AGENCY OF TRANSPORTATION **OFFICE MEMORANDUM**

To: Adam Goudreau, P.E., Structures Project Manager

From: August Arles, Geotechnical Engineer, via, Callie Ewald, P.E., Senior Geotechnical Engineer

Date: December 11th, 2024

Subject: Brookfield ER P23-1(668) – Geotechnical Design Parameters Report

1.0 INTRODUCTION

As requested, we have completed our geotechnical assessment of the proposed foundations for the replacement structure as part of the Brookfield ER P23-1(668) project. The project consists of replacing the existing Bridge 3 carrying Vermont Route 65 over Sunset Brook in the town of Brookfield, VT. Bridge 3 is located approximately 2.0 miles west of the intersection of VT Route 65 and VT Route 14. Contained herein are the results of our geotechnical analysis and design parameter recommendations for use in the design of the proposed replacement structure, as determined using the 2020 AASHTO LRFD Bridge Design Specifications.

2.0 FIELD INVESTIGATION

An initial field investigation was conducted between August 22nd and August 23rd, 2023. Two standard penetration borings and one bedrock probe were performed to evaluate the subsurface profile for design and construction of the replacement structure. A summary of the findings and the previous borings can be found in the geotechnical data report provided to Adam Goudreau of the Structures Section dated July 2024.

3.0 SHALLOW FOUNDATION ANALYSIS

AASHTO's LRFD Bridge Design Specifications Manual (2020) 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 due to the designed embedment of the structure, per Section C.10.6.3.1.2a. Hough's Method, used to calculate settlement in normally consolidated cohesionless soils, can be found in Section 10.6.2.4.2.

It is recommended that the bottom of the wingwall footings be at least 4 ft below the ground surface based on frost susceptibility and bearing stratum at the site. For wingwalls of the inlet and outlet of the culvert, an embedment value of 4 ft was used for the strength limit state analysis and an embedment value of 0 ft was used for the service limit state analysis, which tends to control the design, to account for potential scour conditions at the design flood elevation per Section 2.6.4.4.2. A conservative groundwater depth of 4.0 ft below ground surface was used in design for both the inlet and outlet based on conditions encountered during drilling.

As per section 10.5.5.1 of the 2020 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 *effective* footing widths. The soil profiles used in these analyses can be found below in Table 3.1 and Table 3.2.

Table 3.1 Soil Profile Located at Inlet (B-101)

Approximate Elevation (ft)	Soil Profile
1255.3 – 1245 ft	Loose GRAVEL, little Sand, trace Silt
1245 – 1243.3 ft	Dense GRAVEL, some Sand
< 1243.3 ft	Bedrock (PHYLLITE)

Table 3.2 Soil Profile Located at Outlet (B-102)

Approximate Elevation (ft)	Soil Profile
1254.9 – 1243 ft	Loose GRAVEL, little Sand
1243 – 1240.7 ft	Dense GRAVEL, some Sand
< 1240.7 ft	Bedrock (PHYLLITE)

3.1 Bearing Resistance (Inlet Bearing Stratum, B-101 and B-103)

The maximum length of wingwalls used in the analysis was 11.0 ft, based on an email from Adam Goudreau dated November 27th, 2024. A bottom of footing elevation of 1244.0 ft was specified for the inlet of the proposed culvert. Based on the geometry and elevations the footings will bear on a dense GRAVEL, some sand layer. Based on the boring information and subsequent calculations, the soil in this layer was assigned a friction angle, $\phi = 38^{o}$ and density, $\gamma = 135$ lb/ft^3.

For effective footing widths of 3 ft through 8 ft, the maximum factored bearing resistances for the strength and service limit states are given in Table 3.1.1. Soil settlement values were calculated for various footing widths based on the nominal bearing pressure at the service limit state using Hough's Method, as stated above in Section 3.0. Bearing pressures values that resulted in 1.0-inch of settlement are higher than the anticipated bearing pressures and were not included in the table below. Considering the granular nature of the foundation soils, any settlement is expected to occur during or immediately after construction. Based on calculations, bearing resistance in the service limit state was found to govern design. Attached to this report, as Appendix B and Appendix C, are graphs that detail the corresponding bearing resistances for various effective footing widths and settlement graphs based on various bearing pressures, respectively

Table 3.1.1 Factored Bearing Resistances at Various Effective Footing Widths (Inlet)

Maximum Wingwall Length (ft)	Effective Footing Width (ft)	Factored Bearing Resistance, Strength Limit State (ksf)	Factored Bearing Resistance, Service Limit State (ksf)
11.0	3	17.5	7.0
	4	19.2	9.0
	5	21.0	10.8
	6	22.5	12.3
	7	24.0	13.8
	8	25.4	15.0

3.2 Bearing Resistance (Outlet Bearing Stratum, B-102)

The maximum length of wingwalls used in the analysis was 8.58 ft, based on an email from Adam Goudreau dated November 27th, 2024. A bottom of footing elevation of 1243.8 ft was specified for the outlet of the proposed culvert. Based on the geometry and elevations the footings will bear on a loose GRAVEL, little Sand layer. Based on the boring information and subsequent calculations, the soil in this layer was assigned a friction angle, $\phi = 32^{o}$ and density, $\gamma = 115$ lb/ft^3.

