

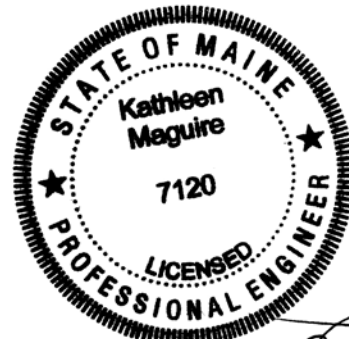
**MAINE DEPARTMENT OF TRANSPORTATION
HIGHWAY PROGRAM
GEOTECHNICAL SECTION
AUGUSTA, MAINE**

GEOTECHNICAL DESIGN REPORT

For the Construction of:

**BRIGHTON ROAD BRIDGE
ROUTE 151
ATHENS, MAINE**

Prepared by:
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Assistant Geotechnical Engineer



A handwritten signature in black ink, appearing to read "Kathleen Maguire", written over the bottom right portion of the professional seal.

Reviewed by:
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Senior Geotechnical Engineer

Somerset County
WIN 23513.00

Soils Report 2018-12
Bridge No. 6579

March 29, 2018

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1.0 INTRODUCTION

The purpose of this Geotechnical Design Report is to present subsurface information and make geotechnical recommendations for the replacement of an existing cross culvert (#159147) on Route 151 in Athens, Maine. A subsurface investigation has been completed at the site to evaluate subsurface conditions and to develop geotechnical design and construction recommendations for the replacement structure. This report presents the subsurface information obtained during the subsurface investigation and soil laboratory testing programs, and provides design and construction recommendations and geotechnical design parameters for the culvert replacement.

The existing structure consists of an approximately 40-foot long, 48-inch diameter Corrugated Metal Pipe (CMP) culvert on a skew of approximately 13 degrees to the roadway centerline on Route 151 in Athens. The CMP is separated along the sides, the top section is beginning to fold down, and the inlet is deformed. Route 151 is a Highway Corridor Priority 4 road.

The proposed replacement structure will be a 10-foot span by 5-foot rise by 68-foot long precast concrete box culvert on a skew of approximately 16 degrees to the roadway centerline. The invert of the proposed culvert is approximately 10 feet below the existing road grade at the roadway centerline. The invert of the proposed culvert will be lined with approximately 2 feet of Special Fill to facilitate fish passage. The roadway embankment slopes at the proposed culvert inlet and outlet shall be no steeper than 2H:1V to protect against erosion.

2.0 GEOLOGIC SETTING

The existing culvert carries Corson Brook under Route 151 (Brighton Road) in Athens and is located approximately 0.37 of a mile north of Leavitt Road as shown in Sheet 1 – Location Map.

The Maine Geological Survey (MGS) map titled Reconnaissance Surficial Geology of the Skowhegan Quadrangle, Maine Open File 86-38 (1986) the surficial soils at the site consist of till. These soils consist of a heterogeneous mixture of sand, silt, clay, and stones with rare stratification. The till includes two varieties: basal till and ablation till. Basal till is fine grained and very compact, with low permeability and poor drainage. Ablation till is loose, sandy, and stony, with moderate permeability and fair to good drainage.

The MGS map Bedrock Geology of Maine (1985), cites bedrock at the culvert as interbedded pelite and limestone and/or dolostone of the Sangerville Formation.

3.0 SUBSURFACE INVESTIGATION

One (1) boring (HB-ATH-101) and one (1) probe (HB-ATH-102) were drilled for this project on January 29, 2016 by S.W. Cole (SWC) using a track mounted drill rig. Exploration locations are shown on Sheet 2 – Boring Location Plan & Interpretive Subsurface Profile with Boring Logs. Details and sampling methods used, field data obtained, and soil and groundwater conditions encountered are presented on the Boring Log in Appendix A.

Boring HB-ATH-101 was drilled using hollow stem auger techniques. Soil samples were obtained in boring HB-ATH-101 at 5-foot intervals using Standard Penetration Test (SPT) methods. The SWC drill rig is equipped with an automatic hammer to drive the split spoon. The SWC calibrated automatic hammer delivers approximately 32 percent more energy during driving than the standard rope and cathead system. All N-values discussed in this report are corrected values computed by applying an average energy transfer factor of 0.79 to the raw field N-values. Probe HB-ATH-102 was drilled using solid stem auger techniques. No soil samples were obtained in the probe.

The MaineDOT Geotechnical Team member selected the boring and probe locations, drilling methods, designated type and depth of sampling, reviewed field logs for accuracy and identified field and laboratory testing requirements. An experienced Northeast Transportation Training and Certification Program (NETTCP) certified subsurface inspector logged the subsurface conditions encountered. The boring and probes were located in the field by taping to surveyed site features after completion of the drilling program.

