AGENCY OF TRANSPORTATION **OFFICE MEMORANDUM**

To: Danny Landry, Structures Project Manager

SPM CEE

From: Stephen Madden, Geotechnical Engineer via Callie Ewald, P.E. Geotechnical Engineering Manager

Date: December 7th, 2016

Subject: Waterford BF 0225(4)– Geotechnical Report

1.0 INTRODUCTION

As requested, we have calculated geotechnical soil parameters to be used in the culvert design for the Waterford BF 0225(4) project located on VT Route 18 over the Mad Brook in Waterford, Vermont. The proposed project includes the replacement of the existing culvert located approximately 5.9 miles south of the junction of VT Route 18 and US Route 2. Contained herein are the results of our geotechnical analysis and design parameter recommendations as determined using the 2014 AASHTO LRFD *Bridge Design Specifications.*

2.0 FIELD INVESTIGATION

The initial field investigation was completed in April, 2014. The findings of this investigation are detailed in the report dated April 11th, 2014 and submitted by Marcy Meyers to Chris Williams, Structures Project Manager. Refer to this report for a detailed description of the field investigation and field and laboratory testing.

3.0 SOIL PROFILE

Review of laboratory data and boring logs revealed the following information pertaining to the soil strata. It should be noted that groundwater elevations are subject to change given the fact that boreholes were generally left open for a short period of time. Because groundwater elevations can fluctuate seasonally and are affected by temperature and precipitation, groundwater may be encountered during construction when not previously noted in the logs

B-101 (Outlet) The ground surface elevation at B-101 was approximately 911.1 feet. The groundwater was measured at a depth of 5.0 feet below the ground surface during drilling on April 1, 2014, and at a depth of 8.0 feet before drilling resumed on April 2, 2014. Bedrock was encountered at a depth of 28.3 feet and a 10 foot NX rock core was sampled to confirm the presence of bedrock.

Depth (Below Ground Surface Elevation)	Soil Profile	Soil Layer ID
0 – 12 feet	V. Dense Gravelly Sand/Sandy Gravel	A
12 – 28.3 feet	V. Dense Gravelly Sandy Silt	B
>28.3 feet	Bedrock	N/A

B-102 (Inlet) The ground surface elevation at B-102 was approximately 914.1 feet. The groundwater was measured after drilling on April 3, 2014 at a depth of 7.0 feet, and at depths of 9.0 feet and 6.6 feet on April 4, 2014 before and after drilling, respectively. Bedrock was encountered at a depth of 41.0 feet and a 10 foot NX rock core was sampled to confirm the presence of bedrock.

Depth (Below Ground Surface Elevation)	Soil Profile	Soil Layer ID
0 – 5 feet	V. Dense Gravelly Sand/Sandy Silt	B
5 – 11 feet	V. Dense Sandy Gravel	A
11 – 35 feet	V. Dense Sandy Silt/Gravelly Silt	B
35 – 41 feet	V. Dense Till	C
>41 feet	Bedrock	N/A

4.0 ANALYSIS

4.1 Shallow Foundation Analysis

AASHTO's LRFD Bridge Design Specifications Manual (2014) was used as the reference for settlement and bearing resistance equations. Section 10.6.3.1.2 contains the equation used for bearing resistance. Neither depth factors nor load inclination factors were used in the analysis as they were not considered pertinent. Hough's Method, used to calculate settlement in normally consolidated cohesionless soils, can be found in section 10.6.2.4.2.

We recommend the bottom of the wingwall footings to be 4 feet below the ground surface based on frost susceptibility and bearing stratum at the site. An embedment value of 4 feet was used for the strength limit state analysis and an embedment value of 0 feet was used for the service limit state analysis to account for potential scour conditions. A conservative groundwater elevation at the bottom of footing elevation was used in design.

