Hwy 4 Hydro Hill Slope Stability Project
LKI Seg 2383 65.48 km
PO# 16975

Geotechnical Design Report

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APPENDIX SECTIONS

1.0 INTRODUCTION

The Regional Geotechnical Engineering Group has been engaged by Mike Pearson, P.Eng. (Vancouver Island District Director, Ministry of Transportation and Infrastructure) to develop a remedial design for a fill slope instability located on Highway 4, near the top of Hydro Hill, between Port Alberni and Ucluelet.

An initial inspection was completed on January 13, 2017 and was summarized in a draft memo dated February 2, 2017. A subsequent drilling investigation was completed in March of 2017 to investigate the subsurface conditions in the vicinity of the failure area. Detailed design work for the project commenced in 2022.

A slope stabilization system using micropiles and tie back anchors was selected as the preferred remedial solution due to the steep downslope geometry, limited construction space, and geologic site conditions. Background information, observations from the drilling investigation and rock mapping, as well as a geotechnical design for the stabilization system are summarized in this report.

2.0 PROJECT BACKGROUND

2.1 Site Description

The site is located on Highway 4 at the top of "Hydro Hill", where the BCHydro transmission line alignment descends a steep, bedrock-controlled draw that corresponds to the drainage extending from Larry Lake (at El. 100 m) into Kennedy Lake (El. 7 m). Highway 4 descends this slope via a steep switchback that is cut into the rock slopes south of the BCHydro Right of Way (ROW). Rock cuts in this area are up to approximately 20 m in height, and Highway 4 varies from full bench to partial bench construction. The site location is shown in Figure 1 below:

Figure 1: Hydro Hill Site Location (Google Earth)

Distressed pavement associated with fill slope instability (detailed in Section 2.2) is located in the westbound lane of Highway 4 at:

- LKI Segment 2383, km 65.48
- Offset from Ucluelet Junction 22.30 km
- Lat/Long: 49° 6' 58.44"N, 125° 26' 23.95"W

2.2 Site History

A preliminary site inspection was completed on January 13, 2017 and was summarized in a draft memo dated February 2, 2017. Key observations from this inspection include:

- An approximate 17 m long distressed area of the pavement structure was observed, which had settled by up to 40 cm or more as of January 2017.
- Pavement distress is located between the pullout from the westbound lane to BCHydro Pole 58/3 (east of site) and the cast in place (CIP) retaining wall 3429R (south of site). The pullout is constructed as a full bench rock cut, and the eastbound side of wall 3429R abuts into full bench rock cut construction.
- Based on the geometry of the existing cut and the outcrops on each side of the site, it is expected that the site is constructed as a partial bench, with the edge of the blasted rock surface corresponding to the location of the observed distress, near the middle of the westbound lane.
- The fill slope corresponding to the distressed area consists of end dumped blast rock fill, and extends approximately 20 m vertically below the site location.
- A single row lock-block structure occupies the distress zone and is assumed to be a prior effort to stabilize.
- No constructed ditches are present at the site. No evidence of surficial erosion was noted at the site or on the fill slope below the site.

Additional pavement distress and deformation has been observed since the 2017 memo. It is understood that the Maintenance Contractor has been patching the area as required. A photo showing the pavement distress from March 2017 is shown in Figure 2.

Figure 2: March 2017 Pavement Destress, Looking East

2.3 Geotechnical Site Investigation

The investigation program was completed on March 28 and 29, 2017 and consisted of ten (10) sonic testholes including Standard Penetration Tests (SPT). Sonic drilling was carried out by Drillwell Enterprises Ltd. (Drillwell) and logged by British Columbia Ministry of Transportation and Infrastructure (MoTI) Geotechnical Engineer, Ryan Gustafson. Drilling was completed using the method outlined by ASTM D6914 for Sonic Drilling. The testholes were drilled in the westbound lane near the observed pavement distress. The results of the investigation are presented on the borehole logs in Appendix A. The locations of the boreholes are shown in the Issued for Tender (IFT) design drawings.

Rock mapping of nearby rock cuts was completed on March 2, 2023. Spot mapping data is included in Appendix B.

3.0 SITE CONDITIONS

3.1 Geology Mapping

British Columbia Ministry of Environment (MOE), Soils of Southern Vancouver Island, Report 17 (1:50,000) maps the surficial geology at the site as Reeses map unit. Reeses soil units have developed in shallow boulder sand and/or sandy rubbly colluvial and/or marine deposits. Reeses soils are well drained and consist of very gravelly sandy loam.

The bedrock geology at the site is mapped on iMapBC as the Middle to Upper Triassic Vancouver Group, which is described as basaltic volcanic rocks of the Karmutsen Formation. These rocks are described as basalt pillowed flows, pillow breccia, hyaloclastite tuff and breccia, massive amygdaloidal flows, minor tuffs, interflow sediment and limestone lenses. Fault mapping (1:20,000) indicates a NW/SE trending fault is present approximately 120 m to the south of the site.

3.2 Soil Conditions

The results of the geotechnical site investigation are generally consistent with the soil conditions anticipated from the published surficial geology mapping and expected road construction methods. The interpreted soil stratigraphy is described below:

Asphalt: Testholes conducted along Highway 4 at the site area encountered approximately 80 mm to 230 mm of asphalt, with larger thicknesses of asphalt encountered near the center of the pavement distress. Additional paving has occurred since the investigation.

Granular Fill (Road Base): The asphalt was underlain by granular fill generally comprising of sand and gravel, trace silt, containing cobbles. The layer thickness ranges from 0.2 m to 2.4 m. Boreholes BH17-01, BH17-02, BH17-05, BH17-06 and BH17-09 encountered at least one layer of nonwoven geotextile within the first 1.7 m of soil. The fill is generally described as wet.

Blast Rock Fill: The granular fill was underlain by a blast rock fill unit comprising of cobble to boulder sized particles with varying portions of sand, gravel, and silt. The blast rock fill unit was encountered in all boreholes except for BH17-01 and BH17-03 and BH17-10. The blast rock fill layer ranges in thickness from 0.2 m to 2.6 m, with thicknesses generally decreasing in the upslope direction. Blast rock fill was not observed in BH22-04, however, is assumed to occur from 2.4 m to 5.2 m where there was no recovery. The blast rock fill unit is generally described as moist to wet.

Organic Silt: A 0.61 m thick layer of organic silt was observed in BH17-04 underlying absent drill recovery. This layer was not observed at any other location.

Till-Like: A dense till-like unit was encountered in BH17-03, BH17-04 and BH17-05 with thicknesses ranging from 0.2 m to 1.5 m before encountering bedrock.

3.3 Bedrock Conditions

Depth to bedrock encountered in the sonic holes varied from about 0.5 m to 7.3 m. Generally, bedrock is interpreted to be near surface at the centerline of the roadway with the rock surface dipping steeply in the downslope direction.

The bedrock materials encountered in the sonic holes are observed to be grey to green basalt with pyrite inclusions, occasional calcite infill and occasional quartz veinlets up to 1 mm. No bedrock coring or laboratory strength testing to characterize the bedrock was conducted.

Bedrock is exposed at the site on the slope above the highway in several large rock cuts. The following rock strength descriptions are based on qualitative visual assessments in addition to rock hammer strength tests completed on nearby outcrops. The basalt is described to have a Geological Strength Index (GSI) between 50 to 70.

3.4 Sulfate Testing

One chemical sample was collected from Larry Lake at the Larry Lake pullout just north of site on May 11, 2023. The sample was submitted to CARO Analytical Services in Burnaby, BC, for sulfate testing. The results show that the water sulfate level is <1.0 mg/L, as shown in in Appendix C.

3.5 Groundwater

The soils at the site are anticipated to be well drained. It is anticipated that seasonal fluctuations, weather events, seasonal runoff, and water level changes in Larry Lake will have an influence on groundwater levels at the site location.

The Maintenance Contractor has reported seepage from pavement cracks in the east bound lane during wet periods.

LiDAR data and orthophotos for the site were provided by the Ministry's Geomatics Group. A review of the LiDAR data suggests that Highway 4 groundwater may be influenced by Larry Lake as shown in Figure 3.

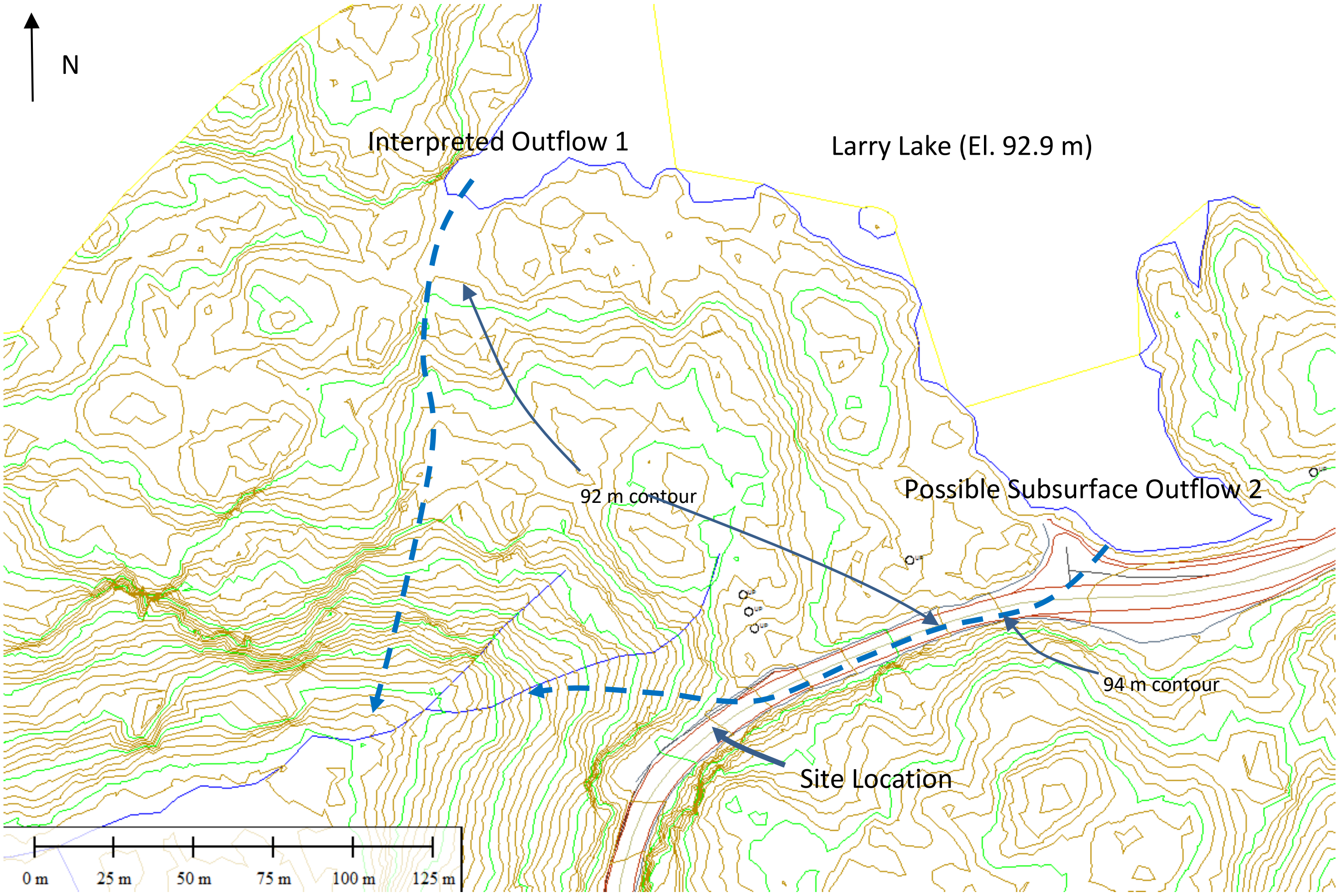

Figure 3: Overview Site Topography and Interpretation (not to scale, 2 m contour interval)

4.0 GEOTECHNICAL DESIGN CRITERIA

The geotechnical design was completed in accordance with BC MoTI Geotechnical Design Criteria Technical Circular (T-04/17), the Canadian Highway Bridge Design Code (S6-19), the BC MoTI Supplement to CHBDC S6-19 (Ministry Supplement) and the Resilient Infrastructure Engineering Design – Adaptation to the Impacts of Climate Change and Weather Extremes (T-04/19). American Association of State Highway and Transportation Officials (AASHTO) Bridge Design Specifications (Ninth Edition) was also considered for wall design where guidance was not available in CHBDC S6-19.

