Resource International, Inc.

FRA-70-14.05 PROJECT 4B
RETAINING WALL 4W15
PID NO. 96053
FRANKLIN COUNTY, OHIO

STRUCTURE FOUNDATION EXPLORATION REPORT

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

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

Rii Project No. W-15-126

June 2022

RESOURCE INTERNATIONAL, INC.
6350 Presidential Gateway
Columbus, Ohio 43231
T: 614.823.4949

Planning

Engineering

Construction Management

Technology

June 27, 2022

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

Re: Structure Foundation Exploration Report
FRA-70-14.05 Project 4B
Retaining Wall 4W15
PID No. 96053
Rii Project No. W-15-126

Mr. Luzier:

Resource International, Inc. (Rii) is pleased to submit this structure foundation exploration report for the above referenced project. Engineering logs have been prepared and are attached to this report along with the results of laboratory testing. This report includes recommendations for the design and construction of proposed Retaining Wall 4W15 as part of the FRA-70-14.05 Project 4B in Columbus, Ohio.

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

Sincerely,

RESOURCE INTERNATIONAL, INC.

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

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

Enclosure: Structure Foundation Exploration Report

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APPENDICIES

EXECUTIVE SUMMARY

Resource International, Inc. (Rii) has completed a structure foundation exploration for retaining wall 4W15 as part of the FRA-70-14.05 (Project 4B) project. Retaining wall 4W15 extends from existing bridge structure FRA-23-1075 to the existing retaining wall between Sta. 205+67.15 and Sta. 210+26.67 along the south side of I-70 eastbound. Retaining wall 4W15 measures approximately 465.3 lineal feet in length, with a proposed stem height above the footing varying from 28.1 to 30.6 feet. The retaining wall is proposed to be constructed as a cast-in-place (CIP) cantilevered wall.

Shallow Foundation Recommendations

It is understood that the shallow spread foundations will be utilized for the retaining wall 4W15. The bearing soils for wall 4W15 are anticipated to consist of dense and very dense gravel with sand and coarse and fine sand (ODOT A-1-b, A-3a) with intermittent seams of hard sandy silt, silt and silt and clay (ODOT A-4a, A-4b, A-6a). Shallow spread foundations bearing on these competent natural soils may be proportioned for a nominal bearing resistance as presented in Table 6 in Section 5.1 of the full report.

Based on the maximum service limit bearing pressures provided in the design documents and noted above, total settlements ranging from 0.852 to 1.193 inches are anticipated along the alignment of retaining wall 4W15. Additionally, the maximum factored bearing pressure will not exceed the factored bearing resistance at the strength limit.

For concrete footing that rest on cohesionless soil, a coefficient “f” of 0.78 times the total vertical force on the base should be taken as the sliding resistance. A geotechnical resistance factor of $\varphi_\tau = 1.0$ should be considered when calculating the factored shear resistance between the soil and foundation for sliding.

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

1.0 INTRODUCTION

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

This report is a presentation of the structure foundation exploration performed for the design and construction of proposed retaining wall 4W15, 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 4W15 begins at Sta. 205+67.51 and ends at Sta. 210+26.67 and will support the grade separation earth between parking lot for Africentric Early College K-12 School along Livingston Avenue and I-70. Retaining wall 4W15 measures approximately 460 lineal feet, with a proposed wall height ranging from 26.0 to 32.5 feet. The retaining wall is proposed to be constructed as a cast-in-place (CIP) wall.

2.0 GEOLOGY AND OBSERVATIONS OF THE PROJECT

2.1 Site Geology

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

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

The bedrock surface in the vicinity of the site forms a broad valley which roughly follows the present day Scioto River valley. The site lies on a slight plateaued area and slope along the east side of the valley where the underlying bedrock surface lies at an approximate elevation of 625 to 630 feet mean sea level and slopes down toward the west to an approximate elevation of 600 feet msl in the bedrock valley. According to bedrock topography mapping, the depth to the bedrock surface below the site ranges between approximately 105 to 135 feet below existing grade. Shale bedrock was encountered in several of the borings performed along the corridor at elevations ranging from 630 to 650 feet msl, increasing in elevation from west to east across the project alignment. Within the borings performed for this current investigation, shale bedrock was encountered at a depth of 93.5 feet below the ground surface which corresponds to El. 641.2 feet msl.

2.2 Existing Conditions

The proposed retaining wall 4W15 structure will be located on the south side of eastbound I-70 between S. Fourth Street and the existing retaining wall - which is located between S. Fourth Street and S. Grant Avenue. The proposed retaining wall is for grade separation between Africentric Early College K-12 School along Livingston Avenue and I-70. The existing I-70/I-71 in the vicinity of the proposed structure is a six-lane, bi-directional, composite asphalt and concrete composite paved roadway along with the ramp merging from S. Fourth Street, that is generally east-west aligned through downtown Columbus, Ohio. The existing I-70 profile grades 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 along S. Fourth Street. Immediately adjacent to the pavements south of EB I-70, the right of way has light to medium dense vegetation growth consisting of grasses and small trees. 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 December 3 and 4, 2015, one (1) structural boring, designated as B-037-1-15, was drilled to completion depth of 60.0 feet below the existing ground surface along the proposed alignment of retaining wall 4W15. In addition to the boring performed by Rii as part of the current exploration, one (1) boring, designated as B-036-0-08, were performed by DLZ for the preliminary engineering exploration in the vicinity of the proposed alignment of retaining wall 4W15. Boring B-031-0-08 was advanced to a depth of 115.6 feet below the existing ground surface. 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-036-0-08	BL I-70 EB	206+71.43	61.2' Rt.	39.953425	-82.993682	734.7	115.6
B-037-1-15	BL I-70 EB	208+42.08	65.7' Rt.	39.953492	-82.993082	736.3	60.0

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 was drilled using a truck 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 5.0-foot increments for the first 15 feet and then followed by 2.5-foot increments of depth to 35 feet, 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 hammer for the Mobile CME 55 drill rig used by Rii was calibrated on October 20th, 2014, and has drill rod energy ratio of 92.0 percent. The hammer for the CME 75 drill rig operated by DLZ was calibrated on February 11, 2009, and has a drill rod energy ratio 62.1 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	15
Plastic and Liquid Limits	AASHTO T89, T90	8
Gradation – Sieve/Hydrometer	AASHTO T88	8

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 boring B-036-0-08 was extended into the underlying bedrock by DLZ, an NMX or NQ-sized double-tube diamond bit core barrel (utilizing wire line equipment) was used to core the bedrock. The Rock Quality Designation (RQD) for each rock core run was provided on the boring log.

In addition to the boring B-037-0-18 performed as part of the current exploration and B-036-0-08 by DLZ, historic borings performed in 1959 by the Department of Highways as part of the original FRA-40-12.82 project for the existing S. Fourth Street bridge structure and the existing retaining wall Wall-D structure were obtained from the construction documents on record.

Two (2) borings, designated as B-001-4-59 and B-001-D-59, were obtained at the southeast side of the existing S. Fourth Street bridge alignment, near the west end of the proposed Retaining Wall 4W15 alignment, and at south of the existing retaining wall Wall-D, on the east end, respectively. Based on the elevation provided on the boring logs, it is anticipated that the borings were performed from the then-existing ground surface prior to the construction of existing I-70/I-71. Both the borings were extended to a depth of 56.0 feet below the ground surface at the time the boring was obtained (to an approximate elevation 696.9 and 700.3 feet-msl, respectively).

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-037-1-15 was drilled through the I-70 EB driving lane 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. Boring B-036-0-08 was also drilled through the EB driving lane pavement, and encountered composite pavement of 9.25 inches of asphalt over 11.0 inches of concrete followed by 4.0 inches of aggregate base at the ground surface.

4.2 Subsurface Soils

Beneath the surficial pavement materials, natural soils encountered consist of both granular and cohesive material. The granular soils were generally described as, brown and gray gravel, gravel and/or stone fragments with sand, gravel with sand, gravel with sand silt and clay, coarse and fine sand, sandy silt, and silt (ODOT A-1-a, A-1-b, A-2-6, A-3a, A-4a, and A-4b). The cohesive soils were generally described as stiff to hard, gray sandy silt, silt, and silt and clay (ODOT A-4a).

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 dense ($30 \leq N_{60} \leq 50$ blows per foot [bpf]) to very dense ($N_{60} > 50$ bpf). Overall blow counts recorded from the SPT sampling ranged from 38 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 1.0 tsf to over 4.5 tsf (limit of instrument).

Natural moisture contents of the soil samples tested ranged from 4 to 15 percent. The natural moisture content of the cohesive soil samples tested for plasticity index ranged from 0 percent below to 2 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-036-0-08, 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-036-0-08	734.7	94.25	640.45	94.9	639.8

Severely weathered shale bedrock was encountered in boring B-036-0-08 at a depth of 94.25 feet below the ground surface (El. 640.45 feet msl). Auger refusal occurred at depth 94.9 feet below ground surface and therefore, rock coring was initiated. The cored shale bedrock encountered in this boring was described as blue-gray and dark gray, highly weathered, very weak to weak, laminated, pyritic, fissile, friable, jointed, moderately fractured to fractured, tight, and slightly rough. It is indicated that the rock was interbedded with 90% shale and 10% limestone. The boring was terminated at depth 115.6 feet from the surface after performing four (4) 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	639.8 to 634.1	100.0	100.0	N/A
	R-2	634.1 to 629.1	100.0	83.0	1442
	R-3	629.1 to 624.1	100.0	60.0	N/A
	R-4	624.1 to 619.1	100.0	68.0	N/A

It should be noted that bedrock naturally experiences mechanical breaks during the drilling and coring processes.

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-036-0-08	737.7	14.0 [1]	723.7	11.8 [2]	725.9
B-037-1-15	736.3	18.5	717.8	N/A [3]	-

1. *Observed seepage*
2. *Includes drilling water. Advanced wash boring due to sand heave.*
3. *The groundwater level at completion could not be obtained. Advanced washed boring at 18.5-feet.*

Groundwater was encountered initially during the drilling process in both borings at depths ranging from 14.0 to 18.5 feet below existing grade, which corresponds to elevations ranging from 723.7 to 717.8 feet msl, respectively. The groundwater level at the completion of drilling in boring B-037-1-15 was not recorded due to the wash boring was advanced till the end of the boring. Additionally, DLZ noted that they frequently added water to the borehole to clean out the augers after encountering heaving sand 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 as noted in Section 3.0 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 4W15 extends from existing bridge structure FRA-23-1075 to the existing retaining wall between Sta. 205+67.51 and Sta. 210+26.67, along the south side of I-70 eastbound. Based on plan information provided by GPD GROUP, the retaining wall is proposed to be constructed as cast-in-place (CIP) cantilevered wall type with a proposed height ranging from 26.0 to 32.5 feet. Based on design calculations provided by GPD GROUP, the footing for retaining wall 4W15 has been designed to produce a maximum service limit bearing pressure of 5.56 ksf and a maximum factored bearing pressure of 8.09 ksf at the strength limit state.

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

5.1 Shallow Foundation Recommendations

Based on plan information provided by GPD GROUP and soil conditions encountered at four (4) borings, the foundations for the proposed retaining walls will bear at a minimum depth of 7.0 feet below the existing grade of I-70, at elevations ranging from 723.5 to 733.0 feet msl. At these elevations, the bearing soils for wall 4W15 are anticipated to consist of dense and very dense gravel with sand and coarse and fine sand (ODOT A-1-b, A-3a) with intermittent seams of hard sandy silt, silt and silt and clay (ODOT A-4a, A-4b, A-6a). 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 4W15. It is understood that the external stability calculations (including check for sliding, overturning and bearing) for retaining wall 4W15 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 system.

