STRUCTURE FOUNDATION EXPLORATION REPORT

LAK–20-19.59
PID: 108665
LAKE COUNTY, OHIO

SME Project Number: 080953.01
February 4, 2022

SME
9375 Chillicothe Road
Kirtland, OH 44094-8501
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February 4, 2022

Mr. William D. Baker, Jr., P.E.
Principal
CT Consultants, Inc.
8150 Sterling Court
Mentor, Ohio 44060

Via Email: bbaker@ctconsultants.com (PDF file)

RE: Structure Foundation Exploration Report
LAK-20-19.59
PID 108665
Lake County, Ohio
SME Project No. 080953.01

Dear Mr. Baker:

We have completed the structure foundation exploration for the culvert and retaining wall replacements along US-20 in Lake County, Ohio. The attached report presents the results of our subsurface investigation and our recommendations for design and construction of these structures.

We appreciate the opportunity to work with you on this project. If you have questions, please call.

Sincerely,

SME

Brendan Lieske

Brendan P. Lieske, PE
Project Manager

TABLE OF CONTENTS

EXECUTIVE SUMMARY 1
1. INTRODUCTION 2
2. GEOLOGY AND OBSERVATIONS 2
3. EXPLORATION 2
  3.1 FIELD EXPLORATION 2
  3.2 LABORATORY TESTING 3
4. FINDINGS 3
5. ANALYSES AND RECOMMENDATIONS 3
  5.1 CULVERT 3
  5.2 RETAINING WALLS 4
6. SIGNATURES 5

APPENDIX A
BORING LOCATION PLANS
BORING LOG TERMINOLOGY
SME BORING LOGS
HISTORIC BORING LOGS

APPENDIX B
RETAINING WALL CALCULATIONS

APPENDIX C
IMPORTANT INFORMATION ABOUT THIS GEOTECHNICAL ENGINEERING REPORT

EXECUTIVE SUMMARY

This report presents the results of our structure foundation exploration for the culvert and retaining walls planned as part of the pavement replacement project along Ridge Road (US-20) from SR-2 to SR-528 in Perry and Madison, Lake County, Ohio. The exploration and analysis were conducted in general accordance with the January 2021 version of ODOT's Specifications for Geotechnical Engineering (SGE).

ODOT plans to replace the existing 4-foot by 3-foot box culvert located near Station 254+00 with a 6-foot diameter Type A pipe culvert near Station 253+75. The culvert's invert will be near elevation 659 feet. Two replacement retaining walls and one new wall are also planned, each about 100 feet in length with exposed heights of about 6 feet and 2-foot minimum embedment. The walls will have about 1 to 3-foot tall back slopes, at approximately 3H:1V slope ratios or flatter.

Subsurface conditions were identified by 40-foot deep borings for the culvert and 15-foot deep borings for the retaining walls. Soils encountered in the area of the culvert consisted of very loose to medium dense sand over very stiff to hard sandy silt or silt and clay. Bearing soils encountered in the area of the retaining walls consisted of medium dense gravel with stone fragments and sand.

The culvert should be designed to resist the vertical load from the backfill soil plus the effect of traffic surcharge. The excavation for the culvert will extend through OSHA Type C soils. OSHA Type C soils require a layback of 1½ feet horizontally for each foot vertically (1½ H:1V) and would result in a large excavation. Thus, it is likely a braced excavation will be used for construction of the culvert. The excavation should be checked for bottom heave and piping and may require temporary dewatering. Based on the sandy soils encountered, we recommend using vacuum well points for dewatering or driving the vertical sheets deep enough to cut off seepage and maintain trench bottom stability. This will likely require driving the sheeting into the deeper till, then dewatering the interior of the excavation. If the sheeting is driven deep enough to cut off groundwater, it should be sufficient to pump from shallow sumps to maintain a stable bottom to the excavation.

The retaining walls should be designed using a factored bearing resistance of 4,500 psf. Backfill behind the retaining walls should consist of clean, free draining, compacted, crushed aggregate meeting an AASHTO #8 or #57 gradation wrapped in a non-woven geosynthetic separating fabric. The free-draining fill should be capped at the surface with 1-foot of compacted soil followed by topsoil.

The summary presented above includes selected elements of our findings and recommendations and is provided as an overview. It does not present details needed for the proper application of our findings and recommendations.

1. INTRODUCTION

This report presents the results of our structure foundation exploration for the culvert and retaining walls planned as part of the pavement replacement project along Ridge Road (US-20) from SR-2 in Perry to SR-528 in Madison, Lake County, Ohio. We performed this work in accordance with our proposal dated April 17, 2020, which was authorized on May 15, 2020. We understand that ODOT plans to replace the existing 4-foot by 3-foot box culvert near Station 254+00 with a 6-foot diameter Type A pipe culvert near Station 253+75. The culvert's invert will be near elevation 659 feet. Two replacement retaining walls and one new retaining wall are also planned, each about 100-feet in length with exposed heights of about 6-feet and 2-foot minimum embedment. The walls have 1 to 3-foot high back slopes at approximately 3H:1V slope ratios or flatter. Retaining Wall 1 will be located from approximately Station 300+25 to Station 301+25. Retaining Wall 2 will be located from approximately Station 305+25 to Station 306+25. Retaining Wall 3 was initially to be located between Station 320+25 and Station 326+00. Based on the revised grading plan, the wall was shortened and will now be between Station 325+00 and Station 326+00. The retaining walls will be modular block construction.

2. GEOLOGY AND OBSERVATIONS

The project site is located along the northernmost beach ridge in Lake County, Ohio. Beach ridges in this area consist of fine to coarse sand with some gravel deposited in ridges that can be 5 to 30 feet high. The ridges are above and adjacent to lacustrine plain deposits of silt and sand followed by glacial till deposits. Geologic references indicate that bedrock consisting of Ohio Shale is about 50 feet below the surface in this area.

The existing wall at Retaining Wall 1 consists of dry stacked cut stone blocks and the existing wall at Retaining Wall 2 consists of cast-in-place concrete. Retaining Wall 3 is new.

3. EXPLORATION

3.1 FIELD EXPLORATION

Subsurface conditions within the project limits were identified by a field exploration program consisting of Standard Penetration Test (SPT) borings at nine locations. B-016-1-19 and B-016-2-19 were drilled to depths of 40 feet below existing grade in opposite traffic lanes and on each side of the planned culvert. B-022-1-19 and B-022-2-19 were drilled to depths of 15 feet below existing grade at proposed Retaining Wall 1 and Retaining Wall 2, respectively. Borings B-024-1-19, B-024-2-19, B-025-1-19, B-025-2-19, and B-025-3-19 were drilled to 15 feet below existing grade along the original alignment of Retaining Wall 3. With the reduced length of this wall, only boring B-025-3-19 remains within the length of the wall. The approximate boring locations are shown on the attached boring location diagrams, Figure 2 for Wall 1, Figure 3 for Wall 2, and Figure 5 for Wall 3.

SME mobilized to the site on July 13, 2020, and again on April 26, 2021, to drill the borings. At each location, we augured through the existing pavement, measured thicknesses of the pavement materials then obtained SPT samples at 2.5-foot depth intervals. At completion, the boreholes were backfilled with a blend of soil cuttings and bentonite chips. We patched the pavement with cold-mix asphalt. The field-measured SPT blow counts are corrected to N_{60} based on energy measurements obtained from hammer calibrations made on July 30, 2020.

3.2 LABORATORY TESTING

Soil samples were taken to our laboratory for visual classification and testing in accordance with Section 600 of the ODOT Specifications for Geotechnical Explorations (SGE), updated July 2020. The soil samples were visually inspected for the presence of gypsum. A representative portion from each split-spoon sample was tested for its water content. We performed 22 complete classifications on soil samples, including visual classification, and moisture content, Atterberg limits, and particle size distribution tests. The results of our field exploration are presented on the enclosed boring logs.

4. FINDINGS

The pavement section at the boring locations consists of 3 to 7 inches of asphalt over 6 to 9 inches of concrete. No base material was encountered. The subgrade generally consists of beach ridge deposits of sand with some gravel over glacial till.

At B-016-1-19 and B-016-2-19, we generally encountered loose to medium dense coarse and fine sand (A-3a) or fine sand (A-3). Very loose sands were encountered at or just below the groundwater table. The sands transition to glacial till near elevations 655 feet and 650 feet at B-016-1-19 and B-016-2-19, respectively. The till consists of very stiff to hard sandy silt (A-4a) or silt and clay (A-6a). At B-022-1-19 and B-022-2-19, we encountered medium dense to dense gravel and gravel with sand (A-1-a and A-1-b) with layers of fine sand (A-3). Borings at the location of Retaining Wall 3 encountered medium dense to very dense gravel and stone fragments with sand (A-1-b) followed by loose to medium dense coarse to fine sand and fine sand (A-3a and A-3). At B-025-1-19, we encountered stiff to very soft sandy silt (A-4b).

We encountered groundwater between depths of 11 and 13 feet (elevations 645-655 feet near the retaining walls and elevation 665 feet near the culvert) except at B-022-1-19 and B-024-2-19 where groundwater was not encountered. Groundwater conditions indicated by the borings represent conditions at the time the readings were taken. Groundwater levels at the time of construction may vary from the conditions described.

5. ANALYSES AND RECOMMENDATIONS

5.1 CULVERT

Based on the feasibility study plan and profile sheets provided by CT Consultants, the planned culvert's invert will be at elevation 659 feet. We anticipate this culvert will be constructed in an open cut excavation. Based on our findings, we anticipate the trenches for the open cut will extend through very loose to medium dense A-3 and A-3a soils. These should be considered OSHA Type C soil. Type C soils should be sloped at a ratio of 1½ feet horizontally for each foot of vertical change (1½ H:1V) or a braced excavation should be used. The shoring system should be designed for a uniform lateral pressure of 30 pcf above the groundwater level and 75 pcf below the groundwater level, plus the effect of surcharges from construction equipment and stored or stockpiled materials. Surcharges would result in a uniform lateral loading on the wall equal to 0.33 times the vertical surcharge.

Groundwater was encountered in both borings at approximately elevation 665 feet. Therefore, seepage into excavations is expected and dewatering will be needed. Based on the sandy soils encountered, we recommend using vacuum well points for dewatering or driving sheeting deep enough to maintain trench bottom stability. We recommend driving sheeting into the glacial till, below elevation 650 feet, to reduce the potential for bottom heave, instability, or piping. For either approach, contractors should also be prepared to use conventional sumps and pumps to remove any water that seeps into the excavation.

After the trench is excavated to the planned subgrade elevation, the trench bottom should be compacted prior to the placement of pipe bedding. Bedding and initial backfill surrounding the pipe and at least 12 inches above the pipe, should consist of either structural backfill, in accordance with ODOT 703.11, or low strength mortar, in accordance with ODOT 613. If structural backfill is used, the bedding and initial backfill should be wrapped entirely with Type A geotextile fabric to prevent the migration of fines, in accordance with ODOT 611.06. Densify the bedding and initial backfill surrounding the culvert until no further densification is observed. Compaction equipment should be sized to avoid damage to the culvert pipe during construction.

Above the initial backfill, at least 12 inches above the top of the pipe, the final backfill should meet the requirements of ODOT 203. Based on the borings, we anticipate the soils excavated for the trench will consist of fine sand (A-3) and coarse and fine sand (A-3a). These soil types are suitable for reuse as final backfill material. Backfill uniformly on both sides of the culvert to avoid displacement or damage to the pipe. Hand compact fill placed below the spring line of the pipe to provide uniform support.

5.2 RETAINING WALLS

Based on the findings, we anticipate the walls will bear on medium dense to very dense gravel and stone fragments or gravel and stone fragments with sand (A-1-a or A-1-b). Based on the borings, it seems reasonable to expect that loose sand may also be encountered within the length of the walls. We recommend using a factored bearing resistance of 4,500 psf to design the retaining walls. Calculations for the bearing resistance are included in Appendix B. Groundwater was encountered between 11 and 13 feet below the pavement surface at most borings but was not encountered at B-022-1-19 and B-024-2-19. Therefore, design should assume no groundwater effects. The following soil properties should be considered for the retaining wall design.

Table 1. Properties of soil types for retaining wall design.

DESCRIPTION	FRICTION ANGLE (DEGREES)	COHESION (PSF)	TOTAL UNIT WEIGHT (PCF)
Foundation Soils (A-1-a, A-1-b, and A-3a soils)	33	0	125
Granular Level Pad	34	0	120
Backfill/Retained Soils	30	0	120

The retaining walls should be backfilled with clean, free draining, compacted, crushed aggregate meeting an AASHTO #8 or #57 gradation. Do not use slag products or shale. The free draining fill should be wrapped in a non-woven geosynthetic separating fabric to prevent finer soils from being transported into the pore space of the drainage fill. The free-draining fill should be capped at the surface with 1 foot of compacted soil compatible with the surrounding soils followed by topsoil. Grade the surface to direct surface water away from the wall.

The zone of free draining fill should, as a minimum, begin at the base of the wall and extend upward and outward at a 2V:1H slope. A drain should be placed at the bottom of the free draining fill. The drainage backfill should be placed in lifts and consolidated until no further densification is noted. Compaction equipment should be sized so the walls are not damaged during construction.

Since the walls are planned on the cut side of the road, we do not anticipate traffic surcharges affecting the walls. Surcharges were not considered in our stability calculations. If any surcharges are close enough to impact the walls, we should be contacted to review and amend our calculations.

SME performed external stability analyses to evaluation overturning, eccentricity, sliding, and overall (global) stability based on the latest design drawings prepared by CT Consultants, provided to us on October 19, 2021. Calculations are included in Appendix B. Based on our analyses, an R-60B block should be used in place of the R-41B for Section B-B (the 7.5 foot tall wall section) to meet sliding stability requirements. Our calculations are based on the assumption that this change is made. If so, our analysis indicates this wall meets the LRFD requirements for overturning, eccentricity, sliding, and overall (global) stability. Our calculations show that the shorter walls in Sections A-A and C-C meet the stability requirements as currently designed.

6. SIGNATURES

Report Prepared by:

STATE OF OHIO
BRENDAN PATRICK LIESKE
E-81254
REGISTERED PROFESSIONAL ENGINEER

Brendan P. Lieske, PE
Senior Project Engineer

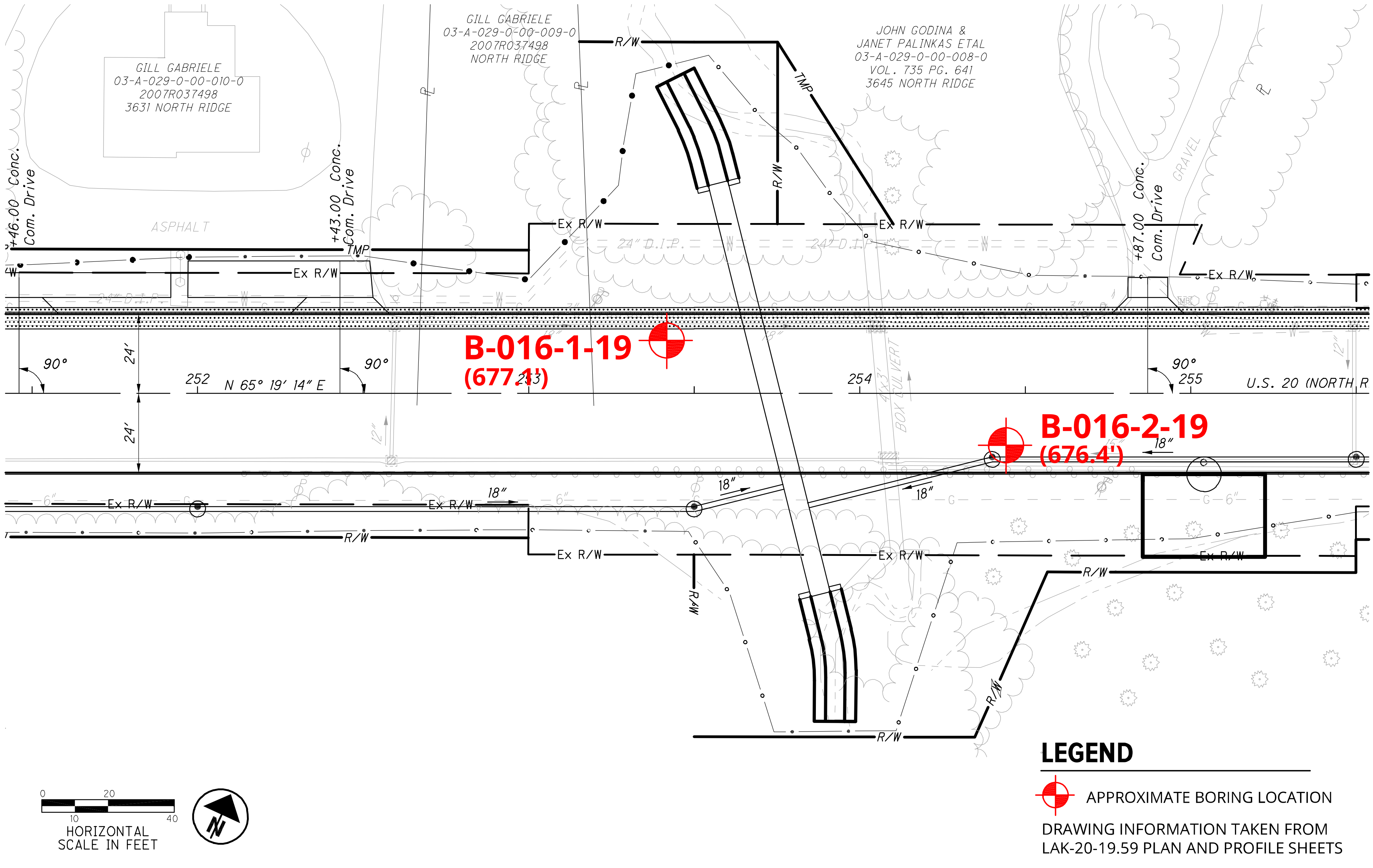
Report Reviewed by:

Wess Mekhael
Feb 4 2022 2:48 PM

Alan J. Esser, PE, D.GE
Chief Consultant

APPENDIX A

BORING LOCATION DIAGRAMS
BORING LOG TERMINOLOGY
SME BORING LOGS
HISTORIC BORING LOGS



No.	Revision Date		
1	08/19/20		

Date	7/31/2020
Drawn By	APF
Designed By	
Scale	NTS
Project	080953.01

Boring Location Diagram
LAK-020-19.59
Geneva, Ohio

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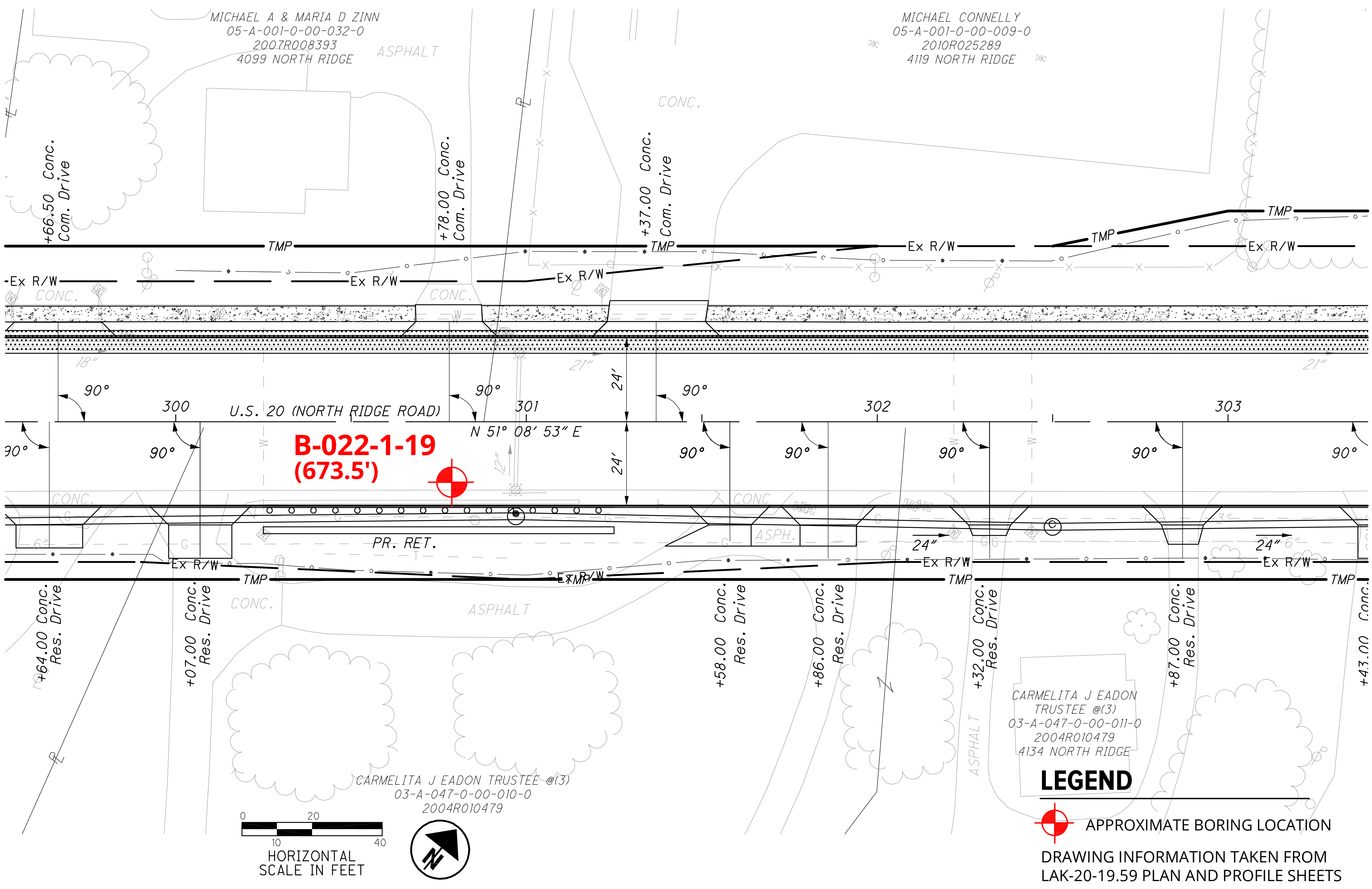
Figure No. 1