In accordance with S6-19 and the Ministry Supplement, the site is defined as a Major-route with Typical Consequence. The design is based on:

- Typical Degree of Understanding
- Seismic Performance Category (SPC) 3
- Seismic performance criteria per 6.14.2.3 of the MoTI Supplement

The seismic hazard was determined using the 2020 National Building Code of Canada Seismic Hazard Tool. Site Class C soil was assigned, corresponding to Firm Ground. The Peak Ground Acceleration for the 1:475 year design earthquake event is 0.261g according to the National Building Code of Canada's Seismic Hazard Calculator for the site area.

5.0 GEOTECHNICAL ANALYSIS

5.1 Design Objectives

In addition to stabilizing the highway in accordance with the geotechnical design criteria noted above, the slope stabilization system using micropiles and tieback anchors has the following objectives:

- No modification to the upslope rock slope as it is performing adequately.
- The stabilization system must be constructable while maintaining single lane alternating traffic. There is no detour at this site along Highway 4.
- The proposed structure must provide adequate subsurface drainage. Groundwater seepage is expected, as previously discussed.

The design of the slope stabilization system using micropiles and tieback anchors was carried out in conjunction with McElhanney structural team Chad Amiel, P.Eng and Destin Saba, EIT. The IFT drawings provide the general arrangement, pile layout, and pile details.

5.2 Proposed Slope Stabilization Considerations

The slope stabilization system using micropiles and tieback anchors was selected as an appropriate mitigation strategy considering the steep downslope geometry, limited construction space, and geologic site conditions. Additional design and construction considerations include:

- It is expected that access to the site will only be feasible from the road alignment. Due to the steep bedrock-controlled topography, access from the toe of the slope does not appear feasible;
- Due to the steep topography, no suitable toe location was identified where a retaining wall structure could be founded and keyed into competent materials without use of anchors or dowels. It is expected that the toe of any structure will require anchorage to the bedrock surface;
- The site is located in a localized depression in the bedrock outcrop. This depression could be associated with a locally faulted/highly jointed area. This implies there is the potential for poor rock quality at the site location;
- Use of anchors/dowels is likely required as a component of any repair at the site; and
- The fill materials are non-engineered and expected to predominately consist of cobble and boulder sized rock particles.

5.3 Geotechnical Design Assumptions

Simplifying assumptions considered for geotechnical design include:

- Depth to bedrock is inferred and extrapolated based on conditions encountered in the site investigation.
- The structure acts as a continuous wall with uniform flat soils behind the slope stabilization structure.
- The earth load is generated from a theoretical soil failure wedge behind the slope stabilization structure.
- Active pressures were considered above the “effective height” for each design case (Figure 4). Below this point, active and passive pressures are assumed to be in equilibrium.
- No reduction to the PGA was considered due to the rigid nature of the stabilization structure for the seismic case.
- The post seismic design case assumes temporary loading conditions with reinstatement of slopes below the stabilization system within two years.

5.4 Analysis Approach Summary

The design was completed in accordance with the design criteria outlined in Section 4. Generally, the design of the structure involved input and analysis iterations between structural engineering and geotechnical engineering.

The analysis considers three design cases:

1. Static Conditions
2. Seismic Event – Seismic Conditions
3. Post-Seismic Event – Static Conditions

A back-analysis was completed using limit equilibrium method (LEM) to estimate the “effective wall height” in the static case and to confirm appropriate engineering parameters. The “effective wall height” is the height from the top of grade beam to the soil surface. A 6 m wall height was adopted for the “effective wall height” when the downslope soils fail or deform in the seismic event and is carried forward for the post seismic design case. The “effective height” considers the results of the static back-analysis and short critical “wall” width which was inferred from the depth to bedrock encountered in the site investigation.

Based on the location of the bedrock horizon at site which supports one lane, the seismic performance criteria defined in MoTI Supplement 6.14.2.3 (b) are met without the proposed stabilization measures.

Ultimate limit state (ULS) load combination cases were considered for the static and seismic cases and are presented in Table 2. Static earth pressures were determined based on Rankine's Lateral Earth Pressure Theory. The seismic load was determined using Generalized Limit Equilibrium (GLE) method corresponding to a factor of safety of 1.3 (6.14.4.2 of the MoTI Supplement to S6-19 Commentary). The critical seismic load was determined through a sensitivity analysis of the load application height and the resultant applied load angle. The seismic design criteria constrained the design.

Minimum micropile embedment into bedrock was determined through lateral analysis using RSPile. Micropile and tie-back anchor details including spacing, sizing, bond lengths and free stressing lengths were determined in iteration with structural engineering. Further analysis details are included in the following sub-sections.

The geotechnical design was completed in accordance with applicable Code requirements as mentioned in section 4.0. Reference to specific code clauses utilized in the design are included in the following sections.

5.5 Design Cases

A summary of the three design load cases considered in the geotechnical analysis for the structure is shown in Table 1 and illustrated in Figure 4.

Table 1: Design Cases Summary Table

Design Load Case Number	Design Load Case	Analysis Condition	Design Seismic Event	PGA (g)	"Effective Wall Height" (m)	Target FOS	Reference (MoTI S6-19 Supplement)
1	Static Event	Static	-	-	4.0	1.54	6.9.1 (Permanent/Typical/Typical)
2	Seismic Event	Seismic	1:475	0.261	6.0	1.3[1] For FBM	6.14.4.2 6.14.2.1 6.14.2.3
3	Post-Seismic Event	Static	-	-	6.0	1.33	6.9.1 (Temporary/Typical/Typical)

Note: 1. Permanent displacements induced by shear strains along the global slip surfaces are expected to be negligible with a FOS of 1.3 per 6.14.4.2 of the MoTI Supplement to S6-19.

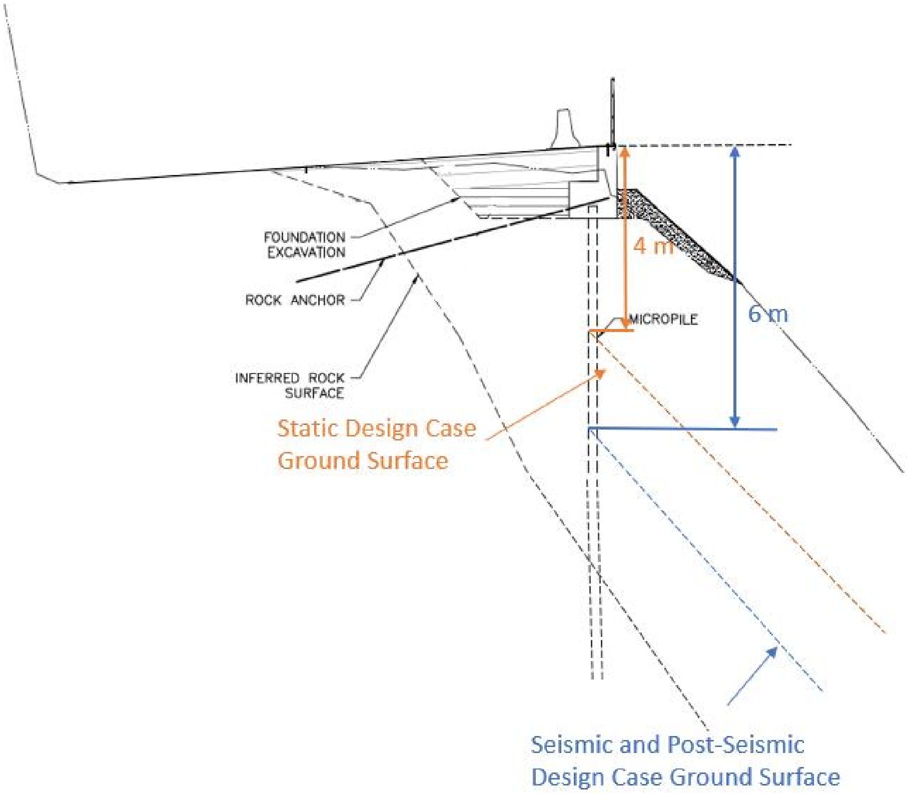

Figure 4: Design Cases – "Effective Wall Height" Schematic (not to scale)

5.6 Engineering Parameters

A back analysis was completed using Geostudio SLOPE/W for the distress observed at site. One soil unit was modelled due to the similar nature of the native colluvial soils and the blast rock fill materials, and the uncertainty of the depth of transition between those two materials. Blast rock fill underlain by bedrock was considered an appropriate depiction of site conditions at the location of the observed distress due to our understanding of site conditions. The back analysis was completed to inform the engineering properties of the fill materials. Results of the back analysis are shown in Appendix D.

Engineering properties including a unit weight of 20 kN/m^3, friction angle of 38 degrees and no cohesion were assigned to the Road Fill. Due to the expected variability of the fill, these parameters are judged reasonable. The organic silt and till-like material were not found in any of the critical design sections; therefore, no engineering properties were assigned to these units. The bedrock was assigned a GSI of 50 with a UCS of 100 MPa.

5.7 Load Results for Design

The loading conditions for the Ultimate Limit State (ULS) were calculated for each design case by McElhanney structural engineering with MoTI geotechnical engineering input. A summary of the loading results is shown in Table 2. It was determined in iteration with structural, that the seismic design criteria constrained the design.

