JACOBS

Bruce Freeman Rail Trail

New Bridge

Elevated Boardwalk

Town of Sudbury, MA

Geotechnical Report

November 22, 2019

Sudbury, MA

TABLE OF CONTENTS

LIST OF TABLES

APPENDICES

1.0 EXECUTIVE SUMMARY

Jacobs Engineering Group, Inc. (Jacobs) is under contract with the Town of Sudbury for engineering services related to the Bruce Freeman Rail Trail (BFRT) project including design of a proposed boardwalk structure, replacement of Bridge No. S-31-013 (BF2) over Pantry Brook and repair and rehabilitation of Bridge No. S-31-007 (BF0) over Hop Brook in Sudbury, Massachusetts. The existing rail trail will be replaced by a proposed bike path that spans a total length of approximately 4.5 miles and extends between Sta. 100+10 in the south to Sta. 335+52 in the north at the Sudbury/Concord town line. This report presents a summary of the work performed in investigating and determining the subsurface conditions present along the BFRT in Sudbury, MA, along with preliminary recommendations for foundation design for the proposed boardwalk structure and the proposed bridge replacement at Pantry Brook.

A geotechnical subsurface investigation was performed to assess subsurface conditions at the site and make foundation recommendations. Based on our evaluation we are providing recommendations for shallow foundations for support of the proposed bridge replacement at Pantry Brook and for the proposed boardwalk structure.

This report discusses also the principal construction considerations, including dewatering. As depth to groundwater is expected to be at or above the proposed foundation elevation, dewatering will likely be required during construction.

2.0 INTRODUCTION

2.1 Scope of Report

Included in this report are subsurface data pertaining to the proposed project location that were collected during our geotechnical subsurface exploration program performed in August and September of 2019. Our recommendations are based on interpretation of the data collected during the explorations. The boring explorations were performed by New England Boring Contractors, Inc. (NEBC) and were monitored by Jacobs personnel.

All elevations indicated in this report are in feet and are referenced to North American Vertical Datum of 1988 (NAVD 88).

2.2 Existing Configuration

Boardwalk Section

This section of the project is located to the south of Hudson Road (Route 27). The site is currently traversed by rail tracks with wetland areas bordering the west side of the tracks. The existing grade varies between approximately El. 180 and El. 190.

Hop Brook Bridge

The existing bridge over Hop Brook is a single span structure with steel girders and timber deck carrying a railroad track. It is supported by granite block gravity abutments. The overall span length is approximately 28 feet and the overall bridge width is approximately 14 feet.

Pantry Brook Bridge

The existing bridge over Pantry Brook is a single span structure with steel girders and timber deck carrying a railroad track. It is supported by stone masonry gravity abutments. The overall span length is approximately 12 feet. The bridge abutments have collapsed and the superstructure is damaged and has shifted from its original position. Sets of abandoned railroad tracks run across the deck of the bridge.

2.3 Proposed Construction

Boardwalk Section

An approximately 750 feet long boardwalk structure supported on shallow foundations is proposed between Sta. 166+50 and Sta. 174+00. The proposed structure is offset approximately 9 feet from the centerline of the existing tracks. The final grade of the proposed boardwalk will be 5 feet higher than the existing grade.

Hop Brook Bridge

The existing bridge abutment will be cleaned and retained. The superstructure will undergo repairs including removal of existing railroad tracks and ties.

Pantry Brook Bridge

The proposed construction involves the removal of the existing bridge, and replacing it with a single span bridge in the same location. The proposed structure is 34 feet long, 14 feet wide (curb-to-curb) and will be supported on reinforced concrete shallow foundations. The proposed final grade is 1 foot lower than the existing grade.

3.0 SUBSURFACE CONDITIONS

3.1 Local Geology

Based on USGS Bedrock Geologic Map of Massachusetts, USGS, 1983, the Hop Brook site is a part of the Milford-Dedham Zone with Tertiary and older rocks. The formation consists of volcaniclastic and hypabyssal intrusive rocks of metamorphosed mafic to felsic flow. The bedrock is majorly metavolcanic rock with minor inclusions of igneous rocks such as volcaniclastic-volcanic breccia, plutonic gabbro and diorite and hypabyssal intrusive rocks. The rocks belong to the Proterozoic Z geologic age. This is consistent with the metavolcanic rock observed in boring BB-103B at Hop Brook.

The Pantry Brook site is a part of the Nashoba Zone with Silurian and older rocks. The formation consists of orange-pink, medium- to coarse-grained biotite granite to granodiorite with rusty-weathering and locally porphyritic texture. The rocks belong to the Silurian geologic age. This is consistent with the granodiorite rock observed in borings BB-101 and BB-102B at Pantry Brook.

The boardwalk site is at the contact of the Milford-Dedham Zone and Nashoba Zone geologic units. Metavolcanic rock was observed at the southern end of the boardwalk section in borings BB-108 and BB-109B.

3.2 Subsurface Exploration Program

Eight test borings and seven test pits were performed for the site investigation - one boring behind each existing abutment at Pantry Brook bridge and one test pit at its north abutment; one boring and one test pit at the north abutment of Hop Brook bridge; and five borings and five test pits along the centerline of the existing tracks at the boardwalk section. A Jacobs representative located the borings in the field during an initial site reconnaissance. A Boring Location Plan is provided in Appendix A, which provides the approximate drilled locations of the borings and test pits as determined by Jacobs personnel during the time of drilling.

New England Boring Contractors (NEBC) performed the borings and test pits between August 12 and September 4, 2019. Jacobs personnel observed and recorded the subsurface explorations in the field. Jacobs also visually classified all soil and rock samples at the time of drilling and prepared field logs detailing the observations of the site investigation.

The test borings were drilled with using an ATV Mobile B-53 drill rig with the exception of BB-103A/B which was drilled using an ATV Acker Soil Scout. The test pits were performed using a Kubota KX057-4 excavator with the exception of TP-207 which was performed using a Kubota KX71-3 excavator. Test borings were advanced using rotary wash techniques using 3 and 4-inch diameter casing.

Continuous split-spoon sampling was performed in the top 20 feet of each boring, and at five-foot intervals thereafter. Sampling was conducted in general accordance with ASTM D1586-11 ("*Standard Test Method for Standard Penetration (SPT) and Split-Barrel Sampling of Soils*") and applicable requirements of the 1988 Massachusetts Highway Department Standard Specifications for Highway Bridges. At each sampling depth the split spoon sampler was driven a full 2 feet, or to practical refusal. The number of blows of a 140-pound auto/safety hammer falling 30 inches required to drive the split spoon sampler for each 6-inch increment was recorded. The Standard Penetration Test (SPT) N-value was determined as the sum of the blow counts recorded over the 2nd and 3rd increments of penetration. N-values shown on the attached boring logs are uncorrected values.

Soil samples were visually classified in general accordance with the MassDOT Visual Identification Manual and the Burmeister Classification system. The descriptions include the observed color, apparent moisture content, density/consistency, apparent grain size, and major and minor soil type components of the samples.

Bedrock was cored using an NX sized double tube core barrel, with an impregnated diamond core bit and typical 5 foot core runs, in general accordance with ASTM D2113 ("*Standard Practice for Rock Core Drilling and Sampling of Rock for Site Investigation*"). Bedrock was cored in borings BB-101, BB-102B, BB-103B, BB-108 and BB-109B. The outer tube of the core barrel was damaged while coring BB-101 and the rock core run was stopped at 4 feet.

Bedrock samples were classified per the International Society of Rock Mechanics (ISRM) system. Bedrock samples were visually classified to describe the rock continuity (frequency of fractures), hardness, weathering, color and grain size. Additionally, the Rock Quality Designation (RQD) of the core was determined in accordance with ASTM D6032 (*"Determining Rock Quality Designation (RQD) of Rock Core"*). The RQD is the percentage of the sum of all pieces 4 inches or longer, as measured along the core centerline, as compared to the overall core run length.

General boring information such as surface elevations and elevations at which the groundwater table (GWT) and bedrock were encountered are included in Table 1 below.

Table 1 – 2019 Subsurface Exploration Program

Boring	Elevations (ft)		
	Surface	GWT	Bedrock
BB-101	131.0	121.7	80.0
BB-102A/B	131.0	119.5	79.0
BB-103A/B	142.5	133.1	111.0
BB-105	189.0	185.0	NE[1]
BB-106	188.0	185.5	NE
BB-107A/B	187.0	185.9	NE
BB-108	185.0	178.3	169.0
BB-109A/B	184.0	181.5	173.0

Notes:
1. NE = Not encountered

The boring logs and a boring log key are included in Appendix B.

3.3 Laboratory Soil Testing

Laboratory tests were conducted by Thielsch Engineering, of Cranston, RI, to confirm visual classification of selected split spoon samples. Testing included grain size (ASTM D6913 and D1140), natural moisture content (ASTM D2216), organic content (ASTM D2874) and Atterberg limits (ASTM D4318). The laboratory test results are summarized in Table 2. Detailed laboratory test data are presented in Appendix C.

Table 2 – Summary of Laboratory Soil Classification Testing

Boring	Sample No.	Sample Depth (ft.)	Water Content (%)	Gravel (%)	Sand (%)	Fines (%)	LL	PL	PI	Org (%)
BB-101	S3	4-6	19.3	1.1	65.9	33.0	-	-	-	-
BB-101	S8	14-16	202.8	-	-	-	213	113	100	-
BB-101	S9	16-18	59.3	1.6	63.2	35.2	-	-	-	-
BB-101	S10	18-20	21.3	6.8	79.9	13.3	-	-	-	-
BB-101	S11	24-26	7.7	45.8	36.1	18.1	-	-	-	-
BB-102A	S4	6-8	20.6	0.0	51.8	48.2	-	-	-	-
BB-102A	S7	12-14	35.5	-	-	-	89	66	23	-
BB-102A	S9	16-18	19.8	1.2	92.2	6.6	-	-	-	-

Boring	Sample No.	Sample Depth (ft.)	Water Content (%)	Gravel (%)	Sand (%)	Fines (%)	LL	PL	PI	Org (%)
BB-102A	S11	24-26	18.5	19.4	15.2	65.4	-	-	-	-
BB-103B	S8	14-16	54.0	-	-	-	-	-	-	5.1
BB-103B	S9	16-18	28.0	-	-	-	NV[1]	NP[2]	NP	-
BB-103B	S12	29-31	7.5	38.8	45.4	15.8	-	-	-	-
BB-105	S5	8-10	9.2	35.5	47.6	16.9	-	-	-	-
BB-105	S7	12-14	9.9	30.5	62.7	6.8	-	-	-	-
BB-106	S6	10-12	25.1	0.0	51.6	48.4	-	-	-	-
BB-106	S10	18-19.8	13.3	19.3	67.6	13.1	-	-	-	-
BB-107B	S7	12.5-14.4	8.8	50.0	42.2	7.8	-	-	-	-
BB-108	S3	4-6	28.8	-	-	-	NV	NP	NP	-
BB-108	S7	12-14	11.8	24.9	49.4	25.7	-	-	-	-

Notes:
1. NV = No Value
2. NP = Non-Plastic

3.4 Corrosivity Testing

Five bag samples were collected from test pits TP-201 through TP-205 at the boardwalk section at approximately 5 feet depth and evaluated for corrosivity tests including the following suite of tests.

- Electrical Resistivity
- pH
- Sulfate
- Chloride

These properties are related to concrete corrosion. Based on the laboratory test results, the soils can be classified as nonaggressive in accordance with the FHWA Publication NHI-09-087. The corrosivity results are presented in Table 3 and the lab data is presented in Appendix C.

Table 3 – Summary of Corrosivity Testing

Test Pit No.	Sample Depth (feet)	Electrical Resistivity (ohm-cm)	Soil pH	Chlorides (ppm)	Sulfates (ppm)
TP-201	6	23,000	6.15	ND	ND
TP-202	6	3,000	6.25	121	ND
TP-203	5	7,000	6.47	ND	ND
TP-204	5	7,000	6.78	39	ND
TP-205	6	7,000	6.83	39	ND

Notes:

1. ND= Not detected at the reporting limit (RL) for the sample.

3.5 Subsurface Profile

Ballast and Topsoil

Borings drilled along existing railroad tracks encountered up to 12 inches of ballast and topsoil. The topsoil generally consisted of dry, black sand with trace gravel and roots.

Fill

Soils identified as fill soils were noted below the topsoil and ballast in all the borings and varied in thickness from 2 to 10 feet. The fill soils typically consist of fine to medium sands with trace to little gravel and varying amounts of silt. The fill soils were generally loose to dense with field Standard Penetration Test (SPT) N-values ranging from 5 to 35 blows per foot (bpf). Refusal was encountered in boring BB-103A at approximately 9.4 feet depth, but this was likely due to an obstruction encountered during drilling.

Silt

A silt layer was noted below the fill materials in all the borings with the exceptions of BB-105 and BB-109A and varied in thickness between 2 to 14 feet. The silt was non-plastic with varying amounts of granular material and trace amounts of clay and organics. The layer was generally medium stiff to very stiff, with field SPT N-values ranging from 4 to 29 bpf. Refusal encountered in boring BB-107A is likely due to the presence of boulders at the sample depth.

An 8 to 10 feet thick silt layer was encountered below the granular soils at the Pantry Brook site in borings BB-101 and BB-102B at depths of 39 to 44 feet and extends to depths of 49 to 52 feet below grade. The silt layer was generally hard with trace to little granular material. Some clay was also noted in BB-102B. Field SPT N-values ranged from 59 to refusal.

Organics

A layer of peat approximately 2 feet thick was noted at the Pantry Brook site in borings BB-101 and BB-102A at depths of 12 to 14 feet and extends to depths of 14 to 16 feet below grade. The peat was blackish brown and fine grained. Field SPT N-values ranged from 1 to 5.
Organic silt was noted in the sand layer below the peat in boring BB-101 between depths 16 to 18 feet.

It is expected that these organic soils will be removed while excavating down to the bearing elevation of proposed shallow foundations at the Pantry Brook location.

Granular soils

Granular soils consisting of sand and gravel layers were noted below the silt and fill layers. The layers typically consist of loose to very dense granular sand and gravel with varying amounts of silt. Field SPT N-values ranged from 8 to refusal.

Bedrock

Competent bedrock was encountered at a depth of 51 to 52 feet in borings BB-101 and BB-102B at Pantry Brook. A total of 4 feet of rock was cored at BB-101 and 10.8 feet at BB-102B. Generally, the rock was hard, moderately to severely weathered, coarse grained Granodiorite.

At the Boardwalk section bedrock was encountered at a depth of 11 to 16 feet in borings BB-108 and BB-109B and at Hop Brook bedrock was encountered at a depth of 31.5 feet in boring BB-103B. The bedrock in these areas was generally fine grained, slightly to severely weathered Metavolcanic rock.

Table 4 provides the core recovery and Rock Quality Designation (RQD) measurements.

Table 4 – Rock Core Measurements

Location	Boring	Core Run	Depth[1] (ft)	Recovery[2] (%)	RQD[3] (%)
Pantry Brook	BB-101	RC-1	51-55	96	42
	BB-102B	RC-1	52-55.8	100	57
	BB-102B	RC-2	55.8-60.8	100	55
	BB-102B	RC-3	60.8-62.8	100	73
Boardwalk	BB-108	RC-1	16-21	100	38
	BB-108	RC-2	21-26	100	80
	BB-109B	RC-1	11-16	100	17
	BB-109B	RC-2	16-19.5	100	36
	BB-109B	RC-3	19.5-21	100	25
Hop Brook	BB-103B	RC-1	31.5-36.5	95	94
	BB-103B	RC-2	36.5-41.5	100	78

Notes:
1. Depths are noted below existing grades
2. Recovery is the percentage of rock core recovered versus drilled length.
3. RQD is a percentage calculated by dividing the sum the length of all portions of core greater than 4 inches long, measured along the core centerline, by the drilled core length.

Groundwater

Groundwater was encountered in the borings approximately between 9.3 to 11.5 feet below existing grade at Pantry Brook; approximately 9.4 feet below existing grade at Hop Brook; and approximately between 1.1 to 6.7 feet below existing grade at the Boardwalk section. Groundwater levels recorded on the boring logs are based on field observations and visual classification of the soil samples at the time of drilling and may not be representative of the long-term groundwater levels at the site. We also note that groundwater levels may fluctuate with season, precipitation, local construction activity, and other factors.

4.0 SEISMIC DESIGN PARAMETERS

Seismic design parameters for the project sites were determined in accordance with AASHTO Guide Specifications for LRFD Seismic Bridge Design, 2nd Edition, 2011. See the attached Appendix D for site specific seismic calculations.

Based on the SPT N-values noted in borings BB-101, BB-102A/B and BB-103A/B, the project bridge sites may be classified as <u>Site Class D</u>. The consistency of the soils along the Boardwalk section is as dense or denser than the soils at the bridge sites and accordingly may also be conservatively classified as Site Class D. The seismic response spectra were determined by interpolation from figures provided in AASHTO guidelines, using the latitude and longitude of the project site.

On the basis of our analyses, we recommend the design response spectra for the proposed structures be constructed using the following coefficients, at a minimum:

$A_s = 0.11$ $S_{DS}= 0.23$ $S_{D1}= 0.09$

where:

- A_s is the response spectral acceleration coefficient based on Site Class D
- S_{DS} is the design spectral acceleration coefficient at 0.2-sec period
- S_{D1} is the design spectral acceleration coefficient at 1.0-sec period

In accordance with Table 3.5-1 of the 2011 AASHTO LRFD Seismic Bridge Design and based on an $S_{D1} < 0.15$, we recommend using Seismic Design Category (SDC) A.

5.0 LIQUEFACTION POTENTIAL

Based on the observed subsurface conditions, soil gradation and sample relative densities, the existing soils underlying the site are judged not susceptible to liquefaction.

Liquefaction potential calculations, provided in Appendix E, were performed at the Pantry Brook and Hop Brook sites where the soils are comparatively less dense and more granular, and the sites were found to be safe against liquefaction.

6.0 GEOTECHNICAL RECOMMENDATIONS

6.1 Pantry Brook Bridge

Based on the information obtained from test borings and our preliminary analysis, the proposed bridge replacement at Pantry Brook may be supported on shallow foundations.

The final foundation design should consider the constructability of the foundation type and the effects of scour. Organic soils, if present, must be over-excavated and backfilled with compacted Gravel Borrow to the proposed bearing elevation.

6.1.1 Shallow Foundation Recommendations

Shallow foundations were analyzed in accordance with 2017 AASHTO LRFD Bridge Design Specifications. The strength and service bearing capacities of the foundations were evaluated. Our analysis considered 14-ft long shallow foundations of variable width, bearing 5.3 feet below the existing bottom of stream elevation. The assumed bearing elevation incorporates a 4-foot frost depth. Foundation widths used in our analyses ranged between 4 and 8 ft, with maximum load eccentricities. See Appendix F for corrected N values and inferred soil properties used in our calculations.

The results of our analyses, including the allowable bearing resistance for a limiting total settlement of approximately 0.5 to 1 inch, are presented in Table 5 below. Our computations are presented in Appendix G. The final bearing and settlement of the proposed foundations should be verified once final foundation dimensions and bearing elevation are established.

Table 5 – Pantry Brook Bridge Shallow Foundation Analysis Results

Footing Width (ft)	Eccentricity (ft)	Factored bearing resistance (ksf)	Bearing Resistance for 0.5 inch settlement (ksf)	Bearing Resistance for 1 inch settlement (ksf)
4	1.33	5.2	7.3	14.6
6	2.00	5.7	5.7	11.4
8	2.67	6.1	4.9	9.8

Design bearing elevation of shallow foundations must consider the effects of scour. At a minimum, final bearing depth must be specified below the maximum anticipated depth of scour, as established by engineering analysis.

Construction of shallow foundations must consider the potential presence of boulders within the existing bridge backfill and within the existing stream bed when determining how to construct any required support of excavation or cofferdam to allow excavation to the proposed footing depths. Shallow foundation construction should be performed in the dry; extensive dewatering should be expected during foundation construction. It is recommended that construction be performed during the summer months when groundwater and stream levels are the lowest.

6.1.2 Settlement

In our analyses we have assumed that the total settlement of the proposed bridge foundations will be limited to 0.5 to 1 inch. Footing dimensions that are consistent with this criterion may be determined based on Section 6.1.1 and Table 5 above. We note that the site soils at the assumed bearing elevation (El. 113.7) largely consist of incompressible sand and gravel soils; accordingly, the settlement should be of an immediate nature and will likely occur during or shortly after completion of construction. Once the final foundation loading and dimensions have been determined the settlement should be re-evaluated for a final settlement estimate.

6.1.3 Lateral Earth Pressures and Wall Stability

The following lateral earth pressures presented in Table 6 are recommended for the design of abutment walls, wing walls and temporary support of excavation. Backfill material should meet the requirements of "Gravel Borrow – M1.03.0b" per the MassDOT Standard Specifications for Highways and Bridges.

Considering their silty nature, the site soils excavated from behind the existing abutments may not be suitable for re-use as backfill.

Table 6 – Recommended Earth Pressure Parameters for Wall Design

	Backfill	Fill	Silt (w/Organics)	Sand	Gravel and hard Silt
Internal Angle of Friction (ϕ)	34°	32°	28°	34°	40°
Unit weight (γ_{wet})	130 pcf	120 pcf	120 pcf	120 pcf	130 pcf
Lateral Earth Pressure Coefficients					
• Active	0.28	0.31	0.36	0.28	0.22
• Passive	3.54	3.25	2.77	3.54	4.60
At-Rest Condition	0.44	0.47	0.53	0.44	0.36
Coefficient of Sliding Friction μ (see Note 1)	0.67 – Cast in Place 0.54 – Precast	n/a – see Note 1 and text below	n/a – see Note 1 and text below	0.67 – Cast in Place 0.54 – Precast	0.67 – Cast in Place 0.54 – Precast (conservative)

NOTES:
1. The coefficient of sliding friction is based on an assumed friction angle of the bearing materials of 34 degrees. Accordingly, the coefficient of sliding friction in this table is not appropriate for the fill or silt layers, which have an internal angle of friction of less than 34 degrees. The sliding friction coefficient varies if the foundation is cast in place concrete, or otherwise is a precast foundation. See AASHTO Section 10.6.3.4, Eq. 10.6.3.4-2.

Overturning and sliding resistance should be evaluated at the Strength Limit. Friction along the base of the shallow foundations may be used to resist horizontal forces. The Nominal Sliding resistance, R_τ, can be estimated by multiplying the Total Vertical Force, V, by the coefficient of sliding friction, μ, as indicated in Table 6 above for cast-in-place footings and precast footings. This recommendation assumes that the concrete footings are on natural coarse-grained soils or compacted Gravel Borrow (MassDOT M1.03.0b), and assumes an internal friction angle of 34 degrees for the subgrade soil. Per AASHTO Table 10.5.5.2.2-1, a geotechnical resistance factor of 0.8, suitable for cast-in-place concrete on sand or 0.9, suitable for precast concrete on sand, must be applied to the nominal sliding resistance, R_τ, to determine the factored resistance. We recommend that the passive resistance component of the total sliding resistance be disregarded in the design, to account for temporary conditions, and for potential excavation and scour in front of the footings. It is also recommended that the maximum bearing pressure at the bottom of the shallow foundations not exceed the recommended factored bearing resistance.

In addition, an appropriate live load surcharge applied beyond the backfill of the bridge's abutment walls and the bridge's wingwalls should be used to evaluate wall stability. However, no live load surcharge should be considered acting on locations where the presence of the surcharge may result in an unconservative overprediction of safety against stability failure. A comprehensive wall stability analysis should include external (i.e., sliding, overturning and bearing capacity) and global stability.

All abutment and wingwalls must be provided with backfill drainage to prevent the buildup of hydrostatic pressures. A commercial drain board or one-foot thick geotextile wrapped drainage layer should be placed behind the walls. A collector drain pipe or weepholes should be used to prevent collected water from accumulating behind the walls. Weepholes should be a minimum 3 inches in diameter and spaced no more than 10 feet apart. A slotted HDPE drain pipe, typically 4 inches in diameter can be used to allow water to drain to daylight.

6.1.4 Approach Slabs

Approach slabs, if required, should be structurally tied to the proposed bridge and designed to allow rotation. The intent is to avoid abrupt differential settlement between the bridge structure and approach embankment backfill.

6.1.5 Permanent Slopes

Unprotected permanent slopes should be no steeper than 2 horizontal to 1 vertical (2H: 1V), in order to limit erosion and surficial sloughing. Revetment protection consisting of riprap, underlain by geotextile fabric, may be used where required for stabilization and protection of steeper permanent slopes, subject to a slope stability assessment by a licensed geotechnical engineer.

6.2 Boardwalk Structure

The proposed boardwalk structure may be supported on shallow spread footings. Driven piles are also a viable foundation option. The final foundation design should consider the constructability of the foundation type. This report provides recommendations for shallow spread footings.

Significant dewatering will likely be required at the site during construction due to high groundwater elevations.

6.2.1 Shallow Foundation Recommendations

Shallow foundations were analyzed in accordance with 2017 AASHTO LRFD Bridge Design Specifications. The strength and service bearing capacities of the foundations were evaluated. Our analysis considered shallow foundations of dimensions 3ft x 3ft, bearing 4 feet below the proposed ground elevation. The assumed bearing elevation incorporates a 4-foot frost depth. A maximum eccentricity of 0.2 ft was used in our calculations based on values provided by the Jacobs Structural Engineer.

Based on our analysis a factored bearing resistance of 3.5 ksf is recommended for these footings. The maximum bearing pressure acting on these footings is expected to be 2.4 ksf based on loads provided by Structural Engineer at Strength V load case. Allowable pressures for a limiting total settlement of approximately 0.5 and 1 inch were computed to be 10.3 and 20.6 ksf respectively. Settlement will not control design. Our computations are presented in Appendix H. The final bearing and settlement of the proposed foundations should be verified once final foundation dimensions and bearing elevation are established.

Shallow foundation construction should be performed in the dry; extensive dewatering should be expected during foundation construction. It is recommended that construction be performed during the summer months when groundwater and stream levels are the lowest.

6.2.1 Settlement

In our analyses we have assumed that the total settlement of the proposed foundations will be limited to 0.5 to 1 inch. We note that the site soils at the assumed bearing elevation largely consist of incompressible granular soils; accordingly, the settlement should be of an immediate nature and will likely occur during or shortly after completion of construction. Once the final foundation loading and dimensions have been determined the settlement should be re-evaluated for a final settlement estimate.

6.2.2 Lateral Stability

Overturning and sliding resistance should be evaluated at the Strength Limit. Friction along the base of the shallow foundations may be used to resist horizontal forces. The Nominal Sliding resistance, R_τ, can be estimated by multiplying the Total Vertical Force, V, by the coefficient of sliding friction, μ (0.58 for cast in place and 0.46 for precast concrete on sand based on AASHTO Section 10.6.3.4, Eq. 10.6.3.4-2). This recommendation assumes that the concrete footings are on natural coarse-grained soils or compacted Gravel Borrow (MassDOT M1.03.0b), and assumes an internal friction angle of 30 degrees for the subgrade soil. Per AASHTO Table 10.5.5.2.2-1, a geotechnical resistance factor of 0.8, suitable for cast-in-place concrete on sand or 0.9, suitable for precast concrete on sand, must be applied to the nominal sliding resistance, R_τ, to determine the factored resistance. We recommend that the passive resistance component of the total sliding resistance be disregarded in the design to account for temporary conditions. It is also recommended that the maximum bearing pressure at the bottom of the shallow foundations not exceed the recommended factored bearing resistance.

7.0 CONSTRUCTION CONSIDERATIONS

7.1 General Site Safety

Construction site safety is the sole responsibility of the Contractor, who shall also be solely responsible for the means, methods, and sequencing of all construction operations. We provide the recommendations herein in good faith and solely as a service to our client. Under no circumstances shall the recommendations and information herein be interpreted to convey that Jacobs assumes responsibility for construction site safety or for the safety of the Contractor's activities. We recommend that all work discussed in this report be performed by qualified and experienced contractors and subcontractors at all tiers.

7.2 Subgrade Preparation

Prior to performing any required grading operations and excavations for the proposed foundations, these areas should be stripped of the existing topsoil/vegetation, if present; and the existing ties and tracks should be removed. Exposed shallow foundation bearing surfaces should be proof-compacted to prepare a working surface suitable for forming and be protected from further disturbance. With Geotechnical Engineer’s concurrence, bearing surfaces or cap subgrade soils located below the level of the adjacent brook should be compacted using static proof-compaction methods, in lieu of vibratory methods. Exposed subgrade soils should be protected from disturbance at all times. Soil subgrades should also be protected against frost both during and after construction. Proper drainage of construction areas should be provided to protect the subgrades from the detrimental effects of weather conditions and precipitation.

7.3 Placement and Compaction of Structural Fill

Material placed immediately adjacent to the abutment and wing retaining walls should consist of non-cohesive free-draining material to permit the free flow of water behind the walls. We recommend using “Gravel Borrow - M1.03.0b” per the MassDOT Standard Specifications for Highways and Bridges.

Fill should be compacted to at least 95 percent of the maximum dry density and within 2 percent of the optimum moisture content, as determined by the Standard Proctor Test (ASTM D-698), in accordance with MassDOT Standard Specifications. Compaction should be performed in lifts not exceeding 12 inches in loose thickness. Compaction within 5 feet of the proposed walls should be performed using a vibratory walk-behind roller or plate compactor. Fill must not be placed over frozen soil. Soil subgrades must be protected against frost both during and after construction.

7.4 Excavation Slopes

The Contractor should be aware that slope height, slope inclination, or excavation depths (including utility trench excavations) should in no case exceed those specified in local, state, or federal safety regulations, e.g., OSHA Health and Safety Standards for Excavations, 29 CFR Part 1926, or successor regulations; such regulations are strictly enforced and, if they are not followed, the Owner, Contractor, and/or earthwork and utility subcontractors could be liable for substantial penalties.

If any excavation, including a utility trench, is extended to a depth of more than 20 feet, it will be necessary to have the side slopes or excavation support system designed and stamped by a Professional Engineer registered in the Commonwealth of Massachusetts. At Engineer’s discretion, temporary excavation support systems may be partially or completely abandoned in place (using acceptable methods) where otherwise their removal may result in unacceptable ground disturbance or distress of adjacent structures or improvements.

As a safety measure, we recommended that all vehicles and any surcharges such as soil or material stockpiles be kept a safe distance away from excavations (i.e., at least 1.5 times the excavation depth). Also, the exposed slope face of open-cut excavations should be protected against erosion due to precipitation and runoff. Surficial runoff from adjacent areas should be directed away from open excavations. Excavations which are to remain open for extended periods of time should be visually inspected daily by the Contractor for possible signs of erosion or slope degradation, and all issues should be corrected immediately.

7.5 Construction Dewatering

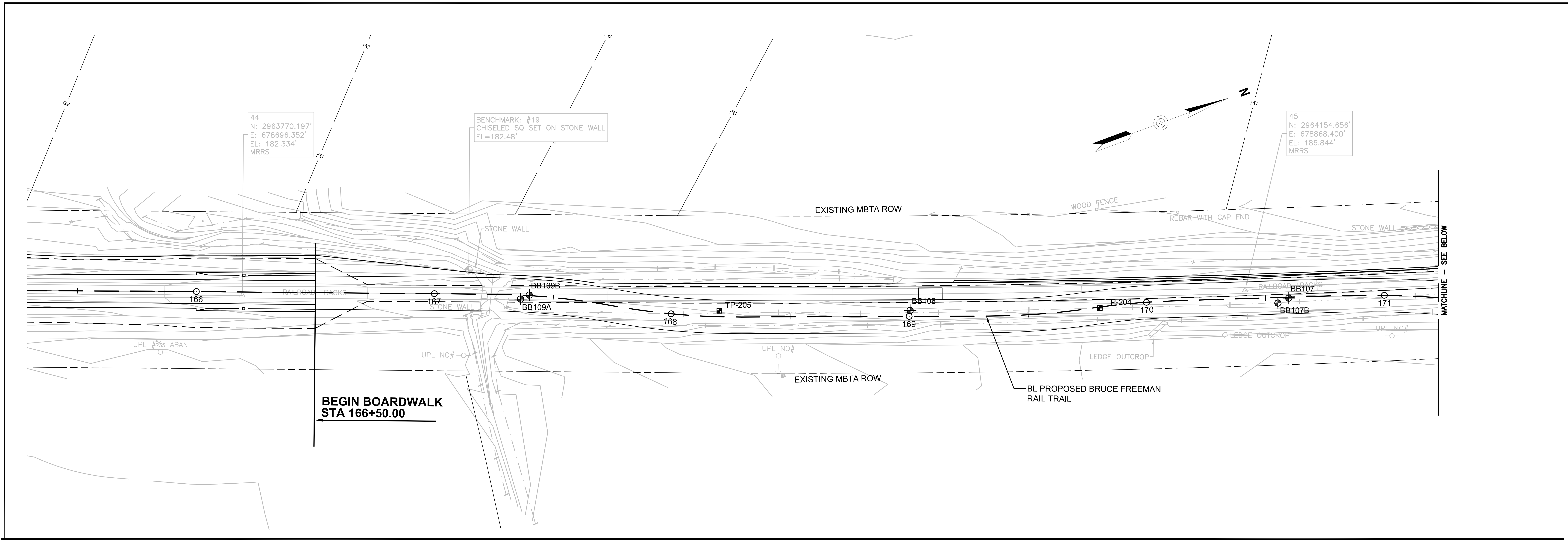
Foundation bearing surfaces located below the existing stream elevation must be protected from potential seepage inflow or scour, as well as frost depth. Accordingly, the Contractor should be prepared to manage and control groundwater during excavation and to divert surface water from the excavations to provide a dry and stable subgrade throughout construction. The Contractor should retain full responsibility for selecting its own dewatering methods, based on its own experience and its own means and methods of construction. All aspects of the dewatering system should be designed by an experienced Professional Engineer registered in the Commonwealth of Massachusetts and retained by the Contractor. The method of dewatering selected must account for seasonal weather conditions, size of excavation and the length of time that the excavation will remain open. Dewatering and water discharge/disposal efforts must be in accordance with applicable local, state, and federal environmental and conservation regulations. At Engineer’s discretion construction dewatering systems may be partially or completely abandoned in place (using acceptable methods) where otherwise their removal may result in unacceptable ground disturbance or distress of adjacent structures or improvements.

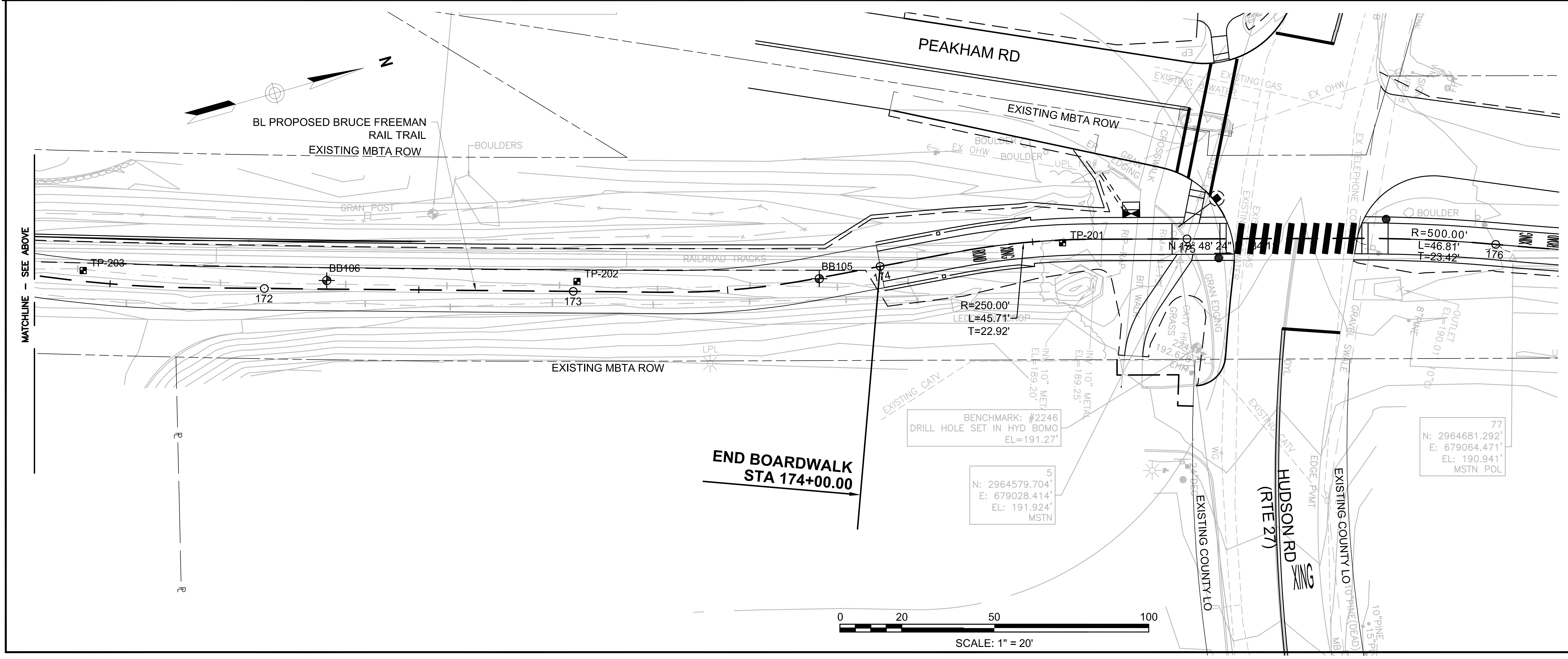
8.0 LIMITATIONS

This report and the recommendations contained herein have been prepared for the exclusive use of the Town of Sudbury and their representatives for specific application to the design and construction of the proposed bridges and boardwalk structure.

