Resource International, Inc.

FRA-70-12.68 PROJECT 4R
RETAINING WALL 4W13
PID NO. 105523
FRANKLIN COUNTY, OHIO

STRUCTURE FOUNDATION EXPLORATION REPORT

Prepared For:
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Rii Project No. W-13-045

July 2018

RESOURCE INTERNATIONAL, INC.

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Planning

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July 13, 2018

Mr. Christopher W. Luzier, P.E.
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Re: Structure Foundation Exploration Report
FRA-70-12.68 Project 4R
Retaining Wall 4W13
PID No. 105523
Rii Project No. W-13-045

Mr. Luzier:

Resource International, Inc. (Rii) is pleased to submit this structure foundation exploration report for the above referenced project. Engineering logs have been prepared and are attached to this report along with the results of laboratory testing. This report includes recommendations for the design and construction of proposed Retaining Wall 4W13 as part of the FRA-70-12.68 Project 4R 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.

Hanumanth S. Kulkarni, Ph.D.
Project Engineer

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

Enclosure: Structure Foundation Exploration Report

TABLE OF CONTENTS

APPENDICIES

Appendix I	**Vicinity Map and Boring Plan**
Appendix II	**Description of Soil Terms**
Appendix III	**Project Boring Logs: B-030-1-15, B-031-0-08, B-032-0-08, B-032-2-15 and B-032-3-15**
Appendix IV	**Bearing Resistance Charts**
Appendix V	**Shallow Foundation Calculations**
Appendix VI	**External Stability Analysis Calculations by GPD GROUP**
Appendix VII	**Global Stability Analysis Output**

EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for retaining wall 4W13 as part of the FRA-70-12.68 (Project 4R) project. Retaining wall 4W13 measures approximately 540.72 lineal feet in length, with a proposed stem height above the footing varying from 25.3 to 33.7 feet. The retaining wall is proposed to be constructed as a cast-in-place (CIP) wall, and in the interim condition, the wall will have an extended stem designed to support the future engineered fill and roadway under design project FRA-70-1405.

Exploration and Findings

Between October 6 and December 3, 2015, three (3) structural borings, designated as B-030-1-15, B-032-2-15, and B-032-3-15, were drilled to completion depths ranging from 59.4 to 75.0 feet below the existing ground surface along the proposed alignment of retaining wall 4W13. In addition to the borings performed by Rii as part of the current exploration, two (2) borings, designated as B-031-0-08 and B-032-0-08, from the preliminary engineering exploration were performed by DLZ in the vicinity of the proposed alignment of retaining wall 4W13. Boring B-031-0-08 was advanced to a depth of 60.0 feet and B-032-0-08 was advanced to completion depth of 128.5 feet below the existing ground surface within the existing ramp from I-70 eastbound to City Park Avenue and 3rd Street and Livingston Avenue for evaluation of the proposed retaining walls for the trench widening.

Boring B-030-1-15 was drilled through the I-70 eastbound shoulder pavement, and encountered composite pavement of 6.0 inches of asphalt over 12.0 inches of concrete followed by 6.0 inches of aggregate base at the ground surface. Borings B-032-2-15 and B-032-3-15 were drilled through the graded embankment south of I-70 and encountered 3.0 inches of topsoil. Boring B-031-0-08, drilled along the south of I-70 eastbound and encountered 8.0 inches of topsoil. Boring B-032-0-08 was drilled through the existing pavement of the ramp from I-70 eastbound to Third Street and Livingston Avenue and encountered 5.0 inches of asphalt overlying 3.0 inches of concrete followed by 5.0 inches of aggregate base at the ground surface.

Beneath the surface materials in borings B-030-1-15, B-031-0-08, and B-032-0-08 along the alignment of the proposed retaining wall 4W13, material identified as existing fill or possible fill was encountered extending to depths up to 4.0 feet below the ground surface. The fill material was described as brown sandy silt and silty clay (ODOT A-4a, A-6b) and contained brick fragments throughout. In borings B-032-2-15 and B-032-3-15, natural deposits of cohesive and non-cohesive materials were encountered underneath the surface material. The cohesive material identified as brown to gray sandy silt (ODOT A-4a) and the granular material in B-032-3-15 is identified as medium dense to very dense brown gravel and sand (ODOT A-1-b).

Underlying the surficial materials and existing fill, where encountered, natural soils were encountered consisting of both granular and cohesive material. The granular soils were generally described as, brown and gray gravel, gravel with sand, gravel with sand and silt, coarse and fine sand, sandy silt and silt (ODOT A-1-a, A-1-b, A-2-4, A-3a, A-4a, A-4b). The cohesive soils were generally described as stiff to hard, gray sandy silt, silt and silt and clay (ODOT A-4a, A-4b, A-6a).

Severely weathered shale bedrock was encountered in boring B-032-0-08 at a depth of 120.0 feet below the ground surface (El. 631.4 feet msl). Auger refusal occurred at depth 120.5 feet below ground surface and therefore, rock coring was initiated. It was indicated that a thin layer of lime stone was encountered between depths 125.2 to 125.5 feet below the surface. The cored shale bedrock encountered in this boring was described as dark gray, highly to severely weathered, very weak to weak, laminated, calcareous, pyritic, fissile, friable, jointed, fractured, tight, and slightly rough. The boring was terminated at depth 128.5 feet from the surface due to difficult conditions and it was recorded that the core steel was damaged during performing the core runs.

Analyses and Recommendations

Design details of the proposed retaining walls were provided by GPD GROUP. Retaining wall 4W13 extends between proposed FRA-70-1405C and FRA-33-1747C along the south side of I-70 eastbound. Based on plan information provided by GPD GROUP, the footings for retaining wall 4W13 have been designed to produce a maximum service limit bearing pressure of 4.97 ksf and a maximum factored bearing pressure of 7.14 ksf at the strength limit state. The retaining wall is proposed to be constructed as cast-in-place (CIP) wall type with a proposed stem height above the footing varying from 25.3 to 33.7 feet, and in the interim condition, the wall will have an extended stem designed to support future engineered fill.

The retaining wall is proposed to be constructed as a cast-in-place (CIP) wall, and in the interim condition, the wall will have an extended stem designed to support the future engineered fill and roadway under design project FRA-70-1405.

Based on plan information provided by GPD GROUP, the foundations for the proposed retaining walls will bear at a minimum depth of 6.0 feet below the existing grade of I-70, at elevations ranging from 725.0 to 731.0 feet msl. At these elevations, the bearing soils for wall 4W13 are anticipated to consist of hard sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b), and dense and very dense gravel and sand (ODOT A-1-b). Shallow foundations bearing on these competent natural soils may be proportioned for a nominal bearing resistance as presented in Table 6 for the retaining wall 4W13. Based on correspondence with GPD GROUP, it is understood that the external stability calculations for both retaining walls are being performed by the wall designer, GPD GROUP. Therefore, Rii has provided a graphical plot and tabulated the nominal and factored bearing resistance, as well as the anticipated settlement resulting from the service limit bearing pressure, as a function of the base width for use in final design of the wall systems.

Shallow Foundation Analysis – Retaining Wall 4W13

Effective Footing Width (feet)	Service Limit Bearing Pressure (ksf) [1]			Bearing Resistance at Strength Limit (ksf)	
	0.5-inch	1.0-inch	2.0-inch	Nominal	Factored [2]
5	1.87	4.83	7.84	31.68	17.42
7	1.69	4.06	7.01	31.70	17.43
9	1.59	3.62	6.45	31.72	17.45
11	1.52	3.33	6.11	31.74	17.46
13	1.47	3.12	5.89	31.76	17.47
15	1.43	2.97	5.74	31.79	17.48
17	1.41	2.86	5.63	31.81	17.49
19	1.38	2.77	5.54	31.83	17.51
21	1.37	2.69	5.47	31.85	17.52
23	1.35	2.63	5.41	31.88	17.53
25	1.34	2.58	5.36	31.90	17.54

1. *Service limit bearing pressure was calculated at total settlement values of 0.5, 1.0 and 2.0 inches.*
2. *Resistance factor of $\varphi_b = 0.55$ was utilized in calculating the factored nominal bearing resistance at the strength limit state.*

Based on the maximum service limit bearing pressures provided in the design documents and noted above, total settlements ranging from 0.653 to 1.427 inches are anticipated along the alignment of retaining wall 4W13. Additionally, the maximum factored bearing pressure will not exceed the factored bearing resistance at the strength limit for either retaining wall.

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

1.0 INTRODUCTION

The overall purpose of this project is to provide detailed subsurface information and recommendations for the design and construction of the FRA-70-12.68/13.11/14.05C (Project 4R/4H/4A) projects in Columbus, Ohio. The projects represent the central portion of FRA-70-8.93 (PID 77369) I-70/71 south innerbelt improvements project. The FRA-70-12.68 (Project 4R) phase will consist of all work associated with the construction of Ramp C5, starting at the bridge over Souder Avenue and extending east to Front Street. The proposed Ramp C5 will be a two-lane to four-lane ramp that will collect and direct traffic from I-71 northbound and SR-315 southbound as well as I-70 eastbound to exit in downtown at the intersection of Front Street and W. Fulton Avenue. This project includes the construction of six (6) new bridge structures for the proposed Ramp C5 alignment and replacement of three (3) bridge structures, two along I-70 and the Front Street Structure over I-70, as well as the construction of fourteen (14) new retaining walls and a culvert structure to accommodate the new configuration.

This report is a presentation of the structure foundation exploration performed for the design and construction of proposed retaining wall 4W13, as shown on the vicinity map and boring plan presented in Appendix I. Based on the proposed plan information provided by GPD GROUP, retaining wall 4W13 begins at Sta. 193+26.21, 50.03 feet right and continues to the east to Sta. 198+64.94, 49.75 feet right where, in the final condition, it will become a median barrier on the south side of eastbound I-70 and will support the higher eastbound exit ramp to Fourth Street and Livingston Avenue between the bridge structures FRA-70-1405C and FRA-33-1747C. Retaining wall 4W13 measures approximately 540.72 lineal feet in length, with a proposed stem height above the footing varying from 25.3 to 33.7 feet. The retaining wall is proposed to be constructed as a cast-in-place (CIP) wall, and in the interim condition, the wall will have an extended stem designed to support the future engineered fill and roadway under design project FRA-70-1405.

2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1 Site Geology

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

According to the bedrock geology and topography maps obtained from the Ohio Department of Natural Resources (ODNR), the underlying bedrock consists predominantly of the Middle to Lower Devonian-aged Columbus Limestone Formation. This formation is further subdivided into two members in the central portion of the state, known as the Delhi and Bellepoint Members. The Delhi Member consists of light gray, finely to coarsely crystalline, irregularly bedded, fossiliferous limestone. The Bellepoint Member consists of variable brown, finely crystalline, massively bedded limy dolomite. Both of these members contain chert nodules. Just east of the Scioto River, the underlying bedrock consists of the Upper Devonian Ohio Shale Formation overlying the Middle Devonian-aged Delaware Limestone Formation. The Ohio Shale formation consists of brownish black to greenish gray, thinly bedded, fissile, carbonaceous shale. The Delaware Limestone consists of bluish gray, thin to medium bedded dolomitic limestone with nodules and layers of chert. Regionally, the bedrock surface forms a broad valley aligned roughly north-to-south beneath the Scioto River. According to bedrock topography mapping, the elevation of the bedrock surface ranges from approximately 600 feet mean sea level (msl) in the valley to approximately 625 feet msl near the project limits. Within the borings performed for this current investigation, shale bedrock was encountered at a depth of 113.5 feet below the ground surface which corresponds to El. 628.8 feet msl.

2.2 Existing Conditions

The proposed retaining wall 4W13 structure will be located on the south side of eastbound I-70 between S. High Street and S. 3rd Street and will support the higher eastbound exit ramp to Fourth Street and Livingston Avenue to the south. 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 grades down from west to east into the downtown area, and is generally lower in elevation with respect to the surrounding terrain, as the existing corridor was cut approximately 20 to 25 below the existing grade of S. High Street and the surrounding downtown area. Adjacent to the pavements, the right of way has light to medium vegetation growth consisting of grasses and small trees. To the north is the entrance ramp from S. 3rd Street to I-70 westbound and to the north and the south, the embankments slope upwards with vegetation coverage. The 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 toward the Scioto River.

3.0 EXPLORATION

Between October 6 and December 3, 2015, three (3) structural borings, designated as B-030-1-15, B-032-2-15, and B-032-3-15, were drilled to completion depths ranging from 59.4 to 75.0 feet below the existing ground surface along the proposed alignment of retaining wall 4W13. In addition to the borings performed by Rii as part of the current exploration, two (2) borings, designated as B-031-0-08 and B-032-0-08, from the preliminary engineering exploration were performed by DLZ in the vicinity of the proposed alignment of retaining wall 4W13. Boring B-031-0-08 was advanced to a depth of 60.0 feet and B-032-0-08 was advanced to completion depth of 128.5 feet below the existing ground surface within the existing ramp from I-70 eastbound to City Park Avenue and 3rd Street and Livingston Avenue for evaluation of the proposed retaining walls for the trench widening. The current project boring locations are shown on the boring plan provided in Appendix I of this report and summarized in Table 1 below.

Table 1. Test Boring Summary

Boring Number	Reference Alignment	Station	Offset	Latitude	Longitude	Ground Elevation (feet msl)	Boring Depth (feet)
B-030-1-15	BL I-70 EB	194+37.05	70.0' Rt.	39.952814	-82.998014	748.9	59.4
B-031-0-08	BL I-70 EB	196+17.42	32.8' Rt.	39.953001	-82.997403	735.6	60.0
B-032-0-08	BL I-70 EB	196+22.20	79.7' Rt.	39.952876	-82.997357	751.4	128.5
B-032-2-15	BL I-70 EB	197+39.71	39.1' Rt.	39.953042	-82.996969	733.1	60.0
B-032-3-15	BL I-70 EB	198+77.78	40.8' Rt.	39.953103	-82.996483	732.8	75.0

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

The borings performed by Rii for the current exploration were drilled using a truck or an all-terrain vehicle (ATV) mounted rotary drilling machine, utilizing a 3.25-inch inside diameter, hollow-stem augers to advance the holes. Standard penetration test (SPT) and split spoon sampling were performed in the borings at 2.5-foot increments of depth to 20 feet in boring B-031-1-15 and 25 feet in boring B-032-2-15 and 30 feet in boring B-033-3-15 and at 5.0-foot increments 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. Rii utilized a calibrated automatic drop hammer to generate consistent energy transfer to the sampler. Driving resistance is recorded on the boring logs in terms of blow per 6.0-inch interval of the driving distance.

The second and third intervals are added to obtain the number of blows per foot (N). Standard penetration blow counts aid in determining soil properties applicable in foundation system design. Measured blow count (N) values are corrected to an equivalent (60%) energy ratio, N_{60}, by the following equation. Both values are represented on boring logs in Appendix III.

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

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

The hammers for the Mobile CME 55 and the CME 750X drill rigs used by Rii were calibrated on October 20th, 2014, and have drill rod energy ratios of 92.0 and 85.7 percent, respectively. The hammer for the CME 750X drill rig used by DLZ for the preliminary exploration borings had a drill rod energy ratio of 63.1 percent.

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

Table 2. Laboratory Test Schedule

Laboratory Test	Test Designation	Number of Tests Performed
Natural Moisture Content	ASTM D 2216	56
Plastic and Liquid Limits	AASHTO T89, T90	26
Gradation – Sieve/Hydrometer	AASHTO T88	26

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, in part, on the boring logs in Appendix III. A description of the soil terms used throughout this report is presented in Appendix II.

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

Where borings that were performed by DLZ were extended into the underlying bedrock, an NXM or NQ double-tube diamond bit core barrel (utilizing wire line equipment) was used to core the bedrock. Coring produced 1.85 inch diameter cores from which the type of rock and its geological characteristics were determined.

Rock cores were analyzed to identify the type of rock, color, mineral content, bedding planes and other geological and mechanical features of interest in this project. The Rock Quality Designation (RQD) for each rock core run was calculated according to the following equation:

$$RQD = \frac{\sum \text{segments equal to or longer than 4.0 inches}}{\text{core run length}} x100$$

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-030-1-15 was drilled through the I-70 eastbound shoulder pavement, and encountered composite pavement of 6.0 inches of asphalt over 12.0 inches of concrete followed by 6.0 inches of aggregate base at the ground surface. Borings B-032-2-15 and B-032-3-15 were drilled through the graded embankment south of I-70 and encountered 3.0 inches of topsoil. Boring B-031-0-08, drilled along the south of I-70 eastbound and encountered 8.0 inches of topsoil. Boring B-032-0-08 was drilled through the existing pavement of the ramp from I-70 eastbound to Third Street and Livingston Avenue and encountered 5.0 inches of asphalt overlying 3.0 inches of concrete followed by 5.0 inches of aggregate base at the ground surface.

4.2 Subsurface Soils

Beneath the surface materials in borings B-030-1-15, B-031-0-08, and B-032-0-08 along the alignment of the proposed retaining wall 4W13, material identified as existing fill or possible fill was encountered extending to depths up to 4.0 feet below the ground surface. The fill material was described as brown sandy silt and silty clay (ODOT A-4a, A-6b) and contained brick fragments throughout. In borings B-032-2-15 and B-032-3-15, natural deposits of cohesive and non-cohesive materials were encountered underneath the surface material. The cohesive material identified as brown to gray sandy silt (ODOT A-4a) and the granular material in B-032-3-15 is identified as medium dense to very dense brown gravel and sand (ODOT A-1-b).

Underlying the surficial materials and existing fill, where encountered, natural soils were encountered consisting of both granular and cohesive material. The granular soils were generally described as, brown and gray gravel, gravel with sand, gravel with sand and silt, coarse and fine sand, sandy silt and silt (ODOT A-1-a, A-1-b, A-2-4, A-3a, A-4a, A-4b). The cohesive soils were generally described as stiff to hard, gray sandy silt, silt and silt and clay (ODOT A-4a, A-4b, A-6a).