Table 6. Shallow Foundation Analysis – Retaining Wall 4W15

Boring Number	Effective Footing Width (feet)	Service Limit Bearing Pressure (ksf) [1]			Nominal Bearing Resistance (ksf)	Factored Bearing Resistance [2] (ksf)
		0.5-inch	1.0-inch	1.5-inch		
B-001-4-59	5	4.33	12.99	20.73	22.87	12.58
	7	3.75	10.32	15.79	22.89	12.59
	9	3.42	8.84	13.11	22.91	12.60
	11	3.22	7.91	11.45	22.93	12.61
	13	3.08	7.28	10.32	22.95	12.62
	15	2.98	6.82	9.52	22.97	12.63
	17	2.90	6.48	8.94	22.99	12.64
	19	2.84	6.21	8.50	23.01	12.65
	21	2.79	6.00	8.14	23.02	12.66
	23	2.75	5.83	7.85	23.04	12.67
	25	2.72	5.70	7.62	23.06	12.68
B-036-0-08	5	4.04	10.28	20.95	43.93	24.16
	7	3.50	8.15	16.00	50.55	27.80
	9	3.20	6.96	13.25	57.39	31.56
	11	3.01	6.21	11.50	64.35	35.39
	13	2.87	5.68	10.29	71.39	39.26
	15	2.77	5.30	9.41	78.46	43.15
	17	2.69	5.00	8.73	85.55	47.05
	19	2.63	4.77	8.20	92.65	50.96
	21	2.58	4.58	7.77	99.75	54.86
	23	2.54	4.43	7.41	106.84	58.76
	25	2.51	4.30	7.11	113.92	62.66

Boring Number	Effective Footing Width (feet)	Service Limit Bearing Pressure (ksf) [1]			Nominal Bearing Resistance (ksf)	Factored Bearing Resistance [2] (ksf)
		0.5-inch	1.0-inch	1.5-inch		
B-037-1-15	5	3.04	6.57	9.02	22.86	12.57
	7	2.67	5.86	7.82	22.88	12.58
	9	2.46	5.43	7.16	22.90	12.59
	11	2.32	4.98	6.73	22.92	12.60
	13	2.23	4.59	6.41	22.94	12.61
	15	2.16	4.30	6.18	22.96	12.63
	17	2.10	4.08	6.00	22.97	12.64
	19	2.06	3.90	5.87	22.99	12.65
	21	2.03	3.76	5.76	23.01	12.66
	23	2.00	3.64	5.66	23.03	12.67
	25	1.97	3.55	5.59	23.05	12.68
B-001-D-59	5	4.02	11.43	16.70	41.53	22.84
	7	3.44	9.14	13.10	41.57	22.86
	9	3.12	7.95	11.17	41.60	22.88
	11	2.92	7.23	9.98	41.64	22.90
	13	2.78	6.77	9.20	41.67	22.92
	15	2.68	6.45	8.62	41.71	22.94
	17	2.60	6.21	8.21	41.74	22.96
	19	2.55	6.03	7.87	41.78	22.98
	21	2.50	5.90	7.61	41.81	23.00
	23	2.46	5.79	7.40	41.85	23.01
	25	2.43	5.71	7.22	41.88	23.03

1. *Service limit bearing pressure was calculated at total settlement values of 0.5, 1.0 and 1.5 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 1.5 inches was calculated and presented in Table 6 for retaining wall 4W15. A geotechnical resistance factor of φ_b = 0.55 has been considered in calculating the factored bearing resistance at the strength limit state. 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. A graphical representation of the service limit bearing pressures and factored bearing resistance at the strength limit state is presented in Appendix V. Calculations for settlement and nominal and factored bearing resistance for the shallow spread foundations are provided in Appendix VI.

Based on the maximum service limit bearing pressures provided in the design documents and noted in Section 5.0, total settlements ranging from 0.852 to 1.193 inches are anticipated along the alignment of retaining wall 4W15. Additionally, the maximum factored bearing pressure will not exceed the factored bearing resistance at the strength limit for retaining wall 4W15.

5.1.1 Sliding Resistance

The resistance of the footings to sliding will be dependent on the friction between the concrete footing and bearing soils. 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 38 degrees and a coefficient of sliding friction “f” of 0.78 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 resisting 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
Granular Backfill Material	120	30	0	N/A
Stiff to Hard Cohesive Soils	125 to 135	25 to 26	0	2,000 to 4,000
Medium Dense to Very Dense Granular Soils	120 to 135	33 to 38	0	N/A

Per Section 11.6.2.3 of the 2012 AASHTO LRFD BDS, overall (global) stability for CIP wall 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. 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 4W15 was greater than 1.33. Calculations for overall (global) stability of the CIP Cantilevered Wall 4W15 is provided in Appendix VIII.

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 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
Very Stiff to Hard Cohesive Soil	125	3,000	0°	N/A	N/A	N/A
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. Estimated Drained (Long-term) Soil Parameters for Design

Soil Type	γ (pcf) [1]	c (psf)	φ'	k_a	k_o	k_p
Very Stiff to Hard Cohesive Soil	125	50	28°	0.32	0.53	5.07
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 4W15. 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.

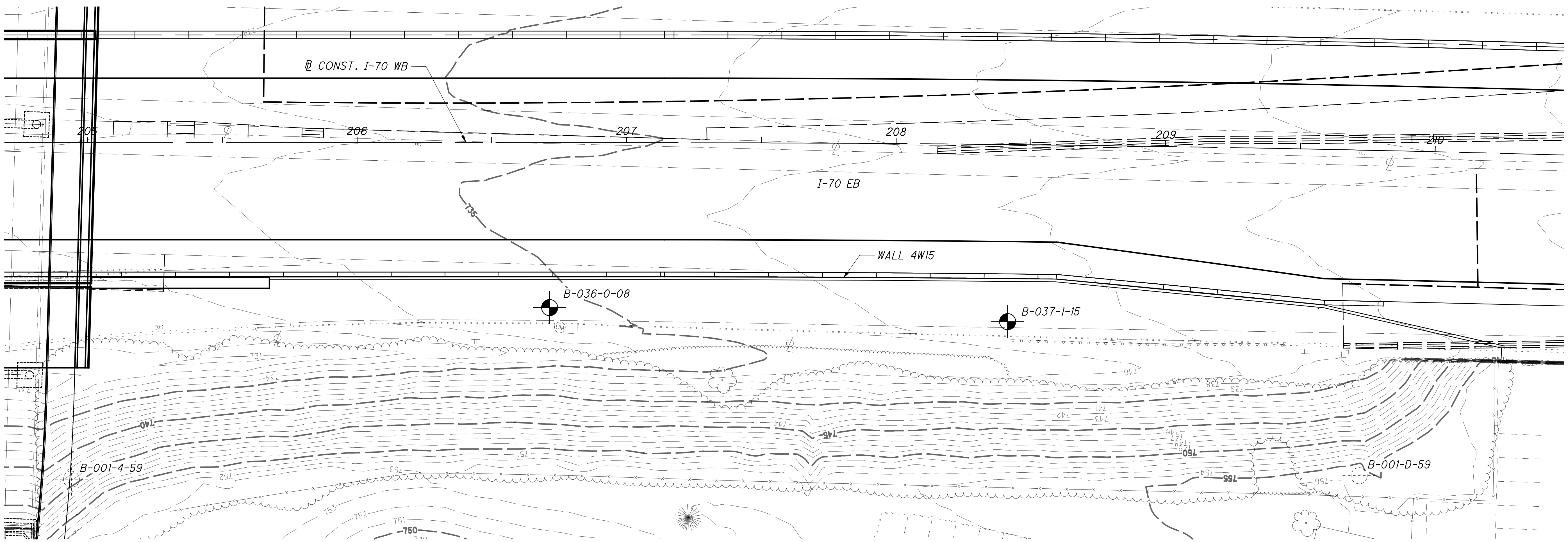
The conclusions and recommendations herein have been based upon the available soil and bedrock information and the design details furnished by a representative of the owner of the proposed project. Any revision in the plans for the proposed construction from those anticipated in this report should be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



BORING PLAN - WALL 4W15 1-70 EB

FRA-70-14.05

FRANKLIN COUNTY, OHIO

RII PROJECT NO. W-15-126		DRAWN JAS
SCALE: 1"=20' (0 10 20)	N	REVIEWED BRT
		DATE 11-27-18

APPENDIX II

DESCRIPTION OF SOIL TERMS

DESCRIPTION OF SOIL TERMS

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

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

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

MATERIAL CLASSIFIED BY VISUAL INSPECTION

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

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

DESCRIPTION OF ROCK TERMS

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

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

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

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

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

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

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

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

Degree of Fracturing

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

Aperture Width

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

Surface Roughness

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

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

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

APPENDIX III

PROJECT BORING LOGS:

B-036-0-08 and B-037-1-15

BORING LOGS

Definitions of Abbreviations

AS = Auger sample

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

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

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

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

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

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

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

RC = Rock core sample

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

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

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

S = Sulfate content (parts per million)

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

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

SS = Split spoon sample

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

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

TR = Top of rock

W = Initial water level measured during drilling

▼ = Water level measured at completion of drilling

Classification Test Data

Gradation (as defined on Description of Soil Terms):

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

Atterberg Limits:

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

WC = Water content (%)

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

LOG OF: Boring B-036-0-08 | *Location:* Sta. 206+71.43, 61.17' RT., BL I-70 EB | *Date Drilled:* 7/14/2008 to 7/16/2008

WATER OBSERVATIONS:
Water seepage at: 14.0'
Water level at completion: 11.8' (includes drilling water)

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

Depth (ft)	Elev. (ft) 734.7	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 / Non-Plastic - NP
							Asphalt Concrete - 9.5" Portland Cement Concrete - 11" Aggregate Base - 4"								
2.0	732.7	16 22 27	13	1			Dense to very dense brown GRAVEL WITH SAND (A-1-b), trace to little silt; damp to moist.								
		20 24 25	13	2											
5		12 15 23	14	3					17	43	---	23	--17--		NP
		14 24 38	14	4					22	44	---	21	--13--		NP; 63
		16 23 25	14	5					32	36	---	20	--12--		NP
10		19 32 34	15	6					36	34	---	17	--13--		NP; 67
11.0	723.7	10 25 26	15	7			Very dense brown COARSE AND FINE SAND (A-3a), little silt, trace gravel; moist.		1	41	---	44	--14--		NP; 52
12.5	722.2	17 29 31	16	8			Dense to very dense brown GRAVEL WITH SAND (A-1-b), little silt; moist to wet. @ 14.0', becomes wet.								61
15		4 22 27	14	9											
		6 18 21	15	10											
		9 20 21	13	11											
20		28 32 50/5	14	12					37	31	---	16	--16--		NP; 50+
		17 30 35	12	13											66
25	709.7	18 28 29	13	14											58

Blows per foot: 10 20 30 40

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

LOG OF: Boring B-036-0-08 | Location: Sta. 206+71.43, 61.17' RT., BL I-70 EB | Date Drilled: 7/14/2008 to 7/16/2008

WATER OBSERVATIONS:
Water seepage at: 14.0'
Water level at completion: 11.8' (includes drilling water)

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

Surface Elev. (ft): 709.7

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)
							Very dense brown COARSE AND FINE SAND (A-3a), little silt, trace to little gravel; wet.							
		19 32 33	18	15										66
28.5	706.2						Stiff to very stiff gray SANDY SILT (A-4a), some to "and" fine to coarse sand, trace to little gravel; moist.							
		14 30 41	14	16		2.5	@ 29.0'-29.5', sandy silt seam.	5	12	---	38	42	3	72
		24 42 50/5	14	17		--	@ 33.5'-34.9', contains sand seams.	10	23	---	25	35	7	50+
		29 50/4	10	18		1.0	@ 39.0'-39.3', silt seam.							50+
42.0	692.7						Very dense gray GRAVEL WITH SAND (A-1-b), trace to little silt; wet.							
		17 49 39	14	19			@ 45.0'-55.0', difficult drilling.	43	33	---	14	--10--		90 (NP)
							@ 48.5', 2.3 feet sand heave.							
50	684.7	23 42 50/5	12	20										50+

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

LOG OF: Boring B-036-0-08 | Location: Sta. 206+71.43, 61.17' RT., BL I-70 EB | Date Drilled: 7/14/2008 to 7/16/2008

WATER OBSERVATIONS:
Water seepage at: 14.0'
Water level at completion: 11.8' (includes drilling water)

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

Depth (ft)	Elev. (ft) 684.7	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, % / PL–LL / Non-Plastic - NP
							Very dense gray GRAVEL WITH SAND (A-1-b), trace to little silt; wet.							
55		45 50/4	9	21			@ 53.5'-54.3', contains silty clay seams.							50+
60		19 35 45	12	22				30	38	---	21	--11--		NP; 82
65		33 50/5	11	23			@ 63.5', 1.9 feet sand heave. @ 63.5'-64.4', brown.							50+
70		20 39 50/5	13	24										50+
75	659.7	35 46 50/6	13	25										50+

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

LOG OF: Boring B-036-0-08 | *Location:* Sta. 206+71.43, 61.17' RT., BL I-70 EB | *Date Drilled:* 7/14/2008 to 7/16/2008

WATER OBSERVATIONS:
Water seepage at: 14.0'
Water level at completion: 11.8' (includes drilling water)

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

Depth (ft)	Elev. (ft) 659.7	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, %
							Very dense gray GRAVEL WITH SAND (A-1-b), trace to little silt; wet.								
		49 50/3	8	26			@ 78.5', 0.9 feet sand heave.								50+
80															
		28 46 48	11	27					42	35	---	11	--12--		NP; 96
85															
		50/1	0	28			@ 88.5'-93.5', encountered boulders.								50+
90															
93.5	641.2	27 50/3	8	29			Severely weathered gray SHALE.								50+
94.9 (95)	639.8						Shale, blue-gray, highly weathered, very weak to weak, laminated, friable, fissile, pyritic, jointed, moderately fractured to fractured, tight, slightly rough, RQD 100%, Loss 0%. Contains dark gray, well cemented shale zones [thin, dark bands]. Dark shale zones are typically 1-2 inches thick, spaced at intervals of 12 to 18 inches.								
96.6	638.1						Interbedded Shale (90%) and Limestone (10%)								
100	634.7														

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-036-0-08 | Location: Sta. 206+71.43, 61.17' RT., BL I-70 EB | Date Drilled: 7/14/2008 to 7/16/2008

WATER OBSERVATIONS:
Water seepage at: 14.0'
Water level at completion: 11.8' (includes drilling water)

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

Depth (ft)	Elev. (ft) 634.7	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)
							Interbedded Shale (90%) and Limestone (10%) RQD 74% Loss 0%; Shale, dark gray, highly weathered, weak, laminated, friable, fissile, pyritic, jointed, moderately fractured to fractured, tight, slightly rough; Limestone, gray, moderately weathered, strong, thinly bedded, pyritic, slightly rough. @ 103.7' - 104.2', qu = 1442 psi								
		Core 60"	Rec 60"	RQD 83%	R2										
105															
		Core 60"	Rec 60"	RQD 60%	R3										
110															
		Core 60"	Rec 60"	RQD 68%	R4										
115															
115.6	619.1						Bottom of Boring - 115.6'								
120															
125															

RESOURCE INTERNATIONAL, INC.