Table 2: Load Summary Results

Design Load Case Number	Design Load Case	"Effective Wall Height" (m)	ULS Combination	Applicable Loads	Load Factor	Load Calculation Method	Unfactored Load (kN/m)	Load Orientation and Location[4]
1	Static Event	4.0	1	Earth Load (EL)	1.25	AASHTO 3.11.5.7.1	51	Lateral load applied at 1.9 m depth
				Live Load (LL)	1.7	S6-19 6.12.5	19	Lateral load applied at 2.4 m
				Dead Load[1] (DL)	1.2	-	36[2]	Axial load applied at surface
2	Seismic Event	6.0	5	Earth Load (EL)	1.25	AASHTO 3.11.5.7.1	115[3]	Lateral load applied at 2.5 m depth
				Dead Load[1] (DL)	1.25	-	36[2]	Axial load applied at surface
				Earthquake Load (EQ)	1.0	AASHTO A11.3-3, NCHRP Report 611, section 7.4	255	25 degrees applied at 3.0 m depth
3	Post-Seismic Event (Static)	6.0	1	Earth Load (EL)	1.25	AASHTO 3.11.5.7.1	115[3]	Lateral load applied at 2.5 m depth
				Live Load (LL)	1.7	S6-19 6.12.5	26	Lateral load applied at 3.4 m depth
				Dead Load[1] (DL)	1.2	-	36[2]	Axial load applied at surface

Note:
1. Provided by McElhaney structural engineering.
2. Load is in the downwards direction.
3. Earth pressures were calculated considering a tie-back depth of 1.1 m.
4. Location of load is reported from ground surface.

6.0 GEOTECHNICAL DESIGN RECOMMENDATIONS

6.1 Micropiles

6.1.1 Design Loads and Layout

The design includes 177.8 mm diameter API-N80 Casing steel pipe micropiles, with an 18.5 mm wall thickness. The analysis and design are based on plumb micropiles with an even center-to-center spacing of 0.4 m. Each micropile can be divided into three segments: cased in overburden, cased in rock, and uncased rock socket. The length of each micropile depends on the location of the bedrock surface. The micropile lengths vary with the bedrock profile.

6.1.2 Axial Analysis

Compressive axial loads result from the combination of dead load and the downward component of the seismic load. No uplift loads are expected.

Minimum rock socket bond zones were calculated considering a Low Degree of Understanding of the bedrock conditions at the sockets, requiring a resistance factor of 0.35 as per S6-19, Table 6.2. The minimum rock socket bond length was calculated based on an assumed 141 mm drillhole diameter and an assumed factored bond stress of 700 kPa based on the anticipated rock type, basalt. The result indicated a minimum bond length of 0.3 m. End bearing was not relied upon for the axial analysis.

6.1.3 Lateral Analysis

The lateral pile analysis was completed in Rocscience's RSPile for the critical seismic scenario (Design Load Case 2). A 12 m long, 178 mm diameter steel pipe micropile, with an 18.5 mm wall thickness was analyzed. No soil resistance was considered for the "effective wall height" of 6 m in accordance with the simplifying assumption previously outlined. Native soils were modeled from a depth of 6 m to 9 m, followed by 3 m of bedrock embedment. The vertical datum was adjusted for the lateral pile analysis. A depth of 0 m in the lateral analysis represents the location of the tieback force, which is equivalent to 1.1 m below ground surface.

Profiles of lateral demand in the micropile (shear and moment) were output and provided to the McElhanney structural engineer and are provided in Appendix E. The results include shear and moment diagrams with and without the tie-back force, applied as a point force. The results indicate lateral resistance is achieved approximately 1.6 m into the intact rock.

6.1.4 Micropile Installation

A buffer zone was also considered to accommodate uncertainties with weathered bedrock, geomechanical discontinuities and pile group effect. Therefore, a minimum total embedment depth of 3.0 m into the bedrock including a 1.0 m rock socket bond length is required when considering required bond length, lateral demand, and uncertainties within the bedrock.

Installation methods should be capable of penetrating anticipated ground conditions which include logs, cobbles, boulders, rockfill and bedrock. Preparation for the uncased rock sockets should include removal of loose material and muddy water to provide a clean surface for bonding between the concrete and rock.

Micropiles should be grouted in accordance with the Special Provisions for this project. The required grout for micropile installation shall have a minimum compressive strength of 40 MPa at 28 days, tested in accordance with CSA A23.2.

6.1.5 Soil Arching

Loads on the structure drive the micropile spacing and the resulting spacing is adequate to achieve soil arching in the coarse rock fill and colluvial materials. Micropiles are spaced close enough for soil arching between micropiles to transmit lateral earth pressures to micropiles to limit soil deformation and soil flow between the micropiles. It is anticipated that subsurface particle size will also contribute to effective soil arching. Soil arching effects have been studied by several authors and it is generally accepted that soil arching occurs between two to four times the pile diameter as detailed in State of California Department of Transportation, Assessment of Soil Arching Factor for Retaining Wall Pile Foundations Technical Report (CA 16-2532). Therefore a 177.8 m diameter micropile with spacing of 0.4 m is sufficient. Soil arching is not required to meet seismic performance criteria outlined in 6.14.2.3 of the MoTI Supplement.

6.2 Tie-Back Anchors

6.2.1 Design Loads and Layout

The tie-back anchors are located near the base of the grade beam and head of the micropiles. They provide lateral support and control deformations in the stabilization system. The anchors are 35 mm nominal diameter, threadbar, rock bonded and double corrosion protected (DCP). The expected length between the grade beam and bedrock surface is approximately 3 to 6 m.

Anchors are typically spaced at 1.6 m to match an even multiple of the micropile spacing. The anchor size was selected to satisfy loading requirements based on the desired spacing. The size was selected to accommodate 80% of the rated yield capacity provided by the bar for the seismic case (Design Load Case 2).

6.2.2 Anchor Bond

A Low Degree of Understanding of the bedrock conditions at the anchor bond zones requires a resistance factor of 0.35 for ground anchor pullout, as per S6-19, Table 6.2. The minimum bond length was calculated based on an assumed 150 mm diameter drill hole in rock and an assumed factored bond stress of 700 kPa based on the anticipated rock type. A weathered rock zone was also considered, resulting in a minimum anchor bond length of 2.5 m with a free stressing length of 1 m into the rock surface.

A pullout cone check for a row of overlapping anchors was performed using a FOS of 3.0. The pullout cone calculation assumes the cone initiates 1 m past rock surface, which is ½ of the bond length with a tensile rock strength of 56 kPa. No resistance was applied to the cone calculation, however, a resistance factor of 0.35 was applied to the assumed tensile strength of the rock, resulting in a tensile strength of 19.6 kPa. The breakout angle was assumed to be 60 degrees, informed by the jointing on site. The calculation is conservative and does not consider the overburden confinement and strength above the rock interface.

Anchors should be installed and grouted in accordance with the Standard Specifications for Rock Bolts and the Special Provisions for this project. The required grout for the anchors shall have a minimum compressive strength of 40 MPa at 28 days, tested in accordance with CSA A23.2.

6.2.3 Anchor Testing

Testing of the anchors should be performed based on recommendations in Post-Tensioning Institute's (PTI) Recommendations for Prestressed Rock and Soil Anchors Manual (2004). This should include:

- **Preproduction Test**: One pre-production test to confirm bond design assumptions.
- **Performance Tests:** completed for the first two anchors installed. Thereafter, Performance Tests shall be completed for a minimum of 2% of the remaining anchors.
- **Proof Tests:** completed for all anchors not subject to a Performance Test.

Test tensioning and the interim lock-off are to be completed before backfilling the stabilization structure. The final static lock-off load shall be 80% of the unfactored ULS Combination 1 loading case, 100 kN, as per Article 11.9.8.1 of AASHTO.

Two additional full length tie-back anchors should be installed to allow for future extraction for long-term inspection and testing as per MoTI Supplement 6.2.1.

6.3 Temporary Slopes

A temporary cut slope will be required downslope of the existing highway to facilitate micropile installation and slope stabilization construction. Temporary slope stability is the responsibility of the Contractor and should follow Worksafe BC Regulations and Guidelines.

As previously mentioned in Section 3.5, downslope groundwater seepage has been observed and should be considered for constructability.

We expect that a Safe Work Procedure for wet weather shutdowns will be required for work on or adjacent to the unstable slope until a degree of stabilization is achieved by the proposed works.

6.4 Permanent Cut Slopes

No significant permanent cut slopes are anticipated. A minor transition is required on the west side of the project as shown on the IFT design drawings. For these slopes, we recommend soil cut slope angles of 2H:1V and rock cut slope angles of 0.25H:1V.

The existing rock slopes above the highway will not be modified by the design. The existing rock slopes have performed satisfactorily and are managed through the Ministry's Provincial Rock Work Program. Therefore, the stability of the slopes above the highway will be left as-is and has not been assessed or modified by the design.

6.5 Backfill

Stabilization system backfill should be completed in accordance with MoTI Standard Specification for Highway Construction (Standard Specifications), Sections 201 and 202. Well Graded Base Course (WGB) is the recommended backfill material.

One layer of biaxial geogrid should be installed on the exposed subgrade below the pavement structure with an ultimate tensile strength greater than 19.2 kN/m. Specifications for the biaxial geogrid are specified in the Special Provisions.

6.6 Subdrainage

Subdrainage construction below HDPE pipe crossing, as shown in the IFT design drawings should be completed in accordance with Standard Specifications, Section 317. Subdrain with filter fabric should have a minimum cross-sectional area of 3 m^2. Subdrain construction shall include geotextile with a minimum grab tensile strength and apparent opening size informed by the Standard Specifications. Rock excavation will likely be required for installation.

6.7 Pavement

Pavement design considered MoTI Technical Circular T-01/15, traffic data from the MoTI traffic data website and the structural number method from AASHTO 1993. Pavement Structure Type B from Technical Circular T-01/15 was considered. This project has adopted 100 mm thick asphalt pavement to be consistent with the other areas along the Highway 4 corridor.

The recommended pavement structure is as follows:

- Hot Mix Asphalt (HMA): 100 mm thickness applied in two 50 mm lifts;
- 25 mm Well Graded Base (WGB): 600 mm thickness in soil or 450 mm thickness in rock.

6.8 Climate Change Considerations

Climate change is anticipated to result in an increase in the frequency and intensity of severe precipitation events. It is uncertain how changes in precipitation will be reflected in groundwater levels at site. However, as the retaining structure was designed for the relatively severe seismic hazard, it is anticipated that there is significant capacity for the wall to accommodate intermittent groundwater pressures. Additionally, subdrain construction and spacing between micropiles facilitates drainage of the slope.

7.0 CLOSURE

This report is intended to present the geotechnical design report for the Highway 4 Hydro Hill Project. Please contact the undersigned with any comments or questions.

