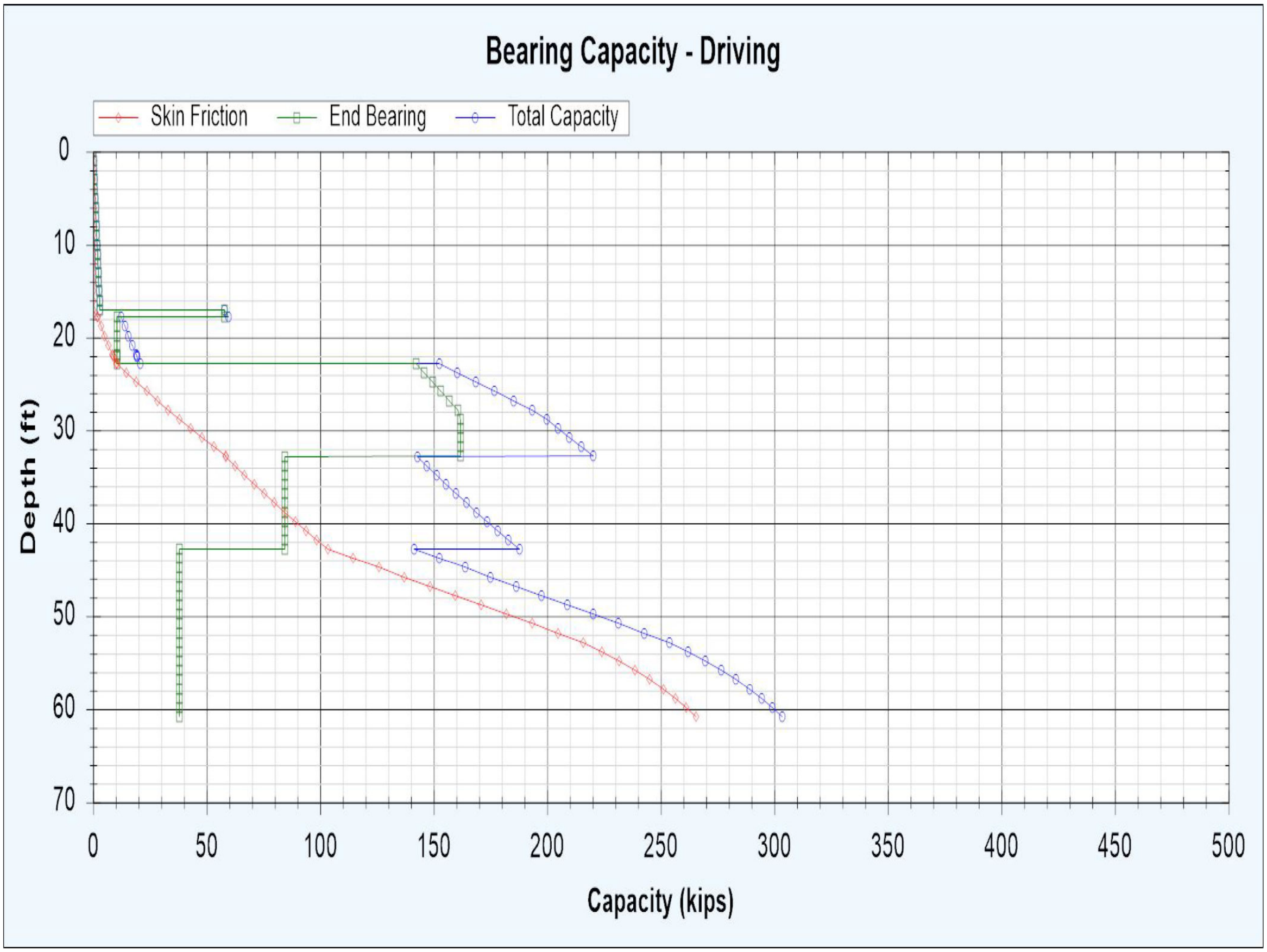
Depth	Skin Friction	End Bearing	Total Capacity
35.80 ft	85.17 kips	84.51 kips	169.68 kips
36.80 ft	90.43 kips	84.51 kips	174.93 kips
37.80 ft	95.77 kips	84.51 kips	180.28 kips
38.80 ft	101.22 kips	84.51 kips	185.73 kips
39.80 ft	106.76 kips	84.51 kips	191.27 kips
40.80 ft	112.39 kips	84.51 kips	196.90 kips
41.80 ft	118.12 kips	84.51 kips	202.62 kips
42.79 ft	123.88 kips	84.51 kips	208.39 kips
42.81 ft	124.11 kips	37.99 kips	162.10 kips
43.80 ft	140.82 kips	37.99 kips	178.82 kips
44.80 ft	157.71 kips	37.99 kips	195.70 kips
45.80 ft	174.60 kips	37.99 kips	212.59 kips
46.80 ft	191.48 kips	37.99 kips	229.47 kips
47.80 ft	208.37 kips	37.99 kips	246.36 kips
48.80 ft	225.25 kips	37.99 kips	263.25 kips
49.80 ft	242.14 kips	37.99 kips	280.13 kips
50.80 ft	259.03 kips	37.99 kips	297.02 kips
51.80 ft	275.91 kips	37.99 kips	313.91 kips
52.80 ft	292.80 kips	37.99 kips	330.79 kips
53.80 ft	305.04 kips	37.99 kips	343.03 kips
54.80 ft	316.44 kips	37.99 kips	354.43 kips
55.80 ft	326.99 kips	37.99 kips	364.99 kips
56.80 ft	336.70 kips	37.99 kips	374.70 kips
57.80 ft	345.57 kips	37.99 kips	383.56 kips
58.80 ft	353.59 kips	37.99 kips	391.58 kips
59.80 ft	360.76 kips	37.99 kips	398.76 kips
60.79 ft	367.04 kips	37.99 kips	405.03 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
100
200
300
400
500

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.02 kips	57.74 kips	57.77 kips
17.79 ft	1.84 kips	57.74 kips	59.59 kips
17.81 ft	1.88 kips	10.46 kips	12.34 kips
18.80 ft	3.40 kips	10.46 kips	13.86 kips
19.80 ft	5.01 kips	10.46 kips	15.48 kips
20.80 ft	6.71 kips	10.46 kips	17.17 kips
21.80 ft	8.50 kips	10.46 kips	18.96 kips
21.99 ft	8.84 kips	10.46 kips	19.31 kips
22.01 ft	8.88 kips	10.46 kips	19.34 kips
22.79 ft	10.33 kips	10.46 kips	20.79 kips
22.81 ft	10.39 kips	142.14 kips	152.53 kips
23.80 ft	14.65 kips	145.78 kips	160.43 kips
24.80 ft	19.06 kips	149.46 kips	168.52 kips
25.80 ft	23.58 kips	153.14 kips	176.72 kips
26.80 ft	28.21 kips	156.82 kips	185.03 kips
27.80 ft	32.95 kips	160.50 kips	193.45 kips
28.80 ft	37.80 kips	161.82 kips	199.63 kips
29.80 ft	42.76 kips	161.82 kips	204.59 kips
30.80 ft	47.84 kips	161.82 kips	209.66 kips
31.80 ft	53.02 kips	161.82 kips	214.84 kips
32.79 ft	58.25 kips	161.82 kips	220.08 kips
32.81 ft	58.35 kips	84.51 kips	142.86 kips
33.80 ft	62.45 kips	84.51 kips	146.96 kips
34.80 ft	66.67 kips	84.51 kips	151.18 kips

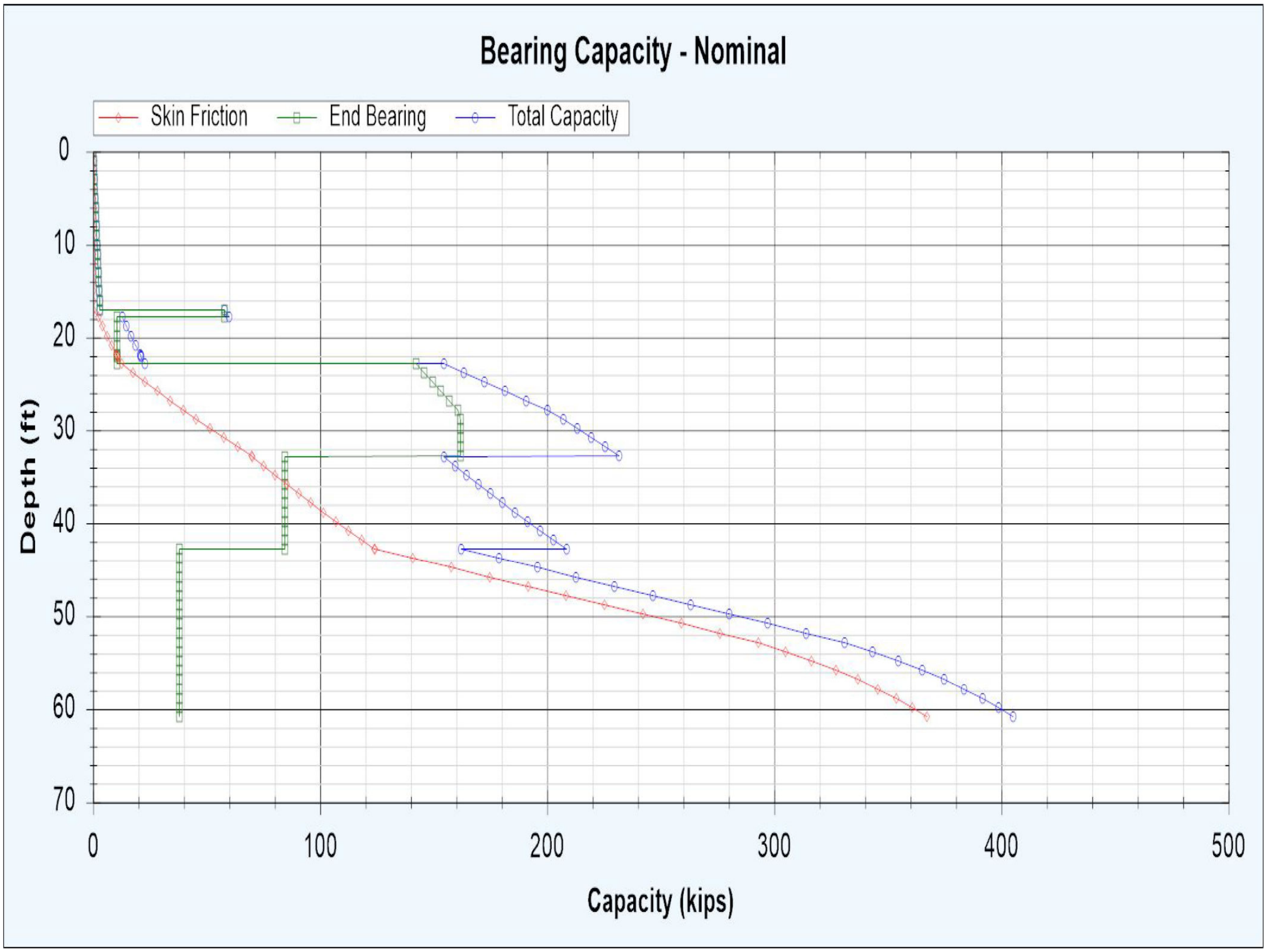
Depth	Skin Friction	End Bearing	Total Capacity
35.80 ft	70.97 kips	84.51 kips	155.48 kips
36.80 ft	75.35 kips	84.51 kips	159.86 kips
37.80 ft	79.81 kips	84.51 kips	164.32 kips
38.80 ft	84.35 kips	84.51 kips	168.85 kips
39.80 ft	88.96 kips	84.51 kips	173.47 kips
40.80 ft	93.65 kips	84.51 kips	178.16 kips
41.80 ft	98.43 kips	84.51 kips	182.93 kips
42.79 ft	103.23 kips	84.51 kips	187.74 kips
42.81 ft	103.39 kips	37.99 kips	141.38 kips
43.80 ft	114.53 kips	37.99 kips	152.53 kips
44.80 ft	125.79 kips	37.99 kips	163.79 kips
45.80 ft	137.05 kips	37.99 kips	175.04 kips
46.80 ft	148.31 kips	37.99 kips	186.30 kips
47.80 ft	159.56 kips	37.99 kips	197.56 kips
48.80 ft	170.82 kips	37.99 kips	208.81 kips
49.80 ft	182.08 kips	37.99 kips	220.07 kips
50.80 ft	193.34 kips	37.99 kips	231.33 kips
51.80 ft	204.59 kips	37.99 kips	242.59 kips
52.80 ft	215.85 kips	37.99 kips	253.84 kips
53.80 ft	224.01 kips	37.99 kips	262.01 kips
54.80 ft	231.61 kips	37.99 kips	269.60 kips
55.80 ft	238.65 kips	37.99 kips	276.64 kips
56.80 ft	245.12 kips	37.99 kips	283.11 kips
57.80 ft	251.03 kips	37.99 kips	289.02 kips
58.80 ft	256.38 kips	37.99 kips	294.37 kips
59.80 ft	261.16 kips	37.99 kips	299.16 kips
60.79 ft	265.34 kips	37.99 kips	303.34 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
0
50
100
150
200
250
300
350
400
450
500
Capacity (kips)

Nominal - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.03 kips	57.74 kips	57.77 kips
17.79 ft	2.21 kips	57.74 kips	59.96 kips
17.81 ft	2.26 kips	10.46 kips	12.72 kips
18.80 ft	4.08 kips	10.46 kips	14.54 kips
19.80 ft	6.02 kips	10.46 kips	16.48 kips
20.80 ft	8.06 kips	10.46 kips	18.52 kips
21.80 ft	10.20 kips	10.46 kips	20.66 kips
21.99 ft	10.61 kips	10.46 kips	21.07 kips
22.01 ft	10.66 kips	10.46 kips	21.12 kips
22.79 ft	12.40 kips	10.46 kips	22.86 kips
22.81 ft	12.47 kips	142.14 kips	154.61 kips
23.80 ft	17.58 kips	145.78 kips	163.36 kips
24.80 ft	22.87 kips	149.46 kips	172.33 kips
25.80 ft	28.30 kips	153.14 kips	181.44 kips
26.80 ft	33.86 kips	156.82 kips	190.67 kips
27.80 ft	39.55 kips	160.50 kips	200.04 kips
28.80 ft	45.37 kips	161.82 kips	207.19 kips
29.80 ft	51.32 kips	161.82 kips	213.14 kips
30.80 ft	57.40 kips	161.82 kips	219.23 kips
31.80 ft	63.62 kips	161.82 kips	225.45 kips
32.79 ft	69.91 kips	161.82 kips	231.73 kips
32.81 ft	70.02 kips	84.51 kips	154.53 kips
33.80 ft	74.94 kips	84.51 kips	159.45 kips
34.80 ft	80.01 kips	84.51 kips	164.52 kips

Depth	Skin Friction	End Bearing	Total Capacity
35.80 ft	85.17 kips	84.51 kips	169.68 kips
36.80 ft	90.43 kips	84.51 kips	174.93 kips
37.80 ft	95.77 kips	84.51 kips	180.28 kips
38.80 ft	101.22 kips	84.51 kips	185.73 kips
39.80 ft	106.76 kips	84.51 kips	191.27 kips
40.80 ft	112.39 kips	84.51 kips	196.90 kips
41.80 ft	118.12 kips	84.51 kips	202.62 kips
42.79 ft	123.88 kips	84.51 kips	208.39 kips
42.81 ft	124.11 kips	37.99 kips	162.10 kips
43.80 ft	140.82 kips	37.99 kips	178.82 kips
44.80 ft	157.71 kips	37.99 kips	195.70 kips
45.80 ft	174.60 kips	37.99 kips	212.59 kips
46.80 ft	191.48 kips	37.99 kips	229.47 kips
47.80 ft	208.37 kips	37.99 kips	246.36 kips
48.80 ft	225.25 kips	37.99 kips	263.25 kips
49.80 ft	242.14 kips	37.99 kips	280.13 kips
50.80 ft	259.03 kips	37.99 kips	297.02 kips
51.80 ft	275.91 kips	37.99 kips	313.91 kips
52.80 ft	292.80 kips	37.99 kips	330.79 kips
53.80 ft	305.04 kips	37.99 kips	343.03 kips
54.80 ft	316.44 kips	37.99 kips	354.43 kips
55.80 ft	326.99 kips	37.99 kips	364.99 kips
56.80 ft	336.70 kips	37.99 kips	374.70 kips
57.80 ft	345.57 kips	37.99 kips	383.56 kips
58.80 ft	353.59 kips	37.99 kips	391.58 kips
59.80 ft	360.76 kips	37.99 kips	398.76 kips
60.79 ft	367.04 kips	37.99 kips	405.03 kips


Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
100
200
300
400
500

Forward Abutment
Boring B-077-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - FA (B-077-0-19).dvn
Project Name: FRA-00070-22.919 Brice Rd Bridge over WB-CD Ramp - Forward Abutment (B-077-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	24.90 ft
Driving/Restrike:	24.90 ft
Nominal:	24.90 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	17.00 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesive	3.40 ft	1.750	120.00 pcf	1625.00 psf	T-80 Same
3	Cohesionless	5.00 ft	1.200	125.00 pcf	31.0/31.0	Nordlund
4	Cohesionless	5.00 ft	1.200	135.00 pcf	37.0/37.0	Nordlund
5	Cohesionless	10.00 ft	1.000	125.00 pcf	32.0/32.0	Nordlund
6	Cohesive	5.00 ft	1.500	120.00 pcf	3125.00 psf	T-80 Sand
7	Cohesive	5.00 ft	1.500	130.00 pcf	8000.00 psf	T-80 Same
8	Cohesionless	6.00 ft	1.200	135.00 pcf	33.0/33.0	Nordlund
9	Cohesive	7.00 ft	1.500	125.00 pcf	4375.00 psf	T-80 Sand

Restrike: 204.2 kips
Driving: 174.6 kips

Estimated Ground Surface Elevation: 820.6 ft-msl
Bottom of Footing Elevation: 809.0 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 792.0 ft-msl

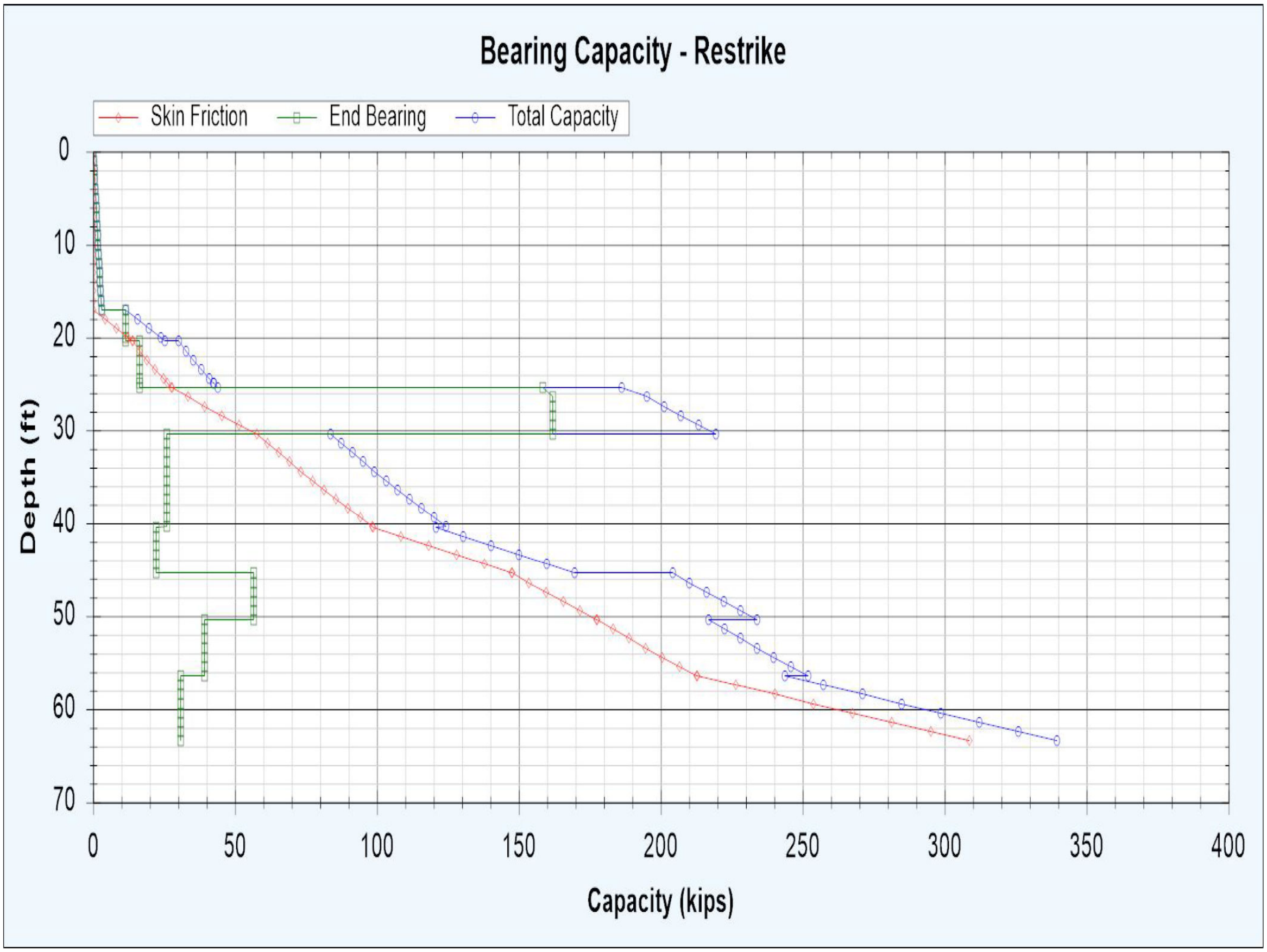
Estimated Pile Top Elevation: 810.0 ft-msl
Estimated Pile Tip Elevation: 763.6 ft-msl

Embedment Depth Below Bottom of Footing Elevation: 45.4 ft
Estimated Pile Length: 50.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.04 kips	11.49 kips	11.53 kips
18.00 ft	4.08 kips	11.49 kips	15.56 kips
19.00 ft	8.16 kips	11.49 kips	19.64 kips
20.00 ft	12.23 kips	11.49 kips	23.72 kips
20.39 ft	13.82 kips	11.49 kips	25.31 kips
20.41 ft	13.89 kips	16.23 kips	30.12 kips
21.40 ft	16.38 kips	16.23 kips	32.61 kips
22.40 ft	19.01 kips	16.23 kips	35.24 kips
23.40 ft	21.77 kips	16.23 kips	38.00 kips
24.40 ft	24.64 kips	16.23 kips	40.87 kips
24.89 ft	26.10 kips	16.23 kips	42.33 kips
24.91 ft	26.16 kips	16.23 kips	42.39 kips
25.39 ft	27.60 kips	16.23 kips	43.83 kips
25.41 ft	27.69 kips	158.49 kips	186.18 kips
26.40 ft	33.38 kips	161.82 kips	195.21 kips
27.40 ft	39.26 kips	161.82 kips	201.09 kips
28.40 ft	45.27 kips	161.82 kips	207.10 kips
29.40 ft	51.42 kips	161.82 kips	213.24 kips
30.39 ft	57.63 kips	161.82 kips	219.45 kips
30.41 ft	57.73 kips	25.92 kips	83.65 kips
31.40 ft	61.47 kips	25.92 kips	87.39 kips
32.40 ft	65.32 kips	25.92 kips	91.24 kips
33.40 ft	69.23 kips	25.92 kips	95.15 kips
34.40 ft	73.21 kips	25.92 kips	99.13 kips

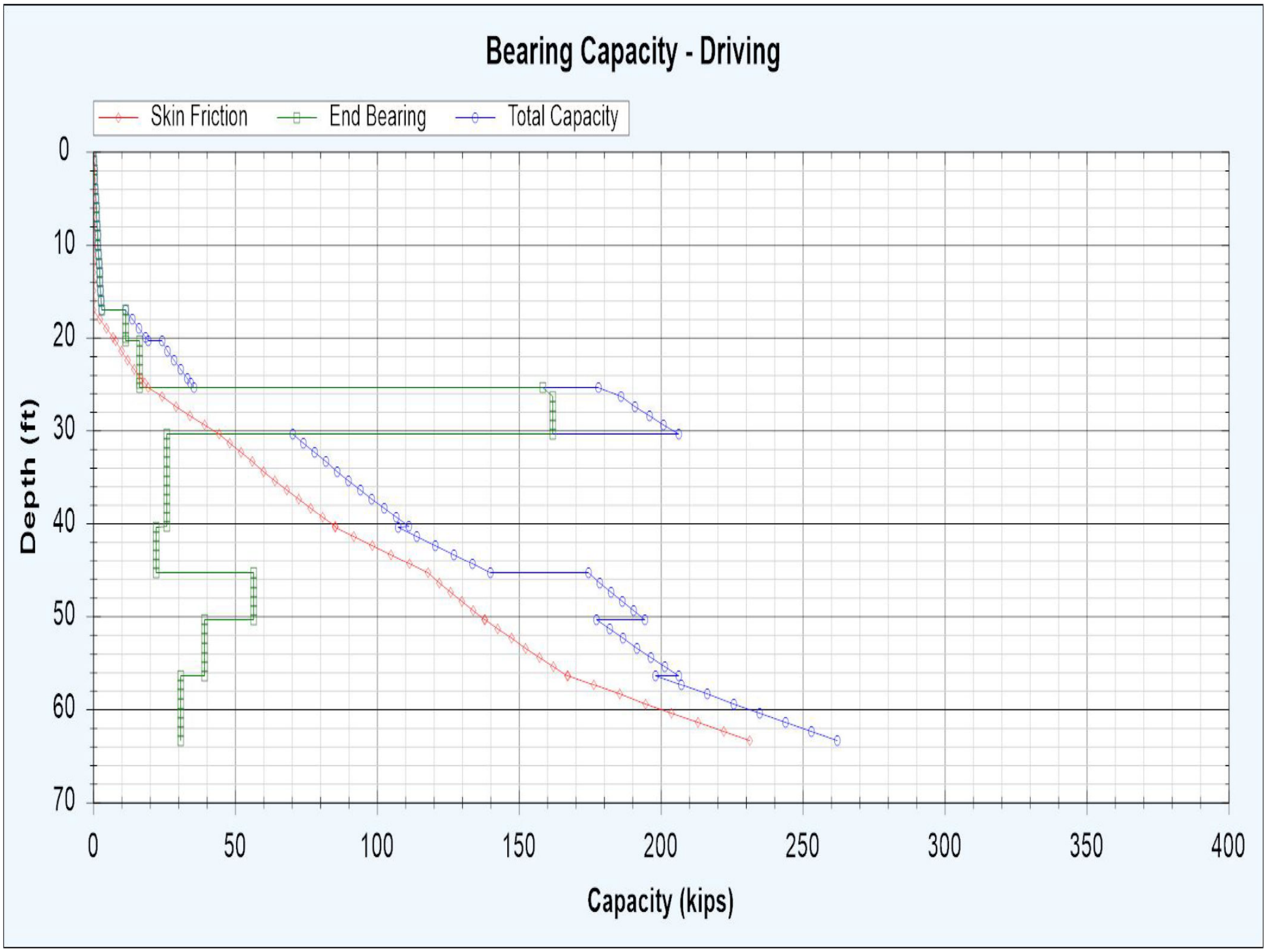
Depth	Skin Friction	End Bearing	Total Capacity
35.40 ft	77.26 kips	25.92 kips	103.18 kips
36.40 ft	81.38 kips	25.92 kips	107.29 kips
37.40 ft	85.56 kips	25.92 kips	111.48 kips
38.40 ft	89.81 kips	25.92 kips	115.73 kips
39.40 ft	94.12 kips	25.92 kips	120.04 kips
40.39 ft	98.46 kips	25.92 kips	124.38 kips
40.41 ft	98.61 kips	22.09 kips	120.69 kips
41.40 ft	108.32 kips	22.09 kips	130.41 kips
42.40 ft	118.14 kips	22.09 kips	140.23 kips
43.40 ft	127.96 kips	22.09 kips	150.05 kips
44.40 ft	137.78 kips	22.09 kips	159.87 kips
45.39 ft	147.50 kips	22.09 kips	169.59 kips
45.41 ft	147.65 kips	56.55 kips	204.20 kips
46.40 ft	153.58 kips	56.55 kips	210.12 kips
47.40 ft	159.56 kips	56.55 kips	216.11 kips
48.40 ft	165.54 kips	56.55 kips	222.09 kips
49.40 ft	171.52 kips	56.55 kips	228.07 kips
50.39 ft	177.44 kips	56.55 kips	233.99 kips
50.41 ft	177.56 kips	39.27 kips	216.83 kips
51.40 ft	183.14 kips	39.27 kips	222.41 kips
52.40 ft	188.86 kips	39.27 kips	228.13 kips
53.40 ft	194.67 kips	39.27 kips	233.94 kips
54.40 ft	200.56 kips	39.27 kips	239.83 kips
55.40 ft	206.54 kips	39.27 kips	245.81 kips
56.39 ft	212.54 kips	39.27 kips	251.81 kips
56.41 ft	212.74 kips	30.93 kips	243.67 kips
57.40 ft	226.35 kips	30.93 kips	257.28 kips
58.40 ft	240.09 kips	30.93 kips	271.02 kips
59.40 ft	253.84 kips	30.93 kips	284.76 kips
60.40 ft	267.58 kips	30.93 kips	298.51 kips
61.40 ft	281.33 kips	30.93 kips	312.25 kips
62.40 ft	295.07 kips	30.93 kips	326.00 kips
63.39 ft	308.68 kips	30.93 kips	339.60 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
50
100
150
200
250
300
350
400

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.02 kips	11.49 kips	11.51 kips
18.00 ft	2.33 kips	11.49 kips	13.82 kips
19.00 ft	4.66 kips	11.49 kips	16.15 kips
20.00 ft	6.99 kips	11.49 kips	18.48 kips
20.39 ft	7.90 kips	11.49 kips	19.39 kips
20.41 ft	7.94 kips	16.23 kips	24.17 kips
21.40 ft	10.02 kips	16.23 kips	26.25 kips
22.40 ft	12.21 kips	16.23 kips	28.44 kips
23.40 ft	14.51 kips	16.23 kips	30.74 kips
24.40 ft	16.90 kips	16.23 kips	33.13 kips
24.89 ft	18.12 kips	16.23 kips	34.35 kips
24.91 ft	18.17 kips	16.23 kips	34.40 kips
25.39 ft	19.37 kips	16.23 kips	35.60 kips
25.41 ft	19.44 kips	158.49 kips	177.94 kips
26.40 ft	24.19 kips	161.82 kips	186.01 kips
27.40 ft	29.09 kips	161.82 kips	190.91 kips
28.40 ft	34.10 kips	161.82 kips	195.92 kips
29.40 ft	39.21 kips	161.82 kips	201.04 kips
30.39 ft	44.39 kips	161.82 kips	206.22 kips
30.41 ft	44.48 kips	25.92 kips	70.40 kips
31.40 ft	48.22 kips	25.92 kips	74.14 kips
32.40 ft	52.07 kips	25.92 kips	77.99 kips
33.40 ft	55.98 kips	25.92 kips	81.90 kips
34.40 ft	59.96 kips	25.92 kips	85.88 kips

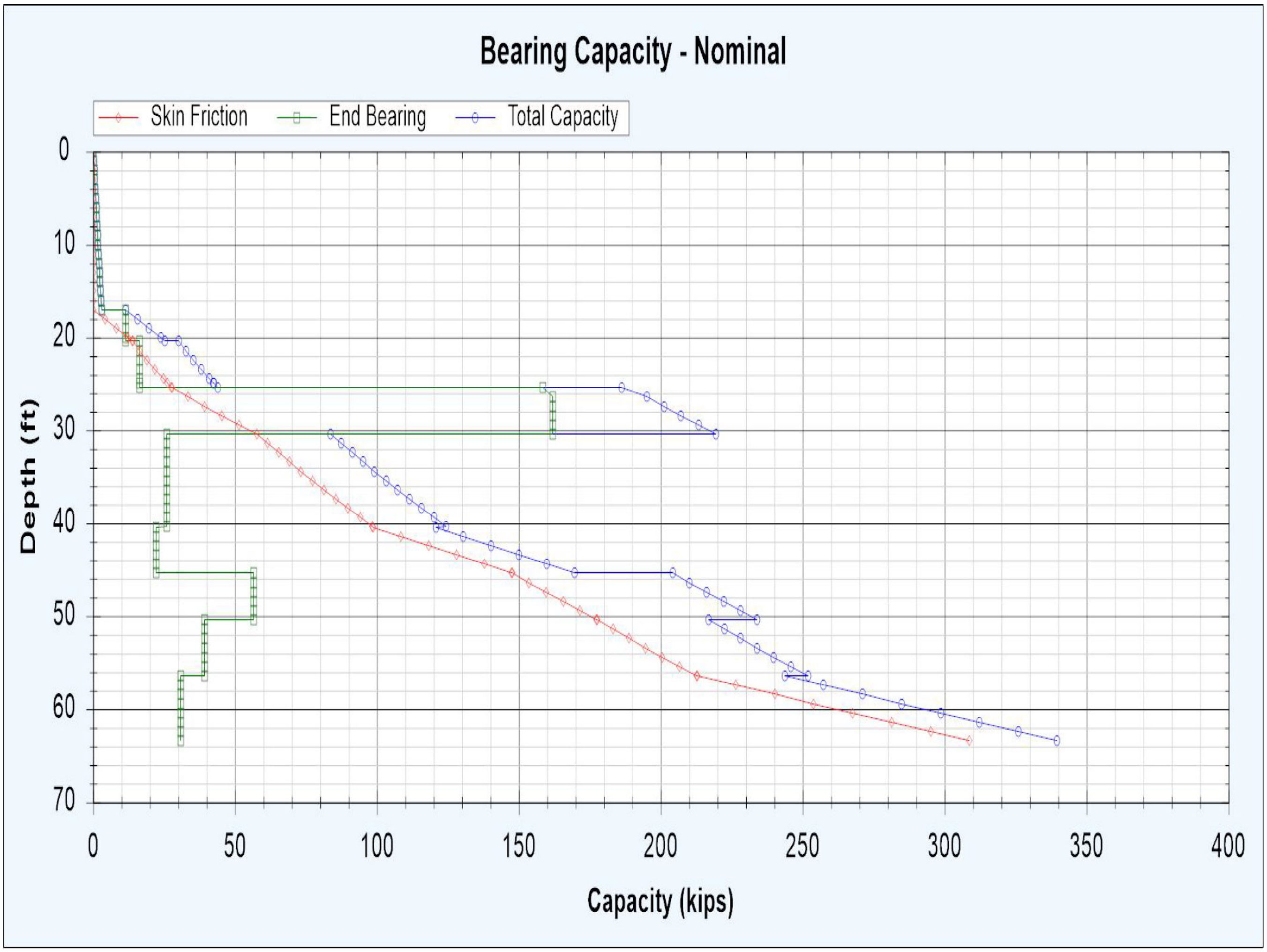
Depth	Skin Friction	End Bearing	Total Capacity
35.40 ft	64.01 kips	25.92 kips	89.93 kips
36.40 ft	68.13 kips	25.92 kips	94.04 kips
37.40 ft	72.31 kips	25.92 kips	98.23 kips
38.40 ft	76.56 kips	25.92 kips	102.48 kips
39.40 ft	80.87 kips	25.92 kips	106.79 kips
40.39 ft	85.21 kips	25.92 kips	111.13 kips
40.41 ft	85.32 kips	22.09 kips	107.41 kips
41.40 ft	91.80 kips	22.09 kips	113.89 kips
42.40 ft	98.35 kips	22.09 kips	120.44 kips
43.40 ft	104.89 kips	22.09 kips	126.98 kips
44.40 ft	111.44 kips	22.09 kips	133.53 kips
45.39 ft	117.92 kips	22.09 kips	140.01 kips
45.41 ft	118.02 kips	56.55 kips	174.57 kips
46.40 ft	121.97 kips	56.55 kips	178.52 kips
47.40 ft	125.96 kips	56.55 kips	182.51 kips
48.40 ft	129.95 kips	56.55 kips	186.50 kips
49.40 ft	133.94 kips	56.55 kips	190.48 kips
50.39 ft	137.88 kips	56.55 kips	194.43 kips
50.41 ft	137.97 kips	39.27 kips	177.24 kips
51.40 ft	142.62 kips	39.27 kips	181.89 kips
52.40 ft	147.39 kips	39.27 kips	186.66 kips
53.40 ft	152.23 kips	39.27 kips	191.50 kips
54.40 ft	157.14 kips	39.27 kips	196.41 kips
55.40 ft	162.12 kips	39.27 kips	201.39 kips
56.39 ft	167.12 kips	39.27 kips	206.39 kips
56.41 ft	167.27 kips	30.93 kips	198.19 kips
57.40 ft	176.34 kips	30.93 kips	207.26 kips
58.40 ft	185.50 kips	30.93 kips	216.43 kips
59.40 ft	194.67 kips	30.93 kips	225.59 kips
60.40 ft	203.83 kips	30.93 kips	234.75 kips
61.40 ft	212.99 kips	30.93 kips	243.92 kips
62.40 ft	222.16 kips	30.93 kips	253.08 kips
63.39 ft	231.23 kips	30.93 kips	262.15 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
50
100
150
200
250
300
350
400

Nominal - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.04 kips	11.49 kips	11.53 kips
18.00 ft	4.08 kips	11.49 kips	15.56 kips
19.00 ft	8.16 kips	11.49 kips	19.64 kips
20.00 ft	12.23 kips	11.49 kips	23.72 kips
20.39 ft	13.82 kips	11.49 kips	25.31 kips
20.41 ft	13.89 kips	16.23 kips	30.12 kips
21.40 ft	16.38 kips	16.23 kips	32.61 kips
22.40 ft	19.01 kips	16.23 kips	35.24 kips
23.40 ft	21.77 kips	16.23 kips	38.00 kips
24.40 ft	24.64 kips	16.23 kips	40.87 kips
24.89 ft	26.10 kips	16.23 kips	42.33 kips
24.91 ft	26.16 kips	16.23 kips	42.39 kips
25.39 ft	27.60 kips	16.23 kips	43.83 kips
25.41 ft	27.69 kips	158.49 kips	186.18 kips
26.40 ft	33.38 kips	161.82 kips	195.21 kips
27.40 ft	39.26 kips	161.82 kips	201.09 kips
28.40 ft	45.27 kips	161.82 kips	207.10 kips
29.40 ft	51.42 kips	161.82 kips	213.24 kips
30.39 ft	57.63 kips	161.82 kips	219.45 kips
30.41 ft	57.73 kips	25.92 kips	83.65 kips
31.40 ft	61.47 kips	25.92 kips	87.39 kips
32.40 ft	65.32 kips	25.92 kips	91.24 kips
33.40 ft	69.23 kips	25.92 kips	95.15 kips
34.40 ft	73.21 kips	25.92 kips	99.13 kips

Depth	Skin Friction	End Bearing	Total Capacity
35.40 ft	77.26 kips	25.92 kips	103.18 kips
36.40 ft	81.38 kips	25.92 kips	107.29 kips
37.40 ft	85.56 kips	25.92 kips	111.48 kips
38.40 ft	89.81 kips	25.92 kips	115.73 kips
39.40 ft	94.12 kips	25.92 kips	120.04 kips
40.39 ft	98.46 kips	25.92 kips	124.38 kips
40.41 ft	98.61 kips	22.09 kips	120.69 kips
41.40 ft	108.32 kips	22.09 kips	130.41 kips
42.40 ft	118.14 kips	22.09 kips	140.23 kips
43.40 ft	127.96 kips	22.09 kips	150.05 kips
44.40 ft	137.78 kips	22.09 kips	159.87 kips
45.39 ft	147.50 kips	22.09 kips	169.59 kips
45.41 ft	147.65 kips	56.55 kips	204.20 kips
46.40 ft	153.58 kips	56.55 kips	210.12 kips
47.40 ft	159.56 kips	56.55 kips	216.11 kips
48.40 ft	165.54 kips	56.55 kips	222.09 kips
49.40 ft	171.52 kips	56.55 kips	228.07 kips
50.39 ft	177.44 kips	56.55 kips	233.99 kips
50.41 ft	177.56 kips	39.27 kips	216.83 kips
51.40 ft	183.14 kips	39.27 kips	222.41 kips
52.40 ft	188.86 kips	39.27 kips	228.13 kips
53.40 ft	194.67 kips	39.27 kips	233.94 kips
54.40 ft	200.56 kips	39.27 kips	239.83 kips
55.40 ft	206.54 kips	39.27 kips	245.81 kips
56.39 ft	212.54 kips	39.27 kips	251.81 kips
56.41 ft	212.74 kips	30.93 kips	243.67 kips
57.40 ft	226.35 kips	30.93 kips	257.28 kips
58.40 ft	240.09 kips	30.93 kips	271.02 kips
59.40 ft	253.84 kips	30.93 kips	284.76 kips
60.40 ft	267.58 kips	30.93 kips	298.51 kips
61.40 ft	281.33 kips	30.93 kips	312.25 kips
62.40 ft	295.07 kips	30.93 kips	326.00 kips
63.39 ft	308.68 kips	30.93 kips	339.60 kips


Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
Capacity (kips)
0
50
100
150
200
250
300
350
400

Forward Abutment
Boring B-078-0-19

DrivenPiles - Report

General Project Information

Filename: ...\Analysis\FRA-70-22.85 CD Ramp Tunnel\Prelim\Driven\WB-CD Ramp Bridge - FA (B-078-0-19).dvn
Project Name: FRA-70-22.85 Brice Rd Bridge over WB-CD Ramp - Forward Abutment (B-078-0-19)
Project Client: EMH&T
Prepared By: Hanu S. Kulkarni, Ph.D., P.E.
Project Manager: Brian R. Trenner, P.E.

Pile Information

Pile Type: Pipe Pile - Closed End
Top of Pile: 0.00 ft
Diameter of Pile: 12.00 in

Nominal Considerations

Water Table Depth At Time Of:

Drilling:	22.90 ft
Driving/Restrike:	22.90 ft
Nominal:	22.90 ft

Nominal Considations:

Local Scour:	0.00 ft
Long Term Scour:	0.00 ft
Soft Soil:	0.00 ft

Nominal Profile

Layer	Soil Type	Thickness	Setup Factor	Unit Weight	Strength	Nominal Curve
1	Cohesionless	17.00 ft	1.000	125.00 pcf	0.0/0.0	Nordlund
2	Cohesive	0.90 ft	2.000	120.00 pcf	2750.00 psf	T-80 Same
3	Cohesive	5.00 ft	1.500	115.00 pcf	1375.00 psf	T-80 Same
4	Cohesionless	10.00 ft	1.000	130.00 pcf	32.0/32.0	Nordlund
5	Cohesionless	5.00 ft	1.000	135.00 pcf	37.0/37.0	Nordlund
6	Cohesive	5.00 ft	1.500	120.00 pcf	3000.00 psf	T-80 Sand
7	Cohesive	15.00 ft	1.500	130.00 pcf	5500.00 psf	T-80 Same
8	Cohesive	8.00 ft	1.500	130.00 pcf	6000.00 psf	T-80 Same

Restrike: 190.9 kips
Driving: 162.1 kips

Estimated Ground Surface Elevation: 818.1 ft-msl
Bottom of Footing Elevation: 809.0 ft-msl
Bottom of Wall (Top of Leveling Pad) Elevation: 792.0 ft-msl

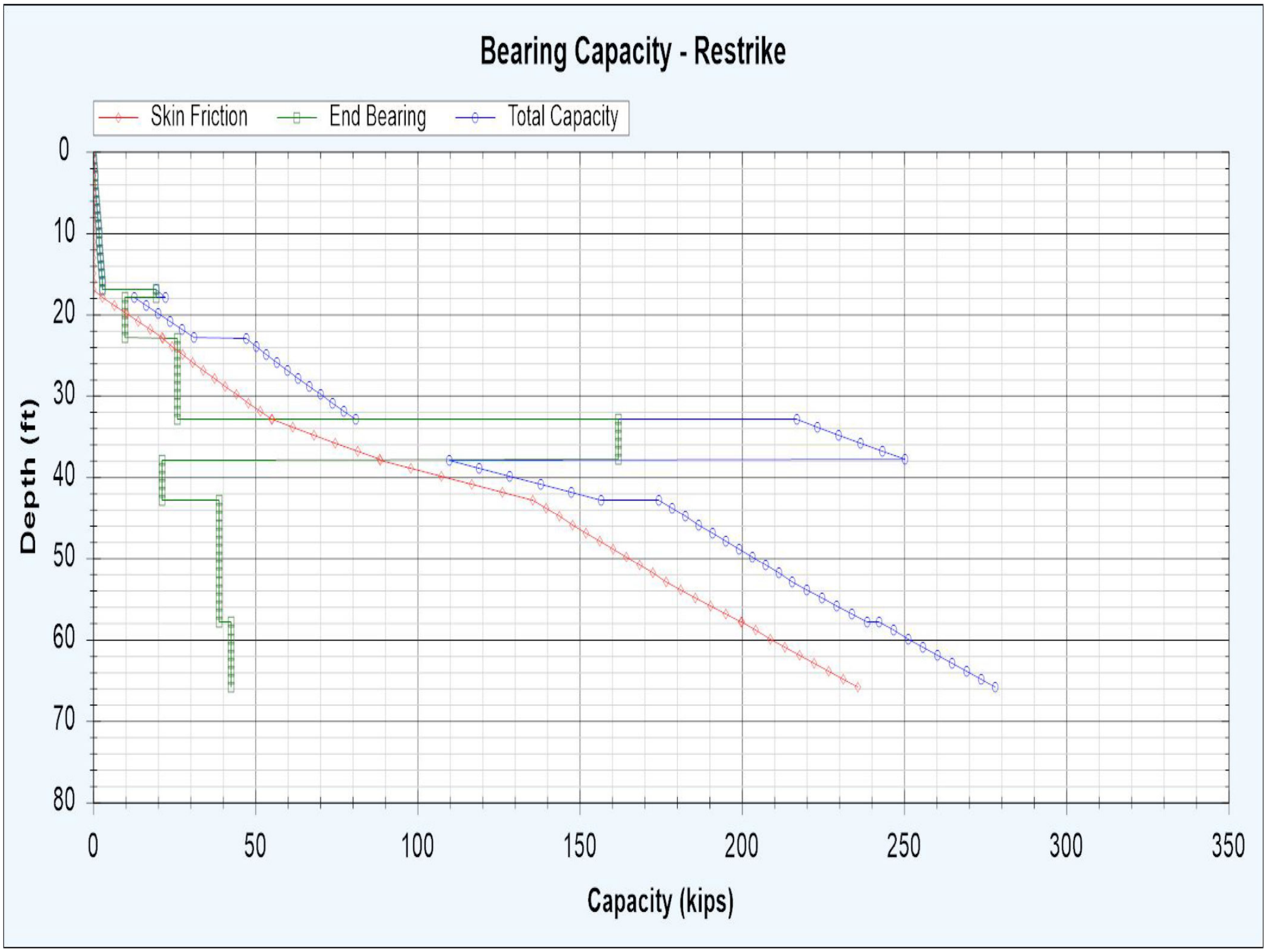
Estimated Pile Top Elevation: 810.0 ft-msl
Estimated Pile Tip Elevation: 762.1 ft-msl

Embedment Depth Below Bottom of Footing Elevation: 46.9 ft
Estimated Pile Length: 50.0 ft

Restrike - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.03 kips	19.44 kips	19.47 kips
17.89 ft	2.77 kips	19.44 kips	22.21 kips
17.91 ft	2.84 kips	9.72 kips	12.56 kips
18.90 ft	6.51 kips	9.72 kips	16.23 kips
19.90 ft	10.22 kips	9.72 kips	19.94 kips
20.90 ft	13.92 kips	9.72 kips	23.64 kips
21.90 ft	17.63 kips	9.72 kips	27.35 kips
22.89 ft	21.30 kips	9.72 kips	31.02 kips
22.91 ft	21.37 kips	25.92 kips	47.29 kips
23.90 ft	24.39 kips	25.92 kips	50.31 kips
24.90 ft	27.51 kips	25.92 kips	53.43 kips
25.90 ft	30.71 kips	25.92 kips	56.62 kips
26.90 ft	33.97 kips	25.92 kips	59.89 kips
27.90 ft	37.31 kips	25.92 kips	63.23 kips
28.90 ft	40.73 kips	25.92 kips	66.64 kips
29.90 ft	44.21 kips	25.92 kips	70.13 kips
30.90 ft	47.77 kips	25.92 kips	73.69 kips
31.90 ft	51.40 kips	25.92 kips	77.32 kips
32.89 ft	55.06 kips	25.92 kips	80.98 kips
32.91 ft	55.17 kips	161.82 kips	216.99 kips
33.90 ft	61.50 kips	161.82 kips	223.32 kips
34.90 ft	68.03 kips	161.82 kips	229.85 kips
35.90 ft	74.69 kips	161.82 kips	236.51 kips
36.90 ft	81.48 kips	161.82 kips	243.31 kips

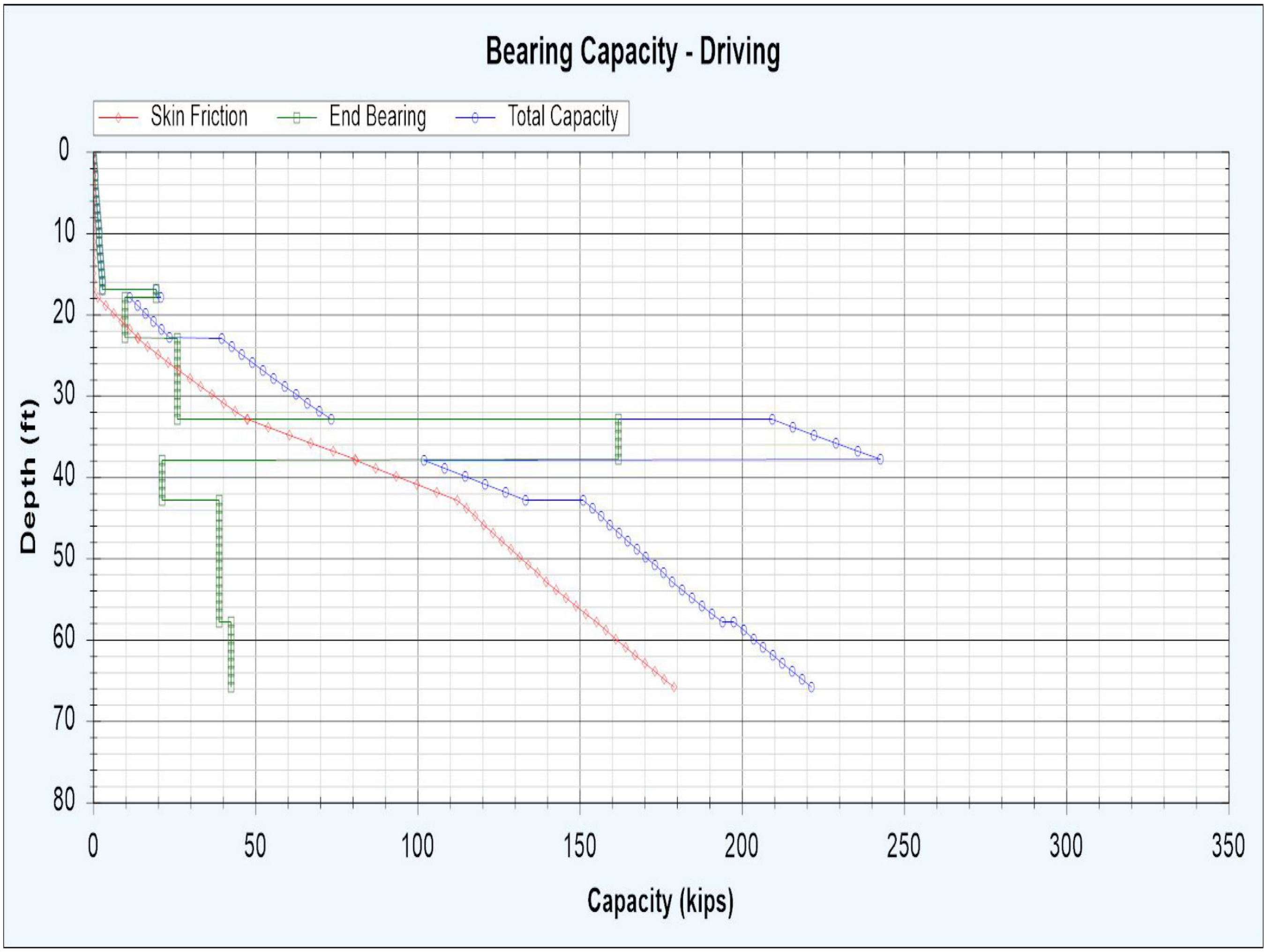
Depth	Skin Friction	End Bearing	Total Capacity
37.89 ft	88.34 kips	161.82 kips	250.16 kips
37.91 ft	88.50 kips	21.21 kips	109.71 kips
38.90 ft	97.83 kips	21.21 kips	119.04 kips
39.90 ft	107.26 kips	21.21 kips	128.46 kips
40.90 ft	116.68 kips	21.21 kips	137.89 kips
41.90 ft	126.11 kips	21.21 kips	147.31 kips
42.89 ft	135.44 kips	21.21 kips	156.64 kips
42.91 ft	135.57 kips	38.88 kips	174.45 kips
43.90 ft	139.64 kips	38.88 kips	178.52 kips
44.90 ft	143.76 kips	38.88 kips	182.63 kips
45.90 ft	147.87 kips	38.88 kips	186.75 kips
46.90 ft	151.98 kips	38.88 kips	190.86 kips
47.90 ft	156.09 kips	38.88 kips	194.97 kips
48.90 ft	160.20 kips	38.88 kips	199.08 kips
49.90 ft	164.32 kips	38.88 kips	203.19 kips
50.90 ft	168.43 kips	38.88 kips	207.31 kips
51.90 ft	172.54 kips	38.88 kips	211.42 kips
52.90 ft	176.65 kips	38.88 kips	215.53 kips
53.90 ft	181.15 kips	38.88 kips	220.03 kips
54.90 ft	185.72 kips	38.88 kips	224.60 kips
55.90 ft	190.36 kips	38.88 kips	229.24 kips
56.90 ft	195.07 kips	38.88 kips	233.95 kips
57.89 ft	199.80 kips	38.88 kips	238.68 kips
57.91 ft	199.90 kips	42.41 kips	242.31 kips
58.90 ft	204.34 kips	42.41 kips	246.75 kips
59.90 ft	208.82 kips	42.41 kips	251.23 kips
60.90 ft	213.31 kips	42.41 kips	255.72 kips
61.90 ft	217.80 kips	42.41 kips	260.21 kips
62.90 ft	222.28 kips	42.41 kips	264.69 kips
63.90 ft	226.77 kips	42.41 kips	269.18 kips
64.90 ft	231.25 kips	42.41 kips	273.67 kips
65.89 ft	235.70 kips	42.41 kips	278.11 kips


Bearing Capacity - Restrike
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
Capacity (kips)
0
50
100
150
200
250
300
350

Driving - Summary of Capacities

Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.02 kips	19.44 kips	19.45 kips
17.89 ft	1.39 kips	19.44 kips	20.83 kips
17.91 ft	1.43 kips	9.72 kips	11.15 kips
18.90 ft	3.87 kips	9.72 kips	13.59 kips
19.90 ft	6.34 kips	9.72 kips	16.06 kips
20.90 ft	8.82 kips	9.72 kips	18.54 kips
21.90 ft	11.29 kips	9.72 kips	21.01 kips
22.89 ft	13.73 kips	9.72 kips	23.45 kips
22.91 ft	13.79 kips	25.92 kips	39.71 kips
23.90 ft	16.81 kips	25.92 kips	42.73 kips
24.90 ft	19.93 kips	25.92 kips	45.85 kips
25.90 ft	23.13 kips	25.92 kips	49.04 kips
26.90 ft	26.39 kips	25.92 kips	52.31 kips
27.90 ft	29.73 kips	25.92 kips	55.65 kips
28.90 ft	33.15 kips	25.92 kips	59.06 kips
29.90 ft	36.63 kips	25.92 kips	62.55 kips
30.90 ft	40.19 kips	25.92 kips	66.11 kips
31.90 ft	43.82 kips	25.92 kips	69.74 kips
32.89 ft	47.49 kips	25.92 kips	73.40 kips
32.91 ft	47.59 kips	161.82 kips	209.41 kips
33.90 ft	53.92 kips	161.82 kips	215.74 kips
34.90 ft	60.45 kips	161.82 kips	222.27 kips
35.90 ft	67.11 kips	161.82 kips	228.93 kips
36.90 ft	73.90 kips	161.82 kips	235.73 kips

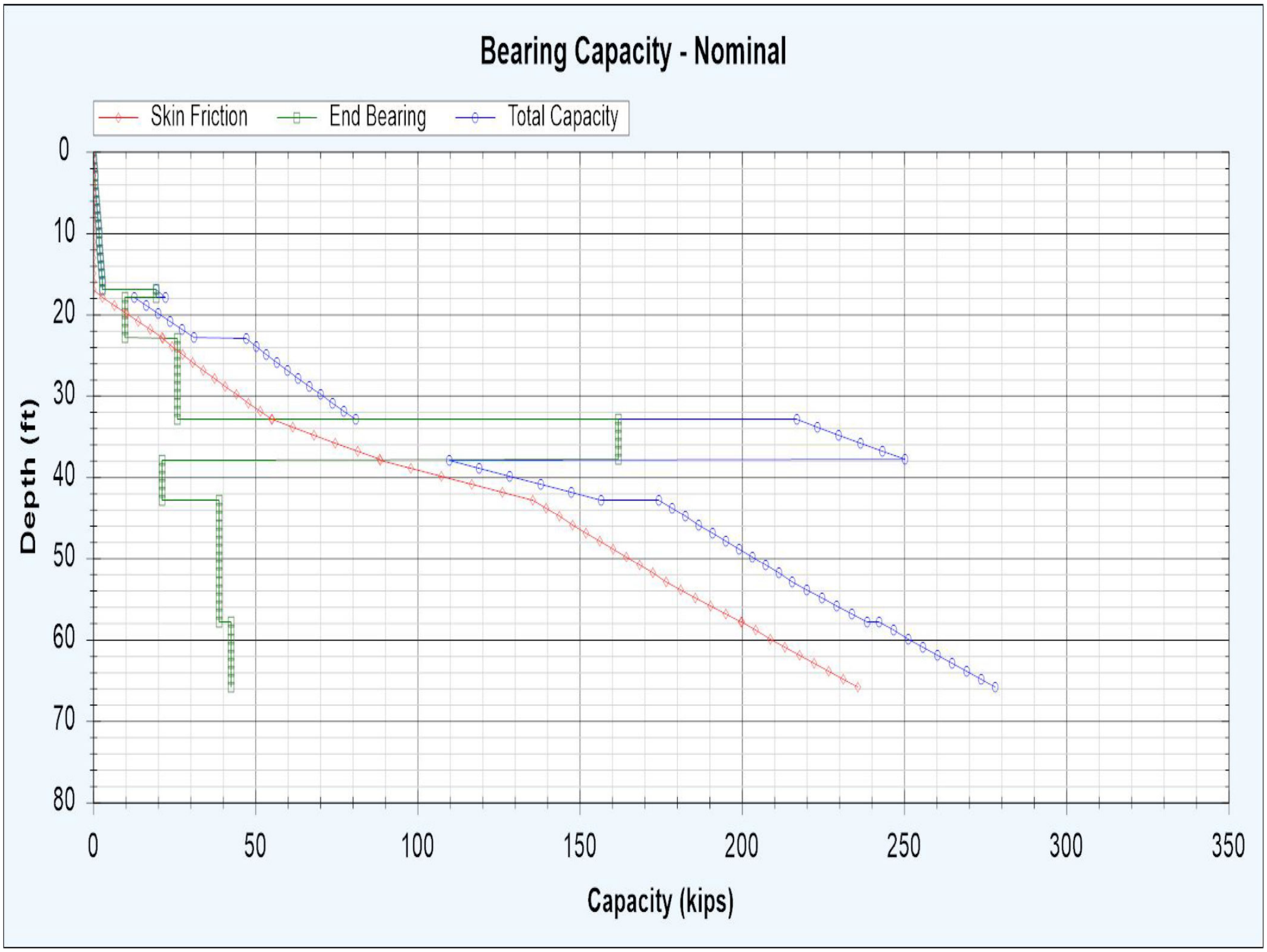
Depth	Skin Friction	End Bearing	Total Capacity
37.89 ft	80.76 kips	161.82 kips	242.58 kips
37.91 ft	80.89 kips	21.21 kips	102.10 kips
38.90 ft	87.11 kips	21.21 kips	108.32 kips
39.90 ft	93.39 kips	21.21 kips	114.60 kips
40.90 ft	99.68 kips	21.21 kips	120.88 kips
41.90 ft	105.96 kips	21.21 kips	127.17 kips
42.89 ft	112.18 kips	21.21 kips	133.39 kips
42.91 ft	112.27 kips	38.88 kips	151.15 kips
43.90 ft	114.99 kips	38.88 kips	153.86 kips
44.90 ft	117.73 kips	38.88 kips	156.61 kips
45.90 ft	120.47 kips	38.88 kips	159.35 kips
46.90 ft	123.21 kips	38.88 kips	162.09 kips
47.90 ft	125.95 kips	38.88 kips	164.83 kips
48.90 ft	128.70 kips	38.88 kips	167.57 kips
49.90 ft	131.44 kips	38.88 kips	170.31 kips
50.90 ft	134.18 kips	38.88 kips	173.06 kips
51.90 ft	136.92 kips	38.88 kips	175.80 kips
52.90 ft	139.66 kips	38.88 kips	178.54 kips
53.90 ft	142.66 kips	38.88 kips	181.54 kips
54.90 ft	145.71 kips	38.88 kips	184.58 kips
55.90 ft	148.80 kips	38.88 kips	187.68 kips
56.90 ft	151.94 kips	38.88 kips	190.82 kips
57.89 ft	155.10 kips	38.88 kips	193.97 kips
57.91 ft	155.16 kips	42.41 kips	197.57 kips
58.90 ft	158.12 kips	42.41 kips	200.53 kips
59.90 ft	161.11 kips	42.41 kips	203.52 kips
60.90 ft	164.10 kips	42.41 kips	206.51 kips
61.90 ft	167.09 kips	42.41 kips	209.50 kips
62.90 ft	170.08 kips	42.41 kips	212.49 kips
63.90 ft	173.07 kips	42.41 kips	215.48 kips
64.90 ft	176.06 kips	42.41 kips	218.48 kips
65.89 ft	179.02 kips	42.41 kips	221.44 kips


Bearing Capacity - Driving
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
Capacity (kips)
0
50
100
150
200
250
300
350

Nominal - Summary of Capacities

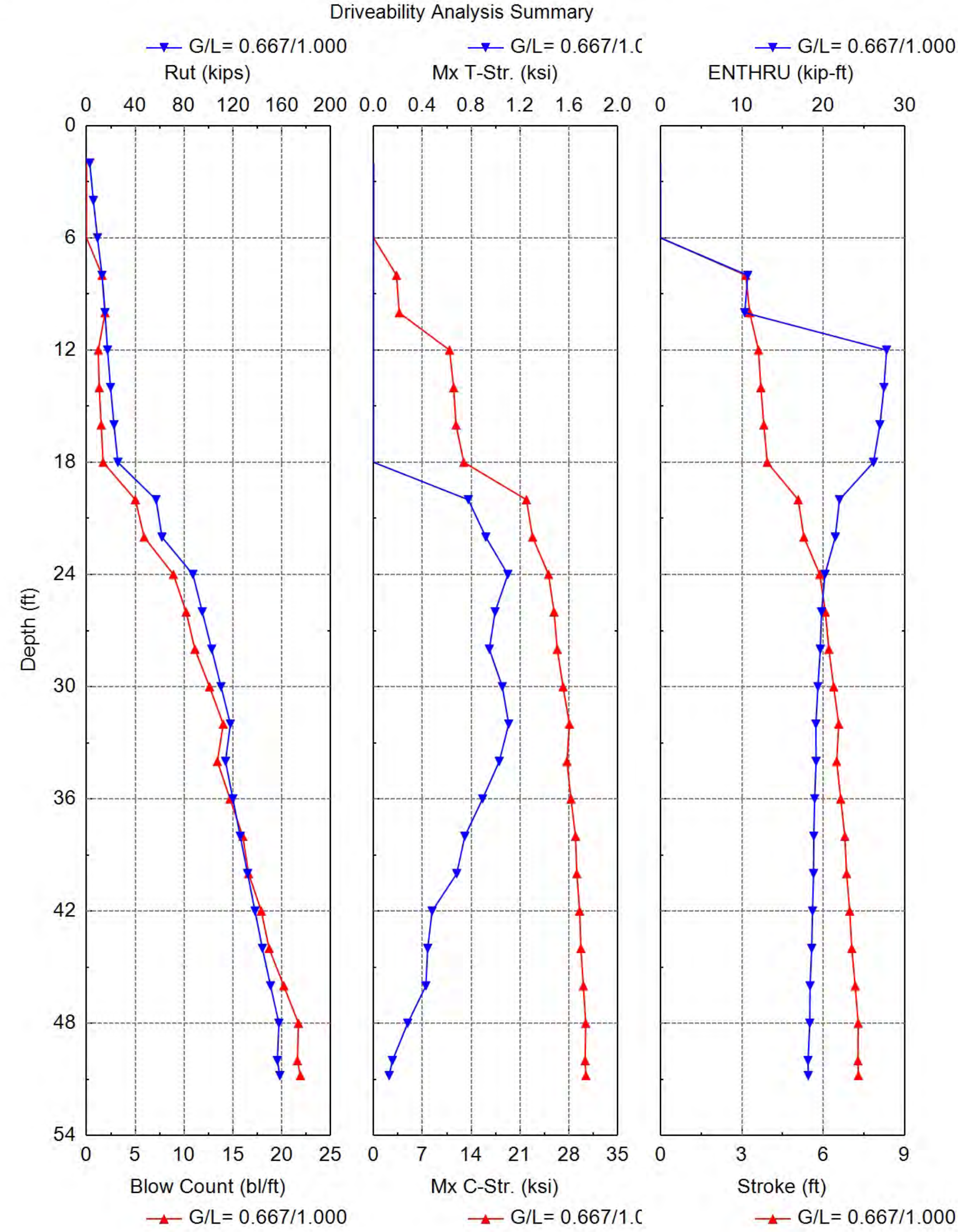
Depth	Skin Friction	End Bearing	Total Capacity
0.01 ft	0.00 kips	0.00 kips	0.00 kips
1.00 ft	0.00 kips	0.17 kips	0.17 kips
2.00 ft	0.00 kips	0.34 kips	0.34 kips
3.00 ft	0.00 kips	0.52 kips	0.52 kips
4.00 ft	0.00 kips	0.69 kips	0.69 kips
5.00 ft	0.00 kips	0.86 kips	0.86 kips
6.00 ft	0.00 kips	1.03 kips	1.03 kips
7.00 ft	0.00 kips	1.20 kips	1.20 kips
8.00 ft	0.00 kips	1.38 kips	1.38 kips
9.00 ft	0.00 kips	1.55 kips	1.55 kips
10.00 ft	0.00 kips	1.72 kips	1.72 kips
11.00 ft	0.00 kips	1.89 kips	1.89 kips
12.00 ft	0.00 kips	2.06 kips	2.06 kips
13.00 ft	0.00 kips	2.24 kips	2.24 kips
14.00 ft	0.00 kips	2.41 kips	2.41 kips
15.00 ft	0.00 kips	2.58 kips	2.58 kips
16.00 ft	0.00 kips	2.75 kips	2.75 kips
16.99 ft	0.00 kips	2.92 kips	2.92 kips
17.01 ft	0.03 kips	19.44 kips	19.47 kips
17.89 ft	2.77 kips	19.44 kips	22.21 kips
17.91 ft	2.84 kips	9.72 kips	12.56 kips
18.90 ft	6.51 kips	9.72 kips	16.23 kips
19.90 ft	10.22 kips	9.72 kips	19.94 kips
20.90 ft	13.92 kips	9.72 kips	23.64 kips
21.90 ft	17.63 kips	9.72 kips	27.35 kips
22.89 ft	21.30 kips	9.72 kips	31.02 kips
22.91 ft	21.37 kips	25.92 kips	47.29 kips
23.90 ft	24.39 kips	25.92 kips	50.31 kips
24.90 ft	27.51 kips	25.92 kips	53.43 kips
25.90 ft	30.71 kips	25.92 kips	56.62 kips
26.90 ft	33.97 kips	25.92 kips	59.89 kips
27.90 ft	37.31 kips	25.92 kips	63.23 kips
28.90 ft	40.73 kips	25.92 kips	66.64 kips
29.90 ft	44.21 kips	25.92 kips	70.13 kips
30.90 ft	47.77 kips	25.92 kips	73.69 kips
31.90 ft	51.40 kips	25.92 kips	77.32 kips
32.89 ft	55.06 kips	25.92 kips	80.98 kips
32.91 ft	55.17 kips	161.82 kips	216.99 kips
33.90 ft	61.50 kips	161.82 kips	223.32 kips
34.90 ft	68.03 kips	161.82 kips	229.85 kips
35.90 ft	74.69 kips	161.82 kips	236.51 kips
36.90 ft	81.48 kips	161.82 kips	243.31 kips

Depth	Skin Friction	End Bearing	Total Capacity
37.89 ft	88.34 kips	161.82 kips	250.16 kips
37.91 ft	88.50 kips	21.21 kips	109.71 kips
38.90 ft	97.83 kips	21.21 kips	119.04 kips
39.90 ft	107.26 kips	21.21 kips	128.46 kips
40.90 ft	116.68 kips	21.21 kips	137.89 kips
41.90 ft	126.11 kips	21.21 kips	147.31 kips
42.89 ft	135.44 kips	21.21 kips	156.64 kips
42.91 ft	135.57 kips	38.88 kips	174.45 kips
43.90 ft	139.64 kips	38.88 kips	178.52 kips
44.90 ft	143.76 kips	38.88 kips	182.63 kips
45.90 ft	147.87 kips	38.88 kips	186.75 kips
46.90 ft	151.98 kips	38.88 kips	190.86 kips
47.90 ft	156.09 kips	38.88 kips	194.97 kips
48.90 ft	160.20 kips	38.88 kips	199.08 kips
49.90 ft	164.32 kips	38.88 kips	203.19 kips
50.90 ft	168.43 kips	38.88 kips	207.31 kips
51.90 ft	172.54 kips	38.88 kips	211.42 kips
52.90 ft	176.65 kips	38.88 kips	215.53 kips
53.90 ft	181.15 kips	38.88 kips	220.03 kips
54.90 ft	185.72 kips	38.88 kips	224.60 kips
55.90 ft	190.36 kips	38.88 kips	229.24 kips
56.90 ft	195.07 kips	38.88 kips	233.95 kips
57.89 ft	199.80 kips	38.88 kips	238.68 kips
57.91 ft	199.90 kips	42.41 kips	242.31 kips
58.90 ft	204.34 kips	42.41 kips	246.75 kips
59.90 ft	208.82 kips	42.41 kips	251.23 kips
60.90 ft	213.31 kips	42.41 kips	255.72 kips
61.90 ft	217.80 kips	42.41 kips	260.21 kips
62.90 ft	222.28 kips	42.41 kips	264.69 kips
63.90 ft	226.77 kips	42.41 kips	269.18 kips
64.90 ft	231.25 kips	42.41 kips	273.67 kips
65.89 ft	235.70 kips	42.41 kips	278.11 kips

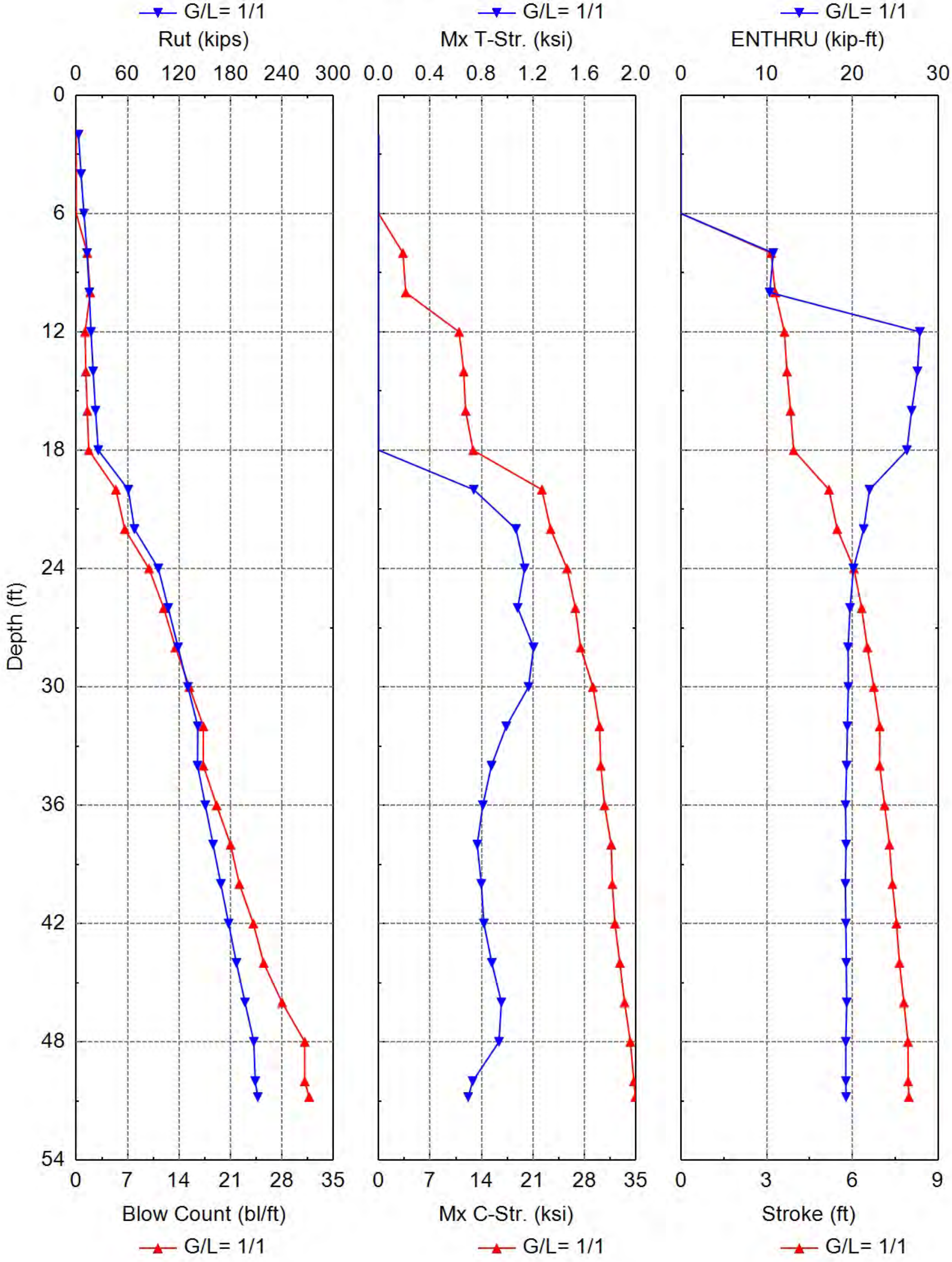

Bearing Capacity - Nominal
Skin Friction
End Bearing
Total Capacity
Depth (ft)
0
10
20
30
40
50
60
70
80
Capacity (kips)
0
50
100
150
200
250
300
350

APPENDIX VII

GRLWEAP OUTPUTS


Driveability Analysis Summary
G/L= 0.667/1.000
Rut (kips)
0 40 80 120 160 200
G/L= 0.667/1.(
Mx T-Str. (ksi)
0.0 0.4 0.8 1.2 1.6 2.0
G/L= 0.667/1.000
ENTHRU (kip-ft)
0 10 20 30
Depth (ft)
0 6 12 18 24 30 36 42 48 54
0 5 10 15 20 25
Blow Count (bl/ft)
0 7 14 21 28 35
Mx C-Str. (ksi)
0 3 6 9
Stroke (ft)
G/L= 0.667/1.000
G/L= 0.667/1.(
G/L= 0.667/1.000

Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.667/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.6	3.291	0.000	3.14	10.7	D 19-42
10.0	15.1	4.7	10.4	1.9	3.682	0.000	3.29	10.3	D 19-42
12.0	17.2	6.8	10.5	1.2	10.890	0.000	3.61	27.8	D 19-42
14.0	19.7	9.2	10.5	1.3	11.483	0.000	3.70	27.4	D 19-42
16.0	22.5	12.0	10.5	1.5	11.824	0.000	3.81	27.0	D 19-42
18.0	25.7	15.2	10.5	1.7	12.941	0.000	3.93	26.2	D 19-42
20.0	57.0	23.4	33.6	5.0	21.915	0.776	5.07	22.0	D 19-42
22.0	61.8	28.2	33.6	5.9	22.801	0.920	5.28	21.5	D 19-42
24.0	87.2	33.3	53.9	8.9	25.086	1.100	5.87	20.2	D 19-42
26.0	94.9	41.0	53.9	10.2	25.877	0.996	6.07	19.8	D 19-42
28.0	102.5	48.6	53.9	11.1	26.339	0.949	6.20	19.6	D 19-42
30.0	110.2	56.3	53.9	12.6	27.166	1.055	6.38	19.3	D 19-42
32.0	117.9	64.0	53.9	14.0	28.085	1.107	6.57	19.1	D 19-42
34.0	113.9	71.5	42.4	13.4	27.725	1.030	6.49	19.1	D 19-42
36.0	119.9	77.5	42.4	14.7	28.307	0.893	6.64	18.9	D 19-42
38.0	126.0	83.5	42.4	16.0	28.951	0.747	6.79	18.8	D 19-42
40.0	132.0	89.6	42.4	16.6	29.146	0.682	6.86	18.8	D 19-42
42.0	138.0	95.6	42.4	17.9	29.552	0.480	6.97	18.7	D 19-42
44.0	144.1	101.7	42.4	18.7	29.732	0.443	7.05	18.6	D 19-42
46.0	150.8	108.4	42.4	20.2	30.080	0.429	7.17	18.4	D 19-42
48.0	157.6	115.2	42.4	21.7	30.423	0.280	7.29	18.3	D 19-42
50.0	156.4	121.0	35.3	21.6	30.337	0.154	7.28	18.1	D 19-42
50.8	158.4	123.0	35.3	21.9	30.445	0.128	7.29	18.1	D 19-42

Summary_Total driving time: 10 minutes; Total Number of Blows: 471 (starting at penetration 2.0 ft)

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.5	3.304	0.000	3.15	10.8	D 19-42
10.0	15.1	4.7	10.4	1.9	3.687	0.000	3.30	10.3	D 19-42
12.0	17.2	6.8	10.5	1.2	10.946	0.000	3.62	27.9	D 19-42
14.0	19.7	9.2	10.5	1.3	11.575	0.000	3.71	27.6	D 19-42
16.0	22.5	12.0	10.5	1.5	11.828	0.000	3.83	26.9	D 19-42
18.0	25.7	15.2	10.5	1.7	12.849	0.000	3.94	26.3	D 19-42
20.0	60.7	27.1	33.6	5.4	22.217	0.740	5.18	22.0	D 19-42
22.0	67.9	34.3	33.6	6.6	23.399	1.068	5.46	21.3	D 19-42
24.0	95.8	41.9	53.9	9.9	25.637	1.135	6.05	20.1	D 19-42
26.0	107.3	53.4	53.9	11.9	26.764	1.081	6.32	19.7	D 19-42
28.0	118.8	64.9	53.9	13.5	27.472	1.205	6.52	19.5	D 19-42

30.0	130.3	76.4	53.9	15.4	29.160	1.166	6.74	19.5	D 19-42
32.0	141.8	87.9	53.9	17.3	30.055	0.992	6.95	19.4	D 19-42
34.0	141.5	99.1	42.4	17.3	30.232	0.877	6.95	19.3	D 19-42
36.0	150.6	108.2	42.4	19.1	30.736	0.810	7.12	19.2	D 19-42
38.0	159.6	117.2	42.4	21.0	31.645	0.767	7.29	19.2	D 19-42
40.0	168.7	126.3	42.4	22.2	31.804	0.799	7.40	19.2	D 19-42
42.0	177.7	135.3	42.4	24.1	32.153	0.818	7.54	19.2	D 19-42
44.0	186.9	144.4	42.4	25.5	32.823	0.880	7.64	19.3	D 19-42
46.0	196.8	154.4	42.4	28.0	33.469	0.954	7.80	19.3	D 19-42
48.0	207.1	164.7	42.4	31.1	34.260	0.936	7.94	19.2	D 19-42
50.0	208.8	173.4	35.3	31.1	34.738	0.731	7.95	19.2	D 19-42
50.8	211.8	176.4	35.3	31.7	34.935	0.696	7.97	19.2	D 19-42

Summary_Total driving time: 14 minutes; Total Number of Blows: 611 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - RA - B-073-0-19 + 12" CIP - 0.3125" Wall Thick 12/3/2022
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
18.5	Sand	125.0	0.0	28.0	0.55	13.32
18.5	Clay	125.0	4.7	0.0	4.75	42.75
19.0	Clay	125.0	4.7	0.0	4.75	42.75
19.0	Clay	125.0	4.7	0.0	1.14	42.75
23.8	Clay	125.0	4.7	0.0	1.14	42.75
23.8	Clay	130.0	7.6	0.0	1.83	68.62
33.8	Clay	130.0	7.6	0.0	1.83	68.62
33.8	Clay	130.0	6.0	0.0	1.50	54.00
48.8	Clay	130.0	6.0	0.0	1.50	54.00
48.8	Clay	130.0	5.0	0.0	1.20	45.00
56.8	Clay	130.0	5.0	0.0	1.20	45.00
56.8	Clay	130.0	8.0	0.0	1.92	72.00
61.8	Clay	130.0	8.0	0.0	1.92	72.00

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	55.000	Pile Penetration: (ft)	50.800
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	11.5	30,000.0	492.0	3.1	0
55.0	11.5	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

DRIVE SYSTEM FOR DELMAG D 19-42-OED

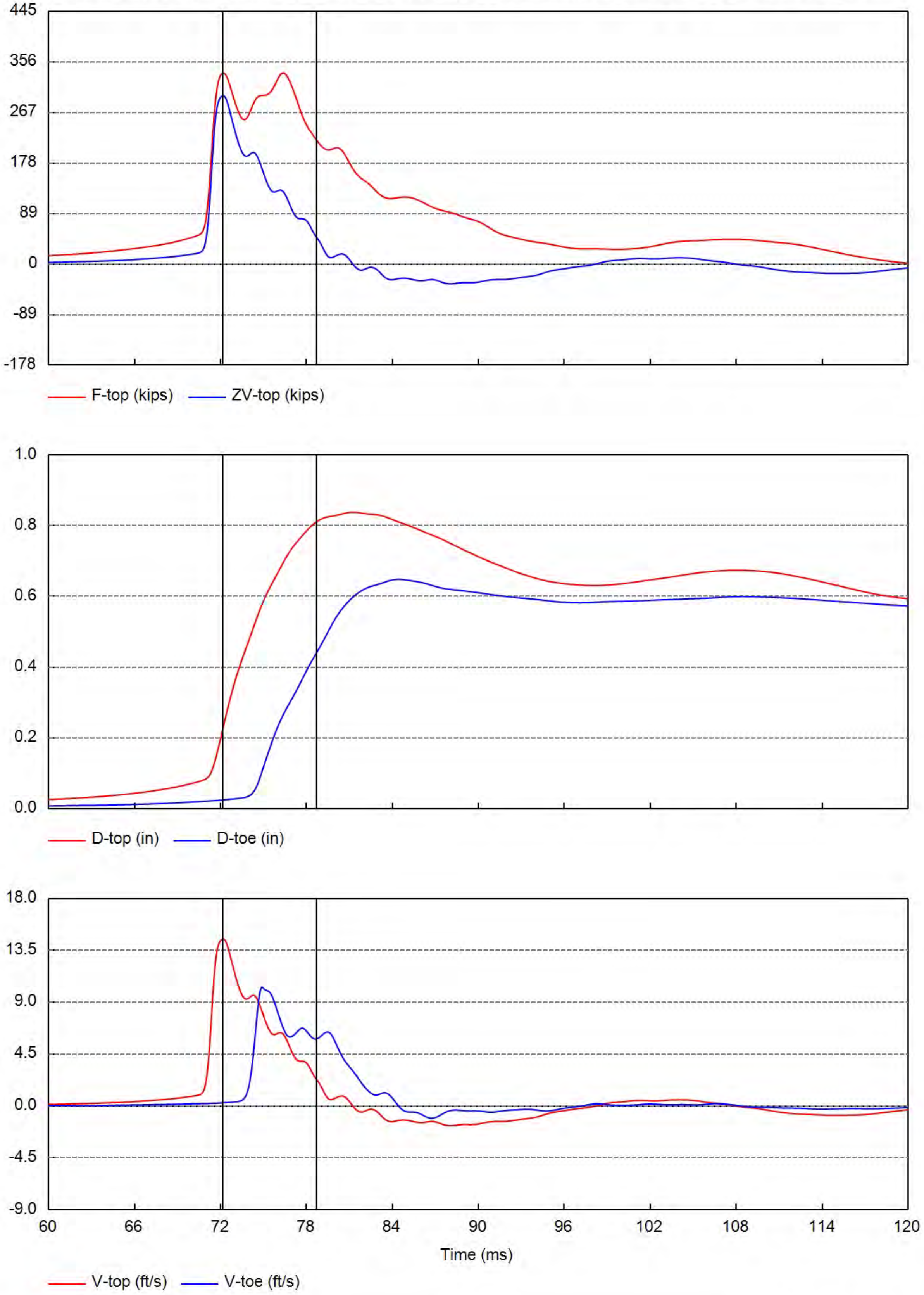
Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

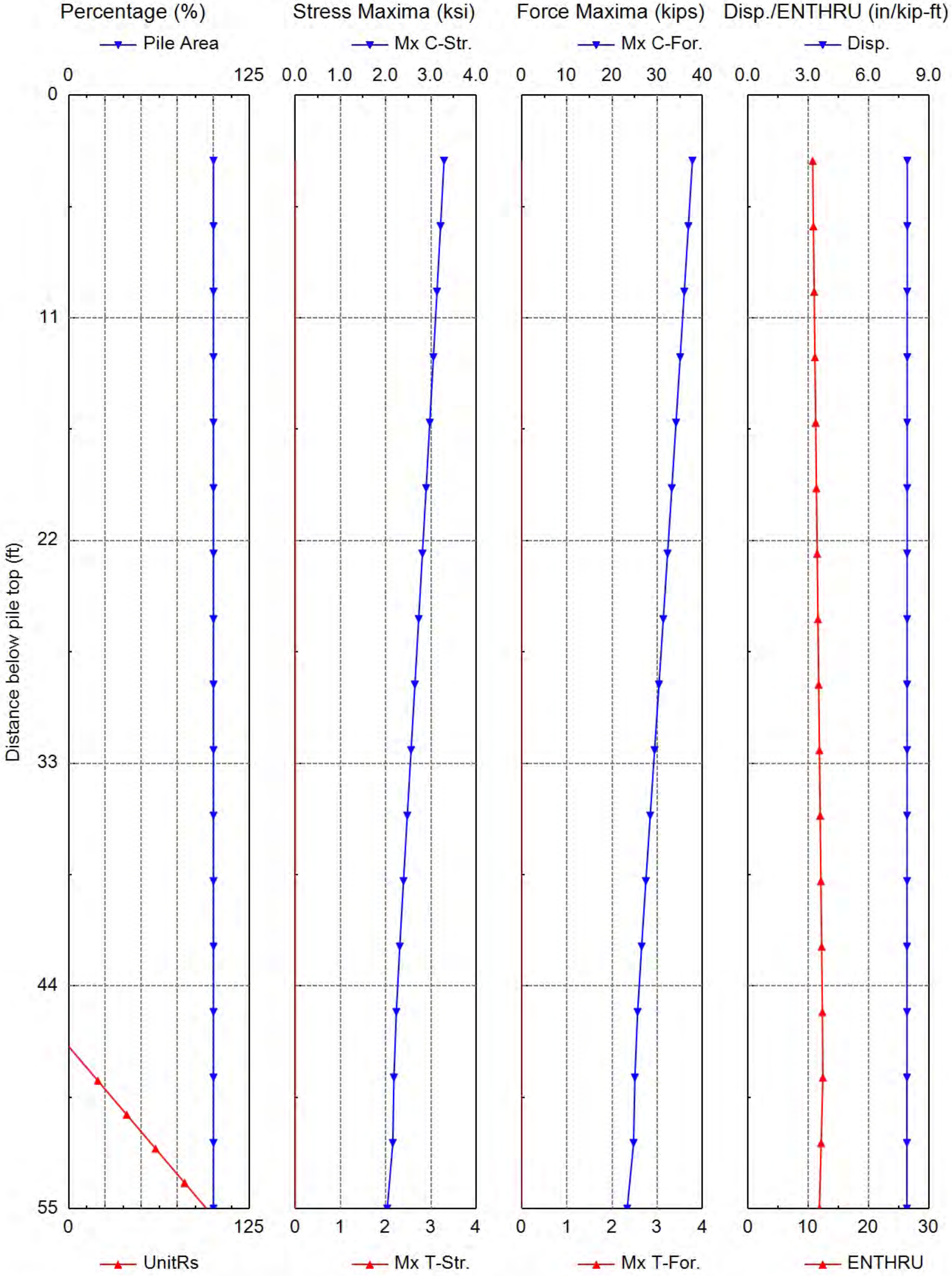
Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1

3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.0	0.2	7.8	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
6.7	0.2	10.4	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.4	0.3	13.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.1	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.8	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.5	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.1	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
16.8	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	0.6	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	4.7	42.7	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
19.0	4.7	42.7	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
19.0	1.1	42.7	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
21.4	1.1	42.7	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
23.8	1.1	42.7	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
23.8	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
25.5	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
27.1	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
28.8	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
30.5	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
32.1	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
33.8	1.8	68.6	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
33.8	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
35.5	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
37.1	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
38.8	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
40.5	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
42.1	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
43.8	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
45.5	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
47.1	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
48.8	1.5	54.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
48.8	1.2	45.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1
50.8	1.2	45.0	0.10	0.10	0.20	0.15	1.5	6.6	168.0	113.1

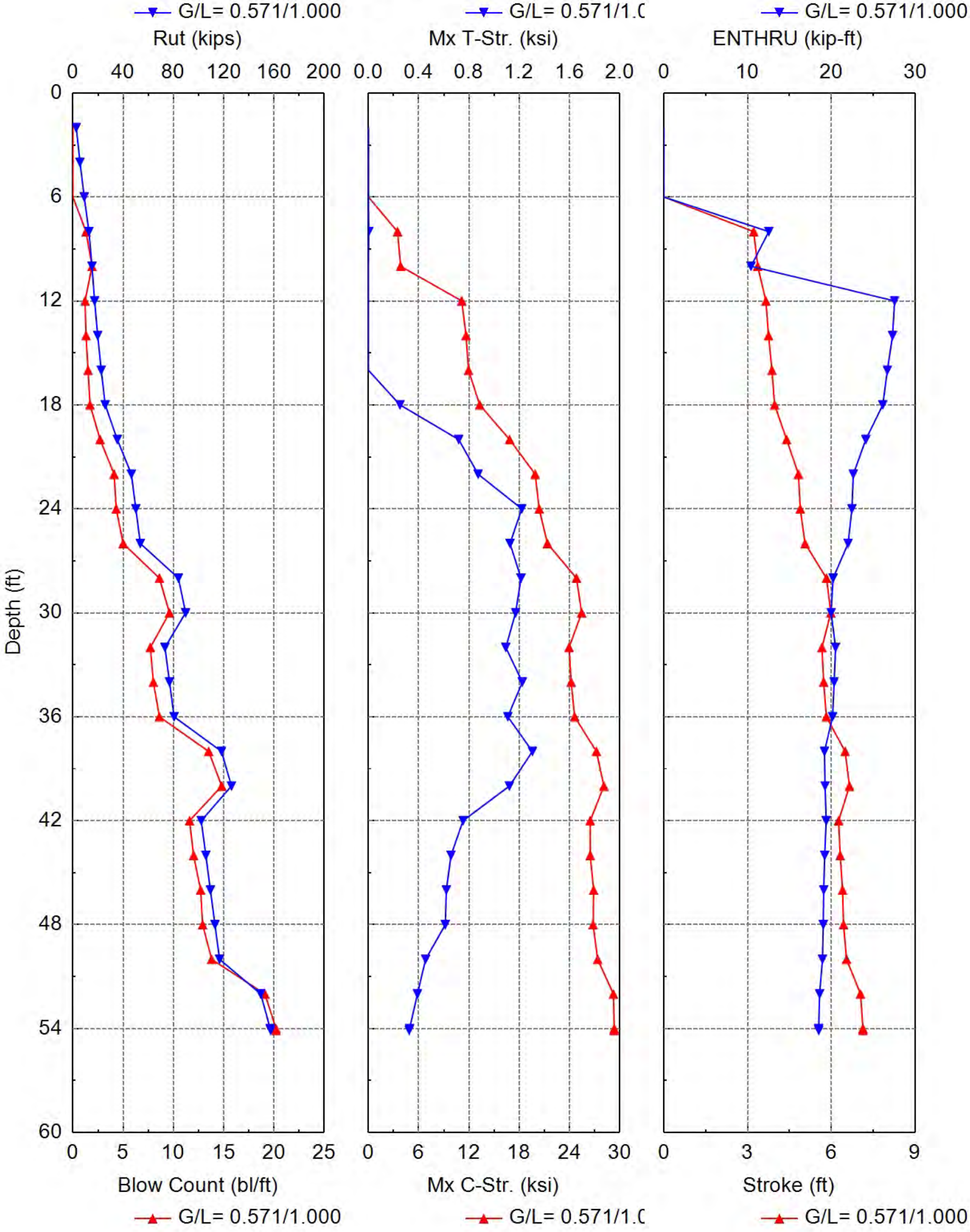
Variable Time Hisotry with DELMAG D 19-42; Depth = 50.80ft; Shaft/Toe G/L = 0.667/1.000



Extrema Results of Gain/Loss at Shaft/Toe = 0.667/1.000 and Depth = 8.00 ft



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.571/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.3	3.475	0.002	3.22	12.5	D 19-42
10.0	15.1	4.7	10.4	1.9	3.845	0.000	3.36	10.4	D 19-42
12.0	17.2	6.8	10.5	1.2	11.144	0.000	3.65	27.5	D 19-42
14.0	19.7	9.2	10.5	1.3	11.659	0.000	3.75	27.3	D 19-42
16.0	22.5	12.0	10.5	1.5	11.947	0.000	3.87	26.7	D 19-42
18.0	25.7	15.2	10.5	1.7	13.292	0.251	3.97	26.1	D 19-42
20.0	35.3	20.3	15.0	2.7	16.854	0.719	4.40	24.1	D 19-42
22.0	46.5	24.4	22.1	4.1	19.913	0.873	4.82	22.6	D 19-42
24.0	50.1	28.0	22.1	4.3	20.389	1.221	4.88	22.5	D 19-42
26.0	53.6	31.5	22.1	5.0	21.372	1.127	5.06	22.0	D 19-42
28.0	83.9	37.1	46.8	8.6	24.837	1.215	5.82	20.2	D 19-42
30.0	89.6	42.8	46.8	9.6	25.457	1.171	5.98	20.0	D 19-42
32.0	73.2	47.6	25.6	7.7	23.958	1.094	5.66	20.5	D 19-42
34.0	76.9	51.2	25.6	8.0	24.206	1.225	5.72	20.3	D 19-42
36.0	80.5	54.9	25.6	8.6	24.619	1.110	5.82	20.1	D 19-42
38.0	118.2	62.6	55.7	13.5	27.219	1.306	6.49	19.2	D 19-42
40.0	126.2	70.5	55.7	14.8	28.116	1.122	6.65	19.2	D 19-42
42.0	102.1	76.5	25.6	11.6	26.485	0.754	6.26	19.4	D 19-42
44.0	105.7	80.1	25.6	12.0	26.480	0.657	6.31	19.2	D 19-42
46.0	109.4	83.8	25.6	12.7	26.892	0.620	6.40	19.1	D 19-42
48.0	113.0	87.4	25.6	12.9	26.830	0.612	6.44	19.0	D 19-42
50.0	116.7	91.1	25.6	13.8	27.368	0.455	6.54	18.9	D 19-42
52.0	149.5	96.4	53.0	19.1	29.252	0.390	7.04	18.6	D 19-42
54.0	157.0	104.0	53.0	20.2	29.349	0.327	7.13	18.5	D 19-42
54.1	157.4	104.4	53.0	20.2	29.337	0.324	7.13	18.5	D 19-42

Summary_Total driving time: 8 minutes; Total Number of Blows: 377 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - RA - B-074-0-19 + 12" CIP - 0.3125" Wall Thick 12/3/2022
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
18.5	Sand	125.0	0.0	28.0	0.55	13.32
18.5	Clay	120.0	2.1	0.0	2.12	19.12
19.0	Clay	120.0	2.1	0.0	2.12	19.12
19.0	Clay	120.0	2.1	0.0	1.28	19.12
21.1	Clay	120.0	2.1	0.0	1.28	19.12
21.1	Clay	120.0	3.1	0.0	0.85	28.12
26.1	Clay	120.0	3.1	0.0	0.85	28.12
26.1	Clay	130.0	6.6	0.0	1.59	59.62
31.1	Clay	130.0	6.6	0.0	1.59	59.62
31.1	Clay	125.0	3.6	0.0	0.87	32.62
36.1	Clay	125.0	3.6	0.0	0.87	32.62
36.1	Clay	130.0	7.9	0.0	1.89	70.87
41.1	Clay	130.0	7.9	0.0	1.89	70.87
41.1	Clay	125.0	3.6	0.0	0.87	32.62
51.1	Clay	125.0	3.6	0.0	0.87	32.62
51.1	Clay	130.0	7.5	0.0	1.80	67.50
56.1	Clay	130.0	7.5	0.0	1.80	67.50
56.1	Clay	130.0	6.1	0.0	1.47	55.12
60.1	Clay	130.0	6.1	0.0	1.47	55.12
60.1	Clay	125.0	4.4	0.0	1.05	39.37
64.1	Clay	125.0	4.4	0.0	1.05	39.37

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	60.000	Pile Penetration: (ft)	54.100
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	11.5	30,000.0	492.0	3.1	0
60.0	11.5	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