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 medium dense ($11 \leq N_{60} \leq 30$ blows per foot [bpf]) to very dense ($N_{60} > 50$ bpf). Overall blow counts recorded from the SPT sampling ranged from 15 bpf to split spoon sampler refusal. The shear strength and consistency of the cohesive soils are primarily derived from the hand penetrometer values (HP). The cohesive soil encountered ranged from stiff (1.0 ≤ HP ≤ 2.0 tsf) to hard (HP > 4.0 tsf). The unconfined compressive strength of the cohesive soil samples tested, obtained from the hand penetrometer, ranged from 1.5 tsf to over 4.5 tsf (limit of instrument).

Natural moisture contents of the soil samples tested ranged from 4 to 23 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 6 percent below to 4 percent above their corresponding plastic limits. In general, the soil exhibited natural moisture contents considered to be moderately below to moderately above optimum moisture levels.

4.3 Bedrock

Bedrock was encountered in boring B-032-0-08, as presented in Table 3.

Table 3. Top of Bedrock Elevations

Boring Number	Ground Surface Elevation (feet msl)	Top of Bedrock (Sampler Refusal)		Top of Bedrock Core (Auger Refusal)	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-032-0-08	751.4	120.0	631.4	120.5	630.9

Severely weathered shale bedrock was encountered in boring B-032-0-08 at a depth of 120.0 feet below the ground surface (El. 631.4 feet msl). Auger refusal occurred at depth 120.5 feet below ground surface and therefore, rock coring was initiated. It was indicated that a thin layer of lime stone was encountered between depths 125.2 to 125.5 feet below the surface. The cored shale bedrock encountered in this boring was described as dark gray, highly to severely weathered, very weak to weak, laminated, calcareous, pyritic, fissile, friable, jointed, fractured, tight, and slightly rough. The boring was terminated at depth 128.5 feet from the surface due to difficult conditions and it was recorded that the core steel was damaged during performing the core runs.

The percent recovery, RQD values and unconfined compressive strengths of the bedrock core runs are summarized in Table 4.

Table 4. Rock Core Summary

Boring	Core No.	Elevation (feet msl)	Recovery (%)	RQD (%)	Unconfined Compressive Strength
B-032-0-08	R-1	630.9 to 626.4	36.6	8	N/A
	R-2	626.4 to 622.9	63.8	0	N/A

It should be noted that bedrock naturally experiences mechanical breaks during the drilling and coring processes. The quality of the shale bedrock, according to the RQD values, was very poor (RQD < 25%).

4.4 Groundwater

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

Table 5. Groundwater

Boring Number	Ground Surface Elevation (feet msl)	Initial Groundwater		Upon Completion	
		Depth (feet)	Elevation (feet msl)	Depth (feet)	Elevation (feet msl)
B-030-1-15	748.9	28.5	720.4	28.5	720.4
B-031-0-08	735.6	9.5	726.1	8.3 [1]	727.3
B-032-0-08	751.4	47.0	704.4	25.7 [1]	725.7
B-032-2-15	733.1	16.0	717.1	N/A [2]	-
B-032-3-15	732.8	11.5	721.3	11.5	721.3

1. *Includes drilling water. Advanced wash boring due to sand heave.*
2. *The groundwater level at completion could not be obtained due cave-in occurred at 17.0'.*

Groundwater was encountered initially during the drilling process in all of the borings at depths ranging from 9.5 to 47.0 feet below existing grade, which corresponds to elevations ranging from 704.4 to 726.1 feet msl, respectively. The groundwater level at the completion of drilling in boring B-032-2-15 was not recorded due the cave-in condition occurred at 17.0 feet below existing grade. Additionally, DLZ noted that they frequently added water to the borehole to clean out the augers after encountering sand heave of varying amounts at various depths.

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 various exploration programs have been used to determine the foundation support capabilities and the settlement potential for the soil encountered at the site. These parameters have been used to provide guidelines for the design of foundation systems for the subject structure, 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 walls were provided by GPD GROUP. Retaining wall 4W13 extends between proposed FRA-70-1405C and FRA-33-1747C along the south side of I-70 eastbound. Based on plan information provided by GPD GROUP, the footings for retaining wall 4W13 have been designed to produce a maximum service limit bearing pressure of 4.97 ksf and a maximum factored bearing pressure of 7.14 ksf at the strength limit state. The retaining wall is proposed to be constructed as cast-in-place (CIP) wall type with a proposed stem height above the footing varying from 25.3 to 33.7 feet, and in the interim condition, the wall will have an extended stem designed to support future engineered fill.

The stability analysis on the bearing, wall eccentricity (overturning), sliding and final CIP wall dimensions and design considerations were performed by GPD GROUP and the calculations are presented in Appendix VI.

5.1 Shallow Foundation Recommendations

Based on plan information provided by GPD GROUP, the foundations for the proposed retaining walls will bear at a minimum depth of 6.0 feet below the existing grade of I-70, at elevations ranging from 725.0 to 731.0 feet msl. At these elevations, the bearing soils for wall 4W13 are anticipated to consist of hard sandy silt, silt and clay and silty clay (ODOT A-4a, A-6a, A-6b), and dense and very dense gravel and sand (ODOT A-1-b). Shallow foundations bearing on these competent natural soils may be proportioned for a nominal bearing resistance as presented in Table 6 for the retaining wall 4W13. Based on correspondence with GPD GROUP, it is understood that the external stability calculations for both retaining walls are being performed by the wall designer, GPD GROUP. Therefore, Rii has provided a graphical plot and tabulated the nominal and factored bearing resistance, as well as the anticipated settlement resulting from the service limit bearing pressure, as a function of the base width for use in final design of the wall systems.

Table 6. Shallow Foundation Analysis – Retaining Wall 4W13

Effective Footing Width (feet)	Service Limit Bearing Pressure (ksf) [1]			Bearing Resistance at Strength Limit (ksf)	
	0.5-inch	1.0-inch	2.0-inch	Nominal	Factored [2]
5	1.87	4.83	7.84	31.68	17.42
7	1.69	4.06	7.01	31.70	17.43
9	1.59	3.62	6.45	31.72	17.45
11	1.52	3.33	6.11	31.74	17.46
13	1.47	3.12	5.89	31.76	17.47
15	1.43	2.97	5.74	31.79	17.48
17	1.41	2.86	5.63	31.81	17.49
19	1.38	2.77	5.54	31.83	17.51
21	1.37	2.69	5.47	31.85	17.52
23	1.35	2.63	5.41	31.88	17.53
25	1.34	2.58	5.36	31.90	17.54

1. *Service limit bearing pressure was calculated at total settlement values of 0.5, 1.0 and 2.0 inches.*
2. *Resistance factor of φ_b = 0.55 was utilized in calculating the factored nominal bearing resistance at the strength limit state.*

The service limit bearing pressure that results in a maximum total settlement of 0.5, 1.0 and 2.0 inches was calculated and presented in Table 6 for retaining wall 4W13. A geotechnical resistance factor of φ_b = 0.55 has been considered in calculating the factored bearing resistance at the strength limit state for both retaining walls. Based on the bearing pressures provided in Table 6, and applying the geotechnical resistance factor provided to the nominal bearing resistance at the strength limit state, the service limit state should control the minimum footing dimensions for all effective footing widths analyzed for the total settlement values considered in the analysis of both retaining walls. A graphical representation of the service limit bearing pressures and factored bearing resistance at the strength limit state is presented in Appendix IV for both structures. Calculations for settlement and nominal and factored bearing resistance for the shallow spread foundations for both structures are provided in Appendix V.

Based on the maximum service limit bearing pressures provided in the design documents and noted in Section 5.0, total settlements ranging from 0.653 to 1.427 inches are anticipated along the alignment of retaining wall 4W13. Additionally, the maximum factored bearing pressure will not exceed the factored bearing resistance at the strength limit for either retaining wall.

5.1.1 Sliding Resistance

The resistance of the footings to sliding will be dependent on the friction between the concrete footing and bearing surface. The bearing soils consist of cohesionless soil and transitions to cohesive material along the middle of the wall alignment. Therefore, it is recommended to consider the sliding resisting for both drained and undrained conditions. For drained conditions, we recommend using a friction angle of 41 degrees and a coefficient of sliding friction "f" of 0.87 to calculate the total vertical force on the base. For undrained conditions, it is recommended to use an undrained shear strength of 6,000 psf. A geotechnical resistance factor of φ_τ = 1.0 should be considered when calculating the factored shear resistance between the soil and foundation for sliding.

5.1.2 Overall (Global) Stability

A slope stability analysis was performed to check the global stability of the walls along the alignments. As per AASHTO LRFD BDS, safety against global stability failure shall be evaluated at the service limit state. Soil parameters utilized in external stability analyses are presented in Table 7. For the global stability condition, it was considered that the failure plane will not cross through any portion of the supported soil mass above the concrete or through the concrete footing itself.

Table 7. Shear Strength Parameters Utilized in Stability Analyses

Material Type	Unit Weight, γ (pcf)	Effective Friction Angle, φ' (°)	Effective Cohesion, c' (psf)	Undrained Shear Strength, S_u (psf)
Item 203 Embankment Fill	120	30	0	2,000
Stiff to Hard Cohesive Soils	120 to 130	28 to 32	0	2,000 to 4,000
Loose to Very Dense Granular Soils	120 to 135	32 to 42	0	N/A

Per Section 11.6.2.3 of the 2012 AASHTO LRFD BDS, overall (global) stability for CIP walls not supporting structural foundations on spread footings is satisfied if the product of the factor of safety from the slope stability output multiplied by the resistance factor φ=0.75 is greater than 1.0. Therefore, global stability is satisfied when a minimum factor of safety of 1.33 is obtained. For retaining wall 4W13, global stability was evaluated considering the final configuration (post construction for FRA-70-12.68 Phase 4R). Based on the footing dimensions provided in the proposed design documents, the resulting factor of safety under drained conditions (long-term stability) and undrained (short-term stability) along the alignment or retaining wall 4W13 was greater than 1.33. Calculations for overall (global) stability of the CIP Wall 4W13 is provided in Appendix VII.

5.2 Lateral Earth Pressure

For the soil types encountered in the borings, the "in-situ" unit weight (γ), cohesion (c), effective angle of friction (φ'), and lateral earth pressure coefficients for at-rest conditions (k_o), active conditions (k_a), and passive conditions (k_p) have been estimated and are provided in Table 8 and

Soil Type	γ (pcf) [1]	c (psf)	φ	k_a	k_o	k_p
Soft to Stiff Cohesive Soil	115	1,500	0°	N/A	N/A	N/A
Very Stiff to Hard Cohesive Soil	125	3,000	0°	N/A	N/A	N/A
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	2,000	0°	N/A	N/A	N/A
Compacted Granular Engineered Fill	130	0	33°	0.30	0.46	3.39

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

Table 9.

Table 8. Estimated Undrained (Short-term) Soil Parameters for Design

Soil Type	γ (pcf) [1]	c (psf)	φ	k_a	k_o	k_p
Soft to Stiff Cohesive Soil	115	1,500	0°	N/A	N/A	N/A
Very Stiff to Hard Cohesive Soil	125	3,000	0°	N/A	N/A	N/A
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	2,000	0°	N/A	N/A	N/A
Compacted Granular Engineered Fill	130	0	33°	0.30	0.46	3.39

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

Table 9. Estimated Drained (Long-term) Soil Parameters for Design

Soil Type	γ (pcf) [1]	c (psf)	φ'	k_a	k_o	k_p
Soft to Stiff Cohesive Soil	115	0	26°	0.35	0.56	4.53
Very Stiff to Hard Cohesive Soil	125	50	28°	0.32	0.53	5.07
Loose Granular Soil	120	0	28°	0.32	0.53	5.07
Medium Dense Granular Soil	125	0	32°	0.27	0.47	6.82
Dense to Very Dense Granular Soil	130	0	36°	0.23	0.41	9.09
Compacted Cohesive Engineered Fill	120	0	30°	0.30	0.50	5.58
Compacted Granular Engineered Fill	130	0	33°	0.26	0.46	7.41

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

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

5.2.1 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 10. 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 Groundwater Considerations

Based on the groundwater observations made during drilling, groundwater may be encountered during excavation of the foundation for retaining wall 4W3. Where/if groundwater is encountered, proper groundwater control should be employed and maintained to prevent disturbance to excavation bottoms consisting of cohesive soil, and to prevent the possible development of a quick or "boiling" condition where soft silts and/or fine sands are encountered. It is preferable that the groundwater level, if encountered, be maintained at least 36 inches below the deepest excavation. Any seepage or groundwater encountered at this site should be able to be controlled by pumping from temporary sumps. Additional measures may be required depending on seasonal fluctuations of the groundwater level. Note that determining and maintaining actual groundwater levels during construction is the responsibility of the contractor.

6.0 LIMITATIONS OF STUDY

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

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

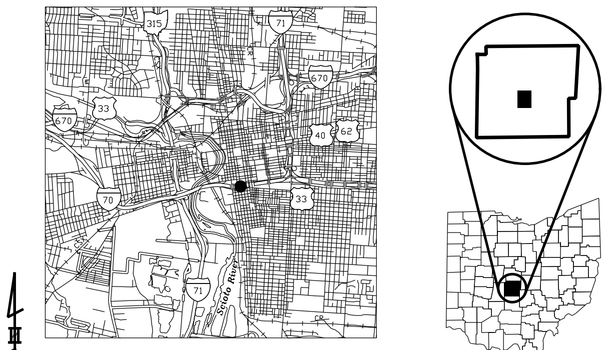
The conclusions and recommendations herein have been based upon the available soil and bedrock information and the design details furnished by a representative of the owner of the proposed project. Any revision in the plans for the proposed construction from those anticipated in this report should be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

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

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

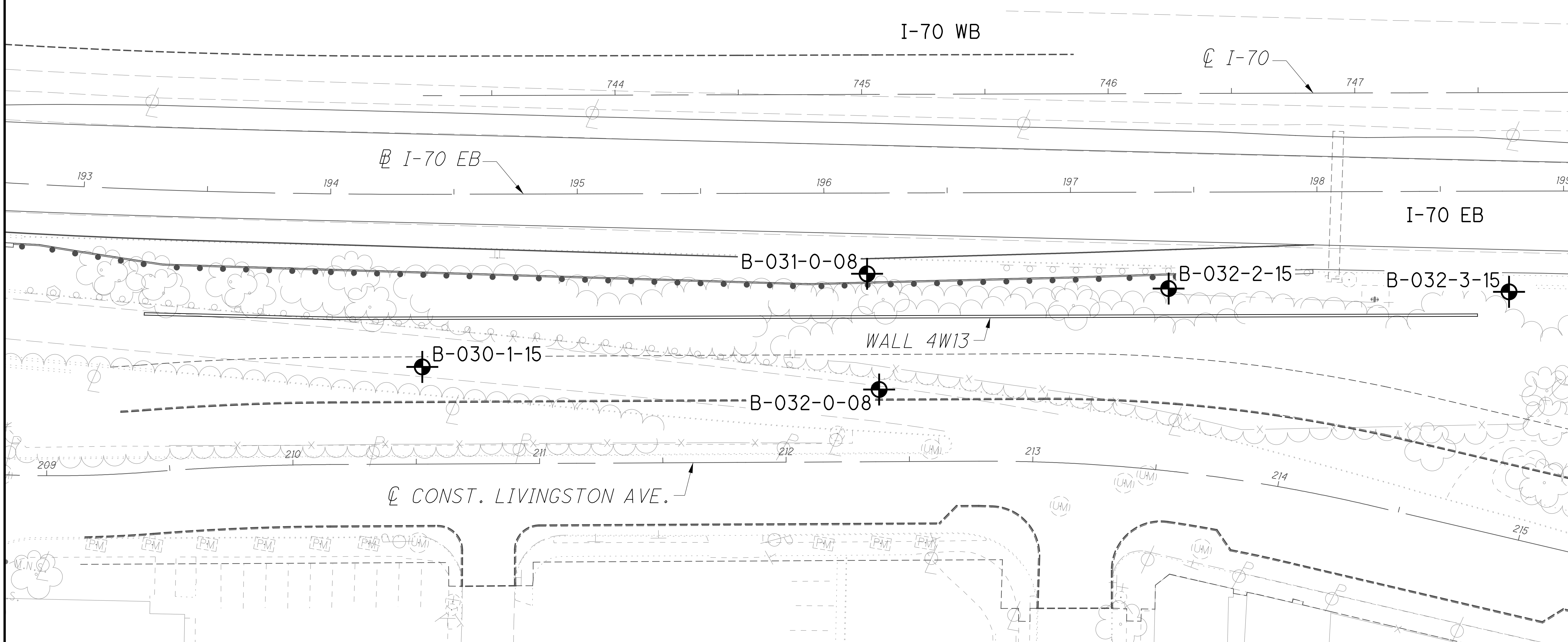
APPENDIX I

VICINITY MAP AND BORING PLAN



FRANKLIN COUNTY

VICINITY MAP



BORING PLAN

WALL 4W13

FRANKLIN COUNTY, OHIO

RII PROJECT NO. W-15-126	DRAWN RRM	RESOURCE INTERNATIONAL, INC.
SCALE: 1"=40' 0 20 40	REVIEWED BRT	
	DATE 7-12-18	

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:

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

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

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

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

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

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

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

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

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

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

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

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

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

CLASSIFICATION OF SOILS

Ohio Department of Transportation

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

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

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

APPENDIX III

BORING LOGS:

B-030-1-15, B-032-2-15 AND B-032-3-15, B-031-0-08 AND B-032-0-08

BORING LOGS

Definitions of Abbreviations

AS = Auger sample

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

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

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

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

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

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

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

RC = Rock core sample

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

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

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

S = Sulfate content (parts per million)

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

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

SS = Split spoon sample

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

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

TR = Top of rock

W = Initial water level measured during drilling

▼ = Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

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

Atterberg Limits:

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

WC = Water content (%)

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 55 (SN 386345)	STATION / OFFSET: 194+37.05 / 70' RT
TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: CME AUTOMATIC	ALIGNMENT: I-70 EB
PID: 96053 BR ID: NA	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 748.9 (MSL) EOB: 59.4 ft.
START: 12/2/15 END: 12/3/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	COORD: 39.952814, -82.998014