This report was prepared in accordance with generally accepted soil and foundation engineering practices. No warranty, expressed or implied, is made. The analysis, design and recommendations presented in this report are based in part upon the data obtained from subsurface explorations available at the time of this report. Subsurface stratification variations between borings are anticipated. The reported groundwater levels were short-term observations and only represented the water levels at the time of drilling. The nature and extent of variations between these explorations may not become evident until construction. If significant variations then appear, or if there are changes in the nature, design or location of the proposed structure, it may be necessary to reevaluate the recommendations of this report.

Appendix A – Boring Location Plan





PROJECT FILE NO. 608164

massDOT
Massachusetts Department of Transportation
Highway Division

BORING PLAN OF

SUDBURY

BRUCE FREEMAN RAIL TRAIL

MASSACHUSETTS DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
10 PARK PLAZA BOSTON, MASS

SCALE: 1" = 20'–0" OCTOBER 18, 2019

BRIDGE NO. S–31–XXX (XXX)

608184_BOR(FIELD)_RECOVER.DWG Plotted on 20-Nov-2019 2:04 PM

608184_BOR(FIELD).DWG Plotted on 10-Oct-2019 2:06 PM

NOTES:

1. LOCATION OF DRIVE SAMPLE BORINGS ARE SHOWN THUS: ⊕
2. LOCATION OF SAMPLE TEST PITS ARE SHOWN THUS: ▚
3. APPROXIMATE BORING AND TEST PIT LOCATIONS ARE PRESENTED BASED ON FIELD OBSERVATION BY JACOBS PERSONNEL.
4. FOR SUBSURFACE EXPLORATION LOGS SEE GEOTECHNICAL REPORT, APPENDIX B.
5. EXISTING CONDITIONS AND TOPOGRAPHICAL INFORMATION ARE FROM AN ACTUAL FIELD SURVEY CONDUCTED BY VHB, INC. IN DECEMBER 2015 THROUGH APRIL 2016.
6. THE HORIZONTAL CONTROL IS BASED ON THE MASSACHUSETTS MAINLAND STATE PLANE COORDINATE SYSTEM AND THE NATIONAL GEODETIC SURVEY (NAD83). ALL ELEVATIONS ARE US FEET, REFERENCED TO THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).
7. BORINGS AND TEST PITS WERE PERFORMED BY NEW ENGLAND BORING CONTRACTORS AND LOGGED BY JACOBS PERSONNEL IN AUGUST 2019 THROUGH SEPTEMBER 2019.

0 20 50 100

SCALE: 1" = 20'

PROJECT FILE NO. 608164

massDOT
Massachusetts Department of Transportation
Highway Division

BORING PLAN OF
BRIDGE REHABILITATION

SUDBURY

BRUCE FREEMAN RAIL TRAIL
OVER HOP BROOK

MASSACHUSETTS DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
10 PARK PLAZA BOSTON, MASS

SCALE: 1" = 20'-0"
OCTOBER 18, 2019

BRIDGE NO. S-31-007 (BF0)

NOTES:

1. LOCATION OF DRIVE SAMPLE BORINGS ARE SHOWN THUS: ⊕
2. LOCATION OF SAMPLE TEST PITS ARE SHOWN THUS: ▨
3. APPROXIMATE BORING AND TEST PIT LOCATIONS ARE PRESENTED BASED ON FIELD OBSERVATION BY JACOBS PERSONNEL.
4. FOR SUBSURFACE EXPLORATION LOGS SEE GEOTECHNICAL REPORT, APPENDIX B.
5. EXISTING CONDITIONS AND TOPOGRAPHICAL INFORMATION ARE FROM AN ACTUAL FIELD SURVEY CONDUCTED BY VHB, INC. IN DECEMBER 2015 THROUGH APRIL 2016.
6. THE HORIZONTAL CONTROL IS BASED ON THE MASSACHUSETTS MAINLAND STATE PLANE COORDINATE SYSTEM AND THE NATIONAL GEODETIC SURVEY (NAD83). ALL ELEVATIONS ARE US FEET, REFERENCED TO THE NORTH AMERICAN VERTICAL DATUM OF 1988 (NAVD88).
7. BORINGS AND TEST PITS WERE PERFORMED BY NEW ENGLAND BORING CONTRACTORS AND LOGGED BY JACOBS PERSONNEL IN AUGUST 2019 THROUGH SEPTEMBER 2019.

PROJECT FILE NO. 608164

massDOT
Massachusetts Department of Transportation
Highway Division

BORING PLAN OF
BRIDGE REHABILITATION
SUDBURY

BRUCE FREEMAN RAIL TRAIL
OVER PANTRY BROOK

MASSACHUSETTS DEPARTMENT OF TRANSPORTATION
HIGHWAY DIVISION
10 PARK PLAZA BOSTON, MASS

SCALE: 1" = 20'-0"   OCTOBER 18, 2019

BRIDGE NO. S-31-013 (BF2)

Appendix B – Subsurface Exploration Logs

JACOBS

BORING LOG KEY

120 St. James Ave
5th Floor
Boston, Massachusetts
02116

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
1	2	3	4	5	6	7	8	9	10	11

COLUMN DESCRIPTIONS

1 ELEV (feet): Elevation in feet as per datum specified on log.
2 DEPTH (feet): Depth in feet below the ground surface or barge.
3 SAMPLE DATA: Type of soil/rock sample and data collected over the depth interval shown.
4 N-VALUE (Uncorrected): Cumulative number of uncorrected blows for the middle two six-inch intervals (blows/foot).
5 SAMPLE NUMBER: Sample identification number.
6 DEPTH INTERVAL (feet): Depth interval of the soil or rock sample collected.
7 PEN/REC (inch/inch): Soil or rock sample penetration / amount of soil or rock recovered.
8 PID (parts per million): PID reading observed during drilling.
9 LAYER NAME: Inferred name and delineation of subsurface strata.
10 SOIL AND ROCK DESCRIPTION: Description of material encountered.
11 NOTES: Comments/observations regarding drilling/sampling made by driller or field personnel.

BURMISTER SOIL CLASSIFICATION (INORGANIC)

COMPONENT	NAME	PROPORTIONAL TERM	PERCENT BY WEIGHT
MAJOR	GRAVEL SAND FINES*	n/a	> 50
Minor	Gravel Sand Fines*	and some little trace	35 - 50 20 - 35 10 - 20 0 - 10

GRADATION DESIGNATIONS	PROPORTIONS OF GRANULAR COMPONENT
fine	< 10% coarse & medium
medium	< 10% coarse & fine
fine to medium	< 10% coarse
medium to coarse	< 10% fine
fine to coarse	all > 10%

PARTICLE SIZE DEFINITIONS			
SOIL	*FRACTION*	*SIEVE NO.*	*SIEVE SIZE*
Gravel	coarse fine	3 in to 3/4 in 3/4 in to No.4	75mm - 19mm 19mm - 4.75mm
Sand	coarse medium fine	No.4 to No.10 No.10 to No.40 No.40 to No.200	4.75mm - 2.0mm 2.0mm - .43mm 0.43mm - 0.08mm
Silt	n/a	< No.200	< 0.075mm

GRANULAR SOILS	
DENSITY	*SPT N-VALUE*
Very Loose	< 4
Loose	4 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	> 50

PLASTICITY	PLASTICITY INDEX	FINES*	THREAD DIAMETER
Non-Plastic	0	SILT	None
Slight	1 - 5	Clayey SILT	1/4" (6mm)
Low	5 - 10	SILT & CLAY	1/8" (3mm)
Medium	10 - 20	CLAY & SILT	1/16" (1.5mm)
High	20 - 40	Silty CLAY	1/32" (0.75mm)
Very High	> 40	CLAY	1/64" (0.4mm)

FINE SOILS		
CONSISTENCY	*SPT N-VALUE*	*UC STRENGTH*
Very Soft	< 2	< 0.25 tsf
Soft	2 - 4	0.25 - 0.50 tsf
Medium	4 - 8	0.50 - 1.0 tsf
Stiff	8 - 15	1.0 - 2.0 tsf
Very Stiff	15 - 30	2.0 - 4.0 tsf
Hard	> 30	> 4.0 tsf

BURMISTER SOIL CLASSIFICATION (ORGANIC)

Fibrous PEAT - Light weight, spongy, mostly visible organic matter, water squeezes readily from sample. Typically near top of deposit.
Fine Grained PEAT - Light weight, spongy, little visible organic matter, water squeezes readily from sample. Typically below fibrous PEAT.
Organic SILT - Typically gray to dark gray, often has strong H2S odor. Typically contains shells or shell fragment. Light weight. Usually found near coastal regions. May contain wide range of sand fractions.

MASSDOT VISUAL IDENTIFICATION OF SOILS

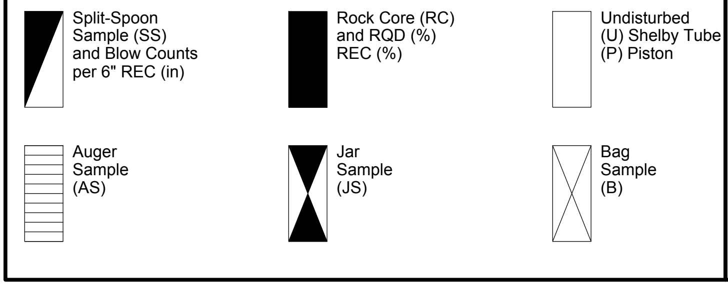
COMPONENT	NAME	PROPORTIONAL TERM	PERCENT BY WEIGHT
MAJOR	GRAVEL SAND FINES	n/a	> 50
Minor	Gravel Sand Fines	and some trace	40 - 50 10 - 40 < 10

PARTICLE SIZE DEFINITIONS			
SOIL	*FRACTION*	*SIEVE NO.*	*SIEVE SIZE*
Boulders	n/a	> 12 in	> 305mm
Cobbles	n/a	12 in to 3 in	305mm - 75mm
Gravel	coarse medium fine	3 to 1 in 1 in to 3/8 in 3/8 in to No.10	75mm - 25mm 25mm - 9.5mm 9.5mm - 2.0mm
Sand	coarse fine	No.10 to No.40 No.40 to No.200	2.0mm - 0.425mm 0.425mm - 0.075mm
Silt	n/a	< No.200	< 0.075mm

GRANULAR SOILS	
DENSITY	*SPT N-VALUE*
Very Loose	< 4
Loose	4 - 10
Medium Dense	10 - 30
Dense	30 - 50
Very Dense	> 50

FINE SOILS	
CONSISTENCY	*SPT N-VALUE*
Very Soft	< 2
Soft	2 - 4
Medium Stiff	4 - 8
Stiff	8 - 15
Very Stiff	15 - 30
Hard	> 30

GRAPHIC SYMBOLS



ABBREVIATIONS

SS = Split Spoon Sampler
U = Undisturbed Sample (Shelby Tube)
P = Piston Sample
WOR = Weight of Rods
WOH = Weight of Hammer
SPT = Stadard Penetration Test (ASTM D2487)
PP = Pocket Penetrometer
PI = Plasticity Index
UC STRENGTH = Unconfined Compressive Strength

PID = Photoionization Detector
ppm = Part Per Million
REC = Recovery
RQD = Rock Quality Designation
▽ Water Level

LOG OF TEST BORING

JACOBS	PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-101
	LOCATION	Sudbury, MA		
	OWNER	MASSDOT		
	JOB NUMBER	E2X81800		SHEET 1 OF 2

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	B. Cross	ELEVATION	131
METHOD OF DRILLING		GROUNDWATER READINGS		DRILL RIG	Mobile B-53	DATUM	NAVD 88
0.0	Split Spoon Sample	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID N 2973226
4.0	Wash Boring w/ 4" Casing	08-19-2019 / 8:18 am	9.3	During Drilling (In Casing)		COORD E	681132
51.0	NX Rock Core					DATE START	8/16/19
55.0	Terminated					DATE END	8/19/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
130		2 5 6 6	11	S1	0 - 2	24/10		FILL	S1: (0-5") Top Soil Dry, medium dense, brown, medium SAND, trace Gravel.	
		5 6 7 8	13	S2	2 - 4	24/18			S2: Dry, medium dense, brown, medium SAND, little Gravel, little Silt.	
	5	5 5 5 5	10	S3	4 - 6	24/4			S3: Wet, medium dense, brown, fine SAND, some Silt.	
125		5 6 7 6	13	S4	6 - 8	24/12			S4: Similar to S3.	
		6 8 7 7	15	S5	8 - 10	24/20		10	S5: Wet, medium dense, brown, medium SAND, some Silt, trace Gravel.	
120	10	4 4 4 4	8	S6	10 - 12	24/10		SILT	S6: Wet, medium stiff, brown SILT, some fine to medium Sand.	
		1 2 2 3	4	S7	12 - 14	24/6		14	S7: Wet, medium stiff, brown SILT and fine SAND.	
	15	WOH WOH 1 2	1	S8	14 - 16	24/24		PEAT 16	S8: Wet, blackish brown, fine grained PEAT, trace Gravel.	
115		2 2 10 12	12	S9	16 - 18	24/7		SAND	S9: Wet, medium dense, blackish brown, fine to medium SAND and Organic Silt, trace Gravel.	
		7 12 9 10	21	S10	18 - 20	24/24			S10: Wet, medium dense, fine to medium SAND, little Silt, trace Gravel.	
110	20							24		
105	25	7 22 24 16	46	S11	24 - 26	24/14		GRAVEL	S11: Wet, dense, fine GRAVEL and fine to coarse Sand, little Silt.	
100	30	47 46 55 37	101	S12	29 - 31	24/18			S12: Wet, very dense, fine to coarse GRAVEL, trace Silt, trace coarse Sand.	1
	35	50/5"	50/5"	S13	34 - 34.3	5/4			S13: Wet, very dense, coarse GRAVEL, trace Silt.	

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Hard drilling at 32'.

LOG OF TEST BORING

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-101
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 2 OF 2

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
95										2
90	40	21 29 50 31	79	S14	39 - 41	24/9		39 SILT	S14: Wet, hard SILT, trace fine Sand, trace Gravel.	
85	45	30 68/4"	68/4"	S15	44 - 44.8	10/5		SILT	S15: Wet, hard SILT, some fine Gravel, little fine to coarse Sand, trace Clay.	
	50	70/2"	70/2"	S16	49 - 49.2	2/2		49 SAND	S16: Wet, very dense, coarse SAND, weathered rock fragments.	
80		RQD=42		RC-1	51 - 55	48/46		51 GRANODIORITE	RC-1: Coring time: 12, 9, 9, 10 (mins/ft) Pinkish gray, hard, moderately weathered GRANODIORITE, fractures dipping at 30 degree angle. Clay seam noted between 42 to 43".	3
75	55							55	Bottom of Borehole at 55 feet.	
70	60									
65	65									
60	70									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

2. Boulders encountered between 36 and 39'.
3. Outer barrel of core bit broke in the borehole during drilling at 55'. Could not continue boring any further.

LOG OF TEST BORING

JACOBS	PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-102A	
	LOCATION	Sudbury, MA			
	OWNER	MASSDOT			
	JOB NUMBER	E2X81800		SHEET 1 OF 1	

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	B. Cross	ELEVATION		131
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Mobile B-53	DATUM		NAVD 88
0.0	Split Spoon Sample	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID	N	2973187
4.0	Wash Boring w/ 4" Casing	08-20-2019 / 1:36 pm	11.5	Upon Completion (Casing pulled)			COORD	E	681121
							DATE START		8/20/19
							DATE END		8/20/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
130		2 4 6 5	10	S1	0 - 2	24/17		FILL	S1: (0-12") Dry, black, medium SAND, trace Gravel, roots (topsoil). (12-17") Dry, brown, fine to medium SAND, trace Silt.	
		4 4 7 5	11	S2	2 - 4	24/15			S2: Dry, medium dense, brown, fine to medium SAND,little Silt, trace Gravel.	
	5	4 2 4 3	6	S3	4 - 6	24/9			S3: Wet, loose, brown, fine SAND, some Silt, trace Gravel.	
125		5 6 5 6	11	S4	6 - 8	24/10			S4: Wet, medium dense, brown, fine SAND and SILT.	
		6 7 5 6	12	S5	8 - 10	24/5		10	S5: Wet, medium dense, fine to medium SAND, some Silt, trace Gravel.	
120	10 ▼	2 3 1 1	4	S6	10 - 12	24/4		SILT 12	S6: Wet, medium stiff, brown, SILT, some fine to medium Sand, trace Clay, trace Gravel.	
		1 2 3 3	5	S7	12 - 14	24/23		PEAT 14	S7: Wet, blackish brown, fine grained PEAT.	
	15	5 8 11 12	19	S8	14 - 16	24/19		SAND	S8: Wet, medium dense, brownish gray, medium to coarse SAND, some Silt.	
115		5 20 21 16	41	S9	16 - 18	24/15			S9: Wet, dense, brown, fine to medium SAND, trace Silt, trace fine Gravel.	
	20	11 13 16 20	29	S10	18 - 20	24/19			S10: Wet, medium dense, grayish brown, medium to coarse SAND, little Silt.	
110								24		
105	25	15 14 19 10	33	S11	24 - 26	24/5		SILT 26	S11: Wet, hard, gray SILT, little fine Sand, little fine Gravel.	1
									Bottom of Borehole at 26 feet.	2
100	30									
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Boring terminated at 26' due to an obstruction.
2. Boring offset 6' south and continued. See boring log BB-102B.

LOG OF TEST BORING

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-102B
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 2

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	B. Cross	ELEVATION	131
				DRILL RIG	Mobile B-53	DATUM	NAVD 88
				SPT HAMMER	140 lb Auto	GRID N	2973181
						COORD E	681121
						DATE START	8/21/19
						DATE END	8/23/19

METHOD OF DRILLING		GROUNDWATER READINGS		
		DATE/TIME	DEPTH(ft)	REMARKS
0.0	Wash Boring w/ 3" Casing			
30.0	Wash Boring w/ 4" Casing	08-21-2019 / 8:34 am	10.8	During Drilling (In Casing)
52.0	NX Rock Core	08-22-2019 / 9:02 am	11.9	During Drilling (In Casing)
62.8	Terminated	08-23-2019 / 9:06 am	11.8	During Drilling (In Casing)

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
									Drill through.	
130										
	5									
125										
	10									
120										
	▼									
	15									
115										
	20									
110										
	25									
105										
	30	55/4"	55/4"	S12	29.5 - 29.8	4/3			S12: Wet, very dense, gray, fine to coarse GRAVEL, trace coarse Sand.	
100										
		24	52	S13	34 - 36	24/10			S13: Wet, very dense, gray GRAVEL and SAND, little Silt.	
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-102B
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 2 OF 2

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
95		31 21 33						GRAVEL		
90	40	30 53/4"	53/4"	S14	39 - 39.8	10/5			S14: Wet, very dense, gray, fine to coarse GRAVEL, little coarse Sand, trace Silt.	
85	45	18 25 34 41	59	S15	44 - 46	24/21		44 SILT	S15: Wet, hard, gray SILT, some Clay, trace fine Sand, trace Gravel.	
80	50	16 37 45 50/4"	82	S16	49 - 50.8	22/22			S16: Wet, hard, gray SILT, some Clay, trace fine to coarse Sand, little Gravel.	
75	55	RQD=57		RC-1	52 - 55.8	46/46		52 GRANODIORITE	RC-1: Coring time: 4.5, 5, 4.5, 11 (mins/ft) Wet, gray, pink grained, moderately to severely weathered, coarse grained GRANODIORITE.	
70	60	RQD=55		RC-2	55.8 - 60.8	60/60			RC-2: Coring time: 6, 5, 3.5, 2.5, 2 (mins/ft) Similar to RC-1.	
		RQD=73		RC-3	60.8 - 62.8	24/24			RC-3: Coring time: 2, 3.5 (mins/ft) Similar to RC-1.	
								62.8	Bottom of Borehole at 62.8 feet.	
65	65									
60	70									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

JACOBS	PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-103A	
	LOCATION	Sudbury, MA			
	OWNER	MASSDOT			
	JOB NUMBER	E2X81800		SHEET 1 OF 1	

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	S. Cooley	ELEVATION	142.5

METHOD OF DRILLING		GROUNDWATER READINGS							
					DRILL RIG	Acker Soil Scout	DATUM		NAVD 88
0.0	Split Spoon Sample	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb R&C Safety	GRID	N	2960021
10.0	Terminated	09-03-2019 /		None Encountered			COORD	E	677573
							DATE START		9/3/19
							DATE END		9/3/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
		2 3 2 2	5	S1	0 - 2	24/10		FILL	S1: (0-4") Topsoil. Dry, black, medium SAND, trace Gravel. (4-10") Dry, brown, fine SAND, trace Silt.	
140		1 3 3 4	6	S2	2 - 4	24/12			S2: Dry, loose, brown, medium SAND, little Gravel.	
		3 3 3 3	6	S3	4 - 6	24/16			S3: Dry, loose, brown, fine to medium SAND, some Silt.	
	5									
		3 4 3 5	7	S4	6 - 8	24/17			S4: Dry, loose, brown, fine to medium SAND, little Silt.	
135										
		2 8 50/5"	50/5"	S5	8 - 9.4	17/12			S5: Dry, very dense, brown, medium to coarse SAND, little Gravel, trace Silt.	
	10	50/0"	50/0"	S6	10 - 10	0/0		10	Bottom of Borehole at 10 feet.	1 2
130										
	15									
125										
	20									
120										
	25									
115										
	30									
110										
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Boring terminated at 10' due to an obstruction.
2. Boring offset 5' north and continued. See boring log BB-103B.

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-103B
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 2

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	S. Cooley	ELEVATION	142.5
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Acker Soil Scout	DATUM	NAVD 88
0.0	Split Spoon Sample	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb R&C Safety	GRID COORD N	2960026
14.0	Wash Boring w/ 3" Casing	09-04-2019 / 7:07 am	9.4	During Drilling (In Casing)			E	677573
31.5	NX Rock Core						DATE START	9/3/19
41.5	Terminated						DATE END	9/4/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
									Drill through.	
140										
	5									
135										
	▼									
	10	3 3 1 3	4	S6	10 - 12	24/18			S6: Wet, medium stiff, brownish black SILT and fine SAND, trace roots.	
130		4 5 8 9	13	S7	12 - 14	24/22			S7: Wet, stiff, brownish black SILT and fine SAND, trace roots.	
	15	2 6 7 11	13	S8	14 - 16	24/15			S8: Wet, stiff, black, non-plastic SILT, some fine Sand, trace wood chips, faint organic odor in sample.	1
		14 14 15 17	29	S9	16 - 18	24/21		SILT	S9: Wet, very stiff, brown, non-plastic SILT, trace fine Sand.	
125										
		21 12 11 12	23	S10	18 - 20	24/16			S10: Similar to S9.	
	20									
120										
								24		
	25	64 24 24 14	48	S11	24 - 26	24/16			S11: Wet, dense, gray, fine to coarse GRAVEL, little medium to coarse Sand.	
115								GRAVEL		
	30	26 41 44 50/5"	85	S12	29 - 30.9	23/14			S12: Wet, very dense, gray, fine to coarse SAND and fine GRAVEL, little non-plastic Silt.	
								31.5		
110				RC-1	31.5 - 36.5	60/57			RC-1: Coring time: 3.5, 3, 3.5, 3.5, 3 (mins/ft) Wet, gray, fine grained, slightly weathered, mildly fractured METAVOLCANIC ROCK.	
		RQD=94								
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Some likely wash recovered in sample.

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail
LOCATION	Sudbury, MA
OWNER	MASSDOT
JOB NUMBER	E2X81800

BORING NO. BB-103B

SHEET 2 OF 2

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
				RC-2	36.5 - 41.5	60/60		METAVOLCANIC ROCK	RC-2: Coring time: 3, 4, 3.5, 2.5, 4 (mins/ft) Similar to RC-1.	
105										
		RQD=78								
	40									
								41.5	Bottom of Borehole at 41.5 feet.	
100										
	45									
95										
	50									
90										
	55									
85										
	60									
80										
	65									
75										
	70									
70										

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

JACOBS	PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-105
	LOCATION	Sudbury, MA		
	OWNER	MASSDOT		
	JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	B. Cross	ELEVATION	189
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Mobile B-53	DATUM	NAVD 88
0.0	Wash Boring w/ 4" Casing	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID N	2964468
20.7	Terminated	08-29-2019 / 12:48 pm	4.0	Upon Completion (In Casing)			COORD E	678994
							DATE START	8/29/19
							DATE END	8/29/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
		3 3 8 7	11	S1	0 - 2	24/11		FILL	S1: (0-4") Ballast. Moist, medium dense, black, medium SAND, trace fine Gravel, trace Silt.	
		9 11 14 14	25	S2	2 - 4	24/16			S2: Moist, medium dense, brown, fine to medium SAND, some Silt.	
185	▼	7 10 14 12	24	S3	4 - 6	24/16			S3: Similar to S2.	
	5	11 14 21 34	35	S4	6 - 8	24/24		8	S4: Moist to wet, dense, brown, medium to coarse SAND, little fine Gravel, little Silt.	
180		25 24 29 32	53	S5	8 - 10	24/14		SAND	S5: Wet, very dense, brown, fine to coarse SAND and fine Gravel, little Silt.	
	10	22 22 19 20	41	S6	10 - 12	24/12			S6: Wet, very dense, brown, medium SAND and fine GRAVEL, trace Silt.	
		25 22 21 31	43	S7	12 - 14	24/10			S7: Wet, very dense, brown, fine to coarse SAND, some fine to coarse GRAVEL, trace Silt.	
175	15	11 12 38 50/4"	50	S8	14 - 15.8	22/11		15.8	S8: Wet, very dense, brown, medium SAND, some fine Gravel, little Silt.	
		50/5"	50/5"	S9	16 - 16.4	5/4		GRAVEL	S9: Wet, very dense, brown, fine GRAVEL, some coarse Sand.	
170		4 1 8 50/5"	9	S10	18 - 19.9	23/8			S10: Wet, loose, gray, fine GRAVEL, trace coarse Sand.	
	20	26 50/2"	50/2"	S11	20 - 20.7	8/5		20.7	S11: Wet, very dense, gray, fine GRAVEL, trace coarse Sand. Bottom of Borehole at 20.7 feet.	

ELEV. (ft)	185	180	175	170	165	160	155
DEPTH (ft)	5	10	15	20	25	30	35

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-106
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	B. Cross	ELEVATION	188
METHOD OF DRILLING		GROUNDWATER READINGS		DRILL RIG	Mobile B-53	DATUM	NAVD 88
0.0	Split Spoon Sample	DATE/TIME	DEPTH(ft)	REMARKS / SPT HAMMER	140 lb Auto	GRID N	2964318
4.0	Wash Boring w/ 4" Casing	08-29-2019 / 9:54 am	2.5	Upon Completion (In Casing)		COORD E	678940
20.4	Terminated					DATE START	8/29/19
						DATE END	8/29/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
		1 3 4 9	7	S1	0 - 2	24/7		FILL	S1: (0-4") Ballast. Moist, loose, blackish brown, medium SAND, trace Gravel, trace Silt.	
185		12 15 20 24	35	S2	2 - 4	24/14			S2: Moist, dense, brown, fine to medium SAND, some Silt.	
	5	11 18 15 11	33	S3	4 - 6	24/15		6	S3: Wet, dense, brown, fine to medium SAND, some Silt.	
		7 9 11 12	20	S4	6 - 8	24/24		SILT 8	S4: Wet, very stiff, brown SILT, little fine Sand.	
180		6 8 9 10	17	S5	8 - 10	24/22		SAND	S5: Wet, medium dense, brown, coarse SAND, some Silt, trace Gravel.	
	10	4 4 4 3	8	S6	10 - 12	24/16			S6: Wet, loose, brown, fine SAND and SILT, trace Clay.	
175		4 32 23 17	55	S7	12 - 14	24/19			S7: Wet, very dense, brown, coarse SAND, little Silt, trace Gravel.	
	15	14 12 11 9	23	S8	14 - 16	24/10			S8: Wet, medium dense, brown, coarse SAND, little fine Gravel, trace Silt.	
170		9 16 15 49	31	S9	16 - 18	24/19			S9: Wet, very dense, brown, medium SAND, some fine Gravel, trace Silt.	
		6 17 25 50/3"	42	S10	18 - 19.8	21/21			S10: Wet, very dense, brown, fine to coarse SAND, little fine Gravel, little Silt.	
	20	50/5"	50/5"	S11	20 - 20.4	5/5		20.4	S11: Similar to S10. Bottom of Borehole at 20.4 feet.	
165	25									
160	30									
155	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-107A
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	B. Cross	ELEVATION		187
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Mobile B-53	DATUM		NAVD 88
0.0	Wash Boring w/ 4" Casing	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID	N	2964170
7.5	Wash Boring w/ 3" Casing	08-28-2019 / 12:08 pm	1.1	Upon Completion (Casing pulled)			COORD	E	678879
11.0	Terminated						DATE START		8/28/19
							DATE END		8/28/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
	▼	1 6 8 16	14	S1	0 - 2	24/18		FILL	S1: (0-9") Ballast. Dry, medium dense, brown, medium SAND, trace Gravel, trace Silt.	
185		15 17 15 16	32	S2	2 - 4	24/20		4	S2: Moist, dense, brown, fine to medium SAND, some Silt.	
	5	6 8 7 7	15	S3	4 - 6	24/18		SILT	S3: Moist, stiff, brown SILT, little fine to medium Sand.	
		9 50/4"	50/4"	S4	6 - 6.8	10/10		6.8	S4: Wet, hard, brown SILT, some fine to medium Sand, trace Clay.	
180				RC-1	6.8 - 7.8	12/0		BLDR 8.3	RC-1: Coring time: 3.5 mins/ft. No recovery. Probable boulder.	
		21 24 22 50/5"	46	RC-2 S5	8 - 8.3 8.3 - 10.2	3/3 23/14		SAND	RC-2: Coring time: 2.5 mins/ 0.25 ft. Boulder. S5: Wet, dense, brown, coarse SAND, some fine Gravel, little Silt.	
	10	50/5"	50/5"	S6	10.3 - 10.7	5/5		11	S6: Wet, very dense, gray, fine GRAVEL, trace coarse Sand. Bottom of Borehole at 11 feet.	1 2
175										
	15									
170										
	20									
165										
	25									
160										
	30									
155										
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Unable to drill boring any deeper than 11' due to obstruction.
2. Boring offset 5' to the south and continued. See boring log BB-107B.

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-107B
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	B. Cross	ELEVATION	187
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Mobile B-53	DATUM	NAVD 88
0.0	Wash Boring w/ 4" Casing	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID N	2964165
20.0	Terminated	08-28-2019 / 3:14 pm	3.0	Upon Completion (In Casing)			COORD E	678879
							DATE START	8/28/19
							DATE END	8/28/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
185 180 175	5 10								Drill through.	
		2 3 9 50/5"	12	S7	12.5 - 14.4	23/5		GRAVEL	S7: Wet, medium dense, gray, fine GRAVEL and medium to coarse SAND, trace Silt.	
	15	50/3"	50/3"	S8	14.5 - 14.8	3/2			S8: Wet, very dense, brown, fine GRAVEL, little coarse Sand.	
170		50/3"	50/3"	S9	16 - 16.3	3/3			S9: Similar to S8.	
		50/2"	50/2"	S10	18 - 18.2	2/0			S10: No recovery.	
	20	50/0"	50/0"	S11	20 - 20	0/0		20	Bottom of Borehole at 20 feet.	
165 160 155	25 30 35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

JACOBS

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-108
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	B. Cross
				DRILL RIG	Mobile B-53
				SPT HAMMER	140 lb Auto

ELEVATION	185		
DATUM	NAVD 88		
GRID COORD	N	2964023	
	E	678818	
DATE START	8/27/19		
DATE END	8/27/19		

METHOD OF DRILLING	
0.0	Wash Boring w/ 4" Casing
16.0	NX Rock Core
26.0	Terminated

GROUNDWATER READINGS		
DATE/TIME	DEPTH(ft)	REMARKS
08-27-2019 / 3:17 pm	6.7	During Drilling (In Casing)

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
185		1 3 7 12	10	S1	0 - 2	24/14		FILL	S1: (0-5") Ballast. Dry, medium dense, brown, fine to medium SAND, little Silt, trace Gravel.	
		15 14 12 16	26	S2	2 - 4	24/20		4	S2: Moist to wet, medium dense, brown, fine to medium SAND, some Silt.	
		6 7 6 4	13	S3	4 - 6	24/18		SILT	S3: Wet, stiff, brown, non-plastic SILT, trace fine Gravel.	
180	5									
		6 9 12 54/5"	21	S4	6 - 7.9	23/16		8	S4: Wet, very stiff, brown SILT, trace Clay, trace fine Sand.	
		50/5"	50/5"	S5	8 - 8.4	5/0		GRAVEL	S5: No recovery.	
175	10									
		16 45 22 19	67	S6	10 - 12	24/9			S6: Wet, very dense, grayish brown GRAVEL, little coarse Sand, little Silt.	
		36 20 21 39	41	S7	12 - 14	24/24			S7: Wet, dense, grayish brown, fine to coarse SAND, some fine Gravel, some non-plastic Silt.	
		50 50/4"	50/4"	S8	14 - 14.8	10/6			S8: Wet, very dense, blackish gray GRAVEL, trace Silt, trace medium Sand (rock fragments in spoon tip).	
170	15							16		
		RQD=38		RC-1	16 - 21	60/60		METAVOLCANIC ROCK	RC-1: Coring time: 3, 4, 6, 6, 5 (mins/ft) Wet, gray, fine grained, highly fractured, severely weathered METAVOLCANIC ROCK.	
165	20									
		RQD=80		RC-2	21 - 26	60/60			RC-2: Coring time: 6, 6, 5, 8.5, 5.5 (mins/ft) Similar to RC-1.	
160	25							26	Bottom of Borehole at 26 feet.	
155	30									
150	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

LOG OF TEST BORING

PROJECT	Bruce Freeman Rail Trail	BORING NO.	BB-109A
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC	DRILLER	B. Cross	ELEVATION	184
				DRILL RIG	Mobile B-53	DATUM	NAVD 88
				SPT HAMMER	140 lb Auto	GRID COORD	N 2963876 E 678746
						DATE START	8/26/19
						DATE END	8/26/19

METHOD OF DRILLING	
0.0	Hollow Stem Auger
9.0	Terminated

GROUNDWATER READINGS		
DATE/TIME	DEPTH(ft)	REMARKS
08-26-2019 / 3:00 pm		Refer to log BB-109B for GW readings.

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
		1 4 8 10	12	S1	0 - 2	24/16		FILL 2	S1: Dry, medium dense, blackish brown, medium SAND, little fine Gravel.	
		9 33 35 20	68	S2	2 - 4	24/18			S2: Dry, very dense, brown, medium SAND, some Silt, trace fine Gravel.	
180	5	14 36 40 39	76	S3	4 - 6	24/19		SAND	S3: Dry, very dense, brown SAND and GRAVEL, some Silt.	
		18 39 44 54/5"	83	S4	6 - 7.9	23/16		7.9	S4: Wet, very dense, brown, fine to medium SAND, some fine Gravel, some Silt.	
		50/5"	50/5"	S5	8 - 8.4	5/5		GRAVEL 9	S5: Wet, very dense, gray, fine GRAVEL, trace coarse Sand, trace Silt.	1
175									Bottom of Borehole at 9 feet.	2
	10									
170	15									
165	20									
160	25									
155	30									
150	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

1. Auger could not drill any further at 9' Terminated boring at 9'.
2. Boring offset 4' north and continued. See boring log BB-109B.