DRIVE SYSTEM FOR DELMAG D 19-42-OED

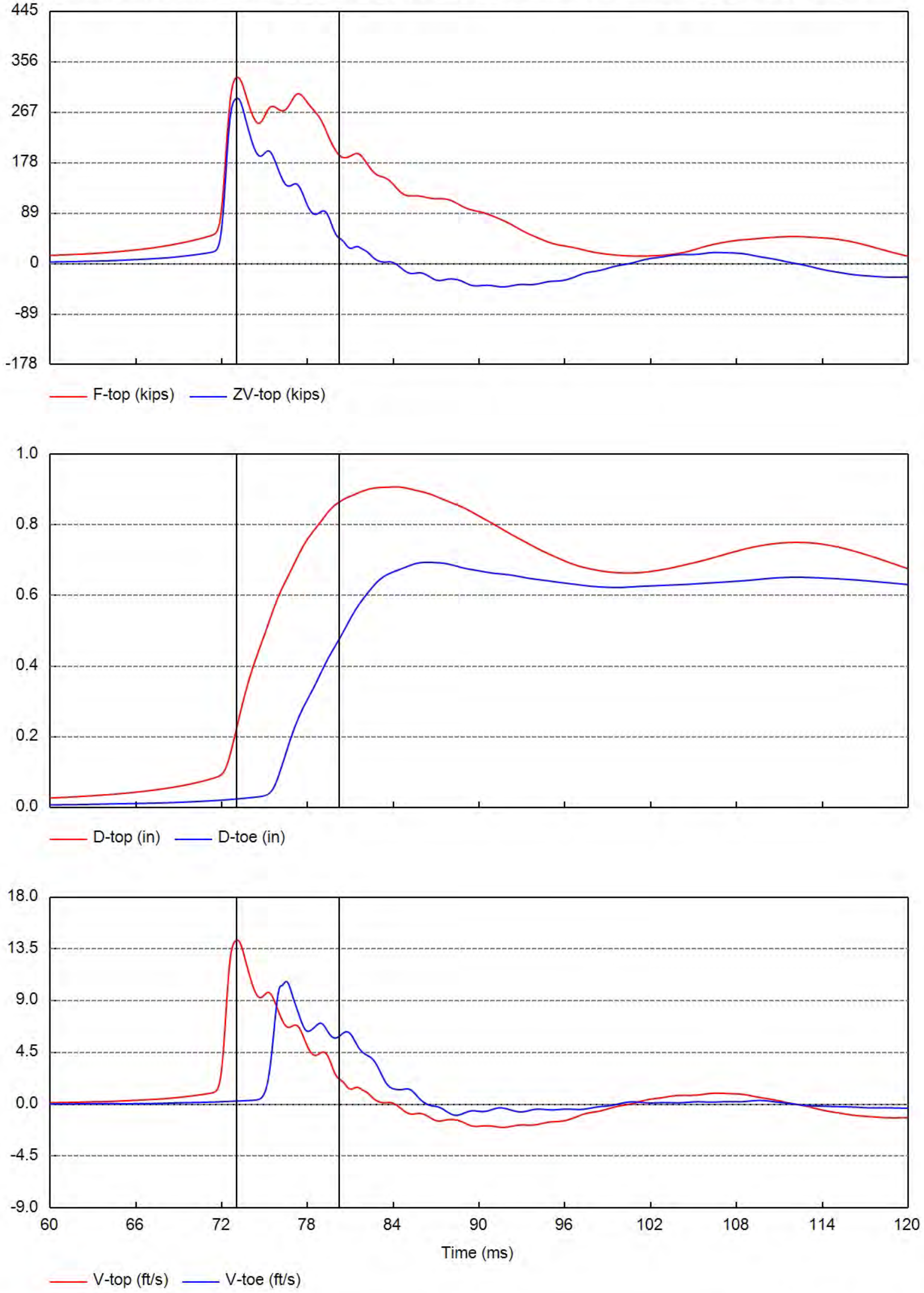
Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in

Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

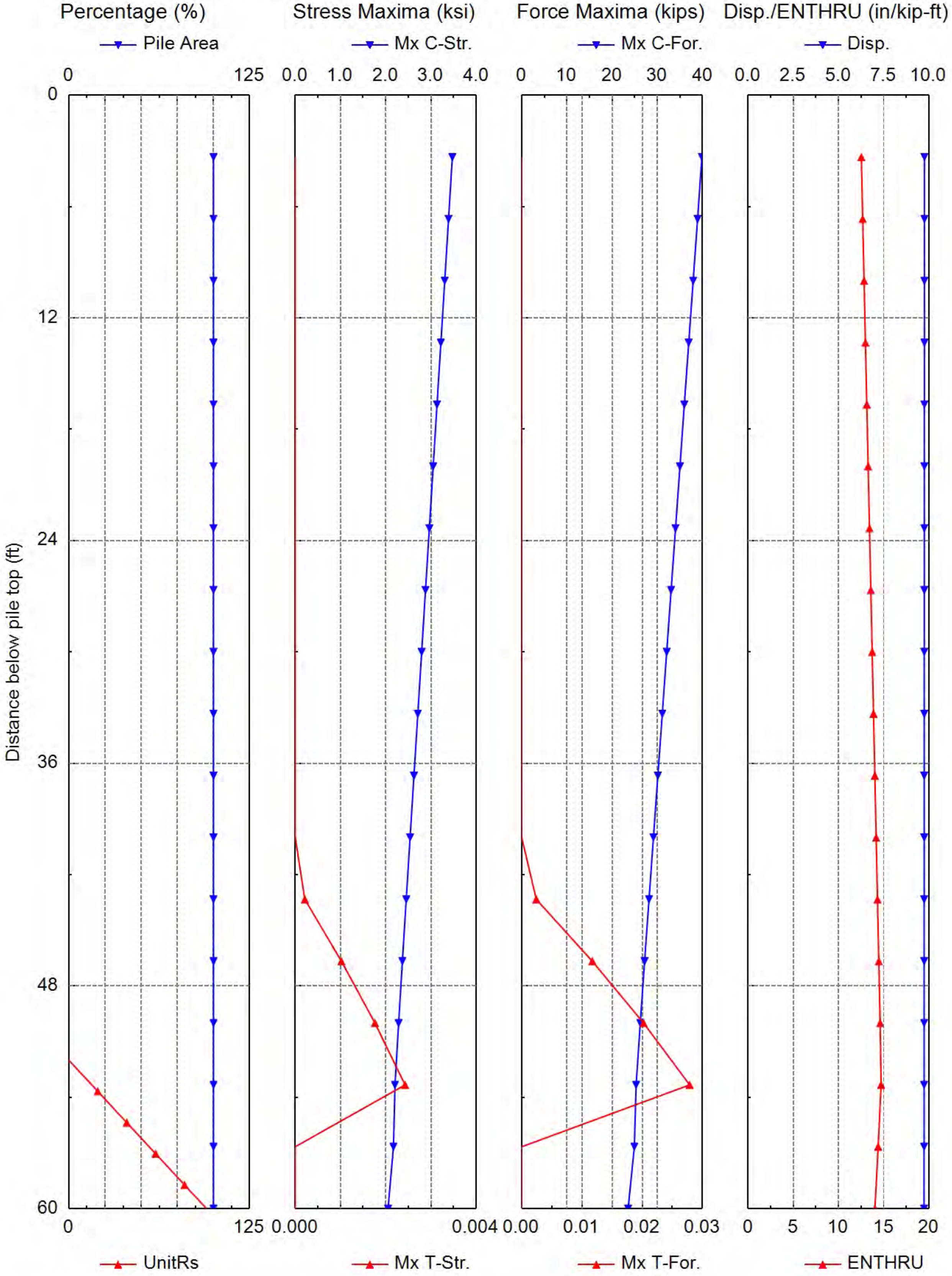
SOIL RESISTANCE DISTRIBUTION

Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.0	0.2	7.8	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
6.7	0.2	10.4	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.4	0.3	13.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.1	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.8	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.5	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.1	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
16.8	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	0.6	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	2.1	19.1	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
19.0	2.1	19.1	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
19.0	1.3	19.1	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
20.1	1.3	19.1	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
21.1	1.3	19.1	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
21.1	0.8	28.1	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
22.8	0.8	28.1	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
24.4	0.8	28.1	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
26.1	0.8	28.1	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
26.1	1.6	59.6	0.10	0.10	0.20	0.15	1.8	6.6	168.0	113.1
27.8	1.6	59.6	0.10	0.10	0.20	0.15	1.8	6.6	168.0	113.1
29.4	1.6	59.6	0.10	0.10	0.20	0.15	1.8	6.6	168.0	113.1
31.1	1.6	59.6	0.10	0.10	0.20	0.15	1.8	6.6	168.0	113.1
31.1	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
32.8	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
34.4	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
36.1	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
36.1	1.9	70.9	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
37.8	1.9	70.9	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
39.4	1.9	70.9	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
41.1	1.9	70.9	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
41.1	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
42.8	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
44.4	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
46.1	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
47.8	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
49.4	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
51.1	0.9	32.6	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
51.1	1.8	67.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
52.8	1.8	67.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
54.4	1.8	67.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1

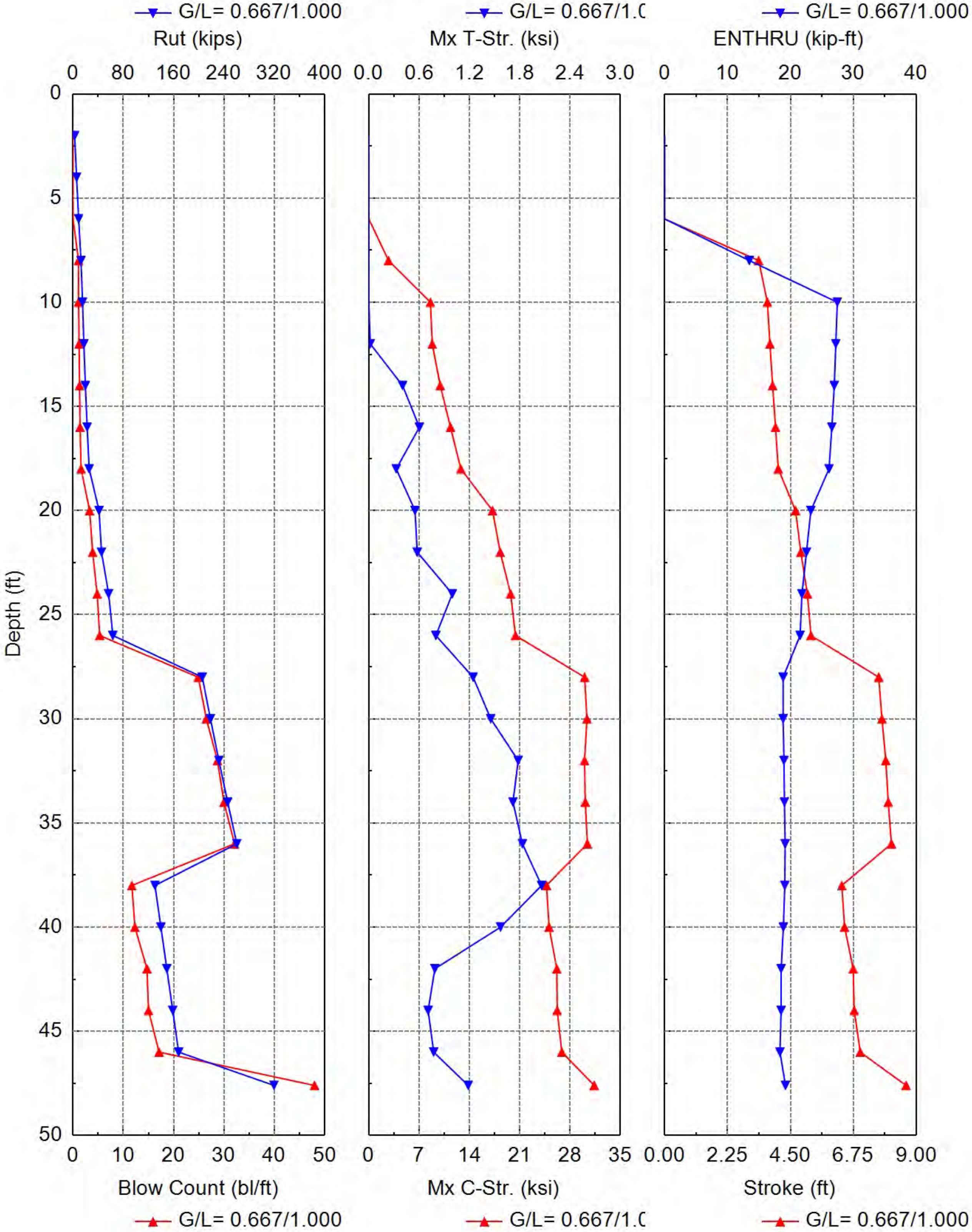
Variable Time Hisotry with DELMAG D 19-42; Depth = 54.10ft; Shaft/Toe G/L = 0.571/1.000



Extrema Results of Gain/Loss at Shaft/Toe = 0.571/1.000 and Depth = 8.00 ft



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.667/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.1	2.739	0.000	3.36	13.5	D 19-42
10.0	15.1	4.7	10.4	1.1	8.567	0.000	3.68	27.5	D 19-42
12.0	17.2	6.8	10.5	1.2	8.823	0.017	3.77	27.2	D 19-42
14.0	19.7	9.2	10.5	1.3	9.935	0.402	3.86	27.0	D 19-42
16.0	22.5	12.0	10.5	1.4	11.366	0.603	3.97	26.6	D 19-42
18.0	25.7	15.2	10.5	1.6	12.803	0.327	4.06	26.1	D 19-42
20.0	41.4	21.1	20.3	3.3	17.203	0.551	4.68	23.2	D 19-42
22.0	45.3	25.0	20.3	3.9	18.281	0.577	4.87	22.6	D 19-42
24.0	56.6	30.6	26.0	4.8	19.726	0.996	5.11	21.8	D 19-42
26.0	63.3	37.4	26.0	5.3	20.406	0.799	5.23	21.5	D 19-42
28.0	205.5	45.9	159.6	24.9	30.024	1.243	7.66	18.8	D 19-42
30.0	218.5	58.8	159.6	26.5	30.346	1.454	7.77	18.8	D 19-42
32.0	231.9	72.3	159.6	28.7	30.016	1.781	7.91	19.0	D 19-42
34.0	245.9	86.3	159.6	30.0	30.111	1.719	8.00	19.0	D 19-42
36.0	260.4	100.8	159.6	32.1	30.408	1.831	8.11	19.2	D 19-42
38.0	130.3	114.4	15.9	11.7	24.716	2.061	6.34	19.1	D 19-42
40.0	139.7	123.8	15.9	12.3	25.079	1.571	6.44	18.9	D 19-42
42.0	149.1	133.2	15.9	14.7	26.153	0.788	6.75	18.5	D 19-42
44.0	158.6	142.7	15.9	15.0	26.210	0.707	6.78	18.5	D 19-42
46.0	168.0	152.1	15.9	17.1	26.850	0.773	7.00	18.3	D 19-42
47.6	319.5	159.9	159.6	48.0	31.358	1.185	8.64	19.2	D 19-42

Summary_Total driving time: 12 minutes; Total Number of Blows: 511 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - RA - B-075-0-19 + 12" CIP - 0.4375" Wall Thick 5/6/2023
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
18.5	Sand	125.0	0.0	28.0	0.55	13.32
18.5	Clay	120.0	2.9	0.0	2.87	25.87
19.0	Clay	120.0	2.9	0.0	2.87	25.87
19.0	Clay	120.0	2.9	0.0	0.94	25.87
22.5	Clay	120.0	2.9	0.0	0.94	25.87
22.5	Sand	130.0	2.9	32.0	0.96	33.09
27.5	Sand	130.0	2.9	32.0	1.18	33.09
27.5	Sand	135.0	0.0	37.0	1.99	203.27
37.5	Sand	135.0	0.0	37.0	2.42	203.27
37.5	Clay	120.0	2.2	37.0	2.25	20.25
47.5	Clay	120.0	2.2	37.0	2.25	20.25
47.5	Sand	135.0	0.0	37.0	2.75	203.27
57.5	Sand	135.0	0.0	37.0	3.18	203.27

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	50.000	Pile Penetration: (ft)	47.600
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	15.9	30,000.0	492.0	3.1	0
50.0	15.9	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

DRIVE SYSTEM FOR DELMAG D 19-42-OED

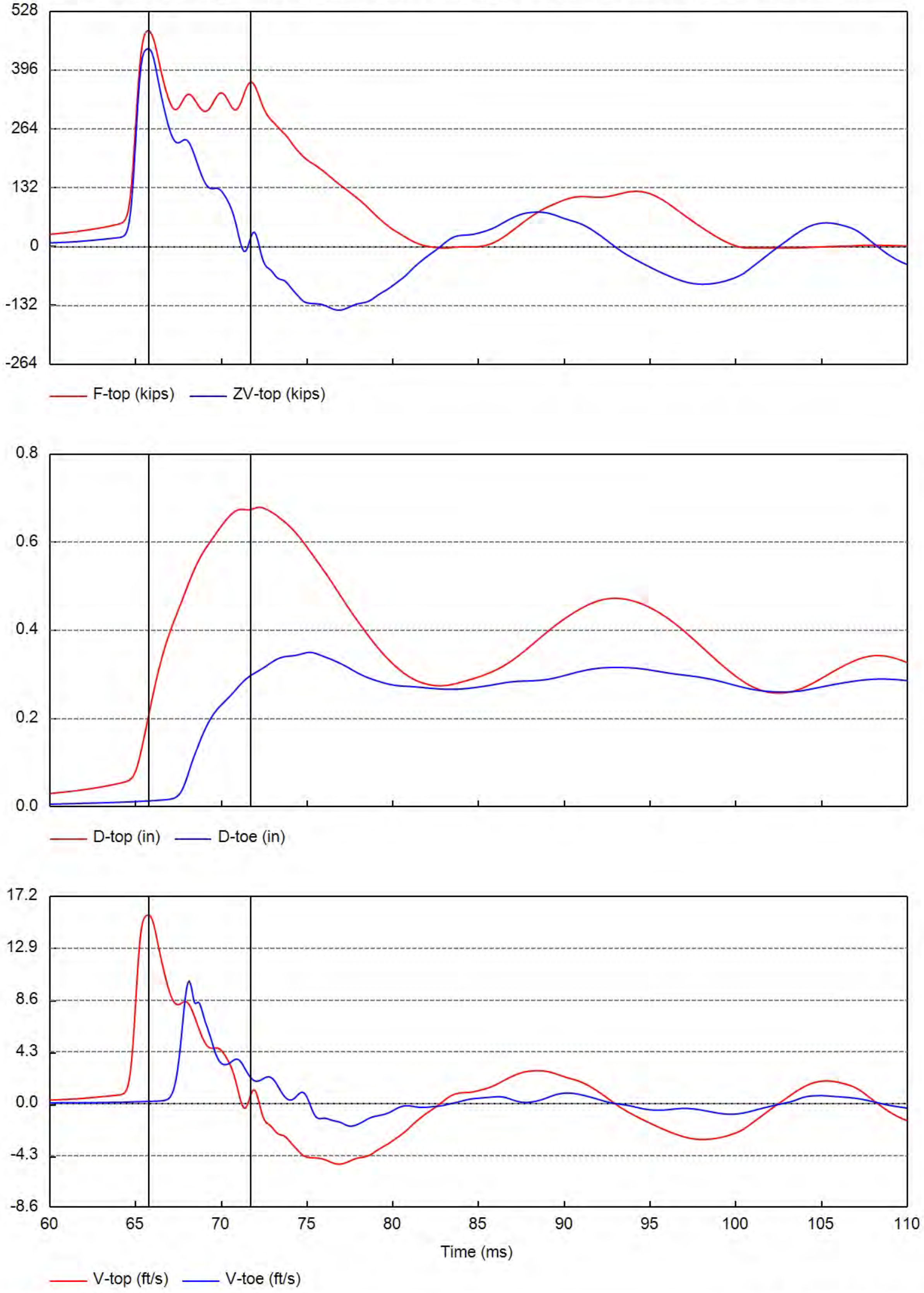
Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

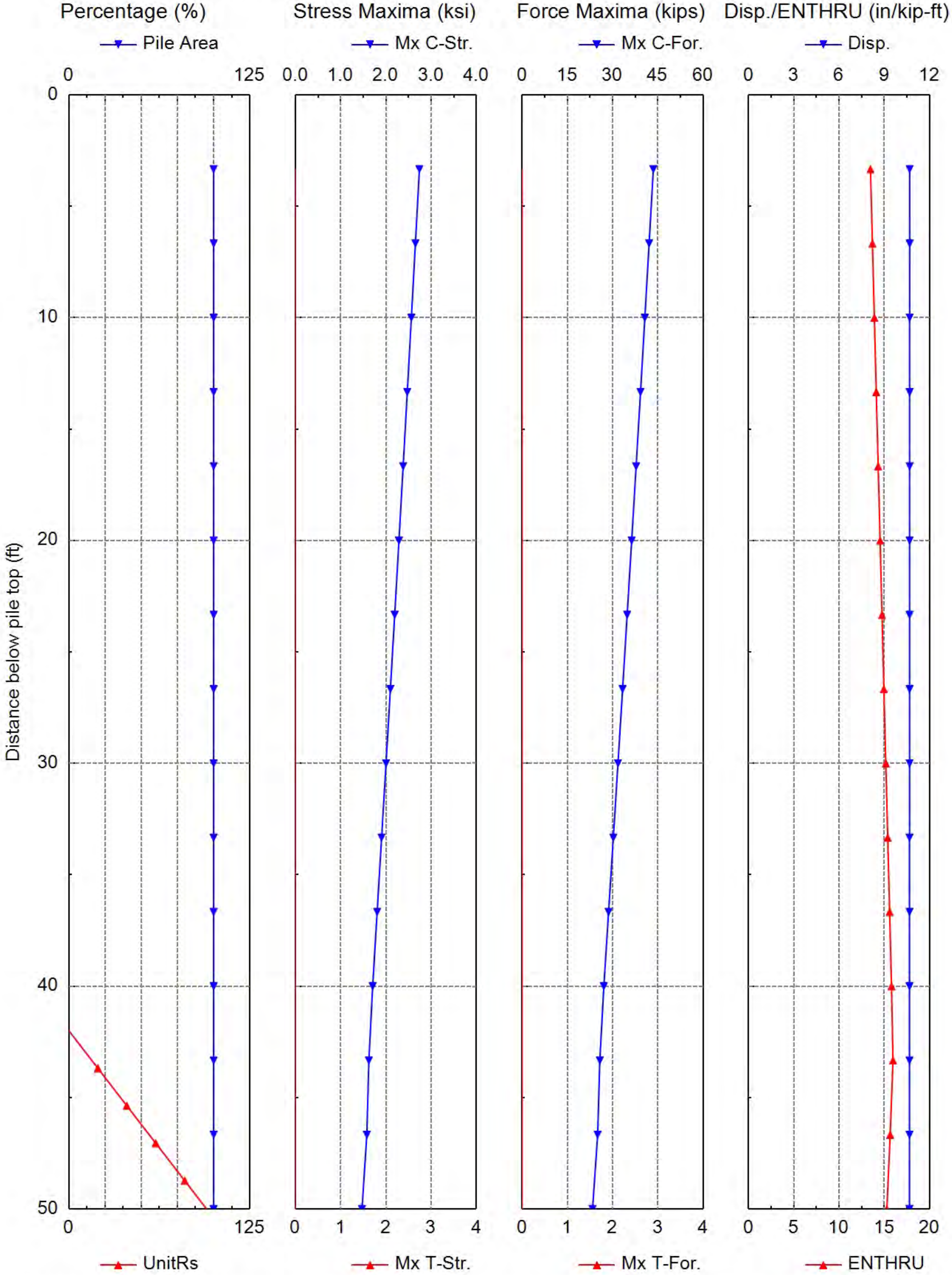
Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1

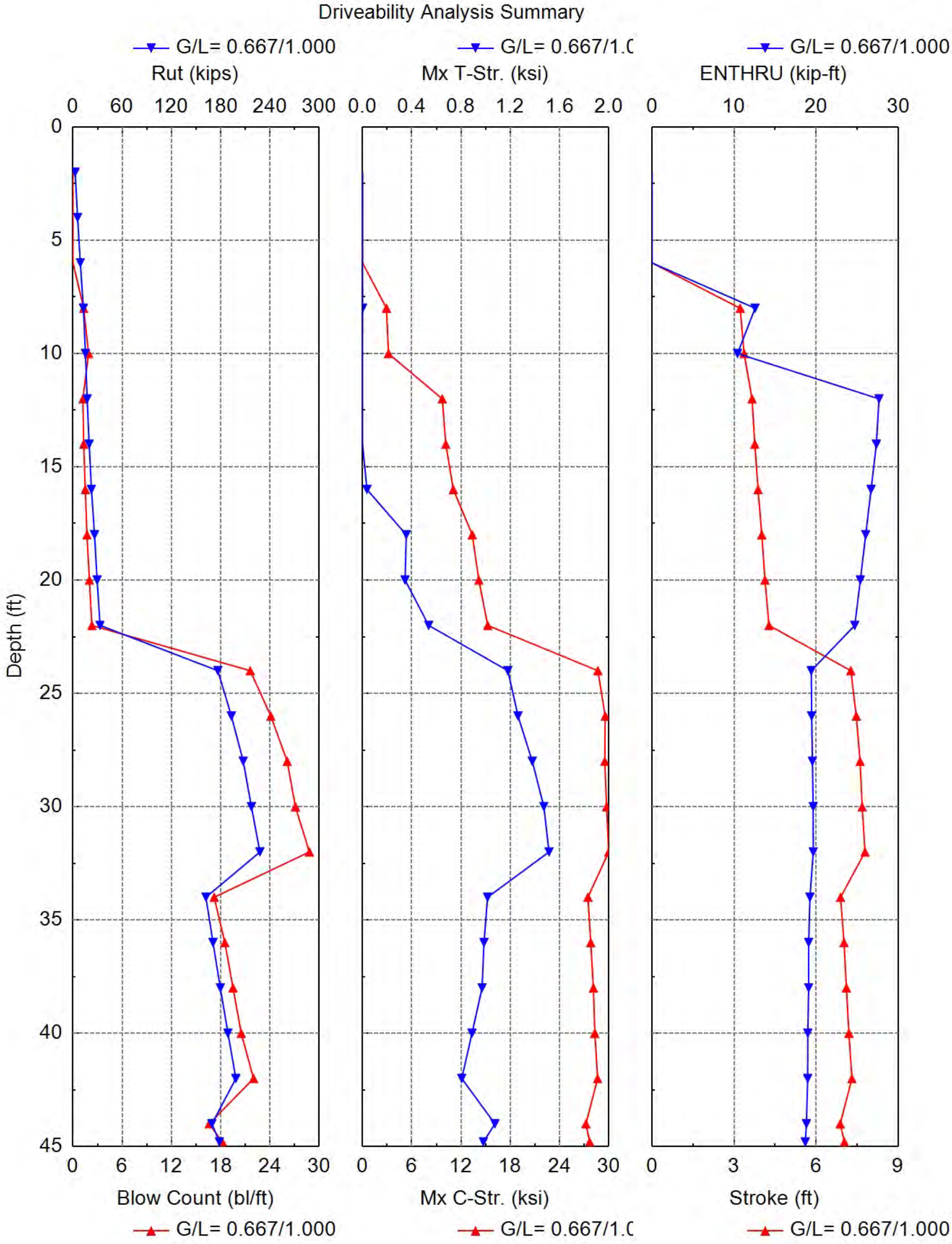
3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.0	0.2	7.8	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
6.7	0.2	10.4	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.4	0.3	13.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.1	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.8	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.5	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.1	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
16.8	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	0.6	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
18.5	2.9	25.9	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
19.0	2.9	25.9	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
19.0	0.9	25.9	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
20.8	0.9	25.9	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
22.5	0.9	25.9	0.10	0.15	0.20	0.15	1.5	6.6	168.0	113.1
22.5	1.0	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
24.2	1.0	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
25.8	1.1	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
27.5	1.2	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
27.5	2.0	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
29.2	2.1	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
30.8	2.1	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
32.5	2.2	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
34.2	2.3	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
35.8	2.3	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
37.5	2.4	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
37.5	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
39.2	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
40.8	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
42.5	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
44.2	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
45.8	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
47.5	2.2	20.2	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
47.5	2.8	203.3	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1
49.2	2.8	203.3	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1

Variable Time Hisotry with DELMAG D 19-42; Depth = 47.60ft; Shaft/Toe G/L = 0.667/1.000

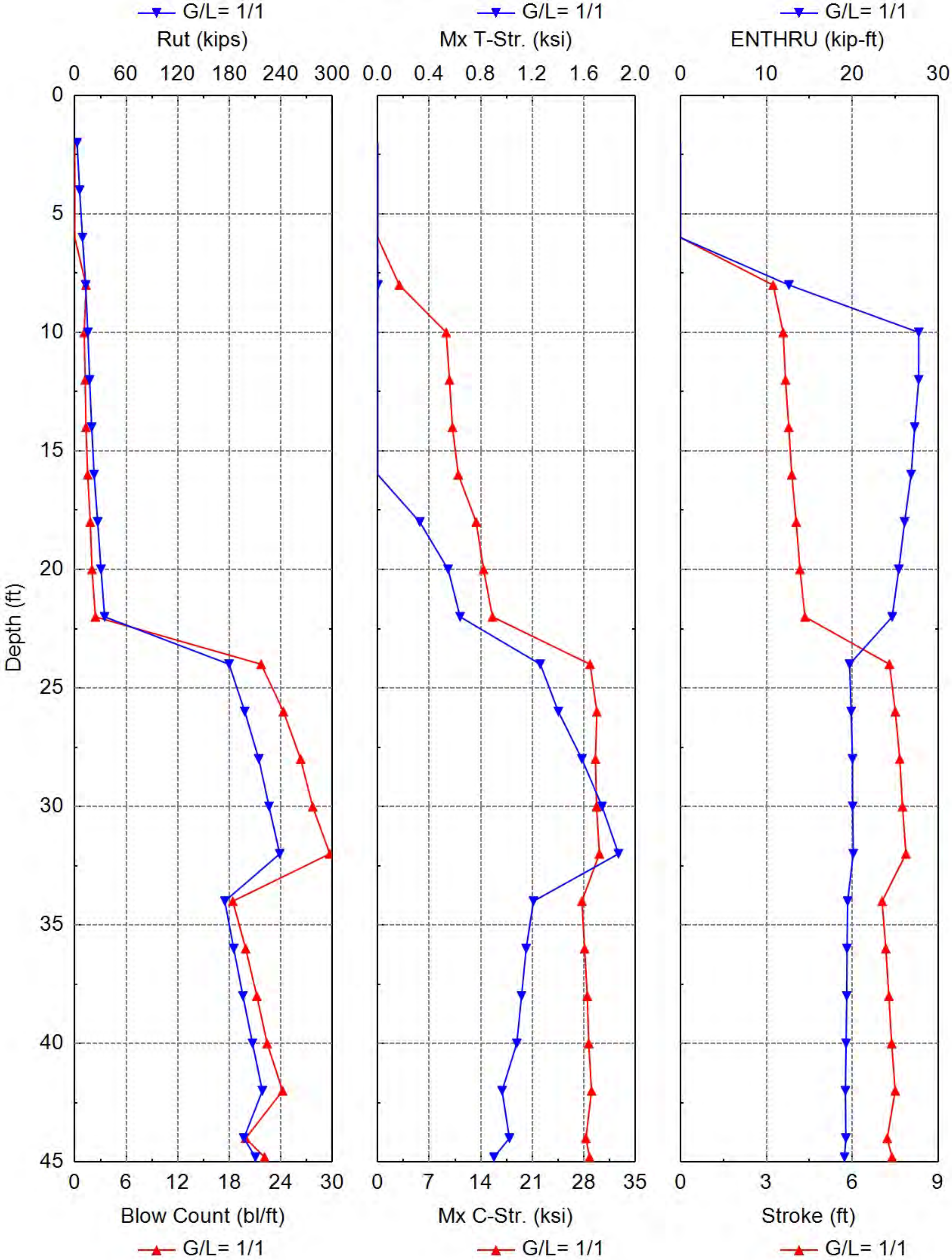


Extrema Results of Gain/Loss at Shaft/Toe = 0.667/1.000 and Depth = 8.00 ft




Driveability Analysis Summary
G/L= 0.667/1.000
Rut (kips)
G/L= 0.667/1.(
Mx T-Str. (ksi)
G/L= 0.667/1.000
ENTHRU (kip-ft)
0
60
120
180
240
300
0.0
0.4
0.8
1.2
1.6
2.0
0
10
20
30
Depth (ft)
0
5
10
15
20
25
30
35
40
45
0
6
12
18
24
30
Blow Count (bl/ft)
0
6
12
18
24
30
Mx C-Str. (ksi)
0
3
6
9
Stroke (ft)
G/L= 0.667/1.000
G/L= 0.667/1.(
G/L= 0.667/1.000

Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.667/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.3	2.923	0.001	3.22	12.6	D 19-42
10.0	15.1	4.7	10.4	1.9	3.163	0.000	3.37	10.4	D 19-42
12.0	17.2	6.8	10.5	1.2	9.718	0.000	3.66	27.7	D 19-42
14.0	19.7	9.2	10.5	1.3	10.148	0.000	3.76	27.3	D 19-42
16.0	22.5	12.0	10.5	1.5	11.068	0.036	3.88	26.7	D 19-42
18.0	26.2	15.8	10.5	1.7	13.371	0.355	4.01	26.0	D 19-42
20.0	29.4	19.0	10.5	2.0	14.178	0.346	4.13	25.4	D 19-42
22.0	32.9	22.5	10.5	2.3	15.256	0.538	4.28	24.7	D 19-42
24.0	176.5	29.2	147.3	21.6	28.684	1.181	7.27	19.4	D 19-42
26.0	193.0	38.3	154.7	24.1	29.568	1.263	7.47	19.4	D 19-42
28.0	207.4	47.8	159.6	26.1	29.522	1.379	7.61	19.5	D 19-42
30.0	217.4	57.7	159.6	27.1	29.738	1.473	7.68	19.6	D 19-42
32.0	227.8	68.1	159.6	28.8	29.998	1.515	7.79	19.6	D 19-42
34.0	161.9	77.4	84.5	17.2	27.466	1.016	6.89	19.2	D 19-42
36.0	170.6	86.1	84.5	18.5	27.810	0.987	7.02	19.1	D 19-42
38.0	179.5	95.0	84.5	19.5	28.133	0.971	7.11	19.1	D 19-42
40.0	188.8	104.3	84.5	20.5	28.311	0.889	7.20	19.0	D 19-42
42.0	198.4	113.9	84.5	22.0	28.648	0.806	7.31	19.0	D 19-42
44.0	169.3	131.3	38.0	16.6	27.221	1.076	6.88	18.8	D 19-42
44.8	178.3	140.3	38.0	18.2	27.677	0.982	7.03	18.7	D 19-42

Summary_Total driving time: 12 minutes; Total Number of Blows: 507 (starting at penetration 2.0 ft)

Gain/Loss Factor at Shaft/Toe = 1.000/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.3	2.935	0.001	3.23	12.6	D 19-42
10.0	15.1	4.7	10.4	1.1	9.308	0.000	3.58	27.7	D 19-42
12.0	17.2	6.8	10.5	1.2	9.748	0.000	3.66	27.7	D 19-42
14.0	19.7	9.2	10.5	1.3	10.153	0.000	3.78	27.3	D 19-42
16.0	22.5	12.0	10.5	1.5	10.949	0.000	3.88	26.8	D 19-42
18.0	26.7	16.2	10.5	1.8	13.380	0.327	4.04	26.1	D 19-42
20.0	30.5	20.0	10.5	2.0	14.385	0.547	4.17	25.4	D 19-42
22.0	34.7	24.3	10.5	2.4	15.593	0.640	4.34	24.6	D 19-42
24.0	179.7	32.3	147.3	21.7	28.852	1.262	7.30	19.7	D 19-42
26.0	197.9	43.2	154.7	24.3	29.773	1.403	7.50	19.9	D 19-42
28.0	214.3	54.6	159.6	26.3	29.584	1.585	7.66	20.0	D 19-42
30.0	226.2	66.6	159.6	27.7	29.726	1.742	7.75	20.0	D 19-42
32.0	238.7	79.0	159.6	29.7	30.123	1.870	7.87	20.1	D 19-42
34.0	174.7	90.2	84.5	18.4	27.740	1.209	7.04	19.4	D 19-42

36.0	185.1	100.6	84.5	19.9	28.110	1.153	7.17	19.4	D 19-42
38.0	195.8	111.3	84.5	21.2	28.476	1.117	7.28	19.3	D 19-42
40.0	206.9	122.4	84.5	22.4	28.671	1.080	7.37	19.3	D 19-42
42.0	218.4	133.9	84.5	24.2	29.053	0.966	7.50	19.2	D 19-42
44.0	196.9	158.9	38.0	19.9	28.287	1.023	7.22	19.2	D 19-42
44.8	210.4	172.4	38.0	22.1	28.790	0.903	7.39	19.1	D 19-42

Summary_Total driving time: 12 minutes; Total Number of Blows: 533 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - FA - B-076-0-19 + 12" CIP - 0.375" Wall Thick 12/3/2022
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
17.0	Sand	125.0	0.0	28.0	0.51	13.32
17.0	Sand	130.0	0.0	34.0	0.88	73.64
17.8	Sand	130.0	0.0	34.0	0.92	73.64
17.8	Sand	125.0	0.0	29.0	0.58	13.32
22.8	Sand	125.0	0.0	29.0	0.72	13.32
22.8	Sand	135.0	0.0	37.0	1.64	181.94
32.8	Sand	135.0	0.0	37.0	2.06	203.27
32.8	Sand	130.0	0.0	35.0	1.58	107.60
42.8	Sand	130.0	0.0	35.0	1.89	107.60
42.8	Clay	130.0	5.4	0.0	5.37	48.37
60.8	Clay	130.0	5.4	0.0	5.37	48.37

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	50.000	Pile Penetration: (ft)	44.800
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	13.7	30,000.0	492.0	3.1	0
50.0	13.7	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

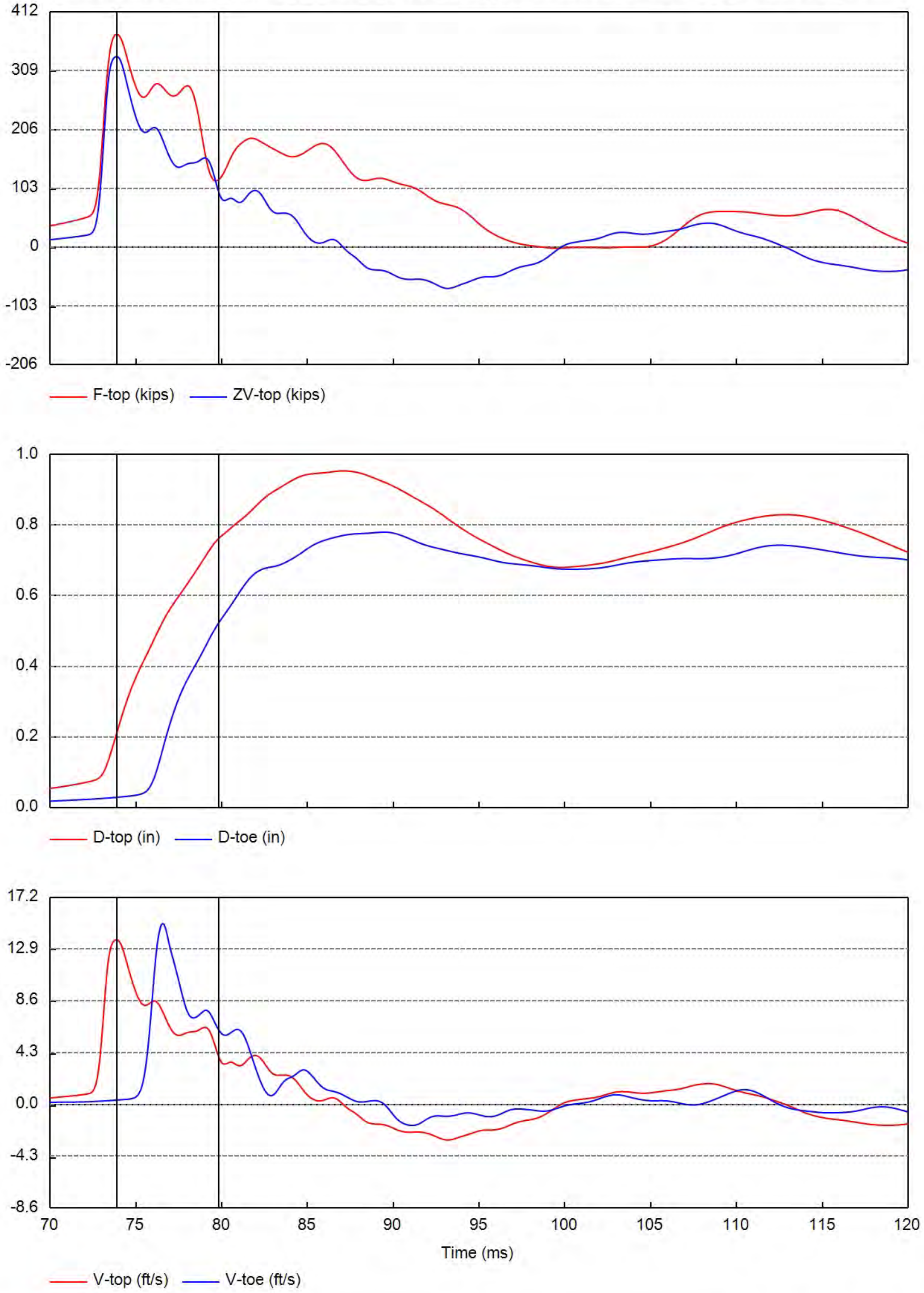
DRIVE SYSTEM FOR DELMAG D 19-42-OED

Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

SOIL RESISTANCE DISTRIBUTION

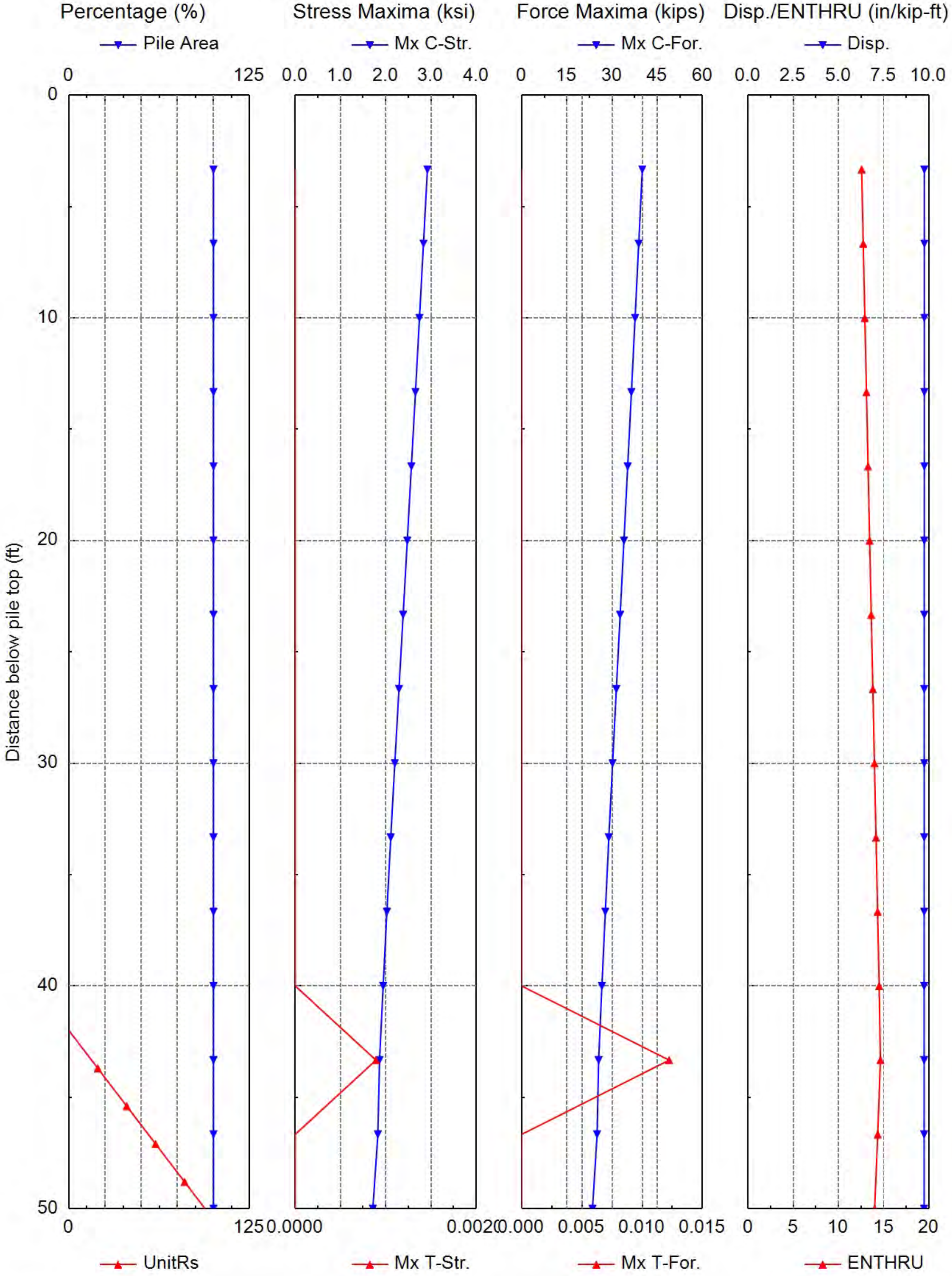
Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.1	0.2	7.9	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1

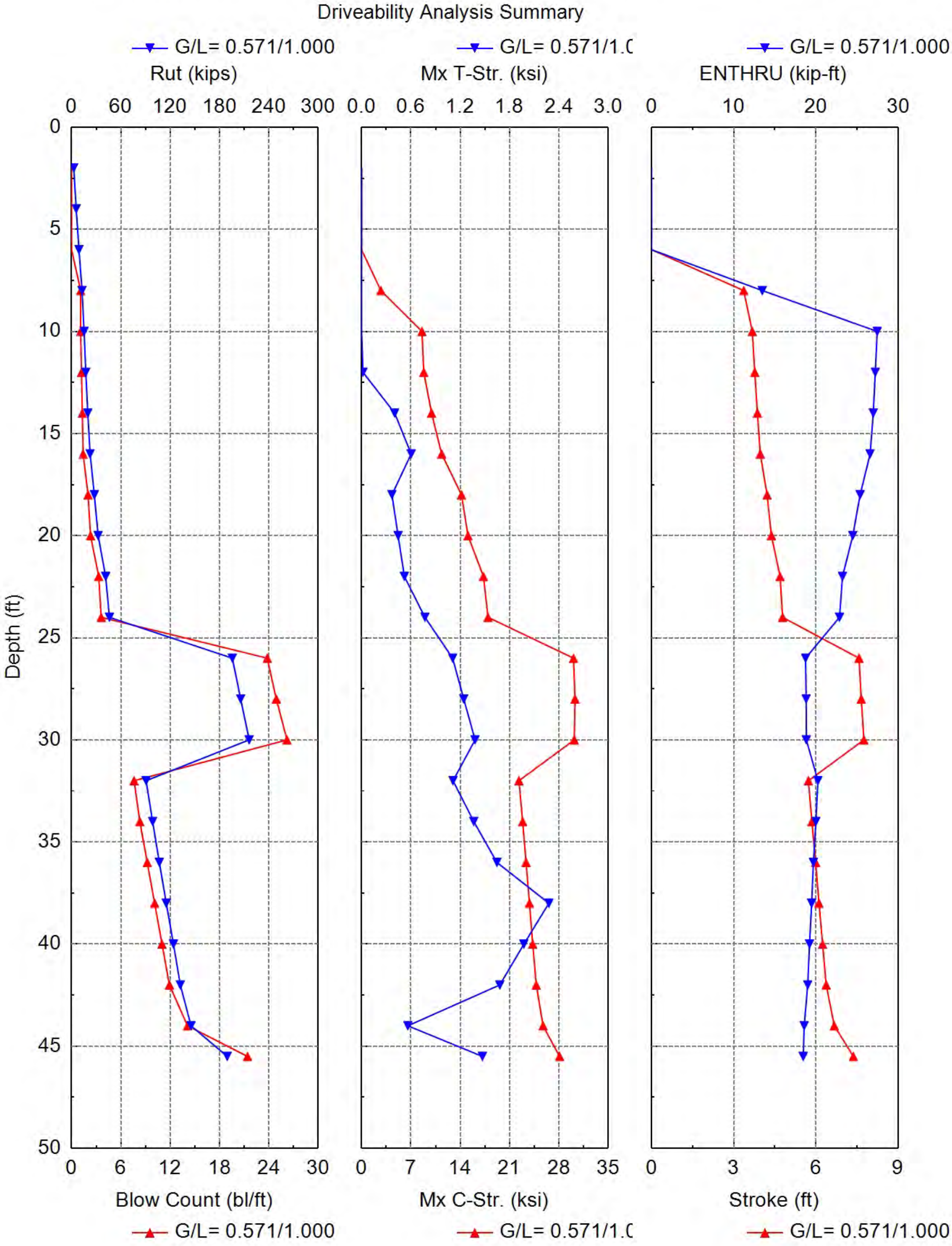
6.8	0.2	10.5	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.5	0.3	13.1	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.2	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.9	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.6	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.3	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	0.9	73.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
17.8	0.9	73.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
17.8	0.6	13.3	0.10	0.15	0.10	0.15	1.2	6.6	1.0	113.1
19.5	0.6	13.3	0.10	0.15	0.10	0.15	1.2	6.6	1.0	113.1
21.1	0.7	13.3	0.10	0.15	0.10	0.15	1.2	6.6	1.0	113.1
22.8	0.7	13.3	0.10	0.15	0.10	0.15	1.2	6.6	1.0	113.1
22.8	1.6	181.9	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
24.5	1.7	189.8	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
26.1	1.8	197.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
27.8	1.8	203.3	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
29.5	1.9	203.3	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
31.1	2.0	203.3	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
32.8	2.1	203.3	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
32.8	1.6	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
34.5	1.6	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
36.1	1.7	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
37.8	1.7	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
39.5	1.8	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
41.1	1.8	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
42.8	1.9	107.6	0.10	0.20	0.05	0.15	1.2	6.6	1.0	113.1
42.8	5.4	48.4	0.10	0.20	0.15	0.15	1.5	6.6	1.0	113.1
44.6	5.4	48.4	0.10	0.20	0.15	0.15	1.5	6.6	1.0	113.1
46.4	5.4	48.4	0.10	0.20	0.15	0.15	1.5	6.6	1.0	113.1



Variable Time Hisotry with DELMAG D 19-42; Depth = 44.80ft; Shaft/Toe G/L = 0.667/1.000

Extrema Results of Gain/Loss at Shaft/Toe = 0.667/1.000 and Depth = 8.00 ft




Driveability Analysis Summary
G/L= 0.571/1.000
Rut (kips)
0 60 120 180 240 300
G/L= 0.571/1.(
Mx T-Str. (ksi)
0.0 0.6 1.2 1.8 2.4 3.0
G/L= 0.571/1.000
ENTHRU (kip-ft)
0 10 20 30
Depth (ft)
0 5 10 15 20 25 30 35 40 45 50
0 6 12 18 24 30
Blow Count (bl/ft)
G/L= 0.571/1.000
0 7 14 21 28 35
Mx C-Str. (ksi)
G/L= 0.571/1.(
0 3 6 9
Stroke (ft)
G/L= 0.571/1.000

Gain/Loss Factor at Shaft/Toe = 0.571/1.000

Depth	Rut	Rshaft	Rtoe	Blow Ct	Mx C-Str.	Mx T-Str.	Stroke	ENTHRU	Hammer
ft	kips	kips	kips	bl/ft	ksi	ksi	ft	kip-ft	-
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.1	2.739	0.000	3.36	13.5	D 19-42
10.0	15.1	4.7	10.4	1.1	8.570	0.000	3.68	27.5	D 19-42
12.0	17.2	6.8	10.5	1.2	8.823	0.017	3.77	27.2	D 19-42
14.0	19.7	9.2	10.5	1.3	9.935	0.402	3.86	27.0	D 19-42
16.0	22.5	12.0	10.5	1.4	11.366	0.603	3.97	26.6	D 19-42
18.0	27.7	16.2	11.5	2.0	14.179	0.369	4.22	25.4	D 19-42
20.0	32.3	20.8	11.5	2.3	15.104	0.444	4.37	24.5	D 19-42
22.0	41.4	25.1	16.3	3.3	17.297	0.520	4.69	23.2	D 19-42
24.0	46.0	29.7	16.3	3.6	17.949	0.771	4.78	22.9	D 19-42
26.0	195.5	36.1	159.4	23.8	30.082	1.108	7.57	18.7	D 19-42
28.0	205.7	46.0	159.6	24.9	30.288	1.243	7.65	18.8	D 19-42
30.0	216.0	56.4	159.6	26.2	30.193	1.381	7.75	18.8	D 19-42
32.0	90.6	64.6	26.0	7.6	22.336	1.112	5.72	20.2	D 19-42
34.0	98.5	72.5	26.0	8.3	22.865	1.365	5.85	20.0	D 19-42
36.0	106.7	80.7	26.0	9.2	23.341	1.646	5.99	19.7	D 19-42
38.0	115.2	89.2	26.0	10.1	23.830	2.278	6.11	19.5	D 19-42
40.0	123.9	97.9	26.0	11.0	24.289	1.975	6.24	19.2	D 19-42
42.0	132.2	110.1	22.1	11.9	24.793	1.682	6.37	19.0	D 19-42
44.0	145.3	123.2	22.1	14.1	25.757	0.563	6.67	18.6	D 19-42
45.5	189.3	132.8	56.5	21.4	28.098	1.471	7.37	18.5	D 19-42

Summary_Total driving time: 7 minutes; Total Number of Blows: 341 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - FA - B-077-0-19 + 12" CIP - 0.4375" Wall Thick 12/3/2022
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
17.0	Sand	125.0	0.0	28.0	0.51	13.32
17.0	Clay	120.0	1.6	0.0	1.62	14.62
17.5	Clay	120.0	1.6	0.0	1.62	14.62
17.5	Clay	120.0	1.6	0.0	1.28	14.62
20.4	Clay	120.0	1.6	0.0	1.28	14.62
20.4	Sand	125.0	0.0	31.0	0.79	20.71
25.4	Sand	125.0	0.0	31.0	0.97	20.71
25.4	Sand	135.0	0.0	37.0	1.83	202.88
30.4	Sand	135.0	0.0	37.0	2.04	203.27
30.4	Sand	125.0	0.0	32.0	1.20	33.09
40.4	Sand	125.0	0.0	32.0	1.42	33.09
40.4	Clay	120.0	3.1	0.0	3.12	28.12
45.4	Clay	120.0	3.1	0.0	3.12	28.12
45.4	Clay	130.0	8.0	0.0	1.92	72.00
50.4	Clay	130.0	8.0	0.0	1.92	72.00
50.4	Sand	135.0	0.0	33.0	1.80	50.11
56.4	Sand	135.0	0.0	33.0	1.96	50.11
56.4	Clay	125.0	4.4	0.0	4.37	39.37
60.9	Clay	125.0	4.4	0.0	4.37	39.37

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	50.000	Pile Penetration: (ft)	45.500
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	15.9	30,000.0	492.0	3.1	0
50.0	15.9	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

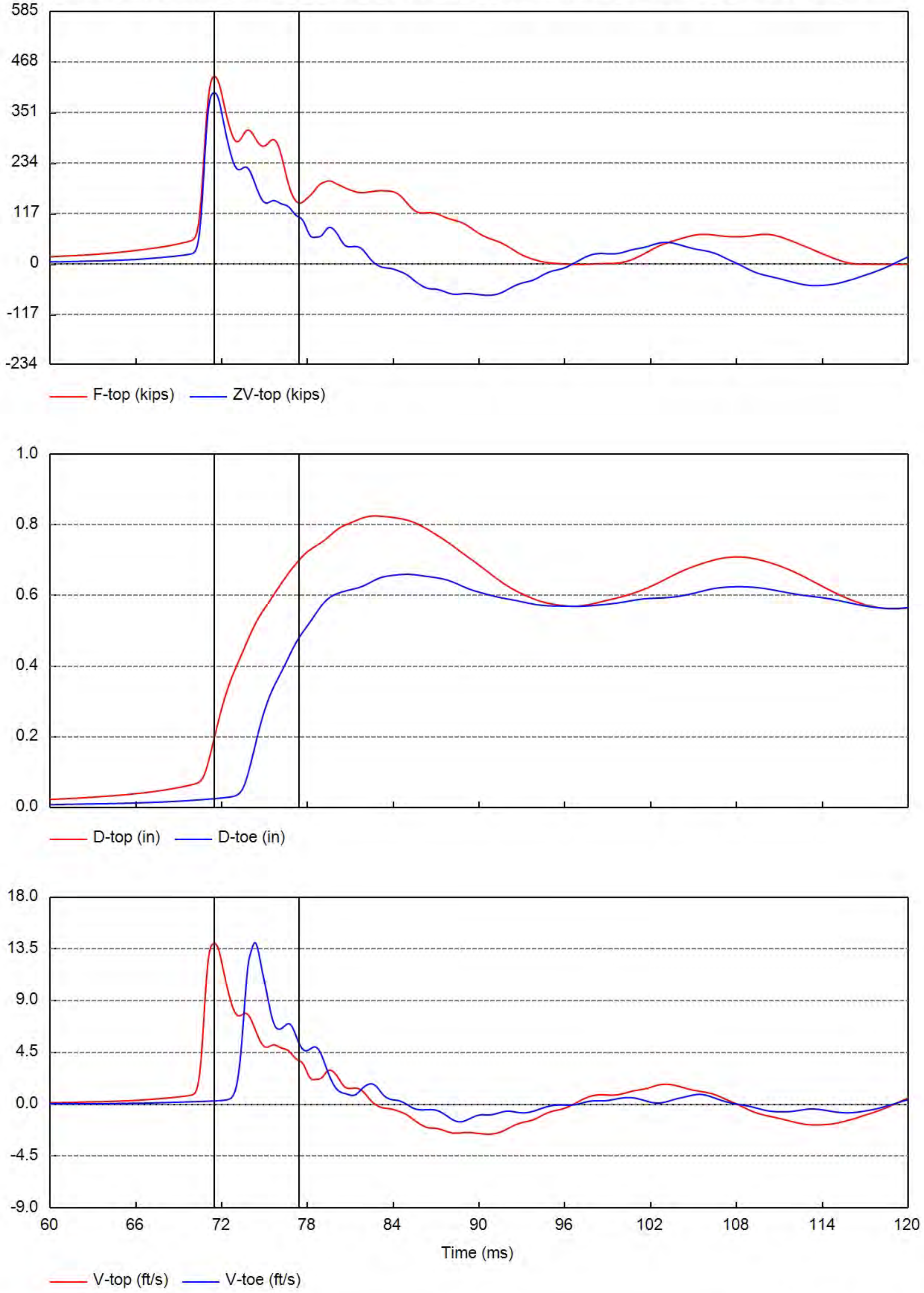
DRIVE SYSTEM FOR DELMAG D 19-42-OED

Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

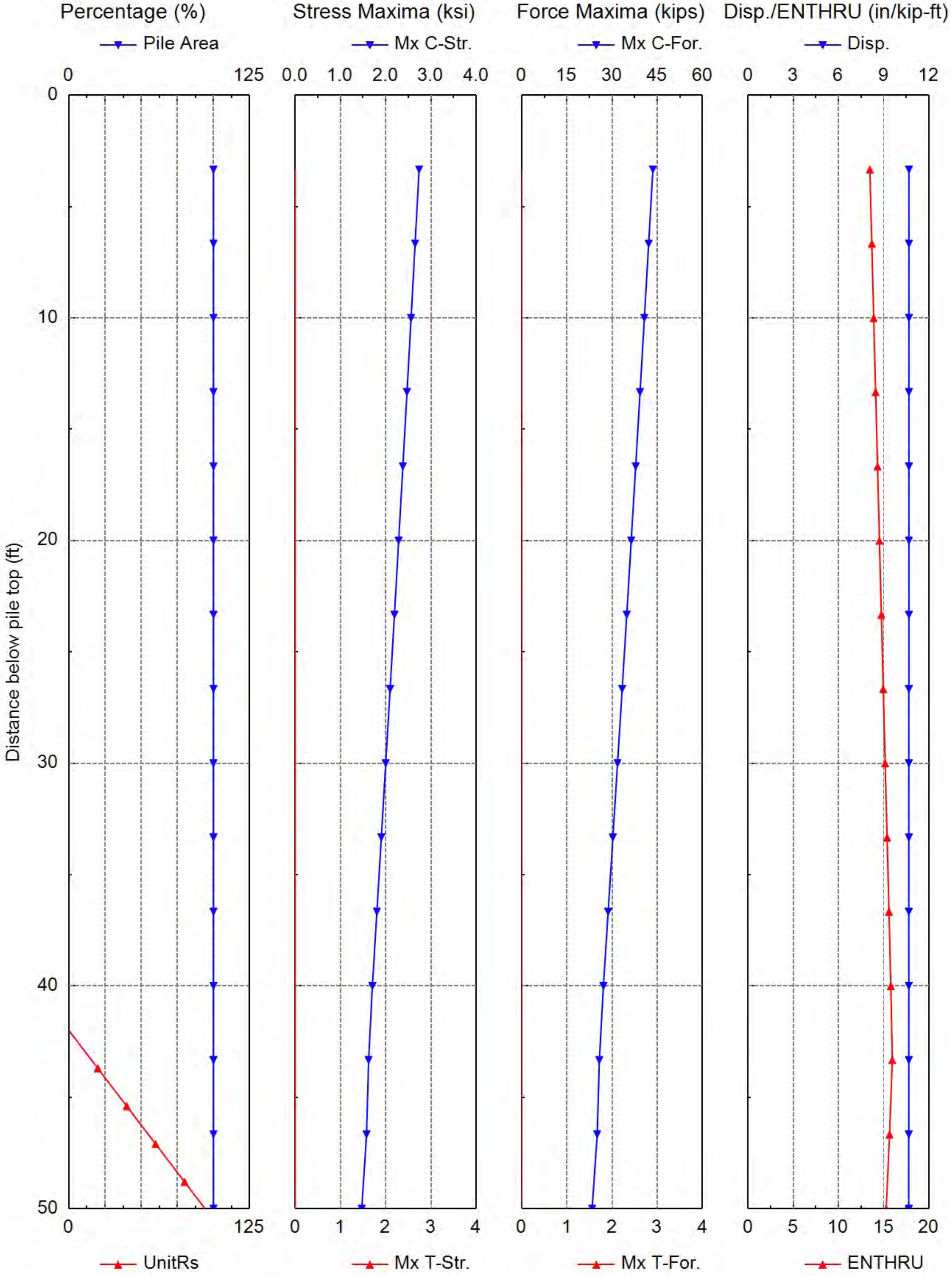
SOIL RESISTANCE DISTRIBUTION

Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.1	0.2	7.9	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
6.8	0.2	10.5	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.5	0.3	13.1	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.2	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.9	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.6	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.3	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	1.6	14.6	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
17.5	1.6	14.6	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
17.5	1.3	14.6	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
19.0	1.3	14.6	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
20.4	1.3	14.6	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
20.4	0.8	20.7	0.10	0.15	0.05	0.15	1.2	6.6	1.0	113.1
22.1	0.8	20.7	0.10	0.15	0.05	0.15	1.2	6.6	1.0	113.1
23.7	0.9	20.7	0.10	0.15	0.05	0.15	1.2	6.6	1.0	113.1
25.4	1.0	20.7	0.10	0.15	0.05	0.15	1.2	6.6	1.0	113.1
25.4	1.8	202.9	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1
27.1	1.9	203.3	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1
28.7	2.0	203.3	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1
30.4	2.0	203.3	0.10	0.10	0.05	0.15	1.2	6.6	1.0	113.1
30.4	1.2	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
32.1	1.2	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
33.7	1.3	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
35.4	1.3	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
37.1	1.3	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
38.7	1.4	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
40.4	1.4	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
40.4	3.1	28.1	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
42.1	3.1	28.1	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
43.7	3.1	28.1	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
45.4	3.1	28.1	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
45.4	1.9	72.0	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
47.1	1.9	72.0	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1

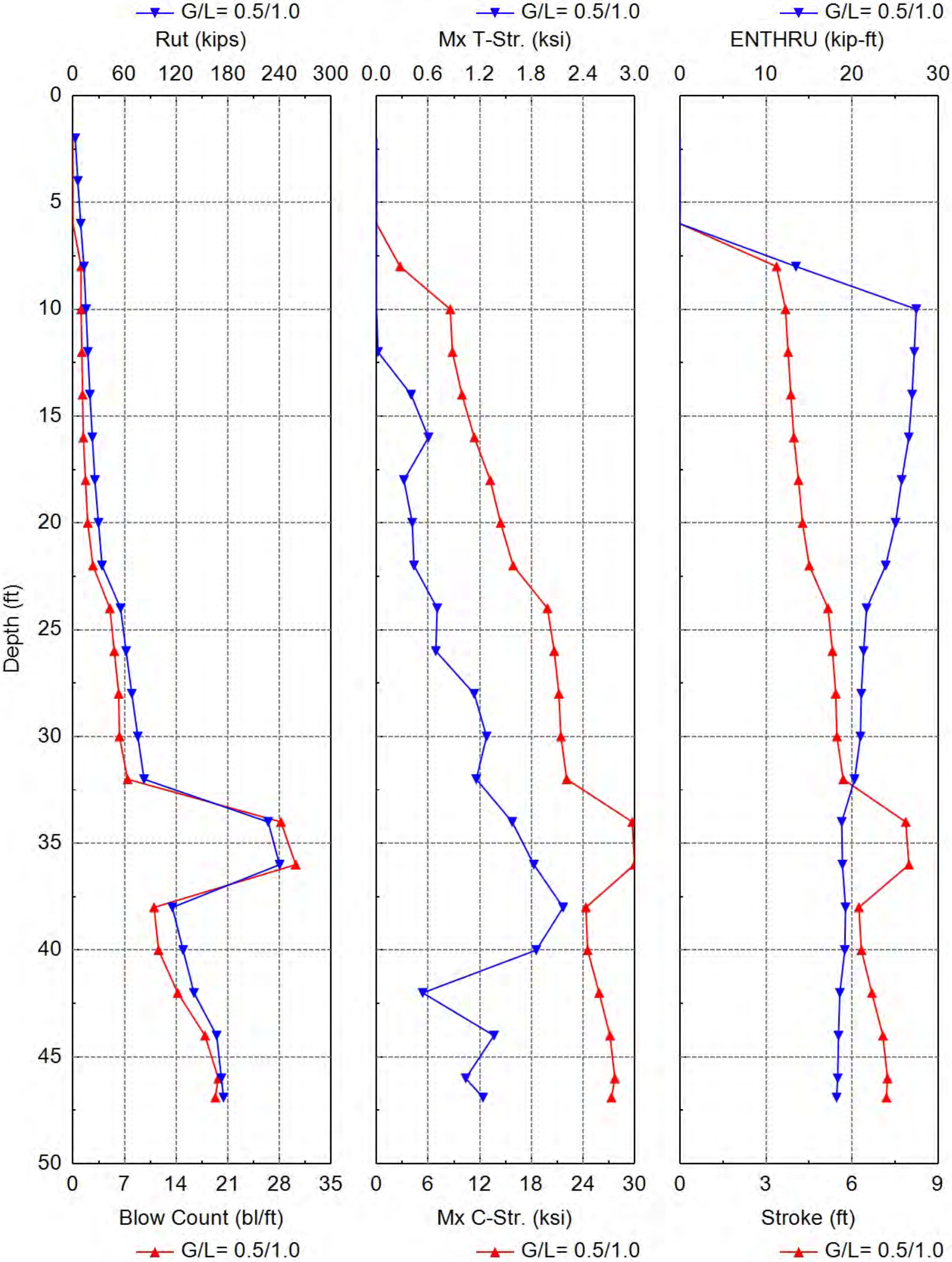
Variable Time Hisotry with DELMAG D 19-42; Depth = 45.50ft; Shaft/Toe G/L = 0.571/1.000



Extrema Results of Gain/Loss at Shaft/Toe = 0.571/1.000 and Depth = 8.00 ft



Driveability Analysis Summary



Gain/Loss Factor at Shaft/Toe = 0.500/1.000

Depth ft	Rut kips	Rshaft kips	Rtoe kips	Blow Ct bl/ft	Mx C-Str. ksi	Mx T-Str. ksi	Stroke ft	ENTHRU kip-ft	Hammer -
2.0	2.6	0.2	2.4	0.3	0.000	0.000	10.81	0.0	D 19-42
4.0	5.6	0.8	4.8	0.0	0.000	0.000	0.00	0.0	D 19-42
6.0	9.0	1.7	7.3	0.0	0.000	0.000	0.00	0.0	D 19-42
8.0	12.7	3.0	9.7	1.1	2.739	0.000	3.36	13.5	D 19-42
10.0	15.1	4.7	10.4	1.1	8.570	0.000	3.68	27.5	D 19-42
12.0	17.2	6.8	10.5	1.2	8.823	0.017	3.77	27.2	D 19-42
14.0	19.7	9.2	10.5	1.3	9.935	0.402	3.86	27.0	D 19-42
16.0	22.5	12.0	10.5	1.4	11.366	0.603	3.97	26.6	D 19-42
18.0	25.4	15.7	9.7	1.7	13.220	0.319	4.13	25.8	D 19-42
20.0	29.6	19.9	9.7	2.0	14.422	0.415	4.27	25.0	D 19-42
22.0	33.8	24.1	9.7	2.7	15.877	0.436	4.50	23.9	D 19-42
24.0	55.3	29.3	26.0	5.0	19.866	0.705	5.16	21.7	D 19-42
26.0	61.7	35.7	26.0	5.6	20.652	0.689	5.31	21.3	D 19-42
28.0	68.4	42.4	26.0	6.2	21.193	1.135	5.43	21.1	D 19-42
30.0	75.4	49.4	26.0	6.3	21.430	1.279	5.47	21.0	D 19-42
32.0	82.6	56.6	26.0	7.4	22.104	1.159	5.69	20.3	D 19-42
34.0	226.8	67.1	159.6	28.2	29.736	1.577	7.87	18.8	D 19-42
36.0	240.1	80.5	159.6	30.2	29.975	1.829	7.98	18.9	D 19-42
38.0	115.5	94.3	21.2	11.0	24.336	2.169	6.24	19.2	D 19-42
40.0	128.0	106.8	21.2	11.6	24.533	1.857	6.32	19.1	D 19-42
42.0	140.6	119.4	21.2	14.2	25.876	0.537	6.69	18.6	D 19-42
44.0	167.0	128.1	38.9	17.9	27.131	1.365	7.07	18.4	D 19-42
46.0	172.5	133.6	38.9	19.7	27.698	1.037	7.23	18.3	D 19-42
46.9	175.0	136.1	38.9	19.3	27.297	1.237	7.20	18.2	D 19-42

Summary_Total driving time: 8 minutes; Total Number of Blows: 350 (starting at penetration 2.0 ft)

GRLWEAP: Wave Equation Analysis of Pile Foundations

FRA-00070-22.919 - FA - B-078-0-19 + 12" CIP - 0.4375" Wall Thick 12/3/2022
RESOURCE INTERNATIONAL INC GRLWEAP 14.1.15.0

ABOUT THE WAVE EQUATION ANALYSIS RESULTS

The GRLWEAP program simulates the behavior of a preformed pile driven by either an impact hammer or a vibratory hammer. The program is based on mathematical models, which describe motion and forces of hammer, driving system, pile and soil under the hammer action. Under certain conditions, the models only crudely approximate, often complex, dynamic situations.

A wave equation analysis generally relies on input data, which represents normal situations. In particular, the hammer data file supplied with the program assumes that the hammer is in good working order. All of the input data selected by the user may be the best available information at the time when the analysis is performed. However, input data and therefore results may significantly differ from actual field conditions.

Therefore, the program authors recommend prudent use of the GRLWEAP results. Soil response and hammer performance should be verified by static and/or dynamic testing and measurements. Estimates of bending or other local stresses (e.g., helmet or clamp contact, uneven rock surfaces etc.), prestress effects and others must also be accounted for by the user.

The calculated capacity-blow count relationship, i.e. the bearing graph, should be used in conjunction with observed blow counts for the capacity assessment of a driven pile. Soil setup occurring after pile installation may produce bearing capacity values that differ substantially from those expected from a wave equation analysis due to soil setup or relaxation. This is particularly true for pile driven with vibratory hammers. The GRLWEAP user must estimate such effects and should also use proper care when applying blow counts from restrike because of the variability of hammer energy, soil resistance and blow count during early restriking.

Finally, the GRLWEAP capacities are ultimate values. They MUST be reduced by means of an appropriate factor of safety to yield a design or working load. The selection of a factor of safety should consider the quality of the construction control, the variability of the site conditions, uncertainties in the loads, the importance of structure and other factors.

SOIL PROFILE

Depth ft	Soil Type -	Spec. Wt lb/ft³	Su ksf	Phi °	Unit Rs ksf	Unit Rt ksf
0.0	Sand	125.0	0.0	28.0	0.00	0.00
17.0	Sand	125.0	0.0	28.0	0.51	13.32
17.0	Clay	120.0	2.7	0.0	2.75	24.75
17.2	Clay	120.0	2.7	0.0	2.75	24.75
17.2	Clay	120.0	2.7	0.0	0.97	24.75
17.9	Clay	120.0	2.7	0.0	0.97	24.75
17.9	Clay	115.0	1.4	0.0	1.16	12.37
22.9	Clay	115.0	1.4	0.0	1.16	12.37
22.9	Sand	130.0	0.0	32.0	0.97	33.09
32.9	Sand	130.0	0.0	32.0	1.20	33.09
32.9	Sand	135.0	0.0	37.0	2.03	203.27
37.9	Sand	135.0	0.0	37.0	2.25	203.27
37.9	Clay	120.0	3.0	0.0	3.00	27.00
42.9	Clay	120.0	3.0	0.0	3.00	27.00
42.9	Clay	130.0	5.5	0.0	1.32	49.50
57.9	Clay	130.0	5.5	0.0	1.32	49.50
57.9	Clay	130.0	6.0	0.0	1.44	54.00
65.9	Clay	130.0	6.0	0.0	1.44	54.00

PILE INPUT

Uniform Pile		Pile Type:	Pipe
Pile Length: (ft)	50.000	Pile Penetration: (ft)	46.900
Pile Size: (ft)	1.00	Toe Area: (in²)	113.10

Pile Profile

Lb Top ft	X-Area in²	E-Modulus ksi	Spec. Wt lb/ft³	Perim. ft	Crit. Index -
0.0	15.9	30,000.0	492.0	3.1	0
50.0	15.9	30,000.0	492.0	3.1	0

HAMMER INPUT

ID	41	Made By:	DELMAG
Model	D 19-42	Type:	OED

Hammer Data

ID -	Ram Wt kips	Ram L. in	Ram Ar. in²	Rtd. Stk ft	Effic. -	Rtd. Energy kip-ft
41	4.000	129.1	124.7	10.8	0.80	43.2

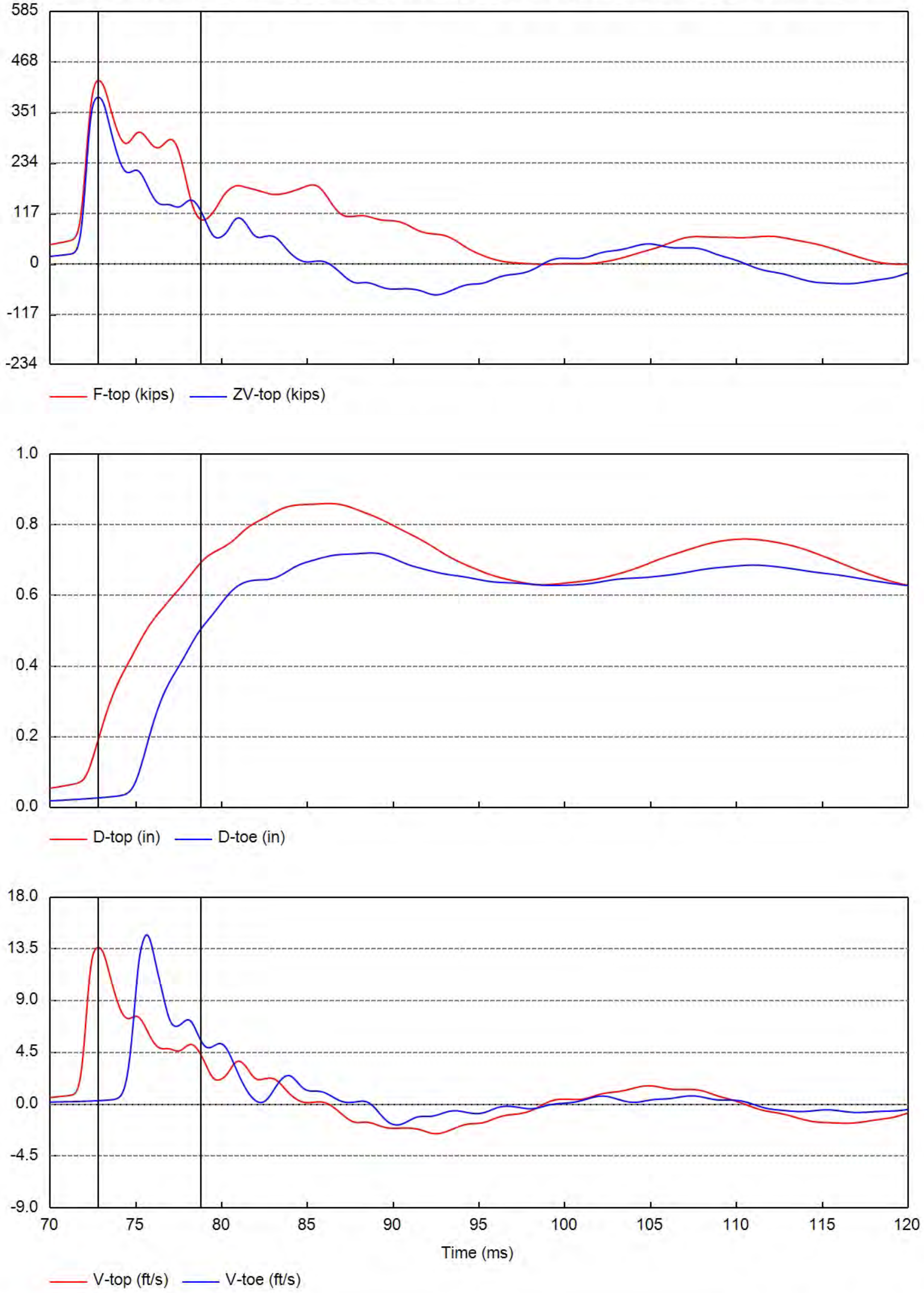
DRIVE SYSTEM FOR DELMAG D 19-42-OED

Type -	X-Area in²	E-Modulus ksi	Thickness in	COR -	Round-out in	Stiffness kips/in
Hammer C.	227.000	530.000	2.000	0.800	0.120	60155.550
Helmet Wt.	1.900	kips				

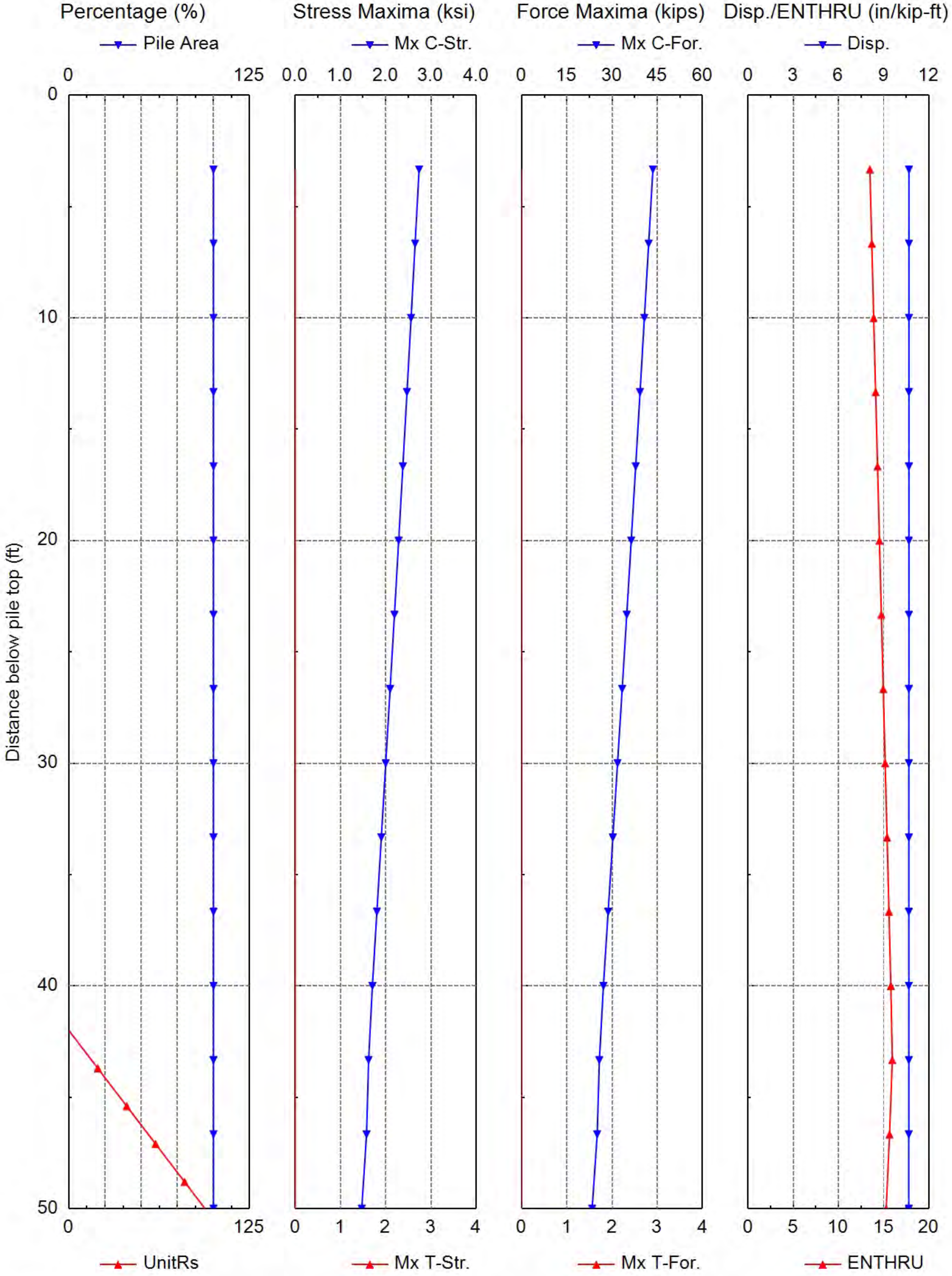
SOIL RESISTANCE DISTRIBUTION

Depth ft	Unit Rs ksf	Unit Rt ksf	Qs in	Qt in	Js s/ft	Jt s/ft	Set. F. -	Limit D. ft	Set. T. Hours	EB Area in²
0.0	0.0	0.0	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
1.7	0.1	2.6	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
3.4	0.1	5.2	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
5.1	0.2	7.9	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
6.8	0.2	10.5	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
8.5	0.3	13.1	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
10.2	0.3	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
11.9	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
13.6	0.4	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
15.3	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	0.5	13.3	0.10	0.20	0.05	0.15	1.0	6.6	1.0	113.1
17.0	2.7	24.7	0.10	0.15	0.20	0.15	2.0	6.6	168.0	113.1
17.2	2.7	24.7	0.10	0.15	0.20	0.15	2.0	6.6	168.0	113.1
17.2	1.0	24.7	0.10	0.15	0.20	0.15	2.0	6.6	168.0	113.1
17.9	1.0	24.7	0.10	0.15	0.20	0.15	2.0	6.6	168.0	113.1
17.9	1.2	12.4	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
19.6	1.2	12.4	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
21.2	1.2	12.4	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
22.9	1.2	12.4	0.10	0.15	0.20	0.15	1.8	6.6	168.0	113.1
22.9	1.0	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
24.6	1.0	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
26.2	1.0	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
27.9	1.1	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
29.6	1.1	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
31.2	1.2	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
32.9	1.2	33.1	0.10	0.15	0.05	0.15	1.0	6.6	1.0	113.1
32.9	2.0	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
34.6	2.1	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
36.2	2.2	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
37.9	2.2	203.3	0.10	0.10	0.05	0.15	1.0	6.6	1.0	113.1
37.9	3.0	27.0	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
39.6	3.0	27.0	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
41.2	3.0	27.0	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
42.9	3.0	27.0	0.10	0.15	0.15	0.15	1.5	6.6	168.0	113.1
42.9	1.3	49.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
44.6	1.3	49.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
46.2	1.3	49.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1
47.9	1.3	49.5	0.10	0.10	0.15	0.15	1.5	6.6	168.0	113.1

Variable Time Hisotry with DELMAG D 19-42; Depth = 46.90ft; Shaft/Toe G/L = 0.500/1.000



Extrema Results of Gain/Loss at Shaft/Toe = 0.500/1.000 and Depth = 8.00 ft



APPENDIX VIII

DESIGN SOIL PARAMETERS

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-039-0-21	788.6	25.0	1	A-6b	C	9.0	9.0	779.6	115	115	518	1,035	10	1,250	0	26	3	365	0.0080				
			2	A-4a	C	25.0	16.0	763.6	120	120	1,995	2,955	25	3,125	0	30	3	1,040	0.0050				
B-040-0-19	788.6	13.0	1	A-6b	C	3.0	3.0	785.6	115	115	173	345	12	1,500	0	26	3	500	0.0070				
			2	A-4b	C	8.0	5.0	780.6	115	115	633	920	8	1,000	0	27	3	235	0.0090				
			3	A-1-b	G	10.5	2.5	778.1	130	130	1,083	1,245	33			34	4	115					
			4	A-6a	C	16.0	5.5	772.6	125	62.6	1,573	1,933	30	3,750	0	28	2	1,250	0.0048				
			5	A-6a	C	25.0	9.0	763.6	130	67.6	2,050	3,103	40	5,000	50	28	2	1,665	0.0043				
B-040-1-21	788.7	6.5	1	A-6a	C	3.0	3.0	785.7	115	115	173	345	8	1,000	0	26	3	235	0.0090				
			2	A-6b	C	5.5	2.5	783.2	115	115	489	633	8	1,000	0	25	3	235	0.0090				
			3	A-1-b	G	10.5	5.0	778.2	125	62.6	851	1,258	17			30	4	30					
			4	A-4a	C	20.0	9.5	768.7	125	62.6	1,305	2,445	30	3,750	0	30	2	1,250	0.0048				
B-041-0-19	789.5	13.7	1	A-6a	C	5.5	5.5	784.0	115	115	316	633	12	1,500	0	27	3	500	0.0070				
			2	A-2-4	G	10.5	5.0	779.0	125	125	945	1,258	16			30	4	35					
			3	A-6a	C	13.0	2.5	776.5	120	120	1,408	1,558	19	2,375	0	27	3	790	0.0058				
			4	A-4a	C	15.5	2.5	774.0	115	52.6	1,667	1,845	11	1,375	0	29	2	435	0.0075				
			5	A-6a	C	18.0	2.5	771.5	120	57.6	1,805	2,145	17	2,125	0	27	2	710	0.0062				
			6	A-4a	C	20.5	2.5	769.0	120	57.6	1,949	2,445	25	3,125	0	30	2	1,040	0.0050				
			7	A-2-4	G	23.0	2.5	766.5	130	67.6	2,105	2,770	42			35	4	90					
			8	A-4a	C	30.0	7.0	759.5	125	62.6	2,409	3,645	31	3,875	25	30	2	1,290	0.0047				
B-042-0-19	790.0	5.6	1	A-4a	C	3.0	3.0	787.0	120	120	180	360	18	2,250	0	29	3	750	0.0060				
			2	A-1-b	G	8.0	5.0	782.0	125	125	673	985	13			29	4	25					
			3	A-4b	C	9.5	1.5	780.5	120	57.6	878	1,165	13	1,625	0	28	2	540	0.0068				
			4	A-1-b	G	13.0	3.5	777.0	130	67.6	1,040	1,620	39			35	4	90					
			5	A-1-b	G	15.5	2.5	774.5	125	62.6	1,236	1,933	16			30	4	30					
			6	A-4a	C	18.0	2.5	772.0	115	52.6	1,380	2,220	7	875	0	28	1	165	0.0095				
			7	A-4a	C	25.0	7.0	765.0	120	57.6	1,648	3,060	17	2,125	0	29	2	710	0.0062				
B-043-0-19	793.2	11.0	1	A-2-4	G	5.5	5.5	787.7	125	125	344	688	15			30	4	35					
			2	A-2-4	G	10.5	5.0	782.7	130	130	1,013	1,338	44			36	4	185					
			3	A-4a	C	13.0	2.5	780.2	120	57.6	1,441	1,638	15	1,875	0	29	2	625	0.0065				
			4	A-4a	C	18.0	5.0	775.2	120	57.6	1,657	2,238	24	3,000	0	30	2	1,000	0.0050				
			5	A-3a	G	20.0	2.0	773.2	135	72.6	1,873	2,508	49			36	4	125					
			6	A-1-b	G	23.0	3.0	770.2	125	62.6	2,040	2,883	17			30	4	30					
			7	A-1-b	G	25.0	2.0	768.2	135	72.6	2,206	3,153	64			37	4	125					
			8	A-4a	C	30.0	5.0	763.2	130	67.6	2,448	3,803	48	5,000	50	30	2	1,665	0.0043				
B-044-0-19	799.4	18.0	1	A-6a	C	8.0	8.0	791.4	120	120	480	960	14	1,750	0	27	3	585	0.0067				
			2	A-6a	C	10.5	2.5	788.9	125	125	1,116	1,273	31	3,875	25	28	3	1,290	0.0047				
			3	A-3a	G	13.0	2.5	786.4	125	125	1,429	1,585	15			29	4	35					
			4	A-1-b	G	20.5	7.5	778.9	130	130	2,073	2,560	29			33	4	90					
			5	A-3a	G	30.0	9.5	769.4	125	62.6	2,701	3,748	22			30	4	35					

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-045-0-19	793.7	14.0	1	A-6a	C	8.0	8.0	785.7	125	125	500	1,000	26	3,250	0	28	3	1,085	0.0049				
			2	A-2-4	G	10.5	2.5	783.2	130	130	1,163	1,325	38			35	4	150					
			3	A-6b	C	15.5	5.0	778.2	130	130	1,650	1,975	41	5,000	50	27	3	1,665	0.0043				
			4	A-3a	G	20.5	5.0	773.2	125	62.6	2,038	2,600	17			29	4	30					
			5	A-4a	C	23.0	2.5	770.7	120	57.6	2,266	2,900	14	1,750	0	29	2	585	0.0067				
			6	A-4a	C	30.0	7.0	763.7	125	62.6	2,558	3,775	32	4,000	25	30	2	1,335	0.0047				
B-046-0-20	805.8	29.0	1	A-6a	C	5.5	5.5	800.3	120	120	330	660	15	1,875	0	27	3	625	0.0065				
			2	A-6b	C	12.0	6.5	793.8	120	120	1,050	1,440	13	1,625	0	26	3	540	0.0068				
			3	A-2-4	G	18.0	6.0	787.8	125	125	1,815	2,190	25			32	4	65					
			4	A-4a	C	23.0	5.0	782.8	120	120	2,490	2,790	25	3,125	0	30	3	1,040	0.0050				
			5	A-1-b	G	27.0	4.0	778.8	130	130	3,050	3,310	27			32	4	65					
			6	A-2-6	G	33.0	6.0	772.8	130	67.6	3,638	4,090	28			32	4	60					
			7	A-4a	C	42.0	9.0	763.8	120	57.6	4,100	5,170	25	3,125	0	30	2	1,040	0.0050				
			8	A-6b	C	47.0	5.0	758.8	125	62.6	4,515	5,795	36	4,500	25	27	2	1,500	0.0045				
			9	A-4a	C	55.0	8.0	750.8	130	67.6	4,942	6,835	40	5,000	50	30	2	1,665	0.0043				
B-047-0-19	794.9	14.5	1	A-1-b	G	5.5	5.5	789.4	125	125	344	688	20			31	4	50					
			2	A-4a	C	10.5	5.0	784.4	115	115	975	1,263	11	1,375	0	29	3	435	0.0075				
			3	A-1-b	G	20.5	10.0	774.4	125	62.6	1,825	2,513	20			31	4	35					
			4	A-3a	G	23.0	2.5	771.9	130	67.6	2,223	2,838	32			32	4	60					
			5	A-4a	C	30.0	7.0	764.9	125	62.6	2,526	3,713	30	3,750	0	30	2	1,250	0.0048				
B-070-0-19	796.6	13.5	1	A-4a	C	10.5	10.5	786.1	120	120	630	1,260	14	1,750	0	29	3	585	0.0067				
			2	A-2-4	G	13.0	2.5	783.6	125	125	1,416	1,573	24			32	4	65					
			3	A-2-6	G	21.0	8.0	775.6	125	62.6	1,854	2,573	24			31	4	50					
			4	A-3a	G	23.0	2.0	773.6	125	62.6	2,167	2,823	24			31	4	50					
			5	A-1-a	G	28.0	5.0	768.6	135	72.6	2,411	3,498	50			38	4	125					
			6	A-4a	C	47.0	19.0	749.6	125	62.6	3,187	5,873	31	3,875	25	30	2	1,290	0.0047				
			7	A-4a	C	62.0	15.0	734.6	130	67.6	4,289	7,823	95	5,000	100	30	2	1,665	0.0043				
			8	A-4a	C	67.0	5.0	729.6	125	62.6	4,953	8,448	33	4,125	25	30	2	1,375	0.0046				
			9	A-6b	C	75.0	8.0	721.6	125	62.6	5,360	9,448	27	3,375	0	27	2	1,125	0.0049				
B-071-0-19	820.7	34.0	1	A-6b	C	8.0	8.0	812.7	120	120	480	960	19	2,375	0	26	3	790	0.0058				
			2	A-6b	C	10.5	2.5	810.2	125	125	1,116	1,273	32	4,000	25	27	3	1,335	0.0047				
			3	A-6b	C	18.0	7.5	802.7	120	120	1,723	2,173	23	2,875	0	26	3	960	0.0052				
			4	A-6b	C	23.5	5.5	797.2	130	130	2,530	2,888	45	5,625	50	27	3	1,875	0.0041				
			5	A-6a	C	27.0	3.5	793.7	130	130	3,115	3,343	51	6,375	100	28	3	2,125	0.0039				
			6	A-6a	C	32.0	5.0	788.7	125	125	3,655	3,968	29	3,625	0	28	3	1,210	0.0048				
			7	A-6a	C	37.0	5.0	783.7	125	62.6	4,249	4,593	34	4,250	25	28	2	1,415	0.0046				
			8	A-2-4	G	52.0	15.0	768.7	130	67.6	4,912	6,543	36			34	4	75					
			9	A-6b	C	62.0	10.0	758.7	120	57.6	5,707	7,743	22	2,750	0	26	2	915	0.0053				
			10	A-6b	C	75.0	13.0	745.7	130	67.6	6,435	9,433	45	5,625	50	27	2	1,875	0.0041				

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-072-0-19	820.8	38.7	1	A-6a	C	5.5	5.5	815.3	125	125	344	688	26	3,250	0	28	3	1,085	0.0049				
			2	A-6a	C	20.5	15.0	800.3	120	120	1,588	2,488	20	2,500	0	27	3	835	0.0057				
			3	A-6a	C	23.0	2.5	797.8	130	130	2,650	2,813	62	7,750	100	28	3	2,585	0.0034				
			4	A-6a	C	27.5	4.5	793.3	125	125	3,094	3,375	29	3,625	0	28	3	1,210	0.0048				
			5	A-6a	C	31.5	4.0	789.3	125	125	3,625	3,875	27	3,375	0	28	3	1,125	0.0049				
			6	A-2-4	G	37.0	5.5	783.8	125	125	4,219	4,563	17			30	4	35					
			7	A-1-b	G	47.0	10.0	773.8	130	67.6	5,007	5,863	31			33	4	60					
			8	A-2-4	G	52.0	5.0	768.8	135	72.6	5,526	6,538	67			37	4	125					
			9	A-6a	C	57.0	5.0	763.8	130	67.6	5,877	7,188	45	5,625	50	28	2	1,875	0.0041				
			10	A-4a	C	62.0	5.0	758.8	120	57.6	6,190	7,788	24	3,000	0	30	2	1,000	0.0050				
			11	A-2-4	G	75.0	13.0	745.8	135	72.6	6,805	9,543	100			37	4	125					
B-073-0-19	822.7	17.5	1	A-6b	C	5.5	5.5	817.2	120	120	330	660	16	2,000	0	26	3	665	0.0063				
			2	A-6a	C	15.5	10.0	807.2	120	120	1,260	1,860	22	2,750	0	27	3	915	0.0053				
			3	A-6a	C	23.0	7.5	799.7	120	57.6	2,201	2,760	13	1,625	0	27	2	540	0.0068				
			4	A-2-6	G	28.0	5.0	794.7	130	67.6	2,586	3,410	44			35	4	105					
			5	A-6a	C	30.0	2.0	792.7	120	57.6	2,812	3,650	13	1,625	0	27	2	540	0.0068				
			6	A-6a	C	37.0	7.0	785.7	125	62.6	3,089	4,525	38	4,750	25	28	2	1,585	0.0044				
			7	A-6a	C	47.0	10.0	775.7	130	67.6	3,646	5,825	61	7,625	100	28	2	2,540	0.0035				
			8	A-6a	C	62.0	15.0	760.7	130	67.6	4,491	7,775	48	6,000	50	28	2	2,000	0.0040				
			9	A-6a	C	70.0	8.0	752.7	130	67.6	5,269	8,815	40	5,000	50	28	2	1,665	0.0043				
			10	A-6a	C	75.0	5.0	747.7	130	67.6	5,708	9,465	87	8,000	100	28	2	2,665	0.0033				
B-074-0-19	820.4	44.0	1	A-6a	C	3.0	3.0	817.4	120	120	180	360	20	2,500	0	27	3	835	0.0057				
			2	A-2-4	G	5.5	2.5	814.9	135	135	529	698	62			37	4	225					
			3	A-2-6	G	8.0	2.5	812.4	120	120	848	998	11			28	4	25					
			4	A-6b	C	10.5	2.5	809.9	120	120	1,148	1,298	13	1,625	0	26	3	540	0.0068				
			5	A-4a	C	13.0	2.5	807.4	120	120	1,448	1,598	13	1,625	0	29	3	540	0.0068				
			6	A-4a	C	18.0	5.0	802.4	130	130	1,923	2,248	44	5,500	50	30	3	1,835	0.0042				
			7	A-4a	C	27.0	9.0	793.4	125	125	2,810	3,373	26	3,250	0	30	3	1,085	0.0049				
			8	A-6b	C	32.0	5.0	788.4	120	120	3,673	3,973	17	2,125	0	26	3	710	0.0062				
			9	A-6a	C	37.0	5.0	783.4	120	120	4,273	4,573	25	3,125	0	28	3	1,040	0.0050				
			10	A-6b	C	42.0	5.0	778.4	130	130	4,898	5,223	53	6,625	100	27	3	2,210	0.0038				
			11	A-4a	C	47.0	5.0	773.4	125	62.6	5,504	5,848	29	3,625	0	30	2	1,210	0.0048				
			12	A-4a	C	52.0	5.0	768.4	130	67.6	5,829	6,498	63	7,875	100	30	2	2,625	0.0034				
			13	A-4a	C	62.0	10.0	758.4	125	62.6	6,311	7,748	29	3,625	0	30	2	1,210	0.0048				
			14	A-6a	C	67.0	5.0	753.4	130	67.6	6,793	8,398	60	7,500	100	28	2	2,500	0.0035				
			15	A-4a	C	71.0	4.0	749.4	130	67.6	7,098	8,918	49	6,125	50	30	2	2,040	0.0040				
			16	A-4a	C	75.0	4.0	745.4	125	62.6	7,358	9,418	35	4,375	25	30	2	1,460	0.0045				