EXPLORATION ID B-030-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 748.9
0.5' - ASPHALT (6.0")	748.4
1.0' - CONCRETE (12.0")	747.4
0.5' - AGGREGATE BASE (6.0")	746.9
VERY STIFF, BROWN **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP.	745.4
DENSE TO VERY DENSE, BROWN TO BROWNISH GRAY **GRAVEL WITH SAND AND SILT**, TRACE CLAY, MOIST. -COBBLES PRESENT THROUGHOUT	738.4
HARD, GRAY **SILT AND CLAY**, SOME COARSE TO FINE SAND, LITTLE TO SOME FINE GRAVEL, DAMP.	729.2
VERY DENSE, GRAY TO BROWN **GRAVEL AND SAND**, TRACE SILT, TRACE CLAY, DAMP TO MOIST. -COBBLES PRESENT @ 22.0' -WATER ADDED TO AUGERS @ 28.5' (W)	

SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
7-8-11	29	100	SS-1	4.00	25	16	12	27	20	24	15	9	12	A-4a (2)
8-12-9	32	67	SS-2	-	-	-	-	-	-	-	-	-	7	A-2-4 (V)
9-15-16	48	100	SS-3	-	49	21	9	14	7	24	17	7	8	A-2-4 (0)
19-20-16	55	100	SS-4	-	-	-	-	-	-	-	-	-	8	A-2-4 (V)
26-42-37	121	33	SS-5	4.5+	22	9	12	31	26	26	13	13	9	A-6a (6)
10-19-24	66	0	SS-6	-	-	-	-	-	-	-	-	-	-	A-6a (V)
45	-	100	3S-6A	4.5+	-	-	-	-	-	-	-	-	10	A-6a (V)
11-14-17	48	100	SS-7	4.5+	-	-	-	-	-	-	-	-	10	A-6a (V)
6-16-50/3"	-	100	SS-8	4.5+	12	9	13	38	28	25	13	12	10	A-6a (7)
				-	-	-	-	-	-	-	-	-	5	A-1-b (V)
22-32-37	106	100	SS-9	-	23	34	29	9	5	NP	NP	NP	4	A-1-b (0)
24-31-29	92	100	SS-10	-	-	-	-	-	-	-	-	-	12	A-1-b (V)

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

PID: 96053	BR ID: NA	PROJECT: FRA-70-14.05 PROJECT 4B	STATION / OFFSET: 194+37.05 / 70 RT	START: 12/2/15	END: 12/3/15	PG 2 OF 2	B-030-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 718.9	DEPTHS
VERY DENSE, GRAY TO BROWN **GRAVEL AND SAND**, TRACE SILT, TRACE CLAY, DAMP TO MOIST. *(same as above)*	711.9	
VERY DENSE, GRAY **SILT**, "AND" COARSE TO FINE SAND, TRACE CLAY, TRACE FINE GRAVEL, MOIST.	706.9	
HARD, GRAY **SANDY SILT**, LITTLE FINE GRAVEL, LITTLE CLAY, MOIST.	696.9	
MEDIUM DENSE TO VERY DENSE, GRAY **GRAVEL AND SAND**, TRACE SILT, TRACE CLAY, MOIST TO WET. -HEAVING SANDS ENCOUNTERED @ 53.5'	689.5	EOB

Depth	SPT/RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
34	5 19 30	75	100	SS-11	-	43	26	17	10	4	NP	NP	NP	10	A-1-b (0)	
39	5 25 33	89	100	SS-12	-	1	0	38	54	7	NP	NP	NP	17	A-4b (5)	
44	36 48 50/4"	-	100	SS-13	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	
49	24 50/5"	-	100	SS-14	4.5+	16	13	23	37	11	18	13	5	10	A-4a (3)	
54	1 2 8	15	78	SS-15	-	-	-	-	-	-	-	-	-	17	A-1-b (V)	
59	14 50/5"	-	100	SS-16	-	33	47	12	6	2	NP	NP	NP	11	A-1-b (0)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED 28.5'

ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 200 LBS BENTONITE CHIPS AND SOIL CUTTINGS

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

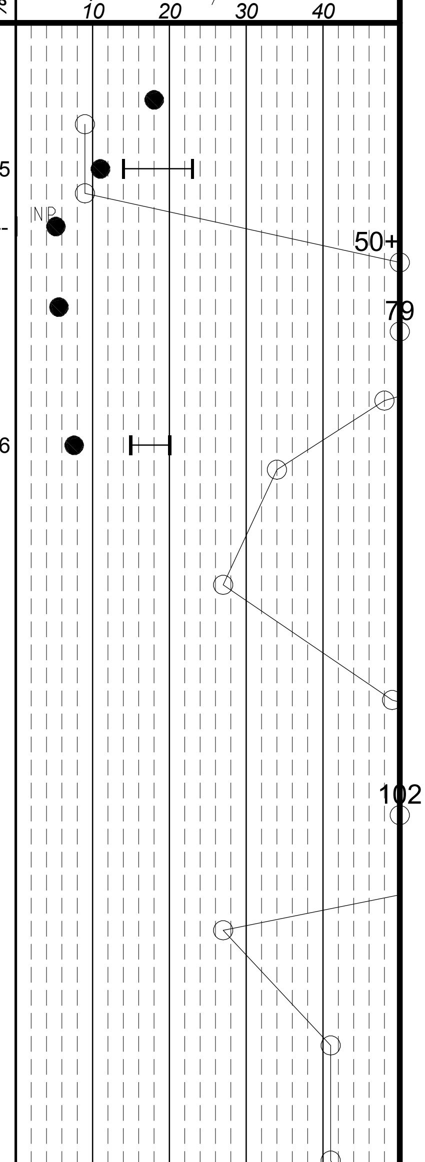
Client: ms consultants	Project: FRA-70-8.93	Job No. 0221-1004.01
LOG OF: Boring B-031-0-08	Location: Sta. 196+17.42, 32.8' RT., BL I-70 EB	Date Drilled: 7/7/2008 to 7/8/2008

WATER OBSERVATIONS:
Water seepage at: 9.5'
Water level at completion: 8.3' (includes drilling water)

FIELD NOTES:
Advanced boring using 3.25" diameter hollowstem augers.

Depth (ft)	Elev. (ft) 735.6	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
0.7	734.9						Topsoil - 8"						
		2 4 5	18	1		3.75	FILL: Very stiff to hard brown SILT (A-4b), some clay, little fine to coarse sand, trace to little gravel; contains few brick and coal fragments; damp.						
4.0	731.6	3 4 5	18	2		4.5+		12	5	---	6	52	25
5		16 50/5	5	3			Dense to very dense brownish gray GRAVEL WITH SAND (A-1-b), little silt; damp.	50	20	---	13	--17--	
		42 44 31	1	4			@ 5.0', encountered refusal; offset boring approx. three feet west.						
8.5	727.1	18 21 25	1	5			@ 5.5'-8.5', rock fragments; possible cobble blocking shoe.						
9.5	726.1	9 15 17	18	6A		4.5	Hard gray SANDY SILT (A-4a), little gravel; damp.	15	12	---	25	32	16
10				6B			Medium dense to dense gray SILT (A-4b), some fine sand; wet.						
13.5	722.1	4 12 14	18	7									
15		18 22 25	12	8		4.5+	Very stiff to hard gray SANDY SILT (A-4a), some fine to coarse sand, little gravel; damp.						
18.5	717.1	14 48 49	18	9		3.5							
20		11 13 13	18	10			Medium dense gray SILT (A-4b), trace fine sand; moist.						
21.0	714.6												
23.5	712.1	7 18 21	18	11			Dense gray COARSE AND FINE SAND (A-3a), some silt; wet.						
25	710.6	12 18 21	18	12		4.5+	Hard gray SANDY SILT (A-4a), some fine to coarse sand, trace gravel; damp.						

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ├──┤ LL
Blows per foot - ○ / Non-Plastic - NP



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

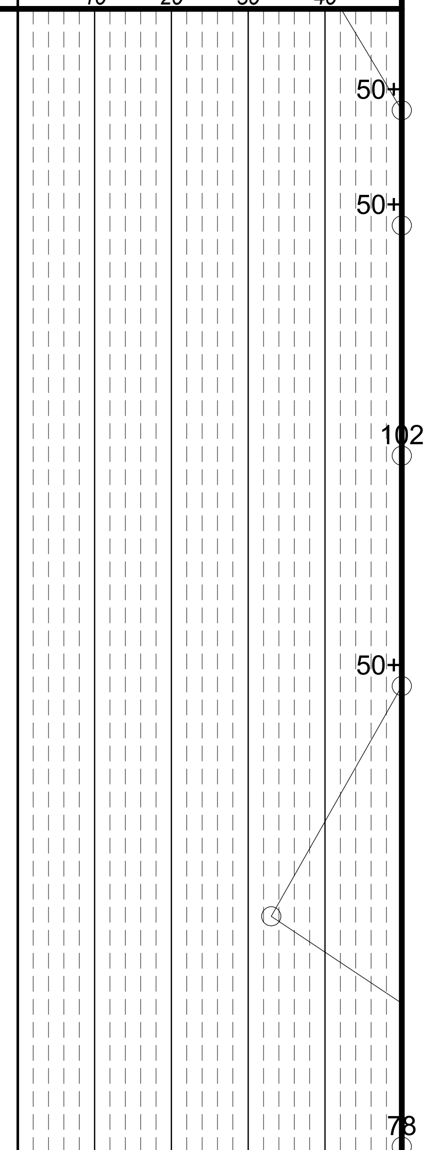
LOG OF: Boring B-031-0-08 | *Location:* Sta. 196+17.42, 32.8' RT., BL I-70 EB | *Date Drilled:* 7/7/2008 to 7/8/2008

WATER OBSERVATIONS:
Water seepage at: 9.5'
Water level at completion: 8.3' (includes drilling water)

FIELD NOTES:
Advanced boring using 3.25" diameter hollowstem augers.

Depth (ft)	Elev. (ft) 710.6	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
		20 50/5	10	13		4.5+	Hard gray SANDY SILT (A-4a), some fine to coarse sand, trace to little gravel; damp.							
28.0	707.6	50/5	5	14			Very dense gray SANDY SILT (A-4a), some fine to coarse sand, trace to little gravel; wet. @ 28.5'-38.9', possible cobbles.							
35		24 49 48	18	15										
40		50/5	5	16										
42.0	693.6						Dense gray FINE SAND (A-3), trace silt; wet.							
45		11 13 18	18	17										
47.0	688.6						Very dense gray COARSE AND FINE SAND (A-3a), little silt, little gravel; wet. @ 48.5', ten feet sand heave; triconed and washed out.							
50	685.6	16 33 41	18	18										

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



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

LOG OF: Boring B-031-0-08 | Location: Sta. 196+17.42, 32.8' RT., BL I-70 EB | Date Drilled: 7/7/2008 to 7/8/2008

WATER OBSERVATIONS:
Water seepage at: 9.5'
Water level at completion: 8.3' (includes drilling water)

FIELD NOTES:
Advanced boring using 3.25" diameter hollowstem augers.

Depth (ft)	Elev. (ft) 685.6	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) / Natural Moisture Content, % / PL–LL / Blows per foot / Non-Plastic - NP
							Very dense gray COARSE AND FINE SAND (A-3a), trace to little gravel, trace silt; wet.								
55		25 33 40	18	19											77
60.0 (60)	675.6	38 42 49	18	20											96
							Bottom of Boring - 60.0'								
65															
70															
75															

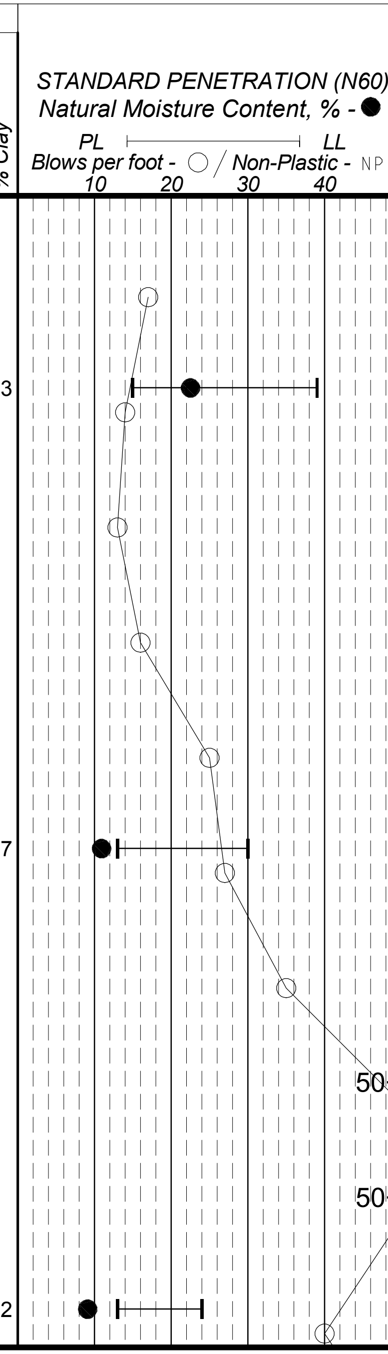
Client: ms consultants | *Project:* FRA-70-8.93 | *Job No.* 0221-1004.01

LOG OF: Boring B-032-0-08 | *Location:* Sta. 196+22.20, 79.7' RT., BL I-70 EB | *Date Drilled:* 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

Depth (ft)	Elev. (ft) 751.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
1.1	750.3						Asphalt Concrete - 5"						
2.0	749.4						Portland Cement Concrete - 3"						
		5 10 6	9	1		4.5+	Aggregate Base - 5"						
							FILL: Medium dense brown COARSE AND FINE SAND (A-3a), little silt, little gravel; moist.						
6.0	745.4	5 7 6	18	2		2.0	FILL: Very stiff to hard brown SILTY CLAY (A-6b), little to some fine to coarse sand, trace gravel; contains few brick fragments; damp to moist.	8	7	---	13	29	43
8.5	742.9	3 4 8	3	3		2.5	Very stiff brown SILT AND CLAY (A-6a), little fine to coarse sand, trace gravel; moist.						
11.0	740.4	4 7 8	3	4			Medium dense gray COARSE AND FINE SAND (A-3a), little silt, little gravel; damp. (POSSIBLE FOUNDRY SAND)						
		5 8 16	18	5		4.5+	Hard gray SILTY CLAY (A-6b), little to some fine to coarse sand, trace to little gravel; damp. @ 11.0'-12.5', brown and gray.						
		12 12 14	18	6		4.5+		12	8	---	15	38	27
							@ 13.0'-35.0', difficult drilling; possible cobbles and boulders.						
		5 16 17	1	7		--							
		50/1	0	8		--	@ 18.5'-20.0', only gravel recovered in auger cuttings sample.						
23.5	727.9	50/3	0	9		--							
25	726.4	34 17 21	18	10		4.5+	Hard gray SILT AND CLAY (A-6a), some fine to coarse sand, trace gravel; damp.	7	14	---	20	37	22



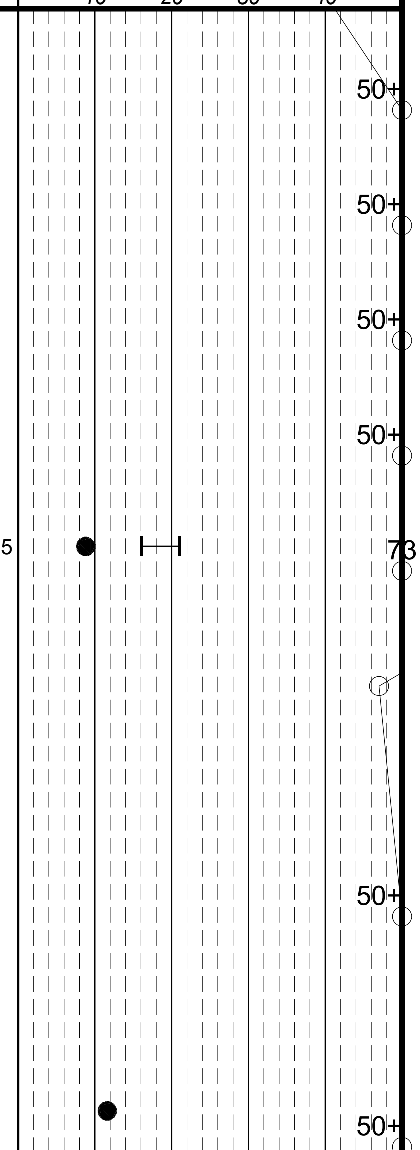
Client: ms consultants	Project: FRA-70-8.93	Job No. 0221-1004.01
LOG OF: Boring B-032-0-08	Location: Sta. 196+22.20, 79.7' RT., BL I-70 EB	Date Drilled: 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

Depth (ft)	Elev. (ft) 726.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay
							Hard gray SILT AND CLAY (A-6a), some fine to coarse sand, trace gravel; damp.							
		50/1	1	11		--								
		50/4	0	12		--								
30														
		50/1	0	13		--								
		50/3	1	14		--								
35														
36.0	715.4													
		10 24 45	18	15		4.5+	Hard gray SANDY SILT (A-4a), some to "and" fine to coarse sand, little gravel; damp.		16	20	---	23	26	15
		11 17 28	18	16		4.5+								
40														
		11 50/4	10	17		4.5+								
45														
		32 50/3	9	18		4.5+	@ 48.5'-49.3', contains occasional thin sand seams.							
50	701.4													

STANDARD PENETRATION (N60)
Natural Moisture Content, % - ●
PL ⊢⊣ LL
Blows per foot - ○ / Non-Plastic - NP
10 20 30 40



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

LOG OF: Boring B-032-0-08 | Location: Sta. 196+22.20, 79.7' RT., BL I-70 EB | Date Drilled: 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

Ground elevation: 701.4

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	Natural Moisture Content, %	Blows per foot (N60)
							Very dense gray FINE SAND (A-3); contains silty clay seams; wet.								
		26 50/3	9	19			@ 53.5', 1.5 feet sand heave; used tricone bit to wash out.								50+
57.0	694.4						Very dense gray GRAVEL WITH SAND (A-1-b), trace silt; contains silty clay seams; wet.								
		18 50/4	10	20				42	30	---	20	--8--		NP	50+
		28 50/3	9	21											50+
		16 42 50/3	15	22											50+
		33 50/5	11	23											50+
75	676.4														

DLZ Ohio, Inc. * 6121 Huntley Road, Columbus, Ohio 43229 * (614) 888-0040

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

LOG OF: Boring B-032-0-08 | Location: Sta. 196+22.20, 79.7' RT., BL I-70 EB | Date Drilled: 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

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

Depth (ft)	Elev. (ft) 676.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	SPT (N60) / Moisture
							Very dense gray COARSE AND FINE SAND (A-3a), trace to little silt, trace to little gravel; wet.							
80		17 50/4	10	24										50+
85		17 41 49	18	25				10	15	---	62	--13--		NP; 95
90		17 49 50/3	15	26			@ 88.5'-90.0', few limestone fragments.							50+
95		20 50/4	8	27										50+
100	651.4	17 50/4	10	28										50+

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

LOG OF: Boring B-032-0-08 | Location: Sta. 196+22.20, 79.7' RT., BL I-70 EB | Date Drilled: 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

Depth (ft)	Elev. (ft)	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) / Natural Moisture Content, %
	651.4						Very dense gray GRAVEL WITH SAND (A-1-b), trace silt; wet.							
105		5 / 37 / 50/3	15	29										50+
110		27 / 50/4	10	30				38	43	---	13	6		NP; 50+
115		50/5	5	31			@ 113.5'-113.9', possible cobbles.							50+
117.0	634.4						Very dense gray GRAVEL (A-1-a), "and" fine to coarse sand, trace silt; wet.							
		22 / 50/4	10	32				55	24	---	14	7		NP; 50+
120.0	631.4	50/3	3	33			Severely weathered gray SHALE.							50+
120.5	630.9	Core 60"	Rec 22"	RQD 8%	R1		Shale, dark gray, highly to severely weathered, very weak to weak, laminated, calcareous, friable, fissile, pyritic, jointed, fractured to highly fractured, tight, slightly rough; RQD 5% Loss 53%.							
125	626.4													

PL ⊢⊣ LL; Blows per foot - ○ / Non-Plastic - NP; scale 10 20 30 40

Client: ms consultants	Project: FRA-70-8.93	Job No. 0221-1004.01
LOG OF: Boring B-032-0-08	Location: Sta. 196+22.20, 79.7' RT., BL I-70 EB	Date Drilled: 7/8/2008 to 7/15/2008

WATER OBSERVATIONS:
Water seepage at: 47.0'
Water level at completion: 25.7' (includes drilling water)

FIELD NOTES:
3.25" diameter hollowstem augers to 120.5';
4.0" diameter flush joint casing from 120.5' to 128.5'.