LOG OF TEST BORING

JACOBS	PROJECT	Bruce Freeman Rail Trail		BORING NO.	BB-109B
	LOCATION	Sudbury, MA			
	OWNER	MASSDOT			
	JOB NUMBER	E2X81800			SHEET 1 OF 1

INSPECTOR	S. Ramesh	CONTRACTOR	NEBC		DRILLER	B. Cross	ELEVATION		184
METHOD OF DRILLING		GROUNDWATER READINGS			DRILL RIG	Mobile B-53	DATUM		NAVD 88
0.0	Wash Boring w/ 4" Casing	DATE/TIME	DEPTH(ft)	REMARKS	SPT HAMMER	140 lb Auto	GRID	N	2963880
11.0	NX Rock Core	08-27-2019 / 7:21 am	2.5	During Drilling (In Casing)			COORD	E	678746
21.0	Terminated						DATE START		8/26/19
							DATE END		8/27/19

ELEV. (ft)	DEPTH (ft)	SAMPLE DATA	N-VALUE	SAMPLE NO.	DEPTH INTERVAL (ft)	PEN/REC (in)/(in)	PID (ppm)	LAYER NAME	SOIL AND ROCK DESCRIPTION	NOTES
									Drill through.	
	▼									
180										
	5									
175										
	10									
				RC-1	11 - 16	60/60		METAVOLCANIC ROCK	RC-1: Coring time: 4.5, 4, 4, 2.5, 3.5 (mins/ft) Wet, gray, fine grained, highly fractured, moderately weathered METAVOLCANIC ROCK.	
170		RQD=17								
	15									
				RC-2	16 - 19.5	42/42			RC-2: Coring time: 4.5, 3, 2.5 (mins/ft), 2 (mins/0.5 ft) Similar to RC-1.	
		RQD=36								
165										
	20			RC-3	19.5 - 21	18/18			RC-2: Coring time: 1 (min/0.5 ft), 3 (mins/ft). Similar to RC-1.	
		RQD=25						21	Bottom of Borehole at 21 feet.	
160										
	25									
155										
	30									
150										
	35									

Page 1: 0-35 feet. Each subsequent page displays 40 feet.

NOTES

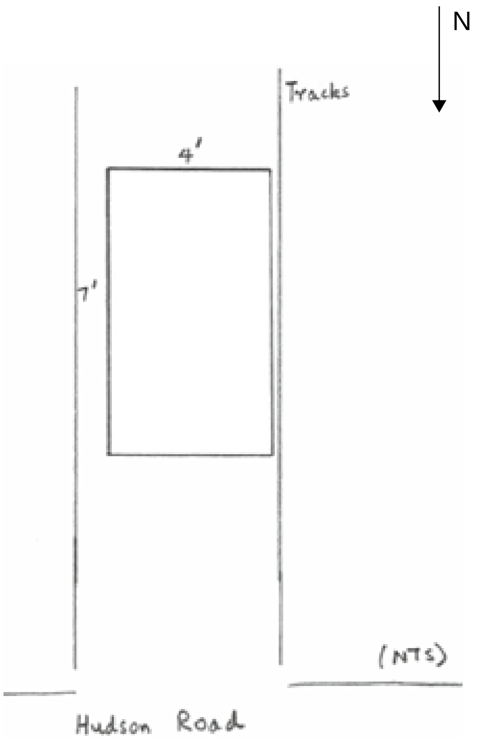
LOG OF TEST PIT

JACOBS	PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-201
	LOCATION	Sudbury, MA		
	OWNER	MASSDOT		SHEET 1 OF 1
	JOB NUMBER	E2X81800		

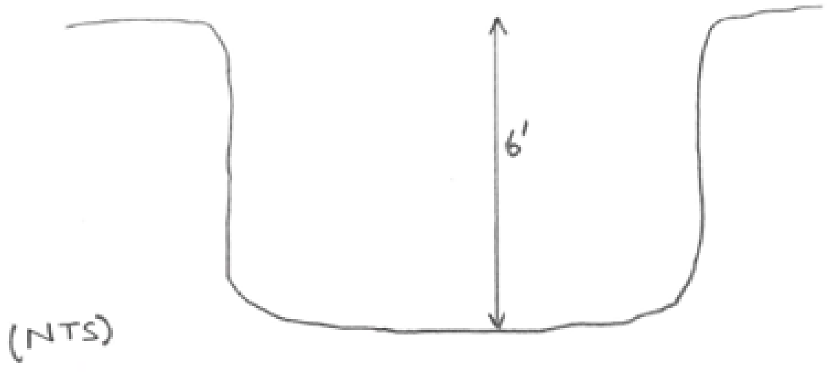
CONTRACTOR	NEBC	GROUNDWATER READING			OPERATOR	B. Cross	ELEVATION		191
EXCAVATOR	Kubota KX057-4	DATE/TIME	DEPTH(ft)	REMARKS	INSPECTOR	S. Ramesh	DATUM		NAVD88
BUCKET	1/3 cubic yard	08-15-2019 / 8:31 am	5.5	Water seeping in	DATE START	8/15/2019	GRID	N	2964546
					DATE END	8/15/2019	COORD	E	679010

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Ballast and topsoil.
		190.00	Moist, brown, medium to coarse SAND, some Silt, trace to little Gravel. Boulders noted at 3'.
		187.00	Moist, brown, fine to coarse GRAVEL, little to some Sand, little Silt.
5		▼	
		185.00	
10			Test pit was terminated at 6 feet due to water seeping in.
15			
20			

PLAN VIEW



SKETCHES



REMARKS:
Test pit was conducted at the boardwalk section at approximately Sta. 174+50. Bag sample was collected at 6' at the bottom of test pit.

LEGEND

▼ WATER LEVEL	⧗ JAR SAMPLE	⊠ BAG SAMPLE

RELATIVE PROPORTIONS

< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-201

LOG OF TEST PIT

JACOBS

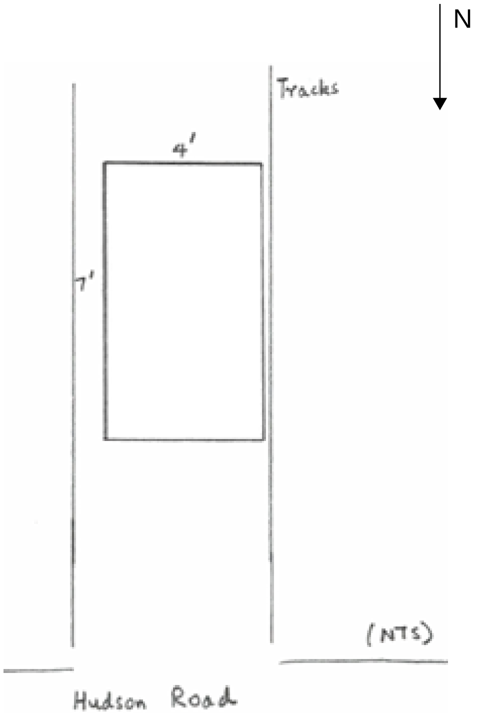
PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-202
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

CONTRACTOR	NEBC	GROUNDWATER READING		
EXCAVATOR	Kubota KX057-4	DATE/TIME	DEPTH(ft)	REMARKS
BUCKET	1/3 cubic yard	08-14-2019 / 3:00 pm	3.5	Water seeping in

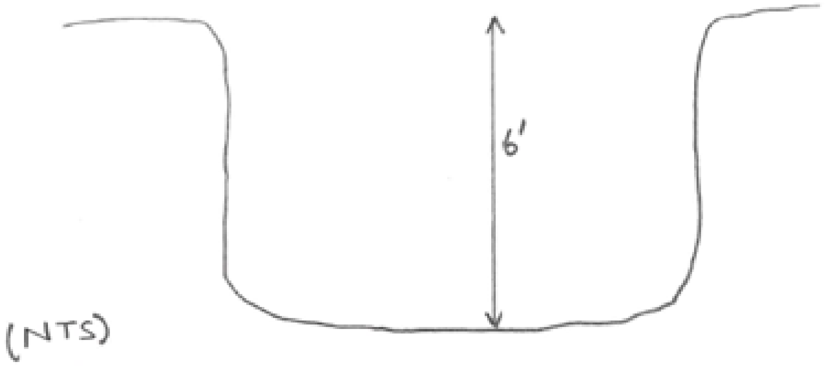
OPERATOR	B. Cross	ELEVATION		189
INSPECTOR	S. Ramesh	DATUM		NAVD88
DATE START	8/14/2019	GRID	N	2964394
DATE END	8/14/2019	COORD	E	678968

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Ballast and topsoil.
		188.00	Moist, brown, medium to coarse SAND, little Gravel, little Silt.
		18[illegible]0	Moist, brown, coarse SAND, trace Gravel, some Silt.
5			
		183.00	Boulder encountered at 6'. Could not excavate further. Test pit terminated at 6'.
10			
15			
20			

PLAN VIEW



SKETCHES



REMARKS:

Test pit was conducted at the boardwalk section at approximately Sta. 173+00. Bag sample was collected at 6' at the bottom of test pit.

LEGEND

▼ WATER LEVEL ⧗ JAR SAMPLE ⧖ BAG SAMPLE

RELATIVE PROPORTIONS	
< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-202

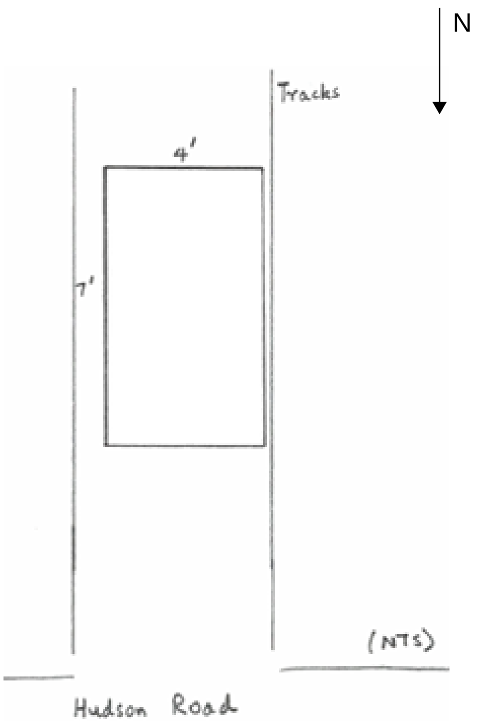
LOG OF TEST PIT

JACOBS	PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-203
	LOCATION	Sudbury, MA		
	OWNER	MASSDOT		
	JOB NUMBER	E2X81800		SHEET 1 OF 1

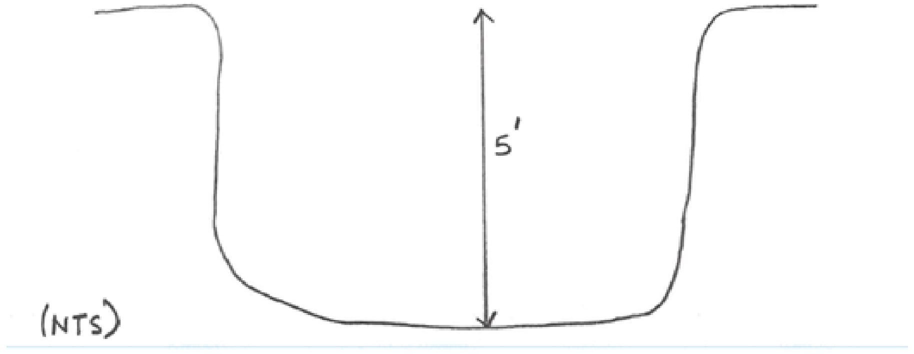
CONTRACTOR	NEBC	GROUNDWATER READING			OPERATOR	B. Cross	ELEVATION		187.5
EXCAVATOR	Kubota KX057-4	DATE/TIME	DEPTH(ft)	REMARKS	INSPECTOR	S. Ramesh	DATUM		NAVD88
BUCKET	1/3 cubic yard	08-14-2019 / 2:02 pm	3	Water seeping in	DATE START	8/14/2019	GRID	N	2964245
					DATE END	8/14/2019	COORD	E	678910

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Ballast and topsoil.
		186.50	Moist, brown, medium to coarse SAND and GRAVEL, little Silt.
	▼	185.50	Moist, brown, fine to coarse GRAVEL, some Sand, some Silt. Boulders ranging from 1' to 1.5' in width encountered between depths 2' to 5'.
5		182.50	
			Very dense gravel encountered at 5'. Could not excavate further. Test pit terminated at 5'.
10			
15			
20			

PLAN VIEW



SKETCHES



REMARKS:

Test pit was conducted at the boardwalk section at approximately Sta. 171+50. Bag sample was collected at 5' at the bottom of test pit.

LEGEND

▼ WATER LEVEL	⧗ JAR SAMPLE	☒ BAG SAMPLE

RELATIVE PROPORTIONS			
< 10%	TRACE	TEST PIT NO.	TP-203
10 - 20%	LITTLE		
20 - 35%	SOME		
35 - 50%	AND		

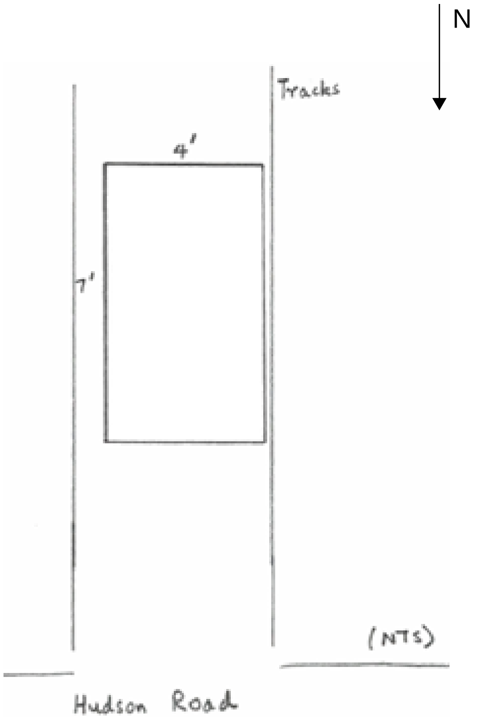
LOG OF TEST PIT

JACOBS	PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-204
	LOCATION	Sudbury, MA		
	OWNER	MASSDOT		SHEET 1 OF 1
	JOB NUMBER	E2X81800		

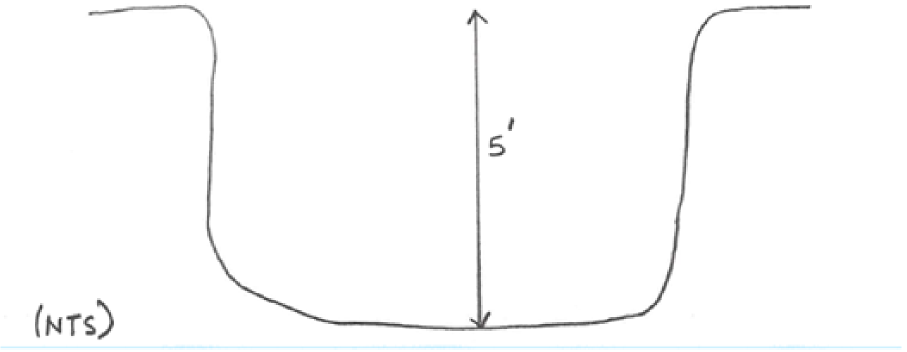
CONTRACTOR	NEBC	GROUNDWATER READING			OPERATOR	B. Cross	ELEVATION		185.5
EXCAVATOR	Kubota KX057-4	DATE/TIME	DEPTH(ft)	REMARKS	INSPECTOR	S. Ramesh	DATUM		NAVD88
BUCKET	1/3 cubic yard	08-14-2019 / 12:54 pm	3.5	Water seeping in	DATE START	8/14/2019	GRID	N	2964096
					DATE END	8/14/2019	COORD	E	678850

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
0			Ballast and topsoil.
		184.50	Moist, brown, medium to coarse SAND, trace to little Gravel, little Silt. Boulders noted at 2-4' depth.
		▼	
		181.50	Moist to wet, brown, medium to coarse SAND, some Gravel, some Silt. Boulder noted at 5'.
5		180.50	
			Test pit was terminated at 5 feet due to water seeping in.
10			
15			
20			

PLAN VIEW



SKETCHES



REMARKS:

Test pit was conducted at the boardwalk section at approximately Sta. 170+00. Bag sample was collected at 5' at the bottom of test pit.

LEGEND

▼ WATER LEVEL	⧗ JAR SAMPLE	☒ BAG SAMPLE

RELATIVE PROPORTIONS

< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-204

LOG OF TEST PIT

PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-205
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

CONTRACTOR	NEBC	OPERATOR	B. Cross
EXCAVATOR	Kubota KX057-4	INSPECTOR	S. Ramesh
BUCKET	1/3 cubic yard	DATE START	8/14/2019
		DATE END	8/14/2019

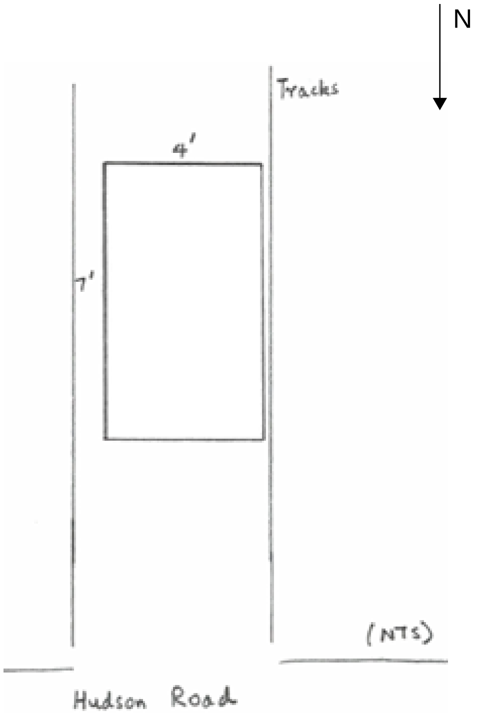
GROUNDWATER READING

DATE/TIME	DEPTH(ft)	REMARKS
08-14-2019 / 12:05 pm	3	Water seeping in

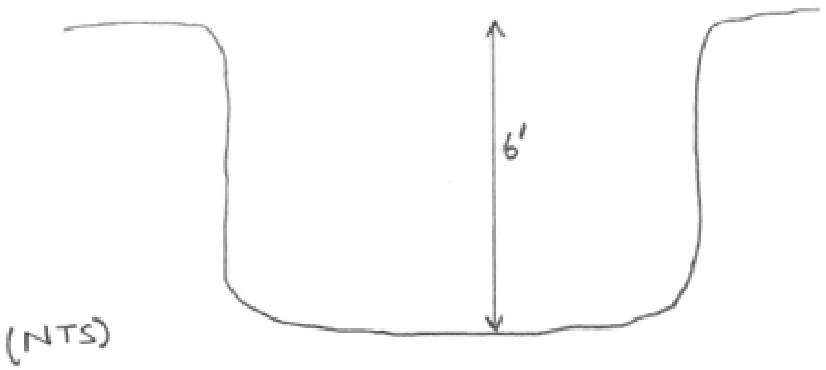
ELEVATION		184.5	
DATUM		NAVD88	
GRID COORD	N	2963950	
	E	678785	

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Ballast and topsoil.
		183.50	Moist, brown, medium to coarse SAND, little Gravel, little Silt.
		▼ 181.50	Moist, brown, medium to coarse SAND, some Gravel, some Silt.
		180.50	Moist to wet, coarse SAND and GRAVEL, some Silt.
5			
		178.50	
			Test pit was terminated at 6 feet due to water seeping in.
10			
15			
20			

PLAN VIEW



SKETCHES



REMARKS:

Test pit was conducted at the boardwalk section at approximately Sta. 168+00. Bag sample was collected at 6' at the bottom of test pit.

LEGEND

▼ WATER LEVEL ⧗ JAR SAMPLE ⊠ BAG SAMPLE

RELATIVE PROPORTIONS

< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-205

LOG OF TEST PIT

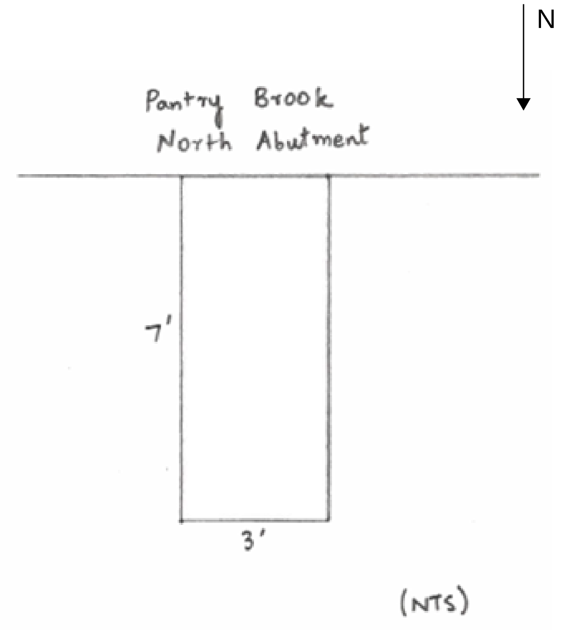
PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-206
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

CONTRACTOR	NEBC	GROUNDWATER READING			OPERATOR	B. Cross
EXCAVATOR	Kubota KX057-4	DATE/TIME	DEPTH(ft)	REMARKS	INSPECTOR	S. Ramesh
BUCKET	1/3 cubic yard	08-12-2019 / 9:00 am		None Encountered	DATE START	8/12/2019
					DATE END	8/12/2019

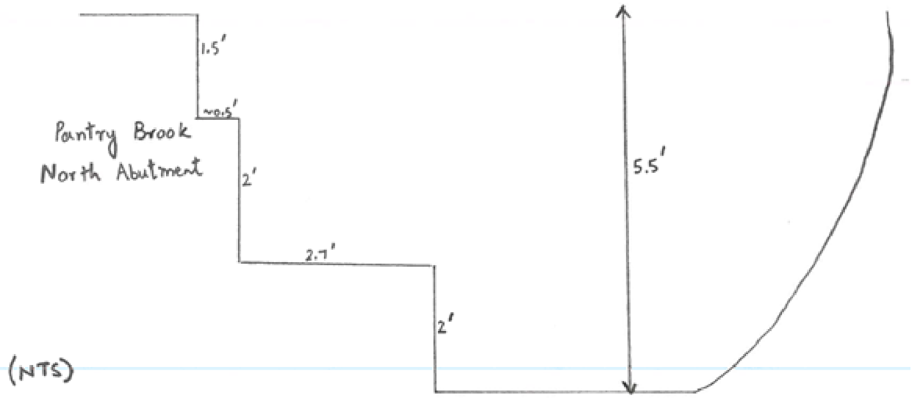
ELEVATION		119
DATUM		NAVD88
GRID	N	2973211
COORD	E	681132

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Dry, dark brown, medium to coarse SAND, some Gravel, trace roots.
		117.00	Dry, brown, fine to medium SAND, little Gravel, little to some Silt.
5		113.50	
10			Test pit was terminated at 5.5 feet.
15			
20			

PLAN VIEW



SKETCHES



REMARKS:
Test pit was conducted at the north abutment of Pantry Brook Bridge. Bag sample was collected at 5.5' at the bottom of test pit.

LEGEND

▼ WATER LEVEL ⧗ JAR SAMPLE ☒ BAG SAMPLE

RELATIVE PROPORTIONS	
< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-206

LOG OF TEST PIT

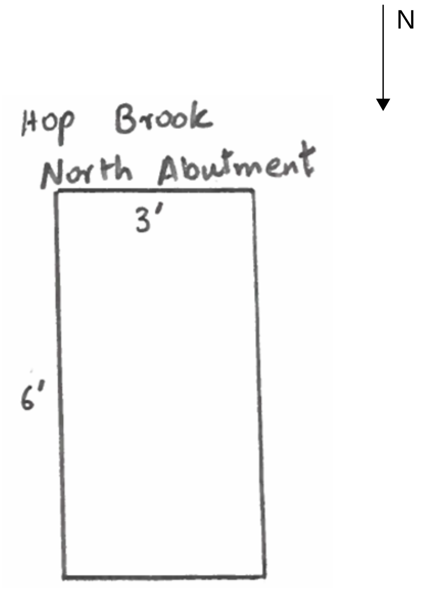
JACOBS

PROJECT	Bruce Freeman Rail Trail	TEST PIT NO.	TP-207
LOCATION	Sudbury, MA		
OWNER	MASSDOT		
JOB NUMBER	E2X81800		SHEET 1 OF 1

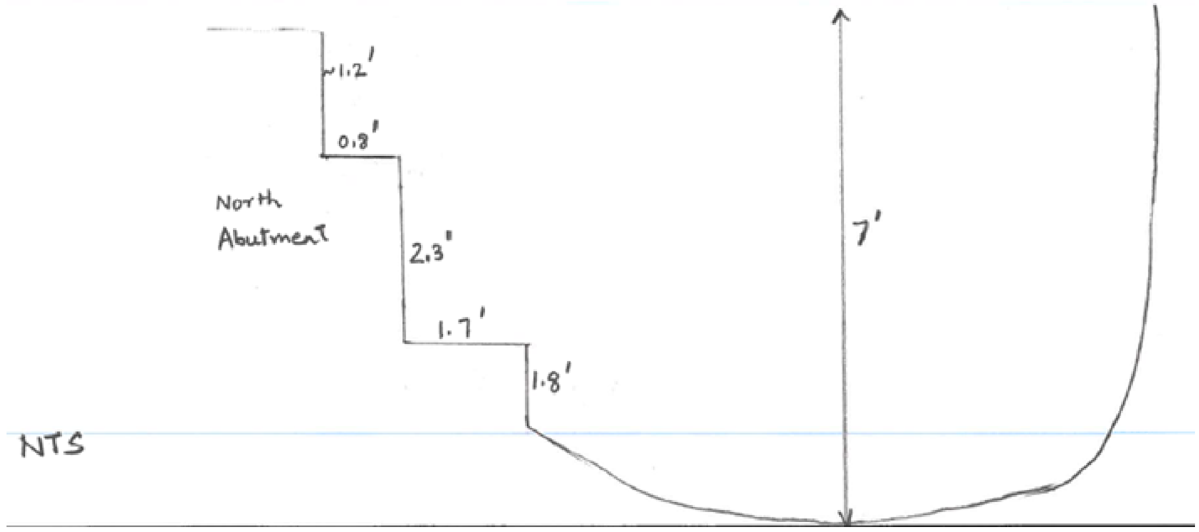
CONTRACTOR	NEBC	GROUNDWATER READING			OPERATOR	D. Thompson	ELEVATION		135
EXCAVATOR	Kubota KX71-3	DATE/TIME	DEPTH(ft)	REMARKS	INSPECTOR	S. Ramesh	DATUM		NAVD88
BUCKET	1/4 cubic yard	08-30-2019 / 9:05 am		None Encountered	DATE START	8/30/2019	GRID	N	2960005
					DATE END	8/30/2019	COORD	E	677570

DEPTH (ft)	STRATA SYMBOL	ELEV (ft)	FIELD CLASSIFICATION AND REMARKS
			Topsoil. Dry, black, medium to coarse SAND, little fine Gravel, little roots.
		134.00	Dry, brown, fine to coarse SAND, some Silt, trace to little, fine Gravel.
		131.00	Dry, brown, fine to medium SAND, some Silt, little to some Gravel.
5			
		128.00	
10			Test pit was terminated at 7 feet.
15			
20			

PLAN VIEW



SKETCHES



REMARKS:

Test pit was conducted at the north abutment of Hop Brook Bridge. Bag sample was collected at 7' at the bottom of test pit.

LEGEND

WATER LEVEL

JAR SAMPLE

BAG SAMPLE

RELATIVE PROPORTIONS

< 10%	TRACE
10 - 20%	LITTLE
20 - 35%	SOME
35 - 50%	AND

TEST PIT NO. TP-207

Appendix C – Laboratory Testing Results

THIELSCH
ENGINEERING

195 Frances Avenue
Cranston RI, 02910
Phone: (401)-467-6454
Fax: (401)-467-2398
thielsch.com
Let's Build a Solid Foundation

Client Information:
Jacobs Engineering Group, Inc.
Boston, MA
PM: Nolan Scheemaker
Assigned By: Nolan Scheemaker
Collected By: Sanjana Ramesh

Project Information:
Bruce Freeman Rail Trail
Sudbury, MA
Jacobs Project Number: E2X81800
Summary Page: 1 of 2
Report Date: 09.20.19

LABORATORY TESTING DATA SHEET

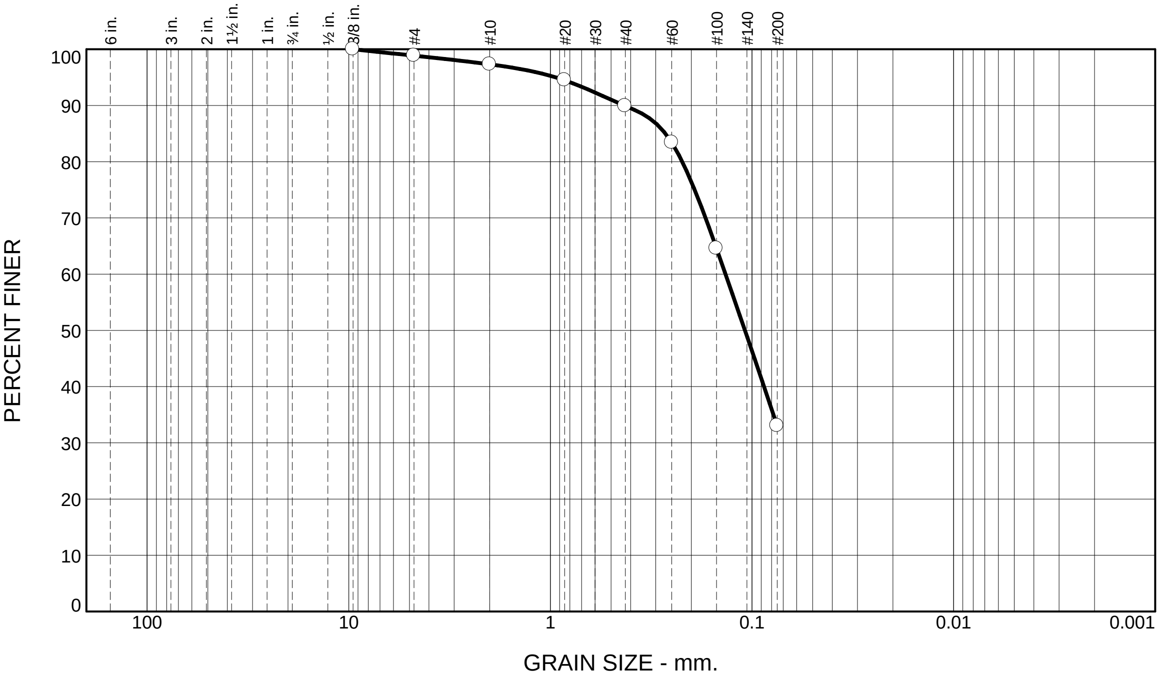
				Identification Tests							Corrosivity Tests								
Boring ID	Sample No.	Depth (ft)	Laboratory No.	As Received Water Content %	LL %	PL %	Gravel %	Sand %	Fines %	Org. %	Resitivity (Mohms-cm)	Sulfate (mg/kg)	Chloride (mg/kg)	Sulfide (mg/kg)	Redox Potential (mv)	pH	Electrical Resist. As Received Ohm-cm @ 60°F	Electrical Resist. Saturated Ohm-cm @ 60°F	Laboratory Log and Soil Description
				D2216	D4318		D6913			D2874	EPA						G57		
TP-201	B-1	6	19-S-1788								0.023	ND	ND			6.15			Analytical Only
TP-202	B-1	6	19-S-1789								0.003	ND	121			6.25			Analytical Only
TP-203	B-1	5	19-S-1790								0.007	ND	ND			6.47			Analytical Only
TP-204	B-1	5	19-S-1791								0.007	ND	39			6.78			Analytical Only
TP-205	B-1	6	19-S-1792								0.007	ND	39			6.83			Analytical Only
BB-101	S3	4-6	19-S-1793	19.3			1.1	65.9	33.0										Light Brown silty sand
BB-101	S8	14-16	19-S-1794	202.8	213	113													Very Dark Brown fine grained peat
BB-101	S9	16-18	19-S-1795	59.3			1.6	63.2	35.2										Dark Brown Organic silty sand
BB-101	S10	18-20	19-S-1796	21.3			6.8	79.9	13.3										Light Brown silty sand
BB-101	S11	24-26	19-S-1797	7.7			45.8	36.1	18.1										Gray silty gravel with sand
BB-102A	S4	6-8	19-S-1798	20.6			0.0	51.8	48.2										Brown silty sand
BB-102A	S7	12-14	19-S-1799	35.5	89	66													Very Dark Brown fine grained peat

Date Received: 09.12.19

Reviewed By:

Date Reviewed: 09.20.19

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.1	1.6	7.4	56.9	33.0	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	98.9		
#10	97.3		
#20	94.5		
#40	89.9		
#60	83.4		
#100	64.6		
#200	33.0		

* (no specification provided)

Material Description

Light Brown silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 0.4297	D_{85}= 0.2687	D_{60}= 0.1353
D_{50}= 0.1084	D_{30}=	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Sample visually classified as non-plastic.

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

Source of Sample: BB-101 **Depth:** 4-6' **Date Sampled:** 08.16.19

Sample Number: S3

Thielsch Engineering Inc.

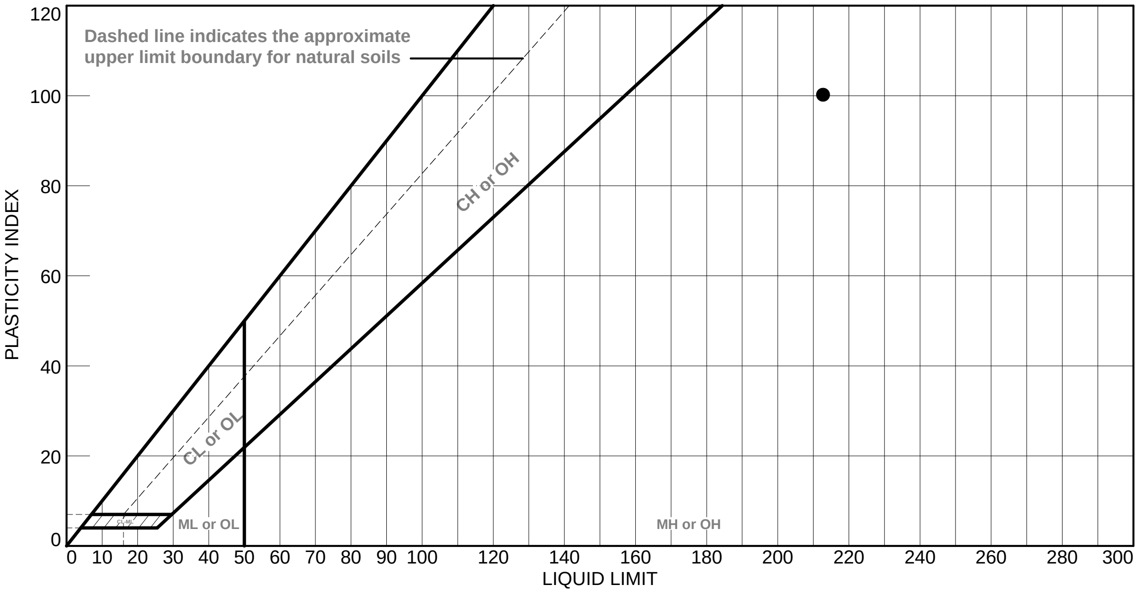
Cranston, RI

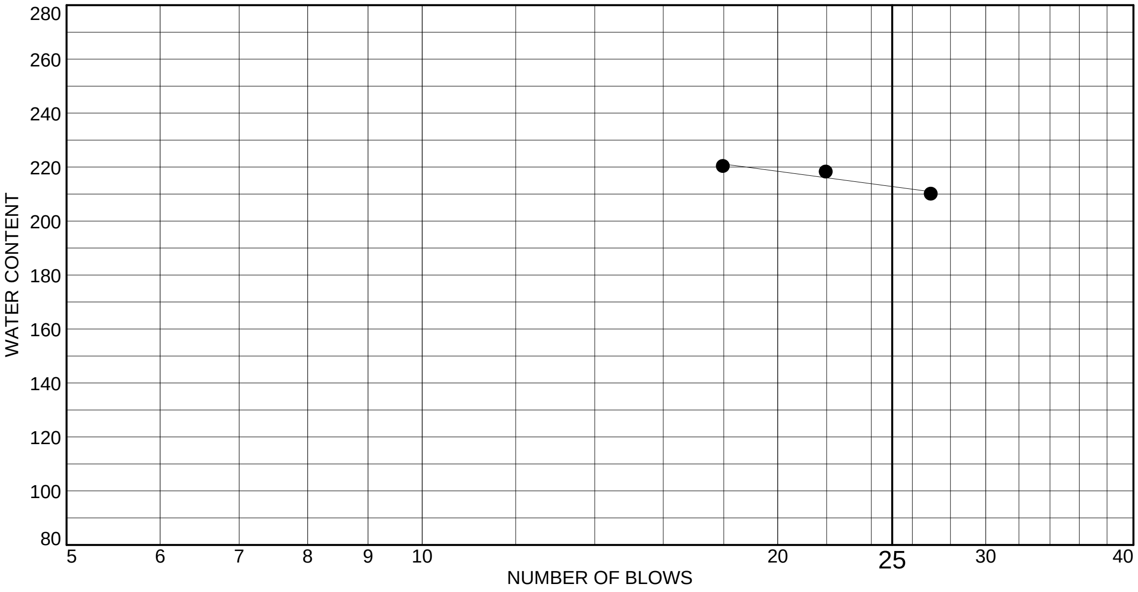
Client: Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail
Sudbury, MA

Project No: 74-19-0002.98 **Figure** 19-S-1793

LIQUID AND PLASTIC LIMITS TEST REPORT





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Very Dark Brown fine grained peat	213	113	100			

Project No. 74-19- **Client:** Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail

Sudbury, MA

Source of Sample: BB-101 **Depth:** 14-16'

Sample Number: S8

Thielsch Engineering Inc.

