

**FRA-70-14.05 PROJECT 4B  
RETAINING WALL 4W17  
PID NO. 96053  
FRANKLIN COUNTY, OHIO**

# **STRUCTURE FOUNDATION EXPLORATION REPORT**

***Prepared For:*  
GPD GROUP  
1801 Watermark Drive, Suite 210  
Columbus, OH 43215**

***Prepared By:*  
Resource International, Inc.  
6350 Presidential Gateway  
Columbus, Ohio 43231**

**Rii Project No. W-15-126**

**July 2022**



**RESOURCE INTERNATIONAL, INC.**

6350 Presidential Gateway  
Columbus, Ohio 43231  
T: 614.823.4949

Planning

Engineering

Construction  
Management

Technology

July 8, 2022

Mr. Christopher W. Luzier, P.E.  
Project Manager  
GPD GROUP  
1801 Watermark Drive, Suite 210  
Columbus, OH 43215

**Re: Structure Foundation Exploration Report  
FRA-70-14.05 Project 4B  
Retaining Wall 4W17  
PID No. 96053  
Rii Project No. W-15-126**

Mr. Luzier:

Resource International, Inc. (Rii) is pleased to submit this structure foundation exploration report for the above referenced project. Engineering logs have been prepared and are attached to this report along with the results of laboratory testing. This report includes recommendations for the design and construction of the proposed Retaining Wall 4W17 as part of the FRA-70-14.05 Project 4B in Columbus, Ohio.

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

Sincerely,

**RESOURCE INTERNATIONAL, INC.**

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

Jonathan P. Sterenberg, P.E.  
Vice President – Geotechnical Services

Enclosure: Structure Foundation Exploration Report

**ISO 9001:2015 QMS**

Committed to providing a high quality,  
accurate service to our clients in a timely manner

## TABLE OF CONTENTS

Section	Page
EXECUTIVE SUMMARY .....	I
1.0 INTRODUCTION .....	1
2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT .....	1
2.1 Site Geology .....	1
2.2 Existing Conditions .....	2
3.0 EXPLORATION .....	3
4.0 FINDINGS .....	5
4.1 Surface Materials .....	5
4.2 Subsurface Soils .....	6
4.3 Bedrock .....	7
4.4 Groundwater .....	8
5.0 ANALYSES AND RECOMMENDATIONS .....	9
5.1 Drilled Shaft Recommendations .....	9
5.1.1 Group Efficiency .....	11
5.1.2 Lateral Design .....	12
5.1.3 Drilled Shaft Axial Resistance .....	13
5.1.4 Drilled Shaft Considerations .....	14
5.2 Lateral Earth Pressure .....	15
5.3 Construction Considerations .....	16
5.3.1 Excavation Considerations .....	16
5.3.2 Groundwater Considerations .....	17
6.0 LIMITATIONS OF STUDY .....	17

## **APPENDICIES**

<b>Appendix I</b>	<b>Vicinity Map and Boring Plan</b>
<b>Appendix II</b>	<b>Description of Soil Terms</b>
<b>Appendix III</b>	<b>Project Boring Logs: B-032-6-15, B-033-2-15 and B-034-0-08</b>
<b>Appendix IV</b>	<b>Drilled Shaft Calculations</b>
<b>Appendix V</b>	<b>Lateral Design Parameters</b>

## EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for the design and construction of the proposed Retaining Wall 4W17 located along the north side of I-70 westbound between the S. Third Street bridge (FRA-33-1747) and the S. Fourth Street bridge (FRA-23-1075) over I-70/I-71. Based on design information provided by GPD GROUP, it is understood that the proposed structure will consist of a tangent drilled shaft retaining wall type, which will connect to the forward abutment of the FRA-33-1747 bridge structure at Sta. 200+56.26 (BL I-70 WB) and extend east to connect to the forward abutment of the FRA-23-1072 bridge structure at Sta. 203+60.76 (BL I-70 WB). The wall height along the alignment of the wall ranges from 29.5 to 32.4 feet, as measured from the bottom of footing (bottom of wall facing panels) to the top of the wall, and the overall length of the wall is 304.5 feet.

### Drilled Shaft Recommendations

While the design of a tangent shaft retaining wall is controlled by lateral check of the shaft elements, the drilled shafts may be designed using the axial design parameters provided in Table 6 in Section 5.1 of the full report. Based on the subsurface conditions encountered, the embedded sections of the shafts will bear in medium dense to very dense gravel, gravel and sand, fine sand, sandy silt and silt (ODOT A-1-a, A-1-b, A-3, A-4a, A-4b) with seams of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a). Given that the drilled shafts will be constructed tangent to each other, group efficiency of the foundation for axial resistance will also need to be considered, as outlined in Section 5.1.1 of the full report. Lateral analysis of the shafts should be performed to determine the required embedment depth and cross section of the shafts as outlined in Section 5.1.2 of the full report.

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



## 1.0 INTRODUCTION

The overall purpose of this project is to provide detailed subsurface information and recommendations for the design and construction of the FRA-70-14.05 Project 4B in Columbus, Ohio. The project represents the central portion of FRA-70-8.93 (PID 77369) I-70/71 south innerbelt improvements project. The FRA-70-14.05 Project 4B phase will consist of all work associated with the construction of the I-70/I-71 corridor from just east of S. High Street to just west of Grant Avenue, as well as a minimal amount of work Fulton Street and at the intersections of S. Third Street and S. Fourth Street with Livingston Avenue. This project includes the replacement of the FRA-33-1747 (S. Third Street) and FRA-23-1075 (S. Fourth Street) bridge structures over I-70/71, as well as the construction of three (3) new retaining walls along the north side and two (2) new retaining walls along the south side of I-70/71 to accommodate the new configuration.

This report is a presentation of the structure foundation exploration performed for the design and construction of the proposed Retaining Wall 4W17 located along the north side of I-70 westbound between the S. Third Street bridge (FRA-33-1747) and the S. Fourth Street bridge (FRA-23-1075) over I-70/I-71, as shown on the vicinity map and boring plan presented in Appendix I. Based on design information provided by GPD GROUP, it is understood that the proposed structure will consist of a tangent drilled shaft retaining wall type, which will connect to the forward abutment of the FRA-33-1747 bridge structure at Sta. 200+56.26 (BL I-70 WB) and extend east to connect to the forward abutment of the FRA-23-1072 bridge structure at Sta. 203+60.76 (BL I-70 WB). The wall height along the alignment of the wall ranges from 29.5 to 32.4 feet, as measured from the bottom of footing (bottom of wall facing panels) to the top of the wall, and the overall length of the wall is 304.5 feet.

## 2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

### 2.1 Site Geology

Several episodes of ice advanced throughout Ohio during the Pleistocene Epoch. Both the Illinoian and Wisconsinan glaciers advanced over two-thirds of the state, leaving behind glacial features such as moraines, kame deposits, lacustrine deposits and outwash terraces. The glacial and non-glacial regions comprise five physiographic sections grouped by age, depositional process and geomorphic occurrence (physical features or landforms). The project area lies within the Columbus Lowland District of the Till Plains Section. The project area is characterized by flat to gently rolling ground moraine deposits of the Late Wisconsinan age with large alluvium and outwash deposits bordering the Scioto River, its tributaries and floodplain areas. Ground moraines are deposited during the retreat of a glacier, which results in an undifferentiated mixture of clay, silt, sand and gravel. Alluvium and alluvial terrace deposits range from silty clay to cobble sized deposits, usually deposited in present and former floodplain areas. Outwash deposits consist of undifferentiated sand and gravel deposited by meltwater in front of glacial ice.

Based on bedrock geology and topography maps obtained from Ohio Department of Natural Resources (ODNR), the bedrock beneath the project site consists of three formations. The project alignment extends east from the top of the eastern slope of a bedrock valley that generally follows the Scioto River valley, with the youngest formation at the top of the slope and the oldest formation within the bedrock valley. The youngest formation consists of the Upper Devonian-aged Ohio Shale Formation, which consists of three members, from youngest to oldest: the Cleveland, Chagrin, and Huron Members. These members consist of primarily shale with siltstone and very fine-grained sandstone, varying in color from brownish black to greenish gray. The bedding ranges from laminated to thinly bedded and the overall formation ranges between 250 to over 500 feet thick. The Middle Devonian-aged Delaware Limestone formation, which can be present along the slopes of the bedrock valley, consists of bluish-gray, dolomitic limestone, with thin to medium bedding, and contains nodules and layers of chert. The formation ranges between 0 to 45 feet thick and is not present south of Franklin County. The oldest unit, which present within the bedrock valley, is the Middle to Lower Devonian-aged Columbus Limestone Formation, which is further subdivided into four members, two of which are predominant in the central portion of the state, known as the Delhi and Bellepoint Members. The Delhi Member consists of light gray, finely to coarsely crystalline, irregularly bedded, fossiliferous limestone. The Bellepoint Member consists of variable brown, finely crystalline, massively bedded, limy dolomite. Both of these members contain chert nodules, and the entire formation ranges between 0 to 105 feet thick.

The bedrock surface in the vicinity of the site forms a broad valley which roughly follows the present day Scioto River valley. The site lies on a slight plateaued area and slope along the east side of the valley where the underlying bedrock surface lies at an approximate elevation of 625 to 630 feet mean sea level and slopes down toward the west to an approximate elevation of 600 feet msl in the bedrock valley. According to bedrock topography mapping, the depth to the bedrock surface below the site ranges between approximately 105 to 135 feet below existing grade. Shale bedrock was encountered in several of the borings performed along the corridor at elevations ranging from 630 to 650 feet msl, increasing in elevation from west to east across the project alignment.