No.	Revision Date		
1	08/19/20	Date	7/31/2020
		Drawn By	APF
		Designed By	
		Scale	NTS
		Project	080953.01

Boring Location Diagram
LAK-020-19.59
Geneva, Ohio

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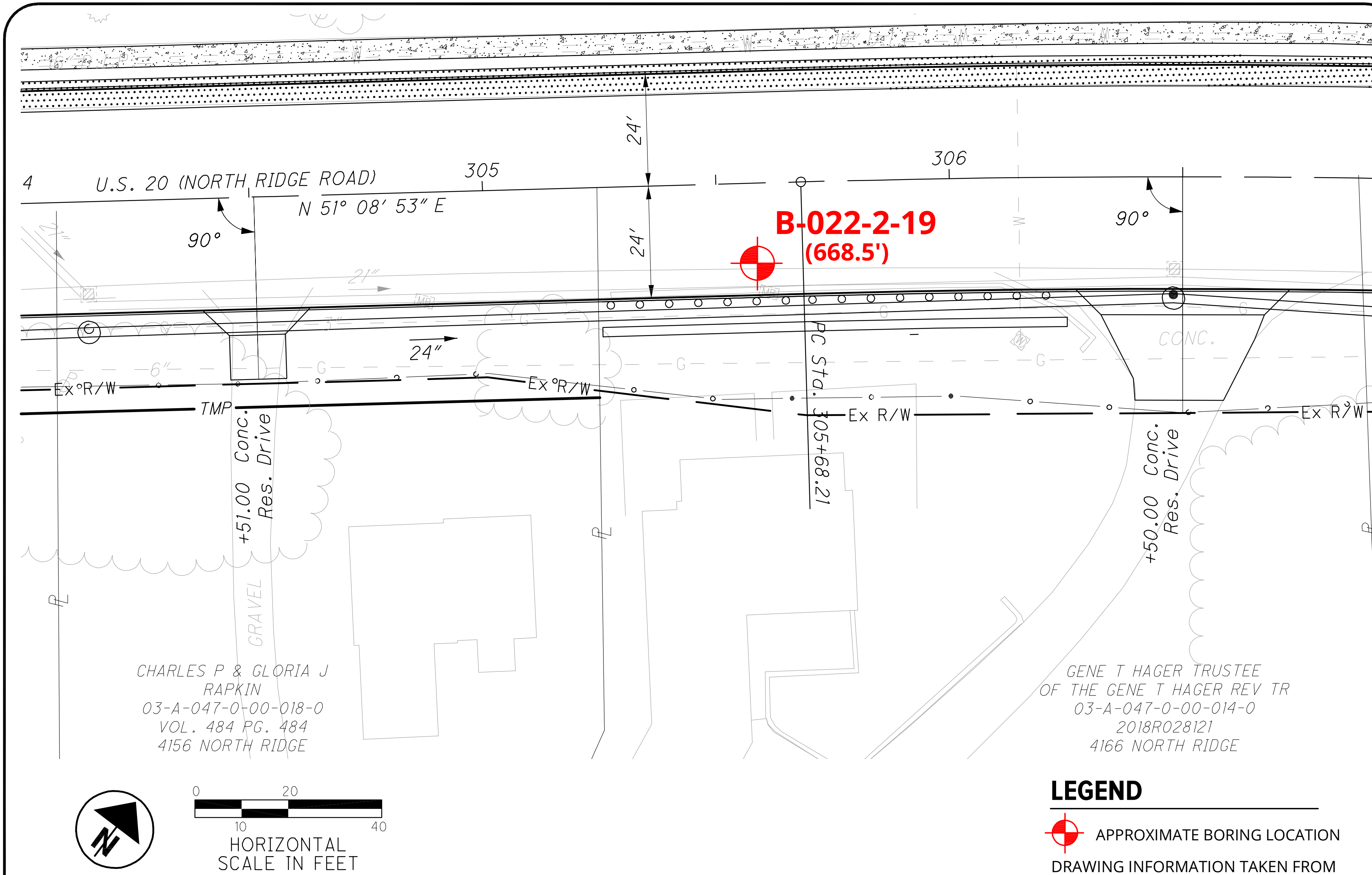
Figure No. 2



LEGEND

APPROXIMATE BORING LOCATION

DRAWING INFORMATION TAKEN FROM LAK-20-19.59 PLAN AND PROFILE SHEETS

No.	Revision Date	Date	7/31/2020
1	08/19/20	Drawn By	APF
		Designed By	
		Scale	NTS
		Project	080953.01

Boring Location Diagram
LAK-020-19.59
Geneva, Ohio

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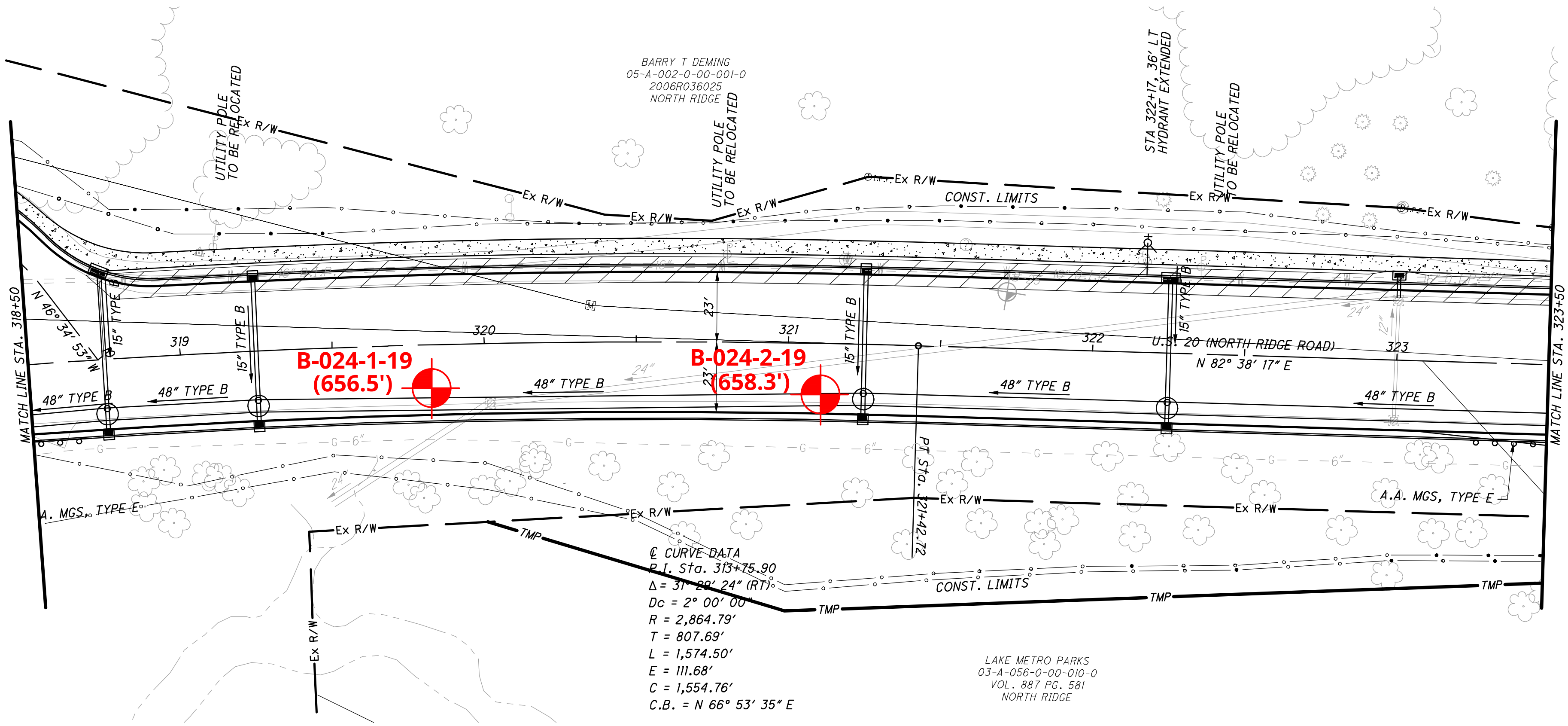
Figure No. 3



LEGEND

APPROXIMATE BORING LOCATION

NOTES:
DRAWING INFORMATION TAKEN FROM THE US-20 PLAN AND PROFILE SHEETS

NORTH

No.	Revision Date		
		Date	05/26/21
		Drawn By	TPO
		Designed By	
		Scale	NTS
		Project	080953.01

BORING LOCATION DIAGRAM
LAK-20-19.59
RETAINING WALL
LAKE COUNTY, OHIO

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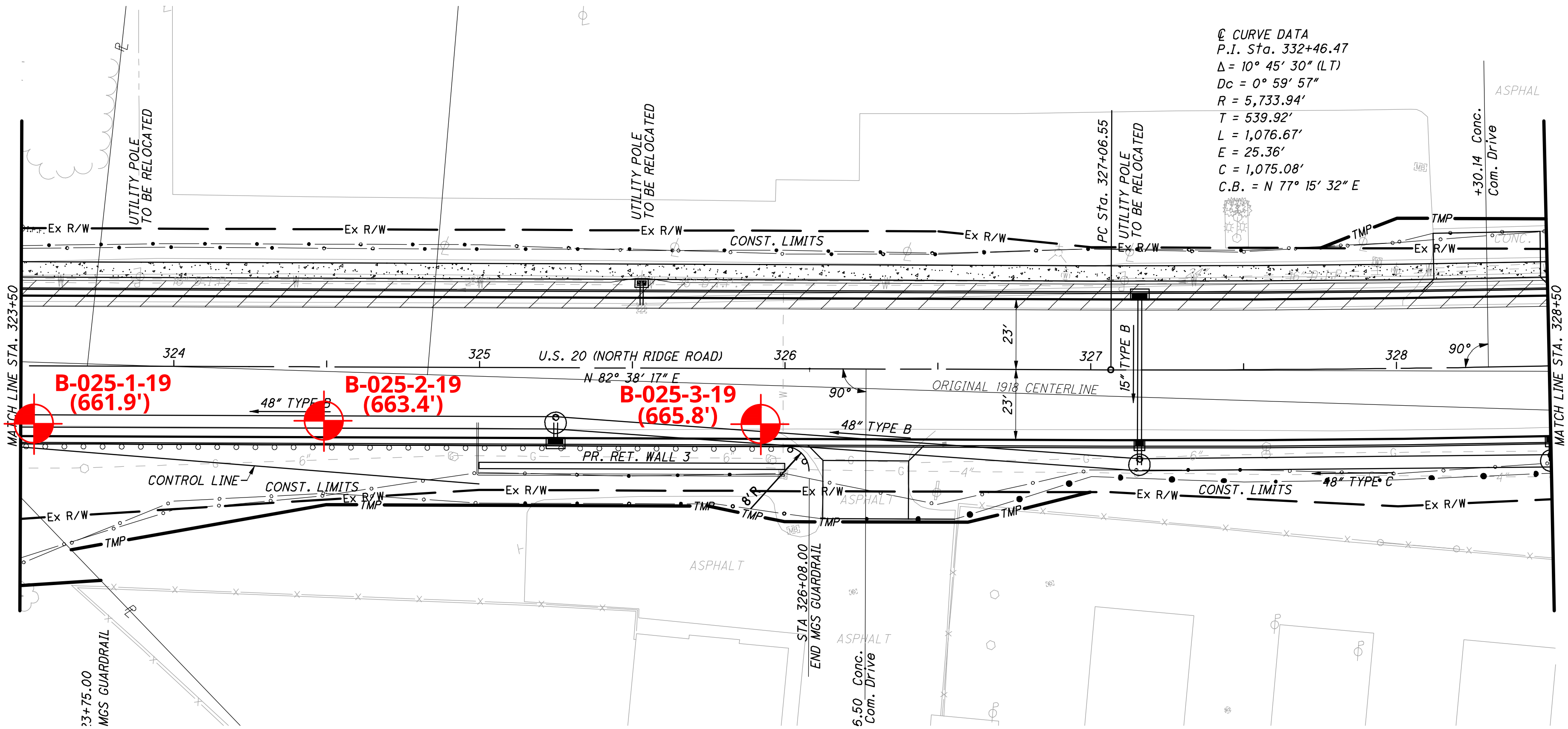
Figure No. 4



LEGEND

APPROXIMATE BORING LOCATION

NOTES:
DRAWING INFORMATION TAKEN FROM THE US-20 PLAN AND PROFILE SHEETS

NORTH

No.	Revision Date		
		Date	05/26/21
		Drawn By	TPO
		Designed By	
		Scale	NTS
		Project	080953.01

BORING LOCATION DIAGRAM
LAK-20-19.59
RETAINING WALL
LAKE COUNTY, OHIO

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Figure No. 5

1) STRENGTH OF SOIL:

Non-Cohesive (granular) Soils - Compactness	
Description	**Blows Per Ft.**
Very Loose	≤ 4
Loose	5 – 10
Medium Dense	11 – 30
Dense	31 – 50
Very Dense	> 50

2) COLOR :

If a color is a uniform color throughout, the term is single, modified by an adjective such as light or dark. If the predominate color is shaded by a secondary color, the secondary color procedes the primary color. If two major and distinct colors are swirled throughout the soil, the colors are modified by the term "mottled"

3) PRIMARY COMPONENT

Use **DESCRIPTION** from ODOT Soil Classification Chart on Back

Cohesive (fine grained) Soils - Consistency

Description	**Qu (TSF)**	**Blows Per Ft.**	**Hand Manipulation**
Very Soft	<0.25	<2	Easily penetrates 2" by fist
Soft	0.25-0.5	2 - 4	Easily penetrates 2" by thumb
Medium Stiff	0.5-1.0	5 - 8	Penetrates by thumb with moderate effort
Stiff	1.0-2.0	9 - 15	Readily indents by thumb, but not penetrate
Very Stiff	2.0-4.0	16 - 30	Readily indents by thumbnail
Hard	>4.0	>30	Indent with difficulty by thumbnail

4) COMPONENT MODIFIERS:

Description	**Percentage By Weight**
Trace	0% - 10%
Little	10% - 20%
Some	20% - 35%
"And"	35% -50%

5) Soil Organic Content

Description	**% by Weight**
Slightly Organic	2% - 4%
Moderately Organic	4% - 10%
Highly Organic	> 10%

6) Relative Visual Moisture

Description	**Criteria**	
	Cohesive Soil	**Non-cohesive Soils**
Dry	Powdery; Cannot be rolled; Water content well below the plastic limit	No moisture present
Damp	Leaves very little moisture when pressed between fingers; Crumbles at or before rolled to $^1/_8$"; Water content below plastic limit	Internal moisture, but no to little surface moisture
Moist	Leaves small amounts of moisture when pressed between fingers; Rolled to $^1/_8$" or smaller before crumbling; Water content above plastic limit to -3% of the liquid limit	Free water on surface, moist (shiny) appearance
Wet	Very mushy; Rolled multiple times to $^1/_8$" or smaller before crumbles; Near or above the liquid limit	Voids filled with free water, can be poured from split spoon.

CLASSIFICATION OF SOILS

Ohio Department of Transportation

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

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

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 5/26/21 13:15 - \\SME-INC\PZ\WIP\080953.01\PROJECT DATA\GINT\080953.01_LAK-20-1959 RETAINING WALL.GPJ

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 253+42, 16' LT.
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / JF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20
PID: 108665 SFN:	DRILLING METHOD: 3.75" HSA	CALIBRATION DATE: 7/30/20	ELEVATION: 677.1 (MSL) EOB: 40.0 ft.
START: 7/13/20 END: 7/13/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.777329, -81.155701

EXPLORATION ID B-016-1-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 677.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
4" ASPHALT AND 6" CONCRETE (DRILLER'S DESCRIPTION)	676.3																
DENSE, BROWN, **FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP	674.1		9-14-11	34	67	SS-1	-	-	-	-	-	-	-	-	-	5	A-3 (V)
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE GRAVEL, LITTLE SILT, TRACE CLAY	670.1		6-6-5	15	78	SS-2	-	18	16	49	12	5	NP	NP	NP	7	A-3a (0)
			2-2-2	6	78	SS-3A	-	-	-	-	-	-	-	-	-	11	A-3a (V)
LOOSE, BROWN, **FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, DAMP	666.6					SS-3B	-	-	-	-	-	-	-	-	-	-	A-3 (V)
			2-2-2	6	78	SS-4	-	-	-	-	-	-	-	-	-	9	A-3 (V)
VERY LOOSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, MOIST TO WET	660.6	W 665.1	1-1-1	3	100	SS-5	-	0	11	73	12	4	NP	NP	NP	23	A-3a (0)
			0-0-1	1	100	SS-6	-	-	-	-	-	-	-	-	-	21	A-3a (V)
			1-4-7	15	100	SS-7A	-	-	-	-	-	-	-	-	-	21	A-3a (V)
LOOSE TO MEDIUM DENSE, BROWN AND GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, TRACE ORGANICS, DAMP	658.1					SS-7B	-	-	-	-	-	-	-	-	-	-	A-3a (V)
			2-2-2	6	100	SS-8A	-	-	-	-	-	-	-	-	-	32	A-3a (V)
LOOSE, GRAY, **FINE SAND**, SOME SILT, TRACE CLAY, TRACE GRAVEL, WET	655.1					SS-8B	-	-	-	-	-	-	-	-	-	-	A-3 (V)
			4-3-3	8	100	SS-9A	-	-	-	-	-	-	-	-	-	20	A-3 (V)
VERY STIFF TO HARD, GRAY, **SANDY SILT**, AND TO SOME CLAY, TRACE GRAVEL, DAMP						SS-9B	3.00	-	-	-	-	-	-	-	-	-	A-4a (V)
			5-6-9	21	78	SS-10	4.50	2	3	6	46	43	27	19	8	17	A-4a (8)
			5-7-8	21	78	SS-11A	4.50	-	-	-	-	-	-	-	-	13	A-4a (V)
						SS-11B	4.50	-	-	-	-	-	-	-	-	-	A-4a (V)
			4-7-9	22	100	SS-12	4.50	-	-	-	-	-	-	-	-	14	A-4a (V)

PID: 108665	SFN:	PROJECT: LAK-20-19.59	STATION / OFFSET: 253+42, 16' LT.	START: 7/13/20	END: 7/13/20	PG 2 OF 2	B-016-1-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 647.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
VERY STIFF TO HARD, GRAY, **SANDY SILT**, AND TO SOME CLAY, TRACE GRAVEL, DAMP *(continued)*		31–32	4 7 10	23	100	SS-13	4.50	-	-	-	-	-	-	-	-	13	A-4a (V)	
		34–35	9 10 14	33	100	SS-14	4.50	8	8	14	43	27	24	17	7	14	A-4a (7)	
		36–37	8 11 12	32	100	SS-15	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	
	∇ 639.1	38																
	637.1	39–40 EOB	9 10 14	33	100	SS-16	4.50	-	-	-	-	-	-	-	-	12	A-4a (V)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: AUGER CUTTINGS; BENTONITE CHIPS; SAND