Cranston, RI

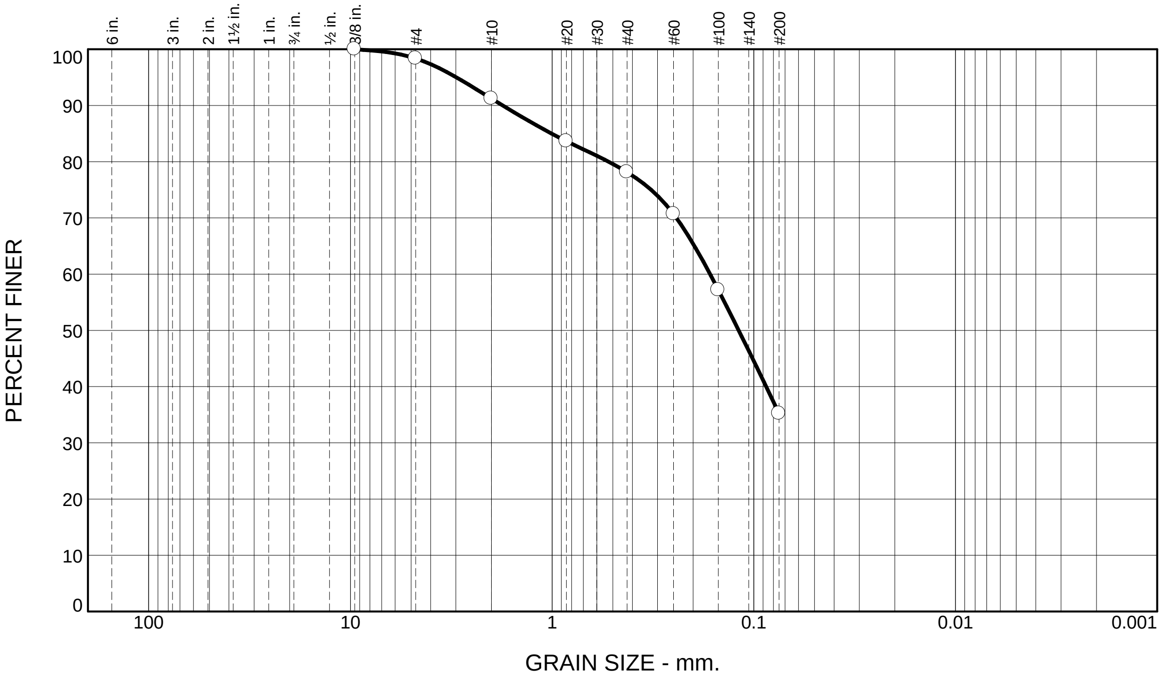
Remarks:

●Sample was washed through a #40 sieve and air dried.

Figure 19-L-1794

Tested By: IA **Checked By:** SA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.6	7.2	13.1	42.9	35.2	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	98.4		
#10	91.2		
#20	83.7		
#40	78.1		
#60	70.7		
#100	57.2		
#200	35.2		

* (no specification provided)

Material Description

Dark Brown Organic silty sand

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= SC **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 1.7575 D_{85}= 1.0043 D_{60}= 0.1648
D_{50}= 0.1188 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Sample visually classified as plastic. Sample rolled to 1/8".

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

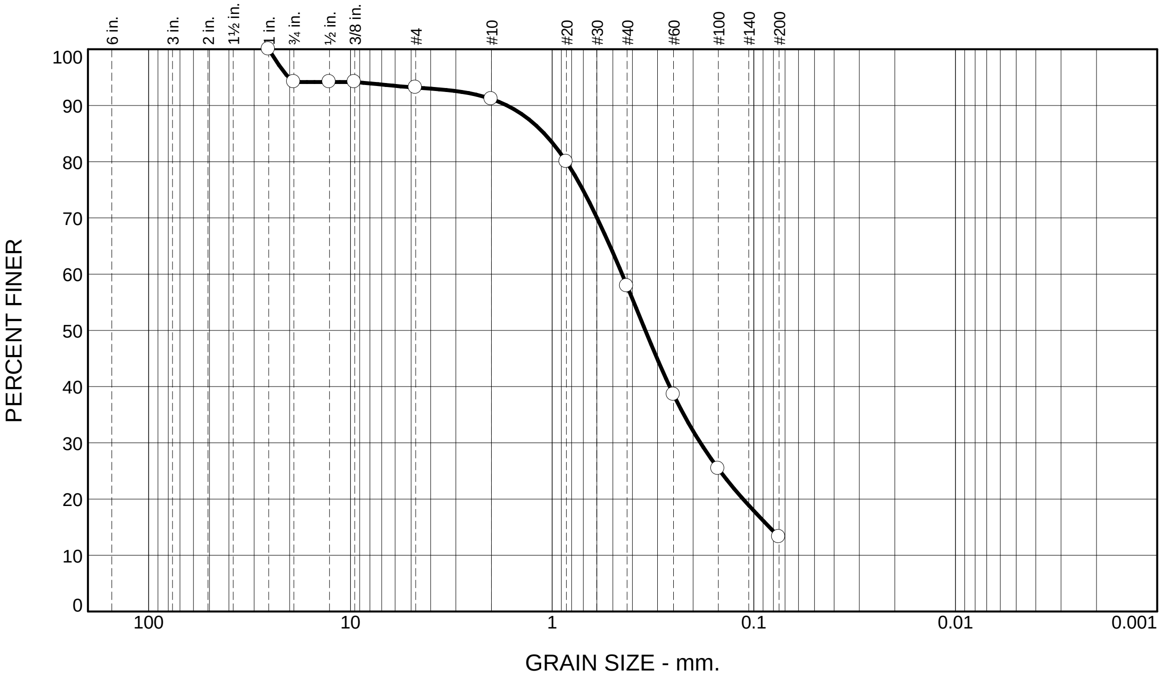
Source of Sample: BB-101 **Depth:** 16-18' **Date Sampled:** 08.16.19
Sample Number: S9

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1795

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	5.8	1.0	2.0	33.3	44.6	13.3	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	94.2		
0.5"	94.2		
0.375"	94.2		
#4	93.2		
#10	91.2		
#20	80.0		
#40	57.9		
#60	38.6		
#100	25.4		
#200	13.3		

* (no specification provided)

Material Description

Light Brown silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 1.6722 D_{85}= 1.0923 D_{60}= 0.4497
D_{50}= 0.3450 D_{30}= 0.1840 D_{15}= 0.0837
D_{10}= C_u= C_c=

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

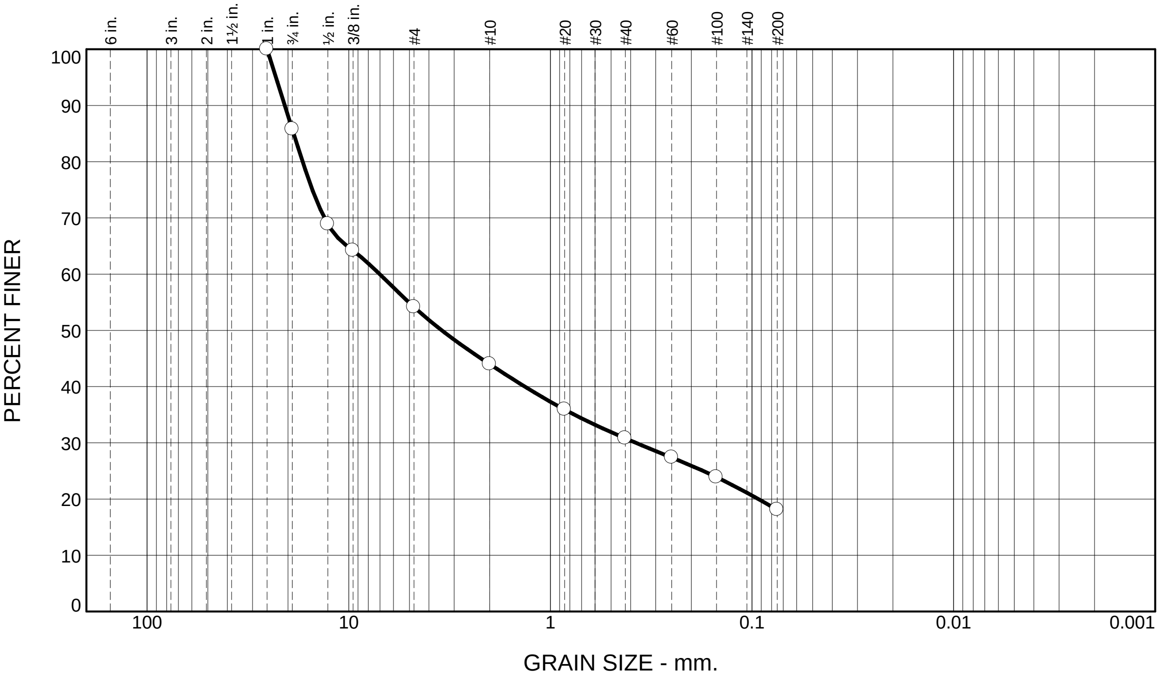
Source of Sample: BB-101 **Depth:** 18-20' **Date Sampled:** 08.16.19
Sample Number: S10

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1796

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	14.2	31.6	10.2	13.2	12.7	18.1	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	85.8		
0.5"	68.9		
0.375"	64.2		
#4	54.2		
#10	44.0		
#20	35.9		
#40	30.8		
#60	27.4		
#100	23.9		
#200	18.1		

* (no specification provided)

Material Description

Gray silty gravel with sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= GM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 20.7500	D_{85}= 18.7520	D_{60}= 7.0172
D_{50}= 3.4548	D_{30}= 0.3765	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

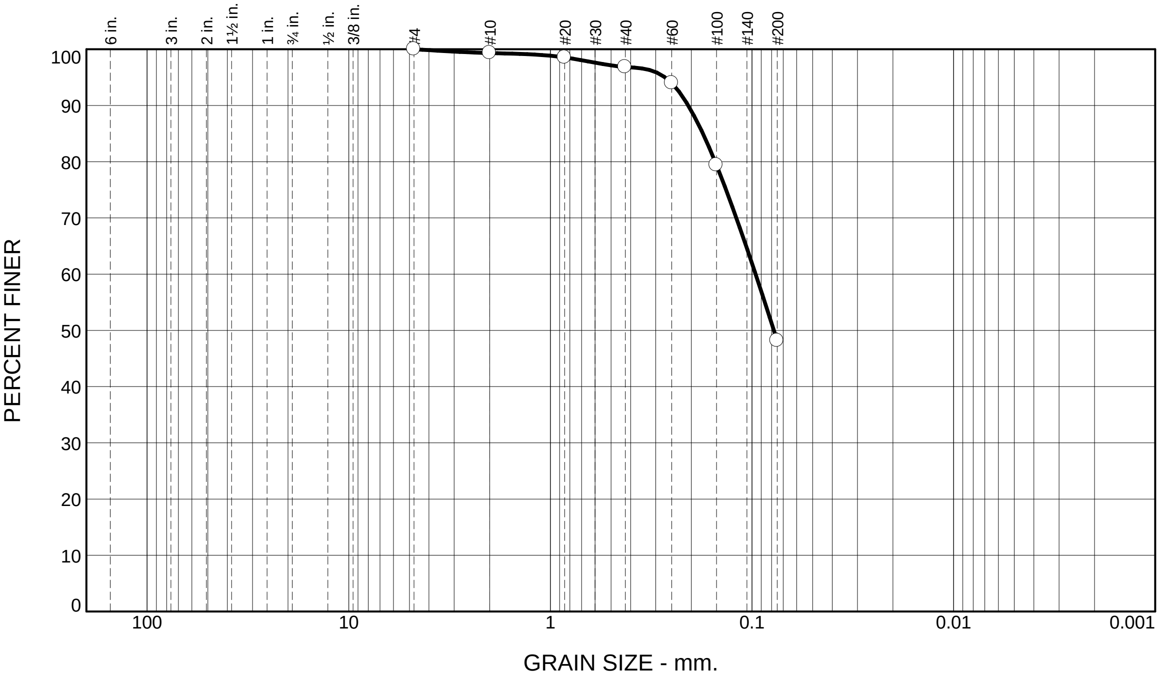
Source of Sample: BB-101 **Depth:** 24-26' **Date Sampled:** 08.16.19
Sample Number: S11

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1797

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.7	2.5	48.6	48.2	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#4	100.0		
#10	99.3		
#20	98.6		
#40	96.8		
#60	94.0		
#100	79.4		
#200	48.2		

* (no specification provided)

Material Description

Brown silty sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 0.2069	D_{85}= 0.1751	D_{60}= 0.0960
D_{50}= 0.0779	D_{30}=	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Sample visually classified as non-plastic.

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

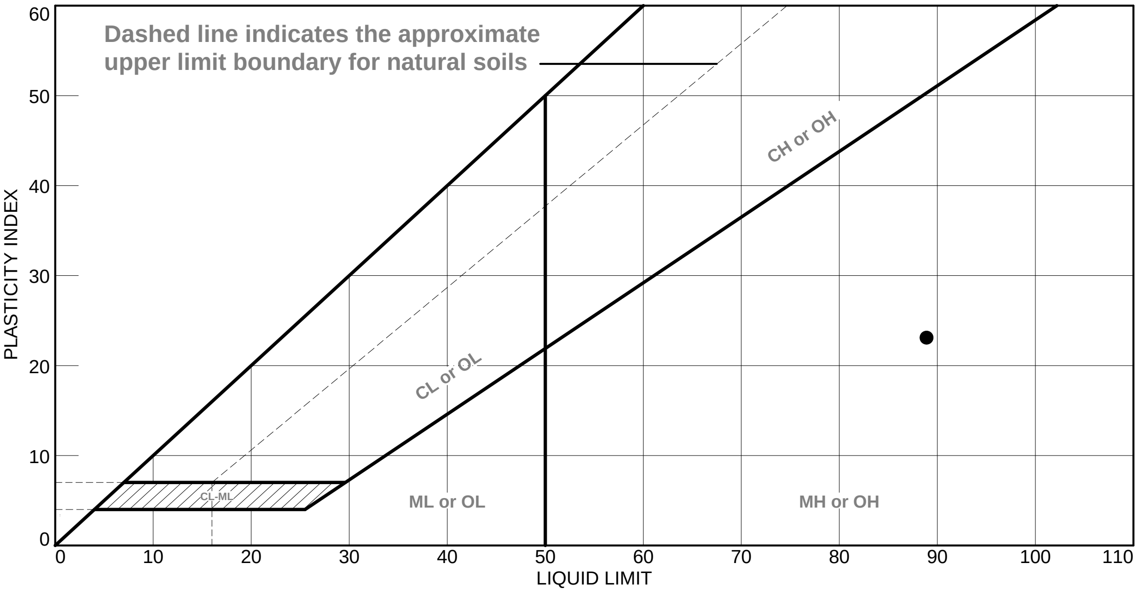
Source of Sample: BB-102A **Depth:** 6-8' **Date Sampled:** 08.20.19
Sample Number: S4

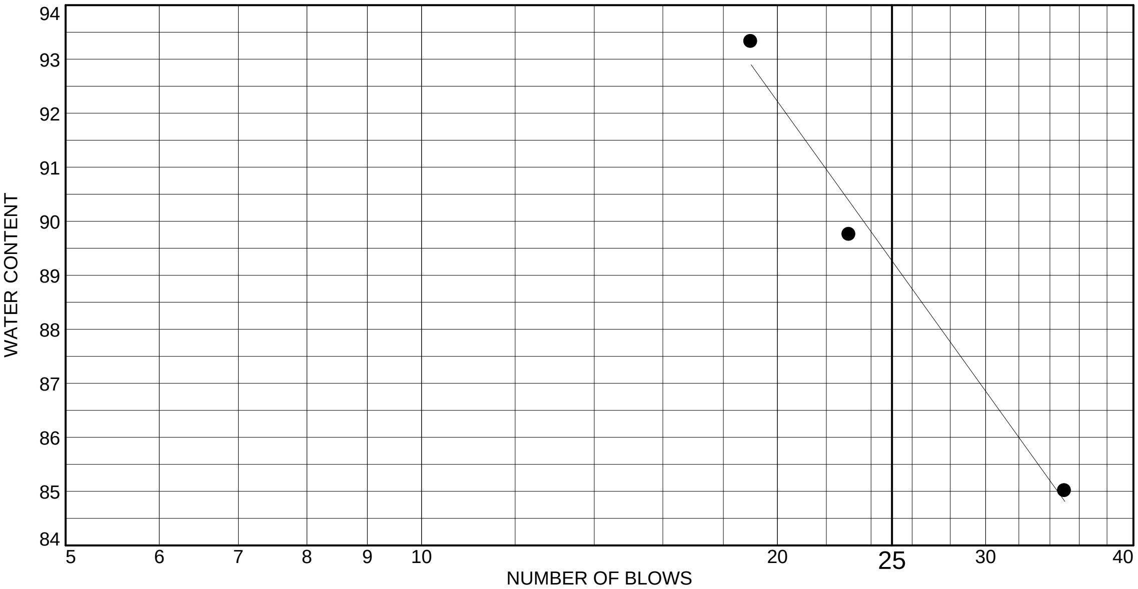
Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1798

LIQUID AND PLASTIC LIMITS TEST REPORT





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Very Dark Brown fine grained peat	89	66	23			

Project No. 74-19- **Client:** Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail

Sudbury, MA

Source of Sample: BB-102A **Depth:** 12-14'

Sample Number: S7

Thielsch Engineering Inc.

Cranston, RI

Remarks:

●Sample was washed through a #40 sieve and air dried.

Figure 19-L-1799

Tested By: IA **Checked By:** SA

ESS Laboratory
Division of Thielsch Engineering, Inc.

BAL Laboratory
The Microbiology Division
of Thielsch Engineering, Inc.

CERTIFICATE OF ANALYSIS

Steve Accetta
Thielsch Engineering, Inc.
195 Frances Avenue
Cranston, RI 02910

RE: Bruce Freeman Rail Trail - Jacobs Engineering (E2X81800)
ESS Laboratory Work Order Number: 19I0383

This signed Certificate of Analysis is our approved release of your analytical results. These results are only representative of sample aliquots received at the laboratory. ESS Laboratory expects its clients to follow all regulatory sampling guidelines. Beginning with this page, the entire report has been paginated. This report should not be copied except in full without the approval of the laboratory. Samples will be disposed of thirty days after the final report has been delivered. If you have any questions or concerns, please feel free to call our Customer Service Department.

REVIEWED
By ESS Laboratory at 1:56 pm, Sep 19, 2019

Laurel Stoddard

Laurel Stoddard
Laboratory Director

Analytical Summary

The project as described above has been analyzed in accordance with the ESS Quality Assurance Plan. This plan utilizes the following methodologies: US EPA SW-846, US EPA Methods for Chemical Analysis of Water and Wastes per 40 CFR Part 136, APHA Standard Methods for the Examination of Water and Wastewater, American Society for Testing and Materials (ASTM), and other recognized methodologies. The analyses with these noted observations are in conformance to the Quality Assurance Plan. In chromatographic analysis, manual integration is frequently used instead of automated integration because it produces more accurate results.

The test results present in this report are in compliance with TNI and relative state standards, and/or client Quality Assurance Project Plans (QAPP). The laboratory has reviewed the following: Sample Preservations, Hold Times, Initial Calibrations, Continuing Calibrations, Method Blanks, Blank Spikes, Blank Spike Duplicates, Duplicates, Matrix Spikes, Matrix Spike Duplicates, Surrogates and Internal Standards. Any results which were found to be outside of the recommended ranges stated in our SOPs will be noted in the Project Narrative.

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering
ESS Laboratory Work Order: 19I0383

SAMPLE RECEIPT

The following samples were received on September 12, 2019 for the analyses specified on the enclosed Chain of Custody Record.

The client did not deliver the samples in a cooler.

Lab Number	Sample Name	Matrix	Analysis
19I0383-01	TP-201	Soil	9038, 9045, 9050A, 9250
19I0383-02	TP-202	Soil	9038, 9045, 9050A, 9250
19I0383-03	TP-203	Soil	9038, 9045, 9050A, 9250
19I0383-04	TP-204	Soil	9038, 9045, 9050A, 9250
19I0383-05	TP-205	Soil	9038, 9045, 9050A, 9250

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering ESS Laboratory Work Order: 19I0383

PROJECT NARRATIVE

No unusual observations noted.

End of Project Narrative.

DATA USABILITY LINKS

To ensure you are viewing the most current version of the documents below, please clear your internet cookies for www.ESSLaboratory.com. Consult your IT Support personnel for information on how to clear your internet cookies.

Definitions of Quality Control Parameters

Semivolatile Organics Internal Standard Information

Semivolatile Organics Surrogate Information

Volatile Organics Internal Standard Information

Volatile Organics Surrogate Information

EPH and VPH Alkane Lists

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering
ESS Laboratory Work Order: 19I0383

CURRENT SW-846 METHODOLOGY VERSIONS

Analytical Methods

1010A - Flashpoint
6010C - ICP
6020A - ICP MS
7010 - Graphite Furnace
7196A - Hexavalent Chromium
7470A - Aqueous Mercury
7471B - Solid Mercury
8011 - EDB/DBCP/TCP
8015C - GRO/DRO
8081B - Pesticides
8082A - PCB
8100M - TPH
8151A - Herbicides
8260B - VOA
8270D - SVOA
8270D SIM - SVOA Low Level
9014 - Cyanide
9038 - Sulfate
9040C - Aqueous pH
9045D - Solid pH (Corrosivity)
9050A - Specific Conductance
9056A - Anions (IC)
9060A - TOC
9095B - Paint Filter
MADEP 04-1.1 - EPH
MADEP 18-2.1 - VPH

Prep Methods

3005A - Aqueous ICP Digestion
3020A - Aqueous Graphite Furnace / ICP MS Digestion
3050B - Solid ICP / Graphite Furnace / ICP MS Digestion
3060A - Solid Hexavalent Chromium Digestion
3510C - Separatory Funnel Extraction
3520C - Liquid / Liquid Extraction
3540C - Manual Soxhlet Extraction
3541 - Automated Soxhlet Extraction
3546 - Microwave Extraction
3580A - Waste Dilution
5030B - Aqueous Purge and Trap
5030C - Aqueous Purge and Trap
5035A - Solid Purge and Trap

SW846 Reactivity Methods 7.3.3.2 (Reactive Cyanide) and 7.3.4.1 (Reactive Sulfide) have been withdrawn by EPA. These methods are reported per client request and are not NELAP accredited.

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering

ESS Laboratory Work Order: 19I0383

Classical Chemistry

Client Sample ID: TP-201
Date Sampled: 09/12/19 14:00
Percent Solids: 91

ESS Laboratory Sample ID: 19I0383-01
Sample Matrix: Soil

Analyte		Results	Units	MRL	Method	DF	Analyst	Analyzed
Chloride	WL	ND	mg/kg dry	33	9250	1	EEM	09/16/19 14:40
Corrosivity (pH)		**6.15**	S.U.	N/A	9045	1	CCP	09/12/19 21:22
Corrosivity (pH) Sample Temp		**Soil pH measured in water at 20.6 °C.**						
Resistivity	WL	**0.023**	Mohms-cm	N/A	9050A	1	EEM	09/17/19 15:40
Sulfate	WL	ND	mg/kg dry	55	9038	1	JLK	09/17/19 15:38

Client Sample ID: TP-202
Date Sampled: 09/12/19 14:00
Percent Solids: 88

ESS Laboratory Sample ID: 19I0383-02
Sample Matrix: Soil

Analyte		Results	Units	MRL	Method	DF	Analyst	Analyzed
Chloride	WL	**121**	mg/kg dry	34	9250	1	EEM	09/16/19 14:41
Corrosivity (pH)		**6.25**	S.U.	N/A	9045	1	CCP	09/12/19 21:22
Corrosivity (pH) Sample Temp		**Soil pH measured in water at 20.6 °C.**						
Resistivity	WL	**0.003**	Mohms-cm	N/A	9050A	1	EEM	09/17/19 15:40
Sulfate	WL	ND	mg/kg dry	56	9038	1	JLK	09/17/19 15:38

Client Sample ID: TP-203
Date Sampled: 09/12/19 14:00
Percent Solids: 89

ESS Laboratory Sample ID: 19I0383-03
Sample Matrix: Soil

Analyte		Results	Units	MRL	Method	DF	Analyst	Analyzed
Chloride	WL	ND	mg/kg dry	33	9250	1	EEM	09/16/19 14:46
Corrosivity (pH)		**6.47**	S.U.	N/A	9045	1	CCP	09/12/19 21:22
Corrosivity (pH) Sample Temp		**Soil pH measured in water at 20.6 °C.**						
Resistivity	WL	**0.007**	Mohms-cm	N/A	9050A	1	EEM	09/17/19 15:40
Sulfate	WL	ND	mg/kg dry	56	9038	1	JLK	09/17/19 15:38

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering
ESS Laboratory Work Order: 19I0383

Classical Chemistry

Client Sample ID: TP-204
Date Sampled: 09/12/19 14:00
Percent Solids: 88
ESS Laboratory Sample ID: 19I0383-04
Sample Matrix: Soil

Analyte		Results	Units	MRL	Method	DF	Analyst	Analyzed
Chloride	WL	**39**	mg/kg dry	34	9250	1	EEM	09/16/19 14:47
Corrosivity (pH)		**6.78**	S.U.	N/A	9045	1	CCP	09/12/19 21:22
Corrosivity (pH) Sample Temp		**Soil pH measured in water at 20.6 °C.**						
Resistivity	WL	**0.007**	Mohms-cm	N/A	9050A	1	EEM	09/17/19 15:40
Sulfate	WL	ND	mg/kg dry	57	9038	1	JLK	09/17/19 15:38

Client Sample ID: TP-205
Date Sampled: 09/12/19 14:00
Percent Solids: 86
ESS Laboratory Sample ID: 19I0383-05
Sample Matrix: Soil

Analyte		Results	Units	MRL	Method	DF	Analyst	Analyzed
Chloride	WL	**39**	mg/kg dry	35	9250	1	EEM	09/16/19 14:48
Corrosivity (pH)		**6.83**	S.U.	N/A	9045	1	CCP	09/12/19 21:22
Corrosivity (pH) Sample Temp		**Soil pH measured in water at 20.6 °C.**						
Resistivity	WL	**0.007**	Mohms-cm	N/A	9050A	1	EEM	09/17/19 15:40
Sulfate	WL	ND	mg/kg dry	58	9038	1	JLK	09/17/19 15:38

Quality Control Data

Classical Chemistry

Analyte	Result	MRL	Units	Spike Level	Source Result	%REC	%REC Limits	RPD	RPD Limit	Qualifier
Batch CI91623 - General Preparation										
Blank										
Chloride	ND	3	mg/kg wet							
LCS										
Chloride	30		mg/L	30.00		100	90-110			
Batch CI91734 - General Preparation										
Blank										
Sulfate	ND	5	mg/kg wet							
LCS										
Sulfate	10		mg/L	9.988		96	80-120			

CERTIFICATE OF ANALYSIS

Client Name: Thielsch Engineering, Inc.
Client Project ID: Bruce Freeman Rail Trail - Jacobs Engineering
ESS Laboratory Work Order: 19I0383

Notes and Definitions

Z-10	Soil pH measured in water at 20.6 ºC.
WL	Results obtained from a deionized water leach of the sample.
U	Analyte included in the analysis, but not detected
ND	Analyte NOT DETECTED at or above the MRL (LOQ), LOD for DoD Reports, MDL for J-Flagged Analytes
dry	Sample results reported on a dry weight basis
RPD	Relative Percent Difference
MDL	Method Detection Limit
MRL	Method Reporting Limit
LOD	Limit of Detection
LOQ	Limit of Quantitation
DL	Detection Limit
I/V	Initial Volume
F/V	Final Volume
§	Subcontracted analysis; see attached report
1	Range result excludes concentrations of surrogates and/or internal standards eluting in that range.
2	Range result excludes concentrations of target analytes eluting in that range.
3	Range result excludes the concentration of the C9-C10 aromatic range.
Avg	Results reported as a mathematical average.
NR	No Recovery
[CALC]	Calculated Analyte
SUB	Subcontracted analysis; see attached report
RL	Reporting Limit
EDL	Estimated Detection Limit
MF	Membrane Filtration
MPN	Most Probably Number
TNTC	Too numerous to Count
CFU	Colony Forming Units

ESS LABORATORY CERTIFICATIONS AND ACCREDITATIONS

ENVIRONMENTAL

Rhode Island Potable and Non Potable Water: LAI00179
http://www.health.ri.gov/find/labs/analytical/ESS.pdf

Connecticut Potable and Non Potable Water, Solid and Hazardous Waste: PH-0750
http://www.ct.gov/dph/lib/dph/environmental_health/environmental_laboratories/pdf/OutofStateCommercialLaboratories.pdf

Maine Potable and Non Potable Water, and Solid and Hazardous Waste: RI00002
http://www.maine.gov/dhhs/mecdc/environmental-health/dwp/partners/labCert.shtml

Massachusetts Potable and Non Potable Water: M-RI002
http://public.dep.state.ma.us/Labcert/Labcert.aspx

New Hampshire (NELAP accredited) Potable and Non Potable Water, Solid and Hazardous Waste: 2424
http://des.nh.gov/organization/divisions/water/dwgb/nhelap/index.htm

New York (NELAP accredited) Non Potable Water, Solid and Hazardous Waste: 11313
http://www.wadsworth.org/labcert/elap/comm.html

New Jersey (NELAP accredited) Non Potable Water, Solid and Hazardous Waste: RI006
http://datamine2.state.nj.us/DEP_OPRA/OpraMain/pi_main?mode=pi_by_site&sort_order=PI_NAMEA&Select+a+Site:=58715

United States Department of Agriculture Soil Permit: P330-12-00139

Pennsylvania: 68-01752
http://www.dep.pa.gov/Business/OtherPrograms/Labs/Pages/Laboratory-Accreditation-Program.aspx

ESS Laboratory Sample and Cooler Receipt Checklist

Client: Thielsch Engineering, Inc - ESS/DS

Shipped/Delivered Via: Client

ESS Project ID: 1910383
Date Received: 9/12/2019
Project Due Date: 9/19/2019
Days for Project: 5 Day

1. Air bill manifest present? No
   Air No.: NA
2. Were custody seals present? No
3. Is radiation count <100 CPM? Yes
4. Is a Cooler Present? No
   Temp: 21.2 Iced with: None
5. Was COC signed and dated by client? Yes
6. Does COC match bottles? Yes
7. Is COC complete and correct? Yes
8. Were samples received intact? Yes
9. **Were labs informed about <u>short holds & rushes</u>?** [✓ Yes] / No / NA
10. Were any analyses received outside of hold time? Yes / [✓ No]

---

11. Any Subcontracting needed? Yes / [✓ No]
    ESS Sample IDs:
    Analysis:
    TAT:
12. Were VOAs received? Yes / [✓ No]
    a. Air bubbles in aqueous VOAs? Yes / No
    b. Does methanol cover soil completely? Yes / No / NA
13. Are the samples properly preserved? [✓ Yes] / No
    a. If metals preserved upon receipt: Date: Time: By:
    b. Low Level VOA vials frozen: Date: Time: By:

Sample Receiving Notes:

14. Was there a need to contact Project Manager? Yes / [✓ No]
    a. Was there a need to contact the client? Yes / No
    Who was contacted? Date: Time: By:

Sample Number	Container ID	Proper Container	Air Bubbles Present	Sufficient Volume	Container Type	Preservative	Record pH (Cyanide and 608 Pesticides)
01	387736	Yes	NA	Yes	8 oz. Jar - Unpres	NP	
02	387735	Yes	NA	Yes	8 oz. Jar - Unpres	NP	
03	387734	Yes	NA	Yes	8 oz. Jar - Unpres	NP	
04	387733	Yes	NA	Yes	8 oz. Jar - Unpres	NP	
05	387732	Yes	NA	Yes	8 oz. Jar - Unpres	NP	

2nd Review

Were all containers scanned into storage/lab? Initials Ur
Are barcode labels on correct containers? [✓ Yes] / No
Are all Flashpoint stickers attached/container ID # circled? Yes / No / [✓ NA]
Are all Hex Chrome stickers attached? Yes / No / [✓ NA]
Are all QC stickers attached? Yes / No / [✓ NA]
Are VOA stickers attached if bubbles noted? Yes / No / [✓ NA]

Completed By: Date & Time: 9/12/19 1606
Reviewed By: Date & Time: 9/12/19 16:27
Delivered By: 9/12/19 16:27

ESS Laboratory
Division of Thielsch Engineering, Inc.
185 Frances Avenue, Cranston, RI 02910-2211
Tel. (401) 461-7181 Fax (401) 461-4486
www.esslaboratory.com

CHAIN OF CUSTODY

ESS LAB PROJECT ID 19I0383

Turn Time Standard X Rush____ Approved By: ___________

Reporting Limits -

State where samples were collected: **MA**

Is this project for any of the following: (please circle)
MA-MCP CT-RCP RGP DOD Other________

Electonic Deliverable Yes_X__ No____
Format: Excel___ Access___ PDF_X_ Other_____

Project Manager: Steven Accetta
Company: Thielsch Engineering, Inc
Address: 195 Frances Ave
Cranston, RI 02910

Project # E2X81800

Project Name/Client Name: Bruce Freeman Rail Trail / Jacobs Engineering Group, Inc.

Contract Pricing __x___
Special Pricing WO#: ________________

ESS Lab Sample ID	Date	Collection Time	Grab -G Composite-C	Matrix	Sample Identification	# of Containers	pH	Sulfate	Chloride	Resistivity								Comment #
1	09.12.19	14:00	G	S	TP-201	1	X	X	X	X								
2	09.12.19	14:00	G	S	TP-202	1	X	X	X	X								
3	09.12.19	14:00	G	S	TP-203	1	X	X	X	X								
4	09.12.19	14:00	G	S	TP-204	1	X	X	X	X								
5	09.12.19	14:00	G	S	TP-205	1	X	X	X	X								
Preservation Code: 1-NP, 2-HCl, 3-H2SO4, 4-HNO3, 5-NaOH, 6-MeOH, 7-Asorbic Acid, 8-ZnAct, 9-_CH_3OH____							1	1	1	1								
Container Type: P-Poly G-Glass AG-Amber Glass S-Sterile V-VOA							AG	AG	AG	AG								

Matrix: S-Soil SD-Solid D-Sludge WW-Wastewater GW-Groundwater SW-Surface Water DW-Drinking Water O-Oil W-Wipes F-Filter

Cooler Present _____Yes X No
Seals Intact _____ Yes _____No NA: _____
Cooler Temperature: 21.2 no ice

Sampled by : Imitiaz Ahmed / Jacobs Engineering

Comments: Please send report to: Matt Colman: mcolman@thielsch.com, Steve Accetta: saccetta@thielsch.com, Rebecca Roth: rroth@thielsch.com

Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)
Imtiaz Ahmed 15:30		9/12/19 1530			
Relinquished by: (Signature)	Date/Time	Received by: (Signature)	Relinquished by: (Signature)	Date/Time	Received by: (Signature)

Please E-mail all changes to Chain of Custody in writing.