For effective footing widths of 3 ft through 8 ft, the maximum factored bearing resistances for the strength and service limit states are given in Table 3.2.1. Soil settlement values were calculated for various footing widths based on the nominal bearing pressure at the service limit state using Hough's Method, as stated above in Section 3.0. Bearing pressure values that resulted in 1.0 inch of settlement are higher than the anticipated bearing pressures and were not included in the table below. Considering the granular nature of the foundation soils, any settlement is expected to occur during or immediately after construction. Based on calculations, bearing resistance in the service limit state was found to govern design. Attached to this report, as Appendix B and Appendix C, are graphs that detail the corresponding bearing resistances for various effective footing widths and settlement graphs based on various bearing pressures, respectively.

Table 3.2.1 Factored Bearing Resistances at Various Effective Footing Widths (Outlet)

Maximum Wingwall Length (ft)	Effective Footing Width (ft)	Factored Bearing Resistance, Strength Limit State (ksf)	Factored Bearing Resistance, Service Limit State (ksf)
8.58	3	8.3	3.9
	4	9.0	4.6
	5	9.7	5.3
	6	10.3	5.9
	7	10.9	6.4
	8	11.5	6.9

4.0 RECOMMENDATIONS

Shallow foundations appear to be feasible for the proposed wingwalls as detailed by Adam Goudreau in an email dated November 2024. Factored bearing resistances for various footing widths were calculated for the wingwalls and can be found in Table 3.1.1 and Table 3.2.1. These calculations are based on the geometric and geotechnical assumptions outlined in Section 3.0 of this report. The bearing resistances presented in this report at the service limit state were calculated assuming a conservative scour condition (0 ft embedment). 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 4.1 shows the appropriate resistance factors for various design states.

Table 4.1: Summary of Resistance Factors

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

4.1 Plan Notes & Details

Based on the variability of the soils encountered during the subsurface investigation, and locations of the borings with relation to the inlet and outlet, we recommend including the following information on the plans:

- For strength limit state, using a resistance factor of 0.45, the factored bearing resistance is 8.3 ksf
- For service limit state, using a resistance factor of 1.0, the factored bearing resistance is 3.9 ksf

Loose soils were encountered at the anticipated elevation of the outlet of the culvert. In order to achieve the above recommended bearing resistances, we recommend over-excavating a minimum of 12 inches below bottom of footing elevations and replacing with a suitable material, such as crushed stone or 704.08 Granular Backfill for Structures. Material placement should extend a minimum of 2 ft horizontally from the edge of the footing. The addition of this material is required in order to achieve the above resistances.

Based on the subsurface investigation, shallow bedrock was encountered in the borings, ranging at an elevation of 1240.7 ft to 1243.3 ft. While the elevations of the footings are anticipated to lay above bedrock, bedrock may be variable along the profile of the new structure location and found at higher elevations than encountered during this investigation. The bedrock at the project site consists of Phyllite and Limestone. Based on the rock type and condition of the cores, we anticipate the phyllite to be quite rippable, while the limestone would likely require hammering to remove if it is exposed in abundance. We recommend including a small quantity of solid rock excavation to account for the potential variability in the bedrock within the footprint of the box and wingwalls.

4.2 Design Parameters

Table 4.2.1 highlights engineering properties assigned to the in-situ soils and common construction materials. These values should be used when designing any 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 backfill) and a vertical wall face.

Table 4.2.1: Engineering Properties of In-Situ Soils and Construction Materials

	Dense GRAVEL, some sand (Inlet Bearing)	**Loose GRAVEL, little Sand** (Outlet Bearing)	**703.04 – Granular Borrow**	**704.08 – Granular Backfill for Structures**
Unit Weight, γ (lbs/ft^3):	135	115	130	140
Internal Friction Angle, φ (degrees):	38	32	32	34
Coefficient of Friction, f				
- mass concrete cast against soil:	0.60	0.45	0.45	0.55
- soil against precast/formed concrete:	0.49	0.40	0.40	0.48
Active Earth Pressure Coef., K_a:	0.24	0.31	0.31	0.28
Passive Earth Pressure Coef., K_p:	4.20	3.26	3.26	3.57
At-Rest Earth Pressure Coefficient, K_o:	0.38	0.47	0.47	0.44

4.3 Construction Considerations

4.3.1 Cofferdams/Temporary Earthwork Support

The Contractor should be reminded that Section 208.06 of VTrans' *2024 Standard Specifications for Construction* indicates that "The Contractor shall prepare detailed plans and a schedule of operations for each cofferdam specified in the Contract. Construction drawings shall be submitted in accordance with Subsection 105.06."