## **2.2 Existing Conditions**

As stated, the proposed Retaining Wall 4W17 is located along the north side of I-70/I-71 between S. Third Street and S. Fourth Street, approximately 0.95 miles east of the Scioto River. The existing I-70/I-71 in the vicinity of the structure is a six-lane, bi-directional, composite asphalt and concrete paved roadway that is generally east-west aligned through downtown Columbus, Ohio. The existing I-70 profile is lowered from the surrounding terrain, as the existing corridor was cut approximately 25 to 30 feet below the existing grade of S. Third Street and S. Fourth Street as well as the surrounding downtown area. The proposed wall alignment is situated along the top of the grass covered graded slope that extends down from the south side of W. Fulton Street to the I-70 roadway. This traffic volume along the project alignment is very high,

and the alignment traverses primarily commercial and government properties. The regional topography generally slopes downward to the west and south toward the Scioto River.

### 3.0 EXPLORATION

Between October 1 and 5, 2015, two (2) structure borings, designated as B-032-6-15 and B-033-2-15, were advanced to a completion depth of 80.0 and 70.0 feet below the existing ground surface, respectively, along the proposed wall alignment. In addition to the borings performed by Rii as part of the current exploration, one (1) boring, designated as B-034-0-08, was performed by DLZ along the proposed wall alignment as part of the FRA-70-8.93 preliminary exploration (PID 77369), and their findings were published in a report dated September 24, 2009. The boring was performed between August 7 and 14, 2008, and was advanced to a completion depth of 135.5 feet below the existing ground surface. The current and preliminary exploration boring locations are shown on the boring plan provided in Appendix I of this report and summarized in Table 1 below.

**Table 1. Test Boring Summary**

Boring Number	Reference Alignment	Station	Offset	Latitude	Longitude	Ground Elevation (feet msl)	Boring Depth (feet)
B-032-6-15	CL Third St.	1152+85.60	44.9' Rt.	39.953656	-82.996128	753.0	80.0
B-033-2-15	BL I-70 WB	202+00.30	84.3' Lt.	39.953812	-82.995473	751.6	70.0
B-034-0-08	BL I-70 WB	203+85.26	56.6' LT	39.953825	-82.994806	751.5	135.5

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

The borings performed by Rii for the current exploration were drilled using an all-terrain vehicle (ATV) mounted rotary drilling machine, utilizing a 3.25-inch inside diameter hollow-stem auger to advance the holes. The boring performed by DLZ was drilled using an ATV mounted rotary drilling machine, utilizing a 4.0-inch flush joint casing to advance the holes.

Standard penetration test (SPT) and split spoon sampling were performed in borings B-033-2-15 and B-034-0-08 at 2.5-foot intervals to a depth of 20.0 and 45.0 feet, respectively, and at 5.0-foot intervals thereafter to the boring termination depth in boring B-033-2-15 and to the top of bedrock in boring B-034-0-08. Boring B-032-6-15 was



sampled at 5.0-foot intervals to a depth of 20.0 feet, at 2.5-foot intervals to a depth of 50.0 feet and at 5.0-foot intervals thereafter to the boring termination depth. The SPT, per the American Society for Testing and Materials (ASTM) designation D1586, is conducted using a 140-pound hammer falling 30.0 inches to drive a 2.0-inch outside diameter split spoon sampler 18.0 inches. A calibrated automatic drop hammer was utilized by Rii and DLZ to generate consistent energy transfer to the sampler. Driving resistance is recorded on the boring logs in terms of blows per 6.0-inch interval of the driving distance. The second and third intervals are added to obtain the number of blows per foot (N). Standard penetration blow counts aid in determining soil properties applicable in foundation system design. Measured blow count (N) values are corrected to an equivalent (60%) energy ratio,  $N_{60}$ , by the following equation. Both values are represented on boring logs in Appendix III.

$$N_{60} = N_m \cdot (ER/60)$$

Where:

$N_m$  = measured N value

ER = drill rod energy ratio, expressed as a percent, for the system used

The hammer for the CME 750X ATV mounted drill rig operated by Rii was calibrated on October 20, 2014, and has a drill rod energy ratio of 85.7 percent. The hammer for the CME 750X drill rig operated by DLZ was calibrated on February 15, 2018, and has a drill rod energy ratio of 63.1 percent.

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

Where boring B-034-0-08 was extended into the underlying bedrock by DLZ, an NMX or NQ-sized double-tube diamond bit core barrel (utilizing wire line equipment) was used to core the bedrock. The Rock Quality Designation (RQD) for each rock core run was provided on the boring log.

The borings performed by Rii for the current exploration were backfilled with a mixture of bentonite chips and soil cuttings, and the pavement surface was patched with an equivalent thickness of quick set concrete. Abandonment notes for the boring performed by DLZ were not provided on the boring log.

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

**Table 2. Laboratory Test Schedule**

Laboratory Test	Test Designation	Number of Tests Performed
Natural Moisture Content	ASTM D 2216	40
Plastic and Liquid Limits	AASHTO T89, T90	17
Gradation – Sieve/Hydrometer	AASHTO T88	17
Sulfate Content – Colorimetric Method	TEX-145-E	1

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

## 4.0 FINDINGS

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

### 4.1 Surface Materials

Boring B-032-6-15 was performed in the existing pavement of S. Third Street and encountered 4.0 inches of asphalt overlying 6.0 inches of concrete followed by 26.0 inches of aggregate base at the ground surface. Boring B-033-2-15 was performed in the existing pavement of Fulton Street and encountered 4.0 inches of asphalt overlying 8.0 inches of concrete followed by 6.0 inches of aggregate base at the ground surface. Boring B-034-0-08 was performed at the top of the slope in the grass berm on the south side of Fulton Street, west of S. Fourth Street, and encountered 3.0 inches of topsoil at the ground surface.

## 4.2 Subsurface Soils

Beneath the topsoil in boring B-034-0-08, material identified as existing fill was encountered extending to a depth of 18.5 feet below existing grade, which corresponds to an elevation of 733.0 feet msl. The fill material was described as loose to medium dense, brown gravel and sand (ODOT A-1-b) and stiff, brown sandy silt (ODOT A-4a) and contained brick fragments throughout, as noted on the visual descriptions provided on the boring logs. Two thick layers of brick fragments were also present within the fill material.

Underlying the surficial materials and existing fill, natural granular soils were encountered with intermittent seams and layers of cohesive material. The granular soils were described as loose to very dense, gray, brown and brownish gray gravel, gravel and sand, fine sand, coarse and fine sand, sandy silt and silt (ODOT A-1-a, A-1-b, A-3, A-3a, A-4a, A-4b). The seams and layers of cohesive material were described as very soft to hard, gray, brown and dark brown sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b).

The relative density of granular soils is primarily derived from SPT blow counts ( $N_{60}$ ). Based on the SPT blow counts obtained, the granular soil encountered ranged from loose ( $5 \leq N_{60} \leq 10$  blows per foot [bpf]) to very dense ( $N_{60} > 50$  bpf). Blow counts recorded from the SPT sampling within the granular soils ranged from 8 bpf to split spoon sampler refusal. Split spoon sampler refusal is defined as exceeding 50 blows from the hammer with less than 6.0 inches of penetration by the split spoon sampler. The shear strength and consistency of the cohesive soils are primarily derived from the hand penetrometer values (HP). The cohesive soil encountered ranged from very soft ( $HP \leq 0.25$  tsf) to hard ( $HP > 4.0$  tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 0.25 to over 4.5 tsf (limit of instrument).

Natural moisture contents of the cohesive soil samples ranged from 7 to 23 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 1 to 5 percent below their corresponding plastic limits. The seams of cohesive soil exhibited natural moisture contents considered to be slightly to moderately below optimum moisture levels. Natural moisture contents of the granular soil samples ranged from 4 to 22 percent, which were visually described as moist to wet.

### 4.3 Bedrock

Bedrock was encountered in boring B-034-0-08 as presented in Table 3.

**Table 3. Top of Bedrock Elevations**

Boring Number	Ground Surface Elevation (feet msl)	Top of Bedrock		Top of Bedrock Core	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-034-0-08	751.5	115.0	636.5	115.5	636.0

Top of bedrock was encountered in boring B-034-0-08 at a depth of 115.0 feet below existing grade, which corresponds to an elevation of 636.5 feet msl. The bedrock consisted of gray, severely weathered shale overlying dark gray, highly to severely weathered shale. The cored shale bedrock is described as dark gray, highly to severely weathered, weak, thinly laminated, calcareous, pyritic, fissile, jointed and fractured with tight, slightly rough apertures.

The percent recovery and RQD values from the bedrock core runs in boring B-034-0-08 are summarized in Table 4.

**Table 4. Rock Core Summary**

Boring	Core No.	Depth (feet)	Recovery (%)	RQD (%)
B-034-0-08	R-1	115.5 to 120.5	65	55
	R-2	120.5 to 125.5	88	77
	R-3	125.5 to 130.5	100	57
	R-5	130.5 to 135.5	100	85

It should be noted that bedrock can experience mechanical breaks during the drilling and coring processes. It is anticipated that DLZ attempted to account for fresh, manmade breaks during tabulation of the RQD analysis, per ODOT SGE specifications. The quality of the shale bedrock, according to the RQD values, was fair ( $50 < \text{RQD} \leq 75\%$ ) to good ( $75 < \text{RQD} \leq 90\%$ ).

#### 4.4 Groundwater

Groundwater was encountered in the borings as presented in Table 5.

**Table 5. Groundwater Levels**

Boring Number	Ground Elevation (feet msl)	Initial Groundwater		Upon Completion	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-032-6-15	753.0	31.0	722.0	N/A <sup>1</sup>	-
B-033-2-15	751.6	33.5	718.1	N/A <sup>1</sup>	-
B-034-0-08	751.5	28.5	723.0	43.3 <sup>2</sup>	708.2

1. The groundwater level at completion could not be obtained due to the addition of water or mud as a drilling fluid.
2. Groundwater level at completion of drilling was measured inside the casing, and may be influenced by the introduction of water during the coring process.