PROJECT: FRA-70-14.05 PROJECT 4B	DRILLING FIRM / OPERATOR: RII / S.B.	DRILL RIG: CME 55 (SN 386345)	STATION / OFFSET: 208+42.08 / 65.7" RT
TYPE: ROADWAY	SAMPLING FIRM / LOGGER: RII / C.D.	HAMMER: CME AUTOMATIC	ALIGNMENT: BL CONST. I-70 EB
PID: 96053 BR ID: NA	DRILLING METHOD: 3.25" - HSA	CALIBRATION DATE: 10/20/14	ELEVATION: 736.3 (MSL) EOB: 60.0 ft.
START: 12/3/15 END: 12/4/15	SAMPLING METHOD: SPT	ENERGY RATIO (%): 92	COORD: 39.953492, -82.993082

EXPLORATION ID **B-037-1-15**

MATERIAL DESCRIPTION AND NOTES	ELEV. 736.3
0.5' - ASPHALT (6.0")	735.8
1.0' - CONCRETE (12.0")	734.8
0.5' - AGGREGATE BASE (6.0")	734.3
HARD, BROWN TO GRAY **SANDY SILT**, SOME CLAY, LITTLE FINE GRAVEL, DAMP. -COBBLES PRESENT FROM 13.5' to 18.0'	718.3
DENSE, GRAY **GRAVEL AND/OR STONE FRAGMENTS WITH SAND**, LITTLE SILT, TRACE CLAY, MOIST TO WET. -WATER ADDED TO AUGERS @ 18.5'	715.8
STIFF TO VERY STIFF, GRAY **SANDY SILT**, LITTLE CLAY, LITTLE FINE GRAVEL, DAMP.	710.8
VERY DENSE, GRAY **GRAVEL WITH SAND, SILT, AND CLAY**, MOIST.	708.3
VERY DENSE, GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST.	

W (water level at approx. 18.5')

SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GR	CS	FS	SI	CL	LL	PL	PI	WC	ODOT CLASS (GI)
5 6 9	23	100	SS-1	4.5+	-	-	-	-	-	-	-	-	9	A-4a (V)
10 9 14	35	100	SS-2	4.5+	17	11	17	34	21	22	13	9	9	A-4a (4)
50/1"	-	0	SS-3	-	-	-	-	-	-	-	-	-	-	
50/3"	-	0	SS-4	-	-	-	-	-	-	-	-	-	-	
50/1"	-	0	SS-4A	-	-	-	-	-	-	-	-	-	-	
11 26 22	72	78	SS-5	-	36	33	15	11	5	NP	NP	NP	11	A-1-b (0)
50/4"	-	50	SS-6	4.5+	-	-	-	-	-	-	-	-	11	A-4a (V)
50/5"	-	80	SS-7	-	16	23	17	26	18	23	13	10	12	A-4a (2)
50/3"	-	100	SS-8	-	-	-	-	-	-	-	-	-	15	A-2-6 (V)
2 33 27	90	89	SS-9	-	54	25	8	9	4	20	14	6	9	A-1-a (0)

PID: 96053	BR ID: NA	PROJECT: FRA-70-14.05 PROJECT 4B	STATION / OFFSET: 208+42.08 / 65.7' RT	START: 12/3/15	END: 12/4/15	PG 2 OF 2	B-037-1-15

MATERIAL DESCRIPTION AND NOTES	ELEV. 706.3	DEPTHS	SPT/ RQD	N_{60}	REC (%)	SAMPLE ID	HP (tsf)	GRADATION (%) GR	CS	FS	SI	CL	ATTERBERG LL	PL	PI	WC	ODOT CLASS (GI)	BACK FILL
VERY DENSE, GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. *(same as above)* -HEAVING SANDS ENCOUNTERED @ 31.0'		31–32	6 25 37	93	100	SS-10	-	57	22	8	9	4	20	14	6	8	A-1-a (0)	
	701.8	34	8 34 32	99	100	SS-11A	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
HARD, GRAY **SANDY SILT**, SOME FINE GRAVEL, LITTLE CLAY, DAMP.	699.3	35				SS-11B	4.5+	28	11	14	32	15	23	14	9	10	A-4a (2)	
MEDIUM DENSE, GRAY **SILT**, SOME COARSE TO FINE SAND, TRACE CLAY, TRACE FINE GRAVEL, WET.	694.3	39–40	4 10 19	44	100	SS-12	-	1	2	32	56	9	NP	NP	NP	19	A-4b (6)	
VERY DENSE, GRAY **GRAVEL**, SOME COARSE TO FINE SAND, TRACE SILT, TRACE CLAY, MOIST. -HEAVING SANDS ENCOUNTERED @ 43.5'		44	22 38 50/4"	-	100	SS-13	-	-	-	-	-	-	-	-	-	9	A-1-a (V)	
-HEAVING SANDS ENCOUNTERED @ 48.5'		49–50	36 43 44	131	100	SS-14	-	54	21	13	8	4	NP	NP	NP	7	A-1-a (0)	
-HEAVING SANDS ENCOUNTERED @ 53.5' -ROCK FRAGMENTS PRESENT IN SS-15		54	50/5"	-	20	SS-15	-	-	-	-	-	-	-	-	-	1	A-1-a (V)	
	676.3	59–60 (EOB)	34 36 32	102	100	SS-16	-	-	-	-	-	-	-	-	-	12	A-1-a (V)	

NOTES: GROUNDWATER ENCOUNTERED INITIALLY @ 18.5'

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

APPENDIX IV

HISTORIC BORING LOGS:

B-001-4-59 and B-001-D-59

SHEET 4

STATE OF OHIO
DEPARTMENT OF HIGHWAYS
TESTING LABORATORY

B-001-4-59

LOG OF BORING

CO., RT. NO., SEC. FRA-40-12.82 BRIDGE NO. FRA-40-1334
REAR ABUTMENT SOUTH INNERBELT UNDER FOURTH STREET
LOCATION: T.H. 1 B STA. 51+36 OFFSET 37' RT FED. NO.

ELEV.	DEPTH	NO. BLOWS	SAMPLE NO.	DESCRIPTION
752.9	0			
	2			
	4			
747.9	6	17/42	21530	Brown Silty Sandy Gravel W/Stone Fragts.
	8			
742.9	10			
	12	25/35	21531	Gray Silty Sandy Gravel
740.4	14	20/36	21532	Gray Gravelly Sandy Silt
737.9	16	24/36	21533	Gray Gravelly Sandy Silt
735.4	18	24/49	21534	Gray Gravelly Sandy Silt
732.9	20			
	22	36/46	21535	Gray Sandy Gravel
730.4	24	9/14	21536	Gray Sandy Gravel
727.9	26	43/60	21537	Gray Sandy Gravel
725.4	28	39/56	21538	Gray Gravelly Sand
722.9	30			
	32	43/70	21539	Gray Gravelly Sand
	34			
717.9	36	50/65	21540	Gray Sandy Gravel

BM
7-7-59

LOG OF BORING (CONTINUED)

B-001-4-59

BRIDGE NO. FRA-40-1334 T.H. 1B

ELEV.	DEPTH	NO. BLOWS	SAMPLE NO.	DESCRIPTION
	38			
712.9	40	10/25	21541	Gray Silt
	42			
	44			
707.9	46	22/40	21542	Gray Silt and Clay
	48			
702.9	50	50/50	21543	Gray Gravelly Sandy Silt
	52			
	54			
697.9 696.9	56	82/100	21544	Gray Sandy Silt BOTTOM OF BORING
	58			
	60			
	62			
	64			
	66			
	68			
	70			
	72			
	74			
	76			
	78			
	80			
	82			

STATE OF OHIO
DEPARTMENT OF HIGHWAYS
TESTING LABORATORY

B-001-D-59

LOG OF BORING

CO., RT. NO., SEC. FRA-40-12.82 BRIDGE NO.
RETAINING WALL-D SOUTH-EAST INNERBELT

LOCATION: T.H. 1-D STA. 83+46 OFFSET 117'Rt. FED. NO.

ELEV.	DEPTH	NO. BLOWS	SAMPLE NO.	DESCRIPTION
756.3	0			
	2			
	4			
751.3	6	-----	22563	Brown Sandy Gravelly Clay
	8			
746.3	10			
	12	20/25	22564	Brown Sandy Gravelly Silt
	14			
741.3	16	18/30	22565	Brown Sandy Silt
	18			
736.3	20			
	22	15/20	22566	Brown Sandy Gravelly Silt
	24			
731.3	26	18/30	22567	Gray Gravelly Sandy Silt
728.8	28	20/33	22568	Gray Gravelly Sandy Silt
726.3	30			
	32	18/30	22569	Gray Silty Sandy Gravel
723.8	34	50/55	22570	Gray Clayey Sandy Gravel
721.3	36	25/45	22571	Gray Gravelly Sandy Silt

MA
8.3.59

LOG OF BORING (CONTINUED)