As per section 10.5.5.1 of the 2014 AASHTO LRFD Bridge Design Specifications, a resistance factor of 1.0 should be applied to the unfactored bearing resistance for use in service limit state design. Service limit state design includes, but is not limited to, settlement and scour. Section 10.5.5.2.2 specifies that a resistance factor of 0.45 should be applied to the unfactored bearing resistance for use in strength limit state design for spread footings on rock and soil. Strength limit state design includes, but is not limited to, checks for bearing resistance, sliding and constructability. Potential for overturning is limited by controlling the location of the resultant of the reaction forces (eccentricity). Eccentricity, e, shall be limited as follows:

Foundations on soil: $|e| < b/3$
Foundations on rock: $|e| < 0.45b$

Eccentricity should be considered for settlement and bearing resistance design of spread footings by using effective footing widths based on AASHTO Section 10.6.1.3. All footing widths presented in this report are <u>effective</u> footing widths.

4.1.1: Bearing Resistance

Due to the similar soil strata found in both borings at the bottom of footing elevations, one conservative profile was used in the analysis. The maximum wingwall length was assumed to be 12 feet based off the Boring Information Sheet from the Preliminary Plans dated September 21, 2016. It was determined the soil at this location has a friction angle $\phi = 38^{o}$ and density, $\gamma = 120$

lb/ft^3 (soil layer B). A bottom of footing elevation of 899.00 feet and 897.30 feet, at the inlet wingwalls and outlet wingwalls, respectively, was provided in an email from Thomas Levins of GM2 Associates dated November 30, 2016 and used in the analysis. The embedment was assumed to be 4 feet below the ground surface. Figure 4.1 displays the minimum effective footing width per maximum bearing resistance, factored due to LRFD strength and service limit states.

For effective footing widths of 2, 4, 6, and 8 feet, the maximum factored bearing resistances for the controlling service limit state are 4.4, 8.1, 11.2, and 13.7 kips/ft^2 (ksf), respectively, as seen in Figure 4.1.

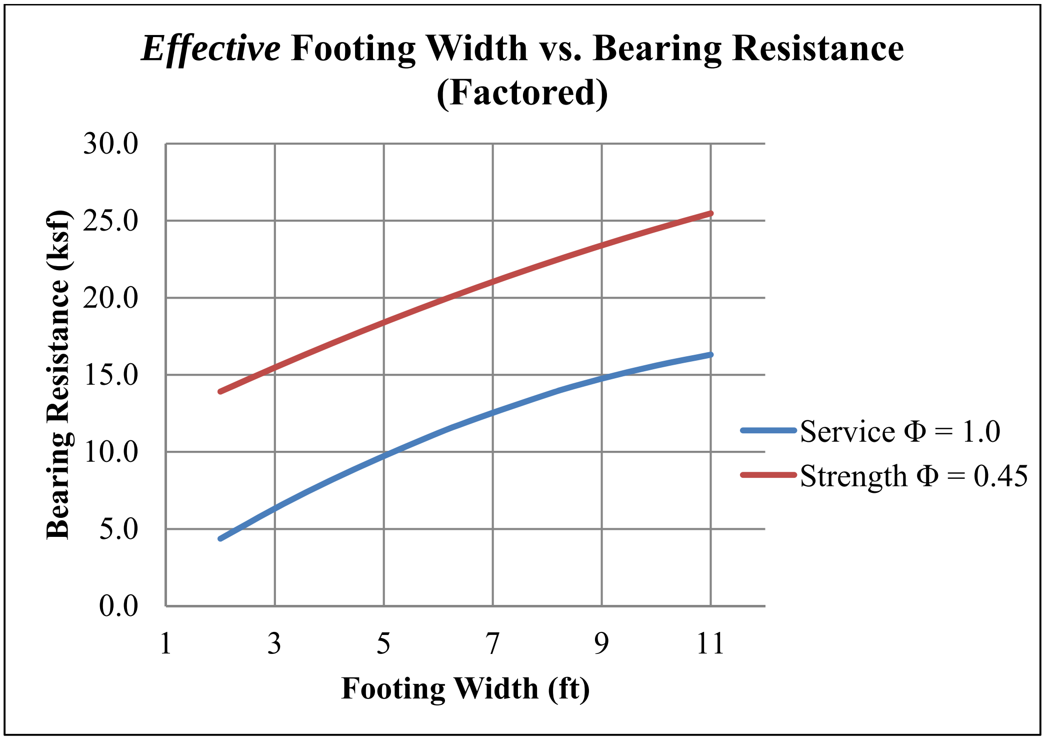

Figure 4.1: *Effective* Footing Width vs. Bearing Resistance for Culvert Wingwalls

Soil settlement values were calculated for various footing widths based on the nominal bearing pressure. Found in Figure 4.2 are the settlement values for effective footing widths of 2 to 8 feet for the wingwalls. Due to the granular nature of the foundation soils, settlement is expected to occur during or immediately after construction.