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EGBC Permit to Practice No. 1003429

Appendix A – Borehole Logs

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

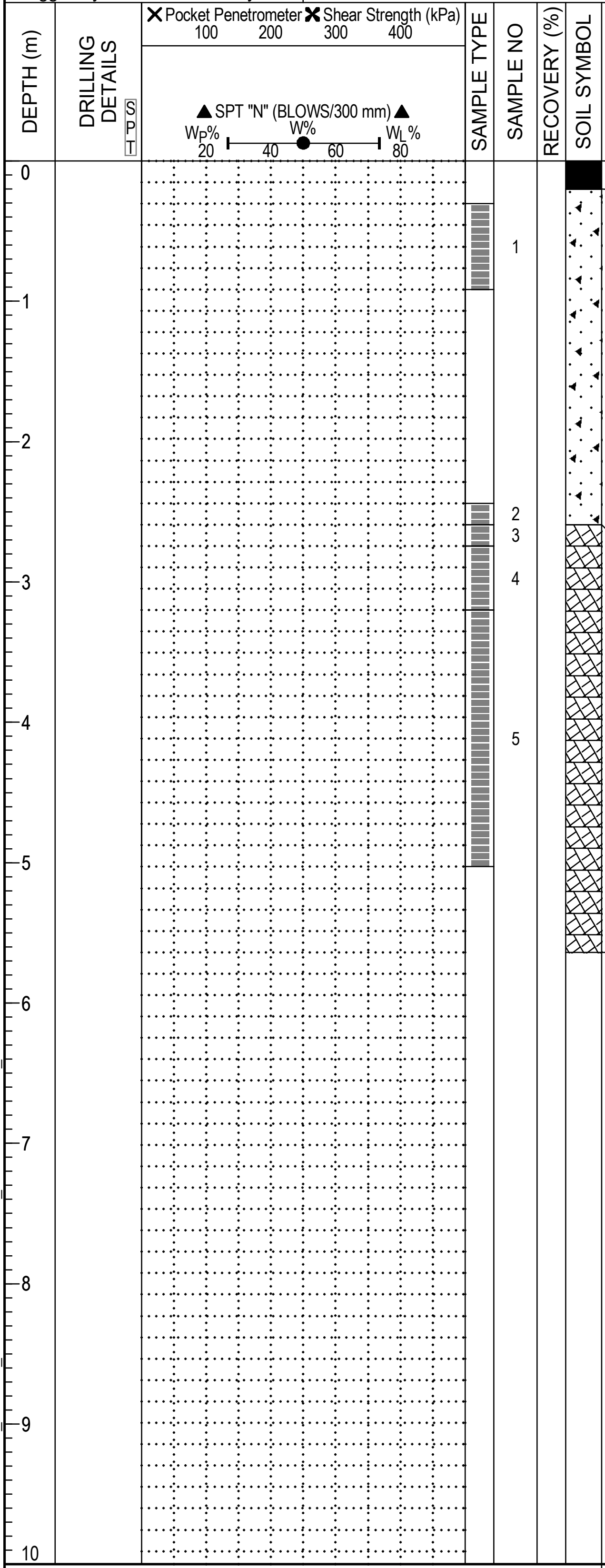
SUMMARY LOG

Drill Hole #: BH17-01

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Northing/Easting: 5443240.066 , 321961.178
Elevation: 81.9 m
Alignment:
Station/Offset:
Coordinates Surveyed

Prepared by: Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Date(s) Drilled: March 28, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic



SAMPLE NO	SOIL DESCRIPTION		CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*
	ASPHALT	0.2m	AP	
1 2	SAND and GRAVEL, trace silt, subrounded to angular, well graded, wet, brown -piece of heavy non-woven fabric at depth -some silt, light brown at 2.4m	2.6m	GW SW	
3 4 5	BEDROCK, soft, no significant shear zone -pyrite inclusions at 5.0m	5.6m	BR	
	End of Hole at 5.6m -Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected. -Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.			

ELEVATION (m): 81, 80, 79, 78, 77, 76, 75, 74, 73, 72

Legend
Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 5.6 m
Depth to Top of Rock:

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

SUMMARY LOG

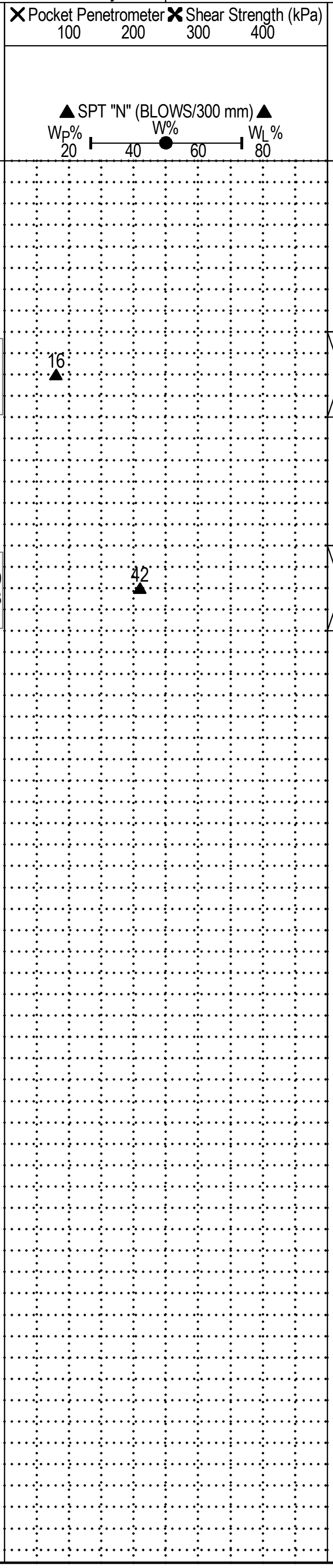
Drill Hole #: BH17-02

Project: **Highway 4 Hydro Hill**
Location:

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Datum: UTM 10
Northing/Easting: 5443236.811 , 321957.274
Elevation: 81.38 m
Alignment:
Station/Offset:
Coordinates Surveyed

Date(s) Drilled: March 28, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic



DEPTH (m)	DRILLING DETAILS SPT	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL DESCRIPTION		CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*	ELEVATION (m)
0		G-Grab			ASPHALT	0.1m	AP		
		G-Grab			GRAVEL, sandy, trace silt, poorly graded, angular to subrounded, fine to coarse gravel, coarse sand, inferred compact, grey, wet -heavy non-woven fabric at 0.3m	0.3m	GW		81
1		G-Grab	1		SAND and GRAVEL, trace to some silt, well graded, subrounded to subangular, inferred compact, moist to wet, occasional asphalt inclusions -heavy non-woven fabric at 1.7m	1.2m	SW GW		
	2 5 11 4	S-Split Spoon	2						80
2		G-Grab	3		COBBLES (blast rock), compact, wet, grey	2.7m	SB		79
3	8 19 23 21	S-Split Spoon	4	33	COBBLES, gravel, some sand, some silt, angular, compact, grey, wet	3.4m	SB		78
4					BEDROCK, basalt, grey, occasonal pyrite cubes	6.4m	BR		77
5									76
6									75
7									74
8									73
9									72
10									

End of Hole at 6.4m
-Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected.
-Reported SPT N values are uncorrected, field values.
-SPT blow counts in coarse grained granular material may not be representative due to grain size effects.
-Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.

Legend
Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 6.4 m
Depth to Top of Rock:

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: **BH17-03**

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Alignment:
Northing/Easting: 5443233.53 , 321953.372
Station/Offset:
Elevation: 80.89 m
Coordinates Surveyed

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Date(s) Drilled: March 28, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

DEPTH (m)	DRILLING DETAILS / SPT	✕ Pocket Penetrometer ✕ Shear Strength (kPa) 100 200 300 400 ▲ SPT "N" (BLOWS/300 mm) ▲ W_P% W% W_L% 20 40 60 80	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL SYMBOL	SOIL DESCRIPTION	CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*	ELEVATION (m)
0							ASPHALT	AP		
0.1m							SAND and GRAVEL, some silt, well graded, (fill)	GW		
0.3m				1			GRAVEL and SAND, silty to some silt, dense to very dense, poorly graded, angular to subangular, fine to coarse gravel, coarse sand, contains cobbles, brown, moist, till-like	GP SP		80
0.8m				2			BEDROCK, basalt, grey -pyrite inclusions at 1.2m	BR		79
4m							End of Hole at 4.0m -Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected. -Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.			77

Depth scale (m): 0, 1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Elevation scale (m): 80, 79, 78, 77, 76, 75, 74, 73, 72, 71

Legend
Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 4.0 m
Depth to Top of Rock:

BRITISH COLUMBIA Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: **BH17-04**

Project: **Highway 4 Hydro Hill**
Location:

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Datum: UTM 10
Northing/Easting: 5443248.439 , 321973.761
Elevation: 83.87 m
Alignment:
Station/Offset:
Coordinates Surveyed

Date(s) Drilled: March 28, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

✕ Pocket Penetrometer ✕ Shear Strength (kPa) 100 200 300 400
▲ SPT "N" (BLOWS/300 mm) ▲
W_P% W% W_L% 20 40 60 80

DEPTH (m)	DRILLING DETAILS / SPT	SPT "N"	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL DESCRIPTION		CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*	ELEVATION (m)
0						ASPHALT	0.1m	AP		83.87
0.1						SAND and GRAVEL, trace silt, well graded, wet, subrounded to subangular, contains cobbles, inferred compact, brown	1.2m	GW SW		
1.2	13 4 5 8	9	G-Grab S-Split Spoon	1 2	 8	SAND and GRAVEL, silty, contains cobbles, loose to compact, poorly graded, moist, brown, (till-like) -wet at 1.5m	2.4m	GP		
2.4						No Recovery	5.2m			
5.2						Organic SILT, brown, wet	6.7m	OL		
6.7						SILT, clayey, sandy, gravelly, trace organics, contains cobbles, inferred soft, wet, poorly graded, fine sand, brown to grey, (till-like)	7.3m	ML		
7.3						BEDROCK	7.6m	BR		

End of Hole at 7.6m
-Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected.
-Reported SPT N values are uncorrected, field values.
-SPT blow counts in coarse grained granular material may not be representative due to grain size effects.
-Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.