B-001-D-59

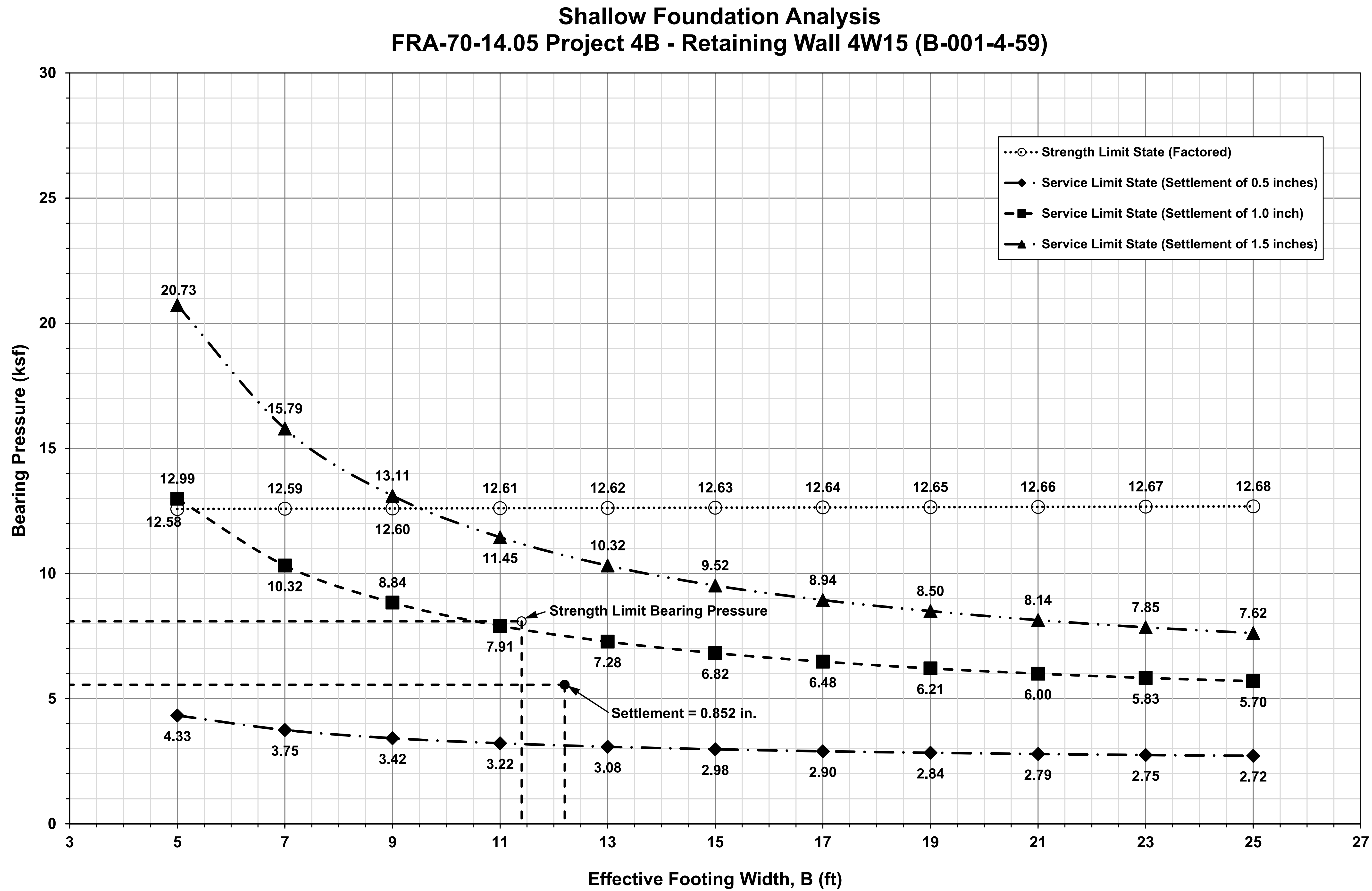
SHEET 6

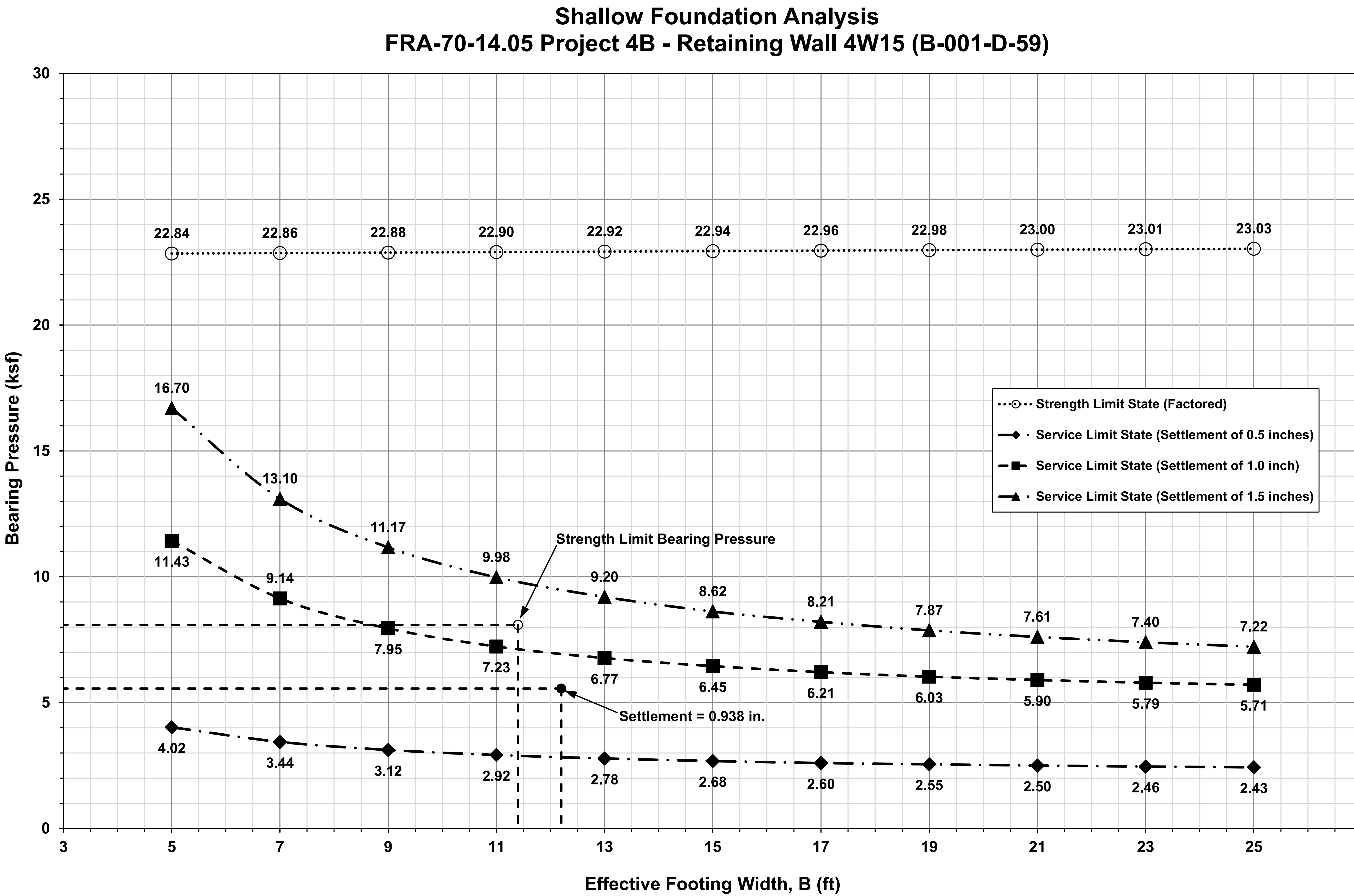
BRIDGE NO. ______ T.H. 1-D

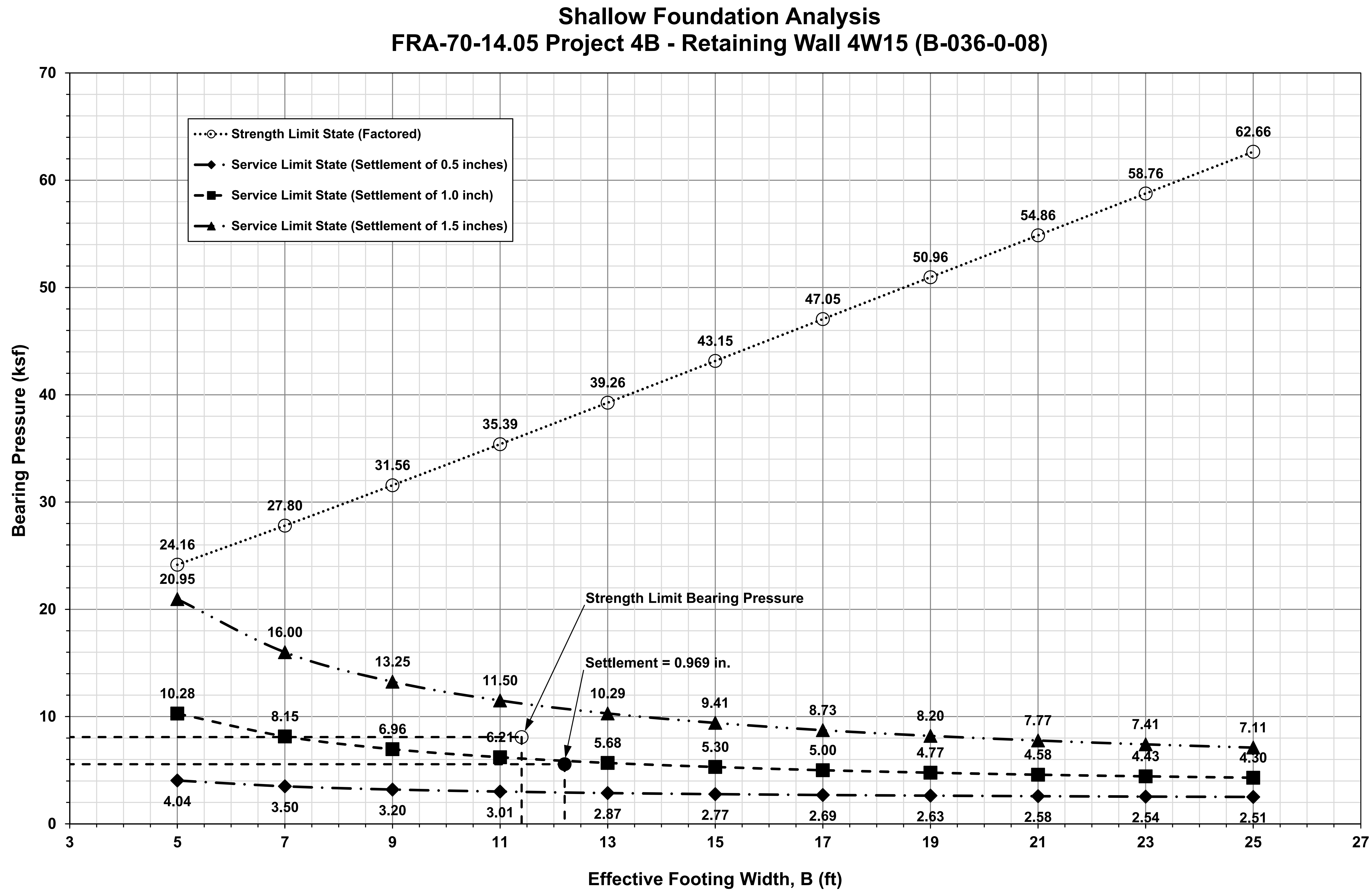
ELEV.	DEPTH	NO. BLOWS	SAMPLE NO.	DESCRIPTION
718.8	38	30/45	22572	Gray Gravelly Sandy Silt
716.3	40	35/60	22573	Gray Silty Sandy Gravel
	42			
713.8	44	28/58	22574	Gray Gravelly Sandy Silt
711.3	46	32/40	22575	Gray Gravelly Sandy Silt
	48			
706.3	50	35/56	22576	Gray Silty Sandy Gravel
	52			
	54			
701.3				
700.3	56	*	22577	Gray Sandy Gravel
				BOTTOM OF BORING
	58			
	60			* Refusal
	62			
	64			
	66			
	68			
	70			
	72			
	74			
	76			
	78			
	80			
	82			

APPENDIX V

BEARING RESISTANCE CHARTS

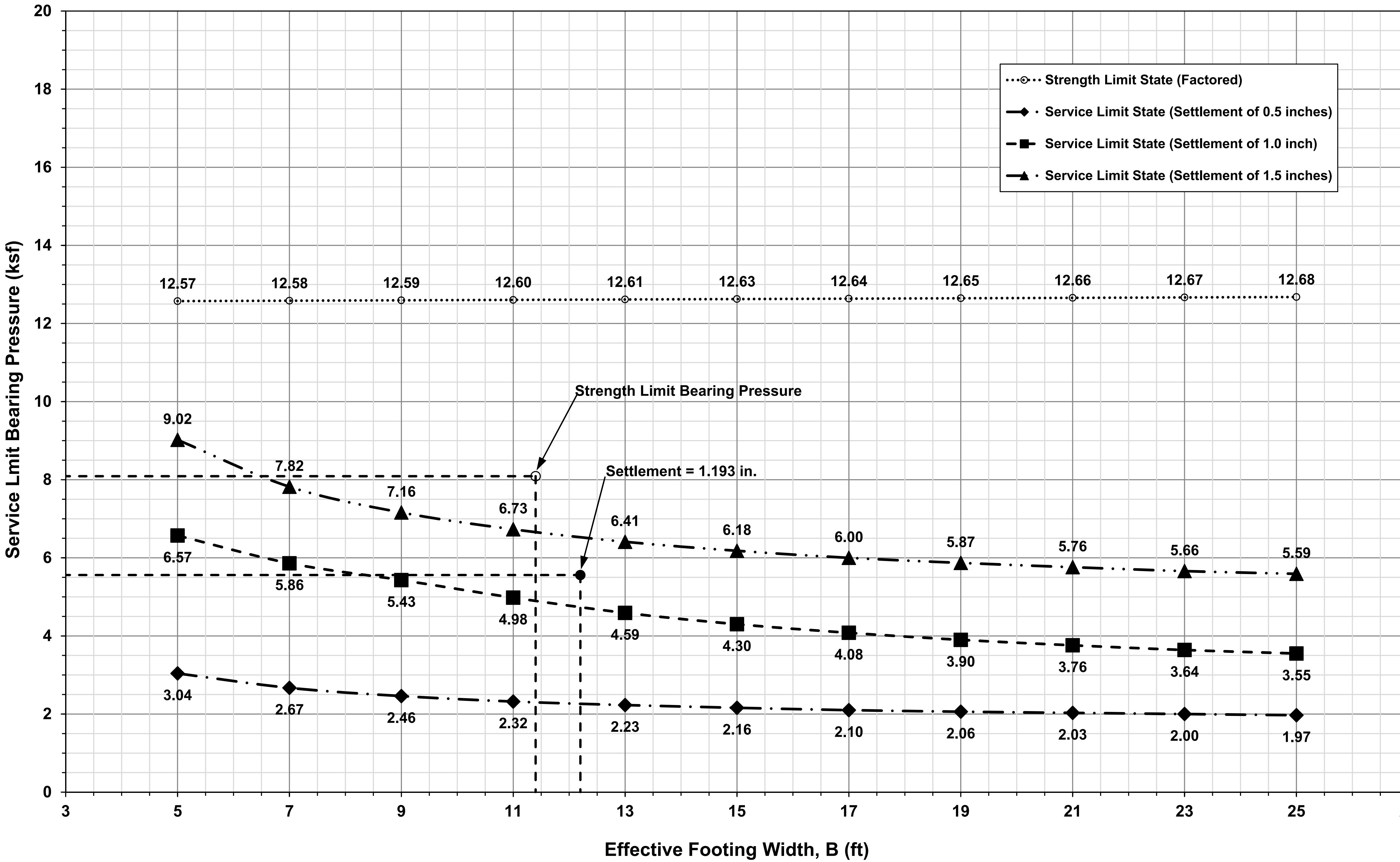

Shallow Foundation Analysis
FRA-70-14.05 Project 4B - Retaining Wall 4W15 (B-001-4-59)
Bearing Pressure (ksf)
Effective Footing Width, B (ft)
Strength Limit State (Factored)
Service Limit State (Settlement of 0.5 inches)
Service Limit State (Settlement of 1.0 inch)
Service Limit State (Settlement of 1.5 inches)
Strength Limit Bearing Pressure
Settlement = 0.852 in.
20.73
15.79
13.11
11.45
10.32
9.52
8.94
8.50
8.14
7.85
7.62
12.99
10.32
8.84
7.91
7.28
6.82
6.48
6.21
6.00
5.83
5.70
12.58
12.59
12.60
12.61
12.62
12.63
12.64
12.65
12.66
12.67
12.68
4.33
3.75
3.42
3.22
3.08
2.98
2.90
2.84
2.79
2.75
2.72