4.0 LABORATORY TESTING

A laboratory testing program was conducted to assist in soil classification, evaluation of engineering properties of the soils and geologic assessment of the project site. Laboratory testing consisted of three (3) standard grain size analyses with natural water content and two (2) grain size analysis with hydrometer and natural water content. The results of the laboratory testing program are discussed in the following section and are included in Appendix B – Laboratory Test Results. Laboratory test information is also shown on the Boring Logs in Appendix A.

5.0 SUBSURFACE CONDITIONS

Subsurface conditions encountered at the test boring and probe generally consisted sand fill overlying native silty sand and silt (glacial till). An interpretive subsurface profile depicting the generalized soil stratigraphy at the boring location is shown on Sheet 2 - Boring Location Plan & Interpretive Subsurface Profile with Boring Logs.

Boring HB-ATH-101 was drilled to a depth of approximately 17.0 feet below ground surface (bgs). No refusal surface was encountered in the boring. Probe HB-ATH-102 to a depth of approximately 18.3 feet bgs where it encountered a refusal surface. The exact nature of the refusal surface in the probe was not determined during the drilling activities.

The table below summarizes the field and laboratory information obtained in boring HB-ATH-101:

Approx. Depth BGS ¹ (feet)	Soil Description	AASHTO ² Classification	USCS ³	WC% ⁴
0.0 – 6.5	Fill – Brown, damp, fine to coarse sand, little silt, little to some gravel.	A-1-b	SM	10.9 - 13.8
6.5 – 10.0	Glacial Till – Grey, wet, silty fine to coarse sand, trace gravel.	A-4	SM	15.7
10.0 – 17.0	Grey, moist, silt, some sand, little clay, trace gravel.	A-4	CL	9.6- 10.4

¹BGS = below ground surface

²AASHTO = American Association of State Highway and Transportation Officials

³USCS = Unified Soil Classification System

⁴WC% = Water content in percent

One (1) corrected N-values obtained in the fill was 25 blows per foot (bpf) indicating that the fill is medium dense in consistency. One corrected N-value obtained in the silty sand till was 25 bpf, indicating that the silty sand is medium dense in consistency. N-values obtained in the silt till ranged from 43 to 46 indicating that the silt till is hard in consistency.

Groundwater was not recorded in the boring or the probe. Groundwater levels can be expected to fluctuate subject to seasonal variations, local soil conditions, topography, precipitation, and construction activity.

6.0 GEOTECHNICAL DESIGN AND CONSTRUCTION RECOMMENDATIONS

The proposed replacement structure will consist of a 10-foot span by 5-foot rise by 68-foot long precast concrete box culvert on a skew of approximately 16 degrees to the roadway centerline. The invert of the proposed culvert will be lined with approximately 2 feet of Special Fill to facilitate fish passage. The proposed structure inlet and outlet slopes shall be riprapped with slopes no steeper than 2H:1V to protect against erosion. The following sections discuss geotechnical recommendations for the design and construction of the proposed culvert.

6.1 Precast Concrete Box Culvert Design and Construction

The proposed replacement structure will consist of a 10-foot span by 5-foot rise by 68-foot long precast concrete box culvert at a skew of approximately 16 degrees to the roadway centerline. The proposed box culvert shall be designed and constructed in accordance with MaineDOT Standard Specification 534.

The inverts of the proposed box culvert range from approximately 726.23 feet at the inlet to approximately 725.97 feet at the outlet with a 0.375 percent slope and will be lined with approximately 2 feet of Special Fill to facilitate fish passage.

The full nature of the culvert bearing surface will not become evident until the culvert excavation is made. Any cobbles or boulders in excess of 6 inches encountered at the bedding elevation shall be removed and replaced with compacted Granular Borrow Material for Underwater Backfill or Crushed Stone ¾-Inch. The prepared subgrade shall be proof-rolled using a static roller to visually confirm the prepared subgrade is firm and stable. The exposed subgrade shall be free of ponded water so that bedding material placement and compaction can be completed in the dry.

The proposed structure shall be bedded on a 1-foot thick layer of Granular Borrow, Material for Underwater Backfill meeting the requirements of MaineDOT Standard Specification 703.19. The soil envelope and backfill shall consist of Standard Specification 703.19 - Granular Borrow with a maximum particle size of 4 inches. The granular borrow bedding and backfill material shall be placed in lifts of 6 to 8 inches loose measure and compacted to the manufacturer’s specifications or, in the absence of manufacturer’s specifications, the bedding and backfill soil shall be compacted to at least 92 percent of the AASHTO T-180 maximum dry density.

6.2 Settlement

No settlement issues are anticipated at the site. No changes to the existing vertical or horizontal alignment are currently planned for this project. The proposed precast concrete box culvert is larger than the existing culvert and will result in a net unloading of the site soils at the structure location. Any settlement due to elastic compression of the subgrade soils and bedding material will be immediate and negligible.

6.3 Bearing Resistance

The factored bearing resistances for the precast concrete box culvert bearing on compacted granular bedding material placed on native soils at the service and strength limit states are presented in the table below. Supporting calculations in accordance with AASHTO LRFD Bridge Design Specifications 8th Edition 2017 (LRFD) are provided in Appendix C – Calculations.