4.3.2 Construction Dewatering

The bottom of footing elevations for the wingwalls are estimated to be beneath the water table based on where water was encountered during the subsurface investigation therefore temporary construction dewatering will likely be required to construct the foundations. 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 water, 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.

4.3.3 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 is used, such as a small vibratory plate compactor, 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 no less than 95% of the maximum dry density determined in accordance with AASHTO T-99, Method C. 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.

5.0 CONCLUSION

If you have any questions or would like to discuss this report, please contact the Geotechnical Engineering Section via email.

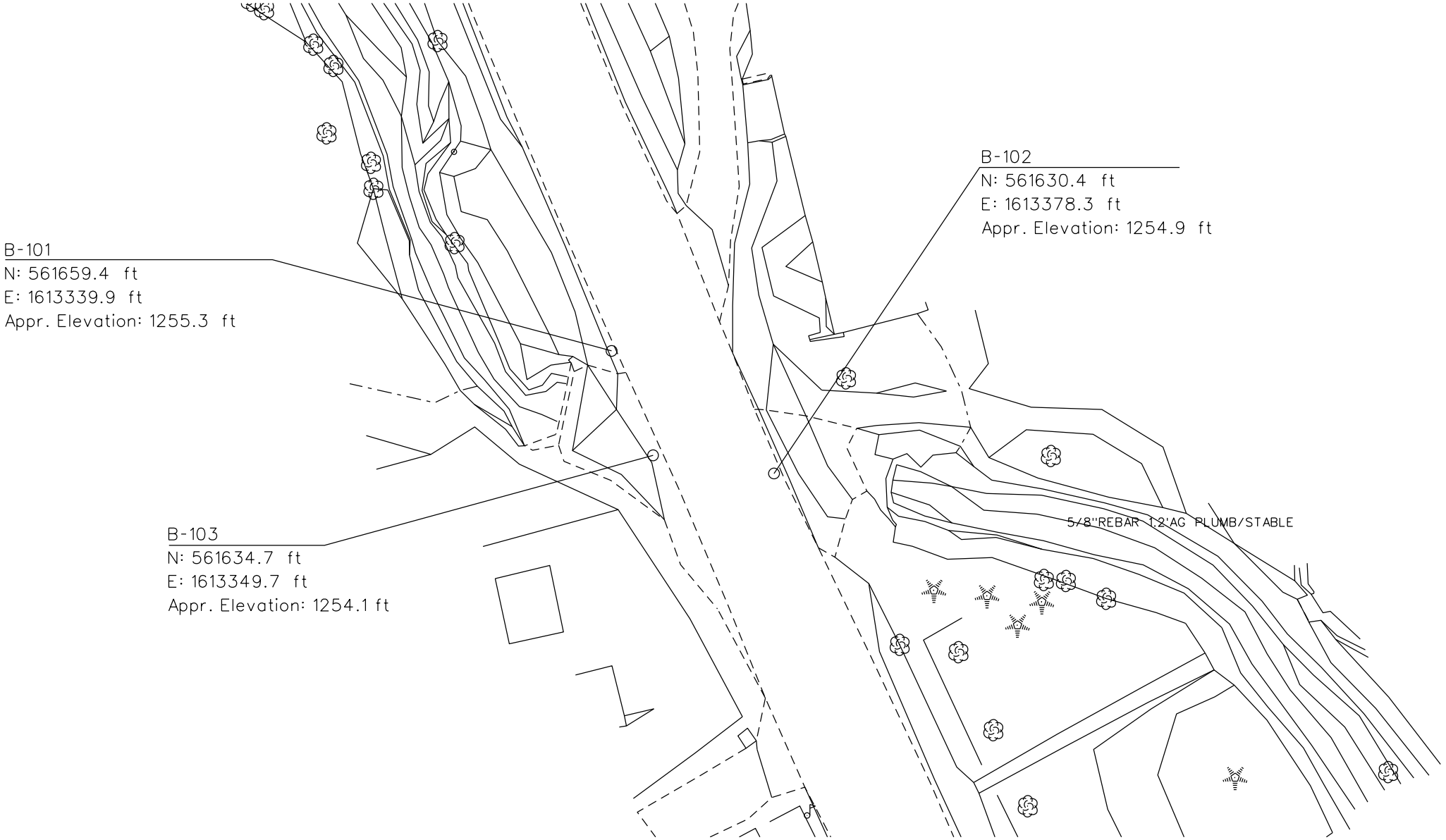
Reviewed by: Eric Denardo, P.E., Geotechnical Engineer END