Shallow Foundation Analysis
FRA-70-14.05 Project 4B - Retaining Wall 4W15 (B-001-D-59)
Bearing Pressure (ksf)
Effective Footing Width, B (ft)
Strength Limit State (Factored)
Service Limit State (Settlement of 0.5 inches)
Service Limit State (Settlement of 1.0 inch)
Service Limit State (Settlement of 1.5 inches)
Strength Limit Bearing Pressure
Settlement = 0.938 in.
22.84
22.86
22.88
22.90
22.92
22.94
22.96
22.98
23.00
23.01
23.03
16.70
13.10
11.17
9.98
9.20
8.62
8.21
7.87
7.61
7.40
7.22
11.43
9.14
7.95
7.23
6.77
6.45
6.21
6.03
5.90
5.79
5.71
4.02
3.44
3.12
2.92
2.78
2.68
2.60
2.55
2.50
2.46
2.43
0
5
10
15
20
25
30
3
5
7
9
11
13
15
17
19
21
23
25
27



Shallow Foundation Analysis
FRA-70-14.05 Project 4B - Retaining Wall 4W15 (B-036-0-08)
Strength Limit State (Factored)
Service Limit State (Settlement of 0.5 inches)
Service Limit State (Settlement of 1.0 inch)
Service Limit State (Settlement of 1.5 inches)
Strength Limit Bearing Pressure
Settlement = 0.969 in.
Bearing Pressure (ksf)
Effective Footing Width, B (ft)
24.16
27.80
31.56
35.39
39.26
43.15
47.05
50.96
54.86
58.76
62.66
20.95
16.00
13.25
11.50
10.29
9.41
8.73
8.20
7.77
7.41
7.11
10.28
8.15
6.96
6.21
5.68
5.30
5.00
4.77
4.58
4.43
4.30
4.04
3.50
3.20
3.01
2.87
2.77
2.69
2.63
2.58
2.54
2.51

Shallow Foundation Analysis
FRA-70-14.05 Project 4B - Retaining Wall 4W15 (B-037-1-15)



APPENDIX VI

SHALLOW FOUNDATION CALCULATIONS

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15
Shallow Foundation Analysis - Settlement

Calculated By: BRT Date: 6/26/2022
Checked By: JPS Date: 6/27/2022

Boring B-001-4-59

B =	12.2	ft	Effective Footing width
D_w =	0.0	ft	Depth below bottom of footing
q =	5,560	psf	Service limit bearing pressure at bottom of wall
q_{net} =	3,935	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,625 psf from 12.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	N_{60}	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_m (1) (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	$(N1)_{60}$ (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-3a	G	0.0	0.6	0.6	0.3	113	135	81	41	22							226	300	0.02	1.000	3,935	3,957	0.005	0.054
A-3a	G	0.6	1.6	1.0	1.1	113	135	216	149	80							226	300	0.09	0.998	3,926	4,005	0.006	0.068
A-3a	G	1.6	2.6	1.0	2.1	113	135	351	284	152							210	300	0.17	0.985	3,875	4,028	0.005	0.057
A-3a	G	2.6	3.6	1.0	3.1	113	135	486	419	225							196	300	0.25	0.958	3,769	3,994	0.004	0.050
A-1-a	G	3.6	5.1	1.5	4.4	115	135	689	587	316							186	300	0.36	0.907	3,567	3,883	0.005	0.065
A-1-a	G	5.1	6.6	1.5	5.9	115	135	891	790	425							175	300	0.48	0.831	3,271	3,696	0.005	0.056
A-1-a	G	6.6	8.6	2.0	7.6	115	135	1,161	1,026	552							165	300	0.62	0.741	2,917	3,469	0.005	0.064
A-4b	C	8.6	10.1	1.5	9.4	35	130	1,356	1,259	675	4,000	4,675	17	0.063	0.006	0.405			0.77	0.659	2,595	3,270	0.005	0.055
A-4b	C	10.1	11.6	1.5	10.9	35	130	1,551	1,454	776	4,000	4,776	17	0.063	0.006	0.405			0.89	0.598	2,353	3,130	0.004	0.049
A-4b	C	11.6	13.6	2.0	12.6	35	135	1,821	1,686	900	4,000	4,900	17	0.063	0.006	0.405			1.03	0.537	2,112	3,012	0.005	0.056
A-6a	C	13.6	15.1	1.5	14.4	62	135	2,024	1,922	1,027	4,000	5,027	21	0.099	0.010	0.436			1.18	0.485	1,909	2,936	0.005	0.057
A-6a	C	15.1	16.6	1.5	15.9	62	135	2,226	2,125	1,136	4,000	5,136	21	0.099	0.010	0.436			1.30	0.447	1,760	2,896	0.004	0.050
A-6a	C	16.6	18.6	2.0	17.6	62	135	2,496	2,361	1,263	4,000	5,263	21	0.099	0.010	0.436			1.44	0.409	1,611	2,874	0.005	0.059
A-4a	C	18.6	20.1	1.5	19.4	100	135	2,699	2,597	1,390	4,000	5,390	17	0.063	0.006	0.405			1.59	0.377	1,483	2,873	0.002	0.025
A-4a	C	20.1	21.6	1.5	20.9	100	135	2,901	2,800	1,499	4,000	5,499	17	0.063	0.006	0.405			1.71	0.353	1,388	2,887	0.002	0.023
A-4a	C	21.6	24.1	2.5	22.9	100	140	3,251	3,076	1,650	4,000	5,650	17	0.063	0.006	0.405			1.87	0.325	1,278	2,928	0.003	0.034
A-4a	C	24.1	26.6	2.5	25.4	100	140	3,601	3,426	1,844	4,000	5,844	17	0.063	0.006	0.405			2.08	0.295	1,161	3,006	0.002	0.029
																						Total Settlement:		0.852 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 6-9, FHWA GEC 5
3. C_r = 0.10(C_c); Ref. Chapter 8.11, Holtz and Kovacs 1981
4. e_o = (C_c/0.54)+0.35; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (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)

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15
Shallow Foundation Analysis - Strength Limit State

Calculated By: BRT Date: 6/26/2022
Checked By: JPS Date: 6/27/2022

Boring B-001-4-59

B =	11.4	ft	
L =	460	ft	
c =	4,375	psf	
γ =	135	pcf	
D_f =	5.0	ft	
φ =	0	deg	
D_w =	0.0	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 22.93 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+(11.4 ft/460 ft)(1/5.14) =	1.005	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(5 ft/11.4 ft) =	1.000
N_q =	1.00	s_q =	1+(11.4 ft/460 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	0.0 ft < 5.0 ft =	0.500
N_γ =	0.00	s_γ =	1-0.4(11.4 ft/460 ft) =	0.990	i_γ =	1.000	$C_{w\gamma}$ =	0.0 ft < 1.5(11.4 ft) + 5 ft =	0.500

$$q_R = q_n \cdot \phi_b$$ = 12.61 ksf

φ_b = 0.55 (Per Table 11.5.7-1, AASHTO LRFD BDS) Semigravity Wall

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15
Shallow Foundation Analysis - Settlement

Calculated By: BRT Date: 6/26/2022
Checked By: JPS Date: 6/27/2022

Boring B-001-D-59

B =	12.2	ft	Effective Footing width
D_w =	0.0	ft	Depth below bottom of footing
q =	5,560	psf	Service limit bearing pressure at bottom of wall
q_{net} =	4,325	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,235 psf from 9.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	N_{60}	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_m (1) (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	$(N1)_{60}$ (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	1.5	1.5	0.8	48	130	195	98	51	4,000	4,051	17	0.063	0.006	0.405			0.06	0.999	4,322	4,372	0.015	0.180
A-4a	C	1.5	2.7	1.2	2.1	48	130	351	273	142	4,000	4,142	17	0.063	0.006	0.405			0.17	0.985	4,260	4,402	0.009	0.112
A-1-b	G	2.7	5.2	2.5	4.0	48	130	676	514	267	4,000	4,267	17	0.063	0.006	0.405	80	300	0.32	0.925	3,999	4,266	0.010	0.120
A-2-6	G	5.2	7.7	2.5	6.5	105	135	1,014	845	442							158	300	0.53	0.800	3,460	3,903	0.008	0.095
A-4a	C	7.7	9.2	1.5	8.5	72	130	1,209	1,111	584	4,000	4,584	17	0.063	0.006	0.405			0.69	0.700	3,028	3,612	0.005	0.064
A-4a	C	9.2	10.7	1.5	10.0	72	130	1,404	1,306	685	4,000	4,685	17	0.063	0.006	0.405			0.82	0.634	2,741	3,426	0.005	0.056
A-4a	C	10.7	12.7	2.0	11.7	72	135	1,674	1,539	808	4,000	4,808	17	0.063	0.006	0.405			0.96	0.567	2,452	3,260	0.005	0.065
A-1-b	G	12.7	14.2	1.5	13.5	95	140	1,884	1,779	939							119	300	1.10	0.511	2,208	3,147	0.003	0.032
A-1-b	G	14.2	15.2	1.0	14.7	95	140	2,024	1,954	1,036							116	300	1.20	0.476	2,058	3,094	0.002	0.019
A-4a	C	15.2	16.7	1.5	16.0	79	135	2,226	2,125	1,129	4,000	5,129	17	0.063	0.006	0.405			1.31	0.445	1,924	3,054	0.003	0.035
A-4a	C	16.7	18.2	1.5	17.5	79	135	2,429	2,327	1,238	4,000	5,238	17	0.063	0.006	0.405			1.43	0.412	1,784	3,022	0.003	0.031
A-4a	C	18.2	19.7	1.5	19.0	79	135	2,631	2,530	1,347	4,000	5,347	17	0.063	0.006	0.405			1.55	0.384	1,661	3,008	0.002	0.028
A-4a	C	19.7	21.2	1.5	20.5	79	135	2,834	2,732	1,456	4,000	5,456	17	0.063	0.006	0.405			1.68	0.359	1,552	3,009	0.002	0.025
A-2-4	G	21.2	22.7	1.5	22.0	91	140	3,044	2,939	1,569							99	300	1.80	0.337	1,457	3,025	0.001	0.017
A-2-4	G	22.7	24.2	1.5	23.5	91	140	3,254	3,149	1,685							96	300	1.92	0.317	1,372	3,057	0.001	0.016
A-2-4	G	24.2	26.2	2.0	25.2	91	140	3,534	3,394	1,821							94	300	2.07	0.297	1,284	3,105	0.002	0.019
A-1-a	G	26.2	29.2	3.0	27.7	120	140	3,954	3,744	2,015							120	300	2.27	0.272	1,175	3,190	0.002	0.024
																					Total Settlement:			0.938 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 6-9, FHWA GEC 5
3. C_r = 0.10(C_c); Ref. Chapter 8.11, Holtz and Kovacs 1981
4. e_o = (C_c/0.54)+0.35; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_N N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (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-001-D-59

B =	11.4	ft	
L =	460	ft	
c =	8,000	psf	
γ =	130	pcf	
D_f =	5.0	ft	
φ =	0	deg	
D_w =	0.0	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 41.64 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+(11.4 ft/460 ft)(1/5.14) =	1.005	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(5 ft/11.4 ft) =	1.000
N_q =	1.00	s_q =	1+(11.4 ft/460 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	0.0 ft < 5.0 ft =	0.500
N_γ =	0.00	s_γ =	1-0.4(11.4 ft/460 ft) =	0.990	i_γ =	1.000	$C_{w\gamma}$ =	0.0 ft < 1.5(11.4 ft) + 5 ft =	0.500

$$q_R = q_n \cdot \phi_b$$ = 22.90 ksf

φ_b = 0.55 (Per Table 11.5.7-1, AASHTO LRFD BDS) Semigravity Wall

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15
Shallow Foundation Analysis - Settlement