Depth (ft)	Elev. (ft) 626.4	Blows per 6"	Recovery	Sample No. Drive	Sample No. Press / Core	Hand Penetrometer (tsf)	DESCRIPTION	Graphic Log	% Aggregate	% C. Sand	% M. Sand	% F. Sand	% Silt	% Clay	STANDARD PENETRATION (N60) Natural Moisture Content, % - ● PL ⊢ ⊣ LL Blows per foot - ○ / Non-Plastic - NP 10 20 30 40
		Core 36"	Rec 23"	RQD 0%	R2		Shale, dark gray, highly to severely weathered, very weak to weak, laminated, calcareous, friable, fissile, pyritic, jointed, fractured to highly fractured, tight, slightly rough; RQD 5% Loss 53%. @ 125.2' - 125.5', encountered thin limestone layer.								
128.5	622.9						@ 128.5', boring terminated due to difficult coring conditions (core steel broke off during both core runs).								
							Bottom of Boring - 128.5'								

Depth scale: 130, 135, 140, 145, 150

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750X (SN 310218)	STATION / OFFSET: 197+39.71 / 39.1' RT	EXPLORATION ID **B-032-2-15**
TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / CD/BW	HAMMER: CME AUTOMATIC	ALIGNMENT: I-70 EB	
PID: 96053 BR ID: NA	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 733.1 (MSL) EOB: 60.0 ft.	PAGE 1 OF 2
START: 10/6/15 END: 10/6/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 85.7	COORD: 39.953042, -82.996969	

MATERIAL DESCRIPTION AND NOTES	ELEV. 733.1	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
0.3' - TOPSOIL (3.0")	732.8																
HARD, BROWN TO GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP.		5 6 11	24	100	SS-1	4.5+	11	12	20	34	23	25	15	10	10	A-4a (4)	
		8 14 19	47	100	SS-2	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	
-SS-3: SULFATE CONTENT = 907 PPM		9 15 19	49	100	SS-3	4.5+	-	-	-	-	-	-	-	-	8	A-4a (V)	
		10 17 21	54	100	SS-4	4.5+	-	-	-	-	-	-	-	-	8	A-4a (V)	
	720.1	9 10 18	40	100	SS-5	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)	
VERY DENSE, GRAY **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST.	717.6	7 18 32	71	100	SS-6	-	36	25	17	14	8	17	11	6	6	A-1-b (0)	
MEDIUM DENSE TO VERY DENSE, GRAY **COARSE AND FINE SAND**, LITTLE SILT, TRACE CLAY, TRACE FINE GRAVEL, MOIST TO WET.	W	2 3 12	21	100	SS-7	-	5	10	70	12	3	NP	NP	NP	19	A-3a (0)	
	712.6	9 22 38	86	100	SS-8	-	-	-	-	-	-	-	-	-	15	A-3a (V)	
HARD, GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, DAMP.		6 21 35	80	100	SS-9	-	12	16	24	35	13	18	12	6	10	A-4a (3)	
		11 26 48	106	100	SS-10	4.5+	-	-	-	-	-	-	-	-	10	A-4a (V)	
		12 47 50/3"	-	100	SS-11	4.5+	13	11	22	38	16	20	11	9	8	A-4a (4)	

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

PID: 96053	BR ID: NA	PROJECT: FRA-70-14.05 PROJECT 4B	STATION / OFFSET: 197+39.71 / 39.1 RT	START: 10/6/15	END: 10/6/15	PG 2 OF 2	B-032-2-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 703.1	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
HARD, GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, DAMP. *(same as above)*	701.1	31–32																
MEDIUM DENSE TO VERY DENSE, GRAY **GRAVEL AND SAND**, TRACE SILT, TRACE CLAY, MOIST TO WET.		34	23 45 50/4"	-	100	SS-12	-	-	-	-	-	-	-	-	-	12	A-1-b (V)	
-HEAVING SANDS ENCOUNTERED @ 38.5' -WATER ADDED TO AUGERS @ 38.5'		39	17 41 50/5"	-	88	SS-13	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
		44	4 8 13	30	100	SS-14	-	21	55	17	5	2	NP	NP	NP	13	A-1-b (0)	
		49	9 18 33	73	100	SS-15	-	-	-	-	-	-	-	-	-	13	A-1-b (V)	
		54	11 42 50/4"	-	100	SS-16	-	11	47	30	8	4	NP	NP	NP	13	A-1-b (0)	
	673.1	59	16 44 47	130	67	SS-17	-	-	-	-	-	-	-	-	-	9	A-1-b (V)	
		EOB 60																

NOTES: GROUNDWATER INITIALLY ENCOUNTERED @ 16.0'; CAVE-IN DEPTH @ 17.0'

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

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 750X (SN 310218)	STATION / OFFSET: 198+77.78 / 40.8' RT
TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: CME AUTOMATIC	ALIGNMENT: I-70 EB
PID: 96053 BR ID: FRA-33-1747	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 732.8 (MSL) EOB: 75.0 ft.
START: 10/7/15 END: 10/8/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 85.7	COORD: 39.953103, -82.996483

EXPLORATION ID B-032-3-15

MATERIAL DESCRIPTION AND NOTES (ELEV. 732.8)

0.3' - TOPSOIL (3.0") — 732.5

MEDIUM DENSE TO VERY DENSE, BROWN **GRAVEL AND SAND**, LITTLE SILT, TRACE CLAY, MOIST.
- -ROCK FRAGMENTS PRESENT THROUGHOUT
- -COBBLES PRESENT @ 8.0'

— 722.3

DENSE TO VERY DENSE, BROWNISH GRAY TO GRAY **GRAVEL**, AND COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, WET.
- -MUD ADDED TO AUGERS @ 11.0'
- -ROCK FRAGMENTS PRESENT THROUGHOUT
- -HEAVING SANDS ENCOUNTERED @ 18.5'
- -COBBLES PRESENT FROM 18.5' TO 21.0'

— 708.3

HARD, GRAY **SANDY SILT**, LITTLE FINE GRAVEL, LITTLE CLAY, DAMP.

W (water level) @ 11.0'

DEPTHS	SPT/RQD	N60	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
1-2.5	4-7-8	21	100	SS-1	-	-	-	-	-	-	-	-	-	6	A-1-b (V)
3.5-5	8-13-13	37	100	SS-2	-	-	-	-	-	-	-	-	-	5	A-1-b (V)
6-7.5	11-14-24	54	78	SS-3	-	57	21	6	13	3	NP	NP	NP	7	A-1-b (0)
8.5-10	14-18-15	47	100	SS-4	-	-	-	-	-	-	-	-	-	7	A-1-b (V)
11-12.5	9-12-78	129	83	SS-5	-	99	1	0	0	0	NP	NP	NP	10	A-1-a (0)
13.5-15	26-20-20	57	89	SS-6	-	-	-	-	-	-	-	-	-	11	A-1-a (V)
16-17.5	7-13-16	41	100	SS-7	-	61	21	8	7	3	NP	NP	NP	11	A-1-a (0)
18.5-20	6-11-14	36	100	SS-8	-	-	-	-	-	-	-	-	-	9	A-1-a (V)
21-22.5	9-10-14	34	100	SS-9	-	55	27	9	7	2	NP	NP	NP	12	A-1-a (0)
23.5-25	17-11-21	46	100	SS-10	-	-	-	-	-	-	-	-	-	8	A-1-a (V)
					4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)
26-27.5	16-23-35	83	100	SS-11	4.5+	19	11	18	37	15	21	14	7	10	A-4a (3)
28.5-30	8-15-23	54	100	SS-12	4.5+	-	-	-	-	-	-	-	-	12	A-4a (V)

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

PID: 96053 | BR ID: FRA-33-1747 | PROJECT: FRA-70-14.05 PROJECT 4B | STATION / OFFSET: 198+77.78 / 40.8 RT | START: 10/7/15 | END: 10/8/15 | PG 2 OF 3 | B-032-3-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 702.8	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
HARD, GRAY **SANDY SILT**, LITTLE FINE GRAVEL, LITTLE CLAY, DAMP. *(same as above)*	700.8	31–32																
VERY DENSE, GRAY **SILT**, SOME COARSE TO FINE SAND, TRACE CLAY, TRACE FINE GRAVEL, MOIST.		34	28 48 50/4"	-	100	SS-13	1.50	5	5	22	61	7	NP	NP	NP	17	A-4b (7)	
	695.8	37																
VERY DENSE, DARK GRAY TO GRAY **GRAVEL AND SAND**, TRACE SILT, TRACE CLAY, WET.		39	26 26 36	89	100	SS-14	-	-	-	-	-	-	-	-	-	14	A-1-b (V)	
-COBBLES PRESENT @ 41.0'		41																
-HEAVING SANDS ENCOUNTERED @ 43.5'		44	15 47 50/2"	-	100	SS-15	-	-	-	-	-	-	-	-	-	8	A-1-b (V)	
-HEAVING SANDS ENCOUNTERED @ 48.5'		49	8 23 38	87	100	SS-16	-	36	28	26	9	1	NP	NP	NP	11	A-1-b (0)	
-COBBLES PRESENT @ 50.5'		51																
		54	32 30 47	110	100	SS-17	-	44	27	18	9	2	NP	NP	NP	10	A-1-b (0)	
		59	10 40 46	123	100	SS-18	-	-	-	-	-	-	-	-	-	15	A-1-b (V)	
	670.8	61–62																

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

PID: 96053	BR ID: FRA-33-1747	PROJECT: FRA-70-14.05 PROJECT 4B	STATION / OFFSET: 198+77.78 / 40.8 RT	START: 10/7/15	END: 10/8/15	PG 3 OF 3	B-032-3-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 670.7	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY DENSE, GRAY **SILT**, SOME COARSE TO FINE SAND, TRACE CLAY, WET. *(same as above)*		63																
		64–65	9 20 48	97	100	SS-19	-	0	1	20	74	5	NP	NP	NP	23	A-4b (8)	
-COBBLES PRESENT @ 66.0'	665.8	66																
MEDIUM DENSE TO DENSE, GRAY **COARSE AND FINE SAND**, TRACE SILT, TRACE FINE GRAVEL, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 68.5'		67–68																
		69–70	6 9 10	27	100	SS-20	-	5	40	42	10	3	NP	NP	NP	14	A-3a (0)	
		71–73																
	657.8	74–75 EOB	7 11 11	31	100	SS-21	-	-	-	-	-	-	-	-	-	12	A-3a (V)	

NOTES: GROUNDWATER INITIALLY ENCOUNTERED 11.5'

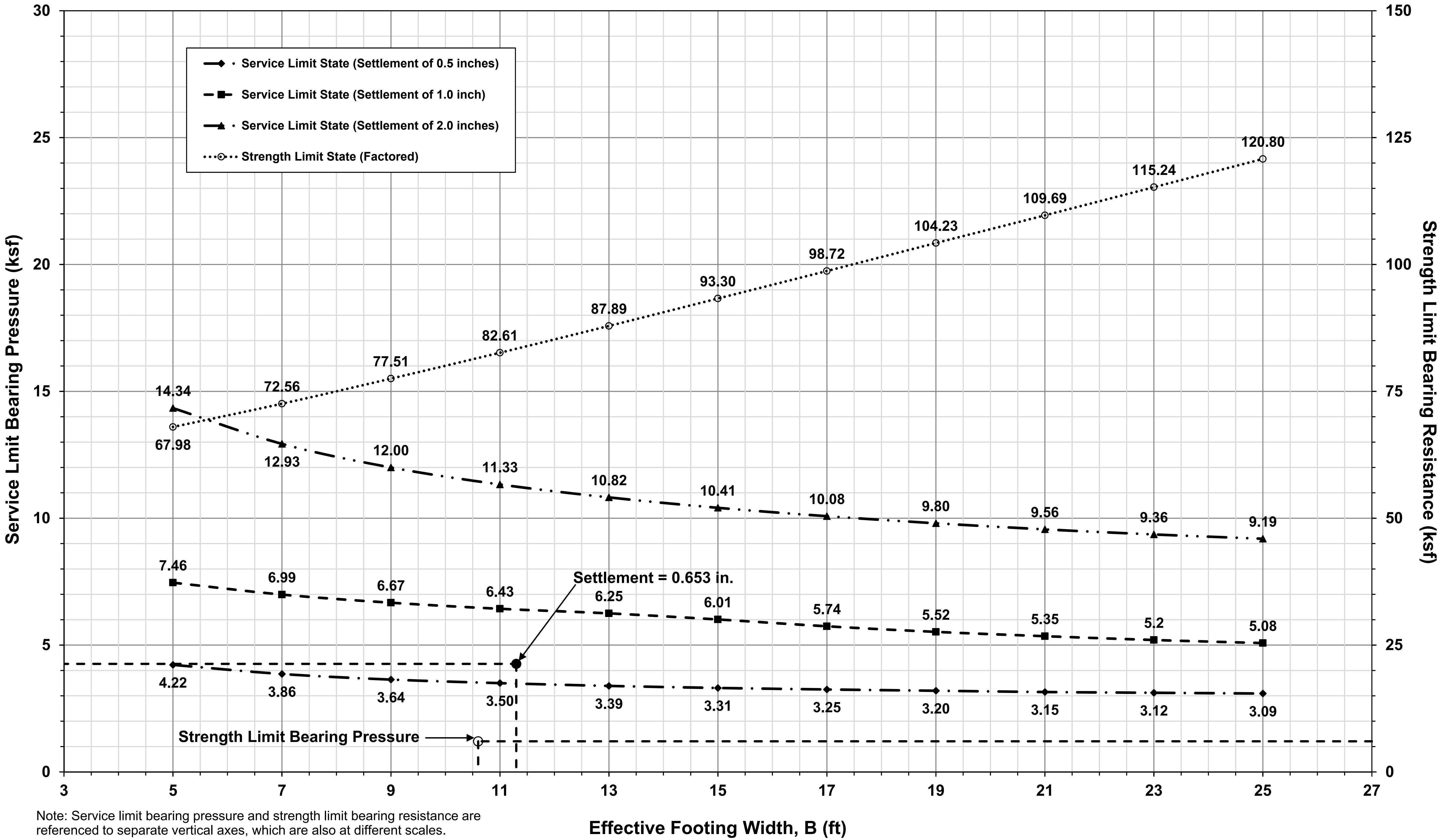
ABANDONMENT METHODS, MATERIALS, QUANTITIES: COMPACTED WITH THE AUGER 200 LBS BENTONITE CHIPS AND SOIL CUTTINGS