Depth scale (m): 0 1 2 3 4 5 6 7 8 9 10
Elevation scale (m): 83 82 81 80 79 78 77 76 75 74

Legend Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 7.6 m
Depth to Top of Rock:

BRITISH COLUMBIA Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: **BH17-05**

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Northing/Easting: 5443245.634 , 321969.573
Elevation: 83.21 m
Alignment:
Station/Offset:
Coordinates Surveyed

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

✕ Pocket Penetrometer ✕ Shear Strength (kPa) 100 200 300 400
▲ SPT "N" (BLOWS/300 mm) ▲
W_P% W% W_L% 20 40 60 80

DEPTH (m)	SPT	SPT "N"	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL DESCRIPTION	Depth	CLASSIFICATION	COMMENTS TESTING Drillers Estimate {G % S % F %}	ELEVATION (m)
0						ASPHALT	0.1m	AP		83
						SAND and GRAVEL, trace silt, well graded, angular to sub rounded, brown, inferred compact, wet -non woven fabric at 0.9m	0.9m	GW		
1			G	1		COBBLES and GRAVEL, sandy, silty, angular, well graded, inferred compact, brown matrix, dark grey, basalt with occasional pyrite clasts, wet	1.2m	CB		82
	4 9 7 4	16	S	2	24	No Recovery	1.8m			
2			G	3		COBBLES and GRAVEL, sandy, silty, trace organics, angular, well graded,inferred compact, brown matrix, dark grey, basalt with occasional pyrite, cobble sized particles, moist	2.7m	SB		81
			S	5		SAND and GRAVEL, some silt to silty, angular, well graded, clasts of grey basalt, inferred dense, brown, moist to wet, (till-like)	2.9m	GW		
3	0	R	G S	4 6						80
4						BEDROCK, basalt		BR		79
5			G	7		-pyrite inclusions, oxidized surface on joints at 5.3m	5.8m			78
6						End of Hole at 5.8m -Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected. -Reported SPT N values are uncorrected, field values. -SPT blow counts in coarse grained granular material may not be representative due to grain size effects. -Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.				77
7										76
8										75
9										74
10										

Legend Sample Type:
- A-Auger
- B-Becker
- C-Core
- G-Grab
- V-Vane
- L#-Lab Sample
- S-Split Spoon
- O-Odex (air rotary)
- W-Wash (mud return)
- T-Shelby Tube

Final Depth of Hole: 5.8 m
Depth to Top of Rock:

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: **BH17-06**

Project: **Highway 4 Hydro Hill**
Location:

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Datum: UTM 10
Northing/Easting: 5443243.124 , 321965.484
Elevation: 82.63 m
Alignment:
Station/Offset:
Coordinates Surveyed

DEPTH (m)	DRILLING DETAILS / SPT	Pocket Penetrometer / Shear Strength (kPa); SPT "N" (BLOWS/300 mm); Wp% W% WL%	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL DESCRIPTION	CLASSIFICATION	COMMENTS TESTING Drillers Estimate {G % S % F %}	ELEVATION (m)
0 – 0.1m						ASPHALT	AP		
0.1 – 0.6m						SAND and GRAVEL, trace silt, well graded, wet, compact, subangular to angular, brown -non woven fabric at 0.6m	GW		82
0.6 – 1.2m	24 50	R ▲	S-Split Spoon	2		COBBLES (blast rock), gravel, sand, some silt to silty, angular, dense, brown, moist to wet	SB		
1.2 – 4.6m			C-Core	3		BEDROCK, grey, basalt with occasional quartz vienlets to 1mm	BR		81 80 79 78

End of Hole at 4.6m
-Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected.
-Reported SPT N values are uncorrected, field values.
-SPT blow counts in coarse grained granular material may not be representative due to grain size effects.
-Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.

Legend
Sample Type:
- A-Auger
- B-Becker
- C-Core
- G-Grab
- V-Vane
- L#-Lab Sample
- S-Split Spoon
- O-Odex (air rotary)
- W-Wash (mud return)
- T-Shelby Tube

Final Depth of Hole: 4.6 m
Depth to Top of Rock:

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: **BH17-07**

Prepared by: Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Northing/Easting: 5443236.926 , 321960.46
Elevation: 81.69 m
Alignment:
Station/Offset:
Coordinates Surveyed

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

✕ Pocket Penetrometer ✕ Shear Strength (kPa): 100 200 300 400
▲ SPT "N" (BLOWS/300 mm) ▲: 20 40 60 80
W_P% —●— W% — W_L%

DEPTH (m)	SAMPLE TYPE	SAMPLE NO	SOIL DESCRIPTION	CLASSIFICATION
0 – 0.1m			ASPHALT	AP
0.1m – 0.3m			SAND and GRAVEL, well graded, subangular, brown, moist (fill)	GW
0.3m – 0.5m	▤	1	SAND and GRAVEL, silty, well graded, trace wood, inferred compact, moist, angular to sub rounded, brown	GW
0.5m – 1.1m			COBBLES (blast rock), sandy, gravelly, some silt, well graded, angular, grey to brown, moist	SB
1.1m – 2.7m			BEDROCK, basalt, grey to green, pyrite inclusions, occasional calcite infill to 1mm -fractured zone, weathered zone, or boulder from 1.7m to 2.0m	BR

End of Hole at 2.7m
-Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected.
-Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.

COMMENTS TESTING
Drillers Estimate {G % S % F %}

DEPTH (m): 0, 1, 2, 3, 4, 5, 6, 7, 7.5
ELEVATION (m): 81, 80, 79, 78, 77, 76, 75

Legend Sample Type:
- A-Auger
- B-Becker
- C-Core
- G-Grab
- V-Vane
- L#-Lab Sample
- S-Split Spoon
- O-Odex (air rotary)
- W-Wash (mud return)
- T-Shelby Tube

Final Depth of Hole: 2.7 m
Depth to Top of Rock:

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

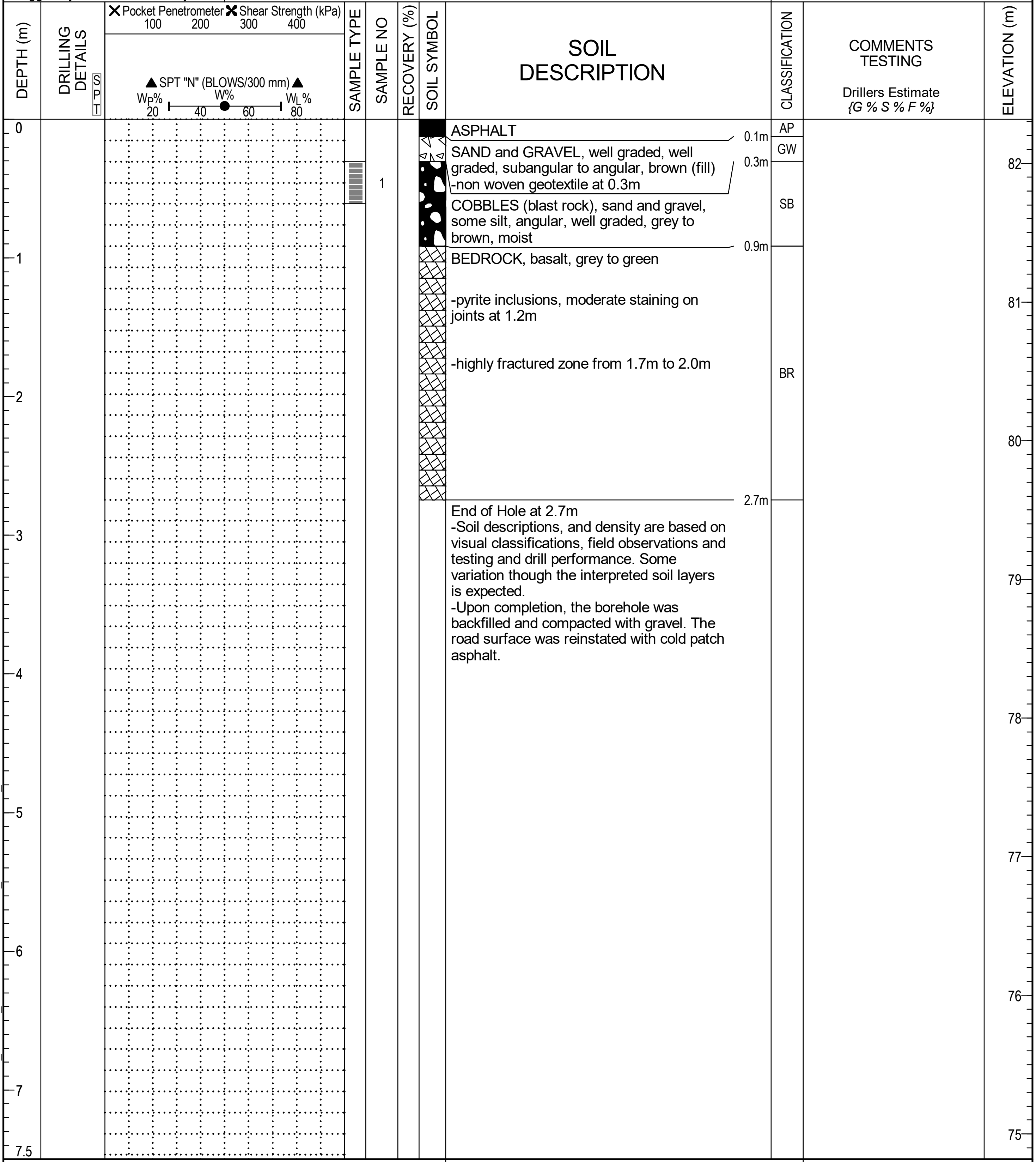
SUMMARY LOG

Drill Hole #: **BH17-08**

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Northing/Easting: 5443239.871 , 321964.775
Elevation: 82.32 m
Alignment:
Station/Offset:
Coordinates Surveyed

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic



DEPTH (m)	SAMPLE NO	SOIL DESCRIPTION	CLASSIFICATION
0.1m		ASPHALT	AP
0.3m		SAND and GRAVEL, well graded, well graded, subangular to angular, brown (fill) -non woven geotextile at 0.3m	GW
0.9m	1	COBBLES (blast rock), sand and gravel, some silt, angular, well graded, grey to brown, moist	SB
2.7m		BEDROCK, basalt, grey to green -pyrite inclusions, moderate staining on joints at 1.2m -highly fractured zone from 1.7m to 2.0m	BR

End of Hole at 2.7m
-Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected.
-Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.

Legend
Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 2.7 m
Depth to Top of Rock:

BRITISH COLUMBIA | Ministry of Transportation and Infrastructure

SUMMARY LOG

Drill Hole #: BH17-09

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Alignment:
Northing/Easting: 5443233.703 , 321956.613
Station/Offset:
Elevation: 81.08 m
Coordinates Surveyed

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB

✕ Pocket Penetrometer ✖ Shear Strength (kPa) 100 200 300 400

▲ SPT "N" (BLOWS/300 mm) ▲

W_P% W% W_L% 20 40 60 80

DEPTH (m)	DRILLING DETAILS	SPT	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL DESCRIPTION		CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*	ELEVATION (m)
0						ASPHALT	0.1m	AP		81
						SAND and GRAVEL, well graded, subangular to angular, brown, (fill) -non woven geotextile at 0.3m	0.3m	GW		
						COBBLES (blast rock), sandy, gravelly, some silt, angular, well graded, grey to brown, moist	0.5m	SB		
1						BEDROCK, basalt, grey to green, pyrite inclusions, occasional calcite infill in joints	1.4m	BR		80
						End of Hole at 1.4m -Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected. -Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.				
2										79
3										78
4										77
5										

Legend Sample Type:
- A-Auger
- B-Becker
- C-Core
- G-Grab
- V-Vane
- L#-Lab Sample
- S-Split Spoon
- O-Odex (air rotary)
- W-Wash (mud return)
- T-Shelby Tube

Final Depth of Hole: 1.4 m
Depth to Top of Rock:

BRITISH COLUMBIA
Ministry of Transportation and Infrastructure

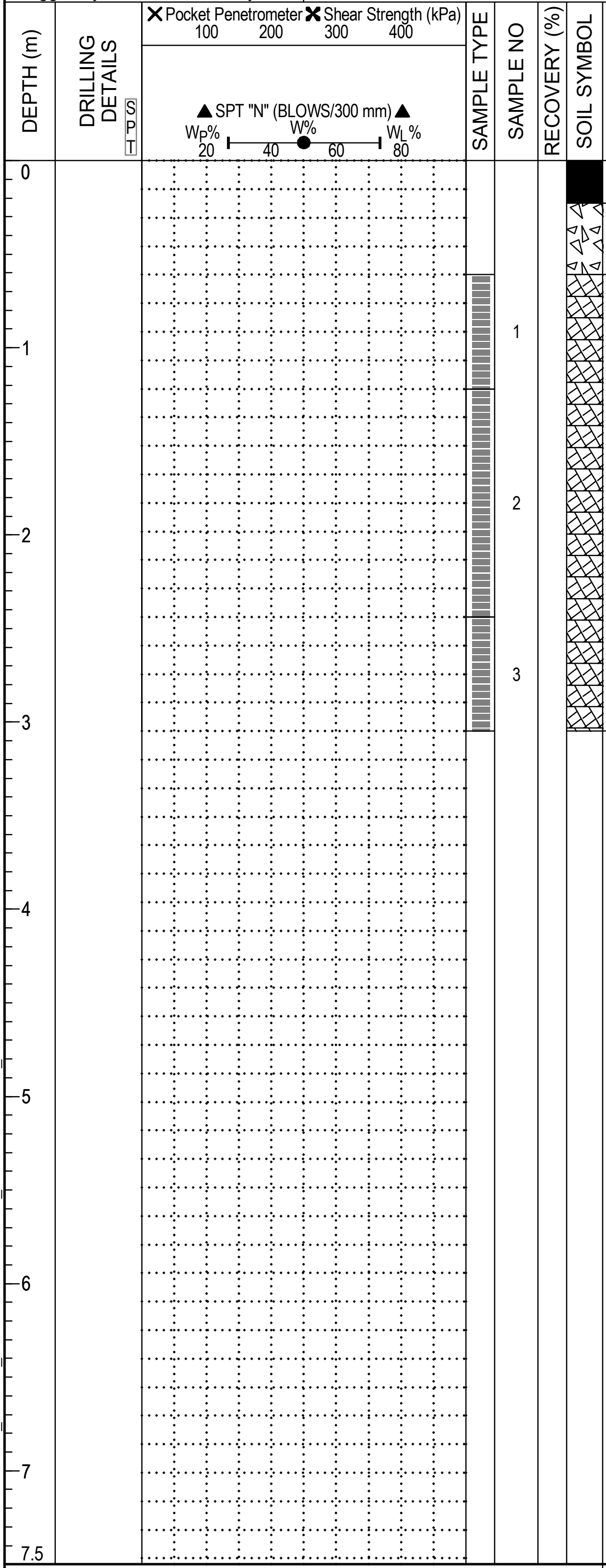
SUMMARY LOG

Drill Hole #: BH17-10

Project: **Highway 4 Hydro Hill**
Location:
Datum: UTM 10
Northing/Easting: 5443242.374 , 321968.54
Elevation: 82.87 m
Alignment:
Station/Offset:
Coordinates Surveyed

Date(s) Drilled: March 29, 2017
Company: Drillwell
Driller:
Drill Make/Model:
Drilling Method: Sonic

Prepared by:
Ministry of Transportation & Infrastructure
Logged by: RG Reviewed by: KB



SOIL DESCRIPTION		CLASSIFICATION	COMMENTS TESTING Drillers Estimate *{G % S % F %}*	ELEVATION (m)
ASPHALT	0.2m	AP		
SAND and GRAVEL, well graded, subangular to angular, well graded, brown	0.6m	GW		82
BEDROCK Fractured zone from 2.4m to 2.7m BEDROCK -highly oxidized from 2.7m to 3.0m	3m	BR		81 80
End of Hole at 3.1m -Soil descriptions, and density are based on visual classifications, field observations and testing and drill performance. Some variation though the interpreted soil layers is expected. -Upon completion, the borehole was backfilled and compacted with gravel. The road surface was reinstated with cold patch asphalt.				79 78 77 76

Legend
Sample Type:
A-Auger
B-Becker
C-Core
G-Grab
V-Vane
L#-Lab Sample
S-Split Spoon
O-Odex (air rotary)
W-Wash (mud return)
T-Shelby Tube

Final Depth of Hole: 3.0 m
Depth to Top of Rock:
Page 1 of 1

Appendix B – Surface Rock Spot Mapping Data

Measurement Number	Dip (°)	Dip Direction (°)	Measurement Number	Dip (°)	Dip Direction (°)	Measurement Number	Dip (°)	Dip Direction (°)
1	42	305	28	86	103	55	36	303
2	83	69	29	81	89	56	32	274
3	81	65	30	86	298	57	32	279
4	61	7	31	50	234	58	46	8
5	84	105	32	87	132	59	38	7
6	75	313	33	2	34	60	81	58
7	79	114	34	87	84	61	59	85
8	70	118	35	62	9	62	46	29
9	57	324	36	85	121	63	78	61
10	49	125	37	80	222	64	76	124
11	41	20	38	79	96	65	83	64
12	73	85	39	32	8	66	73	59
13	55	221	40	80	85	67	74	65
14	57	71	41	87	306	68	40	38
15	72	327	42	84	88	69	30	227
16	44	220	43	85	108	70	86	52
17	43	223	44	80	87	71	87	302
18	17	222	45	82	90	72	71	53
19	40	36	46	76	88	73	85	301
20	23	63	47	48	284	74	82	30
21	80	275	48	66	39	75	51	24
22	85	279	49	88	188	76	83	239
23	82	289	50	61	48	77	62	27
24	53	28	51	28	335	78	82	107
25	35	17	52	80	180	79	33	78
26	85	88	53	54	122	80	87	107
27	45	327	54	64	117	81	40	322

Measurement Number	Dip (°)	Dip Direction (°)	Measurement Number	Dip (°)	Dip Direction (°)	Measurement Number	Dip (°)	Dip Direction (°)
82	75	88	101	17	279	120	41	265
83	73	299	102	35	252	121	27	151
84	79	57	103	62	308	122	68	227
85	62	47	104	73	242	123	87	108
86	60	37	105	40	236	124	34	247
87	71	64	106	31	338	125	90	286
88	44	261	107	90	62	126	90	104
89	79	49	108	84	289	127	71	81
90	80	107	109	89	241	128	33	11
91	66	225	110	87	297	129	40	336
92	74	25	111	89	66	130	71	136
93	83	54	112	83	239	131	79	251
94	71	301	113	87	289	132	45	271
95	37	273	114	82	244	133	42	310
96	52	320	115	17	32	134	37	303
97	78	233	116	80	236	135	86	204
98	90	309	117	87	281	136	79	266
99	56	71	118	86	289	137	62	228
100	78	232	119	51	23	138	53	21

Notes:

1) Reported dip direction considers a declination of positive (east) 16.8 degrees.
2) Discontinuity data is not statistically representative of rock mass. This data was collected through spot mapping.

Appendix C – Water Sulfate Testing

CERTIFICATE OF ANALYSIS

REPORTED TO

Ministry of Transportation &Infrastructure-Nanaimo
#301 - 2100 Labieux Road
Nanaimo, BC V9T 6E9

ATTENTION	Katrina Berrube	**WORK ORDER**	23E1567
PO NUMBER		**RECEIVED / TEMP**	2023-05-11 15:35 / 27.4°C
PROJECT	Hwy 4 - Hydro Hill	**REPORTED**	2023-05-16 11:17
PROJECT INFO			

Introduction:

CARO Analytical Services is a testing laboratory full of smart, engaged scientists driven to make the world a safer and healthier place. Through our clients' projects we become an essential element for a better world. We employ methods conducted in accordance with recognized professional standards using accepted testing methodologies and quality control efforts. CARO is accredited by the Canadian Association for Laboratories Accreditation (CALA) to ISO/IEC 17025:2017 for specific tests listed in the scope of accreditation approved by CALA.

Big Picture Sidekicks

You know that the sample you collected after snowshoeing to site, digging 5 meters, and racing to get it on a plane so you can submit it to the lab for time sensitive results needed to make important and expensive decisions (whew) is VERY important. We know that too.

We've Got Chemistry

It's simple. We figure the more you enjoy working with our fun and engaged team members; the more likely you are to give us continued opportunities to support you.

Ahead of the Curve

Through research, regulation knowledge, and instrumentation, we are your analytical centre for the technical knowledge you need, BEFORE you need it, so you can stay up to date and in the know.

By engaging our services, you are agreeing to CARO Analytical Service's Standard Terms and Conditions outlined here:
https://www.caro.ca/terms-conditions

If you have any questions or concerns, please contact me at bwhitehead@caro.ca

Authorized By:

Brent Whitehead
Account Manager

TEST RESULTS

REPORTED TO Ministry of Transportation &Infrastructure-Nanaimo
PROJECT Hwy 4 - Hydro Hill
WORK ORDER 23E1567
REPORTED 2023-05-16 11:17

Analyte	Result	RL	Units	Analyzed	Qualifier
WT23-01-HH (23E1567-01) | Matrix: Water | Sampled: 2023-05-05 19:00					
Anions					
Sulfate	< 1.0	1.0	mg/L	2023-05-14	

APPENDIX 1: SUPPORTING INFORMATION

REPORTED TO	Ministry of Transportation &Infrastructure-Nanaimo	**WORK ORDER**	23E1567
PROJECT	Hwy 4 - Hydro Hill	**REPORTED**	2023-05-16 11:17

Analysis Description	Method Ref.	Technique	Accredited	Location
Anions in Water	SM 4110 B (2020)	Ion Chromatography	✓	Kelowna

Glossary of Terms:

RL	Reporting Limit (default)
<	Less than the specified Reporting Limit (RL) - the actual RL may be higher than the default RL due to various factors
mg/L	Milligrams per litre
SM	Standard Methods for the Examination of Water and Wastewater, American Public Health Association

General Comments:

The results in this report apply to the received samples analyzed in accordance with the Chain of Custody document. This analytical report must be reproduced in its entirety. CARO is not responsible for any loss or damage resulting directly or indirectly from error or omission in the conduct of testing. Liability is limited to the cost of analysis. Caro will dispose of all samples within 30 days of sample receipt, unless otherwise agreed.

Results in **Bold** indicate values that are above CARO's method reporting limits. Any results that are above regulatory limits are highlighted **red**. Please note that results will only be highlighted red if the regulatory limits are included on the CARO report. Any Bold and/or highlighted results do not take into account method uncertainty. If you would like method uncertainty or regulatory limits to be included on your report, please contact your Account Manager:bwhitehead@caro.ca

Please note any regulatory guidelines applied to this report are added as a convenience to the client, at their request, to help provide some initial context to analytical results obtained. Although CARO makes every effort to ensure accuracy of the associated regulatory guideline(s) applied, the guidelines applied cannot be assumed to be correct due to a variety of factors and as such CARO Analytical Services assumes no liability or responsibility for the use of those guidelines to make any decisions. The original source of the regulation should be verified and a review of the guideline(s) should be validated as correct in order to make any decisions arising from the comparison of the analytical data obtained to the relevant regulatory guideline for one's particular circumstances. Further, CARO Analytical Services assumes no liability or responsibility for any loss attributed from the use of these guidelines in any way.