Page ____ of ____

THIELSCH
ENGINEERING

195 Frances Avenue
Cranston RI, 02910
Phone: (401)-467-6454
Fax: (401)-467-2398
thielsch.com
Let's Build a Solid Foundation

Client Information:
Jacobs Engineering Group, Inc.
Boston, MA
PM: Nolan Scheemaker
Assigned By: Nolan Scheemaker
Collected By: Sanjana Ramesh

Project Information:
Bruce Freeman Rail Trail
Sudbury, MA
Jacobs Project Number: E2X81800
Summary Page: 2 of 2
Report Date: 09.20.19

LABORATORY TESTING DATA SHEET

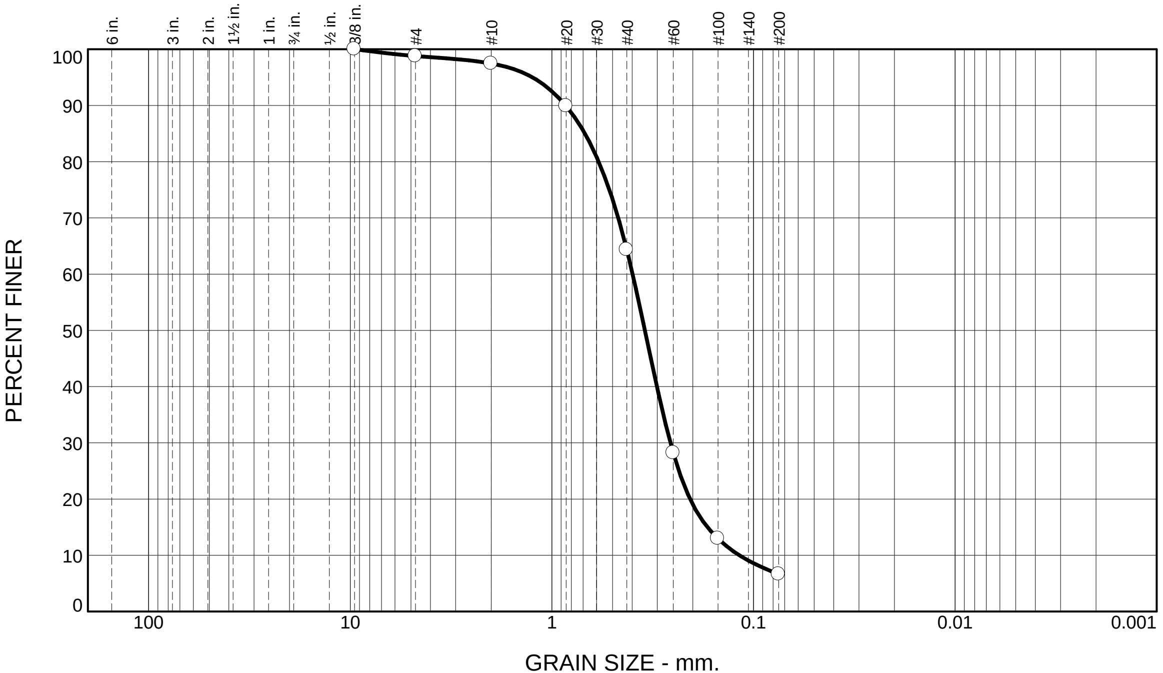
				Identification Tests							Corrosivity Tests								
Boring ID	Sample No.	Depth (ft)	Laboratory No.	As Received Water Content %	LL %	PL %	Gravel %	Sand %	Fines %	Org. %	Resitivity (Mohms-cm)	Sulfate (mg/kg)	Chloride (mg/kg)	Sulfide (mg/kg)	Redox Potential (mv)	pH	Electrical Resist. As Received Ohm-cm @ 60°F	Electrial Resist. Saturated Ohm-cm @ 60°F	Laboratory Log and Soil Description
				D2216	D4318		D6913			D2874	EPA						G57		
BB-102A	S9	16-18	19-S-1800	19.8			1.2	92.2	6.6										Brown poorly graded sand with silt
BB-102A	S11	24-26	19-S-1801	18.5			19.4	15.2	65.4										Gray gravelly silt with sand
BB-103B	S8	14-16	19-S-1802	54.0						5.1									Organic Content Only
BB-103B	S9	16-18	19-S-1803	28.0	NV	NP													Light Brown silt
BB-103B	S12	29-31	19-S-1804	7.5			38.8	45.4	15.8										Light Brown silty sand with gravel
BB-105	S5	8-10	19-S-1805	9.2			35.5	47.6	16.9										Light Brown silty sand with gravel
BB-105	S7	12-14	19-S-1806	9.9			30.5	62.7	6.8										Light Brown well-graded sand with silt and gravel
BB-106	S6	10-12	19-S-1807	25.1			0.0	51.6	48.4										Light Brown silty sand
BB-106	S10	18-19.8	19-S-1808	13.3			19.3	67.6	13.1										Light Brown silty sand with gravel
BB-107B	S7	12.5-14.4	19-S-1809	8.8			50.0	42.2	7.8										Brown well-graded gravel with silt and sand
BB-108	S3	4-6	19-S-1810	28.8	NV	NP													Light Brown silt
BB-108	S7	12-14	19-S-1811	11.8			24.9	49.4	25.7										Light Brown silty sand with gravel

Date Received: *09.12.19*

Reviewed By:

Date Reviewed: *09.20.19*

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	1.2	1.3	33.2	57.7	6.6	

Test Results (D6913 & ASTM D 1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.375"	100.0		
#4	98.8		
#10	97.5		
#20	89.9		
#40	64.3		
#60	28.2		
#100	13.0		
#200	6.6		

* (no specification provided)

Material Description

Brown poorly graded sand with silt

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SP-SM **AASHTO (M 145)=** A-3

Coefficients

D_{90}= 0.8545	D_{85}= 0.6850	D_{60}= 0.3978
D_{50}= 0.3457	D_{30}= 0.2581	D_{15}= 0.1693
D_{10}= 0.1175	C_u= 3.39	C_c= 1.43

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

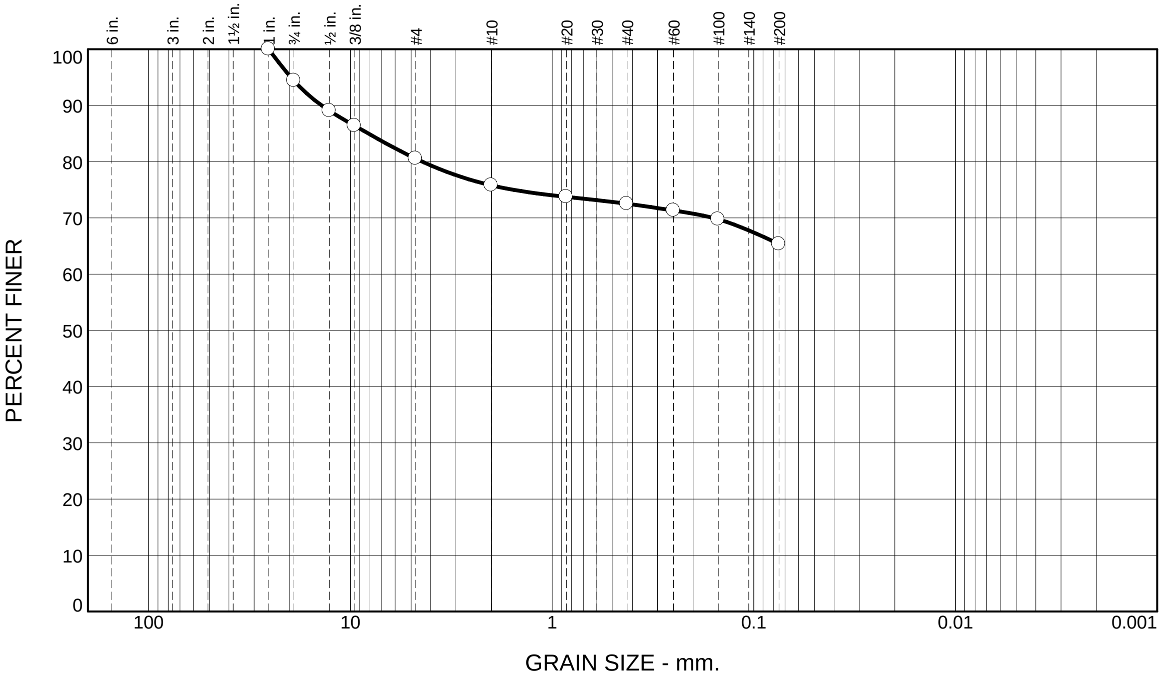
Source of Sample: BB-102A **Depth:** 16-18' **Date Sampled:** 08.20.19
Sample Number: S9

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1800

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	5.6	13.8	4.8	3.3	7.1	65.4	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	94.4		
0.5"	89.1		
0.375"	86.4		
#4	80.6		
#10	75.8		
#20	73.8		
#40	72.5		
#60	71.3		
#100	69.8		
#200	65.4		

* (no specification provided)

Material Description

Gray gravelly silt with sand

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= ML **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 13.8612	D_{85}= 8.1290	D_{60}=
D_{50}=	D_{30}=	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Sample visually classified as plastic. Sample rolled to 1/4".

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

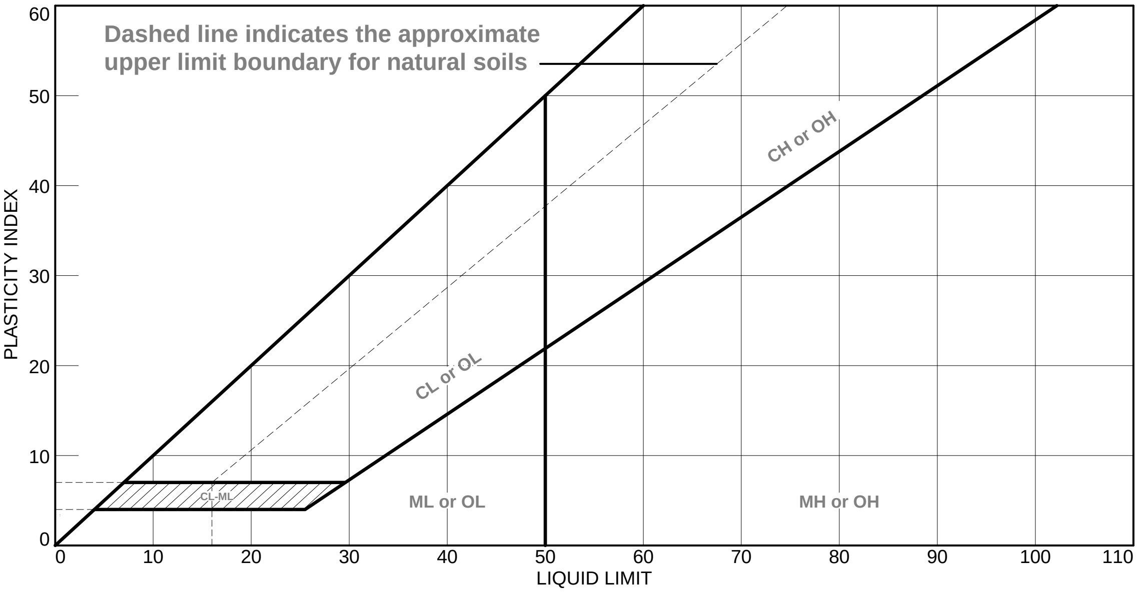
Source of Sample: BB-102A **Depth:** 24-26' **Date Sampled:** 08.20.19
Sample Number: S11

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1801

LIQUID AND PLASTIC LIMITS TEST REPORT



	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Light Brown silt	NV	NP	NP			

Project No. 74-19- **Client:** Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail

Sudbury, MA

Source of Sample: BB-103B **Depth:** 16-18'

Sample Number: S9

Thielsch Engineering Inc.

Cranston, RI

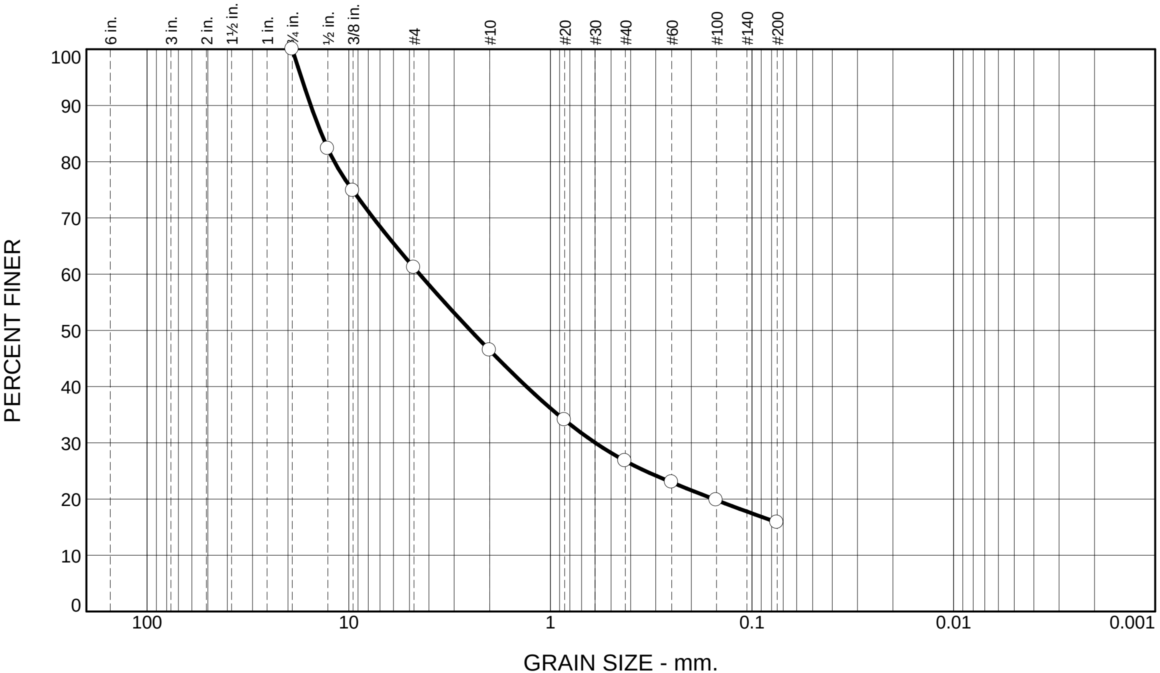
Remarks:

●Sample received with standing water, could not roll past 1/4".

Figure 19-L-1803

Tested By: JM **Checked By:** SA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	38.8	14.7	19.7	11.0	15.8	

Test Results (D6913 & ASTM D 1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.75"	100.0		
0.5"	82.3		
0.375"	74.8		
#4	61.2		
#10	46.5		
#20	34.1		
#40	26.8		
#60	23.0		
#100	19.8		
#200	15.8		

* (no specification provided)

Material Description

Light Brown silty sand with gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 15.4169	D_{85}= 13.6764	D_{60}= 4.4527
D_{50}= 2.4877	D_{30}= 0.5983	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

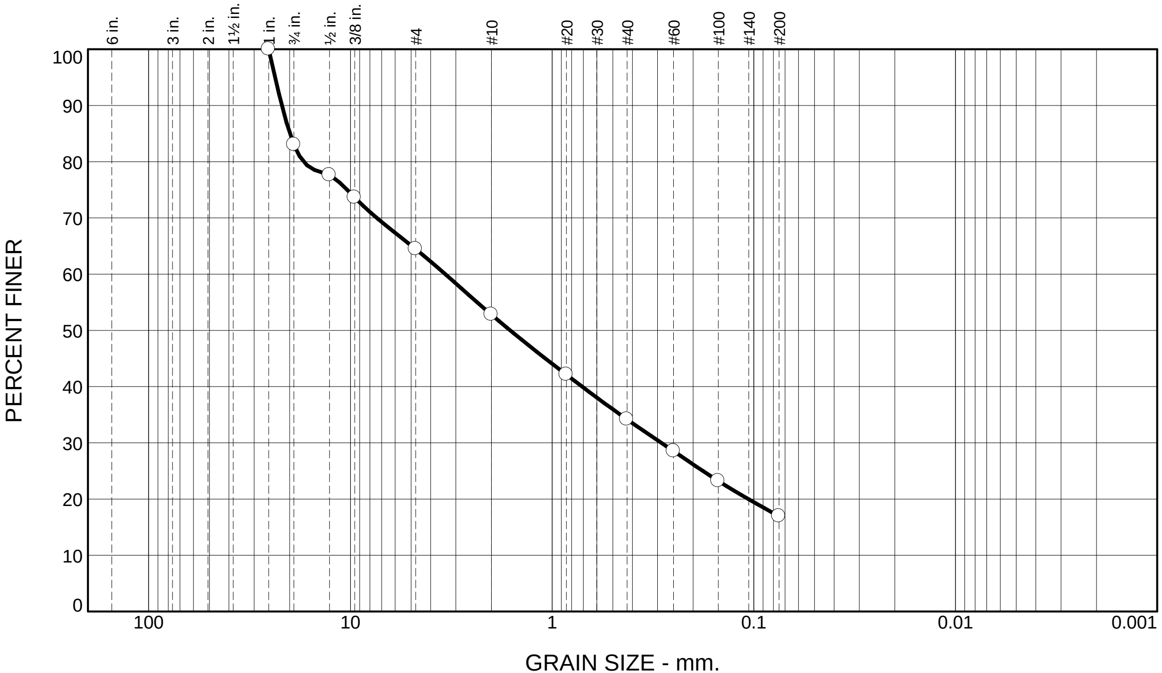
Source of Sample: BB-103B **Depth:** 29-31' **Date Sampled:** 09.03.19
Sample Number: S12

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1804

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	17.0	18.5	11.7	18.6	17.3	16.9	

Test Results (D6913 & ASTM D 1140)			
Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	83.0		
0.5"	77.6		
0.375"	73.6		
#4	64.5		
#10	52.8		
#20	42.1		
#40	34.2		
#60	28.5		
#100	23.2		
#200	16.9		

* (no specification provided)

Material Description

Light Brown silty sand with gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}= 21.8568	D_{85}= 19.9452	D_{60}= 3.3853
D_{50}= 1.6133	D_{30}= 0.2872	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Date Received: 09.12.19 **Date Tested:** 09.12.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

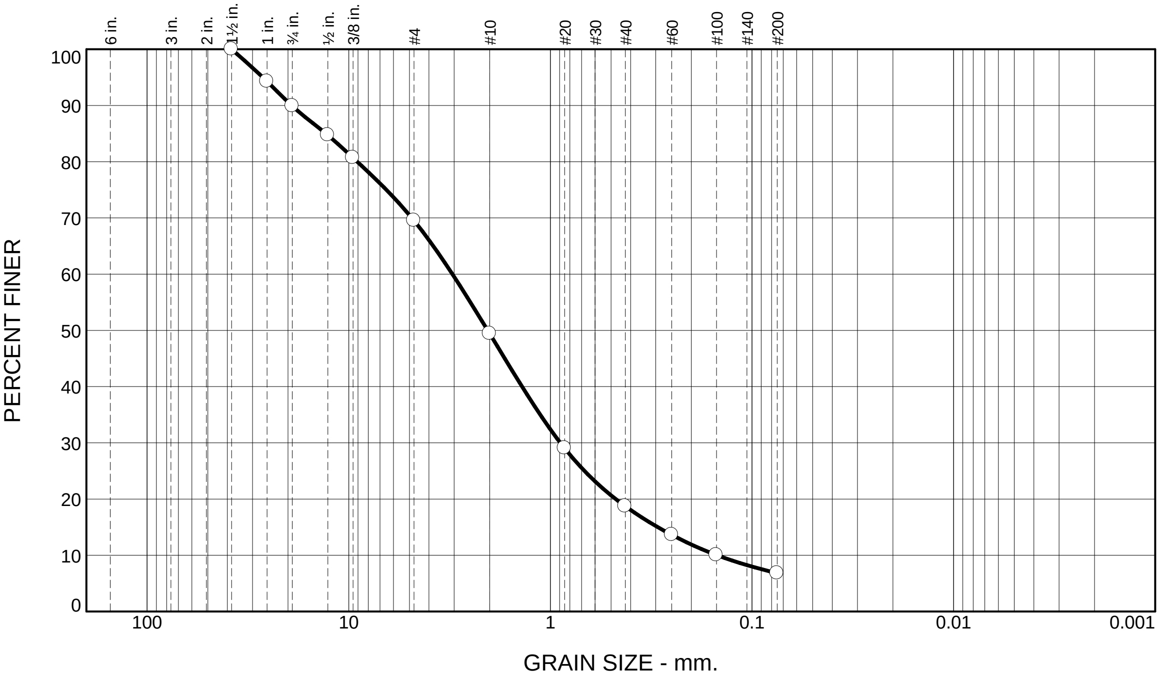
Source of Sample: BB-105 **Depth:** 8-10' **Date Sampled:** 08.29.19
Sample Number: S5

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1805

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	10.1	20.4	20.1	30.7	11.9	6.8	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1-1/2"	100.0		
1"	94.3		
3/4"	89.9		
1/2"	84.7		
3/8"	80.7		
#4	69.5		
#10	49.4		
#20	29.0		
#40	18.7		
#60	13.6		
#100	10.0		
#200	6.8		

* (no specification provided)

Material Description

Light Brown well-graded sand with silt and gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SW-SM **AASHTO (M 145)=** A-1-a

Coefficients

D_{90}= 19.1859 D_{85}= 12.9746 D_{60}= 3.0588
D_{50}= 2.0455 D_{30}= 0.8919 D_{15}= 0.2930
D_{10}= 0.1490 C_u= 20.53 C_c= 1.75

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

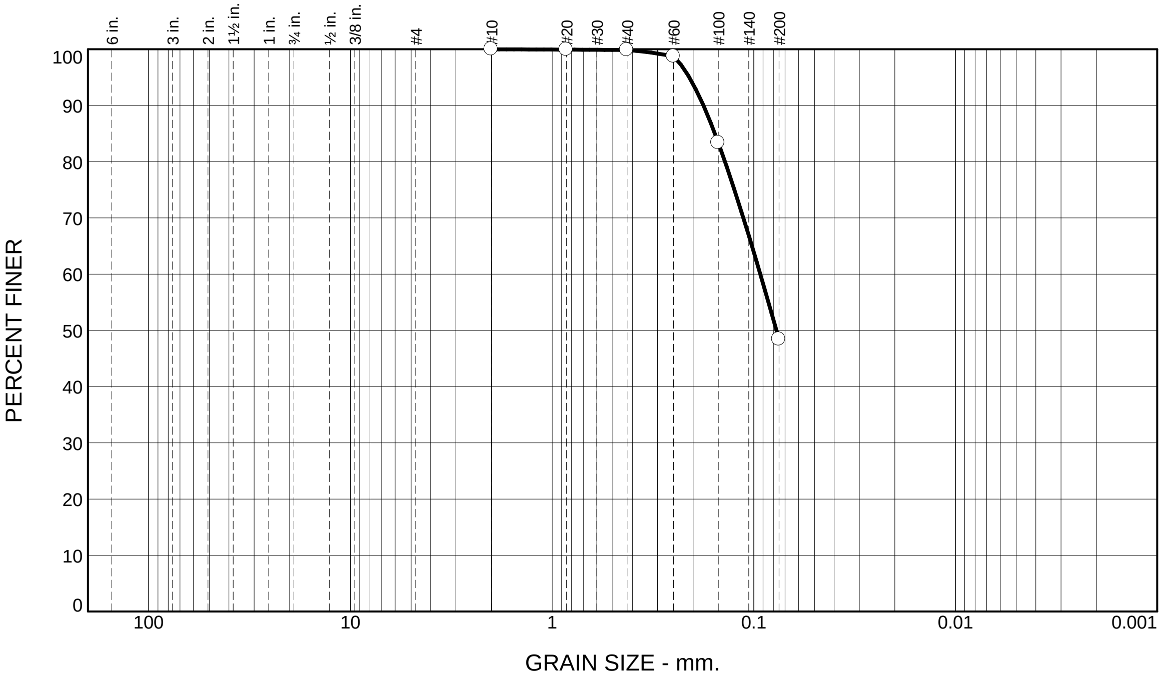
Source of Sample: BB-105 **Depth:** 12-14' **Date Sampled:** 08.29.19
Sample Number: S7

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1806

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	0.0	0.0	0.1	51.5	48.4	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
#10	100.0		
#20	99.9		
#40	99.9		
#60	98.7		
#100	83.4		
#200	48.4		

* (no specification provided)

Material Description

Light Brown silty sand

Atterberg Limits (ASTM D 4318)

PL= **LL=** **PI=**

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-4(0)

Coefficients

D_{90}= 0.1777 D_{85}= 0.1560 D_{60}= 0.0929
D_{50}= 0.0772 D_{30}= D_{15}=
D_{10}= C_u= C_c=

Remarks

Sample visually classified as plastic. Sample rolled to 1/4".

Date Received: 09.12.19 **Date Tested:** 09.16.19
Tested By: IA / JM
Checked By: Steven Accetta
Title: Laboratory Coordinator

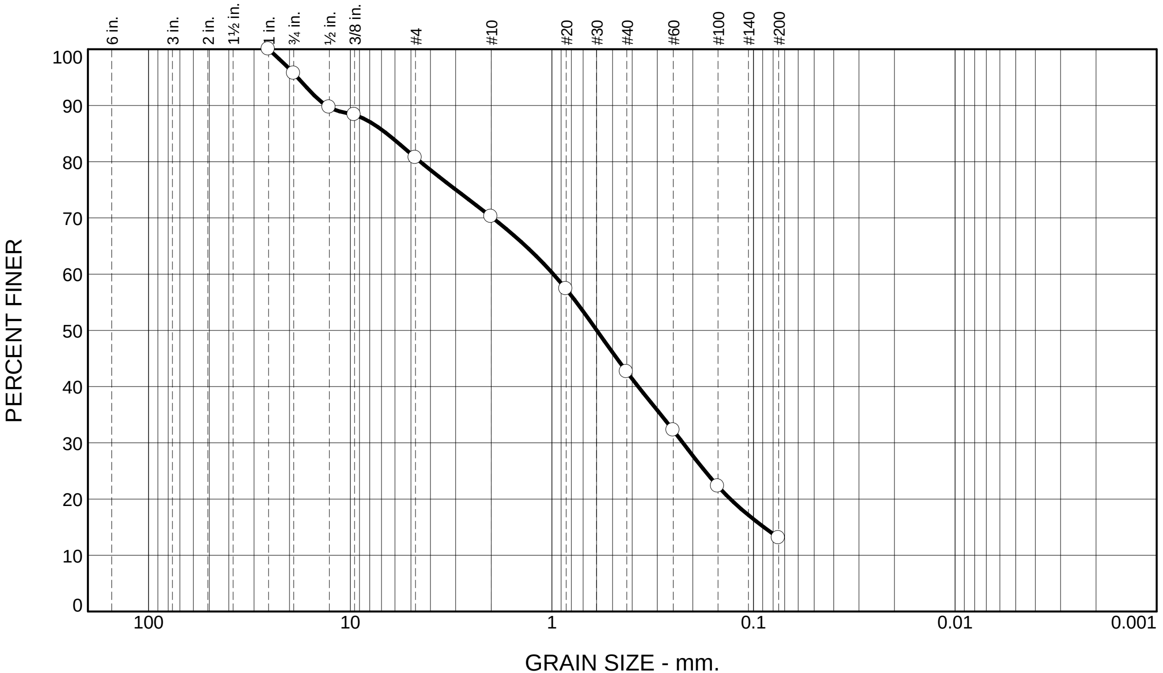
Source of Sample: BB-106 **Depth:** 10-112' **Date Sampled:** 08.29.19
Sample Number: S6

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1807

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	4.3	15.0	10.5	27.6	29.5	13.1	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
1"	100.0		
0.75"	95.7		
0.5"	89.7		
0.375"	88.3		
#4	80.7		
#10	70.2		
#20	57.4		
#40	42.6		
#60	32.2		
#100	22.3		
#200	13.1		

* (no specification provided)

Material Description

Light Brown silty sand with gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-1-b

Coefficients

D_{90}=	13.1735	D_{85}=	6.5844	D_{60}=	0.9822
D_{50}=	0.5981	D_{30}=	0.2237	D_{15}=	0.0888
D_{10}=		C_u=		C_c=	

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

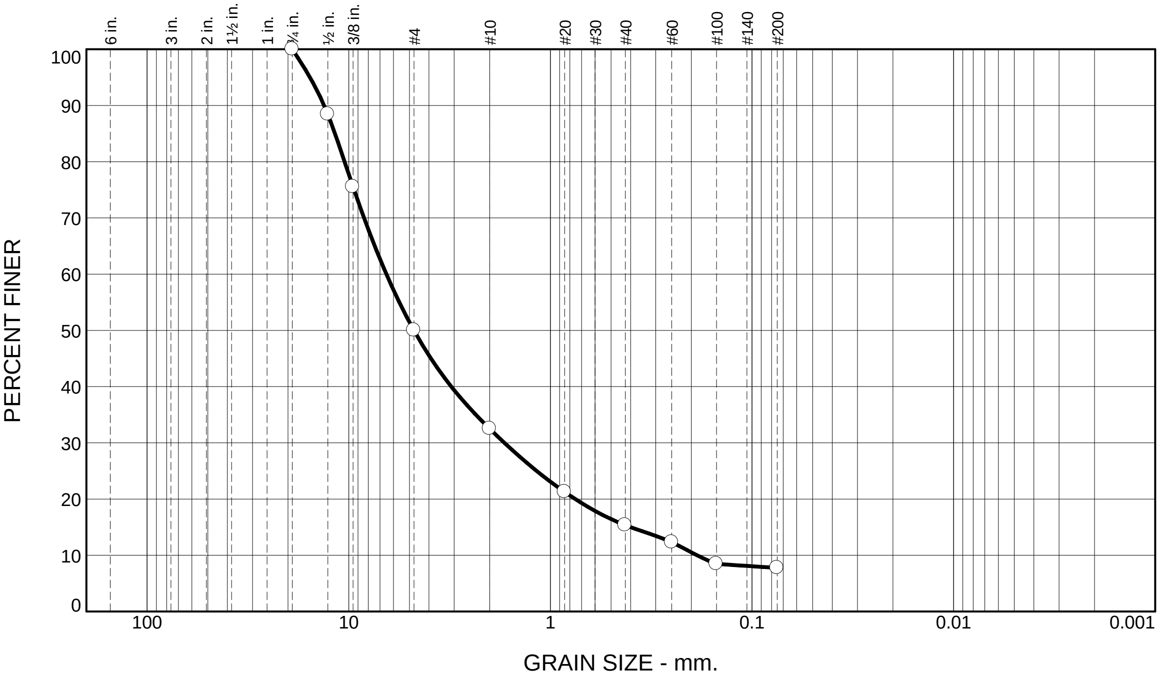
Source of Sample: BB-106 **Depth:** 18-19.8' **Date Sampled:** 08.29.19
Sample Number: S10

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1808

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	50.0	17.5	17.1	7.6	7.8	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.75"	100.0		
0.5"	88.4		
0.375"	75.6		
#4	50.0		
#10	32.5		
#20	21.3		
#40	15.4		
#60	12.3		
#100	8.5		
#200	7.8		

* (no specification provided)

Material Description

Brown well-graded gravel with silt and sand

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= GW-GM **AASHTO (M 145)=** A-1-a

Coefficients

D_{90}= 13.2486	D_{85}= 11.6940	D_{60}= 6.5032
D_{50}= 4.7500	D_{30}= 1.6904	D_{15}= 0.4002
D_{10}= 0.1873	C_u= 34.72	C_c= 2.35

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

Source of Sample: BB-107B **Depth:** 12.5-14.4' **Date Sampled:** 08.28.19
Sample Number: S7

Thielsch Engineering Inc.

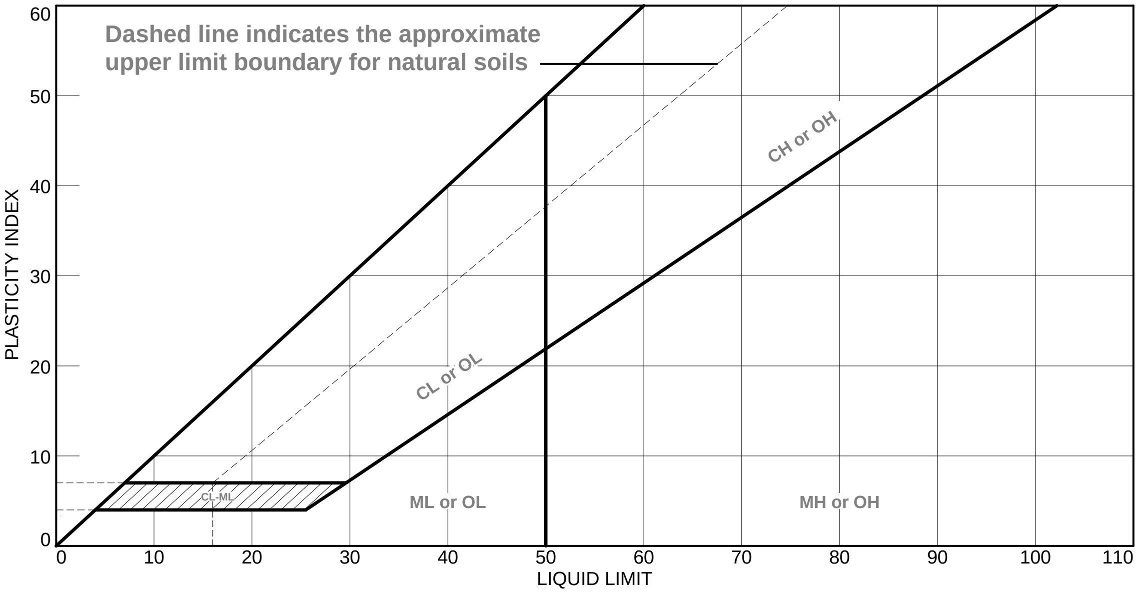
Cranston, RI

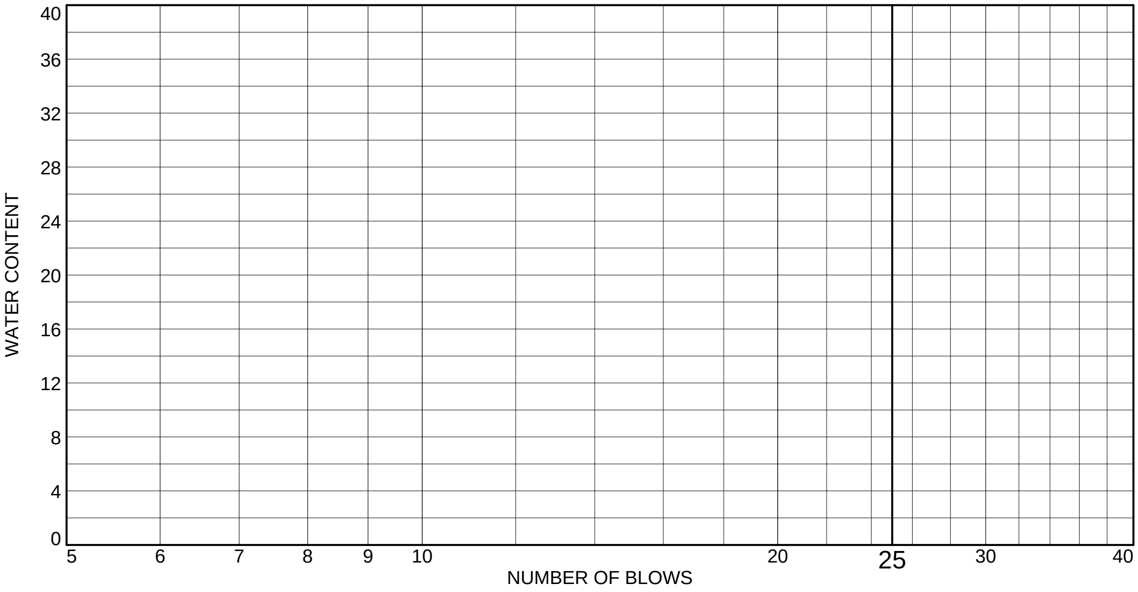
Client: Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail
Sudbury, MA

Project No: 74-19-0002.98 **Figure** 19-S-1809

LIQUID AND PLASTIC LIMITS TEST REPORT





	MATERIAL DESCRIPTION	LL	PL	PI	%<#40	%<#200	USCS
●	Light Brown silt	NV	NP	NP			

Project No. 74-19- **Client:** Jacobs Engineering Group, Inc.

Project: Bruce Freeman Rail Trail

Sudbury, MA

Source of Sample: BB-108 **Depth:** 4-6'

Sample Number: S3

Thielsch Engineering Inc.