Enclosures: Appendix A: Boring Location Plan and Logs (4 Pages)
Appendix B: Bearing Resistance Graphs (1 Page)
Appendix C: Settlement Graphs (1 Page)

cc: Electronic Read File/MG
Project File/CEE
AJA

Appendix A

Boring Layout Plan and Logs


B-101
N: 561659.4 ft
E: 1613339.9 ft
Appr. Elevation: 1255.3 ft
B-102
N: 561630.4 ft
E: 1613378.3 ft
Appr. Elevation: 1254.9 ft
B-103
N: 561634.7 ft
E: 1613349.7 ft
Appr. Elevation: 1254.1 ft
5/8"REBAR 1.2'AG PLUMB/STABLE

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BORING LOG

Brookfield
ER E23-1(668)
VT 65 MM 0.93 Bridge 3

Boring No.: **B-101**
Page No.: 1 of 1
Pin No.: 24D007
Checked By: AJA

Boring Crew: McGinley, Thurston, Arles
Date Started: 8/23/23 Date Finished: 8/23/23
VTSPG NAD83: N 561659.40 ft E 1613339.90 ft
Station: Offset:
Ground Elevation: 1255.3 ft

	Casing	Sampler
Type:	WB	SS
I.D.:	4 in	1.5 in
Hammer Wt:	N.A.	140 lb.
Hammer Fall:	N.A.	30 in.
Hammer/Rod Type:		Auto/AWJ
Rig:	Acker Renegade	C_E = 1.3

Groundwater Observations

Date	Depth (ft)	Notes
08/22/23		See Notes

Depth (ft)	Strata (1)	CLASSIFICATION OF MATERIALS (Description)	Run (Dip deg.)	Core Rec. % (RQD %)	Drill Rate minutes/ft	Blows/6" (N Value)	Moisture Content %	Gravel %	Sand %	Fines %
2.5		Field Note, Spun Casing to 10 ft without sampling. Encountered wood in hole at 7.8 ft								
5.0										
7.5										
10.0		Field Description, Rec. = 0.5 ft, Very Dense, Poorly Graded, GRAVEL, some Sand. Refusal @ 11.2', 10 blows, no movement. Rollercone Cleanout 11.2'-12.0'				10-16-R@2" (R)				
12.5		12.0 ft - 17.0 ft, Light gray LIMESTONE, PHYLLITE, and QUARTZ vein. Slight brown staining on Limestone joints. Rest of run is fresh. Phyllite is sulfidic. Run is highly fractured and low RQD could be due to mechanical breakage. Medium hard to hard, Unweathered, Poor rock, BXDC, RMR = 30	R-1 (40 to 45)	66 (0)	6 5 5 5 7					
15.0										
17.5		Hole stopped @ 17.0 ft								
20.0		Remarks: Hole Collapse @ 17.0 ft No water in hole after collapse								
22.5										

Top of Bedrock @ 12.0 ft

Notes:
1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
2. N Values have not been corrected for hammer energy. C_E is the hammer energy correction factor.
3. Water level readings have been made at times and under conditions stated. Fluctuations may occur due to other factors than those present at the time measurements were made.
4. "bgs" is used as the shorthand stand in for "Below Ground Surface".

BORING LOG BROOKFIELD ER E23-1(668).GPJ VERMONT AOT.GDT 6/26/24

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BORING LOG

Brookfield
ER E23-1(668)
VT 65 MM 0.93 Bridge 3

Boring No.: **B-102**
Page No.: 1 of 1
Pin No.: 24D007
Checked By: AJA

Boring Crew: McGinley, Thurston, Arles
Date Started: 8/22/23 Date Finished: 8/22/23
VTSPG NAD83: N 561630.40 ft E 1613378.30 ft
Station: Offset:
Ground Elevation: 1254.9 ft

	Casing	Sampler
Type:	WB	SS
I.D.:	4 in	1.5 in
Hammer Wt:	N.A.	140 lb.
Hammer Fall:	N.A.	30 in.
Hammer/Rod Type:	Auto/AWJ	
Rig:	Acker Renegade	C_E = 1.3