Limit State	Resistance Factor ϕ_b	AASHTO LRFD Reference	Factored Bearing Resistance (ksf)
Service	1.0	Article 10.5.5.1	8.0
Strength	0.45	Table 10.5.5.2.2-1	6.0

6.4 Modulus of Subgrade Reaction

A modulus of subgrade reaction (k_s) equal to 390 pounds per cubic inch shall be used for the structural design of the box culvert’s base slab. Calculations are included in Appendix C - Calculations.

6.5 Scour and Riprap

Both the inlet and outlet of the precast concrete box culvert shall be protected against scour with riprap conforming to MaineDOT Standard Specification Section 703.26 Plain and Hand Laid Riprap. Slopes shall be no steeper than 2H:1V. No specific scour protection recommendations are needed other than armoring with riprap. The riprap on the slopes shall be underlain by a non-woven, Class 1 Erosion Control Geotextile meeting the requirements of MaineDOT Standard Specification 722.03 that is underlain by a 1-foot layer of protective aggregate cushion consisting of Granular Borrow Material for Underwater Backfill (703.19). The toe of the riprap sections shall be keyed into the existing soils 1 foot below the streambed elevation.

6.6 Seismic Design Considerations

In conformance with LRFD Article 3.10.1, seismic analysis is not required for buried structures, except where they cross active faults. There are no known active faults in Maine; therefore, seismic analysis is not required.

6.7 Construction Considerations

Construction activities will include construction of cofferdams and earth support systems to control stream flow during construction. Construction activities will also include common earth excavation. Construction of the proposed precast concrete box culvert will require deep soil excavation. Earth support systems shall be implemented if laying back slopes is not feasible. It is likely that the use of complex (four-sided) braced excavations with dewatering will be necessary due to the depth of the excavation. If this is the case, adequate embedment into the till will be necessary to allow for the excavation and maintenance of a stable excavation bottom. All earth support systems shall be designed by a Professional Engineer licensed in the State of Maine. Regardless of the method of excavation, all excavations and earth support systems shall meet all applicable OSHA regulations.

The Contractor shall control groundwater and surface water infiltration using temporary ditches, sumps, granular drainage blankets, stone ditch protection or hand-laid riprap with geotextile underlayment to divert groundwater and surface water as needed to maintain a stable excavation and allow work in the dry.

Using the excavated native soils as backfill around the culvert shall not be permitted. The native soils may only be used as common borrow in accordance with MaineDOT Standard Specifications 203 and 703.

The Contractor will have to excavate the existing subbase and subgrade fill soils in the vicinity of the culvert. These materials should not be used to re-base the roadway. Excavated subbase sand and gravel may be used as fill below roadway subgrade level in fill areas provided all other requirements of MaineDOT Standard Specifications 203 and 703 are met.