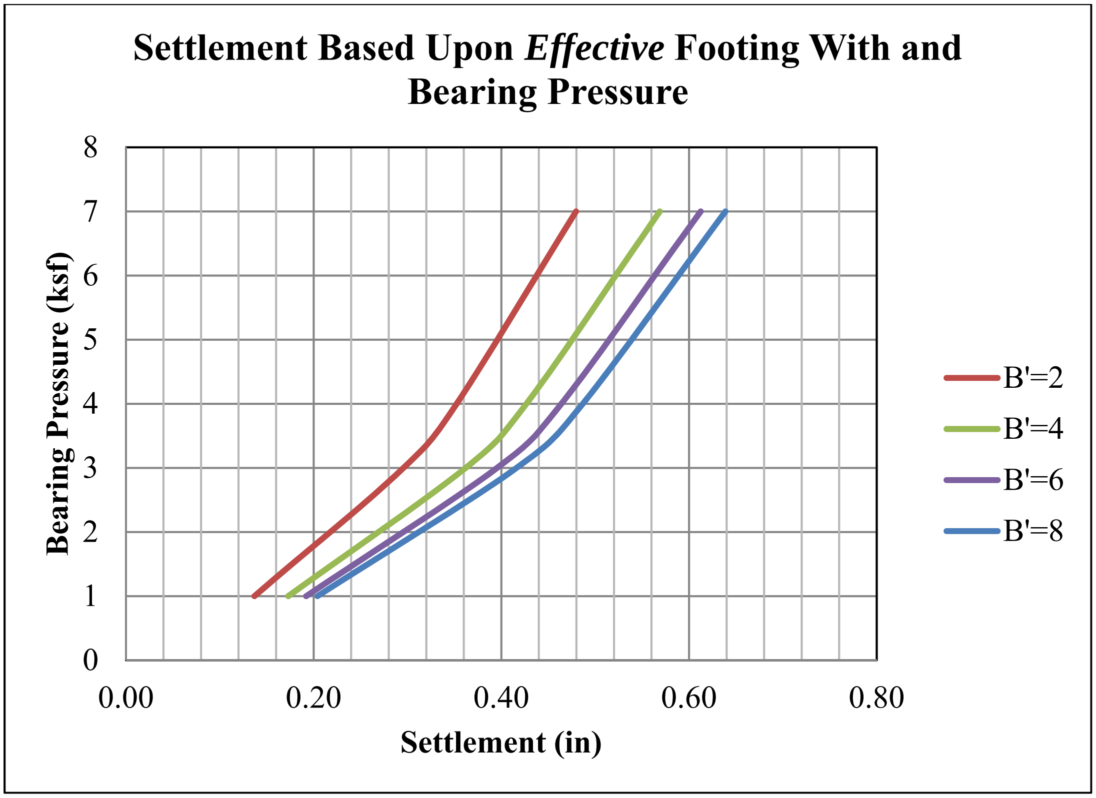

Figure 4.2: Settlement vs. Nominal Bearing Pressure (Wingwalls)

5.0 RECOMMENDATIONS

Shallow foundations appear to be feasible for the bottom of box elevation as well as for the wingwalls at the inlet and outlet. Factored bearing resistances were calculated for various footing widths of the wingwalls and can be found in Figure 4.1. The settlement is expected to occur during or immediately after construction. Recommended geotechnical parameters for use in design can be found below in Tables 5.2 and 5.3. These calculations are based on the geometric and geotechnical assumptions outlined in Section 4.0. Sections 10.5.2 and 10.5.3 of AASHTO outline all design states relevant to spread footing design and their respective resistance factors. Eccentricity should be considered for settlement and bearing resistance design of spread footings by using effective footing widths based on AASHTO Section 10.6.1.3. Table 5.1 shows the appropriate resistance factors for various design states.

