AGENCY OF TRANSPORTATION **OFFICE MEMORANDUM**

To: Ken Robie, Highway Safety and Design Project Manager

LAR CCB

From: Laura Ripley, E.I., Geotechnical Engineer via Christopher C. Benda, P.E., Soils and Foundations Engineer

Date: September 12th, 2012

Subject: Cabot – Danville FEGC-F-208-3(26) – Geotechnical Recommendations

1.0 INTRODUCTION

We have completed our geotechnical analysis for the spread footing foundation of a precast arch structure for Bridge No. 87 over Molly's Brook on US Rt. 2 in Cabot, VT. This analysis was requested by Michael Cruz and Erik Atkins of Green International Affiliates, Inc (Green) in an email dated June 5th, 2012. The geotechnical analysis was performed according to 2010 AASHTO LRFD Bridge Design Specifications.

2.0 FIELD INVESTIGATION

The field investigation was conducted between July 31st and August 3rd, 2012. Two standard penetration (SPT) borings were drilled to determine the subsurface profile to aid in design and construction. A summary of the boring location and ground surface elevations can be found in Table 2.1. The values for Northings and Eastings are based on the Vermont State Plane Grid Coordinate System NAD 83.

Table 2.1 Boring locations and elevations.

Boring Number	Substructure	Easting (ft)	Northing(ft)	Ground Elevation (ft)
B-102	Southern Abut	1700612.0	681951.6	1428.95
B-104	Northern Abut at the Wingwall	1700529.3	681881.7	1428.45

During the boring operations, split spoon samples and SPT tests were taken at five foot intervals in both borings. Bedrock was not encountered in either boring. For each boring, soil samples were visually classified and SPT blow counts were recorded on the boring logs.

3.0 FIELD AND LABORATORY TESTING

The standard penetration resistance of the in-situ soil is determined by the number of blows required to drive a 2 inch OD split barrel sampler into the soil with a 140 pound hammer dropped from a height of 30 inches, in accordance with procedures specified in AASHTO T206. During the standard penetration test (SPT), the sampler is driven for a total length of 2 feet, while counting the blows for each 6 inch increment. The SPT N-value, which is defined as the sum of the number of blows required to drive the sampler through the second and third increments, is commonly used with established correlations to estimate a number of soil parameters, particularly the shear strength and density of cohesionless soils. The N-values provided on the boring logs are raw values and have not been corrected for energy, borehole diameter, rod length or overburden pressure. The VT Agency of Transportation has determined a hammer correction value, C_E, to account for the efficiency of the SPT hammer on the drill rig. For this project a CME 45C Track Rig was used, with a hammer energy correction factor of 1.34. This value, included on the boring logs, was used in calculations to determine soil parameters. Laboratory tests were conducted on all samples to evaluate grain size, moisture content, and percent finer than No. 200 sieve. This testing was conducted on all of the soil samples and results can be found on the attached boring logs.

4.0 SOIL PROFILE

Review of the SPT results, lab data, geologist's reports and borings revealed the following information about the soil strata at the location of proposed Abutments:

4.1 Southern Abutment (Boring B-102)

A ground water measurement was recorded at a depth of 6.0 feet below the ground surface elevation (GSE) after allowing the bore hole to stabilize overnight. Bedrock was not encountered.

Depth (below GSE)	Soil Type
0.0 – 16.0 feet	Silt with cobbles
16.0 – 26.0 feet	Dense sandy silt
26.0 – 40.0 feet	Medium dense silt with thin clay seams

4.2 Northern Abutment at the Wingwall (Boring B-104)

A ground water measurement was recorded at a depth of 6.0 feet below the ground surface elevation after allowing the bore hole to stabilize overnight. Bedrock was not encountered.

Depth (below GSE)	Soil Type
0.0 – 16.0 feet	Sand with cobbles
16.0 – 23.0 feet	Gravelly sandy silt
23.0 – 30.0 feet	Medium dense silt with thin clay seams

5.0 ANALYSIS

Shallow Foundation Analysis: As requested by Green, shallow foundations at both abutments were evaluated using Load and Resistance Factor Design (LRFD). Using information gathered from borehole logs and laboratory tests, empirical relationships were utilized to determine soil properties for analysis.