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 254+45, 16' RT.	EXPLORATION ID B-016-2-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / JF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 3.75" HSA	CALIBRATION DATE: 7/30/20	ELEVATION: 676.4 (MSL) EOB: 40.0 ft.	PAGE 1 OF 2
START: 7/13/20 END: 7/13/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.777363, -81.155309	

MATERIAL DESCRIPTION AND NOTES	ELEV. 676.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
4" ASPHALT AND 6" CONCRETE (DRILLER'S DESCRIPTION)	675.6																	
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, DAMP		1–2	9 6 4	14	100	SS-1	-	-	-	-	-	-	-	-	-	5	A-3a (V)	
		4–5	2 2 2	6	100	SS-2	-	7	18	54	16	5	NP	NP	NP	9	A-3a (0)	
		6–7	2 2 3	7	100	SS-3A	-	-	-	-	-	-	-	-	-	-	A-3a (V)	
						SS-3B	-	-	-	-	-	-	-	-	-	10	A-3a (V)	
	665.9	9–10	2 3 3	8	89	SS-4	-	-	-	-	-	-	-	-	-	11	A-3a (V)	
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, TRACE CLAY, TRACE GRAVEL, MOIST TO WET		11–12 (W 664.4)	10 6 4	14	56	SS-5	-	-	-	-	-	-	-	-	-	11	A-3 (V)	
	660.9	14–15	3 3 4	10	56	SS-6	-	0	0	72	23	5	NP	NP	NP	20	A-3a (0)	
VERY LOOSE, BROWN, **COARSE AND FINE SAND**, AND SILT, TRACE CLAY, TRACE GRAVEL, WET	658.4	16–17	2 1 2	4	67	SS-7	-	-	-	-	-	-	-	-	-	35	A-3 (V)	
VERY LOOSE, GRAY, **FINE SAND**, TRACE SILT, TRACE CLAY, TRACE GRAVEL, WET	655.9	19–20	2 1 2	4	100	SS-8	-	-	-	-	-	-	-	-	-	33	A-3 (V)	
MEDIUM DENSE TO DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE TO LITTLE GRAVEL, TRACE CLAY, WET		21–22	4 5 7	17	100	SS-9	-	-	-	-	-	-	-	-	-	32	A-3 (V)	
	650.4	24–25	5 11 13	33	100	SS-10	-	-	-	-	-	-	-	-	-	13	A-3a (V)	
VERY STIFF, GRAY, **SILT AND CLAY**, TRACE SAND, TRACE GRAVEL, MOIST		26–27	4 5 7	17	100	SS-11	3.50	-	-	-	-	-	-	-	-	21	A-6a (V)	
		29–	3 4 7	15	100	SS-12	3.00	0	2	6	37	55	34	20	14	24	A-6a (10)	

PID: 108665	SFN:	PROJECT: LAK-20-19.59	STATION / OFFSET: 254+45, 16' RT.	START: 7/13/20	END: 7/13/20	PG 2 OF 2	B-016-2-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 646.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
HARD, GRAY, **SANDY SILT**, SOME CLAY, TRACE GRAVEL, DAMP	645.9	▽ 644.4 / 31–32	2 6 9	21	100	SS-13	4.50	6	9	13	45	27	24	17	7	15	A-4a (7)	
		33–35	4 7 9	22	100	SS-14	4.25	-	-	-	-	-	-	-	-	15	A-4a (V)	
		36–38	7 8 14	30	56	SS-15	4.50	-	-	-	-	-	-	-	-	15	A-4a (V)	
	636.4	39 – EOB – 40	9 9 6	21	100	SS-16	4.50	-	-	-	-	-	-	-	-	15	A-4a (V)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: AUGER CUTTINGS; BENTONITE CHIPS; SAND

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 5/26/21 13:15 - \\SME-INC\PZ\WIP\080953.01\PROJECT DATA\GINT\080953.01_LAK-20-1959 RETAINING WALL.GPJ

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 5/26/21 13:15 - \\SME-INC\PZ\WIP\080953.01\PROJECT DATA\GINT\080953.01_LAK-20-1959 RETAINING WALL.GPJ

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 300+79, 17' RT.	EXPLORATION ID B-022-1-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / JF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 3.75" HSA	CALIBRATION DATE: 7/30/20	ELEVATION: 673.5 (MSL) EOB: 15.0 ft.	PAGE 1 OF 1
START: 7/13/20 END: 7/13/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.783225, -81.140335	

MATERIAL DESCRIPTION AND NOTES	ELEV. 673.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
4" ASPHALT AND 6" CONCRETE (DRILLER'S DESCRIPTION)	672.7																	
MEDIUM DENSE TO DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP		1–2	12 12 14	36	56	SS-1	-	42	39	8	9	2	NP	NP	NP	4	A-1-b (0)	
		4–5	8 9 9	25	56	SS-2	-	-	-	-	-	-	-	-	-	2	A-1-b (V)	
		6–7	9 12 16	39	33	SS-3	-	-	-	-	-	-	-	-	-	4	A-1-b (V)	
		9–10	10 19 10	40	56	SS-4	-	24	51	14	9	2	NP	NP	NP	6	A-1-b (0)	
		11–12	10 9 9	25	0	SS-5	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	
	658.5	14–15 EOB	6 5 8	18	22	SS-6	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: AUGER CUTTINGS

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 305+59, 17' RT.	EXPLORATION ID B-022-2-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / JF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	PAGE 1 OF 1
PID: 108665 SFN:	DRILLING METHOD: 3.75" HSA	CALIBRATION DATE: 7/30/20	ELEVATION: 668.5 (MSL) EOB: 15.0 ft.	
START: 7/13/20 END: 7/13/20	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.784035, -81.138947	

MATERIAL DESCRIPTION AND NOTES	ELEV. 668.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
4" ASPHALT AND 8" CONCRETE (DRILLER'S DESCRIPTION)	667.8																	
MEDIUM DENSE, BROWN, **FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, MOIST	666.5	1–2	6 6 5	15	78	SS-1A	-	-	-	-	-	-	-	-	-	15	A-3 (V)	
MEDIUM DENSE TO DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS**, AND SAND, TRACE SILT, TRACE CLAY, DAMP						SS-1B	-	-	-	-	-	-	-	-	-	-	A-1-a (V)	
		4–5	5 6 8	19	44	SS-2	-	50	33	8	7	2	NP	NP	NP	7	A-1-a (0)	
		6–7	12 16 8	33	0	SS-3	-	-	-	-	-	-	-	-	-	4	A-1-a (V)	
		9–10	12 6 8	19	50	SS-4	-	-	-	-	-	-	-	-	-	7	A-1-a (V)	
	655.5	11–12; 655.5	6 6 9	21	17	SS-5	-	-	-	-	-	-	-	-	-	5	A-1-a (V)	
DENSE, BROWN, **FINE SAND**, SOME GRAVEL, TRACE SILT, TRACE CLAY, WET	653.5	14–15; EOB	7 11 19	41	44	SS-6	-	31	8	55	4	2	NP	NP	NP	17	A-3 (0)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: AUGER CUTTINGS

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 319+82, 16' RT.	EXPLORATION ID B-024-1-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / APF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 4" SSA	CALIBRATION DATE: 7/30/20	ELEVATION: 656.5 (MSL) EOB: 15.0 ft.	PAGE 1 OF 1
START: 4/26/21 END: 4/26/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.785595, -81.134253	

MATERIAL DESCRIPTION AND NOTES	ELEV. 656.5	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
3" ASPHALT AND 7" CONCRETE	655.6																	
DENSE, BROWN, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, MOIST	653.0	1–3	14 16 18	47	56	SS-1	-	49	13	27	8	3	NP	NP	NP	6	A-1-b (0)	
MEDIUM DENSE TO DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, MOIST		4–5	4 3 7	14	78	SS-2	-	-	-	-	-	-	-	-	-	6	A-3a (V)	
		6–7	5 8 8	22	100	SS-3	-	-	-	-	-	-	-	-	-	9	A-3a (V)	
	645.5	9–10 (W 645.5)	7 13 13	36	100	SS-4	-	-	-	-	-	-	-	-	-	8	A-3a (V)	
MEDIUM DENSE TO DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, MOIST		11–12	7 8 11	26	100	SS-5	-	-	-	-	-	-	-	-	-	25	A-3a (V)	
	641.5	14–15 EOB	17 14 16	41	100	SS-6	-	1	14	63	18	4	NP	NP	NP	22	A-3a (0)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: ASPHALT PATCH; AUGER CUTTINGS MIXED WITH BENTONITE CHIPS

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 321+13, 18' RT.	EXPLORATION ID B-024-2-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / APF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 4" SSA	CALIBRATION DATE: 7/30/20	ELEVATION: 658.3 (MSL) EOB: 15.0 ft.	PAGE
START: 4/26/21 END: 4/26/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.785642, -81.133780	1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 658.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
3" ASPHALT AND 7" CONCRETE	657.4																	
DENSE, BROWN, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP		1–2	12 15 10	34	78	SS-1	-	-	-	-	-	-	-	-	-	4	A-1-b (V)	
	652.3	4–5	15 15 16	43	39	SS-2	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, SOME SILT, TRACE CLAY, DAMP		6–7	6 8 8	22	89	SS-3	-	0	1	66	26	7	NP	NP	NP	9	A-3a (0)	
	647.3	9–10	9 6 7	18	67	SS-4	-	-	-	-	-	-	-	-	-	10	A-3a (V)	
DENSE, GRAY, **COARSE AND FINE SAND**, LITTLE TO SOME SILT, TRACE CLAY, TRACE GRAVEL, MOIST		11–12	9 14 17	43	89	SS-5	-	-	-	-	-	-	-	-	-	20	A-3a (V)	
	643.3	14–15 EOB	9 15 16	43	100	SS-6	-	1	8	65	20	6	NP	NP	NP	21	A-3a (0)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: ASPHALT PATCH; AUGER CUTTINGS MIXED WITH BENTONITE CHIPS

PROJECT: LAK-20-19.59 TYPE: RETAINING WALL PID: 108665 SFN: START: 4/26/21 END: 4/26/21	DRILLING FIRM / OPERATOR: SME / JH/RM SAMPLING FIRM / LOGGER: SME / APF DRILLING METHOD: 4" SSA SAMPLING METHOD: SPT	DRILL RIG: 293-CME55-TRK HAMMER: AUTOMATIC HAMMER CALIBRATION DATE: 7/30/20 ENERGY RATIO (%): 82.5	STATION / OFFSET: 323+55, 19' RT. ALIGNMENT: U.S. 20 ELEVATION: 661.9 (MSL) EOB: 15.0 ft. LAT / LONG: 41.785714, -81.132900

EXPLORATION ID B-025-1-19

MATERIAL DESCRIPTION AND NOTES	ELEV. 661.9	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
3" ASPHALT AND 7" CONCRETE	661.0																	
DENSE, BROWN, **FINE SAND**, TRACE GRAVEL, TRACE SILT, TRACE CLAY, DAMP		1–2	22 12 18	41	56	SS-1	-	-	-	-	-	-	-	-	-	10	A-3 (V)	
		4–5	12 16 18	47	56	SS-2	-	8	9	74	7	2	NP	NP	NP	6	A-3 (0)	
	655.9																	
STIFF, GRAY, **SANDY SILT**, SOME CLAY, WET		6–7	5 4 5	12	78	SS-3	2.00	-	-	-	-	-	-	-	-	28	A-4b (V)	
	653.9																	
VERY SOFT, BROWN, **SANDY SILT**, SOME CLAY, WET		9–10	5 6 6	17	67	SS-4	0.10	-	-	-	-	-	-	-	-	34	A-4b (V)	
	651.4																	
MEDIUM DENSE TO DENSE, BROWN, **SANDY SILT**, TRACE CLAY, WET		11–12 (W 649.4)	10 18 12	41	0	SS-5	-	-	-	-	-	-	-	-	-	-	A-4a (V)	
	646.9	14–15 EOB	5 5 9	19	72	SS-6	-	0	1	55	36	8	NP	NP	NP	25	A-4a (2)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: ASPHALT PATCH; AUGER CUTTINGS MIXED WITH BENTONITE CHIPS

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 324+49, 18' RT.	EXPLORATION ID B-025-2-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / APF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 4" SSA	CALIBRATION DATE: 7/30/20	ELEVATION: 663.4 (MSL) EOB: 15.0 ft.	PAGE 1 OF 1
START: 4/26/21 END: 4/26/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.785747, -81.132556	

MATERIAL DESCRIPTION AND NOTES	ELEV. 663.4	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
8" ASPHALT AND 2.5" CONCRETE	662.5																	
DENSE TO VERY DENSE, BROWN, **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP		1–2	44 32 50	113	44	SS-1	-	-	-	-	-	-	-	-	-	4	A-1-b (V)	
	657.4	4–5	18 17 15	44	44	SS-2	-	-	-	-	-	-	-	-	-	6	A-1-b (V)	
MEDIUM DENSE, BROWN, **FINE SAND**, SOME SILT, TRACE CLAY, DAMP	654.9	6–7	8 7 5	17	78	SS-3	-	0	1	66	26	7	NP	NP	NP	6	A-3a (0)	
MEDIUM DENSE, BROWN, **SANDY SILT**, TRACE CLAY, WET		9	4 3 4	10	78	SS-4	-	-	-	-	-	-	-	-	-	10	A-4a (V)	
		W 652.4; 11–12	5 6 7	18	78	SS-5	-	0	0	64	29	7	NP	NP	NP	28	A-4a (0)	
	648.4	14–15 EOB	8 7 9	22	78	SS-6	-	-	-	-	-	-	-	-	-	32	A-4a (V)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: ASPHALT PATCH; AUGER CUTTINGS MIXED WITH BENTONITE CHIPS

STANDARD ODOT SOIL BORING LOG (8.5 X 11) - OH DOT.GDT - 6/7/21 11:29 - \\SME-INC\PZWIP\080953.01\PROJECT DATA\GINT\80953.01 ODOT DRAFT LOGS.GPJ

PROJECT: LAK-20-19.59	DRILLING FIRM / OPERATOR: SME / JH/RM	DRILL RIG: 293-CME55-TRK	STATION / OFFSET: 325+90, 18' RT.	EXPLORATION ID B-025-3-19
TYPE: RETAINING WALL	SAMPLING FIRM / LOGGER: SME / APF	HAMMER: AUTOMATIC HAMMER	ALIGNMENT: U.S. 20	
PID: 108665 SFN:	DRILLING METHOD: 4" SSA	CALIBRATION DATE: 7/30/20	ELEVATION: 665.8 (MSL) EOB: 15.0 ft.	PAGE
START: 4/26/21 END: 4/26/21	SAMPLING METHOD: SPT	ENERGY RATIO (%): 82.5	LAT / LONG: 41.785789, -81.132045	1 OF 1

MATERIAL DESCRIPTION AND NOTES	ELEV. 665.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	ABAN-DONED
2.75" ASPHALT AND 9" CONCRETE	664.8																	
MEDIUM DENSE TO DENSE, BROWN, **GRAVEL AND STONE FRAGMENTS WITH SAND**, TRACE SILT, TRACE CLAY, DAMP		1–2	11 16 12	39	78	SS-1	-	37	25	26	9	3	NP	NP	NP	5	A-1-b (0)	
	659.8	4–5	4 5 5	14	44	SS-2	-	-	-	-	-	-	-	-	-	7	A-1-b (V)	
MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, DAMP		6–7	4 5 6	15	78	SS-3	-	-	-	-	-	-	-	-	-	6	A-3a (V)	
	655.3	9–10	4 4 5	12	78	SS-4	-	4	2	75	15	4	NP	NP	NP	11	A-3a (0)	
LOOSE TO MEDIUM DENSE, BROWN, **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE GRAVEL, WET		11–12 (W 653.3)	3 3 3	8	78	SS-5	-	-	-	-	-	-	-	-	-	34	A-3a (V)	
	650.8	14–15 EOB	8 7 8	21	78	SS-6	-	-	-	-	-	-	-	-	-	26	A-3a (V)	

NOTES: NONE

ABANDONMENT METHODS, MATERIALS, QUANTITIES: ASPHALT PATCH; AUGER CUTTINGS MIXED WITH BENTONITE CHIPS

TEST BORING LOG

B-049-0-92

ACT PROJECT NO. 9209.27 BORING NO. B-49 SHEET 1 OF 1

CLIENT: CT CONSULTANTS DATE DRILLED: 11-10-92

PROJECT: "LAK" 20-18.40 - STATE ROUTE 20 IMPROVEMENTS

DRILLING METHOD: ROTARY DRIVE - HOLLOW STEM AUGERS SURFACE ELEVATION: 677.66'

SAMPLE Depth (Ft.)	SAMPLE No.	SAMPLE Type	SYMBOL	SAMPLE IDENTIFICATION	BLOW COUNT ON SS/6"	PROPERTIES W (%)	LL/PI	γd (PCF)	qu (KSF)	qp (TSF)
0				4" Asphalt						
				5" Concrete						
	1	SS		Brown coarse to fine sand, little gravel. Medium dense to loose. Moist. (A-3a) (Visual)	11-12-8	8.1				
2.5										
	2	SS			2-2-2	11.7				
5.0										
	3	SS			2-3-5	11.6				
7.5										
	4	SS			6-7-6	10.5				
10.0				END OF BORING @ 10.0'						

GROUNDWATER

ENCOUNTERED AT: NONE

ON COMPLETION: NONE

AFTER:

REMARKS: BULK SAMPLE @ 1.0'-5.0'

AS - Auger Sample
ST - Shelby Tube Sample
SS - 2" O.D. Split Spoon Sample
W - Moisture Content

LL/PI - Liquid Limit/Plasticity Index
γ_d - Dry Density
q_u - Unconfined Strength
q_p - Pocket Penetrometer Reading

APPLIED CONSTRUCTION TECHNOLOGIES, INC.

TEST BORING LOG

B-061-0-92

ACT PROJECT NO. 9209.27 BORING NO. B-61 SHEET 1 OF 1

CLIENT: CT CONSULTANTS DATE DRILLED: 11-10-92

PROJECT: "LAK" 20-18.40 - STATE ROUTE 20 IMPROVEMENTS

DRILLING METHOD: ROTARY DRIVE - HOLLOW STEM AUGERS SURFACE ELEVATION: 673.73'

SAMPLE Depth (Ft.)	No.	Type	SYMBOL	SAMPLE IDENTIFICATION	BLOW COUNT ON SS/6"	W (%)	LL/PI	γd (PCF)	qu (KSF)	qp (TSF)
0				3" Asphalt						
				6" Concrete						
	1	SS		Brown coarse and fine sand, trace gravel and silt. Medium dense to loose. Moist. (A-3a) (Visual)	5-6-5	9.6				
2.5	2	ST			Rec.21"	7.8		105.7		
5.0	3	SS			5-4-4	6.1				
7.5										
	4	SS			4-4-5	7.8 6.0				
10.0				END OF BORING @ 10.0'						

GROUNDWATER

ENCOUNTERED AT: NONE

ON COMPLETION: NONE

AFTER:

REMARKS:

AS - Auger Sample
ST - Shelby Tube Sample
SS - 2" O.D. Split Spoon Sample
W - Moisture Content

LL/PI - Liquid Limit/Plasticity Index
γ_d - Dry Density
q_u - Unconfined Strength
q_p - Pocket Penetrometer Reading

APPLIED CONSTRUCTION TECHNOLOGIES, INC.