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO Ministry of Transportation &Infrastructure-Nanaimo
PROJECT Hwy 4 - Hydro Hill
WORK ORDER 23E1567
REPORTED 2023-05-16 11:17

The following section displays the quality control (QC) data that is associated with your sample data. Groups of samples are prepared in “batches” and analyzed in conjunction with QC samples that ensure your data is of the highest quality. Common QC types include:

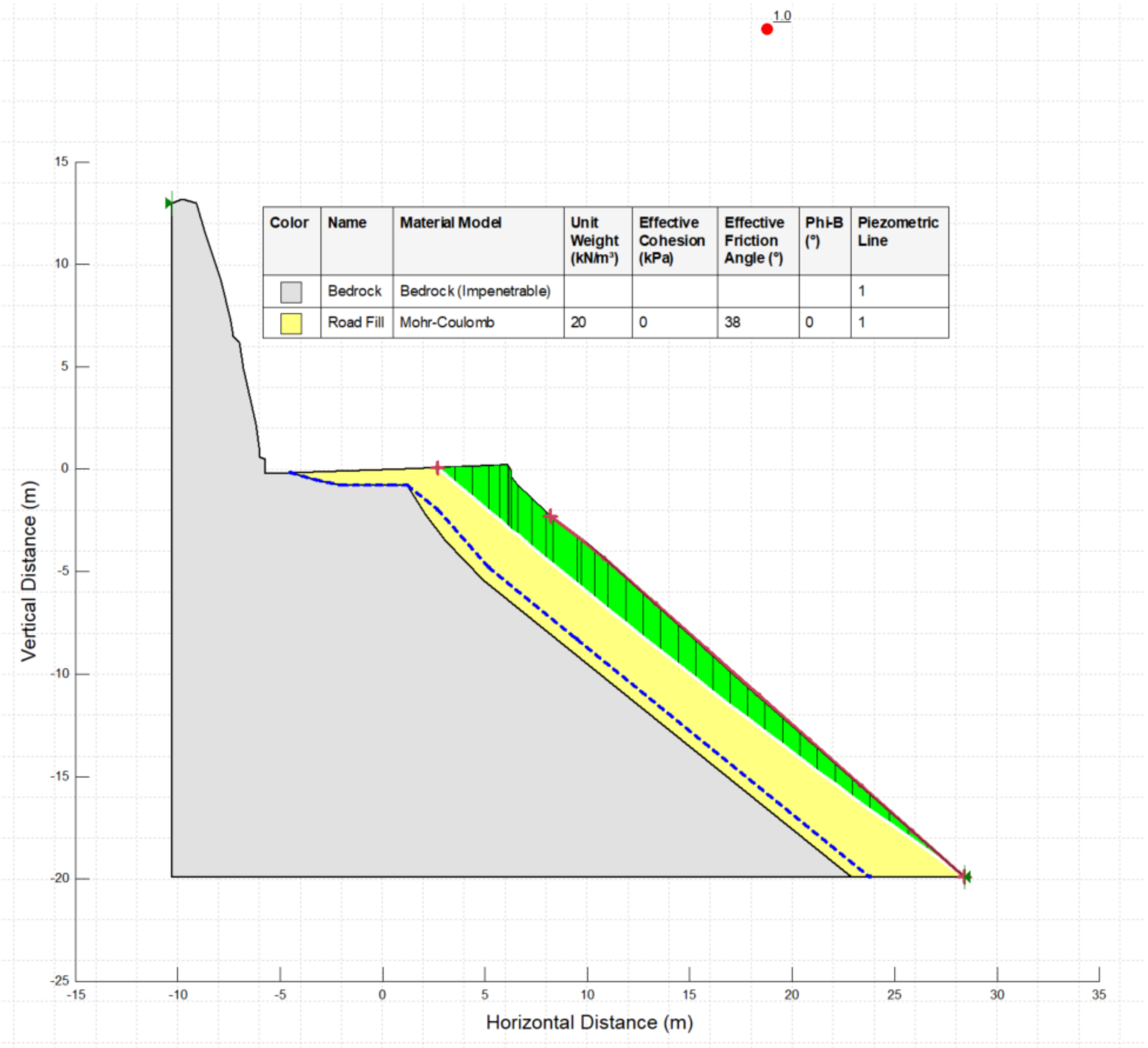
- **Method Blank (Blk)**: A blank sample that undergoes sample processing identical to that carried out for the test samples. Method blank results are used to assess contamination from the laboratory environment and reagents.
- **Duplicate (Dup)**: An additional or second portion of a randomly selected sample in the analytical run carried through the entire analytical process. Duplicates provide a measure of the analytical method's precision (reproducibility).
- **Blank Spike (BS)**: A sample of known concentration which undergoes processing identical to that carried out for test samples, also referred to as a laboratory control sample (LCS). Blank spikes provide a measure of the analytical method's accuracy.
- **Matrix Spike (MS)**: A second aliquot of sample is fortified with a known concentration of target analytes and carried through the entire analytical process. Matrix spikes evaluate potential matrix effects that may affect the analyte recovery.
- **Reference Material (SRM)**: A homogenous material of similar matrix to the samples, certified for the parameter(s) listed. Reference Materials ensure that the analytical process is adequate to achieve acceptable recoveries of the parameter(s) tested.

Each QC type is analyzed at a 5-10% frequency, i.e. one blank/duplicate/spike for every 10-20 samples. For all types of QC, the specified recovery (% Rec) and relative percent difference (RPD) limits are derived from long-term method performance averages and/or prescribed by the reference method.

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
Anions, Batch B3E1568										
Blank (B3E1568-BLK1)				Prepared: 2023-05-14, Analyzed: 2023-05-14						
Sulfate	< 1.0	1.0	mg/L							
LCS (B3E1568-BS1)				Prepared: 2023-05-14, Analyzed: 2023-05-14						
Sulfate	16.0	1.0	mg/L	16.0		100	90-110			

Appendix D –Back Analysis Results

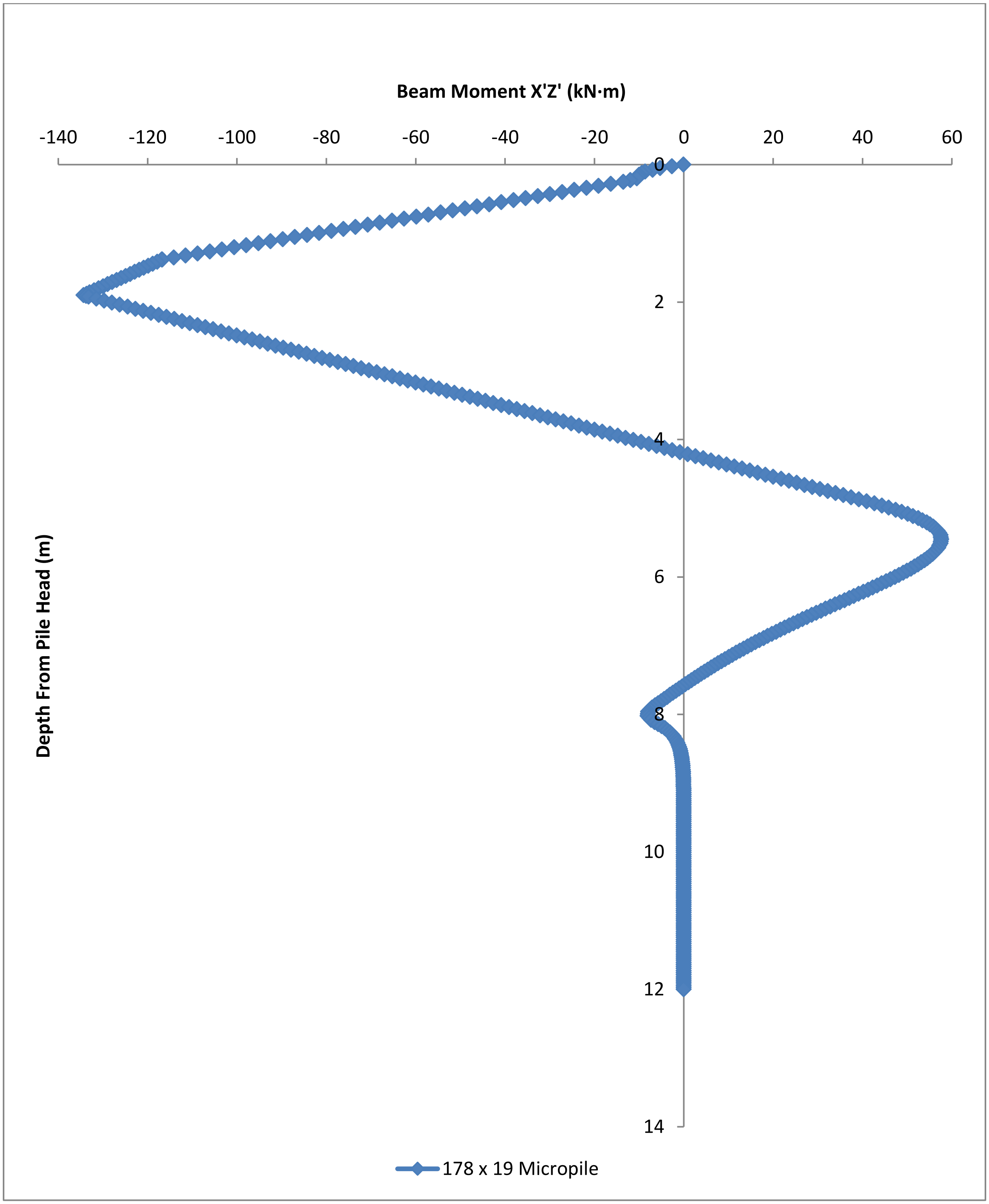
SLOPEW Back Analysis Results



Color	Name	Material Model	Unit Weight (kN/m³)	Effective Cohesion (kPa)	Effective Friction Angle (°)	Phi-B (°)	Piezometric Line
⬜	Bedrock	Bedrock (Impenetrable)					1
🟨	Road Fill	Mohr-Coulomb	20	0	38	0	1