AASHTO's LRFD Bridge Design Specifications Manual (2010) 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 analysis as they were not considered pertinent. Hough's Method, used to calculate settlement in normally consolidated cohesionless soils, is found in section 10.6.2.4.2. The specifics for each abutment follow this section.

As shown in a preliminary plan set provided by Michael Cruz on June 25th, 2012, the bottom of footing elevation was assumed to be at 1413 feet. The footing embedment depths varied slightly between abutments. A conservative footing embedment depth of 6 feet was used in the analysis. As per section 10.5.5.1 of the 2010 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 designs include, but are 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:	$\|e\| < b/4$
Foundations on rock:	$\|e\| < 3b/8$

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.

5.1 Abutments: The bottom of footing elevation was assumed to be 1413 feet for both abutments. Based on the profile and empirical relationships with SPT values from the sandy silt bearing stratum, it was determined the soil had a friction angle (φ) of 35° and a density (γ) of 125 lbs/ft^3. One soil profile was used for both abutments due to the similarity of composition and blow counts recorded in the field. Figure 5.1 below displays the minimum effective footing width versus bearing resistance, factored due to LRFD strength limit state. For footing widths of 6, 9, and 11 feet, the maximum bearing resistance are 9.9, 12.0, and 13.3 ksf, respectively.

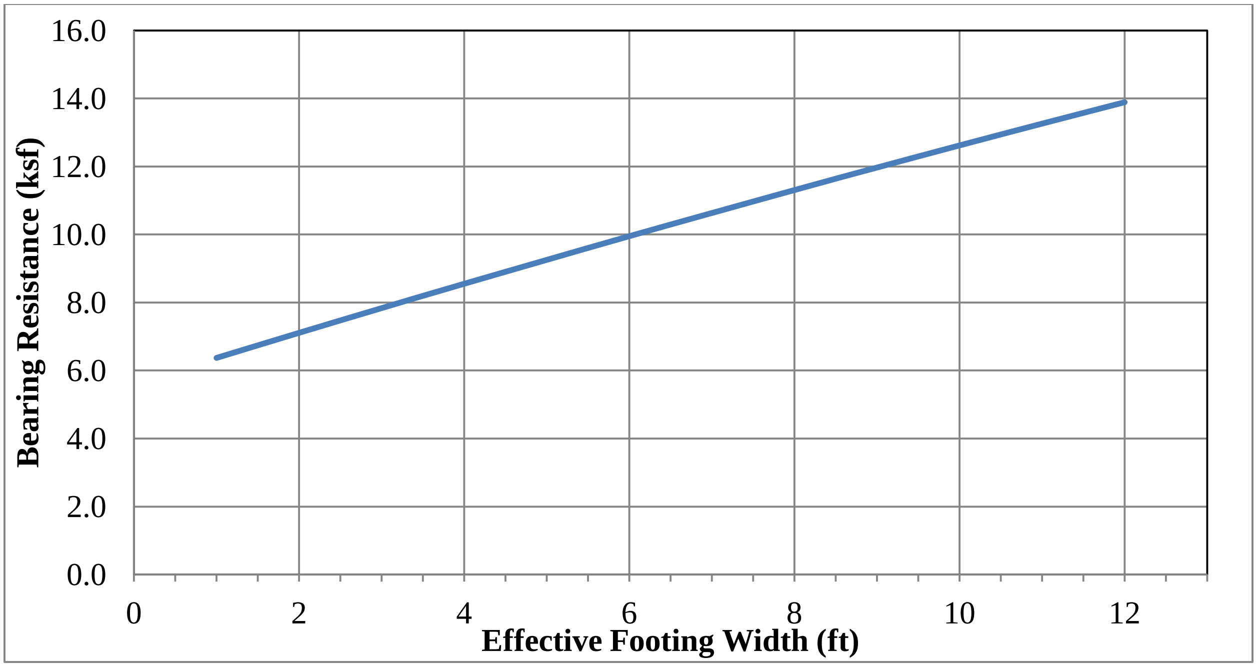


Figure 5.1. *Effective* Footing Width vs. Bearing Resistance (factor of Φ=0.45)

Soil settlement values were calculated for various footing widths based on the nominal bearing pressure. Found in Figure 5.2 are the settlement values for effective footing widths of 4.5 to 12 feet. Due to the granular nature of the soils, settlement is expected to occur during or immediately after construction. Figure 5.3 displays the bearing pressure expected to yield 1-inch of settlement for various effective footing widths.