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-075-0-19	819.0	33.1	1	A-6a	C	3.0	3.0	816.0	115	115	173	345	11	1,375	0	27	3	435	0.0075				
			2	A-4a	C	10.5	7.5	808.5	115	115	776	1,208	10	1,250	0	29	3	365	0.0080				
			3	A-6a	C	18.0	7.5	801.0	120	120	1,658	2,108	17	2,125	0	27	3	710	0.0062				
			4	A-4a	C	20.5	2.5	798.5	120	120	2,258	2,408	20	2,500	0	29	3	835	0.0057				
			5	A-6a	C	32.0	11.5	787.0	120	120	3,098	3,788	23	2,875	0	27	3	960	0.0052				
			6	A-1-b	G	37.0	5.0	782.0	130	67.6	4,025	4,438	27			32	4	50					
			7	A-1-b	G	47.0	10.0	772.0	135	72.6	4,557	5,788	57			37	4	125					
			8	A-4a	C	57.0	10.0	762.0	120	57.6	5,208	6,988	18	2,250	0	29	2	750	0.0060				
			9	A-2-4	G	60.0	3.0	759.0	135	72.6	5,605	7,393	87			37	4	125					
B-076-0-19	823.2	29.0	1	A-6a	C	13.0	13.0	810.2	120	120	780	1,560	19	2,375	0	27	3	790	0.0058				
			2	A-6b	C	18.0	5.0	805.2	110	110	1,835	2,110	5	625	0	25	1	85	0.0125				
			3	A-6a	C	20.5	2.5	802.7	120	120	2,260	2,410	15	1,875	0	27	3	625	0.0065				
			4	A-6a	C	23.0	2.5	800.2	130	130	2,573	2,735	97	8,000	100	28	3	2,665	0.0033				
			5	A-2-4	G	27.0	4.0	796.2	125	125	2,985	3,235	25			32	4	65					
			6	A-2-4	G	32.0	5.0	791.2	130	67.6	3,529	3,885	34			34	4	75					
			7	A-4a	G	37.0	5.0	786.2	125	62.6	3,854	4,510	20			29	4	35					
			8	A-2-4	G	47.0	10.0	776.2	135	72.6	4,374	5,860	67			37	4	125					
			9	A-2-4	G	57.0	10.0	766.2	130	67.6	5,075	7,160	38			35	4	90					
			10	A-4a	C	75.0	18.0	748.2	130	67.6	6,021	9,500	43	5,375	50	30	2	1,790	0.0042				
B-077-0-19	820.6	36.5	1	A-6b	C	8.0	8.0	812.6	120	120	480	960	15	1,875	0	26	3	625	0.0065				
			2	A-6a	C	15.5	7.5	805.1	120	120	1,410	1,860	18	2,250	0	27	2	750	0.0060				
			3	A-6a	C	27.0	11.5	793.6	125	125	2,579	3,298	28	3,500	0	28	2	1,165	0.0048				
			4	A-6b	C	32.0	5.0	788.6	120	120	3,598	3,898	13	1,625	0	26	2	540	0.0068				
			5	A-2-4	G	37.0	5.0	783.6	125	125	4,210	4,523	21			31	4	35					
			6	A-2-4	G	42.0	5.0	778.6	135	72.6	4,673	5,198	100			37	4	125					
			7	A-1-b	G	52.0	10.0	768.6	125	62.6	5,167	6,448	25			32	4	50					
			8	A-4a	C	57.0	5.0	763.6	120	57.6	5,624	7,048	25	3,125	0	30	2	1,040	0.0050				
			9	A-4a	C	62.0	5.0	758.6	130	67.6	5,937	7,698	83	8,000	100	30	2	2,665	0.0033				
			10	A-2-4	G	68.0	6.0	752.6	130	67.6	6,309	8,478	28			33	4	60					
			11	A-6b	C	75.0	7.0	745.6	125	62.6	6,731	9,353	35	4,375	25	27	2	1,460	0.0045				
B-078-0-19	818.1	32.0	1	A-6a	C	8.0	8.0	810.1	120	120	480	960	15	1,875	0	27	3	625	0.0065				
			2	A-6b	C	10.5	2.5	807.6	120	120	1,110	1,260	15	1,875	0	26	3	625	0.0065				
			3	A-4a	C	20.5	10.0	797.6	120	120	1,860	2,460	25	3,125	0	30	3	1,040	0.0050				
			4	A-7-6	C	27.0	6.5	791.1	120	120	2,850	3,240	22	2,750	0	25	3	915	0.0053				
			5	A-6b	C	32.0	5.0	786.1	115	115	3,528	3,815	11	1,375	0	26	3	435	0.0075				
			6	A-1-b	G	42.0	10.0	776.1	130	67.6	4,153	5,115	26			32	4	50					
			7	A-1-b	G	47.0	5.0	771.1	135	72.6	4,673	5,790	48			37	4	125					
			8	A-4a	C	52.0	5.0	766.1	120	57.6	4,998	6,390	24	3,000	0	30	2	1,000	0.0050				
			9	A-4a	C	67.0	15.0	751.1	130	67.6	5,649	8,340	44	5,500	50	30	2	1,835	0.0042				
			10	A-6a	C	75.0	8.0	743.1	130	67.6	6,426	9,380	48	6,000	50	28	2	2,000	0.0040				

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-086-0-19	800.0	16.0	1	A-6a	C	5.5	5.5	794.5	130	130	358	715	49	6,125	50	28	3	2,040	0.0040				
			2	A-6b	C	8.0	2.5	792.0	125	125	871	1,028	28	3,500	0	27	3	1,165	0.0048				
			3	A-4a	C	10.5	2.5	789.5	120	120	1,178	1,328	14	1,750	0	29	3	585	0.0067				
			4	A-4a	C	13.0	2.5	787.0	125	125	1,484	1,640	33	4,125	25	30	3	1,375	0.0046				
			5	A-1-b	G	27.0	14.0	773.0	130	67.6	2,300	3,460	37			34	4	75					
			6	A-1-b	G	30.0	3.0	770.0	135	72.6	2,883	3,865	86			37	4	125					
B-087-0-19	822.7	48.5	1	A-6a	C	3.0	3.0	819.7	120	120	180	360	20	2,500	0	27	3	835	0.0057				
			2	A-6b	C	5.5	2.5	817.2	120	120	510	660	20	2,500	0	26	3	835	0.0057				
			3	A-6b	C	10.5	5.0	812.2	115	115	948	1,235	12	1,500	0	26	3	500	0.0070				
			4	A-6a	C	15.5	5.0	807.2	120	120	1,535	1,835	19	2,375	0	27	3	790	0.0058				
			5	A-6b	C	18.0	2.5	804.7	120	120	1,985	2,135	14	1,750	0	26	3	585	0.0067				
			6	A-4a	C	20.5	2.5	802.2	130	130	2,298	2,460	100	8,000	100	30	3	2,665	0.0033				
			7	A-1-b	G	23.0	2.5	799.7	125	125	2,616	2,773	25			32	4	65					
			8	A-1-b	G	27.0	4.0	795.7	135	135	3,043	3,313	100			37	4	225					
			9	A-1-a	G	31.0	4.0	791.7	135	135	3,583	3,853	100			38	4	225					
			10	A-6a	C	33.0	2.0	789.7	120	120	3,973	4,093	17	2,125	0	27	3	710	0.0062				
			11	A-4b	G	35.5	2.5	787.2	125	125	4,249	4,405	24			29	4	65					
			12	A-4a	C	48.0	12.5	774.7	125	125	5,186	5,968	34	4,250	25	30	3	1,415	0.0046				
			13	A-2-6	G	57.0	9.0	765.7	135	72.6	6,325	7,183	66			36	4	125					
			14	A-6b	C	62.0	5.0	760.7	130	67.6	6,821	7,833	42	5,250	50	27	2	1,750	0.0043				
			15	A-2-4	G	67.0	5.0	755.7	135	72.6	7,172	8,508	55			37	4	125					
			16	A-6b	C	70.0	3.0	752.7	130	67.6	7,455	8,898	55	6,875	100	27	2	2,290	0.0037				
B-088-0-19	817.4	26.0	1	A-6a	C	6.5	6.5	810.9	125	125	406	813	26	3,250	0	28	3	1,085	0.0049				
			2	A-3a	G	8.0	1.5	809.4	125	125	906	1,000	24			31	4	65					
			3	A-4a	C	18.0	10.0	799.4	115	115	1,575	2,150	10	1,250	0	29	3	365	0.0080				
			4	A-1-b	G	22.5	4.5	794.9	135	135	2,454	2,758	100			37	4	225					
			5	A-6a	C	27.0	4.5	790.4	120	120	3,028	3,298	17	2,125	0	27	3	710	0.0062				
			6	A-6a	C	31.0	4.0	786.4	125	62.6	3,360	3,798	26	3,250	0	28	2	1,085	0.0049				
			7	A-6b	C	33.0	2.0	784.4	120	57.6	3,543	4,038	22	2,750	0	26	2	915	0.0053				
			8	A-4a	C	38.0	5.0	779.4	125	62.6	3,757	4,663	26	3,250	0	30	2	1,085	0.0049				
			9	A-2-4	G	47.0	9.0	770.4	135	72.6	4,240	5,878	50			37	4	125					
			10	A-4b	C	52.0	5.0	765.4	125	62.6	4,724	6,503	29	3,625	0	29	2	1,210	0.0048				
			11	A-6b	C	55.0	3.0	762.4	125	62.6	4,974	6,878	32	4,000	25	27	2	1,335	0.0047				
B-089-0-19	804.6	31.0	1	A-6a	C	8.0	8.0	796.6	130	130	520	1,040	41	5,000	50	28	3	1,665	0.0043				
			2	A-6a	C	13.0	5.0	791.6	120	120	1,340	1,640	25	3,125	0	28	3	1,040	0.0050				
			3	A-6b	C	18.0	5.0	786.6	115	115	1,928	2,215	12	1,500	0	26	3	500	0.0070				
			4	A-4a	C	27.0	9.0	777.6	120	120	2,755	3,295	15	1,875	0	29	3	625	0.0065				
			5	A-4a	C	30.0	3.0	774.6	125	125	3,483	3,670	35	4,375	25	30	3	1,460	0.0045				

FRA-70-22.85
FRA-00070-23.919 Brice Road Bridge over I-70 WB-CD Ramp
Design Soil Parameters

Boring	Ground Elevation (ft msl)	D_w (ft)	Layer No.	Soil Class.	Material Type	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	γ (pcf)	γ' (pcf)	σ_v' (Midpoint) (psf)	σ_v (Bottom) (psf)	N_{60} (bpf)	S_u (psf)	c' (psf)	φ' (deg)	Strata	K (pci)	ε_{50}	Q_u (psi)	E_i (psi)	k_{rm}	RQD
B-007-0-65	793.4	10.3	1	A-2-4	G	6.5	6.5	786.9	130	130	423	845	43			36	4	185					
			2	A-1-a	G	9.0	2.5	784.4	130	130	1,008	1,170	31			34	4	90					
			3	A-1-a	G	19.0	10.0	774.4	135	72.6	1,614	2,520	71			38	4	125					
			4	A-6b	C	24.5	5.5	768.9	125	62.6	2,149	3,208	35	4,375	25	27	2	1,460	0.0045				
			5	A-4a	C	28.0	3.5	765.4	125	62.6	2,431	3,645	33	4,125	25	30	2	1,375	0.0046				
			6	A-4a	C	38.0	10.0	755.4	130	67.6	2,879	4,945	54	5,000	100	30	2	1,665	0.0043				
			7	A-4a	C	41.0	3.0	752.4	125	62.6	3,310	5,320	39	4,875	25	30	2	1,625	0.0044				
B-090-0-19	800.5	6.5	1	A-1-b	G	1.5	1.5	799.0	130	130	98	195	45			36	4	185					
			2	A-6a	C	10.0	8.5	790.5	120	120	705	1,215	18	2,250	0	27	3	750	0.0060				
B-091-0-19	798.0	10.5	1	A-6a	C	3.2	3.2	794.8	120	120	192	384	16	2,000	0	27	3	665	0.0063				
			2	A-6b	C	8.0	4.8	790.0	120	120	672	960	17	2,125	0	26	3	710	0.0062				
			3	A-2-4	G	15.0	7.0	783.0	125	62.6	1,335	1,835	20			31	4	35					
B-092-0-19	797.7	8.0	1	A-6a	C	3.5	3.5	794.2	120	120	210	420	20	2,500	0	27	3	835	0.0057				
			2	A-6b	C	5.5	2.0	792.2	120	120	540	660	15	1,875	0	26	3	625	0.0065				
			3	A-4a	C	8.0	2.5	789.7	120	120	810	960	24	3,000	0	30	3	1,000	0.0050				
			4	A-2-4	G	15.5	7.5	782.2	125	62.6	1,195	1,898	17			30	4	30					
B-094-0-19	803.3	4.0	1	A-4a	C	3.0	3.0	800.3	125	125	188	375	37	4,625	25	30	3	1,540	0.0045				
			2	A-4a	C	5.5	2.5	797.8	115	52.6	503	663	7	875	0	28	1	165	0.0095				
			3	A-7-6	C	10.0	4.5	793.3	120	57.6	699	1,203	14	1,750	0	25	2	585	0.0067				

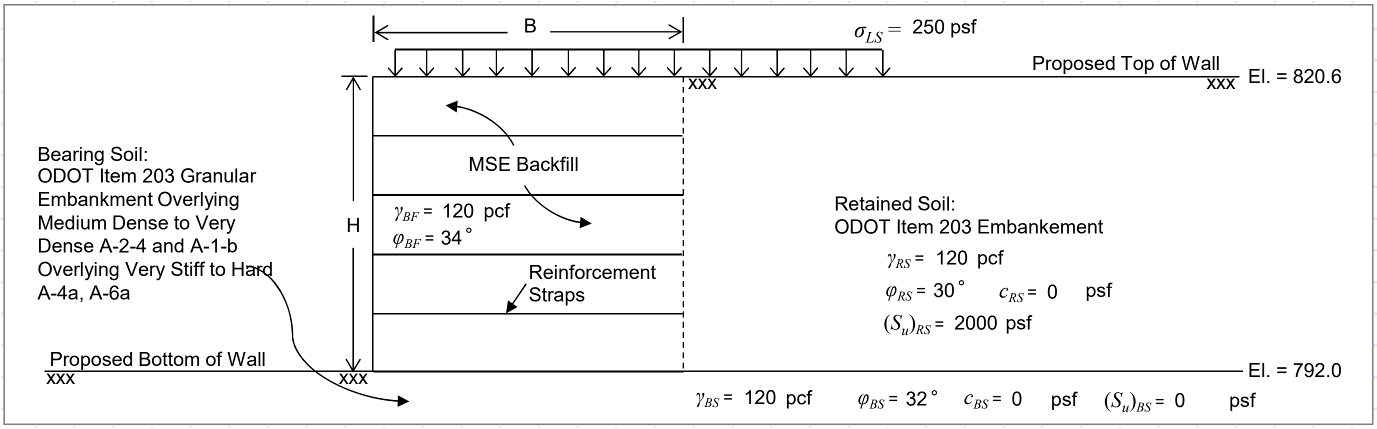
APPENDIX IX

MSE WALL CALCULATIONS

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	1	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 3 - Sta. 10+00 to 12+70 (BL Wall 3)

Retaining Wall 3 - Sta. 10+00 to 12+70 (BL Wall 3) - FRA-BRICE-04409 Fwd. Abut. - B-076-0-19 thru B-078-0-19 - Level Backfill - 28.6 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.6	ft
MSE Wall Width (Reinforcement Length), (B) =	20.0	ft
MSE Wall Length, (L) =	270	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	0	0	psf
Embedment Depth, (D_f) =	3.0		ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.9		ft

LRFD Load Factors

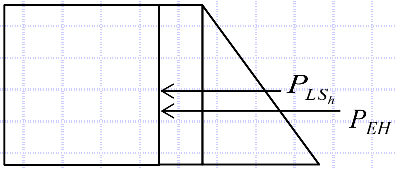
	EV	EH	LS	
Strength Ia	1.00	1.50	1.75	*(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)*
Strength Ib	1.35	1.50	1.75	
Service I	1.00	1.00	1.00	

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$

Sliding Force at Bottom of Wall (Top of Foundation Preparation):



$P_{EH} = \frac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(28.6 ft)²(0.297)(1.5) = 21.86 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(28.6 ft)(0.297)(1.75) = 3.72 kip/ft

P_H = 21.86 kip/ft + 3.72 kip/ft = 25.58 kip/ft

Sliding Force at Bottom of Foundation Preparation:

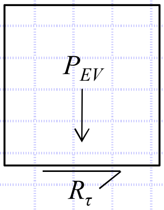
$P_{EH} = \frac{1}{2}\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(28.6 ft + 1 ft)²(0.297)(1.5) = 23.42 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(28.6 ft + 1 ft)(0.297)(1.75) = 3.85 kip/ft

P_H = 23.42 kip/ft + 3.85 kip/ft = 27.27 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(28.6 ft + 1 ft)(20.0 ft)(1.00) = 71.04 kip/ft

$\tan\delta = \left(\tan\varphi_{BS} \le \tan\varphi_{BF}\right) \longrightarrow$ tan(32) ≤ tan(34) ⟶ 0.62 ≤ 0.67 = 0.62

R_τ = (71.04 kip/ft)(0.62) = 44.04 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 27.27 kip/ft ≤ (44.04 kip/ft)(1.0) = 44.04 kip/ft ⟶ 27.27 kip/ft ≤ 44.04 kip/ft **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.6	ft
MSE Wall Width (Reinforcement Length), (B) =	20.0	ft
MSE Wall Length, (L) =	270	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	0	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	5.9 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

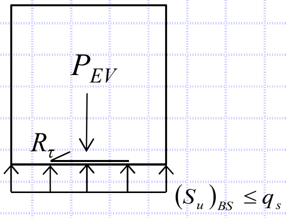
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

[1] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:



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

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

$q_s = \sigma_v / 2$ = (3.55 ksf) / 2 = 1.78 ksf

$\sigma_v = P_{EV} / B$ = (71.04 kip/ft) / (20 ft) = 3.55 ksf

R_τ = (N/A ksf ≤ 1.78 ksf)(20.0 ft) = N/A kip/ft

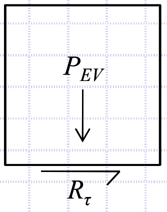
Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

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

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance:



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

$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(28.6 ft)(20.0 ft)(1.00) = 68.64 kip/ft

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

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

R_τ = (68.64 kip/ft)(0.67) = 45.99 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 25.58 kip/ft ≤ (45.99 kip/ft)(1.0) = 45.99 kip/ft ⟶ 25.58 kip/ft ≤ 45.99 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 3 - Sta. 10+00 to 12+70 (BL Wall 3)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.6	ft
MSE Wall Width (Reinforcement Length), (B) =	20.0	ft
MSE Wall Length, (L) =	270	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.9 ft		

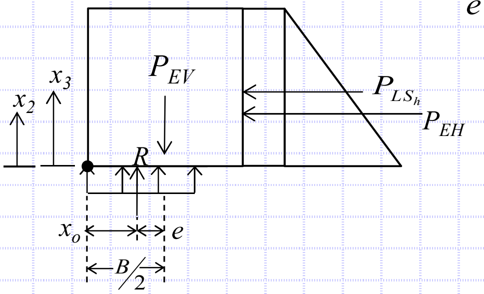
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



$$e = B/2 - x_o$$

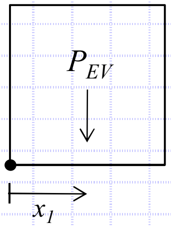
$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(686.4 kip·ft/ft - 261.52 kip·ft/ft) / (68.64 kip/ft)} = 6.19 \text{ ft}$$

M_{EV} = 686.40 kip·ft/ft
M_H = 261.52 kip·ft/ft
P_{EV} = 68.64 kip/ft

Defined below

$$e = \text{(20 ft)/2 - 6.19 ft} = 3.81 \text{ ft}$$

Resisting Moment, M_{EV}:



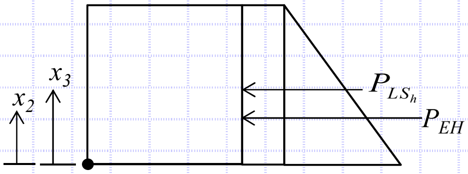
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(28.6 ft)(20.0 ft)(1.00)} = 68.64 \text{ kip/ft}$$

$$x_1 = B/2 = \text{(20.0 ft) / 2} = 10.00 \text{ ft}$$

$$M_{EV} = \text{(68.64 kip/ft)(10.00 ft)} = 686.40 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(28.6 ft)²(0.297)(1.5)} = 21.86 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(28.6 ft)(0.297)(1.75)} = 3.72 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(28.6 ft) / 3} = 9.53 \text{ ft}$$

$$x_3 = H/2 = \text{(28.6 ft) / 2} = 14.30 \text{ ft}$$

$$M_H = \text{(21.86 kip/ft)(9.53 ft) + (3.72 kip/ft)(14.30 ft)} = 261.52 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.81 ft < 6.67 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (20.0 ft) / 3 = 6.67 ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	4	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 3 - Sta. 10+00 to 12+70 (BL Wall 3)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.6	ft
MSE Wall Width (Reinforcement Length), (B) =	20.0	ft
MSE Wall Length, (L) =	270	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 ^{1}:

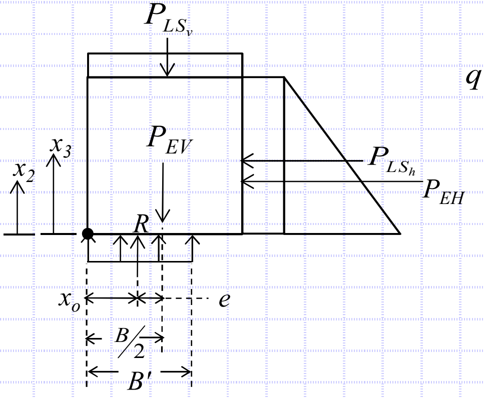
	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	5.9 ft		

LRFD Load Factors

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 20.0 ft - 2(2.58 ft) = 14.84 ft

$e = B/2 - x_o$ = (20.0 ft) / 2 - 7.42 ft = 2.58 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (1014.14 kip·ft/ft - 261.51 kip·ft/ft) / 101.41 kip/ft = 7.42 ft

q_{eq} = (101.41 kip/ft) / (14.84 ft) = 6.83 ksf

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

M_V = [(120 pcf)(28.6 ft)(20.0 ft)(1.35)](10 ft) + [(250 psf)(20.0 ft)(1.75)](10 ft) = 1014.14 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)(28.6 ft)²(0.297)(1.5)](9.53 ft) + [(250 psf)(28.6 ft)(0.297)(1.75)](14.3 ft) = 261.51 kip·ft/ft

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

P_V = (120 pcf)(28.6 ft)(20.0 ft)(1.35) + (250 psf)(20.0 ft)(1.75) = 101.41 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 36.77

N_c = 35.49
s_c = 1+(14.84 ft/270 ft)(23.18/35.49)
= 1.036
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 24.45

N_q = 23.18
s_q = 1.000
d_q = 1+2tan(32°)[1-sin(32°)]²tan⁻¹(3.0 ft/14.84 ft)
1.055
i_q = 1.000 (Assumed)
C_{wq} = 5.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 29.55

N_γ = 30.21
s_γ = 0.978
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 5.9 ft < 1.5(14.84 ft) + 3.0 ft = 0.633

q_n = (0 psf)(36.768) + (120 pcf)(3.0 ft)(24.455)(1.000) + ½(120 pcf)(14.8 ft)(29.545)(0.633) = 25.46 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ → 6.83 ksf ≤ (25.46 ksf)(0.65) = 16.55 ksf → 6.83 ksf ≤ 16.55 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	28.6	ft
MSE Wall Width (Reinforcement Length), (B) =	20.0	ft
MSE Wall Length, (L) =	270	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.9 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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.210

N_c = 5.140
s_c = 1+(14.84 ft/[(5)(270 ft)]) = 1.014
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/14.84 ft)
1.000
i_q = 1.000 (Assumed)
C_{wq} = 5.9 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)
$C_{w\gamma}$ = 5.9 ft < 1.5(14.84 ft) + 3.0 ft = 0.633

$q_n =$ (0 psf)(5.210) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(14.8 ft)(0.000)(0.633) = N/A ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ $\longrightarrow$ 6.83 ksf ≤ (N/A ksf)(0.65) = N/A ksf $\longrightarrow$ N/A

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 28.6 ft
MSE Wall Width (Reinforcement Length), (B) = 20.0 ft
MSE Wall Length, (L) = 270 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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	32	32	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	0	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.9 ft		

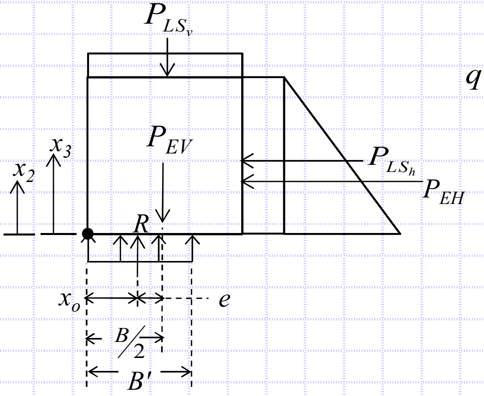
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



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

$$B' = B - 2e \;=\; 20.0 \text{ ft} - 2(2.3 \text{ ft}) \;=\; 15.40 \text{ ft}$$

$$e = B/2 - x_o \;=\; (20.0 \text{ ft}) / 2 - 7.7 \text{ ft} \;=\; 2.30 \text{ ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \;=\; (736.40 \text{ kip·ft/ft} - 169.28 \text{ kip·ft/ft}) / 73.64 \text{ kip/ft} \;=\; 7.7 \text{ ft}$$

$$q_{eq} = (73.64 \text{ kip/ft}) / (15.4 \text{ ft}) \;=\; 4.78 \text{ ksf}$$

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

$$M_V = [(120 \text{ pcf})(28.6 \text{ ft})(20.0 \text{ ft})(1.00)](10.0 \text{ ft}) + [(250 \text{ psf})(20.0 \text{ ft})(1.00)](10.0 \text{ ft}) \;=\; 736.40 \text{ kip·ft/ft}$$

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

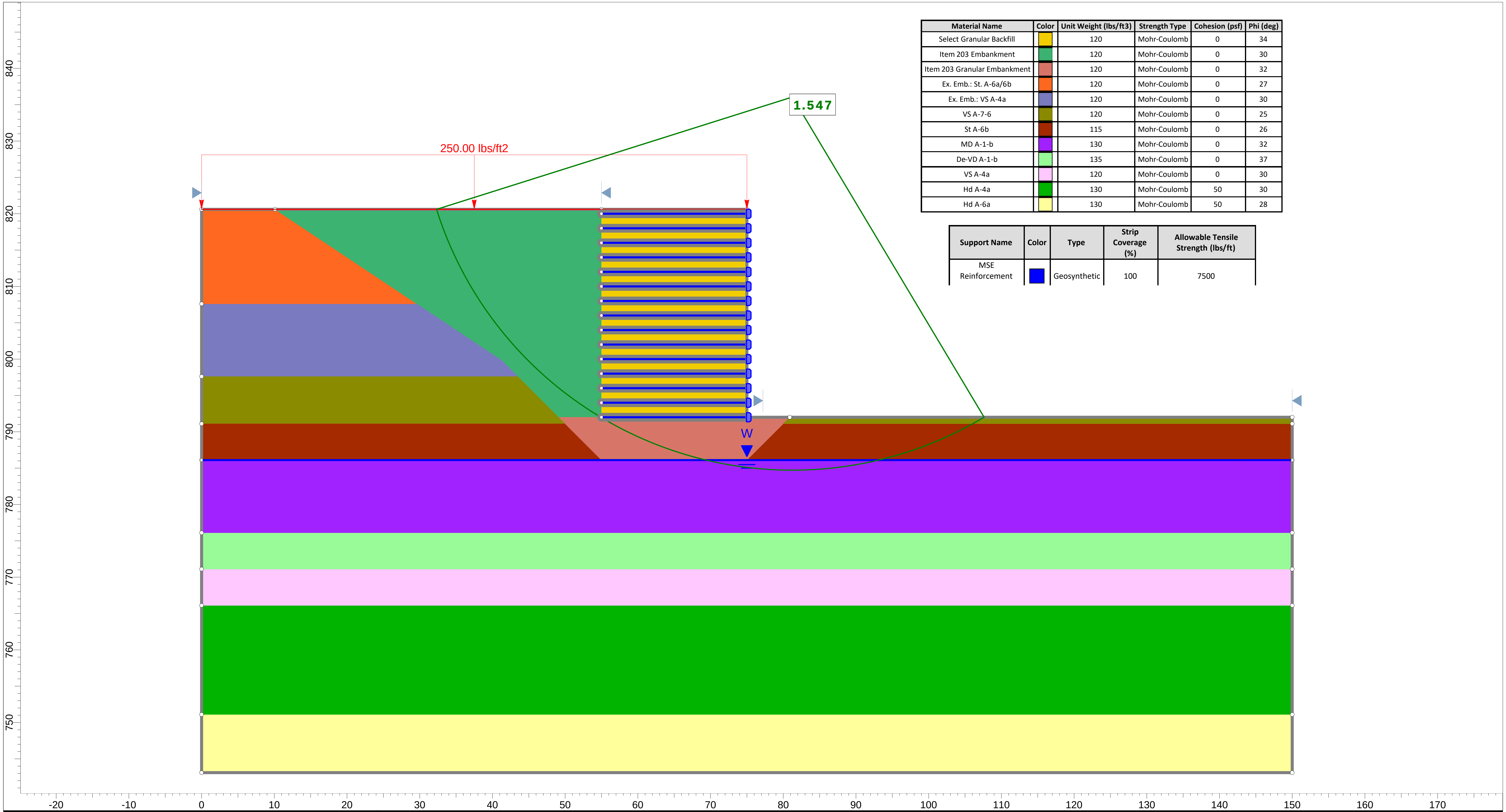
$$M_H = [\tfrac{1}{2}(120 \text{ pcf})(28.6 \text{ ft})^2(0.297)(1.00)](9.53 \text{ ft}) + [(250 \text{ psf})(28.6 \text{ ft})(0.297)(1.00)](14.3 \text{ ft}) \;=\; 169.28 \text{ kip·ft/ft}$$

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

$$P_V = (120 \text{ pcf})(28.6 \text{ ft})(20.0 \text{ ft})(1.00) + (250 \text{ psf})(20.0 \text{ ft})(1.00) \;=\; 73.64 \text{ kip/ft}$$

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 3	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Item 203 Granular Embankment	🟥	120	Mohr-Coulomb	0	32
Ex. Emb.: St. A-6a/6b	🟧	120	Mohr-Coulomb	0	27
Ex. Emb.: VS A-4a	🟦	120	Mohr-Coulomb	0	30
VS A-7-6	🟫	120	Mohr-Coulomb	0	25
St A-6b	🟫	115	Mohr-Coulomb	0	26
MD A-1-b	🟪	130	Mohr-Coulomb	0	32
De-VD A-1-b	🟩	135	Mohr-Coulomb	0	37
VS A-4a	🟪	120	Mohr-Coulomb	0	30
Hd A-4a	🟩	130	Mohr-Coulomb	50	30
Hd A-6a	🟨	130	Mohr-Coulomb	50	28

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

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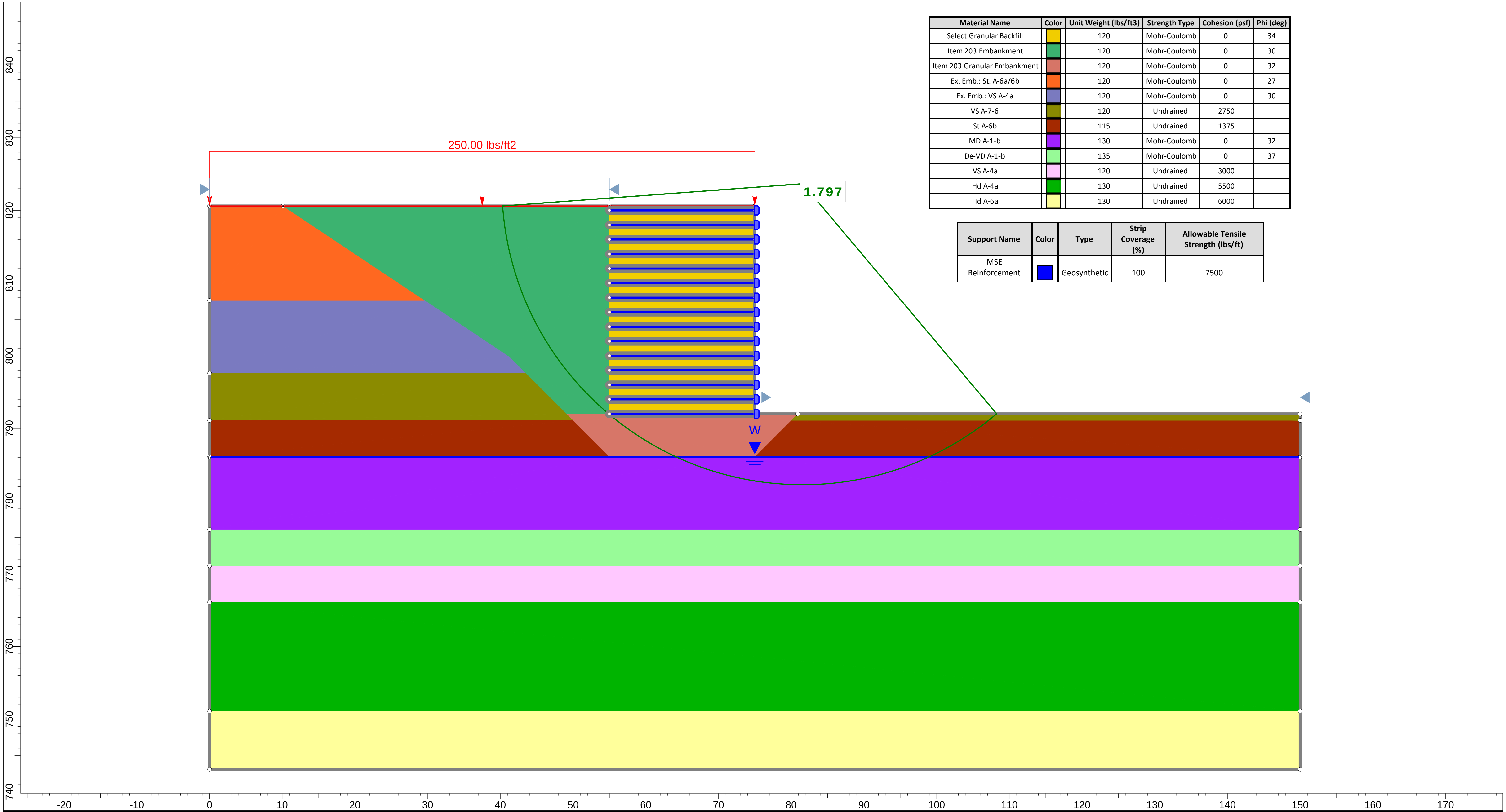
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 3 - FRA-BRICE-04409 Forward Abutment
Analysis Description	Global Stability - Sta. 10+00 to 12+70 (BL Wall 3) - B-076-0-19 through B-078-0-19 - Level Backfill - 28.6 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:150
Company	BRT
Date	4/1/2022, 3:14:35 PM
File Name	Wall 6 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Item 203 Granular Embankment	🟥	120	Mohr-Coulomb	0	32
Ex. Emb.: St. A-6a/6b	🟧	120	Mohr-Coulomb	0	27
Ex. Emb.: VS A-4a	🟦	120	Mohr-Coulomb	0	30
VS A-7-6	🟫	120	Undrained	2750	
St A-6b	🟫	115	Undrained	1375	
MD A-1-b	🟪	130	Mohr-Coulomb	0	32
De-VD A-1-b	🟩	135	Mohr-Coulomb	0	37
VS A-4a	🟪	120	Undrained	3000	
Hd A-4a	🟩	130	Undrained	5500	
Hd A-6a	🟨	130	Undrained	6000	

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

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

SLIDEINTERPRET 9.019

Project
FRA-70-22.85 FEF - Retaining Wall 3 - FRA-BRICE-04409 Forward Abutment

Analysis Description
Global Stability - Sta. 10+00 to 12+70 (BL Wall 3) - B-076-0-19 through B-078-0-19 - Level Backfill - 28.6 ft. Wall Height - Undrained - Circular

Drawn By Resource International, Inc.

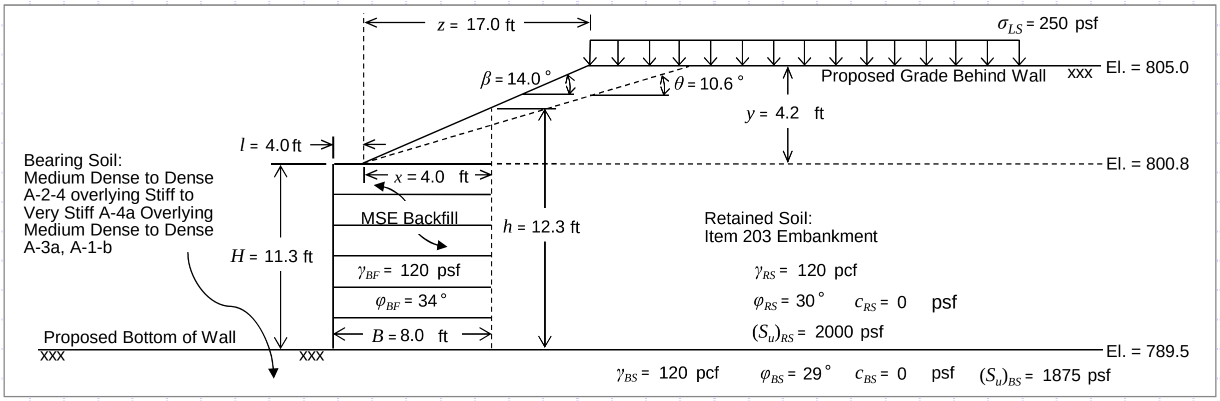
Scale 1:150

Company BRT

Date 4/1/2022, 3:14:35 PM

File Name Wall 6 - Global Stability.slmd

Retaining Wall 4B - Sta. 10+00 to 10+75 (BL Wall 4B) - B-043-0-19 - 4:1 Broken Backslope - 11.3 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	7.3 ft		

LRFD Load Factors

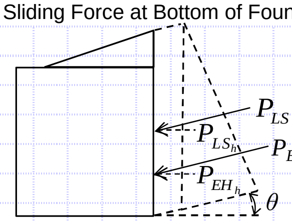
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

[1] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Sliding Force at Bottom of Foundation Preparation: $P_H = (P_{EH} + P_{LS})\cos\theta$



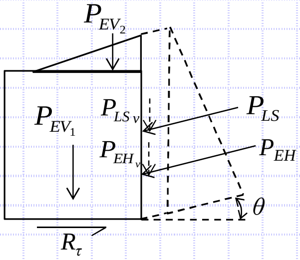
$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH} =$ ½(120 pcf)(12.3 ft + 1 ft)²(0.343)(1.50) = 5.46 kip/ft

$P_{EH} = \sigma_{LS}(h+1)K_a\gamma_{LS} =$ (250 psf)(12.3 ft + 1 ft)(0.343)(1.75) = 1.94 kip/ft

$P_H =$ (5.46 kip/ft + 1.94 kip/ft)cos(10.6°) = 7.27 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$P_{EV1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(11.3 ft + 1 ft)(8.0 ft)(1.00) = 11.81 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.00) = 0.24 kip/ft

$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH} =$ ½(120 pcf)(12.3 ft + 1 ft)²(0.343)(1.50) = 5.46 kip/ft

$\tan\delta = (\tan\varphi_{BS} \leq \tan\varphi_{BF}) \longrightarrow$ tan(30) ≤ tan(34) $\longrightarrow$ 0.58 ≤ 0.67 = 0.58

$R_\tau =$ [11.81 kip/ft + 0.24 kip/ft + (5.46 kip/ft)sin(10.6°)](0.58) = 7.57 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (At Bottom of Wall)

$P_H \leq R_\tau \cdot \phi_\tau \longrightarrow$ 7.27 kip/ft ≤ (7.57 kip/ft)(1.0) = 7.57 kip/ft $\longrightarrow$ 7.27 kip/ft ≤ 7.57 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 10+00 to 10+75 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	7.3 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)

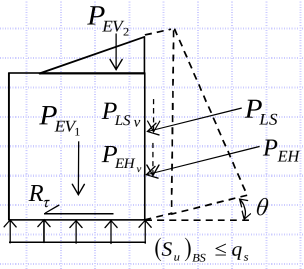
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



(Neglect P_{LS_v} for conservatism)

$$\left(S_u\right)_{BS} = \text{N/A} \quad \text{ksf}$$

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV} = \text{(120 pcf)(11.3 ft + 1 ft)(8.0 ft)(1.00)} = 11.81 \text{ kip/ft}$$

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

$$P_{EV_2} = \text{½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.00)} = 0.24 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$$

$$P_{EH} = \text{½(120 pcf)(12.3 ft + 1 ft)²(0.343)(1.50)} = 5.46 \text{ kip/ft}$$

$$P_V = \text{11.81 kip/ft + 0.24 kip/ft + (5.46 kip/ft)sin(10.6°)} = 13.05 \text{ kip/ft}$$

$$\sigma_v = \text{(13.05 kip/ft) / (8.0 ft)} = 1.63 \text{ ksf}$$

$$q_s = \text{(1.63 ksf) / 2} = 0.82 \text{ ksf}$$

$$R_\tau = \text{(N/A ksf ≤ 0.82 ksf)(8.0 ft)} = \text{N/A} \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

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

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_w) =	7.3 ft		

LRFD Load Factors

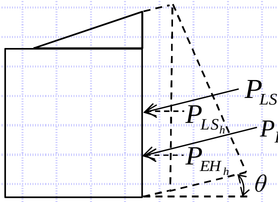
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Top of Foundation Preparation:



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

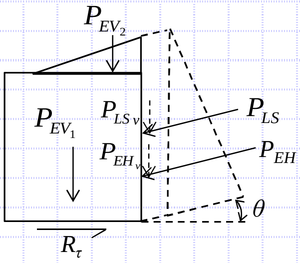
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad ½(120 \text{ pcf})(12.3 \text{ ft})²(0.343)(1.50) \quad = \quad 4.67 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \quad (250 \text{ psf})(12.3 \text{ ft})(0.343)(1.75) \quad = \quad 1.79 \text{ kip/ft}$$

$$P_H = \quad (4.67 \text{ kip/ft} + 1.79 \text{ kip/ft})\cos(10.6°) \quad = \quad 6.35 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad (120 \text{ pcf})(11.3 \text{ ft})(8.0 \text{ ft})(1.00) \quad = \quad 10.85 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} \quad = ½(120 \text{ pcf})(12.3 \text{ ft} - 11.3 \text{ ft})(8.0 \text{ ft} - 4.0 \text{ ft})(1.00) = \quad 0.24 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} \quad = \quad ½(120 \text{ pcf})(12.3 \text{ ft})²(0.343)(1.50) \quad = \quad 4.67 \text{ kip/ft}$$

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

$$R_\tau = \quad [10.85 \text{ kip/ft} + 0.24 \text{ kip/ft} + (4.67 \text{ kip/ft})\sin(10.6°)](0.67) \quad = \quad 8.01 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow 6.35 \text{ kip/ft} \le (8.01 \text{ kip/ft})(1.0) = 8.01 \text{ kip/ft} \longrightarrow 6.35 \text{ kip/ft} \le 8.01 \text{ kip/ft}$$ **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	7.3 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)

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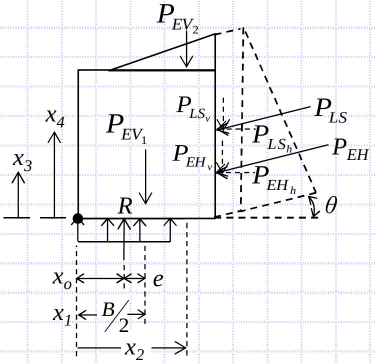
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (51.87 kip·ft/ft - 30 kip·ft/ft) / (11.95 kip/ft) = 1.83 ft

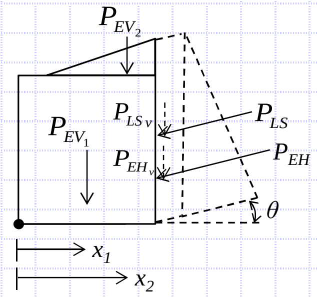
M_V = 51.87 kip·ft/ft
M_H = 30.00 kip·ft/ft
Defined below

P_V = $P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 10.85 kip/ft + 0.24 kip/ft + (4.67 kip/ft)sin(10.6°) = 11.95 kip/ft

$e =$ (8.0 ft/ 2) - 1.83 ft = 2.17 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)(11.3 ft)(8.0 ft)(1.00) = 10.85 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.00) = 0.24 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(12.3 ft)²(0.343)(1.50) = 4.67 kip/ft

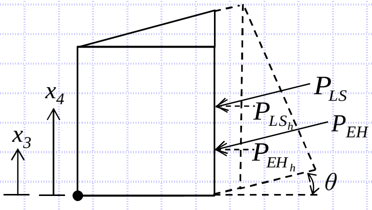
$x_1 = B/2$ = (8.0 ft) / 2 = 4.00 ft

$x_2 = l + \tfrac{2}{3}(B-l)$ = 4.0 ft + ⅔(8.0 ft - 4.0 ft) = 6.67 ft

M_V = (10.85 kip/ft)(4.00 ft) + (0.24 kip/ft)(6.67 ft) + (4.67 kip/ft)sin(10.6°)(8 ft) = 51.87 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(12.3 ft)²(0.343)(1.50) = 4.67 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(12.3 ft)(0.343)(1.75) = 1.85 kip/ft

$x_3 = h/3$ = (12.3 ft) / 3 = 4.10 ft

$x_4 = h/2$ = (12.3 ft) / 2 = 6.15 ft

M_H = (4.67 kip/ft)cos(10.6°)(4.10 ft) + (1.85 kip/ft)cos(10.6°)(6.15 ft) = 30.00 kip·ft/ft

---

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (8.0 ft) / 3 = 2.67 ft

$e < e_{\max} \longrightarrow$ 2.17 ft < 2.67 ft **OK**

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 10+00 to 10+75 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	7.3 ft		

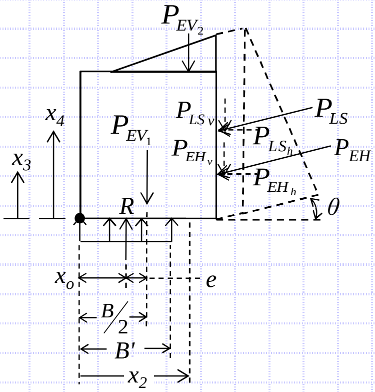
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 8.0 ft - 2(1.63 ft) = 4.74 ft

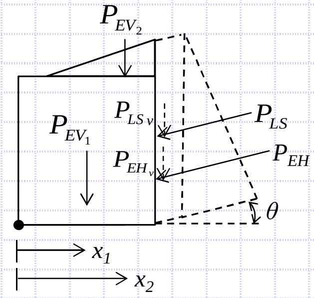
$e = B/2 - x_o$ = (8.0 ft / 2) - 2.37 ft = 1.63 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (67.57 kip·ft/ft - 30.00 kip·ft/ft) / 15.82 kip/ft = 2.37 ft

q_{eq} = (15.82 kip/ft) / (4.74 ft) = 3.34 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)(11.3 ft)(8.0 ft)(1.35) = 14.64 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.35) = 0.32 kip/ft

$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(12.3 ft)²(0.343)(1.50) = 4.67 kip/ft

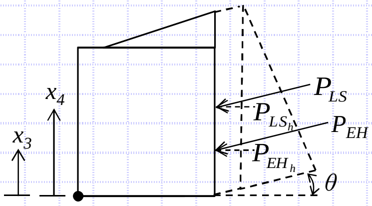
$x_1 = B/2$ = (8.0 ft) / 2 = 4.00 ft

$x_2 = l + \tfrac{2}{3}(B - l)$ = 4.0 ft + ⅔(8.0 ft - 4.0 ft) = 6.67 ft

M_V = (14.64 kip/ft)(4.00 ft) + (0.32 kip/ft)(6.7 ft) + (4.67 kip/ft)sin(10.6°)(8 ft) = 67.57 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(12.3 ft)²(0.343)(1.50) = 4.67 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(12.3 ft)(0.343)(1.75) = 1.85 kip/ft

$x_3 = h/3$ = (12.3 ft) / 3 = 4.10 ft

$x_4 = h/2$ = (12.3 ft) / 2 = 6.15 ft

M_H = (4.67 kip/ft)cos(10.6°)(4.10 ft) + (1.85 kip/ft)cos(10.6°)(6.15 ft) = 30.00 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 14.64 kip/ft + 0.32 kip/ft + (4.67 kip/ft)sin(10.6°) = 15.82 kip/ft

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 6 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 10+00 to 10+75 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties ^{1}:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
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. *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 27.86

N_c = 27.86
s_c = 1+(4.74 ft/352 ft)(16.44/27.86)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 19.7

N_q = 16.44
s_q = 1+(4.74 ft/352 ft)tan(29°) = 1.000
d_q = 1+2tan(29°)[1-sin(29°)]²tan⁻¹(3.0 ft/4.74 ft)
= 1.200
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 19.3

N_γ = 19.34
s_γ = 1-0.4(4.74 ft/352 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(4.74 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(27.86) + (120 pcf)(3.0 ft)(19.7)(1.0) + ½(120 pcf)(4.7 ft)(19.3)(0.5) = 9.85 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.34 ksf ≤ (9.85 ksf)(0.65) = 6.40 ksf ⟶ 3.34 ksf ≤ 6.40 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+(4.74 ft/[(5)(352 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/4.74 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(4.74 ft) + 3.0 ft = 0.500

$q_n =$ (1875 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(4.7 ft)(0.0)(0.5) = 10.00 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.34 ksf ≤ (10.00 ksf)(0.65) = 6.50 ksf ⟶ 3.34 ksf ≤ 6.50 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 7 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 10+00 to 10+75 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	11.3	ft
MSE Wall Width (Reinforcement Length), (B) =	8.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	12.3	ft
Retained Soil Backslope, (β) =	14	°
Effective Retained Soil Backslope, (θ) =	10.6	°
Distance from Toe to Top of Backslope, (z) =	17.0	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) =	0.343	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	30	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1875	0	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	7.3 ft		

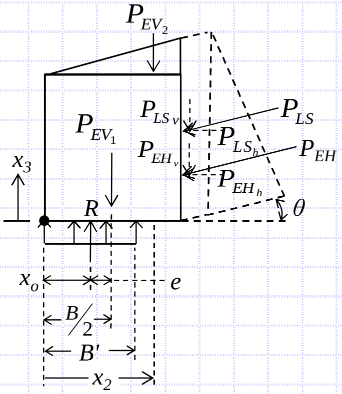
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 8.0 \text{ ft - } 2(1.37 \text{ ft}) \quad = \quad 5.26 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (8.0 \text{ ft / } 2) - 2.63 \text{ ft} \quad = \quad 1.37 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (49.57 \text{ kip·ft/ft - } 18.91 \text{ kip·ft/ft) / } 11.66 \text{ kip/ft} \quad = \quad 2.63 \quad \text{ft}$$

$$q_{eq} \quad = \quad (11.66 \text{ kip/ft) / } (5.26 \text{ ft}) \quad = \quad 2.22 \quad \text{ksf}$$

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

M_V = [(120 pcf)(11.3 ft)(8.0 ft)(1.00)][½(8.0 ft)] + [½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(8.0 ft - 4.0 ft)] = 49.57 kip·ft/ft
+ [½(120 pcf)(12.3 ft)²(0.343)(1.00)sin(10.6°)](8.0 ft)

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

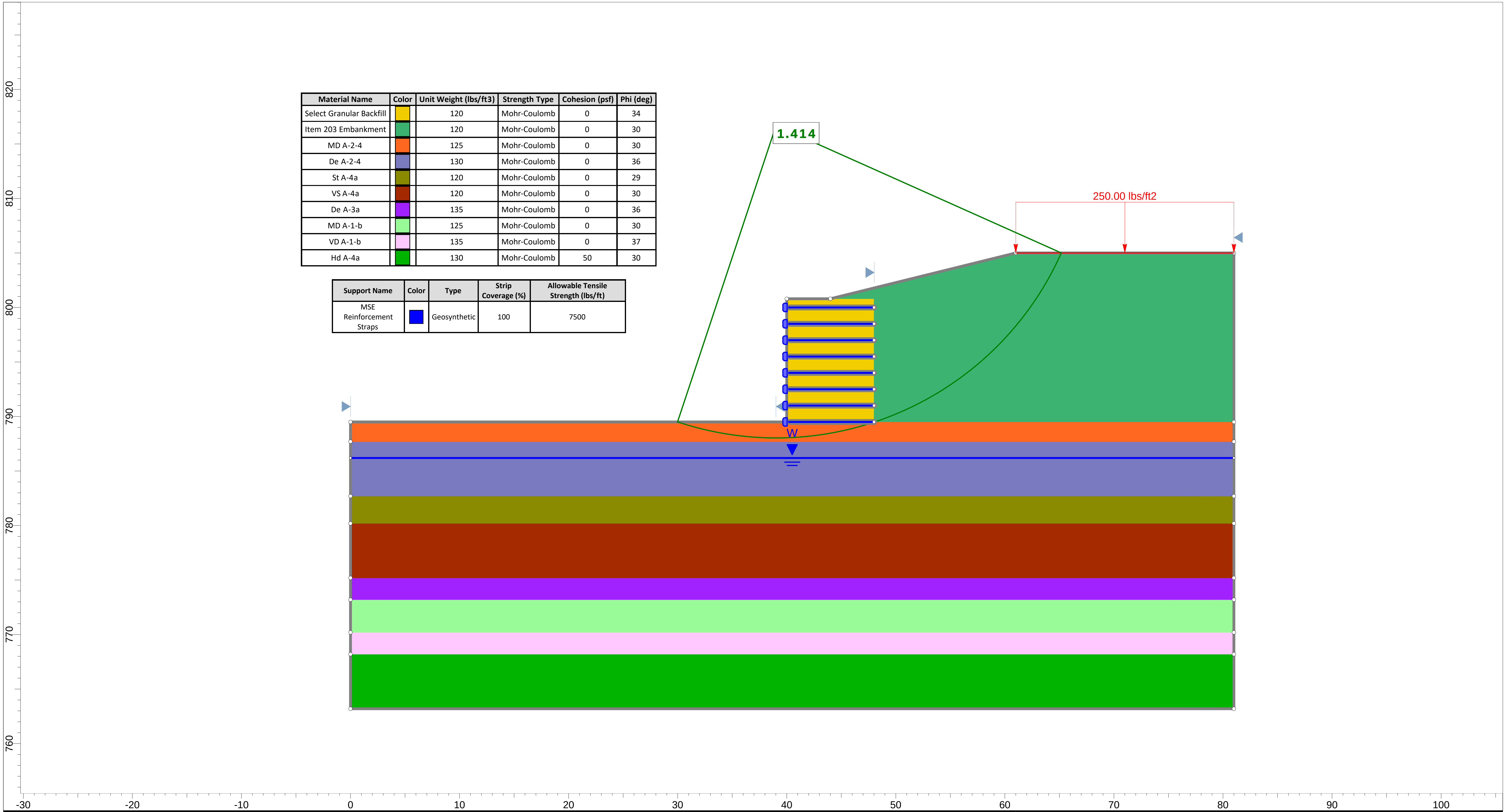
M_H = ½[(120 pcf)(12.3 ft)²(0.343)(1.00)cos(10.6°)](12.3 ft /3) = 18.91 kip·ft/ft
+ [(250 psf)(12.3 ft)(0.343)(1.00)cos(10.6°)](12.3 ft /2)

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

P_V = (120 pcf)(11.3 ft)(8.0 ft)(1.00) + ½(120 pcf)(12.3 ft - 11.3 ft)(8.0 ft - 4.0 ft)(1.00) = 11.66 kip/ft
+ ½(120 pcf)(12.3 ft)²(0.343)(1.00)sin(10.6°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 4B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
MD A-2-4	🟧	125	Mohr-Coulomb	0	30
De A-2-4	🟪	130	Mohr-Coulomb	0	36
St A-4a	🟫	120	Mohr-Coulomb	0	29
VS A-4a	🟥	120	Mohr-Coulomb	0	30
De A-3a	🟪	135	Mohr-Coulomb	0	36
MD A-1-b	🟩	125	Mohr-Coulomb	0	30
VD A-1-b	🟪	135	Mohr-Coulomb	0	37
Hd A-4a	🟩	130	Mohr-Coulomb	50	30

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

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

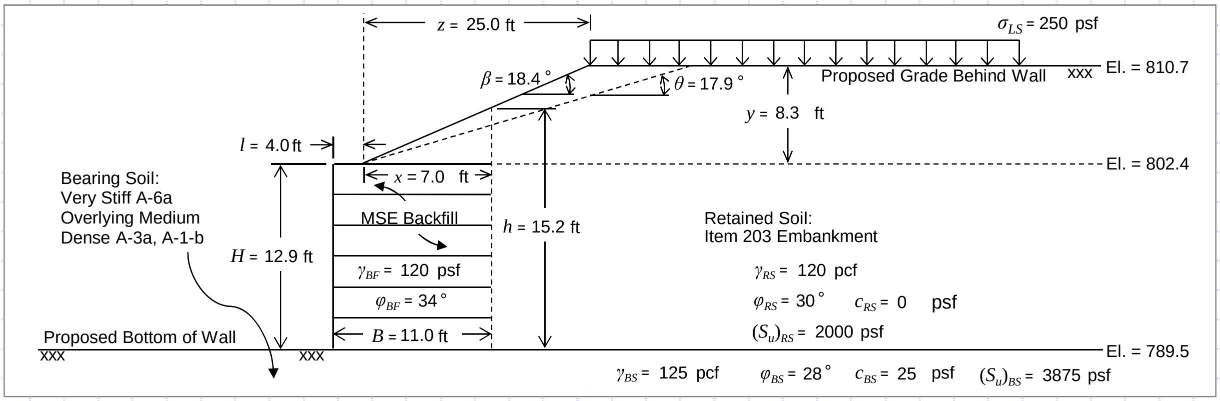
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 4B
Analysis Description	Global Stability - Sta. 10+00 to 10+75 (BL Wall 4B) - B-043-0-19 - 4:1 Broken Backslope - 11.3 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:100
Company	BRT
Date	4/1/2022, 5:31:14 PM
File Name	Wall 4B - Sta. 10+00 to 10+75 - Global Stability.slmd

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	1	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B)

Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B) - B-044-0-19 - 3:1 Broken Backslope - 12.9 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25	25	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	3875	3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120		pcf
MSE Backfill Friction Angle, (φ_{BF}) =	34		°
Embedment Depth, (D_f) =	3.0		ft
Depth to GW (Below Bot. of Wall), (D_w) =	8.1		ft

LRFD Load Factors

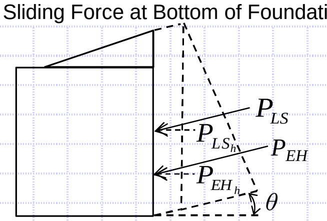
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Bottom of Foundation Preparation: $P_H = (P_{EH} + P_{LS})\cos\theta$



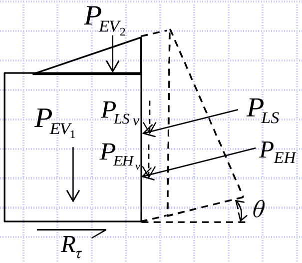
$P_{EH} = ½\gamma_{RS}(h+1)^2 K_a \gamma_{EH} =$ ½(120 pcf)(15.2 ft + 1 ft)²(0.394)(1.50) = 9.34 kip/ft

$P_{EH} = \sigma_{LS}(h+1) K_a \gamma_{LS} =$ (250 psf)(15.2 ft + 1 ft)(0.394)(1.75) = 2.65 kip/ft

$P_H =$ (9.34 kip/ft + 2.65 kip/ft)cos(17.9°) = 11.41 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$P_{EV\,1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(12.9 ft + 1 ft)(11.0 ft)(1.00) = 18.35 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00) = 0.98 kip/ft

$P_{EH} = ½\gamma_{RS}(h+1)^2 K_a \gamma_{EH} =$ ½(120 pcf)(15.2 ft + 1 ft)²(0.394)(1.50) = 9.34 kip/ft

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

$R_\tau =$ [18.35 kip/ft + 0.98 kip/ft + (9.34 kip/ft)sin(17.9°)](0.53) = 11.77 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (At Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 11.41 kip/ft ≤ (11.77 kip/ft)(1.0) = 11.77 kip/ft $\longrightarrow$ 11.41 kip/ft ≤ 11.77 kip/ft **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 2 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing		Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125		125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28		28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25		25	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3875		3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34	°		
Embedment Depth, (D_f) =	3.0	ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1	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

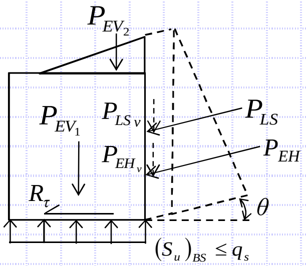
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

[1] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

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



(Neglect $P_{LS\,v}$ for conservatism)

$(S_u)_{BS}$ = 3.88 ksf

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$P_{EV1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(12.9 ft + 1 ft)(11.0 ft)(1.00) = 18.35 kip/ft

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

P_{EV_2} = ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00) = 0.98 kip/ft

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$$

P_{EH} = ½(120 pcf)(15.2 ft + 1 ft)²(0.394)(1.50) = 9.34 kip/ft

P_V = 18.35 kip/ft + 0.98 kip/ft + (9.34 kip/ft)sin(17.9°) = 22.2 kip/ft

σ_v = (22.2 kip/ft) / (11.0 ft) = 2.02 ksf

q_s = (2.02 ksf) / 2 = 1.01 ksf

R_τ = (3.88 ksf ≤ 1.01 ksf)(11.0 ft) = 42.63 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 11.41 kip/ft ≤ (42.63 kip/ft)(1.0) = 42.63 kip/ft ⟶ 11.41 kip/ft ≤ 42.63 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25	25	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3875	3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

LRFD Load Factors

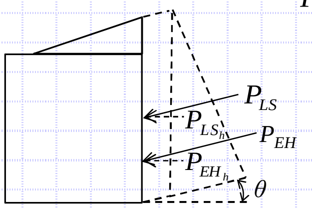
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Top of Foundation Preparation:



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

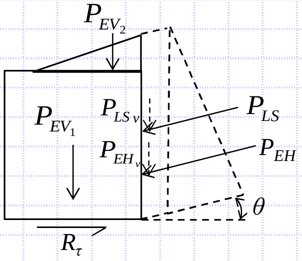
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(15.2 ft)(0.394)(1.75) = 2.49 kip/ft

P_H = (8.22 kip/ft + 2.49 kip/ft)cos(17.9°) = 10.19 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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)(11.0 ft)(1.00) = 17.03 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00) = 0.98 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

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

R_τ = [17.03 kip/ft + 0.98 kip/ft + (8.22 kip/ft)sin(17.9°)](0.67) = 13.76 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 10.19 kip/ft ≤ (13.76 kip/ft)(1.0) = 13.76 kip/ft ⟶ 10.19 kip/ft ≤ 13.76 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) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing		Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125		125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28		28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25		25	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3875		3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34	°		
Embedment Depth, (D_f) =	3.0	ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1	ft		

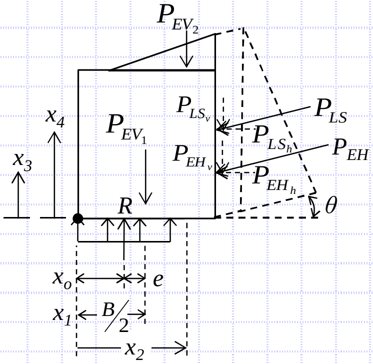
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = {}^{B}\!/_{2} - x_o$$

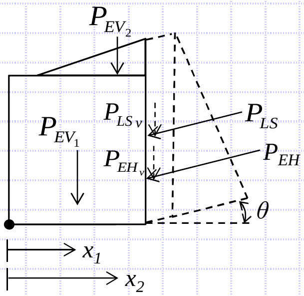
$$x_o = \frac{M_V - M_H}{P_V}$$ = (129.95 kip·ft/ft - 58.78 kip·ft/ft) / (20.54 kip/ft) = 3.46 ft

M_V = 129.95 kip·ft/ft
M_H = 58.78 kip·ft/ft
} Defined below
$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 17.03 kip/ft + 0.98 kip/ft + (8.22 kip/ft)sin(17.9°) = 20.54 kip/ft

$e =$ (11.0 ft/ 2) - 3.46 ft = 2.04 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)(12.9 ft)(11.0 ft)(1.00) = 17.03 kip/ft

$P_{EV_2} = {}^{1}\!/_{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00) = 0.98 kip/ft

$P_{EH} = {}^{1}\!/_{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

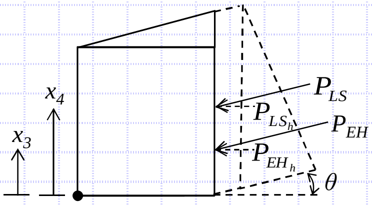
$x_1 = {}^{B}\!/_{2}$ = (11.0 ft) / 2 = 5.50 ft

$x_2 = l + {}^{2}\!/_{3}(B - l)$ = 4.0 ft + ⅔(11.0 ft - 4.0 ft) = 8.67 ft

M_V = (17.03 kip/ft)(5.50 ft) + (0.98 kip/ft)(8.67 ft) + (8.22 kip/ft)sin(17.9°)(11 ft) = 129.95 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = {}^{1}\!/_{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(15.2 ft)(0.394)(1.75) = 2.63 kip/ft

$x_3 = {}^{h}\!/_{3}$ = (15.2 ft) / 3 = 5.08 ft

$x_4 = {}^{h}\!/_{2}$ = (15.2 ft) / 2 = 7.61 ft

M_H = (8.22 kip/ft)cos(17.9°)(5.08 ft) + (2.63 kip/ft)cos(17.9°)(7.61 ft) = 58.78 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{\max} = {}^{B}\!/_{3} \longrightarrow e_{\max} =$ (11.0 ft) / 3 = 3.67 ft

$e < e_{\max} \longrightarrow$ 2.04 ft < 3.67 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25	25	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3875	3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

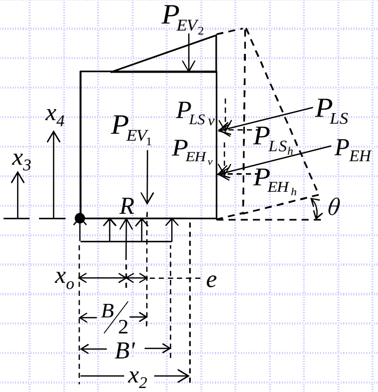
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

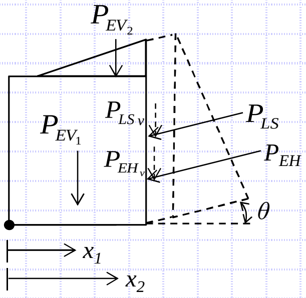
$B' = B - 2e$ = 11.0 ft - 2(1.52 ft) = 7.96 ft

$e = B/2 - x_o$ = (11.0 ft / 2) - 3.98 ft = 1.52 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (165.68 kip·ft/ft - 58.78 kip·ft/ft) / 26.84 kip/ft = 3.98 ft

q_{eq} = (26.84 kip/ft) / (7.96 ft) = 3.37 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)(11.0 ft)(1.35) = 22.99 kip/ft

$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.35) = 1.32 kip/ft

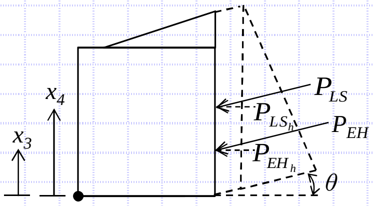
$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

$x_1 = B/2$ = (11.0 ft) / 2 = 5.50 ft

$x_2 = l + \tfrac{2}{3}(B-l)$ = 4.0 ft + ⅔(11.0 ft - 4.0 ft) = 8.67 ft

M_V = (22.99 kip/ft)(5.50 ft) + (1.32 kip/ft)(8.7 ft) + (8.22 kip/ft)sin(17.9°)(11 ft) = 165.68 kip·ft/ft

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



$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.394)(1.50) = 8.22 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(15.2 ft)(0.394)(1.75) = 2.63 kip/ft

$x_3 = h/3$ = (15.2 ft) / 3 = 5.08 ft

$x_4 = h/2$ = (15.2 ft) / 2 = 7.61 ft

M_H = (8.22 kip/ft)cos(17.9°)(5.08 ft) + (2.63 kip/ft)cos(17.9°)(7.61 ft) = 58.78 kip·ft/ft

Vertical Forces, P_V: $P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$

P_V = 22.99 kip/ft + 1.32 kip/ft + (8.22 kip/ft)sin(17.9°) = 26.84 kip/ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 12.9 ft
MSE Wall Width (Reinforcement Length), (B) = 11.0 ft
Distance from Wall Face to Toe of Backslope, (l) = 4.0 ft
MSE Wall Length, (L) = 352 ft
MSE Wall Effective Height, (h) = 15.2 ft
Retained Soil Backslope, (β) = 18.4 °
Effective Retained Soil Backslope, (θ) = 17.9 °
Distance from Toe to Top of Backslope, (z) = 25.0 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) = 0.394
Live Surcharge Load, (σ_{LS}) = 250 psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	125	125 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28 °
Bearing Soil Drained Cohesion, (c_{BS}) =	25	25 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3875	3875 psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf	
MSE Backfill Friction Angle, (φ_{BF}) =	34 °	
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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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+(7.96 ft/352 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+(7.96 ft/352 ft)tan(28°) = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/7.96 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(7.96 ft/352 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(7.96 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(25.8) + (125 pcf)(3.0 ft)(16.2)(1.0) + ½(125 pcf)(8.0 ft)(16.7)(0.5) = 10.23 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 3.37 ksf ≤ (10.23 ksf)(0.65) = 6.65 ksf ⟶ 3.37 ksf ≤ 6.65 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+(7.96 ft/[(5)(352 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/7.96 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(7.96 ft) + 3.0 ft = 0.500

$q_n =$ (3875 psf)(5.14) + (125 pcf)(3.0 ft)(1.0)(1.0) + ½(125 pcf)(8.0 ft)(0.0)(0.5) = 20.29 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 3.37 ksf ≤ (20.29 ksf)(0.65) = 13.19 ksf ⟶ 3.37 ksf ≤ 13.19 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 7 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 10+75 to 11+50 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	12.9	ft
MSE Wall Width (Reinforcement Length), (B) =	11.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	15.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	25.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	25	25	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3875	3875	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

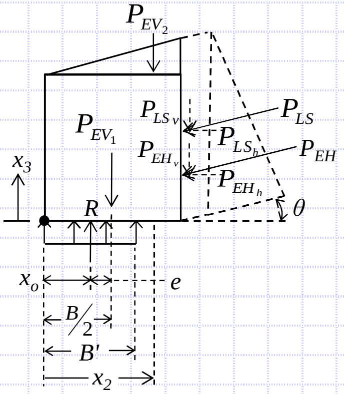
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



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

$$B' = B - 2e \quad = \quad 11.0\text{ ft - 2(1.27 ft)} \quad = \quad 8.46 \quad \text{ft}$$

$$e = \frac{B}{2} - x_o \quad = \quad (11.0\text{ ft / 2) - 4.23 ft} \quad = \quad 1.27 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (120.67\text{ kip·ft/ft - 37.35 kip·ft/ft) / 19.69 kip/ft} \quad = \quad 4.23 \quad \text{ft}$$

$$q_{eq} = \quad (19.69\text{ kip/ft) / (8.46 ft)} \quad = \quad 2.33 \quad \text{ksf}$$

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

M_V = [(120 pcf)(12.9 ft)(11.0 ft)(1.00)][½(11.0 ft)] + [½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(11.0 ft - 4.0 ft)] = 120.67 kip·ft/ft
+ [½(120 pcf)(15.2 ft)²(0.394)(1.00)sin(17.9°)](11.0 ft)

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

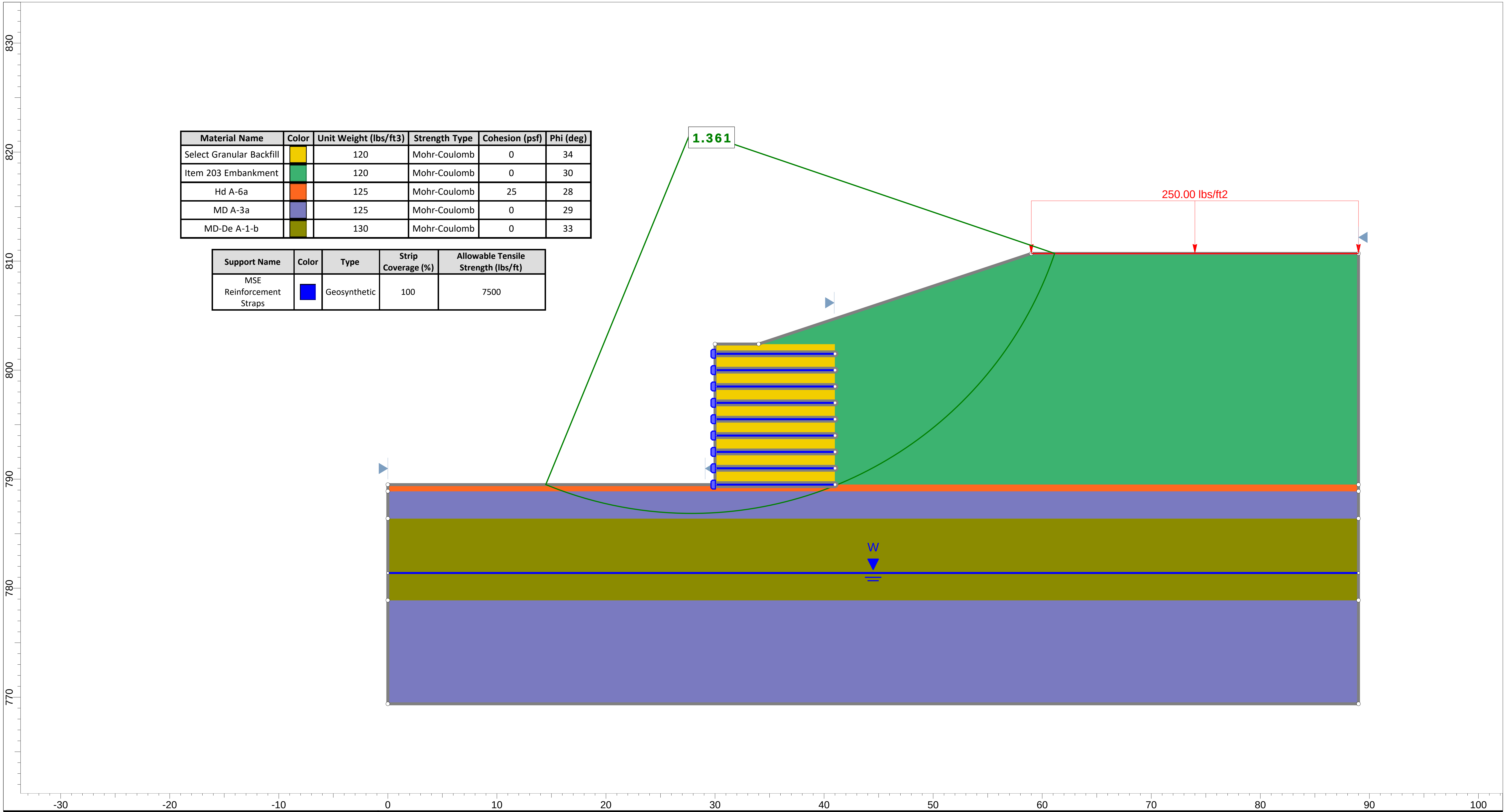
M_H = ½[(120 pcf)(15.2 ft)²(0.394)(1.00)cos(17.9°)](15.2 ft /3) = 37.35 kip·ft/ft
+ [(250 psf)(15.2 ft)(0.394)(1.00)cos(17.9°)](15.2 ft /2)

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

P_V = (120 pcf)(12.9 ft)(11.0 ft)(1.00) + ½(120 pcf)(15.2 ft - 12.9 ft)(11.0 ft - 4.0 ft)(1.00) = 19.69 kip/ft
+ ½(120 pcf)(15.2 ft)²(0.394)(1.00)sin(17.9°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 4B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Hd A-6a	🟧	125	Mohr-Coulomb	25	28
MD A-3a	🟪	125	Mohr-Coulomb	0	29
MD-De A-1-b	🟫	130	Mohr-Coulomb	0	33

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

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

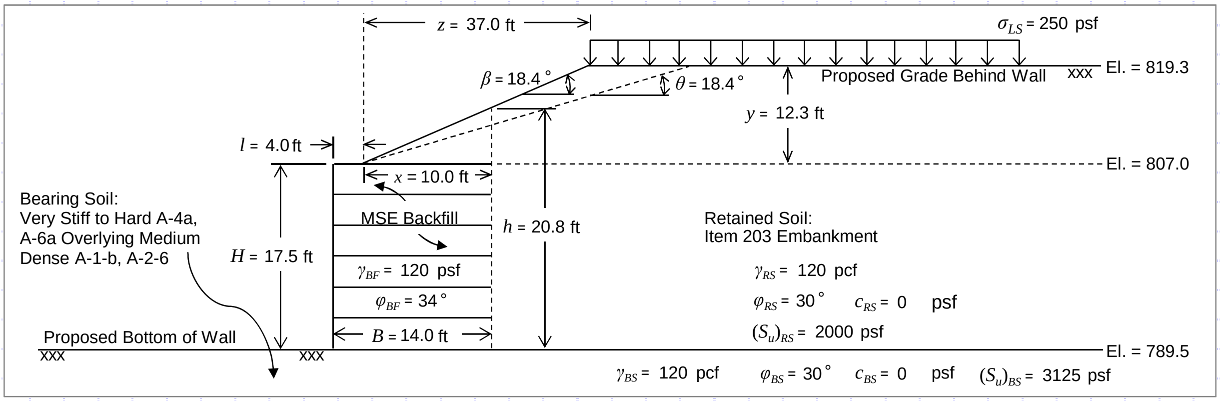
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 4B		
Analysis Description	Global Stability - Sta. 10+75 to 11+50 (BL Wall 4B) - B-044-0-19 - 3:1 Broken Backslope - 12.9 ft. Wall Height - Drained - Circular		
Drawn By	Resource International, Inc.	*Scale*	1:100
Company	BRT		
Date	4/1/2022, 5:56:50 PM	*File Name*	Wall 4B - Sta. 10+75 to 11+50 - Global Stability.slmd

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	1	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B)

Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B) - B-046-0-19 and B-073-0-19 - 3:1 Broken Backslope - 17.5 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_w) =	8.1 ft		

LRFD Load Factors

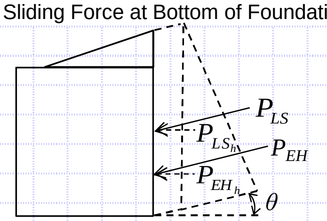
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Bottom of Foundation Preparation: $P_H = \left(P_{EH} + P_{LS}\right)\cos\theta$



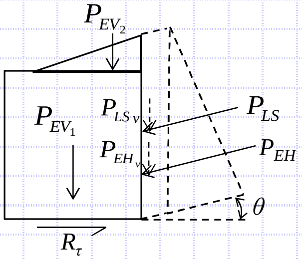
$P_{EH} = ½\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$ = ½(120 pcf)(20.8 ft + 1 ft)²(0.398)(1.50) = 17.06 kip/ft

$P_{EH} = \sigma_{LS}(h+1) K_a \gamma_{LS}$ = (250 psf)(20.8 ft + 1 ft)(0.398)(1.75) = 3.61 kip/ft

P_H = (17.06 kip/ft + 3.61 kip/ft)cos(18.4°) = 19.61 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(17.5 ft + 1 ft)(14.0 ft)(1.00) = 31.08 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00) = 2.00 kip/ft

$P_{EH} = ½\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$ = ½(120 pcf)(20.8 ft + 1 ft)²(0.398)(1.50) = 17.06 kip/ft

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

R_τ = [31.08 kip/ft + 2.00 kip/ft + (17.06 kip/ft)sin(18.4°)](0.53) = 20.39 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (At Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 19.61 kip/ft ≤ (20.39 kip/ft)(1.0) = 20.39 kip/ft $\longrightarrow$ 19.61 kip/ft ≤ 20.39 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) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 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

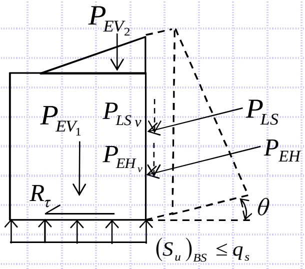
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

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



(Neglect P_{LS_V} for conservatism)

$(S_u)_{BS}$ = 4.53 ksf

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(17.5 ft + 1 ft)(14.0 ft)(1.00) = 31.08 kip/ft

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

P_{EV_2} = ½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00) = 2 kip/ft

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$$

P_{EH} = ½(120 pcf)(20.8 ft + 1 ft)²(0.398)(1.50) = 17.06 kip/ft

P_V = 31.08 kip/ft + 2 kip/ft + (17.06 kip/ft)sin(18.4°) = 38.46 kip/ft

σ_V = (38.46 kip/ft) / (14.0 ft) = 2.75 ksf

q_s = (2.75 ksf) / 2 = 1.38 ksf

R_τ = (4.53 ksf ≤ 1.38 ksf)(14.0 ft) = 63.35 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 19.61 kip/ft ≤ (63.35 kip/ft)(1.0) = 63.35 kip/ft $\longrightarrow$ 19.61 kip/ft ≤ 63.35 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

LRFD Load Factors

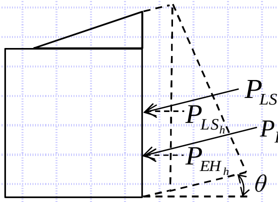
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Top of Foundation Preparation:



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

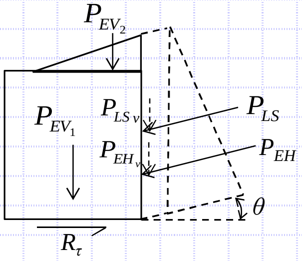
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} = \quad \text{½(120 pcf)(20.8 ft)²(0.398)(1.50)} \quad = \quad 15.54 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \quad \text{(250 psf)(20.8 ft)(0.398)(1.75)} \quad = \quad 3.44 \text{ kip/ft}$$

$$P_H = \quad \text{(15.54 kip/ft + 3.44 kip/ft)cos(18.4°)} \quad = \quad 18.01 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad \text{(120 pcf)(17.5 ft)(14.0 ft)(1.00)} \quad = \quad 29.4 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} \quad = \text{½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00)} = \quad 2 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} \quad = \quad \text{½(120 pcf)(20.8 ft)²(0.398)(1.50)} \quad = \quad 15.54 \text{ kip/ft}$$

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

$$R_\tau = \quad \text{[29.40 kip/ft + 2.00 kip/ft + (15.54 kip/ft)sin(18.4°)](0.67)} \quad = \quad 24.32 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow \text{18.01 kip/ft ≤ (24.32 kip/ft)(1.0) = 24.32 kip/ft} \longrightarrow \text{18.01 kip/ft ≤ 24.32 kip/ft}$$

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) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

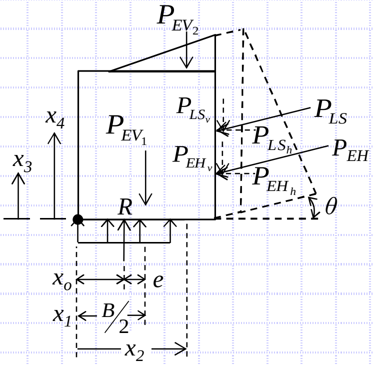
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (295.81 kip·ft/ft - 138.19 kip·ft/ft) / (36.31 kip/ft) = 4.34 ft

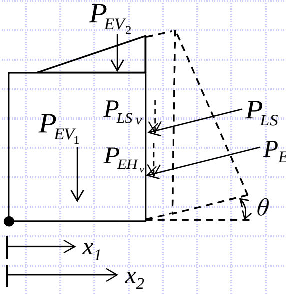
M_V = 295.81 kip·ft/ft
M_H = 138.19 kip·ft/ft
} Defined below

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 29.4 kip/ft + 2 kip/ft + (15.54 kip/ft)sin(18.4°) = 36.31 kip/ft

$e =$ (14.0 ft/ 2) - 4.34 ft = 2.66 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)(17.5 ft)(14.0 ft)(1.00) = 29.40 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00) = 2 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH}$ = ½(120 pcf)(20.8 ft)²(0.398)(1.50) = 15.54 kip/ft

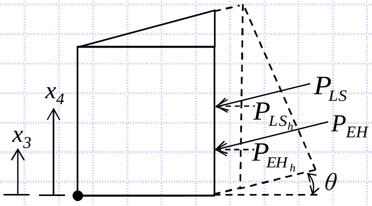
$x_1 = B/2$ = (14.0 ft) / 2 = 7.00 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(14.0 ft - 4.0 ft) = 10.67 ft

M_V = (29.4 kip/ft)(7.00 ft) + (2 kip/ft)(10.67 ft) + (15.54 kip/ft)sin(18.4°)(14 ft) = 295.81 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)(20.8 ft)²(0.398)(1.50) = 15.54 kip/ft

$P_{LS} = \sigma_{LS}hK_a\gamma_{LS}$ = (250 psf)(20.8 ft)(0.398)(1.75) = 3.63 kip/ft

$x_3 = h/3$ = (20.8 ft) / 3 = 6.94 ft

$x_4 = h/2$ = (20.8 ft) / 2 = 10.41 ft

M_H = (15.54 kip/ft)cos(18.4°)(6.94 ft) + (3.63 kip/ft)cos(18.4°)(10.41 ft) = 138.19 kip·ft/ft

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (14.0 ft) / 3 = 4.67 ft

$e < e_{\max} \longrightarrow$ 2.66 ft < 4.67 ft **OK**

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 5 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

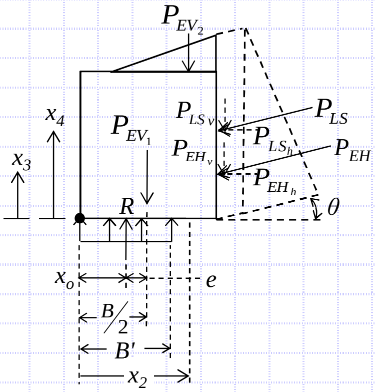
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 14.0 ft - 2(1.99 ft) = 10.02 ft

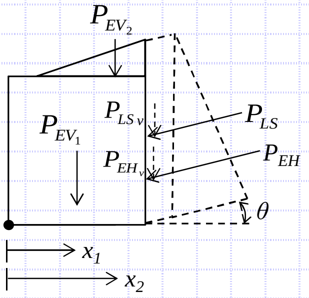
$e = B\big/2 - x_o$ = (14.0 ft / 2) - 5.01 ft = 1.99 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (375.20 kip·ft/ft - 138.19 kip·ft/ft) / 47.29 kip/ft = 5.01 ft

q_{eq} = (47.29 kip/ft) / (10.02 ft) = 4.72 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)(17.5 ft)(14.0 ft)(1.35) = 39.69 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.35) = 2.69 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(20.8 ft)²(0.398)(1.50) = 15.54 kip/ft

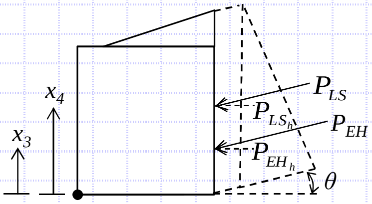
$x_1 = B\big/2$ = (14.0 ft) / 2 = 7.00 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 4.0 ft + ⅔(14.0 ft - 4.0 ft) = 10.67 ft

M_V = (39.69 kip/ft)(7.00 ft) + (2.69 kip/ft)(10.7 ft) + (15.54 kip/ft)sin(18.4°)(14 ft) = 375.20 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)(20.8 ft)²(0.398)(1.50) = 15.54 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(20.8 ft)(0.398)(1.75) = 3.63 kip/ft

$x_3 = h\big/3$ = (20.8 ft) / 3 = 6.94 ft

$x_4 = h\big/2$ = (20.8 ft) / 2 = 10.41 ft

M_H = (15.54 kip/ft)cos(18.4°)(6.94 ft) + (3.63 kip/ft)cos(18.4°)(10.41 ft) = 138.19 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 39.69 kip/ft + 2.69 kip/ft + (15.54 kip/ft)sin(18.4°) = 47.29 kip/ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters		
MSE Wall Height, (H) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 30.14

N_c = 30.14
s_c = 1+(10.02 ft/352 ft)(18.4/30.14)
= 1.000
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 20.2

N_q = 18.40
s_q = 1+(10.02 ft/352 ft)tan(30°) = 1.000
d_q = 1+2tan(30°)[1-sin(30°)]²tan⁻¹(3.0 ft/10.02 ft)
= 1.100
i_q = 1.000 (Assumed)
C_{wq} = 7.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 22.4

N_γ = 22.40
s_γ = 1-0.4(10.02 ft/352 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(10.02 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(30.14) + (120 pcf)(3.0 ft)(20.2)(1.0) + ½(120 pcf)(10.0 ft)(22.4)(0.5) = 14.02 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.72 ksf ≤ (14.02 ksf)(0.65) = 9.11 ksf ⟶ 4.72 ksf ≤ 9.11 ksf **OK**

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

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.140

N_c = 5.140
s_c = 1+(10.02 ft/[(5)(352 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/10.02 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(10.02 ft) + 3.0 ft = 0.500

$q_n =$ (3125 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(10.0 ft)(0.0)(0.5) = 16.42 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.72 ksf ≤ (16.42 ksf)(0.65) = 10.67 ksf ⟶ 4.72 ksf ≤ 10.67 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 7 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 11+50 to 13+52 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.5	ft
MSE Wall Width (Reinforcement Length), (B) =	14.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	352	ft
MSE Wall Effective Height, (h) =	20.8	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	18.4	°
Distance from Toe to Top of Backslope, (z) =	37.0	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) =	0.398	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties ^{1}:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	25	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	4525	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	8.1 ft		

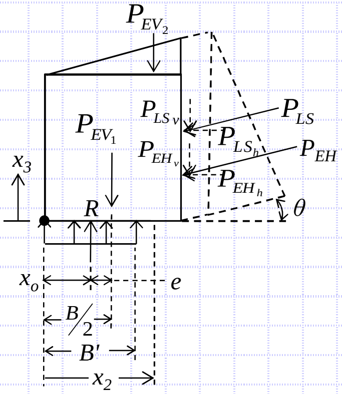
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e = 14.0\text{ ft} - 2(1.69\text{ ft}) = 10.62 \text{ ft}$$

$$e = B \big/ 2 - x_o = (14.0\text{ ft} / 2) - 5.31\text{ ft} = 1.69 \text{ ft}$$

$$x_o = \frac{M_V - M_H}{P_V} = (272.86\text{ kip·ft/ft} - 88.71\text{ kip·ft/ft}) / 34.67\text{ kip/ft} = 5.31 \text{ ft}$$

$$q_{eq} = (34.67\text{ kip/ft}) / (10.62\text{ ft}) = 3.26 \text{ ksf}$$

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

M_V = [(120 pcf)(17.5 ft)(14.0 ft)(1.00)][½(14.0 ft)] + [½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(14.0 ft - 4.0 ft)] = 272.86 kip·ft/ft
+ [½(120 pcf)(20.8 ft)²(0.398)(1.00)sin(18.4°)](14.0 ft)

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

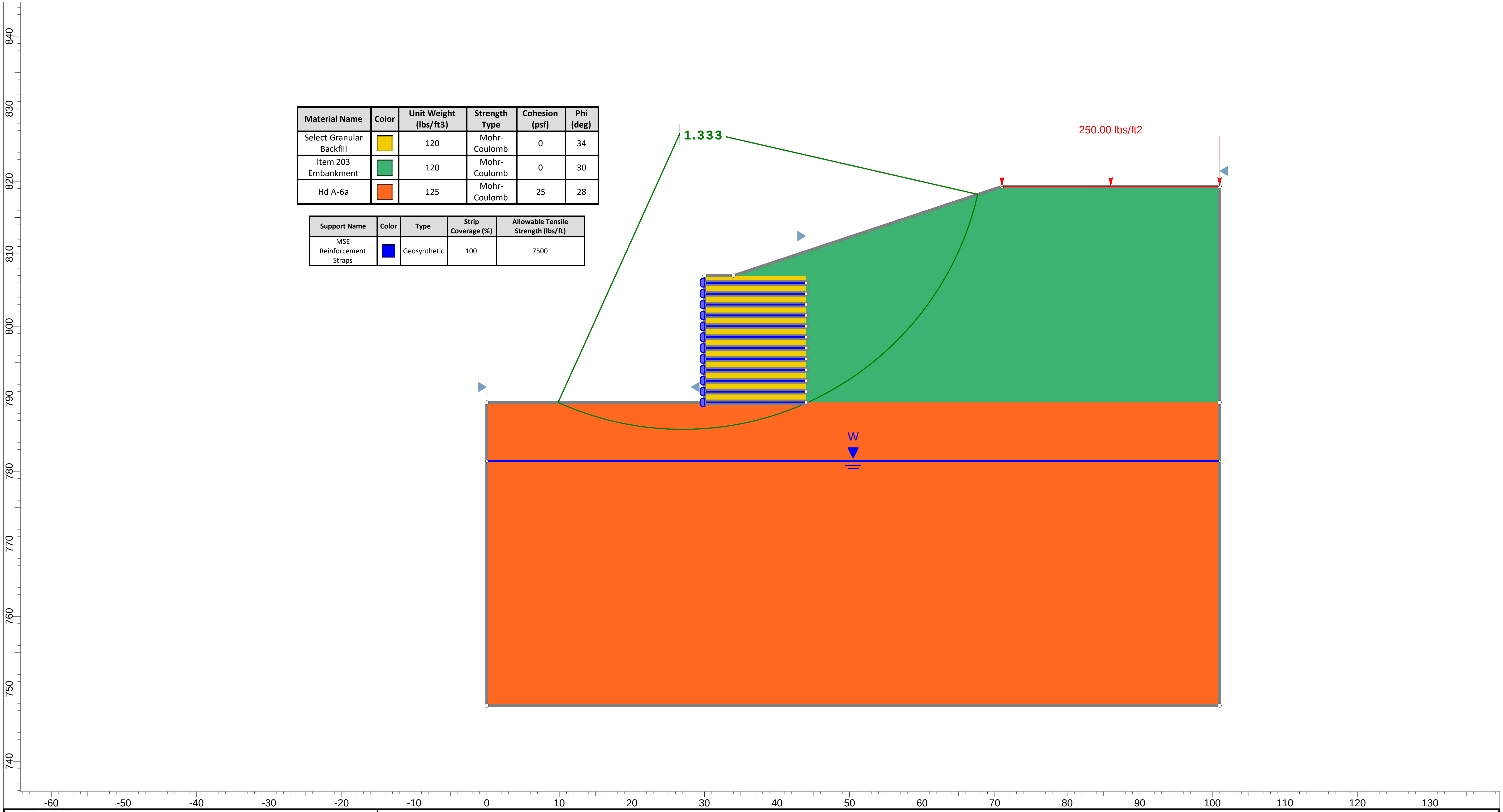
M_H = ½[(120 pcf)(20.8 ft)²(0.398)(1.00)cos(18.4°)](20.8 ft /3) = 88.71 kip·ft/ft
+ [(250 psf)(20.8 ft)(0.398)(1.00)cos(18.4°)](20.8 ft /2)

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

P_V = (120 pcf)(17.5 ft)(14.0 ft)(1.00) + ½(120 pcf)(20.8 ft - 17.5 ft)(14.0 ft - 4.0 ft)(1.00) = 34.67 kip/ft
+ ½(120 pcf)(20.8 ft)²(0.398)(1.00)sin(18.4°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 4B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Hd A-6a	🟧	125	Mohr-Coulomb	25	28

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

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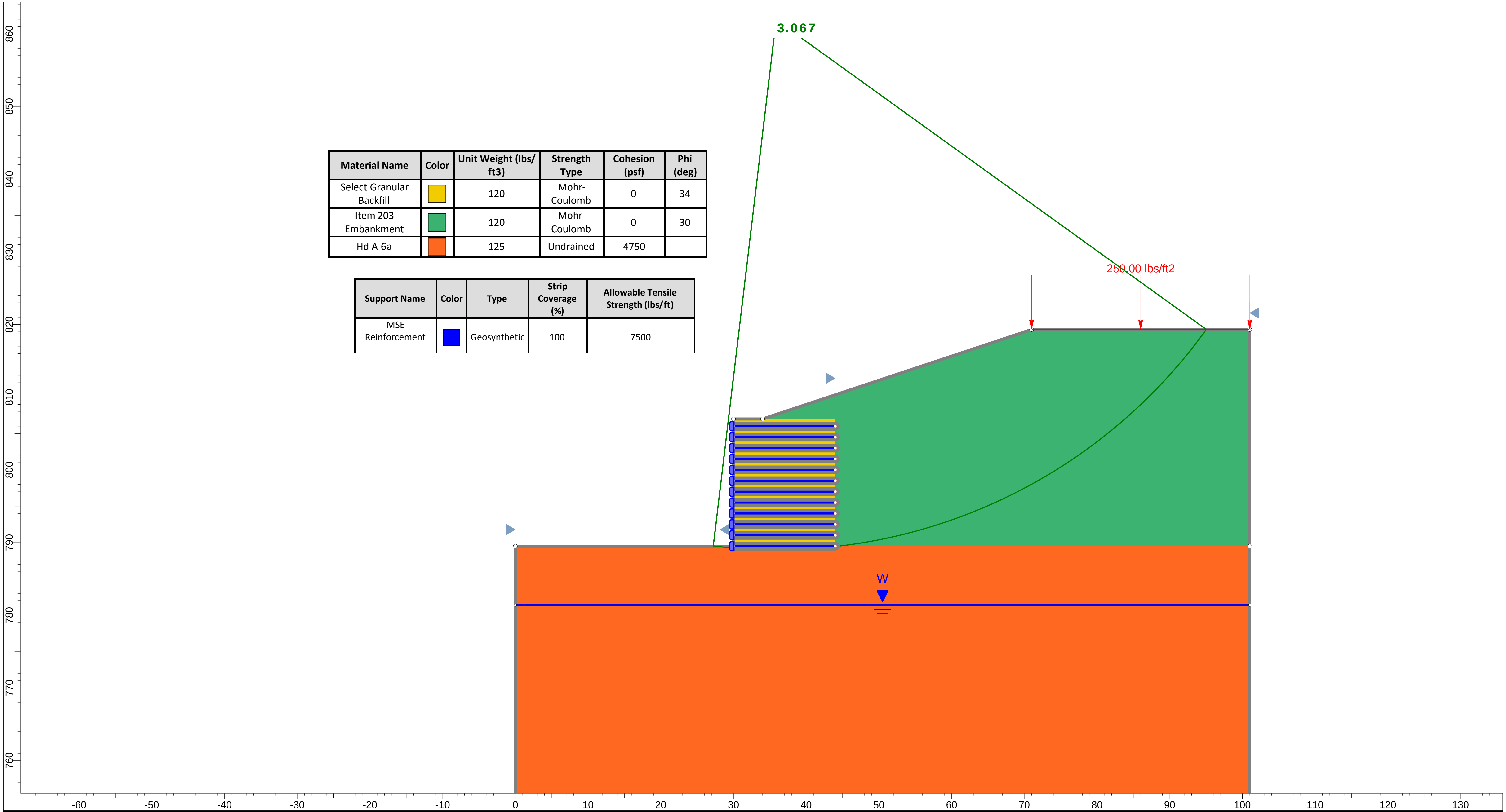
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 4B
Analysis Description	Global Stability - Sta. 11+50 to 13+52 (BL Wall 4B) - B-046-0-19 and B-073-0-19 - 3:1 Broken Backslope - 17.5 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:150
Company	BRT
Date	4/1/2022, 6:41:04 PM
File Name	Wall 4B - Sta. 11+50 to 13+52 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Hd A-6a	🟧	125	Undrained	4750	