Seepage was observed in boring B-033-2-15 at a depth of 28.5 feet below the existing ground surface. Groundwater was encountered initially during the drilling process in borings B-032-6-15, B-033-2-15 and B-034-0-08 at a depths ranging from 28.5 to 33.5 feet below the existing ground surface, which corresponds to elevations ranging from 718.1 to 723.0 feet msl. At the completion of drilling, groundwater was encountered in boring B-034-0-08 at a depth of 43.3 feet below grade, which corresponds to an elevation of 708.2 feet msl. It should be noted that the groundwater level at completion of drilling in boring B-034-0-08 was measured inside the casing, and may be influenced by the introduction of water during the coring process. The groundwater level at the completion of drilling in borings B-032-6-15 and B-033-2-15 could not be measured due to the addition of water or mud to counteract heaving sands.

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

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

## 5.0 ANALYSES AND RECOMMENDATIONS

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

Design details of the proposed retaining wall were provided by GPD GROUP. Based on the information provided, it is understood that Retaining Wall 4W17 will be a tangent drilled shaft wall type. The roadway profile grade along the proposed I-70 westbound will be cut approximately 22 to 24.5 feet from the existing ground surface grade to the proposed roadway profile grade, as measured from the top of the wall to the toe of the barrier at the facing of the wall. Based the top of wall elevations provided, it is anticipated that no cut or fill will be required behind the walls.

### 5.1 Drilled Shaft Recommendations

While the design of a tangent shaft retaining wall is controlled by lateral check of the shaft elements, the drilled shafts may be designed using the axial design parameters provided in Table 6. In the analysis, the top of shaft elevations for the embedded sections of the shafts were considered at the bottom of wall elevation. Based on the subsurface conditions encountered, the embedded sections of the shafts will bear in medium dense to very dense gravel, gravel and sand, fine sand, sandy silt and silt (ODOT A-1-a, A-1-b, A-3, A-4a, A-4b) with seams of very stiff to hard sandy silt and silt and clay (ODOT A-4a, A-6a). The drilled shafts should be proportioned for a nominal bearing resistance as presented in Table 6.

**Table 6. Retaining Wall 4W17 Drilled Shaft Axial Design Parameters**

Boring	Elevation <sup>1</sup> (feet msl)	Shaft Length (feet)	Soil Type	Nominal Unit Resistance (ksf)		Resistance Factor	
				End	Side	End	Side
B-032-6-15	720.5-712.5	0.0-8.0	A-1-a	60	1.42	0.50	0.55
	712.5-707.5	8.0-13.0	A-1-b	44	1.22	0.50	0.55
	707.5-701.0	13.0-19.5	A-1-a	46	1.54	0.50	0.55
	701.0-696.0	19.5-24.5	A-1-b	36	1.39	0.50	0.55
	696.0-686.0	24.5-34.5	A-1-a	60	2.62	0.50	0.55
	686.0-673.0	34.5-47.5	A-1-a	60	4.79	0.50	0.55

Boring	Elevation <sup>1</sup> (feet msl)	Shaft Length (feet)	Soil Type	Nominal Unit Resistance (ksf)		Resistance Factor	
				End	Side	End	Side
B-033-2-15	720.5-719.6	0.0-0.9	A-1-b	60	0.86	0.50	0.55
	719.6-712.1	0.9-8.4	A-1-b	44	0.92	0.50	0.55
	712.1-709.6	8.4-10.9	A-3	60	1.56	0.50	0.55
	709.6-704.6	10.9-15.9	A-4a	72	3.60	0.40	0.45
	704.6-701.6	15.9-18.9	A-3	60	1.79	0.50	0.55
	701.6-699.6	18.9-20.9	A-4a	56	2.81	0.40	0.45
	699.6-681.6	20.9-38.9	A-1-b	60	4.41	0.50	0.55
B-034-0-08	720.5-718.0	0.0-2.5	A-1-a	20	0.30	0.50	0.55
	718.0-713.0	2.5-7.5	A-1-b	58	1.17	0.50	0.55
	713.0-710.5	7.5-10.0	A-4b	60	2.11	0.50	0.55
	710.5-707.5	10.0-13.0	A-1-a	21	0.77	0.50	0.55
	707.5-704.5	13.0-16.0	A-6a	65	3.26	0.40	0.45
	704.5-701.5	16.0-19.0	A-1-a	60	3.77	0.50	0.55
	701.5-689.5	19.0-31.0	A-4a	42	2.26	0.40	0.45
	689.5-684.5	31.0-36.0	A-1-a	60	4.72	0.50	0.55
	684.5-664.5	36.0-56.0	A-1-b	60	4.85	0.50	0.55
	664.5-659.5	56.0-61.0	A-4a	60	5.59	0.50	0.55
	659.5-636.5	61.0-84.0	A-1-b	60	5.54	0.50	0.55

1. Top of shaft elevation based on structure information provided by GPD GROUP.

Drilled shaft lengths should measure a minimum of three (3) times the shaft diameter. Per Section 10.8.3.5.3 of the AASHTO LRFD Bridge Design Specifications (BDS), where drilled shafts are extended to end bear in a strong soil layer overlying a weaker soil layer, the end bearing resistance shall be reduced if the tip elevation is within 1.5 times the diameter of the drilled shaft above the top of the weaker soil layer. A weighted average that varies linearly from the full end bearing resistance in the overlying strong soil layer at a distance of 1.5 times the diameter of the drilled shaft above the top of the weak soil layer to the end bearing resistance of the weak soil layer at the top of the weak soil layer should be used to determine the end bearing resistance utilized in the design. Therefore, the end bearing resistance utilized in the design will need to be adjusted accordingly if the tip elevation of the drilled shafts will be within 1.5 times the diameter of the drilled shaft above the underlying weaker soil layer.



It is anticipated that 100 percent of the side friction resistance will be mobilized at a displacement of 1.0 percent of the diameter of the shaft, which is approximately 0.4 inches for a 3.5-foot diameter shaft. At this displacement, approximately 30 percent of the end bearing resistance will be mobilized. Therefore, the nominal end bearing resistance noted in Table 6 should be reduced to 30 percent of the values provided for the respective tip elevation in the determination of the design shaft resistance. Drilled shaft calculations are provided in Appendix IV.

### 5.1.1 Group Efficiency

The axial resistance of a group of shafts may be less than the sum of the individual shaft resistance within a group of shafts. Per Section 10.8.3.6.3 of the AASHTO LRFD BDS, for soil profiles that consist of primarily granular soils, the individual nominal resistance of each drilled shaft shall be reduced by applying an adjustment factor,  $\eta$ , as defined in Table 10.8.3.6.1-1 of the AASHTO LRFD BDS. The following criteria are recommended for the group resistance of any shaft groups:

- $\eta = 0.9$  for a center-to-center spacing of 2.0 diameters,
- $\eta = 1.0$  for a center-to-center spacing of 3.0 diameters or greater,
- For intermediate spacing, the value of  $\eta$  may be determined by liner interpolation.

Please note that the adjustment factor should be applied to the total individual nominal shaft resistance (including both end bearing side resistance along the shaft length).

Given that the drilled shafts will be constructed tangent to each other, the shaft group capacity should also be checked using the block failure mechanism. Since the soil profile consists primarily of dense granular soils, the analysis should be performed considering the entire drilled shaft group as an equivalent strip footing with a length equal to the length of the tangent shaft wall and equivalent width equal to the total end area of the drilled shafts divided by the length of the drilled shaft wall. A resistance factor of  $\phi_b = 0.45$  should be utilized in calculating the factored bearing resistance for the this failure mode at the strength limit state.

The total group resistance shall be the lesser of the sum of the individual drilled shafts multiplied by the applicable group efficiency factor,  $\eta$ , or the factored resistance of the group in block failure mode.



### 5.1.2 Lateral Design

If lateral load or moments are expected to be applied on the foundation elements, they should be analyzed to verify the shaft has enough lateral and bending resistance against these loads. A boring-by-boring tabulation of parameters that should be used for lateral loading design is provided in Appendix V. In order to evaluate the lateral capacity, it is recommended that a derivation of COM624, such as LPILE, be utilized to determine the proper embedment depth and cross section required to resist the lateral load for a given end condition and deflection. Table 7 lists the eleven different soil types internal to the LPILE program. These strata were utilized to define the soil strata in the soil profile for each boring provided in Appendix V.

**Table 7. Subsurface Strata Description**

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

For the case of closely spaced drilled shafts, a pile group reduction factor will need to be applied to the p-y curves that are internally generated by the lateral analysis software. Reese, Isenhower, and Wang published an equation for the pile group p-reduction factor, otherwise known as p-multiplier ( $\beta_a$ ), for a single row of piles placed side by side in the publication "Analysis and Design of Shallow and Deep Foundations" (2006), as follows:

$$\beta_a = 0.64(S/D)^{0.34}$$

In which:

$$1 \leq S/D < 3.75 \text{ and } 0.5 \leq \beta_a \leq 1.0$$

Where:

S = center to center spacing of the drilled shafts

D = diameter of drilled shafts

It is understood that GPD GROUP has performed an analysis of the lateral loading on the drilled shaft elements, which were utilized to determine the shaft tip elevation provided in the design plans.

### 5.1.3 Drilled Shaft Axial Resistance

The nominal and factored drilled shaft axial resistance has been calculated for Retaining Wall 4W17, which is summarized in Table 8 below. The tip elevation ranges from 671.9 to 674.0 feet msl based on the plan information provided, so the higher elevation of 674.0 feet msl was utilized in the axial resistance calculations. For the traditional drilled shaft analysis, only end bearing resistance was accounted for in the determination of the nominal and factored axial resistance. A group reduction factor of 0.9 was utilized based on the center to center spacing of the shafts. Based on the tip elevation provided, the drilled shafts will end bear within a layer of very dense gravel and gravel with sand (ODOT A-1-a, A-1-b), which has a calculated nominal end bearing resistance of 60 ksf.