Cranston, RI

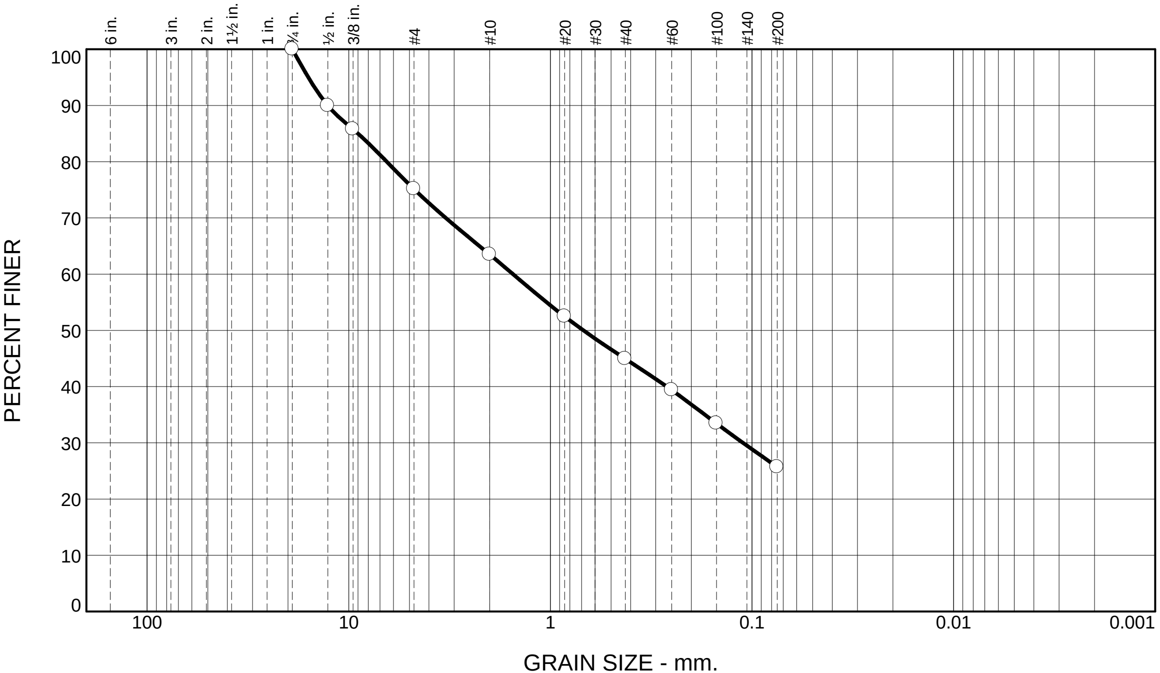
Remarks:

●Sample received with standing water, could not roll past 1/4".

Figure 19-L-1810

Tested By: JM **Checked By:** SA

Particle Size Distribution Report



% +3"	% Gravel		% Sand			% Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0	0.0	24.9	11.6	18.6	19.2	25.7	

Test Results (D6913 & ASTM D 1140)

Opening Size	Percent Finer	Spec.* (Percent)	Pass? (X=Fail)
0.75"	100.0		
0.5"	90.0		
0.375"	85.8		
#4	75.1		
#10	63.5		
#20	52.5		
#40	44.9		
#60	39.4		
#100	33.5		
#200	25.7		

* (no specification provided)

Material Description

Light Brown silty sand with gravel

Atterberg Limits (ASTM D 4318)

PL= NP **LL=** NV **PI=** NP

Classification

USCS (D 2487)= SM **AASHTO (M 145)=** A-2-4(0)

Coefficients

D_{90}= 12.7177	D_{85}= 8.9952	D_{60}= 1.5322
D_{50}= 0.6853	D_{30}= 0.1107	D_{15}=
D_{10}=	C_u=	C_c=

Remarks

Date Received: 09.12.19 **Date Tested:** 09.16.19

Tested By: IA / JM

Checked By: Steven Accetta

Title: Laboratory Coordinator

Source of Sample: BB-108 **Depth:** 12-14' **Date Sampled:** 08.27.19
Sample Number: S7

Thielsch Engineering Inc.

Cranston, RI

Client: Jacobs Engineering Group, Inc.
Project: Bruce Freeman Rail Trail
Sudbury, MA
Project No: 74-19-0002.98 **Figure** 19-S-1811

Appendix D – Seismic Site Class Evaluation

Seismic Site Class Evaluation
Authored by: SR 9/11/2019
Checked by: DH 9/26/2019

Determine seismic site class in accordance with 2011 AASHTO LRFD Seismic Bridge Design, 2nd Edition.

__Bruce Freeman Rail Trail, Sudbury, MA__

Boring No.	Sample No.	N Value	Di	Di/N_i	N_{bar}
BB-101	S1	11	2	0.18	21
	S2	13	2	0.15	
	S3	10	2	0.20	
	S4	13	2	0.15	
	S5	15	2	0.13	
	S6	8	2	0.25	
	S7	4	2	0.50	
	S8	1	2	2.00	
	S9	12	2	0.17	
	S10	21	6	0.29	
	S11	46	5	0.11	
	S12	101	5	0.05	
	S13	100	5	0.05	
	S14	79	5	0.06	
	S15	100	5	0.05	
	S16	100	2	0.02	
	Bedrock	100	49	0.49	
	Total Depth =	100	Σ	4.86	
	Depth to Rock =	51			

N = Σ Di / Σ(Di/Ni) = 100 / 4.86 = **21**

Per Table 3.4.2.1-1, 15 ≤ N_{bar} ≤ 50, Site Class D

Seismic Site Class Evaluation Authored by: SR 9/11/2019
Checked by: DH 9/26/2019

Determine seismic site class in accordance with 2011 AASHTO LRFD Seismic Bridge Design, 2nd Edition.

Bruce Freeman Rail Trail, Sudbury, MA

Boring No.	Sample No.	N Value	Di	Di/N_i	N_{bar}
BB-102A/B	S1	10	2	0.20	30
	S2	11	2	0.18	
	S3	6	2	0.33	
	S4	11	2	0.18	
	S5	12	2	0.17	
	S6	4	2	0.50	
	S7	5	2	0.40	
	S8	19	2	0.11	
	S9	41	2	0.05	
	S10	29	6	0.21	
	S11	33	5.5	0.17	
	S12	100	4.5	0.05	
	S13	52	5	0.10	
	S14	100	5	0.05	
	S15	59	5	0.08	
	S16	82	3	0.04	
	Bedrock	100	48	0.48	
	Total Depth =	100	Σ	3.28	
	Depth to Rock =	52			

N = Σ Di / Σ(Di/Ni) = 100 / 3.28 = **30**

Per Table 3.4.2.1-1, 15 ≤ N_{bar} ≤ 50, Site Class D

Seismic Site Class Evaluation

Authored by: SR 9/11/2019
Checked by: DH 9/26/2019

Determine seismic site class in accordance with 2011 AASHTO LRFD Seismic Bridge Design, 2nd Edition.

<u>Bruce Freeman Rail Trail, Sudbury, MA</u>

Boring No.	Sample No.	N Value	Di	Di/N_i	N_{bar}
BB-103A/B	S1	5	2	0.40	30
	S2	6	2	0.33	
	S3	6	2	0.33	
	S4	7	2	0.29	
	S5	100	2	0.02	
	S6	4	2	0.50	
	S7	13	2	0.15	
	S8	13	2	0.15	
	S9	29	2	0.07	
	S10	23	6	0.26	
	S11	48	5	0.10	
	S12	85	2.5	0.03	
	Bedrock	100	68.5	0.69	
	Total Depth =	100	Σ	3.33	
	Depth to Rock =	31.5			

N = Σ Di / Σ(Di/Ni) = 100 / 3.33 = **30**

Per Table 3.4.2.1-1, 15 ≤ N_{bar} ≤ 50, Site Class D

Table 3.4.2.1-1—Site Class Definitions

Site Class	Soil Type and Profile
A	Hard rock with measured shear wave velocity, $\overline{v}_s > 5000$ ft/sec
B	Rock with 2500 ft/sec $< \overline{v}_s <$ 5000 ft/sec
C	Very dense soil and soil rock with 1200 ft/sec $< \overline{v}_s <$ 2500 ft/sec, or with either $\overline{N} > 50$ blows/ft or $\overline{s}_u > 2.0$ ksf
D	Stiff soil with 600 ft/sec $< \overline{v}_s <$ 1200 ft/sec, or with either 15 blows/ft $< \overline{N} <$ 50 blows/ft or 1.0 ksf $< \overline{s}_u <$ 2.0 ksf
E	Soil profile with $\overline{v}_s < 600$ ft/sec, or with either $\overline{N} < 15$ blows/ft or $\overline{s}_u < 1.0$ ksf, or any profile with more than 10 ft of soft clay defined as soil with $PI > 20$, $w > 40\%$, and $\overline{s}_u < 0.5$ ksf
F	Soils requiring site-specific ground motion response evaluations, such as: • Peats or highly organic clays ($H > 10$ ft of peat or highly organic clay, where H = thickness of soil) • Very high plasticity clays ($H > 25$ ft with $PI > 75$) • Very thick soft/medium stiff clays ($H > 120$ ft)

Exceptions:

Where the soil properties are not known in sufficient detail to determine the site class, a site investigation shall be undertaken sufficient to determine the site class. Site Class E or F should not be assumed unless the authority having jurisdiction determines that Site Class E or F could be present at the site or in the event that Site Class E or F is established by geotechnical data.

where:

$\overline{v}_s$ = average shear wave velocity for the upper 100 ft of the soil profile as defined in Article 3.4.2.2

$\overline{N}$ = average standard penetration test (SPT) blow count (blows/ft) (ASTM D 1586) for the upper 100 ft of the soil profile as defined in Article 3.4.2.2

$\overline{s}_u$ = average undrained shear strength in ksf (ASTM D 2166 or D 2850) for the upper 100 ft of the soil profile as defined in Article 3.4.2.2

PI = plasticity index (ASTM D 4318)

w = moisture content (ASTM D 2216)

JOB Bruce Freeman Rail Trail, Sudbury, MA
SUBJECT Seismic Site Class
CALCULATED BY SR **DATE** 9/11/2019
CHECKED BY DH **DATE** 9/26/2019

AASHTO Seismic Site Class Summary

PURPOSE: Determine seismic site class in accordance with 2011 AASHTO LRFD Seismic Bridge Design, 2nd Edition.

SUBSURFACE INFORMATION: SPT borings performed by New England Boring Contractors in 2019.

APPROACH:
1) Categorize the site using one of the V_s, N and s_u methods.
2) Determine the appropriate Site Class based on the boring-specific results.

Boring	N_bar	Site Class
BB-101	21	D
BB-102A/B	30	D
BB-103A/B	30	D

SITE CLASS RESULTS PER BORING: By AASHTO Table 3.4.2.1-1, all three borings indicate Site Class D.

SITE CLASS: We recommend the site be classified as Site Class D.

Approx. Project Coordinates

Lat	42°22'55.78"N
Long	71°24'55.24"W

Seismic Coefficients (1000-Year Return Period)

Per AASHTO

PGA =	0.07	(AASHTO Figure 3.4.1-2b)
S_S =	0.146	(AASHTO Figure 3.4.1-3b)
S_1 =	0.039	(AASHTO Figure 3.4.1-4b)

For Site Class D

F_{pga} =	1.6	(See Table 3.4.2.3-1)
F_a =	1.6	(See Table 3.4.2.3-1)
F_v =	2.4	(See Table 3.4.2.3-2)

Design Spectral Response Parameters

$A_S = F_{pga} \times PGA =$	**0.11**	(Eqn. 3.4.1-1)
$S_{DS} = F_a \times S_s =$	**0.23**	(Eqn. 3.4.1-2)
$S_{D1} = F_v \times S_1 =$	**0.09**	(Eqn. 3.4.1-3)

Seismic Design Category (SDC): **A** (AASHTO Table 3.5.1)

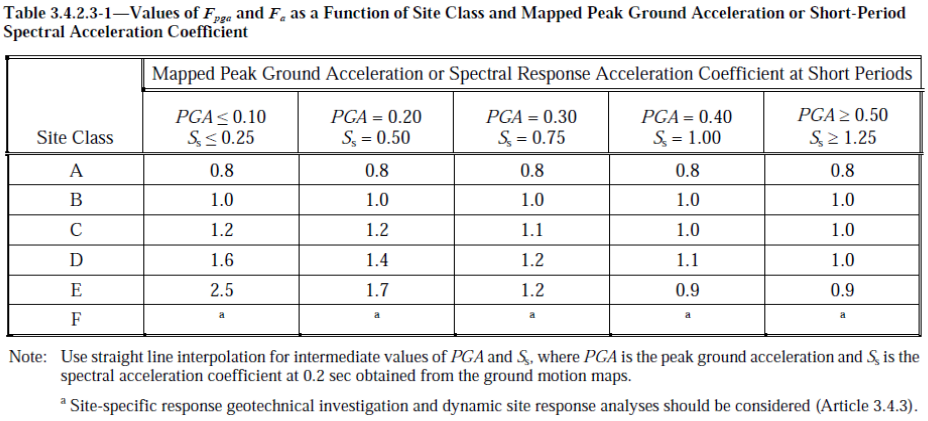


Table 3.4.2.3-1—Values of F_{pga} and F_a as a Function of Site Class and Mapped Peak Ground Acceleration or Short-Period Spectral Acceleration Coefficient

Site Class	Mapped Peak Ground Acceleration or Spectral Response Acceleration Coefficient at Short Periods				
	$PGA \leq 0.10$ $S_s \leq 0.25$	$PGA = 0.20$ $S_s = 0.50$	$PGA = 0.30$ $S_s = 0.75$	$PGA = 0.40$ $S_s = 1.00$	$PGA \geq 0.50$ $S_s \geq 1.25$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.2	1.2	1.1	1.0	1.0
D	1.6	1.4	1.2	1.1	1.0
E	2.5	1.7	1.2	0.9	0.9
F	[a]	[a]	[a]	[a]	[a]

Note: Use straight line interpolation for intermediate values of PGA and S_s, where PGA is the peak ground acceleration and S_s is the spectral acceleration coefficient at 0.2 sec obtained from the ground motion maps.

[a] Site-specific response geotechnical investigation and dynamic site response analyses should be considered (Article 3.4.3).

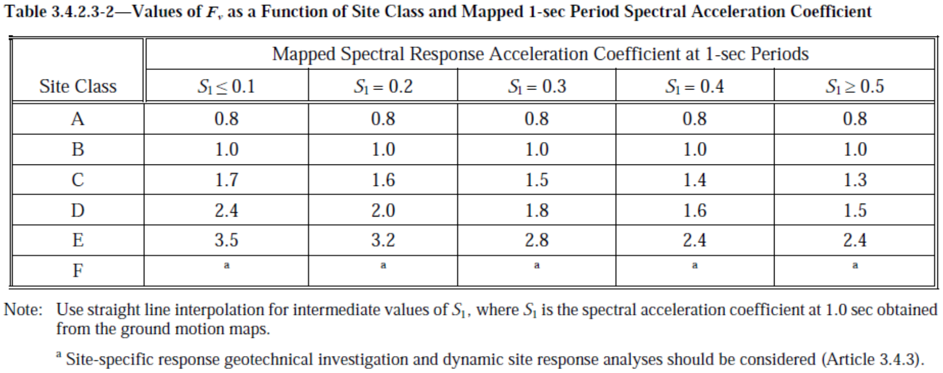


Table 3.4.2.3-2—Values of F_v as a Function of Site Class and Mapped 1-sec Period Spectral Acceleration Coefficient

Site Class	Mapped Spectral Response Acceleration Coefficient at 1-sec Periods				
	$S_1 \leq 0.1$	$S_1 = 0.2$	$S_1 = 0.3$	$S_1 = 0.4$	$S_1 \geq 0.5$
A	0.8	0.8	0.8	0.8	0.8
B	1.0	1.0	1.0	1.0	1.0
C	1.7	1.6	1.5	1.4	1.3
D	2.4	2.0	1.8	1.6	1.5
E	3.5	3.2	2.8	2.4	2.4
F	[a]	[a]	[a]	[a]	[a]

Note: Use straight line interpolation for intermediate values of S_1, where S_1 is the spectral acceleration coefficient at 1.0 sec obtained from the ground motion maps.

[a] Site-specific response geotechnical investigation and dynamic site response analyses should be considered (Article 3.4.3).

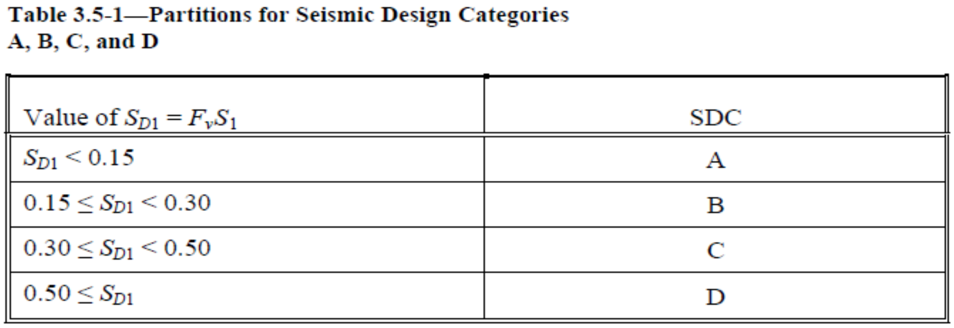


Table 3.5-1—Partitions for Seismic Design Categories A, B, C, and D

Value of $S_{D1} = F_v S_1$	SDC
$S_{D1} < 0.15$	A
$0.15 \leq S_{D1} < 0.30$	B
$0.30 \leq S_{D1} < 0.50$	C
$0.50 \leq S_{D1}$	D

Appendix E – Liquefaction Analysis

Calc By: SR 9/30/2019
Checked by: DH 10/8/2019

L I Q U E F A C T I O N   A N A L Y S I S

EQ MAGNITUDE SCALING FACTOR
(MSF) = **1.648**

AVG. SHEAR WAVE VELOCITY (top 40')
$V^*_{s,40'}$ = **736** FT./SEC.

PGA CALCULATOR
Earthquake Moment Magnitude = 6
Source-To-Site Distance, R (km) = 86.37
PGA = **0.070**

REFERENCE BORING NUMBER ====================================== BB-101
ELEVATION OF BORING GROUND SURFACE ========================== 131.0 FT. (NAVD88)
DEPTH TO GROUNDWATER - DURING DRILLING ======================= 9.30 FT. (Below Boring Ground Surface)
DEPTH TO GROUNDWATER - DURING EARTHQUAKE ==================== 8.30 FT. (Below Finished Grade Cut or Fill Surface)
PEAK HORIZ. GROUND SURFACE ACCELERATION COEFFICIENT (PGA_M) === 0.112
EARTHQUAKE MOMENT MAGNITUDE ================================ 6.0
FINISHED GRADE FILL OR CUT FROM BORING SURFACE ================ -1.00 FT. (Cut Depth)
HAMMER EFFICIENCY=== 80 %
BOREHOLE DIAMETER==2.5 to 4.5 IN.
SAMPLING METHOD== 1 3/8 inch ID

	BORING DATA							CONDITIONS DURING DRILLING					CONDITIONS DURING EARTHQUAKE							
ELEV. OF SAMPLE (FT.)	BORING SAMPLE DEPTH (FT.)	SPT N VALUE (BLOWS)	UNCONF. COMPR. STR., Q_u (TSF.)	% FINES < #200 (%)	PLAST. INDEX PI	LIQUID LIMIT LL	MOIST. CONTENT w_c (%)	EFFECTIVE UNIT WT. (KCF.)	EFFECTIVE VERT. STRESS (KSF.)	CORR. SPT N VALUE $(N_1)_{60}$	EQUIV. CLN. SAND SPT N VALUE $(N_1)_{60cs}$	CRR RESIST. MAG 7.5 $CRR_{7.5}$	EFFECTIVE UNIT WT. (KCF.)	EFFECTIVE VERT. STRESS (KSF.)	TOTAL VERT. STRESS (KSF.)	OVER-BURDEN CORR. FACT. (Ks)	CORR. RESIST. $CRR_{7.5}$ CRR	SOIL MASS PART. FACTOR (r_d)	EQ INDUCED CSR	FACTOR OF SAFETY * CRR/CSR
130	1	11		5				0.119	0.119	22.197	22.197	0.245								
128	3	13		10				0.121	0.361	25.228	26.643	0.329	0.121	0.242	0.242	1.500	**0.813**	0.999	**0.073**	**N.L. (1)**
126	5	10		20				0.118	0.597	17.054	22.023	0.242	0.118	0.478	0.478	1.500	**0.599**	0.997	**0.073**	**N.L. (1)**
124	7	13		20				0.121	0.839	21.135	26.428	0.323	0.121	0.720	0.720	1.435	**0.764**	0.996	**0.072**	**N.L. (1)**
122	9	15		20				0.123	1.085	24.312	29.858	0.458	0.123	0.966	0.966	1.322	**0.998**	0.994	**0.072**	**N.L. (1)**
120	11	8		50				0.059	1.203	12.189	19.627	0.211	0.059	1.084	1.190	1.216	**0.422**	0.991	**0.079**	**5.342 (D)**
118	13	4		50				0.053	1.309	6.160	12.392	0.135	0.053	1.190	1.421	1.153	**0.256**	0.988	**0.086**	**2.977 (C)**
116	15	1		50				0.043	1.395	1.551	6.861	0.087	0.043	1.276	1.632	1.114	**0.159**	0.984	**0.092**	**1.728 (C)**
114	17	12		35				0.063	1.521	19.068	27.882	0.365	0.063	1.402	1.882	1.153	**0.694**	0.980	**0.096**	**7.229 (D)**
112	19	21		10				0.068	1.657	35.586	37.225	-0.039	0.068	1.538	2.143	1.137	**-0.073**	0.975	**0.099**	**N.L. (3)**
106	25	46		10				0.075	2.107	76.435	78.957	0.558	0.075	1.988	2.968	1.026	**0.943**	0.952	**0.103**	**N.L. (3)**
101	30	101		5				0.083	2.522	155.940	155.940	1.142	0.083	2.403	3.695	0.951	**1.790**	0.924	**0.103**	**N.L. (3)**
96.8	34.2	100		5				0.083	2.871	145.417	145.417	1.063	0.083	2.752	4.305	0.901	**1.578**	0.894	**0.102**	**N.L. (3)**
91	40	79		50				0.080	3.335	106.595	132.914	0.969	0.080	3.216	5.131	0.847	**1.352**	0.845	**0.098**	**N.L. (3)**
86.6	44.4	100		50				0.083	3.700	127.672	158.207	1.159	0.083	3.581	5.771	0.811	**1.548**	0.806	**0.095**	**N.L. (3)**
81.9	49.1	100		5				0.083	4.090	120.721	120.721	0.878	0.083	3.971	6.454	0.778	**1.125**	0.767	**0.091**	**N.L. (3)**

* FACTOR OF SAFETY DESCRIPTIONS
N.L. (1) = NOT LIQUEFIABLE, ABOVE EQ GROUND WATER ELEVATION
N.L. (2) = NOT LIQUEFIABLE, PI ≥ 12 OR w_c/LL ≤ 0.85
N.L. (3) = NOT LIQUEFIABLE, $(N_1)_{60}$ > 25
(C) = CONTRACTIVE SOIL TYPES
(D) = DILATIVE SOIL TYPES

Calc By: SR 9/30/2019
Checked by: DH 10/8/2019

LIQUEFACTION ANALYSIS

REFERENCE BORING NUMBER ======================================= BB-102A/B
ELEVATION OF BORING GROUND SURFACE ========================== 131.0 FT. (NAVD88)
DEPTH TO GROUNDWATER - DURING DRILLING ======================= 11.50 FT. (Below Boring Ground Surface)
DEPTH TO GROUNDWATER - DURING EARTHQUAKE =================== 10.50 FT. (Below Finished Grade Cut or Fill Surface)
PEAK HORIZ. GROUND SURFACE ACCELERATION COEFFICIENT (PGA$_M$) === 0.112
EARTHQUAKE MOMENT MAGNITUDE ================================ 6.0
FINISHED GRADE FILL OR CUT FROM BORING SURFACE ================ -1.00 FT. (Cut Depth)
HAMMER EFFICIENCY=== 80 %
BOREHOLE DIAMETER==2.5 to 4.5 IN.
SAMPLING METHOD=== 1 3/8 inch ID

EQ MAGNITUDE SCALING FACTOR
(MSF) = **1.648**

AVG. SHEAR WAVE VELOCITY (top 40')
$V^*_{s,40'}$ = **828** FT./SEC.

PGA CALCULATOR
Earthquake Moment Magnitude = 6
Source-To-Site Distance, R (km) = 86.37
PGA = **0.070**

	BORING DATA							*CONDITIONS DURING DRILLING*					*CONDITIONS DURING EARTHQUAKE*							
ELEV. OF SAMPLE (FT.)	*BORING SAMPLE DEPTH (FT.)*	*SPT N VALUE (BLOWS)*	*UNCONF. COMPR. STR., Q_u (TSF.)*	*% FINES < #200 (%)*	*PLAST. INDEX PI*	*LIQUID LIMIT LL*	*MOIST. CONTENT w_c (%)*	*EFFECTIVE UNIT WT. (KCF.)*	*EFFECTIVE VERT. STRESS (KSF.)*	*CORR. SPT N VALUE $(N_1)_{60}$*	*EQUIV. CLN. SAND SPT N VALUE $(N_1)_{60cs}$*	*CRR RESIST. MAG 7.5 $CRR_{7.5}$*	*EFFECTIVE UNIT WT. (KCF.)*	*EFFECTIVE VERT. STRESS (KSF.)*	*TOTAL VERT. STRESS (KSF.)*	*OVER-BURDEN CORR. FACT. (Ks)*	*CORR. RESIST. $CRR_{7.5}$ CRR*	*SOIL MASS PART. FACTOR (r_d)*	*EQ INDUCED CSR*	*FACTOR OF SAFETY * CRR/CSR*
130	1	10		5				0.118	0.118	19.890	19.890	0.214								
128	3	11		10				0.119	0.356	20.821	22.140	0.244	0.119	0.238	0.238	1.500	**0.603**	1.000	**0.073**	**N.L. (1)**
126	5	6		20				0.113	0.582	9.847	14.244	0.153	0.113	0.464	0.464	1.480	**0.372**	0.999	**0.073**	**N.L. (1)**
124	7	11		35				0.119	0.820	17.577	26.092	0.315	0.119	0.702	0.702	1.443	**0.750**	0.998	**0.073**	**N.L. (1)**
122	9	12		20				0.120	1.060	18.969	24.090	0.275	0.120	0.942	0.942	1.296	**0.587**	0.998	**0.073**	**N.L. (1)**
120	11	4		50				0.108	1.276	5.978	12.174	0.133	0.108	1.158	1.158	1.160	**0.254**	0.997	**0.073**	**N.L. (1)**
118	13	5		50				0.055	1.386	7.549	14.059	0.151	0.055	1.268	1.362	1.141	**0.283**	0.996	**0.078**	**3.628 (C)**
116	15	19		20				0.067	1.520	31.627	37.755	0.009	0.067	1.402	1.620	1.180	**0.017**	0.994	**0.084**	**N.L. (3)**
114	17	41		5				0.074	1.668	71.847	71.847	0.501	0.074	1.550	1.893	1.133	**0.935**	0.993	**0.088**	**N.L. (3)**
112	19	29		10				0.071	1.810	49.987	51.937	0.324	0.071	1.692	2.160	1.094	**0.585**	0.991	**0.092**	**N.L. (3)**
106	25	33		50				0.072	2.242	53.287	68.945	0.477	0.072	2.124	2.966	0.999	**0.786**	0.982	**0.100**	**N.L. (3)**
101.3	29.7	100		5				0.083	2.632	151.027	151.027	1.105	0.083	2.514	3.650	0.934	**1.701**	0.971	**0.103**	**N.L. (3)**
96	35	52		10				0.076	3.035	73.470	75.928	0.534	0.076	2.917	4.383	0.880	**0.774**	0.953	**0.104**	**N.L. (3)**
91.6	39.4	100		5				0.083	3.400	133.348	133.348	0.973	0.083	3.282	5.023	0.840	**1.346**	0.932	**0.104**	**N.L. (3)**
86	45	59		50				0.077	3.831	73.820	93.584	0.671	0.077	3.713	5.804	0.799	**0.884**	0.899	**0.102**	**N.L. (3)**
81.1	49.9	82		50				0.081	4.228	97.036	121.443	0.883	0.081	4.110	6.506	0.767	**1.117**	0.868	**0.100**	**N.L. (3)**

* FACTOR OF SAFETY DESCRIPTIONS
N.L. (1) = NOT LIQUEFIABLE, ABOVE EQ GROUND WATER ELEVATION
N.L. (2) = NOT LIQUEFIABLE, PI ≥ 12 OR w_c/LL ≤ 0.85
N.L. (3) = NOT LIQUEFIABLE, $(N_1)_{60}$ > 25
(C) = CONTRACTIVE SOIL TYPES
(D) = DILATIVE SOIL TYPES

Calc By: SR 9/30/2019
Checked by: DH 10/8/2019

L I Q U E F A C T I O N   A N A L Y S I S

REFERENCE BORING NUMBER ===================================== BB-103A/B
ELEVATION OF BORING GROUND SURFACE ========================== 142.5 FT. (NAVD88)
DEPTH TO GROUNDWATER - DURING DRILLING ====================== 9.40 FT. (Below Boring Ground Surface)
DEPTH TO GROUNDWATER - DURING EARTHQUAKE ==================== 9.40 FT. (Below Finished Grade Cut or Fill Surface)
PEAK HORIZ. GROUND SURFACE ACCELERATION COEFFICIENT (PGA$_M$) === 0.112
EARTHQUAKE MOMENT MAGNITUDE ================================ 6.0
FINISHED GRADE FILL OR CUT FROM BORING SURFACE ================ 0.00 FT.
HAMMER EFFICIENCY== 60 %
BOREHOLE DIAMETER===2.5 to 4.5 IN.
SAMPLING METHOD=== 1 3/8 inch ID

EQ MAGNITUDE SCALING FACTOR
(MSF) = **1.648**

AVG. SHEAR WAVE VELOCITY (top 40')
$V^*_{s,40'}$ = **706** FT./SEC.

PGA CALCULATOR
Earthquake Moment Magnitude = 6
Source-To-Site Distance, R (km) = 86.37
PGA = **0.070**

	BORING DATA							CONDITIONS DURING DRILLING					CONDITIONS DURING EARTHQUAKE							
ELEV. OF SAMPLE (FT.)	BORING SAMPLE DEPTH (FT.)	SPT N VALUE (BLOWS)	UNCONF. COMPR. STR., Q_u (TSF.)	% FINES < #200 (%)	PLAST. INDEX PI	LIQUID LIMIT LL	MOIST. CONTENT w_c (%)	EFFECTIVE UNIT WT. (KCF.)	EFFECTIVE VERT. STRESS (KSF.)	CORR. SPT N VALUE $(N_1)_{60}$	EQUIV. CLN. SAND SPT N VALUE $(N_1)_{60cs}$	CRR RESIST. MAG 7.5 $CRR_{7.5}$	EFFECTIVE UNIT WT. (KCF.)	EFFECTIVE VERT. STRESS (KSF.)	TOTAL VERT. STRESS (KSF.)	OVER-BURDEN CORR. FACT. (Ks)	CORR. RESIST. $CRR_{7.5}$ CRR	SOIL MASS PART. FACTOR (r_d)	EQ INDUCED CSR	FACTOR OF SAFETY * CRR/CSR
141.5	1	5		5				0.111	0.111	7.013	7.013	0.088	0.111	0.111	0.111	1.500	**0.217**	0.999	**0.073**	**N.L. (1)**
139.5	3	6		5				0.113	0.337	8.013	8.013	0.096	0.113	0.337	0.337	1.496	**0.237**	0.997	**0.073**	**N.L. (1)**
137.5	5	6		20				0.113	0.563	7.431	11.636	0.128	0.113	0.563	0.563	1.378	**0.290**	0.995	**0.072**	**N.L. (1)**
135.5	7	7		10				0.114	0.791	8.076	9.120	0.105	0.114	0.791	0.791	1.250	**0.217**	0.993	**0.072**	**N.L. (1)**
133.8	8.7	100		5				0.147	1.041	132.912	132.912	0.969	0.147	1.041	1.041	1.329	**2.123**	0.990	**0.072**	**N.L. (1)**
131.5	11	4		50				0.053	1.163	4.620	10.544	0.118	0.053	1.163	1.263	1.152	**0.224**	0.986	**0.078**	**2.872 (C)**
129.5	13	13		50				0.063	1.289	15.893	24.071	0.275	0.063	1.289	1.513	1.172	**0.531**	0.981	**0.084**	**6.321 (D)**
127.5	15	13		50				0.063	1.415	15.773	23.928	0.272	0.063	1.415	1.764	1.137	**0.510**	0.976	**0.089**	**5.730 (D)**
125.5	17	29		50				0.071	1.557	39.148	51.977	0.325	0.071	1.557	2.031	1.131	**0.605**	0.969	**0.092**	**N.L. (3)**
123.5	19	23		50				0.068	1.693	29.456	40.347	0.137	0.068	1.693	2.292	1.094	**0.246**	0.962	**0.095**	**N.L. (3)**
117.5	25	48		5				0.075	2.143	59.362	59.362	0.395	0.075	2.143	3.116	0.996	**0.649**	0.930	**0.098**	**N.L. (3)**
112.6	29.9	85		10				0.081	2.540	98.066	101.056	0.729	0.081	2.540	3.819	0.930	**1.117**	0.894	**0.098**	**N.L. (3)**

* FACTOR OF SAFETY DESCRIPTIONS
N.L. (1) = NOT LIQUEFIABLE, ABOVE EQ GROUND WATER ELEVATION
N.L. (2) = NOT LIQUEFIABLE, PI ≥ 12 OR w_c/LL ≤ 0.85
N.L. (3) = NOT LIQUEFIABLE, $(N_1)_{60}$ > 25
(C) = CONTRACTIVE SOIL TYPES
(D) = DILATIVE SOIL TYPES

U.S. Geological Survey - Earthquake Hazards Program

Unified Hazard Tool

Please do not use this tool to obtain ground motion parameter values for the design code reference documents covered by the U.S. Seismic Design Maps web tools (e.g., the International Building Code and the ASCE 7 or 41 Standard). The values returned by the two applications are not identical.

