Revelstoke Remote Avalanche Control System (RACS) Geotechnical Design Report Victor Lake (Path No. 14.4)

Presented To:

British Columbia — The Best Place on Earth
Ministry of Transportation and Infrastructure

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MoTI Project No.:	26062

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Presented To:

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PERMIT TO PRACTICE # 1001040
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Version Control and Revision History

Version	Date	Prepared By	Reviewed By	Notes/Revisions
0	2023-08-04	DJK	MJL	ISSUED FOR USE

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Acronyms and Abbreviations

AEP	Annual Exceedance Probability
ASCE	American Society of Civil Engineers
BC	(Province of) British Columbia
BCBC	British Columbia Building Code (2018)
BC MoTI	British Columbia Ministry of Transportation and Infrastructure
CFEM	Canadian Foundation Engineering Manual
CHBDC	Canadian Highway Bridge Design Code (2019)
CPR	Canadian Pacific Railway
DEM	Digital Elevation Model
EGBC	Engineers and Geoscientists British Columbia
FOS	Factor of Safety
LiDAR	Light Detection and Ranging
LKI	Landmark Kilometer Inventory
m asl	meter(s) above sea level
MCRR	Maintenance Contractor Rockfall Reports
NBCC	National Building Code of Canada (2020)
P.Eng.	Professional Engineer (registered with EGBC)
PGA	Peak Ground Acceleration
PLT	Point Load Test
PTI	Post-Tensioning Institute
RACS	Remote Avalanche Control System
Sa(T)	Spectral Acceleration
SSHC	Standard Specifications for Highways
TCH 1	Trans-Canada Highway 1
UBC	University of British Columbia
UCS	Uniaxial Compressive Strength

1. Introduction

1.1 General

Ecora Engineering & Resource Group Ltd. (Ecora) has been retained by the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) to provide engineering services for several proposed Remote Avalanche Control System (RACS) sites to be situated along the Trans-Canada Highway (TCH) near Revelstoke, British Columbia (BC).

It is proposed that a Wyssen Avalanche Control (Wyssen) RACS tower be constructed at the Victor Lake site, which is approximately 15.5 km west of Revelstoke in BC. The Wyssen RACS towers are between 8 and 12 m tall and are inclined to overhang an avalanche initiation zone. The system allows the BC MoTI to undertake avalanche control during all weather conditions, at any time, thereby reducing the risk of uncontrolled avalanches impacting highway traffic and allows the BC MoTI to better manages its assets.

This work was approved by Andre van Wyk PmP, Senior Project Manager with Stites Consulting Inc. (Stites). The work will be carried out in accordance with applicable BC MoTI Standards and Technical Circulars, the Professional Governance Act (2021), and relevant Professional Practice Guidelines, as published by Engineers and Geoscientists British Columbia (EGBC).

1.2 Scope of Work

This design report addresses Task 2.3 Detailed Design Verification and Task 2.4 Detailed Design Report as provided in Ecora’s Geotechnical Proposed Work Plan TransCanada Highway (Hwy 1) – RACS-TCH Revelstoke East and West Detailed Design as follows:

- Rock fall run out assessment.
- Micro-pile and inclined shear relief anchor design.
- Kinematic stability analysis.
- Global stability analysis.
- Structural pile cap design.
- Preparation of detailed design drawings.

1.3 Site Description

The TCH is a major transcontinental west-east highway that traverses the breadth of Canada between the Pacific and Atlantic Oceans. Within British Columbia (BC) it traverses through several mountain passes which are subject to seasonal avalanches. The Victor Lake site is located just outside the eastern boundary of Victor Lake Provincial Park, BC.

The proposed site is located on a southeast facing slope in the Selkirk Mountain range and lies at an elevation of approximately 950 m above sea level (m asl). The TCH elevation is approximately 400 m below the proposed site at an elevation of 535 m asl. Victor Lake lies immediately downslope (south) of the project site, below the TCH, and drains to the southwest via Victor Creek into the Eagle River.

Two proposed tower locations have been identified during a site visit on 14 June 2023, which are indicated on the design drawings provided in Appendix A. Both the proposed tower location and proposed alternate tower location fall within the avalanche initiation area, and the two locations have been evaluated geotechnically for suitability for the construction of the tower.