7.0 CLOSURE

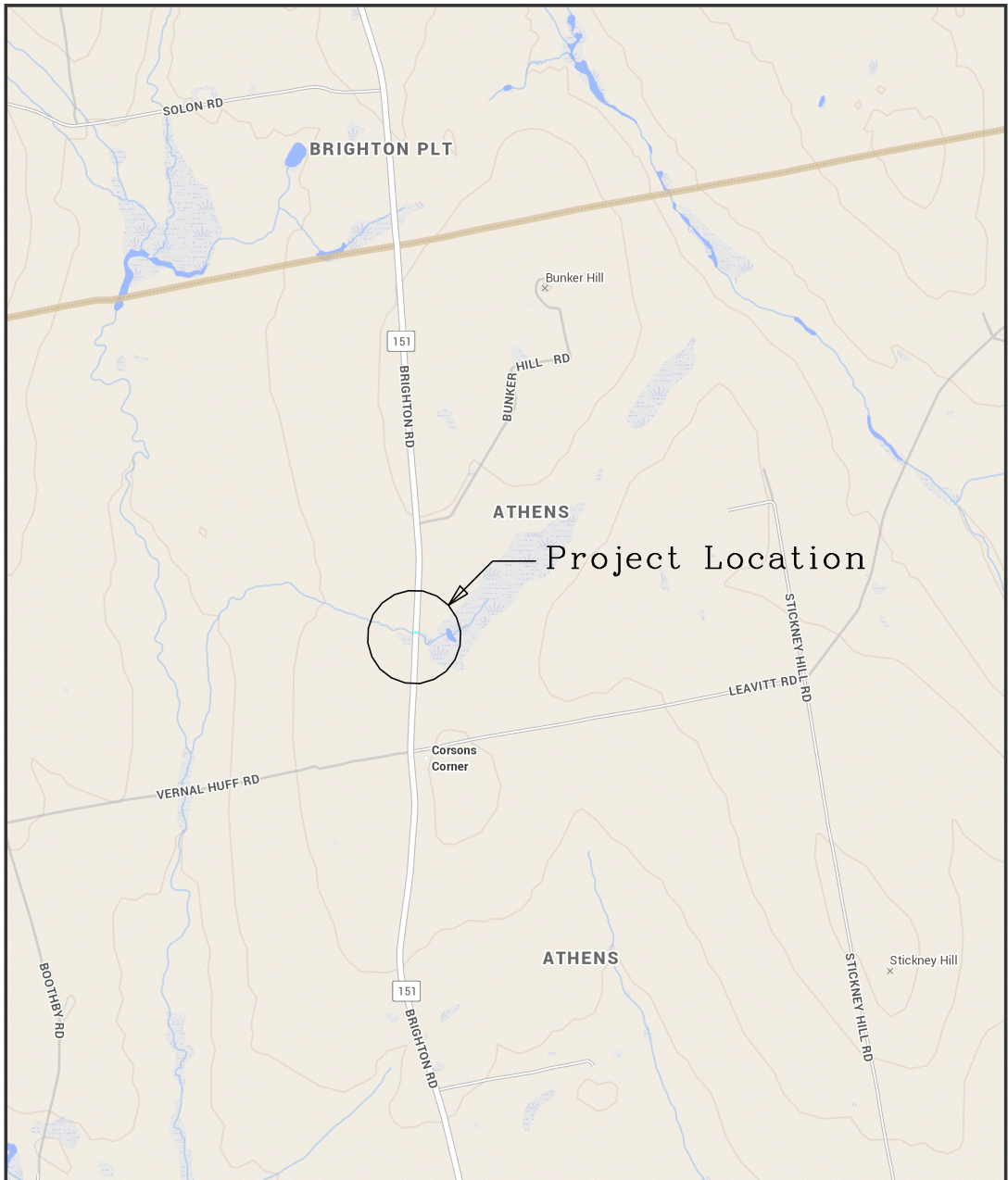
This report has been prepared for the use of the MaineDOT Highway Program for specific application to the proposed construction of Brighton Road Bridge on Route 151 in Athens, Maine in accordance with generally accepted geotechnical and foundation engineering practices. No other intended use or warranty is expressed or implied.

In the event that any changes in the nature, design, or location of the proposed project are planned, this report should be reviewed by a geotechnical engineer to assess the appropriateness of the conclusions and recommendations and to modify the recommendations as appropriate to reflect the changes in design. These analyses and recommendations are based in part upon a limited subsurface investigation at discrete exploratory location completed at the site. If variations from the conditions encountered during the investigation appear evident during construction, it may also become necessary to re-evaluate the recommendations made in this report.

It is recommended that a geotechnical engineer be provided the opportunity for a review of the design and specifications in order that the earthwork and foundation recommendations and construction considerations presented in this report are properly interpreted and implemented in the design and specifications.

Sheets

ATHENS, MAINE



The Maine Department of Transportation provides this publication for information only. Reliance upon this information is at user risk. It is subject to revision and may be incomplete depending upon changing conditions. The Department assumes no liability if injuries or damages result from this information. This map is not intended to support emergency dispatch.

0.5 Miles
1 inch = 0.54 miles

Date: 2/6/2018
Time: 6:56:29 AM

<p>SHEET NUMBER</p> <p style="font-size: 2em; text-align: center;">1</p> <p>OF 2</p>	<p style="text-align: center;">ATHENS</p> <p style="text-align: center;">ROUTE 151</p> <hr/> <p style="text-align: center;">LOCATION MAP</p>	<p style="text-align: center;">STATE OF MAINE</p> <p style="text-align: center;">DEPARTMENT OF TRANSPORTATION</p> <hr/> <p style="text-align: center;">2351300</p> <hr/> <p style="text-align: center;">WIN</p> <p style="text-align: center;">23513.00 HIGHWAY PLANS</p>
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Appendix A