TEST BORING LOG

B-067-0-92

ACT PROJECT NO. 9209.27 BORING NO. B-67 SHEET 1 OF 1

CLIENT: CT CONSULTANTS DATE DRILLED: 11-06-92

PROJECT: "LAK" 20-18.40 - STATE ROUTE 20 IMPROVEMENTS

DRILLING METHOD: ROTARY DRIVE - HOLLOW STEM AUGERS SURFACE ELEVATION: 666.35'

SAMPLE Depth (Ft.)	No.	Type	SYMBOL	SAMPLE IDENTIFICATION	BLOW COUNT ON SS/6"	W (%)	LL/PI	γ_d (PCF)	q_u (KSF)	q_p (TSF)
0				6" Coarse sand and gravel.						
	1	SS		Brown coarse and fine sand, some gravel, trace silt. Loose to medium dense. Moist. (A-3a) (Visual)	5-5-4	9.1				
2.5	2	SS			3-3-5	6.8				
5.0										
	3	SS			1-3-9	10.0				
7.5										
	4	SS			9-6-7	7.6				
10.0				END OF BORING @ 10.0'						

GROUNDWATER

ENCOUNTERED AT: NONE

ON COMPLETION: NONE

AFTER:

REMARKS:

AS - Auger Sample
ST - Shelby Tube Sample
SS - 2" O.D. Split Spoon Sample
W - Moisture Content

LL/PI - Liquid Limit/Plasticity Index
γ_d - Dry Density
q_u - Unconfined Strength
q_p - Pocket Penetrometer Reading

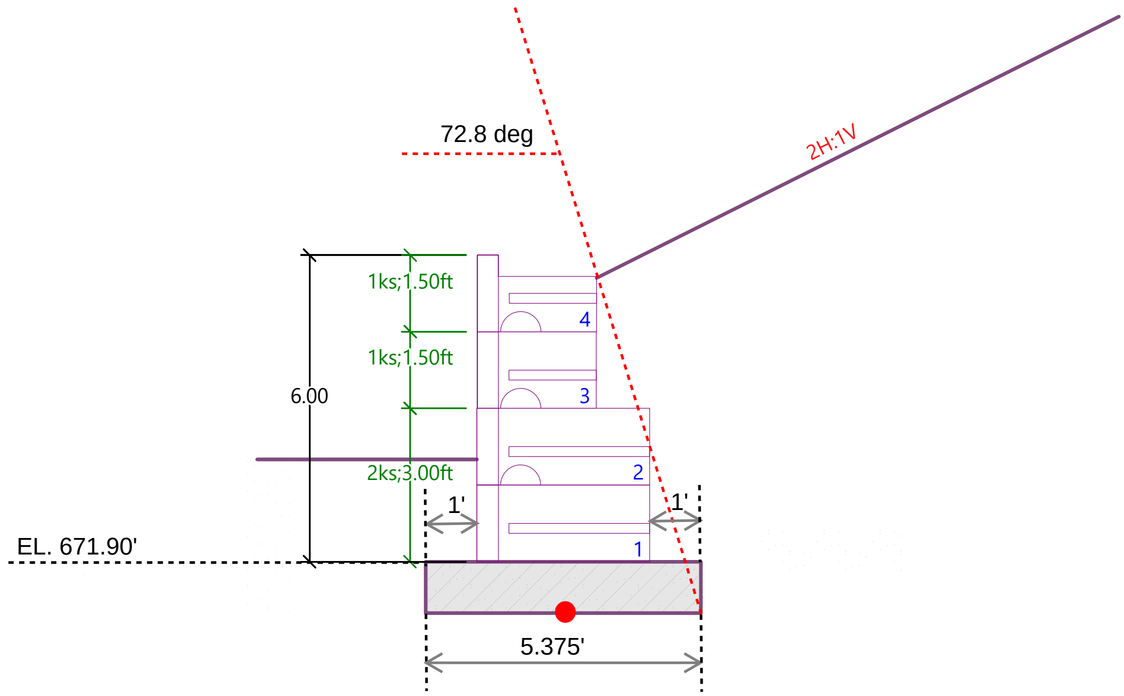
APPLIED CONSTRUCTION TECHNOLOGIES, INC.

APPENDIX B
RETAINING WALL CALCULATIONS

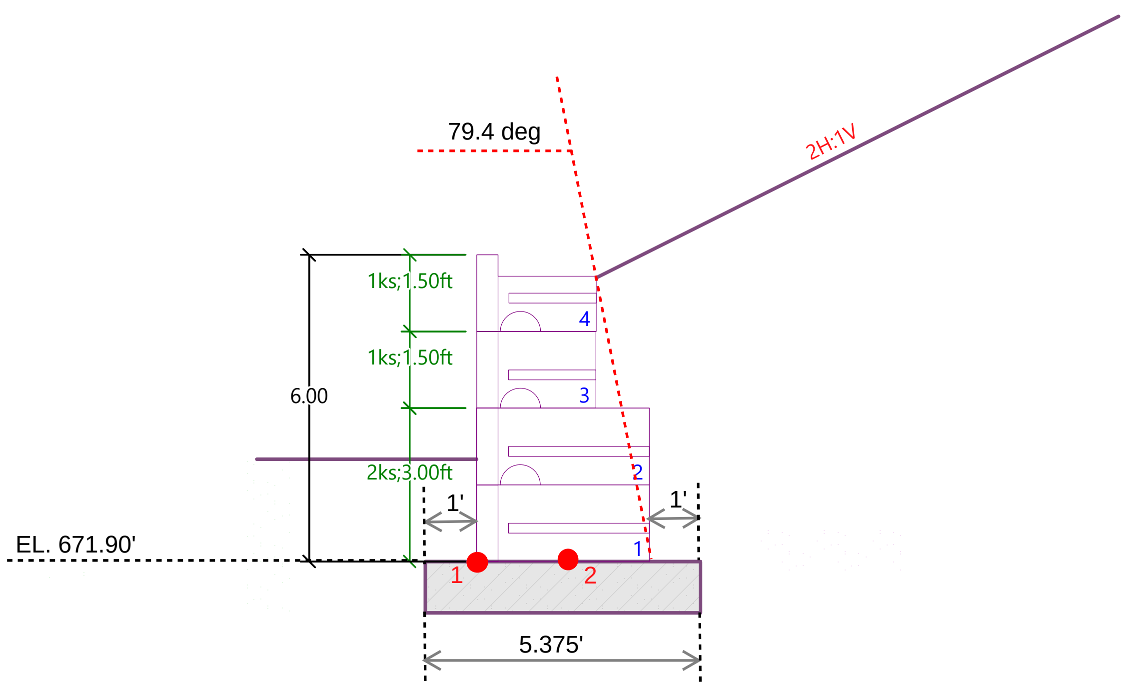
Date: December 27, 2021
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

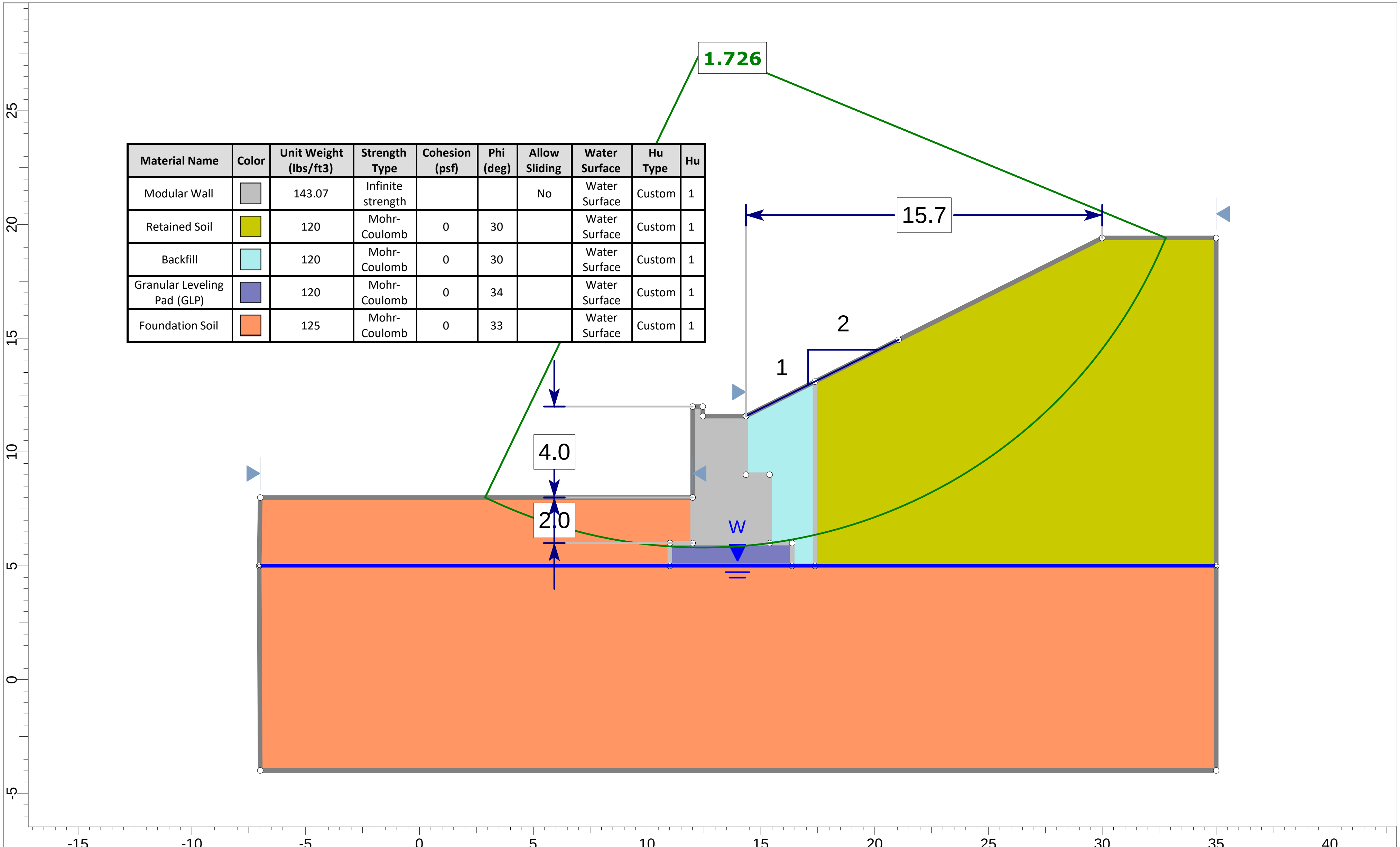
Retaining Wall 1 (A-A)

Bearing and sliding check at bottom of granular leveling pad (GLP)



Sliding, overturning, and eccentricity at bottom of base block:





Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface	Hu Type	Hu
Modular Wall		143.07	Infinite strength			No	Water Surface	Custom	1
Retained Soil		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Backfill		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Granular Leveling Pad (GLP)		120	Mohr-Coulomb	0	34		Water Surface	Custom	1
Foundation Soil		125	Mohr-Coulomb	0	33		Water Surface	Custom	1

Project	LAK-20		
Group	Section A-A	*Scenario*	Master Scenario
Drawn By	JF	*Company*	SME
Date	1/3/2022, 8:30:30 AM	*File Name*	Retaining Wall Section A-A.slmd

SLIDEINTERPRET 9.012

Retaining Wall 1 (A-A)

Date: December 27, 2021
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

Computed By: Jalal Fatemi
Checked By: Alan J. Esser, PE, DGE

Material Properties:

$\gamma_{GLP} := 120\ pcf$ — Granular leveling pad unit weight - BDM Table 307-1

$\phi'_{GLP} := 34\ deg$ — Granular leveling pad friction angle - BDM Table 307-1

Foundation Soil Properties:

A-1-b soil with average N60= 29 per B-022-1-19

$\gamma_s := 125\ pcf$ — Unit weight - GB-7, Table 1

$\phi'_s := 33\ deg$ — Friction angle - GB-7, Table 2

$c_s' := 0\ ksf$ — Cohesion

Backfill and Retained Soils Properties:

$\gamma_{backfill} := 120\ pcf$ — Backfill unit weight - BDM Table 307-1

$\phi'_{backfill} := 30\ deg$ — Backfill friction angle - BDM Table 307-1

$\delta_a := 0.7 \cdot \phi'_{backfill} = 21\ deg$ — Soil-structure interface friction angle - BDM Article 307.1.1

$\gamma_{retained} := 120\ pcf$ — Retained soil unit weight - BDM Table 307-1

$\phi'_{retained} := 30\ deg$ — Retained soil friction angle - BDM Table 307-1

Load Combinations and Load Factors (AASHTO Tables 3.4.1-1 and 3.4.1-2):

Strength I
DC -----> Min. = 0.9 ; Max. = 1.25
EH -----> Min. = 0.9 ; Max. = 1.5
EV -----> Min. = 1.0 ; Max. = 1.35

Service I
DC -----> 1.0
EH -----> 1.0
EV -----> 1.0

Retaining Wall 1 (A-A)

Strength Limit State Resistance Factors:

$\varphi_b := 0.55$	Bearing capacity - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{\tau 1} := 1.00$	Sliding (soil on soil) - ASHTO Table 11.5.7-1 and and C10.5.5.2.2
$\varphi_{\tau 2} := 1.00$	Sliding (precast concrete on soil) - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{passive} := 0.50$	Passive pressure for sliding - AASHTO Table 10.5.5.2.2-1 and C10.6.3.4

Prefabricated Modular Blocks Info (Cobble/Limestone):

	Weight	Cenetr of gravity (From the back of blocks)	Block width
R-28T:	$W_{R28T} := 1230\ lbf$	$c_{R28T} := 14.9\ in$	$d_{R28T} := 28\ in$
R-28M:	$W_{R28M} := 1610\ lbf$	$c_{R28M} := 13.9\ in$	$d_{R28M} := 28\ in$
R-41M:	$W_{R41M} := 2310\ lbf$	$c_{R41M} := 20.4\ in$	$d_{R41M} := 40.5\ in$
R-41B:	$W_{R41B} := 2440\ lbf$	$c_{R41B} := 20.7\ in$	$d_{R41B} := 40.5\ in$

Design Loads:

Assumptions:
1. Passive resistance in front of the wall is neglected.
2. Forces are calculated for a block with a length of 46-1/8 in (3.84 ft).
3. Groundwater table, even though deeper than base of the wall, is assumed to be at the wall base. No water pressure will be appied to the wall assuming drained conditions.

Active Earth Pressure:

Bottom of granular leveling pad (GLP):

$$\theta_1 := \text{atan}\left(\frac{13\ in + 3 \cdot 18\ in + 12\ in}{12\ in + 12.5\ in}\right) = 72.77\ deg \qquad \beta := \text{atan}\left(\frac{1}{2}\right) = 26.565\ deg$$

Retaining Wall 1 (A-A)

$$\Gamma_1 := \left(1 + \left(\frac{\sin(\phi'_{backfill} + \delta_a) \cdot \sin(\phi'_{backfill} - \beta)}{\sin(\theta_1 - \delta_a) \cdot \sin(\theta_1 + \beta)}\right)^{0.5}\right)^2 = 1.55$$

$$K_{a1} := \frac{(\sin(\theta_1 + \phi'_{backfill}))^2}{\Gamma_1 \cdot (\sin(\theta_1))^2 \cdot \sin(\theta_1 - \delta_a)} = 0.856$$

$H_1 := 13\ in + 3 \cdot 18\ in + 12\ in = 6.583\ ft$ $\quad L := 3.84\ ft$ Block length 46-1/8 in

$$P_{a1} := 0.5 \cdot K_{a1} \cdot \gamma_{backfill} \cdot H_1^{\ 2} \cdot L = 8.549\ kip$$

$$P_{a1H} := P_{a1} \cdot \cos(90\ deg - \theta_1 + \delta_a) = 6.716\ kip$$

$$P_{a1V} := P_{a1} \cdot \sin(90\ deg - \theta_1 + \delta_a) = 5.291\ kip$$

Bottom of base block:

$$\theta_2 := \text{atan}\left(\frac{13\ in + 3 \cdot 18\ in}{12.5\ in}\right) = 79.432\ deg$$

$$\Gamma_2 := \left(1 + \left(\frac{\sin(\phi'_{backfill} + \delta_a) \cdot \sin(\phi'_{backfill} - \beta)}{\sin(\theta_2 - \delta_a) \cdot \sin(\theta_2 + \beta)}\right)^{0.5}\right)^2 = 1.534$$

$$K_{a2} := \frac{(\sin(\theta_2 + \phi'_{backfill}))^2}{\Gamma_1 \cdot (\sin(\theta_2))^2 \cdot \sin(\theta_2 - \delta_a)} = 0.697$$

$$H_2 := 13\ in + 3 \cdot 18\ in = 5.583\ ft$$

$$P_{a2} := 0.5 \cdot K_{a2} \cdot \gamma_{backfill} \cdot H_2^{\ 2} \cdot L = 5.004\ kip$$

$$P_{a2H} := P_{a2} \cdot \cos(90\ deg - \theta_2 + \delta_a) = 4.264\ kip$$

$$P_{a2V} := P_{a2} \cdot \sin(90\ deg - \theta_2 + \delta_a) = 2.62\ kip$$

Soil on Soil Friction:

$\delta_p := 0.67 \cdot \phi'_s = 22.11\ deg$ Soil-on-soil interface friction angle - BDM Article 307.1.1

$$\phi'_s = 33\ deg$$

Retaining Wall 1 (A-A)

GLP and Soil Wedge Weights:

$B_{GLP} := 5.375\ ft$ GLP width $t_{GLP} := 1\ ft$ GLP thickness

$W_{GLP} := B_{GLP} \cdot t_{GLP} \cdot L \cdot \gamma_{GLP} = 2.477\ kip$

$W_{SoilWedge} := (18\ in + 13\ in) \cdot 12.5\ in \cdot L \cdot \gamma_{backfill} = 1.24\ kip$

Bearing and Sliding (bottom of GLP):

$DC := W_{R28T} + W_{R28M} + W_{R41M} + W_{R41B} = 7.59\ kip$ Vertical Dead Loads

$P_{a1H} = 6.716\ kip$ $W_{GLP} = 2.477\ kip$

$P_{a1V} = 5.291\ kip$ $W_{SoilWedge} = 1.24\ kip$

Moments:

$$M1 := P_{a1H} \cdot \frac{H_1}{3} - P_{a1V} \cdot \left(\frac{B_{GLP}}{2} - \frac{H_1}{3} \tan\left(90\ deg - \theta_1\right)\right) = 4.12\ ft \cdot kip$$

$$M2_{R28T} := W_{R28T} \cdot \left(\frac{B_{GLP}}{2} - \left(c_{R28T} + d_{R41B} - d_{R28T} + 1\ ft\right)\right) = -0.733\ ft \cdot kip$$

$$M2_{R28M} := W_{R28M} \cdot \left(\frac{B_{GLP}}{2} - \left(c_{R28M} + d_{R41B} - d_{R28M} + 1\ ft\right)\right) = -0.825\ ft \cdot kip$$

$$M2_{R41M} := W_{R41M} \cdot \left(\frac{B_{GLP}}{2} - c_{R41M} - 1\ ft\right) = -0.029\ ft \cdot kip$$

$$M2_{R41B} := W_{R41B} \cdot \left(\frac{B_{GLP}}{2} - c_{R41B} - 1\ ft\right) = -0.091\ ft \cdot kip$$

$$M2 := -M2_{R28T} - M2_{R28M} - M2_{R41M} - M2_{R41B} = 1.678\ ft \cdot kip$$

$$M3 := W_{GLP} \cdot \left(\frac{B_{GLP}}{2} - \frac{B_{GLP}}{2}\right) - W_{SoilWedge} \cdot \left(\frac{B_{GLP}}{2} - \left(\frac{d_{R41B} - d_{R28T}}{2} + 1\ ft\right)\right) = -1.447\ ft \cdot kip$$

Retaining Wall 1 (A-A)

Service I (load factors=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(DC + P_{a1V} + W_{GLP} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{GLP}\right) = 11.195\ (kip)$

$R_{R1} = 11.195\ (kip) > P_{a1H} = 6.716\ kip$ ----->OK

Bearing:

$$e_1 := \frac{M1 + M2 + M3}{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}} = 0.262\ ft$$

$B := B_{GLP} = 5.375\ ft$ $\frac{e_1}{B} = 0.049$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 4.851\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 18.627\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{A'} = 0.891\ ksf$$

For $\frac{e_1}{B} = 0.049$ < 1/6:

$$\sigma_{vmax} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.039\ ksf$$

$$\sigma_{vmin} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 0.569\ ksf$$

$L' := 100\ ft$ Total length of the wall

$\gamma_s = 125\ pcf$ $\phi'_s = 33\ deg$ $c_s' = 0\ ksf$ Foundation soil properties

$D_f := 3\ ft$

$N_\gamma := 35.2$ $N_q := 26.1$ $N_c := 38.6$

AASHTO LRFD Table 10.6.3.1.2a-1

$i_\gamma := 1$ $i_q := 1$ $i_c := 1$

Retaining Wall 1 (A-A)

$$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.033 \qquad s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.032$$

$$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.981$$

$$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\text{atan}\left(\frac{D_f}{B'}\right)\right) = 1.149$$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 10.801\ ksf$$