Groundwater Observations

Date	Depth (ft)	Notes
08/23/23		See Notes

Depth (ft)	Strata (1)	CLASSIFICATION OF MATERIALS (Description)	Run (Dip deg.)	Core Rec. % (RQD %)	Drill Rate minutes/ft	Blows/6" (N Value)	Moisture Content %	Gravel %	Sand %	Fines %
5		Field Note, NO RECOVERY. Gravel in end of sampler. Rollercone Cleanout 9.1'-10.0'				3-4-2-2 (6)				
10		Field Description, Rec. = 0.6 ft, Loose, Poorly Graded, GRAVEL, little Sand, trace Silt.				5-3-3-12 (6)				
		Field Description, Rec. = 1.1 ft, Very Dense, Poorly Graded, GRAVEL and WEATHERED ROCK, some Sand. Weathered Rock in the end of sampler. Rollercone cleanout 12.6'-14.0'. Refusal @ 13.7', 100 blows.				5-9-48-R@3" (57)				
15		Field Description, Refusal @ 14.2', 10 blows, no movement. Spun Casing to 15.0'. Rollercone would not advance past 14.2'.	R-1 (10 to 20)	76 (55)	2 3 2 2 3	R@3" (R)				
		14.2 ft - 19.2 ft, Gray LIMESTONE. Rusty brown staining on joints. Medium hard, Slightly to moderately weathered, Fair rock, BXDC, RMR = 55				Top of Bedrock @ 14.2 ft				
20		19.2 ft - 24.2 ft, Gray to light gray LIMESTONE and PHYLLITE. Limestone present from 19.2 ft to 20.4 ft then transitions to sulfidic phyllite for remainder of run. Phyllite is highly fractured. Slight rust staining on some phyllite surfaces, otherwise fresh. Medium hard, Very slightly weathered, Poor rock, BXDC, RMR = 35. Low RQD could be contributed to mechainal breakage of core	R-2 (30 to 40)	100 (24)	2 2 2 2 3					
25		Hole stopped @ 24.2 ft								

Remarks:
Hole Collapse @ 2.0 ft
No water in hole after collapse

Notes:
1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
2. N Values have not been corrected for hammer energy. C_E is the hammer energy correction factor.
3. Water level readings have been made at times and under conditions stated. Fluctuations may occur due to other factors than those present at the time measurements were made.
4. "bgs" is used as the shorthand stand in for "Below Ground Surface".

BORING LOG BROOKFIELD ER E23-1(668).GPJ VERMONT AOT.GDT 6/26/24

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BORING LOG

Brookfield
ER E23-1(668)
VT 65 MM 0.93 Bridge 3

Boring No.: **B-103**
Page No.: 1 of 1
Pin No.: 24D007
Checked By: AJA

Boring Crew: McGinley, Thurston, Arles
Date Started: 8/23/23 Date Finished: 8/23/23
VTSPG NAD83: N 561634.70 ft E 1613349.70 ft
Station: Offset:
Ground Elevation: 1254.1 ft

	Casing	Sampler
Type:	WB	SS
I.D.:	4 in	1.5 in
Hammer Wt:	N.A.	140 lb.
Hammer Fall:	N.A.	30 in.
Hammer/Rod Type:	Auto/AWJ	
Rig:	Acker Renegade	C_E = 1.3

Groundwater Observations

Date	Depth (ft)	Notes
08/23/23	4.6	WT After Drilling

Depth (ft)	Strata (1)	CLASSIFICATION OF MATERIALS (Description)	Blows/6" (N Value)	Moisture Content %	Gravel %	Sand %	Fines %
2.5		Field Note, Advanced Casing to 12.5' without sampling					
5.0							
7.5							
10.0							
		Field Note, Rollercone Cleanout 10.0'-12.5'					
12.5		Field Note, Casing refused to advanced past 12.5 ft. Assumed top of rock due to water wash color and similarity to other borings — Top of Bedrock @ 12.5 ft					
		Hole stopped @ 12.5 ft					
		Remarks: Hole Collapse @ 7.8 ft					
15.0							
17.5							
20.0							
22.5							

Notes:
1. Stratification lines represent approximate boundary between material types. Transition may be gradual.
2. N Values have not been corrected for hammer energy. C_E is the hammer energy correction factor.
3. Water level readings have been made at times and under conditions stated. Fluctuations may occur due to other factors than those present at the time measurements were made.
4. "bgs" is used as the shorthand stand in for "Below Ground Surface".