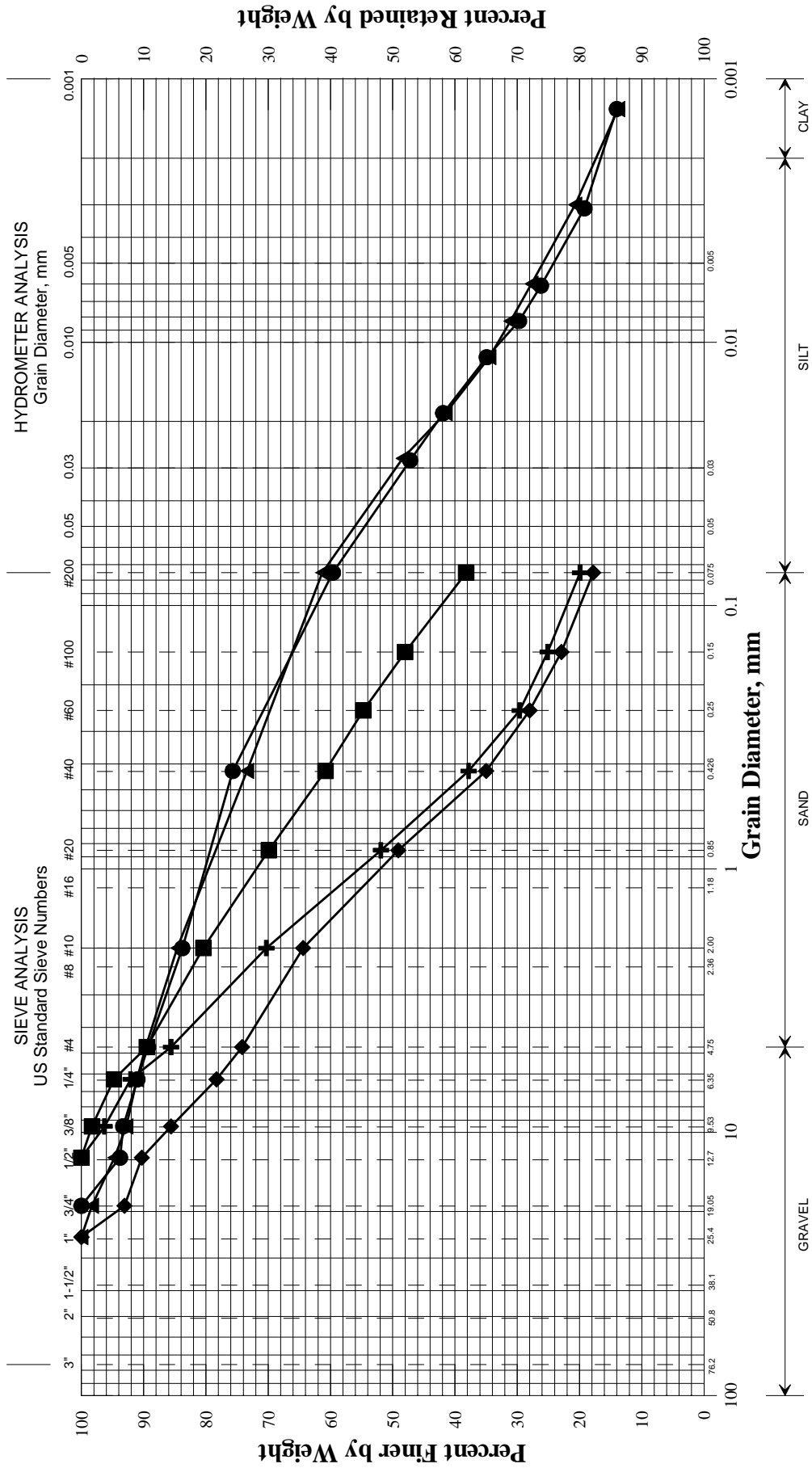
Boring Logs

UNIFIED SOIL CLASSIFICATION SYSTEM				MODIFIED BURMISTER SYSTEM																												
MAJOR DIVISIONS		GROUP SYMBOLS	TYPICAL NAMES	Descriptive Term	Portion of Total (%)																											
COARSE-GRAINED SOILS (more than half of material is larger than No. 200 sieve size)	GRAVELS (more than half of coarse fraction is larger than No. 4 sieve size)	CLEAN GRAVELS	GW Well-graded gravels, gravel-sand mixtures, little or no fines.	trace little some adjective (e.g. sandy, clayey)	0 - 10 11 - 20 21 - 35 36 - 50																											
		(little or no fines)	GP Poorly-graded gravels, gravel sand mixtures, little or no fines.																													
	SANDS (more than half of coarse fraction is smaller than No. 4 sieve size)	GRAVEL WITH FINES (Appreciable amount of fines)	GM Silty gravels, gravel-sand-silt mixtures.			TERMS DESCRIBING DENSITY/CONSISTENCY																										
		CLEAN SANDS	SW Well-graded sands, gravelly sands, little or no fines			Coarse-grained soils (more than half of material is larger than No. 200 sieve): Includes (1) clean gravels; (2) silty or clayey gravels; and (3) silty, clayey or gravelly sands. Density is rated according to standard penetration resistance (N-value).																										
		(little or no fines)	SP Poorly-graded sands, gravelly sand, little or no fines.			<table border="1"> <thead> <tr> <th>Density of Cohesionless Soils</th> <th>Standard Penetration Resistance N-Value (blows per foot)</th> </tr> </thead> <tbody> <tr><td>Very loose</td><td>0 - 4</td></tr> <tr><td>Loose</td><td>5 - 10</td></tr> <tr><td>Medium Dense</td><td>11 - 30</td></tr> <tr><td>Dense</td><td>31 - 50</td></tr> <tr><td>Very Dense</td><td>> 50</td></tr> </tbody> </table>			Density of Cohesionless Soils	Standard Penetration Resistance N-Value (blows per foot)	Very loose	0 - 4	Loose	5 - 10	Medium Dense	11 - 30	Dense	31 - 50	Very Dense	> 50												
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Dense	31 - 50																															
Very Dense	> 50																															
SANDS WITH FINES (Appreciable amount of fines)	SM Silty sands, sand-silt mixtures	Fine-grained soils (more than half of material is smaller than No. 200 sieve): Includes (1) inorganic and organic silts and clays; (2) gravelly, sandy or silty clays; and (3) clayey silts. Consistency is rated according to undrained shear strength as indicated.																														
	SC Clayey sands, sand-clay mixtures.	<table border="1"> <thead> <tr> <th>Consistency of Cohesive soils</th> <th>SPT N-Value (blows per foot)</th> <th>Approximate Undrained Shear Strength (psf)</th> <th>Field Guidelines</th> </tr> </thead> <tbody> <tr><td>Very Soft</td><td>WOH, WOR, WOP, <2</td><td>0 - 250</td><td>Fist easily penetrates</td></tr> <tr><td>Soft</td><td>2 - 4</td><td>250 - 500</td><td>Thumb easily penetrates</td></tr> <tr><td>Medium Stiff</td><td>5 - 8</td><td>500 - 1000</td><td>Thumb penetrates with moderate effort</td></tr> <tr><td>Stiff</td><td>9 - 15</td><td>1000 - 2000</td><td>Indented by thumb with great effort</td></tr> <tr><td>Very Stiff</td><td>16 - 30</td><td>2000 - 4000</td><td>Indented by thumbnail</td></tr> <tr><td>Hard</td><td>>30</td><td>over 4000</td><td>Indented by thumbnail with difficulty</td></tr> </tbody> </table>			Consistency of Cohesive soils	SPT N-Value (blows per foot)	Approximate Undrained Shear Strength (psf)	Field Guidelines	Very Soft	WOH, WOR, WOP, <2	0 - 250	Fist easily penetrates	Soft	2 - 4	250 - 500	Thumb easily penetrates	Medium Stiff	5 - 8	500 - 1000	Thumb penetrates with moderate effort	Stiff	9 - 15	1000 - 2000	Indented by thumb with great effort	Very Stiff	16 - 30	2000 - 4000	Indented by thumbnail	Hard	>30	over 4000	Indented by thumbnail with difficulty