$q_n = 10.801\ ksf$ > $\sigma_{vmax} = 1.039\ ksf$ --------> OK

Strength I-a (DC&W$_{CLP}$=0.9; EH=1.5; EV=1.5; W$_{GLP,SoilWedge}$=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$$R_{R1A} := \left(0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}\right) = 18.484\ kip$$

$$R_{R1} := \varphi_{\tau1} \cdot C \cdot R_{R1A} \cdot \tan\left(\phi'_{GLP}\right) = 12.467\ (kip)$$

$R_{R1} = 12.467\ (kip) > 1.5 \cdot P_{a1H} = 10.074\ kip$ -----> OK

Bearing:

$$e_1 := \frac{1.5 \cdot M1 + 0.9 \cdot M2 + M3}{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}} = 0.338\ ft$$

$B := B_{GLP} = 5.375\ ft$ $\frac{e_1}{B} = 0.063$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 4.699\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 18.046\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{A'} = 1.024\ ksf$$

For $\frac{e_1}{B} = 0.063$ < 1/6:

Retaining Wall 1 (A-A)

$$\sigma_{vmax} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.233\ ksf$$

$$\sigma_{vmin} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 0.558\ ksf$$

$i_\gamma := 1 \quad i_q := 1 \quad i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.032 \qquad s_q := 1 + \left(\frac{B'}{L'} \tan(\phi'_s)\right) = 1.031$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.981$

$d_q := 1 + 2 \tan(\phi'_s) \left(1 - \sin(\phi'_s)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.153$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5 \quad C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s{}' \cdot N_c \cdot s_c \cdot i_c\right) = 10.654\ ksf$$

$q_R := \varphi_b \cdot q_n = 5.86\ ksf$ > $\sigma_{vmax} = 1.233\ ksf$ --------> OK

Strength I-b (DC&W_{CLP}=1.25; EH=1.5; EV=1.5; $W_{GLP,SoilWedge}$=1.35):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$R_{R1A} := \left(1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}\right) = 22.441\ kip$

$R_{R1} := \varphi_{\tau 1} \cdot C \cdot R_{R1A} \cdot \tan(\phi'_{GLP}) = 15.137\ (kip)$

$R_{R1} = 15.137\ (kip) > 1.5 \cdot P_{a1H} = 10.074\ kip$ -----> OK

Bearing:

$$e_1 := \frac{1.5 \cdot M1 + 1.25 \cdot M2 + 1.35 \cdot M3}{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}} = 0.282\ ft$$

$B := B_{GLP} = 5.375\ ft \qquad \frac{e_1}{B} = 0.052$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

Retaining Wall 1 (A-A)

$B' := B - 2 \cdot e_1 = 4.811\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 18.476\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{A'} = 1.215\ ksf$$

For $\frac{e_1}{B} = 0.052$ < 1/6:

$$\sigma_{vmax} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.429\ ksf$$

$$\sigma_{vmin} := \left(\frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right)\right) = 0.745\ ksf$$

$i_\gamma := 1 \quad i_q := 1 \quad i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.033 \qquad s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.031$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.981$

$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.15$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5 \quad C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s{}' \cdot N_c \cdot s_c \cdot i_c\right) = 10.763\ ksf$$

$q_R := \varphi_b \cdot q_n = 5.92\ ksf$ > $\sigma_{vmax} = 1.429\ ksf$ --------> OK

Eccentricity, Sliding and Overturning (top of CLP):

$DC = 7.59\ kip$ Vertical Dead Loads

$P_{a2H} = 4.264\ kip \qquad W_{SoilWedge} = 1.24\ kip$

$P_{a2V} = 2.62\ kip$

Retaining Wall 1 (A-A)

Moments for point of rotation 1:

$M1_D := P_{a2H} \cdot \frac{H_2}{3} = 7.935\ ft \cdot kip$ Driving Moment

$M1_{R28T} := W_{R28T} \cdot (d_{R28T} - c_{R28T}) = 1.343\ ft \cdot kip$

$M1_{R28M} := W_{R28M} \cdot (d_{R28M} - c_{R28M}) = 1.892\ ft \cdot kip$

$M1_{R41M} := W_{R41M} \cdot (d_{R41M} - c_{R41M}) = 3.869\ ft \cdot kip$

$M1_{R41B} := W_{R41B} \cdot (d_{R41B} - c_{R41B}) = 4.026\ ft \cdot kip$

$M1_{R1} := M1_{R28T} + M1_{R28M} + M1_{R41M} + M1_{R41B} = 11.13\ ft \cdot kip$ Resisting Moment 1

$M1_{R2} := P_{a2V} \cdot \left(d_{R41B} - \frac{H_2}{3} \tan(90\ deg - \theta_2)\right) = 7.932\ ft \cdot kip$ Resisting Moment 2

$M1_{R3} := W_{SoilWedge} \cdot \left(d_{R41B} - \left(\frac{d_{R41B} - d_{R28T}}{2}\right)\right) = 3.539\ ft \cdot kip$ Resisting Moment 3

Moments for point of rotation 2:

$M2_1 := P_{a2H} \cdot \frac{H_2}{3} - P_{a2V} \cdot \left(\frac{d_{R41B}}{2} - \frac{H_2}{3} \tan(90\ deg - \theta_2)\right) = 4.424\ ft \cdot kip$

$M2_{R28T} := W_{R28T} \cdot \left(\frac{d_{R41B}}{2} - (c_{R28T} + d_{R41B} - d_{R28T})\right) = -0.733\ ft \cdot kip$

$M2_{R28M} := W_{R28M} \cdot \left(\frac{d_{R41B}}{2} - (c_{R28M} + d_{R41B} - d_{R28M})\right) = -0.825\ ft \cdot kip$

$M2_{R41M} := W_{R41M} \cdot \left(\frac{d_{R41B}}{2} - c_{R41M}\right) = -0.029\ ft \cdot kip$

$M2_{R41B} := W_{R41B} \cdot \left(\frac{d_{R41B}}{2} - c_{R41B}\right) = -0.091\ ft \cdot kip$

$M2_2 := -M2_{R28T} - M2_{R28M} - M2_{R41M} - M2_{R41B} = 1.678\ ft \cdot kip$

$M2_3 := -W_{SoilWedge} \cdot \left(\frac{d_{R41B}}{2} - \frac{d_{R41B} - d_{R28T}}{2}\right) = -1.447\ ft \cdot kip$

Service I (load factors=1.0):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$R_{R1} := \varphi_{\tau 2} \cdot C \cdot (DC + P_{a2V} + W_{SoilWedge}) \cdot \tan(\phi'_{GLP}) = 6.178\ (kip)$

$R_{R1} = 6.178\ (kip) >\ P_{a2H} = 4.264\ kip$ ----->OK

Retaining Wall 1 (A-A)

Overturning:

$$\frac{M1_{R1}+M1_{R2}+M1_{R3}}{M1_D}=2.848$$ >1.5 ----->OK

Eccentricity:

$$e_2:=\frac{M2_1+M2_2+M2_3}{DC+P_{a2V}+W_{SoilWedge}}=0.407\ ft$$

$B:=d_{R41B}=3.375\ ft$ $\frac{e_2}{B}=0.12$ <1/3 -----> OK Per AASHTO Article 11.6.3.3

$B':=B-2\cdot e_2=2.562\ ft$ AASHTO Eq. 10.6.1.3-1

$A':=B'\cdot L=9.837\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v:=\frac{DC+P_{a2V}+W_{SoilWedge}}{A'}=1.164\ ksf$$

For $\frac{e_2}{B}=0.12$ < 1/6:

$$\sigma_{vmax}:=\frac{DC+P_{a2V}+W_{SoilWedge}}{B\cdot L}\cdot\left(1+6\cdot\frac{e_2}{B}\right)=1.522\ ksf$$

$$\sigma_{vmin}:=\frac{DC+P_{a2V}+W_{SoilWedge}}{B\cdot L}\cdot\left(1-6\cdot\frac{e_2}{B}\right)=0.245\ ksf$$

Strength I-a (DC=0.9; EH=1.5; EV=1.5; $W_{SoilWedge}$=1.0):

Sliding:

$C:=0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1}:=\varphi_{\tau 2}\cdot C\cdot\left(0.9\cdot DC+1.5\cdot P_{a2V}+W_{SoilWedge}\right)\cdot\tan\left(\phi'_{GLP}\right)=6.476\ kip$$

$R_{R1}=6.476\ kip$ > $1.5\cdot P_{a2H}=6.395\ kip$ ----->OK

Retaining Wall 1 (A-A)

Overturning:

$$\frac{0.9 \cdot M1_{R1} + 1.5\ M1_{R2} + M1_{R3}}{1.5 \cdot M1_D} = 2.138$$ >1.0 ----->OK

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 0.9 \cdot M2_2 + M2_3}{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}} = 0.558\ ft$$

$B := d_{R41B} = 3.375\ ft$ $\qquad \frac{e_2}{B} = 0.165$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 2.258\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 8.672\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V}}{A'} = 1.241\ ksf$$

For $\frac{e_2}{B} = 0.165$ < 1/6:

$$\sigma_{vmax} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 1.845\ ksf$$

$$\sigma_{vmin} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.007\ ksf$$

Strength I-b (DC=1.25; EH=1.5; EV=1.5; $W_{SoilWedge}$=1.35):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot \left(1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}\right) \cdot \tan\left(\phi'_{GLP}\right) = 8.143\ kip$$

$R_{R1} = 8.143\ kip$ > $1.5 \cdot P_{a2H} = 6.395\ kip$ ----->OK

Overturning:

$$\frac{1.25 \cdot M1_{R1} + 1.5\ M1_{R2} + 1.35 \cdot M1_{R3}}{1.5 \cdot M1_D} = 2.57$$ >1.0 ----->OK

Retaining Wall 1 (A-A)

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 1.25 \cdot M2_2 + 1.35 \cdot M2_3}{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}} = 0.449\ ft$$

$B := d_{R41B} = 3.375\ ft$ $\frac{e_2}{B} = 0.133$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 2.476\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 9.509\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{A'} = 1.587\ ksf$$

For $\frac{e_2}{B} = 0.133$ >1/6:

$$\sigma_{vmax} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 2.095\ ksf$$

$$\sigma_{vmin} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.234\ ksf$$

Modular Wall Unit Weight:

$V_{R28T} := 8.57\ ft^3$ $V_{R41M} := 16.14\ ft^3$

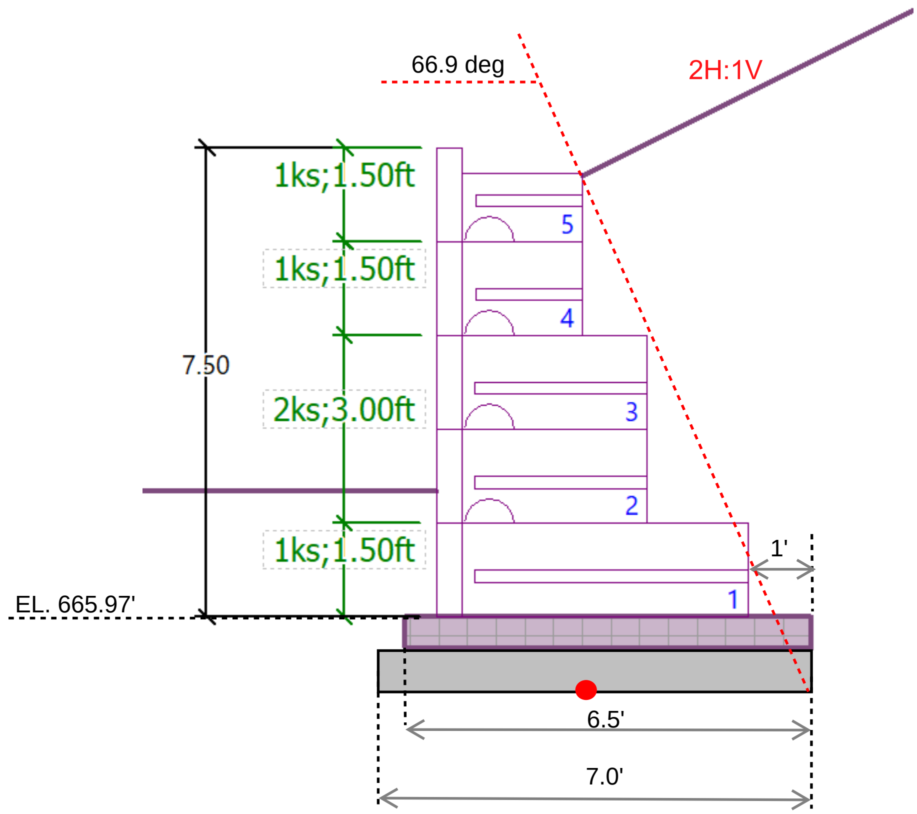
$V_{R28M} := 11.28\ ft^3$ $V_{R41B} := 17.06\ ft^3$

$$\gamma_{ModularWall} := \frac{W_{R28T} + W_{R28M} + W_{R41M} + W_{R41B}}{V_{R28T} + V_{R28M} + V_{R41M} + V_{R41B}} = 143.073\ pcf$$

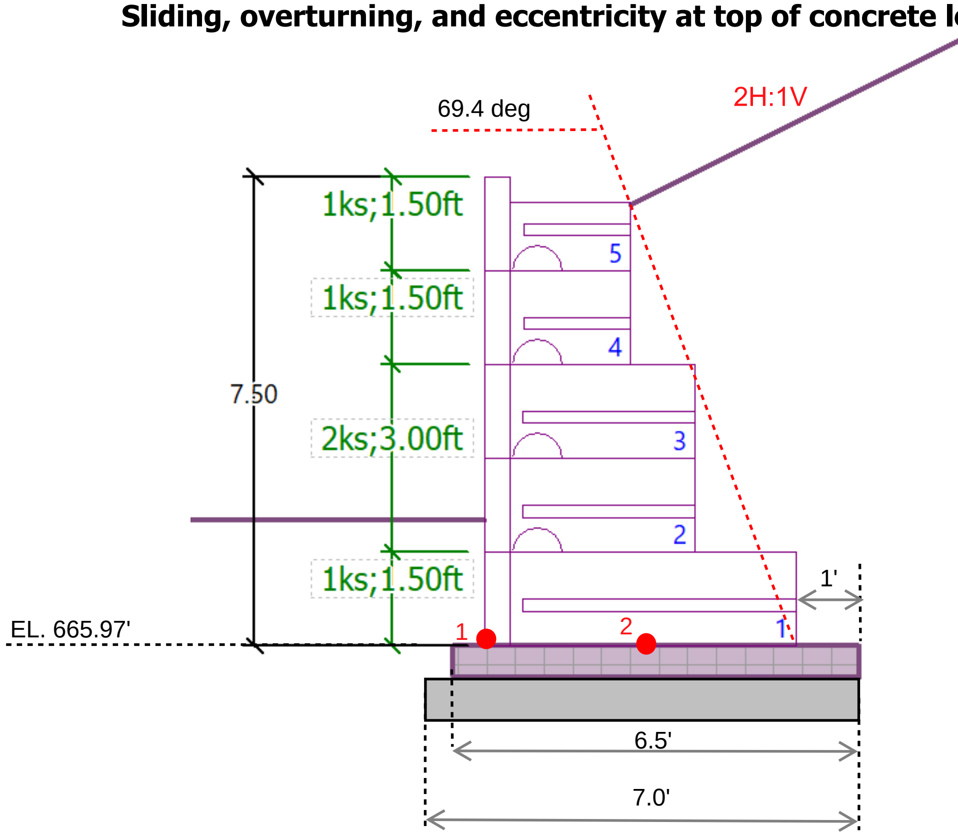
Date: February 3, 2022
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

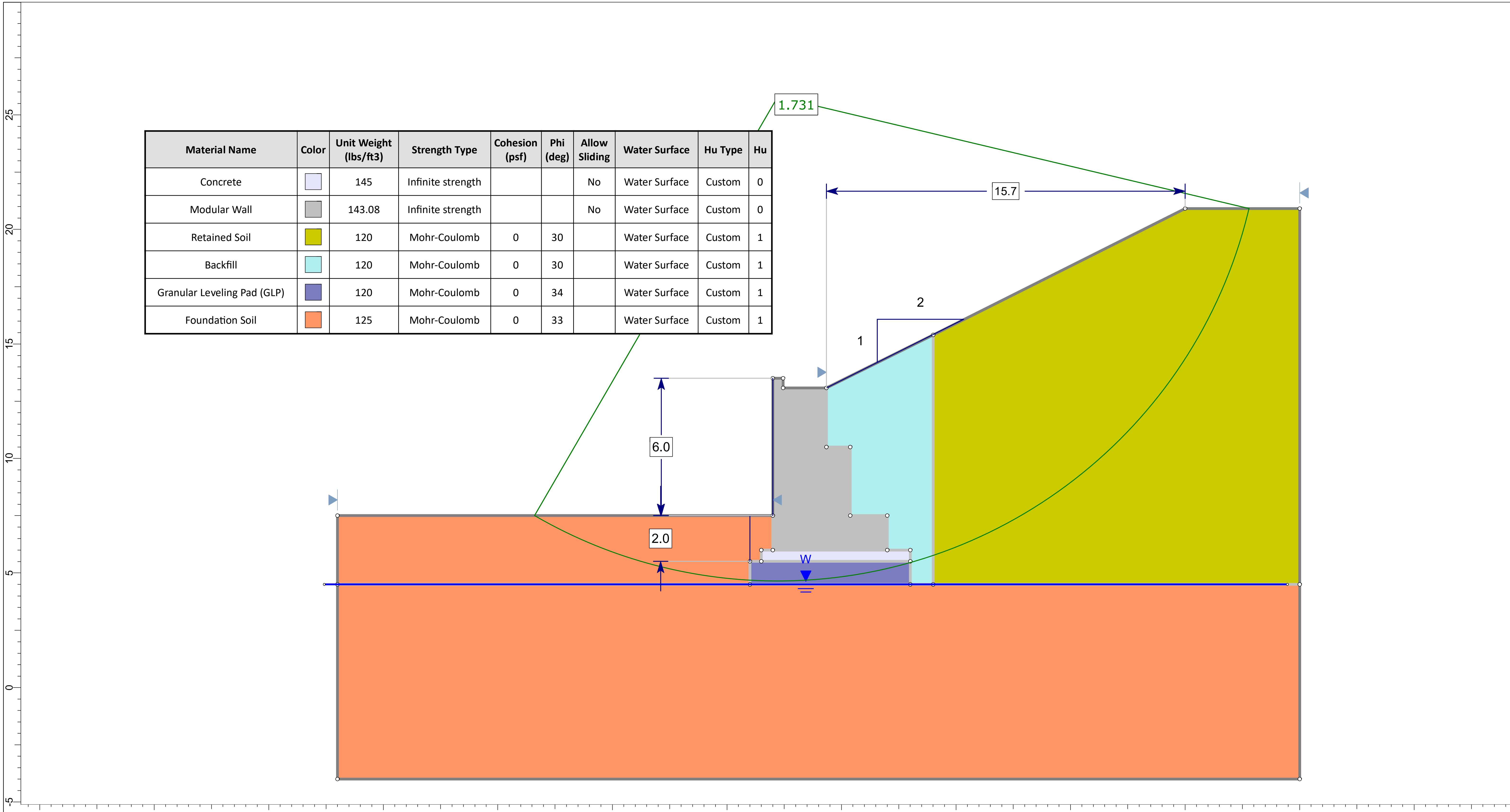
Retaining Wall 2 (B-B)

Bearing and sliding check at bottom of granular leveling pad (GLP)



Sliding, overturning, and eccentricity at top of concrete leveling pad (CLP)





Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface	Hu Type	Hu
Concrete		145	Infinite strength			No	Water Surface	Custom	0
Modular Wall		143.08	Infinite strength			No	Water Surface	Custom	0
Retained Soil		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Backfill		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Granular Leveling Pad (GLP)		120	Mohr-Coulomb	0	34		Water Surface	Custom	1
Foundation Soil		125	Mohr-Coulomb	0	33		Water Surface	Custom	1

SME

SLIDEINTERPRET 8.032

Project	LAK-20
Analysis Description	Upper Slope - Non-Circular Slope Stability Analysis
Drawn By JF	*Company* SME
Date: 1/13/2022	*File Name* Retaining Wall Section B-B.slmd