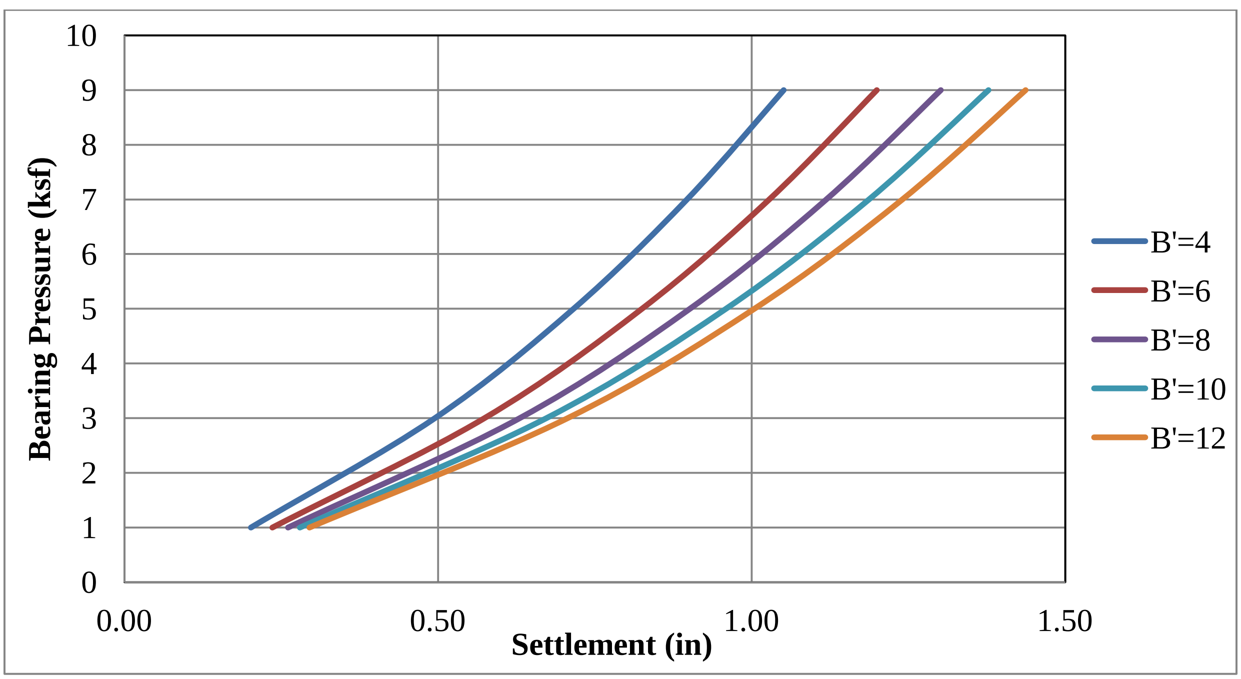


Figure 5.2. Settlement vs. Nominal Bearing Pressure for Abutment No. 1

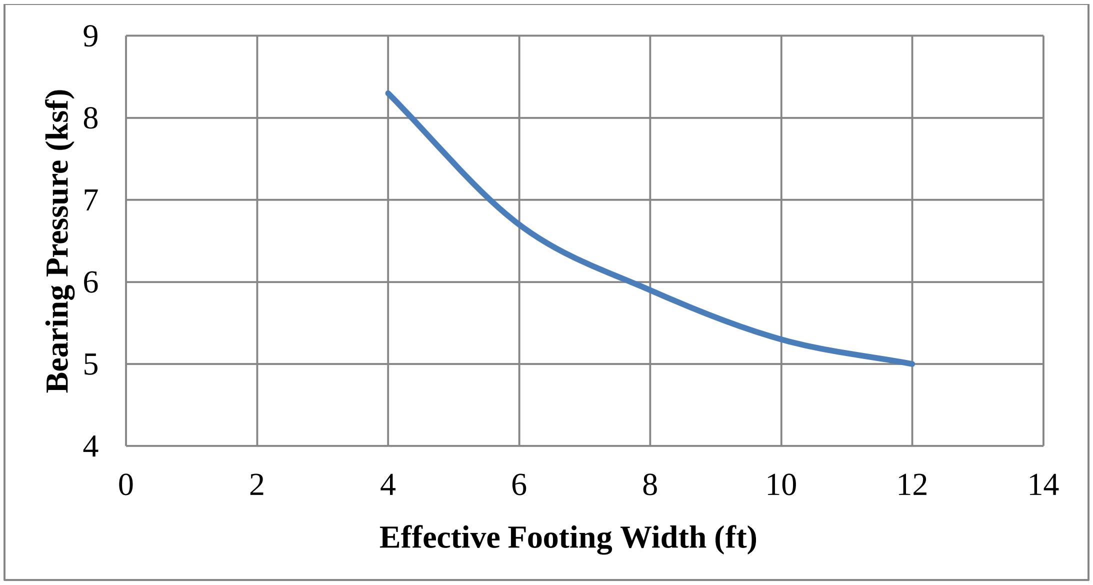


Figure 5.3. Bearing Pressure vs. Effective Footing Width for 1-inch of Settlement

6.0 RECOMMENDATIONS

Shallow foundations appear to be feasible at the proposed footing elevation of 1413 feet. The static water table was found to be above this footing elevation in the borings performed, therefore it is likely that water will be encountered during excavation and pumping will be required. The material underlying the bottom of footing may consist of as much as 2 feet of soft silty material. In order to achieve full capacity, this material may need to be undercut and filled with a competent base material. Plans should detail a minimum 1-foot undercut. Before backfilling with a competent material, we recommend placing a geotextile meeting the requirements of VTrans Pay Item 649.11, Geotextile for Roadbed Separation.

Factored bearing resistances were calculated for various footing widths and can be found in Figures 5.1, 5.2 and 5.3. The settlement is expected to occur during or immediately after construction. These calculations are based on the geometric and geotechnical assumptions outlined in Sections 2.1 and 2.2. 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 6.1 shows the appropriate resistance factors for various design states.

Table 3.1. Summary of resistance factors

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

6.1 Construction Considerations

6.1.1 Cofferdams/Temporary Earthwork Support: The Contractor should be reminded that Section 208.07 of VTrans' *2006 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)."

6.1.2 Construction Dewatering: The bottom of foundation elevation for the spread footing is estimated to be at 1413 feet while the elevation of the groundwater table during drilling was encountered as shallow as 6 feet below ground surface at an elevation of 1423 feet. Therefore, temporary construction dewatering may be required to construct the foundation. Temporary dewatering may 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.

6.1.3 Subgrade Preparation: The subgrade shall be compacted until it is able to provide a firm and stable condition. Wet subgrade soils shall be proofrolled without vibration. Areas exhibiting excessive weaving, soft, or unstable soils should be excavated and replaced with compacted Granular Backfill for Structures (VTrans' pay item 204.30) in the area of the abutments and Granular Borrow (VTrans' pay item 203.32) in the embankments. In areas of steep terrain, the subgrade should be stripped, benched, and proofrolled to provide a level surface on which to place fill.

6.1.4 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.

General embankment fills should be compacted to a dry density of at least 90% of the maximum dry density determined in accordance with AASHTO T-99. 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.