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

Resource International, Inc.
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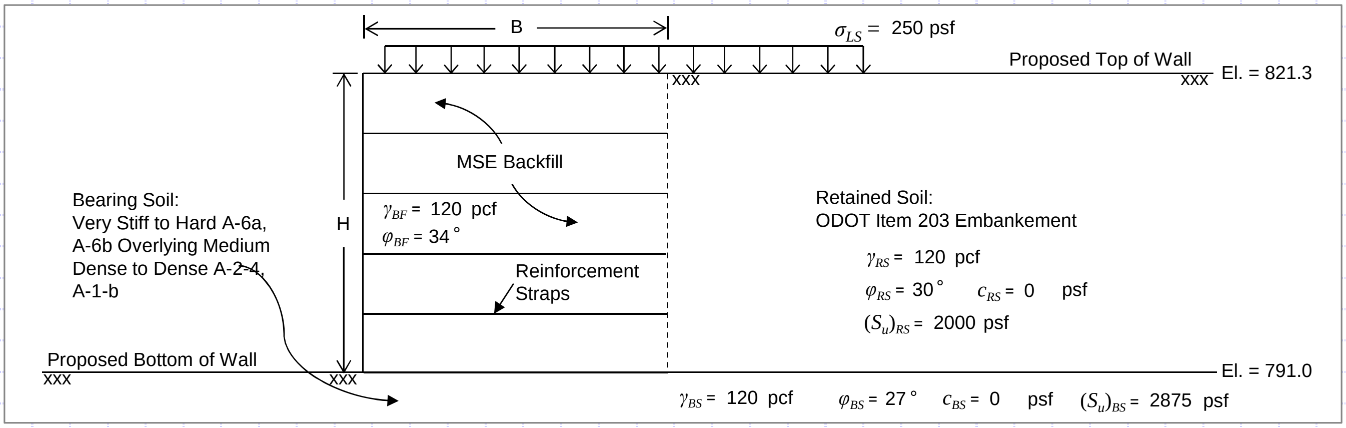
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 4B		
Analysis Description	Global Stability - Sta. 11+50 to 13+52 (BL Wall 4B) - B-046-0-19 and B-073-0-19 - 3:1 Broken Backslope - 17.5 ft. Wall Height - Undrained - Circular		
Drawn By	Resource International, Inc.	*Scale*	1:150
Company	BRT		
Date	4/1/2022, 6:41:04 PM	*File Name*	Wall 4B - Sta. 11+50 to 13+52 - Global Stability.slmd

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	1	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 4B - Sta. 13+52 to 15+92 (BL Wall 4B)

Retaining Wall 4B - Sta. 13+52 to 15+92 (BL Wall 4B) - FRA-BRICE-04409 Re. Abut. - B-071-0-19 thru B-075-0-19 - Level Backfill - 30.3 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	5.1 ft		

LRFD Load Factors

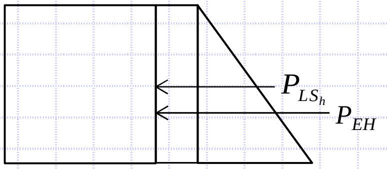
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = ½\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(30.3 ft)²(0.297)(1.5) = 24.54 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(30.3 ft)(0.297)(1.75) = 3.94 kip/ft

P_H = 24.54 kip/ft + 3.94 kip/ft = 28.48 kip/ft

Sliding Force at Bottom of Foundation Preparation:

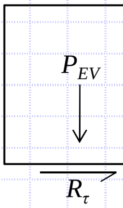
$P_{EH} = ½\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(30.3 ft + 1 ft)²(0.297)(1.5) = 26.19 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(30.3 ft + 1 ft)(0.297)(1.75) = 4.07 kip/ft

P_H = 26.19 kip/ft + 4.07 kip/ft = 30.26 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(30.3 ft + 1 ft)(25.8 ft)(1.00) = 96.9 kip/ft

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

R_τ = (96.9 kip/ft)(0.51) = 49.42 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 30.26 kip/ft ≤ (49.42 kip/ft)(1.0) = 49.42 kip/ft ⟶ 30.26 kip/ft ≤ 49.42 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) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.1 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

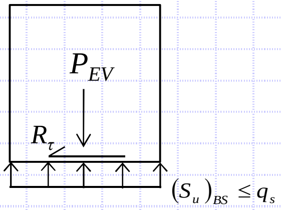
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

[1] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

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



$(S_u)_{BS} =$ 2.88 ksf

$q_s = \sigma_v / 2$ = (3.76 ksf) / 2 = 1.88 ksf

$\sigma_v = P_{EV} / B$ = (96.9 kip/ft) / (25.8 ft) = 3.76 ksf

R_τ = (2.88 ksf ≤ 1.88 ksf)(25.8 ft) = 48.50 kip/ft

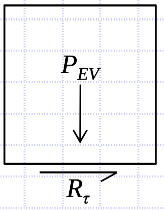
Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 30.26 kip/ft ≤ (48.50 kip/ft)(1.0) = 48.50 kip/ft ⟶ 30.26 kip/ft ≤ 48.50 kip/ft **OK**

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(30.3 ft)(25.8 ft)(1.00) = 93.81 kip/ft

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

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

R_τ = (93.81 kip/ft)(0.67) = 62.85 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 28.48 kip/ft ≤ (62.85 kip/ft)(1.0) = 62.85 kip/ft ⟶ 28.48 kip/ft ≤ 62.85 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 4B - Sta. 13+52 to 15+92 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	5.1 ft		

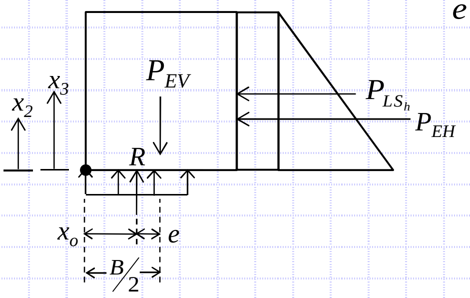
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = {}^{B}\!/_{2} - x_o$$

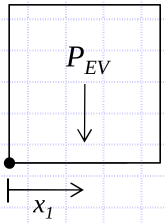
$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(1210.15 kip·ft/ft - 307.55 kip·ft/ft) / (93.81 kip/ft)} = 9.62 \text{ ft}$$

M_{EV} = 1210.15 kip·ft/ft
M_H = 307.55 kip·ft/ft
P_{EV} = 93.81 kip/ft

Defined below

$$e = \text{(25.8 ft)/2 - 9.62 ft} = 3.28 \text{ ft}$$

Resisting Moment, M_{EV}:



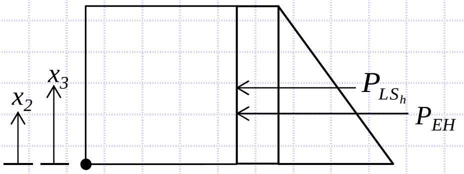
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(30.3 ft)(25.8 ft)(1.00)} = 93.81 \text{ kip/ft}$$

$$x_1 = {}^{B}\!/_{2} = \text{(25.8 ft) / 2} = 12.90 \text{ ft}$$

$$M_{EV} = \text{(93.81 kip/ft)(12.90 ft)} = 1210.15 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = {}^{1}\!/_{2}\,\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(30.3 ft)²(0.297)(1.5)} = 24.54 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(30.3 ft)(0.297)(1.75)} = 3.94 \text{ kip/ft}$$

$$x_2 = {}^{H}\!/_{3} = \text{(30.3 ft) / 3} = 10.10 \text{ ft}$$

$$x_3 = {}^{H}\!/_{2} = \text{(30.3 ft) / 2} = 15.15 \text{ ft}$$

$$M_H = \text{(24.54 kip/ft)(10.1 ft) + (3.94 kip/ft)(15.15 ft)} = 307.55 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.28 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) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.1 ft		

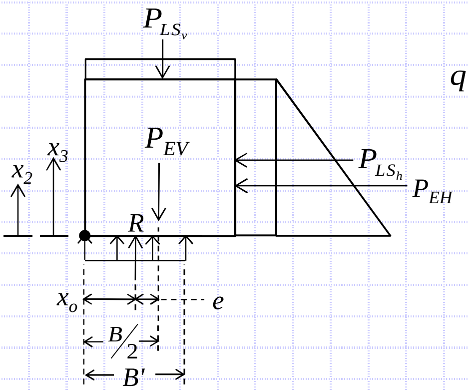
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 25.8 \text{ ft - 2(2.23 ft)} \quad = \quad 21.34 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad \text{(25.8 ft) / 2 - 10.67 ft} \quad = \quad 2.23 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(1779.29 kip·ft/ft - 307.51 kip·ft/ft) / 137.93 kip/ft} \quad = \quad 10.67 \quad \text{ft}$$

$$q_{eq} = \quad \text{(137.93 kip/ft) / (21.34 ft)} \quad = \quad 6.46 \quad \text{ksf}$$

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

$$M_V = \quad \text{[(120 pcf)(30.3 ft)(25.8 ft)(1.35)](12.9 ft) + [(250 psf)(25.8 ft)(1.75)](12.9 ft)} \quad = \quad 1779.29 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad \text{[½(120 pcf)(30.3 ft)²(0.297)(1.5)](10.1 ft) + [(250 psf)(30.3 ft)(0.297)(1.75)](15.15 ft)} \quad = \quad 307.51 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad \text{(120 pcf)(30.3 ft)(25.8 ft)(1.35) + (250 psf)(25.8 ft)(1.75)} \quad = \quad 137.93 \quad \text{kip/ft}$$

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 25.28

N_c = 23.94

s_c = 1+(21.34 ft/211 ft)(13.2/23.94)

= 1.056

i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 13.75

N_q = 13.20

s_q = 1.000

d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/21.34 ft)

1.042

i_q = 1.000 (Assumed)

C_{wq} = 5.1 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 13.89

N_γ = 14.47

s_γ = 0.960

i_γ = 1.000 (Assumed)

$C_{w\gamma}$ = 5.1 ft < 1.5(21.34 ft) + 3.0 ft = 0.580

$$q_n = \quad \text{(0 psf)(25.281) + (120 pcf)(3.0 ft)(13.754)(1.000) + ½(120 pcf)(21.3 ft)(13.891)(0.580)} \quad = \quad 15.27 \quad \text{ksf}$$

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ $\longrightarrow$ 6.46 ksf ≤ (15.27 ksf)(0.65) = 9.93 ksf $\longrightarrow$ 6.46 ksf ≤ 9.93 ksf **OK**

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 4B - Sta. 13+52 to 15+92 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.1 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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.230

N_c = 5.140

s_c = 1+(21.34 ft/[(5)(211 ft)]) = 1.018

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/21.34 ft)

1.000

i_q = 1.000 (Assumed)

C_{wq} = 5.1 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)

$C_{w\gamma}$ = 5.1 ft < 1.5(21.34 ft) + 3.0 ft = 0.580

$q_n =$ (2875 psf)(5.230) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(21.3 ft)(0.000)(0.580) = 15.40 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 6.46 ksf ≤ (15.40 ksf)(0.65) = 10.01 ksf ⟶ 6.46 ksf ≤ 10.01 ksf **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 4B - Sta. 13+52 to 15+92 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	30.3	ft
MSE Wall Width (Reinforcement Length), (B) =	25.8	ft
MSE Wall Length, (L) =	211	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2875	2875	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	5.1 ft		

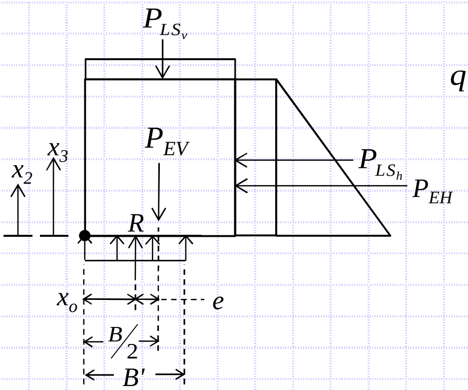
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 25.8 \text{ ft} - 2(1.99 \text{ ft}) \quad = \quad 21.82 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (25.8 \text{ ft}) / 2 - 10.91 \text{ ft} \quad = \quad 1.99 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (1293.34 \text{ kip·ft/ft} - 199.32 \text{ kip·ft/ft}) / 100.26 \text{ kip/ft} \quad = \quad 10.91 \quad \text{ft}$$

$$q_{eq} = \quad (100.26 \text{ kip/ft}) / (21.82 \text{ ft}) \quad = \quad 4.59 \quad \text{ksf}$$

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

$$M_V = \quad [(120 \text{ pcf})(30.3 \text{ ft})(25.8 \text{ ft})(1.00)](12.9 \text{ ft}) + [(250 \text{ psf})(25.8 \text{ ft})(1.00)](12.9 \text{ ft}) \quad = \quad 1293.34 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad [\tfrac{1}{2}(120 \text{ pcf})(30.3 \text{ ft})^2(0.297)(1.00)](10.1 \text{ ft}) + [(250 \text{ psf})(30.3 \text{ ft})(0.297)(1.00)](15.15 \text{ ft}) \quad = \quad 199.32 \quad \text{kip·ft/ft}$$

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

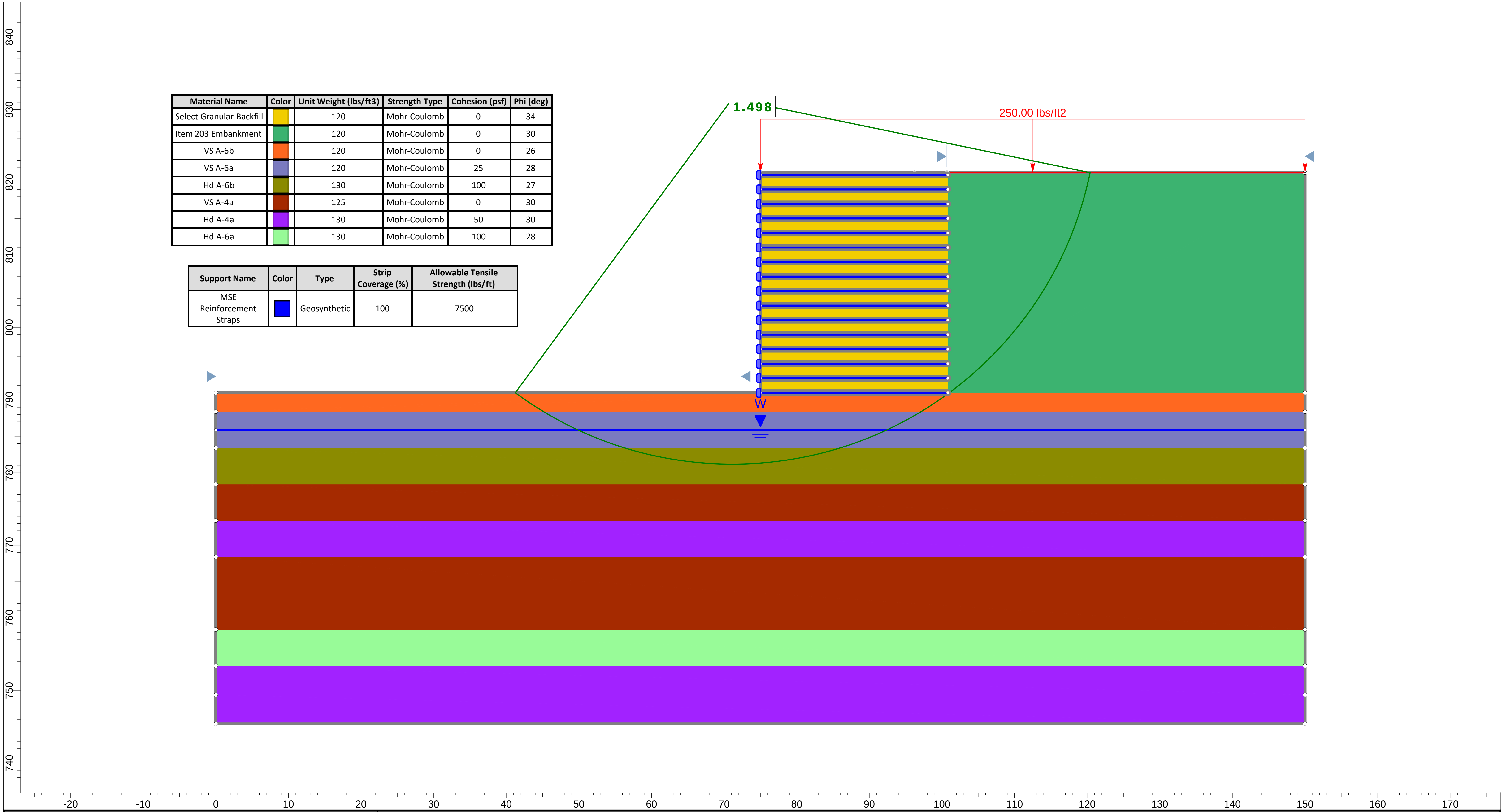
$$P_V = \quad (120 \text{ pcf})(30.3 \text{ ft})(25.8 \text{ ft})(1.00) + (250 \text{ psf})(25.8 \text{ ft})(1.00) \quad = \quad 100.26 \quad \text{kip/ft}$$

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6b	🟧	120	Mohr-Coulomb	0	26
VS A-6a	🟪	120	Mohr-Coulomb	25	28
Hd A-6b	🟫	130	Mohr-Coulomb	100	27
VS A-4a	🟥	125	Mohr-Coulomb	0	30
Hd A-4a	🟪	130	Mohr-Coulomb	50	30
Hd A-6a	🟩	130	Mohr-Coulomb	100	28

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



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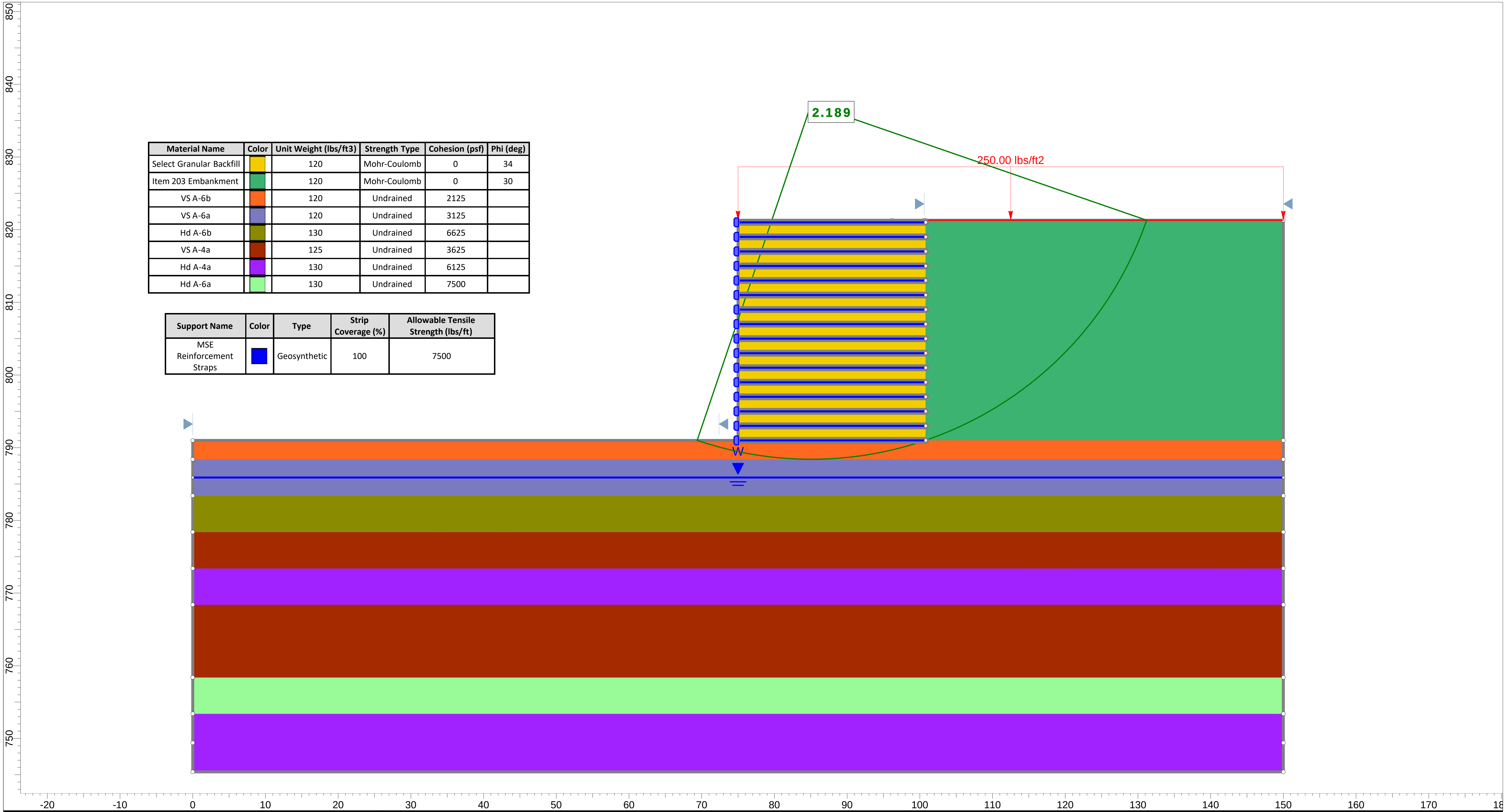
Project	FRA-70-22.85 FEF - Retaining Wall 4B - FRA-BRICE-04409 Forward Abutment
Analysis Description	Global Stability - Sta. 13+25 to 15+92 (BL Wall 4B) - B-071-0-19 through B-075-0-19 - Level Backfill - 30.3 ft. Wall Height - Drained - Circular

Drawn By	Resource International, Inc.	*Scale*	1:150	*Company*	BRT
Date	4/1/2022, 4:39:59 PM			*File Name*	Wall 4B - Sta. 13+52 to 15+92 - Global Stability.slmd

SLIDEINTERPRET 9.019



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6b	🟧	120	Undrained	2125	
VS A-6a	🟦	120	Undrained	3125	
Hd A-6b	🟫	130	Undrained	6625	
VS A-4a	🟥	125	Undrained	3625	
Hd A-4a	🟪	130	Undrained	6125	
Hd A-6a	🟩	130	Undrained	7500	

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

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

SLIDEINTERPRET 9.019

Project
FRA-70-22.85 FEF - Retaining Wall 4B - FRA-BRICE-04409 Forward Abutment

Analysis Description
Global Stability - Sta. 13+25 to 15+92 (BL Wall 4B) - B-071-0-19 through B-075-0-19 - Level Backfill - 30.3 ft. Wall Height - Undrained - Circular

Drawn By
Resource International, Inc.

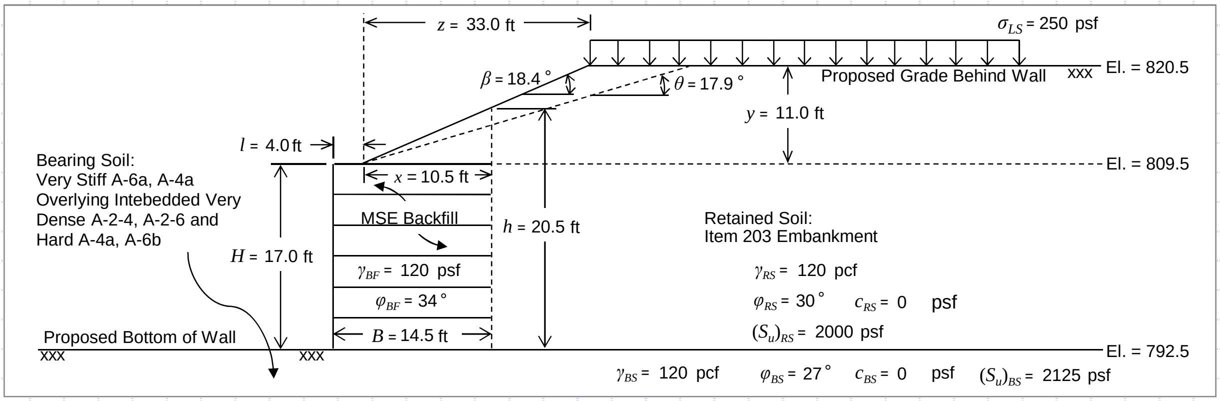
Scale
1:150

Company
BRT

Date
4/1/2022, 4:39:59 PM

File Name
Wall 4B - Sta. 13+52 to 15+92 - Global Stability.slmd

Retaining Wall 4B - Sta. 15+92 to 17+80 (BL Wall 4B) - B-087-0-19 and B-088-0-19 - 3:1 Broken Backslope - 17.0 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_w) =	1.1 ft		

LRFD Load Factors

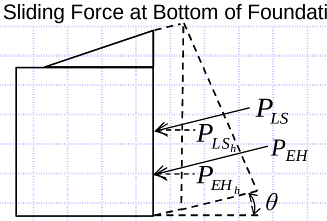
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Bottom of Foundation Preparation: $P_H = (P_{EH} + P_{LS})\cos\theta$



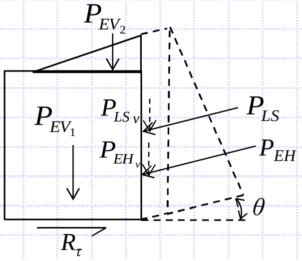
$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH}$ = ½(120 pcf)(20.5 ft + 1 ft)²(0.394)(1.50) = 16.38 kip/ft

$P_{EH} = \sigma_{LS}(h+1)K_a\gamma_{LS}$ = (250 psf)(20.5 ft + 1 ft)(0.394)(1.75) = 3.52 kip/ft

P_H = (16.38 kip/ft + 3.52 kip/ft)cos(17.9°) = 18.94 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(17.0 ft + 1 ft)(14.5 ft)(1.00) = 31.32 kip/ft

$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00) = 2.2 kip/ft

$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH}$ = ½(120 pcf)(20.5 ft + 1 ft)²(0.394)(1.50) = 16.38 kip/ft

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

R_τ = [31.32 kip/ft + 2.20 kip/ft + (16.38 kip/ft)sin(17.9°)](0.51) = 19.66 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (At Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 18.94 kip/ft ≤ (19.66 kip/ft)(1.0) = 19.66 kip/ft $\longrightarrow$ 18.94 kip/ft ≤ 19.66 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) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing		Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120		120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27		27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0		0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2125		2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34	°		
Embedment Depth, (D_f) =	3.0	ft		
Depth to GW (Below Bot. of Wall), (D_W) =	1.1	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)

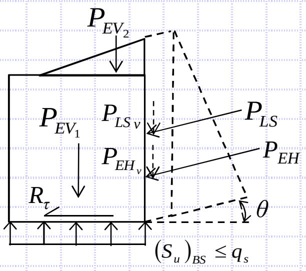
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



(Neglect P_{LS_V} for conservatism)

$$(S_u)_{BS} = 2.13 \text{ ksf}$$

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV} = \text{(120 pcf)(17.0 ft + 1 ft)(14.5 ft)(1.00)} = 31.32 \text{ kip/ft}$$

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

$$P_{EV_2} = \text{½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00)} = 2.2 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$$

$$P_{EH} = \text{½(120 pcf)(20.5 ft + 1 ft)}^2\text{(0.394)(1.50)} = 16.38 \text{ kip/ft}$$

$$P_V = \text{31.32 kip/ft + 2.2 kip/ft + (16.38 kip/ft)sin(17.9°)} = 38.55 \text{ kip/ft}$$

$$\sigma_v = \text{(38.55 kip/ft) / (14.5 ft)} = 2.66 \text{ ksf}$$

$$q_s = \text{(2.66 ksf) / 2} = 1.33 \text{ ksf}$$

$$R_\tau = \text{(2.13 ksf} \le \text{1.33 ksf)(14.5 ft)} = 30.81 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 18.94 kip/ft ≤ (30.81 kip/ft)(1.0) = 30.81 kip/ft ⟶ 18.94 kip/ft ≤ 30.81 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 15+92 to 17+80 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	1.1 ft		

LRFD Load Factors

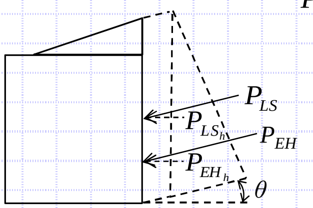
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Top of Foundation Preparation:



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

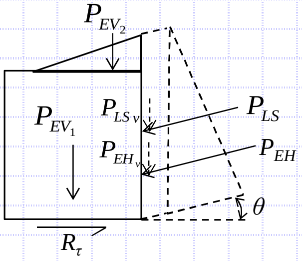
$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(20.5 ft)²(0.394)(1.50)} = 14.89 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = \text{(250 psf)(20.5 ft)(0.394)(1.75)} = 3.35 \text{ kip/ft}$$

$$P_H = \text{(14.89 kip/ft + 3.35 kip/ft)cos(17.9°)} = 17.36 \text{ kip/ft}$$

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$$P_{EV_1} = \gamma_{BF}\cdot H\cdot B\cdot\gamma_{EV} = \text{(120 pcf)(17.0 ft)(14.5 ft)(1.00)} = 29.58 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00)} = 2.2 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(20.5 ft)²(0.394)(1.50)} = 14.89 \text{ kip/ft}$$

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

$$R_\tau = \text{[29.58 kip/ft + 2.20 kip/ft + (14.89 kip/ft)sin(17.9°)](0.67)} = 24.36 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$$P_H \le R_\tau\cdot\phi_\tau \longrightarrow \text{17.36 kip/ft} \le \text{(24.36 kip/ft)(1.0) = 24.36 kip/ft} \longrightarrow \text{17.36 kip/ft} \le \text{24.36 kip/ft}$$

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) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	120	120 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0 psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2125	2125 psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf	
MSE Backfill Friction Angle, (φ_{BF}) =	34 °	
Embedment Depth, (D_f) =	3.0 ft	
Depth to GW (Below Bot. of Wall), (D_W) =	1.1 ft	

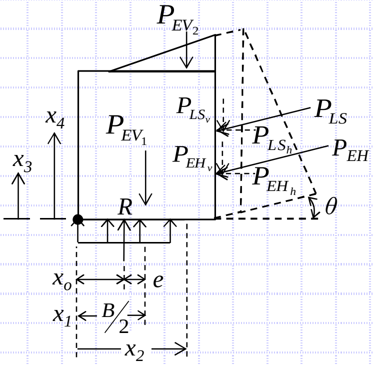
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = \text{(305.01 kip·ft/ft - 131.21 kip·ft/ft) / (36.36 kip/ft)} = 4.78 \text{ ft}$$

$$M_V = 305.01 \text{ kip·ft/ft}$$
$$M_H = 131.21 \text{ kip·ft/ft}$$

Defined below

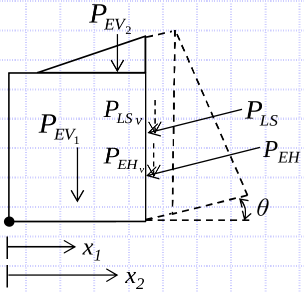
$$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta = \text{29.58 kip/ft + 2.2 kip/ft + (14.89 kip/ft)sin(17.9°)} = 36.36 \text{ kip/ft}$$

$$e = \text{(14.5 ft/ 2) - 4.78 ft} = 2.47 \text{ ft}$$

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)



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(17.0 ft)(14.5 ft)(1.00)} = 29.58 \text{ kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \text{½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00)} = 2.2 \text{ kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(20.5 ft)²(0.394)(1.50)} = 14.89 \text{ kip/ft}$$

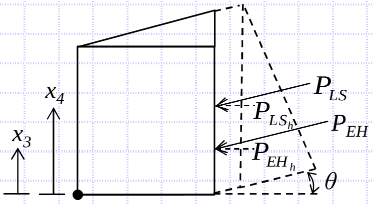
$$x_1 = B/2 = \text{(14.5 ft) / 2} = 7.25 \text{ ft}$$

$$x_2 = l + \tfrac{2}{3}(B-l) = \text{4.0 ft + ⅔(14.5 ft - 4.0 ft)} = 11.00 \text{ ft}$$

$$M_V = \text{(29.58 kip/ft)(7.25 ft) + (2.2 kip/ft)(11 ft) + (14.89 kip/ft)sin(17.9°)(14.5 ft)} = 305.01 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(20.5 ft)²(0.394)(1.50)} = 14.89 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = \text{(250 psf)(20.5 ft)(0.394)(1.75)} = 3.53 \text{ kip/ft}$$

$$x_3 = h/3 = \text{(20.5 ft) / 3} = 6.83 \text{ ft}$$

$$x_4 = h/2 = \text{(20.5 ft) / 2} = 10.25 \text{ ft}$$

$$M_H = \text{(14.89 kip/ft)cos(17.9°)(6.83 ft) + (3.53 kip/ft)cos(17.9°)(10.25 ft)} = 131.21 \text{ kip·ft/ft}$$

Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (14.5 ft) / 3 = 4.83 ft

$e < e_{\max} \longrightarrow$ 2.47 ft < 4.83 ft **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	1.1 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)

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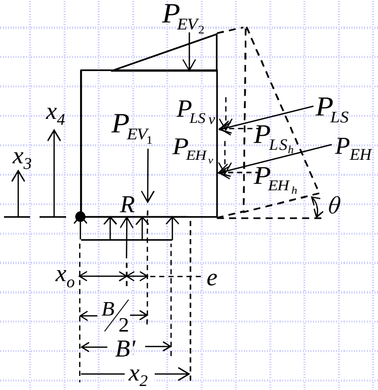
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 14.5\text{ ft} - 2(1.83\text{ ft}) \quad = \quad 10.84 \quad \text{ft}$$

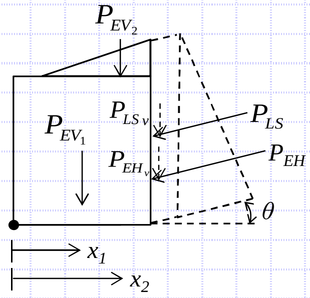
$$e = B/2 - x_o \quad = \quad (14.5\text{ ft} / 2) - 5.42\text{ ft} \quad = \quad 1.83 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (388.52\text{ kip·ft/ft} - 131.21\text{ kip·ft/ft}) / 47.48\text{ kip/ft} \quad = \quad 5.42 \quad \text{ft}$$

$$q_{eq} = (47.48\text{ kip/ft}) / (10.84\text{ ft}) \quad = \quad 4.38 \quad \text{ksf}$$

Resisting Moment, M_V:

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



$$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad (120\text{ pcf})(17.0\text{ ft})(14.5\text{ ft})(1.35) \quad = \quad 39.93 \quad \text{kip/ft}$$

$$P_{EV_2} = \tfrac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV} = \tfrac{1}{2}(120\text{ pcf})(20.5\text{ ft} - 17.0\text{ ft})(14.5\text{ ft} - 4.0\text{ ft})(1.35) = \quad 2.97 \quad \text{kip/ft}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} \quad = \quad \tfrac{1}{2}(120\text{ pcf})(20.5\text{ ft})^2(0.394)(1.50) \quad = \quad 14.89 \quad \text{kip/ft}$$

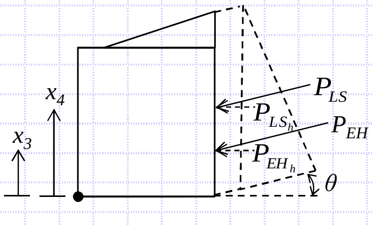
$$x_1 = B/2 \quad = \quad (14.5\text{ ft}) / 2 \quad = \quad 7.25 \quad \text{ft}$$

$$x_2 = l + \tfrac{2}{3}(B - l) \quad = \quad 4.0\text{ ft} + \tfrac{2}{3}(14.5\text{ ft} - 4.0\text{ ft}) \quad = \quad 11.00 \quad \text{ft}$$

$$M_V = (39.93\text{ kip/ft})(7.25\text{ ft}) + (2.97\text{ kip/ft})(11.0\text{ ft}) + (14.89\text{ kip/ft})\sin(17.9°)(14.5\text{ ft}) \quad = \quad 388.52 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \quad \tfrac{1}{2}(120\text{ pcf})(20.5\text{ ft})^2(0.394)(1.50) \quad = \quad 14.89 \quad \text{kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} \quad = \quad (250\text{ psf})(20.5\text{ ft})(0.394)(1.75) \quad = \quad 3.53 \quad \text{kip/ft}$$

$$x_3 = h/3 \quad = \quad (20.5\text{ ft}) / 3 \quad = \quad 6.83 \quad \text{ft}$$

$$x_4 = h/2 \quad = \quad (20.5\text{ ft}) / 2 \quad = \quad 10.25 \quad \text{ft}$$

$$M_H = (14.89\text{ kip/ft})\cos(17.9°)(6.83\text{ ft}) + (3.53\text{ kip/ft})\cos(17.9°)(10.25\text{ ft}) \quad = \quad 131.21 \quad \text{kip·ft/ft}$$

Vertical Forces, P_V:

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

$$P_V = 39.93\text{ kip/ft} + 2.97\text{ kip/ft} + (14.89\text{ kip/ft})\sin(17.9°) \quad = \quad 47.48 \quad \text{kip/ft}$$

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JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 15+92 to 17+80 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	120	120 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0 psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2125	2125 psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf	
MSE Backfill Friction Angle, (φ_{BF}) =	34 °	
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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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+(10.84 ft/268 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+(10.84 ft/268 ft)tan(27°) = 1.000
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/10.84 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(10.84 ft/268 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(10.84 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(23.94) + (120 pcf)(3.0 ft)(14.5)(1.0) + ½(120 pcf)(10.8 ft)(14.5)(0.5) = 9.93 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.38 ksf ≤ (9.93 ksf)(0.65) = 6.45 ksf ⟶ 4.38 ksf ≤ 6.45 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+(10.84 ft/[(5)(268 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/10.84 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(10.84 ft) + 3.0 ft = 0.500

$q_n =$ (2125 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(10.8 ft)(0.0)(0.5) = 11.28 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 4.38 ksf ≤ (11.28 ksf)(0.65) = 7.33 ksf ⟶ 4.38 ksf ≤ 7.33 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 7 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 15+92 to 17+80 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	17.0	ft
MSE Wall Width (Reinforcement Length), (B) =	14.5	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	20.5	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	17.9	°
Distance from Toe to Top of Backslope, (z) =	33.0	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) =	0.394	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	120	120 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2125	2125 psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf	
MSE Backfill Friction Angle, (φ_{BF}) =	34 °	
Embedment Depth, (D_f) =	3.0 ft	
Depth to GW (Below Bot. of Wall), (D_W) =	1.1 ft	

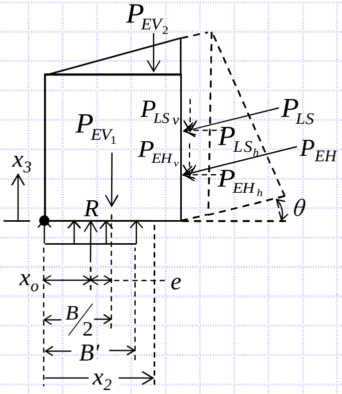
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 14.5 ft - 2(1.55 ft) = 11.40 ft

$e = B/2 - x_o$ = (14.5 ft / 2) - 5.7 ft = 1.55 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (282.91 kip·ft/ft - 84.22 kip·ft/ft) / 34.83 kip/ft = 5.70 ft

q_{eq} = (34.83 kip/ft) / (11.4 ft) = 3.06 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)(17.0 ft)(14.5 ft)(1.00)][½(14.5 ft)] + [½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(14.5 ft - 4.0 ft)] = 282.91 kip·ft/ft
+ [½(120 pcf)(20.5 ft)²(0.394)(1.00)sin(17.9°)](14.5 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)(20.5 ft)²(0.394)(1.00)cos(17.9°)](20.5 ft /3) = 84.22 kip·ft/ft
+ [(250 psf)(20.5 ft)(0.394)(1.00)cos(17.9°)](20.5 ft /2)

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

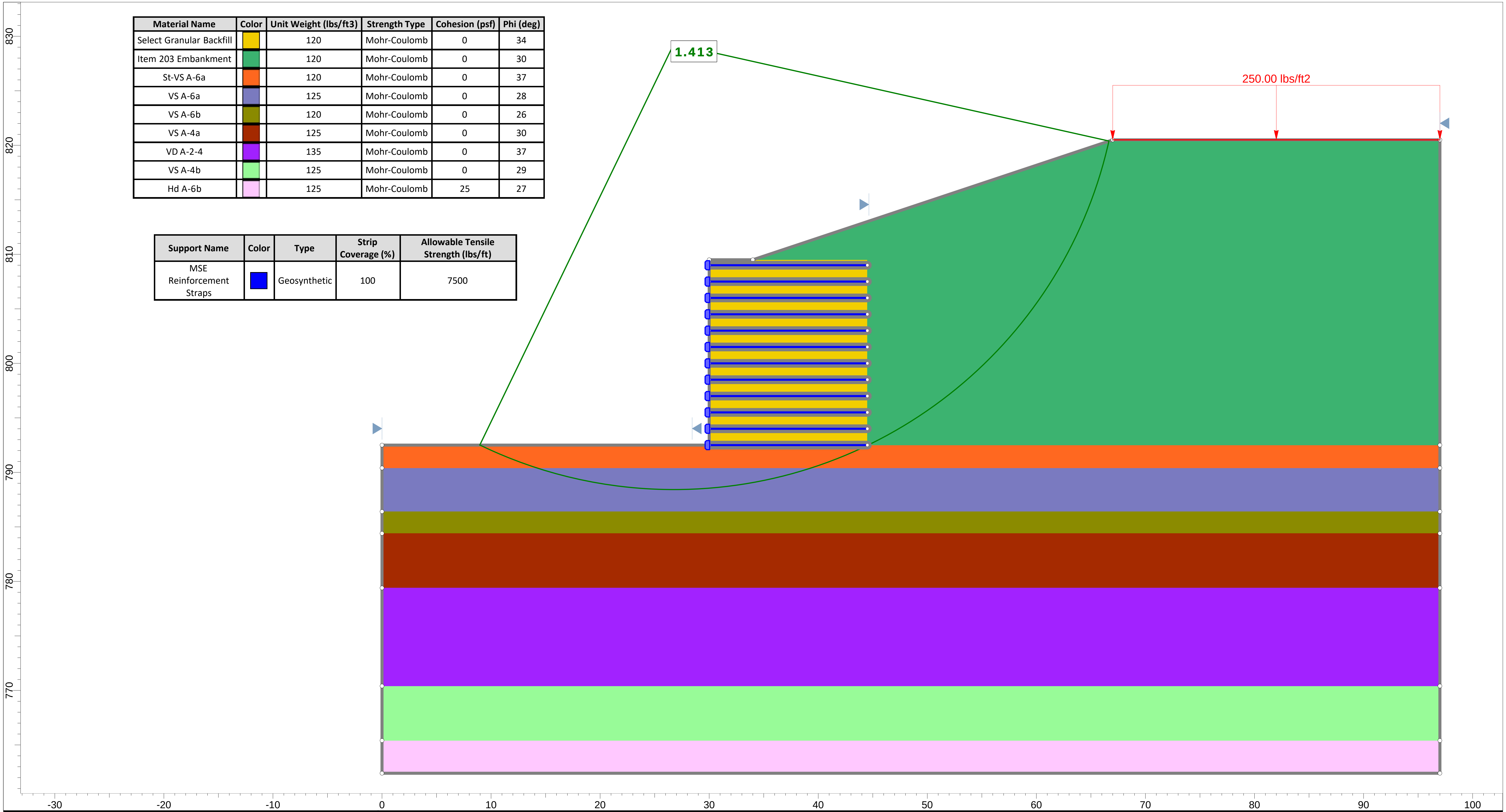
P_V = (120 pcf)(17.0 ft)(14.5 ft)(1.00) + ½(120 pcf)(20.5 ft - 17.0 ft)(14.5 ft - 4.0 ft)(1.00) = 34.83 kip/ft
+ ½(120 pcf)(20.5 ft)²(0.394)(1.00)sin(17.9°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 4B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St-VS A-6a	🟧	120	Mohr-Coulomb	0	37
VS A-6a	🟦	125	Mohr-Coulomb	0	28
VS A-6b	🟫	120	Mohr-Coulomb	0	26
VS A-4a	🟥	125	Mohr-Coulomb	0	30
VD A-2-4	🟪	135	Mohr-Coulomb	0	37
VS A-4b	🟩	125	Mohr-Coulomb	0	29
Hd A-6b	🟪	125	Mohr-Coulomb	25	27

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



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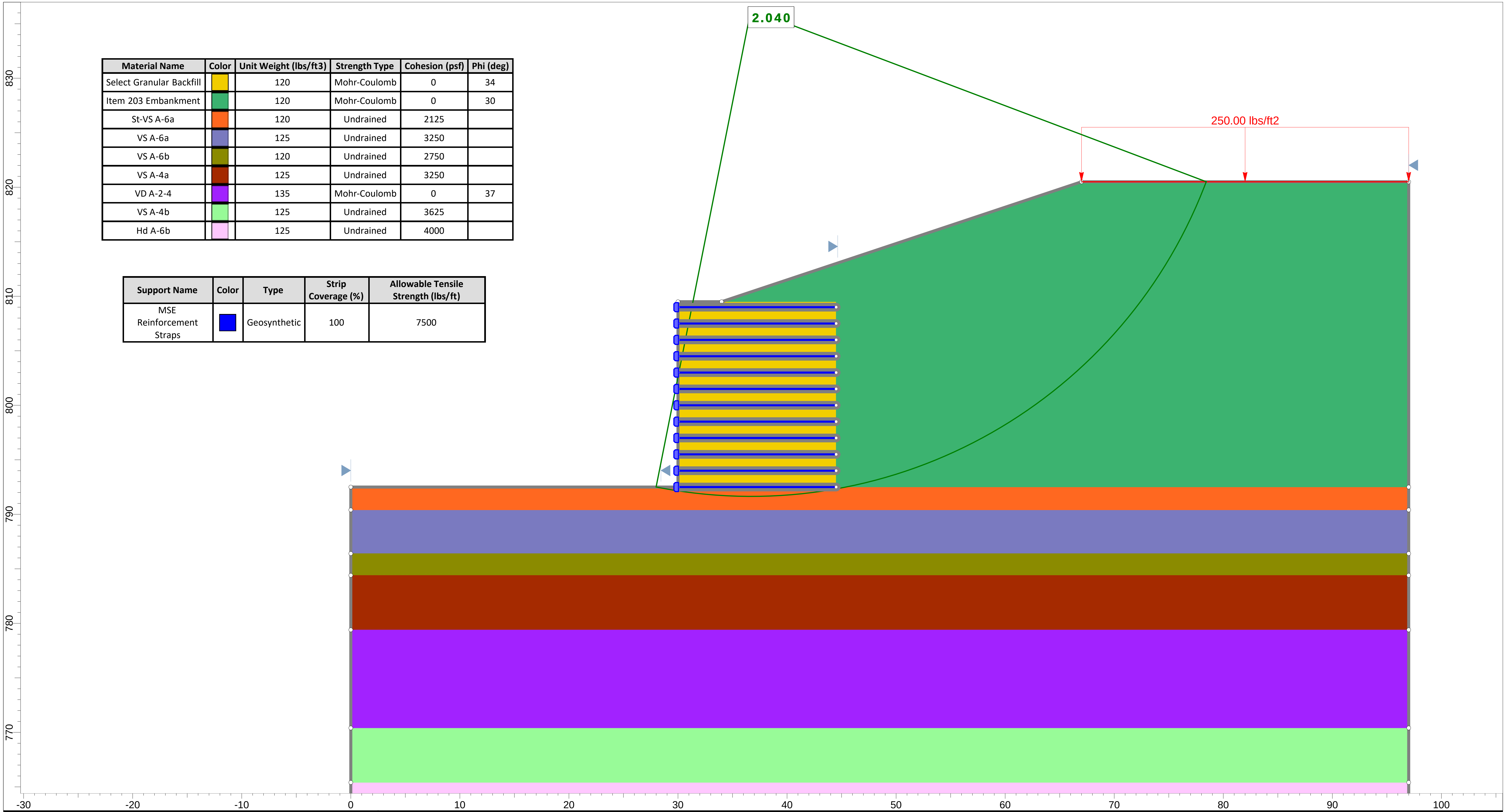
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 4B
Analysis Description	Global Stability - Sta. 15+92 to 17+80 (BL Wall 4B) - B-087-0-19 and B-088-0-19 - 3:1 Broken Backslope - 17.0 ft. Wall Height - Drained - Circular

Drawn By	Resource International, Inc.	Scale	1:100	Company	BRT
Date	4/1/2022, 9:08:18 PM			File Name	Wall 4B - Sta. 15+92 to 17+80 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St-VS A-6a	🟧	120	Undrained	2125	
VS A-6a	🟦	125	Undrained	3250	
VS A-6b	🟫	120	Undrained	2750	
VS A-4a	🟥	125	Undrained	3250	
VD A-2-4	🟪	135	Mohr-Coulomb	0	37
VS A-4b	🟩	125	Undrained	3625	
Hd A-6b	⬜	125	Undrained	4000	

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

Resource International, Inc.
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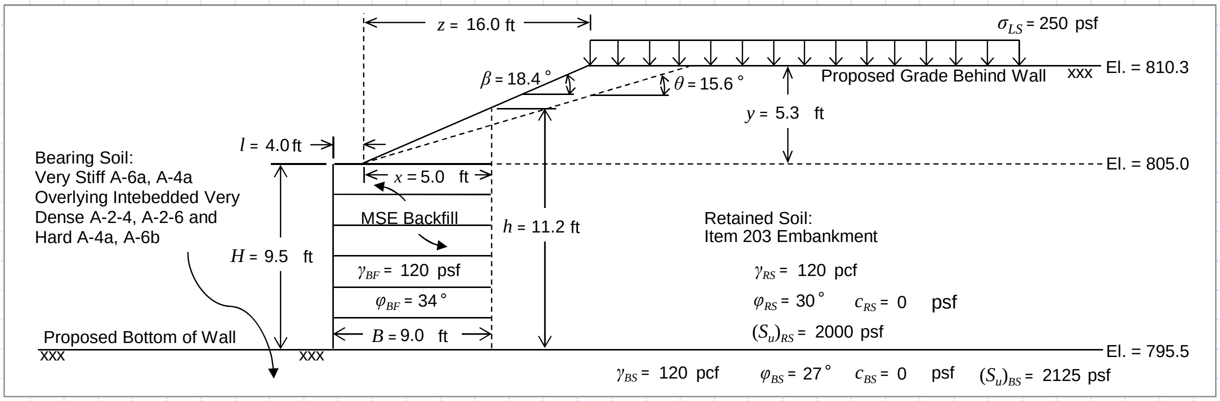
Project	FRA-70-22.85 FEF - Retaining Wall 4B
Analysis Description	Global Stability - Sta. 15+92 to 17+80 (BL Wall 4B) - B-087-0-19 and B-088-0-19 - 3:1 Broken Backslope - 17.0 ft. Wall Height - Undrained - Circular
Drawn By	Resource International, Inc.
Scale	1:100
Company	BRT
Date	4/1/2022, 9:08:18 PM
File Name	Wall 4B - Sta. 15+92 to 17+80 - Global Stability.slmd

SLIDEINTERPRET 9.019

Retaining Wall 4B - Sta. 17+80 to 18+60 (BL Wall 4B) - B-088-0-19 - 3:1 Broken Backslope - 9.5 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1 ft		

LRFD Load Factors

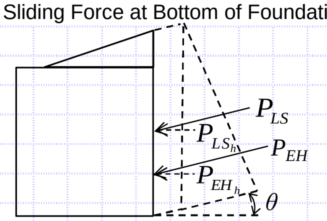
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Bottom of Foundation Preparation: $$P_H = (P_{EH} + P_{LS})\cos\theta$$



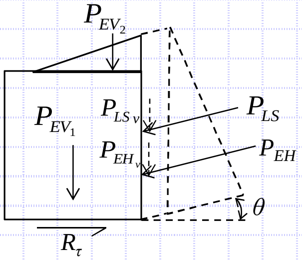
$$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH} =$$ ½(120 pcf)(11.2 ft + 1 ft)²(0.375)(1.50) = 4.99 kip/ft

$$P_{EH} = \sigma_{LS}(h+1)K_a\gamma_{LS} =$$ (250 psf)(11.2 ft + 1 ft)(0.375)(1.75) = 1.89 kip/ft

P_H = (4.99 kip/ft + 1.89 kip/ft)cos(15.6°) = 6.63 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV} =$$ (120 pcf)(9.5 ft + 1 ft)(9.0 ft)(1.00) = 11.34 kip/ft

$$P_{EV_2} = ½\gamma_{RS}(h-H)(B-l)\gamma_{EV}$$ = ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00) = 0.5 kip/ft

$$P_{EH} = ½\gamma_{RS}(h+1)^2K_a\gamma_{EH} =$$ ½(120 pcf)(11.2 ft + 1 ft)²(0.375)(1.50) = 4.99 kip/ft

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

R_τ = [11.34 kip/ft + 0.50 kip/ft + (4.99 kip/ft)sin(15.6°)](0.51) = 6.72 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (At Bottom of Wall)

$$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$$ 6.63 kip/ft ≤ (6.72 kip/ft)(1.0) = 6.72 kip/ft ⟶ 6.63 kip/ft ≤ 6.72 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) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1 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

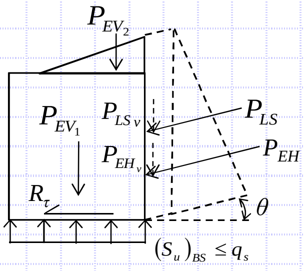
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

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



(Neglect P_{LS_v} for conservatism)

$(S_u)_{BS}$ = 2.13 ksf

$$q_s = \sigma_v / 2$$

$$\sigma_v = P_V / B$$

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

$P_{EV_1} = \gamma_{BF}(H+1)B\gamma_{EV}$ = (120 pcf)(9.5 ft + 1 ft)(9.0 ft)(1.00) = 11.34 kip/ft

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

P_{EV_2} = ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00) = 0.5 kip/ft

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}(h+1)^2 K_a \gamma_{EH}$$

P_{EH} = ½(120 pcf)(11.2 ft + 1 ft)²(0.375)(1.50) = 4.99 kip/ft

P_V = 11.34 kip/ft + 0.5 kip/ft + (4.99 kip/ft)sin(15.6°) = 13.18 kip/ft

σ_v = (13.18 kip/ft) / (9.0 ft) = 1.46 ksf

q_s = (1.46 ksf) / 2 = 0.73 ksf

R_τ = (2.13 ksf ≤ 0.73 ksf)(9.0 ft) = 19.13 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 6.63 kip/ft ≤ (19.13 kip/ft)(1.0) = 19.13 kip/ft ⟶ 6.63 kip/ft ≤ 19.13 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) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing		Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120		120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27		27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0		0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2125		2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120	pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34	°		
Embedment Depth, (D_f) =	3.0	ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1	ft		

LRFD Load Factors

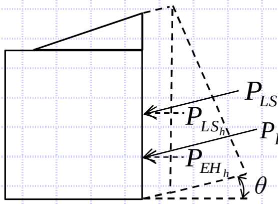
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force at Top of Foundation Preparation:



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

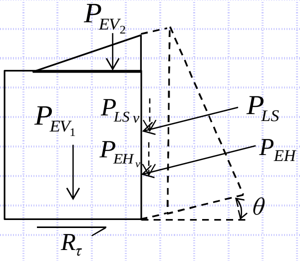
$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} =$ ½(120 pcf)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} =$ (250 psf)(11.2 ft)(0.375)(1.75) = 1.74 kip/ft

$P_H =$ (4.21 kip/ft + 1.74 kip/ft)cos(15.6°) = 5.73 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

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



$P_{EV_1} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(9.5 ft)(9.0 ft)(1.00) = 10.26 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00) = 0.5 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

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

R_τ = [10.26 kip/ft + 0.50 kip/ft + (4.21 kip/ft)sin(15.6°)](0.67) = 7.97 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 5.73 kip/ft ≤ (7.97 kip/ft)(1.0) = 7.97 kip/ft $\longrightarrow$ 5.73 kip/ft ≤ 7.97 kip/ft **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 4 OF 7
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/27/2022
Retaining Wall 4B - Sta. 17+80 to 18+60 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1 ft		

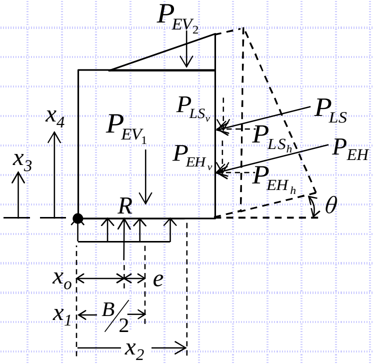
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (60.02 kip·ft/ft - 24.92 kip·ft/ft) / (11.89 kip/ft) = 2.95 ft

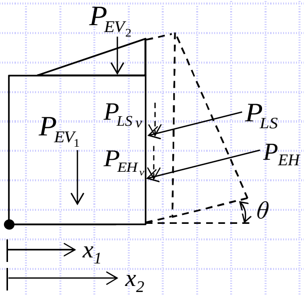
M_V = 60.02 kip·ft/ft
M_H = 24.92 kip·ft/ft } Defined below

$P_V = P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ = 10.26 kip/ft + 0.5 kip/ft + (4.21 kip/ft)sin(15.6°) = 11.89 kip/ft

$e =$ (9.0 ft/ 2) - 2.95 ft = 1.55 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)(9.5 ft)(9.0 ft)(1.00) = 10.26 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h-H)(B-l)\gamma_{EV}$ = ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00) = 0.5 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

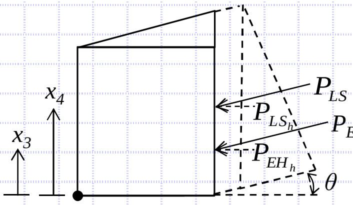
$x_1 = B/2$ = (9.0 ft) / 2 = 4.50 ft

$x_2 = l + \frac{2}{3}(B-l)$ = 4.0 ft + ⅔(9.0 ft - 4.0 ft) = 7.33 ft

M_V = (10.26 kip/ft)(4.50 ft) + (0.5 kip/ft)(7.33 ft) + (4.21 kip/ft)sin(15.6°)(9 ft) = 60.02 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)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(11.2 ft)(0.375)(1.75) = 1.83 kip/ft

$x_3 = h/3$ = (11.2 ft) / 3 = 3.72 ft

$x_4 = h/2$ = (11.2 ft) / 2 = 5.58 ft

M_H = (4.21 kip/ft)cos(15.6°)(3.72 ft) + (1.83 kip/ft)cos(15.6°)(5.58 ft) = 24.92 kip·ft/ft

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Check Eccentricity

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (9.0 ft) / 3 = 3.00 ft

$e < e_{\max} \longrightarrow$ 1.55 ft < 3.00 ft **OK**

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 17+80 to 18+60 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1 ft		

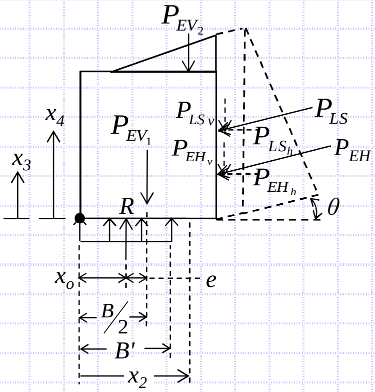
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 9.0 ft - 2(1.14 ft) = 6.72 ft

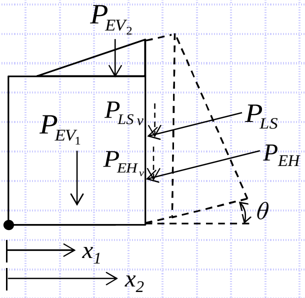
$e = B/2 - x_o$ = (9.0 ft / 2) - 3.36 ft = 1.14 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (77.43 kip·ft/ft - 24.92 kip·ft/ft) / 15.65 kip/ft = 3.36 ft

$q_{eq} =$ (15.65 kip/ft) / (6.72 ft) = 2.33 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)(9.5 ft)(9.0 ft)(1.35) = 13.85 kip/ft

$P_{EV_2} = \frac{1}{2}\gamma_{RS}(h - H)(B - l)\gamma_{EV}$ = ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.35) = 0.67 kip/ft

$P_{EH} = \frac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

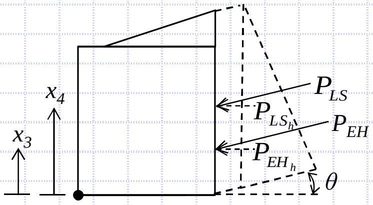
$x_1 = B/2$ = (9.0 ft) / 2 = 4.50 ft

$x_2 = l + \frac{2}{3}(B - l)$ = 4.0 ft + ⅔(9.0 ft - 4.0 ft) = 7.33 ft

M_V = (13.85 kip/ft)(4.50 ft) + (0.67 kip/ft)(7.3 ft) + (4.21 kip/ft)sin(15.6°)(9 ft) = 77.43 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)(11.2 ft)²(0.375)(1.50) = 4.21 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(11.2 ft)(0.375)(1.75) = 1.83 kip/ft

$x_3 = h/3$ = (11.2 ft) / 3 = 3.72 ft

$x_4 = h/2$ = (11.2 ft) / 2 = 5.58 ft

M_H = (4.21 kip/ft)cos(15.6°)(3.72 ft) + (1.83 kip/ft)cos(15.6°)(5.58 ft) = 24.92 kip·ft/ft

Vertical Forces, P_V:

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

P_V = 13.85 kip/ft + 0.67 kip/ft + (4.21 kip/ft)sin(15.6°) = 15.65 kip/ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 17+80 to 18+60 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	120	120 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0 psf
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	2125	2125 psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf	
MSE Backfill Friction Angle, (φ_{BF}) =	34 °	
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)

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1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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+(6.72 ft/268 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+(6.72 ft/268 ft)tan(27°) = 1.000
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/6.72 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(6.72 ft/268 ft) = 1.000
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.9 ft < 1.5(6.72 ft) + 3.0 ft = 0.500

$q_n =$ (0 psf)(23.94) + (120 pcf)(3.0 ft)(14.5)(1.0) + ½(120 pcf)(6.7 ft)(14.5)(0.5) = 8.14 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.33 ksf ≤ (8.14 ksf)(0.65) = 5.29 ksf ⟶ 2.33 ksf ≤ 5.29 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+(6.72 ft/[(5)(268 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/6.72 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(6.72 ft) + 3.0 ft = 0.500

$q_n =$ (2125 psf)(5.14) + (120 pcf)(3.0 ft)(1.0)(1.0) + ½(120 pcf)(6.7 ft)(0.0)(0.5) = 11.28 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.33 ksf ≤ (11.28 ksf)(0.65) = 7.33 ksf ⟶ 2.33 ksf ≤ 7.33 ksf **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	7	OF	7
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/27/2022

Retaining Wall 4B - Sta. 17+80 to 18+60 (BL Wall 4B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	9.5	ft
MSE Wall Width (Reinforcement Length), (B) =	9.0	ft
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
MSE Wall Length, (L) =	268	ft
MSE Wall Effective Height, (h) =	11.2	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	15.6	°
Distance from Toe to Top of Backslope, (z) =	16.0	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) =	0.375	
Live Surcharge Load, (σ_{LS}) =	250	psf

MSE Backfill and Bearing Soil Properties [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	2125	2125	psf
MSE Backfill Unit Weight, (γ_{BF}) =	120 pcf		
MSE Backfill Friction Angle, (φ_{BF}) =	34 °		
Embedment Depth, (D_f) =	3.0 ft		
Depth to GW (Below Bot. of Wall), (D_W) =	4.1 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)

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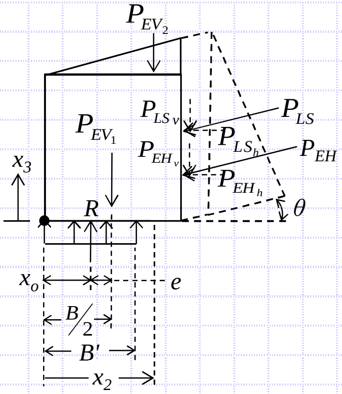
[1] Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 9.0 ft - 2(0.94 ft) = 7.12 ft

$e = B/2 - x_o$ = (9.0 ft / 2) - 3.56 ft = 0.94 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (56.62 kip·ft/ft - 15.68 kip·ft/ft) / 11.51 kip/ft = 3.56 ft

q_{eq} = (11.51 kip/ft) / (7.12 ft) = 1.62 ksf

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

M_V = [(120 pcf)(9.5 ft)(9.0 ft)(1.00)][½(9.0 ft)] + [½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00)][4.0 ft + ⅔(9.0 ft - 4.0 ft)] = 56.62 kip·ft/ft
+ [½(120 pcf)(11.2 ft)²(0.375)(1.00)sin(15.6°)](9.0 ft)

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

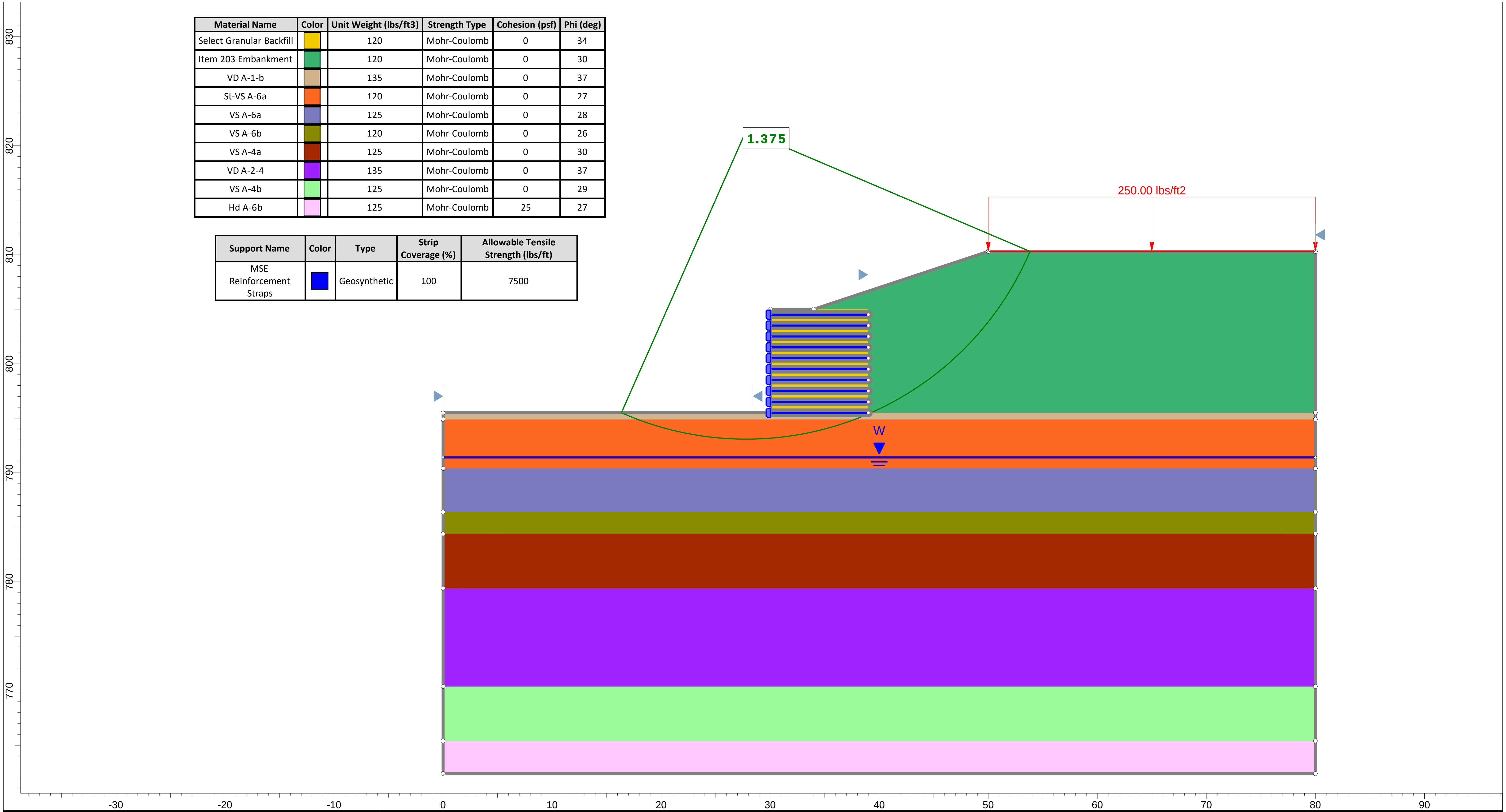
M_H = ½[(120 pcf)(11.2 ft)²(0.375)(1.00)cos(15.6°)](11.2 ft /3) = 15.68 kip·ft/ft
+ [(250 psf)(11.2 ft)(0.375)(1.00)cos(15.6°)](11.2 ft /2)

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

P_V = (120 pcf)(9.5 ft)(9.0 ft)(1.00) + ½(120 pcf)(11.2 ft - 9.5 ft)(9.0 ft - 4.0 ft)(1.00) = 11.51 kip/ft
+ ½(120 pcf)(11.2 ft)²(0.375)(1.00)sin(15.6°)

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 4B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VD A-1-b	🟫	135	Mohr-Coulomb	0	37
St-VS A-6a	🟧	120	Mohr-Coulomb	0	27
VS A-6a	🟦	125	Mohr-Coulomb	0	28
VS A-6b	🟫	120	Mohr-Coulomb	0	26
VS A-4a	🟥	125	Mohr-Coulomb	0	30
VD A-2-4	🟪	135	Mohr-Coulomb	0	37
VS A-4b	🟩	125	Mohr-Coulomb	0	29
Hd A-6b	🟪	125	Mohr-Coulomb	25	27

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

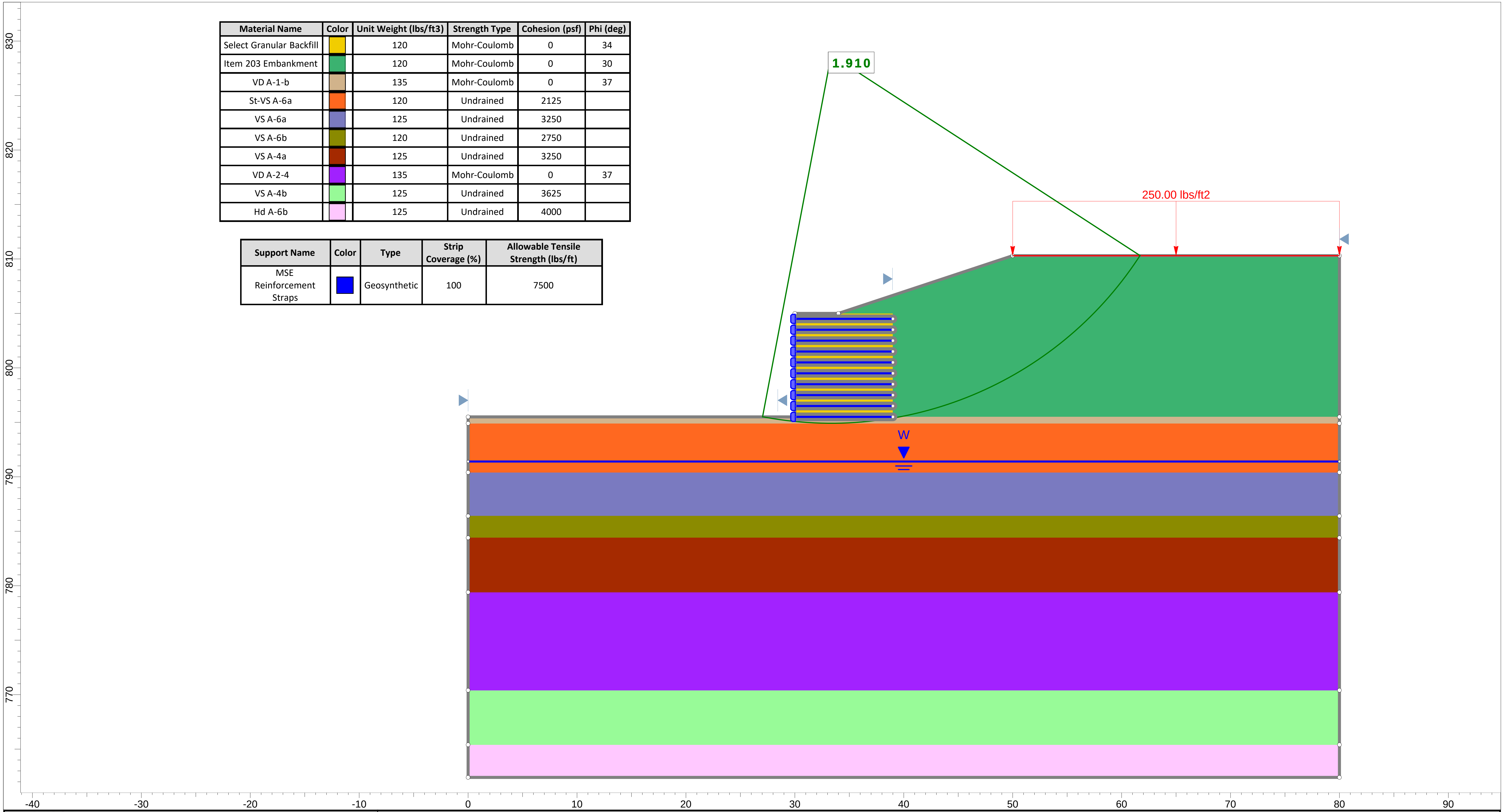
Resource International, Inc.
Planning | Engineering | Construction Management | Technology

Project	FRA-70-22.85 FEF - Retaining Wall 4B
Analysis Description	Global Stability - Sta. 17+80 to 18+60 (BL Wall 4B) - B-088-0-19 - 3:1 Broken Backslope - 9.5 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:100
Company	BRT
Date	4/1/2022, 9:08:18 PM
File Name	Wall 4B - Sta. 17+80 to 18+60 - Global Stability.slmd

SLIDEINTERPRET 9.019

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VD A-1-b	🟫	135	Mohr-Coulomb	0	37
St-VS A-6a	🟧	120	Undrained	2125	
VS A-6a	🟦	125	Undrained	3250	
VS A-6b	🟩	120	Undrained	2750	
VS A-4a	🟥	125	Undrained	3250	
VD A-2-4	🟪	135	Mohr-Coulomb	0	37
VS A-4b	🟩	125	Undrained	3625	
Hd A-6b	🟪	125	Undrained	4000	

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



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

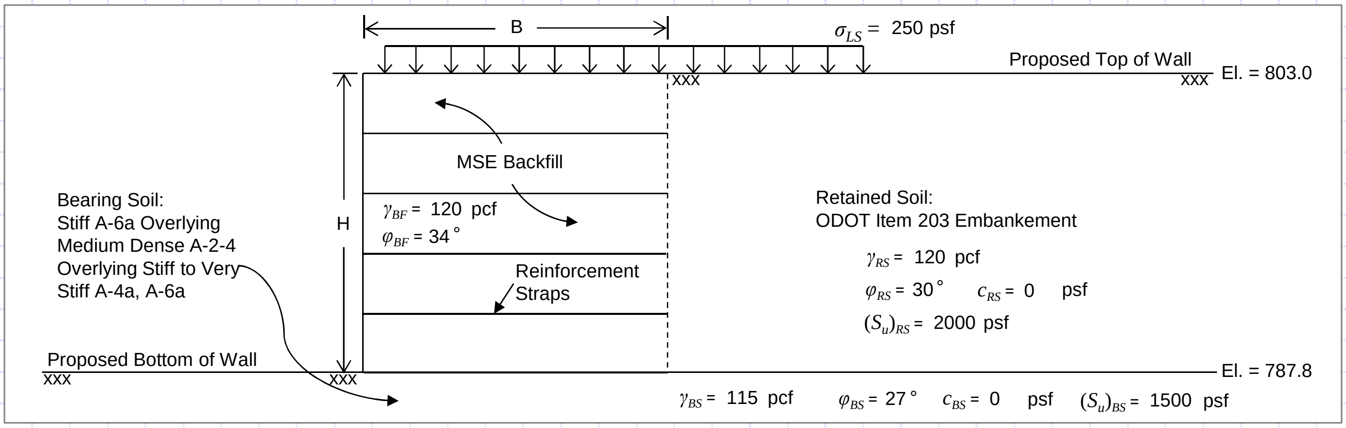
Project
FRA-70-22.85 FEF - Retaining Wall 4B

Analysis Description
Global Stability - Sta. 17+80 to 18+60 (BL Wall 4B) - B-088-0-19 - 3:1 Broken Backslope - 9.5 ft. Wall Height - Undrained - Circular

Drawn By	Resource International, Inc.	*Scale*	1:100	*Company*	BRT
Date	4/1/2022, 9:08:18 PM			*File Name*	Wall 4B - Sta. 17+80 to 18+60 - Global Stability.slmd

SLIDEINTERPRET 9.019

Retaining Wall 5B - Sta. 10+00 to 12+00 (BL Wall 5B) - B-041-0-19 - Level Backfill - 15.2 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	12.0 ft		

LRFD Load Factors

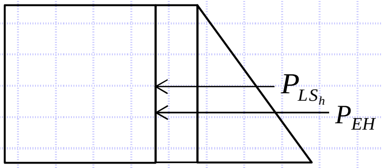
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = \frac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.297)(1.5) = 6.18 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(15.2 ft)(0.297)(1.75) = 1.98 kip/ft

P_H = 6.18 kip/ft + 1.98 kip/ft = 8.16 kip/ft

Sliding Force at Bottom of Foundation Preparation:

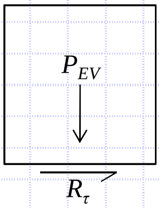
$P_{EH} = \frac{1}{2}\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(15.2 ft + 1 ft)²(0.297)(1.5) = 7.02 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(15.2 ft + 1 ft)(0.297)(1.75) = 2.1 kip/ft

P_H = 7.02 kip/ft + 2.1 kip/ft = 9.12 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(15.2 ft + 1 ft)(10.6 ft)(1.00) = 20.61 kip/ft

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

R_τ = (20.61 kip/ft)(0.51) = 10.51 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \leq R_\tau \cdot \phi_\tau \longrightarrow$ 9.12 kip/ft ≤ (10.51 kip/ft)(1.0) = 10.51 kip/ft ⟶ 9.12 kip/ft ≤ 10.51 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) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	12.0 ft		

LRFD Load Factors

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

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

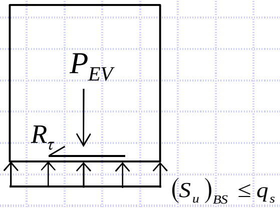
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



$(S_u)_{BS} =$ 1.50 ksf

$q_s = \sigma_v / 2$ = (1.94 ksf) / 2 = 0.97 ksf

$\sigma_v = P_{EV} / B$ = (20.61 kip/ft) / (10.6 ft) = 1.94 ksf

R_τ = (1.50 ksf ≤ 0.97 ksf)(10.6 ft) = 10.28 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

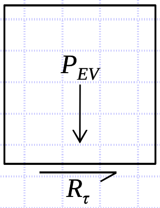
$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 9.12 kip/ft ≤ (10.28 kip/ft)(1.0) = 10.28 kip/ft ⟶ 9.12 kip/ft ≤ 10.28 kip/ft **OK**

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance:

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



$P_{EV} = \gamma_{BF}\cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(15.2 ft)(10.6 ft)(1.00) = 19.33 kip/ft

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

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

R_τ = (19.33 kip/ft)(0.67) = 12.95 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 8.16 kip/ft ≤ (12.95 kip/ft)(1.0) = 12.95 kip/ft ⟶ 8.16 kip/ft ≤ 12.95 kip/ft **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	12.0 ft		

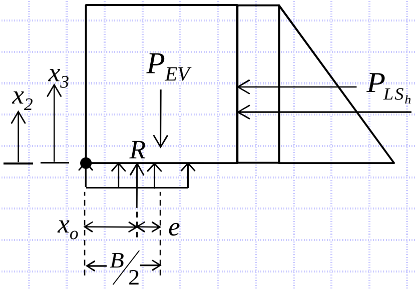
LRFD Load Factors

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

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (102.45 kip·ft/ft - 46.38 kip·ft/ft) / (19.33 kip/ft) = 2.90 ft

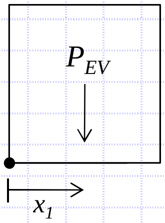
M_{EV} = 102.45 kip·ft/ft
M_H = 46.38 kip·ft/ft
P_{EV} = 19.33 kip/ft

Defined below

$e =$ (10.6 ft)/2 - 2.9 ft = 2.40 ft

Resisting Moment, M_{EV}:

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



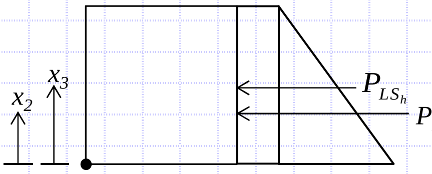
$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(15.2 ft)(10.6 ft)(1.00) = 19.33 kip/ft

$x_1 = B/2$ = (10.6 ft) / 2 = 5.30 ft

M_{EV} = (19.33 kip/ft)(5.30 ft) = 102.45 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = ½\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(15.2 ft)²(0.297)(1.5) = 6.18 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(15.2 ft)(0.297)(1.75) = 1.98 kip/ft

$x_2 = H/3$ = (15.2 ft) / 3 = 5.07 ft

$x_3 = H/2$ = (15.2 ft) / 2 = 7.60 ft

M_H = (6.18 kip/ft)(5.07 ft) + (1.98 kip/ft)(7.60 ft) = 46.38 kip·ft/ft

Check Eccentricity

$e < e_{max} \longrightarrow$ 2.40 ft < 3.53 ft **OK**

Limiting Eccentricity: $e_{max} = B/3 \longrightarrow e_{max}$ = (10.6 ft) / 3 = 3.53 ft

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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 ^{1}:

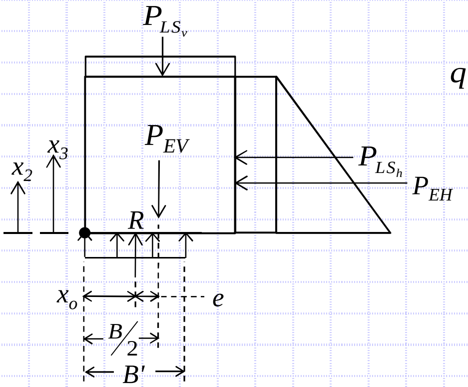
	Bearing		Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115		115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27		27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0		0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500		1500	psf
Embedment Depth, (D_f) =	3.0	ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	12.0	ft		

LRFD Load Factors

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 10.6 ft - 2(1.51 ft) = 7.58 ft

$e = B/2 - x_o$ = (10.6 ft) / 2 - 3.79 ft = 1.51 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (162.92 kip·ft/ft - 46.32 kip·ft/ft) / 30.74 kip/ft = 3.79 ft

$q_{eq} =$ (30.74 kip/ft) / (7.58 ft) = 4.06 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)(15.2 ft)(10.6 ft)(1.35)](5.3 ft) + [(250 psf)(10.6 ft)(1.75)](5.3 ft) = 162.92 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)(15.2 ft)²(0.297)(1.5)](5.07 ft) + [(250 psf)(15.2 ft)(0.297)(1.75)](7.6 ft) = 46.32 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)(15.2 ft)(10.6 ft)(1.35) + (250 psf)(10.6 ft)(1.75) = 30.74 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 24.11

N_c = 23.94
s_c = 1+(7.58 ft/585 ft)(13.2/23.94)
= 1.007
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.70

N_q = 13.20
s_q = 1.000
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/7.58 ft)
1.114
i_q = 1.000 (Assumed)
C_{wq} = 12.0 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 14.40

N_γ = 14.47
s_γ = 0.995
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 12.0 ft < 1.5(7.58 ft) + 3.0 ft = 1.028

$q_n =$ (0 psf)(24.108) + (115 pcf)(3.0 ft)(14.705)(1.000) + ½(115 pcf)(7.6 ft)(14.398)(1.028) = 11.52 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ $\longrightarrow$ 4.06 ksf ≤ (11.52 ksf)(0.65) = 7.49 ksf $\longrightarrow$ 4.06 ksf ≤ 7.49 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	12.0 ft		

LRFD Load Factors

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

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140

s_c = 1+(7.58 ft/[(5)(585 ft)]) = 1.007

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/7.58 ft)

1.000

i_q = 1.000 (Assumed)

C_{wq} = 12.0 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)

$C_{w\gamma}$ = 12.0 ft < 1.5(7.58 ft) + 3.0 ft = 1.028

q_n = (1500 psf)(5.180) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(7.6 ft)(0.000)(1.028) = 8.12 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 4.06 ksf ≤ (8.12 ksf)(0.65) = 5.28 ksf ⟶ 4.06 ksf ≤ 5.28 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 6 OF 6
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/26/2022
Retaining Wall 5B - Sta. 10+00 to 12+00 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.2	ft
MSE Wall Width (Reinforcement Length), (B) =	10.6	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	27	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0		ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	12.0		ft

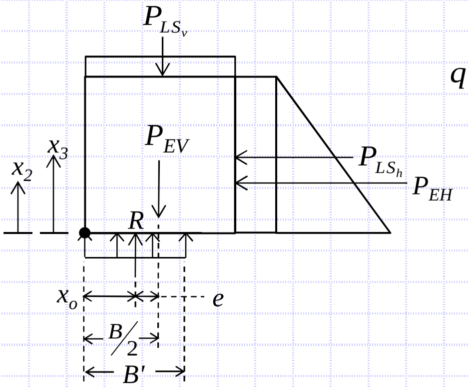
LRFD Load Factors

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

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e$$ = 10.6 ft - 2(1.34 ft) = 7.92 ft

$$e = {B}/{2} - x_o$$ = (10.6 ft) / 2 - 3.96 ft = 1.34 ft

$$x_o = \frac{M_V - M_H}{P_V}$$ = (116.52 kip·ft/ft - 29.45 kip·ft/ft) / 21.98 kip/ft = 3.96 ft

q_{eq} = (21.98 kip/ft) / (7.92 ft) = 2.78 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)(15.2 ft)(10.6 ft)(1.00)](5.3 ft) + [(250 psf)(10.6 ft)(1.00)](5.3 ft) = 116.52 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)(15.2 ft)²(0.297)(1.00)](5.07 ft) + [(250 psf)(15.2 ft)(0.297)(1.00)](7.6 ft) = 29.45 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)(15.2 ft)(10.6 ft)(1.00) + (250 psf)(10.6 ft)(1.00) = 21.98 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
B-041-0-19	10+50	1.299 in	1.002 in	6 days		
B-045-0-19	13+50	1.721 in	1.311 in	8 days	300 ft	1 in / 970 ft
B-047-0-19	14+55	1.885 in	1.345 in	4 days	105 ft	1 in / 3,050 ft
B-007-0-65	15+85	0.997 in	0.777 in	80 days	130 ft	1 in / 230 ft
B-070-0-19	17+96	2.222 in	1.643 in	155 days	211 ft	1 in / 240 ft
B-086-0-19	18+30	1.575 in	1.145 in	5 days	34 ft	1 in / 70 ft
B-088-0-19	20+00	1.840 in	1.350 in	27 days	170 ft	1 in / 830 ft
B-089-0-19	21+95	1.084 in	0.814 in	27 days	195 ft	1 in / 360 ft

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 10+00 to 12+00 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-041-0-19

H =	15.2	ft	Wall height
B =	10.6	ft	Width of wall
D_w =	12.0	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	1,824	psf	Bearing pressure at bottom of wall

																				Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6a	C	0.0	1.8	787.8	786.0	1.8	0.9	115	207	104	104	3,104	33	0.207	0.021	0.530				0.08	0.998	1,820	1,924	0.031	0.371	0.500	912	1,015	0.024	0.290
	A-6a	C	1.8	3.8	786.0	784.0	2.0	2.8	115	437	322	322	3,322	33	0.207	0.021	0.530				0.26	0.954	1,739	2,061	0.022	0.262	0.496	905	1,227	0.016	0.189
2	A-2-4	G	3.8	6.3	784.0	781.5	2.5	5.1	125	750	593	593	3,593					16	23	80	0.48	0.833	1,520	2,113	0.017	0.207	0.482	879	1,473	0.012	0.148
	A-2-4	G	6.3	8.8	781.5	779.0	2.5	7.6	125	1,062	906	906	3,906					16	20	75	0.71	0.689	1,257	2,163	0.013	0.152	0.453	827	1,733	0.009	0.113
3	A-6a	C	8.8	11.3	779.0	776.5	2.5	10.1	120	1,362	1,212	1,212	4,212	28	0.162	0.016	0.491				0.95	0.572	1,043	2,255	0.007	0.088	0.417	761	1,973	0.006	0.069
4	A-4a	C	11.3	13.8	776.5	774.0	2.5	12.6	115	1,650	1,506	1,471	4,471	23	0.117	0.012	0.452				1.18	0.483	880	2,352	0.004	0.049	0.380	693	2,165	0.003	0.041
5	A-6a	C	13.8	16.3	774.0	771.5	2.5	15.1	120	1,950	1,800	1,609	4,609	28	0.162	0.016	0.491				1.42	0.415	757	2,366	0.005	0.055	0.345	630	2,239	0.004	0.047
6	A-4a	C	16.3	18.8	771.5	769.0	2.5	17.6	120	2,250	2,100	1,753	4,753	23	0.117	0.012	0.452				1.66	0.363	662	2,415	0.003	0.034	0.314	572	2,326	0.002	0.030
7	A-2-4	G	18.8	21.3	769.0	766.5	2.5	20.1	135	2,587	2,418	1,916	4,916					42	43	140	1.89	0.322	587	2,503	0.002	0.025	0.286	522	2,438	0.002	0.022
8	A-4a	C	21.3	28.3	766.5	759.5	7.0	24.8	125	3,462	3,025	2,226	5,226	23	0.117	0.012	0.452				2.34	0.264	482	2,708	0.005	0.058	0.244	444	2,670	0.004	0.054
																						Total Settlement:			1.299 in		Total Settlement:			1.002 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 10+00 to 12+00 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-041-0-19

H = 15.2 ft Wall height
B = 10.6 ft Width of wall
D_w = 12.0 ft Depth below bottom of wall
γ_{BF} = 120 Unit weight of backfill
q = 1,824 psf Bearing pressure at bottom of wall

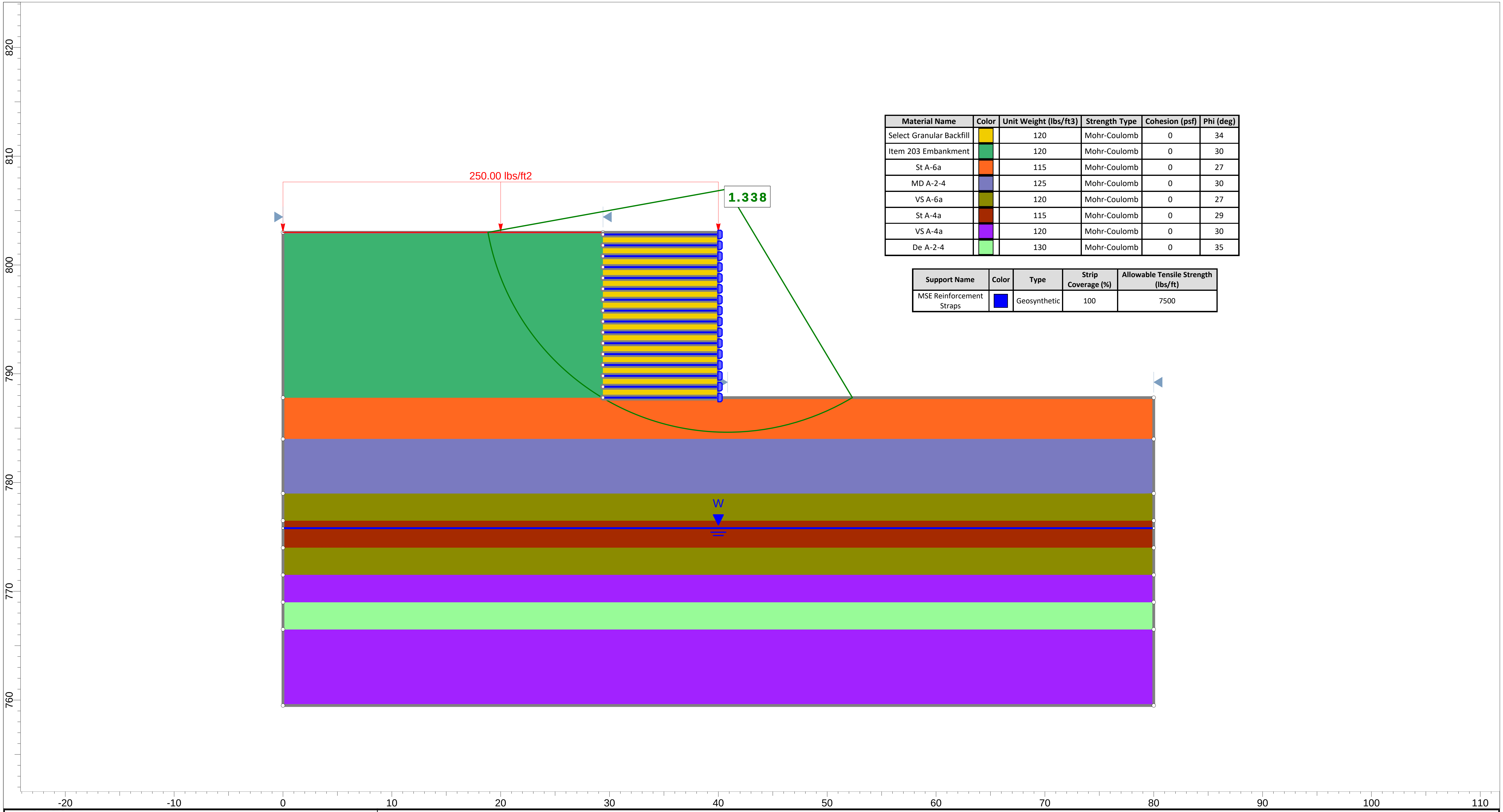
t = 6 days Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 91% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness H (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' (1) (psf)**	**LL**	**C_c (2)**	**C_r (3)**	**e_o (4)**	**N_{60}**	**$(N1)_{60}$ (5)**	**C' (6)**	**Z_f/B**	**I (7)**	**$\Delta\sigma_v$ (8) (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c (9,10) (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ (11) (in)**	**Layer Settlement (in)**
1	A-6a	C	0.0	1.8	787.8	786.0	1.8	0.9	115	207	104	104	3,104	33	0.207	0.021	0.530				0.08	0.500	912	1,015	0.024	0.290	0.478	300	1.8	1.522	98	0.284	0.467
	A-6a	C	1.8	3.8	786.0	784.0	2.0	2.8	115	437	322	322	3,322	33	0.207	0.021	0.530				0.26	0.496	905	1,227	0.016	0.189		300	1.9	1.366	97	0.183	
2	A-2-4	G	3.8	6.3	784.0	781.5	2.5	5.1	125	750	593	593	3,593					16	23	80	0.48	0.482	879	1,473	0.012	0.148	0.261				100	0.148	0.261
	A-2-4	G	6.3	8.8	781.5	779.0	2.5	7.6	125	1,062	906	906	3,906					16	20	75	0.71	0.453	827	1,733	0.009	0.113					100	0.113	
3	A-6a	C	8.8	11.3	779.0	776.5	2.5	10.1	120	1,362	1,212	1,212	4,212	28	0.162	0.016	0.491				0.95	0.417	761	1,973	0.006	0.069	0.069	300	2.5	0.789	88	0.061	0.061
4	A-4a	C	11.3	13.8	776.5	774.0	2.5	12.6	115	1,650	1,506	1,471	4,471	23	0.117	0.012	0.452				1.18	0.380	693	2,165	0.003	0.041	0.041	400	5.0	0.263	58	0.024	0.024
5	A-6a	C	13.8	16.3	774.0	771.5	2.5	15.1	120	1,950	1,800	1,609	4,609	28	0.162	0.016	0.491				1.42	0.345	630	2,239	0.004	0.047	0.047	300	5.0	0.197	50	0.023	0.023
6	A-4a	C	16.3	18.8	771.5	769.0	2.5	17.6	120	2,250	2,100	1,753	4,753	23	0.117	0.012	0.452				1.66	0.314	572	2,326	0.002	0.030	0.030	400	2.5	1.052	94	0.028	0.028
7	A-2-4	G	18.8	21.3	769.0	766.5	2.5	20.1	135	2,587	2,418	1,916	4,916					42	43	140	1.89	0.286	522	2,438	0.002	0.022	0.022				100	0.022	0.022
8	A-4a	C	21.3	28.3	766.5	759.5	7.0	24.8	125	3,462	3,025	2,226	5,226	23	0.117	0.012	0.452				2.34	0.244	444	2,670	0.004	0.054	0.054	400	7.0	0.134	41	0.022	0.022

$(S_c)_t$ = 0.908 in

Settlement Remaining After Hold Period: 0.093 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 2,000 psf for slightly to moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6a	🟧	115	Mohr-Coulomb	0	27
MD A-2-4	🟦	125	Mohr-Coulomb	0	30
VS A-6a	🟫	120	Mohr-Coulomb	0	27
St A-4a	🟥	115	Mohr-Coulomb	0	29
VS A-4a	🟪	120	Mohr-Coulomb	0	30
De A-2-4	🟩	130	Mohr-Coulomb	0	35

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

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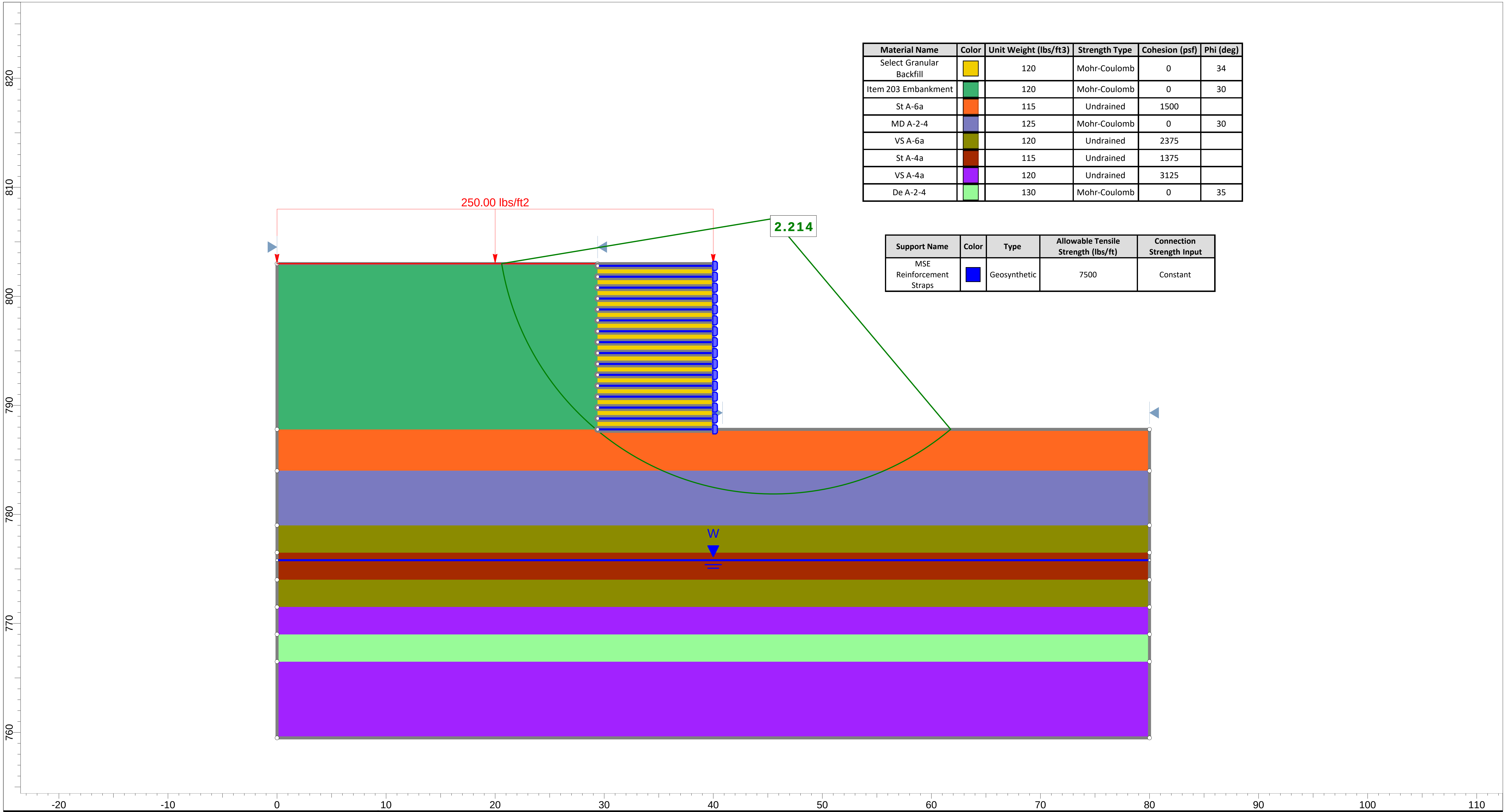
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 10+00 to 12+00 (BL Wall 5B) - B-041-0-19 - Level Backfill - 15.2 ft. Wall Height - Drained - Circular
Drawn By	Reource International, Inc.
Scale	1:100
Company	BRT
Date	4/1/2022, 11:49:36 PM
File Name	Wall 5B - Sta. 10+00 to 12+00 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6a	🟧	115	Undrained	1500	
MD A-2-4	🟦	125	Mohr-Coulomb	0	30
VS A-6a	🟫	120	Undrained	2375	
St A-4a	🟥	115	Undrained	1375	
VS A-4a	🟪	120	Undrained	3125	
De A-2-4	🟩	130	Mohr-Coulomb	0	35