BORING LOG BROOKFIELD ER E23-1(668).GPJ VERMONT AOT.GDT 6/26/24

Appendix B

Bearing Resistance Graphs

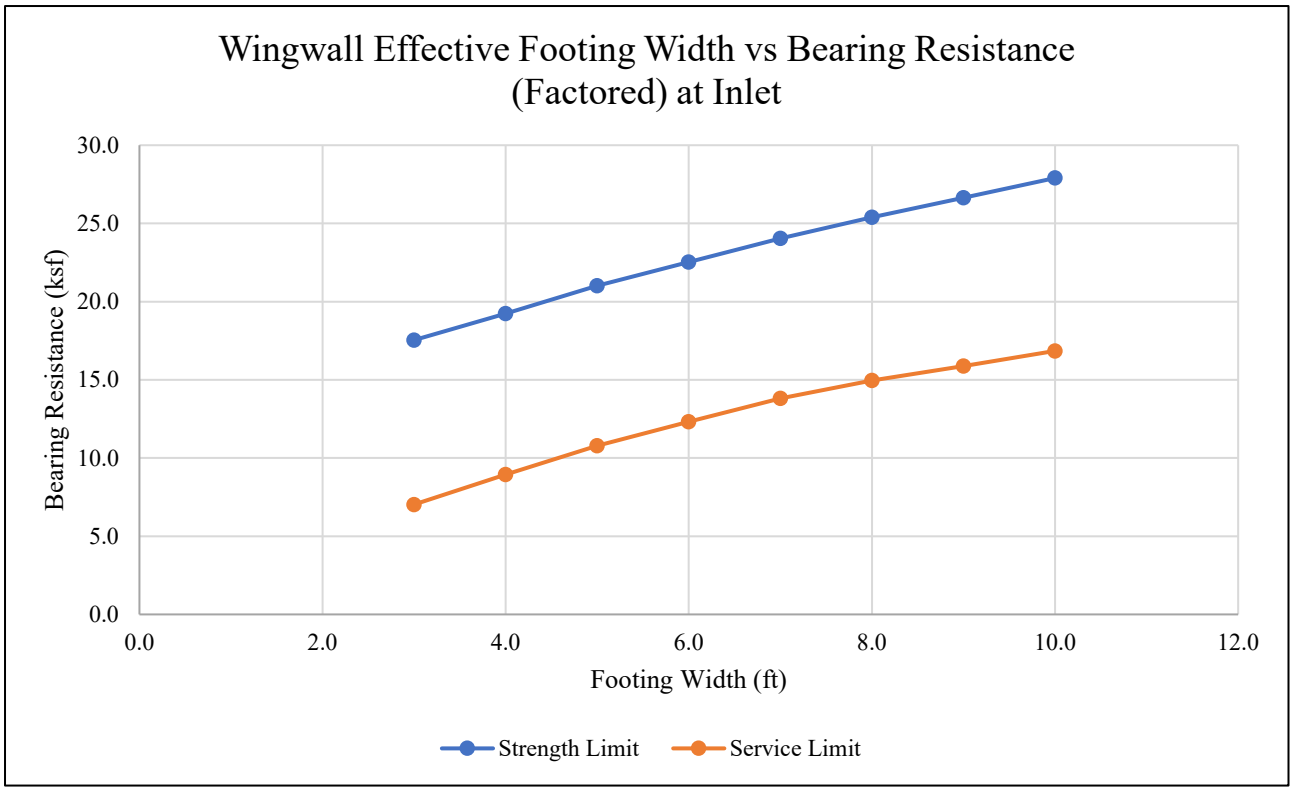


Figure B.1 Bearing Resistance vs. Effective Footing Width at Inlet of Culvert