Retaining Wall 2 (B-B)

Date: February 2, 2022
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

Computed By: Brendan P. Lieske, PE
Checked By: Alan J. Esser, PE, DGE

Material Properties:

$\gamma_c := 145\ pcf$ — Concrete unit weight - AASHTO Table 3.5.1-1

$\gamma_{GLP} := 120\ pcf$ — Granular leveling pad unit weight - BDM Table 307-1

$\phi'_{GLP} := 34\ deg$ — Granular leveling pad friction angle - BDM Table 307-1

Foundation Soil Properties:

A-1-a and A-3 soils with average N60= 28 per B-022-2-19

$\gamma_s := 125\ pcf$ — Unit weight - GB-7, Table 1

$\phi'_s := 33\ deg$ — Friction angle - GB-7, Table 2

$c_s' := 0\ ksf$ — Cohesion

Backfill and Retained Soils Properties:

$\gamma_{backfill} := 120\ pcf$ — Backfill unit weight - BDM Table 307-1

$\phi'_{backfill} := 30\ deg$ — Backfill friction angle - BDM Table 307-1

$\delta_a := 0.7 \cdot \phi'_{backfill} = 21\ deg$ — Soil-structure interface friction angle - BDM Article 307.1.1

$\gamma_{retained} := 120\ pcf$ — Retained soil unit weight - BDM Table 307-1

$\phi'_{retained} := 30\ deg$ — Retained soil friction angle - BDM Table 307-1

Load Combinations and Load Factors (AASHTO Tables 3.4.1-1 and 3.4.1-2):

Strength I
DC -----> Min. = 0.9 ; Max. = 1.25
EH -----> Min. = 0.9 ; Max. = 1.5
EV -----> Min. = 1.0 ; Max. = 1.35

Service I
DC -----> 1.0
EH -----> 1.0
EV -----> 1.0

Retaining Wall 2 (B-B)

Strength Limit State Resistance Factors:

$\varphi_b := 0.55$	Bearing capacity - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{\tau 1} := 1.00$	Sliding (soil on soil) - ASHTO Table 11.5.7-1 and and C10.5.5.2.2
$\varphi_{\tau 2} := 1.00$	Sliding (precast concrete on soil) - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{passive} := 0.50$	Passive pressure for sliding - AASHTO Table 10.5.5.2.2-1 and C10.6.3.4

Prefabricated Modular Blocks Info (Cobble/Limestone):

	Weight	Center of gravity (From the back of blocks)	Block width
R-28T:	$W_{R28T} := 1230\ lbf$	$c_{R28T} := 14.9\ in$	$d_{R28T} := 28\ in$
R-28M:	$W_{R28M} := 1610\ lbf$	$c_{R28M} := 13.9\ in$	$d_{R28M} := 28\ in$
R-41M:	$W_{R41M} := 2310\ lbf$	$c_{R41M} := 20.4\ in$	$d_{R41M} := 40.5\ in$
R-60B:	$W_{R60B} := 3420\ lbf$	$c_{R60B} := 31.6\ in$	$d_{R60B} := 60\ in$

Design Loads:

Assumptions:
1. Passive resistance in front of the wall is neglected.
2. Forces are calculated for a block with a length of 46-1/8 in (3.84 ft).
3. Groundwater table, even though deeper than base of the wall, is assumed to be at the wall base. No water pressure will be appied to the wall assuming drained conditions.

Active Earth Pressure:

Bottom of granular leveling pad (GLP):

$$\theta_1 := \operatorname{atan}\left(\frac{13\ in + 4 \cdot 18\ in + 6\ in + 12\ in}{12\ in + 32\ in}\right) = 66.869\ deg \qquad \beta := \operatorname{atan}\left(\frac{1}{2}\right) = 26.565\ deg$$

Retaining Wall 2 (B-B)

$$\Gamma_1 := \left(1 + \left(\frac{\sin(\phi'_{backfill} + \delta_a) \cdot \sin(\phi'_{backfill} - \beta)}{\sin(\theta_1 - \delta_a) \cdot \sin(\theta_1 + \beta)}\right)^{0.5}\right)^2 = 1.575$$

$$K_{a1} := \frac{\left(\sin(\theta_1 + \phi'_{backfill})\right)^2}{\Gamma_1 \cdot \left(\sin(\theta_1)\right)^2 \cdot \sin(\theta_1 - \delta_a)} = 1.031$$

$H_1 := 18\ in + 4 \cdot 18\ in + 13\ in = 8.583\ ft$ $\qquad L := 3.84\ ft$

$P_{a1} := 0.5 \cdot K_{a1} \cdot \gamma_{backfill} \cdot H_1^{\ 2} \cdot L = 17.503\ kip$

$P_{a1H} := P_{a1} \cdot \cos(90\ deg - \theta_1 + \delta_a) = 12.563\ kip$

$P_{a1V} := P_{a1} \cdot \sin(90\ deg - \theta_1 + \delta_a) = 12.188\ kip$

Top of concrete leveling pad (CLP):

$$\theta_2 := \operatorname{atan}\left(\frac{13\ in + 4 \cdot 18\ in}{32\ in}\right) = 69.37\ deg$$

$$\Gamma_2 := \left(1 + \left(\frac{\sin(\phi'_{backfill} + \delta_a) \cdot \sin(\phi'_{backfill} - \beta)}{\sin(\theta_2 - \delta_a) \cdot \sin(\theta_2 + \beta)}\right)^{0.5}\right)^2 = 1.563$$

$$K_{a2} := \frac{\left(\sin(\theta_2 + \phi'_{backfill})\right)^2}{\Gamma_1 \cdot \left(\sin(\theta_2)\right)^2 \cdot \sin(\theta_2 - \delta_a)} = 0.944$$

$H_2 := 4 \cdot 18\ in + 13\ in = 7.083\ ft$

$P_{a2} := 0.5 \cdot K_{a2} \cdot \gamma_{backfill} \cdot H_2^{\ 2} \cdot L = 10.915\ kip$

$P_{a2H} := P_{a2} \cdot \cos(90\ deg - \theta_2 + \delta_a) = 8.159\ kip$

$P_{a2V} := P_{a2} \cdot \sin(90\ deg - \theta_2 + \delta_a) = 7.251\ kip$

Soil on Soil Friction

$\delta_p := 0.67 \cdot \phi'_s = 22.11\ deg$ Soil-on-soil interface friction angle - BDM Article 307.1.1

$\phi'_s = 33\ deg$

Retaining Wall 2 (B-B)

GLP, CLP, Soil Wedge Weights:

$B_{GLP} := 7.0\ ft$ GLP width $t_{GLP} := 1\ ft$ GLP thickness

$W_{GLP} := B_{GLP} \cdot t_{GLP} \cdot L \cdot \gamma_{GLP} = 3.226\ kip$

$B_{CLP} := 6.5\ ft$ CLP width $t_{CLP} := 0.5\ ft$ CLP thickness

$W_{CLP} := B_{CLP} \cdot t_{CLP} \cdot L \cdot \gamma_c = 1.81\ kip$

$W_{SoilWedge} := ((18\ in + 13\ in) \cdot (12.5\ in + 19.5\ in) + 2 \cdot 18\ in \cdot 19.5\ in) \cdot L \cdot \gamma_{backfill} = 5.421\ kip$

$$C_{SoilWedge} := \frac{(387.5\ in^2 \cdot 25.75\ in + 1306.5\ in^2 \cdot 9.75\ in)}{387.5\ in^2 + 1306.5\ in^2} = 1.117\ ft$$

From Right Heal of Soil Wedge

Bearing and Sliding (bottom of GLP):

$DC := W_{R28T} + W_{R28M} + 2 \cdot W_{R41M} + W_{R60B} = 10.88\ kip$ Vertical Dead Loads

$P_{a1H} = 12.563\ kip$ $W_{GLP} = 3.226\ kip$

$P_{a1V} = 12.188\ kip$ $W_{CLP} = 1.81\ kip$ $W_{SoilWedge} = 5.421\ kip$

Moments:

$$M1 := P_{a1H} \cdot \frac{H_1}{3} - P_{a1V} \cdot \left(\frac{B_{GLP}}{2} - \frac{H_1}{3} \tan(90\ deg - \theta_1)\right) = 8.183\ ft \cdot kip$$

$$M2_{R28T} := -W_{R28T} \cdot \left(\frac{B_{GLP}}{2} - (c_{R28T} + d_{R60B} - d_{R28T} + 1\ ft)\right) = 1.732\ ft \cdot kip$$

$$M2_{R28M} := -\left(W_{R28M} \cdot \left(\frac{B_{GLP}}{2} - (c_{R28M} + d_{R60B} - d_{R28M} + 1\ ft)\right)\right) = 2.133\ ft \cdot kip$$

$$M2_{R41M} := -\left(2 \cdot W_{R41M} \cdot \left(\frac{B_{GLP}}{2} - (c_{R41M} + d_{R60B} - d_{R41M} + 1\ ft)\right)\right) = 3.812\ ft \cdot kip$$

$$M2_{R60B} := -W_{R60B} \cdot \left(\frac{B_{GLP}}{2} - c_{R60B} - 1\ ft\right) = 0.456\ ft \cdot kip$$

$$M2 := M2_{R28T} + M2_{R28M} + M2_{R41M} + M2_{R60B} = 8.133\ ft \cdot kip$$

Retaining Wall 2 (B-B)

$$M3 := -W_{SoilWedge} \cdot \left(\frac{B_{GLP}}{2} - \left(C_{SoilWedge}\right)\right) = -12.915\ ft \cdot kip$$

$$M4 := -W_{CLP} \cdot \left(\frac{B_{GLP}}{2} - \frac{B_{CLP}}{2}\right) = -0.452\ ft \cdot kip$$

Service I (load factors=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(DC + P_{a1V} + W_{GLP} + W_{SoilWedge} + W_{CLP}\right) \cdot \tan\left(\phi'_{GLP}\right) = 22.612\ (kip)$$

$R_{R1} = 22.612\ (kip) >\ P_{a1H} = 12.563\ kip$ ----->OK

Bearing:

$$e_1 := \frac{M1 + M2 + M3 + M4}{DC + P_{a1V} + W_{GLP} + W_{SoilWedge} + W_{CLP}} = 0.088\ ft$$

$B := B_{GLP} = 7\ ft$ $\frac{e_1}{B} = 0.013$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 6.824\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 26.204\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge} + W_{CLP}}{A'} = 1.279\ ksf$$

For $\frac{e_1}{B} = 0.013$ < 1/6:

$$\sigma_{vmax} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge} + W_{CLP}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.341\ ksf$$

$$\sigma_{vmin} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge} + W_{CLP}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 1.153\ ksf$$

$L' := 100\ ft$ Total length of the wall

$\gamma_s = 125\ pcf$ $\phi'_s = 33\ deg$ $c_s' = 0\ ksf$ $D_f := 3\ ft$ Foundation soil properties

Retaining Wall 2 (B-B)

$N_\gamma := 35.2$ $N_q := 26.1$ $N_c := 38.6$ AASHTO LRFD Table 10.6.3.1.2a-1

$i_\gamma := 1$ $i_q := 1$ $i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.046$ $s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.044$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.973$

$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.112$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 12.755\ ksf$$

$q_n = 12.755\ ksf$ > $\sigma_{vmax} = 1.341\ ksf$ --------> OK

Retaining Wall 2 (B-B)

Strength I-a (DC&W_{CLP}=0.9; EH=1.5; EV=1.5; $W_{GLP,SoilWedge}$=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$$R_{R1A} := 0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge} + 0.9 \cdot W_{CLP} = 38.349\ kip$$

$$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(R_{R1A}\right) \cdot \tan\left(\phi'_{GLP}\right) = 25.867\ (kip)$$

$R_{R1} = 25.867\ (kip) > 1.5 \cdot P_{a1H} = 18.845\ kip$ -----> OK

Bearing:

$$e_1 := \frac{1.5 \cdot M1 + 0.9 \cdot M2 + M3 + 0.9 \cdot M4}{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge} + 0.9 \cdot W_{CLP}} = 0.164\ ft$$

$B := B_{GLP} = 7\ ft$ $\frac{e_1}{B} = 0.023$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 6.673\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 25.624\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge} + 0.9 \cdot W_{CLP}}{A'} = 1.497\ ksf$$

For $\frac{e_1}{B} = 0.023$ < 1/6:

$$\sigma_{vmax} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.558\ ksf$$

$$\sigma_{vmin} := \left(\frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right)\right) = 1.175\ ksf$$

$i_\gamma := 1$ $i_q := 1$ $i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.045$ $s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.043$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.973$ $d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.114$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 12.604\ ksf$$

$q_R := \varphi_b \cdot q_n = 6.932\ ksf$ > $\sigma_{vmax} = 1.558\ ksf$ --------> OK

Strength I-b (DC&W$_{CLP}$=1.25; EH=1.5; EV=1.5; W$_{GLP,SoilWedge}$=1.35):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$$R_{R1A} := \left(1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge} + 1.25 \cdot W_{CLP}\right) = 45.816\ kip$$

$$R_{R1} := \varphi_{\tau 1} \cdot C \cdot R_{R1A} \cdot \tan\left(\phi'_{GLP}\right) = 30.903\ (kip)$$

$R_{R1} = 30.903\ (kip) > 1.5 \cdot P_{a1H} = 18.845\ kip$ -----> OK

Bearing:

$$e_1 := \frac{1.5 \cdot M1 + 1.25 \cdot M2 + 1.35 \cdot M3 + 1.25 \cdot M4}{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge} + 1.25 \cdot W_{CLP}} = 0.097\ ft$$

$B := B_{GLP} = 7\ ft$ $\frac{e_1}{B} = 0.014$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 6.806\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 26.136\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge} + 1.25 \cdot W_{CLP}}{A'} = 1.753\ ksf$$

For $\frac{e_1}{B} = 0.014$ < 1/6:

$$\sigma_{vmax} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 1.755\ ksf$$

$$\sigma_{vmin} := \left(\frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right)\right) = 1.486\ ksf$$

Retaining Wall 2 (B-B)

$i_\gamma := 1 \quad i_q := 1 \quad i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.046 \qquad s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.044$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.973$

$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.112$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5 \quad C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 12.737\ ksf$

$q_R := \varphi_b \cdot q_n = 7.005\ ksf$ > $\sigma_{vmax} = 1.755\ ksf$ --------> OK

Eccentricity, Sliding and Overturning (top of CLP):

$DC = 10.88\ kip$ Vertical Dead Loads

$P_{a2H} = 8.159\ kip \qquad W_{SoilWedge} = 5.421\ kip$

$P_{a2V} = 7.251\ kip$

Moments for point of rotation 1:

$M1_D := P_{a2H} \cdot \frac{H_2}{3} = 19.263\ ft \cdot kip$ Driving Moment

$M1_{R1R28T} := W_{R28T} \cdot \left(d_{R28T} - c_{R28T}\right) = 1.343\ ft \cdot kip$

$M1_{R1R28M} := W_{R28M} \cdot \left(d_{R28M} - c_{R28M}\right) = 1.892\ ft \cdot kip$

$M1_{R1R41M} := 2 \cdot W_{R41M} \cdot \left(d_{R41M} - c_{R41M}\right) = 7.739\ ft \cdot kip$

$M1_{R1R60B} := W_{R60B} \cdot \left(d_{R60B} - c_{R60B}\right) = 8.094\ ft \cdot kip$ Resisting Moment 1

$M1_{R1} := M1_{R1R28T} + M1_{R1R28M} + M1_{R1R41M} + M1_{R1R60B} = 19.067\ ft \cdot kip$

$M1_{R2} := P_{a2V} \cdot \left(d_{R60B} - \frac{H_2}{3} \tan\left(90\ deg - \theta_2\right)\right) = 29.81\ ft \cdot kip$ Resisting Moment 2

Retaining Wall 2 (B-B)

$M1_{R3} := W_{SoilWedge} \cdot \left(d_{R60B} - C_{SoilWedge}\right) = 21.046\ ft \cdot kip$ Resisting Moment 3

Moments for point of rotation 2:

$$M2_1 := P_{a2H} \cdot \frac{H_2}{3} - P_{a2V} \cdot \left(\frac{d_{R60B}}{2} - \frac{H_2}{3}\ \tan\left(90\ deg - \theta_2\right)\right) = 7.581\ ft \cdot kip$$

$$M2_{2R28T} := W_{R28T} \cdot \left(\frac{d_{R60B}}{2} - \left(c_{R28T} + d_{R60B} - d_{R28T}\right)\right) = -1.732\ ft \cdot kip$$

$$M2_{2R28M} := W_{R28M} \cdot \left(\frac{d_{R60B}}{2} - \left(c_{R28M} + d_{R60B} - d_{R28M}\right)\right) = -2.133\ ft \cdot kip$$

$$M2_{2R41M} := 2 \cdot W_{R41M} \cdot \left(\frac{d_{R60B}}{2} - \left(c_{R41M} + d_{R60B} - d_{R41M}\right)\right) = -3.812\ ft \cdot kip$$

$$M2_{2R60B} := W_{R60B} \cdot \left(\frac{d_{R60B}}{2} - c_{R60B}\right) = -0.456\ ft \cdot kip$$

$$M2_2 := -M2_{2R28T} - M2_{2R28M} - M2_{2R41M} - M2_{2R60B} = 8.133\ ft \cdot kip$$

$$M2_3 := -W_{SoilWedge} \cdot \left(\frac{d_{R60B}}{2} - C_{SoilWedge}\right) = -7.494\ ft \cdot kip$$

Service I (load factors=1.0):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$\phi'_{cc} := 35\ deg$ Concrete to concrete interface friction angle

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot \left(DC + P_{a2V} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{cc}\right) = 13.193\ (kip)$$

$R_{R1} = 13.193\ (kip) >\ P_{a2H} = 8.159\ kip$ ----->OK

Overturning:

$$\frac{M1_{R1} + M1_{R2} + M1_{R3}}{M1_D} = 3.63$$ >1.5 ----->OK

Eccentricity:

$$e_2 := \frac{M2_1 + M2_2 + M2_3}{DC + P_{a2V} + W_{SoilWedge}} = 0.349\ ft$$

Retaining Wall 2 (B-B)

$B := d_{R60B} = 5\ ft$ $\frac{e_2}{B} = 0.07$ <1/3 -----> OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 4.302\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 16.52\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{DC + P_{a2V} + W_{SoilWedge}}{A'} = 1.426\ ksf$$

For $\frac{e_2}{B} = 0.07$ < 1/6:

$$\sigma_{vmax} := \frac{DC + P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 1.74\ ksf$$

$$\sigma_{vmin} := \frac{DC + P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.713\ ksf$$

Strength I-a (DC=0.9; EH=1.5; EV=1.5; $W_{SoilWedge}$=1.0):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot \left(0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{cc}\right) = 14.614\ kip$$

$R_{R1} = 14.614\ kip$ > $1.5 \cdot P_{a2H} = 12.238\ kip$ ----->OK

Overturning:

$$\frac{0.9 \cdot M1_{R1} + 1.5\ M1_{R2} + M1_{R3}}{1.5 \cdot M1_D} = 2.87$$ >1.0 ----->OK

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 0.9 \cdot M2_2 + M2_3}{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}} = 0.429\ ft$$

$B := d_{R60B} = 5\ ft$ $\frac{e_2}{B} = 0.086$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 4.142\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 15.904\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{A'} = 1.64\ ksf$$

For $\frac{e_2}{B} = 0.086$ <1/6:

$$\sigma_{vmax} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 2.059\ ksf$$

$$\sigma_{vmin} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.659\ ksf$$

Strength I-b (DC=1.25; EH=1.5; EV=1.5;W$_{SoilWedge}$=1.35):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot \left(1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}\right) \cdot \tan\left(\phi'_{cc}\right) = 17.81\ kip$$

$R_{R1} = 17.81\ kip$ > $1.5 \cdot P_{a2H} = 12.238\ kip$ ----->OK

Overturning:

$$\frac{1.25 \cdot M1_{R1} + 1.5\ M1_{R2} + 1.35 \cdot M1_{R3}}{1.5 \cdot M1_D} = 3.356$$ >1.0 ----->OK

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 1.25 \cdot M2_2 + 1.35 \cdot M2_3}{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}} = 0.359\ ft$$

$B := d_{R60B} = 5\ ft$ $\frac{e_2}{B} = 0.072$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 4.282\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 16.441\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{A'} = 1.934\ ksf$$