Support Name	Color	Type	Allowable Tensile Strength (lbs/ft)	Connection Strength Input
MSE Reinforcement Straps	🟦	Geosynthetic	7500	Constant

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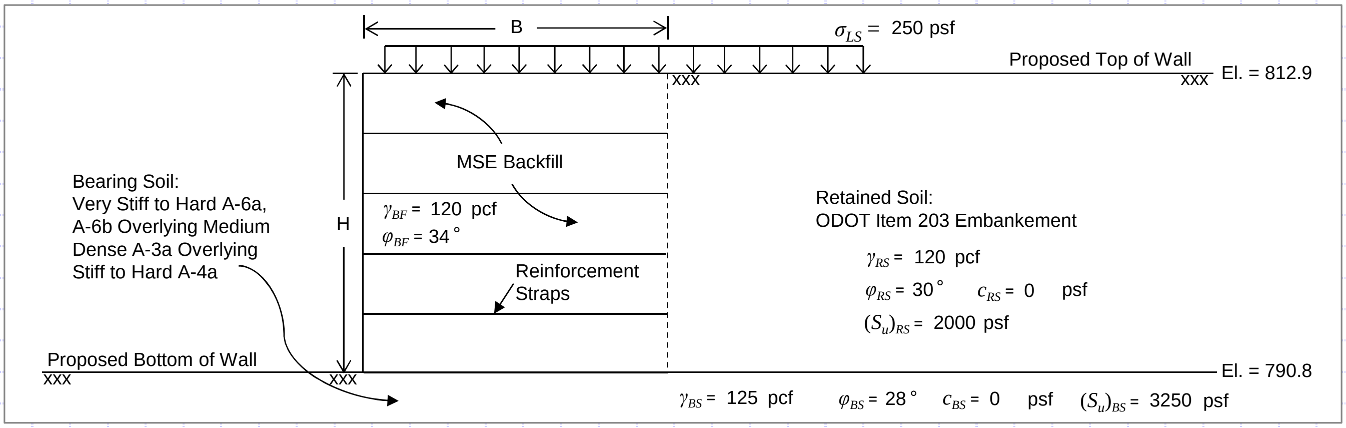
Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 10+00 to 12+00 (BL Wall 5B) - B-041-0-19 - Level Backfill - 15.2 ft. Wall Height - Undrained - Circular
Drawn By	Reource International, Inc.
Scale	1:100
Company	BRT
Date	4/1/2022, 11:49:36 PM
File Name	Wall 5B - Sta. 10+00 to 12+00 - Global Stability.slmd

Retaining Wall 5B - Sta. 12+00 to 14+25 (BL Wall 5B) - B-045-0-19 - Level Backfill - 22.1 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	22.1	ft
MSE Wall Width (Reinforcement Length), (B) =	15.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	3250	3250	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	11.1 ft		

LRFD Load Factors

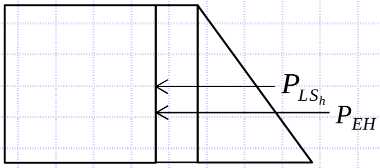
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = \frac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(22.1 ft)²(0.297)(1.5) = 13.06 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(22.1 ft)(0.297)(1.75) = 2.87 kip/ft

P_H = 13.06 kip/ft + 2.87 kip/ft = 15.93 kip/ft

Sliding Force at Bottom of Foundation Preparation:

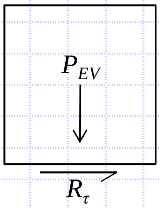
$P_{EH} = \frac{1}{2}\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(22.1 ft + 1 ft)²(0.297)(1.5) = 14.26 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(22.1 ft + 1 ft)(0.297)(1.75) = 3 kip/ft

P_H = 14.26 kip/ft + 3 kip/ft = 17.26 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(22.1 ft + 1 ft)(15.5 ft)(1.00) = 42.97 kip/ft

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

R_τ = (42.97 kip/ft)(0.53) = 22.77 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 17.26 kip/ft ≤ (22.77 kip/ft)(1.0) = 22.77 kip/ft ⟶ 17.26 kip/ft ≤ 22.77 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) =	22.1	ft
MSE Wall Width (Reinforcement Length), (B) =	15.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3250	3250	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.1 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)

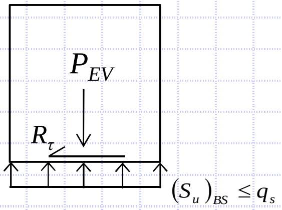
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



$$(S_u)_{BS} = \quad 3.25 \quad \text{ksf}$$

$$q_s = \sigma_v / 2 \quad = \quad (2.77\ \text{ksf}) / 2 \quad = \quad 1.39 \quad \text{ksf}$$

$$\sigma_v = P_{EV} / B \quad = \quad (42.97\ \text{kip/ft}) / (15.5\ \text{ft}) \quad = \quad 2.77 \quad \text{ksf}$$

$$R_\tau \ = \ (3.25\ \text{ksf} \leq 1.39\ \text{ksf})(15.5\ \text{ft}) \quad = \quad 21.55 \quad \text{kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

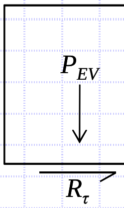
$P_H \leq R_\tau \cdot \phi_\tau$ ⟶ 17.26 kip/ft ≤ (21.55 kip/ft)(1.0) = 21.55 kip/ft ⟶ 17.26 kip/ft ≤ 21.55 kip/ft **OK**

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance:

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



$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \quad (120\ \text{pcf})(22.1\ \text{ft})(15.5\ \text{ft})(1.00) \quad = \quad 41.11 \quad \text{kip/ft}$$

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

$$\tan\delta = \quad \tan(34) \leq \tan(34) \longrightarrow 0.67 \leq 0.67 \longrightarrow \tan\delta = \quad 0.67$$

$$R_\tau \ = \ (41.11\ \text{kip/ft})(0.67) \quad = \quad 27.54 \quad \text{kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \leq R_\tau \cdot \phi_\tau$ ⟶ 15.93 kip/ft ≤ (27.54 kip/ft)(1.0) = 27.54 kip/ft ⟶ 15.93 kip/ft ≤ 27.54 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) = 22.1 ft
MSE Wall Width (Reinforcement Length), (B) = 15.5 ft
MSE Wall Length, (L) = 585 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_{RS}) = 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 [1]:

	Bearing	Sliding
Bearing Soil Unit Weight, (γ_{BS}) =	125	125 pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28 °
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0 psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3250	3250 psf
Embedment Depth, (D_f) =	3.0 ft	
Depth to Groundwater (Below Bot. of Wall), (D_W) =	11.1 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)

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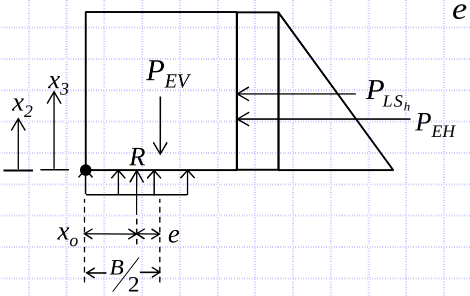
[1] Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



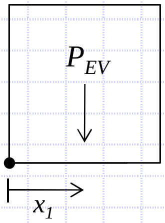
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(318.6 kip·ft/ft - 127.97 kip·ft/ft) / (41.11 kip/ft)} = 4.64 \text{ ft}$$

M_{EV} = 318.60 kip·ft/ft
M_H = 127.97 kip·ft/ft
P_{EV} = 41.11 kip/ft
Defined below

$$e = \text{(15.5 ft)/2 - 4.64 ft} = 3.11 \text{ ft}$$

Resisting Moment, M_{EV}:



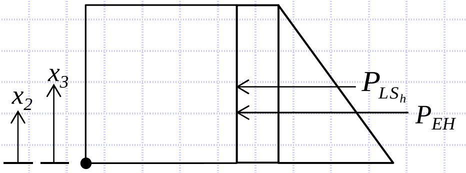
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(22.1 ft)(15.5 ft)(1.00)} = 41.11 \text{ kip/ft}$$

$$x_1 = B/2 = \text{(15.5 ft) / 2} = 7.75 \text{ ft}$$

$$M_{EV} = \text{(41.11 kip/ft)(7.75 ft)} = 318.60 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(22.1 ft)²(0.297)(1.5)} = 13.06 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(22.1 ft)(0.297)(1.75)} = 2.87 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(22.1 ft) / 3} = 7.37 \text{ ft}$$

$$x_3 = H/2 = \text{(22.1 ft) / 2} = 11.05 \text{ ft}$$

$$M_H = \text{(13.06 kip/ft)(7.37 ft) + (2.87 kip/ft)(11.05 ft)} = 127.97 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.11 ft < 5.17 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} = \text{(15.5 ft) / 3} = 5.17$ ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	4	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 12+00 to 14+25 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	22.1	ft
MSE Wall Width (Reinforcement Length), (B) =	15.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3250	3250	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.1 ft		

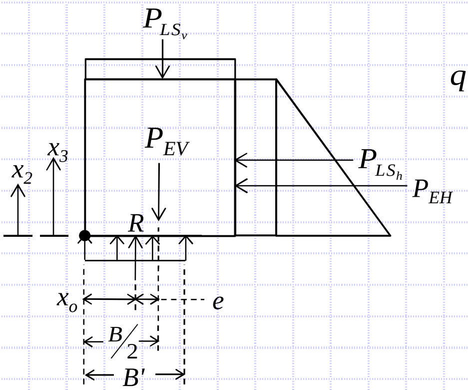
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



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

$B' = B - 2e$ = 15.5 ft - 2(2.05 ft) = 11.40 ft

$e = B/2 - x_o$ = (15.5 ft) / 2 - 5.7 ft = 2.05 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (482.63 kip·ft/ft - 127.95 kip·ft/ft) / 62.27 kip/ft = 5.70 ft

$q_{eq} =$ (62.27 kip/ft) / (11.4 ft) = 5.46 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)(22.1 ft)(15.5 ft)(1.35)](7.75 ft) + [(250 psf)(15.5 ft)(1.75)](7.75 ft) = 482.63 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)(22.1 ft)²(0.297)(1.5)](7.37 ft) + [(250 psf)(22.1 ft)(0.297)(1.75)](11.05 ft) = 127.95 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)(22.1 ft)(15.5 ft)(1.35) + (250 psf)(15.5 ft)(1.75) = 62.27 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 26.08

N_c = 25.8
s_c = 1+(11.4 ft/585 ft)(14.72/25.8)
= 1.011
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 15.85

N_q = 14.72
s_q = 1.000
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/11.4 ft)
1.077
i_q = 1.000 (Assumed)
C_{wq} = 11.1 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)
$C_{w\gamma}$ = 11.1 ft < 1.5(11.4 ft) + 3.0 ft = 0.825

$q_n =$ (0 psf)(26.084) + (125 pcf)(3.0 ft)(15.853)(1.000) + ½(125 pcf)(11.4 ft)(16.586)(0.825) = 15.69 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 5.46 ksf ≤ (15.69 ksf)(0.65) = 10.20 ksf ⟶ 5.46 ksf ≤ 10.20 ksf **OK**

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 12+00 to 14+25 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	22.1	ft
MSE Wall Width (Reinforcement Length), (B) =	15.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3250	3250	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.1 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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140
s_c = 1+(11.4 ft/[(5)(585 ft)]) = 1.007
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/11.4 ft)
1.000
i_q = 1.000 (Assumed)
C_{wq} = 11.1 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)
$C_{w\gamma}$ = 11.1 ft < 1.5(11.4 ft) + 3.0 ft = 0.825

$q_n =$ (3250 psf)(5.180) + (125 pcf)(3.0 ft)(1.000)(1.000) + ½(125 pcf)(11.4 ft)(0.000)(0.825) = 17.21 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ $\longrightarrow$ 5.46 ksf ≤ (17.21 ksf)(0.65) = 11.19 ksf $\longrightarrow$ 5.46 ksf ≤ 11.19 ksf **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	22.1	ft
MSE Wall Width (Reinforcement Length), (B) =	15.5	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	125	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	28	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3250	3250	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.1 ft		

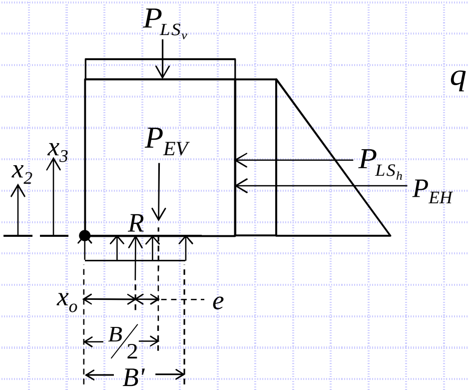
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 15.5 ft - 2(1.83 ft) = 11.84 ft

$e = B/2 - x_o$ = (15.5 ft) / 2 - 5.92 ft = 1.83 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (348.60 kip·ft/ft - 82.28 kip·ft/ft) / 44.98 kip/ft = 5.92 ft

q_{eq} = (44.98 kip/ft) / (11.84 ft) = 3.80 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)(22.1 ft)(15.5 ft)(1.00)](7.8 ft) + [(250 psf)(15.5 ft)(1.00)](7.8 ft) = 348.60 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)(22.1 ft)²(0.297)(1.00)](7.37 ft) + [(250 psf)(22.1 ft)(0.297)(1.00)](11.05 ft) = 82.28 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)(22.1 ft)(15.5 ft)(1.00) + (250 psf)(15.5 ft)(1.00) = 44.98 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
B-041-0-19	10+50	1.299 in	1.002 in	6 days		
B-045-0-19	13+50	1.721 in	1.311 in	8 days	300 ft	1 in / 970 ft
B-047-0-19	14+55	1.885 in	1.345 in	4 days	105 ft	1 in / 3,050 ft
B-007-0-65	15+85	0.997 in	0.777 in	80 days	130 ft	1 in / 230 ft
B-070-0-19	17+96	2.222 in	1.643 in	155 days	211 ft	1 in / 240 ft
B-086-0-19	18+30	1.575 in	1.145 in	5 days	34 ft	1 in / 70 ft
B-088-0-19	20+00	1.840 in	1.350 in	27 days	170 ft	1 in / 830 ft
B-089-0-19	21+95	1.084 in	0.814 in	27 days	195 ft	1 in / 360 ft

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 12+00 to 14+25 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-045-0-19

H =	22.1	ft	Wall height
B =	15.5	ft	Width of wall
D_w =	11.1	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	2,652	psf	Bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6a	C	0.0	2.5	790.8	788.3	2.5	1.3	125	313	156	156	3,156	33	0.207	0.021	0.530				0.08	0.998	2,647	2,804	0.042	0.509	0.500	1,326	1,482	0.033	0.397
	A-6a	C	2.5	5.1	788.3	785.7	2.6	3.8	125	638	475	475	3,475	33	0.207	0.021	0.530				0.25	0.961	2,550	3,025	0.028	0.339	0.497	1,318	1,793	0.020	0.244
2	A-2-4	G	5.1	7.6	785.7	783.2	2.5	6.4	130	963	800	800	3,800					38	50	168	0.41	0.875	2,321	3,121	0.009	0.106	0.488	1,294	2,094	0.006	0.075
3	A-6b	C	7.6	10.1	783.2	780.7	2.5	8.9	130	1,288	1,125	1,125	4,125	35	0.225	0.023	0.546				0.57	0.773	2,051	3,176	0.016	0.197	0.472	1,252	2,377	0.012	0.142
	A-6b	C	10.1	12.6	780.7	778.2	2.5	11.4	130	1,613	1,450	1,434	4,434	35	0.225	0.023	0.546				0.73	0.678	1,798	3,232	0.013	0.154	0.451	1,195	2,629	0.010	0.115
4	A-3a	G	12.6	15.1	778.2	775.7	2.5	13.9	125	1,925	1,769	1,597	4,597					17	18	64	0.89	0.596	1,581	3,178	0.012	0.140	0.426	1,130	2,727	0.009	0.109
	A-3a	G	15.1	17.6	775.7	773.2	2.5	16.4	125	2,238	2,081	1,754	4,754					17	18	63	1.05	0.528	1,401	3,154	0.010	0.121	0.400	1,062	2,816	0.008	0.098
5	A-4a	C	17.6	20.1	773.2	770.7	2.5	18.9	120	2,538	2,388	1,904	4,904	22	0.108	0.011	0.444				1.22	0.472	1,252	3,156	0.004	0.049	0.375	995	2,899	0.003	0.041
6	A-4a	C	20.1	23.6	770.7	767.2	3.5	21.9	125	2,975	2,756	2,085	5,085	22	0.108	0.011	0.444				1.41	0.418	1,107	3,193	0.005	0.058	0.347	919	3,005	0.004	0.050
	A-4a	C	23.6	27.1	767.2	763.7	3.5	25.4	125	3,413	3,194	2,305	5,305	22	0.108	0.011	0.444				1.64	0.367	973	3,278	0.004	0.048	0.316	839	3,144	0.004	0.042
																						Total Settlement:			1.721 in		Total Settlement:			1.311 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 12+00 to 14+25 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-045-0-19

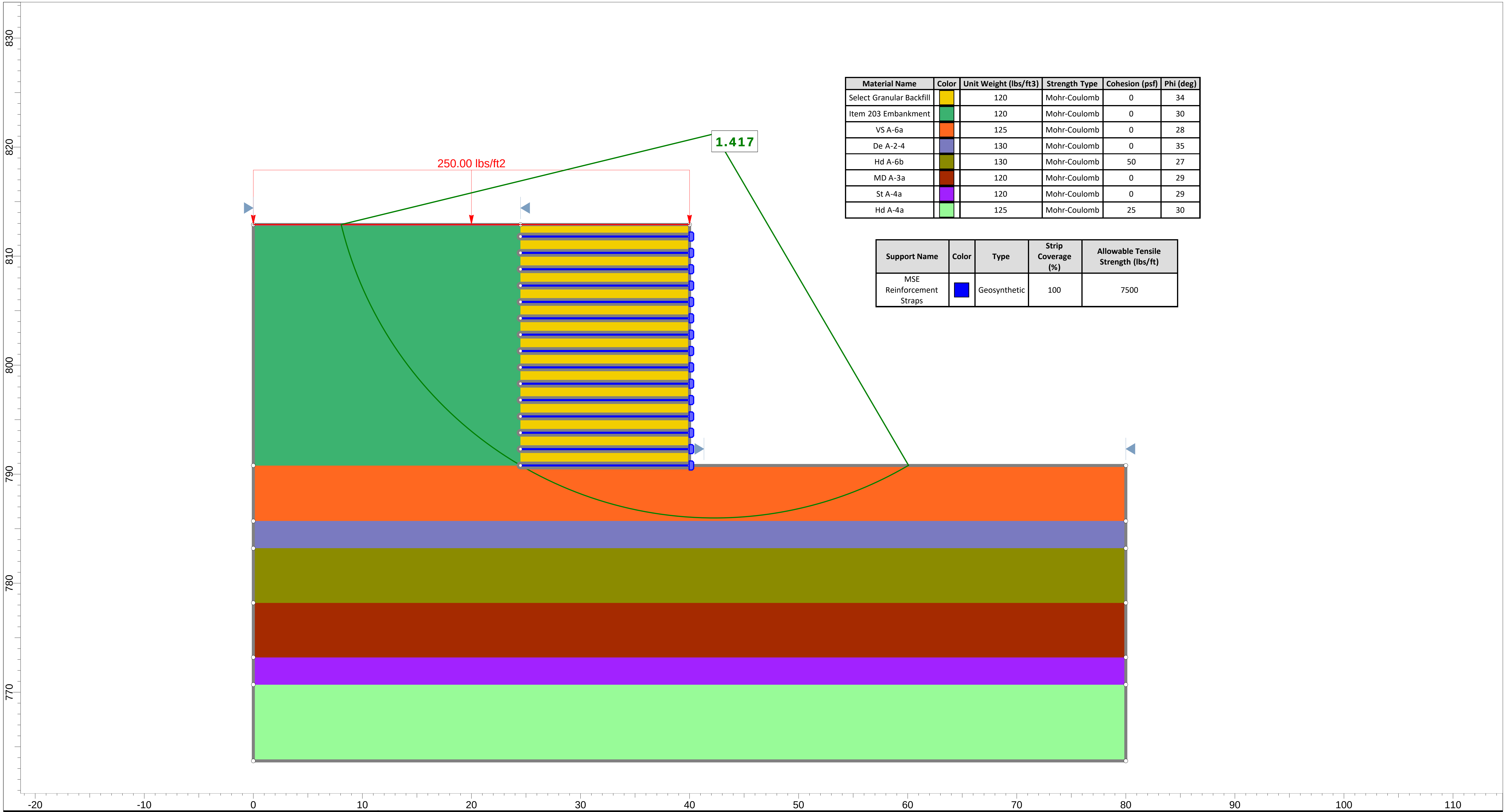
H =	22.1	ft	Wall height
B =	15.5	ft	Width of wall
D_w =	11.1	ft	Depth below bottom of wall
γ_{BF} =	120		Unit weight of backfill
q =	2,652	psf	Bearing pressure at bottom of wall
t =	8	days	Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.5	790.8	788.3	2.5	1.3	125	313	156	156	3,156	33	0.207	0.021	0.530				0.08	0.500	1,326	1,482	0.033	0.397	0.640	300	2.5	1.052	94	0.373	0.599
	A-6a	C	2.5	5.1	788.3	785.7	2.6	3.8	125	638	475	475	3,475	33	0.207	0.021	0.530				0.25	0.497	1,318	1,793	0.020	0.244		300	2.6	1.011	93	0.226	
2	A-2-4	G	5.1	7.6	785.7	783.2	2.5	6.4	130	963	800	800	3,800					38	50	168	0.41	0.488	1,294	2,094	0.006	0.075	0.075				100	0.075	0.075
3	A-6b	C	7.6	10.1	783.2	780.7	2.5	8.9	130	1,288	1,125	1,125	4,125	35	0.225	0.023	0.546				0.57	0.472	1,252	2,377	0.012	0.142	0.257	200	2.5	0.701	86	0.122	0.221
	A-6b	C	10.1	12.6	780.7	778.2	2.5	11.4	130	1,613	1,450	1,434	4,434	35	0.225	0.023	0.546				0.73	0.451	1,195	2,629	0.010	0.115		200	2.5	0.701	86	0.099	
4	A-3a	G	12.6	15.1	778.2	775.7	2.5	13.9	125	1,925	1,769	1,597	4,597					17	18	64	0.89	0.426	1,130	2,727	0.009	0.109	0.206				100	0.109	0.206
	A-3a	G	15.1	17.6	775.7	773.2	2.5	16.4	125	2,238	2,081	1,754	4,754					17	18	63	1.05	0.400	1,062	2,816	0.008	0.098					100	0.098	
5	A-4a	C	17.6	20.1	773.2	770.7	2.5	18.9	120	2,538	2,388	1,904	4,904	22	0.108	0.011	0.444				1.22	0.375	995	2,899	0.003	0.041	0.041	400	2.5	1.403	97	0.040	0.040
6	A-4a	C	20.1	23.6	770.7	767.2	3.5	21.9	125	2,975	2,756	2,085	5,085	22	0.108	0.011	0.444				1.41	0.347	919	3,005	0.004	0.050	0.092	400	6.0	0.244	56	0.028	0.043
	A-4a	C	23.6	27.1	767.2	763.7	3.5	25.4	125	3,413	3,194	2,305	5,305	22	0.108	0.011	0.444				1.64	0.316	839	3,144	0.004	0.042		400	9.5	0.097	35	0.015	

$(S_c)_t$ = 1.183 in

Settlement Remaining After Hold Period: 0.127 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 2,000 psf for slightly to moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, 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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \le \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	125	Mohr-Coulomb	0	28
De A-2-4	🟦	130	Mohr-Coulomb	0	35
Hd A-6b	🟫	130	Mohr-Coulomb	50	27
MD A-3a	🟥	120	Mohr-Coulomb	0	29
St A-4a	🟪	120	Mohr-Coulomb	0	29
Hd A-4a	🟩	125	Mohr-Coulomb	25	30

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

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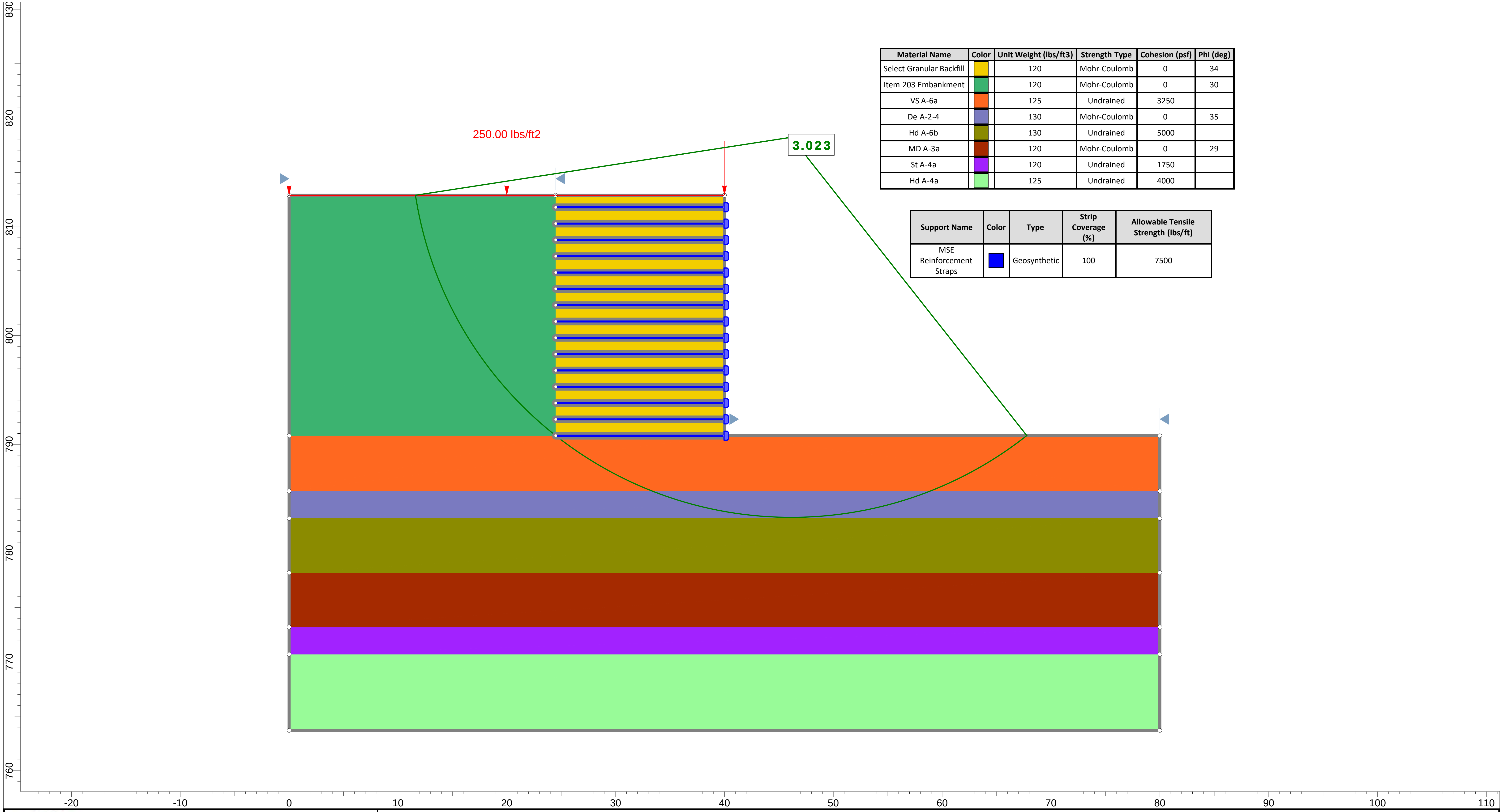
Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 12+00 to 14+25 (BL Wall 5B) - B-045-0-19 - Level Backfill - 22.1 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:100
Company	BRT
Date	4/2/2022, 12:37:48 AM
File Name	Wall 5B - Sta. 12+00 to 14+25 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	125	Undrained	3250	
De A-2-4	🟦	130	Mohr-Coulomb	0	35
Hd A-6b	🟫	130	Undrained	5000	
MD A-3a	🟥	120	Mohr-Coulomb	0	29
St A-4a	🟪	120	Undrained	1750	
Hd A-4a	🟩	125	Undrained	4000	

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

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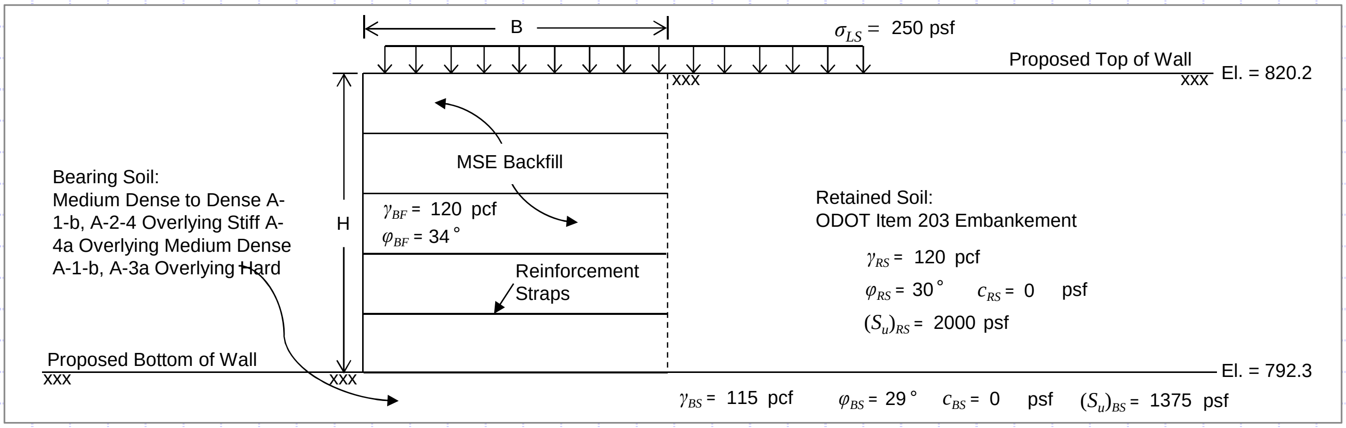
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 12+00 to 14+25 (BL Wall 5B) - B-045-0-19 - Level Backfill - 22.1 ft. Wall Height - Undrained - Circular
Drawn By	Resource International, Inc.
Scale	1:100
Company	BRT
Date	4/2/2022, 12:37:48 AM
File Name	Wall 5B - Sta. 12+00 to 14+25 - Global Stability.slmd

Retaining Wall 5B - Sta. 14+25 to 15+85 (BL Wall 5B) - B-047-0-19 and B-007-0-65 - Level Backfill - 27.9 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	11.9 ft		

LRFD Load Factors

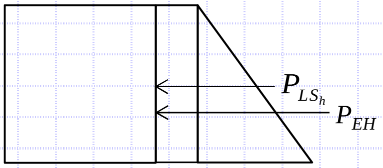
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = \frac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(27.9 ft)²(0.297)(1.5) = 20.81 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(27.9 ft)(0.297)(1.75) = 3.63 kip/ft

P_H = 20.81 kip/ft + 3.63 kip/ft = 24.44 kip/ft

Sliding Force at Bottom of Foundation Preparation:

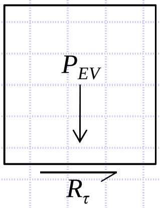
$P_{EH} = \frac{1}{2}\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(27.9 ft + 1 ft)²(0.297)(1.5) = 22.33 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(27.9 ft + 1 ft)(0.297)(1.75) = 3.76 kip/ft

P_H = 22.33 kip/ft + 3.76 kip/ft = 26.09 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(27.9 ft + 1 ft)(19.5 ft)(1.00) = 67.63 kip/ft

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

R_τ = (67.63 kip/ft)(0.60) = 40.58 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 26.09 kip/ft ≤ (40.58 kip/ft)(1.0) = 40.58 kip/ft $\longrightarrow$ 26.09 kip/ft ≤ 40.58 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) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.9 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)

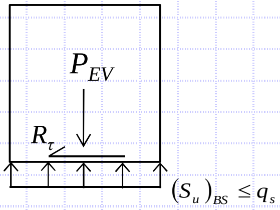
[1] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



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

$$q_s = \sigma_v / 2 \quad = \quad \text{(3.47 ksf) / 2} \quad = \quad 1.74 \quad \text{ksf}$$

$$\sigma_v = P_{EV} / B \quad = \quad \text{(67.63 kip/ft) / (19.5 ft)} \quad = \quad 3.47 \quad \text{ksf}$$

$$R_\tau \quad = \quad \text{(N/A ksf} \le \text{1.74 ksf)(19.5 ft)} \quad = \quad \text{N/A} \quad \text{kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

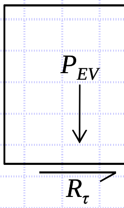
$P_H \le R_\tau \cdot \phi_\tau$ ⟶ N/A ⟶ N/A

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance:

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



$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} \quad = \quad \text{(120 pcf)(27.9 ft)(19.5 ft)(1.00)} \quad = \quad 65.29 \quad \text{kip/ft}$$

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

$$\tan\delta = \quad \tan(34) \le \tan(34) \longrightarrow 0.67 \le 0.67 \longrightarrow \tan\delta = \quad 0.67$$

$$R_\tau \quad = \quad \text{(65.29 kip/ft)(0.67)} \quad = \quad 43.74 \quad \text{kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 24.44 kip/ft ≤ (43.74 kip/ft)(1.0) = 43.74 kip/ft ⟶ 24.44 kip/ft ≤ 43.74 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) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	11.9 ft		

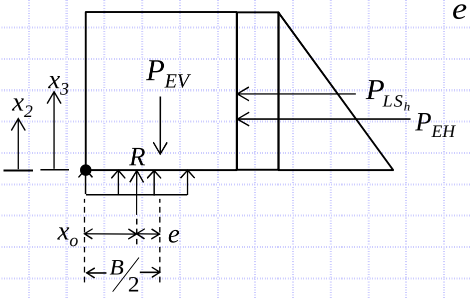
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



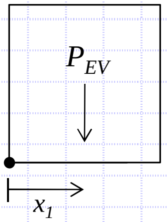
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(636.58 kip·ft/ft - 244.17 kip·ft/ft) / (65.29 kip/ft)} = 6.01 \text{ ft}$$

M_{EV} = 636.58 kip·ft/ft
M_H = 244.17 kip·ft/ft
P_{EV} = 65.29 kip/ft
Defined below

$$e = \text{(19.5 ft)/2 - 6.01 ft} = 3.74 \text{ ft}$$

Resisting Moment, M_{EV}:



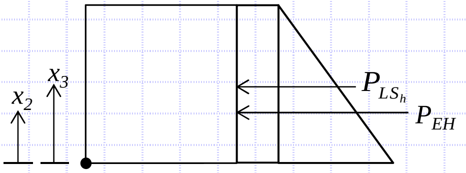
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(27.9 ft)(19.5 ft)(1.00)} = 65.29 \text{ kip/ft}$$

$$x_1 = B/2 = \text{(19.5 ft) / 2} = 9.75 \text{ ft}$$

$$M_{EV} = \text{(65.29 kip/ft)(9.75 ft)} = 636.58 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(27.9 ft)²(0.297)(1.5)} = 20.81 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(27.9 ft)(0.297)(1.75)} = 3.63 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(27.9 ft) / 3} = 9.30 \text{ ft}$$

$$x_3 = H/2 = \text{(27.9 ft) / 2} = 13.95 \text{ ft}$$

$$M_H = \text{(20.81 kip/ft)(9.3 ft) + (3.63 kip/ft)(13.95 ft)} = 244.17 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.74 ft < 6.50 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} = \text{(19.5 ft) / 3} = 6.50 \text{ ft}$

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.9 ft		

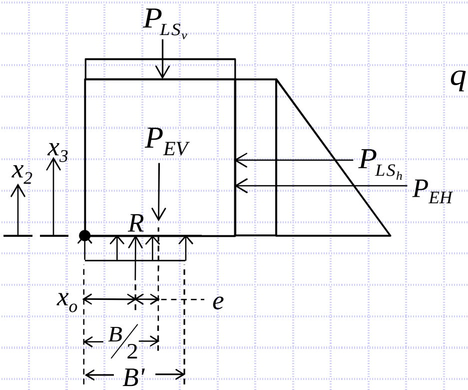
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 19.5\text{ ft} - 2(2.53\text{ ft}) \quad = \quad 14.44 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (19.5\text{ ft}) / 2 - 7.22\text{ ft} \quad = \quad 2.53 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (942.51\text{ kip·ft/ft} - 244.08\text{ kip·ft/ft}) / 96.67\text{ kip/ft} \quad = \quad 7.22 \quad \text{ft}$$

$$q_{eq} = \quad (96.67\text{ kip/ft}) / (14.44\text{ ft}) \quad = \quad 6.69 \quad \text{ksf}$$

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

$$M_V = \quad [(120\text{ pcf})(27.9\text{ ft})(19.5\text{ ft})(1.35)](9.75\text{ ft}) + [(250\text{ psf})(19.5\text{ ft})(1.75)](9.75\text{ ft}) \quad = \quad 942.51 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad [\tfrac{1}{2}(120\text{ pcf})(27.9\text{ ft})^2(0.297)(1.5)](9.3\text{ ft}) + [(250\text{ psf})(27.9\text{ ft})(0.297)(1.75)](13.95\text{ ft}) \quad = \quad 244.08 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad (120\text{ pcf})(27.9\text{ ft})(19.5\text{ ft})(1.35) + (250\text{ psf})(19.5\text{ ft})(1.75) \quad = \quad 96.67 \quad \text{kip/ft}$$

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 28.28

N_c = 27.86
s_c = 1+(14.44 ft/585 ft)(16.44/27.86)
= 1.015
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 17.43

N_q = 16.44
s_q = 1.000
d_q = 1+2tan(29°)[1-sin(29°)]²tan⁻¹(3.0 ft/14.44 ft)
1.060
i_q = 1.000 (Assumed)
C_{wq} = 11.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 19.15

N_γ = 19.34
s_γ = 0.990
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 11.9 ft < 1.5(14.44 ft) + 3.0 ft = 0.775

$$q_n = \quad (0\text{ psf})(28.278) + (115\text{ pcf})(3.0\text{ ft})(17.426)(1.000) + \tfrac{1}{2}(115\text{ pcf})(14.4\text{ ft})(19.147)(0.775) \quad = \quad 18.33 \quad \text{ksf}$$

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 6.69 ksf ≤ (18.33 ksf)(0.65) = 11.91 ksf ⟶ 6.69 ksf ≤ 11.91 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.9 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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ =

N_c =
s_c =
i_c =

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

N_q =
s_q =
d_q =
i_q =
C_{wq} =

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

N_γ =
s_γ =
i_γ =
$C_{w\gamma}$ =

$q_n =$ 12.75 ksf (Bearing Resistance Determined Using Limit Equilibrium Methodology, See Attached Results)

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 6.69 ksf ≤ (12.75 ksf)(0.65) = 8.29 ksf ⟶ 6.69 ksf ≤ 8.29 ksf **OK**

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

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	27.9	ft
MSE Wall Width (Reinforcement Length), (B) =	19.5	ft
MSE Wall Length, (L) =	585	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_{RS}) =	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 ^{1}:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	31	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1375	0	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	11.9 ft		

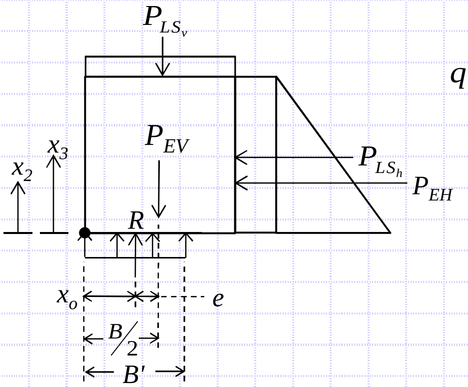
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 19.5\text{ ft} - 2(2.25\text{ ft}) \quad = \quad 15.00 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad (19.5\text{ ft}) / 2 - 7.5\text{ ft} \quad = \quad 2.25 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad (684.07\text{ kip·ft/ft} - 157.9\text{ kip·ft/ft}) / 70.16\text{ kip/ft} \quad = \quad 7.5 \quad \text{ft}$$

$$q_{eq} = \quad (70.16\text{ kip/ft}) / (15\text{ ft}) \quad = \quad 4.68 \quad \text{ksf}$$

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

$$M_V = \quad [(120\text{ pcf})(27.9\text{ ft})(19.5\text{ ft})(1.00)](9.8\text{ ft}) + [(250\text{ psf})(19.5\text{ ft})(1.00)](9.8\text{ ft}) \quad = \quad 684.07 \quad \text{kip·ft/ft}$$

$$M_H = P_{EH}(x_2) + P_{LS_h}(x_3) = (½\gamma_{RS} H^2 K_a \gamma_{EH})(x_2) + (\sigma_{LS} H K_a \gamma_{LS})(x_3)$$

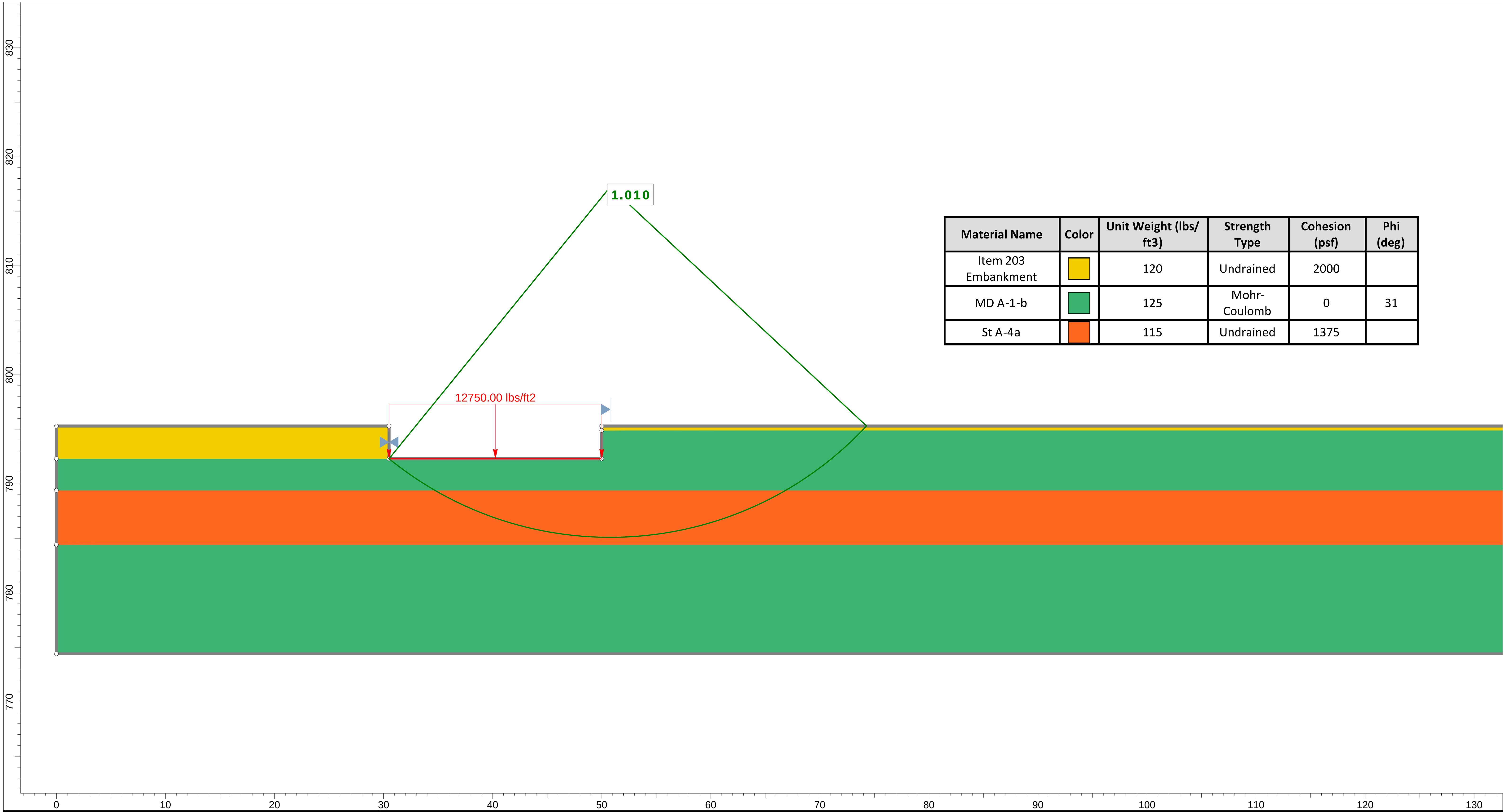
$$M_H = \quad [½(120\text{ pcf})(27.9\text{ ft})^2(0.297)(1.00)](9.3\text{ ft}) + [(250\text{ psf})(27.9\text{ ft})(0.297)(1.00)](13.95\text{ ft}) \quad = \quad 157.90 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad (120\text{ pcf})(27.9\text{ ft})(19.5\text{ ft})(1.00) + (250\text{ psf})(19.5\text{ ft})(1.00) \quad = \quad 70.16 \quad \text{kip/ft}$$

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
B-041-0-19	10+50	1.299 in	1.002 in	6 days		
B-045-0-19	13+50	1.721 in	1.311 in	8 days	300 ft	1 in / 970 ft
B-047-0-19	14+55	1.885 in	1.345 in	4 days	105 ft	1 in / 3,050 ft
B-007-0-65	15+85	0.997 in	0.777 in	80 days	130 ft	1 in / 230 ft
B-070-0-19	17+96	2.222 in	1.643 in	155 days	211 ft	1 in / 240 ft
B-086-0-19	18+30	1.575 in	1.145 in	5 days	34 ft	1 in / 70 ft
B-088-0-19	20+00	1.840 in	1.350 in	27 days	170 ft	1 in / 830 ft
B-089-0-19	21+95	1.084 in	0.814 in	27 days	195 ft	1 in / 360 ft



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟨	120	Undrained	2000	
MD A-1-b	🟩	125	Mohr-Coulomb	0	31
St A-4a	🟧	115	Undrained	1375	

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

SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B - Bearing Resistance
Analysis Description	Sta. 14+25 to 15+85 (BL Wall 5B) - B-047-0-19 and B-007-0-65 - Level Backfill - 27.9 ft. Wall Height - Undrained - Circular - Janbu
Drawn By	BRT
Scale	1:100
Company	Resource International, Inc.
Date	3/26/2022, 2:46:00 PM
File Name	Sta. 14+25 to 15+85 Undrained Bearing - Limit Equilibrium Bearing.slmd

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 14+25 to 15+85 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-047-0-19

H =	27.9	ft	Wall height
B =	19.5	ft	Width of wall
D_w =	16.8	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	3,348	psf	Bearing pressure at bottom of wall

																					Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-1-b	G	0.0	1.4	792.3	790.9	1.4	0.7	125	175	88	88	3,088					20	40	131	0.04	1.000	3,347	3,435	0.017	0.205	0.500	1,674	1,761	0.014	0.168
	A-1-b	G	1.4	2.9	790.9	789.4	1.5	2.2	125	363	269	269	3,269					20	33	109	0.11	0.996	3,334	3,602	0.016	0.186	0.500	1,673	1,942	0.012	0.142
2	A-4a	C	2.9	5.4	789.4	786.9	2.5	4.2	115	650	506	506	3,506	27	0.153	0.015	0.483				0.21	0.973	3,258	3,765	0.030	0.356	0.498	1,668	2,174	0.016	0.196
	A-4a	C	5.4	7.9	786.9	784.4	2.5	6.7	115	938	794	794	3,794	27	0.153	0.015	0.483				0.34	0.915	3,064	3,858	0.019	0.233	0.493	1,649	2,443	0.013	0.151
3	A-1-b	G	7.9	12.9	784.4	779.4	5.0	10.4	125	1,563	1,250	1,250	4,250					20	23	81	0.53	0.797	2,669	3,919	0.031	0.366	0.476	1,594	2,844	0.022	0.263
	A-1-b	G	12.9	17.9	779.4	774.4	5.0	15.4	125	2,188	1,875	1,875	4,875					20	20	75	0.79	0.647	2,166	4,041	0.022	0.266	0.442	1,480	3,355	0.017	0.201
4	A-3a	G	17.9	20.4	774.4	771.9	2.5	19.2	130	2,513	2,350	2,203	5,203					32	31	89	0.98	0.557	1,866	4,069	0.007	0.090	0.412	1,379	3,583	0.006	0.071
5	A-4a	C	20.4	23.9	771.9	768.4	3.5	22.2	125	2,950	2,731	2,397	5,397	27	0.153	0.015	0.483				1.14	0.499	1,670	4,067	0.008	0.099	0.388	1,298	3,695	0.007	0.081
	A-4a	C	23.9	27.4	768.4	764.9	3.5	25.7	125	3,388	3,169	2,617	5,617	27	0.153	0.015	0.483				1.32	0.443	1,482	4,099	0.007	0.084	0.360	1,206	3,823	0.006	0.071
																								Total Settlement:		1.885 in			Total Settlement:		1.345 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 14+25 to 15+85 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/26/2022

Boring B-047-0-19

H = 27.9 ft Wall height
B = 19.5 ft Width of wall
D_w = 16.8 ft Depth below bottom of wall
γ_{BF} = 120 Unit weight of backfill
q = 3,348 psf Bearing pressure at bottom of wall

t = 4 days Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 91% of Primary Consolidation						
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-1-b	G	0.0	1.4	792.3	790.9	1.4	0.7	125	175	88	88	3,088					20	40	131	0.04	0.500	1,674	1,761	0.014	0.168	0.309				100	0.168	0.309
	A-1-b	G	1.4	2.9	790.9	789.4	1.5	2.2	125	363	269	269	3,269					20	33	109	0.11	0.500	1,673	1,942	0.012	0.142					100	0.142	
2	A-4a	C	2.9	5.4	789.4	786.9	2.5	4.2	115	650	506	506	3,506	27	0.153	0.015	0.483				0.21	0.498	1,668	2,174	0.016	0.196	0.347	400	2.5	0.701	86	0.168	0.298
	A-4a	C	5.4	7.9	786.9	784.4	2.5	6.7	115	938	794	794	3,794	27	0.153	0.015	0.483				0.34	0.493	1,649	2,443	0.013	0.151		400	2.5	0.701	86	0.130	
3	A-1-b	G	7.9	12.9	784.4	779.4	5.0	10.4	125	1,563	1,250	1,250	4,250					20	23	81	0.53	0.476	1,594	2,844	0.022	0.263	0.465				100	0.263	0.465
	A-1-b	G	12.9	17.9	779.4	774.4	5.0	15.4	125	2,188	1,875	1,875	4,875					20	20	75	0.79	0.442	1,480	3,355	0.017	0.201					100	0.201	
4	A-3a	G	17.9	20.4	774.4	771.9	2.5	19.2	130	2,513	2,350	2,203	5,203					32	31	89	0.98	0.412	1,379	3,583	0.006	0.071	0.071				100	0.071	0.071
5	A-4a	C	20.4	23.9	771.9	768.4	3.5	22.2	125	2,950	2,731	2,397	5,397	27	0.153	0.015	0.483				1.14	0.388	1,298	3,695	0.007	0.081	0.153	400	3.5	0.358	66	0.054	0.078
	A-4a	C	23.9	27.4	768.4	764.9	3.5	25.7	125	3,388	3,169	2,617	5,617	27	0.153	0.015	0.483				1.32	0.360	1,206	3,823	0.006	0.071		400	7.0	0.089	34	0.024	

$(S_c)_t$ = 1.222 in

Settlement Remaining After Hold Period: 0.123 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 2,000 psf for slightly to moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 14+25 to 15+85 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-007-0-65

H =	27.9	ft	Wall height
B =	19.5	ft	Width of wall
D_w =	16.8	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	3,348	psf	Bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-2-4	G	0.0	2.7	792.3	789.6	2.7	1.4	130	351	176	176	3,176					43	78	300	0.07	0.999	3,344	3,520	0.012	0.141	0.500	1,674	1,849	0.009	0.110
	A-2-4	G	2.7	5.4	789.6	786.9	2.7	4.1	130	702	527	527	3,527					43	62	226	0.21	0.975	3,264	3,790	0.010	0.123	0.498	1,668	2,194	0.007	0.089
2	A-1-a	G	5.4	7.9	786.9	784.4	2.5	6.7	130	1,027	865	865	3,865					31	40	130	0.34	0.915	3,064	3,929	0.013	0.152	0.493	1,649	2,514	0.009	0.107
3	A-1-a	G	7.9	12.9	784.4	779.4	5.0	10.4	135	1,702	1,365	1,365	4,365					71	80	300	0.53	0.797	2,669	4,033	0.008	0.094	0.476	1,594	2,959	0.006	0.067
	A-1-a	G	12.9	17.9	779.4	774.4	5.0	15.4	135	2,377	2,040	2,040	5,040					71	71	272	0.79	0.647	2,166	4,206	0.006	0.069	0.442	1,480	3,519	0.004	0.052
4	A-6b	C	17.9	23.4	774.4	768.9	5.5	20.7	125	3,065	2,721	2,481	5,481	32	0.198	0.020	0.522				1.06	0.527	1,763	4,244	0.017	0.200	0.400	1,338	3,819	0.013	0.161
5	A-4a	C	23.4	26.9	768.9	765.4	3.5	25.2	125	3,502	3,283	2,762	5,762	22	0.108	0.011	0.444				1.29	0.450	1,507	4,269	0.005	0.059	0.364	1,219	3,981	0.004	0.050
6	A-4a	C	26.9	31.9	765.4	760.4	5.0	29.4	130	4,152	3,827	3,041	6,041	22	0.108	0.011	0.444				1.51	0.394	1,319	4,360	0.006	0.070	0.333	1,115	4,156	0.005	0.061
	A-4a	C	31.9	36.9	760.4	755.4	5.0	34.4	130	4,802	4,477	3,379	6,379	22	0.108	0.011	0.444				1.76	0.343	1,148	4,527	0.005	0.057	0.301	1,007	4,386	0.004	0.051
7	A-4a	C	36.9	39.9	755.4	752.4	3.0	38.4	125	5,177	4,990	3,642	6,642	23	0.117	0.012	0.452				1.97	0.310	1,038	4,680	0.003	0.032	0.278	931	4,573	0.002	0.029
																						Total Settlement:			0.997 in		Total Settlement:			0.777 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 14+25 to 15+85 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-007-0-65

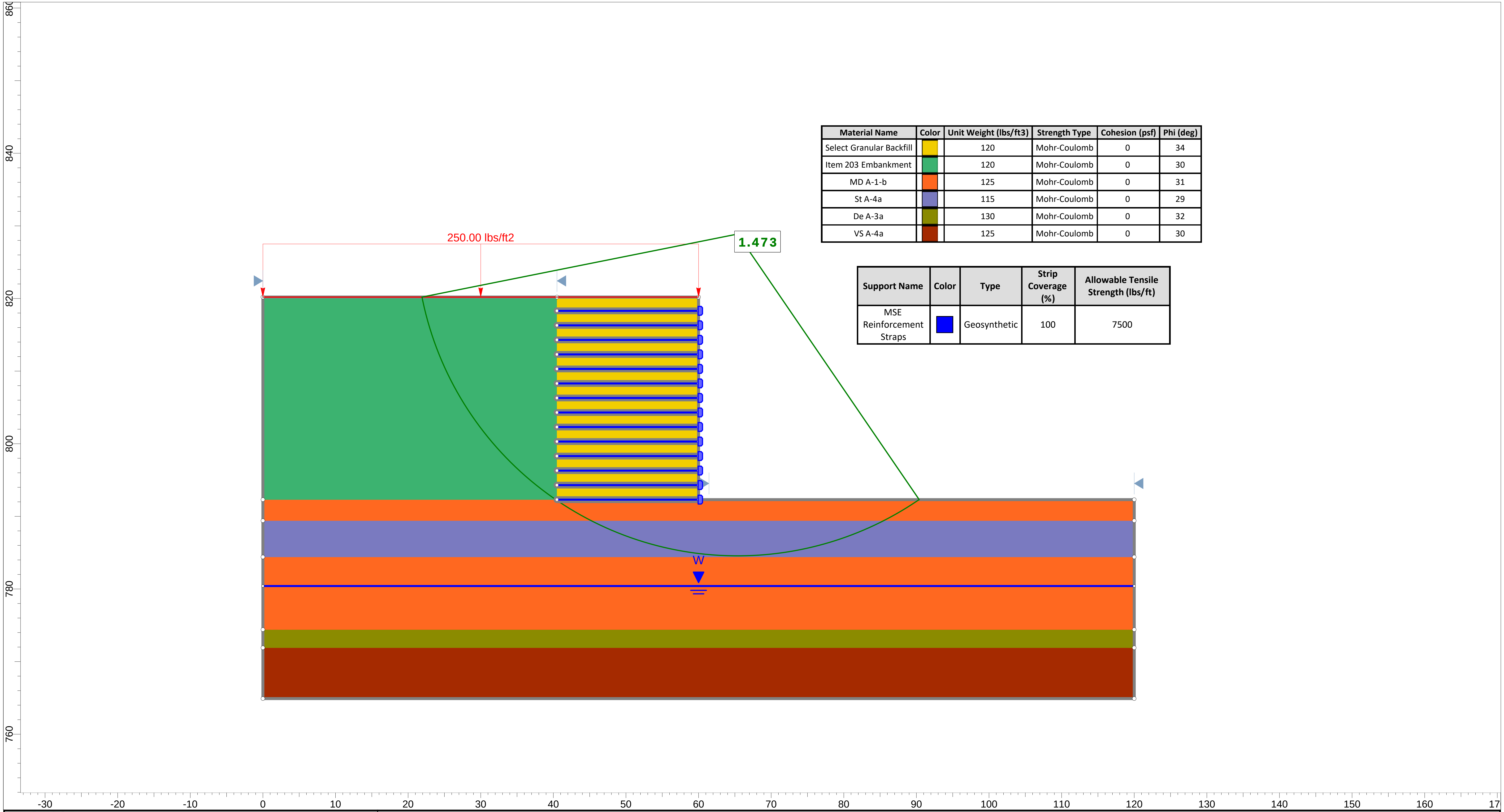
H =	27.9	ft	Wall height
B =	19.5	ft	Width of wall
D_w =	16.8	ft	Depth below bottom of wall
γ_{BF} =	120		Unit weight of backfill
q =	3,348	psf	Bearing pressure at bottom of wall
t =	80	days	Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-2-4	G	0.0	2.7	792.3	789.6	2.7	1.4	130	351	176	176	3,176					43	78	300	0.07	0.500	1,674	1,849	0.009	0.110	0.199				100	0.110	0.199
	A-2-4	G	2.7	5.4	789.6	786.9	2.7	4.1	130	702	527	527	3,527					43	62	226	0.21	0.498	1,668	2,194	0.007	0.089					100	0.089	
2	A-1-a	G	5.4	7.9	786.9	784.4	2.5	6.7	130	1,027	865	865	3,865					31	40	130	0.34	0.493	1,649	2,514	0.009	0.107	0.107				100	0.107	0.107
3	A-1-a	G	7.9	12.9	784.4	779.4	5.0	10.4	135	1,702	1,365	1,365	4,365					71	80	300	0.53	0.476	1,594	2,959	0.006	0.067	0.120				100	0.067	0.120
	A-1-a	G	12.9	17.9	779.4	774.4	5.0	15.4	135	2,377	2,040	2,040	5,040					71	71	272	0.79	0.442	1,480	3,519	0.004	0.052					100	0.052	
4	A-6b	C	17.9	23.4	774.4	768.9	5.5	20.7	125	3,065	2,721	2,481	5,481	32	0.198	0.020	0.522				1.06	0.400	1,338	3,819	0.013	0.161	0.161	100	5.5	0.725	86	0.138	0.138
5	A-4a	C	23.4	26.9	768.9	765.4	3.5	25.2	125	3,502	3,283	2,762	5,762	22	0.108	0.011	0.444				1.29	0.364	1,219	3,981	0.004	0.050	0.050	400	9.0	1.082	94	0.047	0.047
6	A-4a	C	26.9	31.9	765.4	760.4	5.0	29.4	130	4,152	3,827	3,041	6,041	22	0.108	0.011	0.444				1.51	0.333	1,115	4,156	0.005	0.061	0.112	400	14.0	0.447	73	0.044	0.072
	A-4a	C	31.9	36.9	760.4	755.4	5.0	34.4	130	4,802	4,477	3,379	6,379	22	0.108	0.011	0.444				1.76	0.301	1,007	4,386	0.004	0.051		400	19.0	0.243	55	0.028	
7	A-4a	C	36.9	39.9	755.4	752.4	3.0	38.4	125	5,177	4,990	3,642	6,642	23	0.117	0.012	0.452				1.97	0.278	931	4,573	0.002	0.029	0.029	400	22.0	0.181	48	0.014	0.014

$(S_c)_t$ = 0.697 in

Settlement Remaining After Hold Period: 0.080 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 2,000 psf for slightly to moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
MD A-1-b	🟧	125	Mohr-Coulomb	0	31
St A-4a	🟪	115	Mohr-Coulomb	0	29
De A-3a	🟫	130	Mohr-Coulomb	0	32
VS A-4a	🟥	125	Mohr-Coulomb	0	30

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

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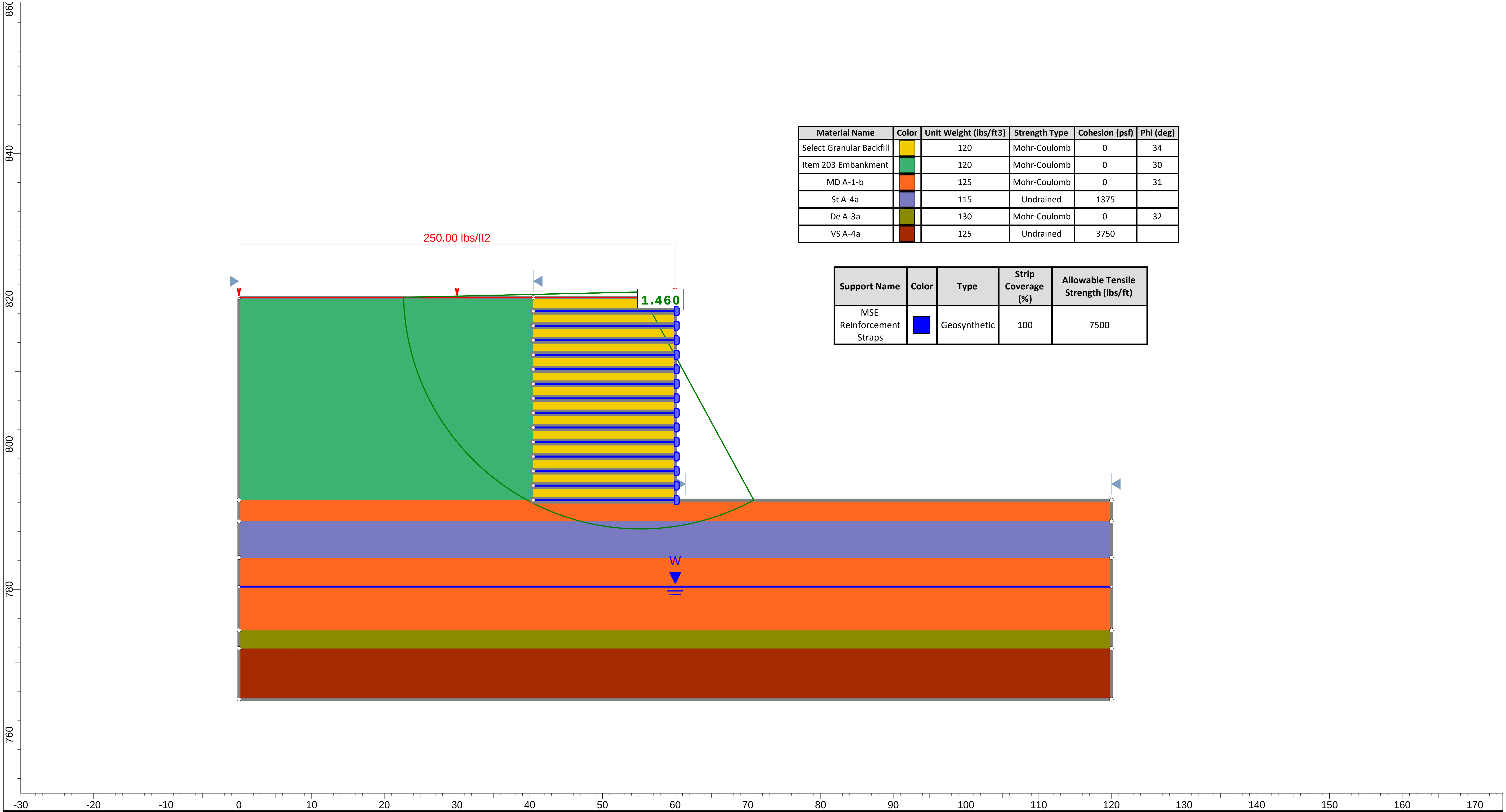
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 14+25 to 15+85 (BL Wall 5B) - B-047-0-19 and B-007-0-65 - Level Backfill - 27.9 ft. Wall Height - Drained - Circular
Drawn By	Resource International, Inc.
Scale	1:150
Company	BRT
Date	4/2/2022, 8:50:31 AM
File Name	Wall 5B - Sta. 14+25 to 15+85 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
MD A-1-b	🟧	125	Mohr-Coulomb	0	31
St A-4a	🟪	115	Undrained	1375	
De A-3a	🟫	130	Mohr-Coulomb	0	32
VS A-4a	🟥	125	Undrained	3750	

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

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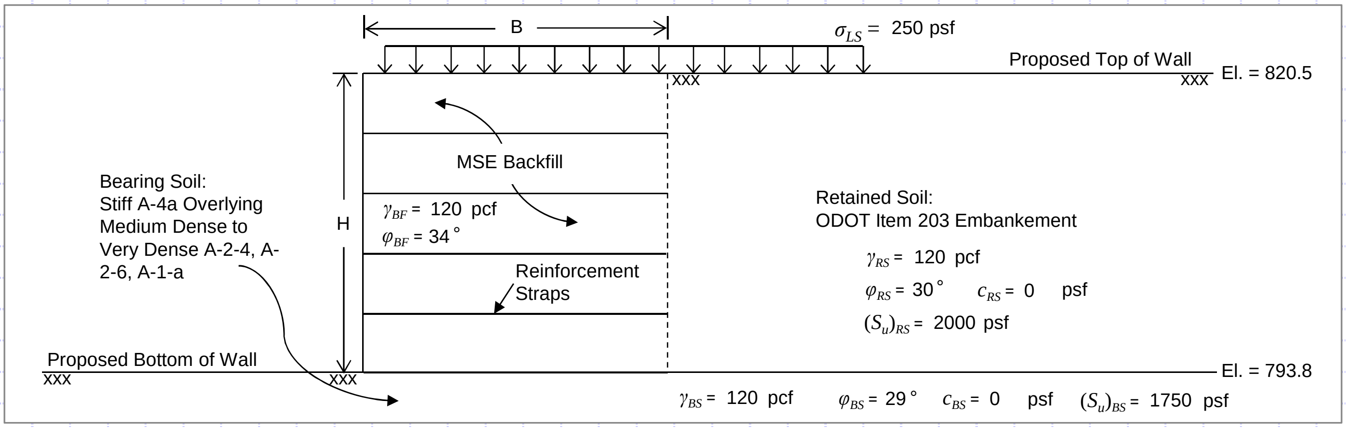
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 14+25 to 15+85 (BL Wall 5B) - B-047-0-19 and B-007-0-65 - Level Backfill - 27.9 ft. Wall Height - Undrained - Circular
Drawn By	Resource International, Inc.
Scale	1:150
Company	BRT
Date	4/2/2022, 8:50:31 AM
File Name	Wall 5B - Sta. 14+25 to 15+85 - Global Stability.slmd

Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B) - B-070-0-19, B-086-0-19 and B-088-0-19 - Level Backfill - 26.7 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 26.7 ft
MSE Wall Width (Reinforcement Length), (B) = 21.4 ft
MSE Wall Length, (L) = 399 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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(S_u)_{BS}]$ =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	10.7 ft		

LRFD Load Factors

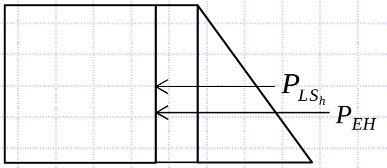
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = ½\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(26.7 ft)²(0.297)(1.5) = 19.06 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(26.7 ft)(0.297)(1.75) = 3.47 kip/ft

P_H = 19.06 kip/ft + 3.47 kip/ft = 22.53 kip/ft

Sliding Force at Bottom of Foundation Preparation:

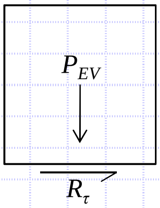
$P_{EH} = ½\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(26.7 ft + 1 ft)²(0.297)(1.5) = 20.51 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(26.7 ft + 1 ft)(0.297)(1.75) = 3.6 kip/ft

P_H = 20.51 kip/ft + 3.6 kip/ft = 24.11 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(26.7 ft + 1 ft)(21.4 ft)(1.00) = 71.13 kip/ft

$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF})$ ⟶ tan(29) ≤ tan(34) ⟶ 0.55 ≤ 0.67 = 0.55

R_τ = (71.13 kip/ft)(0.55) = 39.12 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 24.11 kip/ft ≤ (39.12 kip/ft)(1.0) = 39.12 kip/ft ⟶ 24.11 kip/ft ≤ 39.12 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	26.7	ft
MSE Wall Width (Reinforcement Length), (B) =	21.4	ft
MSE Wall Length, (L) =	399	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 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)

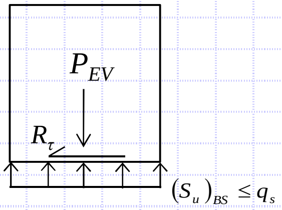
1. *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resisting:

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



$(S_u)_{BS} =$ 1.75 ksf

$q_s = \sigma_v / 2$ = (3.32 ksf) / 2 = 1.66 ksf

$\sigma_v = P_{EV} / B$ = (71.13 kip/ft) / (21.4 ft) = 3.32 ksf

R_τ = (1.75 ksf ≤ 1.66 ksf)(21.4 ft) = 35.52 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

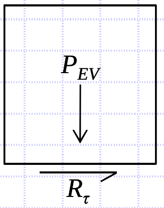
$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 24.11 kip/ft ≤ (35.52 kip/ft)(1.0) = 35.52 kip/ft ⟶ 24.11 kip/ft ≤ 35.52 kip/ft **OK**

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance:

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



$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(26.7 ft)(21.4 ft)(1.00) = 68.57 kip/ft

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

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

R_τ = (68.57 kip/ft)(0.67) = 45.94 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 22.53 kip/ft ≤ (45.94 kip/ft)(1.0) = 45.94 kip/ft ⟶ 22.53 kip/ft ≤ 45.94 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) =	26.7	ft
MSE Wall Width (Reinforcement Length), (B) =	21.4	ft
MSE Wall Length, (L) =	399	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 ft		

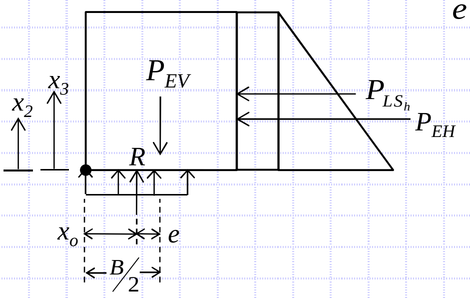
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



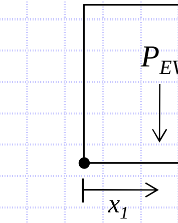
$$e = B/2 - x_o$$

$$x_o = \frac{M_{EV} - M_H}{P_{EV}}$$ = (733.7 kip·ft/ft - 215.96 kip·ft/ft) / (68.57 kip/ft) = 7.55 ft

M_{EV} = 733.70 kip·ft/ft
M_H = 215.96 kip·ft/ft
P_{EV} = 68.57 kip/ft
Defined below

$e =$ (21.4 ft)/2 - 7.55 ft = 3.15 ft

Resisting Moment, M_{EV}:



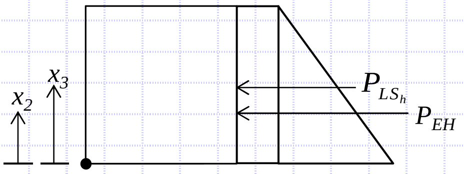
$$M_{EV} = P_{EV}(x_1)$$

$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(26.7 ft)(21.4 ft)(1.00) = 68.57 kip/ft

$x_1 = B/2$ = (21.4 ft) / 2 = 10.70 ft

$M_{EV} =$ (68.57 kip/ft)(10.70 ft) = 733.70 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)(26.7 ft)²(0.297)(1.5) = 19.06 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(26.7 ft)(0.297)(1.75) = 3.47 kip/ft

$x_2 = H/3$ = (26.7 ft) / 3 = 8.90 ft

$x_3 = H/2$ = (26.7 ft) / 2 = 13.35 ft

$M_H =$ (19.06 kip/ft)(8.9 ft) + (3.47 kip/ft)(13.35 ft) = 215.96 kip·ft/ft

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Check Eccentricity

$e < e_{\max} \longrightarrow$ 3.15 ft < 7.13 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (21.4 ft) / 3 = 7.13 ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	4	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 26.7 ft
MSE Wall Width (Reinforcement Length), (B) = 21.4 ft
MSE Wall Length, (L) = 399 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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 ft		

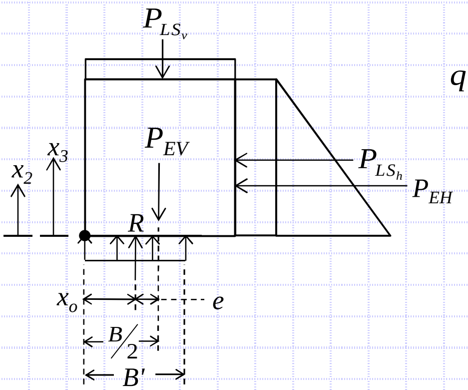
LRFD Load Factors

	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] *Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.*

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



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

$B' = B - 2e$ = 21.4 ft - 2(2.12 ft) = 17.16 ft

$e = B/2 - x_o$ = (21.4 ft) / 2 - 8.58 ft = 2.12 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (1090.61 kip·ft/ft - 215.91 kip·ft/ft) / 101.93 kip/ft = 8.58 ft

q_{eq} = (101.93 kip/ft) / (17.16 ft) = 5.94 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)(26.7 ft)(21.4 ft)(1.35)](10.7 ft) + [(250 psf)(21.4 ft)(1.75)](10.7 ft) = 1090.61 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)(26.7 ft)²(0.297)(1.5)](8.9 ft) + [(250 psf)(26.7 ft)(0.297)(1.75)](13.35 ft) = 215.91 kip·ft/ft

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

P_V = (120 pcf)(26.7 ft)(21.4 ft)(1.35) + (250 psf)(21.4 ft)(1.75) = 101.93 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 28.56

N_c = 27.86
s_c = 1+(17.16 ft/399 ft)(16.44/27.86)
= 1.025
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 17.28

N_q = 16.44
s_q = 1.000
d_q = 1+2tan(29°)[1-sin(29°)]²tan⁻¹(3.0 ft/17.16 ft)
1.051
i_q = 1.000 (Assumed)
C_{wq} = 10.7 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 19.01

N_γ = 19.34
s_γ = 0.983
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 10.7 ft < 1.5(17.16 ft) + 3.0 ft = 0.708

q_n = (0 psf)(28.557) + (120 pcf)(3.0 ft)(17.278)(1.000) + ½(120 pcf)(17.2 ft)(19.011)(0.708) = 20.08 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 5.94 ksf ≤ (20.08 ksf)(0.65) = 13.05 ksf ⟶ 5.94 ksf ≤ 13.05 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) = 26.7 ft
MSE Wall Width (Reinforcement Length), (B) = 21.4 ft
MSE Wall Length, (L) = 399 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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140
s_c = 1+(17.16 ft/[(5)(399 ft)]) = 1.010
i_c = 1.000 (Assumed)

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

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(3.0 ft/17.16 ft)
1.000
i_q = 1.000 (Assumed)
C_{wq} = 10.7 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)
$C_{w\gamma}$ = 10.7 ft < 1.5(17.16 ft) + 3.0 ft = 0.708

$q_n =$ (1750 psf)(5.190) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(17.2 ft)(0.000)(0.708) = 9.44 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 5.94 ksf ≤ (9.44 ksf)(0.65) = 6.14 ksf ⟶ 5.94 ksf ≤ 6.14 ksf **OK**

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

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 6 OF 6
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/26/2022
Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	26.7	ft
MSE Wall Width (Reinforcement Length), (B) =	21.4	ft
MSE Wall Length, (L) =	399	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	120	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	29	29	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1750	1750	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 ft		

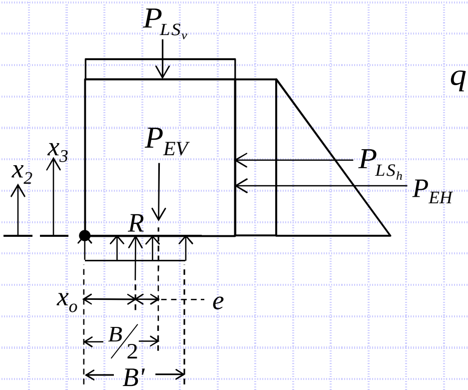
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 21.4 ft - 2(1.89 ft) = 17.62 ft

$e = B/2 - x_o$ = (21.4 ft) / 2 - 8.81 ft = 1.89 ft

$x_o = \frac{M_V - M_H}{P_V}$ = (790.90 kip·ft/ft - 139.53 kip·ft/ft) / 73.92 kip/ft = 8.81 ft

$q_{eq} =$ (73.92 kip/ft) / (17.62 ft) = 4.20 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)(26.7 ft)(21.4 ft)(1.00)](10.7 ft) + [(250 psf)(21.4 ft)(1.00)](10.7 ft) = 790.90 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)(26.7 ft)²(0.297)(1.00)](8.9 ft) + [(250 psf)(26.7 ft)(0.297)(1.00)](13.35 ft) = 139.53 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)(26.7 ft)(21.4 ft)(1.00) + (250 psf)(21.4 ft)(1.00) = 73.92 kip/ft

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
B-041-0-19	10+50	1.299 in	1.002 in	6 days		
B-045-0-19	13+50	1.721 in	1.311 in	8 days	300 ft	1 in / 970 ft
B-047-0-19	14+55	2.055 in	1.457 in	3 days	105 ft	1 in / 720 ft
B-007-0-65	15+85	0.997 in	0.777 in	80 days	130 ft	1 in / 190 ft
B-070-0-19	17+96	2.222 in	1.643 in	155 days	211 ft	1 in / 240 ft
B-086-0-19	18+30	1.575 in	1.145 in	5 days	34 ft	1 in / 70 ft
B-088-0-19	20+00	1.840 in	1.350 in	27 days	170 ft	1 in / 830 ft
B-089-0-19	21+95	1.084 in	0.814 in	27 days	195 ft	1 in / 360 ft

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-070-0-19

H =	26.7	ft	Wall height
B =	21.4	ft	Width of wall
D_w =	10.7	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	3,204	psf	Bearing pressure at bottom of wall

																					Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-4a	C	0.0	3.7	793.8	790.1	3.7	1.9	120	444	222	222	3,222	25	0.135	0.014	0.467				0.09	0.998	3,197	3,419	0.048	0.580	0.500	1,602	1,824	0.031	0.374
	A-4a	C	3.7	7.7	790.1	786.1	4.0	5.7	120	924	684	684	3,684	25	0.135	0.014	0.467				0.27	0.953	3,052	3,736	0.029	0.350	0.496	1,590	2,274	0.019	0.230
2	A-2-4	G	7.7	10.2	786.1	783.6	2.5	9.0	125	1,237	1,080	1,080	4,080					24	29	96	0.42	0.870	2,787	3,867	0.014	0.173	0.487	1,561	2,641	0.010	0.121
3	A-2-6	G	10.2	14.2	783.6	779.6	4.0	12.2	125	1,737	1,487	1,393	4,393					24	27	91	0.57	0.774	2,480	3,873	0.020	0.235	0.472	1,512	2,905	0.014	0.169
	A-2-6	G	14.2	18.2	779.6	775.6	4.0	16.2	125	2,237	1,987	1,643	4,643					24	26	87	0.76	0.664	2,129	3,772	0.017	0.199	0.447	1,432	3,075	0.012	0.150
4	A-3a	G	18.2	20.2	775.6	773.6	2.0	19.2	125	2,487	2,362	1,831	4,831					24	25	76	0.90	0.594	1,904	3,735	0.008	0.098	0.425	1,363	3,194	0.006	0.076
5	A-1-a	G	20.2	25.2	773.6	768.6	5.0	22.7	135	3,162	2,824	2,075	5,075					50	49	167	1.06	0.526	1,685	3,760	0.008	0.093	0.399	1,280	3,355	0.006	0.075
6	A-4a	C	25.2	34.2	768.6	759.6	9.0	29.7	125	4,287	3,724	2,538	5,538	22	0.108	0.011	0.444				1.39	0.423	1,356	3,894	0.013	0.150	0.350	1,120	3,659	0.011	0.128
	A-4a	C	34.2	44.2	759.6	749.6	10.0	39.2	125	5,537	4,912	3,133	6,133	22	0.108	0.011	0.444				1.83	0.331	1,062	4,195	0.009	0.114	0.293	939	4,072	0.009	0.102
7	A-4a	C	44.2	51.7	749.6	742.1	7.5	48.0	130	6,512	6,024	3,700	6,700	23	0.117	0.012	0.452				2.24	0.275	881	4,581	0.006	0.067	0.252	808	4,507	0.005	0.062
	A-4a	C	51.7	59.2	742.1	734.6	7.5	55.5	130	7,487	6,999	4,207	7,207	23	0.117	0.012	0.452				2.59	0.240	768	4,975	0.004	0.053	0.224	718	4,925	0.004	0.050
8	A-4a	C	59.2	64.2	734.6	729.6	5.0	61.7	125	8,112	7,799	4,617	7,617	24	0.126	0.013	0.460				2.88	0.216	694	5,310	0.003	0.031	0.205	656	5,273	0.002	0.030
9	A-6b	C	64.2	72.2	729.6	721.6	8.0	68.2	125	9,112	8,612	5,024	8,024	38	0.252	0.025	0.569				3.19	0.197	630	5,653	0.007	0.079	0.188	601	5,625	0.006	0.076
																					Total Settlement:				2.222 in		Total Settlement:				1.643 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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 continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \le \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-070-0-19

H =	26.7	ft	Wall height
B =	21.4	ft	Width of wall
D_w =	10.7	ft	Depth below bottom of wall
γ_{BF} =	120		Unit weight of backfill
q =	3,204	psf	Bearing pressure at bottom of wall
t =	155	days	Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	C_c $^{(2)}$	C_r $^{(3)}$	e_o $^{(4)}$	N_{60}	$(N1)_{60}$ $^{(5)}$	C' $^{(6)}$	Z_f/B	I $^{(7)}$	$\Delta\sigma_v$ $^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	S_c $^{(9,10)}$ (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ $^{(11)}$ (in)	Layer Settlement (in)
1	A-4a	C	0.0	3.7	793.8	790.1	3.7	1.9	120	444	222	222	3,222	25	0.135	0.014	0.467				0.09	0.500	1,602	1,824	0.031	0.374	0.604	400	3.7	12.408	100	0.374	0.604
	A-4a	C	3.7	7.7	790.1	786.1	4.0	5.7	120	924	684	684	3,684	25	0.135	0.014	0.467				0.27	0.496	1,590	2,274	0.019	0.230		400	3.9	11.460	100	0.230	
2	A-2-4	G	7.7	10.2	786.1	783.6	2.5	9.0	125	1,237	1,080	1,080	4,080					24	29	96	0.42	0.487	1,561	2,641	0.010	0.121	0.121				100	0.121	0.121
3	A-2-6	G	10.2	14.2	783.6	779.6	4.0	12.2	125	1,737	1,487	1,393	4,393					24	27	91	0.57	0.472	1,512	2,905	0.014	0.169	0.319				100	0.169	0.319
	A-2-6	G	14.2	18.2	779.6	775.6	4.0	16.2	125	2,237	1,987	1,643	4,643					24	26	87	0.76	0.447	1,432	3,075	0.012	0.150					100	0.150	
4	A-3a	G	18.2	20.2	775.6	773.6	2.0	19.2	125	2,487	2,362	1,831	4,831					24	25	76	0.90	0.425	1,363	3,194	0.006	0.076	0.076				100	0.076	0.076
5	A-1-a	G	20.2	25.2	773.6	768.6	5.0	22.7	135	3,162	2,824	2,075	5,075					50	49	167	1.06	0.399	1,280	3,355	0.006	0.075	0.075				100	0.075	0.075
6	A-4a	C	25.2	34.2	768.6	759.6	9.0	29.7	125	4,287	3,724	2,538	5,538	22	0.108	0.011	0.444				1.39	0.350	1,120	3,659	0.011	0.128	0.230	400	9.0	2.097	100	0.128	0.205
	A-4a	C	34.2	44.2	759.6	749.6	10.0	39.2	125	5,537	4,912	3,133	6,133	22	0.108	0.011	0.444				1.83	0.293	939	4,072	0.009	0.102		400	19.0	0.471	75	0.077	
7	A-4a	C	44.2	51.7	749.6	742.1	7.5	48.0	130	6,512	6,024	3,700	6,700	23	0.117	0.012	0.452				2.24	0.252	808	4,507	0.005	0.062	0.112	400	26.5	0.242	55	0.034	0.056
	A-4a	C	51.7	59.2	742.1	734.6	7.5	55.5	130	7,487	6,999	4,207	7,207	23	0.117	0.012	0.452				2.59	0.224	718	4,925	0.004	0.050		400	34.0	0.147	43	0.021	
8	A-4a	C	59.2	64.2	734.6	729.6	5.0	61.7	125	8,112	7,799	4,617	7,617	24	0.126	0.013	0.460				2.88	0.205	656	5,273	0.002	0.030	0.030	400	39.0	0.112	38	0.011	0.011
9	A-6b	C	64.2	72.2	729.6	721.6	8.0	68.2	125	9,112	8,612	5,024	8,024	38	0.252	0.025	0.569				3.19	0.188	601	5,625	0.006	0.076	0.076	200	47.0	0.038	22	0.017	0.017

$(S_c)_t$ = 1.484 in

Settlement Remaining After Hold Period: 0.159 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-086-0-19

H =	25.7	ft	Wall height
B =	21.4	ft	Width of wall
D_w =	10.7	ft	Depth below bottom of wall
γ_{BF} =	120	pcf	Unit weight of backfill
q =	3,084	psf	Bearing pressure at bottom of wall

																						Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6b	C	0.0	1.8	793.8	792.0	1.8	0.9	125	225	113	113	3,113	39	0.261	0.026	0.577				0.04	1.000	3,083	3,196	0.046	0.556	0.500	1,542	1,654	0.035	0.417
2	A-4a	C	1.8	4.3	792.0	789.5	2.5	3.1	120	525	375	375	3,375	25	0.135	0.014	0.467				0.14	0.991	3,056	3,431	0.024	0.283	0.499	1,540	1,915	0.016	0.195
3	A-4a	C	4.3	6.8	789.5	787.0	2.5	5.6	125	838	681	681	3,681	25	0.135	0.014	0.467				0.26	0.956	2,947	3,628	0.017	0.200	0.497	1,531	2,213	0.012	0.141
4	A-1-b	G	6.8	9.3	787.0	784.5	2.5	8.1	130	1,163	1,000	1,000	4,000					37	46	152	0.38	0.895	2,761	3,761	0.009	0.114	0.490	1,512	2,512	0.007	0.079
	A-1-b	G	9.3	11.8	784.5	782.0	2.5	10.6	130	1,488	1,325	1,325	4,325					37	42	138	0.49	0.823	2,537	3,862	0.008	0.101	0.480	1,482	2,807	0.006	0.071
	A-1-b	G	11.8	14.3	782.0	779.5	2.5	13.1	130	1,813	1,650	1,503	4,503					37	41	133	0.61	0.749	2,311	3,814	0.008	0.091	0.467	1,441	2,944	0.005	0.066
	A-1-b	G	14.3	16.8	779.5	777.0	2.5	15.6	130	2,138	1,975	1,672	4,672					37	39	128	0.73	0.681	2,100	3,773	0.007	0.083	0.451	1,392	3,064	0.005	0.062
	A-1-b	G	16.8	20.8	777.0	773.0	4.0	18.8	130	2,658	2,398	1,892	4,892					37	38	123	0.88	0.603	1,860	3,752	0.010	0.116	0.428	1,321	3,213	0.007	0.090
5	A-1-b	G	20.8	23.8	773.0	770.0	3.0	22.3	135	3,063	2,860	2,136	5,136					86	84	300	1.04	0.533	1,644	3,780	0.002	0.030	0.402	1,241	3,377	0.002	0.024
																						Total Settlement:				1.575 in	Total Settlement:				1.145 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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 continuous footing
8. $\Delta\sigma_v = q_6(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-086-0-19

H = 25.7 ft Wall height
B = 21.4 ft Width of wall
D_w = 10.7 ft Depth below bottom of wall
γ_{BF} = 120 Unit weight of backfill
q = 3,084 psf Bearing pressure at bottom of wall

t = 5 days Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 91% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6b	C	0.0	1.8	793.8	792.0	1.8	0.9	125	225	113	113	3,113	39	0.261	0.026	0.577				0.04	0.500	1,542	1,654	0.035	0.417	0.613	200	1.8	0.846	90	0.376	0.522
2	A-4a	C	1.8	4.3	792.0	789.5	2.5	3.1	120	525	375	375	3,375	25	0.135	0.014	0.467				0.14	0.499	1,540	1,915	0.016	0.195		400	3.4	0.474	75	0.147	
3	A-4a	C	4.3	6.8	789.5	787.0	2.5	5.6	125	838	681	681	3,681	25	0.135	0.014	0.467				0.26	0.497	1,531	2,213	0.012	0.141	0.141	400	2.5	0.877	91	0.128	0.128
4	A-1-b	G	6.8	9.3	787.0	784.5	2.5	8.1	130	1,163	1,000	1,000	4,000					37	46	152	0.38	0.490	1,512	2,512	0.007	0.079	0.150				100	0.079	0.150
	A-1-b	G	9.3	11.8	784.5	782.0	2.5	10.6	130	1,488	1,325	1,325	4,325					37	42	138	0.49	0.480	1,482	2,807	0.006	0.071					100	0.071	
	A-1-b	G	11.8	14.3	782.0	779.5	2.5	13.1	130	1,813	1,650	1,503	4,503					37	41	133	0.61	0.467	1,441	2,944	0.005	0.066	0.066				100	0.066	0.066
	A-1-b	G	14.3	16.8	779.5	777.0	2.5	15.6	130	2,138	1,975	1,672	4,672					37	39	128	0.73	0.451	1,392	3,064	0.005	0.062	0.062				100	0.062	0.062
	A-1-b	G	16.8	20.8	777.0	773.0	4.0	18.8	130	2,658	2,398	1,892	4,892					37	38	123	0.88	0.428	1,321	3,213	0.007	0.090	0.114				100	0.090	0.114
5	A-1-b	G	20.8	23.8	773.0	770.0	3.0	22.3	135	3,063	2,860	2,136	5,136					86	84	300	1.04	0.402	1,241	3,377	0.002	0.024					100	0.024	

$(S_c)_t$ = 1.042 in

Settlement Remaining After Hold Period: 0.103 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-088-0-19

H = 18.4 ft Wall height
B = 21.4 ft Width of wall
D_w = 10.7 ft Depth below bottom of wall
γ_{BF} = 120 pcf Unit weight of backfill
q = 2,208 psf Bearing pressure at bottom of wall

																					Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-6a	C	0.0	1.7	793.8	792.1	1.7	0.9	125	213	106	106	3,106	38	0.252	0.025	0.569				0.04	1.000	2,208	2,314	0.037	0.438	0.500	1,104	1,210	0.029	0.346
	A-6a	C	1.7	3.4	792.1	790.4	1.7	2.6	125	425	319	319	3,319	38	0.252	0.025	0.569				0.12	0.995	2,196	2,515	0.024	0.294	0.500	1,103	1,422	0.018	0.213
2	A-6a	C	3.4	5.4	790.4	788.4	2.0	4.4	125	675	550	550	3,550	38	0.252	0.025	0.569				0.21	0.976	2,154	2,704	0.022	0.267	0.498	1,100	1,650	0.015	0.184
	A-6a	C	5.4	7.4	788.4	786.4	2.0	6.4	125	925	800	800	3,800	38	0.252	0.025	0.569				0.30	0.937	2,070	2,870	0.018	0.214	0.495	1,093	1,893	0.012	0.144
3	A-6b	C	7.4	9.4	786.4	784.4	2.0	8.4	120	1,165	1,045	1,045	4,045	34	0.216	0.022	0.538				0.39	0.886	1,955	3,000	0.013	0.154	0.489	1,080	2,125	0.009	0.104
4	A-4a	C	9.4	14.4	784.4	779.4	5.0	11.9	125	1,790	1,478	1,403	4,403	24	0.126	0.013	0.460				0.56	0.783	1,728	3,131	0.015	0.181	0.474	1,046	2,448	0.010	0.125
5	A-2-4	G	14.4	23.4	779.4	770.4	9.0	18.9	135	3,005	2,398	1,886	4,886					50	51	174	0.88	0.601	1,327	3,213	0.012	0.144	0.428	944	2,830	0.009	0.109
6	A-4b	C	23.4	28.4	770.4	765.4	5.0	25.9	125	3,630	3,318	2,369	5,369	24	0.126	0.013	0.460				1.21	0.474	1,047	3,416	0.007	0.082	0.376	830	3,199	0.006	0.068
7	A-6b	C	28.4	31.4	765.4	762.4	3.0	29.9	125	4,005	3,818	2,619	5,619	34	0.216	0.022	0.538				1.40	0.421	929	3,548	0.006	0.067	0.348	769	3,389	0.005	0.057
																					Total Settlement:				1.840 in		Total Settlement:			1.350 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 17+96 to 20+80 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-088-0-19

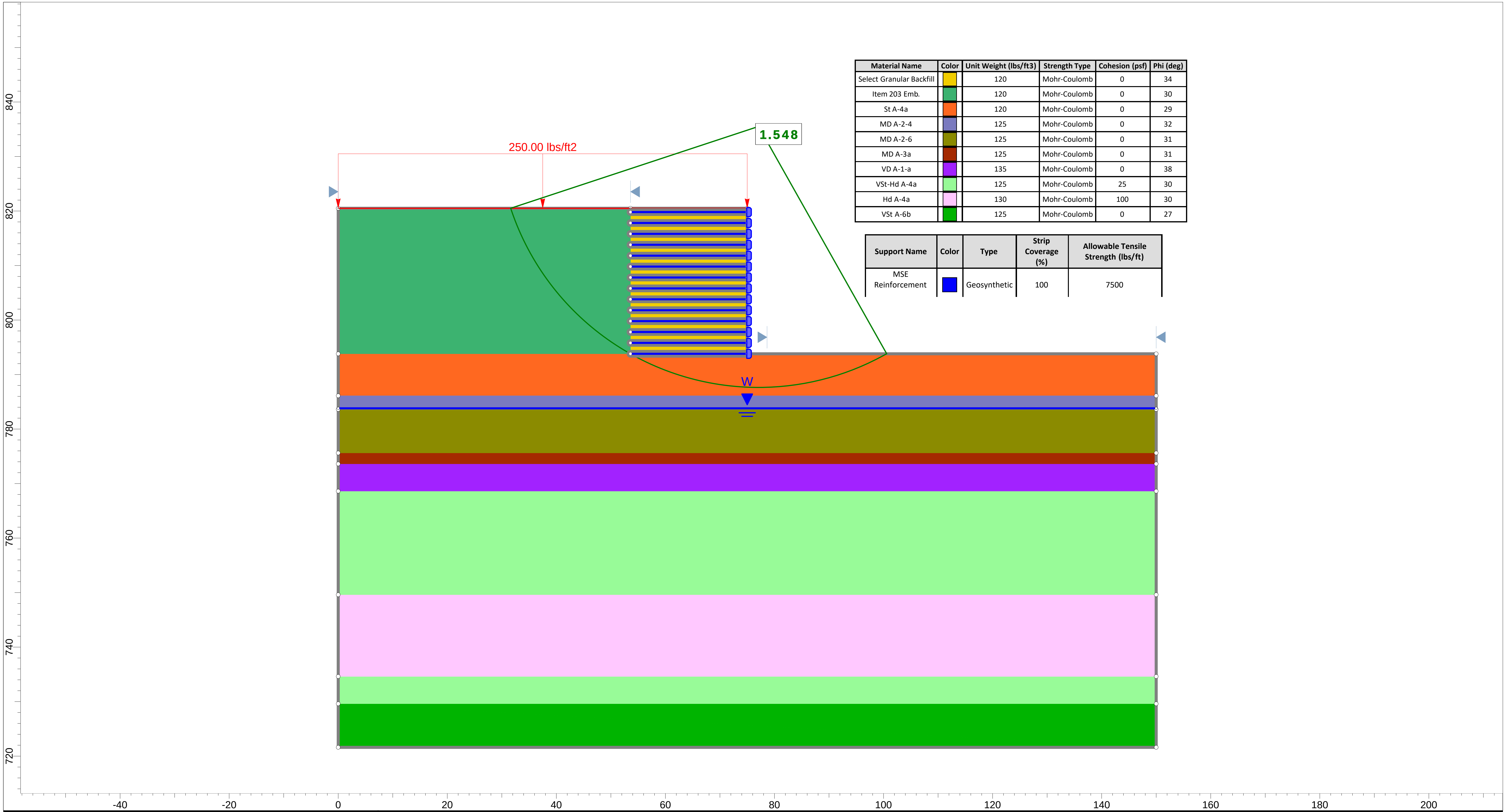
H =	18.4	ft	Wall height
B =	21.4	ft	Width of wall
D_w =	10.7	ft	Depth below bottom of wall
γ_{BF} =	120		Unit weight of backfill
q =	2,208	psf	Bearing pressure at bottom of wall
t =	27	days	Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t^{(11)}$ (in)	Layer Settlement (in)
1	A-6a	C	0.0	1.7	793.8	792.1	1.7	0.9	125	213	106	106	3,106	38	0.252	0.025	0.569				0.04	0.500	1,104	1,210	0.029	0.346	0.559	300	1.7	7.679	100	0.346	0.557
	A-6a	C	1.7	3.4	792.1	790.4	1.7	2.6	125	425	319	319	3,319	38	0.252	0.025	0.569				0.12	0.500	1,103	1,422	0.018	0.213		300	3.4	1.920	99	0.211	
2	A-6a	C	3.4	5.4	790.4	788.4	2.0	4.4	125	675	550	550	3,550	38	0.252	0.025	0.569				0.21	0.498	1,100	1,650	0.015	0.184	0.184	300	5.4	0.761	88	0.162	0.162
	A-6a	C	5.4	7.4	788.4	786.4	2.0	6.4	125	925	800	800	3,800	38	0.252	0.025	0.569				0.30	0.495	1,093	1,893	0.012	0.144	0.248	300	7.4	0.405	70	0.101	0.165
3	A-6b	C	7.4	9.4	786.4	784.4	2.0	8.4	120	1,165	1,045	1,045	4,045	34	0.216	0.022	0.538				0.39	0.489	1,080	2,125	0.009	0.104		200	7.0	0.302	62	0.064	
4	A-4a	C	9.4	14.4	784.4	779.4	5.0	11.9	125	1,790	1,478	1,403	4,403	24	0.126	0.013	0.460				0.56	0.474	1,046	2,448	0.010	0.125	0.125	400	5.0	1.184	96	0.120	0.120
5	A-2-4	G	14.4	23.4	779.4	770.4	9.0	18.9	135	3,005	2,398	1,886	4,886					50	51	174	0.88	0.428	944	2,830	0.009	0.109	0.109				100	0.109	0.109
6	A-4b	C	23.4	28.4	770.4	765.4	5.0	25.9	125	3,630	3,318	2,369	5,369	24	0.126	0.013	0.460				1.21	0.376	830	3,199	0.006	0.068	0.124	400	5.0	1.184	96	0.065	0.095
7	A-6b	C	28.4	31.4	765.4	762.4	3.0	29.9	125	4,005	3,818	2,619	5,619	34	0.216	0.022	0.538				1.40	0.348	769	3,389	0.005	0.057		200	8.0	0.231	54	0.031	