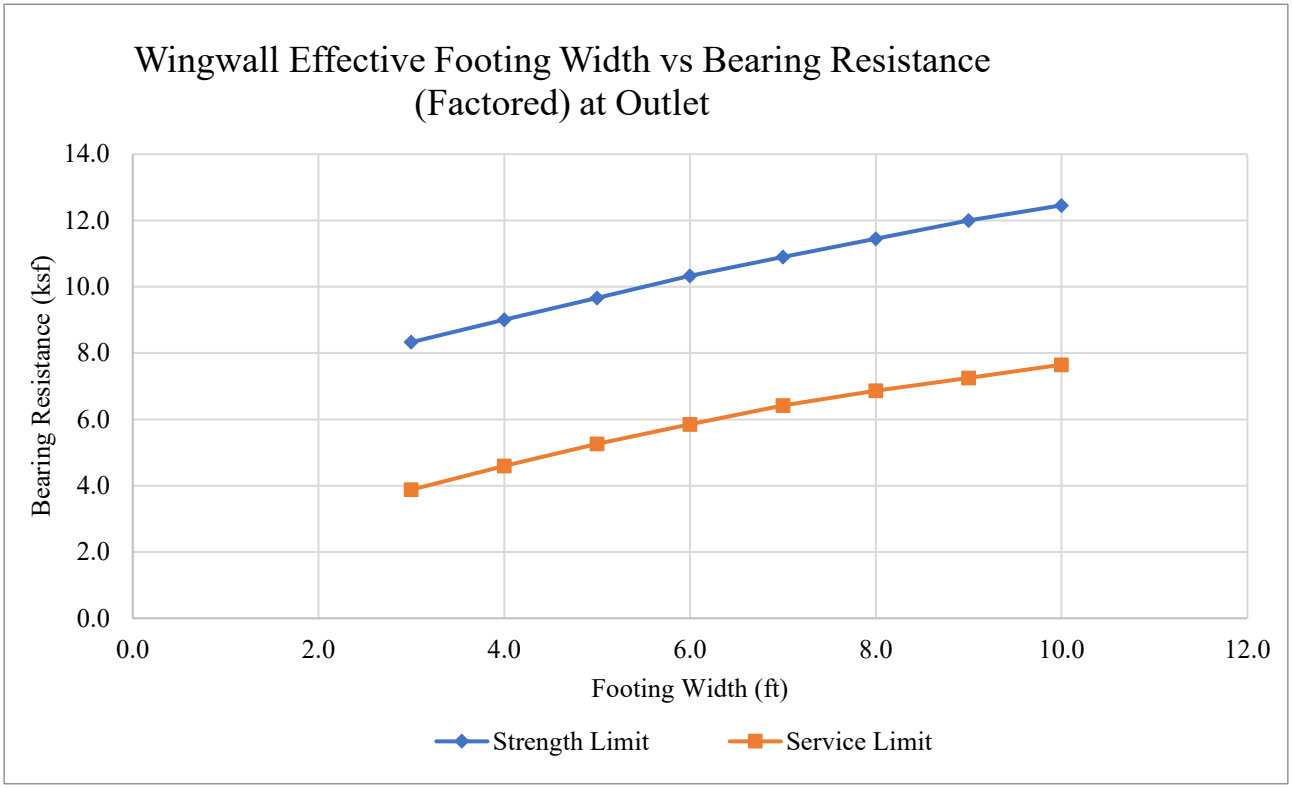


Figure B.2 Bearing Resistance vs. Effective Footing Width at Outlet of Culvert

Appendix C

Settlement Graphs

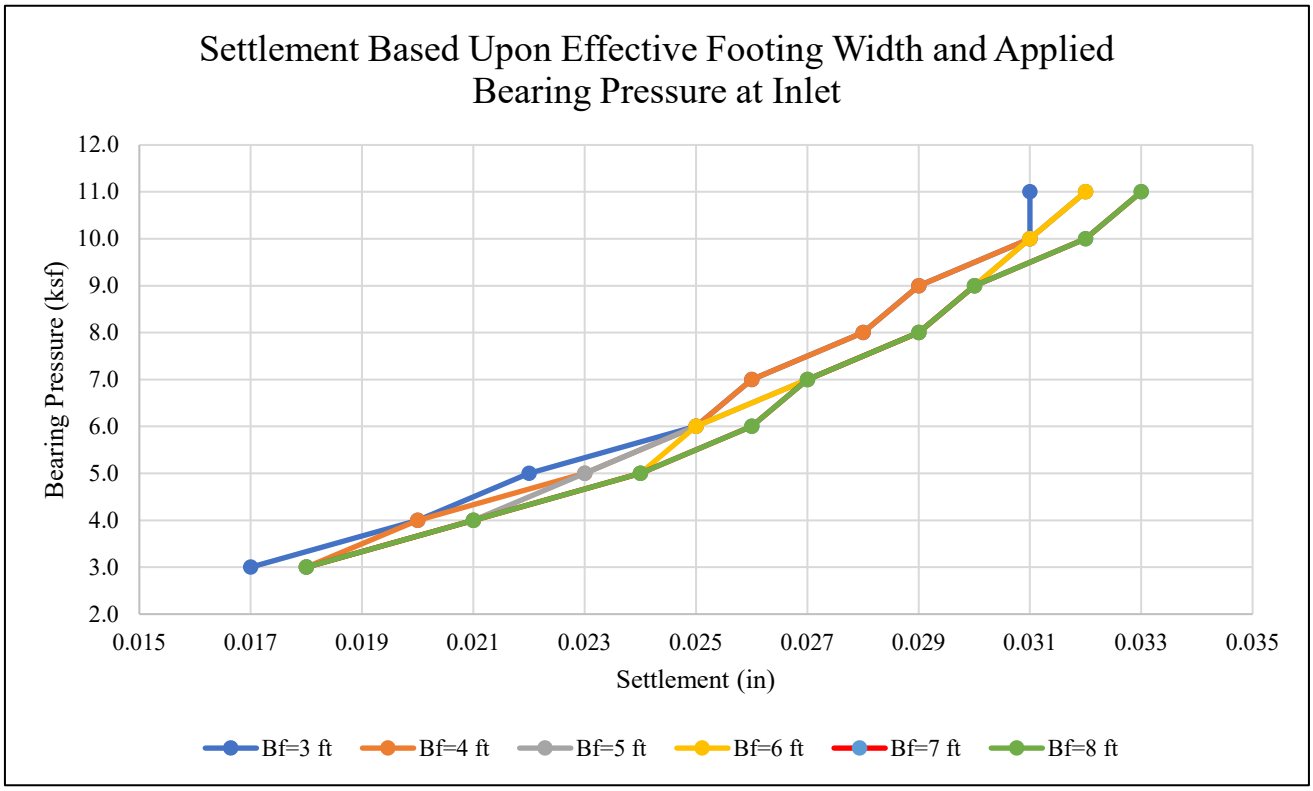