The bearing resistance for the block failure mode was also checked since the drilled shafts will be constructed tangent to each other. Based on the shaft tip elevation provided, the shafts will be bearing in very dense gravel and gravel with sand (ODOT A-1-a, A-1-b). Using the friction angle for the very dense gravel and gravel with sand (ODOT A-1-a, A-1-b), the resulting nominal unit bearing resistance is 370.9 ksf and the factored unit bearing resistance is 185.5 ksf, considering a resistance factor of 0.5.

**Table 8. Retaining Wall 4W17 Drilled Shaft Recommendations**

Drilled Shaft Analysis Methodology	Shaft Diameter (feet)	Shaft Elevation (feet msl)		Shaft Length (feet)	C-C Shaft Spacing (feet)	Nominal Resistance <sup>1</sup> (kips)			Factored Resistance (kips)		
		Top <sup>2</sup>	Tip			End	Side	Total	End <sup>3</sup>	Side	Total
Traditional	4.0	720.5	671.9	48.6	4.0	679	N/A	679	339	N/A	339
Traditional	5.0	720.5	674.0	46.5	5.0	1,060	N/A	1,060	530	N/A	530
Block	4.0 / 5.0	720.5	674.0	46.5	4.0 / 5.0	7,283	N/A	7,283	3,641	N/A	3,641

1. A group reduction factor of 0.9 was utilized based on the center-to-center spacing of the shafts for the traditional analysis methodology.
2. Top of shaft elevation corresponds to the bottom of wall elevation.
3. A resistance factor of 0.5 was utilized for both the traditional drilled shaft analysis methodology and the block failure mode.

The controlling resistance between the traditional drilled shaft analysis methodology and block failure mode is 339 and 530 kips/shaft for 48 and 60-inch diameter shafts, respectively. The maximum factored load per shaft is 108 and 162 kips/shaft for 48 and 60-inch diameter shafts, respectively, based on the structural loading information provided by GPD GROUP. Calculations for the drilled shaft axial resistance are provided in Appendix IV.

#### **5.1.4 Drilled Shaft Considerations**

The minimum requirements for proper inspection of drilled shaft construction are as follows:

- A qualified inspector should record the material types being removed from the hole as excavation proceeds.
- When the bearing material has been encountered and identified and/or the design tip elevation has been reached, the shaft walls and base should be observed for anomalies, unexpected soft soil conditions, obstructions or caving.
- Due to the presence of granular soils with relatively high groundwater, it is recommend mud or slurry be utilized in the shaft excavation to counterbalance the hydrostatic head at the bottom of the excavation and minimize the potential for “heave” of the soils up and into the shaft excavation.
- Concrete placed freefall should not be allowed to hit the sidewalls of the excavation or the rebar cage and should not pass through any water.
- Structural stability of the rebar cage should be maintained during the concrete pour to prevent buckling.
- The volume of concrete should be checked to ensure voids did not result during extraction of the casing (if utilized).
- The placement of all concrete for the drilled shafts shall follow the American Concrete Institute’s Design and Construction of Drilled Piers (ACI 336.3R-93).
- If concrete is placed by tremie method, it must be done so with an adequate head to displace water or slurry if groundwater has entered the caisson (all tremie procedures shall follow applicable ACI specifications).
- Pulling casing with insufficient concrete inside should be restricted.
- The bottom of drilled shaft excavation should be clean and free of loose material. Any loose material observed should be removed using a clean-out bucket (muck bucket).

The use of casing for drilled shafts is recommended under any of the following conditions:

- Caving material is encountered at any time during the drilling of the shaft.
- Groundwater is encountered at any time during the drilling of the shaft, or groundwater seepage occurs in the drilled shaft.
- Down hole inspection is planned (casing is required for this instance).

In addition, it is recommended that if casing is used, it be pulled immediately after the concrete is placed, allowing for re-use of the casing and eliminating reduction of side resistance (between soil and concrete).

It is anticipated that conventional drilled shaft equipment (with a standard soil bit) will be able to penetrate the surficial soils to the required tip elevation. However, based on conditions encountered in other borings performed within the corridor, cobbles and boulders were encountered throughout the very dense sand and gravel deposits. Therefore, difficult drilling conditions or boulders should be anticipated to be encountered during installation of the drilled shafts. If boulders are encountered during installation of the drilled shafts, specialized drilling/coring equipment may be required to advance the drilled shaft excavation beyond the obstruction.

## 5.2 Lateral Earth Pressure

For the soil types encountered in the borings, the “in-situ” unit weight ( $\gamma$ ), cohesion ( $c$ ), effective angle of friction ( $\phi$ ), and lateral earth pressure coefficients for at-rest conditions ( $k_o$ ), active conditions ( $k_a$ ), and passive conditions ( $k_p$ ) have been estimated and are provided in Table 9 and Table 10.

**Table 9. Estimated Undrained (Short-term) Soil Parameters for Design**

Soil Type	$\gamma$ (pcf) <sup>1</sup>	$c$ (psf)	$\phi$	$k_a$	$k_o$	$k_p$
Soft to Stiff Cohesive Soil	120	1,500	0°	N/A	N/A	N/A
Very Stiff to Hard Cohesive Soil	130	3,000	0°	N/A	N/A	N/A
Loose Granular Soil	125	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	130	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	135	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	2,000	0°	N/A	N/A	N/A
Compacted Granular Engineered Fill	120	0	32°	0.27	0.47	6.82

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

**Table 10. Estimated Drained (Long-term) Soil Parameters for Design**

Soil Type	$\gamma$ (pcf) <sup>1</sup>	$c$ (psf)	$\phi'$	$k_a$	$k_o$	$k_p$
Soft to Stiff Cohesive Soil	120	0	26°	0.35	0.56	4.53
Very Stiff to Hard Cohesive Soil	130	0	28°	0.32	0.53	5.07
Loose Granular Soil	125	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	130	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	135	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	0	30°	0.30	0.50	5.58
Compacted Granular Engineered Fill	120	0	32°	0.27	0.47	6.82

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

These parameters are considered appropriate for the design of all subsurface structures and any excavation support systems. Subsurface structures (where the top of the structure is restrained from movement) should be designed based on at-rest conditions ( $k_o$ ). For proposed temporary retaining structures (where the top of the structure is allowed to move), earth pressure distributions should be based on active ( $k_a$ ) and passive ( $k_p$ ) conditions. The values in this table have been estimated from correlation charts based on minimum standards specified for compacted engineered fill materials. These recommendations do not take into consideration the effect of any surcharge loading or a sloped ground surface (a flat surface is considered). Earth pressures on excavation support systems will be dependent on the type of sheeting and method of bracing or anchorage.

### 5.3 Construction Considerations

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

#### 5.3.1 Excavation Considerations

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

**Table 11. Excavation Back Slopes**

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

### **5.3.2 Groundwater Considerations**

Based on the groundwater observations made during drilling, groundwater is anticipated during construction of the drilled shafts. Where groundwater is encountered, proper groundwater control should be employed and maintained to prevent disturbance to excavation bottoms consisting of cohesive soil, and to prevent the possible development of a quick or "boiling" condition where soft silts and/or fine sands are encountered. It is preferable that the groundwater level, if encountered, be maintained at least 36 inches below the deepest excavation.

In the case of drilled shafts, the utilization of casing will be required below the water table to maintain an open hole and prevent the sidewalls from collapse. In addition, concrete placed below the water table should be placed by tremie method using a rigid tremie pipe. Given the granular nature of the soils, groundwater may not be able to be controlled by pumping from temporary sumps, and more significant dewatering efforts, such as deep well or well points system will likely be required. Note that determining and maintaining actual groundwater levels during construction of drilled shafts is the responsibility of the contractor.

## **6.0 LIMITATIONS OF STUDY**

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

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

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

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

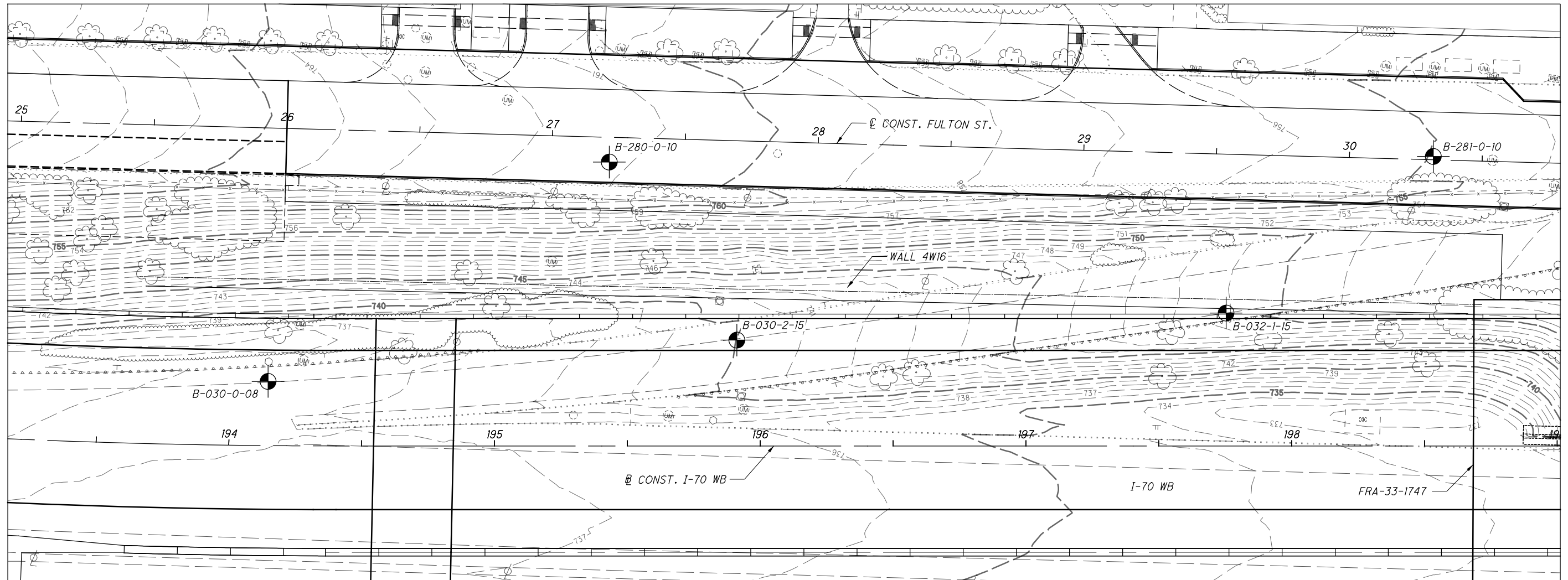
Our professional services have been performed, our findings obtained and our recommendations prepared in accordance with generally accepted geotechnical engineering principles and practices. Resource International is not responsible for the conclusions, opinions or recommendations made by others based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