For $\frac{e_2}{B} = 0.072$ <1/6:

$$\sigma_{vmax} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 2.37\ ksf$$

$$\sigma_{vmin} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.942\ ksf$$

Modular Wall Unit Weight:

$V_{R28T} := 8.57\ ft^3$

$V_{R41M} := 16.14\ ft^3$

$V_{R28M} := 11.28\ ft^3$

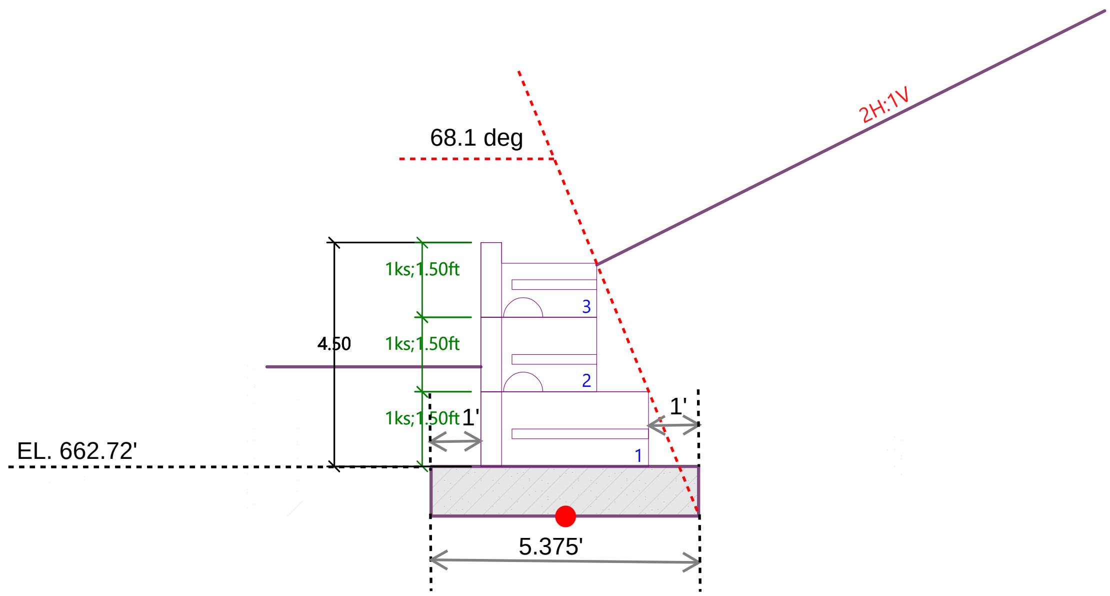
$V_{R60B} := 23.90\ ft^3$

$$\gamma_{ModularWall} := \frac{W_{R28T} + W_{R28M} + 2 \cdot W_{R41M} + W_{R60B}}{V_{R28T} + V_{R28M} + 2 \cdot V_{R41M} + V_{R60B}} = 143.101\ pcf$$

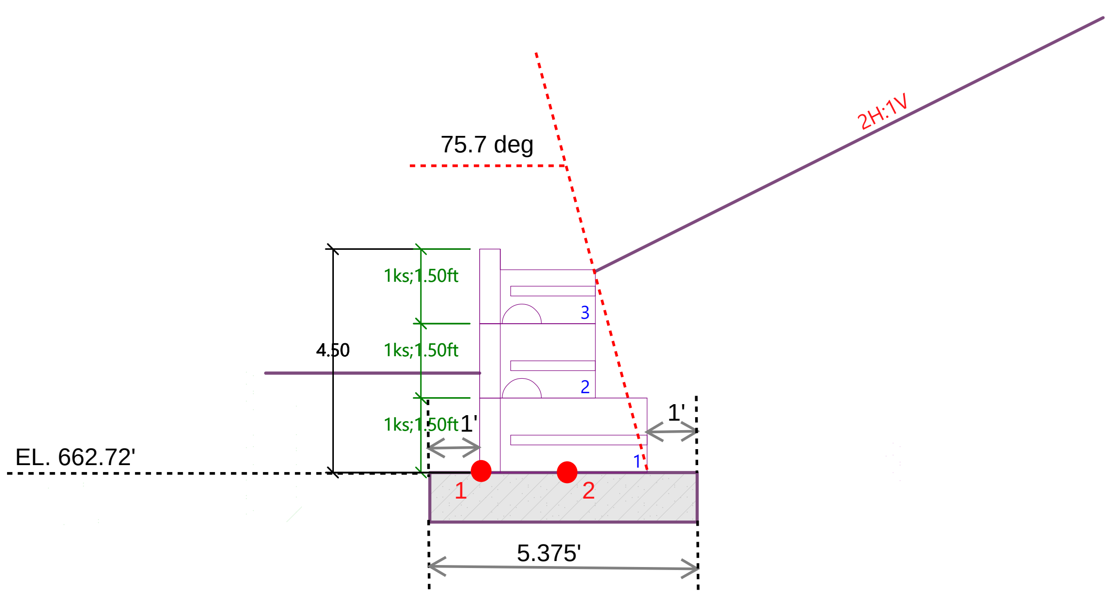
Date: December 27, 2021
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

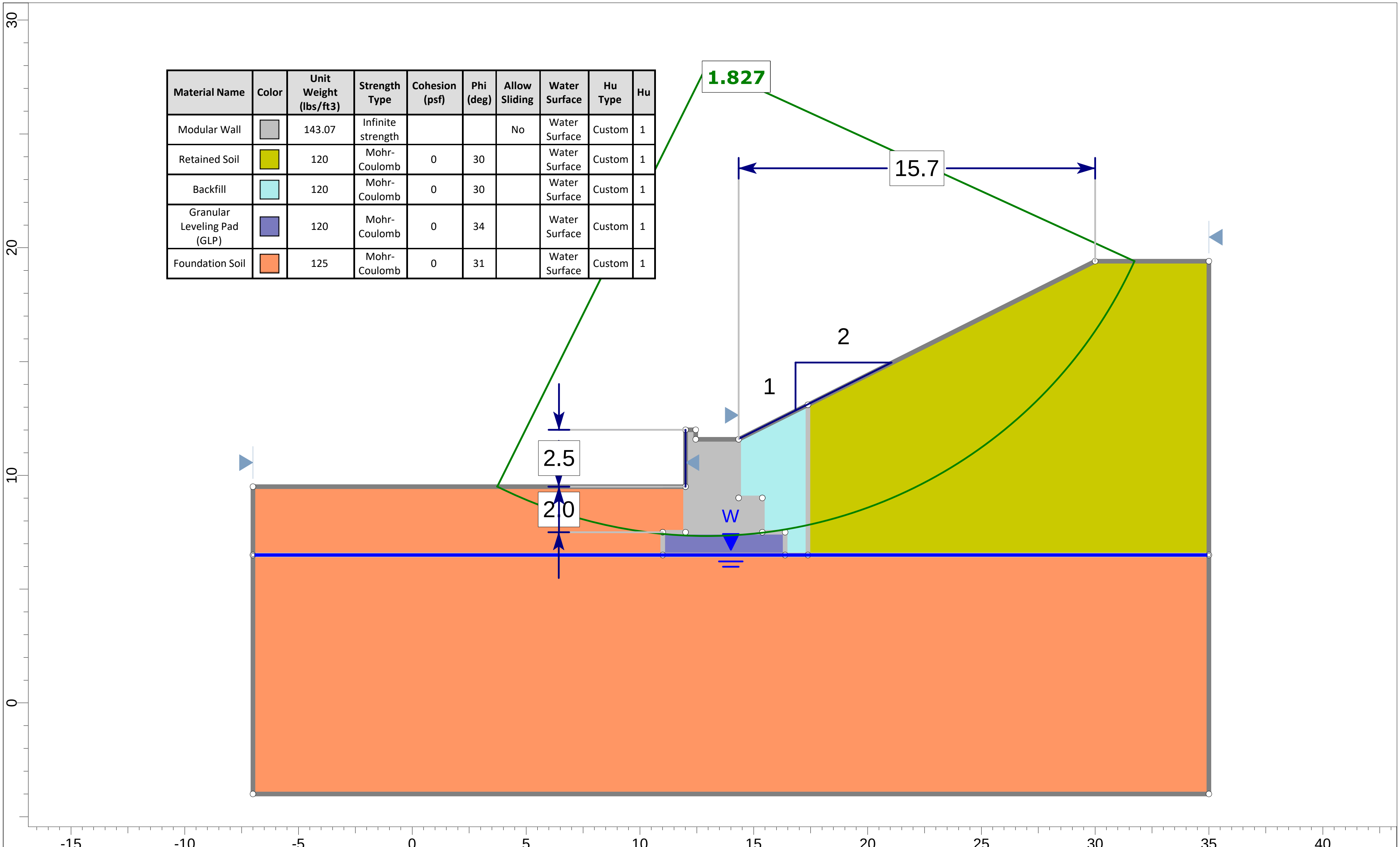
Retaining Wall 3 (C-C)

Bearing and sliding check at bottom of granular leveling pad (GLP)



Sliding, overturning, and eccentricity at bottom of base block:





Material Name	Color	Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Allow Sliding	Water Surface	Hu Type	Hu
Modular Wall		143.07	Infinite strength			No	Water Surface	Custom	1
Retained Soil		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Backfill		120	Mohr-Coulomb	0	30		Water Surface	Custom	1
Granular Leveling Pad (GLP)		120	Mohr-Coulomb	0	34		Water Surface	Custom	1
Foundation Soil		125	Mohr-Coulomb	0	31		Water Surface	Custom	1

Project	LAK-20		
Group	Section C-C	*Scenario*	Master Scenario
Drawn By	JF	*Company*	SME
Date	1/3/2022, 8:30:30 AM	*File Name*	Retaining Wall Section C-C.slmd

SLIDEINTERPRET 9.012

Retaining Wall 3 (C-C)

Date: December 27, 2021
Project Number: 080953.01
Project Name: LAK-20-19.59
Client: CT Consultants

Computed By: Jalal Fatemi
Checked By: Alan J. Esser, PE, DGE

Material Properties:

$\gamma_{GLP} := 120\ pcf$ Granular leveling pad unit weight - BDM Table 307-1

$\phi'_{GLP} := 34\ deg$ Granular leveling pad friction angle - BDM Table 307-1

Foundation Soil Properties:

A-1-b and A-3a soils with average N60= 14 per B-025-3-19

$\gamma_s := 125\ pcf$ Unit weight - GB-7, Table 1

$\phi'_s := 33\ deg$ Friction angle - GB-7, Table 2

$c_s' := 0\ ksf$ Cohesion

Backfill and Retained Soils Properties:

$\gamma_{backfill} := 120\ pcf$ Backfill unit weight - BDM Table 307-1

$\phi'_{backfill} := 30\ deg$ Backfill friction angle - BDM Table 307-1

$\delta_a := 0.7 \cdot \phi'_{backfill} = 21\ deg$ Soil-structure interface friction angle - BDM Article 307.1.1

$\gamma_{retained} := 120\ pcf$ Retained soil unit weight - BDM Table 307-1

$\phi'_{retained} := 30\ deg$ Retained soil friction angle - BDM Table 307-1

Load Combinations and Load Factors (AASHTO Tables 3.4.1-1 and 3.4.1-2):

Strength I
DC -----> Min. = 0.9 ; Max. = 1.25
EH -----> Min. = 0.9 ; Max. = 1.5
EV -----> Min. = 1.0 ; Max. = 1.35

Service I
DC -----> 1.0
EH -----> 1.0
EV -----> 1.0

Retaining Wall 3 (C-C)

Strength Limit State Resistance Factors:

$\varphi_b := 0.55$	Bearing capacity - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{\tau 1} := 1.00$	Sliding (soil on soil) - ASHTO Table 11.5.7-1 and and C10.5.5.2.2
$\varphi_{\tau 2} := 1.00$	Sliding (precast concrete on soil) - AASHTO Table 11.5.7-1 and C10.5.5.2.2
$\varphi_{passive} := 0.50$	Passive pressure for sliding - AASHTO Table 10.5.5.2.2-1 and C10.6.3.4

Prefabricated Modular Blocks Info (Cobble/Limestone):

	Weight	Cenetr of gravity (From the back of blocks)	Block width
R-28T:	$W_{R28T} := 1230\ lbf$	$c_{R28T} := 14.9\ in$	$d_{R28T} := 28\ in$
R-28M:	$W_{R28M} := 1610\ lbf$	$c_{R28M} := 13.9\ in$	$d_{R28M} := 28\ in$
R-41M:	$W_{R41M} := 2310\ lbf$	$c_{R41M} := 20.4\ in$	$d_{R41M} := 40.5\ in$
R-41B:	$W_{R41B} := 2440\ lbf$	$c_{R41B} := 20.7\ in$	$d_{R41B} := 40.5\ in$

Design Loads:

Assumptions:
1. Passive resistance in front of the wall is neglected.
2. Forces are calculated for a block with a length of 46-1/8 in (3.84 ft).
3. Groundwater table, even though deeper than base of the wall, is assumed to be at the wall base. No water pressure will be appied to the wall assuming drained conditions.

Active Earth Pressure:

Bottom of granular leveling pad (GLP):

$$\theta_1 := \operatorname{atan}\left(\frac{13\ in + 2 \cdot 18\ in + 12\ in}{12\ in + 12.5\ in}\right) = 68.118\ deg \qquad \beta := \operatorname{atan}\left(\frac{1}{2}\right) = 26.565\ deg$$

Retaining Wall 3 (C-C)

$$\Gamma_1 := \left(1 + \left(\frac{\sin\left(\phi'_{backfill} + \delta_a\right) \cdot \sin\left(\phi'_{backfill} - \beta\right)}{\sin\left(\theta_1 - \delta_a\right) \cdot \sin\left(\theta_1 + \beta\right)}\right)^{0.5}\right)^2 = 1.569$$

$$K_{a1} := \frac{\left(\sin\left(\theta_1 + \phi'_{backfill}\right)\right)^2}{\Gamma_1 \cdot \left(\sin\left(\theta_1\right)\right)^2 \cdot \sin\left(\theta_1 - \delta_a\right)} = 0.99$$

$H_1 := 13\ in + 2 \cdot 18\ in + 12\ in = 5.083\ ft$ $\quad L := 3.84\ ft$ $\quad$ Block length 46-1/8 in

$$P_{a1} := 0.5 \cdot K_{a1} \cdot \gamma_{backfill} \cdot H_1^{\ 2} \cdot L = 5.895\ kip$$

$$P_{a1H} := P_{a1} \cdot \cos\left(90\ deg - \theta_1 + \delta_a\right) = 4.319\ kip$$

$$P_{a1V} := P_{a1} \cdot \sin\left(90\ deg - \theta_1 + \delta_a\right) = 4.011\ kip$$

Bottom of base block:

$$\theta_2 := \operatorname{atan}\left(\frac{13\ in + 2 \cdot 18\ in}{12.5\ in}\right) = 75.689\ deg$$

$$\Gamma_2 := \left(1 + \left(\frac{\sin\left(\phi'_{backfill} + \delta_a\right) \cdot \sin\left(\phi'_{backfill} - \beta\right)}{\sin\left(\theta_2 - \delta_a\right) \cdot \sin\left(\theta_2 + \beta\right)}\right)^{0.5}\right)^2 = 1.542$$

$$K_{a2} := \frac{\left(\sin\left(\theta_2 + \phi'_{backfill}\right)\right)^2}{\Gamma_1 \cdot \left(\sin\left(\theta_2\right)\right)^2 \cdot \sin\left(\theta_2 - \delta_a\right)} = 0.771$$

$$H_2 := 13\ in + 2 \cdot 18\ in = 4.083\ ft$$

$$P_{a2} := 0.5 \cdot K_{a2} \cdot \gamma_{backfill} \cdot H_2^{\ 2} \cdot L = 2.962\ kip$$

$$P_{a2H} := P_{a2} \cdot \cos\left(90\ deg - \theta_2 + \delta_a\right) = 2.417\ kip$$

$$P_{a2V} := P_{a2} \cdot \sin\left(90\ deg - \theta_2 + \delta_a\right) = 1.712\ kip$$

Soil on Soil Friction:

$\delta_p := 0.67 \cdot \phi'_s = 22.11\ deg$ $\quad$ Soil-on-soil interface friction angle - BDM Article 307.1.1

$$\phi'_s = 33\ deg$$

Retaining Wall 3 (C-C)

GLP and Soil Wedge Weights:

$B_{GLP} := 5.375\ ft$ GLP width $t_{GLP} := 1\ ft$ GLP thickness

$W_{GLP} := B_{GLP} \cdot t_{GLP} \cdot L \cdot \gamma_{GLP} = 2.477\ kip$

$W_{SoilWedge} := (18\ in + 13\ in) \cdot 12.5\ in \cdot L \cdot \gamma_{backfill} = 1.24\ kip$

Bearing and Sliding (bottom of GLP):

$DC := W_{R28T} + W_{R28M} + W_{R41B} = 5.28\ kip$ Vertical Dead Loads

$P_{a1H} = 4.319\ kip$ $W_{GLP} = 2.477\ kip$

$P_{a1V} = 4.011\ kip$ $W_{SoilWedge} = 1.24\ kip$

Moments:

$$M1 := P_{a1H} \cdot \frac{H_1}{3} - P_{a1V} \cdot \left(\frac{B_{GLP}}{2} - \frac{H_1}{3} \tan\left(90\ deg - \theta_1\right) \right) = -0.732\ ft \cdot kip$$

$$M2_{R28T} := W_{R28T} \cdot \left(\frac{B_{GLP}}{2} - \left(c_{R28T} + d_{R41B} - d_{R28T} + 1\ ft\right) \right) = -0.733\ ft \cdot kip$$

$$M2_{R28M} := W_{R28M} \cdot \left(\frac{B_{GLP}}{2} - \left(c_{R28M} + d_{R41B} - d_{R28M} + 1\ ft\right) \right) = -0.825\ ft \cdot kip$$

$$M2_{R41B} := W_{R41B} \cdot \left(\frac{B_{GLP}}{2} - c_{R41B} - 1\ ft \right) = -0.091\ ft \cdot kip$$

$$M2 := -M2_{R28T} - M2_{R28M} - M2_{R41B} = 1.65\ ft \cdot kip$$

$$M3 := W_{GLP} \cdot \left(\frac{B_{GLP}}{2} - \frac{B_{GLP}}{2} \right) - W_{SoilWedge} \cdot \left(\frac{B_{GLP}}{2} - \left(\frac{d_{R41B} - d_{R28T}}{2} + 1\ ft \right) \right) = -1.447\ ft \cdot kip$$

Retaining Wall 3 (C-C)

Service I (load factors=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(DC + P_{a1V} + W_{GLP} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{GLP}\right) = 8.774 \ (kip)$

$R_{R1} = 8.774 \ (kip) > \ P_{a1H} = 4.319 \ kip$ ----->OK

Bearing:

$$e_1 := \text{abs}\left(\frac{M1 + M2 + M3}{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}\right) = 0.041 \ ft$$

$B := B_{GLP} = 5.375 \ ft$ $\frac{e_1}{B} = 0.008$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 5.294 \ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 20.328 \ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{A'} = 0.64 \ ksf$$

For $\frac{e_1}{B} = 0.008$ < 1/6:

$$\sigma_{vmax} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 0.659 \ ksf$$

$$\sigma_{vmin} := \frac{DC + P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 0.602 \ ksf$$

$L' := 100 \ ft$ Total length of the wall

$\gamma_s = 125 \ pcf$ $\phi'_s = 33 \ deg$ $c_s' = 0 \ ksf$ Foundation soil properties

$D_f := 3 \ ft$

$N_\gamma := 35.2$ $N_q := 26.1$ $N_c := 38.6$

AASHTO LRFD Table 10.6.3.1.2a-1

$i_\gamma := 1$ $i_q := 1$ $i_c := 1$

Retaining Wall 3 (C-C)

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.036$ $s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.034$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.979$

$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.139$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 11.234\ ksf$

$q_n = 11.234\ ksf$ > $\sigma_{vmax} = 0.659\ ksf$ --------> OK

Strength I-a (DC&W$_{CLP}$=0.9; EH=1.5; EV=1.5; W$_{GLP,\ SoilWedge}$=1.0):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{GLP}\right) = 9.771\ (kip)$

$R_{R1} = 9.771\ (kip) >\ 1.5 \cdot P_{a1H} = 6.479\ kip$ -----> OK

Bearing:

$e_1 := \operatorname{abs}\left(\frac{1.5 \cdot M1 + 0.9 \cdot M2 + M3}{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}\right) = 0.073\ ft$