Input

Edition

Dynamic: Conterminous U.S. 2008 (v3.3.3)

Latitude

Decimal degrees

42.38216111

Longitude

Decimal degrees, negative values for western longitudes

-71.41534444

Site Class

760 m/s (B/C boundary)

Spectral Period

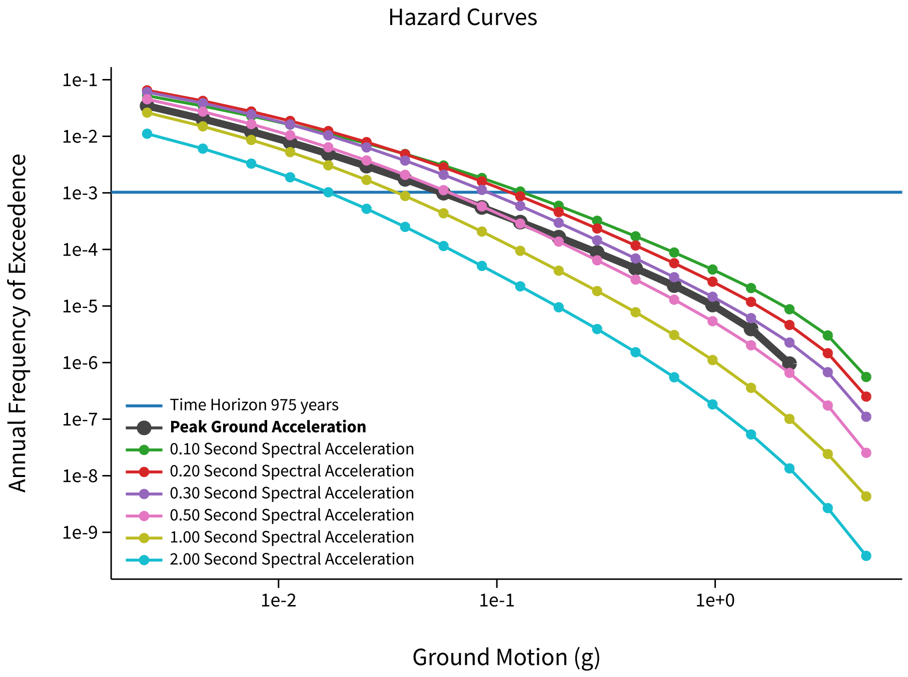
Peak Ground Acceleration

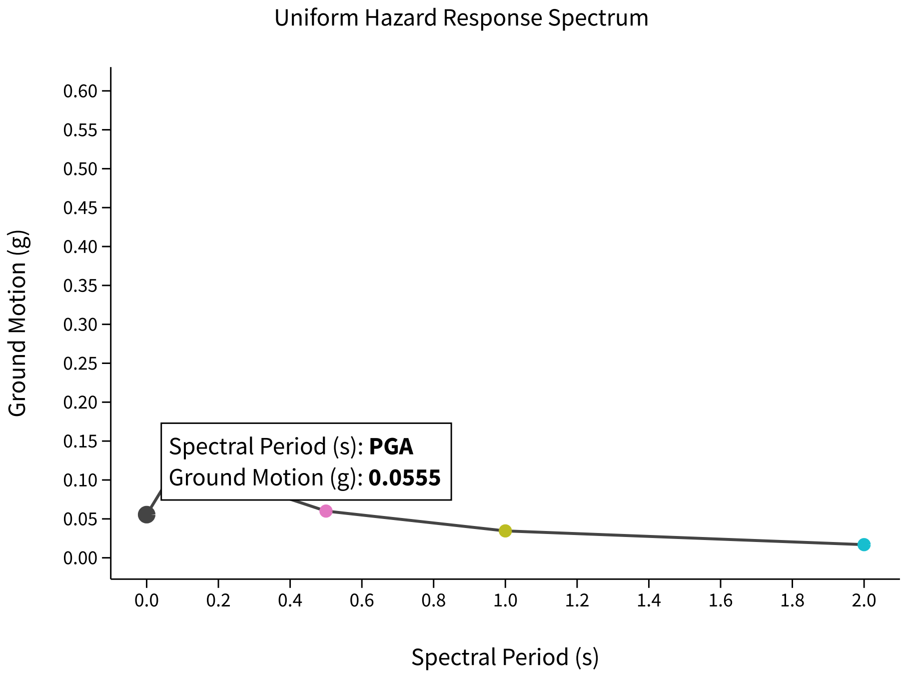
Time Horizon

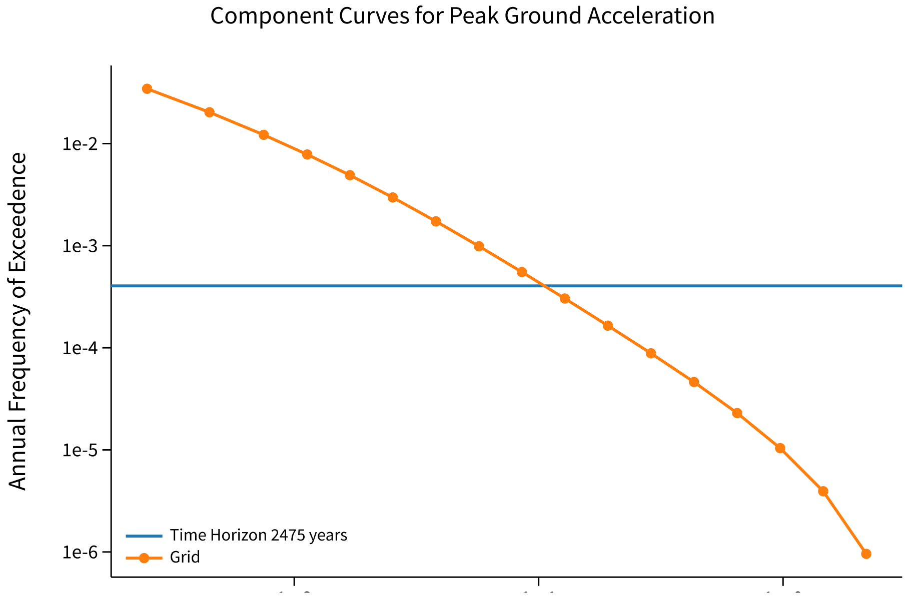
Return period in years

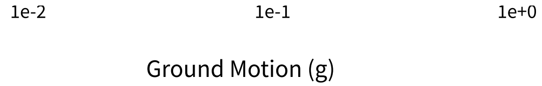
975

^ Hazard Curve


Hazard Curves


Uniform Hazard Response Spectrum


Component Curves for Peak Ground Acceleration

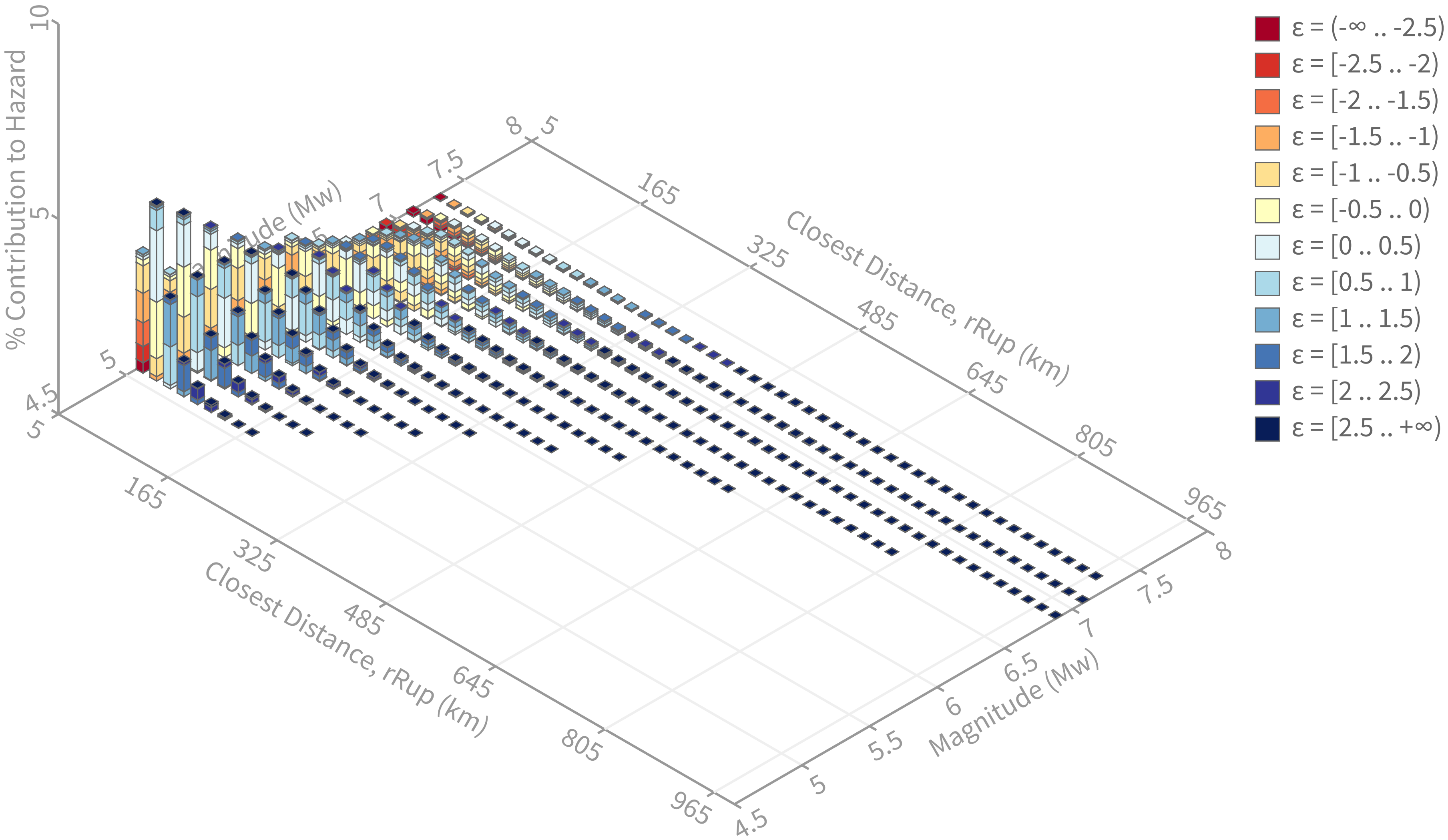


View Raw Data

^ Deaggregation

Component

Total



Summary statistics for, Deaggregation: Total

Deaggregation targets

Return period: 975 yrs
Exceedance rate: 0.001025641 yr^{-1}
PGA ground motion: 0.055468738 g

Recovered targets

Return period: 974.32662 yrs
Exceedance rate: 0.0010263499 yr^{-1}

Totals

Binned: 100 %
Residual: 0 %
Trace: 1.46 %

Mean (over all sources)

m: 6
r: 86.37 km
ε_0: -0.08 σ

Mode (largest m-r bin)

m: 5.1
r: 30.13 km
ε_0: 0.06 σ
Contribution: 4.49 %

Mode (largest m-r-ε_0 bin)

m: 5.09
r: 32.82 km
ε_0: 0.27 σ
Contribution: 1.83 %

Discretization

r: min = 0.0, max = 1000.0, Δ = 20.0 km
m: min = 4.4, max = 9.4, Δ = 0.2
ε: min = -3.0, max = 3.0, Δ = 0.5 σ

Epsilon keys

ε0: [-∞ .. -2.5)
ε1: [-2.5 .. -2.0)
ε2: [-2.0 .. -1.5)
ε3: [-1.5 .. -1.0)
ε4: [-1.0 .. -0.5)
ε5: [-0.5 .. 0.0)
ε6: [0.0 .. 0.5)
ε7: [0.5 .. 1.0)
ε8: [1.0 .. 1.5)
ε9: [1.5 .. 2.0)
ε10: [2.0 .. 2.5)
ε11: [2.5 .. +∞]

Deaggregation Contributors

Source Set ↳ Source	Type	r	m	ε_0	lon	lat	az	%
CEUS.2007all8.J.in (opt)	Grid							56.14
PointSourceFinite: -71.415, 42.629		27.18	5.55	-0.95	71.415°W	42.629°N	0.00	3.20
PointSourceFinite: -71.415, 42.719		36.76	5.63	-0.52	71.415°W	42.719°N	0.00	3.11
PointSourceFinite: -71.415, 42.809		46.29	5.72	-0.22	71.415°W	42.809°N	0.00	2.71
PointSourceFinite: -71.415, 42.899		55.75	5.82	-0.01	71.415°W	42.899°N	0.00	2.31
PointSourceFinite: -71.415, 42.764		41.53	5.68	-0.36	71.415°W	42.764°N	0.00	2.28
PointSourceFinite: -71.415, 42.989		65.19	5.92	0.15	71.415°W	42.989°N	0.00	2.05
PointSourceFinite: -71.415, 42.585		22.41	5.52	-1.23	71.415°W	42.585°N	0.00	2.00
PointSourceFinite: -71.415, 42.674		31.97	5.59	-0.72	71.415°W	42.674°N	0.00	1.92
PointSourceFinite: -71.415, 42.854		51.03	5.77	-0.10	71.415°W	42.854°N	0.00	1.80
PointSourceFinite: -71.415, 43.214		89.16	6.08	0.34	71.415°W	43.214°N	0.00	1.78
PointSourceFinite: -71.415, 42.540		17.69	5.49	-1.58	71.415°W	42.540°N	0.00	1.71
PointSourceFinite: -71.415, 43.124		79.55	6.02	0.30	71.415°W	43.124°N	0.00	1.66
PointSourceFinite: -71.415, 42.944		60.47	5.87	0.08	71.415°W	42.944°N	0.00	1.61
PointSourceFinite: -71.415, 43.079		74.76	5.99	0.27	71.415°W	43.079°N	0.00	1.57
PointSourceFinite: -71.415, 42.495		13.08	5.46	-2.03	71.415°W	42.495°N	0.00	1.49
PointSourceFinite: -71.415, 43.304		98.79	6.13	0.36	71.415°W	43.304°N	0.00	1.42
PointSourceFinite: -71.415, 43.034		69.95	5.96	0.22	71.415°W	43.034°N	0.00	1.41
PointSourceFinite: -71.415, 43.394		108.45	6.18	0.38	71.415°W	43.394°N	0.00	1.29
PointSourceFinite: -71.415, 43.169		84.35	6.05	0.32	71.415°W	43.169°N	0.00	1.26
PointSourceFinite: -71.415, 43.349		103.62	6.16	0.37	71.415°W	43.349°N	0.00	1.17
PointSourceFinite: -71.415, 42.450		8.78	5.44	-2.60	71.415°W	42.450°N	0.00	1.15
PointSourceFinite: -71.415, 43.259		93.97	6.11	0.35	71.415°W	43.259°N	0.00	1.13
PointSourceFinite: -71.415, 43.484		118.13	6.22	0.40	71.415°W	43.484°N	0.00	1.12
CEUS.2007all8.AB.in (opt)	Grid							43.86
PointSourceFinite: -71.415, 42.629		27.03	5.58	-0.78	71.415°W	42.629°N	0.00	2.86
PointSourceFinite: -71.415, 42.719		36.48	5.68	-0.37	71.415°W	42.719°N	0.00	2.64
PointSourceFinite: -71.415, 42.809		45.86	5.79	-0.09	71.415°W	42.809°N	0.00	2.22
PointSourceFinite: -71.415, 42.764		41.18	5.73	-0.22	71.415°W	42.764°N	0.00	1.90
PointSourceFinite: -71.415, 42.899		55.16	5.90	0.09	71.415°W	42.899°N	0.00	1.85
PointSourceFinite: -71.415, 42.585		22.30	5.54	-1.05	71.415°W	42.585°N	0.00	1.83
PointSourceFinite: -71.415, 42.674		31.76	5.63	-0.55	71.415°W	42.674°N	0.00	1.67
PointSourceFinite: -71.415, 42.989		64.43	6.01	0.22	71.415°W	42.989°N	0.00	1.61
PointSourceFinite: -71.415, 42.540		17.62	5.51	-1.38	71.415°W	42.540°N	0.00	1.61
PointSourceFinite: -71.415, 42.854		50.52	5.85	0.01	71.415°W	42.854°N	0.00	1.46
PointSourceFinite: -71.415, 42.495		13.04	5.48	-1.81	71.415°W	42.495°N	0.00	1.44
PointSourceFinite: -71.415, 43.214		87.97	6.21	0.41	71.415°W	43.214°N	0.00	1.32
PointSourceFinite: -71.415, 42.944		59.79	5.96	0.16	71.415°W	42.944°N	0.00	1.28
PointSourceFinite: -71.415, 43.124		78.55	6.13	0.37	71.415°W	43.124°N	0.00	1.26
PointSourceFinite: -71.415, 43.079		73.83	6.09	0.33	71.415°W	43.079°N	0.00	1.20
PointSourceFinite: -71.415, 42.450		8.77	5.45	-2.36	71.415°W	42.450°N	0.00	1.13
PointSourceFinite: -71.415, 43.034		69.11	6.06	0.28	71.415°W	43.034°N	0.00	1.09
PointSourceFinite: -71.415, 43.304		97.42	6.27	0.43	71.415°W	43.304°N	0.00	1.03

Appendix F – Corrected N Values and Inferred Soil Properties

Sheet No. **1**

Project:	**Bruce Freeman Rail Trail, Sudbury, MA**	Authored by:	**SR**	Date	**9/11/2019**
Job No.	**E2X81800**	Checked by:	**DH**	Date	**9/26/2019**

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. **BB-101**
Ground Surface Elevation **131** ft (NGVD 29)
Ground Water Depth during Drilling **9.3** ft
Hammer Efficiency **80** %

Hammer Type **140 lb Auto**
Sampler Type **Standard**
SPT Rod Stickup **4.0** ft

References
1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
130.0	**S1**	**1**	**11**	**Fill**	**4**	1.94	1.33	0.83	1.00	1.00	**12.2**	120	**23.7**
128.0	**S2**	**3**	**13**	**Fill**	**4**	1.57	1.33	0.85	1.00	1.00	**14.7**	366	**23.0**
126.0	**S3**	**5**	**10**	**Fill**	**4**	1.40	1.33	0.86	1.00	1.00	**11.5**	605	**16.1**
124.0	**S4**	**7**	**13**	**Fill**	**4**	1.29	1.33	0.87	1.00	1.00	**15.1**	851	**19.5**
122.0	**S5**	**9**	**15**	**Fill**	**4**	1.20	1.33	0.89	1.00	1.00	**17.7**	1,101	**21.3**
120.0	**S6**	**11**	**8**	**Silt**	**4**	1.16	1.33	0.90	1.00	1.00	**9.6**	1,241	**11.1**
118.0	**S7**	**13**	**4**	**Silt**	**4**	1.13	1.33	0.91	1.00	1.00	**4.9**	1,351	**5.5**
116.0	**S8**	**15**	**1**	**Peat**	**4**	1.11	1.33	0.92	1.00	1.00	**1.2**	1,439	**1.4**
114.0	**S9**	**17**	**12**	**Sand**	**4**	1.08	1.33	0.93	1.00	1.00	**14.9**	1,568	**16.1**
112.0	**S10**	**19**	**21**	**Sand**	**4**	1.06	1.33	0.94	1.00	1.00	**26.3**	1,703	**27.8**
106.0	**S11**	**25**	**46**	**Gravel**	**4**	0.98	1.33	0.97	1.00	1.00	**59.2**	2,109	**58.3**
101.0	**S12**	**30**	**101**	**Gravel**	**4**	0.93	1.33	0.98	1.00	1.00	**132.2**	2,447	**123.6**
96.8	**S13**	**34.2**	**REF**	**Gravel**	**4**	0.90	1.33	1.00	1.00	1.00	**100.0**	2,730	**100.0**
91.0	**S14**	**40**	**79**	**Silt**	**4**	0.85	1.33	1.00	1.00	1.00	**105.3**	3,123	**89.8**
86.6	**S15**	**44.4**	**REF**	**Silt**	**4**	0.82	1.33	1.00	1.00	1.00	**100.0**	3,420	**100.0**
81.9	**S16**	**49.1**	**REF**	**Sand**	**4**	0.79	1.33	1.00	1.00	1.00	**100.0**	3,738	**100.0**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)
$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.
C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$
C_E = SPT correction factor for hammer energy, $C_E = ER/60$
C_R = SPT Correction factor for rod length, C_R = -8E-5*L^2+0.0083*L+0.7922
C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"
C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights
Max $\gamma_{granular, dry}$ (pcf)= 130
Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

			Sheet No.	2
Project:	Bruce Freeman Rail Trail, Sudbury, MA	Authored by: SR	Date	9/11/2019
Job No.	E2X81800	Checked by: DH	Date	9/26/2019

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. BB-102A/B

Ground Surface Elevation 131 ft (NGVD 29)

Ground Water Depth during Drilling 10.8 ft

Hammer Efficiency 80 %

Hammer Type 140 lb Auto

Sampler Type Standard

SPT Rod Stickup 4.0 ft

References
1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
130.0	S1	1	10	Fill	4	1.94	1.33	0.83	1.00	1.00	**11.1**	119	**21.6**
128.0	S2	3	11	Fill	4	1.57	1.33	0.85	1.00	1.00	**12.4**	361	**19.5**
126.0	S3	5	6	Fill	4	1.41	1.33	0.86	1.00	1.00	**6.9**	589	**9.7**
124.0	S4	7	11	Fill	4	1.30	1.33	0.87	1.00	1.00	**12.8**	831	**16.6**
122.0	S5	9	12	Fill	4	1.21	1.33	0.89	1.00	1.00	**14.2**	1,076	**17.2**
120.0	S6	11	4	Silt	4	1.15	1.33	0.90	1.00	1.00	**4.8**	1,297	**5.5**
118.0	S7	13	5	Peat	4	1.12	1.33	0.91	1.00	1.00	**6.1**	1,411	**6.8**
116.0	S8	15	19	Sand	4	1.09	1.33	0.92	1.00	1.00	**23.3**	1,546	**25.4**
114.0	S9	17	41	Sand	4	1.06	1.33	0.93	1.00	1.00	**50.9**	1,681	**54.0**
112.0	S10	19	29	Sand	4	1.03	1.33	0.94	1.00	1.00	**36.4**	1,816	**37.6**
106.0	S11	25	33	Silt	4	0.97	1.33	0.97	1.00	1.00	**42.5**	2,222	**41.1**
101.3	S12	29.7	REF	Gravel	4	0.92	1.33	0.98	1.00	1.00	**100.0**	2,540	**100.0**
96.0	S13	35	52	Gravel	4	0.88	1.33	1.00	1.00	1.00	**69.3**	2,898	**60.9**
91.6	S14	39.4	REF	Gravel	4	0.85	1.33	1.00	1.00	1.00	**100.0**	3,195	**100.0**
86.0	S15	45	59	Silt	4	0.81	1.33	1.00	1.00	1.00	**78.7**	3,574	**63.5**
81.1	S16	49.9	82	Silt	4	0.78	1.33	1.00	1.00	1.00	**109.3**	3,905	**85.1**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)

$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.

C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$

C_E = SPT correction factor for hammer energy, $C_E = ER/60$

C_R = SPT Correction factor for rod length, C_R = -8E-5*L^2+0.0083*L+0.7922

C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"

C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights

Max $\gamma_{granular,\ dry}$ (pcf)= 130

Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]

Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes:
1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Sheet No. 3

Project:	Bruce Freeman Rail Trail, Sudbury, MA	Authored by:	SR	Date	9/11/2019
Job No.	E2X81800	Checked by:	DH	Date	9/26/2019

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. BB-103A/B

Ground Surface Elevation 142.5 ft (NGVD 29)

Ground Water Depth during Drilling 9.4 ft

Hammer Efficiency 60 %

Hammer Type 140 lb Safety

Sampler Type Standard

SPT Rod Stickup 4.0 ft

References
1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
141.5	S1	1	5	Fill	4	1.98	1.00	0.83	1.00	1.00	**4.2**	109	**8.2**
139.5	S2	3	6	Fill	4	1.60	1.00	0.85	1.00	1.00	**5.1**	330	**8.1**
137.5	S3	5	6	Fill	4	1.43	1.00	0.86	1.00	1.00	**5.2**	553	**7.4**
135.5	S4	7	7	Fill	4	1.32	1.00	0.87	1.00	1.00	**6.1**	778	**8.1**
133.8	S5	8.7	REF	Fill	4	1.23	1.00	0.88	1.00	1.00	**100.0**	999	**100.0**
131.5	S6	11	4	Silt	4	1.18	1.00	0.90	1.00	1.00	**3.6**	1,164	**4.3**
129.5	S7	13	13	Silt	4	1.15	1.00	0.91	1.00	1.00	**11.8**	1,288	**13.6**
127.5	S8	15	13	Silt	4	1.12	1.00	0.92	1.00	1.00	**12.0**	1,413	**13.4**
125.5	S9	17	29	Silt	4	1.09	1.00	0.93	1.00	1.00	**27.0**	1,549	**29.4**
123.5	S10	19	23	Silt	4	1.06	1.00	0.94	1.00	1.00	**21.6**	1,684	**22.9**
117.5	S11	25	48	Gravel	4	0.99	1.00	0.97	1.00	1.00	**46.3**	2,089	**45.8**
112.6	S12	29.9	85	Gravel	4	0.94	1.00	0.98	1.00	1.00	**83.4**	2,421	**78.3**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)

$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.

C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$

C_E = SPT correction factor for hammer energy, $C_E = ER/60$

C_R = SPT Correction factor for rod length, $C_R = -8E-5*L^2+0.0083*L+0.7922$

C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"

C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights

Max $\gamma_{granular,\ dry}$ (pcf)= 130

Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]

Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2

2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Sheet No. **4**

Project:	**Bruce Freeman Rail Trail, Sudbury, MA**	Authored by:	**SR**	Date	**9/30/2019**
Job No.	**E2X81800**	Checked by:	**DH**	Date	**10/8/2019**

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. **BB-105**
Ground Surface Elevation **189** ft (NGVD 29)
Ground Water Depth during Drilling **4.0** ft
Hammer Efficiency **80** %

Hammer Type **140 lb Auto**
Sampler Type **Standard**
SPT Rod Stickup **4.0** ft

References 1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter	C_N	C_E	C_R	C_B	C_S			
(ft)	-	(ft)	(blows/ft)	-	(in)						(blows/ft)	(psf)	(blows/ft)
188.0	**S1**	**1**	**11**	**Fill**	**4**	1.94	1.33	0.83	1.00	1.00	**12.2**	120	**23.7**
186.0	**S2**	**3**	**25**	**Fill**	**4**	1.56	1.33	0.85	1.00	1.00	**28.2**	380	**43.9**
184.0	**S3**	**5**	**24**	**Fill**	**4**	1.42	1.33	0.86	1.00	1.00	**27.5**	578	**39.0**
182.0	**S4**	**7**	**35**	**Fill**	**4**	1.35	1.33	0.87	1.00	1.00	**40.8**	713	**54.9**
180.0	**S5**	**9**	**53**	**Sand**	**4**	1.29	1.33	0.89	1.00	1.00	**62.7**	848	**80.7**
178.0	**S6**	**11**	**41**	**Sand**	**4**	1.24	1.33	0.90	1.00	1.00	**49.1**	984	**60.9**
176.0	**S7**	**13**	**43**	**Sand**	**4**	1.20	1.33	0.91	1.00	1.00	**52.2**	1,119	**62.4**
174.1	**S8**	**14.9**	**50**	**Sand**	**4**	1.16	1.33	0.92	1.00	1.00	**61.4**	1,247	**71.2**
172.8	**S9**	**16.2**	**REF**	**Gravel**	**4**	1.14	1.33	0.93	1.00	1.00	**100.0**	1,335	**100.0**
170.1	**S10**	**18.9**	**9**	**Gravel**	**4**	1.10	1.33	0.94	1.00	1.00	**11.3**	1,503	**12.4**
168.6	**S11**	**20.4**	**REF**	**Gravel**	**4**	1.08	1.33	0.95	1.00	1.00	**100.0**	1,604	**100.0**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)
$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.
C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$
C_E = SPT correction factor for hammer energy, $C_E = ER/60$
C_R = SPT Correction factor for rod length, $C_R = -8E-5*L^2+0.0083*L+0.7922$
C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"
C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights
Max $\gamma_{granular,\ dry}$ (pcf)= 130
Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Sheet No. **5**

Project:	**Bruce Freeman Rail Trail, Sudbury, MA**	Authored by:	**SR**	Date	**9/30/2019**
Job No.	**E2X81800**	Checked by:	**DH**	Date	**10/8/2019**

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. **BB-106**
Ground Surface Elevation **188** ft (NGVD 29)
Ground Water Depth during Drilling **2.5** ft
Hammer Efficiency **80** %

Hammer Type **140 lb Auto**
Sampler Type **Standard**
SPT Rod Stickup **4.0** ft

References
1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
187.0	**S1**	**1**	**7**	**Fill**	**4**	1.96	1.33	0.83	1.00	1.00	**7.8**	115	**15.2**
185.0	**S2**	**3**	**35**	**Fill**	**4**	1.59	1.33	0.85	1.00	1.00	**39.5**	344	**62.8**
183.0	**S3**	**5**	**33**	**Fill**	**4**	1.48	1.33	0.86	1.00	1.00	**37.9**	479	**56.0**
181.0	**S4**	**7**	**20**	**Silt**	**4**	1.40	1.33	0.87	1.00	1.00	**23.3**	615	**32.5**
179.0	**S5**	**9**	**17**	**Sand**	**4**	1.33	1.33	0.89	1.00	1.00	**20.1**	749	**26.7**
177.0	**S6**	**11**	**8**	**Sand**	**4**	1.28	1.33	0.90	1.00	1.00	**9.6**	870	**12.3**
175.0	**S7**	**13**	**55**	**Sand**	**4**	1.23	1.33	0.91	1.00	1.00	**66.7**	1,005	**82.2**
173.0	**S8**	**15**	**23**	**Sand**	**4**	1.19	1.33	0.92	1.00	1.00	**28.2**	1,140	**33.6**
171.0	**S9**	**17**	**31**	**Sand**	**4**	1.15	1.33	0.93	1.00	1.00	**38.5**	1,276	**44.3**
169.1	**S10**	**18.9**	**42**	**Sand**	**4**	1.12	1.33	0.94	1.00	1.00	**52.7**	1,404	**59.0**
167.8	**S11**	**20.2**	**REF**	**Sand**	**4**	1.10	1.33	0.95	1.00	1.00	**100.0**	1,492	**100.0**

Notation:
N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)
$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.
C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$
C_E = SPT correction factor for hammer energy, $C_E = ER/60$
C_R = SPT Correction factor for rod length, $C_R = -8E-5*L^2+0.0083*L+0.7922$
C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"
C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights
Max $\gamma_{granular,\ dry}$ (pcf)= 130
Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes:
1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Sheet No. **6**

Project: **Bruce Freeman Rail Trail, Sudbury, MA** Authored by: **SR** Date **9/30/2019**

Job No. **E2X81800** Checked by: **DH** Date **10/8/2019**

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. **BB-107A/B**
Ground Surface Elevation **187** ft (NGVD 29)
Ground Water Depth during Drilling **1.1** ft
Hammer Efficiency **80** %

Hammer Type **140 lb Auto**
Sampler Type **Standard**
SPT Rod Stickup **4.0** ft

References 1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
186.0	**S1**	**1**	**14**	**Fill**	**4**	1.93	1.33	0.83	1.00	1.00	**15.5**	123	**30.0**
184.0	**S2**	**3**	**32**	**Fill**	**4**	1.68	1.33	0.85	1.00	1.00	**36.1**	265	**60.6**
182.0	**S3**	**5**	**15**	**Silt**	**4**	1.54	1.33	0.86	1.00	1.00	**17.2**	396	**26.6**
180.6	**S4**	**6.4**	**REF**	**Silt**	**4**	1.47	1.33	0.87	1.00	1.00	**100.0**	491	**100.0**
177.7	**S5**	**9.3**	**46**	**Sand**	**4**	1.36	1.33	0.89	1.00	1.00	**54.5**	687	**74.1**
176.5	**S6**	**10.5**	**REF**	**Sand**	**4**	1.32	1.33	0.90	1.00	1.00	**100.0**	768	**100.0**
173.6	**S7**	**13.4**	**12**	**Gravel**	**4**	1.25	1.33	0.91	1.00	1.00	**14.6**	954	**18.2**
172.3	**S8**	**14.7**	**REF**	**Gravel**	**4**	1.22	1.33	0.92	1.00	1.00	**100.0**	1,042	**100.0**
170.8	**S9**	**16.2**	**REF**	**Gravel**	**4**	1.19	1.33	0.93	1.00	1.00	**100.0**	1,144	**100.0**
168.9	**S10**	**18.1**	**REF**	**Gravel**	**4**	1.15	1.33	0.94	1.00	1.00	**100.0**	1,272	**100.0**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)
$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.
C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$
C_E = SPT correction factor for hammer energy, $C_E = ER/60$
C_R = SPT Correction factor for rod length, C_R = -8E-5*L^2+0.0083*L+0.7922
C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"
C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights
Max $\gamma_{granular,\ dry}$ (pcf)= 130
Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Sheet No. 7

Project: Bruce Freeman Rail Trail, Sudbury, MA
Authored by: SR Date 9/30/2019
Job No. E2X81800
Checked by: DH Date 10/8/2019

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. BB-108
Ground Surface Elevation 185 ft (NGVD 29)
Ground Water Depth during Drilling 6.7 ft
Hammer Efficiency 80 %

Hammer Type 140 lb Auto
Sampler Type Standard
SPT Rod Stickup 4.0 ft

References 1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
184.0	S1	1	10	Fill	4	1.94	1.33	0.83	1.00	1.00	**11.1**	119	**21.6**
182.0	S2	3	26	Fill	4	1.56	1.33	0.85	1.00	1.00	**29.3**	379	**45.7**
180.0	S3	5	13	Silt	4	1.39	1.33	0.86	1.00	1.00	**14.9**	625	**20.7**
178.1	S4	6.9	21	Silt	4	1.28	1.33	0.87	1.00	1.00	**24.4**	860	**31.4**
176.8	S5	8.2	REF	Silt	4	1.25	1.33	0.88	1.00	1.00	**100.0**	947	**100.0**
174.0	S6	11	67	Gravel	4	1.19	1.33	0.90	1.00	1.00	**80.3**	1,137	**95.6**
172.0	S7	13	41	Gravel	4	1.15	1.33	0.91	1.00	1.00	**49.8**	1,272	**57.4**
170.6	S8	14.4	REF	Gravel	4	1.13	1.33	0.92	1.00	1.00	**100.0**	1,367	**100.0**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)
$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.
C_N = SPT correction factor for overburden pressure, $C_N = \min[0.77*\log(40/\sigma'_v),2]$
C_E = SPT correction factor for hammer energy, $C_E = ER/60$
C_R = SPT Correction factor for rod length, C_R = -8E-5*L^2+0.0083*L+0.7922
C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"
C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights
Max $\gamma_{granular,\ dry}$ (pcf)= 130
Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2
2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

				Sheet No.	8
Project:	Bruce Freeman Rail Trail, Sudbury, MA	Authored by:	SR	Date	9/30/2019
Job No.	E2X81800	Checked by:	DH	Date	10/8/2019

Corrected N Value for Estimation of Soil Strength Parameters

Boring No. BB-109

Ground Surface Elevation 184 ft (NGVD 29)

Ground Water Depth during Drilling 2.5 ft

Hammer Efficiency 80 %

Hammer Type 140 lb Auto

Sampler Type Standard

SPT Rod Stickup 4.0 ft

References
1. FHWA-IF-02-034 (2002)
2. FHWA-NHI-10-0.16 (May 2010)
3. NAVFAC DM-7 (March 1971)
4. IDOT AGMU Memo 10.2
5. Valiquette, Robinson, and Borden (2009)

Elevation of Sample	Boring Data					SPT Correction Factor					Corrected SPT N Value, N_{60}	Vertical Effective Stress, σ'_v	Corrected SPT N Value, $N_{1,60}$
	Sample No.	Sample Depth	SPT N Value	Material	Borehole Diameter								
(ft)	-	(ft)	(blows/ft)	-	(in)	C_N	C_E	C_R	C_B	C_S	(blows/ft)	(psf)	(blows/ft)
183.0	S1	1	12	Fill	4	1.94	1.33	0.83	1.00	1.00	**13.3**	121	**25.8**
181.0	S2	3	68	Fill	4	1.58	1.33	0.85	1.00	1.00	**76.7**	350	**121.6**
179.0	S3	5	76	Silt	4	1.48	1.33	0.86	1.00	1.00	**87.2**	485	**128.6**
177.1	S4	6.9	83	Silt	4	1.40	1.33	0.87	1.00	1.00	**96.6**	614	**135.0**
175.8	S5	8.2	REF	Silt	4	1.35	1.33	0.88	1.00	1.00	**100.0**	702	**100.0**

Notation: N_{60} = SPT blow count corrected for hammer efficiency (blows/ft)

$N_{1,60}$ = SPT blow count corrected for hammer efficiency and overburden pressure.

C_N = SPT correction factor for overburden pressure, C_N = min[0.77*log(40/σ'_v),2]

C_E = SPT correction factor for hammer energy, C_E = ER/60

C_R = SPT Correction factor for rod length, C_R = -8E-5*L^2+0.0083*L+0.7922

C_B = SPT Correction factor for borehole diameter, C_B = 1.0 if D < 4.5", 1.05 if 4.5" < D < 6", 1.15 if D > 6"

C_S = SPT Correction factor for sampler type, C_S = 1.0 if standard sampler, 1.2 if liner space without liners

IDOT AGMU Memo 10.2 Unit Weights

Max $\gamma_{granular, dry}$ (pcf)= 130

Above Water Table: $\gamma_{granular} = 95*(N_{60})^{0.095}$ [pcf]

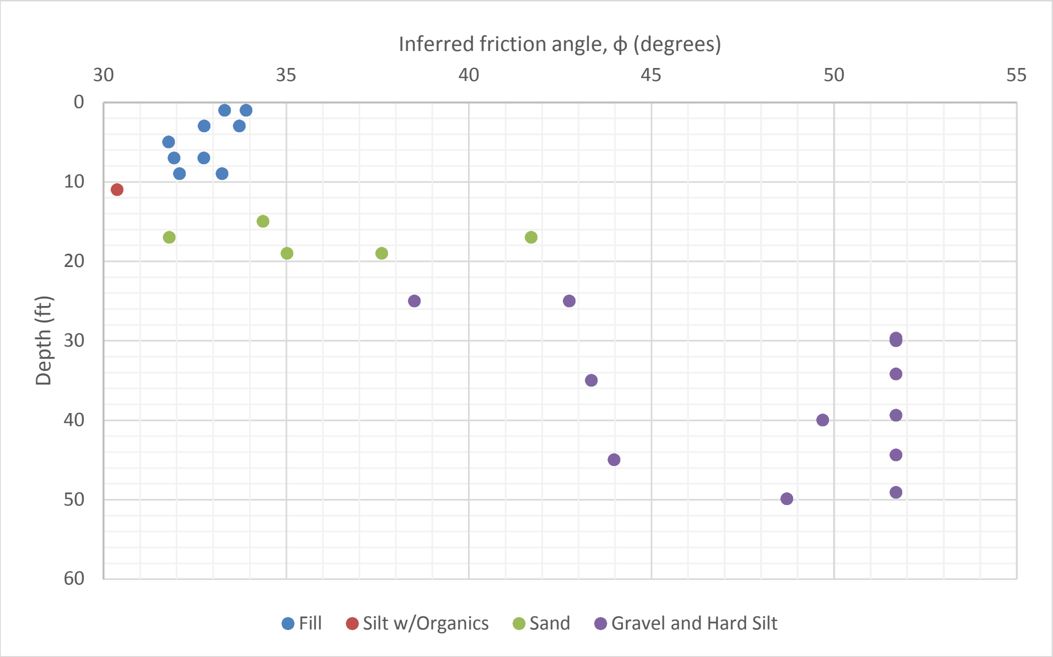
Below Water Table: $\gamma_{granular} = 105*(N_{60})^{0.07} - 62.4$ [pcf]

Notes: 1) Overburden pressure calculated using a unit weight based on IDOT AGMU Memo 10.2

2) Rod length assumes 4' stickup during SPTs, L = depth + 4'

Pantry Brook Site - Inferred Soil Properties

Authored by:	SR	Date	9/30/2019
Checked by:	DH	Date	10/8/2019



Soil Layer	Layer Thickness (ft)	Dry Unit Weight (pcf)	Friction angle ϕ (deg)[1]
Fill	10	120	32
Silt (w/organics)	6	120	28
Sand	8	120	34
Gravel+Hard Silt	28	130	40

1. Based on Wolff (1989), derived from Peck, Hansen and Thornburn (1954). $\phi=27.1 + 0.3*N_{1,60} - 0.00054*(N_{1,60})^2$

Appendix G – Pantry Brook Shallow Foundation Analysis

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

Purpose:

To determine the factored geotechnical bearing resistance of the proposed shallow foundations for the replacement bridge at Pantry Brook.