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Hard	>30	over 4000	Indented by thumbnail with difficulty																													
FINE-GRAINED SOILS (more than half of material is smaller than No. 200 sieve size)	SILTS AND CLAYS (liquid limit less than 50)	ML Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, or clayey silts with slight plasticity.	Rock Quality Designation (RQD): RQD (%) = $\frac{\text{sum of the lengths of intact pieces of core} * > 4 \text{ inches}}{\text{length of core advance}}$ *Minimum NQ rock core (1.88 in. OD of core)																													
		CL Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.																														
		OL Organic silts and organic silty clays of low plasticity.																														
	SILTS AND CLAYS (liquid limit greater than 50)	MH Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.				Correlation of RQD to Rock Mass Quality																										
CH Inorganic clays of high plasticity, fat clays.		<table border="1"> <thead> <tr> <th>Rock Mass Quality</th> <th>RQD (%)</th> </tr> </thead> <tbody> <tr><td>Very Poor</td><td>≤25</td></tr> <tr><td>Poor</td><td>26 - 50</td></tr> <tr><td>Fair</td><td>51 - 75</td></tr> <tr><td>Good</td><td>76 - 90</td></tr> <tr><td>Excellent</td><td>91 - 100</td></tr> </tbody> </table>			Rock Mass Quality	RQD (%)	Very Poor	≤25	Poor	26 - 50	Fair	51 - 75	Good	76 - 90	Excellent	91 - 100																
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Poor	26 - 50																															
Fair	51 - 75																															
Good	76 - 90																															
Excellent	91 - 100																															
	OH Organic clays of medium to high plasticity, organic silts.																															
	HIGHLY ORGANIC SOILS	Pt Peat and other highly organic soils.																														
Desired Soil Observations (in this order, if applicable): Color (Munsell color chart) Moisture (dry, damp, moist, wet) Density/Consistency (from above right hand side) Texture (fine, medium, coarse, etc.) Name (sand, silty sand, clay, etc., including portions - trace, little, etc.) Gradation (well-graded, poorly-graded, uniform, etc.) Plasticity (non-plastic, slightly plastic, moderately plastic, highly plastic) Structure (layering, fractures, cracks, etc.) Bonding (well, moderately, loosely, etc.,) Cementation (weak, moderate, or strong) Geologic Origin (till, marine clay, alluvium, etc.) Groundwater level				Desired Rock Observations (in this order, if applicable): Color (Munsell color chart) Texture (aphanitic, fine-grained, etc.) Rock Type (granite, schist, sandstone, etc.) Hardness (very hard, hard, mod. hard, etc.) Weathering (fresh, very slight, slight, moderate, mod. severe, severe, etc.) Geologic discontinuities/jointing: -dip (horiz - 0-5 deg., low angle - 5-35 deg., mod. dipping - 35-55 deg., steep - 55-85 deg., vertical - 85-90 deg.) -spacing (very close - <2 inch, close - 2-12 inch, mod. close - 1-3 feet, wide - 3-10 feet, very wide >10 feet) -tightness (tight, open, or healed) -infilling (grain size, color, etc.) Formation (Waterville, Ellsworth, Cape Elizabeth, etc.) RQD and correlation to rock mass quality (very poor, poor, etc.) ref: ASTM D6032 and AASHTO Standard Specification for Highway Bridges, 17th Ed. Table 4.4.8.1.2A Recovery (inch/inch and percentage) Rock Core Rate (X.X ft - Y.Y ft (min:sec))																												
Maine Department of Transportation Geotechnical Section Key to Soil and Rock Descriptions and Terms Field Identification Information				Sample Container Labeling Requirements: WIN Blow Counts Bridge Name / Town Sample Recovery Boring Number Date Sample Number Personnel Initials Sample Depth																												