6.2 Design Parameters: Table 6.2 highlights the geotechnical design parameters of the foundation bearing soil as well as regularly specified aggregates. These values should be 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 6.2. Engineering Properties of Construction Materials

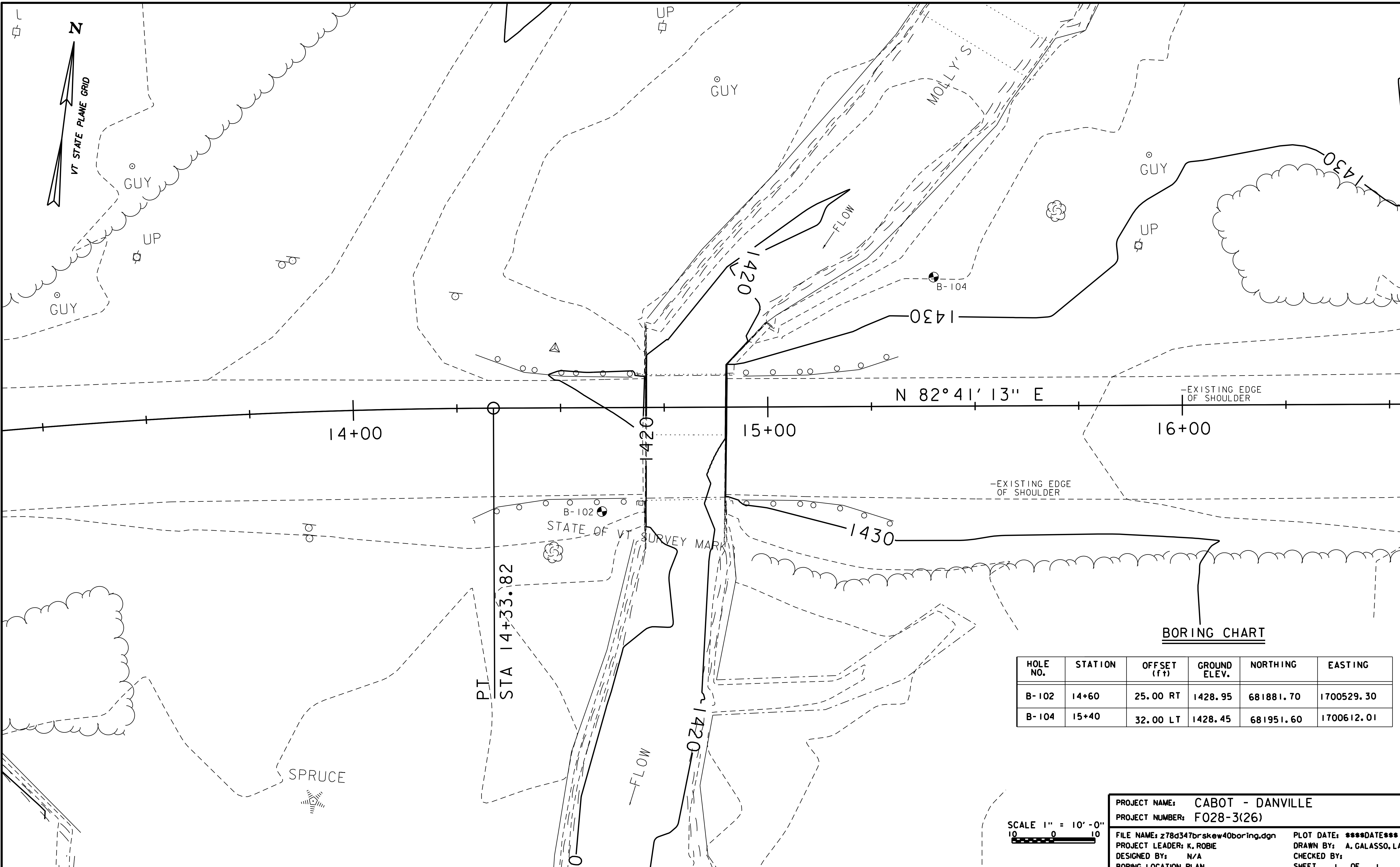
	703.01A - Granular Borrow	**704.08 - Granular Backfill for Structures**	**Medium Dense Sandy Silt**
Density (lb/ft^3):	130	140	125
Internal Friction Angle, φ	32	35	35
Coefficient of Friction, f			
- concrete cast against	0.50	0.55	0.35
- sand against formed	0.40	0.45	0.31
Active Earth Pressure	0.31	0.27	0.27
Passive Earth Pressure	3.22	3.69	3.69
At-Rest Earth Pressure	0.47	0.43	0.43

7.0 CONCLUSION

If any further analysis is needed or 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\78d347\MaterialsResearch\Molly's Brook* folder.