Ecora has previously undertaken a desktop assessment of the Victor Lake site which provide a more detailed description of site conditions, which is attached as Appendix B.

Overall, site is characterized by steep rock faces with little to no overburden materials observed. Scattered trees are located in areas with nominal soil cover. Large rock outcropping is prevalent at the site, and the rock mass consists of horizontally layered widely spaced beds. Further details describing the geotechnical conditions of the site are provided in Section 3.

2. Background Review

2.1 Sources of Information

Ecora reviewed the following relevant background information related to the project.

- BC MoTI Columbia Program Snow Avalanche Atlas (BC MoTI, 2015).
- BC MoTI Road Weather Stations (RWS) data.
- Readily available published sources of geologic data.
- The National Resources Canada (NRCan) seismic hazard information.
- LiDAR data collected for the site by Rekon Solutions Inc (June 2023).
- MC MoTI Maintenance Contractor Rock Fall Reports (MCRR) records for the Victor Lake area
- Revelstoke Remote Avalanche Control Systems (RACS), Site Reconnaissance Report (Ecora, 2023).
- Revelstoke Remote Avalanche Control Systems (RACS), Desktop Assessment Victor Lake Report (Ecora, 2023).

2.2 Background Review Summary

2.2.1 BC MoTI Snow Avalanche Atlas

Table 2-1 has been adapted from BC MoTI Columbia Program Snow Avalanche Atlas (BC MoTI, 2015), and serves as a summary of Victor Lake Path #14.4.

Table 2-1 Columbia Program Path #14.4 Summary

Victor Lake Terrain Characteristics Path Number: 14.4		
Terrain Characteristics		
Vertical Fall: 670m	Starting Zone: 1220m asl - 915 m asl	
Aspect: Southeast	Runout Zone: 570m asl - 550 m asl	
Slope		
Starting Zone: 41°	Track: 40°	Runout Zone: 0°
Slope Hazards		
Type: Avalanche, Rockfall	Event Frequency: 4 per year (3-month return period)	
Infrastructure in Path		

Road Width: 7 m	Road Length: ~750m
Slope Hazard Infrastructure Installed	
Structure Type: Lock-block Wall	Location: West side of runout path
Install Date: 2002	Maintenance: Ongoing – Debris Cleanout

2.2.2 Climate

The BC MoTI weather station RWS Clanwilliam Station (Station Code: 38124) is located approximately 1.5 km east of the Victor Lake Priority Path site, at an elevation of approximately 550 m asl. Table 2-2 provides a summary of the average minimum and maximum temperatures, average monthly sum of new snow, and average total snowpack for the months of October through to April, recorded at the RWS Clanwilliam station between 1999 and 2022.

Table 2-2 Historical Weather Data Summary Clanwilliam Station #38124 (1999-2022)

Month	Average Maximum Temperature (°C)	Average Minimum Temperature (°C)	Average Monthly Sum of New Snow (m)	Average Total Snowpack (m)
October	7.4	4.1	0.07	0.01
November	1.8	-0.3	0.79	0.12
December	-1.8	-3.9	1.61	0.55
January	-1.8	-4.1	1.52	0.98
February	-0.9	-4.3	1.03	1.19
March	2.6	-1.3	0.55	1.18
April	7.0	1.2	0.13	0.72

2.2.3 Geology

MapPlace2 (beta) (Cui et al., 2017) indicates the underlying geology at the Victor Lake site consists of "quartzite, quartz arenite sedimentary rock" of the Monashee Complex of the Proterozoic to the Paleozoic Eons.

The Geologic Survey of Canada (GSC) 1:50,000 scale map "*Geology, Revelstoke, British Columbia*" (Thompson, 2004) indicates the site is predominantly underlain by biotite-quartz-feldspar paragneiss characterized by lenses and boudins of garnetiferous amphibolite; extensive lenticular masses of pegmatite". A chevron fold-like layer is shown to comprise "quartzite; sillimanite garnet biotite schist; biotite quartz feldspar paragneiss" of the Monashee.

2.2.4 Seismicity

The *Bridge Standards and Procedures Manual, Supplement to CHBDC S6-19* (MoTI, 2022) stipulates that structures shall be designed for no-collapse under multiple earthquake design levels (475, 975, and 2,475), with peak ground acceleration (PGA) values as determined by the GSC and reported in the National Building Code of Canada (NBCC, 2020).