$(S_c)_t$ = 1.209 in

Settlement Remaining After Hold Period: 0.141 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Emb.	🟩	120	Mohr-Coulomb	0	30
St A-4a	🟧	120	Mohr-Coulomb	0	29
MD A-2-4	🟦	125	Mohr-Coulomb	0	32
MD A-2-6	🟫	125	Mohr-Coulomb	0	31
MD A-3a	🟥	125	Mohr-Coulomb	0	31
VD A-1-a	🟪	135	Mohr-Coulomb	0	38
VSt-Hd A-4a	🟩	125	Mohr-Coulomb	25	30
Hd A-4a	🟪	130	Mohr-Coulomb	100	30
VSt A-6b	🟩	125	Mohr-Coulomb	0	27

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

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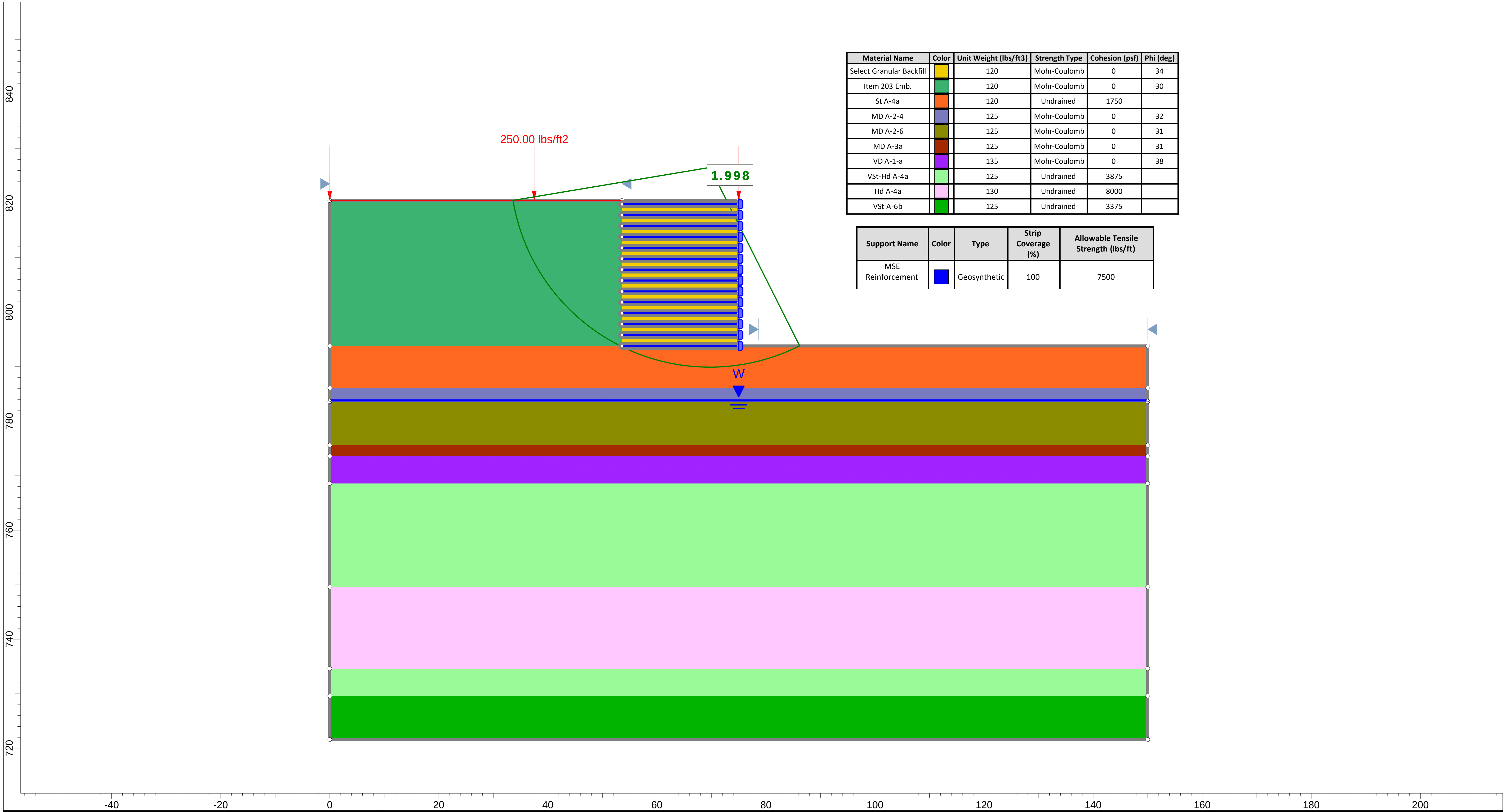
SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B		
Analysis Description	Global Stability - Sta. 17+96 to 20+80 (BL Wall 5B) - B-070-0-19, B-086-0-19 and B-088-0-19 - Level Backfill - 26.7 ft. Wall Height - Drained - Circular		
Drawn By BRT	*Scale* 1:200	*Company*	Resource International, Inc.
Date	4/2/2022	*File Name*	Wall 5B - Sta. 17+96 to 20+80 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granular Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Emb.	🟩	120	Mohr-Coulomb	0	30
St A-4a	🟧	120	Undrained	1750	
MD A-2-4	🟦	125	Mohr-Coulomb	0	32
MD A-2-6	🟫	125	Mohr-Coulomb	0	31
MD A-3a	🟥	125	Mohr-Coulomb	0	31
VD A-1-a	🟪	135	Mohr-Coulomb	0	38
VSt-Hd A-4a	🟩	125	Undrained	3875	
Hd A-4a	🟪	130	Undrained	8000	
VSt A-6b	🟩	125	Undrained	3375	

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

Resource International, Inc.
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SLIDEINTERPRET 9.019

Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 17+96 to 20+80 (BL Wall 5B) - B-070-0-19, B-086-0-19 and B-088-0-19 - Level Backfill - 26.7 ft. Wall Height - Undrained - Circular
Drawn By	BRT
Scale	1:200
Company	Resource International, Inc.
Date	4/2/2022
File Name	Wall 5B - Sta. 17+96 to 20+80 - Global Stability.slmd

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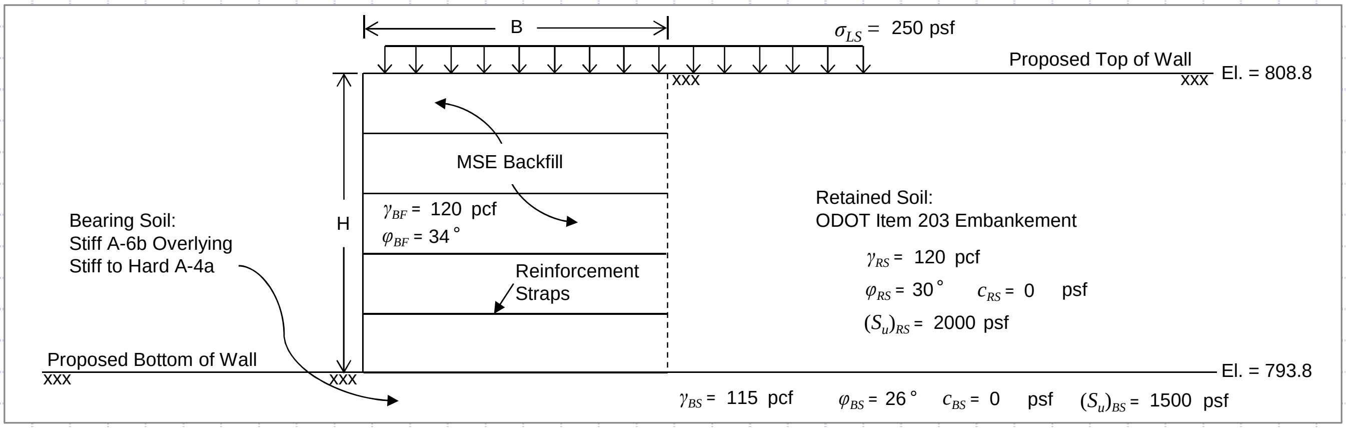
JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	1	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)

Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B) - B-089-0-19 - Level Backfill - 15.0 ft. Wall Height



MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(S_u)_{BS}$] =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	10.7 ft		

LRFD Load Factors

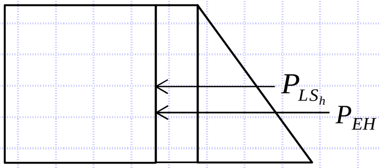
	EV	EH	LS
Strength Ia	1.00	1.50	1.75
Strength Ib	1.35	1.50	1.75
Service I	1.00	1.00	1.00

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

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Sliding Force: $P_H = P_{EH} + P_{LS_h}$



Sliding Force at Bottom of Wall (Top of Foundation Preparation):

$P_{EH} = \frac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH}$ = ½(120 pcf)(15 ft)²(0.297)(1.5) = 6.01 kip/ft

$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS}$ = (250 psf)(15 ft)(0.297)(1.75) = 1.95 kip/ft

P_H = 6.01 kip/ft + 1.95 kip/ft = 7.96 kip/ft

Sliding Force at Bottom of Foundation Preparation:

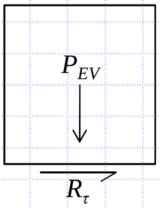
$P_{EH} = \frac{1}{2}\gamma_{RS}(H+1)^2(K_a)(\gamma_{EH})$ = ½(120 pcf)(15 ft + 1 ft)²(0.297)(1.5) = 6.84 kip/ft

$P_{LS_h} = \sigma_{LS}(H+1)(K_a)(\gamma_{LS})$ = (250 psf)(15 ft + 1 ft)(0.297)(1.75) = 2.08 kip/ft

P_H = 6.84 kip/ft + 2.08 kip/ft = 8.92 kip/ft

Check Sliding Resistance - Drained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_E = \gamma_{BF}(H+1)(B)(\gamma_{EV})$ = (120 pcf)(15 ft + 1 ft)(10.5 ft)(1.00) = 20.16 kip/ft

$\tan\delta = (\tan\varphi_{BS} \le \tan\varphi_{BF}) \longrightarrow$ tan(26) ≤ tan(34) $\longrightarrow$ 0.49 ≤ 0.67 = 0.49

R_τ = (20.16 kip/ft)(0.49) = 9.88 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau \longrightarrow$ 8.92 kip/ft ≤ (9.88 kip/ft)(1.0) = 9.88 kip/ft $\longrightarrow$ 8.92 kip/ft ≤ 9.88 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) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 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

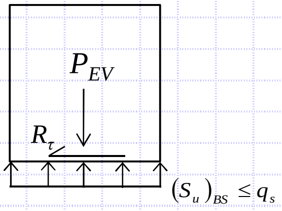
(AASHTO LRFD BDM Tables 3.4.1-1 and 3.4.1-2 - Active Earth Pressure)

1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Sliding Resistance - Undrained Condition (At Bottom of Foundation Preparation, 1.0-foot Below Bottom of Wall)

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



$(S_u)_{BS} =$ 1.50 ksf

$q_s = \sigma_v / 2$ = (1.92 ksf) / 2 = 0.96 ksf

$\sigma_v = P_{EV} / B$ = (20.16 kip/ft) / (10.5 ft) = 1.92 ksf

R_τ = (1.50 ksf ≤ 0.96 ksf)(10.5 ft) = 10.08 kip/ft

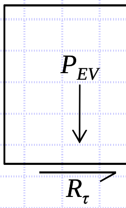
Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition (Bottom of Foundation Preparation)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 8.92 kip/ft ≤ (10.08 kip/ft)(1.0) = 10.08 kip/ft ⟶ 8.92 kip/ft ≤ 10.08 kip/ft **OK**

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

Check Sliding Resistance - Drained Condition (At Bottom of Wall, Top of Foundation Preparation)

Nominal Sliding Resistance: $R_\tau = P_{EV} \cdot \tan\delta$



$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV}$ = (120 pcf)(15 ft)(10.5 ft)(1.00) = 18.9 kip/ft

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

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

R_τ = (18.9 kip/ft)(0.67) = 12.66 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition (Bottom of Wall)

$P_H \le R_\tau \cdot \phi_\tau$ ⟶ 7.96 kip/ft ≤ (12.66 kip/ft)(1.0) = 12.66 kip/ft ⟶ 7.96 kip/ft ≤ 12.66 kip/ft **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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_{RS}) =	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 ^{1}:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Groundwater (Below Bot. of Wall), (D_W) =	10.7 ft		

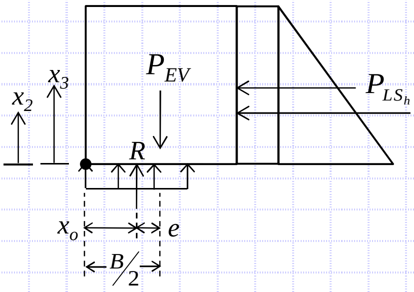
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



$$e = B/2 - x_o$$

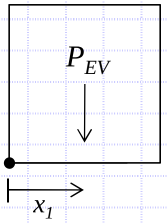
$$x_o = \frac{M_{EV} - M_H}{P_{EV}} = \text{(99.23 kip·ft/ft - 44.68 kip·ft/ft) / (18.9 kip/ft)} = 2.89 \text{ ft}$$

M_{EV} = 99.23 kip·ft/ft
M_H = 44.68 kip·ft/ft
P_{EV} = 18.90 kip/ft

Defined below

$$e = \text{(10.5 ft)/2 - 2.89 ft} = 2.36 \text{ ft}$$

Resisting Moment, M_{EV}:



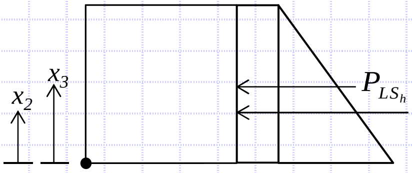
$$M_{EV} = P_{EV}(x_1)$$

$$P_{EV} = \gamma_{BF} \cdot H \cdot B \cdot \gamma_{EV} = \text{(120 pcf)(15 ft)(10.5 ft)(1.00)} = 18.90 \text{ kip/ft}$$

$$x_1 = B/2 = \text{(10.5 ft) / 2} = 5.25 \text{ ft}$$

$$M_{EV} = \text{(18.9 kip/ft)(5.25 ft)} = 99.23 \text{ kip·ft/ft}$$

Overturning Moment, M_H:



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

$$P_{EH} = ½\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(15 ft)²(0.297)(1.5)} = 6.01 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(15 ft)(0.297)(1.75)} = 1.95 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(15 ft) / 3} = 5.00 \text{ ft}$$

$$x_3 = H/2 = \text{(15 ft) / 2} = 7.50 \text{ ft}$$

$$M_H = \text{(6.01 kip/ft)(5 ft) + (1.95 kip/ft)(7.50 ft)} = 44.68 \text{ kip·ft/ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 2.36 ft < 3.50 ft **OK**

Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} = \text{(10.5 ft) / 3} = 3.50 \text{ ft}$

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 4 OF 6
CALCULATED BY PPM DATE 1/21/2022
CHECKED BY BRT DATE 3/26/2022
Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 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)

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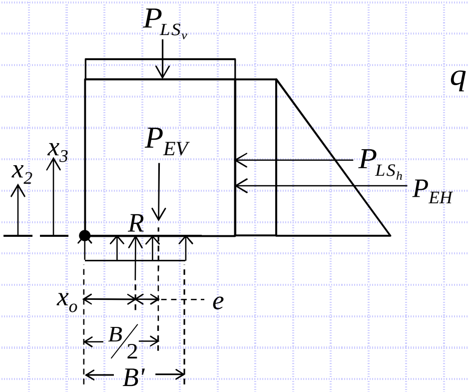
1. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$B' = B - 2e$ = 10.5 ft - 2(1.48 ft) = 7.54 ft

$e = B/2 - x_o$ = (10.5 ft) / 2 - 3.77 ft = 1.48 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (158.07 kip·ft/ft - 44.69 kip·ft/ft) / 30.11 kip/ft = 3.77 ft

q_{eq} = (30.11 kip/ft) / (7.54 ft) = 3.99 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)(15 ft)(10.5 ft)(1.35)](5.25 ft) + [(250 psf)(10.5 ft)(1.75)](5.25 ft) = 158.07 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)(15 ft)²(0.297)(1.5)](5 ft) + [(250 psf)(15 ft)(0.297)(1.75)](7.5 ft) = 44.69 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)(15 ft)(10.5 ft)(1.35) + (250 psf)(10.5 ft)(1.75) = 30.11 kip/ft

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 22.47

N_c = 22.25
s_c = 1+(7.54 ft/399 ft)(11.85/22.25)
= 1.010
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 13.24

N_q = 11.85
s_q = 1.000
d_q = 1+2tan(26°)[1-sin(26°)]²tan⁻¹(3.0 ft/7.54 ft)
1.117
i_q = 1.000 (Assumed)
C_{wq} = 10.7 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 12.44

N_γ = 12.54
s_γ = 0.992
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 10.7 ft < 1.5(7.54 ft) + 3.0 ft = 0.973

q_n = (0 psf)(22.473) + (115 pcf)(3.0 ft)(13.236)(1.000) + ½(115 pcf)(7.5 ft)(12.440)(0.973) = 9.81 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

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

$q_{eq} \le q_n \cdot \phi_b$ $\longrightarrow$ 3.99 ksf ≤ (9.81 ksf)(0.65) = 6.38 ksf $\longrightarrow$ 3.99 ksf ≤ 6.38 ksf **OK**

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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 ^{1}:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0 ft		
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7 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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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

Check Bearing Resistance - Undrained Condition

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

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

N_c = 5.140

s_c = 1+(7.54 ft/[(5)(399 ft)]) = 1.010

i_c = 1.000 (Assumed)

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

N_q = 1.000

s_q = 1.000

d_q = $1+2\tan(0°)[1-\sin(0°)]^2\tan^{-1}(3.0\text{ ft}/7.54\text{ ft})$

1.000

i_q = 1.000 (Assumed)

C_{wq} = 10.7 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)

$C_{w\gamma}$ = 10.7 ft < 1.5(7.54 ft) + 3.0 ft = 0.973

q_n = (1500 psf)(5.190) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(7.5 ft)(0.000)(0.973) = 8.13 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 3.99 ksf ≤ (8.13 ksf)(0.65) = 5.28 ksf ⟶ 3.99 ksf ≤ 5.28 ksf **OK**

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

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	PPM	DATE	1/21/2022
CHECKED BY	BRT	DATE	3/26/2022

Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)

MSE Wall Dimensions and Retained Soil Parameters

MSE Wall Height, (H) =	15.0	ft
MSE Wall Width (Reinforcement Length), (B) =	10.5	ft
MSE Wall Length, (L) =	399	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_{RS}) =	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 [1]:

	Bearing	Sliding	
Bearing Soil Unit Weight, (γ_{BS}) =	115	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	26	°
Bearing Soil Drained Cohesion, (c_{BS}) =	0	0	psf
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	1500	psf
Embedment Depth, (D_f) =	3.0		ft
Depth to Grounwater (Below Bot. of Wall), (D_W) =	10.7		ft

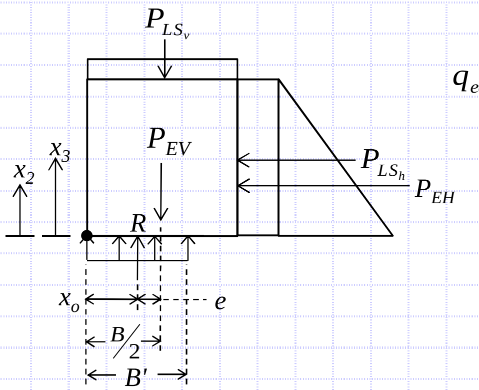
LRFD Load Factors

	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. Soil properties for bearing resistance based on critical soil type w/i 1.5B below the bottom of wall. Soil properties for sliding resistance based on soil type w/i 3.0 ft. below the bottom of wall.

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



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

$$B' = B - 2e \quad = \quad 10.5\text{ ft - 2(1.32 ft)} \quad = \quad 7.86 \quad \text{ft}$$

$$e = B/2 - x_o \quad = \quad \text{(10.5 ft) / 2 - 3.93 ft} \quad = \quad 1.32 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(113.01 kip·ft/ft - 28.4 kip·ft/ft) / 21.53 kip/ft} \quad = \quad 3.93 \quad \text{ft}$$

$$q_{eq} = \quad \text{(21.53 kip/ft) / (7.86 ft)} \quad = \quad 2.74 \quad \text{ksf}$$

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

$$M_V = \quad \text{[(120 pcf)(15.0 ft)(10.5 ft)(1.00)](5.3 ft) + [(250 psf)(10.5 ft)(1.00)](5.3 ft)} \quad = \quad 113.01 \quad \text{kip·ft/ft}$$

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

$$M_H = \quad \text{[½(120 pcf)(15 ft)²(0.297)(1.00)](5 ft) + [(250 psf)(15 ft)(0.297)(1.00)](7.5 ft)} \quad = \quad 28.40 \quad \text{kip·ft/ft}$$

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

$$P_V = \quad \text{(120 pcf)(15.0 ft)(10.5 ft)(1.00) + (250 psf)(10.5 ft)(1.00)} \quad = \quad 21.53 \quad \text{kip/ft}$$

Settlement, Time Rate of Consolidation and Differential Settlement:

Boring	Station Along Wall 5B	Total Settlement at Center of Reinforced Soil Mass	Total Settlement at Wall Facing	Time for 90% Consolidation	Distance Along Wall Facing	Differential Settlement Along Wall Facing
B-041-0-19	10+50	1.299 in	1.002 in	6 days		
B-045-0-19	13+50	1.721 in	1.311 in	8 days	300 ft	1 in / 970 ft
B-047-0-19	14+55	2.055 in	1.457 in	3 days	105 ft	1 in / 720 ft
B-007-0-65	15+85	0.997 in	0.777 in	80 days	130 ft	1 in / 190 ft
B-070-0-19	17+75	2.222 in	1.643 in	155 days	190 ft	1 in / 220 ft
B-086-0-19	18+30	1.575 in	1.145 in	5 days	55 ft	1 in / 110 ft
B-088-0-19	20+00	1.840 in	1.350 in	27 days	170 ft	1 in / 830 ft
B-089-0-19	21+95	1.084 in	0.814 in	27 days	195 ft	1 in / 360 ft

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-089-0-19

H = 15.0 ft Wall height
B = 10.5 ft Width of wall
D_w = 10.7 ft Depth below bottom of wall
γ_{BF} = 120 pcf Unit weight of backfill
q = 1,800 psf Bearing pressure at bottom of wall

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	Total Settlement at Center of Reinforced Soil Mass					Total Settlement at Facing of Wall				
																						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	2.2	793.8	791.6	2.2	1.1	120	264	132	132	3,132	28	0.162	0.016	0.491				0.10	0.996	1,793	1,925	0.028	0.334	0.500	900	1,032	0.021	0.256
2	A-6b	C	2.2	4.7	791.6	789.1	2.5	3.5	115	552	408	408	3,408	37	0.243	0.024	0.561				0.33	0.922	1,660	2,067	0.027	0.329	0.493	888	1,296	0.020	0.234
	A-6b	C	4.7	7.2	789.1	786.6	2.5	6.0	115	839	695	695	3,695	37	0.243	0.024	0.561				0.57	0.776	1,397	2,092	0.019	0.223	0.472	850	1,546	0.014	0.162
3	A-4a	C	7.2	10.2	786.6	783.6	3.0	8.7	120	1,199	1,019	1,019	4,019	20	0.090	0.009	0.428				0.83	0.627	1,129	2,148	0.006	0.073	0.436	785	1,804	0.005	0.056
	A-4a	C	10.2	13.2	783.6	780.6	3.0	11.7	120	1,559	1,379	1,317	4,317	20	0.090	0.009	0.428				1.11	0.506	911	2,228	0.004	0.052	0.391	704	2,020	0.004	0.042
	A-4a	C	13.2	16.2	780.6	777.6	3.0	14.7	120	1,919	1,739	1,489	4,489	20	0.090	0.009	0.428				1.40	0.420	756	2,245	0.003	0.040	0.348	626	2,116	0.003	0.035
4	A-4a	C	16.2	19.2	777.6	774.6	3.0	17.7	125	2,294	2,107	1,670	4,670	20	0.090	0.009	0.428				1.69	0.357	643	2,313	0.003	0.032	0.310	558	2,228	0.002	0.028
																								Total Settlement:		1.084 in			Total Settlement:		0.814 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-20.85 FEF - Retaining Wall 5B - Sta. 20+80 to 21+95 (BL Wall 5B)
MSE Wall Settlement

Calculated By: PPM Date: 1/21/2022
Checked By: BRT Date: 3/23/2022

Boring B-089-0-19

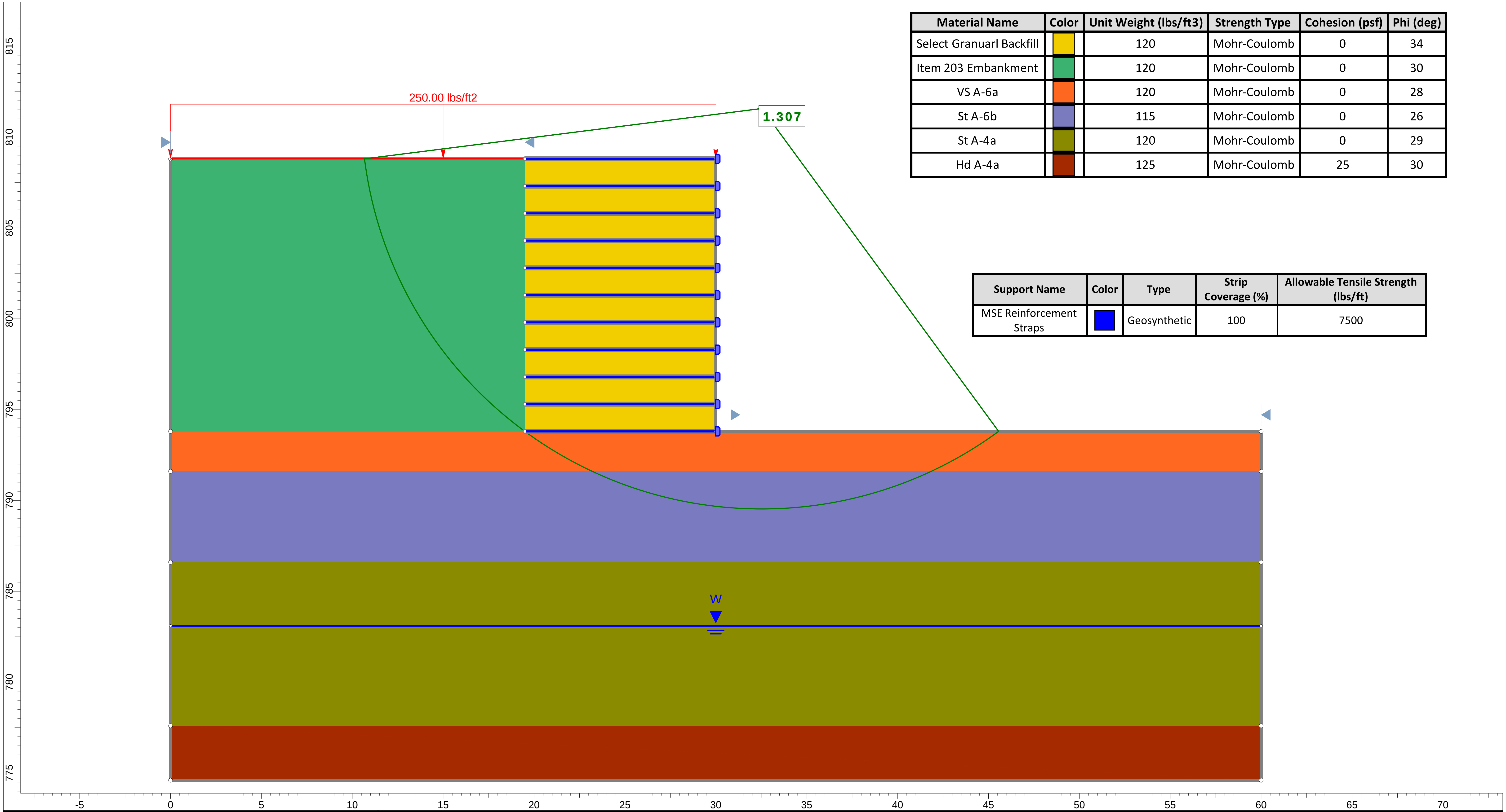
H =	15.0	ft	Wall height
B =	10.5	ft	Width of wall
D_w =	10.7	ft	Depth below bottom of wall
γ_{BF} =	120		Unit weight of backfill
q =	1,800	psf	Bearing pressure at bottom of wall
t =	27	days	Time following completion of construction

																									Total Settlement at Facing of Wall			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	1.7	793.8	792.1	1.7	0.9	125	213	106	106	3,106	38	0.252	0.025	0.569				0.08	0.500	900	1,006	0.027	0.320	0.510	300	1.7	7.679	100	0.320	0.508
	A-6a	C	1.7	3.4	792.1	790.4	1.7	2.6	125	425	319	319	3,319	38	0.252	0.025	0.569				0.24	0.497	895	1,214	0.016	0.190		300	3.4	1.920	99	0.188	
2	A-6a	C	3.4	5.4	790.4	788.4	2.0	4.4	125	675	550	550	3,550	38	0.252	0.025	0.569				0.42	0.487	877	1,427	0.013	0.160	0.160	300	5.4	0.761	88	0.140	0.140
	A-6a	C	5.4	7.4	788.4	786.4	2.0	6.4	125	925	800	800	3,800	38	0.252	0.025	0.569				0.61	0.467	841	1,641	0.010	0.120	0.203	300	7.4	0.405	70	0.084	0.135
3	A-6b	C	7.4	9.4	786.4	784.4	2.0	8.4	120	1,165	1,045	1,045	4,045	34	0.216	0.022	0.538				0.80	0.440	793	1,838	0.007	0.083		200	7.0	0.302	62	0.051	
4	A-4a	C	9.4	14.4	784.4	779.4	5.0	11.9	125	1,790	1,478	1,403	4,403	24	0.126	0.013	0.460				1.13	0.388	698	2,101	0.008	0.091	0.091	400	5.0	1.184	96	0.087	0.087
5	A-2-4	G	14.4	23.4	779.4	770.4	9.0	18.9	135	3,005	2,398	1,886	4,886					50	51	174	1.80	0.297	534	2,420	0.006	0.067	0.067				100	0.067	0.067
6	A-4b	C	23.4	28.4	770.4	765.4	5.0	25.9	125	3,630	3,318	2,369	5,369	24	0.126	0.013	0.460				2.47	0.233	420	2,789	0.003	0.037	0.066	400	5.0	1.184	96	0.035	0.051
7	A-6b	C	28.4	31.4	765.4	762.4	3.0	29.9	125	4,005	3,818	2,619	5,619	34	0.216	0.022	0.538				2.85	0.207	373	2,992	0.002	0.029		200	8.0	0.231	54	0.016	

$(S_c)_t$ = 0.990 in

Settlement Remaining After Hold Period: 0.107 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



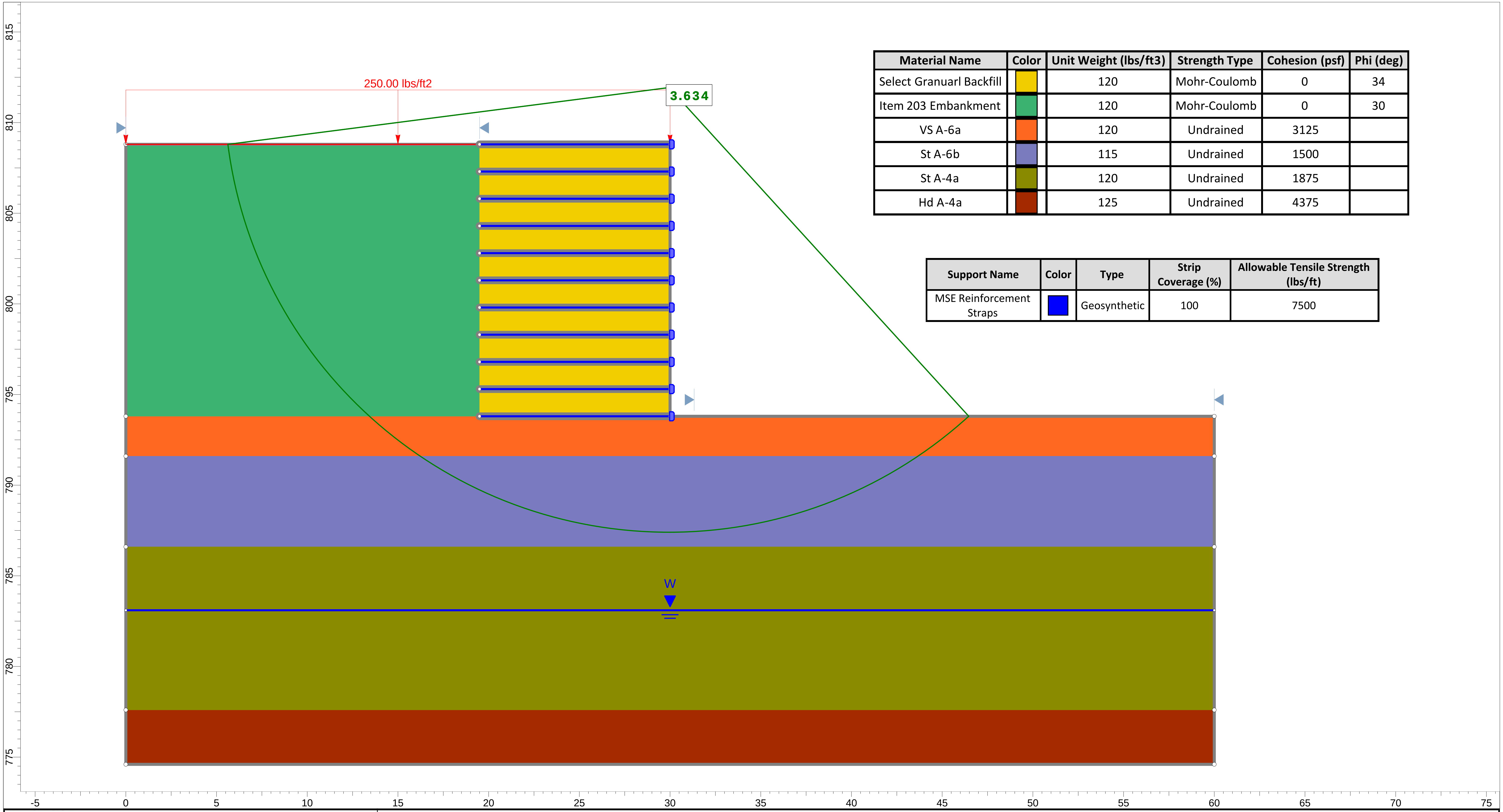
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granuarl Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	120	Mohr-Coulomb	0	28
St A-6b	🟪	115	Mohr-Coulomb	0	26
St A-4a	🟫	120	Mohr-Coulomb	0	29
Hd A-4a	🟥	125	Mohr-Coulomb	25	30

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

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

Project	FRA-70-22.85 FEF - Retaining Wall 5B		
Analysis Description	Global Stability - Sta. 20+80 to 21+95 (BL Wall 5B) - B-089-0-19 - Level Backfill - 15.0 ft. Wall Height - Drained - Circular		
Drawn By BRT	*Scale* 1:60	*Company*	Resource International, Inc.
Date 4/2/2022, 11:11:13 AM		*File Name*	Wall 5B - Sta. 20+80 to 21+95 - Global Stability.slmd

SLIDEINTERPRET 9.019



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Select Granuarl Backfill	🟨	120	Mohr-Coulomb	0	34
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	120	Undrained	3125	
St A-6b	🟪	115	Undrained	1500	
St A-4a	🟫	120	Undrained	1875	
Hd A-4a	🟥	125	Undrained	4375	

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

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

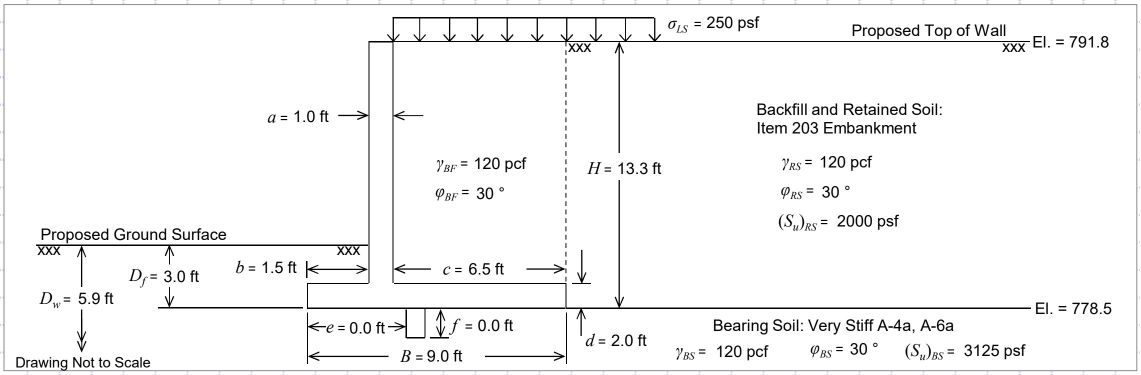
Project	FRA-70-22.85 FEF - Retaining Wall 5B
Analysis Description	Global Stability - Sta. 20+80 to 21+95 (BL Wall 5B) - B-089-0-19 - Level Backfill - 15.0 ft. Wall Height - Undrained - Circular
Drawn By	BRT
Scale	1:60
Company	Resource International, Inc.
Date	4/2/2022, 11:11:13 AM
File Name	Wall 5B - Sta. 20+80 to 21+95 - Global Stability.slmd

SLIDEINTERPRET 9.019

APPENDIX X

CIP WALL CALCULATIONS

Retaining Wall 2A - Sta. 10+00 to 11+30 (BL Wall 2A) - CIP Wall w/o Shear Key - B-039-0-19 and B-040-1-21 - 13.3 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) = 13.3 ft
Foundation Width (Entire Base Width), (B) = 9.0 ft
Stem Width, (a) = 1.0 ft
Toe Width, (b) = 1.5 ft
Heel Width, (c) = 6.5 ft
Footing Thickness, (d) = 2.0 ft
Location of Shear Key, (e) = 0.0 ft
Depth of Shear Key, (f) = 0.0 ft
Embedment Depth, (D_f) = 3.0 ft
Wall Length, (L) = 130 ft
Live Surcharge Load, (σ_{LS}) = 250 psf
Depth to Groundwater, (D_w) = 5.9 ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) = 120 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 30 °
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ = 3125 psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ = 120 pcf
Retained Soil Friction Angle, (φ_{RS}) = 30 °
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ = 2000 psf
Active Earth Pressure Coefficient, (K_a) = 0.297
Passive Earth Pressure Coefficient, (K_p) = 5.576

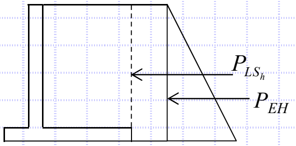
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

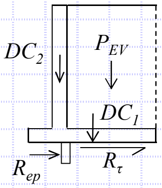
$$P_{EH} = \tfrac{1}{2}\gamma_{RS}H^2K_a\gamma_{EH} = \text{½(120 pcf)(13.3 ft)²(0.297)(1.50)} = 4.73 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS}HK_a\gamma_{LS} = \text{(250 psf)(13.3 ft)(0.297)(1.75)} = 1.73 \text{ kip/ft}$$

$$P_H = \text{4.73 kip/ft + 1.73 kip/ft} = 6.46 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$



$$R_{ep} = \gamma_{BS}D_f fK_p\gamma_{ep} + \tfrac{1}{2}\gamma_{BS}f^2K_p\gamma_{ep}$$

$$R_{ep} = \text{(120 pcf)(3.0 ft)(0.0 ft)(5.58)(0.90) + ½(120 pcf)(0.0 ft)²(5.58)(0.90)} = 0.00 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot [B \cdot d + (H-d)\cdot a]\cdot\gamma_{DC} + \gamma_{BF}\cdot(H-d)\cdot c\cdot\gamma_{EV}$$

$$P_V = \text{(150 pcf) [(9.0 ft)(2.0 ft) + (13.3 ft - 2.0 ft)(1.0 ft)] (0.90) +} \\ \text{(120 pcf)(13.3 ft - 2.0 ft)(6.5 ft)(1.00)} = 12.77 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \text{tan(30)} = 0.58$$

$$R_\tau = \text{(12.77 kip/ft)(0.58)} = 7.41 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep}\cdot R_{ep} \longrightarrow \text{6.46 kip/ft ≤ (7.41 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 7.41 kip/ft}$$

= 6.46 kip/ft ≤ 7.41 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2A - Sta. 10+00 to 11+30 (BL Wall 2A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	13.3	ft
Foundation Width (Entire Base Width), (B) =	9.0	ft
Stem Width, (a) =	1.0	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	6.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	130	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3125	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.576	

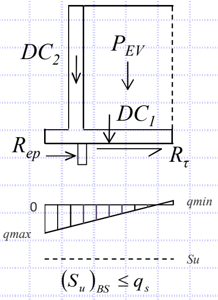
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 *(Continued)*

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



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

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (3.29 ksf) / 2 = 1.65 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (-0.45 ksf) / 2 = -0.23 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1 + 6\frac{e}{B}\right)$ = (12.77 kip/ft / 9.0 ft)[1 + 6(1.98 ft / 9.0 ft)] = 3.29 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1 - 6\frac{e}{B}\right)$ = (12.77 kip/ft / 9.0 ft)[1 - 6(1.98 ft / 9.0 ft)] = -0.45 ksf

R_τ = 0.5(1.65 ksf)[((9.0 ft)(1.65 ksf)) / (1.65 ksf - -0.23 ksf)] = 6.52 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 6.46 kip/ft ≤ (6.52 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 6.52

= 6.46 kip/ft ≤ 6.52 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2A - Sta. 10+00 to 11+30 (BL Wall 2A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	13.3	ft
Foundation Width (Entire Base Width), (B) =	9.0	ft
Stem Width, (a) =	1.0	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	6.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	130	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

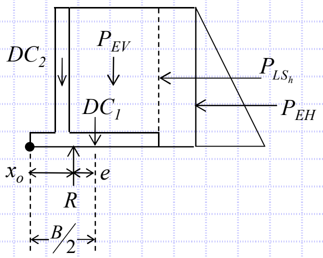
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3125	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.576	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = {}^{B}\!/_{2} - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (64.67 kip·ft/ft - 32.46 kip·ft/ft) / (12.77 kip/ft) = 2.52 ft

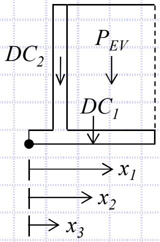
M_V = 64.67 kip·ft/ft
M_H = 32.46 kip·ft/ft
Defined below

$P_V = P_{EV} + DC_1 + DC_2$ = 8.81 kip/ft + 2.43 kip/ft + 1.53 kip/ft = 12.77 kip/ft

$e =$ (9.0 ft / 2) - 2.52 ft = 1.98 ft

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(13.3 ft - 2.0 ft)(6.5 ft)(1.00) = 8.81 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(9.0 ft)(2.0 ft)(0.90) = 2.43 kip/ft

$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(13.3 ft - 2.0 ft)(1.0 ft)(0.90) = 1.53 kip/ft

$x_1 = a + b + {}^{c}\!/_{2}$ = 1.0 ft + 1.5 ft + (6.5 ft / 2) = 5.8 ft

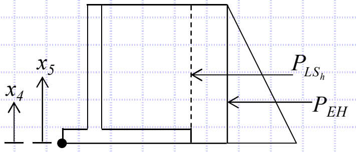
$x_2 = {}^{B}\!/_{2}$ = 9.0 ft / 2 = 4.5 ft

$x_3 = b + {}^{a}\!/_{2}$ = 1.5 ft + (1.0 ft / 2) = 2.0 ft

$M_V =$ (8.81 kip/ft)(5.8 ft) + (2.43 kip/ft)(4.5 ft) + (1.53 kip/ft)(2.0 ft) = 64.67 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = {}^{1}\!/_{2}\,\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(13.3 ft)²(0.297)(1.50) = 4.73 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(13.3 ft)(0.297)(1.75) = 1.73 kip/ft

$x_2 = {}^{H}\!/_{3}$ = (13.3 ft) / 3 = 4.43 ft

$x_3 = {}^{H}\!/_{2}$ = (13.3 ft) / 2 = 6.65 ft

$M_H =$ (4.73 kip/ft)(4.43 ft) + (1.73 kip/ft)(6.65 ft) = 32.46 kip·ft/ft

Limiting Eccentricity:

$e_{\max} = {}^{B}\!/_{3} \longrightarrow e_{\max} =$ (9.0 ft) / 3 = 3.00 ft

Check Eccentricity

$e < e_{\max} \longrightarrow$ 1.98 ft < 3.00 ft **OK**

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	13.3	ft
Foundation Width (Entire Base Width), (B) =	9.0	ft
Stem Width, (a) =	1.0	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	6.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	130	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

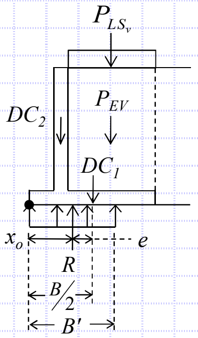
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.576	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

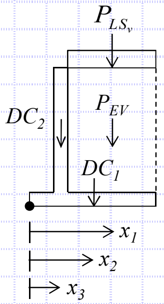
$B' = B - 2e$ = 9.0 ft - 2(0.84 ft) = 7.32 ft (For e < 0, Use B)

$e = B \big/ 2 - x_o$ = (9.0 ft / 2) - 3.66 ft = 0.84 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (110.48 kip·ft/ft - 32.46 kip·ft/ft) / (21.33 kip/ft) = 3.66 ft

q_{eq} = (21.33 kip/ft) / (7.32 ft) = 2.91 ksf

Resisting Moment, M_V:



$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$

$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(13.3 ft - 2.0 ft)(6.5 ft)(1.35) = 11.90 kip/ft

$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS}$ = (250 psf)(9.0 ft)(1.75) = 3.938 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(9.0 ft)(2.0 ft)(1.25) = 3.38 kip/ft

$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(13.3 ft - 2.0 ft)(1.0 ft)(1.25) = 2.12 kip/ft

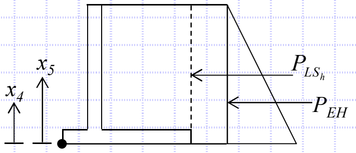
$x_1 = a + b + c \big/ 2$ = 1.0 ft + 1.5 ft + (6.5 ft / 2) = 5.8 ft

$x_2 = B \big/ 2$ = 9.0 ft / 2 = 4.5 ft

$x_3 = b + a \big/ 2$ = 1.5 ft + (1.0 ft / 2) = 2.0 ft

$M_V =$ (11.90 kip/ft)(5.8 ft) + (3.94 kip/ft)(5.8 ft) + (3.38 kip/ft)(4.5 ft) + (2.12 kip/ft)(2.0 ft) = 110.48 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$

$P_{EH} = \tfrac{1}{2} \gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(13.3 ft)²(0.297)(1.50) = 4.73 kip/ft

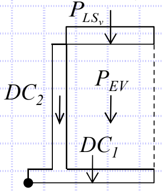
$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(13.3 ft)(0.297)(1.75) = 1.73 kip/ft

$x_4 = H \big/ 3$ = (13.3 ft) / 3 = 4.43 ft

$x_5 = H \big/ 2$ = (13.3 ft) / 2 = 6.65 ft

$M_H =$ (4.73 kip/ft)(4.43 ft) + (1.73 kip/ft)(6.65 ft) = 32.46 kip·ft/ft

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

P_V = 11.90 kip/ft + 3.94 kip/ft + 3.38 kip/ft + 2.12 kip/ft

P_V = 21.33 kip/ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2A - Sta. 10+00 to 11+30 (BL Wall 2A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	13.3	ft
Foundation Width (Entire Base Width), (B) =	9.0	ft
Stem Width, (a) =	1.0	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	6.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	130	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.576	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 31.165

N_c = 30.14
s_c = 1+(7.32 ft/130 ft)(18.401/30.14)
= 1.034
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 21.137

N_q = 18.401
s_q = 1+(7.32 ft/130 ft)tan(30°) = 1.033
d_q = 1+2tan(30°)[1-sin(30°)]²tan⁻¹(3.0 ft/7.32 ft)
= 1.112
i_q = 1.000 (Assumed)
C_{wq} = 5.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 21.887

N_γ = 22.402
s_γ = 1-0.4(7.32 ft/130 ft) = 0.977
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 5.9 ft < 1.5(7.32 ft) + 3.0 ft = 0.769

q_n = (0 psf)(31.165) + (120 pcf)(3.0 ft)(21.137)(1.000) + ½(120 pcf)(7.3 ft)(21.887)(0.769) = 15.00 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 2.91 ksf ≤ (15.00 ksf)(0.55) = 8.25 ksf ⟶ 2.91 ksf ≤ 8.25 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.315

N_c = 5.140
s_c = 1+(7.32 ft/[(5)(130 ft)]) = 1.034
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/7.32 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 5.9 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)
$C_{w\gamma}$ = 5.9 ft < 1.5(7.32 ft) + 3.0 ft = 0.769

q_n = (3125 psf)(5.315) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(7.3 ft)(0.000)(0.769) = 16.97 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 2.91 ksf ≤ (16.97 ksf)(0.55) = 9.33 ksf ⟶ 2.91 ksf ≤ 9.33 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2A - Sta. 10+00 to 11+30 (BL Wall 2A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	13.3	ft
Foundation Width (Entire Base Width), (B) =	9.0	ft
Stem Width, (a) =	1.0	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	6.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	130	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

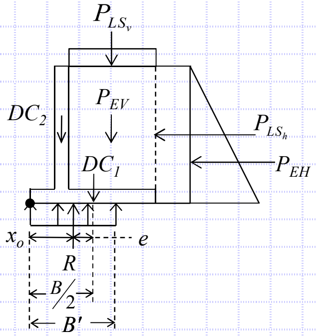
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3125	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.576	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 9.0 ft - 2(0.71 ft) = 7.58 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (9.0 ft / 2) - 3.79 ft = 0.71 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (79.16 kip·ft/ft - 20.54 kip·ft/ft) / (15.46 kip/ft) = 3.79 ft

q_{eq} = (15.46 kip/ft) / (7.58 ft) = 2.04 ksf

$$M_V = [(\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})](a + b + c/2) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2)$$

M_V =[(120 pcf)(13.3 ft - 2.0 ft)(6.5 ft)(1.00) + (250 psf)(9.0 ft)(1.00)](1.0 ft + 1.5 ft + (6.5 ft / 2)) = 79.16 kip·ft/ft
+ [(150 pcf)(9.0 ft)(2.0 ft)(1.00)](9.0 ft / 2) + [(150 pcf)(13.3 ft - 2.0 ft)(1.0 ft)(1.00)](1.5 ft + (1.0 ft / 2))

$$M_H = (\tfrac{1}{2} \gamma_{RS} \cdot H^2 \cdot K_a \cdot \gamma_{EH})(H/3) + (\sigma_{LS} \cdot H \cdot K_a \cdot \gamma_{LS})(H/2)$$

M_H = [½(120 pcf)(13.3 ft)²(0.297)(1.00)](13.3 ft / 3) + [(250 psf)(13.3 ft)(0.297)(1.00)](13.3 ft / 2) = 20.54 kip·ft/ft

$$P_V = (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS}) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})$$

P_V = (120 pcf)(13.3 ft - 2.0 ft)(6.5 ft)(1.00) + (250 psf)(9.0 ft)(1.00) + (150 pcf)(9.0 ft)(2.0 ft)(1.00) = 15.46 kip/ft
+ (150 pcf)(13.3 ft - 2.0 ft)(1.0 ft)(1.00)

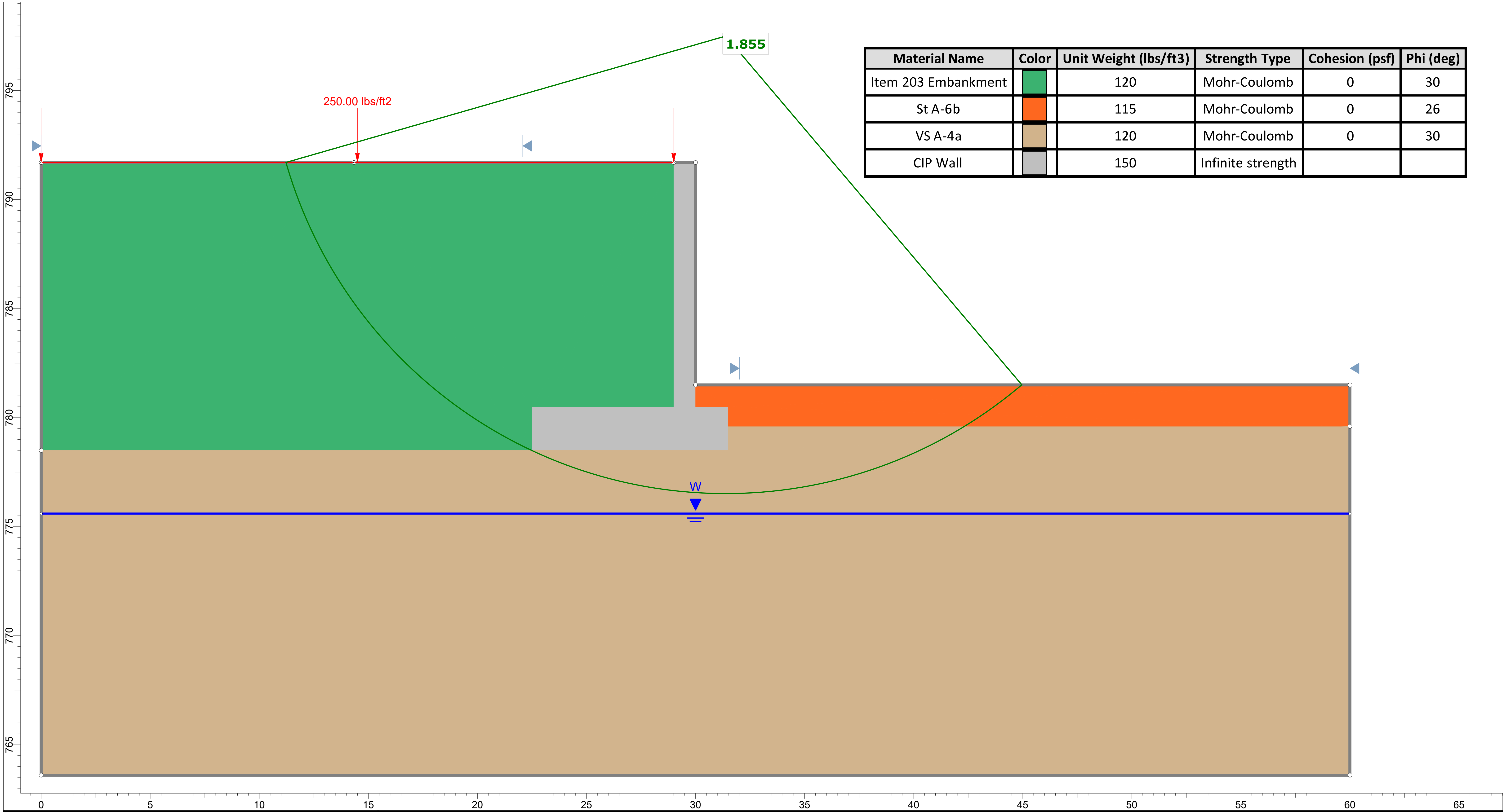
Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: $(S_t)_{max}$ = **N/A** in

Minimum Settlement Along Wall Alignment: $(S_t)_{min}$ = **N/A** in

Differential Settlement Along Wall Alignment: δ_s = N/A ⟶ N/A

$\delta_s < 1/500$ ⟶ N/A < 1/500

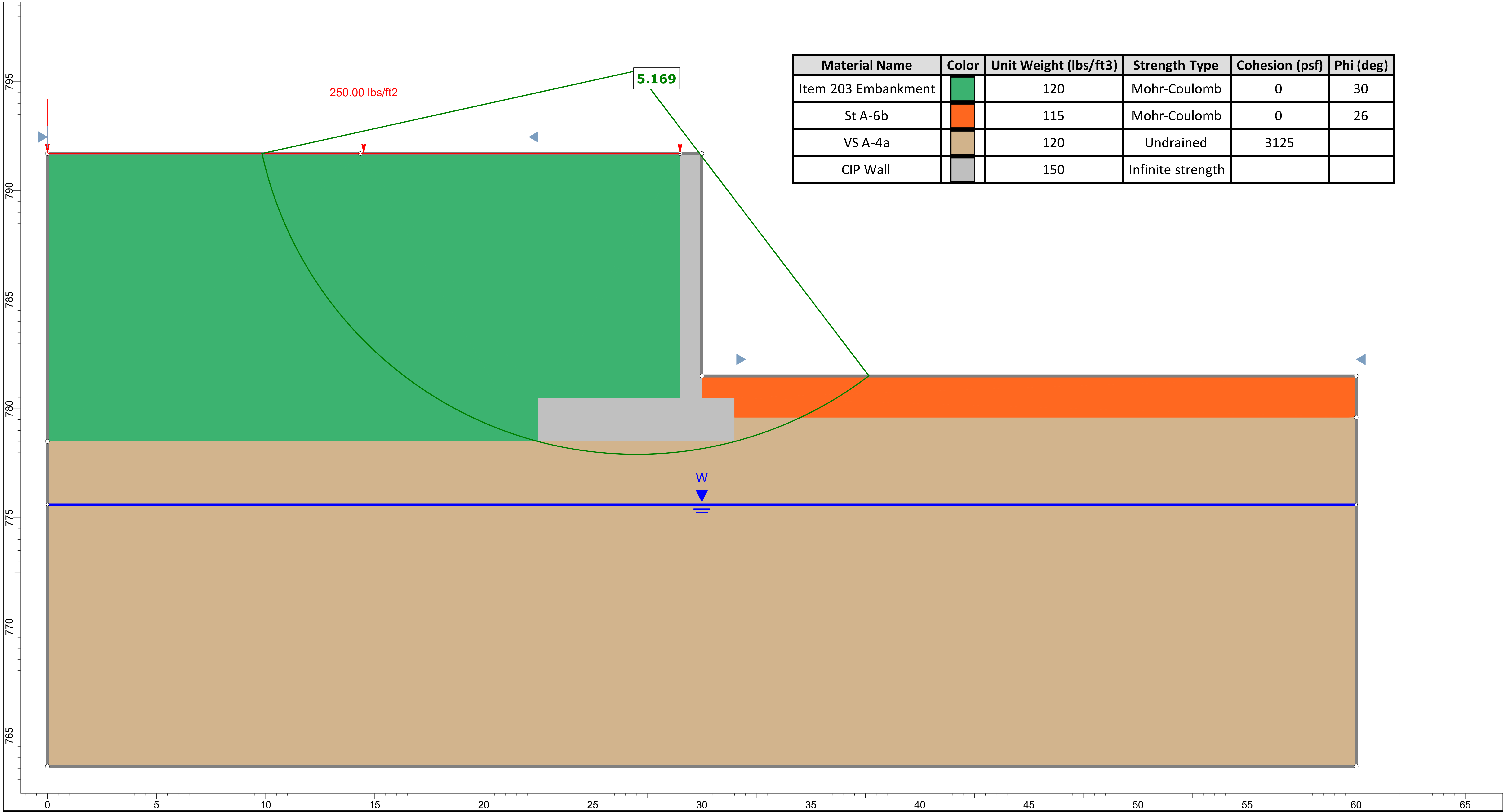


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Mohr-Coulomb	0	26
VS A-4a	🟫	120	Mohr-Coulomb	0	30
CIP Wall	⬜	150	Infinite strength		

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

SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 2A		
Analysis Description	Global Stability - Sta. 10+00 to 11+30 (BL Wall 2A) - CIP Wall w/o Shear Key - B-039-0-19 and B-040-1-21 - 13.3 ft. Wall Height - Drained - Circular		
Drawn By	BRT	*Scale* 1:50	*Company* Resource International, Inc.
Date	4/2/2022, 12:29:06 PM	*File Name*	Wall 2A - Sta. 10+00 to 11+30 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Mohr-Coulomb	0	26
VS A-4a	🟫	120	Undrained	3125	
CIP Wall	⬜	150	Infinite strength		

Resource International, Inc.
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SLIDEINTERPRET 9.024

Project FRA-70-22.85 FEF - Retaining Wall 2A

Analysis Description Global Stability - Sta. 10+00 to 11+30 (BL Wall 2A) - CIP Wall w/o Shear Key - B-039-0-19 and B-040-1-21 - 13.3 ft. Wall Height - Undrained - Circular

Drawn By BRT

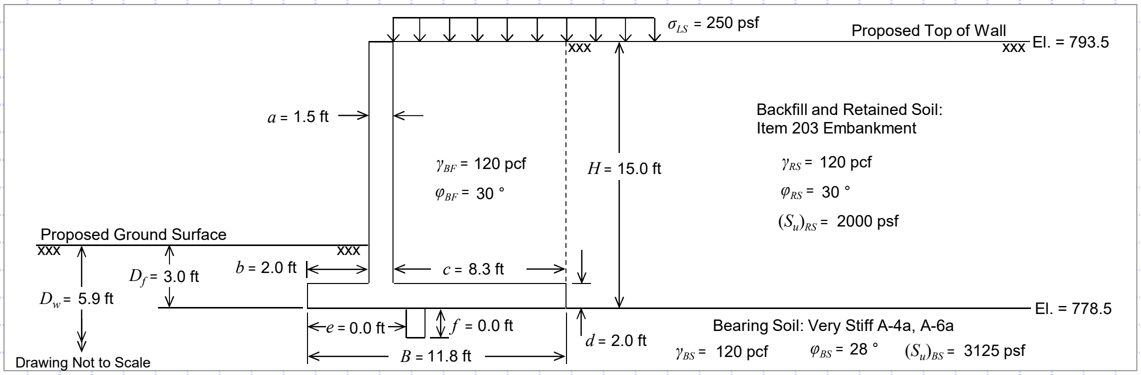
Scale 1:50

Company Resource International, Inc.

Date 4/2/2022, 12:29:06 PM

File Name Wall 2A - Sta. 10+00 to 11+30 - Global Stability.slmd

Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B) - CIP Wall w/o Shear Key - B-039-0-19, B-040-0-19 and B-041-1-21 - 15.0 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

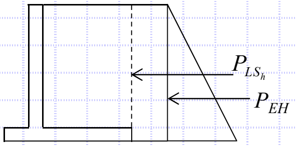
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

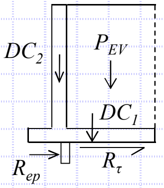
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(15.0 ft)²(0.297)(1.50)} = 6.01 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad \text{(250 psf)(15.0 ft)(0.297)(1.75)} = 1.95 \text{ kip/ft}$$

$$P_H = 6.01 \text{ kip/ft} + 1.95 \text{ kip/ft} = 7.96 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$



$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

$$R_{ep} = \text{(120 pcf)(3.0 ft)(0.0 ft)(5.07)(0.90) + ½(120 pcf)(0.0 ft)²(5.07)(0.90)} = 0.00 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot \left[B \cdot d + (H-d)\cdot a\right] \cdot \gamma_{DC} + \gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}$$

$$P_V = \text{(150 pcf) [(11.8 ft)(2.0 ft) + (15.0 ft - 2.0 ft)(1.5 ft)] (0.90) + (120 pcf)(15.0 ft - 2.0 ft)(8.3 ft)(1.00)} = 18.77 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(28) = 0.53$$

$$R_\tau = \text{(18.77 kip/ft)(0.53)} = 9.95 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow \text{7.96 kip/ft ≤ (9.95 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 9.95 kip/ft}$$

= 7.96 kip/ft ≤ 9.95 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	3125	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

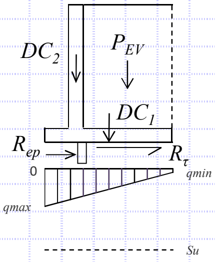
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 *(Continued)*

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



$(S_u)_{BS} \le q_s$

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

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (2.9 ksf) / 2 = 1.45 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (0.28 ksf) / 2 = 0.14 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1 + 6\frac{e}{B}\right)$ = (18.77 kip/ft / 11.8 ft)[1 + 6(1.62 ft / 11.8 ft)] = 2.9 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1 - 6\frac{e}{B}\right)$ = (18.77 kip/ft / 11.8 ft)[1 - 6(1.62 ft / 11.8 ft)] = 0.28 ksf

R_τ = 0.5(1.45 ksf - 0.14 ksf)(11.8 ft) + (0.14 ksf)(11.8 ft) = 9.38 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 7.96 kip/ft ≤ (9.38 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 9.38

= 7.96 kip/ft ≤ 9.38 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

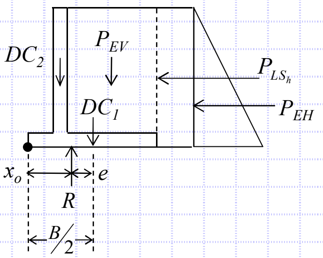
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = {}^{B}\!/_{2} - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(125.09 kip·ft/ft - 44.68 kip·ft/ft) / (18.77 kip/ft)} \quad = \quad 4.29 \text{ ft}$$

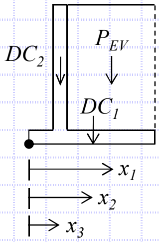
M_V = 125.09 kip·ft/ft
M_H = 44.68 kip·ft/ft
} Defined below

$$P_V = P_{EV} + DC_1 + DC_2 \quad = \text{12.95 kip/ft + 3.19 kip/ft + 2.63 kip/ft} = \quad 18.77 \text{ kip/ft}$$

$$e = \quad \text{(11.8 ft / 2) - 4.29 ft} \quad = \quad 1.62 \text{ ft}$$

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV} \quad = \quad \text{(120 pcf)(15.0 ft - 2.0 ft)(8.3 ft)(1.00)} \quad = \quad 12.95 \text{ kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} \quad = \quad \text{(150 pcf)(11.8 ft)(2.0 ft)(0.90)} \quad = \quad 3.19 \text{ kip/ft}$$

$$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC} \quad = \quad \text{(150 pcf)(15.0 ft - 2.0 ft)(1.5 ft)(0.90)} \quad = \quad 2.63 \text{ kip/ft}$$

$$x_1 = a + b + {}^{c}\!/_{2} \quad = \quad \text{1.5 ft + 2.0 ft + (8.3 ft / 2)} \quad = \quad 7.7 \text{ ft}$$

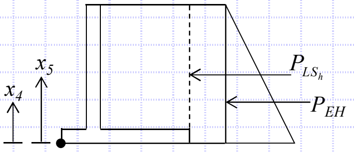
$$x_2 = {}^{B}\!/_{2} \quad = \quad \text{11.8 ft / 2} \quad = \quad 5.9 \text{ ft}$$

$$x_3 = b + {}^{a}\!/_{2} \quad = \quad \text{2.0 ft + (1.5 ft / 2)} \quad = \quad 2.8 \text{ ft}$$

$$M_V = \quad \text{(12.95 kip/ft)(7.7 ft) + (3.19 kip/ft)(5.9 ft) + (2.63 kip/ft)(2.8 ft)} \quad = \quad 125.09 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = {}^{1}\!/_{2}\, \gamma_{RS} H^2 K_a \gamma_{EH} \quad = \quad \text{½(120 pcf)(15.0 ft)²(0.297)(1.50)} \quad = \quad 6.01 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad = \quad \text{(250 psf)(15.0 ft)(0.297)(1.75)} \quad = \quad 1.95 \text{ kip/ft}$$

$$x_2 = {}^{H}\!/_{3} \quad = \quad \text{(15.0 ft) / 3} \quad = \quad 5.00 \text{ ft}$$

$$x_3 = {}^{H}\!/_{2} \quad = \quad \text{(15.0 ft) / 2} \quad = \quad 7.50 \text{ ft}$$

$$M_H = \quad \text{(6.01 kip/ft)(5 ft) + (1.95 kip/ft)(7.50 ft)} \quad = \quad 44.68 \text{ kip·ft/ft}$$

Limiting Eccentricity:

$$e_{\max} = {}^{B}\!/_{3} \quad \longrightarrow \quad e_{\max} = \quad \text{(11.8 ft) / 3} \quad = \quad 3.93 \text{ ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 1.62 ft < 3.93 ft OK

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

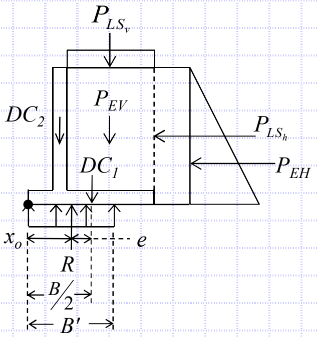
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

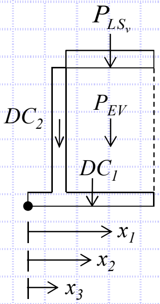
$$B' = B - 2e$$ = 11.8 ft - 2(0.54 ft) = 10.72 ft (For e < 0, Use B)

$$e = B \big/ 2 - x_o$$ = (11.8 ft / 2) - 5.36 ft = 0.54 ft

$$x_o = \frac{M_V - M_H}{P_V}$$ = (209.38 kip·ft/ft - 44.68 kip·ft/ft) / (30.72 kip/ft) = 5.36 ft

q_{eq} = (30.72 kip/ft) / (10.72 ft) = 2.87 ksf

Resisting Moment, M_V:



$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$

$$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$$ = (120 pcf)(15.0 ft - 2.0 ft)(8.3 ft)(1.35) = 17.48 kip/ft

$$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS}$$ = (250 psf)(11.8 ft)(1.75) = 5.163 kip/ft

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$$ = (150 pcf)(11.8 ft)(2.0 ft)(1.25) = 4.43 kip/ft

$$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$$ = (150 pcf)(15.0 ft - 2.0 ft)(1.5 ft)(1.25) = 3.66 kip/ft

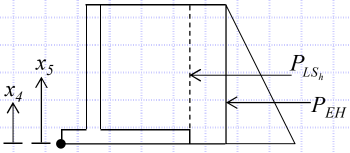
$$x_1 = a + b + c \big/ 2$$ = 1.5 ft + 2.0 ft + (8.3 ft / 2) = 7.7 ft

$$x_2 = B \big/ 2$$ = 11.8 ft / 2 = 5.9 ft

$$x_3 = b + a \big/ 2$$ = 2.0 ft + (1.5 ft / 2) = 2.8 ft

M_V = (17.48 kip/ft)(7.7 ft) + (5.16 kip/ft)(7.7 ft) + (4.43 kip/ft)(5.9 ft) + (3.66 kip/ft)(2.8 ft) = 209.38 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$

$$P_{EH} = \tfrac{1}{2} \gamma_{RS} H^2 K_a \gamma_{EH}$$ = ½(120 pcf)(15.0 ft)²(0.297)(1.50) = 6.01 kip/ft

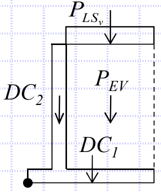
$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$$ = (250 psf)(15.0 ft)(0.297)(1.75) = 1.95 kip/ft

$$x_4 = H \big/ 3$$ = (15.0 ft) / 3 = 5.00 ft

$$x_5 = H \big/ 2$$ = (15.0 ft) / 2 = 7.50 ft

M_H = (6.01 kip/ft)(5 ft) + (1.95 kip/ft)(7.50 ft) = 44.68 kip·ft/ft

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

P_V = 17.48 kip/ft + 5.16 kip/ft + 4.43 kip/ft + 3.66 kip/ft

P_V = 30.72 kip/ft

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	5	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + ½\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 26.525

N_c = 25.803
s_c = 1+(10.72 ft/221 ft)(14.72/25.803)
= 1.028
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 16.341

N_q = 14.72
s_q = 1+(10.72 ft/221 ft)tan(28°) = 1.026
d_q = 1+2tan(28°)[1-sin(28°)]²tan⁻¹(3.0 ft/10.72 ft)
= 1.082
i_q = 1.000 (Assumed)
C_{wq} = 5.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 16.399

N_γ = 16.717
s_γ = 1-0.4(10.72 ft/221 ft) = 0.981
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 5.9 ft < 1.5(10.72 ft) + 3.0 ft = 0.683

$q_n =$ (0 psf)(26.525) + (120 pcf)(3.0 ft)(16.341)(1.000) + ½(120 pcf)(10.7 ft)(16.399)(0.683) = 13.09 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.87 ksf ≤ (13.09 ksf)(0.55) = 7.20 ksf ⟶ 2.87 ksf ≤ 7.20 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

Nominal Bearing Resistance: $q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + ½\gamma B' N_{\gamma m} C_{w\gamma}$

$N_{cm} = N_c s_c i_c$ = 5.284

N_c = 5.140
s_c = 1+(10.72 ft/[(5)(221 ft)]) = 1.028
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/10.72 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 5.9 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)
$C_{w\gamma}$ = 5.9 ft < 1.5(10.72 ft) + 3.0 ft = 0.683

$q_n =$ (3125 psf)(5.284) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(10.7 ft)(0.000)(0.683) = 16.87 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 2.87 ksf ≤ (16.87 ksf)(0.55) = 9.28 ksf ⟶ 2.87 ksf ≤ 9.28 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 6 OF 6
CALCULATED BY BRT DATE 2/5/2023
CHECKED BY JPS DATE 2/6/2023
Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	15.0	ft
Foundation Width (Entire Base Width), (B) =	11.8	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	8.3	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	221	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	5.9	ft

Bearing and Retained/Backfill Soil Properties:

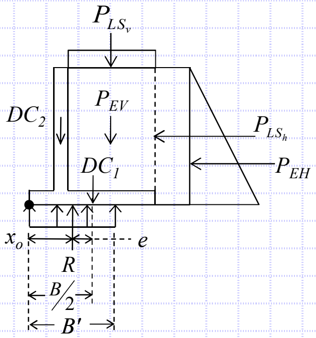
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	28	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	3125	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	5.065	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 11.8 ft - 2(0.44 ft) = 10.92 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (11.8 ft / 2) - 5.46 ft = 0.44 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (150.55 kip·ft/ft - 28.40 kip·ft/ft) / (22.36 kip/ft) = 5.46 ft

q_{eq} = (22.36 kip/ft) / (10.92 ft) = 2.05 ksf

$$M_V = [(\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})](a + b + c/2) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2)$$

M_V =[(120 pcf)(15.0 ft - 2.0 ft)(8.3 ft)(1.00) + (250 psf)(11.8 ft)(1.00)](1.5 ft + 2.0 ft + (8.3 ft / 2)) = 150.55 kip·ft/ft
+ [(150 pcf)(11.8 ft)(2.0 ft)(1.00)](11.8 ft / 2) + [(150 pcf)(15.0 ft - 2.0 ft)(1.5 ft)(1.00)](2.0 ft + (1.5 ft / 2))

$$M_H = (\tfrac{1}{2} \gamma_{RS} \cdot H^2 \cdot K_a \cdot \gamma_{EH})(H/3) + (\sigma_{LS} \cdot H \cdot K_a \cdot \gamma_{LS})(H/2)$$

M_H = [½(120 pcf)(15.0 ft)²(0.297)(1.00)](15.0 ft / 3) + [(250 psf)(15.0 ft)(0.297)(1.00)](15.0 ft / 2) = 28.4 kip·ft/ft

$$P_V = (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS}) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})$$

P_V = (120 pcf)(15.0 ft - 2.0 ft)(8.3 ft)(1.00) + (250 psf)(11.8 ft)(1.00) + (150 pcf)(11.8 ft)(2.0 ft)(1.00) = 22.36 kip/ft
+ (150 pcf)(15.0 ft - 2.0 ft)(1.5 ft)(1.00)

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: (S_t)$_{max}$ = **0.978** in

Minimum Settlement Along Wall Alignment: (S_t)$_{min}$ = **0.653** in

Differential Settlement Along Wall Alignment: δ_s = 0.325 in / 221 ft ⟶ 1 in / 680 ft

$\delta_s < 1/500$ ⟶ 1 in / 680 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-039-0-19

H =	15.0	ft	Wall height
B' =	10.9	ft	Effective base width due to eccentricity
D_w =	2.9	ft	Depth below bottom of wall
q_e =	2,050	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-4a	C	0.0	2.5	778.5	776.0	2.5	1.3	120	300	150	150	3,150	23	0.117	0.012	0.452				0.11	0.995	2,040	2,190	0.023	0.282
	A-4a	C	2.5	5.0	776.0	773.5	2.5	3.8	120	600	450	397	3,397	23	0.117	0.012	0.452				0.34	0.914	1,873	2,270	0.015	0.183
	A-4a	C	5.0	7.5	773.5	771.0	2.5	6.3	120	900	750	541	3,541	23	0.117	0.012	0.452				0.57	0.772	1,582	2,123	0.012	0.144
	A-4a	C	7.5	10.0	771.0	768.5	2.5	8.8	120	1,200	1,050	685	3,685	23	0.117	0.012	0.452				0.80	0.640	1,313	1,998	0.009	0.112
	A-4a	C	10.0	12.5	768.5	766.0	2.5	11.3	120	1,500	1,350	829	3,829	23	0.117	0.012	0.452				1.03	0.537	1,101	1,930	0.007	0.089
2	A-4a	C	12.5	15.0	766.0	763.5	2.5	13.8	120	1,800	1,650	973	3,973	23	0.117	0.012	0.452				1.26	0.458	940	1,913	0.006	0.071
																								Total Settlement:		0.880 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-039-0-19

H =	15.0	ft	Wall height
B =	10.9	ft	Effective base width due to eccentricity
D_w =	2.9	ft	Depth below bottom of wall
q =	2,050	psf	Equivalent bearing pressure due to eccentricity
t =	55	days	Time following completion of construction

																							Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' [(1)] (psf)**	**LL**	**C_c [(2)]**	**C_r [(3)]**	**e_o [(4)]**	**N_{60}**	**$(N1)_{60}$ [(5)]**	**C' [(6)]**	**Z_f/B**	**I [(7)]**	**$\Delta\sigma_v$ [(8)] (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c [(9,10)] (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ [(11)] (in)**	Layer Settlement (in)
1	A-4a	C	0.0	2.5	778.5	776.0	2.5	1.3	120	300	150	150	3,150	23	0.117	0.012	0.452				0.11	0.995	2,040	2,190	0.023	0.282	0.809	400	2.5	9.644	100	0.282	0.753
	A-4a	C	2.5	5.0	776.0	773.5	2.5	3.8	120	600	450	397	3,397	23	0.117	0.012	0.452				0.34	0.914	1,873	2,270	0.015	0.183		400	5.0	2.411	100	0.183	
	A-4a	C	5.0	7.5	773.5	771.0	2.5	6.3	120	900	750	541	3,541	23	0.117	0.012	0.452				0.57	0.772	1,582	2,123	0.012	0.144		400	7.5	1.072	94	0.135	
	A-4a	C	7.5	10.0	771.0	768.5	2.5	8.8	120	1,200	1,050	685	3,685	23	0.117	0.012	0.452				0.80	0.640	1,313	1,998	0.009	0.112		400	10.0	0.603	82	0.092	
	A-4a	C	10.0	12.5	768.5	766.0	2.5	11.3	120	1,500	1,350	829	3,829	23	0.117	0.012	0.452				1.03	0.537	1,101	1,930	0.007	0.089		400	12.5	0.386	69	0.061	
2	A-4a	C	12.5	15.0	766.0	763.5	2.5	13.8	120	1,800	1,650	973	3,973	23	0.117	0.012	0.452				1.26	0.458	940	1,913	0.006	0.071	0.071	400	15.0	0.268	58	0.041	0.041

$(S_c)_t$ = 0.794 in

Settlement Remaining After Hold Period: 0.086 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-0-19

H =	15.0	ft	Wall height
B' =	10.9	ft	Effective base width due to eccentricity
D_w =	2.9	ft	Depth below bottom of wall
q =	2,050	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' $^{(1)}$ (psf)	LL	C_c $^{(2)}$	C_r $^{(3)}$	e_o $^{(4)}$	N_{60}	$(N1)_{60}$ $^{(5)}$	C' $^{(6)}$	Z_f/B	I $^{(7)}$	$\Delta\sigma_v$ $^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	S_c $^{(9,10)}$ (ft)	S_c (in)
1	A-6a	C	0.0	2.5	778.5	776.0	2.5	1.3	125	313	156	156	3,156	25	0.135	0.014	0.467				0.11	0.995	2,040	2,196	0.026	0.317
	A-6a	C	2.5	5.0	776.0	773.5	2.5	3.8	125	625	469	416	3,416	25	0.135	0.014	0.467				0.34	0.914	1,873	2,289	0.017	0.204
	A-6a	C	5.0	7.5	773.5	771.0	2.5	6.3	125	938	781	572	3,572	25	0.135	0.014	0.467				0.57	0.772	1,582	2,155	0.013	0.159
	A-6a	C	7.5	10.0	771.0	768.5	2.5	8.8	125	1,250	1,094	729	3,729	25	0.135	0.014	0.467				0.80	0.640	1,313	2,041	0.010	0.123
	A-6a	C	10.0	12.5	768.5	766.0	2.5	11.3	125	1,563	1,406	885	3,885	25	0.135	0.014	0.467				1.03	0.537	1,101	1,986	0.008	0.097
	A-6a	C	12.5	15.0	766.0	763.5	2.5	13.8	125	1,875	1,719	1,042	4,042	25	0.135	0.014	0.467				1.26	0.458	940	1,981	0.006	0.077
																								Total Settlement:		0.978 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-0-19

H = 15.0 ft Wall height
B = 10.9 ft Effective base width due to eccentricity
D_w = 2.9 ft Depth below bottom of wall
q = 2,050 psf Equivalent bearing pressure due to eccentricity

t = 70 days Time following completion of construction

																								Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' (1) (psf)**	**LL**	**C_c (2)**	**C_r (3)**	**e_o (4)**	**N_{60}**	**$(N1)_{60}$ (5)**	**C' (6)**	**Z_f/B**	**I (7)**	**$\Delta\sigma_v$ (8) (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c (9,10) (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ (11) (in)**	Layer Settlement (in)
1	A-6a	C	0.0	2.5	778.5	776.0	2.5	1.3	125	313	156	156	3,156	25	0.135	0.014	0.467				0.11	0.995	2,040	2,196	0.026	0.317	0.978	300	2.5	9.205	100	0.317	0.878
	A-6a	C	2.5	5.0	776.0	773.5	2.5	3.8	125	625	469	416	3,416	25	0.135	0.014	0.467				0.34	0.914	1,873	2,289	0.017	0.204		300	5.0	2.301	100	0.204	
	A-6a	C	5.0	7.5	773.5	771.0	2.5	6.3	125	938	781	572	3,572	25	0.135	0.014	0.467				0.57	0.772	1,582	2,155	0.013	0.159		300	7.5	1.023	94	0.149	
	A-6a	C	7.5	10.0	771.0	768.5	2.5	8.8	125	1,250	1,094	729	3,729	25	0.135	0.014	0.467				0.80	0.640	1,313	2,041	0.010	0.123		300	10.0	0.575	80	0.099	
	A-6a	C	10.0	12.5	768.5	766.0	2.5	11.3	125	1,563	1,406	885	3,885	25	0.135	0.014	0.467				1.03	0.537	1,101	1,986	0.008	0.097		300	12.5	0.368	67	0.065	
	A-6a	C	12.5	15.0	766.0	763.5	2.5	13.8	125	1,875	1,719	1,042	4,042	25	0.135	0.014	0.467				1.26	0.458	940	1,981	0.006	0.077		300	15.0	0.256	57	0.044	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. C_c = 0.009(LL-10); Ref. Table 6-9, FHWA GEC 5
3. C_r = 0.10(C_c); Ref. Chapter 8.11, Holtz and Kovacs 1981
4. e_o = (C_c/0.54)+0.35; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

$(S_c)_t$ = 0.878 in

Settlement Remaining After Hold Period: 0.099 in

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/18/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-1-21

H =	15.0	ft	Wall height
B' =	10.9	ft	Effective base width due to eccentricity
D_w =	2.9	ft	Depth below bottom of wall
q =	2,050	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' [(1)] (psf)	LL	C_c [(2)]	C_r [(3)]	e_o [(4)]	N_{60}	$(N1)_{60}$ [(5)]	C' [(6)]	Z_f/B	I [(7)]	$\Delta\sigma_v$ [(8)] (psf)	σ_{vf}' Midpoint (psf)	S_c [(9,10)] (ft)	S_c (in)
1	A-4a	C	0.0	2.5	778.5	776.0	2.5	1.3	125	313	156	156	3,156	22	0.108	0.011	0.444				0.11	0.995	2,040	2,196	0.021	0.258
	A-4a	C	2.5	5.0	776.0	773.5	2.5	3.8	125	625	469	416	3,416	22	0.108	0.011	0.444				0.34	0.914	1,873	2,289	0.014	0.166
	A-4a	C	5.0	7.5	773.5	771.0	2.5	6.3	125	938	781	572	3,572	22	0.108	0.011	0.444				0.57	0.772	1,582	2,155	0.011	0.129
	A-4a	C	7.5	10.0	771.0	768.5	2.5	8.8	125	1,250	1,094	729	3,729	22	0.108	0.011	0.444				0.80	0.640	1,313	2,041	0.008	0.100
																						Total Settlement:			0.653 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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 = 0.15(C_c) for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 10+00 to 12+21 (BL Wall 2B)
CIP Wall Settlement

Calculated By: PPM Date: 1/18/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-1-21

H = 15.0 ft Wall height
B = 10.9 ft Effective base width due to eccentricity
D_w = 2.9 ft Depth below bottom of wall
q = 2,050 psf Equivalent bearing pressure due to eccentricity

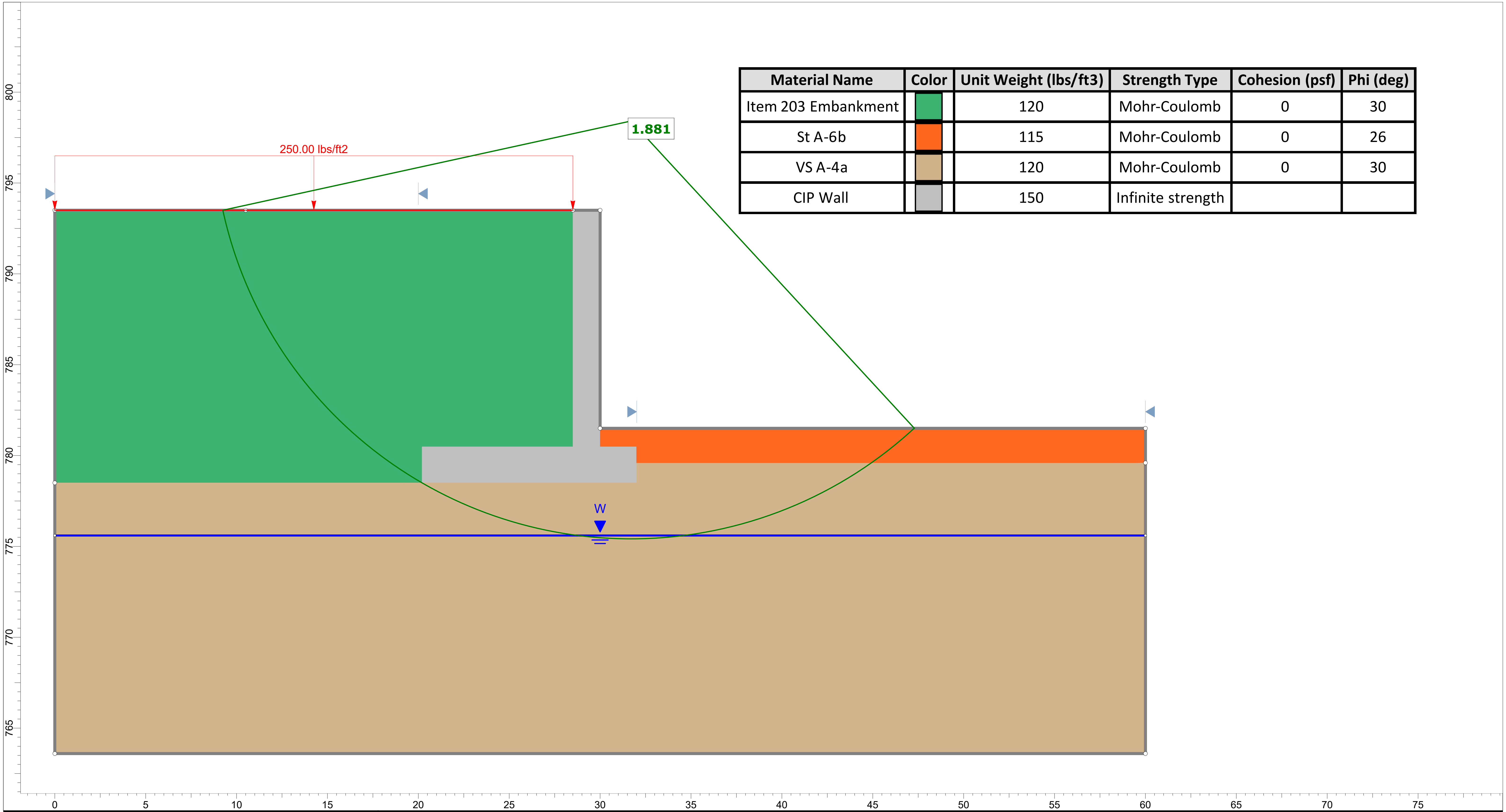
t = 30 days Time following completion of construction

																							Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' [(1)] (psf)**	**LL**	**C_c [(2)]**	**C_r [(3)]**	**e_o [(4)]**	**N_{60}**	**$(N1)_{60}$ [(5)]**	**C' [(6)]**	**Z_f/B**	**I [(7)]**	**$\Delta\sigma_v$ [(8)] (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c [(9,10)] (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ [(11)] (in)**	Layer Settlement (in)
1	A-4a	C	0.0	2.5	778.5	776.0	2.5	1.3	125	313	156	156	3,156	22	0.108	0.011	0.444				0.11	0.995	2,040	2,196	0.021	0.258	0.653	400	2.5	5.260	100	0.258	0.588
	A-4a	C	2.5	5.0	776.0	773.5	2.5	3.8	125	625	469	416	3,416	22	0.108	0.011	0.444				0.34	0.914	1,873	2,289	0.014	0.166		400	5.0	1.315	97	0.161	
	A-4a	C	5.0	7.5	773.5	771.0	2.5	6.3	125	938	781	572	3,572	22	0.108	0.011	0.444				0.57	0.772	1,582	2,155	0.011	0.129		400	7.5	0.584	81	0.105	
	A-4a	C	7.5	10.0	771.0	768.5	2.5	8.8	125	1,250	1,094	729	3,729	22	0.108	0.011	0.444				0.80	0.640	1,313	2,041	0.008	0.100		400	10.0	0.329	64	0.064	

$(S_c)_t$ = 0.588 in

Settlement Remaining After Hold Period: 0.066 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

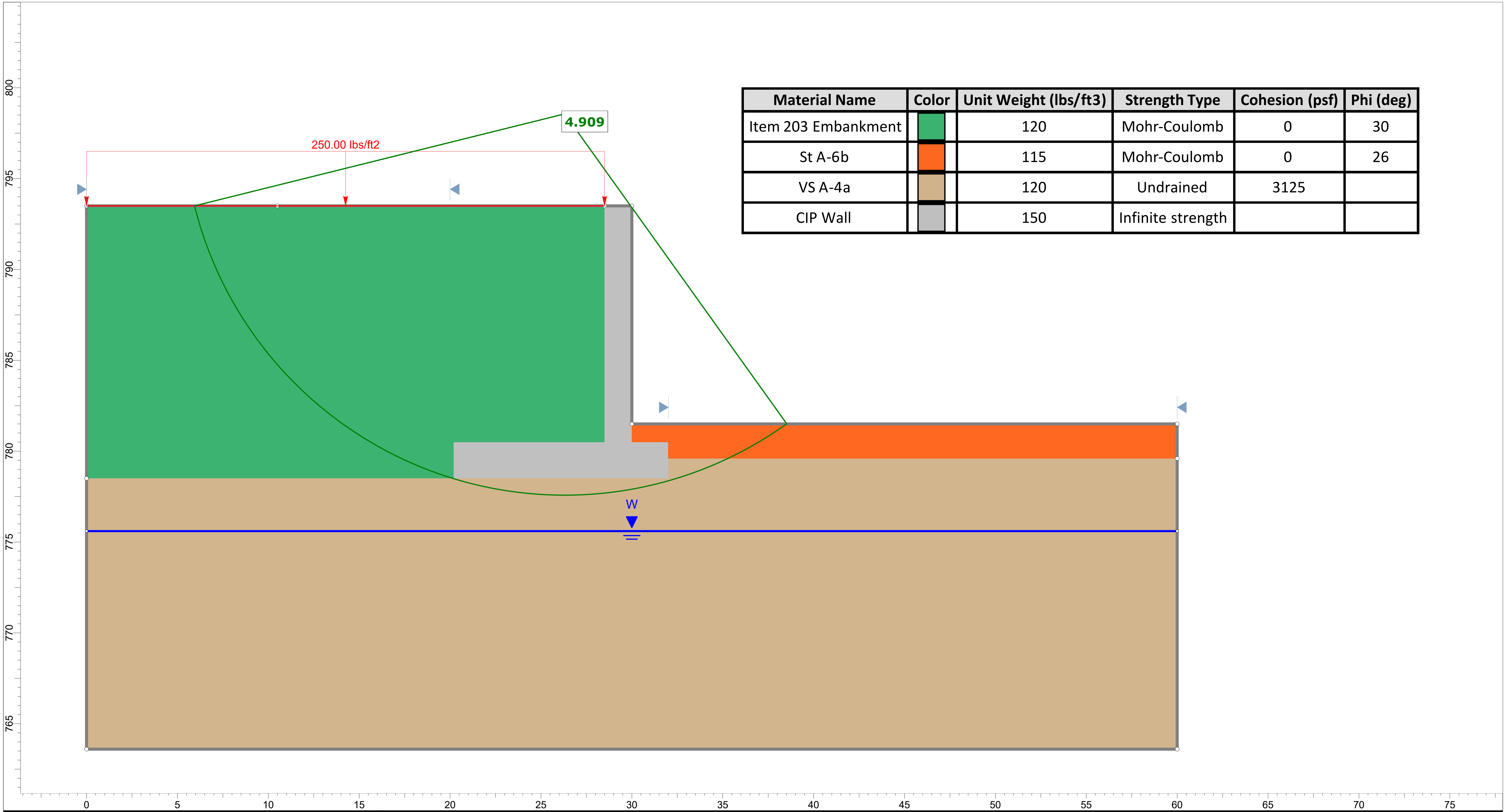


Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Mohr-Coulomb	0	26
VS A-4a	🟫	120	Mohr-Coulomb	0	30
CIP Wall	⬜	150	Infinite strength		

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

Project	FRA-70-22.85 FEF - Retaining Wall 2B		
Analysis Description	Global Stability - Sta. 10+00 to 12+21 (BL Wall 2B) - CIP Wall w/o Shear Key - B-039-0-19, B-040-0-19 and B-041-1-21 - 15.0 ft. Wall Height - Drained - Circular		
Drawn By	BRT	*Scale*	1:60
Company	Resource International, Inc.		
Date	4/2/2022, 12:29:06 PM	*File Name*	Wall 2B - Sta. 10+00 to 12+21 - Global Stability.slmd

SLIDEINTERPRET 9.024



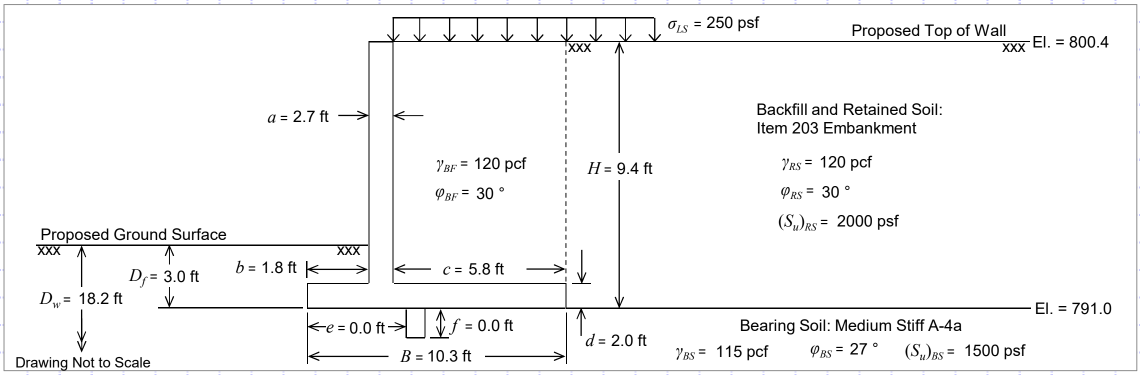
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Mohr-Coulomb	0	26
VS A-4a	🟫	120	Undrained	3125	
CIP Wall	⬜	150	Infinite strength		

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

SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 2B
Analysis Description	Global Stability - Sta. 10+00 to 12+21 (BL Wall 2B) - CIP Wall w/o Shear Key - B-039-0-19, B-040-0-19 and B-041-1-21 - 15.0 ft. Wall Height - Undrained - Circular
Drawn By	BRT
Scale	1:60
Company	Resource International, Inc.
Date	4/2/2022, 12:29:06 PM
File Name	Wall 2B - Sta. 10+00 to 12+21 - Global Stability.slmd

Retaining Wall 4A - Sta. 10+00 to 11+10 (BL Wall 4A) - CIP Wall w/o Shear Key - Level Backslope - B-041-0-19 - 9.4 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	18.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

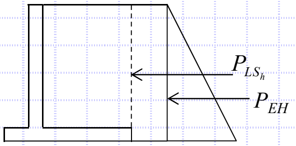
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