Calculated By: BRT Date: 6/26/2022
Checked By: JPS Date: 6/27/2022

Boring B-036-0-08

B =	12.2	ft	Effective Footing width
D_w =	0.0	ft	Depth below bottom of footing
q =	5,560	psf	Service limit bearing pressure at bottom of wall
q_{net} =	3,940	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,625 psf from 12.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	N_{60}	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_m (1) (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	$(N1)_{60}$ (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-3a	G	0.0	0.4	0.4	0.2	51	135	54	27	15							102	300	0.02	1.000	3,940	3,954	0.003	0.039
A-1-b	G	0.4	2.4	2.0	1.4	47	130	314	184	97							94	300	0.11	0.995	3,921	4,018	0.011	0.130
A-1-b	G	2.4	4.4	2.0	3.4	47	130	574	444	232							81	300	0.28	0.947	3,731	3,963	0.008	0.099
A-1-b	G	4.4	6.4	2.0	5.4	47	130	834	704	367							74	289	0.44	0.855	3,367	3,734	0.007	0.084
A-1-b	G	6.4	9.4	3.0	7.9	68	135	1,239	1,037	544							98	300	0.65	0.727	2,863	3,406	0.008	0.096
A-1-b	G	9.4	12.9	3.5	11.2	68	140	1,729	1,484	788							89	300	0.91	0.587	2,312	3,100	0.007	0.083
A-3a	G	12.9	16.4	3.5	14.7	65	140	2,219	1,974	1,060							79	249	1.20	0.477	1,880	2,940	0.006	0.075
A-4a	C	16.4	19.9	3.5	18.2	71	135	2,692	2,455	1,323	4,000	5,323	18	0.072	0.007	0.413			1.49	0.399	1,571	2,893	0.006	0.073
A-4a	C	19.9	23.2	3.3	21.5	50	140	3,147	2,919	1,576	4,000	5,576	18	0.072	0.007	0.413			1.76	0.343	1,351	2,926	0.004	0.053
A-4a	C	23.2	26.7	3.5	24.9	50	140	3,637	3,392	1,838	4,000	5,838	18	0.072	0.007	0.413			2.04	0.300	1,182	3,020	0.004	0.046
A-4a	C	26.7	29.9	3.3	28.3	50	140	4,092	3,864	2,100	4,000	6,100	18	0.072	0.007	0.413			2.32	0.267	1,050	3,150	0.003	0.035
A-1-b	G	29.9	34.9	5.0	32.4	88	140	4,792	4,442	2,420							83	300	2.66	0.234	923	3,343	0.002	0.028
A-1-b	G	34.9	44.9	10.0	39.9	88	140	6,192	5,492	3,002							76	300	3.27	0.192	755	3,757	0.003	0.039
A-1-b	G	44.9	54.9	10.0	49.9	88	140	7,592	6,892	3,778							69	265	4.09	0.154	607	4,385	0.002	0.029
A-1-b	G	54.9	64.9	10.0	59.9	80	140	8,992	8,292	4,554							58	206	4.91	0.129	507	5,061	0.002	0.027
A-1-b	G	64.9	74.9	10.0	69.9	80	140	10,392	9,692	5,330							54	186	5.73	0.111	436	5,765	0.002	0.022
A-1-b	G	74.9	82.8	7.9	78.9	94	140	11,498	10,945	6,024							60	213	6.46	0.098	387	6,411	0.001	0.012
																					Total Settlement:			0.969 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 6-9, FHWA GEC 5
3. C_r = 0.10(C_c); Ref. Chapter 8.11, Holtz and Kovacs 1981
4. e_o = (C_c/0.54)+0.35; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (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)

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15

Shallow Foundation Analysis - Strength Limit State

Calculated By: BRT Date: 6/26/2022

Checked By: JPS Date: 6/27/2022

Boring B-036-0-08

B =	11.4	ft	
L =	460	ft	
c =	0	psf	
γ =	135	pcf	
D_f =	5.0	ft	
φ =	40	deg	
D_w =	0.0	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 65.75 ksf

$N_{cm} = N_c s_c i_c$ = 76.90

$N_{qm} = N_q s_q d_q i_q$ = 71.34

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ = 108.33

N_c =	75.31	s_c =	1+(11.4 ft/460 ft)(64.2/75.31) =	1.021	i_c =	1.000	d_q =	1+2tan(40°)[1-sin(40°)]²tan⁻¹(5 ft/11.4 ft) =	1.089
N_q =	64.20	s_q =	1+(11.4 ft/460 ft)tan(40°) =	1.021	i_q =	1.000	C_{wq} =	0.0 ft < 5.0 ft =	0.500
N_γ =	109.41	s_γ =	1-0.4(11.4 ft/460 ft) =	0.990	i_γ =	1.000	$C_{w\gamma}$ =	0.0 ft < 1.5(11.4 ft) + 5 ft =	0.500

$q_R = q_n \cdot \phi_b$ = 36.16 ksf

φ_b = 0.55 (Per Table 11.5.7-1, AASHTO LRFD BDS) Semigravity Wall

W-15-126 - FRA-70-14.05 Project 4B - Retaining Wall 4W15
Shallow Foundation Analysis - Settlement

Calculated By: BRT Date: 6/26/2022
Checked By: JPS Date: 6/27/2022

Boring B-037-1-15

B =	12.2	ft	Effective Footing width
D_w =	0.0	ft	Depth below bottom of footing
q =	5,560	psf	Service limit bearing pressure at bottom of wall
q_{net} =	4,325	psf	Net bearing pressure at bottom of wall (considers initial overburden stress of 1,235 psf from 9.5-foot cut to bottom of footing elevation)

Soil Class.	Soil Type	Layer Depth (ft)		Layer Thickness H (ft)	Depth to Midpoint (ft)	N_{60}	γ (pcf)	σ_{vo} Bottom (psf)	σ_{vo} Midpoint (psf)	σ_{vo}' Midpoint (psf)	σ_m (1) (psf)	σ_p' (1) (psf)	LL	C_c (2)	C_r (3)	e_o (4)	$(N1)_{60}$ (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	2.5	2.5	1.3	35	130	325	163	85	4,000	4,085	17	0.063	0.006	0.405			0.10	0.997	4,310	4,394	0.022	0.269
A-4a	C	2.5	5.7	3.2	4.1	35	130	741	533	277	4,000	4,277	17	0.063	0.006	0.405			0.34	0.918	3,970	4,248	0.017	0.204
A-4a	C	5.7	7.7	2.0	6.7	120	130	1,001	871	453	4,000	4,453	17	0.063	0.006	0.405			0.55	0.787	3,404	3,857	0.008	0.100
A-4a	C	7.7	10.2	2.5	9.0	120	130	1,326	1,164	605	4,000	4,605	17	0.063	0.006	0.405			0.73	0.677	2,929	3,534	0.009	0.103
A-1-b	G	10.2	12.7	2.5	11.5	72	140	1,676	1,501	787							95	300	0.94	0.576	2,490	3,277	0.005	0.062
A-4a	C	12.7	15.2	2.5	14.0	120	135	2,014	1,845	974	4,000	4,974	17	0.063	0.006	0.405			1.14	0.496	2,146	3,120	0.006	0.068
A-4a	C	15.2	17.7	2.5	16.5	120	135	2,351	2,182	1,156	4,000	5,156	17	0.063	0.006	0.405			1.35	0.434	1,875	3,031	0.005	0.056
A-2-6	G	17.7	20.2	2.5	19.0	120	140	2,701	2,526	1,344							136	300	1.55	0.384	1,661	3,004	0.003	0.035
A-1-a	G	20.2	21.7	1.5	21.0	120	140	2,911	2,806	1,499							132	300	1.72	0.351	1,519	3,018	0.002	0.018
A-1-a	G	21.7	24.2	2.5	23.0	120	140	3,261	3,086	1,654							128	300	1.88	0.323	1,399	3,053	0.002	0.027
A-1-a	G	24.2	26.7	2.5	25.5	120	140	3,611	3,436	1,848							123	300	2.09	0.294	1,272	3,120	0.002	0.023
A-4a	C	26.7	29.2	2.5	28.0	99	140	3,961	3,786	2,042	4,000	6,042	17	0.063	0.006	0.405			2.29	0.269	1,165	3,207	0.002	0.026
A-4b	G	29.2	31.7	2.5	30.5	44	140	4,311	4,136	2,236							42	73	2.50	0.248	1,075	3,311	0.006	0.070
A-4b	G	31.7	34.2	2.5	33.0	44	140	4,661	4,486	2,430							41	71	2.70	0.230	997	3,427	0.005	0.063
A-1-a	G	34.2	40.2	6.0	37.2	131	140	5,501	5,081	2,760							117	300	3.05	0.205	887	3,647	0.002	0.029
A-1-a	G	40.2	46.2	6.0	43.2	131	140	6,341	5,921	3,225							110	300	3.54	0.177	767	3,993	0.002	0.022
A-1-a	G	46.2	52.2	6.0	49.2	131	140	7,181	6,761	3,691							104	300	4.03	0.156	676	4,367	0.001	0.018
																					Total Settlement:		1.193 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 6-9, FHWA GEC 5
3. $C_r = 0.10(C_c)$; Ref. Chapter 8.11, Holtz and Kovacs 1981
4. $e_o = (C_c/0.54)+0.35$; Ref. Table 6-11, FHWA GEC 5
5. $(N1)_{60} = C_n N_{60}$, where $C_N = [0.77\log(40/\sigma_{vo}')] \leq 2.0$ ksf; Ref. Section 10.4.6.2.4, AASHTO LRFD BDS
6. Bearing capacity index; Ref. Figure 10.6.2.4.2-1, AASHTO LRFD BDS
7. Influence factor for strip loaded footing; $I = [\beta+\sin(\beta)\cos(\beta+2\delta)]/\pi$, where $\beta = \tan^{-1}[(x+B/2)/Z_f]-\delta$, $\delta = \tan^{-1}[(x-B/2)/Z_f]$ and x = horizontal distance from center of footing; Ref. Figure 6.13 and Equation 6.24, Das 2005
8. $\Delta\sigma_v = q_e(I)$
9. $S_c = [C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_{vo}')$ for $\sigma_p' \leq \sigma_{vo}' < \sigma_{vf}'$; $[C_r/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')$ for $\sigma_{vo}' < \sigma_{vf}' \leq \sigma_p'$; $[Cr/(1+e_o)](H)\log(\sigma_p'/\sigma_{vo}')+[C_c/(1+e_o)](H)\log(\sigma_{vf}'/\sigma_p')$ for $\sigma_{vo}' < \sigma_p' < \sigma_{vf}'$; Ref. Section 10.6.2.4.3, AASHTO LRFD BDS (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-037-1-15

B =	11.4	ft	
L =	460	ft	
c =	4,375	psf	
γ =	130	pcf	
D_f =	5.0	ft	
φ =	0	deg	
D_w =	0.0	ft	Below ground surface

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + \tfrac{1}{2}\gamma B N_{\gamma m} C_{w\gamma}$$ = 22.92 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+(11.4 ft/460 ft)(1/5.14) =	1.005	i_c =	1.000	d_q =	1+2tan(0°)[1-sin(0°)]²tan⁻¹(5 ft/11.4 ft) =	1.000
N_q =	1.00	s_q =	1+(11.4 ft/460 ft)tan(0°) =	1.000	i_q =	1.000	C_{wq} =	0.0 ft < 5.0 ft =	0.500
N_γ =	0.00	s_γ =	1-0.4(11.4 ft/460 ft) =	0.990	i_γ =	1.000	$C_{w\gamma}$ =	0.0 ft < 1.5(11.4 ft) + 5 ft =	0.500

$$q_R = q_n \cdot \phi_b$$ = 12.61 ksf

φ_b = 0.55 (Per Table 11.5.7-1, AASHTO LRFD BDS) Semigravity Wall

APPENDIX VII

EXTERNAL STABILITY ANALYSIS CALCULATIONS BY GPD GROUP

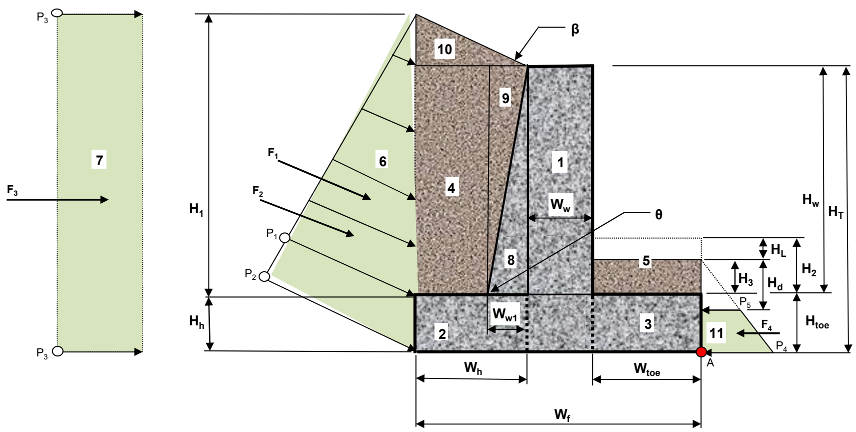
GPD GROUP

Spread Footing Retaining Wall Design

Based on AASHTO LRFD Bridge Design Specifications (9th edition) and the 2020 ODOT BDM.