Table 5.1: Summary of resistance factors

Design State	Resistance Factor, φ
Settlement	1.0
Scour	1.0
Bearing Resistance	0.45
Sliding	0.80

5.1 Construction Considerations

5.1.1 Cofferdams/Temporary Earthwork Support: The Contractor should be reminded that Section 208.07 of VTrans' *2011 Standard Specifications for Construction* indicates that "The Contractor shall prepare detailed plans and a schedule of its operation for each cofferdam specified in the Contract. The design and structural details of the cofferdam shall be signed, stamped, and dated by a Professional Engineer (Structural or Civil)."

5.1.2 Construction Dewatering: The bottom of footing elevation for the culvert is estimated to be near the water table. Therefore, temporary construction dewatering may be required to construct the foundation. Temporary dewatering will also be necessary to limit disturbance to and maintain the integrity of the bearing surface.

Temporary dewatering can likely be accomplished by open pumping from shallow sumps, temporary ditches, and trenches within and around the excavation limits. Sumps should be provided with filters suitable to prevent pumping of fine-grained soil particles. The water trapped by the temporary dewatering controls should be discharged to settling basins or an approved filter "sock" so that the fine particles suspended in the discharge have adequate time to "settle out" prior to discharge. All effluent, or discharge, should comply with all applicable permits and regulations.

Sumps and trenches should lie outside a 1V:1H line extending downward and outward from the edge of footing. Installation and operation of the Contractor's dewatering system should be integrated with other earthwork operations and sequence of cutting, filling, foundation construction, and backfilling.

5.1.3 Placement and Compaction of Soils: Fills should be placed systematically in horizontal layers not more than 12 inches in thickness, prior to compaction. Cobbles larger than 8 inches should be removed from the fill prior to placement. Compaction equipment should preferably consist of large, self-propelled vibratory rollers. Where hand-guided equipment, such as a small vibratory plate compactor, is used the loose lift thickness shall not exceed 6 inches. Cobbles larger than 4 inches should be removed from the fill prior to placement.

Embankment fills should be compacted to a dry density of at least 95% of the maximum dry density determined in accordance with AASHTO T-99. The current specification calls for 90%, however we are in the process of revising it to be 95% as recommended above. Granular Backfill for Structures, or other select materials placed within the roadway base section shall be compacted to a dry density equal to 95% of the maximum dry density as determined in accordance with AASHTO T-99.

5.2 Design Parameters

Table 5.2 highlights the geotechnical design parameters and Table 5.3 highlights the soil design parameters. These values should be included in the contract plans to be used by the contractor and used when designing the substructure units. It is recommended that values of K_o be used for calculating earth pressures where the structure is not allowed to deflect longitudinally, away from or into the retained soil mass. Values for K_a should be utilized for an active earth pressure condition where the structure is moving away from the soil mass and K_p where the structure is moving toward the soil mass. The design earth pressure coefficients are based on horizontal surfaces (non-sloping and backfill) and a vertical wall face.

Table 5.2: Wingwall Geotechnical Design Parameters

Nominal Bearing Resistance (ksf) [Strength Limit State]	13.3
Resistance Factor [Strength Limit State]	0.45
Nominal Bearing Resistance (ksf) [Service Limit State]	6.0
Resistance Factor [Service Limit State]	1.0

Table 5.3: Soil Design Parameters

	703.01A - Granular Borrow	**704.08 - Granular Backfill for Structures**	**Layer B (Wingwall Bearing Stratum)**
Density (lb/ft^3):	130	140	120
Internal Friction Angle, φ (degrees)	32	34	38
Coefficient of Friction			
- soil against mass concrete	0.50	0.55	0.32
- soil against formed concrete	0.40	0.45	0.25
Active Earth Pressure Coefficient, K_a:	0.31	0.28	0.24
Passive Earth Pressure Coefficient, K_p:	3.22	3.54	4.20
At-Rest Earth Pressure Coefficient, K_o:	0.47	0.44	0.38

6.0 CONCLUSION

If you would like to discuss this report, please contact us at (802) 828-2561. Computer generated boring logs are attached and available in the *M:\Projects\13C268\MaterialsResearch* folder.

cc: Gary Laroche, VTrans Structures
Electronic Read File/DJH
Project File/CEE
SPM

Z:\Highways\CMB\GeotechEngineering\Projects\Waterford BF 0225(4)\REPORTS\Waterford BF 0225(4) Geotechnical Report.docx