Figure C.1 Settlement of Inlet Based on Effective Footing width and Applied Bearing Pressure

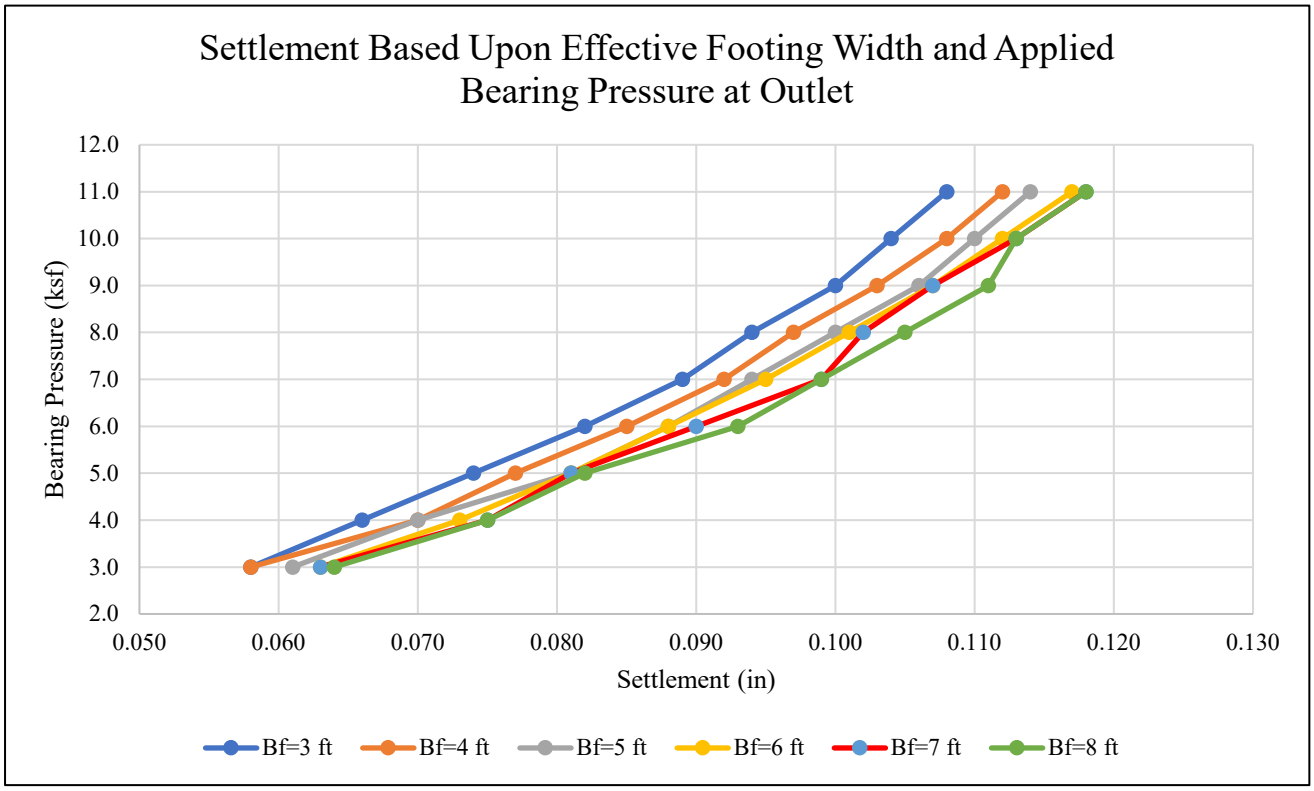


Figure C.2 Settlement of Outlet Based on Effective Footing width and Applied Bearing Pressure