Wall Data:

Concrete Unit Weight, γ_c =	0.150	kcf	
Toe Height, H_{toe} =	3.75	ft	
Heel Height, H_h =	3.50	ft	
Wall Height, H_w =	28.25	ft	
Total Height, $H_T = H_w+H_{toe}$ =	32.00	ft	
Soil Height over Heel, $H_1 = H_T-H_h+(W_h*S_e)$ =	28.50	ft	
Max. Soil Height over Toe, H_2 =	4.00	ft	
Future Loss of Soil over Toe, H_L =	0.00	ft	
Min. Soil Height over Toe, $H_3 = \max(0,H_2-H_L)$ =	4.00	ft	
Depth of Disturbance, H_d =	2.67	ft	
Wall Width, W_w =	1.50	ft	
Toe Width, W_{toe} =	3.75	ft	
Heel Width, W_h =	11.00	ft	
Additional Wall Width, W_{w1} =	2.40	ft	
Theta, θ =	85.19	deg.	
Footing Width, W_f =	16.25	ft	



Soil Data:

Is Retained Soil Sloped?	No		
Slope of Embankment, S_e =	0.00		
Beta, β =	0.00	deg.	
Include Surcharge over Heel?	Yes		
Include Surcharge over Toe?	Yes		
Is traffic < H_T / 2 from back of wall?	Yes		*HT / 2 = 16 ft*
Dist. from back of wall to edge of traffic =	0.00	ft	*LRFD 3.11.6.4*
Minimum Soil Unit Weight for LLS, $\gamma_{soil\ LLS}$ =	0.125	kcf	*BDM 307.1.1*
Surcharge Height behind Wall, H_s =	2.00	ft	*LRFD Table 3.11.6.4-1*
Surcharge Height in front of Wall, H_{sf} =	4.18	ft	
$P_{soil\ LLS} = \gamma_{soil\ LLS}$ * (k_a or k_0) =	41.67	pcf	
Active or At Rest Pressure?	Active		
Retained Soil Unit Weight, γ_{soil} =	0.120	kcf	*BDM Table 307-1*
Footing Resting On?	Granular		
Internal Friction Angle of Soil, δ =	38.00	deg.	*@ Base of the Footer*
Internal Friction Angle of Fill, ϕ'_{fill} =	30.00	deg.	
Friction Angle between Fill & Wall, δ =	20.00	deg.	*LRFD 3.11.5.3*
Active Lateral Earth Press. Coefficient, ka =	0.33		*LRFD 3.11.5.3-1 (Coulomb)*
$P_{soil} = \gamma_{soil}$ * (k_a or k_0) =	40.00	pcf	
Bearing on soil or rock?	Soil		*LRFD 10.6.1.4*
Factor Bearing Resistance (Strength) =	17.474	ksf	
Bearing Capacity (Service) =	6.935	ksf	*To Check Settlement*
Consider Passive Force on Toe?	No		
Passive Lat. Earth Pressure Coeff., k_p =	3.00		$k_p = \tan^2(45°+\phi'_f/2)$

Horizontal Sliding Resistance:
LRFD 10.6.3.4

For cohesionless soils:			
	V_{min} =	64.32	kips
	Resistance, R_τ = V_{min} * tan(δ) =	50.25	kips
For cohesive soils:			
The lesser of:	C_u =	N.A.	ksf
	$0.5*\sigma'_v$ =	N.A.	ksf
	Unit Shear Resistance: Use =	N.A.	ksf
	Resistance, Rτ =	N.A.	kips
Manual Override:			
	Override Friction Factor =		
	Resistance, Rτ =	N.A.	kips

Typical values for friction factor:
LRFD Table C3.11.5.3-1

rock = 0.70
course grained soil w/out silt = 0.55
course grained soil w/silt = 0.45

Additional friction factors for other common substrates
shale = 0.55
silt = 0.35

Soil Pressure Calculations:

$P_1 = P_{soil}*H_1/1000$ =	1.14	ksf
$P_2 = P_{soil}*(H_1+H_h)/1000$ =	1.28	ksf
$P_3 = H_s*P_{soil\ LLS}/1000$ =	0.08	ksf
$P_4 = \gamma_{soil}*k_p*(H_{toe}+H_2-H_L)$ =	2.79	ksf
$P_5 = \gamma_{soil}*k_p*H_d$ =	0.96	ksf

Soil Sliding Force Calculations:

$F_1 = P_1*H_1*0.5$ =	16.25	kips
$F_2 = P_2*(H_1+H_h)*0.5$ =	20.48	kips
$F_3 = P_3*H_1$ =	2.67	kips
F_4 (Trapezoid 11) =	0.00	kips

Additional Dead Load =	0.70	kips	*Assumes 1.25 max. & 0.90 min. load factors.*
Moment Arm for Additional Dead Load =	4.46	ft	*from Point A*

Force and Moment Arm Calculations:

Area 1 = γ_c x W_w x H_T =	0.150 kcf x 1.50 ft. x 32.00 ft. x 1.00 ft. =	**7.20 kips**
Arm 1 = W_{toe} + W_w / 2 =	3.75 ft. + 1.50 ft. / 2.00 =	**4.50 ft.**
Area 2 = γ_c x W_h x H_h =	0.150 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 =	3.75 ft. + 1.50 ft. + 11.00 ft. / 2.00 =	**10.75 ft.**
Area 3 = γ_c x W_{toe} x H_{toe} =	0.150 kcf x 3.75 ft. x 3.75 ft. x 1.00 ft. =	**2.11 kips**
Arm 3 = W_{toe} / 2 =	3.75 ft. / 2.00 =	**1.88 ft.**
Area 4 = γ_s x (W_h -W_{w1}) x H_W =	0.120 kcf x (11.00 ft. - 2.40 ft.) x 28.25 ft. x 1.00 ft. =	**29.17 kips**
Arm 4 = W_{toe} + W_w + W_{w1} + (W_h -W_{w1}) / 2 =	3.75 ft. + 1.50 ft. + 2.40 ft. + (11.00 ft. - 2.40 ft.) / 2 =	**11.95 ft.**
Area 5 **(Max.)** = γ_s x W_{toe} x H_2 =	0.120 kcf x 3.75 ft. x 4.00 ft. x 1.00 ft. =	**1.80 kips**
Area 5 **(Min.)** = γ_s x W_{toe} x H_3 =	0.120 kcf x 3.75 ft. x 4.00 ft. x 1.00 ft. =	**1.80 kips**
Arm 5 = W_{toe} / 2 =	3.75 ft. / 2.00 =	**1.88 ft.**
Area 6 **(Horiz. Comp.)** = F_2 x cos(δ) =	20.48 kips x cos (20.00 deg.) =	**19.25 kips**
Arm 6 = (H_1 + H_h) / 3 =	(28.50 ft. + 3.50 ft.) / 3.00 =	**10.67 ft.**
Area 6 **(Vertical Comp.)** = F_2 x sin(δ) =	20.48 kips x sin (20.00 deg.) =	**7.01 kips**
Arm 6 = Wf =	16.25 ft.	**16.25 ft.**
Area 7 = F_3 =	2.67 kips	**2.67 kips**
Arm 7 = (H_1 + H_h) / 2 =	(28.50 ft. + 3.50 ft.) / 2.00 =	**16.00 ft.**
Area 8 = 0.5 x γ_c x W_{w1} x H_W =	0.5 x 0.150 kcf x 2.40 ft. x 28.25 ft. x 1.00 ft. =	**5.08 kips**
Arm 8 = W_{toe} + W_w + W_{w1} / 3 =	3.75 ft. + 1.50 ft. + 2.40 ft. / 3.00 =	**6.05 ft.**

Force and Moment Arm Calculations (Continued):

Area 9 = 0.5 x γ_s x W_{w1} x H_W =	0.5 x 0.120 kcf x	2.40 ft. x	28.25 ft. x	1.00 ft. =		**4.06 kips**
Arm 9 = W_{toe} + W_w + W_{w1} x 2/3 =	3.75 ft. +	1.50 ft. +	2.40 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 0.120 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 =	16.25 ft. -	11.00 ft.	/ 3.00 =			**12.58 ft.**
Area 11 = F_4 =	0.00 kips					**0.00 kips**
Surcharge on Heel = $\gamma_{soil\ LLS}$ x W_h x H_s =	0.125 kcf x	11.00 ft. x	2.00 ft. x	1.00 ft. =		**2.75 kips**
Arm for Heel Surcharge = W_F - W_h / 2 =	16.25 ft. -	11.00 ft.	/ 2.00 =			**10.75 ft.**
Surcharge on Toe = $\gamma_{soil\ LLS}$ x W_{toe} x H_{sf} =	0.125 kcf x	3.75 ft. x	4.18 ft. x	1.00 ft. =		**1.96 kips**
Arm for Toe Surcharge = W_{toe} / 2 =	3.75 ft.	/ 2.00 =				**1.88 ft.**

Check Bearing Pressure:

per BDM 307.1.5 and LRFD 11.6.3.2.

Factored Bearing Resistance = **17.47 ksf**

Maximum Strength Load Pressures:

Bearing pressure at Toe = **8.09 ksf** **OK**

Bearing pressure at Heel = **8.09 ksf** **OK**

Check Eccentricity:

per BDM 307.1.4 and LRFD 11.6.3.3.

Maximum Allowable e = B/3 = **5.42 ft**

Controlling Eccentricity = **3.66 ft** **OK**

Check Sliding:

per BDM 307.1.3 and LRFD 11.6.3.6.

Resistance factor, ϕ_τ (Sliding) = *1.00* *LRFD Table 11.5.7-1*

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

Sliding Resistance:

Unfactored Horizontal Sliding Resistance = 50.25 kips

Factored Horizontal Sliding Resistance = 50.25 kips

Passive Resistance on Footing Toe:

Unfactored Passive Resistance = 0.00 kips

Factored Passive Resistance = 0.00 kips

Passive Resistance on Footing Key or Sheet Piling (Below bottom of Footing):

Vertical Projection Below Footing = *0.00* ft

Pressure at Bottom of Footing (P_4) = 2.79 ksf

Pressure at Bottom of Disturbance (P_5) = 0.96 ksf

Pressure at Bottom of Key or Sheeting = 2.79 ksf

Unfactored Passive Resistance = 0.00 kips

Factored Passive Resistance = 0.00 kips

Total Factored Resisting Force = **50.25 kips**

Driving Force = **33.54 kips** **OK**

Check Settlement:

Service Bearing Capacity = **6.94 ksf**

Service Bearing Pressure at Toe = **5.56 ksf** **OK**

Service Bearing Pressure at Heel = **5.56 ksf** **OK**

Summary of Load Effects:

	MAX. BEARING PRESSURE	MIN. BEARING PRESSURE	ECCENTRICITY MAX. LF	ECCENTRICITY MIN. LF	SLIDING FORCES MAX. LF	VERTICAL FORCES MIN. LF
STRENGTH I	8.09	8.09	2.71	3.66	33.54	64.32
SERVICE I	5.56	5.56	2.24	N/A	21.91	62.90

Load Modification Factors:

LRFD 1.3.3, LRFD 1.3.4, LRFD 1.3.5, & 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

*1.50*EH+1.75*LS(H). Ignores resisting moments from passive force on toe/key/sheeting, which is conservative.*

ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)		Moment (k-ft) Max. Load Factor	
6 (Horizontal comp.)	19.25	1.50	28.87	10.67		307.95	Horiz. Forces
7	2.67	1.75	4.67	16.00		74.67	
		Σ Sliding Forces, F_s =	33.54 kips		Σ Overturning Moments =	382.62 k*ft.	

Vertical Forces & Resisting Moments

*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	*This column is for stability* Force (k) Min. Load Factor	Moment Arm (ft)	Moment (k-ft) Max. Load Factor	*This column is for stability* Moment (k-ft) Min. Load Factor	
1	7.20	1.25	9.00	0.90	6.48	4.50	40.50	29.16	
2	5.78	1.25	7.22	0.90	5.20	10.75	77.60	55.87	Dead Loads From Concrete
3	2.11	1.25	2.64	0.90	1.90	1.88	4.94	3.56	
8	5.08	1.25	6.35	0.90	4.57	6.05	38.38	27.63	
4	29.17	1.35	39.38	1.00	29.17	11.95	470.47	348.50	Dead Loads From Soil *(Do not include 5 (Min.) and 5 (Max.) simultaneously)*
5 (Max.)	1.80	1.35	2.43	1.00	1.80	1.88	4.56	3.38	
5 (Min.)	1.80	1.35	2.43	1.00	1.80	1.88	4.56	3.38	
6 (Vertical comp.)	7.01	1.50	10.51	1.50	10.51	16.25	170.75	170.75	
9	4.06	1.35	5.48	1.00	4.06	6.85	37.54	27.81	
10	0.00	1.35	0.00	1.00	0.00	12.58	0.00	0.00	
Surcharge on Heel	2.75	1.75	4.81	0.00	0.00	10.75	51.73	0.00	
Surcharge on Toe	1.96	1.75	3.42	0.00	0.00	1.88	6.42	0.00	External Loads
DC	0.70	1.25	0.88	0.90	0.63	4.46	3.92	2.83	
		Σ Vert. Forces =	92.12 kips	Σ Vert. Forces =	64.32 kips	Σ Resist. Moments =	906.82 k*ft.	669.48 k*ft.	

Note: Calculations for each controlling load case are not necessarily shown below, but have been included in the design checks.

Max. Load Factor Calculations (Worst case bearing pressure shown.)	
Overturning Moment = Σ Overturning Moments =	382.62 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	906.82 k-ft.
Net Moment = Resisting Moment - Overturning Moment =	524.21 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	92.12 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	5.69 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	2.43 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	8.09 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	8.09 ksf

Min. Load Factor Calculations (Worst case eccentricity shown.)	
Overturning Moment = Σ Overturning Moments =	382.62 k-ft.
Resisting Moment = Σ Min. Resisting Moments =	669.48 k-ft.
Net Moment = Resisting Moment - Overturning Moment =	286.86 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	64.32 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	4.46 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	3.66 ft.