## **APPENDIX I**

### **VICINITY MAP AND BORING PLAN**





# **BORING PLAN - WALL 4W16 1-70 WB** **FRA-70-14.05** **FRANKLIN COUNTY, OHIO**

RII PROJECT NO.  
W-15-126

SCALE: 1"=20'  
0 10 20



DRAWN  
JAS  
REVIEWED  
BRT  
DATE  
11-27-18



## **APPENDIX II**

### **DESCRIPTION OF SOIL TERMS**

### **DESCRIPTION OF SOIL TERMS**

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

#### **Granular Soils** – ODOT A-1, A-2, A-3, A-4 (non-plastic)

The relative compactness of granular soils is described as:

<u>Description</u>	<u>Blows per foot – SPT (N<sub>60</sub>)</u>		
Very Loose	Below		5
Loose	5	-	10
Medium Dense	11	-	30
Dense	31	-	50
Very Dense	Over		50

#### **Cohesive Soils** – ODOT A-4, A-5, A-6, A-7, A-8

The relative consistency of cohesive soils is described as:

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

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

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

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

<u>Term</u>	<u>Range</u>		
Trace	0%	-	10%
Little	10%	-	20%
Some	20%	-	35%
And	35%	-	50%

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

<u>Term</u>	<u>Range - ODOT</u>
Dry	Well below Plastic Limit
Damp	Below Plastic Limit
Moist	Above PL to 3% below LL
Wet	3% below LL to above LL

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

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

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





















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



# CLASSIFICATION OF SOILS

Ohio Department of Transportation

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


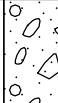






SYMBOL	DESCRIPTION	Classification		LL <sub>O</sub> /LL x 100*	% Pass #40	% Pass #200	Liquid Limit (LL)	Plastic Index (PI)	Group Index Max.	REMARKS
		AASHTO	OHIO							
	Gravel and/or Stone Fragments	A-1-a			30 Max.	15 Max.		6 Max.	0	Min. of 50% combined gravel, cobble and boulder sizes
	Gravel and/or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

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

### **APPENDIX III**

#### **PROJECT BORING LOGS:**

**B-030-0-08, B-030-2-15 and B-032-1-15**

Client: ms consultants						Project: FRA-70-8.93						Job No. 0221-1004.01					
LOG OF: Boring B-030-0-08				Location: Sta. 194+14.54, 24.17' LT., BL I-70 WB						Date Drilled: 7/20/2008 to 7/23/2008							
Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No.		Hand Penetro- meter (tsf)	WATER OBSERVATIONS: Water seepage at: 16.0' Water level at completion: 13.6' (includes drilling water)  FIELD NOTES: Advanced boring using 3.25" diameter hollowstem augers.	Graphic Log	GRADATION						STANDARD PENETRATION (N60) Natural Moisture Content, % - ●  PL ————— LL Blows per foot - ○ / Non-Plastic - NP 10 20 30 40		
				Drive	Press / Core				% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay			
	736.7						DESCRIPTION										
1.4	735.3						Asphalt Concrete - 11" Aggregate Base - 6"										
		4 6 8	11	1			Loose to medium dense brown GRAVEL WITH SAND (A-1-b), some fine to coarse sand, little silt; damp.										
		3															
5.0	731.7	3	1	8	2												
		4															
6.5	730.2	14	21	18	3	4.5+	Hard gray SILTY CLAY (A-6b), some fine to coarse sand, trace gravel; contains few rock fragments; damp to moist.		9	9	---	14	40	28			
		10															
8.0	728.7	16	19	18	4	4.5+	Hard gray SILT AND CLAY (A-6a), some fine to coarse sand, trace gravel; damp.		6	10	---	15	40	29			
		13															
		19	21	18	5	4.5+	Hard gray SANDY SILT (A-4a), some fine to coarse sand, trace gravel; damp.		5	11	---	18	41	25			
		11															
11.0	725.7	15	27	18	6	4.5+											
		16															
		50/5	8	7			Dense to very dense gray GRAVEL (A-1-a), little to some fine to coarse sand, trace to little silty clay; damp.		71	12	---	5	--12--	NP			
		11															
		33															
		38	13	8													
		18															
		23															
		23	13	9			@ 16.0', becomes wet.		61	20	---	8	--11--				
		12															
		13															
		21	12	10													
		13															
		28															
		36	12	11													
23.5	713.2																
		17															
		34															
		40	14	12			Very dense gray COARSE AND FINE SAND (A-3a), some silty clay; wet.										
25	711.7																


Client: ms consultants						Project: FRA-70-8.93						Job No. 0221-1004.01																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
LOG OF: Boring B-030-0-08						Location: Sta. 194+14.54, 24.17' LT., BL I-70 WB						Date Drilled: 7/20/2008 to 7/23/2008																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																							
Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No.		Hand Penetro- meter (tsf)	WATER OBSERVATIONS: Water seepage at: 16.0' Water level at completion: 13.6' (includes drilling water)  FIELD NOTES: Advanced boring using 3.25" diameter hollowstem augers.	Graphic Log	GRADATION						STANDARD PENETRATION (N60) Natural Moisture Content, % - ●  PL ————— LL Blows per foot - ○ / Non-Plastic - NP 10 20 30 40																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																				
				Drive	Press / Core				% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																					
711.7																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																																			










	PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 55 (SN 386345)	STATION / OFFSET: 195+91.21 / 39.9" LT	<b>EXPLORATION ID B-030-2-15</b>
	TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: CME AUTOMATIC	ALIGNMENT: BL CONST. I-70 WB	
	PID: 96053 BR ID: NA	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 740.0 (MSL) EOB: 54.3 ft.	PAGE 1 OF 2
	START: 12/1/15 END: 12/2/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	COORD: 39.953401, -82.997585	

MATERIAL DESCRIPTION AND NOTES	ELEV. 740.0	DEPTHS	SPT/ RQD	N <sub>60</sub>	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.5' - ASPHALT (6.0")	739.5																	
1.0' - AGGREGATE BASE (12.0")	738.5																	
FILL: MEDIUM DENSE TO VERY DENSE, DARK BROWN GRAVEL WITH SAND AND SILT, LITTLE CLAY, MOIST.  -BRICK FRAGMENTS PRESENT IN SS-1 THROUGH SS-3		1	4	7	24	33	SS-1	-	-	-	-	-	-	-	-	8	A-2-4 (V)	
		2		9														
		3																
		4	4	8	27	61	SS-2	-	34	22	10	19	15	21	15	6	10	A-2-4 (O)
		5		10														
		6	6	20	51	67	SS-3	-	-	-	-	-	-	-	-	8	A-2-4 (V)	
		7		14														
		8																
		9	7	8	20	50	SS-4	-	-	-	-	-	-	-	-	-	A-2-4 (V)	
	729.5	10		5														
FILL: MEDIUM DENSE, GRAY GRAVEL (CONCRETE FRAGMENTS), DAMP.		11	33	7	23	44	SS-5	-	-	-	-	-	-	-	-	6	A-1-a (V)	
		12		8														
	726.5	13																
VERY LOOSE TO MEDIUM DENSE, BROWN GRAVEL, "AND" COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST TO WET.  -MUD ADDED @ 17.5'		14	8	6	17	0	SS-6	-	-	-	-	-	-	-	-	-		
		15	5	5	-	100	3S-6A	-	52	32	5	9	2	NP	NP	NP	9	A-1-a (O)
		16	3	1	3	0	SS-7	-	-	-	-	-	-	-	-	-		
		17		1	-	100	3S-7A	-	-	-	-	-	-	-	-	-	13	A-1-a (V)
	721.5	18																
VERY LOOSE, BROWN GRAVEL AND SAND, LITTLE SILT, TRACE CLAY, WET.		19	2	1	3	61	SS-8	-	44	37	6	10	3	NP	NP	NP	21	A-1-b (O)
		20		1														
		21																
	718.0	22																
VERY STIFF, BROWNISH GRAY SANDY SILT, SOME CLAY, TRACE FINE GRAVEL, MOIST.		23																
		24	10	14	44	100	SS-9	4.00	-	-	-	-	-	-	-	-	12	A-4a (V)
		25		15														
		26																
	713.0	27																
VERY DENSE, GRAY COARSE AND FINE SAND, SOME SILT, TRACE CLAY, TRACE FINE GRAVEL, MOIST.		28																
		29	6	14	71	100	SS-10	-	7	26	36	23	8	NP	NP	NP	14	A-3a (O)
				33														