2015-ODOT BORING LOG-BRIDGE ID - OH DOT.GDT - 7/16/18 10:12 - U:\GI8\PROJECTS\2015\W-15-126.GPJ

APPENDIX IV

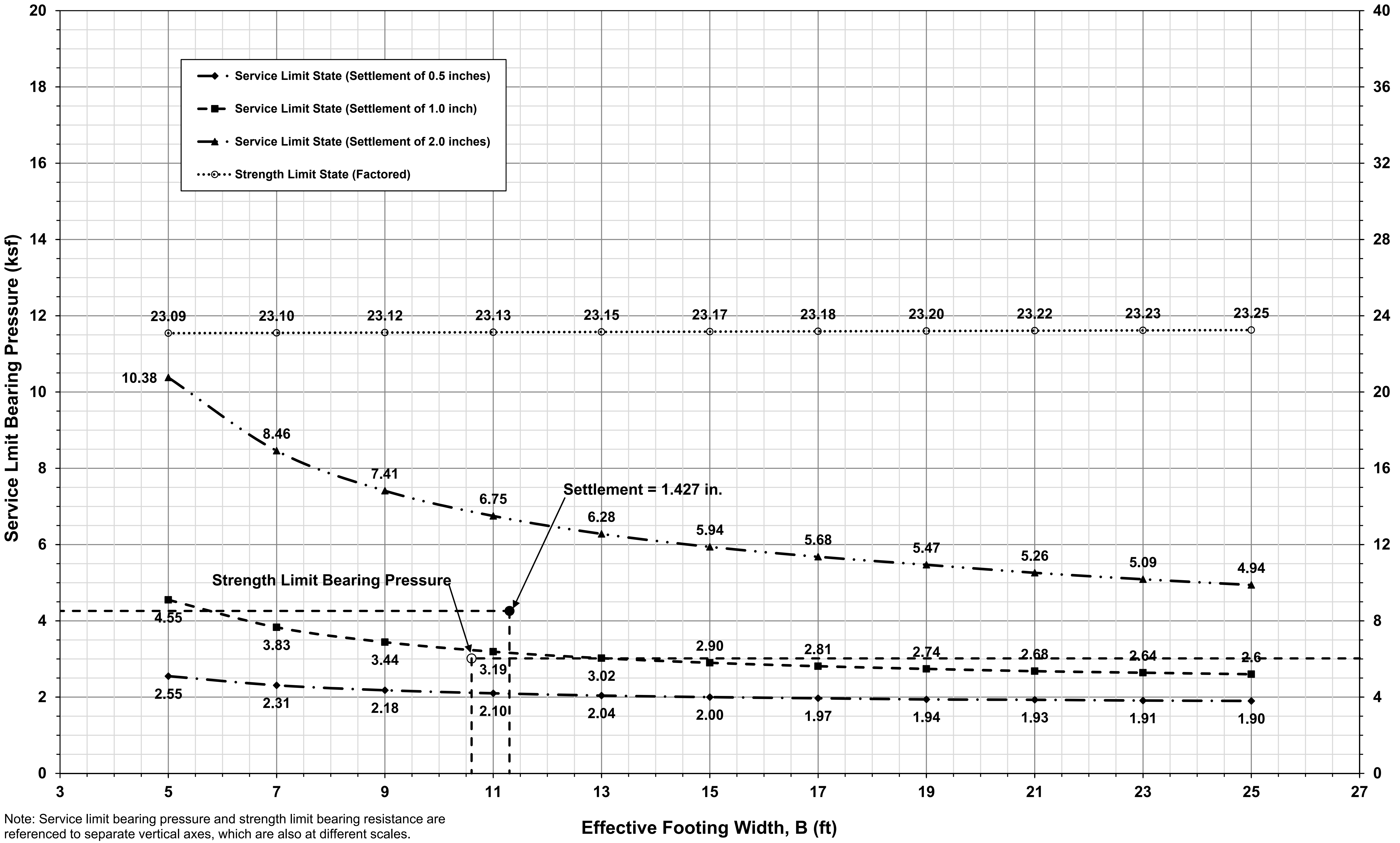
BEARING RESISTANCE CHARTS

Shallow Foundation Analysis
FRA-70-12.68 Project 4R - Retaining Wall 4W13 (B-030-1-15)



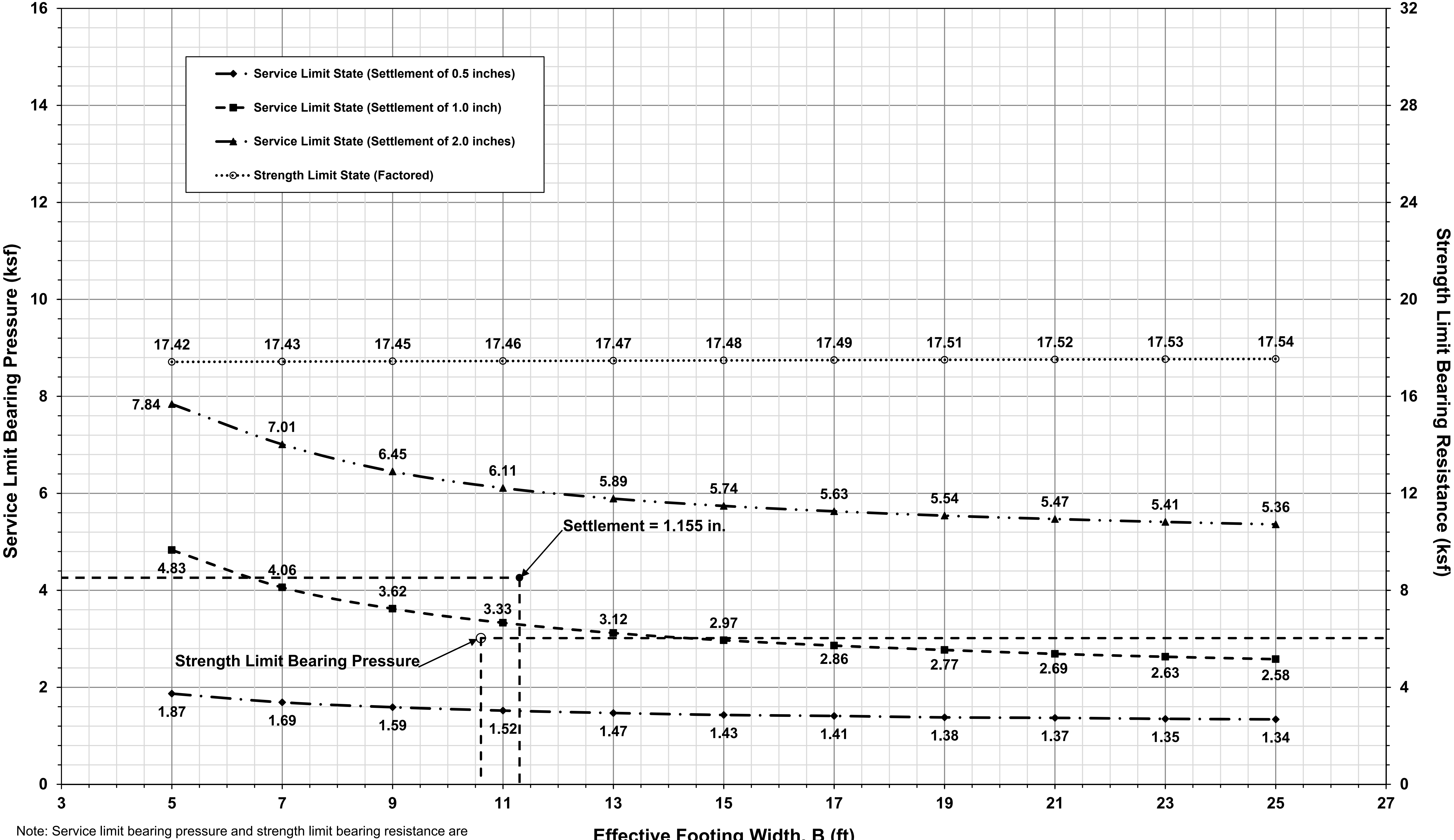
Note: Service limit bearing pressure and strength limit bearing resistance are referenced to separate vertical axes, which are also at different scales.

Shallow Foundation Analysis
FRA-70-12.68 Project 4R - Wall 4W13 (B-031-0-08)

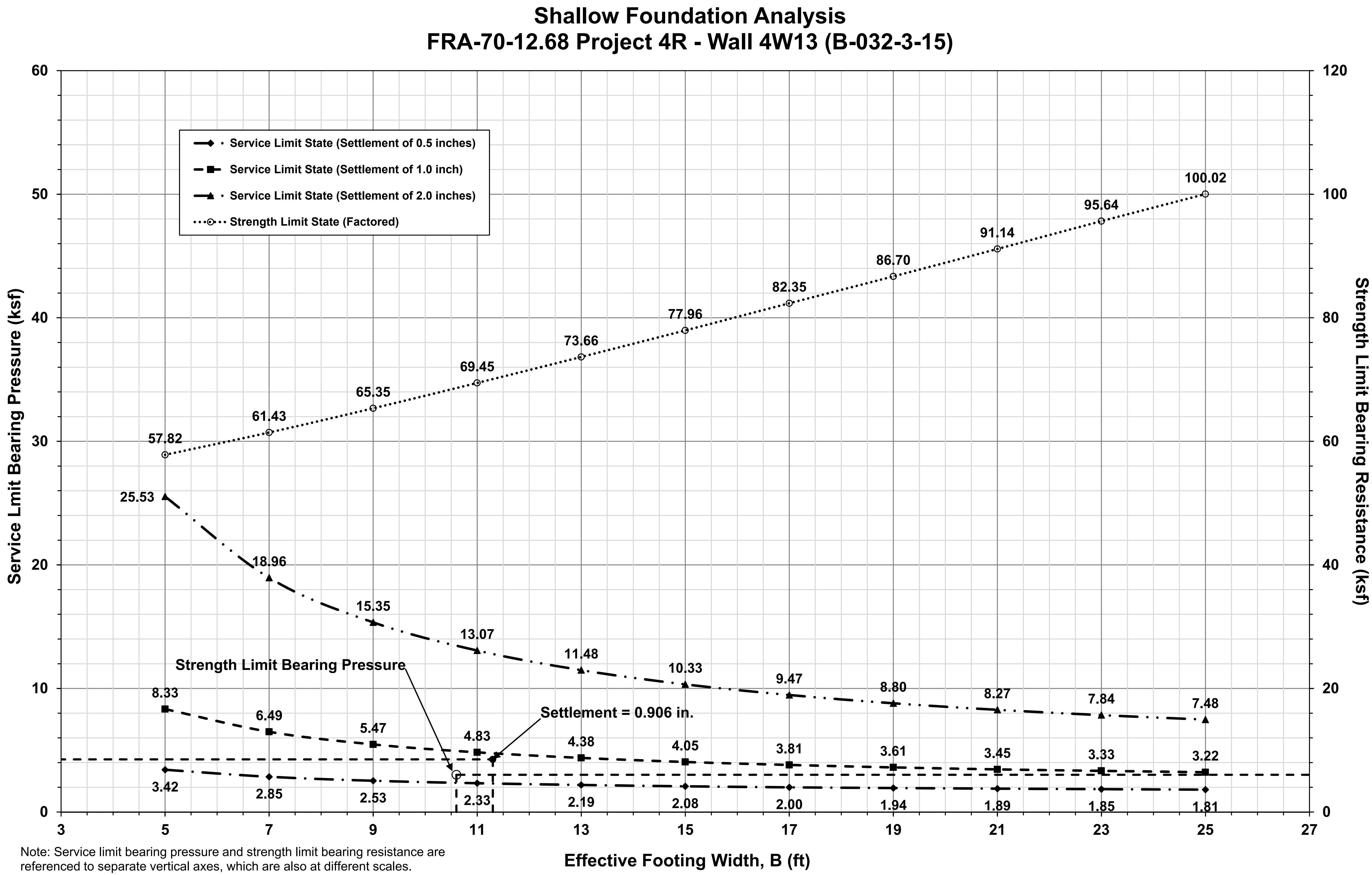


Note: Service limit bearing pressure and strength limit bearing resistance are referenced to separate vertical axes, which are also at different scales.

Shallow Foundation Analysis
FRA-70-12.68 Project 4R - Wall 4W13 (B-032-2-15)



Note: Service limit bearing pressure and strength limit bearing resistance are referenced to separate vertical axes, which are also at different scales.



Note: Service limit bearing pressure and strength limit bearing resistance are referenced to separate vertical axes, which are also at different scales.

APPENDIX V

SHALLOW FOUNDATION CALCULATIONS

W-13-045 - FRA-70-12.68 Project - Retaining Wall 4W13

Shallow Foundation Analysis - Settlement

Calculated By: HSK Date: 3/19/2018

Checked By: BRT Date: 6/25/2018

Boring B-030-1-15

B =	11.3	ft	Effective Footing width
D_w =	10.5	ft	Depth below bottom of footing
q =	4,260	psf	Service limit bearing pressure at bottom of wall
q_{net} =	2,100	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 2,160 psf from 18-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
A-6a	C	0.0	1.5	1.5	0.8	130	195	98	98	4,098	27	0.153	0.015	0.483				0.07	0.999	2,098	2,195	0.021	0.251
A-1-b	G	1.5	3.5	2.0	2.5	135	465	330	330	4,330					91	146	300	0.22	0.970	2,038	2,368	0.006	0.068
A-1-b	G	3.5	6.5	3.0	5.0	135	870	668	668	4,668					91	125	300	0.44	0.855	1,795	2,462	0.006	0.068
A-1-b	G	6.5	9.0	2.5	7.8	135	1,208	1,039	1,039	5,039					91	111	300	0.69	0.704	1,479	2,517	0.003	0.038
A-1-b	G	9.0	11.5	2.5	10.3	135	1,545	1,376	1,376	5,376					91	103	300	0.91	0.590	1,239	2,615	0.002	0.028
A-1-b	G	11.5	14.0	2.5	12.8	135	1,883	1,714	1,573	5,573					91	98	300	1.13	0.501	1,053	2,626	0.002	0.022
A-1-b	G	14.0	16.5	2.5	15.3	135	2,220	2,051	1,755	5,755					91	95	300	1.35	0.433	910	2,665	0.002	0.018
A-1-b	G	16.5	19.0	2.5	17.8	135	2,558	2,389	1,936	5,936					91	92	300	1.57	0.380	798	2,735	0.001	0.015
A-4b	G	19.0	21.5	2.5	20.3	135	2,895	2,726	2,118	6,118					89	87	140	1.79	0.338	710	2,828	0.002	0.027
A-4b	G	21.5	24.0	2.5	22.8	135	3,233	3,064	2,299	6,299					89	85	137	2.01	0.304	638	2,938	0.002	0.023
A-4a	C	24.0	26.5	2.5	25.3	130	3,558	3,395	2,475	6,475	18	0.072	0.007	0.413				2.23	0.276	579	3,054	0.001	0.014
A-4a	C	26.5	29.0	2.5	27.8	130	3,883	3,720	2,644	6,644	18	0.072	0.007	0.413				2.46	0.252	530	3,173	0.001	0.012
A-4a	C	29.0	31.5	2.5	30.3	130	4,208	4,045	2,813	6,813	18	0.072	0.007	0.413				2.68	0.232	488	3,301	0.001	0.011
A-4a	C	31.5	34.0	2.5	32.8	130	4,533	4,370	2,982	6,982	18	0.072	0.007	0.413				2.90	0.215	452	3,434	0.001	0.009
A-1-b	G	34.0	36.5	2.5	35.3	130	4,858	4,695	3,151	7,151					33	28	94	3.12	0.201	421	3,572	0.001	0.017
A-1-b	G	36.5	39.0	2.5	37.8	130	5,183	5,020	3,320	7,320					33	27	92	3.34	0.188	394	3,714	0.001	0.016
A-1-b	G	39.0	41.4	2.4	40.2	130	5,495	5,339	3,485	7,485					33	27	91	3.56	0.177	371	3,856	0.001	0.014
																				Total Settlement:			0.653 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_{m;}$ Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 26, FHWA GEC 5
3. $C_r = 0.15(C_c)$ for the existing fill and $0.10(C_c)$ for the natural soil deposits; Ref. Section 5.4.2.5 of FHWA GEC 5
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index (limited to a value of 300); Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesiv soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

Calculated By: HSK Date: 3/19/2018
Checked By: BRT Date: 6/25/2018

Boring B-030-1-15

B =	11.3	ft	
L =	541	ft	
c =	0	psf	
γ =	135	pcf	
D_f =	6.0	ft	
φ =	42	deg	
D_w =	10.5	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 151.70 ksf

$$N_{cm} = N_c s_c i_c$$ = 95.49

$$N_{qm} = N_q s_q d_q i_q$$ = 95.35

$$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$$ = 154.24

N_c =	93.71	s_c =	1+(11.3 ft/541 ft)(85.37/93.71) =	1.019	i_c =	1.000	d_q =	1+2tan(42°)[1-sin(42°)]²tan⁻¹(6 ft/11.3 ft) =	1.096
N_q =	85.37	s_q =	1+(11.3 ft/541 ft)tan(42°) =	1.019	i_q =	1.000	C_{wq} =	10.5 ft > 6.0 ft =	1.000
N_γ =	155.54	s_γ =	1-0.4(11.3 ft/541 ft) =	0.992	i_γ =	1.000	$C_{w\gamma}$ =	10.5 ft < 1.5(11.3 ft) + 6 ft =	0.633

$$q_R = q_n \cdot \phi_b$$ = 83.44 ksf

φ_b = 0.55

W-13-045 - FRA-70-12.68 Project 4R - Wall 4W13
Shallow Foundation Analysis - Settlement

Calculated By: HSK Date: 6/22/2018
Checked By: BRT Date: 6/26/2018

Boring B-031-0-08

B =	11.3	ft	Effective Footing width
D_w =	3.0	ft	Depth below bottom of footing
q =	4,260	psf	Service limit bearing pressure at bottom of wall
q_{net} =	2,820	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,440 psf from 12-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' [1] (psf)	LL	C_c [2]	C_r [3]	e_o [4]	N_{60}	$(N1)_{60}$ [5]	C' [6]	Z_f/B	I [7]	$\Delta\sigma_v$ [8] (psf)	σ_{vf}' Midpoint (psf)	S_c [9,10] (ft)	S_c (in)
A-1-b	G	0.0	2.0	2.0	1.0	130	260	130	130	4,130					48	92	409	0.09	0.998	2,814	2,944	0.007	0.080
A-4b	G	2.0	3.0	1.0	2.5	125	385	323	323	4,323					31	50	85	0.22	0.970	2,736	3,059	0.012	0.139
A-4b	G	3.0	7.0	4.0	5.0	125	885	635	510	4,510					31	45	77	0.44	0.855	2,410	2,921	0.039	0.470
A-4a	C	7.0	9.5	2.5	8.3	130	1,210	1,048	720	4,720	20	0.090	0.009	0.428				0.73	0.679	1,915	2,635	0.009	0.107
A-4a	C	9.5	12.0	2.5	10.8	130	1,535	1,373	889	4,889	20	0.090	0.009	0.428				0.95	0.570	1,608	2,497	0.007	0.085
A-4b	G	12.0	14.5	2.5	13.3	125	1,848	1,691	1,052	5,052					27	33	59	1.17	0.486	1,371	2,423	0.015	0.184
A-3a	G	14.5	17.0	2.5	15.8	130	2,173	2,010	1,214	5,214					41	48	134	1.39	0.422	1,189	2,403	0.006	0.067
A-4a	C	17.0	19.5	2.5	18.3	130	2,498	2,335	1,383	5,383	20	0.090	0.009	0.428				1.62	0.371	1,046	2,430	0.004	0.046
A-4a	C	19.5	21.5	2.0	20.5	130	2,758	2,628	1,536	5,536	20	0.090	0.009	0.428				1.81	0.334	943	2,478	0.003	0.031
A-4a	G	21.5	24.0	2.5	22.8	135	3,095	2,926	1,694	5,694					114	121	190	2.01	0.304	857	2,551	0.002	0.028
A-4a	G	24.0	26.5	2.5	25.3	135	3,433	3,264	1,875	5,875					114	117	184	2.23	0.276	778	2,653	0.002	0.025
A-4a	G	26.5	31.5	5.0	29.0	135	4,108	3,770	2,148	6,148					114	111	176	2.57	0.242	682	2,830	0.003	0.041
A-4a	G	31.5	35.5	4.0	33.5	135	4,648	4,378	2,474	6,474					114	106	168	2.96	0.211	594	3,069	0.002	0.027
A-3	G	35.5	40.5	5.0	38.0	135	5,323	4,985	2,801	6,801					33	29	74	3.36	0.187	526	3,327	0.005	0.060
A-3a	G	40.5	43.5	3.0	42.0	135	5,728	5,525	3,091	7,091					84	72	219	3.72	0.169	477	3,569	0.001	0.010
A-3a	G	43.5	48.5	5.0	46.0	130	6,378	6,053	3,369	7,369					84	69	209	4.07	0.155	437	3,806	0.001	0.015
A-3a	G	48.5	53.5	5.0	51.0	135	7,053	6,715	3,720	7,720					84	67	198	4.51	0.140	395	4,114	0.001	0.013
																				Total Settlement:			1.427 in