Attachments: Boring Logs (2 pages)
Boring Location Plan (1 page)

cc: Erik C. Atkins, P.E., Green International Affiliates, Inc.
Electronic Read File/WEA
Project File/CCB
LAR



BORING CHART

HOLE NO.	STATION	OFFSET (ft)	GROUND ELEV.	NORTHING	EASTING
B-102	14+60	25.00 RT	1428.95	681881.70	1700529.30
B-104	15+40	32.00 LT	1428.45	681951.60	1700612.01

SCALE 1" = 10'-0"

10 0 10

PROJECT NAME: CABOT - DANVILLE
PROJECT NUMBER: F028-3(26)

FILE NAME: z78d347brskew40boring.dgn
PROJECT LEADER: K. ROBIE
DESIGNED BY: N/A
BORING LOCATION PLAN

PLOT DATE: $$$$DATE$$$
DRAWN BY: A. GALASSO, LAR
CHECKED BY:
SHEET 1 OF 1

STATE OF VERMONT AGENCY OF TRANSPORTATION MATERIALS & RESEARCH SECTION SUBSURFACE INFORMATION	**BORING LOG** **CABOT-DANVILLE** **FEGC-F 028-3(26) C/2** **US-2 BR-87**	Boring No.: **B-102** Page No.: 1 of 1 Pin No.: 78D347 Checked By: LAR

Boring Crew: PORTER, RIPLEY
Date Started: 7/31/12 Date Finished: 8/01/12
VTSPG NAD83: N 681881.70 ft E 1700529.30 ft
Station: 14+60 Offset: 25.00
Ground Elevation: 1428.95 ft

	Casing	Sampler
Type:	WB	SS
I.D.:	3 in	1.5 in
Hammer Wt:	N.A.	140 lb.
Hammer Fall:	N.A.	30 in.
Hammer/Rod Type:	Auto/AWJ	
Rig:	CME 45C TRACK	C_E = 1.34

Groundwater Observations

Date	Depth (ft)	Notes
08/01/12	6.0	AM
08/03/12	11.8	AM

Depth (ft)	Strata (1)	CLASSIFICATION OF MATERIALS (Description)	Blows/6" (N Value)	Moisture Content %	Gravel %	Sand %	Fines %	LL %	PI %
5		Field Note:, No Recovery	4-4-6-6 (10)						
		Field Note:, No Recovery, Traces of Wood & Sand.	4-5-4-2 (9)						
10		A-2-4, SiSa, gry-brn, MTW, Rec. = 1.2 ft, Wood pieces were within sample.	3-2-2-2 (4)	46.2	0.5	64.0	35.5		
		Field Note:, Boulder							
15		Field Note:, Cobbles							
		A-4, SaSi, gry, MTW, Rec. = 1.2 ft	2-2-2-3 (4)	13.8	16.3	28.6	55.1		
		A-4, SaGrSi, gry, MTW, Rec. = 0.8 ft	9-7-8-13 (15)	12.4	27.0	23.9	49.1		
20		A-2-4, GrSiSa, gry, Moist, Rec. = 0.5 ft	15-R@2.5"	12.3	28.9	36.8	34.3		
		A-4, SaSi, gry, Moist, Rec. = 1.1 ft	11-14-12-12 (26)	12.9	15.2	24.1	60.7		
25		Visual Description:, Si, gry, Moist, Rec. = 1.5 ft, Material similar as 26-28 ft.	8-8-11-12 (19)	20.2					
		A-4, Si, gry, Moist, Rec. = 1.6 ft	6-9-11-11 (20)	25.7		3.2	96.8		
		Visual Description:, Si, gry, Moist, Rec. = 1.3 ft, Material similar as 26-28 ft.	7-6-9-10 (15)	27.3					
30		A-4, Si, gry, Moist, Rec. = 1.4 ft	5-7-10-10 (17)	27.0		1.5	98.5		
		Visual Description:, Si, gry, Moist, Rec. = 1.9 ft, Material similar as 34-36 ft.	7-19-21-21 (40)	25.2					
35		A-4, Si, gry, Moist, Rec. = 2.0 ft	10-12-17-19 (29)	26.7		1.2	98.8	31	3
		Visual Description:, Si, gry, Moist, Rec. = 2.0 ft, Material similar as 34-36 ft.	8-10-12-18 (22)	29.6					
		A-4, Si, gry, Moist, Rec. = 1.5 ft	9-13-18-28 (31)	30.0		0.4	99.6		
40		Hole stopped @ 40.0 ft							