SERVICE I Load Combination

Sliding Forces & Overturning Moments

*1.0*EH+1.0*LS $_H$. Ignores resisting moments from passive force on toe/key/sheeting, which is conservative.*

ΣM about point "A"

Area/Force	Unfactored Load	Load Factor	Force (k)	Moment Arm (ft)		Moment (k-ft) Max. Load Factor	
6 (Horizontal comp.)	19.25	1.00	19.25	10.67		205.30	Horiz. Forces
7	2.67	1.00	2.67	16.00		42.67	
		Σ Sliding Forces, F_s =	21.91 kips		Σ Overturning Moments =	247.97 k*ft.	

Vertical Forces & Resisting Moments

*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	7.20	1.00	7.20	4.50		32.40	
2	5.78	1.00	5.78	10.75		62.08	Dead Loads From Concrete
3	2.11	1.00	2.11	1.88		3.96	
8	5.08	1.00	5.08	6.05		30.70	
4	29.17	1.00	29.17	11.95		348.50	Dead Loads From Soil (Do not include 5 (Min.) and 5 (Max.) simultaneously)
5 (Max.)	1.80	1.00	1.80	1.88		3.38	
5 (Min.)	1.80	1.00	1.80	1.88		3.38	
6 (Vertical comp.)	7.01	1.00	7.01	16.25		113.83	
9	4.06	1.00	4.06	6.85		27.81	
10	0.00	1.00	0.00	12.58		0.00	
Surcharge on Heel	2.75	1.00	2.75	10.75		29.56	
Surcharge on Toe	1.96	1.00	1.96	1.88		3.67	External Loads
DC	0.70	1.00	0.70	4.46		3.14	
		Σ Vert. Forces =	67.61 kips		Σ Resisting Moments =	659.03 k*ft.	

Note: Calculations for each controlling load case are not necessarily shown below, but have been included in the design checks.

Calculations for worst case bearing pressure shown.	
Overturning Moment = Σ Overturning Moments =	247.97 k-ft.
Resisting Moment = Σ Max. Resisting Moments =	659.03 k-ft.
Net Moment = Resisting Moment - Overturning Moment =	411.06 k-ft.
Total Vertical Force (TVF) = Σ Vert. Forces =	67.61 kips
Dist. from Point A (Ā) = Net. Moment / TVF =	6.08 ft.
Eccentricity "e" = (0.5*W_f) - Ā =	2.04 ft.
Maximum Bearing Pressure = TVF/(Wf-2*e) =	5.56 ksf
Minimum Bearing Pressure = TVF/(Wf-2*e) =	5.56 ksf

- Where the wall is supported by a soil foundation:

the vertical stress shall be calculated assuming a uniformly distributed pressure over an effective base area as shown in Figure 11.6.3.2-1.

The vertical stress shall be calculated as follows:

$$\sigma_v = \frac{\Sigma V}{B - 2e} \quad (11.6.3.2\text{-}1)$$

- 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:

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

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

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:

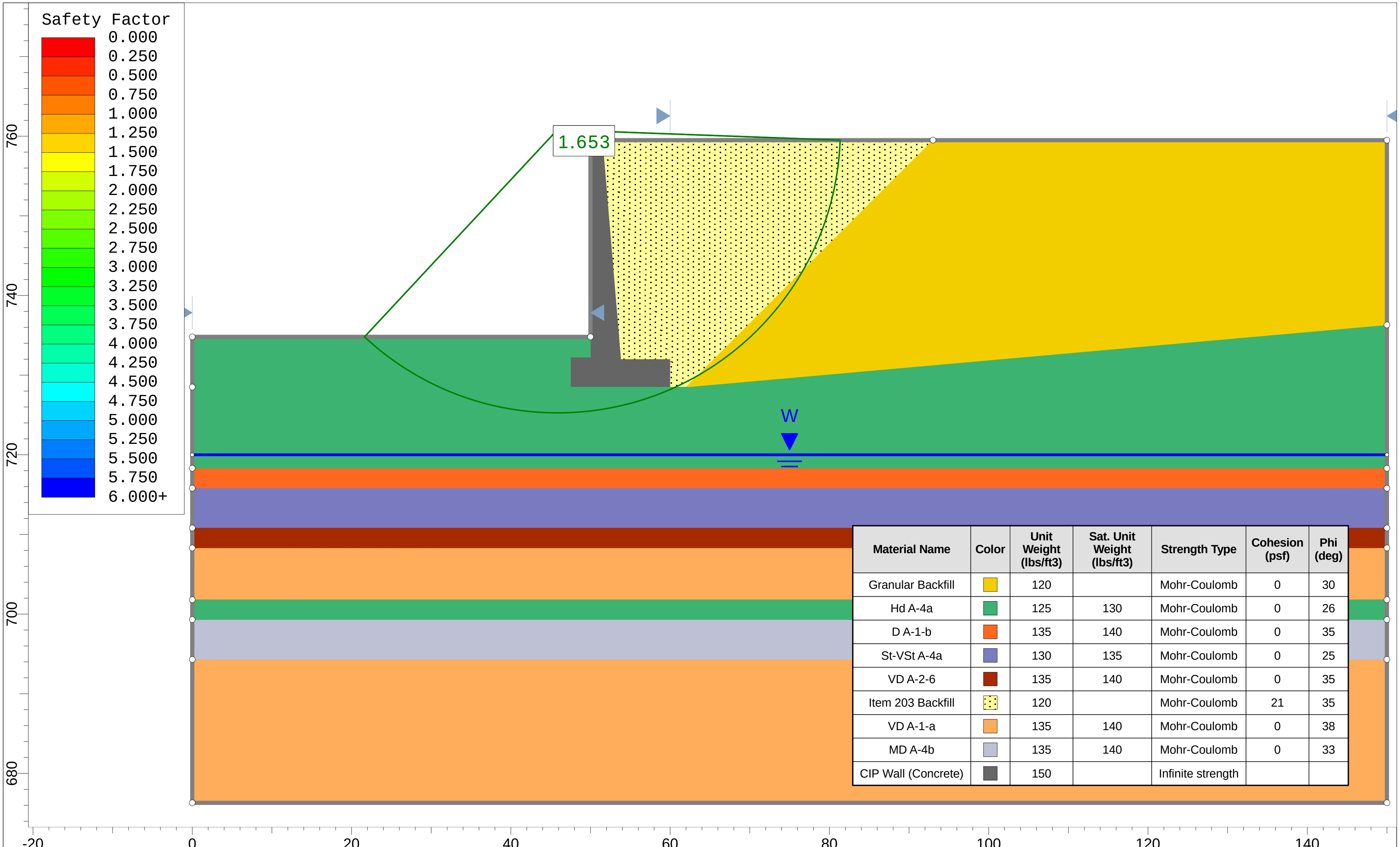
$$\sigma_{vmax} = \frac{2\Sigma V}{3[(B/2) - e)]} \quad (11.6.3.2\text{-}4)$$

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

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

APPENDIX VIII

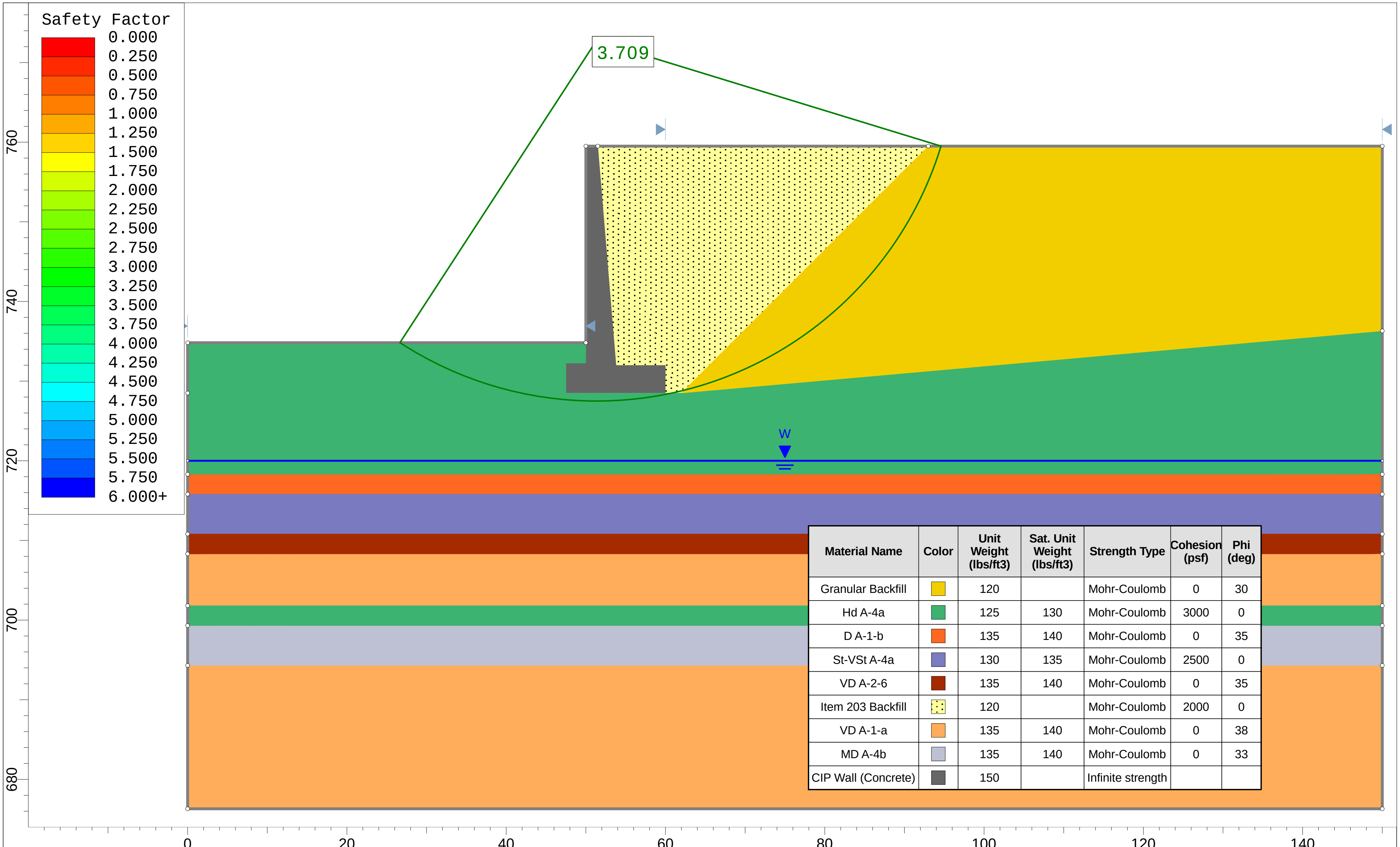
GLOBAL STABILITY ANALYSIS OUTPUT



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Granular Backfill		120		Mohr-Coulomb	0	30
Hd A-4a		125	130	Mohr-Coulomb	0	26
D A-1-b		135	140	Mohr-Coulomb	0	35
St-VSt A-4a		130	135	Mohr-Coulomb	0	25
VD A-2-6		135	140	Mohr-Coulomb	0	35
Item 203 Backfill		120		Mohr-Coulomb	21	35
VD A-1-a		135	140	Mohr-Coulomb	0	38
MD A-4b		135	140	Mohr-Coulomb	0	33
CIP Wall (Concrete)		150		Infinite strength		

Project	FRA-70-14.05 Project 4B ¦ PID No. 96053		
Analysis Description	B-037-1-15 - Spenser's - Overall Global Stability Retaining Wall 4W15		
Drawn By HSK	*Scale* 1:200	*Company*	Resource International, Inc.
Date	11/27/2018 3:42:01 PM	*File Name*	W-15-126 Wall 4W15-Run1.slim

SLIDEINTERPRET 7.036



Material Name	Color	Unit Weight (lbs/ft3)	Sat. Unit Weight (lbs/ft3)	Strength Type	Cohesion (psf)	Phi (deg)
Granular Backfill		120		Mohr-Coulomb	0	30
Hd A-4a		125	130	Mohr-Coulomb	3000	0
D A-1-b		135	140	Mohr-Coulomb	0	35
St-VSt A-4a		130	135	Mohr-Coulomb	2500	0
VD A-2-6		135	140	Mohr-Coulomb	0	35
Item 203 Backfill		120		Mohr-Coulomb	2000	0
VD A-1-a		135	140	Mohr-Coulomb	0	38
MD A-4b		135	140	Mohr-Coulomb	0	33
CIP Wall (Concrete)		150		Infinite strength		

SLIDEINTERPRET 7.036

Project	FRA-70-14.05 Project 4B ¦ PID No. 96053
Analysis Description	B-037-1-15 - Spenser's - Undrained - Overall Global Stability Retaining Wall 4W15
Drawn By	HSK
Scale	1:200
Company	Resource International, Inc.
Date	11/27/2018 5:54:38 PM
File Name	W-15-126 Wall 4W15-Run1-Undrained.slim