Appendix B

Laboratory Test Results

State of Maine Department of Transportation
GRAIN SIZE DISTRIBUTION CURVE



UNIFIED CLASSIFICATION

Boring/Sample No.	Station	Offset, ft	Depth, ft	Description	W, %	LL	PL	PI
+	14+49.1	12.0 RT	2.0-2.5	SAND, little silt, little gravel.	13.8			
◆	14+49.1	12.0 RT	5.0-6.5	SAND, some gravel, little silt.	10.9			
■	14+49.1	12.0 RT	6.5-7.0	Silty SAND, trace silt.	15.7			
●	14+49.1	12.0 RT	10.0-12.0	SILT, some sand, little clay, trace gravel.	9.6			
×	14+49.1	12.0 RT	15.0-17.0	SILT, some sand, little clay, trace gravel.	10.4			

023513.00	WIN
Athens	Town
WHITE, TERRY A	Reported by/Date
	2/12/2018

Appendix C

Calculations

Bearing Resistance - Existing Soils:

Part 1 - Service Limit State

Nominal and factored Bearing Resistance - Box Culvert on Silt Till

Presumptive Bearing Resistance for Service Limit State ONLY

Reference: AASHTO LRFD Bridge Design Specifications 8th Edition 2017
Table C10.6.2.6.1-1 Presumptive Bearing Resistances for Spread Footings at the
Service Limit State Modified after US Department of Navy (1982)

Type of Bearing Material: Silt (CL) (till)

Based on N-values, soils are hard at the bearing elevation

Consistency In Place: Hard

Bearing Resistance: Ordinary Range (ksf) 6 to 12

Recommended Value of Use:

$$q_{nom} := 8 \cdot ksf$$

Resistance factor at the **service limit state** = 1.0 (LRFD Article 10.5.5.1) $\phi_{service_bc} := 1.0$

$$q_{factored_service_bc} := q_{nom} \cdot \phi_{service_bc}$$

$$q_{factored_service_bc} = 8 \cdot ksf$$

Note: This bearing resistance is settlement limited (1 inch) and applies only at the service limit state.

Part 2 - Strength Limit State

Nominal and factored Bearing Resistance - Box Culvert on Silt Till

Reference: AASHTO LRFD Bridge Design Specifications 8th Edition 2017 - Article 10.6.3.1

Assumptions:

1. The box will be founded at ~ Elev 726.0 feet to 726.2 feet

Bottom of Construction will be 2 feet below box invert $D_{footing} := 2.0 \cdot ft$

2. Assumed parameters for fill soils:

Saturated unit weight: $\gamma_s := 125 \cdot pcf$

Internal friction angle: $\phi_{ns} := 32 \cdot deg$

Undrained shear strength: $c_{ns} := 0 \cdot psf$

3. Box Culvert parameters

Width of box culvert, B $B_{box} := 10 \cdot ft$

Length of box culvert, L $L_{box} := 68 \cdot ft$

Nominal Bearing Resistance per LRFD Equation 10.6.3.1.2a-1

$$q_n = cN_{cm} + \gamma D_f N_{qm} C_{wq} + 0.5 \gamma B N_{\gamma m} C_{w\gamma}$$

Bearing Capacity Factors - LRFD Table 10.6.3.1.2a-1

For $\phi=32$ deg $N_c := 35.5$ $N_q := 23.2$ $N_\gamma := 30.2$

Shape Correction Factors LRFD Table 10.6.3.1.2a-3

for $\phi=32$ degrees

$$s_c := 1 + \left(\frac{B_{box}}{L_{box}} \right) \left(\frac{N_q}{N_c} \right) \quad s_c = 1.1$$

$$s_\gamma := 1 - 0.4 \left(\frac{B_{box}}{L_{box}} \right) \quad s_\gamma = 0.9412$$

$$s_q := 1 + \left(\frac{B_{box}}{L_{box}} \cdot \tan(\phi_{ns}) \right) \quad s_q = 1.09$$