MATERIAL DESCRIPTION AND NOTES		ELEV.	DEPTHS	SPT/ RQD	N <sub>60</sub>	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL	
									GR	CS	FS	SI	CL	LL	PL	PI				
VERY DENSE, GRAY <b>COARSE AND FINE SAND</b> , SOME SILT, TRACE CLAY, TRACE FINE GRAVEL, MOIST. ( <i>same as above</i> )		710.0																<L> >V>		
VERY DENSE, GRAY <b>SANDY SILT</b> , SOME FINE GRAVEL, TRACE CLAY, MOIST.		708.0	31															<L> >V>		
			32															<L> >V>		
			33															<L> >V>		
			34	8	31	119	89	SS-11	-	-	-	-	-	-	-	9	A-4a (V)	<L> >V>		
			35	48														<L> >V>		
			36															<L> >V>		
			37															<L> >V>		
			38															<L> >V>		
			39	4	23	84	100	SS-12	-	20	16	21	36	7	NP	NP	NP	10	A-4a (2)	<L> >V>
			40	33															<L> >V>	
VERY DENSE, GRAY <b>GRAVEL AND SAND</b> , TRACE SILT, TRACE CLAY, MOIST.		698.0	41															<L> >V>		
			42																<L> >V>	
			43																<L> >V>	
			44	9	50/5"	-	100	SS-13	-	37	55	4	4	0	NP	NP	NP	11	A-1-b (0)	<L> >V>
			45																<L> >V>	
			46																<L> >V>	
			47																<L> >V>	
			48																<L> >V>	
			49	30	50/2"	-	88	SS-14	-	-	-	-	-	-	-	-	13	A-1-b (V)	<L> >V>	
			50																<L> >V>	
VERY DENSE, GRAY <b>GRAVEL WITH SAND AND SILT</b> , TRACE CLAY, MOIST.		688.0	51															<L> >V>		
			52																<L> >V>	
			53																<L> >V>	
			54	27	50/4"	-	80	SS-15	-	-	-	-	-	-	-	-	8	A-2-4 (V)	<L> >V>	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 17.5'

	PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 55 (SN 386345)	STATION / OFFSET: 197+75.35 / 50.0" LT	EXPLORATION ID <b>B-032-1-15</b>
	TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: CME AUTOMATIC	ALIGNMENT: BL CONST. I-70 WB	
	PID: 96053 BR ID: NA	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 748.9 (MSL) EOB: 65.0 ft.	PAGE 1 OF 3
	START: 11/30/15 END: 12/1/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	COORD: 39.953517, -82.996945	

MATERIAL DESCRIPTION AND NOTES	ELEV.	DEPTHS	SPT/ RQD	N <sub>60</sub>	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%)					ATTERBERG			WC	ODOT CLASS (GI)	BACK FILL
								GR	CS	FS	SI	CL	LL	PL	PI			
0.7' - ASPHALT (8.0")	748.9																	
0.3' - AGGREGATE BASE (4.0")	748.2																	
HARD, BROWN SILT, SOME FINE GRAVEL, LITTLE COARSE TO FINE SAND, LITTLE CLAY, DAMP.	747.9	1	3	26	39	SS-1	4.5+	-	-	-	-	-	-	-	-	12	A-4b (V)	
		2	7 10															
		3																
		4	9	44	100	SS-2	4.5+	21	9	6	50	14	20	15	5	9	A-4b (6)	
		5	15 14															
	743.4	6																
DENSE TO VERY DENSE, GRAY TO BROWNISH GRAY GRAVEL WITH SAND AND SILT, SOME CLAY, DAMP.		7	11	68	100	SS-3	-	-	-	-	-	-	-	-	-	10	A-2-4 (V)	
		8																
		9	13	65	100	SS-4	-	27	23	20	9	21	25	15	10	9	A-2-4 (0)	
		10	19 24															
		11	23															
		12	50/3"	-	89	SS-5	-	-	-	-	-	-	-	-	-	6	A-2-4 (V)	
	735.9	13																
VERY DENSE, BROWNISH GRAY GRAVEL, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, DAMP.		14	45	-	100	SS-6	-	-	-	-	-	-	-	-	-	4	A-1-a (V)	
		15	50/2"															
	733.4	16																
HARD, GRAY SANDY SILT, LITTLE FINE GRAVEL, LITTLE CLAY, DAMP.		17	10	92	100	SS-7 A	4.5+	16	17	17	39	11	21	15	6	10	A-4a (3)	
	731.9	18	16 45			SS-7B	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	
VERY DENSE, BROWN GRAVEL AND SAND, TRACE SILT, TRACE CLAY, MOIST.		19																
		20	16	86	100	SS-8	-	42	51	3	3	1	NP	NP	NP	4	A-1-b (0)	
		21	25 32															
		22																
		23																
		24	13	63	100	SS-9	-	-	-	-	-	-	-	-	-	5	A-1-b (V)	
		25	20 22															
		26																
	721.9	27																
DENSE TO VERY DENSE, BROWNISH GRAY TO GRAY GRAVEL, "AND" COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -INTRODUCED WATER @ 28.5'		28																
		29	7	33	100	SS-10	-	55	37	4	3	1	NP	NP	NP	9	A-1-a (0)	
			9 13															

[illegible]



## **APPENDIX IV**

### **DRILLED SHAFT CALCULATIONS**



Boring	Proposed Top of Shaft Elevation (ft msl)	D <sub>u</sub> (ft)	Shaft Diameter, D (ft)	Soil Class.	Material Type <sup>1</sup>	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	N <sub>60</sub> <sup>2</sup>	γ (pcf)	σ' <sub>v</sub> (Midpoint) (psf)	σ <sub>v</sub> (Bottom) (psf)	S <sub>u</sub> <sup>3</sup> (psf)	N <sub>c</sub> <sup>4</sup>	α <sup>5</sup>	(N <sub>1</sub> ) <sub>60</sub> <sup>6</sup>	φ' <sub>i</sub> <sup>7</sup>	σ' <sub>p</sub> <sup>8</sup> (psf)	β <sup>9</sup>	Boring	Elevation (ft msl)	Shaft Length (ft)	Nominal Unit Tip Resistance, q <sub>p</sub> <sup>10,11</sup> (ksf)	Nominal Unit Side Resistance, q <sub>s</sub> <sup>12,13</sup> (ksf)	Φ <sub>sp</sub> <sup>14</sup>	Φ <sub>as</sub> <sup>15</sup>
B-032-6-15	720.5	0.0	4.0	A-1-a	G	8.0	8.0	712.5	60	135	290	1,080				45	42	19,080	4.90	B-032-6-15	720.5-712.5	0.0-8.0	60	1.42	0.50	0.55
				A-1-b	G	13.0	5.0	707.5	37	130	750	1,730				25	38	11,766	1.64		712.5-707.5	8.0-13.0	44	1.22	0.50	0.55
				A-1-a	G	19.5	6.5	701.0	39	135	1,155	2,608				26	39	12,402	1.34		707.5-701.0	13.0-19.5	46	1.54	0.50	0.55
				A-1-b	G	24.5	5.0	696.0	30	135	1,572	3,283				19	37	9,540	0.89		701.0-696.0	19.5-24.5	36	1.39	0.50	0.55
				A-1-a	G	34.5	10.0	686.0	58	140	2,142	4,683				35	41	18,444	1.23		696.0-686.0	24.5-34.5	60	2.62	0.50	0.55
				A-1-a	G	47.5	13.0	673.0	111	140	3,034	6,503				62	43	35,298	1.58		686.0-673.0	34.5-47.5	60	4.79	0.50	0.55
B-033-2-15	720.5	0.0	4.0	A-1-b	G	0.9	0.9	719.6	84	135	33	121				69	42	28,712	26.48	B-033-2-15	720.5-719.6	0.0-0.9	60	0.86	0.50	0.55
				A-1-b	G	8.4	7.5	712.1	37	130	319	1,097				28	39	11,766	2.91		719.6-712.1	0.9-8.4	44	0.92	0.50	0.55
				A-3	G	10.9	2.5	709.6	120	135	663	1,434				86	39	17,617	2.36		712.1-709.6	8.4-10.9	60	1.56	0.50	0.55
				A-4a	C	15.9	5.0	704.6	104	135	935	2,109	8,000	9.0	0.45						709.6-704.6	10.9-15.9	72	3.60	0.40	0.45
				A-3	G	18.9	3.0	701.6	93	140	1,233	2,529				63	39	15,119	1.45		704.6-701.6	15.9-18.9	60	1.79	0.50	0.55
				A-4a	C	20.9	2.0	699.6	50	135	1,422	2,799	6,250	9.0	0.45						701.6-699.6	18.9-20.9	56	2.81	0.40	0.45
B-034-0-08	720.5	0.0	4.0	A-1-b	G	38.9	18.0	681.6	120	140	2,193	5,319				75	42	38,160	2.01	B-034-0-08	699.6-681.6	20.9-38.9	60	4.41	0.50	0.55
				A-1-a	G	2.5	2.5	718.0	17	125	78	313				13	37	5,406	3.84		720.5-718.0	0.0-2.5	20	0.30	0.50	0.55
				A-1-b	G	7.5	5.0	713.0	49	130	326	963				37	40	15,582	3.60		718.0-713.0	2.5-7.5	58	1.17	0.50	0.55
				A-4b	G	10.0	2.5	710.5	80	135	585	1,300				58	38	33,182	3.61		713.0-710.5	7.5-10.0	60	2.11	0.50	0.55
				A-1-a	G	13.0	3.0	707.5	18	130	777	1,690				13	37	5,724	1.00		710.5-707.5	10.0-13.0	21	0.77	0.50	0.55
				A-6a	C	16.0	3.0	704.5	58	135	988	2,095	7,250	9.0	0.45						707.5-704.5	13.0-16.0	65	3.26	0.40	0.45
				A-1-a	G	19.0	3.0	701.5	120	140	1,213	2,515				82	43	38,160	3.12		704.5-701.5	16.0-19.0	60	3.77	0.50	0.55
				A-4a	C	31.0	12.0	689.5	38	140	1,795	4,195	4,750	9.0	0.48						701.5-689.5	19.0-31.0	42	2.26	0.40	0.45
				A-1-a	G	36.0	5.0	684.5	120	140	2,455	4,895				73	43	38,160	1.93		689.5-684.5	31.0-36.0	60	4.72	0.50	0.55
				A-1-b	G	56.0	20.0	664.5	111	140	3,425	7,695				62	42	35,298	1.42		684.5-664.5	36.0-56.0	60	4.85	0.50	0.55
				A-4a	G	61.0	5.0	659.5	120	140	4,395	8,395				63	38	45,896	1.27		664.5-659.5	56.0-61.0	60	5.59	0.50	0.55
				A-1-b	G	84.0	23.0	636.5	107	140	5,481	11,615				51	42	34,026	1.01		659.5-636.5	61.0-84.0	60	5.54	0.50	0.55