Procedure:

Use the SPT and soil propreties data of borings BB-101 and BB-102A/B and the procedures of the AASHTO 2017, 8th Edition, LRFD Bridge Design Specifications to estimate the factored geotechnical bearing capacity and settlement for shallow foundations.

Calculation Input:

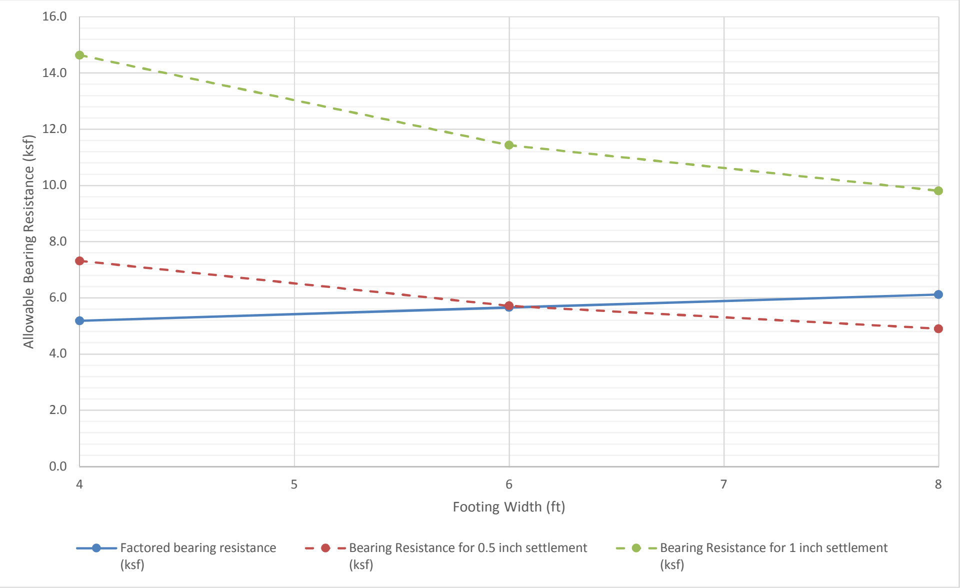
1) Boring N-value information - Corrected

Assumptions:

1) Bearing surface is medium dense to dense sand with trace gravel and little silt, overlying dense gravel.
2) Existing stream bed is at approximately El. 119.
3) Groundwater level based on borings and observed water level is approximately at El. 120.
4) Bottom of footing elevation is at approx El. 113.7.
5) Max footing eccentricity = B/3 (AASHTO Section 10.6.3.3)

Conclusions

Footing Width (ft)	Eccentricity (ft)	Factored bearing resistance (ksf)	Bearing Resistance for 0.5 inch settlement (ksf)	Bearing Resistance for 1 inch settlement (ksf)
4	1.33	5.2	7.3	14.6
6	2.00	5.7	5.7	11.4
8	2.67	6.1	4.9	9.8



JACOBS®

Pantry Brook Bridge Shallow Foundation

Authored by: SR   Date: 9/26/2019

Checked by: DH   Date: 9/26/2019

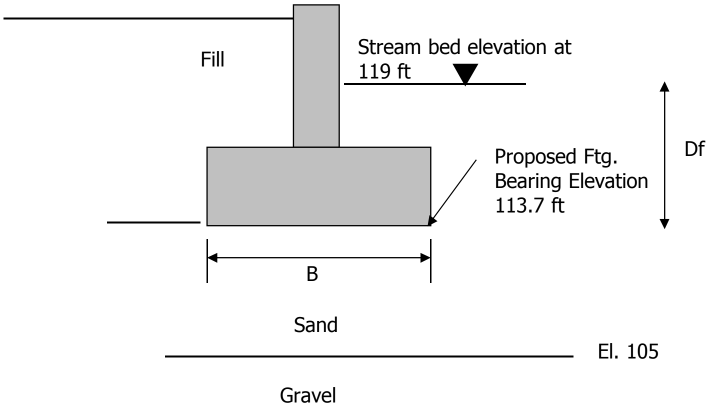
PURPOSE: Evaluate strength and service bearing resistances for abutment shallow foundations.

INPUT: Abutment footing measuring 4 ft wide by 14 ft long at elev. 113.7 ft.

DESIGN CODES: 2017 AASHTO LRFD Bridge Design Specifications

ASSUMPTIONS: Max footing eccentricity = B/3 (Section 10.6.3.3)
See Estimated Soil Properties for selected soil parameters

	γ (pcf)	ϕ
Med dense sand to dense sand/gravel borrow:	120	34



BEARING CAPACITY FACTORS (Table 10.6.3.1.2a-1):

	ϕ	N_c	N_q	N_γ
Med. Dense to dense granular material	34	42.2	29.4	41.1

CALCULATE EFFECTIVE FOOTING WIDTH (B'):

e < B/3   Section 10.6.3.3

where: B = footing width (ft) = 4 (assumed)

e = eccentricity (ft)

Max Ftg eccentricity, thus, e = 1.33

B' = B-2e 1.33

NOMINAL BEARING RESISTANCE (q_n):

$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5\gamma B' N_{\gamma m} C_{w\gamma}$ Eqn. 10.6.3.1.2a-1

where: c = cohesion = 0

γ = total unit weight 120

D_f = depth of footing (ft) = 5.3

B' = effective width of footing (ft) = 1.33

L = length of footing (ft) = 14

B'/L = 0.095

L/B' = 10.5

JACOBS

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

D_f /B' = 3.98

C_{wq} $C_{w\gamma}$ = groundwater correction factors use B'
C_{wq} = 0.50 Table 10.6.3.1.2a-2
$C_{w\gamma}$ = 0.50 Table 10.6.3.1.2a-2

N_{cm} N_{qm} $N_{\gamma m}$ = bearing capacity factors
$N_{qm} = N_q s_q d_q i_q$ Eqn. 10.6.3.1.2a-3

s_q = 1.06 Table 10.6.3.1.2a-3
d_q = 1.0 Table 10.6.3.1.2a-4
i_q = 1.0 AASHTO p. 10-70
N_{qm} = 31.3

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ Eqn. 10.6.3.1.2a-4
s_γ = 0.96 Table 10.6.3.1.2a-3
i_γ = 1 AASHTO p. 10-70
$N_{\gamma m}$ = 39.5
q_n = 11,531 psf

FACTORED BEARING RESISTANCE (q_r):

q_r = RF x q_n Eqn. 10.6.3.1.1-1
where: RF = resistance factor = 0.45 Table 10.5.5.2.2-1

q_r = 5.2 ksf strength limit value

JACOBS®

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

SETTLEMENT CALCULATIONS:

1. Check using Elastic Half-Space Method

$$S_e = \frac{(q_o\,(1-v^2)\sqrt{A'})}{144 E_s \beta_z}$$ Eqn. 10.6.2.4.2-1

where:
q_o = applied vert. stress (ksf)
v = Poisson's Ratio
E_s = Young's Modulus (ksi)
β_z = Shape/Rigidity Factor for flexible foundation Table 10.6.2.4.2-1

v = Poisson's Ratio =	0.30	Table C10.4.6.3-1
E_s = Young's Modulus (ksi) =	4.17	Table C10.4.6.3-1
β_z = Shape/Rigidity Factor =	1.15	Table 10.6.2.4.2-1

where:

B' = eff. width of footing (ft) =	1.33	(from bearing resistance calcs)
L = length of footing (ft):	14	(from bearing resistance calcs)
A' =B'xL = footing area (ft^2):	19	ft^2

Calc. q_o for a given settlement (S_e):

Se = given settlement (inches) =	0.50	inches
	1.00	inches
qo = applied vertical stress (ksf) =	7.32	ksf for 1/2 inch settlement
	14.64	ksf for 1 inch settlement

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

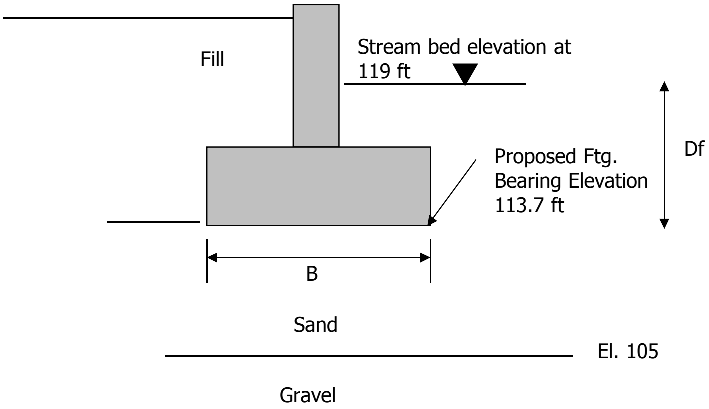
PURPOSE: Evaluate strength and service bearing resistances for abutment shallow foundations.

INPUT: Abutment footing measuring 6 ft wide by 14 ft long at elev. 113.7 ft.

DESIGN CODES: 2017 AASHTO LRFD Bridge Design Specifications

ASSUMPTIONS: Max footing eccentricity = B/3 (Section 10.6.3.3)
See Estimated Soil Properties for selected soil parameters

	γ (pcf)	ϕ
Med dense sand to dense sand/gravel borrow:	120	34



BEARING CAPACITY FACTORS (Table 10.6.3.1.2a-1):

	ϕ	N_c	N_q	N_γ
Med. Dense to dense granular material	34	42.2	29.4	41.1

CALCULATE EFFECTIVE FOOTING WIDTH (B'):

e < B/3 Section 10.6.3.3
where: B = footing width (ft) = 6 (assumed)
e = eccentricity (ft)
Max Ftg eccentricity, thus, e = 2.00
B' = B-2e 2.00

NOMINAL BEARING RESISTANCE (q_n):

$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5\gamma B' N_{\gamma m} C_{w\gamma}$ Eqn. 10.6.3.1.2a-1

where: c = cohesion = 0
γ = total unit weight 120
D_f = depth of footing (ft) = 5.3
B' = effective width of footing (ft) = 2.00
L = length of footing (ft) = 14
B'/L = 0.143
L/B' = 7.0

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

$D_f / B' =$ 2.65

C_{wq} $C_{w\gamma}$ = groundwater correction factors use B'

$C_{wq} =$ 0.50 Table 10.6.3.1.2a-2

$C_{w\gamma} =$ 0.50 Table 10.6.3.1.2a-2

N_{cm} N_{qm} $N_{\gamma m}$ = bearing capacity factors

$N_{qm} = N_q s_q d_q i_q$ Eqn. 10.6.3.1.2a-3

$s_q =$ 1.10 Table 10.6.3.1.2a-3

$d_q =$ 1.0 Table 10.6.3.1.2a-4

$i_q =$ 1.0 AASHTO p. 10-70

$N_{qm} =$ 32.2

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ Eqn. 10.6.3.1.2a-4

$s_\gamma =$ 0.94 Table 10.6.3.1.2a-3

$i_\gamma =$ 1 AASHTO p. 10-70

$N_{\gamma m} =$ 38.8

$q_n =$ 12,575 psf

FACTORED BEARING RESISTANCE (q_r):

$q_r = RF \times q_n$ Eqn. 10.6.3.1.1-1

where: RF = resistance factor = 0.45 Table 10.5.5.2.2-1

$\boxed{q_r = \quad 5.7 \quad \text{ksf}}$ strength limit value

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

SETTLEMENT CALCULATIONS:

1. Check using Elastic Half-Space Method

$$S_e = \frac{\left(q_o\,(1-\nu^2)\sqrt{A'}\right)}{144 E_s \beta_z}$$ Eqn. 10.6.2.4.2-1

where:
q_o = applied vert. stress (ksf)
v = Poisson's Ratio
E_s = Young's Modulus (ksi)
β_z = Shape/Rigidity Factor for flexible foundation Table 10.6.2.4.2-1

v = Poisson's Ratio =	0.30	Table C10.4.6.3-1
E_s = Young's Modulus (ksi) =	4.17	Table C10.4.6.3-1
β_z = Shape/Rigidity Factor =	1.10	Table 10.6.2.4.2-1

where:

B' = eff. width of footing (ft) =	2.00	(from bearing resistance calcs)
L = length of footing (ft):	14	(from bearing resistance calcs)
A' =B'xL = footing area (ft^2):	28	ft^2

Calc. q_o for a given settlement (S_e):

Se = given settlement (inches) =	0.50	inches
	1.00	inches
qo = applied vertical stress (ksf) =	5.72	ksf for 1/2 inch settlement
	11.43	ksf for 1 inch settlement

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

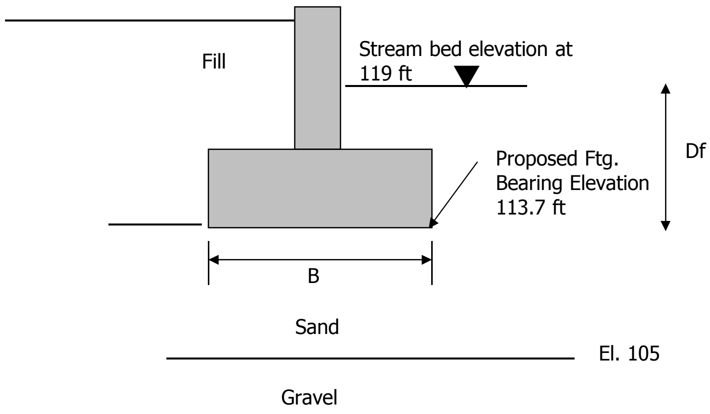
PURPOSE: Evaluate strength and service bearing resistances for abutment shallow foundations.

INPUT: Abutment footing measuring 8 ft wide by 14 ft long at elev. 113.7 ft.

DESIGN CODES: 2017 AASHTO LRFD Bridge Design Specifications

ASSUMPTIONS: Max footing eccentricity = B/3 (Section 10.6.3.3)
See Estimated Soil Properties for selected soil parameters

	γ (pcf)	ϕ
Med dense sand to dense sand/gravel borrow:	120	34



BEARING CAPACITY FACTORS (Table 10.6.3.1.2a-1):

	ϕ	N_c	N_q	N_γ
Med. Dense to dense granular material	34	42.2	29.4	41.1

CALCULATE EFFECTIVE FOOTING WIDTH (B'):

e < B/3 Section 10.6.3.3

where: B = footing width (ft) = 8 (assumed)

e = eccentricity (ft)

Max Ftg eccentricity, thus, e = 2.67

B' = B-2e 2.67

NOMINAL BEARING RESISTANCE (q_n):

$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5\gamma B' N_{\gamma m} C_{w\gamma}$ Eqn. 10.6.3.1.2a-1

where: c = cohesion = 0

γ = total unit weight 120

D_f = depth of footing (ft) = 5.3

B' = effective width of footing (ft) = 2.67

L = length of footing (ft) = 14

B'/L = 0.190

L/B' = 5.3

JACOBS

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

D_f /B' = 1.99

C_{wq} $C_{w\gamma}$ = groundwater correction factors use B'

C_{wq} = 0.50 Table 10.6.3.1.2a-2

$C_{w\gamma}$ = 0.50 Table 10.6.3.1.2a-2

N_{cm} N_{qm} $N_{\gamma m}$ = bearing capacity factors

$N_{qm} = N_q s_q d_q i_q$ Eqn. 10.6.3.1.2a-3

s_q = 1.13 Table 10.6.3.1.2a-3

d_q = 1.0 Table 10.6.3.1.2a-4

i_q = 1.0 AASHTO p. 10-70

N_{qm} = 33.2

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ Eqn. 10.6.3.1.2a-4

s_γ = 0.92 Table 10.6.3.1.2a-3

i_γ = 1 AASHTO p. 10-70

$N_{\gamma m}$ = 38.0

q_n = 13,588 psf

FACTORED BEARING RESISTANCE (q_r):

q_r = RF x q_n Eqn. 10.6.3.1.1-1

where: RF = resistance factor = 0.45 Table 10.5.5.2.2-1

q_r = 6.1 ksf strength limit value

JACOBS®

Pantry Brook Bridge Shallow Foundation

Authored by: SR Date: 9/26/2019
Checked by: DH Date: 9/26/2019

SETTLEMENT CALCULATIONS:

1. Check using Elastic Half-Space Method

$$S_e = \frac{\left(q_o\,(1-\nu^2)\sqrt{A'}\right)}{144 E_s \beta_z}$$

Eqn. 10.6.2.4.2-1

where: q_o = applied vert. stress (ksf)
ν = Poisson's Ratio
E_s = Young's Modulus (ksi)
β_z = Shape/Rigidity Factor for flexible foundation Table 10.6.2.4.2-1

ν = Poisson's Ratio = 0.30 Table C10.4.6.3-1
E_s = Young's Modulus (ksi) = 4.17 Table C10.4.6.3-1
β_z = Shape/Rigidity Factor = 1.09 Table 10.6.2.4.2-1

where: B' = eff. width of footing (ft) = 2.67 (from bearing resistance calcs)
L = length of footing (ft): 14 (from bearing resistance calcs)
A' =B'xL = footing area (ft^2): 37 ft^2

Calc. q_o for a given settlement (S_e):

Se = given settlement (inches) = 0.50 inches
1.00 inches

qo = applied vertical stress (ksf) = 4.90 ksf for 1/2 inch settlement
9.81 ksf for 1 inch settlement

Table 10.4.6.2.4-1—Correlation of *SPT* $N1_{60}$ Values to Drained Friction Angle of Granular Soils (modified after Bowles, 1977)

$N1_{60}$	ϕ_f
<4	25–30
4	27–32
10	30–35
30	35–40
50	38–43

(N1 60) =	34

Table 10.6.2.4.2-1—Elastic Shape and Rigidity Factors, EPRI (1983)

L/B	Flexible, β_z (average)	β_z Rigid
Circular	1.04	1.13
1	1.06	1.08
2	1.09	1.10
3	1.13	1.15
5	1.22	1.24
10	1.41	1.41

Table 10.6.3.1.2a-2—Coefficients C_{wq} and $C_{w\gamma}$ for Various Groundwater Depths

D_w	C_{wq}	$C_{w\gamma}$
0.0	0.5	0.5
D_f	1.0	0.5
$>1.5B + D_f$	1.0	1.0

Table C10.4.6.3-1—Elastic Constants of Various Soils (modified after U.S. Department of the Navy, 1982; Bowles, 1988)

Soil Type	Typical Range of Young's Modulus Values, E_s (ksi)	Poisson's Ratio, ν (dim)
Clay:		0.4–0.5 (undrained)
Soft sensitive	0.347–2.08	
Medium stiff to stiff	2.08–6.94	
Very stiff	6.94–13.89	
Loess	2.08–8.33	0.1–0.3
Silt	0.278–2.78	0.3–0.35
Fine Sand:		0.25
Loose	1.11–1.67	
Medium dense	1.67–2.78	
Dense	2.78–4.17	
Sand:		
Loose	1.39–4.17	0.20–0.36
Medium dense	4.17–6.94	
Dense	6.94–11.11	0.30–0.40
Gravel:		
Loose	4.17–11.11	0.20–0.35
Medium dense	11.11–13.89	
Dense	13.89–27.78	0.30–0.40
Estimating E_s from *SPT N* Value		
Soil Type		E_s (ksi)
Silts, sandy silts, slightly cohesive mixtures		$0.056\ N1_{60}$
Clean fine to medium sands and slightly silty sands		$0.097\ N1_{60}$
Coarse sands and sands with little gravel		$0.139\ N1_{60}$
Sandy gravel and gravels		$0.167\ N1_{60}$
Estimating E_s from q_c (static cone resistance)		
Sandy soils		$0.028q_c$

Table 10.6.3.1.2a-1—Bearing Capacity Factors N_c (Prandtl, 1921), N_q (Reissner, 1924), and N_γ (Vesic, 1975)

ϕ_f	N_c	N_q	N_γ	ϕ_f	N_c	N_q	N_γ
0	5.14	1.0	0.0	23	18.1	8.7	8.2
1	5.4	1.1	0.1	24	19.3	9.6	9.4
2	5.6	1.2	0.2	25	20.7	10.7	10.9
3	5.9	1.3	0.2	26	22.3	11.9	12.5
4	6.2	1.4	0.3	27	23.9	13.2	14.5
5	6.5	1.6	0.5	28	25.8	14.7	16.7
6	6.8	1.7	0.6	29	27.9	16.4	19.3
7	7.2	1.9	0.7	30	30.1	18.4	22.4
8	7.5	2.1	0.9	31	32.7	20.6	26.0
9	7.9	2.3	1.0	32	35.5	23.2	30.2
10	8.4	2.5	1.2	33	38.6	26.1	35.2
11	8.8	2.7	1.4	34	42.2	29.4	41.1
12	9.3	3.0	1.7	35	46.1	33.3	48.0
13	9.8	3.3	2.0	36	50.6	37.8	56.3
14	10.4	3.6	2.3	37	55.6	42.9	66.2
15	11.0	3.9	2.7	38	61.4	48.9	78.0
16	11.6	4.3	3.1	39	67.9	56.0	92.3
17	12.3	4.8	3.5	40	75.3	64.2	109.4
18	13.1	5.3	4.1	41	83.9	73.9	130.2
19	13.9	5.8	4.7	42	93.7	85.4	155.6
20	14.8	6.4	5.4	43	105.1	99.0	186.5
21	15.8	7.1	6.2	44	118.4	115.3	224.6
22	16.9	7.8	7.1	45	133.9	134.9	271.8

Table 10.6.3.1.2a-3—Shape Correction Factors s_c, s_γ, s_q

Factor	Friction Angle	Cohesion Term (s_c)	Unit Weight Term (s_γ)	Surcharge Term (s_q)
Shape Factors s_c, s_γ, s_q	$\phi_f = 0$	$1+\left(\frac{B}{5L}\right)$	1.0	1.0
	$\phi_f > 0$	$1+\left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$	$1-0.4\left(\frac{B}{L}\right)$	$1+\left(\frac{B}{L}\tan\phi_f\right)$

Table 10.6.3.1.2a-4—Depth Correction Factor d_q

Friction Angle, ϕ_f (degrees)	D_f/B	d_q
32	1	1.20
	2	1.30
	4	1.35
	8	1.40
37	1	1.20
	2	1.25
	4	1.30
	8	1.35
42	1	1.15
	2	1.20
	4	1.25
	8	1.30

Table 10.5.5.2.2-1—Resistance Factors for Geotechnical Resistance of Shallow Foundations at the Strength Limit State

Method/Soil/Condition			Resistance Factor
Bearing Resistance	φ_b	Theoretical method (Munfakh et al., 2001), in clay	0.50
		Theoretical method (Munfakh et al., 2001), in sand, using *CPT*	0.50
		Theoretical method (Munfakh et al., 2001), in sand, using *SPT*	0.45
		Semi-empirical methods (Meyerhof, 1957), all soils	0.45
		Footings on rock	0.45
		Plate Load Test	0.55
Sliding	φ_τ	Precast concrete placed on sand	0.90
		Cast-in-Place Concrete on sand	0.80
		Cast-in-Place or precast Concrete on Clay	0.85
		Soil on soil	0.90
	φ_{ep}	Passive earth pressure component of sliding resistance	0.50

Appendix H – Boardwalk Shallow Foundation Analysis

Boardwalk Shallow Foundation

Authored by: PJL Date: 10/28/2019
Checked by: SR Date: 11/6/2019

Purpose:

To determine the factored geotechnical bearing resistance of the proposed shallow foundations for the boardwalk structure.

Procedure:

Use the SPT and soil propreties data of borings BB-105 through BB-109B and the procedures of the AASHTO 2017, 8th Edition, LRFD Bridge Design Specifications to estimate the factored geotechnical bearing capacity and settlement for shallow foundations.

Calculation Input:

1) Boring N-value information - Corrected

Assumptions:

1) Bearing surface is medium dense sand.
2) Assume ground water level is at the surface.
3) Max footing loading and eccentricity is provided by Structural Engineer.

JACOBS

Boardwalk Shallow Foundation

Authored by: PJL Date: 10/28/2019
Checked by: SR Date: 11/6/2019

PURPOSE: Evaluate strength and service bearing resistances for boardwalk shallow foundations.

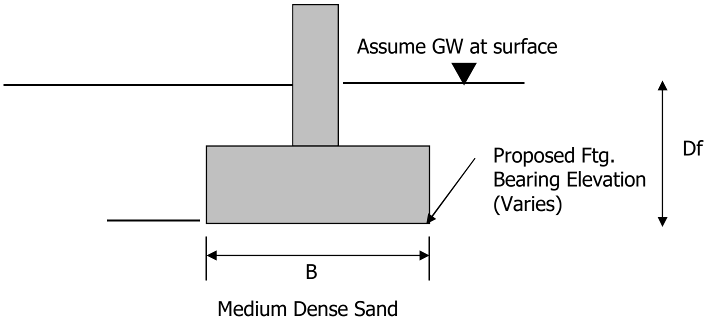
INPUT: Abutment footing measuring 3 ft x 3 ft

DESIGN CODES: 2017 AASHTO LRFD Bridge Design Specifications

ASSUMPTIONS: See Estimated Soil Properties for selected soil parameters

	γ (pcf)	ϕ
Med dense sand	120	30

Conservative Assumption



BEARING CAPACITY FACTORS (Table 10.6.3.1.2a-1):

	ϕ	N_c	N_q	N_γ
Med. Dense to dense granular material	30	30.1	18.4	22.4

CALCULATE EFFECTIVE FOOTING WIDTH (B'):

$e < B/3$ Section 10.6.3.3

where: B = footing width (ft) = 3 (assumed)

e = eccentricity (ft)

Max Ftg eccentricity, thus, e = 0.20 Provided by Structural Engineer

B' = B-2e 2.60

NOMINAL BEARING RESISTANCE (q_n):

$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5\gamma B' N_{\gamma m} C_{w\gamma}$ Eqn. 10.6.3.1.2a-1

where: c = cohesion = 0

γ = total unit weight 120

D_f = depth of footing (ft) = 4

B' = effective width of footing (ft) = 2.60

L = length of footing (ft) = 3

B'/L = 0.867

L/B' = 1.2

D_f /B' = 1.54

Boardwalk Shallow Foundation	Authored by: PJL	Date: 10/28/2019	
	Checked by: SR	Date: 11/6/2019	

C_{wq} $C_{w\gamma}$ = groundwater correction factors — use B'

C_{wq} =	0.50	Table 10.6.3.1.2a-2
$C_{w\gamma}$ =	0.50	Table 10.6.3.1.2a-2

N_{cm} N_{qm} $N_{\gamma m}$ = bearing capacity factors

$N_{qm} = N_q s_q d_q i_q$ — Eqn. 10.6.3.1.2a-3

s_q =	1.50	Table 10.6.3.1.2a-3
d_q =	1.0	Table 10.6.3.1.2a-4
i_q =	1.0	AASHTO p. 10-70
N_{qm} =	27.6	

$N_{\gamma m} = N_\gamma s_\gamma i_\gamma$ — Eqn. 10.6.3.1.2a-4

s_γ =	0.65	Table 10.6.3.1.2a-3
i_γ =	1	AASHTO p. 10-70
$N_{\gamma m}$ =	14.6	

q_n = 7,767 psf

FACTORED BEARING RESISTANCE (q_r):

q_r = RF x q_n — Eqn. 10.6.3.1.1-1

where: RF = resistance factor = 0.45 — Table 10.5.5.2.2-1

q_r = 3.5 ksf — strength limit value

Axial Load on footing (kips) =	18.5	(Provided by Structural Engineer based on Strength V load case)
Effective footing area (ft^2) =	7.8	
Bearing pressure acting on footing (ksf) =	**2.4**	

JACOBS®

Authored by: PJL Date: 10/28/2019
Boardwalk Shallow Foundation Checked by: SR Date: 11/6/2019

SETTLEMENT CALCULATIONS:

1. Check using Elastic Half-Space Method

$$S_e = \frac{\left(q_o\,(1 - v^2)\sqrt{A'}\right)}{144 E_s \beta_z}$$ Eqn. 10.6.2.4.2-1

where:
q_o = applied vert. stress (ksf)
v = Poisson's Ratio
E_s = Young's Modulus (ksi)
β_z = Shape/Rigidity Factor for flexible foundation Table 10.6.2.4.2-1

v = Poisson's Ratio = 0.25 Table C10.4.6.3-1
E_s = Young's Modulus (ksi) = 4.17 Table C10.4.6.3-1
β_z = Shape/Rigidity Factor = 1.08 Table 10.6.2.4.2-1

where:
B' = eff. width of footing (ft) = 2.60 (from bearing resistance calcs)
L = length of footing (ft): 3 (from bearing resistance calcs)
A' =B'xL = footing area (ft^2): 8 ft^2

Calc. q_o for a given settlement (S_e):

Se = given settlement (inches) = 0.50 inches
1.00 inches

qo = applied vertical stress (ksf) = 10.32 ksf for 1/2 inch settlement
20.64 ksf for 1 inch settlement

Settlement does not control design.

Table 10.4.6.2.4-1—Correlation of *SPT* $N1_{60}$ Values to Drained Friction Angle of Granular Soils (modified after Bowles, 1977)

$N1_{60}$	ϕ_f
<4	25–30
4	27–32
10	30–35
30	35–40
50	38–43

(N1 60) = 30

Table 10.6.2.4.2-1—Elastic Shape and Rigidity Factors, EPRI (1983)

L/B	Flexible, β_z (average)	β_z Rigid
Circular	1.04	1.13
1	1.06	1.08
2	1.09	1.10
3	1.13	1.15
5	1.22	1.24
10	1.41	1.41

Table 10.6.3.1.2a-2—Coefficients C_{wq} and $C_{w\gamma}$ for Various Groundwater Depths

D_w	C_{wq}	$C_{w\gamma}$
0.0	0.5	0.5
D_f	1.0	0.5
$>1.5B + D_f$	1.0	1.0

Table C10.4.6.3-1—Elastic Constants of Various Soils (modified after U.S. Department of the Navy, 1982; Bowles, 1988)

Soil Type	Typical Range of Young's Modulus Values, E_s (ksi)	Poisson's Ratio, ν (dim)
Clay:		
Soft sensitive	0.347–2.08	0.4–0.5 (undrained)
Medium stiff to stiff	2.08–6.94	
Very stiff	6.94–13.89	
Loess	2.08–8.33	0.1–0.3
Silt	0.278–2.78	0.3–0.35
Fine Sand:		
Loose	1.11–1.67	0.25
Medium dense	1.67–2.78	
Dense	2.78–4.17	
Sand:		
Loose	1.39–4.17	0.20–0.36
Medium dense	4.17–6.94	
Dense	6.94–11.11	0.30–0.40
Gravel:		
Loose	4.17–11.11	0.20–0.35
Medium dense	11.11–13.89	
Dense	13.89–27.78	0.30–0.40
Estimating E_s from *SPT N* Value		
Soil Type		E_s (ksi)
Silts, sandy silts, slightly cohesive mixtures		$0.056\ N1_{60}$
Clean fine to medium sands and slightly silty sands		$0.097\ N1_{60}$
Coarse sands and sands with little gravel		$0.139\ N1_{60}$
Sandy gravel and gravels		$0.167\ N1_{60}$
Estimating E_s from q_c (static cone resistance)		
Sandy soils		$0.028q_c$

Table 10.6.3.1.2a-1—Bearing Capacity Factors N_c (Prandtl, 1921), N_q (Reissner, 1924), and N_γ (Vesic, 1975)

ϕ_f	N_c	N_q	N_γ	ϕ_f	N_c	N_q	N_γ
0	5.14	1.0	0.0	23	18.1	8.7	8.2
1	5.4	1.1	0.1	24	19.3	9.6	9.4
2	5.6	1.2	0.2	25	20.7	10.7	10.9
3	5.9	1.3	0.2	26	22.3	11.9	12.5
4	6.2	1.4	0.3	27	23.9	13.2	14.5
5	6.5	1.6	0.5	28	25.8	14.7	16.7
6	6.8	1.7	0.6	29	27.9	16.4	19.3
7	7.2	1.9	0.7	30	30.1	18.4	22.4
8	7.5	2.1	0.9	31	32.7	20.6	26.0
9	7.9	2.3	1.0	32	35.5	23.2	30.2
10	8.4	2.5	1.2	33	38.6	26.1	35.2
11	8.8	2.7	1.4	34	42.2	29.4	41.1
12	9.3	3.0	1.7	35	46.1	33.3	48.0
13	9.8	3.3	2.0	36	50.6	37.8	56.3
14	10.4	3.6	2.3	37	55.6	42.9	66.2
15	11.0	3.9	2.7	38	61.4	48.9	78.0
16	11.6	4.3	3.1	39	67.9	56.0	92.3
17	12.3	4.8	3.5	40	75.3	64.2	109.4
18	13.1	5.3	4.1	41	83.9	73.9	130.2
19	13.9	5.8	4.7	42	93.7	85.4	155.6
20	14.8	6.4	5.4	43	105.1	99.0	186.5
21	15.8	7.1	6.2	44	118.4	115.3	224.6
22	16.9	7.8	7.1	45	133.9	134.9	271.8

Table 10.6.3.1.2a-3—Shape Correction Factors s_c, s_γ, s_q

Factor	Friction Angle	Cohesion Term (s_c)	Unit Weight Term (s_γ)	Surcharge Term (s_q)
Shape Factors s_c, s_γ, s_q	$\phi_f = 0$	$1+\left(\frac{B}{5L}\right)$	1.0	1.0
	$\phi_f > 0$	$1+\left(\frac{B}{L}\right)\left(\frac{N_q}{N_c}\right)$	$1-0.4\left(\frac{B}{L}\right)$	$1+\left(\frac{B}{L}\tan\phi_f\right)$

Table 10.6.3.1.2a-4—Depth Correction Factor d_q

Friction Angle, ϕ_f (degrees)	D_f/B	d_q
32	1	1.20
	2	1.30
	4	1.35
	8	1.40
37	1	1.20
	2	1.25
	4	1.30
	8	1.35
42	1	1.15
	2	1.20
	4	1.25
	8	1.30

Table 10.5.5.2.2-1—Resistance Factors for Geotechnical Resistance of Shallow Foundations at the Strength Limit State

Method/Soil/Condition			Resistance Factor
Bearing Resistance	φ_b	Theoretical method (Munfakh et al., 2001), in clay	0.50
		Theoretical method (Munfakh et al., 2001), in sand, using *CPT*	0.50
		Theoretical method (Munfakh et al., 2001), in sand, using *SPT*	0.45
		Semi-empirical methods (Meyerhof, 1957), all soils	0.45
		Footings on rock	0.45
		Plate Load Test	0.55
Sliding	φ_τ	Precast concrete placed on sand	0.90
		Cast-in-Place Concrete on sand	0.80
		Cast-in-Place or precast Concrete on Clay	0.85
		Soil on soil	0.90
	φ_{ep}	Passive earth pressure component of sliding resistance	0.50