Remarks:
1. Very thin layers of clay were noticeable from 26-40 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 of groundwater may occur due to other factors than those present at the time measurements were made.

STATE OF VERMONT
AGENCY OF TRANSPORTATION
MATERIALS & RESEARCH SECTION
SUBSURFACE INFORMATION

BORING LOG

CABOT-DANVILLE
FEGC-F 028-3(26) C/2
US-2 BR-87

Boring No.: **B-104**

Pin No.: 78D347
Checked By: LAR

Boring Crew: PORTER, RIPLEY
Date Started: 8/02/12 Date Finished: 8/03/12
VTSPG NAD83: N 681951.60 ft E 1700612.01 ft
Station: 15+40 Offset: -32.00
Ground Elevation: 1428.45 ft

	Casing	Sampler
Type:	WB	SS
I.D.:	3 in	1.5 in
Hammer Wt:	N.A.	140 lb.
Hammer Fall:	N.A.	30 in.
Hammer/Rod Type:	Auto/AWJ	
Rig:	CME 45C TRACK	C_E = 1.34

Groundwater Observations

Date	Depth (ft)	Notes
08/03/12	6.0	AM

Depth (ft)	Strata (1)	CLASSIFICATION OF MATERIALS (Description)	Blows/6" (N Value)	Moisture Content %	Gravel %	Sand %	Fines %
5		A-4, SiSa, gry-brn, Moist, Rec. = 1.3 ft, Chunks of Wood were within sample.	2-1-2-12 (3)	38.0	11.5	50.9	37.6
		A-1-a, SaGr, gry, MTW, Rec. = 1.1 ft, Pieces of Wood & Broken Rock were within sample.	5-7-10-10 (17)	13.8	65.0	26.0	9.0
10		A-4, SaGrSi, gry, MTW, Rec. = 1.0 ft	12-33-10-R@5.0" (43)	10.4	30.1	25.1	44.8
		A-4, GrSaSi, gry, Moist, Rec. = 0.9 ft, Broken Rock was within sample.	7-7-3-5 (10)	12.1	25.7	28.1	46.2
		Visual Description:, GrSaSi, gry, MTW, Rec. = 1.4 ft, Material similar as 11-13 ft.	20-12-21-16 (33)	12.9			
15		A-4, SaSi, gry, MTW, Rec. = 1.8 ft	5-7-6-7 (13)	16.3	9.5	23.3	67.2
		Visual Description:, SaSi, gry, MTW, Rec. = 1.4 ft, Material similar as 15-17 ft.	48-11-21-18 (32)	13.2			
20		A-4, Si, gry, MTW, Rec. = 1.7 ft	15-20-18-16 (38)	14.8	15.1	18.8	66.1
		A-4, Si, gry, MTW, Rec. = 1.9 ft	8-9-11-14 (20)	25.9	0.5	2.7	96.8
25							
		A-4, Si, gry, MTW, Rec. = 1.9 ft	9-11-17-18 (28)	23.2	3.3	4.4	92.3
30		Hole stopped @ 30.0 ft					

Remarks:
1. Very thin layers of clay were noticeable from 23-30 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 of groundwater may occur due to other factors than those present at the time measurements were made.