Load Inclination Factors:

Assume all are 1.0 (LRFD Article C10.6.3.1.2a)

$i_c := 1.0$ $i_q := 1.0$ $i_\gamma := 1.0$

Depth Correction Factor LRFD Table 10.6.3.1.2a-4

$$\frac{D_{footing}}{B_{box}} = 0.2 \quad \text{for } \phi=32 \text{ degrees} \quad d_q := 1.2$$

$$N_{cm} := N_c \cdot s_c \cdot i_c \quad N_{cm} = 38.9118 \quad \text{LRFD Eq. 10.6.3.1.2a-2}$$

$$N_{qm} := N_q \cdot s_q \cdot d_q \cdot i_q \quad N_{qm} = 30.4 \quad \text{LRFD Eq. 10.6.3.1.2a-3}$$

$$N_{\gamma m} := N_\gamma \cdot s_\gamma \cdot i_\gamma \quad N_{\gamma m} = 28.42 \quad \text{LRFD Eq. 10.6.3.1.2a-4}$$

Coefficients for Groundwater Depths LRFD Table 10.6.3.1.2a-2

Depth the water table: $D_w := 0 \cdot \text{ft}$ $C_{wq} := 0.5$ $C_{w\gamma} := 0.5$

$$q_{nominal} := c_{ns} \cdot N_{cm} + \gamma_s \cdot D_{footing} \cdot N_{qm} \cdot C_{wq} + 0.5(\gamma_s) B_{box} \cdot N_{\gamma m} \cdot C_{w\gamma}$$

$$q_{nominal} = 12.7 \cdot \text{ksf}$$

Factored Bearing Resistance for Strength Limit State

Resistance Factor: $\phi_b := 0.45$ LRFD Table 10.5.5.2.2-1

$$q_{factored} := q_{nominal} \cdot \phi_b$$

$$q_{factored} = 5.7 \cdot \text{ksf}$$

Recommend a limiting factored bearing resistance of 6.0 ksf for the Strength Limit State.

Modulus of Subgrade Reaction:

Reference: Foundation Analysis and Design 5th Edition JE Bowles Section 9-6

Width of box culvert, B $B_{\text{box}} := 10 \cdot \text{ft}$

Length of box culvert, L $L_{\text{box}} := 68 \cdot \text{ft}$

Thickness of box culvert, t $t_{\text{box}} := 12 \cdot \text{in}$ assumed

Depth of box, D $D_{\text{box}} := 9 \cdot \text{ft}$

Bearing Resistance: $q_{\text{factored_service_bc}} = 8 \cdot \text{ksf}$ Calculated above

Modulus of Elasticity: Site soils at bearing elevation are Silt (Hard) (Till)
From Bowles Table 2-8 Modulus E_s for Till ranges from 3100-15000 ksf

Use Modulus of Elasticity, E_s $E_s := 3100 \cdot \text{ksf}$

Poisson's Ratio: Site soils are Silt
From Bowles Table 2-7 Poisson's Ratio μ for Silt ranges from 0.3 - 0.35

Use Poisson's Ratio, μ $\mu := 0.3$

$$E_{\text{prime_s}} := \frac{1 - \mu^2}{E_s} \quad E_{\text{prime_s}} = 0.000294 \cdot \frac{\text{ft}^2}{\text{kip}}$$

Analyze corner:

Take H as 5*B as recommended in Bowles Chapter 5

$$H_{\text{inf}} := \frac{5 \cdot B_{\text{box}}}{B_{\text{box}}} \quad H_{\text{inf}} = 5 \quad \text{N in Table 5-2}$$

From Table 5-2 for N=5 and M=6.8

$$\frac{L_{\text{box}}}{B_{\text{box}}} = 6.8$$

M in Table 5-2

$$I_1 := 0.544$$

$$I_2 := 0.126$$

by interpolation

Determine Steinbrenner influence factor - Bowles Section 5-6:

$$I_s := I_1 + \left[\frac{1 - (2 \cdot \mu)}{1 - \mu} \right] \cdot I_2 \quad I_s = 0.616$$

Determine Influence factor for footing depth - Bowles Figure 5-7

$$\text{Depth ratio: } \frac{D_{\text{box}}}{B_{\text{box}}} = 0.9 \quad \frac{L_{\text{box}}}{B_{\text{box}}} = 6.8 \quad \mu = 0.3 \quad I_F := 0.82$$

Calculate modulus of subgrade reaction - Bowles Eq. 9-7

$$k_s := \frac{1}{B_{\text{box}} \cdot E_{\text{prime_s}} \cdot I_s \cdot I_F} \quad \text{Bowles Eq. 9-7}$$

$$k_s = 390 \cdot \text{pci}$$

Recommend Modulus of Subgrade Reaction of 390 pci