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

B =	11.3	ft	
L =	541	ft	
c =	8,000	psf	
γ =	130	pcf	
D_f =	6.0	ft	
φ =	0	deg	
D_w =	9.5	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma} =$$ 42.07 ksf

$$N_{cm} = N_c s_c i_c =$$ 5.16

$$N_{qm} = N_q s_q d_q i_q =$$ 1.00

$$N_{\gamma m} = N_\gamma s_\gamma i_\gamma =$$ 0.00

N_c =	5.14	s_c =	1+(11.3 ft/541 ft)(1/5.14) =	1.004	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(6 ft/11.3 ft) =	1.000
N_q =	1.00	s_q =	1+(11.3 ft/541 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	9.5 ft > 6.0 ft =	1.000
N_γ =	0.00	s_γ =	1-0.4(11.3 ft/541 ft) =	0.992	i_γ =	1.000	$C_{w\gamma}$ =	9.5 ft < 1.5(11.3 ft) + 6 ft =	0.603

$$q_R = q_n \cdot \phi_b =$$ 23.14 ksf

φ_b = 0.55

FRA-70-12.68 Project 4R - Wall 4W13
Shallow Foundation Analysis - Settlement

Calculated By: HSK Date: 3/19/2018
Checked By: BRT Date: 6/26/2018

Boring B-032-2-15

B =	11.3	ft	Effective Footing width
D_w =	10.0	ft	Depth below bottom of footing
q =	4,260	psf	Service limit bearing pressure at bottom of wall
q_{net} =	3,240	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,020 psf from 8.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
A-4a	C	0.0	2.0	2.0	1.0	130	260	130	130	4,130	25	0.135	0.014	0.467				0.09	0.998	3,233	3,363	0.026	0.312
A-4a	C	2.0	4.0	2.0	3.0	130	520	390	390	4,390	25	0.135	0.014	0.467				0.27	0.953	3,088	3,478	0.017	0.210
A-4a	C	4.0	7.0	3.0	5.5	130	910	715	715	4,715	25	0.135	0.014	0.467				0.49	0.827	2,679	3,394	0.019	0.224
A-1-b	G	7.0	9.5	2.5	8.3	135	1,248	1,079	1,079	5,079					71	86	366	0.73	0.679	2,200	3,279	0.003	0.040
A-3a	G	9.5	12.0	2.5	10.8	135	1,585	1,416	1,369	5,369					53	60	173	0.95	0.570	1,848	3,217	0.005	0.064
A-3a	G	12.0	14.5	2.5	13.3	135	1,923	1,754	1,551	5,551					53	58	165	1.17	0.486	1,576	3,127	0.005	0.055
A-4a	C	14.5	17.0	2.5	15.8	130	2,248	2,085	1,726	5,726	19	0.081	0.008	0.420				1.39	0.422	1,366	3,092	0.004	0.043
A-4a	C	17.0	19.5	2.5	18.3	130	2,573	2,410	1,895	5,895	19	0.081	0.008	0.420				1.62	0.371	1,202	3,097	0.003	0.036
A-4a	C	19.5	22.0	2.5	20.8	130	2,898	2,735	2,064	6,064	19	0.081	0.008	0.420				1.84	0.331	1,071	3,135	0.003	0.031
A-4a	C	22.0	24.0	2.0	23.0	130	3,158	3,028	2,216	6,216	19	0.081	0.008	0.420				2.04	0.301	975	3,191	0.002	0.022
A-4a	C	24.0	26.0	2.0	25.0	130	3,418	3,288	2,352	6,352	19	0.081	0.008	0.420				2.21	0.278	902	3,253	0.002	0.019
A-1-b	G	26.0	31.0	5.0	28.5	135	4,093	3,755	2,601	6,601					120	110	547	2.52	0.246	797	3,398	0.001	0.013
A-1-b	G	31.0	36.0	5.0	33.5	135	4,768	4,430	2,964	6,964					120	104	504	2.96	0.211	683	3,646	0.001	0.011
A-1-b	G	36.0	41.0	5.0	38.5	130	5,418	5,093	3,314	7,314					30	25	86	3.41	0.184	597	3,911	0.004	0.050
A-1-b	G	41.0	45.0	4.0	43.0	135	5,958	5,688	3,628	7,628					104	83	350	3.81	0.165	536	4,164	0.001	0.008
A-1-b	G	45.0	49.0	4.0	47.0	135	6,498	6,228	3,919	7,919					104	81	333	4.16	0.152	491	4,410	0.001	0.007
A-1-b	G	49.0	54.0	5.0	51.5	135	7,173	6,835	4,245	8,245					104	78	315	4.56	0.139	449	4,694	0.001	0.008
																				Total Settlement:			1.155 in

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

FRA-70-12.68 Project 4R - Wall 4W13 | Calculated By: HSK | Date: 3/19/2018
Shallow Foundation Analysis - Strength Limit State | Checked By: BRT | Date: 6/26/2018

Boring B-032-2-15

B =	11.3	ft	
L =	541	ft	
c =	6,000	psf	
γ =	130	pcf	
D_f =	6.0	ft	
φ =	0	deg	
D_w =	16.0	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 31.75 ksf

$N_{cm} = N_c s_c i_c$ = 5.16

$N_{qm} = N_q s_q d_q i_q$ = 1.00

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 0.00

N_c =	5.14	s_c =	1+(11.3 ft/541 ft)(1/5.14) =	1.004	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(6 ft/11.3 ft) =	1.000
N_q =	1.00	s_q =	1+(11.3 ft/541 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	16.0 ft > 6.0 ft =	1.000
N_γ =	0.00	s_γ =	1-0.4(11.3 ft/541 ft) =	0.992	i_γ =	1.000	$C_{w\gamma}$ =	16.0 ft < 1.5(11.3 ft) + 6 ft =	0.795

$q_R = q_n \cdot \phi_b$ = 17.46 ksf

φ_b = 0.55

W-13-045 - FRA-70-12.68 Project 4R - Wall 4W13

Shallow Foundation Analysis - Settlement

Calculated By: HSK Date: 3/19/2018

Checked By: BRT Date: 6/26/2018

Boring B-032-3-15

B =	11.3	ft	Effective Footing width
D_w =	3.5	ft	Depth below bottom of footing
q =	4,260	psf	Service limit bearing pressure at bottom of wall
q_{net} =	3,240	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,020 psf from 8.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	N_{60}	$(N1)_{60}$ (5)	C' (6)	Z_f/B	I (7)	$\Delta\sigma_v$ (8) (psf)	σ_{vf}' Midpoint (psf)	S_c (9,10) (ft)	S_c (in)
A-1-b	G	0.0	2.5	2.5	1.3	130	325	163	163	4,163					47	87	300	0.11	0.996	3,226	3,388	0.011	0.132
A-1-a	G	2.5	5.0	2.5	3.8	135	663	494	478	4,478					88	130	300	0.33	0.920	2,982	3,460	0.007	0.086
A-1-a	G	5.0	7.5	2.5	6.3	135	1,000	831	660	4,660					88	121	300	0.55	0.785	2,542	3,202	0.006	0.069
A-1-a	G	7.5	10.5	3.0	9.0	130	1,390	1,195	852	4,852					39	50	170	0.80	0.644	2,085	2,937	0.009	0.114
A-1-a	G	10.5	13.5	3.0	12.0	130	1,780	1,585	1,055	5,055					39	47	159	1.06	0.525	1,703	2,757	0.008	0.095
A-1-a	G	13.5	16.5	3.0	15.0	130	2,170	1,975	1,257	5,257					39	45	150	1.33	0.439	1,423	2,681	0.007	0.079
A-4a	C	16.5	19.0	2.5	17.8	130	2,495	2,333	1,443	5,443	21	0.099	0.010	0.436				1.57	0.380	1,232	2,675	0.005	0.055
A-4a	C	19.0	21.5	2.5	20.3	130	2,820	2,658	1,612	5,612	21	0.099	0.010	0.436				1.79	0.338	1,095	2,707	0.004	0.047
A-4a	C	21.5	24.0	2.5	22.8	130	3,145	2,983	1,781	5,781	21	0.099	0.010	0.436				2.01	0.304	985	2,766	0.003	0.040
A-4b	G	24.0	29.0	5.0	26.5	135	3,820	3,483	2,047	6,047					120	119	188	2.35	0.264	854	2,901	0.004	0.048
A-1-b	G	29.0	34.0	5.0	31.5	135	4,495	4,158	2,410	6,410					104	98	300	2.79	0.224	725	3,135	0.002	0.023
A-1-b	G	34.0	39.0	5.0	36.5	135	5,170	4,833	2,773	6,773					104	93	300	3.23	0.194	629	3,402	0.001	0.018
A-1-b	G	39.0	44.0	5.0	41.5	135	5,845	5,508	3,136	7,136					104	89	300	3.67	0.171	555	3,691	0.001	0.014
A-1-b	G	44.0	49.0	5.0	46.5	135	6,520	6,183	3,499	7,499					104	85	300	4.12	0.153	496	3,996	0.001	0.012
A-1-b	G	49.0	54.0	5.0	51.5	135	7,195	6,858	3,862	7,862					104	81	300	4.56	0.139	449	4,311	0.001	0.010
A-4b	G	54.0	59.0	5.0	56.5	135	7,870	7,533	4,225	8,225					97	73	119	5.00	0.126	410	4,635	0.002	0.020
A-3a	G	59.0	67.0	8.0	63.0	130	8,910	8,390	4,677	8,677					29	21	68	5.58	0.114	368	5,045	0.004	0.046
																				Total Settlement:			0.906 in

1. $\sigma_p' = \sigma_{vo}' + \sigma_m$; Estimate σ_m of 4,000 psf for moderately overconsolidated soil deposit; Ref. Table 11.2, Coduto 2003
2. $C_c = 0.009(LL-10)$; Ref. Table 26, FHWA GEC 5
3. $C_r = 0.10(C_c)$ for natural soil deposits; Ref. Section 5.4.2.5 of FHWA GEC 5
4. $e_o = (C_c/1.15)+0.35$; Ref. Table 8-2, Holtz and Kovacs 1981
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index (Limited to a value of 300); Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (Cohesiv soil layers)
10. $S_c = H(1/C')\log(\sigma_{vf}'/\sigma_{vo}')$; Ref. Section 10.6.2.4.2, AASHTO LRFD BDS (Granular soil layers)

Boring B-032-3-15

B =	11.3	ft	
L =	541	ft	
c =	0	psf	
γ =	130	pcf	
D_f =	6.0	ft	
φ =	41	deg	
D_w =	11.5	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 127.36 ksf

$N_{cm} = N_c s_c i_c$ = 85.40

$N_{qm} = N_q s_q d_q i_q$ = 82.80

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 129.12

N_c =	83.86	s_c =	1+(11.3 ft/541 ft)(73.9/83.86) =	1.018	i_c =	1.000	d_q =	1+2tan(41°)[1-sin(41°)]²tan⁻¹(6 ft/11.3 ft) =	1.100
N_q =	73.90	s_q =	1+(11.3 ft/541 ft)tan(41°) =	1.018	i_q =	1.000	C_{wq} =	11.5 ft > 6.0 ft =	1.000
N_γ =	130.21	s_γ =	1-0.4(11.3 ft/541 ft) =	0.992	i_γ =	1.000	$C_{w\gamma}$ =	11.5 ft < 1.5(11.3 ft) + 6 ft =	0.662

$q_R = q_n \cdot \phi_b$ = 70.05 ksf

φ_b = 0.55

APPENDIX VI

EXTERNAL STABILITY ANALYSIS CALCULATIONS BY GPD GROUP

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

RETAINING DESIGN ON SPREAD FOOTING LRFD

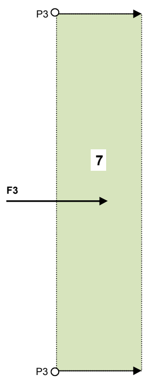
Based on AASHTO LRFD

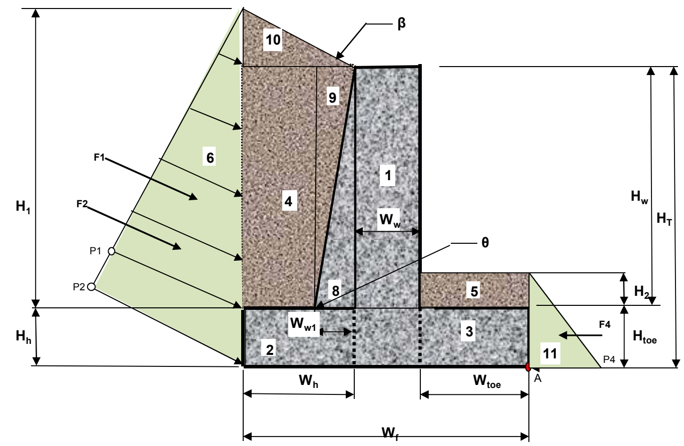
Input values are indicated by the Yellow colored cells

Using cellular concrete backfill? (Y or N) *N*

WALL DATA

Concrete unit weight, γ_c =	*0.15 kcf*
Toe Height, Htoe	*3.75 ft.*
Heel Height, Hh	*3.50 ft.*
Wall Height, Hw	*22.05 ft.*
Total Height, HT = Hw+Htoe	25.80 ft.
Soil over Heel, H1 = HT-Hh	22.30 ft.
Soil Height over Toe, H2	*3.00 ft.*
Future Loss of Soil over Toe	*0%*
Corrected H2 = H2*(1-Future Loss)	3.00 ft.
Wall Width, Ww	*1.5000 ft.*
Toe Width, Wtoe	*3.00 ft.*
Heel Width, Wh	*11.00 ft.*
Additional Wall, Ww1	*0.93 ft.*
Theta, θ =	87.61 deg.
Footing Width, Wf	15.50 ft.





SOIL DATA

Is retained soil sloped?	*N*	
Slope of embankment, Se	*0.00*	
Beta, β =	0.00 deg.	
Include Surcharge over Heel?	*N*	
Include Surcharge over Toe?	*N*	
Is traffic less than HT/2 from wall?	*N*	
Surcharge Height, Hs =	2.00 ft.	*(AASHTO 3.11.6.4-1)*
Surcharge Width, Ws = Wf-(Wtoe+Ww)	11.00 ft.	
Active or At Rest Pressure (A or R)	*A*	
Soil Unit Weight, γ_{soil}	*0.12 kcf*	==> For lateral + weight on heel ======= *0.12 kcf* ==> For passive resistance + weigth on toe
Footing Resting On?	*G*	
Internal Friction Angle of Soil, δ (deg.)	*28.00*	*(@ base of the Footer)*
Internal Friction Angle of Fill, ϕ'_{fill}	*30.00 deg.*	
Friction Angle between Fill & Wall, δ	*0.00 deg.*	
Active Lat. Earth Press. Coeff., ka	0.35	*(AASHTO 3.11.5.3-1)*
$P_{soil} = \gamma_{soil}$ * (k_a or k_0) =	41.96 pcf	
Bearing on soil or rock?(S or R) =	*S*	*(AASHTO 10.6.1.4)*
Factor Bearing Resistance (Strength)=	***10.75 ksf***	
Bearing Capacity (Service) =	*6.30 ksf*	(To check Settlement)
Consider Passive Force on Toe?	*N*	
Passive Lateral Pressure Coeff., kp	3.00	$k_p = \tan^2(45° + \phi'_f/2)$
P1 = P_{soil}*H1/1000 =	0.94 ksf	
P2 = Psoil*(H1+Hh)/1000 =	1.08 ksf	
P3 = Hs*Psoil/1000 =	0.00 ksf	
P4 = Psoil*(H2+Htoe)/1000 =	0.00 ksf	
Soil Sliding Forces:		
F1 = P1*H1*0.5 =	10.43 kips	kips
F2 = P2*(H1+Hh)*0.5 =	13.97 kips	kips
F3 = P3*H1 =	0.00 kips	kips
F4 = P4*(H2 +Htoe)*0.5 =	0.00 kips	kips
Additional Dead Load =	*0.00 kips*	kips
Moment Arm for Addit. Dead Load =	*0.00 ft.*	from Point A

Horizontal sliding Resistance: *(AASHTO 10.6.3.4)*

For cohesionless soils:

V(min) =	42.61 k	
Rτ = V* tanδ =	22.66 k	

For cohesive soils:

The lesser of: Cu =	N.A.	
0.5*σ'v =	N.A.	ksf
Use =	N.A.	ksf
Resistance Rτ=	N.A.	