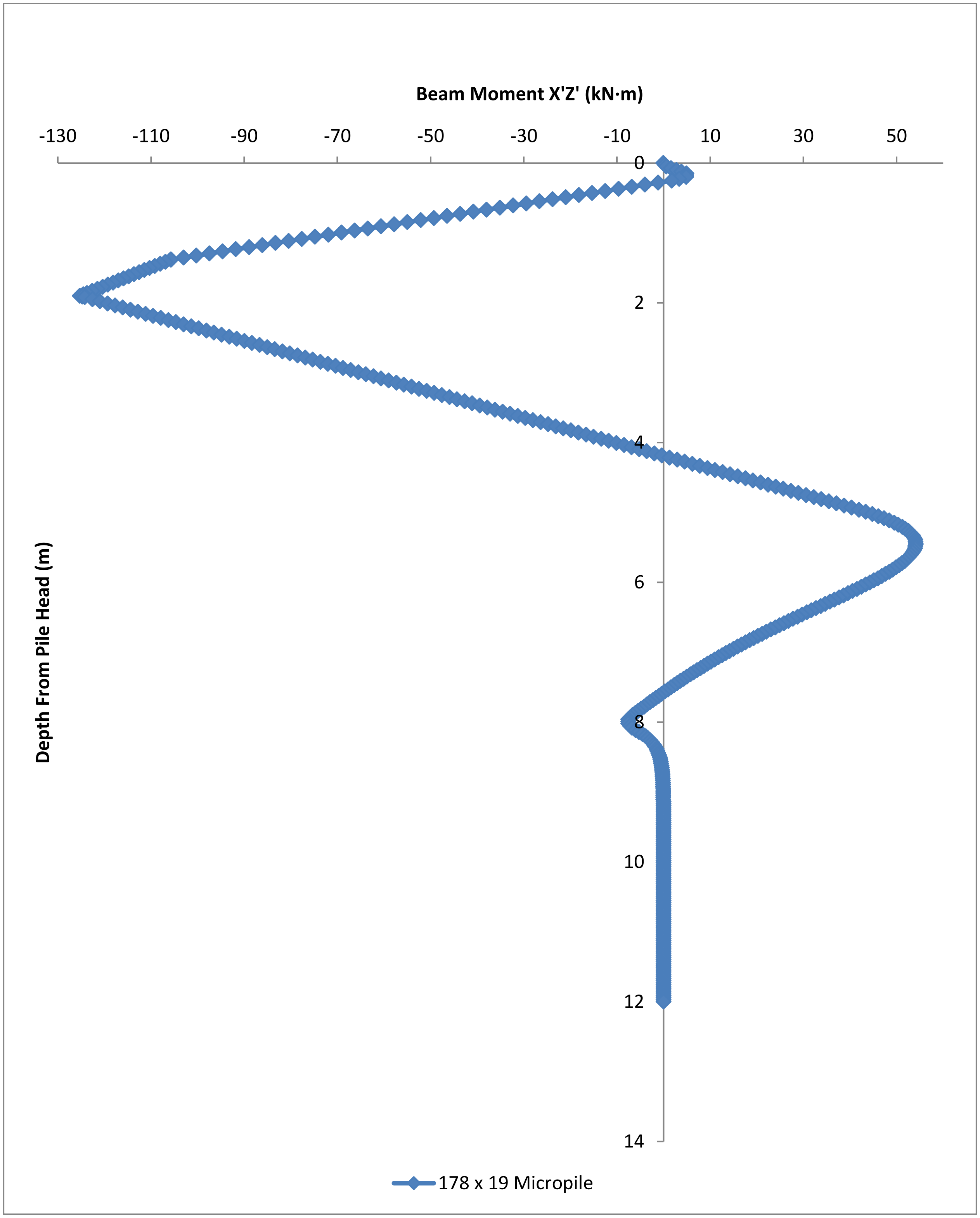
Appendix E – RSPile Plots

Beam Moment Diagram - With Tie-Back Force



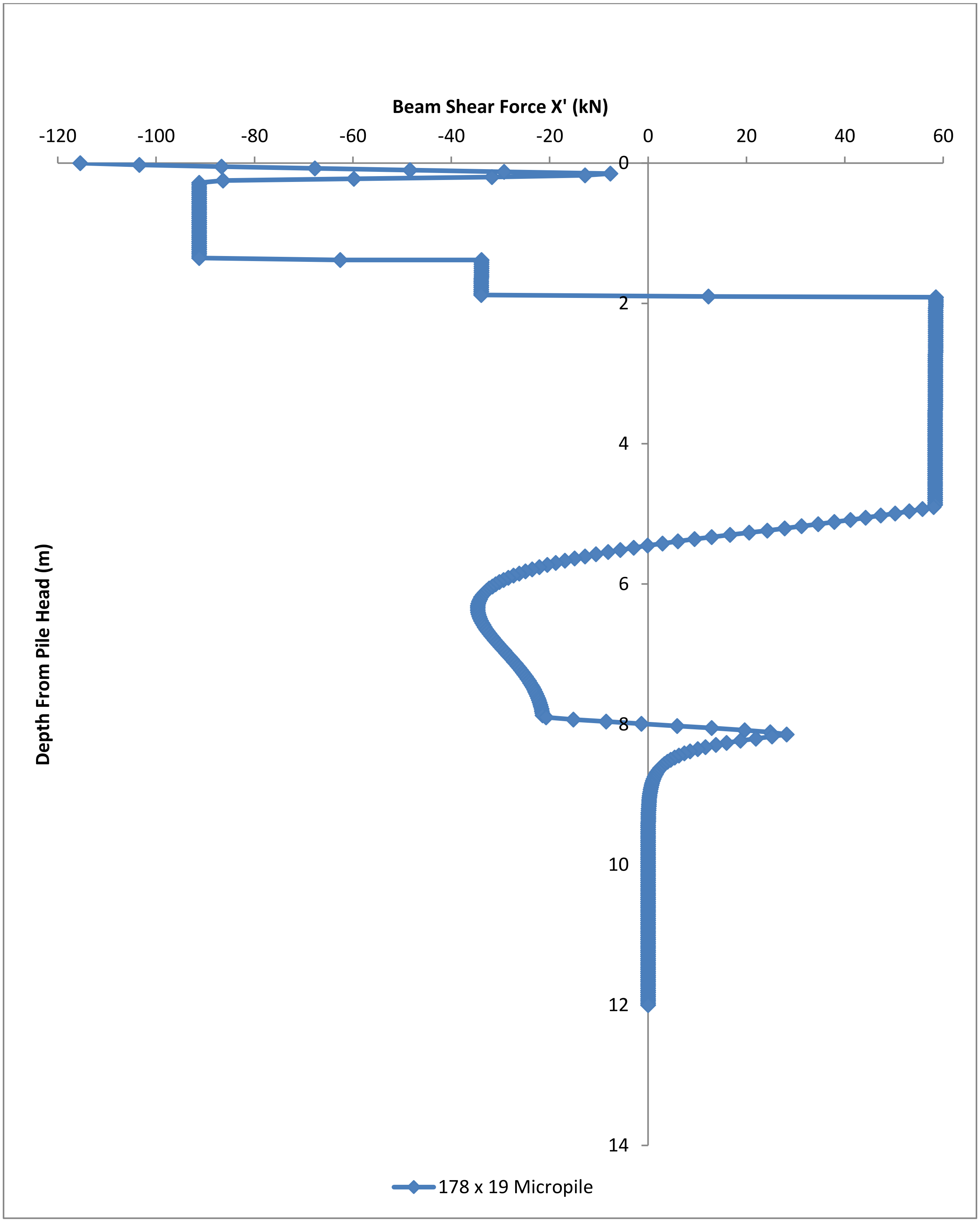
Note: Datum adjusted for lateral pile analysis. A depth of 0 m in the lateral analysis represents the location of the tieback force, which is equivalent to 1.1 m below ground surface.

Beam Moment Diagram - Without Tie-Back Force



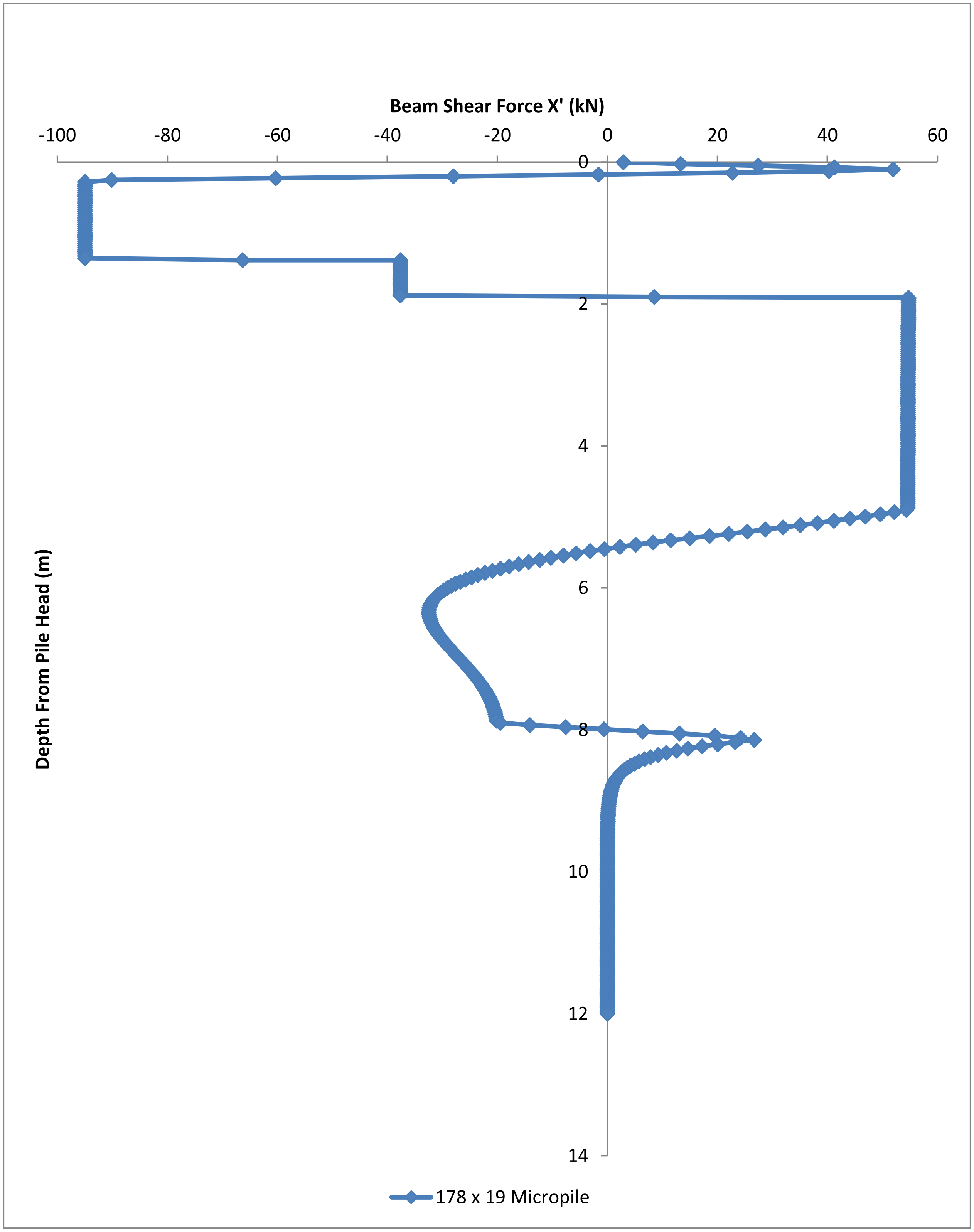
Note: Datum adjusted for lateral pile analysis. A depth of 0 in the lateral analysis represents the location of the tieback force, which is equivalent to 1.1 m below ground surface.

Beam Shear Diagram - With Tie-Back Force



Note: Datum adjusted for lateral pile analysis. A depth of 0 m in the lateral analysis represents the location of the tieback force, which is equivalent to 1.1 m below ground surface.

Beam Shear Diagram - Without Tie-Back Force



Note: Datum adjusted for lateral pile analysis. A depth of 0 m in the lateral analysis represents the location of the tieback force, which is equivalent to 1.1 m below ground surface.