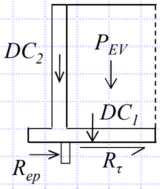
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(9.4 ft)²(0.297)(1.50)} = 2.36 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad \text{(250 psf)(9.4 ft)(0.297)(1.75)} = 1.22 \text{ kip/ft}$$

$$P_H = 2.36 \text{ kip/ft} + 1.22 \text{ kip/ft} = 3.58 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$



$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

$$R_{ep} = \text{(115 pcf)(3.0 ft)(0.0 ft)(4.80)(0.90) + ½(115 pcf)(0.0 ft)²(4.80)(0.90)} = 0.00 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot [B \cdot d + (H - d) \cdot a] \cdot \gamma_{DC} + \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$$

$$P_V = \text{(150 pcf) [(10.3 ft)(2.0 ft) + (9.4 ft - 2.0 ft)(2.7 ft)] (0.90) + (120 pcf)(9.4 ft - 2.0 ft)(5.8 ft)(1.00)} = 10.63 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(27) = 0.51$$

$$R_\tau = \text{(10.63 kip/ft)(0.51)} = 5.42 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow \text{3.58 kip/ft} \le \text{(5.42 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 5.42 kip/ft}$$

= 3.58 kip/ft ≤ 5.42 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 4A - Sta. 10+00 to 11+40 (BL Wall 4A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	18.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

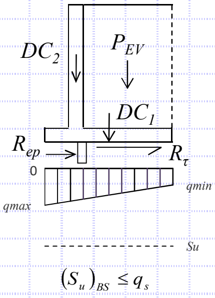
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 ***(Continued)***

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



$(S_u)_{BS}$ = 1.50 ksf

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (1.42 ksf) / 2 = 0.71 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (0.64 ksf) / 2 = 0.32 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1 + 6\frac{e}{B}\right)$ = (10.63 kip/ft / 10.3 ft)[1 + 6(0.65 ft / 10.3 ft)] = 1.42 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1 - 6\frac{e}{B}\right)$ = (10.63 kip/ft / 10.3 ft)[1 - 6(0.65 ft / 10.3 ft)] = 0.64 ksf

R_τ = 0.5(0.71 ksf - 0.32 ksf)(10.3 ft) + (0.32 ksf)(10.3 ft) = 5.3 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 3.58 kip/ft ≤ (5.30 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 5.30

= 3.58 kip/ft ≤ 5.30 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 4A - Sta. 10+00 to 11+40 (BL Wall 4A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) = 9.4 ft
Foundation Width (Entire Base Width), (B) = 10.3 ft
Stem Width, (a) = 2.7 ft
Toe Width, (b) = 1.8 ft
Heel Width, (c) = 5.8 ft
Footing Thickness, (d) = 2.0 ft
Location of Shear Key, (e) = 0.0 ft
Depth of Shear Key, (f) = 0.0 ft
Embedment Depth, (D_f) = 3.0 ft
Wall Length, (L) = 255 ft
Live Surcharge Load, (σ_{LS}) = 250 psf
Depth to Groundwater, (D_w) = 18.2 ft

Bearing and Retained/Backfill Soil Properties:

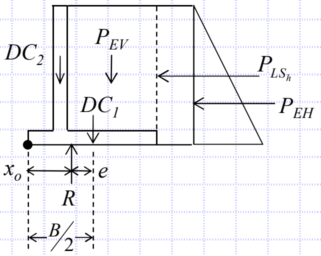
Bearing Soil Unit Weight, (γ_{BS}) = 115 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 27 °
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] = 1500 psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) = 120 pcf
Retained Soil Friction Angle, (φ_{RS}) = 30 °
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] = 2000 psf
Active Earth Pressure Coefficient, (K_a) = 0.297
Passive Earth Pressure Coefficient, (K_p) = 4.801

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V}$$ = (60.93 kip·ft/ft - 13.12 kip·ft/ft) / (10.63 kip/ft) = 4.50 ft

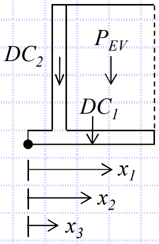
M_V = 60.93 kip·ft/ft
M_H = 13.12 kip·ft/ft
Defined below

$P_V = P_{EV} + DC_1 + DC_2$ = 5.15 kip/ft + 2.78 kip/ft + 2.70 kip/ft = 10.63 kip/ft

$e =$ (10.3 ft / 2) - 4.50 ft = 0.65 ft

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$P_{EV} = \gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(9.4 ft - 2.0 ft)(5.8 ft)(1.00) = 5.15 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(10.3 ft)(2.0 ft)(0.90) = 2.78 kip/ft

$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.4 ft - 2.0 ft)(2.7 ft)(0.90) = 2.70 kip/ft

$x_1 = a + b + c/2$ = 2.7 ft + 1.8 ft + (5.8 ft / 2) = 7.4 ft

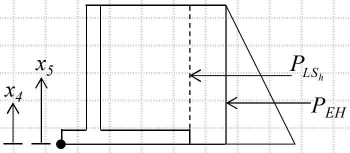
$x_2 = B/2$ = 10.3 ft / 2 = 5.2 ft

$x_3 = b + a/2$ = 1.8 ft + (2.7 ft / 2) = 3.2 ft

$M_V =$ (5.15 kip/ft)(7.4 ft) + (2.78 kip/ft)(5.2 ft) + (2.70 kip/ft)(3.2 ft) = 60.93 kip·ft/ft

Overturning Moment, M_H:

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



$P_{EH} = \frac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(9.4 ft)²(0.297)(1.50) = 2.36 kip/ft

$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(9.4 ft)(0.297)(1.75) = 1.22 kip/ft

$x_2 = H/3$ = (9.4 ft) / 3 = 3.13 ft

$x_3 = H/2$ = (9.4 ft) / 2 = 4.70 ft

$M_H =$ (2.36 kip/ft)(3.13 ft) + (1.22 kip/ft)(4.70 ft) = 13.12 kip·ft/ft

Limiting Eccentricity:

$e_{\max} = B/3 \rightarrow e_{\max} =$ (10.3 ft) / 3 = 3.43 ft

Check Eccentricity

$e < e_{\max} \longrightarrow$ 0.65 ft < 3.43 ft **OK**

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	18.2	ft

Bearing and Retained/Backfill Soil Properties:

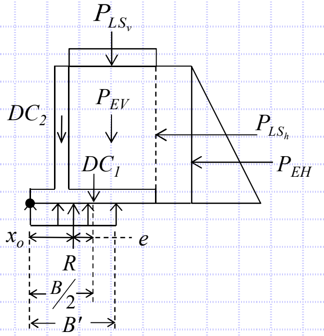
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

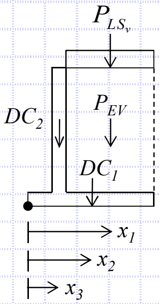
$B' = B - 2e$ = 10.3 ft - 2(-0.27 ft) = 10.30 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.3 ft / 2) - 5.42 ft = -0.27 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (116.49 kip·ft/ft - 13.12 kip·ft/ft) / (19.07 kip/ft) = 5.42 ft

q_{eq} = (19.07 kip/ft) / (10.30 ft) = 1.85 ksf

Resisting Moment, M_V:



$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$

$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(9.4 ft - 2.0 ft)(5.8 ft)(1.35) = 6.95 kip/ft

$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS}$ = (250 psf)(10.3 ft)(1.75) = 4.506 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(10.3 ft)(2.0 ft)(1.25) = 3.86 kip/ft

$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.4 ft - 2.0 ft)(2.7 ft)(1.25) = 3.75 kip/ft

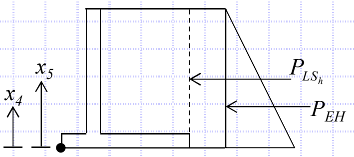
$x_1 = a + b + c/2$ = 2.7 ft + 1.8 ft + (5.8 ft / 2) = 7.4 ft

$x_2 = B/2$ = 10.3 ft / 2 = 5.2 ft

$x_3 = b + a/2$ = 1.8 ft + (2.7 ft / 2) = 3.2 ft

M_V = (6.95 kip/ft)(7.4 ft) + (4.51 kip/ft)(7.4 ft) + (3.86 kip/ft)(5.2 ft) + (3.75 kip/ft)(3.2 ft) = 116.49 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$

$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(9.4 ft)²(0.297)(1.50) = 2.36 kip/ft

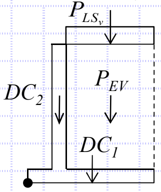
$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(9.4 ft)(0.297)(1.75) = 1.22 kip/ft

$x_4 = H/3$ = (9.4 ft) / 3 = 3.13 ft

$x_5 = H/2$ = (9.4 ft) / 2 = 4.70 ft

M_H = (2.36 kip/ft)(3.13 ft) + (1.22 kip/ft)(4.70 ft) = 13.12 kip·ft/ft

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

P_V = 6.95 kip/ft + 4.51 kip/ft + 3.86 kip/ft + 3.75 kip/ft

P_V = 19.07 kip/ft

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	18.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 24.469

N_c = 23.942
s_c = 1+(10.3 ft/255 ft)(13.199/23.942)
= 1.022
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.635

N_q = 13.199
s_q = 1+(10.3 ft/255 ft)tan(27°) = 1.021
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/10.3 ft)
= 1.086
i_q = 1.000 (Assumed)
C_{wq} = 18.2 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 14.238

N_γ = 14.47
s_γ = 1-0.4(10.3 ft/255 ft) = 0.984
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 18.2 ft < 1.5(10.3 ft) + 3.0 ft = 1.089

$q_n =$ (0 psf)(24.469) + (115 pcf)(3.0 ft)(14.635)(1.000) + ½(115 pcf)(10.3 ft)(14.238)(1.089) = 14.23 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 1.85 ksf ≤ (14.23 ksf)(0.55) = 7.83 ksf ⟶ 1.85 ksf ≤ 7.83 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.253

N_c = 5.140
s_c = 1+(10.3 ft/[(5)(255 ft)]) = 1.022
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/10.3 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 18.2 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)
$C_{w\gamma}$ = 18.2 ft < 1.5(10.3 ft) + 3.0 ft = 1.089

$q_n =$ (1500 psf)(5.253) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(10.3 ft)(0.000)(1.089) = 8.22 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 1.85 ksf ≤ (8.22 ksf)(0.55) = 4.52 ksf ⟶ 1.85 ksf ≤ 4.52 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	18.2	ft

Bearing and Retained/Backfill Soil Properties:

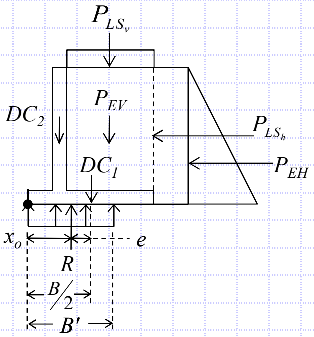
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 10.3 ft - 2(-0.23 ft) = 10.30 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.3 ft / 2) - 5.38 ft = -0.23 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (82.52 kip·ft/ft - 8.21 kip·ft/ft) / (13.81 kip/ft) = 5.38 ft

q_{eq} = (13.81 kip/ft) / (10.30 ft) = 1.34 ksf

$$M_V = [(\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})](a + b + c/2) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2)$$

M_V =[(120 pcf)(9.4 ft - 2.0 ft)(5.8 ft)(1.00) + (250 psf)(10.3 ft)(1.00)](2.7 ft + 1.8 ft + (5.8 ft / 2)) = 82.52 kip·ft/ft
+ [(150 pcf)(10.3 ft)(2.0 ft)(1.00)](10.3 ft / 2) + [(150 pcf)(9.4 ft - 2.0 ft)(2.7 ft)(1.00)](1.8 ft + (2.7 ft / 2))

$$M_H = (\tfrac{1}{2} \gamma_{RS} \cdot H^2 \cdot K_a \cdot \gamma_{EH})(H/3) + (\sigma_{LS} \cdot H \cdot K_a \cdot \gamma_{LS})(H/2)$$

M_H = [½(120 pcf)(9.4 ft)²(0.297)(1.00)](9.4 ft / 3) + [(250 psf)(9.4 ft)(0.297)(1.00)](9.4 ft / 2) = 8.21 kip·ft/ft

$$P_V = (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS}) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})$$

P_V = (120 pcf)(9.4 ft - 2.0 ft)(5.8 ft)(1.00) + (250 psf)(10.3 ft)(1.00) + (150 pcf)(10.3 ft)(2.0 ft)(1.00) = 13.81 kip/ft
+ (150 pcf)(9.4 ft - 2.0 ft)(2.7 ft)(1.00)

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: $(S_t)_{max}$ = **0.766** in

Minimum Settlement Along Wall Alignment: $(S_t)_{min}$ = **0.648** in

Differential Settlement Along Wall Alignment: δ_s = 0.118 in / 255 ft ⟶ 1 in / 2,161 ft

$\delta_s < 1/500$ ⟶ 1 in / 2,161 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 4A - Sta. 10+00 to 11+40 (BL Wall 4A)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-041-0-19

H = 9.4 ft Wall height
B' = 10.3 ft Effective base width due to eccentricity
D_w = 15.2 ft Depth below bottom of wall
q_e = 1,340 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1 (Emb.)	A-6a	C	0.0	1.5	791.0	789.5	1.5	0.8	120	180	90	90	3,090	30	0.180	0.001	0.507				0.07	0.999	1,338	1,428	0.001	0.013
2	A-6a	C	1.5	4.0	789.5	787.0	2.5	2.8	115	468	324	324	3,324	28	0.162	0.016	0.491				0.27	0.952	1,276	1,600	0.019	0.226
	A-6a	C	4.0	7.0	787.0	784.0	3.0	5.5	115	813	640	640	3,640	28	0.162	0.016	0.491				0.53	0.797	1,068	1,708	0.014	0.167
3	A-2-4	G	7.0	9.5	784.0	781.5	2.5	8.3	125	1,125	969	969	3,969					16	20	74	0.80	0.641	859	1,828	0.009	0.112
	A-2-4	G	9.5	12.0	781.5	779.0	2.5	10.8	125	1,438	1,281	1,281	4,281					16	18	71	1.04	0.532	714	1,995	0.007	0.081
4	A-6a	C	12.0	14.5	779.0	776.5	2.5	13.3	120	1,738	1,588	1,588	4,588	28	0.162	0.016	0.491				1.29	0.451	604	2,192	0.004	0.046
5	A-4a	C	14.5	17.0	776.5	774.0	2.5	15.8	115	2,025	1,881	1,847	4,847	23	0.117	0.012	0.452				1.53	0.389	522	2,369	0.002	0.026
6	A-6a	C	17.0	19.5	774.0	771.5	2.5	18.3	120	2,325	2,175	1,985	4,985	28	0.162	0.016	0.491				1.77	0.341	458	2,442	0.002	0.029
7	A-4a	C	19.5	22.0	771.5	769.0	2.5	20.8	120	2,625	2,475	2,129	5,129	23	0.117	0.012	0.452				2.01	0.304	407	2,536	0.002	0.018
8	A-2-4	G	22.0	24.5	769.0	766.5	2.5	23.3	130	2,950	2,788	2,285	5,285					42	40	131	2.26	0.273	366	2,651	0.001	0.015
9	A-4a	C	24.5	28.0	766.5	763.0	3.5	26.3	125	3,388	3,169	2,479	5,479	23	0.117	0.012	0.452				2.55	0.244	326	2,806	0.002	0.018
	A-4a	C	28.0	31.5	763.0	759.5	3.5	29.8	125	3,825	3,606	2,698	5,698	23	0.117	0.012	0.452				2.89	0.216	290	2,988	0.001	0.015
																						Total Settlement:			0.766 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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 = 0.15(C_c) for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 4A - Sta. 10+00 to 11+40 (BL Wall 4A)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-041-0-19

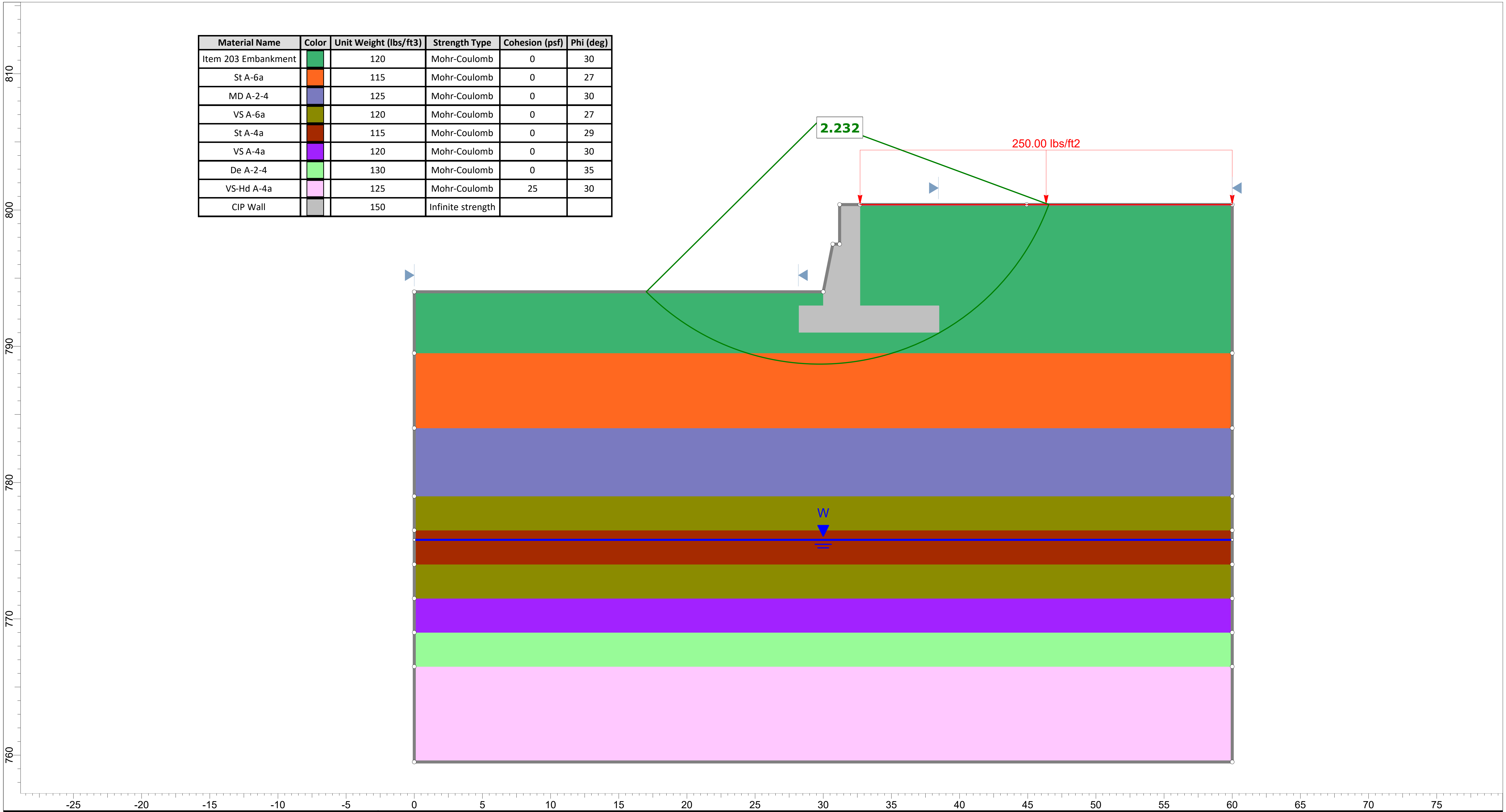
$H =$	9.4	ft	Wall height
$B =$	10.3	ft	Effective base width due to eccentricity
$D_w =$	15.2	ft	Depth below bottom of wall
$q =$	1,340	psf	Equivalent bearing pressure due to eccentricity
$t =$	10	days	Time following completion of construction

																									Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1 (Emb.)	A-6a	C	0.0	1.5	791.0	789.5	1.5	0.8	120	180	90	90	3,090	30	0.180	0.001	0.507				0.07	0.999	1,338	1,428	0.001	0.013	0.013	300	1.5	3.653	100	0.013	0.013
2	A-6a	C	1.5	4.0	789.5	787.0	2.5	2.8	115	468	324	324	3,324	28	0.162	0.016	0.491				0.27	0.952	1,276	1,600	0.019	0.226	0.393	300	3.5	0.671	85	0.192	0.344
	A-6a	C	4.0	7.0	787.0	784.0	3.0	5.5	115	813	640	640	3,640	28	0.162	0.016	0.491				0.53	0.797	1,068	1,708	0.014	0.167		300	3.0	0.913	91	0.152	
3	A-2-4	G	7.0	9.5	784.0	781.5	2.5	8.3	125	1,125	969	969	3,969					16	20	74	0.80	0.641	859	1,828	0.009	0.112	0.193				100	0.112	0.193
	A-2-4	G	9.5	12.0	781.5	779.0	2.5	10.8	125	1,438	1,281	1,281	4,281					16	18	71	1.04	0.532	714	1,995	0.007	0.081					100	0.081	
4	A-6a	C	12.0	14.5	779.0	776.5	2.5	13.3	120	1,738	1,588	1,588	4,588	28	0.162	0.016	0.491				1.29	0.451	604	2,192	0.004	0.046	0.046	300	2.5	1.315	97	0.044	0.044
5	A-4a	C	14.5	17.0	776.5	774.0	2.5	15.8	115	2,025	1,881	1,847	4,847	23	0.117	0.012	0.452				1.53	0.389	522	2,369	0.002	0.026	0.026	400	5.0	0.438	73	0.019	0.019
6	A-6a	C	17.0	19.5	774.0	771.5	2.5	18.3	120	2,325	2,175	1,985	4,985	28	0.162	0.016	0.491				1.77	0.341	458	2,442	0.002	0.029	0.029	300	5.0	0.329	64	0.019	0.019
7	A-4a	C	19.5	22.0	771.5	769.0	2.5	20.8	120	2,625	2,475	2,129	5,129	23	0.117	0.012	0.452				2.01	0.304	407	2,536	0.002	0.018	0.018	400	2.5	1.753	99	0.018	0.018
8	A-2-4	G	22.0	24.5	769.0	766.5	2.5	23.3	130	2,950	2,788	2,285	5,285					42	40	131	2.26	0.273	366	2,651	0.001	0.015	0.015				100	0.015	0.015
9	A-4a	C	24.5	28.0	766.5	763.0	3.5	26.3	125	3,388	3,169	2,479	5,479	23	0.117	0.012	0.452				2.55	0.244	326	2,806	0.002	0.018	0.033	400	3.5	0.895	91	0.017	0.024
	A-4a	C	28.0	31.5	763.0	759.5	3.5	29.8	125	3,825	3,606	2,698	5,698	23	0.117	0.012	0.452				2.89	0.216	290	2,988	0.001	0.015		400	7.0	0.224	53	0.008	

$(S_c)_t =$ 0.689 in

Settlement Remaining After Hold Period: 0.077 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6a	🟧	115	Mohr-Coulomb	0	27
MD A-2-4	🟦	125	Mohr-Coulomb	0	30
VS A-6a	🟫	120	Mohr-Coulomb	0	27
St A-4a	🟥	115	Mohr-Coulomb	0	29
VS A-4a	🟪	120	Mohr-Coulomb	0	30
De A-2-4	🟩	130	Mohr-Coulomb	0	35
VS-Hd A-4a	🟪	125	Mohr-Coulomb	25	30
CIP Wall	⬜	150	Infinite strength		

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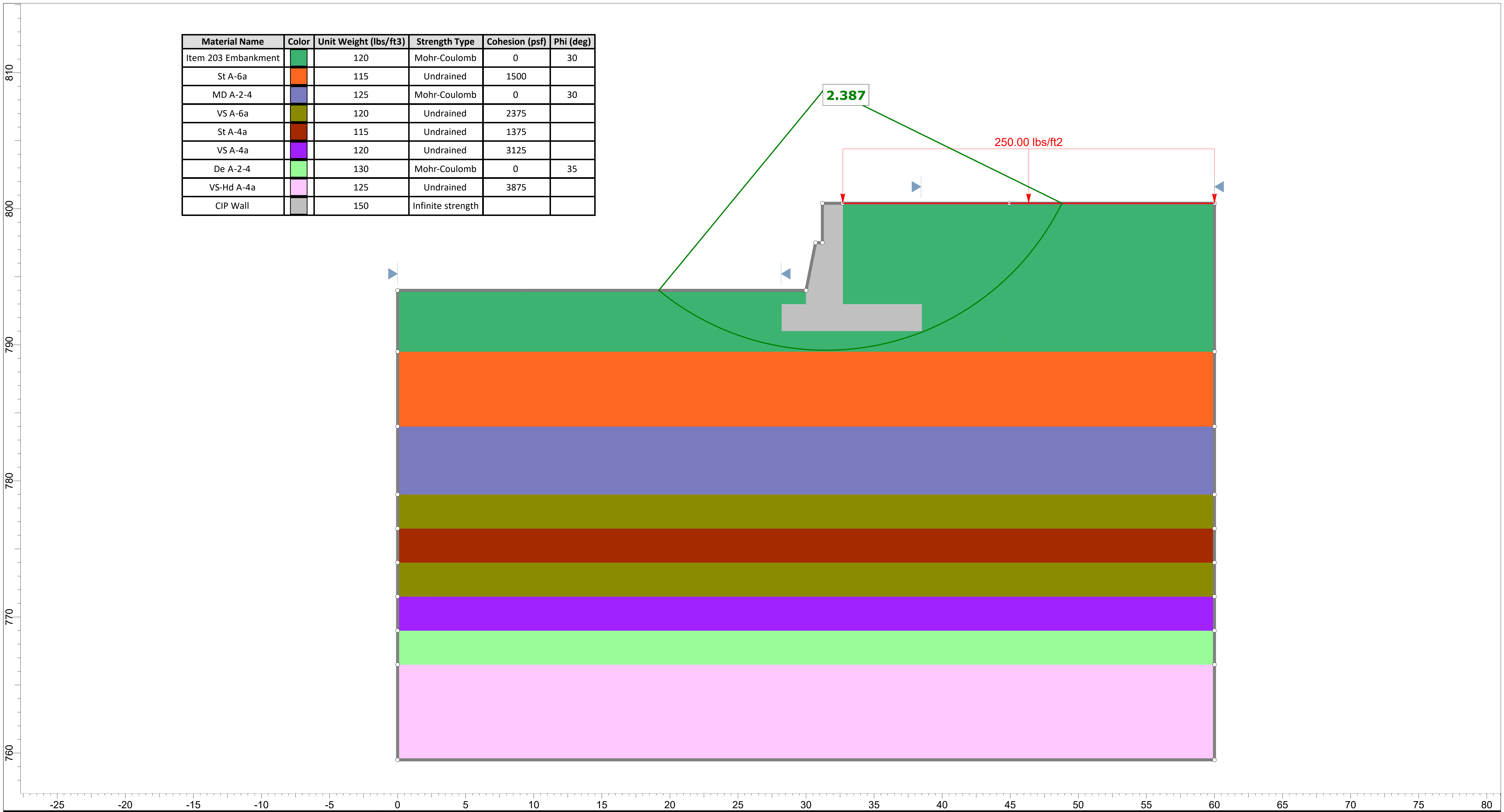
SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 4A
Analysis Description	Global Stability - Sta. 10+00 to 11+10 (BL Wall 4A) - CIP Wall w/o Shear Key - Level Backslope - B-041-0-19 - 9.4 ft. Wall Height - Drained - Circular
Drawn By	BRT
Scale	1:80
Company	Resource International, Inc.
Date	4/2/2022, 1:06:52 PM
File Name	Wall 4A - Sta. 10+00 to 11+10 - Global Stability.slmd

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6a	🟧	115	Undrained	1500	
MD A-2-4	🟦	125	Mohr-Coulomb	0	30
VS A-6a	🟫	120	Undrained	2375	
St A-4a	🟥	115	Undrained	1375	
VS A-4a	🟪	120	Undrained	3125	
De A-2-4	🟩	130	Mohr-Coulomb	0	35
VS-Hd A-4a	🟪	125	Undrained	3875	
CIP Wall	⬜	150	Infinite strength		



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SLIDEINTERPRET 9.024

Project FRA-70-22.85 FEF - Retaining Wall 4A

Analysis Description Global Stability - Sta. 10+00 to 11+10 (BL Wall 4A) - CIP Wall w/o Shear Key - Level Backslope - B-041-0-19 - 9.4 ft. Wall Height - Undrained - Circular

Drawn By BRT

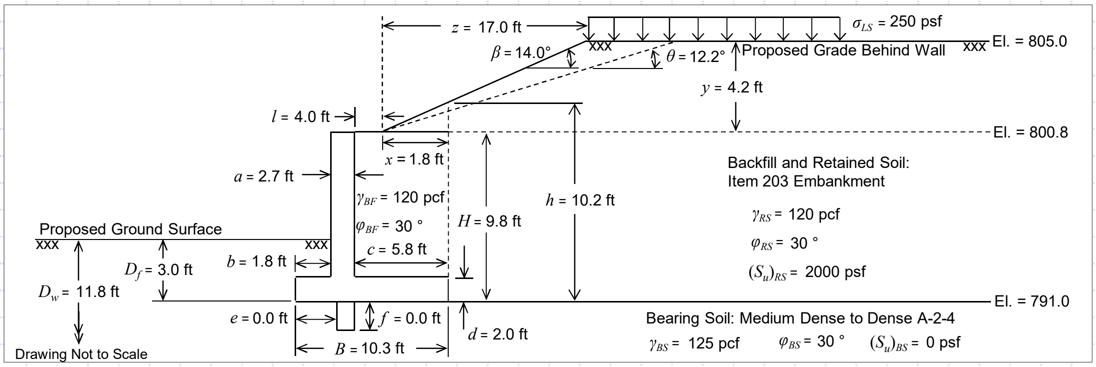
Scale 1:80

Company Resource International, Inc.

Date 4/2/2022, 1:06:52 PM

File Name Wall 4A - Sta. 10+00 to 11+10 - Global Stability.slmd

Retaining Wall 4A - Sta. 11+40 to 12+55 (BL Wall 4A) - CIP Wall w/o Shear Key - 4:1 Backslope - B-043-0-19 - 9.8 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

CIP Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	0	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

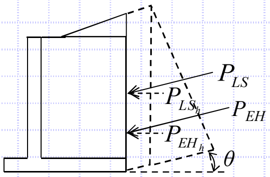
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} h^2 K_a \gamma_{EH} =$$ ½(120 pcf)(10.2 ft)²(0.352)(1.50) = 3.33 kip/ft

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} =$$ (250 psf)(10.2 ft)(0.352)(1.75) = 1.58 kip/ft

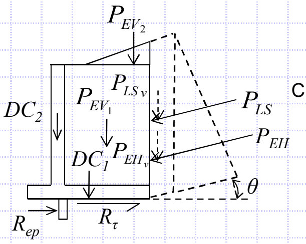
P_H = (3.33 kip/ft + 1.6 kip/ft)cos(12.2°) = 4.80 kip/ft

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$

$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

R_{ep} = (125 pcf)(3.0 ft)(0.0 ft)(5.58)(0.90) + ½(125 pcf)(0.0 ft)²(5.58)(0.90) = 0.00 kip/ft



Check Drained Condition: $R_\tau = (DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta)\tan\delta$
(Neglect P_{LS_v} for conservatism)

$$DC_1 + DC_2 = \gamma_C[B(d) + (H-d)(a)]\gamma_{DC}$$

= (150 pcf) [(10.3 ft)(2.0 ft) + (9.8 ft - 2.0 ft)(2.7 ft)] (0.90) = 5.62 kip/ft

$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV}$ = (120 pcf)(9.8 ft - 2.0 ft)(5.8 ft)(1.00) = 5.43 kip/ft

$P_{EV_2} = {}^1\!/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV}$ = ½(120 pcf)(10.2 ft - 9.8 ft)(5.8 ft - 4.0 ft)(1.00) = 0.05 kip/ft

$\tan\delta = \tan\varphi_{BS}$ = tan(30°) = 0.58

R_τ = [5.62 kip/ft + 5.43 kip/ft + 0.05 kip/ft + (3.33 kip/ft)sin(12.2°)](0.58) = 6.85 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 4.80 kip/ft ≤ (6.85 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 6.85 kip/ft

= 4.80 kip/ft ≤ 6.85 kip/ft **OK** Use φ_τ = **1.00** Use φ_{ep} = **0.50**

(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

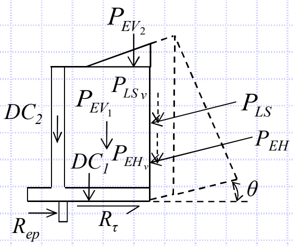
LRFD Load Factors

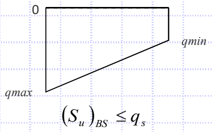
	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	1.00	1.00	1.00

(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 10.6.3.4 *(Continued)*

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





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

$q_{max} = {}^1/_2\, \sigma_{vmax}$ = (1.66 ksf) / 2 = 0.83 ksf

$q_{min} = {}^1/_2\, \sigma_{vmin}$ = (0.63 ksf) / 2 = 0.32 ksf

$\sigma_{vmax} = {}^{P_V}/_B \left(1 + 6\frac{e}{B}\right)$ = (11.80 kip/ft / 10.3 ft)[1 + 6(0.77 ft / 10.3 ft)] = 1.66 ksf

$\sigma_{vmin} = {}^{P_V}/_B \left(1 - 6\frac{e}{B}\right)$ = (11.80 kip/ft / 10.3 ft)[1 - 6(0.77 ft / 10.3 ft)] = 0.63 ksf

$P_V = DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ (Neglect P_{LS_V} for conservatism)

P_V = 5.62 kip/ft + 5.43 kip/ft + 0.05 kip/ft + (3.33 kip/ft)sin(12.2°) = 11.80 kip/ft

R_τ = N/A = N/A kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ N/A

= N/A

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

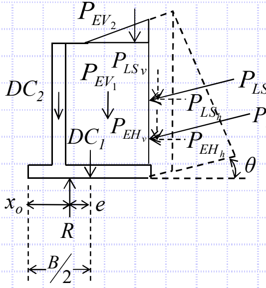
Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = \text{(71.18 kip·ft/ft - 19.48 kip·ft/ft) / (11.80 kip/ft)} = 4.38 \text{ ft}$$

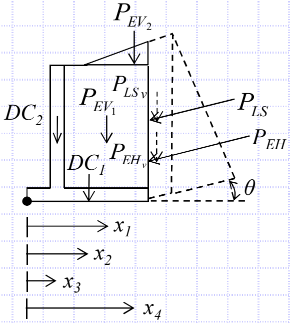
M_V = 71.18 kip·ft/ft
M_H = 19.48 kip·ft/ft } Defined below
P_V = 11.80 kip/ft (Defined on Sheet No. 2)

$$e = \text{(10.3 ft / 2) - 4.38 ft} = 0.77 \text{ ft}$$

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + DC_1(x_2) + DC_2(x_3) + P_{EV_2}(x_4) + P_{EH}\sin\theta\,(B)$$

(Neglect P_{LS_V} for conservatism)



$$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV} = \text{(120 pcf)(9.8 ft - 2.0 ft)(5.8 ft)(1.00)} = 5.43 \text{ kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} = \text{(150 pcf)(10.3 ft)(2.0 ft)(0.90)} = 2.78 \text{ kip/ft}$$

$$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC} = \text{(150 pcf)(9.8 ft - 2.0 ft)(2.7 ft)(0.90)} = 2.84 \text{ kip/ft}$$

$$P_{EV_2} = {}^1/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV} = \text{½(120 pcf)(10.2 ft - 9.8 ft)(5.8 ft - 4.0 ft)(1.00)} = 0.05 \text{ kip/ft}$$

$$P_{EH} = {}^1/_2\,\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(10.2 ft)²(0.352)(1.50)} = 3.33 \text{ kip/ft}$$

$$x_1 = a + b + c/2 = \text{2.7 ft + 1.8 ft + (5.8 ft / 2)} = 7.4 \text{ ft}$$

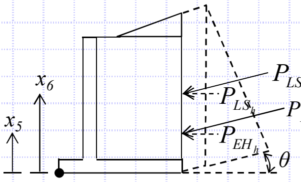
$$x_2 = B/2 = \text{10.3 ft / 2} = 5.2 \text{ ft} \qquad x_3 = b + a/2 = \text{1.8 ft + (2.7 ft / 2)} = 3.2 \text{ ft}$$

$$x_4 = a + b + l + {}^2/_3(c-l) = \text{2.7 ft + 1.8 ft + 4.0 ft + ⅔(5.8 ft - 4.0 ft)} = 9.7 \text{ ft}$$

$$M_V = \text{(5.43 kip/ft)(7.4 ft) + (2.78 kip/ft)(5.2 ft) + (2.84 kip/ft)(3.2 ft) + (0.05 kip/ft)(9.7 ft) + (3.33 kip/ft)sin(12.2°)(10.3 ft)}$$
$$= 71.18 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta\,(x_5) + P_{LS}\cos\theta\,(x_6)$$



$$P_{EH} = {}^1/_2\,\gamma_{RS} h^2 K_a \gamma_{EH} = \text{½(120 pcf)(10.2 ft)²(0.352)(1.50)} = 3.33 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS} h K_a \gamma_{LS} = \text{(250 psf)(10.2 ft)(0.352)(1.75)} = 1.58 \text{ kip/ft}$$

$$x_5 = h/3 = \text{(10.2 ft) / 3} = 3.42 \text{ ft}$$

$$x_6 = h/2 = \text{(10.2 ft) / 2} = 5.12 \text{ ft}$$

$$M_H = \text{(3.33 kip/ft)cos(12.2°)(3.42 ft) + (1.58 kip/ft)cos(12.2°)(5.12 ft)} = 19.48 \text{ kip·ft/ft}$$

Check Eccentricity Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} = \text{(10.3 ft) / 3} = 3.43 \text{ ft}$

$e < e_{\max} \longrightarrow$ 0.77 ft < 3.43 ft OK

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

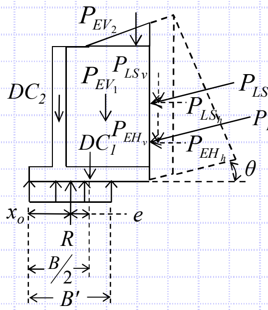
Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	0	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

$B' = B - 2e$ = 10.3 ft - 2(0.44 ft) = 9.42 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.3 ft / 2) - 4.71 ft = 0.44 ft

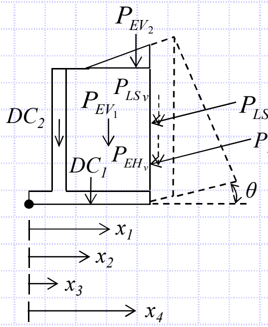
$x_o = \dfrac{M_V - M_H}{P_V}$ = (94.49 kip·ft/ft - 19.48 kip·ft/ft) / (15.91 kip/ft) = 4.71 ft

q_{eq} = (15.91 kip/ft) / (9.42 ft) = 1.69 ksf

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + DC_1(x_2) + DC_2(x_3) + P_{EV_2}(x_4) + P_{EH}\sin\theta\,(B)$$

(Neglect P_{LS_V} for conservatism)



$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV}$ = (120 pcf)(9.8 ft - 2.0 ft)(5.8 ft)(1.35) = 7.33 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(10.3 ft)(2.0 ft)(1.25) = 3.86 kip/ft

$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.8 ft - 2.0 ft)(2.7 ft)(1.25) = 3.95 kip/ft

$P_{EV_2} = {}^1\!/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV}$ = ½(120 pcf)(10.2 ft - 9.8 ft)(5.8 ft - 4.0 ft)(1.35) = 0.07 kip/ft

$P_{EH} = {}^1\!/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.2 ft)²(0.352)(1.50) = 3.33 kip/ft

$x_1 = a + b + c/2$ = 2.7 ft + 1.8 ft + (5.8 ft / 2) = 7.4 ft

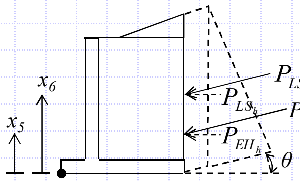
$x_2 = B/2$ = 10.3 ft / 2 = 5.2 ft $x_3 = b + a/2$ = 1.8 ft + (2.7 ft / 2) = 3.2 ft

$x_4 = a + b + l + {}^2\!/_3(c-l)$ = 2.7 ft + 1.8 ft + 4.0 ft + ⅔(5.8 ft - 4.0 ft) = 9.7 ft

M_V = (7.33 kip/ft)(7.4 ft) + (3.86 kip/ft)(5.2 ft) + (3.95 kip/ft)(3.2 ft) + (0.07 kip/ft)(9.7 ft) + (3.33 kip/ft)sin(12.2°)(10.3 ft) = 94.49 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta\,(x_5) + P_{LS}\cos\theta\,(x_6)$$



$P_{EH} = {}^1\!/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.2 ft)²(0.352)(1.50) = 3.33 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(10.2 ft)(0.352)(1.75) = 1.58 kip/ft

$x_5 = h/3$ = (10.2 ft) / 3 = 3.42 ft

$x_6 = h/2$ = (10.2 ft) / 2 = 5.12 ft

M_H = (3.33 kip/ft)cos(12.2°)(3.42 ft) + (1.58 kip/ft)cos(12.2°)(5.12 ft) = 19.48 kip·ft/ft

Vertical Forces, P_V: $P_V = DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ (Neglect P_{LS_V} for conservatism)

P_V = 3.86 kip/ft + 3.95 kip/ft + 7.33 kip/ft + 0.07 kip/ft + (3.33 kip/ft)sin(12.2°) = 15.91 kip/ft

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	0	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 30.833

N_c = 30.14
s_c = 1+(9.42 ft/255 ft)(18.401/30.14)
= 1.023
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 20.460

N_q = 18.401
s_q = 1+(9.42 ft/255 ft)tan(30°) = 1.021
d_q = 1+2tan(30°)[1-sin(30°)]²tan⁻¹(3.0 ft/9.42 ft)
= 1.089
i_q = 1.000 (Assumed)
C_{wq} = 11.8 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 22.066

N_γ = 22.402
s_γ = 1-0.4(9.42 ft/255 ft) = 0.985
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 11.8 ft < 1.5(9.42 ft) + 3.0 ft = 0.918

$q_n =$ (0 psf)(30.833) + (125 pcf)(3.0 ft)(20.460)(1.000) + ½(125 pcf)(9.4 ft)(22.066)(0.918) = 19.60 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ 1.69 ksf ≤ (19.60 ksf)(0.55) = 10.78 ksf ⟶ 1.69 ksf ≤ 10.78 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.258

N_c = 5.140
s_c = 1+(9.42 ft/[(5)(255 ft)]) = 1.023
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/9.42 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 11.8 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)
$C_{w\gamma}$ = 11.8 ft < 1.5(9.42 ft) + 3.0 ft = 0.918

$q_n =$ (0 psf)(5.258) + (125 pcf)(3.0 ft)(1.000)(1.000) + ½(125 pcf)(9.4 ft)(0.000)(0.918) = N/A ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \le q_n \cdot \phi_b$ ⟶ N/A ⟶ N/A

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 4A - Sta. 11+40 to 12+55 (BL Wall 4A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.8	ft
Foundation Width (Entire Base Width), (B) =	10.3	ft
Stem Width, (a) =	2.7	ft
Toe Width, (b) =	1.8	ft
Heel Width, (c) =	5.8	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.2	ft
Retained Soil Backslope, (β) =	14.0	°
Effective Retained Soil Backslope, (θ) =	12.2	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	17.0	ft
Wall Length, (L) =	255	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

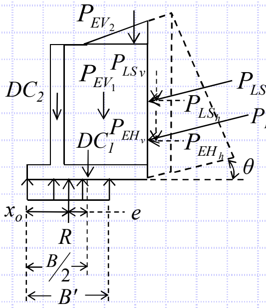
Bearing Soil Unit Weight, (γ_{BS}) =	125	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	30	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	0	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.352	
Passive Earth Pressure Coefficient, (K_p) =	5.576	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	11.8	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 10.3 ft - 2(0.28 ft) = 9.74 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.3 ft / 2) - 4.87 ft = 0.28 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (71.34 kip·ft/ft - 11.92 kip·ft/ft) / (12.20 kip/ft) = 4.87 ft

q_{eq} = (12.20 kip/ft) / (9.74 ft) = 1.25 ksf

$$M_V = (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2) + (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV})(a + b + c/2)$$
$$+ (1/2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV})(a + b + l + 2/3\,(c-l)) + (1/2\,\gamma_{RS} h^2 K_a \gamma_{EH}) \sin\theta (B)$$

M_V = [(150 pcf)(10.3 ft)(2.0 ft)(1.00)](10.3 ft / 2) + [(150 pcf)(9.8 ft - 2.0 ft)(2.7 ft)(1.00)][1.8 ft + (2.7 ft / 2)]
+ [(120 pcf)(9.8 ft - 2.0 ft)(5.8 ft)(1.00)][2.7 ft + 1.8 ft + (5.8 ft / 2)]
+ [½(120 pcf)(10.2 ft - 9.8 ft)(5.8 ft - 4.0 ft)(1.00)][2.7 ft + 1.8 ft + 4.0 ft + ⅔(5.8 ft - 4.0 ft)]
+ [½(120 pcf)(10.2 ft)²(0.352)(1.00)]sin(12.2°)(10.3 ft)

M_V = 71.34 kip·ft/ft

$$M_H = (1/2 \cdot \gamma_{RS} \cdot h^2 \cdot K_a \cdot \gamma_{EH}) \cos\theta \,(h/3) + (\sigma_{LS} h K_a \gamma_{LS}) \cos\theta \,(h/2)$$

M_H = [½(120 pcf)(10.2 ft)²(0.352)(1.00)]cos(12.2°)(10.2 ft / 3) + [(250 psf)(10.2 ft)(0.352)(1.00)]cos(12.2°)(10.2 ft / 2)

M_H = 11.92 kip·ft/ft

$$P_V = (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}) + (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (1/2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV})$$
$$+ (1/2\,\gamma_{RS} h^2 K_a \gamma_{EH}) \sin\theta$$

P_V = (150 pcf)(10.3 ft)(2.0 ft)(1.00) + (150 pcf)(9.8 ft - 2.0 ft)(2.7 ft)(1.00) + (120 pcf)(9.8 ft - 2.0 ft)(5.8 ft)(1.00)
+ ½(120 pcf)(10.2 ft - 9.8 ft)(5.8 ft - 4.0 ft)(1.00) + ½(120 pcf)(10.2 ft)²(0.352)(1.00)sin(12.2°)

P_V = 12.2 kip/ft

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment:	$(S_t)_{max}$ =	**0.766**	in
Minimum Settlement Along Wall Alignment:	$(S_t)_{min}$ =	**0.648**	in

Differential Settlement Along Wall Alignment: δ_s = 0.118 in / 255 ft ⟶ 1 in / 2,161 ft

$\delta_s < 1/500$ ⟶ 1 in / 2,161 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 11+40 to 12+55 (BL Wall 4A)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-043-0-19

H = 9.8 ft Wall height
B' = 9.7 ft Effective base width due to eccentricity
D_w = 8.8 ft Depth below bottom of wall
q = 1,250 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' $^{(1)}$ (psf)	LL	C_c $^{(2)}$	C_r $^{(3)}$	e_o $^{(4)}$	N_{60}	$(N1)_{60}$ $^{(5)}$	C' $^{(6)}$	Z_f/B	I $^{(7)}$	$\Delta\sigma_v$ $^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	S_c $^{(9,10)}$ (ft)	S_c (in)
1	A-2-4	G	0.0	3.3	791.0	787.7	3.3	1.7	125	413	206	206	3,206					15	26	89	0.17	0.985	1,232	1,438	0.031	0.374
2	A-2-4	G	3.3	5.8	787.7	785.2	2.5	4.6	130	738	575	575	3,575					44	62	227	0.47	0.838	1,047	1,622	0.005	0.059
	A-2-4	G	5.8	8.3	785.2	782.7	2.5	7.1	130	1,063	900	900	3,900					44	56	195	0.73	0.681	851	1,751	0.004	0.044
3	A-4a	C	8.3	10.8	782.7	780.2	2.5	9.6	120	1,363	1,213	1,166	4,166	18	0.072	0.007	0.413				0.98	0.556	695	1,861	0.003	0.031
4	A-4a	C	10.8	13.3	780.2	777.7	2.5	12.1	120	1,663	1,513	1,310	4,310	18	0.072	0.007	0.413				1.24	0.464	580	1,890	0.002	0.024
	A-4a	C	13.3	15.8	777.7	775.2	2.5	14.6	120	1,963	1,813	1,454	4,454	18	0.072	0.007	0.413				1.50	0.396	495	1,948	0.002	0.019
5	A-3a	G	15.8	17.8	775.2	773.2	2.0	16.8	135	2,233	2,098	1,598	4,598					49	53	149	1.73	0.349	436	2,034	0.001	0.017
6	A-1-b	G	17.8	20.8	773.2	770.2	3.0	19.3	125	2,608	2,420	1,765	4,765					17	18	70	1.99	0.307	384	2,149	0.004	0.044
7	A-1-b	G	20.8	22.8	770.2	768.2	2.0	21.8	135	2,878	2,743	1,931	4,931					64	65	240	2.25	0.274	343	2,274	0.001	0.007
8	A-4a	C	22.8	25.3	768.2	765.7	2.5	24.1	130	3,203	3,040	2,088	5,088	23	0.117	0.012	0.452				2.48	0.250	313	2,401	0.001	0.015
	A-4a	C	25.3	27.8	765.7	763.2	2.5	26.6	130	3,528	3,365	2,257	5,257	23	0.117	0.012	0.452				2.74	0.228	284	2,542	0.001	0.012
																								Total Settlement:		0.648 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and $0.05(Cc)$ for new embankment fill; 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 continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 2B - Sta. 11+40 to 12+55 (BL Wall 4A)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-043-0-19

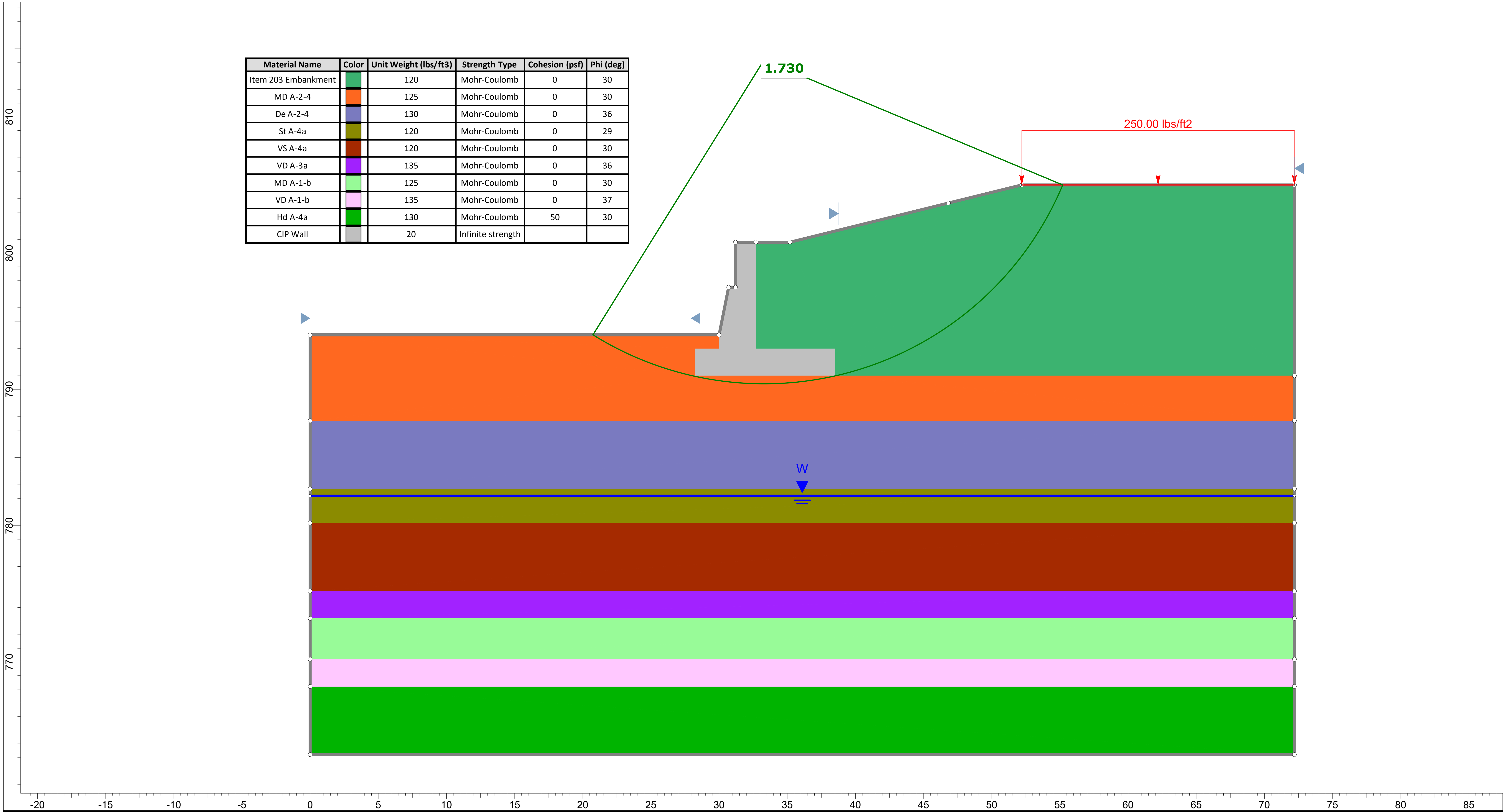
H =	9.8	ft	Wall height
B =	9.7	ft	Effective base width due to eccentricity
D_w =	8.8	ft	Depth below bottom of wall
q =	1,250	psf	Equivalent bearing pressure due to eccentricity
t =	1	days	Time following completion of construction

																									Total Settlement			Settlement Complete at 91% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**$\sigma_p'^{(1)}$ (psf)**	**LL**	**$C_c^{(2)}$**	**$C_r^{(3)}$**	**$e_o^{(4)}$**	**N_{60}**	**$(N1)_{60}^{(5)}$**	**$C'^{(6)}$**	**Z_f/B**	**$I^{(7)}$**	**$\Delta\sigma_v^{(8)}$ (psf)**	**σ_{vf}' Midpoint (psf)**	**$S_c^{(9,10)}$ (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t^{(11)}$ (in)**	Layer Settlement (in)
1	A-2-4	G	0.0	3.3	791.0	787.7	3.3	1.7	125	413	206	206	3,206					15	26	89	0.17	0.985	1,232	1,438	0.031	0.374	0.374				100	0.374	0.374
2	A-2-4	G	3.3	5.8	787.7	785.2	2.5	4.6	130	738	575	575	3,575					44	62	227	0.47	0.838	1,047	1,622	0.005	0.059	0.104				100	0.059	0.104
	A-2-4	G	5.8	8.3	785.2	782.7	2.5	7.1	130	1,063	900	900	3,900					44	56	195	0.73	0.681	851	1,751	0.004	0.044					100	0.044	
3	A-4a	C	8.3	10.8	782.7	780.2	2.5	9.6	120	1,363	1,213	1,166	4,166	18	0.072	0.007	0.413				0.98	0.556	695	1,861	0.003	0.031	0.031	400	2.5	0.175	47	0.015	0.015
4	A-4a	C	10.8	13.3	780.2	777.7	2.5	12.1	120	1,663	1,513	1,310	4,310	18	0.072	0.007	0.413				1.24	0.464	580	1,890	0.002	0.024	0.044	400	3.8	0.078	31	0.008	0.017
	A-4a	C	13.3	15.8	777.7	775.2	2.5	14.6	120	1,963	1,813	1,454	4,454	18	0.072	0.007	0.413				1.50	0.396	495	1,948	0.002	0.019		400	2.5	0.175	47	0.009	
5	A-3a	G	15.8	17.8	775.2	773.2	2.0	16.8	135	2,233	2,098	1,598	4,598					49	53	149	1.73	0.349	436	2,034	0.001	0.017	0.017				100	0.017	0.017
6	A-1-b	G	17.8	20.8	773.2	770.2	3.0	19.3	125	2,608	2,420	1,765	4,765					17	18	70	1.99	0.307	384	2,149	0.004	0.044	0.044				100	0.044	0.044
7	A-1-b	G	20.8	22.8	770.2	768.2	2.0	21.8	135	2,878	2,743	1,931	4,931					64	65	240	2.25	0.274	343	2,274	0.001	0.007	0.007				100	0.007	0.007
8	A-4a	C	22.8	25.3	768.2	765.7	2.5	24.1	130	3,203	3,040	2,088	5,088	23	0.117	0.012	0.452				2.48	0.250	313	2,401	0.001	0.015	0.027	400	2.5	0.175	47	0.007	0.010
	A-4a	C	25.3	27.8	765.7	763.2	2.5	26.6	130	3,528	3,365	2,257	5,257	23	0.117	0.012	0.452				2.74	0.228	284	2,542	0.001	0.012		400	5.0	0.044	24	0.003	

$(S_c)_t$ = 0.587 in

Settlement Remaining After Hold Period: 0.061 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



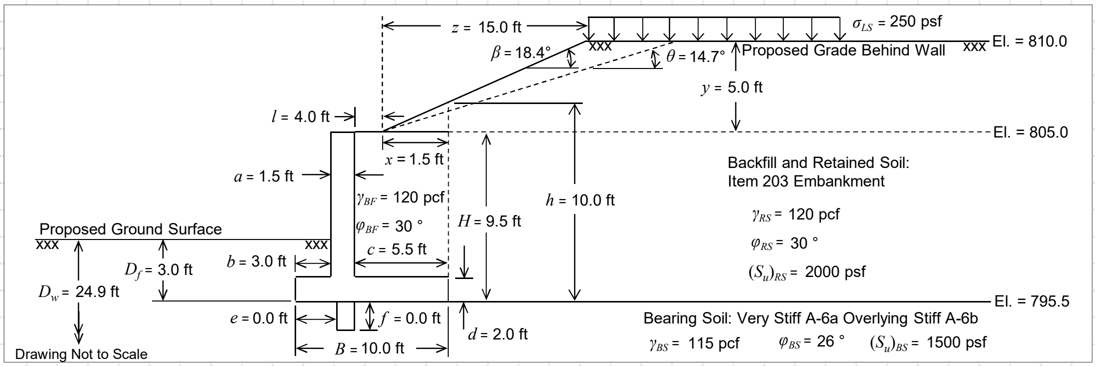
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
MD A-2-4	🟧	125	Mohr-Coulomb	0	30
De A-2-4	🟪	130	Mohr-Coulomb	0	36
St A-4a	🟫	120	Mohr-Coulomb	0	29
VS A-4a	🟥	120	Mohr-Coulomb	0	30
VD A-3a	🟪	135	Mohr-Coulomb	0	36
MD A-1-b	🟩	125	Mohr-Coulomb	0	30
VD A-1-b	🟪	135	Mohr-Coulomb	0	37
Hd A-4a	🟩	130	Mohr-Coulomb	50	30
CIP Wall	⬜	20	Infinite strength		

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

SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 4A		
Analysis Description	Global Stability - Sta. 11+40 to 12+55 (BL Wall 4A) - CIP Wall w/o Shear Key - 4:1 Backslope - B-043-0-19 - 9.8 ft. Wall Height - Drained - Circular		
Drawn By	BRT	*Scale*	1:80
Company	Resource International, Inc.		
Date	4/2/2022, 3:12:33 PM	*File Name*	Wall 4A - Sta. 11+40 to 12+55 - Global Stability.slmd

Retaining Wall 4C - Sta. 10+00 to 11+40 (BL Wall CA) - CIP Wall w/o Shear Key - 3:1 Backslope - B-089-0-19 - 9.5 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

CIP Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

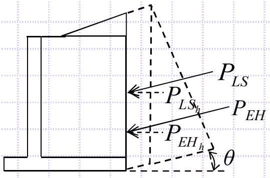
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

$$P_{EH} = \tfrac{1}{2}\gamma_{RS}h^2K_a\gamma_{EH} = \text{½(120 pcf)(10.0 ft)²(0.369)(1.50)} = 3.32 \text{ kip/ft}$$

$$P_{LS} = \sigma_{LS}hK_a\gamma_{LS} = \text{(250 psf)(10.0 ft)(0.369)(1.75)} = 1.61 \text{ kip/ft}$$

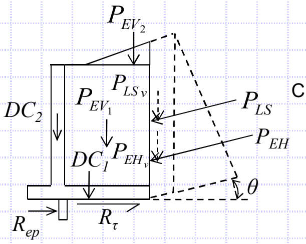
$$P_H = \text{(3.32 kip/ft + 1.6 kip/ft)cos(14.7°)} = 4.77 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$

$$R_{ep} = \gamma_{BS}D_f fK_p\gamma_{ep} + \tfrac{1}{2}\gamma_{BS}f^2K_p\gamma_{ep}$$

$$R_{ep} = \text{(115 pcf)(3.0 ft)(0.0 ft)(4.53)(0.90) + ½(115 pcf)(0.0 ft)²(4.53)(0.90)} = 0.00 \text{ kip/ft}$$



Check Drained Condition: $R_\tau = (DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta)\tan\delta$
(Neglect P_{LS_v} for conservatism)

$$DC_1 + DC_2 = \gamma_C[B(d) + (H-d)(a)]\gamma_{DC}$$
$$= \text{(150 pcf) [(10.0 ft)(2.0 ft) + (9.5 ft - 2.0 ft)(1.5 ft)] (0.90)} = 4.22 \text{ kip/ft}$$

$$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV} = \text{(120 pcf)(9.5 ft - 2.0 ft)(5.5 ft)(1.00)} = 4.95 \text{ kip/ft}$$

$$P_{EV_2} = {}^1\!/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV} = \text{½(120 pcf)(10.0 ft - 9.5 ft)(5.5 ft - 4.0 ft)(1.00)} = 0.04 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(26°) = 0.49$$

$$R_\tau = \text{[4.22 kip/ft + 4.95 kip/ft + 0.04 kip/ft + (3.32 kip/ft)sin(14.7°)](0.49)} = 4.93 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow \text{4.77 kip/ft ≤ (4.93 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 4.93 kip/ft}$$

= 4.77 kip/ft ≤ 4.93 kip/ft **OK** Use φ_τ = **1.00** Use φ_{ep} = **0.50**

(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

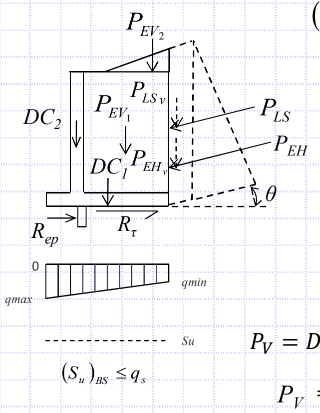
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 *(Continued)*

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



$(S_u)_{BS}$ = 1.50 ksf

$q_{max} = {}^1\!/_2\, \sigma_{vmax}$ = (1.33 ksf) / 2 = 0.67 ksf

$q_{min} = {}^1\!/_2\, \sigma_{vmin}$ = (0.68 ksf) / 2 = 0.34 ksf

$\sigma_{vmax} = {}^{P_V}\!/_B \left(1 + 6\frac{e}{B}\right)$ = (10.05 kip/ft / 10.0 ft)[1 + 6(0.55 ft / 10.0 ft)] = 1.33 ksf

$\sigma_{vmin} = {}^{P_V}\!/_B \left(1 - 6\frac{e}{B}\right)$ = (10.05 kip/ft / 10.0 ft)[1 - 6(0.55 ft / 10.0 ft)] = 0.68 ksf

$P_V = DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH} \sin\theta$ (Neglect P_{LS_V} for conservatism)

P_V = 4.22 kip/ft + 4.95 kip/ft + 0.04 kip/ft + (3.32 kip/ft)sin(14.7°) = 10.05 kip/ft

R_τ = 0.5(0.67 ksf - 0.34 ksf)(10.0 ft) + (0.34 ksf)(10.0 ft) = 5.05 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 4.77 kip/ft ≤ (5.05 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 5.05

= 4.77 kip/ft ≤ 5.05 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	2/5/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 4C - Sta. 10+00 to 11+40 (BL Wall 4C)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

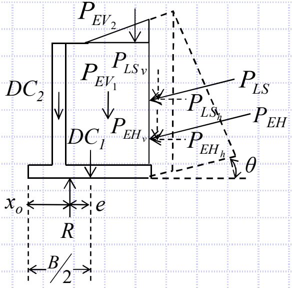
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = \text{(63.89 kip·ft/ft - 19.11 kip·ft/ft) / (10.05 kip/ft)} = 4.46 \text{ ft}$$

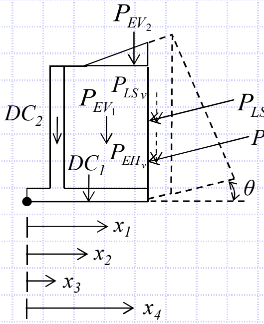
M_V = 63.89 kip·ft/ft } Defined below
M_H = 19.11 kip·ft/ft
P_V = 10.05 kip/ft (Defined on Sheet No. 2)

$e =$ (10.0 ft / 2) - 4.46 ft = 0.55 ft

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + DC_1(x_2) + DC_2(x_3) + P_{EV_2}(x_4) + P_{EH}\sin\theta\,(B)$$

(Neglect P_{LS_V} for conservatism)



$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV}$ = (120 pcf)(9.5 ft - 2.0 ft)(5.5 ft)(1.00) = 4.95 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(10.0 ft)(2.0 ft)(0.90) = 2.70 kip/ft

$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.5 ft - 2.0 ft)(1.5 ft)(0.90) = 1.52 kip/ft

$P_{EV_2} = {}^1/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV}$ = ½(120 pcf)(10.0 ft - 9.5 ft)(5.5 ft - 4.0 ft)(1.00)
= 0.04 kip/ft

$P_{EH} = {}^1/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.0 ft)²(0.369)(1.50) = 3.32 kip/ft

$x_1 = a + b + c/2$ = 1.5 ft + 3.0 ft + (5.5 ft / 2) = 7.3 ft

$x_2 = B/2$ = 10.0 ft / 2 = 5.0 ft

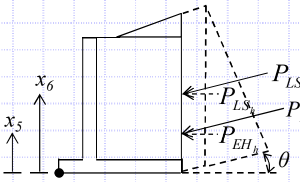
$x_3 = b + a/2$ = 3.0 ft + (1.5 ft / 2) = 3.8 ft

$x_4 = a + b + l + {}^2/_3\,(c-l)$ = 1.5 ft + 3.0 ft + 4.0 ft + ⅔(5.5 ft - 4.0 ft) = 9.5 ft

$M_V =$ (4.95 kip/ft)(7.3 ft) + (2.70 kip/ft)(5.0 ft) + (1.52 kip/ft)(3.8 ft) + (0.04 kip/ft)(9.5 ft) + (3.32 kip/ft)sin(14.7°)(10.0 ft)
= 63.89 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta\,(x_5) + P_{LS}\cos\theta\,(x_6)$$



$P_{EH} = {}^1/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.0 ft)²(0.369)(1.50) = 3.32 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(10.0 ft)(0.369)(1.75) = 1.61 kip/ft

$x_5 = h/3$ = (10.0 ft) / 3 = 3.33 ft

$x_6 = h/2$ = (10.0 ft) / 2 = 5.00 ft

$M_H =$ (3.32 kip/ft)cos(14.7°)(3.33 ft) + (1.61 kip/ft)cos(14.7°)(5.00 ft) = 19.11 kip·ft/ft

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Check Eccentricity Limiting Eccentricity: $e_{\max} = B/3 \longrightarrow e_{\max} =$ (10.0 ft) / 3 = 3.33 ft

$e < e_{\max} \longrightarrow$ 0.55 ft < 3.33 ft OK

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

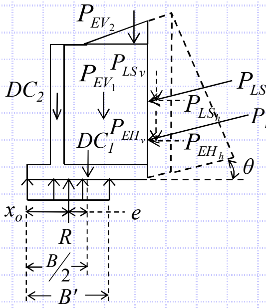
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

$B' = B - 2e$ = 10.0 ft - 2(0.17 ft) = 9.66 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.0 ft / 2) - 4.83 ft = 0.17 ft

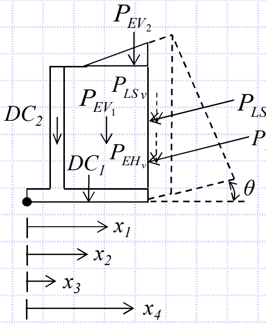
$x_o = \dfrac{M_V - M_H}{P_V}$ = (84.10 kip·ft/ft - 19.11 kip·ft/ft) / (13.44 kip/ft) = 4.83 ft

q_{eq} = (13.44 kip/ft) / (9.66 ft) = 1.39 ksf

Resisting Moment, M_V:

$$M_V = P_{EV_1}(x_1) + DC_1(x_2) + DC_2(x_3) + P_{EV_2}(x_4) + P_{EH}\sin\theta\,(B)$$

(Neglect P_{LS_v} for conservatism)



$P_{EV_1} = \gamma_{BF}(H-d)(c)\gamma_{EV}$ = (120 pcf)(9.5 ft - 2.0 ft)(5.5 ft)(1.35) = 6.68 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(10.0 ft)(2.0 ft)(1.25) = 3.75 kip/ft

$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.5 ft - 2.0 ft)(1.5 ft)(1.25) = 2.11 kip/ft

$P_{EV_2} = {}^1/_2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV}$ = ½(120 pcf)(10.0 ft - 9.5 ft)(5.5 ft - 4.0 ft)(1.35)
= 0.06 kip/ft

$P_{EH} = {}^1\!/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.0 ft)²(0.369)(1.50) = 3.32 kip/ft

$x_1 = a + b + c/2$ = 1.5 ft + 3.0 ft + (5.5 ft / 2) = 7.3 ft

$x_2 = B/2$ = 10.0 ft / 2 = 5.0 ft

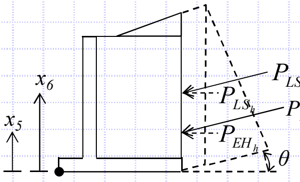
$x_3 = b + a/2$ = 3.0 ft + (1.5 ft / 2) = 3.8 ft

$x_4 = a + b + l + {}^2/_3(c-l)$ = 1.5 ft + 3.0 ft + 4.0 ft + ⅔(5.5 ft - 4.0 ft) = 9.5 ft

$M_V =$ (6.68 kip/ft)(7.3 ft) + (3.75 kip/ft)(5.0 ft) + (2.11 kip/ft)(3.8 ft) + (0.06 kip/ft)(9.5 ft) + (3.32 kip/ft)sin(14.7°)(10.0 ft)
= 84.1 kip·ft/ft

Overturning Moment, M_H:

$$M_H = P_{EH}\cos\theta\,(x_5) + P_{LS}\cos\theta\,(x_6)$$



$P_{EH} = {}^1\!/_2\,\gamma_{RS} h^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.0 ft)²(0.369)(1.50) = 3.32 kip/ft

$P_{LS} = \sigma_{LS} h K_a \gamma_{LS}$ = (250 psf)(10.0 ft)(0.369)(1.75) = 1.61 kip/ft

$x_5 = h/3$ = (10.0 ft) / 3 = 3.33 ft

$x_6 = h/2$ = (10.0 ft) / 2 = 5.00 ft

$M_H =$ (3.32 kip/ft)cos(14.7°)(3.33 ft) + (1.61 kip/ft)cos(14.7°)(5.00 ft) = 19.11 kip·ft/ft

Vertical Forces, P_V: $P_V = DC_1 + DC_2 + P_{EV_1} + P_{EV_2} + P_{EH}\sin\theta$ (Neglect P_{LS_v} for conservatism)

P_V = 3.75 kip/ft + 2.11 kip/ft + 6.68 kip/ft + 0.06 kip/ft + (3.32 kip/ft)sin(14.7°) = 13.44 kip/ft

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 23.077

N_c = 22.254
s_c = 1+(9.66 ft/140 ft)(11.854/22.254)
= 1.037
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 13.397

N_q = 11.854
s_q = 1+(9.66 ft/140 ft)tan(26°) = 1.034
d_q = 1+2tan(26°)[1-sin(26°)]²tan⁻¹(3.0 ft/9.66 ft)
= 1.093
i_q = 1.000 (Assumed)
C_{wq} = 24.9 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 12.188

N_γ = 12.539
s_γ = 1-0.4(9.66 ft/140 ft) = 0.972
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 24.9 ft > 1.5(9.66 ft) + 3.0 ft = 1.000

$q_n =$ (0 psf)(23.077) + (115 pcf)(3.0 ft)(13.397)(1.000) + ½(115 pcf)(9.7 ft)(12.188)(1.000) = 11.39 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b \longrightarrow$ 1.39 ksf ≤ (11.39 ksf)(0.55) = 6.26 ksf $\longrightarrow$ 1.39 ksf ≤ 6.26 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.330

N_c = 5.140
s_c = 1+(9.66 ft/[(5)(140 ft)]) = 1.037
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/9.66 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 24.9 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)
$C_{w\gamma}$ = 24.9 ft > 1.5(9.66 ft) + 3.0 ft = 1.000

$q_n =$ (1500 psf)(5.330) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(9.7 ft)(0.000)(1.000) = 8.34 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b \longrightarrow$ 1.39 ksf ≤ (8.34 ksf)(0.55) = 4.59 ksf $\longrightarrow$ 1.39 ksf ≤ 4.59 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.5	ft
Foundation Width (Entire Base Width), (B) =	10.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	3.0	ft
Heel Width, (c) =	5.5	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
CIP Wall Effective Height, (h) =	10.0	ft
Retained Soil Backslope, (β) =	18.4	°
Effective Retained Soil Backslope, (θ) =	14.7	°
Distance from Wall Face to Toe of Backslope, (l) =	4.0	ft
Distance from Toe to Top of Backslope, (z) =	15.0	ft
Wall Length, (L) =	140	ft
Live Surcharge Load, (σ_{LS}) =	250	psf

Bearing and Retained/Backfill Soil Properties:

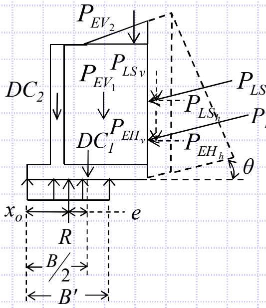
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.369	
Passive Earth Pressure Coefficient, (K_p) =	4.532	
Embedment Depth, (D_f) =	3.0	ft
Depth to Groundwater, (D_w) =	24.9	ft

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 10.0 ft - 2(-0.04 ft) = 10.08 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (10.0 ft / 2) - 5.04 ft = -0.04 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (63.26 kip·ft/ft - 11.60 kip·ft/ft) / (10.24 kip/ft) = 5.04 ft

q_{eq} = (10.24 kip/ft) / (10.08 ft) = 1.02 ksf

$$M_V = (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2) + (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV})(a + b + c/2) + (1/2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV})(a + b + l + 2/3\,(c-l)) + (1/2\,\gamma_{RS}h^2K_a\gamma_{EH})\sin\theta(B)$$

M_V = [(150 pcf)(10.0 ft)(2.0 ft)(1.00)](10.0 ft / 2) + [(150 pcf)(9.5 ft - 2.0 ft)(1.5 ft)(1.00)][3.0 ft + (1.5 ft / 2)]
+ [(120 pcf)(9.5 ft - 2.0 ft)(5.5 ft)(1.00)][1.5 ft + 3.0 ft + (5.5 ft / 2)]
+ [½(120 pcf)(10.0 ft - 9.5 ft)(5.5 ft - 4.0 ft)(1.00)][1.5 ft + 3.0 ft + 4.0 ft + ⅔(5.5 ft - 4.0 ft)]
+ [½(120 pcf)(10.0 ft)^2(0.369)(1.00)]sin(14.7°)(10.0 ft)

M_V = 63.26 kip·ft/ft

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

M_H = [½(120 pcf)(10.0 ft)^2(0.369)(1.00)]cos(14.7°)(10.0 ft / 3) + [(250 psf)(10.0 ft)(0.369)(1.00)]cos(14.7°)(10.0 ft / 2)

M_H = 11.6 kip·ft/ft

$$P_V = (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC}) + (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (1/2\,\gamma_{BF}(h-H)(c-l)\gamma_{EV}) + (1/2\,\gamma_{RS}h^2K_a\gamma_{EH})\sin\theta$$

P_V = (150 pcf)(10.0 ft)(2.0 ft)(1.00) + (150 pcf)(9.5 ft - 2.0 ft)(1.5 ft)(1.00) + (120 pcf)(9.5 ft - 2.0 ft)(5.5 ft)(1.00)
+ ½(120 pcf)(10.0 ft - 9.5 ft)(5.5 ft - 4.0 ft)(1.00) + ½(120 pcf)(10.0 ft)^2(0.369)(1.00)sin(14.7°)

P_V = 10.24 kip/ft

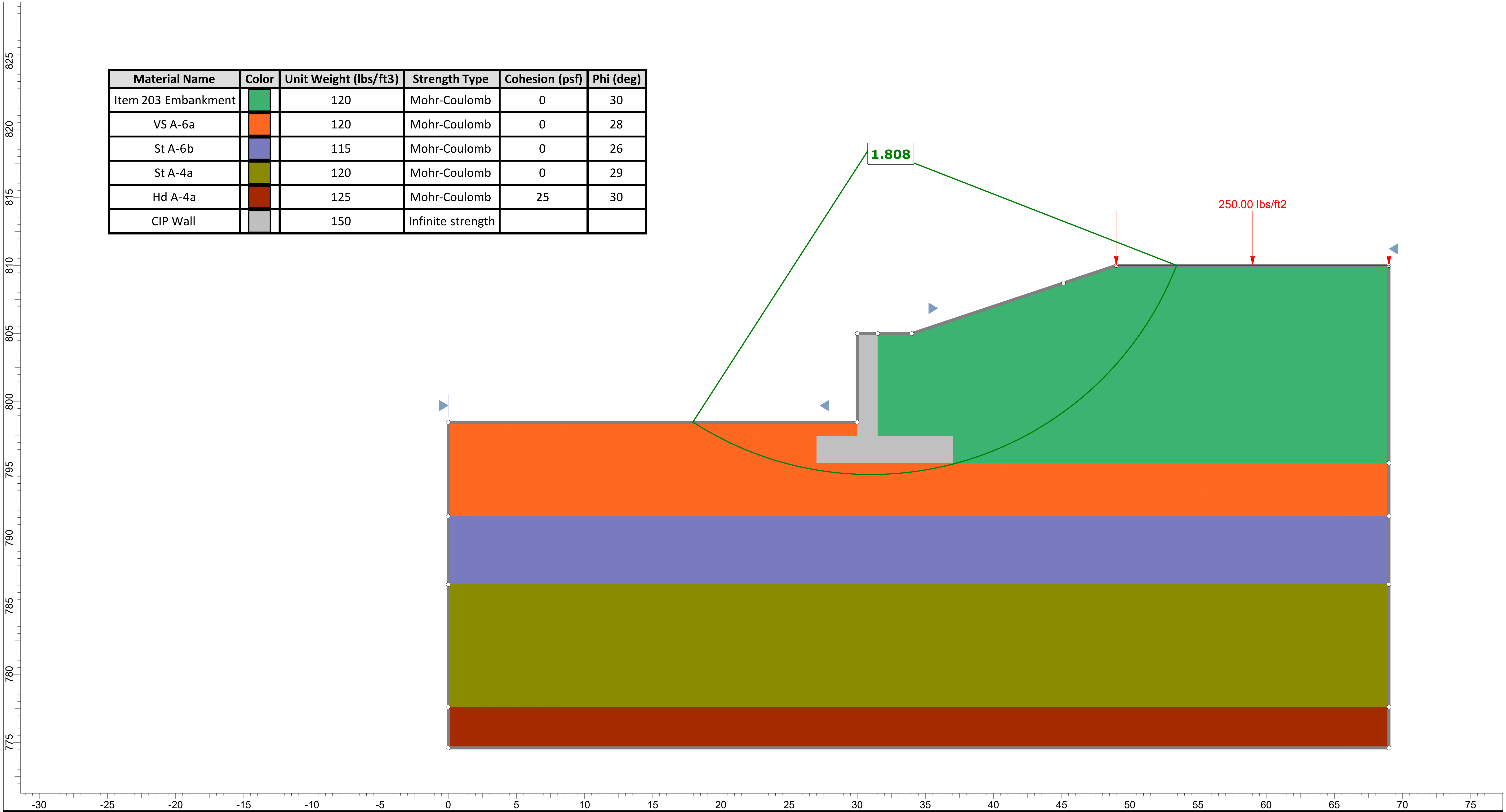
Settlement (See Attached Spreadsheet Calculations): (Wall is in cut condition. Settlement is considered negligible.)

Maximum Settlement Along Wall Alignment: $(S_t)_{\max}$ = **N/A** in

Minimum Settlement Along Wall Alignment: $(S_t)_{\min}$ = **N/A** in

Differential Settlement Along Wall Alignment: δ_s = N/A ⟶ N/A

$\delta_s < 1/500$ ⟶ N/A < 1/500



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	120	Mohr-Coulomb	0	28
St A-6b	🟪	115	Mohr-Coulomb	0	26
St A-4a	🟨	120	Mohr-Coulomb	0	29
Hd A-4a	🟥	125	Mohr-Coulomb	25	30
CIP Wall	⬜	150	Infinite strength		

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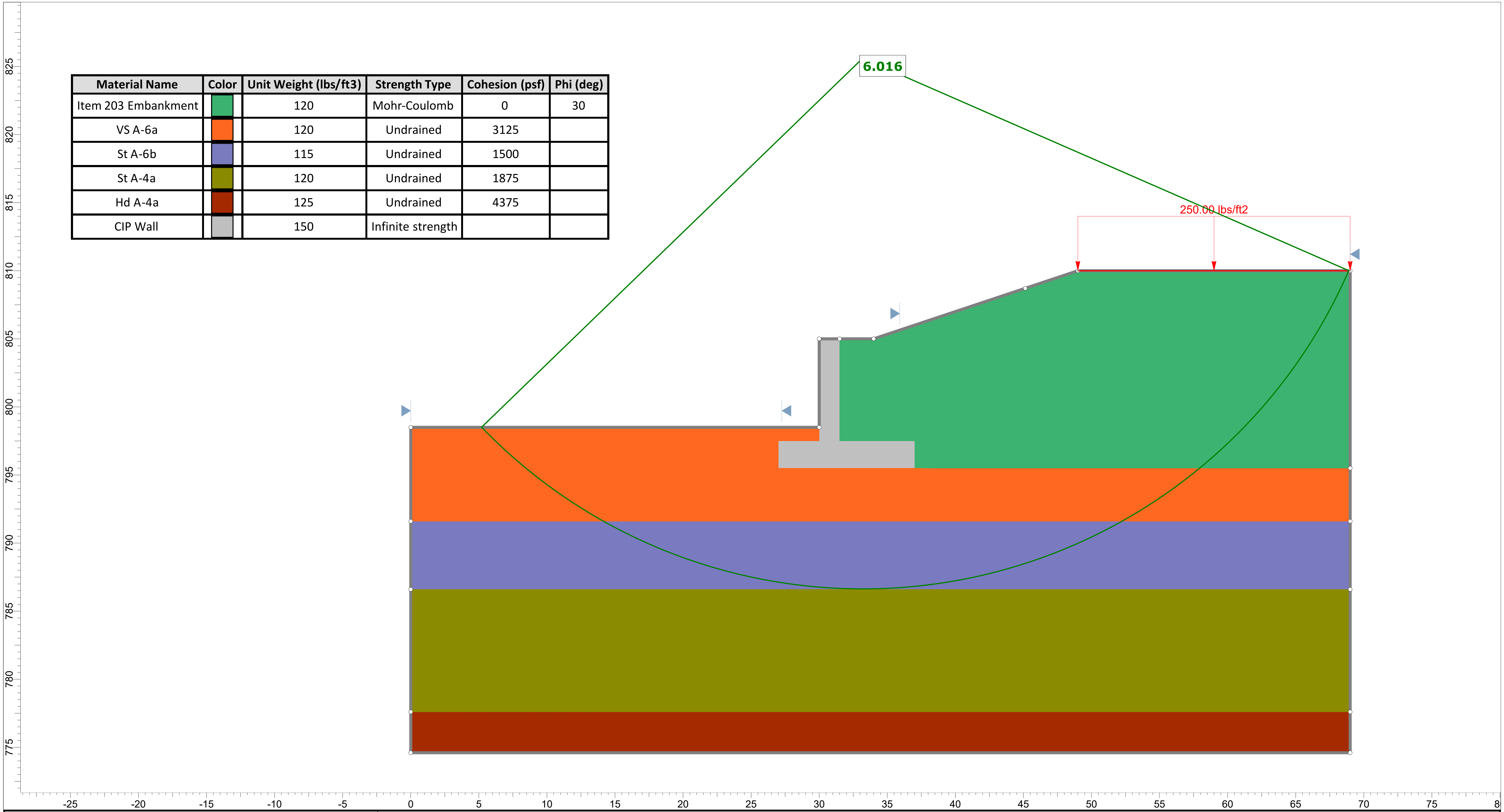
SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 4C
Analysis Description	Global Stability - Sta. 10+00 to 11+40 (BL Wall 4C) - CIP Wall w/o Shear Key - 3:1 Backslope - B-089-0-19 - 9.5 ft. Wall Height - Drained - Circular
Drawn By	BRT
Scale	1:80
Company	Resource International, Inc.
Date	4/3/2022, 12:59:00 AM
File Name	Wall 4C - Sta. 10+00 to 11+40 - Global Stability.slmd

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
VS A-6a	🟧	120	Undrained	3125	
St A-6b	🟪	115	Undrained	1500	
St A-4a	🟨	120	Undrained	1875	
Hd A-4a	🟥	125	Undrained	4375	
CIP Wall	⬜	150	Infinite strength		



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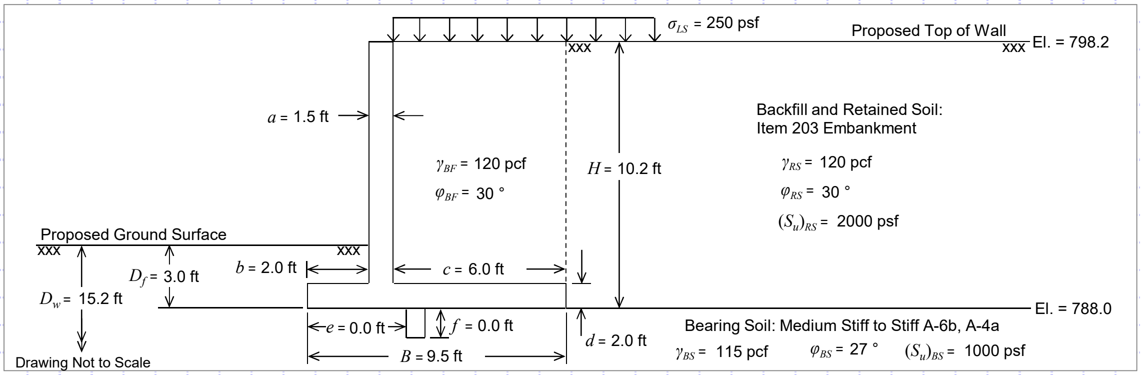
Project
FRA-70-22.85 FEF - Retaining Wall 4C

Analysis Description
Global Stability - Sta. 10+00 to 11+40 (BL Wall 4C) - CIP Wall w/o Shear Key - 3:1 Backslope - B-089-0-19 - 9.5 ft. Wall Height - Undrained - Circular

Drawn By BRT	*Scale* 1:80	*Company* Resource International, Inc.	
Date 4/3/2022, 12:59:00 AM		*File Name* Wall 4C - Sta. 10+00 to 11+40 - Global Stability.slmd	

SLIDEINTERPRET 9.024

Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A) - CIP Wall Without Shear Key - B-040-0-19 and B-041-0-19 - 10.2 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	10.2	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	180	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	15.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	1000	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

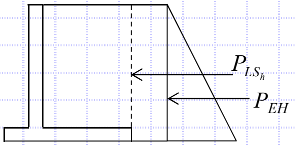
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



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

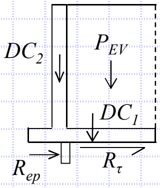
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(10.2 ft)²(0.297)(1.50)} = 2.78 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad \text{(250 psf)(10.2 ft)(0.297)(1.75)} = 1.33 \text{ kip/ft}$$

$$P_H = \text{2.78 kip/ft + 1.33 kip/ft} = 4.11 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$



$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

$$R_{ep} = \text{(115 pcf)(3.0 ft)(0.0 ft)(4.80)(0.90) + ½(115 pcf)(0.0 ft)²(4.80)(0.90)} = 0.00 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot [B \cdot d + (H-d)\cdot a]\cdot \gamma_{DC} + \gamma_{BF}\cdot (H-d)\cdot c \cdot \gamma_{EV}$$

$$P_V = \text{(150 pcf) [(9.5 ft)(2.0 ft) + (10.2 ft - 2.0 ft)(1.5 ft)] (0.90) +} \\ \text{(120 pcf)(10.2 ft - 2.0 ft)(6.0 ft)(1.00)} = 10.13 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(27) = 0.51$$

$$R_\tau = \text{(10.13 kip/ft)(0.51)} = 5.17 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep}\cdot R_{ep} \longrightarrow \text{4.11 kip/ft ≤ (5.17 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 5.17 kip/ft}$$

= 4.11 kip/ft ≤ 5.17 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	10.2	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	180	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	15.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1000	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

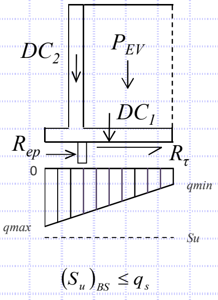
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 *(Continued)*

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



$(S_u)_{BS}$ = 1.00 ksf

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (1.68 ksf) / 2 = 0.84 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (0.45 ksf) / 2 = 0.23 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1 + 6\frac{e}{B}\right)$ = (10.13 kip/ft / 9.5 ft)[1 + 6(0.91 ft / 9.5 ft)] = 1.68 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1 - 6\frac{e}{B}\right)$ = (10.13 kip/ft / 9.5 ft)[1 - 6(0.91 ft / 9.5 ft)] = 0.45 ksf

R_τ = 0.5(0.84 ksf - 0.23 ksf)(9.5 ft) + (0.23 ksf)(9.5 ft) = 5.08 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 4.11 kip/ft ≤ (5.08 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 5.08

= 4.11 kip/ft ≤ 5.08 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	2/4/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	10.2	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	180	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	15.2	ft

Bearing and Retained/Backfill Soil Properties:

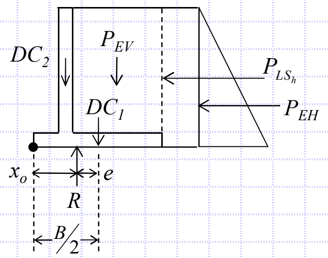
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1000	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = (55.13 \text{ kip·ft/ft} - 16.24 \text{ kip·ft/ft}) / (10.13 \text{ kip/ft}) = 3.84 \text{ ft}$$

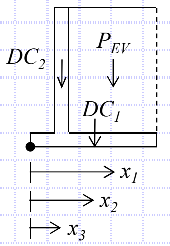
M_V = 55.13 kip·ft/ft
M_H = 16.24 kip·ft/ft
Defined below

$$P_V = P_{EV} + DC_1 + DC_2 = 5.90 \text{ kip/ft} + 2.57 \text{ kip/ft} + 1.66 \text{ kip/ft} = 10.13 \text{ kip/ft}$$

$$e = (9.5 \text{ ft} / 2) - 3.84 \text{ ft} = 0.91 \text{ ft}$$

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV} = (120 \text{ pcf})(10.2 \text{ ft} - 2.0 \text{ ft})(6.0 \text{ ft})(1.00) = 5.90 \text{ kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} = (150 \text{ pcf})(9.5 \text{ ft})(2.0 \text{ ft})(0.90) = 2.57 \text{ kip/ft}$$

$$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC} = (150 \text{ pcf})(10.2 \text{ ft} - 2.0 \text{ ft})(1.5 \text{ ft})(0.90) = 1.66 \text{ kip/ft}$$

$$x_1 = a + b + c/2 = 1.5 \text{ ft} + 2.0 \text{ ft} + (6.0 \text{ ft} / 2) = 6.5 \text{ ft}$$

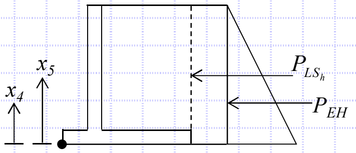
$$x_2 = B/2 = 9.5 \text{ ft} / 2 = 4.8 \text{ ft}$$

$$x_3 = b + a/2 = 2.0 \text{ ft} + (1.5 \text{ ft} / 2) = 2.8 \text{ ft}$$

$$M_V = (5.90 \text{ kip/ft})(6.5 \text{ ft}) + (2.57 \text{ kip/ft})(4.8 \text{ ft}) + (1.66 \text{ kip/ft})(2.8 \text{ ft}) = 55.13 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = ½ \gamma_{RS} H^2 K_a \gamma_{EH} = ½(120 \text{ pcf})(10.2 \text{ ft})^2(0.297)(1.50) = 2.78 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = (250 \text{ psf})(10.2 \text{ ft})(0.297)(1.75) = 1.33 \text{ kip/ft}$$

$$x_2 = H/3 = (10.2 \text{ ft}) / 3 = 3.40 \text{ ft}$$

$$x_3 = H/2 = (10.2 \text{ ft}) / 2 = 5.10 \text{ ft}$$

$$M_H = (2.78 \text{ kip/ft})(3.4 \text{ ft}) + (1.33 \text{ kip/ft})(5.10 \text{ ft}) = 16.24 \text{ kip·ft/ft}$$

Limiting Eccentricity:

$$e_{\max} = B/3 \longrightarrow e_{\max} = (9.5 \text{ ft}) / 3 = 3.17 \text{ ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 0.91 ft < 3.17 ft **OK**

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) = 10.2 ft
Foundation Width (Entire Base Width), (B) = 9.5 ft
Stem Width, (a) = 1.5 ft
Toe Width, (b) = 2.0 ft
Heel Width, (c) = 6.0 ft
Footing Thickness, (d) = 2.0 ft
Location of Shear Key, (e) = 0.0 ft
Depth of Shear Key, (f) = 0.0 ft
Embedment Depth, (D_f) = 3.0 ft
Wall Length, (L) = 180 ft
Live Surcharge Load, (σ_{LS}) = 250 psf
Depth to Groundwater, (D_w) = 15.2 ft

Bearing and Retained/Backfill Soil Properties:

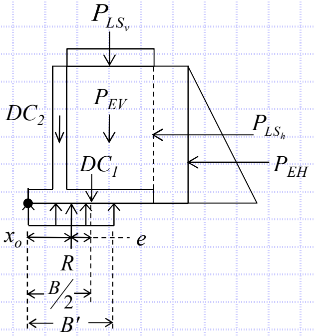
Bearing Soil Unit Weight, (γ_{BS}) = 115 pcf
Bearing Soil Friction Angle, (φ_{BS}) = 27 °
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] = 1000 psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) = 120 pcf
Retained Soil Friction Angle, (φ_{RS}) = 30 °
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] = 2000 psf
Active Earth Pressure Coefficient, (K_a) = 0.297
Passive Earth Pressure Coefficient, (K_p) = 4.801

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

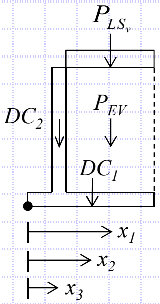
$$B' = B - 2e$$ = 9.5 ft - 2(-0.02 ft) = 9.50 ft (For e < 0, Use B)

$$e = B/2 - x_o$$ = (9.5 ft / 2) - 4.77 ft = -0.02 ft

$$x_o = \frac{M_V - M_H}{P_V}$$ = (102.09 kip·ft/ft - 16.24 kip·ft/ft) / (18.00 kip/ft) = 4.77 ft

q_{eq} = (18.00 kip/ft) / (9.50 ft) = 1.89 ksf

Resisting Moment, M_V:



$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$

$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(10.2 ft - 2.0 ft)(6.0 ft)(1.35) = 7.97 kip/ft

$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS}$ = (250 psf)(9.5 ft)(1.75) = 4.156 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(9.5 ft)(2.0 ft)(1.25) = 3.56 kip/ft

$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(10.2 ft - 2.0 ft)(1.5 ft)(1.25) = 2.31 kip/ft

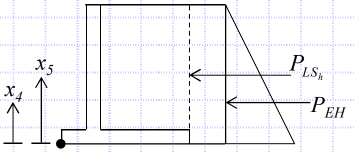
$x_1 = a + b + c/2$ = 1.5 ft + 2.0 ft + (6.0 ft / 2) = 6.5 ft

$x_2 = B/2$ = 9.5 ft / 2 = 4.8 ft

$x_3 = b + a/2$ = 2.0 ft + (1.5 ft / 2) = 2.8 ft

M_V = (7.97 kip/ft)(6.5 ft) + (4.16 kip/ft)(6.5 ft) + (3.56 kip/ft)(4.8 ft) + (2.31 kip/ft)(2.8 ft) = 102.09 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$

$P_{EH} = \frac{1}{2} \gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(10.2 ft)²(0.297)(1.50) = 2.78 kip/ft

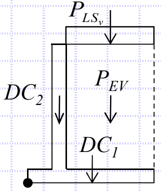
$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(10.2 ft)(0.297)(1.75) = 1.33 kip/ft

$x_4 = H/3$ = (10.2 ft) / 3 = 3.40 ft

$x_5 = H/2$ = (10.2 ft) / 2 = 5.10 ft

M_H = (2.78 kip/ft)(3.4 ft) + (1.33 kip/ft)(5.10 ft) = 16.24 kip·ft/ft

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

P_V = 7.97 kip/ft + 4.16 kip/ft + 3.56 kip/ft + 2.31 kip/ft

P_V = 18.00 kip/ft

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	10.2	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	180	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	15.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1000	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 24.636

N_c = 23.942
s_c = 1+(9.5 ft/180 ft)(13.199/23.942)
= 1.029
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.816

N_q = 13.199
s_q = 1+(9.5 ft/180 ft)tan(27°) = 1.027
d_q = 1+2tan(27°)[1-sin(27°)]²tan⁻¹(3.0 ft/9.5 ft)
= 1.093
i_q = 1.000 (Assumed)
C_{wq} = 15.2 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 14.166

N_γ = 14.47
s_γ = 1-0.4(9.5 ft/180 ft) = 0.979
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 15.2 ft < 1.5(9.5 ft) + 3.0 ft = 1.033

$q_n =$ (0 psf)(24.636) + (115 pcf)(3.0 ft)(14.816)(1.000) + ½(115 pcf)(9.5 ft)(14.166)(1.033) = 13.11 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.89 ksf ≤ (13.11 ksf)(0.55) = 7.21 ksf ⟶ 1.89 ksf ≤ 7.21 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.289

N_c = 5.140
s_c = 1+(9.5 ft/[(5)(180 ft)]) = 1.029
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/9.5 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 15.2 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)
$C_{w\gamma}$ = 15.2 ft < 1.5(9.5 ft) + 3.0 ft = 1.033

$q_n =$ (1000 psf)(5.289) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(9.5 ft)(0.000)(1.033) = 5.63 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.89 ksf ≤ (5.63 ksf)(0.55) = 3.10 ksf ⟶ 1.89 ksf ≤ 3.10 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	2/4/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	10.2	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	180	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	15.2	ft

Bearing and Retained/Backfill Soil Properties:

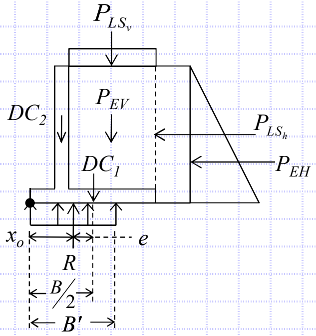
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	27	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1000	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.801	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$$B' = B - 2e \quad = \quad 9.5 \text{ ft - 2(-0.05 ft)} \quad = \quad 9.50 \quad \text{ft} \qquad (\text{For } e < 0\text{, Use } B)$$

$$e = B\big/2 - x_o \quad = \quad \text{(9.5 ft / 2) - 4.80 ft} \quad = \quad -0.05 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(72.42 kip·ft/ft - 10.17 kip·ft/ft) / (12.97 kip/ft)} \quad = \quad 4.8 \quad \text{ft}$$

$$q_{eq} \;=\; \text{(12.97 kip/ft) / (9.50 ft)} \quad = \quad 1.37 \quad \text{ksf}$$

$$M_V = [(\gamma_{BF}\cdot(H-d)\cdot c\cdot\gamma_{EV}) + (\sigma_{LS}\cdot B\cdot\gamma_{LS})](a+b+c\big/2) + (\gamma_c\cdot B\cdot d\cdot\gamma_{DC})(B\big/2) + (\gamma_c\cdot(H-d)\cdot a\cdot\gamma_{DC})(b+a\big/2)$$

M_V =[(120 pcf)(10.2 ft - 2.0 ft)(6.0 ft)(1.00) + (250 psf)(9.5 ft)(1.00)](1.5 ft + 2.0 ft + (6.0 ft / 2)) = 72.42 kip·ft/ft
+ [(150 pcf)(9.5 ft)(2.0 ft)(1.00)](9.5 ft / 2) + [(150 pcf)(10.2 ft - 2.0 ft)(1.5 ft)(1.00)](2.0 ft + (1.5 ft / 2))

$$M_H = (\tfrac{1}{2}\gamma_{RS}\cdot H^2\cdot K_a\cdot\gamma_{EH})(H\big/3) + (\sigma_{LS}\cdot H\cdot K_a\cdot\gamma_{LS})(H\big/2)$$

M_H = [½(120 pcf)(10.2 ft)²(0.297)(1.00)](10.2 ft / 3) + [(250 psf)(10.2 ft)(0.297)(1.00)](10.2 ft / 2) = 10.17 kip·ft/ft

$$P_V = (\gamma_{BF}\cdot(H-d)\cdot c\cdot\gamma_{EV}) + (\sigma_{LS}\cdot B\cdot\gamma_{LS}) + (\gamma_c\cdot B\cdot d\cdot\gamma_{DC}) + (\gamma_c\cdot(H-d)\cdot a\cdot\gamma_{DC})$$

P_V = (120 pcf)(10.2 ft - 2.0 ft)(6.0 ft)(1.00) + (250 psf)(9.5 ft)(1.00) + (150 pcf)(9.5 ft)(2.0 ft)(1.00) = 12.97 kip/ft
+ (150 pcf)(10.2 ft - 2.0 ft)(1.5 ft)(1.00)

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: $(S_t)_{max}$ = **0.883** in

Minimum Settlement Along Wall Alignment: $(S_t)_{min}$ = **0.690** in

Differential Settlement Along Wall Alignment: δ_s = 0.193 in / 180 ft ⟶ 1 in / 933 ft

$\delta_s < 1/500$ ⟶ 1 in / 933 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-0-19

H =	6.7	ft	Wall height
B' =	9.5	ft	Effective base width due to eccentricity
D_w =	12.2	ft	Depth below bottom of wall
q =	1,020	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' [1] (psf)	LL	C_c [2]	C_r [3]	e_o [4]	N_{60}	$(N1)_{60}$ [5]	C' [6]	Z_f/B	I [7]	$\Delta\sigma_v$ [8] (psf)	σ_{vf}' Midpoint (psf)	S_c [9,10] (ft)	S_c (in)
1	A-6b	C	0.0	2.4	788.0	785.6	2.4	1.2	115	276	138	138	3,138	40	0.270	0.027	0.585				0.13	0.994	1,014	1,152	0.038	0.452
2	A-4b	C	2.4	4.9	785.6	783.1	2.5	3.7	115	564	420	420	3,420	27	0.153	0.015	0.483				0.38	0.890	908	1,328	0.013	0.155
	A-4b	C	4.9	7.4	783.1	780.6	2.5	6.2	115	851	707	707	3,707	27	0.153	0.015	0.483				0.65	0.727	741	1,448	0.008	0.096
3	A-1-b	G	7.4	9.9	780.6	778.1	2.5	8.7	130	1,176	1,014	1,014	4,014					33	41	133	0.91	0.588	600	1,614	0.004	0.046
4	A-6a	C	9.9	12.4	778.1	775.6	2.5	11.2	125	1,489	1,332	1,332	4,332	25	0.135	0.014	0.467				1.17	0.486	496	1,828	0.003	0.038
	A-6a	C	12.4	15.4	775.6	772.6	3.0	13.9	125	1,864	1,676	1,570	4,570	25	0.135	0.014	0.467				1.46	0.404	413	1,982	0.003	0.034
	A-6a	C	15.4	18.4	772.6	769.6	3.0	16.9	130	2,254	2,059	1,765	4,765	25	0.135	0.014	0.467				1.78	0.340	347	2,112	0.002	0.026
	A-6a	C	18.4	21.4	769.6	766.6	3.0	19.9	130	2,644	2,449	1,968	4,968	25	0.135	0.014	0.467				2.09	0.293	299	2,267	0.002	0.020
	A-6a	C	21.4	24.4	766.6	763.6	3.0	22.9	130	3,034	2,839	2,171	5,171	25	0.135	0.014	0.467				2.41	0.257	262	2,433	0.001	0.016
																								Total Settlement:		0.883 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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 continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-040-0-19

H =	6.7	ft	Wall height
B =	9.5	ft	Effective base width due to eccentricity
D_w =	12.2	ft	Depth below bottom of wall
q =	1,020	psf	Equivalent bearing pressure due to eccentricity
t =	10	days	Time following completion of construction

																							Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**$\sigma_p'^{(1)}$ (psf)**	**LL**	**$C_c^{(2)}$**	**$C_r^{(3)}$**	**$e_o^{(4)}$**	**N_{60}**	**$(N1)_{60}^{(5)}$**	**$C'^{(6)}$**	**Z_f/B**	**$I^{(7)}$**	**$\Delta\sigma_v^{(8)}$ (psf)**	**σ_{vf}' Midpoint (psf)**	**$S_c^{(9,10)}$ (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t^{(11)}$ (in)**	Layer Settlement (in)
1	A-6b	C	0.0	2.4	788.0	785.6	2.4	1.2	115	276	138	138	3,138	40	0.270	0.027	0.585				0.13	0.994	1,014	1,152	0.038	0.452	0.452	300	2.4	1.427	98	0.443	0.443
2	A-4b	C	2.4	4.9	785.6	783.1	2.5	3.7	115	564	420	420	3,420	27	0.153	0.015	0.483				0.38	0.890	908	1,328	0.013	0.155	0.251	400	3.7	0.801	89	0.138	0.233
	A-4b	C	4.9	7.4	783.1	780.6	2.5	6.2	115	851	707	707	3,707	27	0.153	0.015	0.483				0.65	0.727	741	1,448	0.008	0.096		400	2.5	1.753	99	0.095	
3	A-1-b	G	7.4	9.9	780.6	778.1	2.5	8.7	130	1,176	1,014	1,014	4,014					33	41	133	0.91	0.588	600	1,614	0.004	0.046	0.046				100	0.046	0.046
4	A-6a	C	9.9	12.4	778.1	775.6	2.5	11.2	125	1,489	1,332	1,332	4,332	25	0.135	0.014	0.467				1.17	0.486	496	1,828	0.003	0.038	0.071	300	2.5	1.315	97	0.037	0.057
	A-6a	C	12.4	15.4	775.6	772.6	3.0	13.9	125	1,864	1,676	1,570	4,570	25	0.135	0.014	0.467				1.46	0.404	413	1,982	0.003	0.034		300	5.5	0.272	59	0.020	
5	A-6a	C	15.4	18.4	772.6	769.6	3.0	16.9	130	2,254	2,059	1,765	4,765	25	0.135	0.014	0.467				1.78	0.340	347	2,112	0.002	0.026	0.063	300	8.5	0.114	38	0.010	0.019
	A-6a	C	18.4	21.4	769.6	766.6	3.0	19.9	130	2,644	2,449	1,968	4,968	25	0.135	0.014	0.467				2.09	0.293	299	2,267	0.002	0.020		300	11.5	0.062	28	0.006	
	A-6a	C	21.4	24.4	766.6	763.6	3.0	22.9	130	3,034	2,839	2,171	5,171	25	0.135	0.014	0.467				2.41	0.257	262	2,433	0.001	0.016		300	14.5	0.039	22	0.004	

$(S_c)_t$ = 0.798 in

Settlement Remaining After Hold Period: 0.085 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-22.85 FEF - Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)
CIP Wall Settlement

Calculated By:	PPM	Date:	1/19/2022
Checked By:	BRT	Date:	3/23/2022

Boring B-041-0-19

H =	10.2	ft	Wall height
B' =	9.5	ft	Effective base width due to eccentricity
D_w =	12.2	ft	Depth below bottom of wall
q_e =	1,370	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-6a	C	0.0	2.0	788.0	786.0	2.0	1.0	115	230	115	115	3,115	28	0.162	0.001	0.491				0.11	0.996	1,365	1,480	0.001	0.014
	A-6a	C	2.0	4.0	786.0	784.0	2.0	3.0	115	460	345	345	3,345	28	0.162	0.016	0.491				0.32	0.929	1,272	1,617	0.015	0.175
2	A-2-4	G	4.0	6.5	784.0	781.5	2.5	5.3	125	773	616	616	3,616					16	22	79	0.55	0.785	1,075	1,692	0.014	0.166
	A-2-4	G	6.5	9.0	781.5	779.0	2.5	7.8	125	1,085	929	929	3,929					16	20	75	0.82	0.634	868	1,797	0.010	0.115
3	A-6a	C	9.0	11.5	779.0	776.5	2.5	10.3	120	1,385	1,235	1,235	4,235	28	0.162	0.016	0.491				1.08	0.519	711	1,946	0.005	0.064
4	A-4a	C	11.5	14.0	776.5	774.0	2.5	12.8	115	1,673	1,529	1,494	4,494	23	0.117	0.012	0.452				1.34	0.435	596	2,091	0.003	0.035
5	A-6a	C	14.0	16.5	774.0	771.5	2.5	15.3	120	1,973	1,823	1,632	4,632	28	0.162	0.016	0.491				1.61	0.373	511	2,143	0.003	0.039
6	A-4a	C	16.5	19.0	771.5	769.0	2.5	17.8	120	2,273	2,123	1,776	4,776	23	0.117	0.012	0.452				1.87	0.325	446	2,222	0.002	0.024
7	A-2-4	G	19.0	21.5	769.0	766.5	2.5	20.3	130	2,598	2,435	1,933	4,933					42	43	140	2.13	0.288	395	2,328	0.001	0.017
8	A-4a	C	21.5	25.0	766.5	763.0	3.5	23.3	125	3,035	2,816	2,127	5,127	23	0.117	0.012	0.452				2.45	0.253	347	2,474	0.002	0.022
	A-4a	C	25.0	28.5	763.0	759.5	3.5	26.8	125	3,473	3,254	2,346	5,346	23	0.117	0.012	0.452				2.82	0.221	303	2,649	0.001	0.018
																						Total Settlement:			0.690 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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 continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 5A - Sta. 10+60 to 12+40 (BL Wall 5A)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-041-0-19

$H =$ 10.2 ft Wall height
$B =$ 9.5 ft Effective base width due to eccentricity
$D_w =$ 12.2 ft Depth below bottom of wall
$q =$ 1,370 psf Equivalent bearing pressure due to eccentricity

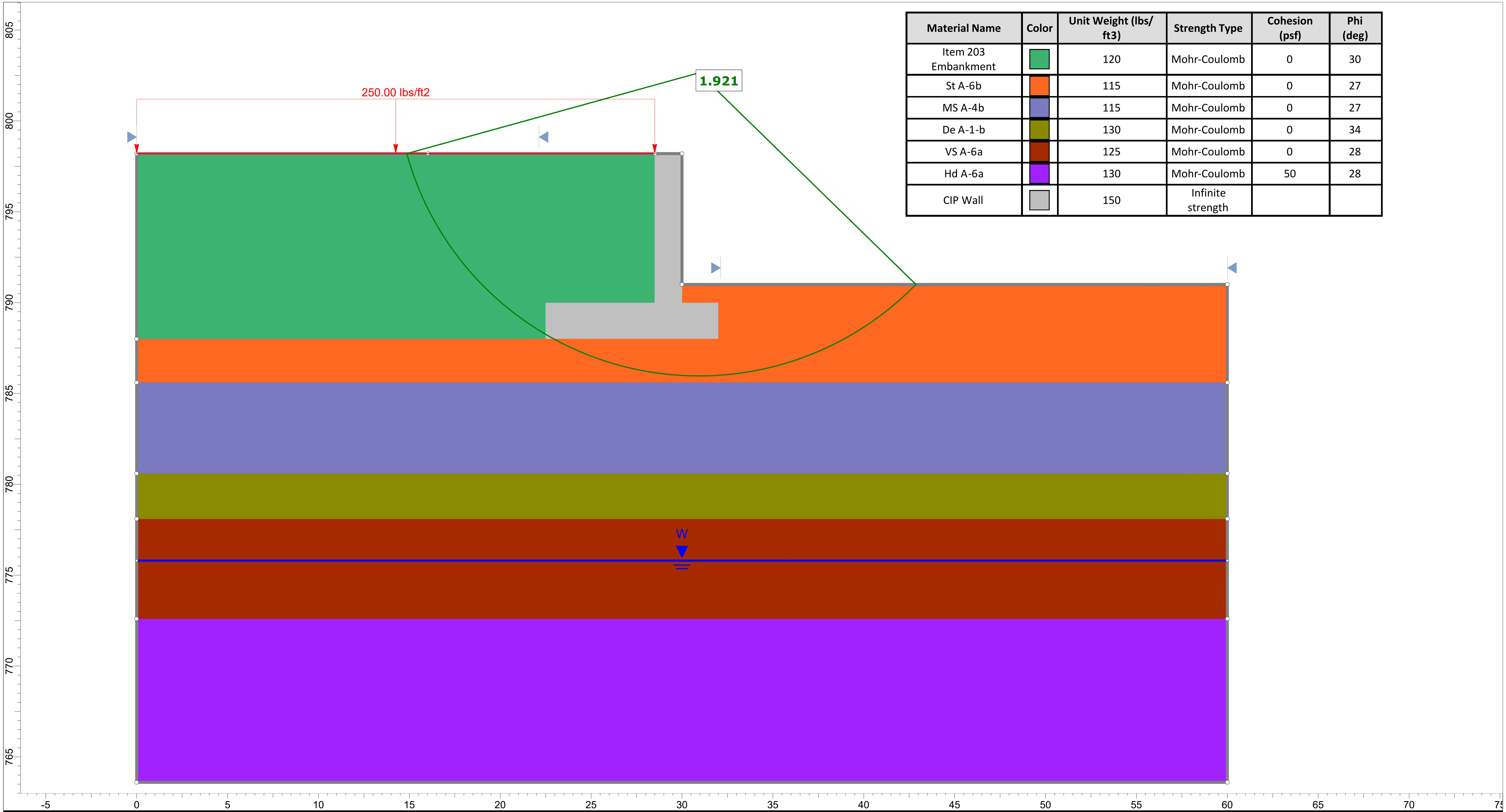
$t =$ 6 days Time following completion of construction

																							Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' [1] (psf)	LL	C_c [2]	C_r [3]	e_o [4]	N_{60}	$(N1)_{60}$ [5]	C' [6]	Z_f/B	I [7]	$\Delta\sigma_v$ [8] (psf)	σ_{vf}' Midpoint (psf)	S_c [9,10] (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ [11] (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.0	788.0	786.0	2.0	1.0	115	230	115	115	3,115	28	0.162	0.001	0.491				0.11	0.996	1,365	1,480	0.001	0.014	0.189	300	2.0	1.233	96	0.014	0.182
	A-6a	C	2.0	4.0	786.0	784.0	2.0	3.0	115	460	345	345	3,345	28	0.162	0.016	0.491				0.32	0.929	1,272	1,617	0.015	0.175		300	2.0	1.233	96	0.168	
2	A-2-4	G	4.0	6.5	784.0	781.5	2.5	5.3	125	773	616	616	3,616					16	22	79	0.55	0.785	1,075	1,692	0.014	0.166	0.281				100	0.166	0.281
	A-2-4	G	6.5	9.0	781.5	779.0	2.5	7.8	125	1,085	929	929	3,929					16	20	75	0.82	0.634	868	1,797	0.010	0.115					100	0.115	
3	A-6a	C	9.0	11.5	779.0	776.5	2.5	10.3	120	1,385	1,235	1,235	4,235	28	0.162	0.016	0.491				1.08	0.519	711	1,946	0.005	0.064	0.064	300	2.5	0.789	88	0.057	0.057
4	A-4a	C	11.5	14.0	776.5	774.0	2.5	12.8	115	1,673	1,529	1,494	4,494	23	0.117	0.012	0.452				1.34	0.435	596	2,091	0.003	0.035	0.035	400	5.0	0.263	58	0.020	0.020
5	A-6a	C	14.0	16.5	774.0	771.5	2.5	15.3	120	1,973	1,823	1,632	4,632	28	0.162	0.016	0.491				1.61	0.373	511	2,143	0.003	0.039	0.039	300	5.0	0.197	50	0.019	0.019
6	A-4a	C	16.5	19.0	771.5	769.0	2.5	17.8	120	2,273	2,123	1,776	4,776	23	0.117	0.012	0.452				1.87	0.325	446	2,222	0.002	0.024	0.024	400	2.5	1.052	94	0.022	0.022
7	A-2-4	G	19.0	21.5	769.0	766.5	2.5	20.3	130	2,598	2,435	1,933	4,933					42	43	140	2.13	0.288	395	2,328	0.001	0.017	0.017				100	0.017	0.017
8	A-4a	C	21.5	25.0	766.5	763.0	3.5	23.3	125	3,035	2,816	2,127	5,127	23	0.117	0.012	0.452				2.45	0.253	347	2,474	0.002	0.022	0.040	400	3.5	0.537	78	0.017	0.025
	A-4a	C	25.0	28.5	763.0	759.5	3.5	26.8	125	3,473	3,254	2,346	5,346	23	0.117	0.012	0.452				2.82	0.221	303	2,649	0.001	0.018		400	7.0	0.134	41	0.007	

$(S_c)_t =$ 0.623 in

Settlement Remaining After Hold Period: 0.066 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \le \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Mohr-Coulomb	0	27
MS A-4b	🟦	115	Mohr-Coulomb	0	27
De A-1-b	🟨	130	Mohr-Coulomb	0	34
VS A-6a	🟫	125	Mohr-Coulomb	0	28
Hd A-6a	🟪	130	Mohr-Coulomb	50	28
CIP Wall	⬜	150	Infinite strength		

Resource International, Inc.
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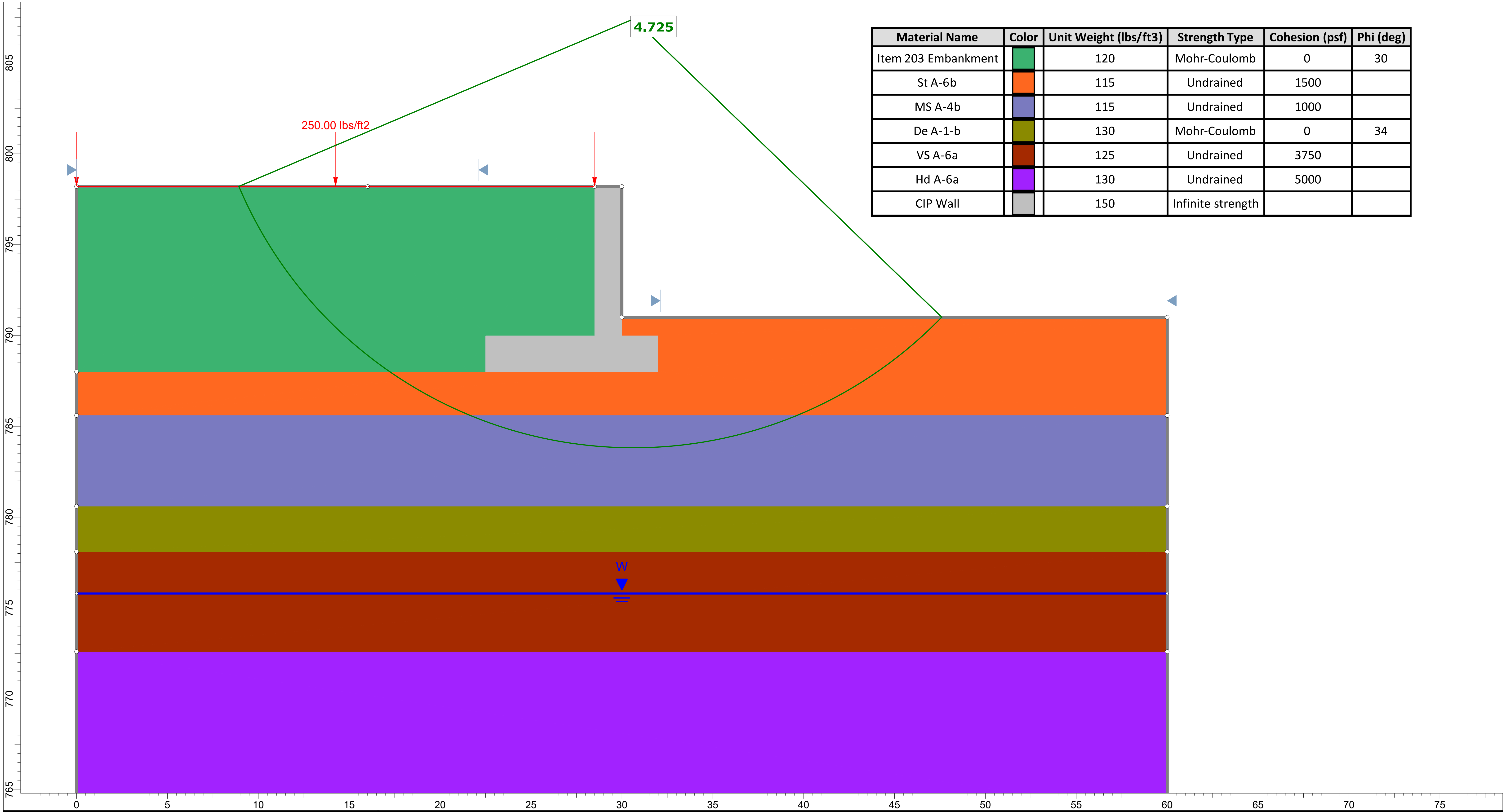
SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 5A
Analysis Description	Global Stability - Sta. 10+60 to 12+40 (BL Wall 5A) - CIP Wall Without Shear Key - B-040-0-19 and B-041-0-19 - 10.2 ft. Wall Height - Drained - Circular
Drawn By	BRT
Scale	1:60
Company	Resource International, Inc.
Date	4/3/2022, 11:27:26 AM
File Name	Wall 5A - Sta. 10+60 to 12+40 - Global Stability.slmd



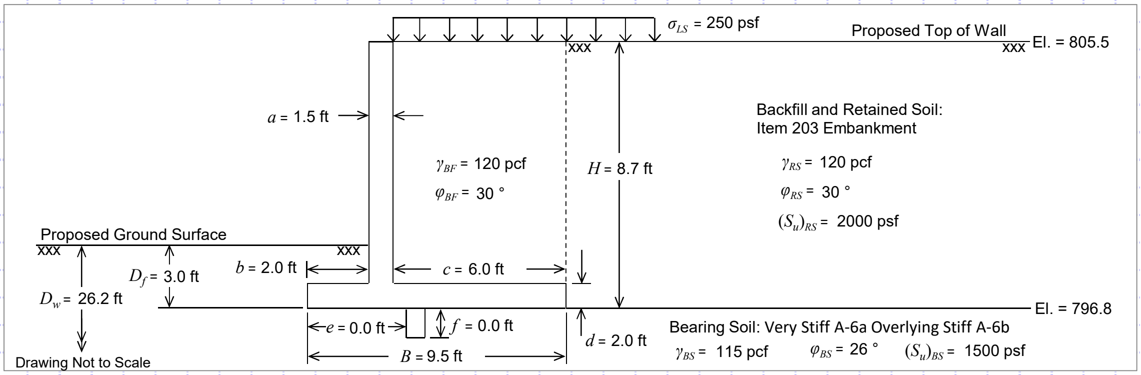
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St A-6b	🟧	115	Undrained	1500	
MS A-4b	🟦	115	Undrained	1000	
De A-1-b	🟨	130	Mohr-Coulomb	0	34
VS A-6a	🟫	125	Undrained	3750	
Hd A-6a	🟪	130	Undrained	5000	
CIP Wall	⬜	150	Infinite strength		

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

Project	FRA-70-22.85 FEF - Retaining Wall 5A
Analysis Description	Global Stability - Sta. 10+60 to 12+40 (BL Wall 5A) - CIP Wall Without Shear Key - B-040-0-19 and B-041-0-19 - 10.2 ft. Wall Height - Undrained - Circular
Drawn By	BRT
Scale	1:60
Company	Resource International, Inc.
Date	4/3/2022, 11:27:26 AM
File Name	Wall 5A - Sta. 10+60 to 12+40 - Global Stability.slmd

SLIDEINTERPRET 9.024

Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C) - CIP Wall Without Shear Key - B-089-0-19 - 8.7 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

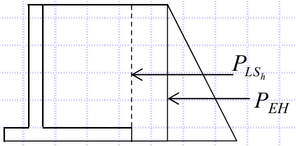
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4

Sliding Force:



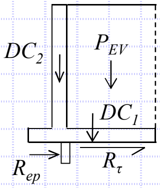
$$P_H = P_{EH} + P_{LS_h}$$

$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(8.7 ft)²(0.297)(1.50)} = 2.02 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad \text{(250 psf)(8.7 ft)(0.297)(1.75)} = 1.13 \text{ kip/ft}$$

$$P_H = \text{2.02 kip/ft + 1.13 kip/ft} = 3.15 \text{ kip/ft}$$

Check Sliding Resistance



Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$

$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

$$R_{ep} = \text{(115 pcf)(3.0 ft)(0.0 ft)(4.53)(0.90) + ½(115 pcf)(0.0 ft)²(4.53)(0.90)} = 0.00 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot \left[B \cdot d + (H-d)\cdot a\right] \cdot \gamma_{DC} + \gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}$$

$$P_V = \text{(150 pcf) [(9.5 ft)(2.0 ft) + (8.7 ft - 2.0 ft)(1.5 ft)] (0.90) + (120 pcf)(8.7 ft - 2.0 ft)(6.0 ft)(1.00)} = 8.75 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(26) = 0.49$$

$$R_\tau = \text{(8.75 kip/ft)(0.49)} = 4.29 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow \text{3.15 kip/ft ≤ (4.29 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 4.29 kip/ft}$$

= 3.15 kip/ft ≤ 4.29 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	2/4/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

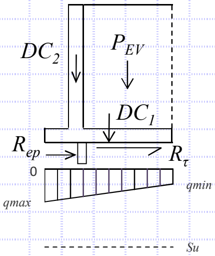
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 ***(Continued)***

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



$(S_u)_{BS} \le q_s$

$(S_u)_{BS}$ = 1.50 ksf

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (1.26 ksf) / 2 = 0.63 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (0.59 ksf) / 2 = 0.30 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1 + 6\frac{e}{B}\right)$ = (8.75 kip/ft / 9.5 ft)[1 + 6(0.58 ft / 9.5 ft)] = 1.26 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1 - 6\frac{e}{B}\right)$ = (8.75 kip/ft / 9.5 ft)[1 - 6(0.58 ft / 9.5 ft)] = 0.59 ksf

R_τ = 0.5(0.63 ksf - 0.3 ksf)(9.5 ft) + (0.3 ksf)(9.5 ft) = 4.42 kip/ft

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 3.15 kip/ft ≤ (4.42 kip/ft)(1.00) + (0.00 kip/ft)(0.50) = 4.42

= 3.15 kip/ft ≤ 4.42 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	3	OF	6
CALCULATED BY	BRT	DATE	2/4/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

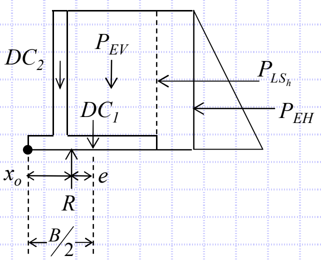
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1500	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = (47.27 \text{ kip·ft/ft} - 10.77 \text{ kip·ft/ft}) / (8.75 \text{ kip/ft}) = 4.17 \text{ ft}$$

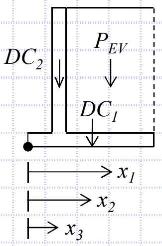
M_V = 47.27 kip·ft/ft
M_H = 10.77 kip·ft/ft
Defined below

$$P_V = P_{EV} + DC_1 + DC_2 = 4.82 \text{ kip/ft} + 2.57 \text{ kip/ft} + 1.36 \text{ kip/ft} = 8.75 \text{ kip/ft}$$

$$e = (9.5 \text{ ft} / 2) - 4.17 \text{ ft} = 0.58 \text{ ft}$$

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$$P_{EV} = \gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV} = (120 \text{ pcf})(8.7 \text{ ft} - 2.0 \text{ ft})(6.0 \text{ ft})(1.00) = 4.82 \text{ kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} = (150 \text{ pcf})(9.5 \text{ ft})(2.0 \text{ ft})(0.90) = 2.57 \text{ kip/ft}$$

$$DC_2 = \gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC} = (150 \text{ pcf})(8.7 \text{ ft} - 2.0 \text{ ft})(1.5 \text{ ft})(0.90) = 1.36 \text{ kip/ft}$$

$$x_1 = a + b + c/2 = 1.5 \text{ ft} + 2.0 \text{ ft} + (6.0 \text{ ft} / 2) = 6.5 \text{ ft}$$

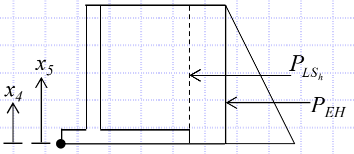
$$x_2 = B/2 = 9.5 \text{ ft} / 2 = 4.8 \text{ ft}$$

$$x_3 = b + a/2 = 2.0 \text{ ft} + (1.5 \text{ ft} / 2) = 2.8 \text{ ft}$$

$$M_V = (4.82 \text{ kip/ft})(6.5 \text{ ft}) + (2.57 \text{ kip/ft})(4.8 \text{ ft}) + (1.36 \text{ kip/ft})(2.8 \text{ ft}) = 47.27 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = ½(120 \text{ pcf})(8.7 \text{ ft})^2(0.297)(1.50) = 2.02 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = (250 \text{ psf})(8.7 \text{ ft})(0.297)(1.75) = 1.13 \text{ kip/ft}$$

$$x_2 = H/3 = (8.7 \text{ ft}) / 3 = 2.90 \text{ ft}$$

$$x_3 = H/2 = (8.7 \text{ ft}) / 2 = 4.35 \text{ ft}$$

$$M_H = (2.02 \text{ kip/ft})(2.9 \text{ ft}) + (1.13 \text{ kip/ft})(4.35 \text{ ft}) = 10.77 \text{ kip·ft/ft}$$

Limiting Eccentricity:

$$e_{\max} = B/3 \longrightarrow e_{\max} = (9.5 \text{ ft}) / 3 = 3.17 \text{ ft}$$

Check Eccentricity

$$e < e_{\max} \longrightarrow 0.58 \text{ ft} < 3.17 \text{ ft}$$

OK

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

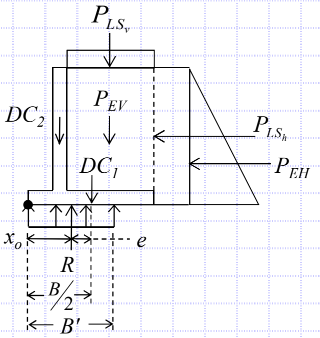
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

$$B' = B - 2e \quad = \quad \text{9.5 ft - 2(-0.26 ft)} \quad = \quad 9.50 \quad \text{ft} \qquad (\text{For } e < 0\text{, Use } B)$$

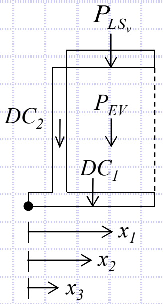
$$e = B/2 - x_o \quad = \quad \text{(9.5 ft / 2) - 5.01 ft} \quad = \quad -0.26 \quad \text{ft}$$

$$x_o = \frac{M_V - M_H}{P_V} \quad = \quad \text{(91.45 kip·ft/ft - 10.77 kip·ft/ft) / (16.12 kip/ft)} \quad = \quad 5.01 \quad \text{ft}$$

$$q_{eq} = \text{(16.12 kip/ft) / (9.50 ft)} \quad = \quad 1.70 \quad \text{ksf}$$

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV} \quad = \quad \text{(120 pcf)(8.7 ft - 2.0 ft)(6.0 ft)(1.35)} \quad = \quad 6.51 \quad \text{kip/ft}$$

$$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS} \quad = \quad \text{(250 psf)(9.5 ft)(1.75)} \quad = \quad 4.156 \quad \text{kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} = \quad \text{(150 pcf)(9.5 ft)(2.0 ft)(1.25)} \quad = \quad 3.56 \quad \text{kip/ft}$$

$$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC} = \quad \text{(150 pcf)(8.7 ft - 2.0 ft)(1.5 ft)(1.25)} \quad = \quad 1.88 \quad \text{kip/ft}$$

$$x_1 = a + b + c/2 \quad = \quad \text{1.5 ft + 2.0 ft + (6.0 ft / 2)} \quad = \quad 6.5 \quad \text{ft}$$

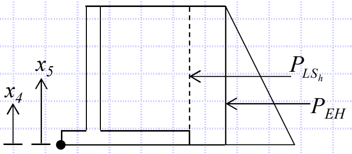
$$x_2 = B/2 \quad = \quad \text{9.5 ft / 2} \quad = \quad 4.8 \quad \text{ft}$$

$$x_3 = b + a/2 \quad = \quad \text{2.0 ft + (1.5 ft / 2)} \quad = \quad 2.8 \quad \text{ft}$$

$$M_V = \quad \text{(6.51 kip/ft)(6.5 ft) + (4.16 kip/ft)(6.5 ft) + (3.56 kip/ft)(4.8 ft) + (1.88 kip/ft)(2.8 ft)} \quad = \quad 91.45 \quad \text{kip·ft/ft}$$

Overturning Moment, M_H:

$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$



$$P_{EH} = \tfrac{1}{2} \gamma_{RS} H^2 K_a \gamma_{EH} \quad = \quad \text{½(120 pcf)(8.7 ft)²(0.297)(1.50)} \quad = \quad 2.02 \quad \text{kip/ft}$$

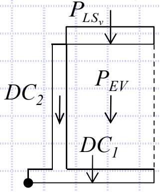
$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} \quad = \quad \text{(250 psf)(8.7 ft)(0.297)(1.75)} \quad = \quad 1.13 \quad \text{kip/ft}$$

$$x_4 = H/3 \quad = \quad \text{(8.7 ft) / 3} \quad = \quad 2.90 \quad \text{ft}$$

$$x_5 = H/2 \quad = \quad \text{(8.7 ft) / 2} \quad = \quad 4.35 \quad \text{ft}$$

$$M_H = \quad \text{(2.02 kip/ft)(2.9 ft) + (1.13 kip/ft)(4.35 ft)} \quad = \quad 10.77 \quad \text{kip·ft/ft}$$

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

$$P_V = \text{6.51 kip/ft + 4.16 kip/ft + 3.56 kip/ft + 1.88 kip/ft}$$

$$P_V = 16.12 \quad \text{kip/ft}$$

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 24.235

N_c = 22.254
s_c = 1+(9.5 ft/57 ft)(11.854/22.254)
= 1.089
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 14.019

N_q = 11.854
s_q = 1+(9.5 ft/57 ft)tan(26°) = 1.081
d_q = 1+2tan(26°)[1-sin(26°)]²tan⁻¹(3.0 ft/9.5 ft)
= 1.094
i_q = 1.000 (Assumed)
C_{wq} = 26.2 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 11.699

N_γ = 12.539
s_γ = 1-0.4(9.5 ft/57 ft) = 0.933
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 26.2 ft > 1.5(9.5 ft) + 3.0 ft = 1.000

$q_n =$ (0 psf)(24.235) + (115 pcf)(3.0 ft)(14.019)(1.000) + ½(115 pcf)(9.5 ft)(11.699)(1.000) = 11.23 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.70 ksf ≤ (11.23 ksf)(0.55) = 6.18 ksf ⟶ 1.70 ksf ≤ 6.18 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.597

N_c = 5.140
s_c = 1+(9.5 ft/[(5)(57 ft)]) = 1.089
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/9.5 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 26.2 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)
$C_{w\gamma}$ = 26.2 ft > 1.5(9.5 ft) + 3.0 ft = 1.000

$q_n =$ (1500 psf)(5.597) + (115 pcf)(3.0 ft)(1.000)(1.000) + ½(115 pcf)(9.5 ft)(0.000)(1.000) = 8.74 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.70 ksf ≤ (8.74 ksf)(0.55) = 4.81 ksf ⟶ 1.70 ksf ≤ 4.81 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	6	OF	6
CALCULATED BY	BRT	DATE	2/4/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	8.7	ft
Foundation Width (Entire Base Width), (B) =	9.5	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	2.0	ft
Heel Width, (c) =	6.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	0.0	ft
Depth of Shear Key, (f) =	0.0	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	57	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	26.2	ft

Bearing and Retained/Backfill Soil Properties:

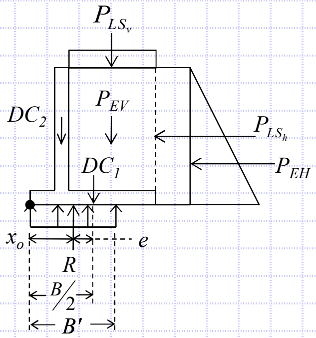
Bearing Soil Unit Weight, (γ_{BS}) =	115	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	26	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1500	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.532	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 9.5 ft - 2(-0.25 ft) = 9.50 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (9.5 ft / 2) - 5.00 ft = -0.25 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (64.48 kip·ft/ft - 6.72 kip·ft/ft) / (11.56 kip/ft) = 5 ft

q_{eq} = (11.56 kip/ft) / (9.50 ft) = 1.22 ksf

$$M_V = [(\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS})](a + b + c/2) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC})(B/2) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})(b + a/2)$$

M_V = [(120 pcf)(8.7 ft - 2.0 ft)(6.0 ft)(1.00) + (250 psf)(9.5 ft)(1.00)](1.5 ft + 2.0 ft + (6.0 ft / 2)) = 64.48 kip·ft/ft
+ [(150 pcf)(9.5 ft)(2.0 ft)(1.00)](9.5 ft / 2) + [(150 pcf)(8.7 ft - 2.0 ft)(1.5 ft)(1.00)](2.0 ft + (1.5 ft / 2))

$$M_H = (1/2\, \gamma_{RS} \cdot H^2 \cdot K_a \cdot \gamma_{EH})(H/3) + (\sigma_{LS} \cdot H \cdot K_a \cdot \gamma_{LS})(H/2)$$

M_H = [½(120 pcf)(8.7 ft)²(0.297)(1.00)](8.7 ft / 3) + [(250 psf)(8.7 ft)(0.297)(1.00)](8.7 ft / 2) = 6.72 kip·ft/ft

$$P_V = (\gamma_{BF} \cdot (H-d) \cdot c \cdot \gamma_{EV}) + (\sigma_{LS} \cdot B \cdot \gamma_{LS}) + (\gamma_c \cdot B \cdot d \cdot \gamma_{DC}) + (\gamma_c \cdot (H-d) \cdot a \cdot \gamma_{DC})$$

P_V = (120 pcf)(8.7 ft - 2.0 ft)(6.0 ft)(1.00) + (250 psf)(9.5 ft)(1.00) + (150 pcf)(9.5 ft)(2.0 ft)(1.00) = 11.56 kip/ft
+ (150 pcf)(8.7 ft - 2.0 ft)(1.5 ft)(1.00)

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: $(S_t)_{max}$ = **0.838** in

Minimum Settlement Along Wall Alignment: $(S_t)_{min}$ = **0.796** in

Differential Settlement Along Wall Alignment: δ_s = 0.042 in / 57 ft ⟶ 1 in / 1,357 ft

$\delta_s < 1/500$ ⟶ 1 in / 1,357 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)

CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022

Checked By: BRT Date: 3/23/2022

Boring B-089-0-19

H = 8.7 ft Wall height

B' = 9.5 ft Effective base width due to eccentricity

D_w = 23.2 ft Depth below bottom of wall

q = 1,220 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-6a	C	0.0	2.6	796.8	794.2	2.6	1.3	120	312	156	156	3,156	28	0.162	0.016	0.491				0.14	0.992	1,210	1,366	0.027	0.319
	A-6a	C	2.6	5.2	794.2	791.6	2.6	3.9	120	624	468	468	3,468	28	0.162	0.016	0.491				0.41	0.875	1,067	1,535	0.015	0.175
2	A-6b	C	5.2	7.7	791.6	789.1	2.5	6.5	115	912	768	768	3,768	37	0.243	0.024	0.561				0.68	0.708	864	1,632	0.013	0.153
	A-6b	C	7.7	10.2	789.1	786.6	2.5	9.0	115	1,199	1,055	1,055	4,055	37	0.243	0.024	0.561				0.94	0.574	701	1,756	0.009	0.103
3	A-4a	C	10.2	13.2	786.6	783.6	3.0	11.7	120	1,559	1,379	1,379	4,379	20	0.090	0.009	0.428				1.23	0.467	570	1,949	0.003	0.034
	A-4a	C	13.2	16.2	783.6	780.6	3.0	14.7	120	1,919	1,739	1,739	4,739	20	0.090	0.009	0.428				1.55	0.385	470	2,209	0.002	0.024
	A-4a	C	16.2	19.2	780.6	777.6	3.0	17.7	120	2,279	2,099	2,099	5,099	20	0.090	0.009	0.428				1.86	0.326	398	2,497	0.001	0.017
4	A-4a	C	19.2	22.2	777.6	774.6	3.0	20.7	125	2,654	2,467	2,467	5,467	20	0.090	0.009	0.428				2.18	0.282	344	2,811	0.001	0.013
																							Total Settlement:		0.838 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_m$; Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)
CIP Wall Settlement

Calculated By: PPM   Date: 1/19/2022
Checked By: BRT   Date: 3/23/2022

Boring B-089-0-19

$H =$ 7.7 ft Wall height
$B' =$ 9.5 ft Effective base width due to eccentricity
$D_w =$ 23.2 ft Depth below bottom of wall
$q =$ 1,120 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-6a	C	0.0	2.6	796.8	794.2	2.6	1.3	120	312	156	156	3,156	28	0.162	0.016	0.491				0.14	0.992	1,111	1,267	0.026	0.308
	A-6a	C	2.6	5.2	794.2	791.6	2.6	3.9	120	624	468	468	3,468	28	0.162	0.016	0.491				0.41	0.875	980	1,448	0.014	0.166
2	A-6b	C	5.2	7.7	791.6	789.1	2.5	6.5	115	912	768	768	3,768	37	0.243	0.024	0.561				0.68	0.708	793	1,561	0.012	0.144
	A-6b	C	7.7	10.2	789.1	786.6	2.5	9.0	115	1,199	1,055	1,055	4,055	37	0.243	0.024	0.561				0.94	0.574	643	1,698	0.008	0.097
3	A-4a	C	10.2	13.2	786.6	783.6	3.0	11.7	120	1,559	1,379	1,379	4,379	20	0.090	0.009	0.428				1.23	0.467	523	1,902	0.003	0.032
	A-4a	C	13.2	16.2	783.6	780.6	3.0	14.7	120	1,919	1,739	1,739	4,739	20	0.090	0.009	0.428				1.55	0.385	431	2,170	0.002	0.022
	A-4a	C	16.2	19.2	780.6	777.6	3.0	17.7	120	2,279	2,099	2,099	5,099	20	0.090	0.009	0.428				1.86	0.326	365	2,464	0.001	0.016
4	A-4a	C	19.2	22.2	777.6	774.6	3.0	20.7	125	2,654	2,467	2,467	5,467	20	0.090	0.009	0.428				2.18	0.282	316	2,783	0.001	0.012
																								Total Settlement:		0.796 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 5C - Sta. 10+00 to 10+57 (BL Wall 5C)
CIP Wall Settlement

Calculated By: PPM Date: 1/19/2022
Checked By: BRT Date: 3/23/2022

Boring B-089-0-19

H = 8.7 ft Wall height
B = 9.5 ft Effective base width due to eccentricity
D_w = 23.2 ft Depth below bottom of wall
q = 1,220 psf Equivalent bearing pressure due to eccentricity

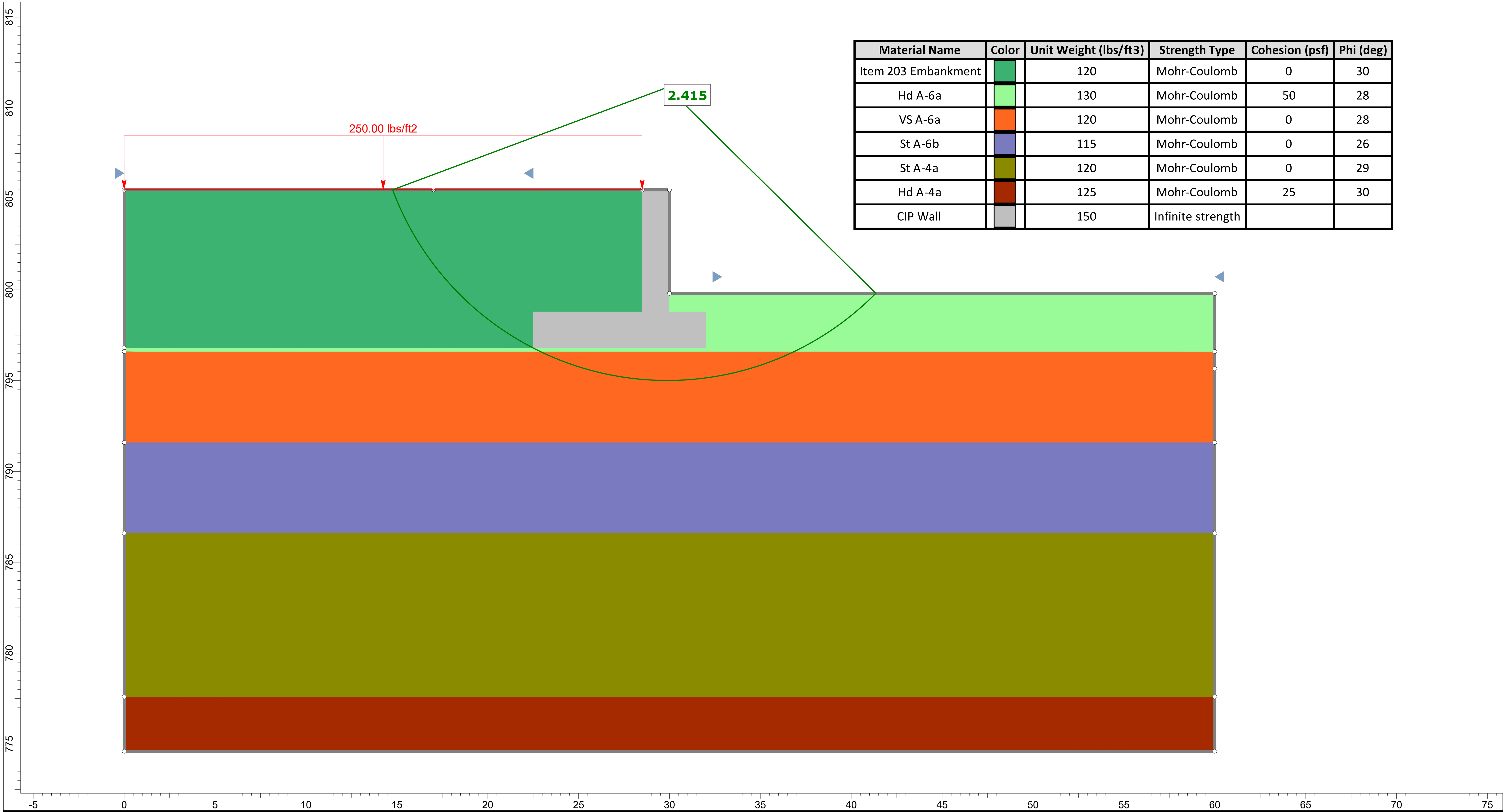
t = 75 days Time following completion of construction

																									Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ (11) (in)	Layer Settlement (in)
1	A-6a	C	0.0	2.6	796.8	794.2	2.6	1.3	120	312	156	156	3,156	28	0.162	0.016	0.491				0.14	0.992	1,210	1,366	0.027	0.319	0.494	300	2.6	9.119	100	0.319	0.319
	A-6a	C	2.6	5.2	794.2	791.6	2.6	3.9	120	624	468	468	3,468	28	0.162	0.016	0.491				0.41	0.875	1,067	1,535	0.015	0.175		300	5.2	2.280	100	0.175	0.305
2	A-6b	C	5.2	7.7	791.6	789.1	2.5	6.5	115	912	768	768	3,768	37	0.243	0.024	0.561				0.68	0.708	864	1,632	0.013	0.153	0.256	200	7.7	0.693	85	0.130	
	A-6b	C	7.7	10.2	789.1	786.6	2.5	9.0	115	1,199	1,055	1,055	4,055	37	0.243	0.024	0.561				0.94	0.574	701	1,756	0.009	0.103		200	10.2	0.395	69	0.071	0.071
3	A-4a	C	10.2	13.2	786.6	783.6	3.0	11.7	120	1,559	1,379	1,379	4,379	20	0.090	0.009	0.428				1.23	0.467	570	1,949	0.003	0.034	0.075	400	13.2	0.472	75	0.026	0.040
	A-4a	C	13.2	16.2	783.6	780.6	3.0	14.7	120	1,919	1,739	1,739	4,739	20	0.090	0.009	0.428				1.55	0.385	470	2,209	0.002	0.024		400	16.2	0.313	63	0.015	
	A-4a	C	16.2	19.2	780.6	777.6	3.0	17.7	120	2,279	2,099	2,099	5,099	20	0.090	0.009	0.428				1.86	0.326	398	2,497	0.001	0.017		400	19.2	0.223	53	0.009	0.015
4	A-4a	C	19.2	22.2	777.6	774.6	3.0	20.7	125	2,654	2,467	2,467	5,467	20	0.090	0.009	0.428				2.18	0.282	344	2,811	0.001	0.013	0.013	400	22.2	0.167	46	0.006	

$(S_c)_t$ = 0.751 in

Settlement Remaining After Hold Period: 0.087 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, 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; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \le \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \le \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0



Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Hd A-6a	🟩	130	Mohr-Coulomb	50	28
VS A-6a	🟧	120	Mohr-Coulomb	0	28
St A-6b	🟪	115	Mohr-Coulomb	0	26
St A-4a	🟫	120	Mohr-Coulomb	0	29
Hd A-4a	🟥	125	Mohr-Coulomb	25	30
CIP Wall	⬜	150	Infinite strength		

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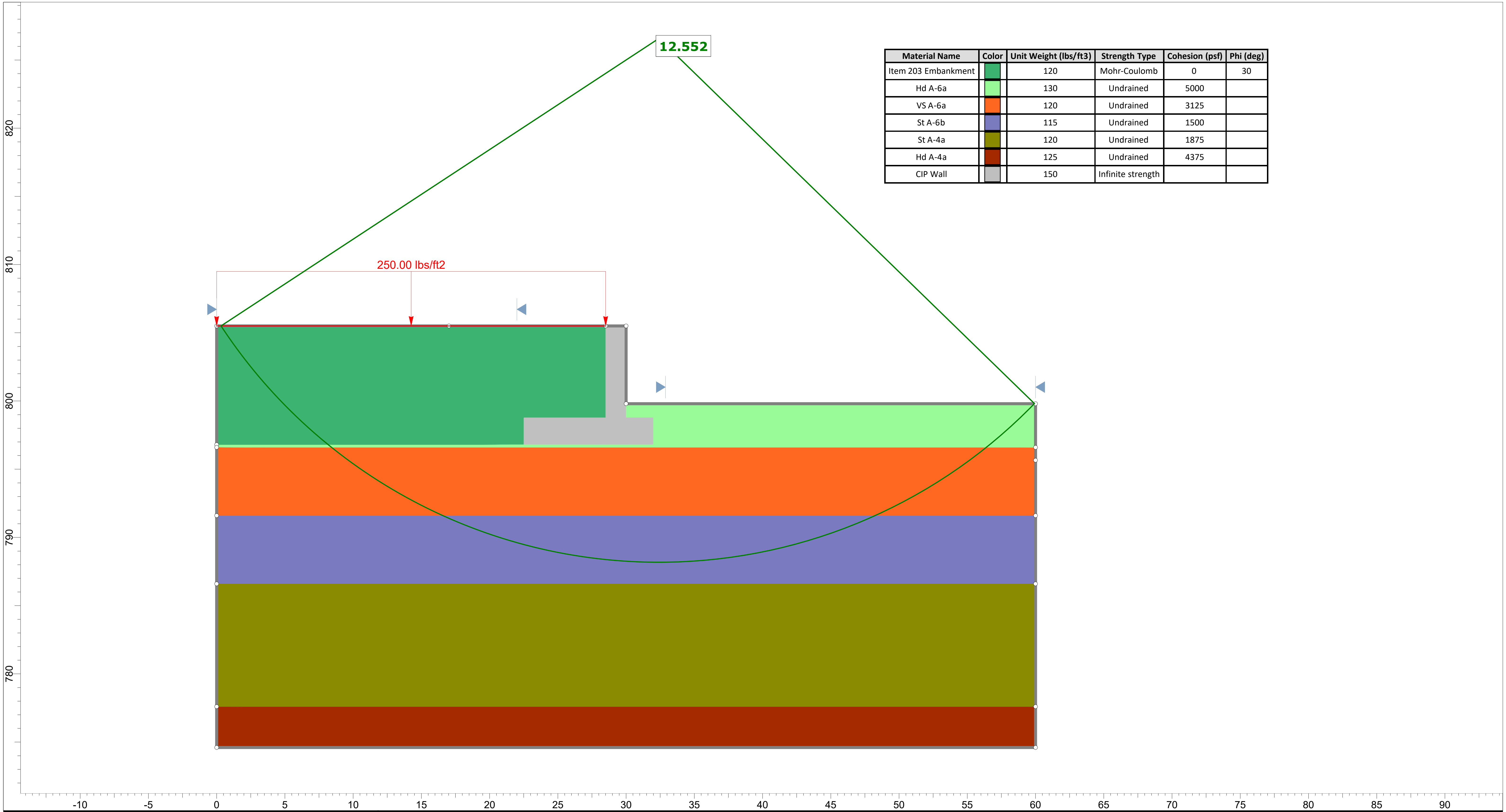
SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 5C
Analysis Description	Global Stability - Sta. 10+00 to 10+57 (BL Wall 5C) - CIP Wall Without Shear Key - B-089-0-19 - 8.7 ft. Wall Height - Drained - Circular
Drawn By	BRT
Scale	1:60
Company	Resource International, Inc.
Date	4/3/2022
File Name	Wall 5C - Sta. 10+00 to 10+57 - Global Stability.slmd



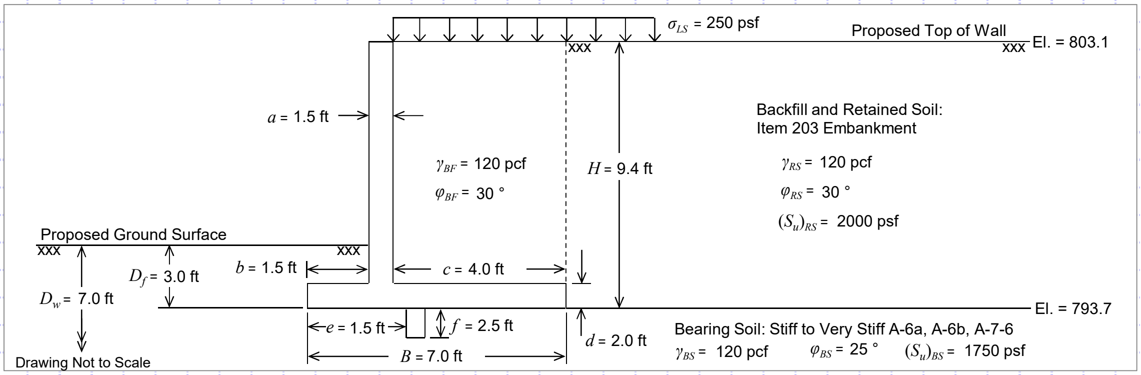
Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
Hd A-6a	🟩	130	Undrained	5000	
VS A-6a	🟧	120	Undrained	3125	
St A-6b	🟪	115	Undrained	1500	
St A-4a	🟫	120	Undrained	1875	
Hd A-4a	🟥	125	Undrained	4375	
CIP Wall	⬜	150	Infinite strength		

Resource International, Inc.
Planning | Engineering | Construction Management | Technology
SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 5C
Analysis Description	Global Stability - Sta. 10+00 to 10+57 (BL Wall 5C) - CIP Wall Without Shear Key - B-089-0-19 - 8.7 ft. Wall Height - Undrained - Circular

Drawn By	BRT	Scale	1:80	Company	Resource International, Inc.
Date	4/3/2022			File Name	Wall 5C - Sta. 10+00 to 10+57 - Global Stability.slmd

Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7) - CIP Wall w/ Shear Key - B-090-0-19, B-091-0-19, B-092-0-19 and B-094-0-19 - 9.4 ft. Wall Height



CIP Wall Dimensions and Surcharge Loading			**Bearing and Retained/Backfill Soil Properties:**		
Wall Height, (H) =	9.4	ft	Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Foundation Width (Entire Base Width), (B) =	7.0	ft	Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Stem Width, (a) =	1.5	ft	Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	1750	psf
Toe Width, (b) =	1.5	ft	Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Heel Width, (c) =	4.0	ft	Retained Soil Friction Angle, (φ_{RS}) =	30	°
Footing Thickness, (d) =	2.0	ft	Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Location of Shear Key, (e) =	1.5	ft	Active Earth Pressure Coefficient, (K_a) =	0.297	
Depth of Shear Key, (f) =	2.5	ft	Passive Earth Pressure Coefficient, (K_p) =	4.258	
Embedment Depth, (D_f) =	3.0	ft			
Wall Length, (L) =	401	ft			
Live Surcharge Load, (σ_{LS}) =	250	psf			
Depth to Groundwater, (D_w) =	7.0	ft			

LRFD Load Factors

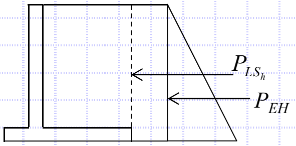
	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	1.00	1.00	1.00

(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 10.6.3.4

Sliding Force:

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



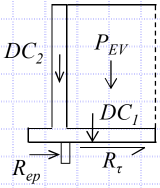
$$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(9.4 ft)²(0.297)(1.50)} = 2.36 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(9.4 ft)(0.297)(1.75)} = 1.22 \text{ kip/ft}$$

$$P_H = \text{2.36 kip/ft + 1.22 kip/ft} = 3.58 \text{ kip/ft}$$

Check Sliding Resistance

Nominal Sliding Resisting: $R_n = R_\tau + R_{ep}$



$$R_{ep} = \gamma_{BS} D_f f K_p \gamma_{ep} + \tfrac{1}{2}\gamma_{BS} f^2 K_p \gamma_{ep}$$

$$R_{ep} = \text{(120 pcf)(3.0 ft)(2.5 ft)(4.26)(0.90) + ½(120 pcf)(2.5 ft)²(4.26)(0.90)} = 4.89 \text{ kip/ft}$$

Check Drained Condition: $R_\tau = P_V \tan\delta$

$$P_V = DC_1 + DC_2 + P_{EV} = \gamma_c \cdot [B \cdot d + (H-d)\cdot a]\cdot \gamma_{DC} + \gamma_{BF} \cdot (H-d)\cdot c \cdot \gamma_{EV}$$

$$P_V = \text{(150 pcf) [(7.0 ft)(2.0 ft) + (9.4 ft - 2.0 ft)(1.5 ft)] (0.90) + (120 pcf)(9.4 ft - 2.0 ft)(4.0 ft)(1.00)} = 6.94 \text{ kip/ft}$$

$$\tan\delta = \tan\varphi_{BS} = \tan(25) = 0.47$$

$$R_\tau = \text{(6.94 kip/ft)(0.47)} = 3.26 \text{ kip/ft}$$

Verify Sliding Force Less Than Factored Sliding Resistance - Drained Condition

$$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow \text{3.58 kip/ft ≤ (3.26 kip/ft)(1.00) + (4.89 kip/ft)(0.50) = 5.70 kip/ft}$$

= 3.58 kip/ft ≤ 5.70 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

JOB	FRA-70-22.85 FEF	NO.	W-17-140
SHEET NO.	2	OF	6
CALCULATED BY	BRT	DATE	2/6/2023
CHECKED BY	JPS	DATE	2/6/2023

Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	7.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	4.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	1.5	ft
Depth of Shear Key, (f) =	2.5	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	401	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	7.0	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	1750	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.258	

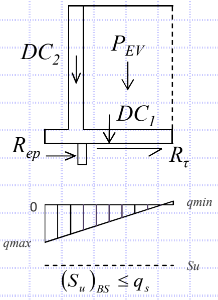
LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 10.6.3.4 *(Continued)*

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



$(S_u)_{BS}$ = 1.75 ksf

$q_{max} = \frac{1}{2}\sigma_{vmax}$ = (2.17 ksf) / 2 = 1.09 ksf

$q_{min} = \frac{1}{2}\sigma_{vmin}$ = (-0.19 ksf) / 2 = -0.10 ksf

$\sigma_{vmax} = \frac{P_V}{B}\left(1+6\frac{e}{B}\right)$ = (6.94 kip/ft / 7.0 ft)[1 + 6(1.39 ft / 7.0 ft)] = 2.17 ksf

$\sigma_{vmin} = \frac{P_V}{B}\left(1-6\frac{e}{B}\right)$ = (6.94 kip/ft / 7.0 ft)[1 - 6(1.39 ft / 7.0 ft)] = -0.19 ksf

R_τ = 0.5(1.09 ksf)[((7.0 ft)(1.09 ksf)) / (1.09 ksf - -0.1 ksf)] = 3.49 kip/ft

---

Verify Sliding Force Less Than Factored Sliding Resistance - Undrained Condition

$P_H \le \phi_n \cdot R_n \longrightarrow P_H \le \phi_\tau \cdot R_\tau + \phi_{ep} \cdot R_{ep} \longrightarrow$ 3.58 kip/ft ≤ (3.49 kip/ft)(1.00) + (4.89 kip/ft)(0.50) = 5.93

= 3.58 kip/ft ≤ 5.93 kip/ft **OK**

Use φ_τ = **1.00** Use φ_{ep} = **0.50** *(Per AASHTO LRFD BDM Tables 10.5.5.2.2-1 and 11.5.7-1)*

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	7.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	4.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	1.5	ft
Depth of Shear Key, (f) =	2.5	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	401	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	7.0	ft

Bearing and Retained/Backfill Soil Properties:

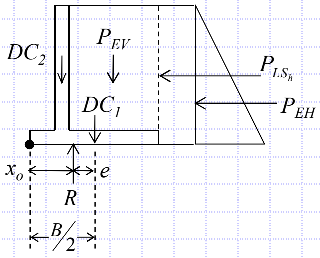
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Undrained Shear Strength, $[(s_u)_{BS}]$ =	1750	psf
Backfill and Retained Soil Unit Weight, $(\gamma_{BF}, \gamma_{RS})$ =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, $[(s_u)_{RS}]$ =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.258	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



$$e = B/2 - x_o$$

$$x_o = \frac{M_V - M_H}{P_V} = \text{(27.75 kip·ft/ft - 13.12 kip·ft/ft) / (6.94 kip/ft)} = 2.11 \text{ ft}$$

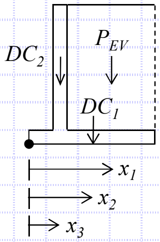
M_V = 27.75 kip·ft/ft
M_H = 13.12 kip·ft/ft
} Defined below

$$P_V = P_{EV} + DC_1 + DC_2 = \text{3.55 kip/ft + 1.89 kip/ft + 1.50 kip/ft} = 6.94 \text{ kip/ft}$$

$$e = \text{(7.0 ft / 2) - 2.11 ft} = 1.39 \text{ ft}$$

Resisting Moment, M_V:

$$M_V = P_{EV}(x_1) + DC_1(x_2) + DC_2(x_3)$$



$$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV} = \text{(120 pcf)(9.4 ft - 2.0 ft)(4.0 ft)(1.00)} = 3.55 \text{ kip/ft}$$

$$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC} = \text{(150 pcf)(7.0 ft)(2.0 ft)(0.90)} = 1.89 \text{ kip/ft}$$

$$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC} = \text{(150 pcf)(9.4 ft - 2.0 ft)(1.5 ft)(0.90)} = 1.50 \text{ kip/ft}$$

$$x_1 = a + b + c/2 = \text{1.5 ft + 1.5 ft + (4.0 ft / 2)} = 5.0 \text{ ft}$$

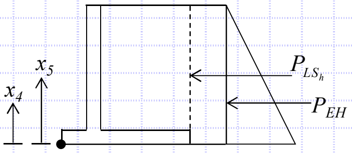
$$x_2 = B/2 = \text{7.0 ft / 2} = 3.5 \text{ ft}$$

$$x_3 = b + a/2 = \text{1.5 ft + (1.5 ft / 2)} = 2.3 \text{ ft}$$

$$M_V = \text{(3.55 kip/ft)(5.0 ft) + (1.89 kip/ft)(3.5 ft) + (1.50 kip/ft)(2.3 ft)} = 27.75 \text{ kip·ft/ft}$$

Overturning Moment, M_H:

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



$$P_{EH} = \tfrac{1}{2} \gamma_{RS} H^2 K_a \gamma_{EH} = \text{½(120 pcf)(9.4 ft)²(0.297)(1.50)} = 2.36 \text{ kip/ft}$$

$$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS} = \text{(250 psf)(9.4 ft)(0.297)(1.75)} = 1.22 \text{ kip/ft}$$

$$x_2 = H/3 = \text{(9.4 ft) / 3} = 3.13 \text{ ft}$$

$$x_3 = H/2 = \text{(9.4 ft) / 2} = 4.70 \text{ ft}$$

$$M_H = \text{(2.36 kip/ft)(3.13 ft) + (1.22 kip/ft)(4.70 ft)} = 13.12 \text{ kip·ft/ft}$$

Limiting Eccentricity:

$$e_{\max} = B/3 \longrightarrow e_{\max} = \text{(7.0 ft) / 3} = 2.33 \text{ ft}$$

Check Eccentricity

$e < e_{\max} \longrightarrow$ 1.39 ft < 2.33 ft **OK**

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	7.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	4.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	1.5	ft
Depth of Shear Key, (f) =	2.5	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	401	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	7.0	ft

Bearing and Retained/Backfill Soil Properties:

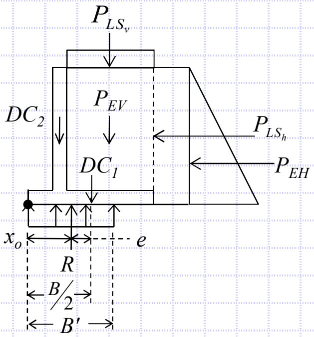
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Undrained Shear Strength, [$(s_u)_{BS}$] =	1750	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [$(s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.258	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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



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

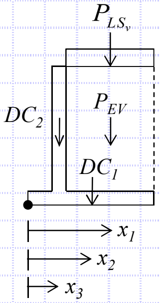
$B' = B - 2e$ = 7.0 ft - 2(0.31 ft) = 6.38 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (7.0 ft / 2) - 3.19 ft = 0.31 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (53.16 kip·ft/ft - 13.12 kip·ft/ft) / (12.56 kip/ft) = 3.19 ft

q_{eq} = (12.56 kip/ft) / (6.38 ft) = 1.97 ksf

Resisting Moment, M_V:



$$M_V = P_{EV}(x_1) + P_{LS_v}(x_1) + DC_1(x_2) + DC_2(x_3)$$

$P_{EV} = \gamma_{BF} \cdot (H - d) \cdot c \cdot \gamma_{EV}$ = (120 pcf)(9.4 ft - 2.0 ft)(4.0 ft)(1.35) = 4.80 kip/ft

$P_{LS_v} = \sigma_{LS} \cdot B \cdot \gamma_{LS}$ = (250 psf)(7.0 ft)(1.75) = 3.063 kip/ft

$DC_1 = \gamma_c \cdot B \cdot d \cdot \gamma_{DC}$ = (150 pcf)(7.0 ft)(2.0 ft)(1.25) = 2.63 kip/ft

$DC_2 = \gamma_c \cdot (H - d) \cdot a \cdot \gamma_{DC}$ = (150 pcf)(9.4 ft - 2.0 ft)(1.5 ft)(1.25) = 2.08 kip/ft

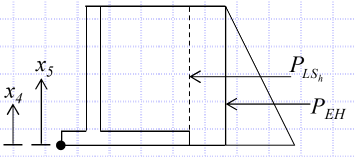
$x_1 = a + b + c/2$ = 1.5 ft + 1.5 ft + (4.0 ft / 2) = 5.0 ft

$x_2 = B/2$ = 7.0 ft / 2 = 3.5 ft

$x_3 = b + a/2$ = 1.5 ft + (1.5 ft / 2) = 2.3 ft

M_V = (4.80 kip/ft)(5.0 ft) + (3.06 kip/ft)(5.0 ft) + (2.63 kip/ft)(3.5 ft) + (2.08 kip/ft)(2.3 ft) = 53.16 kip·ft/ft

Overturning Moment, M_H:



$$M_H = P_{EH}(x_4) + P_{LS_h}(x_5)$$

$P_{EH} = \tfrac{1}{2}\gamma_{RS} H^2 K_a \gamma_{EH}$ = ½(120 pcf)(9.4 ft)²(0.297)(1.50) = 2.36 kip/ft

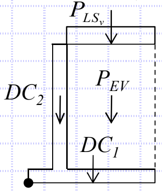
$P_{LS_h} = \sigma_{LS} H K_a \gamma_{LS}$ = (250 psf)(9.4 ft)(0.297)(1.75) = 1.22 kip/ft

$x_4 = H/3$ = (9.4 ft) / 3 = 3.13 ft

$x_5 = H/2$ = (9.4 ft) / 2 = 4.70 ft

M_H = (2.36 kip/ft)(3.13 ft) + (1.22 kip/ft)(4.70 ft) = 13.12 kip·ft/ft

Vertical Force, P_V:



$$P_V = P_{EV} + P_{LS_v} + DC_1 + DC_2$$

P_V = 4.80 kip/ft + 3.06 kip/ft + 2.63 kip/ft + 2.08 kip/ft

P_V = 12.56 kip/ft

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	7.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	4.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	1.5	ft
Depth of Shear Key, (f) =	2.5	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	401	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	7.0	ft

Bearing and Retained/Backfill Soil Properties:

Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Undrained Shear Strength, [(s_u)$_{BS}$] =	1750	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [(s_u)$_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.258	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 *(Continued)*

Check Bearing Resistance - Drained Condition

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

$N_{cm} = N_c s_c i_c$ = 20.887

N_c = 20.721
s_c = 1+(6.38 ft/401 ft)(10.662/20.721)
= 1.008
i_c = 1.000 (Assumed)

$N_{qm} = N_q s_q d_q i_q$ = 12.208

N_q = 10.662
s_q = 1+(6.38 ft/401 ft)tan(25°) = 1.007
d_q = 1+2tan(25°)[1-sin(25°)]²tan⁻¹(3.0 ft/6.38 ft)
= 1.137
i_q = 1.000 (Assumed)
C_{wq} = 7.0 ft > 3.0 ft = 1.000

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 10.811

N_γ = 10.876
s_γ = 1-0.4(6.38 ft/401 ft) = 0.994
i_γ = 1.000 (Assumed)
$C_{w\gamma}$ = 7.0 ft < 1.5(6.38 ft) + 3.0 ft = 0.866

$q_n =$ (0 psf)(20.887) + (120 pcf)(3.0 ft)(12.208)(1.000) + ½(120 pcf)(6.4 ft)(10.811)(0.866) = 7.98 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.97 ksf ≤ (7.98 ksf)(0.55) = 4.39 ksf ⟶ 1.97 ksf ≤ 4.39 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

Check Bearing Resistance - Undrained Condition

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

$N_{cm} = N_c s_c i_c$ = 5.181

N_c = 5.140
s_c = 1+(6.38 ft/[(5)(401 ft)]) = 1.008
i_c = 1.000 (Assumed)

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

N_q = 1.000
s_q = 1.000
d_q = 1+2tan(0°)[1-sin(0°)]²tan⁻¹(3.0 ft/6.38 ft)
= 1.000
i_q = 1.000 (Assumed)
C_{wq} = 7.0 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)
$C_{w\gamma}$ = 7.0 ft < 1.5(6.38 ft) + 3.0 ft = 0.866

$q_n =$ (1750 psf)(5.181) + (120 pcf)(3.0 ft)(1.000)(1.000) + ½(120 pcf)(6.4 ft)(0.000)(0.866) = 9.43 ksf

Verify Equivalent Pressure Less Than Factored Bearing Resistance

$q_{eq} \leq q_n \cdot \phi_b$ ⟶ 1.97 ksf ≤ (9.43 ksf)(0.55) = 5.19 ksf ⟶ 1.97 ksf ≤ 5.19 ksf **OK**

Use φ_b = **0.55** *(Per AASHTO LRFD BDM Table 11.5.7-1)*

JOB FRA-70-22.85 FEF NO. W-17-140
SHEET NO. 6 OF 6
CALCULATED BY BRT DATE 2/6/2023
CHECKED BY JPS DATE 2/6/2023
Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)

CIP Wall Dimensions and Surcharge Loading

Wall Height, (H) =	9.4	ft
Foundation Width (Entire Base Width), (B) =	7.0	ft
Stem Width, (a) =	1.5	ft
Toe Width, (b) =	1.5	ft
Heel Width, (c) =	4.0	ft
Footing Thickness, (d) =	2.0	ft
Location of Shear Key, (e) =	1.5	ft
Depth of Shear Key, (f) =	2.5	ft
Embedment Depth, (D_f) =	3.0	ft
Wall Length, (L) =	401	ft
Live Surcharge Load, (σ_{LS}) =	250	psf
Depth to Groundwater, (D_w) =	7.0	ft

Bearing and Retained/Backfill Soil Properties:

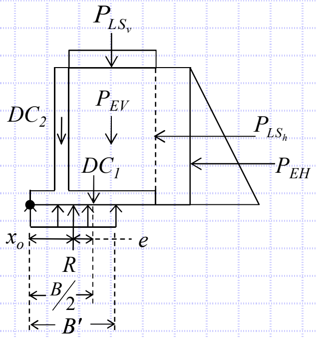
Bearing Soil Unit Weight, (γ_{BS}) =	120	pcf
Bearing Soil Friction Angle, (φ_{BS}) =	25	°
Bearing Soil Undrained Shear Strength, [($s_u)_{BS}$] =	1750	psf
Backfill and Retained Soil Unit Weight, (γ_{BF}, γ_{RS}) =	120	pcf
Retained Soil Friction Angle, (φ_{RS}) =	30	°
Retained Soil Undrained Shear Strength, [($s_u)_{RS}$] =	2000	psf
Active Earth Pressure Coefficient, (K_a) =	0.297	
Passive Earth Pressure Coefficient, (K_p) =	4.258	

LRFD Load Factors

	DC	EV	EH	LS	EP
Strength Ia	0.90	1.00	1.50	1.75	0.90
Strength Ib	1.25	1.35	1.50	1.75	0.90
Service I	1.00	1.00	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 11.6.2



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

$B' = B - 2e$ = 7.0 ft - 2(0.26 ft) = 6.48 ft (For e < 0, Use B)

$e = B/2 - x_o$ = (7.0 ft / 2) - 3.24 ft = 0.26 ft

$x_o = \dfrac{M_V - M_H}{P_V}$ = (37.61 kip·ft/ft - 8.21 kip·ft/ft) / (9.07 kip/ft) = 3.24 ft

q_{eq} = (9.07 kip/ft) / (6.48 ft) = 1.40 ksf

$$M_V = [(\gamma_{BF}\cdot(H-d)\cdot c\cdot\gamma_{EV})+(\sigma_{LS}\cdot B\cdot\gamma_{LS})](a+b+c/2)+(\gamma_c\cdot B\cdot d\cdot\gamma_{DC})(B/2)+(\gamma_c\cdot(H-d)\cdot a\cdot\gamma_{DC})(b+a/2)$$

M_V =[(120 pcf)(9.4 ft - 2.0 ft)(4.0 ft)(1.00) + (250 psf)(7.0 ft)(1.00)](1.5 ft + 1.5 ft + (4.0 ft / 2)) = 37.61 kip·ft/ft
+ [(150 pcf)(7.0 ft)(2.0 ft)(1.00)](7.0 ft / 2) + [(150 pcf)(9.4 ft - 2.0 ft)(1.5 ft)(1.00)](1.5 ft + (1.5 ft / 2))

$$M_H = (\tfrac{1}{2}\gamma_{RS}\cdot H^2\cdot K_a\cdot\gamma_{EH})(H/3)+(\sigma_{LS}\cdot H\cdot K_a\cdot\gamma_{LS})(H/2)$$

M_H = [½(120 pcf)(9.4 ft)²(0.297)(1.00)](9.4 ft / 3) + [(250 psf)(9.4 ft)(0.297)(1.00)](9.4 ft / 2) = 8.21 kip·ft/ft

$$P_V = (\gamma_{BF}\cdot(H-d)\cdot c\cdot\gamma_{EV})+(\sigma_{LS}\cdot B\cdot\gamma_{LS})+(\gamma_c\cdot B\cdot d\cdot\gamma_{DC})+(\gamma_c\cdot(H-d)\cdot a\cdot\gamma_{DC})$$

P_V = (120 pcf)(9.4 ft - 2.0 ft)(4.0 ft)(1.00) + (250 psf)(7.0 ft)(1.00) + (150 pcf)(7.0 ft)(2.0 ft)(1.00) = 9.07 kip/ft
+ (150 pcf)(9.4 ft - 2.0 ft)(1.5 ft)(1.00)

Settlement (See Attached Spreadsheet Calculations):

Maximum Settlement Along Wall Alignment: $(S_t)_{max}$ = **0.980** in

Minimum Settlement Along Wall Alignment: $(S_t)_{min}$ = **0.428** in

Differential Settlement Along Wall Alignment: δ_s = 0.552 in / 401 ft ⟶ 1 in / 726 ft

$\delta_s < 1/500$ ⟶ 1 in / 726 ft < 1/500 **OK**

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-090-0-19

H =	8.0	ft	Wall height
B' =	7.0	ft	Effective base width due to eccentricity
D_w =	4.0	ft	Depth below bottom of wall
q_e =	1,160	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6a	C	0.0	1.6	793.7	792.1	1.6	0.8	120	192	96	96	3,096	31	0.189	0.019	0.514				0.11	0.995	1,154	1,250	0.022	0.267
	A-6a	C	1.6	3.2	792.1	790.5	1.6	2.4	120	384	288	288	3,288	31	0.189	0.019	0.514				0.34	0.914	1,061	1,349	0.013	0.161
																						Total Settlement:				0.428 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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 = 0.15(C_c) for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to 0.10(C_c) for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-090-0-19

H = 8.0 ft Wall height
B = 7.0 ft Effective base width due to eccentricity
D_w = 4.0 ft Depth below bottom of wall
q = 1,160 psf Equivalent bearing pressure due to eccentricity

t = 6 days Time following completion of construction

																								Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' $^{(1)}$ (psf)**	**LL**	**C_c $^{(2)}$**	**C_r $^{(3)}$**	**e_o $^{(4)}$**	**N_{60}**	**$(N1)_{60}$ $^{(5)}$**	**C' $^{(6)}$**	**Z_f/B**	**I $^{(7)}$**	**$\Delta\sigma_v$ $^{(8)}$ (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c $^{(9,10)}$ (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ $^{(11)}$ (in)**	Layer Settlement (in)
1	A-6a	C	0.0	1.6	793.7	792.1	1.6	0.8	120	192	96	96	3,096	31	0.189	0.019	0.514				0.11	0.995	1,154	1,250	0.022	0.267	0.428	300	1.6	1.926	99	0.264	0.385
	A-6a	C	1.6	3.2	792.1	790.5	1.6	2.4	120	384	288	288	3,288	31	0.189	0.019	0.514				0.34	0.914	1,061	1,349	0.013	0.161		300	3.2	0.482	75	0.120	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

$(S_c)_t$ = 0.385 in

Settlement Remaining After Hold Period: 0.043 in

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-091-0-19

H = 8.8 ft Wall height
B' = 6.7 ft Effective base width due to eccentricity
D_w = 4.0 ft Depth below bottom of wall
q = 1,290 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6b	C	0.0	1.8	793.7	791.9	1.8	0.9	120	216	108	108	3,108	33	0.207	0.021	0.530				0.13	0.992	1,280	1,388	0.027	0.324
	A-6b	C	1.8	3.7	791.9	790.0	1.9	2.8	120	444	330	330	3,330	33	0.207	0.021	0.530				0.41	0.875	1,128	1,458	0.017	0.199
2	A-2-4	G	3.7	7.2	790.0	786.5	3.5	5.5	125	882	663	572	3,572					20	28	95	0.81	0.635	819	1,391	0.014	0.171
	A-2-4	G	7.2	10.7	786.5	783.0	3.5	9.0	125	1,319	1,100	791	3,791					20	26	89	1.34	0.437	564	1,355	0.009	0.110
																								Total Settlement:		0.805 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.15(C_c)$ for medium stiff to stiff natural soil deposits and existing fill material, 0.075 to $0.10(C_c)$ for very stiff to hard natural soil deposits, and 0.05(Cc) for new embankment fill; 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. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-091-0-19

H =	8.8	ft	Wall height
B =	6.7	ft	Effective base width due to eccentricity
D_w =	4.0	ft	Depth below bottom of wall
q =	1,290	psf	Equivalent bearing pressure due to eccentricity
t =	4	days	Time following completion of construction

																									Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**$\sigma_p'^{(1)}$ (psf)**	**LL**	**$C_c^{(2)}$**	**$C_r^{(3)}$**	**$e_o^{(4)}$**	**N_{60}**	**$(N1)_{60}^{(5)}$**	**$C'^{(6)}$**	**Z_f/B**	**$I^{(7)}$**	**$\Delta\sigma_v^{(8)}$ (psf)**	**σ_{vf}' Midpoint (psf)**	**$S_c^{(9,10)}$ (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t^{(11)}$ (in)**	Layer Settlement (in)
1	A-6b	C	0.0	1.8	793.7	791.9	1.8	0.9	120	216	108	108	3,108	33	0.207	0.021	0.530				0.13	0.992	1,280	1,388	0.027	0.324	0.523	200	1.8	0.676	85	0.275	0.439
	A-6b	C	1.8	3.7	791.9	790.0	1.9	2.8	120	444	330	330	3,330	33	0.207	0.021	0.530				0.41	0.875	1,128	1,458	0.017	0.199		200	1.9	0.607	82	0.163	
2	A-2-4	G	3.7	7.2	790.0	786.5	3.5	5.5	125	882	663	572	3,572					20	28	95	0.81	0.635	819	1,391	0.014	0.171	0.282				100	0.171	0.282
	A-2-4	G	7.2	10.7	786.5	783.0	3.5	9.0	125	1,319	1,100	791	3,791					20	26	89	1.34	0.437	564	1,355	0.009	0.110					100	0.110	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

$(S_c)_t$ = 0.721 in

Settlement Remaining After Hold Period: 0.084 in

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-092-0-19

$H =$ 9.4 ft Wall height
$B' =$ 6.5 ft Effective base width due to eccentricity
$D_w =$ 4.0 ft Depth below bottom of wall
$q =$ 1,400 psf Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
1	A-6b	C	0.0	1.5	793.7	792.2	1.5	0.8	120	180	90	90	3,090	33	0.207	0.021	0.530				0.12	0.995	1,393	1,483	0.025	0.296
2	A-4a	C	1.5	4.0	792.2	789.7	2.5	2.8	120	480	330	330	3,330	24	0.126	0.013	0.460				0.42	0.867	1,214	1,544	0.014	0.174
3	A-2-4	G	4.0	7.5	789.7	786.2	3.5	5.8	125	918	699	590	3,590					17	24	83	0.88	0.600	840	1,430	0.016	0.194
	A-2-4	G	7.5	11.5	786.2	782.2	4.0	9.5	125	1,418	1,168	824	3,824					17	22	79	1.46	0.405	567	1,391	0.012	0.138
																						Total Settlement:			0.803 in	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-092-0-19

H = 9.4 ft Wall height
B = 6.5 ft Effective base width due to eccentricity
D_w = 4.0 ft Depth below bottom of wall
q = 1,400 psf Equivalent bearing pressure due to eccentricity

t = 3 days Time following completion of construction

																							Total Settlement			Settlement Complete at 93% of Primary Consolidation					
Layer	Soil Class.	Soil Type	Layer Depth (ft)		Elevation (ft msl)		Layer Thickness (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' $^{(1)}$ (psf)	LL	C_c $^{(2)}$	C_r $^{(3)}$	e_o $^{(4)}$	N_{60}	$(N1)_{60}$ $^{(5)}$	C' $^{(6)}$	Z_f/B	I $^{(7)}$	$\Delta\sigma_v$ $^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	S_c $^{(9,10)}$ (ft)	S_c (in)	Layer Settlement (in)	c_v (ft^2/yr)	H_{dr} (ft)	T_v	U (%)	$(S_c)_t$ $^{(11)}$ (in)	Layer Settlement (in)
1	A-6b	C	0.0	1.5	793.7	792.2	1.5	0.8	120	180	90	90	3,090	33	0.207	0.021	0.530				0.12	0.995	1,393	1,483	0.025	0.296	0.296	300	1.5	1.096	95	0.282	0.282
2	A-4a	C	1.5	4.0	792.2	789.7	2.5	2.8	120	480	330	330	3,330	24	0.126	0.013	0.460				0.42	0.867	1,214	1,544	0.014	0.174	0.174	400	2.5	0.526	78	0.135	0.135
3	A-2-4	G	4.0	7.5	789.7	786.2	3.5	5.8	125	918	699	590	3,590					17	24	83	0.88	0.600	840	1,430	0.016	0.194	0.333				100	0.194	0.333
	A-2-4	G	7.5	11.5	786.2	782.2	4.0	9.5	125	1,418	1,168	824	3,824					17	22	79	1.46	0.405	567	1,391	0.012	0.138					100	0.138	

$(S_c)_t$ = 0.750 in

Settlement Remaining After Hold Period: 0.053 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT Date: 2/5/2023
Checked By: JPS Date: 2/6/2023

Boring B-094-0-19

H =	6.4	ft	Wall height
B' =	7.0	ft	Effective base width due to eccentricity
D_w =	4.0	ft	Depth below bottom of wall
q =	990	psf	Equivalent bearing pressure due to eccentricity

Layer	Soil Class.	Soil Type	Layer Depth (ft)		Layer Elevation (ft. msl)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	$\sigma_p'^{(1)}$ (psf)	LL	$C_c^{(2)}$	$C_r^{(3)}$	$e_o^{(4)}$	N_{60}	$(N1)_{60}^{(5)}$	$C'^{(6)}$	Z_f/B	$I^{(7)}$	$\Delta\sigma_v^{(8)}$ (psf)	σ_{vf}' Midpoint (psf)	$S_c^{(9,10)}$ (ft)	S_c (in)
1	A-7-6	C	0.0	2.2	797.7	795.5	2.2	1.1	120	264	132	132	3,132	61	0.459	0.046	0.749				0.16	0.988	978	1,110	0.053	0.641
	A-7-6	C	2.2	4.4	795.5	793.3	2.2	3.3	120	528	396	396	3,396	61	0.459	0.046	0.749				0.47	0.836	828	1,224	0.028	0.340
																								Total Settlement:		0.980 in

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 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. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for continuous footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

FRA-70-22.85 FEF - Retaining Wall 7 - Sta. 10+33 to 14+34 (BL Wall 7)
CIP Wall Settlement

Calculated By: BRT   Date: 2/5/2023
Checked By: JPS   Date: 2/6/2023

Boring B-094-0-19

H = 6.4 ft   Wall height
B = 7.0 ft   Effective base width due to eccentricity
D_w = 4.0 ft   Depth below bottom of wall
q = 990 psf   Equivalent bearing pressure due to eccentricity

t = 32 days   Time following completion of construction

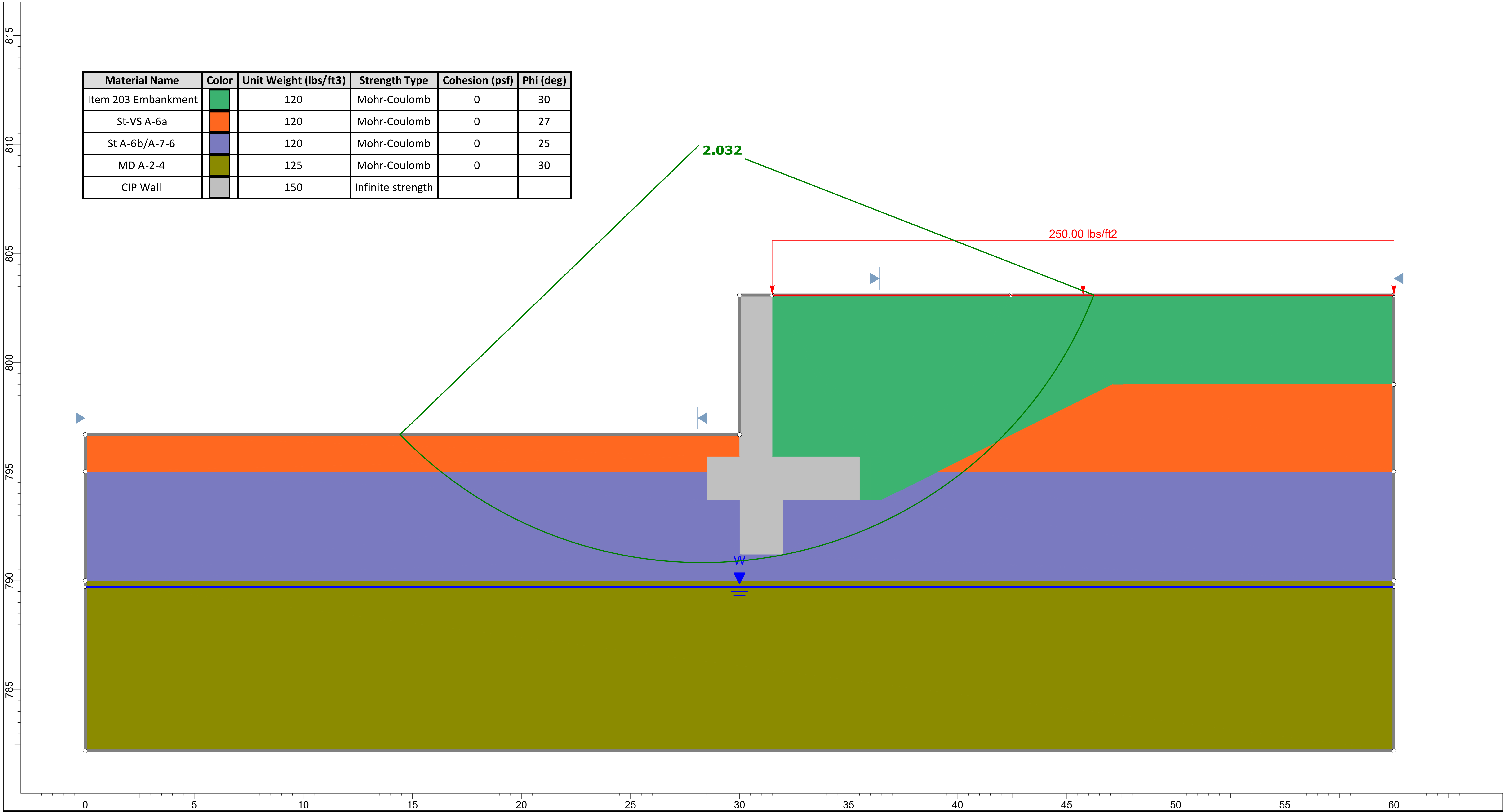
																									Total Settlement			Settlement Complete at 90% of Primary Consolidation					
Layer	**Soil Class.**	**Soil Type**	**Layer Depth (ft)**		**Elevation (ft msl)**		**Layer Thickness (ft)**	**Depth to Midpoint (ft)**	**γ (pcf)**	**σ_{vo} Bottom (psf)**	**σ_{vo} Midpoint (psf)**	**σ_{vo}' Midpoint (psf)**	**σ_p' (1) (psf)**	**LL**	**C_c (2)**	**C_r (3)**	**e_o (4)**	**N_{60}**	**$(N1)_{60}$ (5)**	**C' (6)**	**Z_f/B**	**I (7)**	**$\Delta\sigma_v$ (8) (psf)**	**σ_{vf}' Midpoint (psf)**	**S_c (9,10) (ft)**	**S_c (in)**	**Layer Settlement (in)**	**c_v (ft^2/yr)**	**H_{dr} (ft)**	**T_v**	**U (%)**	**$(S_c)_t$ (11) (in)**	Layer Settlement (in)
1	A-7-6	C	0.0	2.2	797.7	795.5	2.2	1.1	120	264	132	132	3,132	61	0.459	0.046	0.749				0.16	0.988	978	1,110	0.053	0.641	0.980	100	2.2	1.811	99	0.634	0.882
	A-7-6	C	2.2	4.4	795.5	793.3	2.2	3.3	120	528	396	396	3,396	61	0.459	0.046	0.749				0.47	0.836	828	1,224	0.028	0.340		100	4.4	0.453	73	0.248	

1. $\sigma_p' = \sigma_{vo}'+\sigma_{m;}$ Estimate σ_m of 3,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_nN_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesive soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)
11. $(S_c)_t = S_c(U/100)$; U = 100 for all granular soils at time t = 0

$(S_c)_t$ = 0.882 in

Settlement Remaining After Hold Period: 0.098 in

Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St-VS A-6a	🟧	120	Mohr-Coulomb	0	27
St A-6b/A-7-6	🟪	120	Mohr-Coulomb	0	25
MD A-2-4	🟫	125	Mohr-Coulomb	0	30
CIP Wall	⬜	150	Infinite strength		



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SLIDEINTERPRET 9.024

Project FRA-70-22.85 FEF - Retaining Wall 7

Analysis Description Global Stability - Sta. 10+33 to 14+34 (BL Wall 7) - CIP Wall w/ Shear Key - B-090-0-19, B-091-0-19, B-092-0-19 and B-094-0-19 - 9.4 ft. Wall Height - Drained - Circular

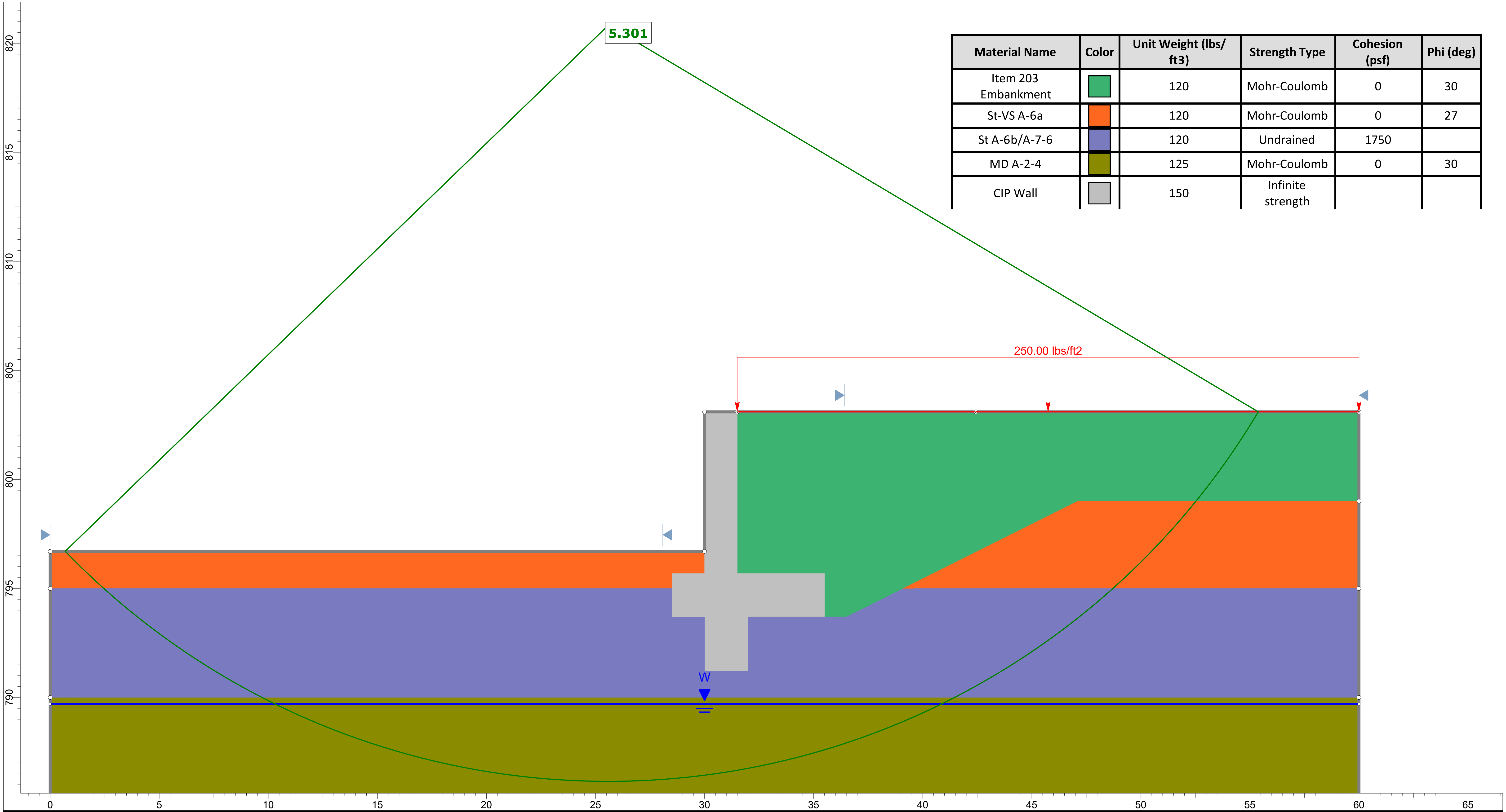
Drawn By BRT

Scale 1:50

Company Resource International, Inc.

Date 4/7/2022, 9:57:59 AM

File Name Wall 7 - Sta. 10+33 to 14+34 - Global Stability.slmd



Material Name	Color	Unit Weight (lbs/ ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Item 203 Embankment	🟩	120	Mohr-Coulomb	0	30
St-VS A-6a	🟧	120	Mohr-Coulomb	0	27
St A-6b/A-7-6	🟪	120	Undrained	1750	
MD A-2-4	🟫	125	Mohr-Coulomb	0	30
CIP Wall	⬜	150	Infinite strength		

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SLIDEINTERPRET 9.024

Project	FRA-70-22.85 FEF - Retaining Wall 7
Analysis Description	Global Stability - Sta. 10+33 to 14+34 (BL Wall 7) - CIP Wall w/ Shear Key - B-090-0-19, B-091-0-19, B-092-0-19 and B-094-0-19 - 9.4 ft. Wall Height - Undrained - Circular
Drawn By	BRT
Scale	1:50
Company	Resource International, Inc.
Date	4/7/2022, 9:57:59 AM
File Name	Wall 7 - Sta. 10+33 to 14+34 - Global Stability.slmd