$B := B_{GLP} = 5.375\ ft$ $\frac{e_1}{B} = 0.014$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_1 = 5.229\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 20.078\ ft^2$ AASHTO Article 10.6.1.3

$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{A'} = 0.721\ ksf$

For $\frac{e_1}{B} = 0.014$ < 1/6:

$$\sigma_{vmax} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 0.759\ ksf$$

$$\sigma_{vmin} := \frac{0.9 \cdot DC + 1.5 \cdot P_{a1V} + W_{GLP} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 0.645\ ksf$$

$i_\gamma := 1 \quad i_q := 1 \quad i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.035 \qquad s_q := 1 + \left(\frac{B'}{L'} \tan\left(\phi'_s\right)\right) = 1.034$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.979$

$d_q := 1 + 2 \tan\left(\phi'_s\right) \left(1 - \sin\left(\phi'_s\right)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.14$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5 \quad C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 11.17\ ksf$$

$q_R := \varphi_b \cdot q_n = 6.144\ ksf \quad > \sigma_{vmax} = 0.759\ ksf$ --------> OK

Strength I-b (DC&W$_{CLP}$=1.25; EH=1.5; EV=1.5; W$_{GLP,\ SoilWedge}$=1.35):

Sliding:

$C := 1.0$ For crushed stone on soil - AASHTO Article 10.6.3.4

$R_{R1A} := \left(1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}\right) = 17.635\ kip$

$R_{R1} := \varphi_{\tau 1} \cdot C \cdot \left(R_{R1A}\right) \cdot \tan\left(\phi'_{GLP}\right) = 11.895\ (kip)$

$R_{R1} = 11.895\ (kip) > 1.5 \cdot P_{a1H} = 6.479\ kip$ -----> OK

Bearing:

$$e_1 := \operatorname{abs}\left(\frac{1.5 \cdot M1 + 1.25 \cdot M2 + 1.35 \cdot M3}{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}\right) = 0.056\ ft$$

$B := B_{GLP} = 5.375\ ft \qquad \frac{e_1}{B} = 0.01$ <1/3 ----->OK Per AASHTO Article 11.6.3.3

Retaining Wall 3 (C-C)

$B' := B - 2 \cdot e_1 = 5.263\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 20.21\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{A'} = 0.873\ ksf$$

For $\frac{e_1}{B} = 0.01$ < 1/6:

$$\sigma_{vmax} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_1}{B}\right) = 0.908\ ksf$$

$$\sigma_{vmin} := \frac{1.25 \cdot DC + 1.5 \cdot P_{a1V} + 1.35 \cdot W_{GLP} + 1.35 \cdot W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_1}{B}\right) = 0.801\ ksf$$

$i_\gamma := 1$ $i_q := 1$ $i_c := 1$

$s_c := 1 + \left(\frac{B'}{L'}\right) \cdot \frac{N_q}{N_c} = 1.036$ $s_q := 1 + \left(\frac{B'}{L'} \tan(\phi'_s)\right) = 1.034$

$s_\gamma := 1 - 0.4 \left(\frac{B'}{L'}\right) = 0.979$

$d_q := 1 + 2 \tan(\phi'_s) \left(1 - \sin(\phi'_s)\right)^2 \left(\operatorname{atan}\left(\frac{D_f}{B'}\right)\right) = 1.14$

$D_w := 0\ ft$ -----> $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$ Assumed
AASHTO LRFD Table 10.6.3.1.2a-2

$$q_n := \left(\frac{1}{2} \cdot \gamma_s \cdot B' \cdot N_\gamma \cdot s_\gamma \cdot i_\gamma \cdot C_{w\gamma}\right) + \left(\gamma_{backfill} \cdot D_f \cdot N_q \cdot s_q \cdot d_q \cdot i_q \cdot C_{wq}\right) + \left(c_s' \cdot N_c \cdot s_c \cdot i_c\right) = 11.204\ ksf$$

$q_R := \varphi_b \cdot q_n = 6.162\ ksf$ > $\sigma_{vmax} = 0.908\ ksf$ --------> OK

Eccentricity, Sliding and Overturning (top of CLP):

$DC = 5.28\ kip$ Vertical Dead Loads

$P_{a2H} = 2.417\ kip$ $W_{SoilWedge} = 1.24\ kip$

$P_{a2V} = 1.712\ kip$

Retaining Wall 3 (C-C)

Moments for point of rotation 1:

$M1_D := P_{a2H} \cdot \frac{H_2}{3} = 3.29\ ft \cdot kip$ Driving Moment

$M1_{R28T} := W_{R28T} \cdot (d_{R28T} - c_{R28T}) = 1.343\ ft \cdot kip$

$M1_{R28M} := W_{R28M} \cdot (d_{R28M} - c_{R28M}) = 1.892\ ft \cdot kip$

$M1_{R41B} := W_{R41B} \cdot (d_{R41B} - c_{R41B}) = 4.026\ ft \cdot kip$

$M1_{R1} := M1_{R28T} + M1_{R28M} + M1_{R41B} = 7.261\ ft \cdot kip$ Resisting Moment 1

$M1_{R2} := P_{a2V} \cdot \left(d_{R41B} - \frac{H_2}{3} \tan(90\ deg - \theta_2)\right) = 5.185\ ft \cdot kip$ Resisting Moment 2

$M1_{R3} := W_{SoilWedge} \cdot \left(d_{R41B} - \left(\frac{d_{R41B} - d_{R28T}}{2}\right)\right) = 3.539\ ft \cdot kip$

Moments for point of rotation 2:

$M2_1 := P_{a2H} \cdot \frac{H_2}{3} - P_{a2V} \cdot \left(\frac{d_{R41B}}{2} - \frac{H_2}{3} \tan(90\ deg - \theta_2)\right) = 0.995\ ft \cdot kip$

$M2_{R28T} := W_{R28T} \cdot \left(\frac{d_{R41B}}{2} - (c_{R28T} + d_{R41B} - d_{R28T})\right) = -0.733\ ft \cdot kip$

$M2_{R28M} := W_{R28M} \cdot \left(\frac{d_{R41B}}{2} - (c_{R28M} + d_{R41B} - d_{R28M})\right) = -0.825\ ft \cdot kip$

$M2_{R41B} := W_{R41B} \cdot \left(\frac{d_{R41B}}{2} - c_{R41B}\right) = -0.091\ ft \cdot kip$

$M2_2 := -M2_{R28T} - M2_{R28M} - M2_{R41B} = 1.65\ ft \cdot kip$

$M2_3 := -W_{SoilWedge} \cdot \left(\frac{d_{R41B}}{2} - \frac{d_{R41B} - d_{R28T}}{2}\right) = -1.447\ ft \cdot kip$

Service I (load factors=1.0):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$R_{R1} := \varphi_{\tau 2} \cdot C \cdot (DC + P_{a2V} + W_{SoilWedge}) \cdot \tan(\phi'_{GLP}) = 4.442\ (kip)$

$R_{R1} = 4.442\ (kip) > P_{a2H} = 2.417\ kip$ ----->OK

Overturning:

$\frac{M1_{R1} + M1_{R2} + M1_{R3}}{M1_D} = 4.858$ >1.5 ----->OK

Retaining Wall 3 (C-C)

Eccentricity:

$$e_2 := \frac{M2_1 + M2_2 + M2_3}{DC + P_{a2V} + W_{SoilWedge}} = 0.146\ ft$$

$B := d_{R41B} = 3.375\ ft$ $\frac{e_2}{B} = 0.043$ <1/3 -----> OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 3.084\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 11.842\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{DC + P_{a2V} + W_{SoilWedge}}{A'} = 0.695\ ksf$$

For $\frac{e_2}{B} = 0.043$ <1/6:

$$\sigma_{vmax} := \frac{DC + P_{a1V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 1.023\ ksf$$

$$\sigma_{vmin} := \frac{DC + P_{a1V} + W_{SoilWedge}}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.602\ ksf$$

Strength I-a (DC=0.9; EH=1.5; EV=1.5; $W_{SoilWedge}$=1.0):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot \left(0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}\right) \cdot \tan\left(\phi'_{GLP}\right) = 4.619\ kip$$

$R_{R1} = 4.619\ kip$ > $1.5 \cdot P_{a2H} = 3.626\ kip$ ----->OK

Overturning:

$$\frac{0.9 \cdot M1_{R1} + 1.5\ M1_{R2} + M1_{R3}}{1.5 \cdot M1_D} = 3.617$$ >1.0 ----->OK

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 0.9 \cdot M2_2 + M2_3}{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}} = 0.179\ ft$$

$B := d_{R41B} = 3.375\ ft$ $\frac{e_2}{B} = 0.053$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 3.017\ ft$ AASHTO Eq. 10.6.1.3-1

$A' := B' \cdot L = 11.587\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge}}{A'} = 0.739\ ksf$$

For $\frac{e_2}{B} = 0.053$ < 1/6:

$$\sigma_{vmax} := \frac{(0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge})}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 0.871\ ksf$$

$$\sigma_{vmin} := \frac{(0.9 \cdot DC + 1.5 \cdot P_{a2V} + W_{SoilWedge})}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.451\ ksf$$

Strength I-b (DC=1.25; EH=1.5; EV=1.5; $W_{SoilWedge}$=1.35):

Sliding:

$C := 0.8$ For precast footing - AASHTO Article 10.6.3.4

$$R_{R1} := \varphi_{\tau 2} \cdot C \cdot (1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}) \cdot \tan(\phi'_{GLP}) = 5.851\ kip$$

$R_{R1} = 5.851\ kip$ > $1.5 \cdot P_{a2H} = 3.626\ kip$ ----->OK

Overturning:

$$\frac{1.25 \cdot M1_{R1} + 1.5\ M1_{R2} + 1.35 \cdot M1_{R3}}{1.5 \cdot M1_D} = 4.383$$ >1.0 ----->OK

Eccentricity:

$$e_2 := \frac{1.5 \cdot M2_1 + 1.25 \cdot M2_2 + 1.35 \cdot M2_3}{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}} = 0.148\ ft$$

$B := d_{R41B} = 3.375\ ft$ $\frac{e_2}{B} = 0.044$ < 1/3 ----->OK Per AASHTO Article 11.6.3.3

$B' := B - 2 \cdot e_2 = 3.08\ ft$ AASHTO Eq. 10.6.1.3-1

Retaining Wall 3 (C-C)

$A' := B' \cdot L = 11.825\ ft^2$ AASHTO Article 10.6.1.3

$$\sigma_v := \frac{1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}}{A'} = 0.917\ ksf$$

For $\frac{e_2}{B} = 0.044$ <1/6:

$$\sigma_{vmax} := \frac{\left(1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}\right)}{B \cdot L} \cdot \left(1 + 6 \cdot \frac{e_2}{B}\right) = 1.056\ ksf$$

$$\sigma_{vmin} := \frac{\left(1.25 \cdot DC + 1.5 \cdot P_{a2V} + 1.35 \cdot W_{SoilWedge}\right)}{B \cdot L} \cdot \left(1 - 6 \cdot \frac{e_2}{B}\right) = 0.617\ ksf$$

Modular Wall Unit Weight:

$V_{R28T} := 8.57\ ft^3$ $V_{R41M} := 16.14\ ft^3$

$V_{R28M} := 11.28\ ft^3$ $V_{R41B} := 17.06\ ft^3$

$$\gamma_{ModularWall} := \frac{W_{R28T} + W_{R28M} + W_{R41B}}{V_{R28T} + V_{R28M} + V_{R41B}} = 143.051\ pcf$$

APPENDIX C

IMPORTANT INFORMATION ABOUT THIS GEOTECHNICAL ENGINEERING REPORT

Important Information about This

Geotechnical-Engineering Report

Subsurface problems are a principal cause of construction delays, cost overruns, claims, and disputes.

While you cannot eliminate all such risks, you can manage them. The following information is provided to help.

The Geoprofessional Business Association (GBA) has prepared this advisory to help you – assumedly a client representative – interpret and apply this geotechnical-engineering report as effectively as possible. In that way, you can benefit from a lowered exposure to problems associated with subsurface conditions at project sites and development of them that, for decades, have been a principal cause of construction delays, cost overruns, claims, and disputes. If you have questions or want more information about any of the issues discussed herein, contact your GBA-member geotechnical engineer. Active engagement in GBA exposes geotechnical engineers to a wide array of risk-confrontation techniques that can be of genuine benefit for everyone involved with a construction project.

Understand the Geotechnical-Engineering Services Provided for this Report

Geotechnical-engineering services typically include the planning, collection, interpretation, and analysis of exploratory data from widely spaced borings and/or test pits. Field data are combined with results from laboratory tests of soil and rock samples obtained from field exploration (if applicable), observations made during site reconnaissance, and historical information to form one or more models of the expected subsurface conditions beneath the site. Local geology and alterations of the site surface and subsurface by previous and proposed construction are also important considerations. Geotechnical engineers apply their engineering training, experience, and judgment to adapt the requirements of the prospective project to the subsurface model(s). Estimates are made of the subsurface conditions that will likely be exposed during construction as well as the expected performance of foundations and other structures being planned and/or affected by construction activities.

The culmination of these geotechnical-engineering services is typically a geotechnical-engineering report providing the data obtained, a discussion of the subsurface model(s), the engineering and geologic engineering assessments and analyses made, and the recommendations developed to satisfy the given requirements of the project. These reports may be titled investigations, explorations, studies, assessments, or evaluations. Regardless of the title used, the geotechnical-engineering report is an engineering interpretation of the subsurface conditions within the context of the project and does not represent a close examination, systematic inquiry, or thorough investigation of all site and subsurface conditions.

Geotechnical-Engineering Services are Performed for Specific Purposes, Persons, and Projects, and At Specific Times

Geotechnical engineers structure their services to meet the specific needs, goals, and risk management preferences of their clients. A geotechnical-engineering study conducted for a given civil engineer will not likely meet the needs of a civil-works constructor or even a different civil engineer. Because each geotechnical-engineering study is unique, each geotechnical-engineering report is unique, prepared *solely* for the client.

Likewise, geotechnical-engineering services are performed for a specific project and purpose. For example, it is unlikely that a geotechnical-engineering study for a refrigerated warehouse will be the same as one prepared for a parking garage; and a few borings drilled during a preliminary study to evaluate site feasibility will not be adequate to develop geotechnical design recommendations for the project.

Do not rely on this report if your geotechnical engineer prepared it:

- for a different client;
- for a different project or purpose;
- for a different site (that may or may not include all or a portion of the original site); or
- before important events occurred at the site or adjacent to it; e.g., man-made events like construction or environmental remediation, or natural events like floods, droughts, earthquakes, or groundwater fluctuations.

Note, too, the reliability of a geotechnical-engineering report can be affected by the passage of time, because of factors like changed subsurface conditions; new or modified codes, standards, or regulations; or new techniques or tools. *If you are the least bit uncertain* about the continued reliability of this report, contact your geotechnical engineer before applying the recommendations in it. A minor amount of additional testing or analysis after the passage of time – if any is required at all – could prevent major problems.

Read this Report in Full

Costly problems have occurred because those relying on a geotechnical-engineering report did not read the report in its entirety. Do not rely on an executive summary. Do not read selective elements only. *Read and refer to the report in full.*

You Need to Inform Your Geotechnical Engineer About Change

Your geotechnical engineer considered unique, project-specific factors when developing the scope of study behind this report and developing the confirmation-dependent recommendations the report conveys. Typical changes that could erode the reliability of this report include those that affect:

- the site's size or shape;
- the elevation, configuration, location, orientation, function or weight of the proposed structure and the desired performance criteria;
- the composition of the design team; or
- project ownership.

As a general rule, *always* inform your geotechnical engineer of project or site changes – even minor ones – and request an assessment of their impact. *The geotechnical engineer who prepared this report cannot accept* *responsibility or liability for problems that arise because the geotechnical engineer was not informed about developments the engineer otherwise would have considered.*

Most of the "Findings" Related in This Report Are Professional Opinions

Before construction begins, geotechnical engineers explore a site's subsurface using various sampling and testing procedures. *Geotechnical engineers can observe actual subsurface conditions only at those specific locations where sampling and testing is performed.* The data derived from that sampling and testing were reviewed by your geotechnical engineer, who then applied professional judgement to form opinions about subsurface conditions throughout the site. Actual sitewide-subsurface conditions may differ – maybe significantly – from those indicated in this report. Confront that risk by retaining your geotechnical engineer to serve on the design team through project completion to obtain informed guidance quickly, whenever needed.

This Report's Recommendations Are Confirmation-Dependent

The recommendations included in this report – including any options or alternatives – are confirmation-dependent. In other words, they are <u>not</u> final, because the geotechnical engineer who developed them relied heavily on judgement and opinion to do so. Your geotechnical engineer can finalize the recommendations *only after observing actual subsurface conditions* exposed during construction. If through observation your geotechnical engineer confirms that the conditions assumed to exist actually do exist, the recommendations can be relied upon, assuming no other changes have occurred. *The geotechnical engineer who prepared this report cannot assume responsibility or liability for confirmation-dependent recommendations if you fail to retain that engineer to perform construction observation.*

This Report Could Be Misinterpreted

Other design professionals' misinterpretation of geotechnical-engineering reports has resulted in costly problems. Confront that risk by having your geotechnical engineer serve as a continuing member of the design team, to:

- confer with other design-team members;
- help develop specifications;
- review pertinent elements of other design professionals' plans and specifications; and
- be available whenever geotechnical-engineering guidance is needed.

You should also confront the risk of constructors misinterpreting this report. Do so by retaining your geotechnical engineer to participate in prebid and preconstruction conferences and to perform construction-phase observations.

Give Constructors a Complete Report and Guidance

Some owners and design professionals mistakenly believe they can shift unanticipated-subsurface-conditions liability to constructors by limiting the information they provide for bid preparation. To help prevent the costly, contentious problems this practice has caused, include the complete geotechnical-engineering report, along with any attachments or appendices, with your contract documents, *but be certain to note conspicuously that you've included the material for information purposes only.* To avoid misunderstanding, you may also want to note that "informational purposes" means constructors have no right to rely on the interpretations, opinions, conclusions, or recommendations in the report. Be certain that constructors know they may learn about specific project requirements, including options selected from the report, *only* from the design drawings and specifications. Remind constructors that they may perform their own studies if they want to, and *be sure to allow enough time* to permit them to do so. Only then might you be in a position to give constructors the information available to you, while requiring them to at least share some of the financial responsibilities stemming from unanticipated conditions. Conducting prebid and preconstruction conferences can also be valuable in this respect.

Read Responsibility Provisions Closely

Some client representatives, design professionals, and constructors do not realize that geotechnical engineering is far less exact than other engineering disciplines. This happens in part because soil and rock on project sites are typically heterogeneous and not manufactured materials with well-defined engineering properties like steel and concrete. That lack of understanding has nurtured unrealistic expectations that have resulted in disappointments, delays, cost overruns, claims, and disputes. To confront that risk, geotechnical engineers commonly include explanatory provisions in their reports. Sometimes labeled "limitations," many of these provisions indicate where geotechnical engineers' responsibilities begin and end, to help others recognize their own responsibilities and risks. *Read these provisions closely.* Ask questions. Your geotechnical engineer should respond fully and frankly.

Geoenvironmental Concerns Are <u>Not</u> Covered

The personnel, equipment, and techniques used to perform an environmental study – e.g., a "phase-one" or "phase-two" environmental site assessment – differ significantly from those used to perform a geotechnical-engineering study. For that reason, a geotechnical-engineering report does not usually provide environmental findings, conclusions, or recommendations; e.g., about the likelihood of encountering underground storage tanks or regulated contaminants. *Unanticipated subsurface environmental problems have led to project failures.* If you have not obtained your own environmental information about the project site, ask your geotechnical consultant for a recommendation on how to find environmental risk-management guidance.

Obtain Professional Assistance to Deal with Moisture Infiltration and Mold

While your geotechnical engineer may have addressed groundwater, water infiltration, or similar issues in this report, the engineer's services were not designed, conducted, or intended to prevent migration of moisture – including water vapor – from the soil through building slabs and walls and into the building interior, where it can cause mold growth and material-performance deficiencies. Accordingly, ***proper implementation of the geotechnical engineer's recommendations will <u>not</u> of itself be sufficient to prevent moisture infiltration. Confront the risk of moisture infiltration*** by including building-envelope or mold specialists on the design team. ***Geotechnical engineers are <u>not</u> building-envelope or mold specialists.***

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