For manual override of above formulas, use friction factor = *0.55* ==> From High St

Resistance Rτ= 23.44 klf

Typical values for friction factor:

course grained soil w/out silt =	0.55
course grained soil w/silt =	0.45
silt =	0.35
shale =	0.55
rock =	0.7

Calculations:

Area 1 = γ_c x W_w x H_T	0.15 kcf x	1.50 ft. x	25.80 ft. x	1.00 ft. =		**5.81 kips**
Arm 1 = W_{toe} + W_w / 2	3.00 ft. +	1.50 ft.	/ 2.00 =			**3.75 ft.**
Area 2 = γ_c x W_h x H_h	0.15 kcf x	11.00 ft. x	3.50 ft. x	1.00 ft. =		**5.78 kips**
Arm 2 = W_{toe} + W_w + W_h / 2	3.00 ft. +	1.50 ft. +	11.00 ft.	/ 2.00 =		**10.00 ft.**
Area 3 = γ_c x W_{toe} x H_{toe}	0.15 kcf x	3.00 ft. x	3.75 ft. x	1.00 ft. =		**1.69 kips**
Arm 3 = W_{toe} / 2	3.00 ft.	/ 2.00 =				**1.50 ft.**
Area 4 = γ_s x (W_h -W_{w1}) x H_1	0.12 kcf x	(11.00 ft. -	0.93 ft.) x	22.30 ft. x	1.00 ft. =	**26.95 kips**
Arm 4 = W_{toe} + W_w + W_{w1} + (W_h -W_{w1}) / 2	3.00 ft. +	1.50 ft. +	0.93 ft. +	(11.00 ft. -	0.93 ft.) / 2 =	**10.46 ft.**
Area 5 = γ_s x W_{toe} x H_2	0.12 kcf x	3.00 ft. x	3.00 ft. x	1.00 ft. =		**1.08 kips**
Arm 5 = W_{toe} / 2	3.00 ft.	/ 2.00 =				**1.50 ft.**
Area 6 **(Horiz. Comp.)** = F_2 x cos(β)	13.97 kips x	cos (	0.00 deg.) =			**13.97 kips**
Arm 6 = (H_1 + H_h) / 3	(22.30 ft. +	3.50 ft.)	/ 3.00 =			**8.60 ft.**
Area 6 **(Vertical Comp.)** = F_2 x sin(β)	13.97 kips x	sin (	0.00 deg.) =			**0.00 kips**
Arm 6 = Wf	15.50 ft.					**15.50 ft.**
Area 7 = F_3	0.00 kips					**0.00 kips**
Arm 7 = (H_1 + H_h) / 2	(22.30 ft. +	3.50 ft.)	/ 2.00 =			**12.90 ft.**
Area 8 = 0.5 x γ_c x W_{w1} x H_1	0.5 x 0.15 kcf x	0.93 ft. x	22.30 ft. x	1.00 ft. =		**1.55 kips**
Arm 8 = W_{toe} + W_w + W_{w1} / 3	3.00 ft. +	1.50 ft. +	0.93 ft.	/ 3.00 =		**4.81 ft.**
Area 9 = 0.5 x γ_s x W_{w1} x H_1	0.5 x 0.12 kcf x	0.93 ft. x	22.30 ft. x	1.00 ft. =		**1.24 kips**
Arm 9 = W_{toe} + W_w + W_{w1} x 2/3	3.00 ft. +	1.50 ft. +	0.93 ft.	x 2.00	/ 3.00 =	**5.12 ft.**
Area 10 = 0.5 x γ_s x (S_e x W_h) x W_h	0.5 x 0.12 kcf x	(0.00 x	11.00 ft.) x	11.00 ft. x	1.00 ft. =	**0.00 kips**
Arm 10 = W_F - W_h / 3	15.50 ft. -	11.00 ft.	/ 3.00 =			**11.83 ft.**
Area 11 = F_4	0.00 kips					**0.00 kips**
Arm 11 = (H_{toe} + H_2) / 3	(3.75 ft. +	3.00 ft.)	/ 3.00 =			**2.25 ft.**
Surcharge on Heel = γ_s x W_s x H_s	0.12 kcf x	11.00 ft. x	2.00 ft. x	1.00 ft. =		**2.64 kips**
Arm for Heel Surcharge = W_F - W_h / 2	15.50 ft. -	11.00 ft.	/ 2.00 =			**10.00 ft.**

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

Surcharge on Toe = γ_s x W_{toe} x H_s	0.12 kcf x	3.00 ft. x	2.00 ft. x	1.00 ft. =	**0.72 kips**
Arm for Toe Surcharge = W_{toe} / 2	3.00 ft.	/ 2.00 =			**1.50 ft.**

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

CHECK BEARING PRESSURE

Factored Bearing Resistance = **10.75 ksf**

Maximum Strength Load Pressure
(AASHTO 11.6.3.2)

Bearing pressure at Toe = **5.21 ksf** **O.K.**

Bearing pressure at Heel = **5.21 ksf** **O.K.**

CHECK ECCENTRICITY

(AASHTO 11.6.3.3)

Maximum allowable e, (B/3) = **5.17 ft.**

Controlling Eccentricity = **3.28 ft.** **O.K.**

CHECK SLIDING (Per Unit Width)

(AASHTO 11.6.3.6)

Resistance factor ϕ_τ (Sliding) = *0.80* *(AASHTO Table 10.5.5.2.2-1)*

Resistance factor ϕ_{ep} (Passive pressure) = *0.50* *(AASHTO Table 10.5.5.2.2-1)*

Additional Resistance (Footing Key or Sheet Piling) :

Pressure for passive resistance = 0.360 kcf

Vertical Projection Below Footing = *3.00* ft.

Pressure at Top/Sheeting or Key = 2.430 ksf

Pressure at Bot./Sheeting or Key = 3.510 ksf

Passive on Footing Toe = 0.000 Kips

Total passive resistance = **8.91 kips**

Factored = **4.46 kips**

Controlling Driving force = **20.95 kips**

Resisting force = **23.20 kips** **O.K.**

AASHTO Table 10.5.5.2.2-1 (Sliding Resistance Factors)

CONDITION	FACTOR
Precast concrete placed on sand	0.90
Cast-in-place concrete on sand	0.80
C.I.P. or precast concrete on clay	0.85
soil on soil	0.90
Passive earth pressure component	0.50

CHECK SETTLEMENT

Service Bearing Capacity = **6.30 ksf**

Service Bearing Pressure at Toe = **3.75 ksf** **O.K.**

Service Bearing Pressure at Heel = **3.75 ksf** **O.K.**

SUMMARY OF LOAD EFFECTS

	MAX. BEARING PRESSURE	MIN. BEARING PRESSURE	ECCENTRICITIES MAXIMUM LF	ECCENTRICITIES MINIMUM LF	SLIDING FORCES MAXIMUM LF	VERTICAL FORCES MINIMUM
STRENGTH I	5.21	5.21	2.18	3.28	20.95	42.61
SERVICE I	3.75	3.75	1.87	NA	13.97	44.09

LOAD MODIFICATION FACTORS *(SEE AASHTO 1.3.3, 1.3.4, 1.3.5 & ODOT BDM 1001)*

Ductility η_D = *1.00* (use 1.00 for all limit states)

Redundancy η_R = *1.00* (use 1.00 for redundant structures and 1.05 for non-redundant structures)

Operational importance η_i = *1.00* (use 1.00 for all limit states)

STRENGTH I LOAD COMBINATION

SLIDING FORCES & OVERTURNING MOMENTS FROM SOIL

1.5*EH+1.75*LSH+0.9EHP

ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	
6	13.97	1.50	20.95	8.60	180.15	Horiz. Forces
7	0.00	1.75	0.00	12.90	0.00	
11	0.00	0.90	0.00	2.25	0.00	
		Σ Sliding Forces, F_s =	20.95 kips	Σ Overturning Moments =	180.15 k*ft.	

RESISTING MOMENTS AND DEAD LOAD FROM RETAINING WALL

$1.5^*DC+1.35^*EV+1.75^*LS_V$ (MAX.)   0.9*DC+1.0*EV (MIN.)

ΣM about point "A"

Area/Force	Force (k) Unfactored Load	Max. Load Factor	Force (k) Max. Load Factor	Min. Load Factor	Force (k) Min. Load Factor (This column is for stability)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	Moment (k-ft) Min. Load Factor (This column is for stability)	
1	5.81	1.25	7.26	0.90	5.22	3.75	27.21	19.59	Dead Load From Concrete
2	5.78	1.25	7.22	0.90	5.20	10.00	72.19	51.98	
3	1.69	1.25	2.11	0.90	1.52	1.50	3.16	2.28	
8	1.55	1.25	1.94	0.90	1.40	4.81	9.34	6.73	
4	26.95	1.35	36.38	1.00	26.95	10.46	380.72	282.02	Forces From Soil
5	1.08	1.35	1.46	1.00	1.08	1.50	2.19	1.62	
6 (Vertical comp.)	0.00	1.50	0.00	1.50	0.00	15.50	0.00	0.00	
9	1.24	1.35	1.68	1.00	1.24	5.12	8.59	6.36	
10	0.00	1.35	0.00	1.00	0.00	11.83	0.00	0.00	
Surcharge on Heel	0.00	1.75	0.00	0.00	0.00	10.00	0.00	0.00	External Loads
Surcharge on Toe	0.00	1.75	0.00	0.00	0.00	1.50	0.00	0.00	
DC	0.00	1.25	0.00	0.90	0.00	0.00	0.00	0.00	
		Σ Vert. Forces =	58.05 kips	Σ Vert. Forces =	42.61 kips	Resisting Moments =	503.41 k*ft.	370.57 k*ft.	

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

Max. Load Factor Results

Overturning Moment = Σ Overturning Moments =	180.15 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	503.41 k-ft.
Sliding Force = F_s =	20.95 kips
Net Moment = Resisting Moment - Overturning Moment =	323.26 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	58.05 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	5.57 ft.
Eccentricity "e" = (0.5^*W_f) - Ā =	2.18 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	5.21 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	5.21 ksf

Min. Load Factor

Overturning Moment = Σ Overturning Moments =	180.15 k-ft.
Resisting Moment = Σ Min. Resisting Moments =	370.57 k-ft.
Sliding Force = F_s =	20.95 kips
Net Moment = Resisting Moment - Overturning Moment =	190.42 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	42.61 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	4.47 ft.
Eccentricity "e" = (0.5^*W_f) - Ā =	3.28 ft.

SERVICE I LOAD COMBINATION

OVERTURNING AND SLIDING FORCES FROM SOIL

$1.0^*EH+1.0^*LS_H+1.0^*EH_P$

ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	
6	13.97	1.00	13.97	8.60	120.10	Horiz. Forces From Soil
7	0.00	1.00	0.00	12.90	0.00	
11	0.00	1.00	0.00	2.25	0.00	
		Σ Sliding Forces, F_s =	13.97 kips	Σ Overturning Moments =	120.10 k*ft.	

RESISTING MOMENTS AND DEAD LOAD FROM SUBSTRUCTURE

$1.0^*DC+1.0^*EV+1.0^*LS_V$

ΣM about point "A"

Area/Force	Force (k) Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft)	
1	5.81	1.00	5.81	3.75	21.77	Dead Load From Concrete
2	5.78	1.00	5.78	10.00	57.75	
3	1.69	1.00	1.69	1.50	2.53	
8	1.55	1.00	1.55	4.81	7.47	
4	26.95	1.00	26.95	10.46	282.02	Forces From Soil
5	1.08	1.00	1.08	1.50	1.62	
6 (Vertical comp.)	0.00	1.00	0.00	15.50	0.00	
9	1.24	1.00	1.24	5.12	6.36	
10	0.00	1.00	0.00	11.83	0.00	
Surcharge on Heel	0.00	1.00	0.00	10.00	0.00	External Loads
Surcharge on Toe	0.00	1.00	0.00	1.50	0.00	
DC	0.00	1.00	0.00	0.00	0.00	
		Σ Vert. Forces =	44.09 kips	Σ Resisting Moments =	379.52 k*ft.	

Overturning Moment = Σ Overturning Moments =	120.10 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	379.52 k-ft.
Sliding Force = F_s =	13.97 kips
Net Moment = Resisting Moment - Overturning Moment =	259.43 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	44.09 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	5.88 ft.
Eccentricity "e" = (0.5^*W_f) - Ā =	1.87 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	3.75 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	3.75 ksf

Where the wall is supported by a rock foundation:

the vertical stress shall be calculated assuming a linearly distributed pressure over an effective base area as shown in Figure 11.6.3.2-2. If the resultant is within the middle one-third of the base:

$$\sigma_{max} = \frac{\Sigma V}{B}\left(1+6\frac{e}{B}\right) \qquad (11.6.3.2\text{-}2)$$

$$\sigma_{min} = \frac{\Sigma V}{B}\left(1-6\frac{e}{B}\right) \qquad (11.6.3.2\text{-}3)$$

where the variables are as defined in Figure 11.6.3.2-2. If the resultant is outside the middle one-third of the base:

$$\sigma_{max} = \frac{2\Sigma V}{3[(B/2)-e)]} \qquad (11.6.3.2\text{-}4)$$

$$\sigma_{min} = 0 \qquad (11.6.3.2\text{-}5)$$

where the variables are as defined in Figure 11.6.3.2-2.

Client:	ODOT - D6	Job No.:	2012048			
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018	
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018	

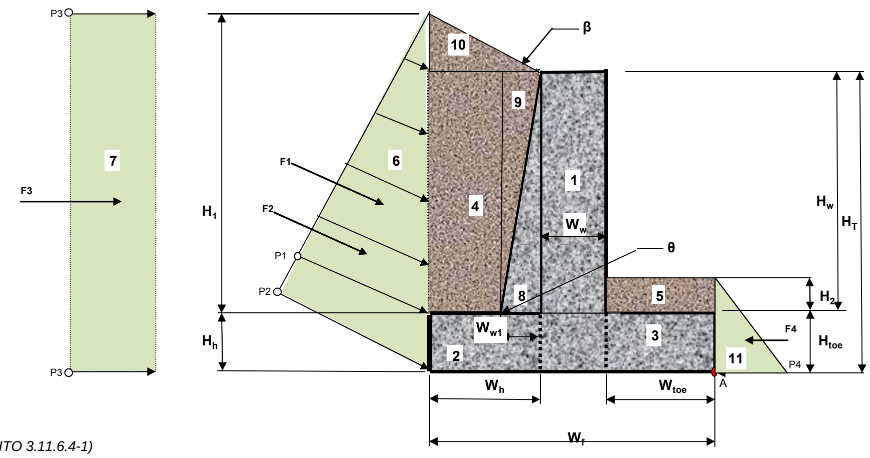
RETAINING DESIGN ON SPREAD FOOTING LRFD

Based on AASHTO LRFD

Input values are indicated by the Yellow colored cells Using cellular concrete backfill? (Y or N) *N*

WALL DATA

Concrete unit weight, γ_c =	*0.15 kcf*
Toe Height, Htoe	*3.75 ft.*
Heel Height, Hh	*3.50 ft.*
Wall Height, Hw	*24.35 ft.*
Total Height, HT = Hw+Htoe	28.10 ft.
Soil over Heel, H1 = HT-Hh	24.60 ft.
Soil Height over Toe, H2	*3.00 ft.*
Future Loss of Soil over Toe	*0%*
Corrected H2 = H2*(1-Future Loss)	3.00 ft.
Wall Width, Ww	*1.5000 ft.*
Toe Width, Wtoe	*4.00 ft.*
Heel Width, Wh	*10.00 ft.*
Additional Wall, Ww1	*2.03 ft.*
Theta, θ =	85.28 deg.
Footing Width, Wf	15.50 ft.