1. C = cohesive soil stratum; G = granular soil stratum
2. N<sub>60</sub> = average energy corrected N-values over stratum thickness
3. S<sub>u</sub> = 125(N<sub>60</sub>) ≤ 8,000 psf (cohesive soil layers)
4. N<sub>C</sub> = 6[1+0.2(Z/D)] ≤ 9; Ref. Section 10.8.3.5.1c, AASHTO LRFD BDS (cohesive soil layers)
5. α = 0.55 for S<sub>u</sub>/P<sub>a</sub> ≤ 1.5; α = 0.55-0.1(S<sub>u</sub>/P<sub>a</sub>-1.5) for 1.5 ≤ S<sub>u</sub>/P<sub>a</sub> ≤ 2.5, where P<sub>a</sub> = 2.12 ksf = 2,120 psf; Ref. Section 10.8.3.5.1b AASHTO LRFD BDS (cohesive soil layers)
6. (N<sub>1</sub>)<sub>60</sub> = C<sub>N</sub>N<sub>60</sub>, where C<sub>N</sub> = [0.77log(40/σ'<sub>v</sub>)] ≤ 2.0 ksf, where σ'<sub>v</sub> = vetical effective stress at midpoint of soil layer with respect to the entire soil profile for the respective boring; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS (granular soil layers)
7. φ'<sub>i</sub> estimated per Table 10.4.6.2.4-1; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS (granular soil layers)
8. σ'<sub>p</sub> = n(N<sub>60</sub>)<sup>m</sup>(P<sub>a</sub>), where n = 0.15 and m = 1.0 for A-1-a/1-b and A-2-4/2-6, n = 0.47 and m = 0.6 for A-3/3a, n = 0.47 and m = 0.8 for A-4a/4b soils, and P<sub>a</sub> = 2.12 ksf = 2,120 psf; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
9. β = tanφ'<sub>i</sub>(1-sinφ'<sub>i</sub>)/(σ'<sub>p</sub>/α<sub>v</sub>)<sup>n</sup>(sinφ'<sub>i</sub>), where α<sub>v</sub> = vetical effective stress at midpoint of soil layer; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
10. q<sub>p</sub> = N<sub>C</sub>S<sub>u</sub> ≤ 80.0 ksf; Ref. Section 10.8.3.5.1c, AASHTO LRFD BDS (cohesive soil layers)
11. q<sub>sp</sub> = 1.2N<sub>60</sub> ≤ 60 ksf; Ref. Section 10.8.3.5.2c, AASHTO LRFD BDS (granular soil layers)
12. q<sub>s</sub> = αS<sub>u</sub>; Ref. Section 10.8.3.5.1b, AASHTO LRFD BDS (cohesive soil layers)
13. q<sub>s</sub> = βσ'<sub>v</sub>, where α<sub>v</sub> = vetical effective stress at midpoint of soil layer; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
14. Φ<sub>sp</sub> = 0.50 for granular soils layers and 0.40 for cohesive soil layers; Ref. Table 10.5.5.2.4-1, AASHTO LRFD BDS
15. Φ<sub>as</sub> = 0.55 for granular soils layers and 0.45 for cohesive soil layers; Ref. Table 10.5.5.2.4-1, AASHTO LRFD BDS

Shaft Length (ft)	Shaft Tip Elevation (ft msl)	Nominal Tip Resistance, R <sub>p</sub> (kips)	Nominal Side Resistance, R <sub>s</sub> (kips)	Total Nominal Resistance, R <sub>n</sub> (kips)	Factored Tip Resistance, Φ <sub>sp</sub> R <sub>p</sub> (kips)	Factored Side Resistance, Φ <sub>as</sub> R <sub>s</sub> (kips)	Total Factored Resistance, R <sub>e</sub> (kips)
48.6	671.9			679			339
		679			339		

Group Efficiency Factor, η<sub>g</sub> =

0.9

Boring	Proposed Top of Shaft Elevation (ft msl)	D <sub>sh</sub> (ft)	Shaft Diameter, D (ft)	Soil Class.	Material Type <sup>1</sup>	Stratum Depth, z (ft)	Stratum Thickness (ft)	Bottom Elevation (ft msl)	N <sub>60</sub> <sup>2</sup>	γ (pcf)	σ' <sub>v</sub> (Midpoint) (psf)	σ <sub>v</sub> (Bottom) (psf)	S <sub>u</sub> <sup>3</sup> (psf)	N <sub>c</sub> <sup>4</sup>	α <sup>5</sup>	(N <sub>1</sub> ) <sub>60</sub> <sup>6</sup>	φ' <sub>i</sub> <sup>7</sup>	σ' <sub>p</sub> <sup>8</sup> (psf)	β <sup>9</sup>	Boring	Elevation (ft msl)	Shaft Length (ft)	Nominal Unit Tip Resistance, q <sub>p</sub> <sup>10,11</sup> (ksf)	Nominal Unit Side Resistance, q <sub>s</sub> <sup>12,13</sup> (ksf)	Φ <sub>sp</sub> <sup>14</sup>	Φ <sub>ss</sub> <sup>15</sup>
B-032-6-15	720.5	0.0	5.0	A-1-a	G	8.0	8.0	712.5	60	135	290	1,080				45	42	19,080	4.90	B-032-6-15	720.5-712.5	0.0-8.0	60	1.42	0.50	0.55
				A-1-b	G	13.0	5.0	707.5	37	130	750	1,730				25	38	11,766	1.64		712.5-707.5	8.0-13.0	44	1.22	0.50	0.55
				A-1-a	G	19.5	6.5	701.0	39	135	1,155	2,608				26	39	12,402	1.34		707.5-701.0	13.0-19.5	46	1.54	0.50	0.55
				A-1-b	G	24.5	5.0	696.0	30	135	1,572	3,283				19	37	9,540	0.89		701.0-696.0	19.5-24.5	36	1.39	0.50	0.55
				A-1-a	G	34.5	10.0	686.0	58	140	2,142	4,683				35	41	18,444	1.23		696.0-686.0	24.5-34.5	60	2.62	0.50	0.55
				A-1-a	G	47.5	13.0	673.0	111	140	3,034	6,503				62	43	35,298	1.58		686.0-673.0	34.5-47.5	60	4.79	0.50	0.55
B-033-2-15	720.5	0.0	5.0	A-1-b	G	0.9	0.9	719.6	84	135	33	121				69	42	28,712	26.48	B-033-2-15	720.5-719.6	0.0-0.9	60	0.86	0.50	0.55
				A-1-b	G	8.4	7.5	712.1	37	130	319	1,097				28	39	11,766	2.91		719.6-712.1	0.9-8.4	44	0.92	0.50	0.55
				A-3	G	10.9	2.5	709.6	120	135	663	1,434				86	39	17,617	2.36		712.1-709.6	8.4-10.9	60	1.56	0.50	0.55
				A-4a	C	15.9	5.0	704.6	104	135	935	2,109	8,000	9.0	0.45						709.6-704.6	10.9-15.9	72	3.60	0.40	0.45
				A-3	G	18.9	3.0	701.6	93	140	1,233	2,529				63	39	15,119	1.45		704.6-701.6	15.9-18.9	60	1.79	0.50	0.55
				A-4a	C	20.9	2.0	699.6	50	135	1,422	2,799	6,250	9.0	0.45						701.6-699.6	18.9-20.9	56	2.81	0.40	0.45
B-034-0-08	720.5	0.0	5.0	A-1-b	G	38.9	18.0	681.6	120	140	2,193	5,319				75	42	38,160	2.01	B-034-0-08	699.6-681.6	20.9-38.9	60	4.41	0.50	0.55
				A-1-a	G	2.5	2.5	718.0	17	125	78	313				13	37	5,406	3.84		720.5-718.0	0.0-2.5	20	0.30	0.50	0.55
				A-1-b	G	7.5	5.0	713.0	49	130	326	963				37	40	15,582	3.60		718.0-713.0	2.5-7.5	58	1.17	0.50	0.55
				A-4b	G	10.0	2.5	710.5	80	135	585	1,300				58	38	33,182	3.61		713.0-710.5	7.5-10.0	60	2.11	0.50	0.55
				A-1-a	G	13.0	3.0	707.5	18	130	777	1,690				13	37	5,724	1.00		710.5-707.5	10.0-13.0	21	0.77	0.50	0.55
				A-6a	C	16.0	3.0	704.5	58	135	988	2,095	7,250	9.0	0.45						707.5-704.5	13.0-16.0	65	3.26	0.40	0.45
				A-1-a	G	19.0	3.0	701.5	120	140	1,213	2,515				82	43	38,160	3.12		704.5-701.5	16.0-19.0	60	3.77	0.50	0.55
				A-4a	C	31.0	12.0	689.5	38	140	1,795	4,195	4,750	9.0	0.48						701.5-689.5	19.0-31.0	42	2.26	0.40	0.45
				A-1-a	G	36.0	5.0	684.5	120	140	2,455	4,895				73	43	38,160	1.93		689.5-684.5	31.0-36.0	60	4.72	0.50	0.55
				A-1-b	G	56.0	20.0	664.5	111	140	3,425	7,695				62	42	35,298	1.42		684.5-664.5	36.0-56.0	60	4.85	0.50	0.55
				A-4a	G	61.0	5.0	659.5	120	140	4,395	8,395				63	38	45,896	1.27		664.5-659.5	56.0-61.0	60	5.59	0.50	0.55
				A-1-b	G	84.0	23.0	636.5	107	140	5,481	11,615				51	42	34,026	1.01		659.5-636.5	61.0-84.0	60	5.54	0.50	0.55