SOIL DATA

Is retained soil sloped?	*N*	
Slope of embankment, Se	*0.00*	
Beta, β =	0.00 deg.	
Include Surcharge over Heel?	*Y*	
Include Surcharge over Toe?	*N*	
Is traffic less than HT/2 from wall?	*N*	
Surcharge Height, Hs =	2.00 ft.	*(AASHTO 3.11.6.4-1)*
Surcharge Width, Ws = Wf-(Wtoe+Ww)	10.00 ft.	
Active or At Rest Pressure (A or R)	*A*	
Soil Unit Weight, γ_{soil}	*0.12 kcf*	==> For lateral + weight on heel ======= *0.12 kcf* ==> For passive resistance + weigth on toe
Footing Resting On?	*G*	
Internal Friction Angle of Soil, δ (deg.)	*28.00*	*(@ base of the Footer)*
Internal Friction Angle of Fill, ϕ'_{fill}	*30.00 deg.*	
Friction Angle between Fill & Wall, δ	*0.00 deg.*	
Active Lat. Earth Press. Coeff., ka	0.37	*(AASHTO 3.11.5.3-1)*
$P_{soil} = \gamma_{soil} * (k_a \text{ or } k_0)$ =	43.95 pcf	
Bearing on soil or rock?(S or R) =	*S*	*(AASHTO 10.6.1.4)*
Factor Bearing Resistance (Strength)=	***10.75 ksf***	
Bearing Capacity (Service) =	*6.30 ksf*	(To check Settlement)
Consider Passive Force on Toe?	*N*	
Passive Lateral Pressure Coeff., kp	3.00	$k_p = \tan^2(45° + \phi'_f/2)$
P1 = P_{soil}*H1/1000 =	1.08 ksf	
P2 = Psoil*(H1+Hh)/1000 =	1.23 ksf	
P3 = Hs*Psoil/1000 =	0.00 ksf	
P4 = Psoil*(H2+Htoe)/1000 =	0.00 ksf	
Soil Sliding Forces:		
F1 = P1*H1*0.5 =	13.30 kips	kips
F2 = P2*(H1+Hh)*0.5 =	17.35 kips	kips
F3 = P3*H1 =	0.00 kips	kips
F4 = P4*(H2 +Htoe)*0.5 =	0.00 kips	kips
Additional Dead Load =	*0.00 kips*	kips
Moment Arm for Addit. Dead Load =	*0.00 ft.*	from Point A

Horizontal sliding Resistance: *(AASHTO 10.6.3.4)*

For cohesionless soils:	V(min) =	43.77 k	
	Rτ = V* tanδ =	23.28 k	
For cohesive soils:			
The lesser of:	Cu =	N.A.	
	0.5*σ'v =	N.A.	ksf
	Use =	N.A.	ksf
	Resistance Rτ=	N.A.	
For manual override of above formulas, use friction factor =		*0.87*	==> From High St use 0.72??
	Resistance Rτ=	38.08 klf	

Typical values for friction factor:

course grained soil w/out silt =	0.55
course grained soil w/silt =	0.45
silt =	0.35
shale =	0.55
rock =	0.7

Calculations:

Area 1 = γ_c x W_w x H_T	0.15 kcf x	1.50 ft. x	28.10 ft. x	1.00 ft. =		**6.32 kips**
Arm 1 = W_{toe} + W_w / 2	4.00 ft. +	1.50 ft.	/ 2.00 =			**4.75 ft.**
Area 2 = γ_c x W_h x H_h	0.15 kcf x	10.00 ft. x	3.50 ft. x	1.00 ft. =		**5.25 kips**
Arm 2 = W_{toe} + W_w + W_h / 2	4.00 ft. +	1.50 ft. +	10.00 ft.	/ 2.00 =		**10.50 ft.**
Area 3 = γ_c x W_{toe} x H_{toe}	0.15 kcf x	4.00 ft. x	3.75 ft. x	1.00 ft. =		**2.25 kips**
Arm 3 = W_{toe} / 2	4.00 ft.	/ 2.00 =				**2.00 ft.**
Area 4 = γ_s x (W_h -W_{w1}) x H_1	0.12 kcf x	(10.00 ft. -	2.03 ft.) x	24.60 ft. x	1.00 ft. =	**23.53 kips**
Arm 4 = W_{toe} + W_w + W_{w1} + (W_h -W_{w1}) / 2	4.00 ft. +	1.50 ft. +	2.03 ft. +	(10.00 ft. -	2.03 ft.) / 2 =	**11.51 ft.**
Area 5 = γ_s x W_{toe} x H_2	0.12 kcf x	4.00 ft. x	3.00 ft. x	1.00 ft. =		**1.44 kips**
Arm 5 = W_{toe} / 2	4.00 ft.	/ 2.00 =				**2.00 ft.**
Area 6 **(Horiz. Comp.)** = F_2 x cos(β)	17.35 kips x	cos (	0.00 deg.) =			**17.35 kips**
Arm 6 = (H_1 + H_h) / 3	(24.60 ft. +	3.50 ft.)	/ 3.00 =			**9.37 ft.**
Area 6 **(Vertical Comp.)** = F_2 x sin(β)	17.35 kips x	sin (	0.00 deg.) =			**0.00 kips**
Arm 6 = Wf	15.50 ft.					**15.50 ft.**
Area 7 = F_3	0.00 kips					**0.00 kips**
Arm 7 = (H_1 + H_h) / 2	(24.60 ft. +	3.50 ft.)	/ 2.00 =			**14.05 ft.**
Area 8 = 0.5 x γ_c x W_{w1} x H_1	0.5 x 0.15 kcf x	2.03 ft. x	24.60 ft. x	1.00 ft. =		**3.74 kips**
Arm 8 = W_{toe} + W_w + W_{w1} / 3	4.00 ft. +	1.50 ft. +	2.03 ft.	/ 3.00 =		**6.18 ft.**
Area 9 = 0.5 x γ_s x W_{w1} x H_1	0.5 x 0.12 kcf x	2.03 ft. x	24.60 ft. x	1.00 ft. =		**3.00 kips**
Arm 9 = W_{toe} + W_w + W_{w1} x 2/3	4.00 ft. +	1.50 ft. +	2.03 ft.	x 2.00	/ 3.00 =	**6.85 ft.**
Area 10 = 0.5 x γ_s x (S_e x W_h) x W_h	0.5 x 0.12 kcf x	(0.00 x	10.00 ft.) x	10.00 ft. x	1.00 ft. =	**0.00 kips**
Arm 10 = W_F - W_h / 3	15.50 ft. -	10.00 ft.	/ 3.00 =			**12.17 ft.**
Area 11 = F_4	0.00 kips					**0.00 kips**
Arm 11 = (H_{toe} + H_2) / 3	(3.75 ft. +	3.00 ft.)	/ 3.00 =			**2.25 ft.**
Surcharge on Heel = γ_s x W_s x H_s	0.12 kcf x	10.00 ft. x	2.00 ft. x	1.00 ft. =		**2.40 kips**
Arm for Heel Surcharge = W_F - W_h / 2	15.50 ft. -	10.00 ft.	/ 2.00 =			**10.50 ft.**

Surcharge on Toe = γ_s x W_{toe} x H_s	0.12 kcf x	4.00 ft. x	2.00 ft. x	1.00 ft. =	**0.96 kips**
Arm for Toe Surcharge = W_{toe} / 2	4.00 ft.	/ 2.00 =			**2.00 ft.**

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

CHECK BEARING PRESSURE

Factored Bearing Resistance = **10.75 ksf**

Maximum Strength Load Pressure
(AASHTO 11.6.3.2)
Bearing pressure at Toe = **6.03 ksf** **O.K.**

Bearing pressure at Heel = **6.03 ksf** **O.K.**

CHECK ECCENTRICITY

(AASHTO 11.6.3.3)
Maximum allowable e, (B/3) = **5.17 ft.**
Controlling Eccentricity = **4.28 ft.** **O.K.**

CHECK SLIDING (Per Unit Width)

(AASHTO 11.6.3.6)
Resistance factor ϕ_τ (Sliding) = *0.80* *(AASHTO Table 10.5.5.2.2-1)*
Resistance factor ϕ_{ep} (Passive pressure) = *0.50* *(AASHTO Table 10.5.5.2.2-1)*

Additional Resistance (Footing Key or Sheet Piling) :
Pressure for passive resistance = 0.360 kcf
Vertical Projection Below Footing = 0.00 ft.
Pressure at Top/Sheeting or Key = 2.430 ksf
Pressure at Bot./Sheeting or Key = 2.430 ksf
Passive on Footing Toe = 0.000 Kips
Total passive resistance = **0.00 kips**
Factored = **0.00 kips**

Controlling Driving force = **26.03 kips**

Resisting force = **30.47 kips** **O.K.**

AASHTO Table 10.5.5.2.2-1 (Sliding Resistance Factors)

CONDITION	FACTOR
Precast concrete placed on sand	0.90
Cast-in-place concrete on sand	0.80
C.I.P. or precast concrete on clay	0.85
soil on soil	0.90
Passive earth pressure component	0.50

CHECK SETTLEMENT

Service Bearing Capacity = **6.30 ksf**
Service Bearing Pressure at Toe = **4.26 ksf** **O.K.**
Service Bearing Pressure at Heel = **4.26 ksf** **O.K.**

SUMMARY OF LOAD EFFECTS

	MAX. BEARING PRESSURE	MIN. BEARING PRESSURE	ECCENTRICITIES MAXIMUM LF	ECCENTRICITIES MINIMUM LF	SLIDING FORCES MAXIMUM LF	VERTICAL FORCES MINIMUM
STRENGTH I	6.03	6.03	2.45	4.28	26.03	43.77
SERVICE I	4.26	4.26	2.12	NA	17.35	47.93

LOAD MODIFICATION FACTORS *(SEE AASHTO 1.3.3, 1.3.4, 1.3.5 & ODOT BDM 1001)*

Ductility η_D = *1.00* (use 1.00 for all limit states)
Redundancy η_R = *1.00* (use 1.00 for redundant structures and 1.05 for non-redundant structures)
Operational importance η_i = *1.00* (use 1.00 for all limit states)

STRENGTH I LOAD COMBINATION

SLIDING FORCES & OVERTURNING MOMENTS FROM SOIL
1.5*EH+1.75*LSH+0.9EHP
ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	
6	17.35	1.50	26.03	9.37	243.79	Horiz. Forces
7	0.00	1.75	0.00	14.05	0.00	
11	0.00	0.90	0.00	2.25	0.00	
		Σ Sliding Forces, F_s =	26.03 kips	Σ Overturning Moments =	243.79 k*ft.	

RESISTING MOMENTS AND DEAD LOAD FROM RETAINING WALL
1.5*DC+1.35*EV+1.75*LS_V (MAX.) 0.9*DC+1.0*EV (MIN.)
ΣM about point "A"

Area/Force	Force (k) Unfactored Load	Max. Load Factor	Force (k) Max. Load Factor	Min. Load Factor	Force (k) Min. Load Factor (This column is for stability)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	Moment (k-ft) Min. Load Factor (This column is for stability)	
1	6.32	1.25	7.90	0.90	5.69	4.75	37.54	27.03	Dead Load From Concrete
2	5.25	1.25	6.56	0.90	4.73	10.50	68.91	49.61	
3	2.25	1.25	2.81	0.90	2.03	2.00	5.63	4.05	
8	3.74	1.25	4.68	0.90	3.37	6.18	28.90	20.81	
4	23.53	1.35	31.77	1.00	23.53	11.51	365.76	270.94	Forces From Soil
5	1.44	1.35	1.94	1.00	1.44	2.00	3.89	2.88	
6 (Vertical comp.)	0.00	1.50	0.00	1.50	0.00	15.50	0.00	0.00	
9	3.00	1.35	4.04	1.00	3.00	6.85	27.71	20.52	
10	0.00	1.35	0.00	1.00	0.00	12.17	0.00	0.00	
Surcharge on Heel	2.40	1.75	4.20	0.00	0.00	10.50	44.10	0.00	External Loads
Surcharge on Toe	0.00	1.75	0.00	0.00	0.00	2.00	0.00	0.00	
DC	0.00	1.25	0.00	0.90	0.00	0.00	0.00	0.00	
		Σ Vert. Forces =	63.91 kips	Σ Vert. Forces =	43.77 kips	Resisting Moments =	582.44 k*ft.	395.84 k*ft.	

Client:	ODOT - D6	Job No.:	2012048		
Project:	FRA-70/71-12.68/14.86	Dgn'd By:	RSN	Date:	5/16/2018
Subject:	**4W13 - South Cantilever Wall**	Chk'd By:	DGN	Date:	6/15/2018

Max. Load Factor Results

Overturning Moment = Σ Overturning Moments =	243.79 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	582.44 k-ft.
Sliding Force = F_s =	26.03 kips
Net Moment = Resisting Moment - Overturning Moment =	338.64 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	63.91 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	5.30 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	2.45 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	6.03 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	6.03 ksf

Min. Load Factor

Overturning Moment = Σ Overturning Moments =	243.79 k-ft.
Resisting Moment = Σ Min. Resisting Moments =	395.84 k-ft.
Sliding Force = F_s =	26.03 kips
Net Moment = Resisting Moment - Overturning Moment =	152.05 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	43.77 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	3.47 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	4.28 ft.

SERVICE I LOAD COMBINATION

OVERTURNING AND SLIDING FORCES FROM SOIL

1.0*EH+1.0*LS_H+1.0*EH_P

ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	
6	17.35	1.00	17.35	9.37	162.53	Horiz. Forces From Soil
7	0.00	1.00	0.00	14.05	0.00	
11	0.00	1.00	0.00	2.25	0.00	
		Σ Sliding Forces, F_s =	17.35 kips	Σ Overturning Moments =	162.53 k*ft.	

RESISTING MOMENTS AND DEAD LOAD FROM SUBSTRUCTURE

1.0*DC+1.0*EV+1.0*LS_V

ΣM about point "A"

Area/Force	Force (k) Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)	Moment (k-ft)	
1	6.32	1.00	6.32	4.75	30.03	Dead Load From Concrete
2	5.25	1.00	5.25	10.50	55.13	
3	2.25	1.00	2.25	2.00	4.50	
8	3.74	1.00	3.74	6.18	23.12	
4	23.53	1.00	23.53	11.51	270.94	Forces From Soil
5	1.44	1.00	1.44	2.00	2.88	
6 (Vertical comp.)	0.00	1.00	0.00	15.50	0.00	
9	3.00	1.00	3.00	6.85	20.52	
10	0.00	1.00	0.00	12.17	0.00	
Surcharge on Heel	2.40	1.00	2.40	10.50	25.20	External Loads
Surcharge on Toe	0.00	1.00	0.00	2.00	0.00	
DC	0.00	1.00	0.00	0.00	0.00	
		Σ Vert. Forces =	47.93 kips	Σ Resisting Moments =	432.32 k*ft.	

Overturning Moment = Σ Overturning Moments =	162.53 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	432.32 k-ft.
Sliding Force = F_s =	17.35 kips
Net Moment = Resisting Moment - Overturning Moment =	269.79 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	47.93 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	5.63 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	2.12 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	4.26 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	4.26 ksf

Where the wall is supported by a rock foundation:

the vertical stress shall be calculated assuming a linearly distributed pressure over an effective base area as shown in Figure 11.6.3.2-2. If the resultant is within the middle one-third of the base:

$$\sigma_{max} = \frac{\Sigma V}{B}\left(1 + 6\frac{e}{B}\right) \quad (11.6.3.2\text{-}2)$$

$$\sigma_{min} = \frac{\Sigma V}{B}\left(1 - 6\frac{e}{B}\right) \quad (11.6.3.2\text{-}3)$$

where the variables are as defined in Figure 11.6.3.2-2. If the resultant is outside the middle one-third of the base:

$$\sigma_{max} = \frac{2\Sigma V}{3[(B/2) - e)]} \quad (11.6.3.2\text{-}4)$$

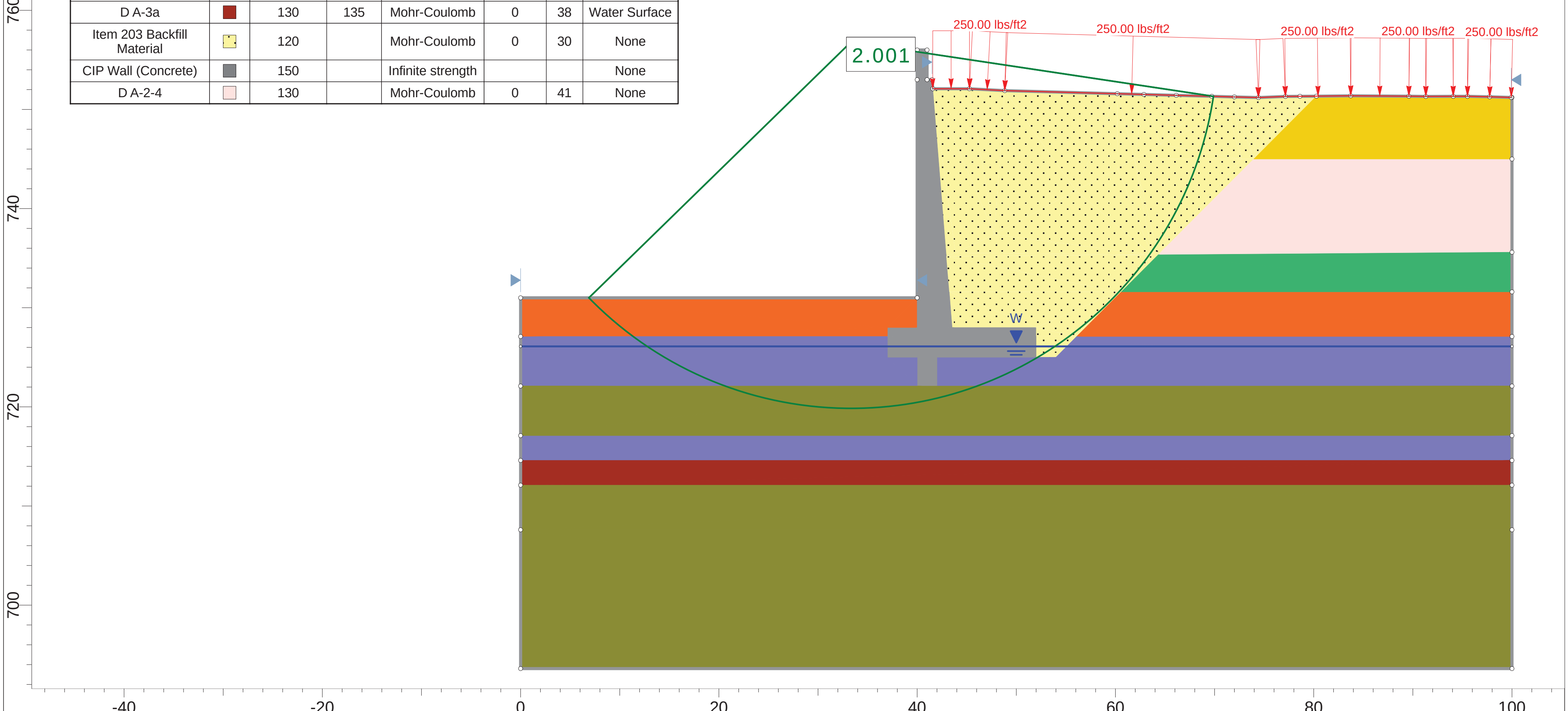
$$\sigma_{min} = 0 \quad (11.6.3.2\text{-}5)$$

where the variables are as defined in Figure 11.6.3.2-2.

APPENDIX VII

GLOBAL STABILITY ANALYSIS OUTPUT

Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)	Water Surface
S A-4a		125		Mohr-Coulomb	0	27	None
VSt A-4b		120		Mohr-Coulomb	0	32	None
D A-1-b		135		Mohr-Coulomb	0	42	None
MD A-4b		135	138	Mohr-Coulomb	0	36	Water Surface
VSt A-4a		130	135	Mohr-Coulomb	0	28	Water Surface
D A-3a		130	135	Mohr-Coulomb	0	38	Water Surface
Item 203 Backfill Material		120		Mohr-Coulomb	0	30	None
CIP Wall (Concrete)		150		Infinite strength			None
D A-2-4		130		Mohr-Coulomb	0	41	None



Project	FRA-70-12.68 Retaining Wall 4W13
Analysis Description	FRA-70-12.68 Retaining Wall 4W13, STA 198+00, B-031-0-08 - Drained Spencer's - Overall Global Stability
Drawn By	HSK
Scale	1:180
Company	Resource International, Inc.
Date	7/5/2018 6:32:20 PM
File Name	W-13-045 RW13.slim

SLIDEINTERPRET 7.009