1. C = cohesive soil stratum; G = granular soil stratum
2. N<sub>60</sub> = average energy corrected N-values over stratum thickness
3. S<sub>u</sub> = 125(N<sub>60</sub>) ≤ 8,000 psf (cohesive soil layers)
4. N<sub>C</sub> = 6[1+0.2(Z/D)] ≤ 9; Ref. Section 10.8.3.5.1c, AASHTO LRFD BDS (cohesive soil layers)
5. α = 0.55 for S<sub>u</sub>/P<sub>a</sub> ≤ 1.5; α = 0.55-0.1(S<sub>u</sub>/P<sub>a</sub>-1.5) for 1.5 ≤ S<sub>u</sub>/P<sub>a</sub> ≤ 2.5, where P<sub>a</sub> = 2.12 ksf = 2,120 psf; Ref. Section 10.8.3.5.1b AASHTO LRFD BDS (cohesive soil layers)
6. (N<sub>1</sub>)<sub>60</sub> = C<sub>N</sub>N<sub>60</sub>, where C<sub>N</sub> = [0.77log(40/σ'<sub>v</sub>)] ≤ 2.0 ksf, where σ'<sub>v</sub> = vetical effective stress at midpoint of soil layer with respect to the entire soil profile for the respective boring; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS (granular soil layers)
7. φ'<sub>i</sub> estimated per Table 10.4.6.2.4-1; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS (granular soil layers)
8. σ'<sub>p</sub> = n(N<sub>60</sub>)<sup>m</sup>(P<sub>a</sub>), where n = 0.15 and m = 1.0 for A-1-a/1-b and A-2-4/2-6, n = 0.47 and m = 0.6 for A-3/3a, n = 0.47 and m = 0.8 for A-4a/4b soils, and P<sub>a</sub> = 2.12 ksf = 2,120 psf; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
9. β = tanφ'<sub>i</sub>(1-sinφ'<sub>i</sub>)/(σ'<sub>v</sub>/α<sub>v</sub>)<sup>n</sup>(sinφ'<sub>i</sub>), where α<sub>v</sub> = vetical effective stress at midpoint of soil layer; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
10. q<sub>p</sub> = N<sub>C</sub>S<sub>u</sub> ≤ 80.0 ksf; Ref. Section 10.8.3.5.1c, AASHTO LRFD BDS (cohesive soil layers)
11. q<sub>sp</sub> = 1.2N<sub>60</sub> ≤ 60 ksf; Ref. Section 10.8.3.5.2c, AASHTO LRFD BDS (granular soil layers)
12. q<sub>s</sub> = αS<sub>u</sub>; Ref. Section 10.8.3.5.1b, AASHTO LRFD BDS (cohesive soil layers)
13. q<sub>s</sub> = βσ'<sub>v</sub>, where α<sub>v</sub> = vetical effective stress at midpoint of soil layer; Ref. Section 10.8.3.5.2b, AASHTO LRFD BDS (granular soil layers)
14. Φ<sub>sp</sub> = 0.50 for granular soils layers and 0.40 for cohesive soil layers; Ref. Table 10.5.5.2.4-1, AASHTO LRFD BDS
15. Φ<sub>ss</sub> = 0.55 for granular soils layers and 0.45 for cohesive soil layers; Ref. Table 10.5.5.2.4-1, AASHTO LRFD BDS

Shaft Length (ft)	Shaft Tip Elevation (ft msl)	Nominal Tip Resistance, R <sub>p</sub> (kips)	Nominal Side Resistance, R <sub>s</sub> (kips)	Total Nominal Resistance, R <sub>n</sub> (kips)	Factored Tip Resistance, Φ <sub>sp</sub> R <sub>p</sub> (kips)	Factored Side Resistance, Φ <sub>ss</sub> R <sub>s</sub> (kips)	Total Factored Resistance, R <sub>e</sub> (kips)
46.5	674.0			1,060			530
		1,060			530		
46.5	674.0			1,060			530
		1,060			530		

Group Efficiency Factor, η<sub>g</sub> =

0.9

W-15-126 - FRA-70-14.05 Project 4B

Tangent Shafts - Block Failure Mode - Retaining Wall 4W17

Calculated By: BRT

Date: 7/8/2022

Checked By: JPS

Date: 7/8/2022

Boring B-034-0-08

D =	5.0	ft	Diameter of individual drilled shafts
B' =	3.9	ft	Equivalent footing width based on overall end bearing area of drilled shafts
L =	302.2	ft	
c =	0	psf	
γ =	135	pcf	
D <sub>f</sub> =	46.5	ft	
φ =	42	deg	
D <sub>w</sub> =	0.0	ft	Below ground surface

$$q_n = cN_{cn} + \gamma D_f N_{qm} C_{wq} + \frac{1}{2} \gamma B' N_{\gamma m} C_{w\gamma} = 370.91 \text{ ksf}$$

$$N_{cn} = N_c s_c i_c = 94.81$$

$$N_{qm} = N_q s_q d_q i_q = 111.68$$

$$N_{\gamma m} = N_{\gamma} s_{\gamma} i_{\gamma} = 154.74$$

N <sub>c</sub> =	93.71	s <sub>c</sub> =	1+(3.9 ft/302.2 ft)(85.37/93.71) =	1.012	i <sub>c</sub> =	1.000	d <sub>q</sub> =	1+2tan(42°)[1-sin(42°)] <sup>2</sup> tan <sup>-1</sup> (46.5 ft/3.9 ft) :	1.293
N <sub>q</sub> =	85.37	s <sub>q</sub> =	1+(3.9 ft/302.2 ft)tan(42°) =	1.012	i <sub>q</sub> =	1.000	C <sub>wq</sub> =	0.0 ft < 46.5 ft =	0.500
N <sub>γ</sub> =	155.54	s <sub>γ</sub> =	1-0.4(3.9 ft/302.2 ft) =	0.995	i <sub>γ</sub> =	1.000	C <sub>wγ</sub> =	0.0 ft < 1.5(3.9 ft) + 46.5 ft =	0.500

$$q_R = q_n \cdot \phi_b = 185.45 \text{ ksf}$$

$$\phi_b = 0.5$$

$$R_R = q_R \cdot A_p = 3,641 \text{ kips}$$

7282.734

## **APPENDIX V**

### **LATERAL DESIGN PARAMETERS**

Boring No.	Elevation (feet msl)	Soil Class.	Soil Type	Strata	N <sub>60</sub>	N <sub>160</sub>	$\gamma$ (pcf)	$\gamma'$ (pcf)	Strength Parameter	k (soil) k <sub>rm</sub> (rock)	$\epsilon_{50}$ (soil) $E_r$ (rock)	RQD (rock)
B-030-0-08	736.7 to 731.7	A-1-b	G	4	9	15	120	120	$\phi = 36^\circ$	160 pci	-	-
	731.7 to 728.7	A-6b	C	3	36	36	130	130	Su = 4,500 psf	1,500 pci	0.0045	-
	728.7 to 725.7	A-4a	C	3	42	42	130	130	Su = 5,250 psf	1,750 pci	0.0043	-
	725.7 to 721.2	A-1-a	G	4	96	101	140	140	$\phi = 43^\circ$	395 pci	-	-
	721.2 to 713.2	A-1-a	G	4	49	47	135	73	$\phi = 42^\circ$	195 pci	-	-
	713.2 to 674.7	A-3a	G	4	99	75	140	78	$\phi = 40^\circ$	155 pci	-	-
	674.7 to 669.7	A-3	G	4	73	47	140	78	$\phi = 38^\circ$	125 pci	-	-
	669.7 to 633.2	A-1-b	G	4	109	61	140	78	$\phi = 42^\circ$	195 pci	-	-
	633.2 to 625.7	Shale	R	9	-	-	150	88	Qu = 750 psi	0.00025	68,000 psi	38
B-030-2-15	740.0 to 729.5	A-2-4	G	4	24	33	125	125	$\phi = 39^\circ$	250 pci	-	-
	729.5 to 724.5	A-1-a	G	4	17	18	130	130	$\phi = 38^\circ$	215 pci	-	-
	724.5 to 718.0	A-1-b	G	4	3	3	120	58	$\phi = 30^\circ$	30 pci	-	-
	718.0 to 713.0	A-4a	C	2	44	44	140	78	Su = 5,500 psf	1,835 pci	0.0042	-
	713.0 to 708.0	A-3a	G	4	71	61	140	78	$\phi = 40^\circ$	155 pci	-	-
	708.0 to 698.0	A-4a	G	4	101	81	140	78	$\phi = 38^\circ$	125 pci	-	-
	698.0 to 688.0	A-1-b	G	4	120	89	140	78	$\phi = 42^\circ$	195 pci	-	-
	688.0 to 686.0	A-2-4	G	4	120	85	140	78	$\phi = 41^\circ$	175 pci	-	-
B-032-1-15	748.9 to 743.4	A-4b	C	3	35	35	130	130	Su = 4,375 psf	1,460 pci	0.0045	-
	743.4 to 738.4	A-2-4	G	4	66	80	135	135	$\phi = 41^\circ$	315 pci	-	-
	738.4 to 733.4	A-2-4	G	4	120	126	140	140	$\phi = 41^\circ$	315 pci	-	-
	733.4 to 731.9	A-4a	C	3	50	50	135	135	Su = 6,250 psf	2,085 pci	0.0039	-
	731.9 to 721.9	A-1-b	G	4	75	65	140	140	$\phi = 42^\circ$	355 pci	-	-
	721.9 to 716.9	A-1-a	G	4	33	26	140	78	$\phi = 39^\circ$	140 pci	-	-
	716.9 to 711.9	A-1-a	G	4	120	89	140	78	$\phi = 43^\circ$	215 pci	-	-
	711.9 to 706.9	A-4a	C	2	120	120	140	78	Su = 8,000 psf	2,665 pci	0.0033	-
	706.9 to 701.9	A-1-b	G	4	9	6	130	68	$\phi = 33^\circ$	60 pci	-	-
	701.9 to 683.9	A-1-b	G	4	82	52	140	78	$\phi = 42^\circ$	195 pci	-	-