The GSC has developed a probabilistic (6^{th} Generation) seismic hazard model (Kolaj et al., 2020) that forms the basis of the seismic design provisions of the 2020 National Building Code of Canada (NBCC, 2020), British Columbia Building Code (BCBC, 2018), and Canadian Highway Bridge Design Code (CHBDC; CSA, 2019).

Peak Ground Accelerations (PGA) and Spectral Accelerations (Sa(T)) for a reference "Site Class B" (Rock) can be obtained from the Earthquakes Canada website for various return periods, with the reference values for the proposed RACS at the Victor Lake Priority Path is summarized in Table 2-3 below.

Table 2-3 "Site Class B" Design PGA and Sa(T) for the RACS at the Victor Lake Priority Path

Annual Exceedance Probability (AEP)	PGA (g)	Sa (0.2) (g)	Sa (0.5) (g)	Sa (1.0) (g)	Sa (2.0) (g)
1/475	0.0203	0.0415	0.0284	0.0177	0.0113
1/975	0.0328	0.0673	0.0424	0.0263	0.0178
1/2,475	0.0578	0.121	0.0691	0.0415	0.0294

2.2.5 Maintenance Contractor Rock Fall Records

The BC MoTI provided Maintenance Contractor Rockfall Report (MCRR) records for the Victor Lake area between LKI km 55.89 to km 56.18 (RFI LM km 2.90 to km 3.19), between 1994 and 2018 as summarized in Table 2-4.

Table 2-4 Estimated Volume of Rock Fall Events

Estimated Volume (m^3)	Number of Events	Cumulative %
< 0.03	15	34
0.03 - 0.1	9	55
0.1 – 0.3	6	68
0.3 – 0.5	2	73
0.5 – 1.0	5	84
1.0 – 5.0	1	86
> 5.0	6	100

The MCRR reports indicate that March has the highest incidence of rock fall events along the TCH in the vicinity of Victor Lake with approximately thirteen reported incidents. June recorded twelve incidents, the second highest occurrence.

Based on historical weather data for Revelstoke BC (Environment Canada, 2023), freeze thaw conditions (when the temperature fluctuates below and above 0°C) occurs frequently during the months of March and April. These weather conditions could contribute to ice jacking and higher pore water pressures in the rock mass, leading to increased frequency in rock fall events (Wyllie, 2015 after Peckover, 1975).

3. Geotechnical Characterization and Stability Analysis

3.1 General

Reliable estimates of the strength and deformation characteristics of rock masses are required to evaluate the stability of rock slopes and rock foundations. The strength and deformability of a jointed rock mass depends on both the properties of the intact rock pieces as well as the freedom of these pieces to slide and rotate relative to each other. Generally speaking, the stability of a rock slope depends on the rock mass properties where, for stronger rocks, rock mass structure likely governs, whereas for weaker rocks, intact rock strength can be the governing factor (Read and Stacey, 2009).

In weaker rock or soils, typically rotational slips occur where movement takes place along a curved shear surface in such a way that the slipping mass slumps down near the top of the slope and bulges near the toe.

In stronger rock, the stability of the slope is frequently controlled by the orientation of discontinuities within the rock mass. Reliable knowledge of the true orientation of discontinuities is therefore required for engineering design. Structurally controlled failure in rock usually occurs as a result of slip or failure along (or from pre-existing geological discontinuities).

The rock mass at the Victor Lake site can be described to consist of two main joint sets which are wide to very widely spaced that intersect to create tabular blocks, including horizontally layered bedding planes.

The geotechnical slope stability of the Victor Lake site has been evaluated to be controlled by the structural features of the rock mass. To evaluate the structural stability of the rock mass, the results of a structural assessment using stereographic projection are presented in the sections that follow.

3.2 UCS from Point Load Testing

Samples were collected from the proposed tower location for Point Load Testing (PLT). Calculation of the PLT test results were carried out in accordance with ASTM D 5731-16 standard.

The PLT results can be empirically correlated to UCS, which is the commonly accepted indicator of rock strength. The standard conversion formula to estimate UCS from Is_{50} values is as follows:

$$UCS = C * Is_{50}$$

A correlation factor C of 20-25 was used, as an initial estimate (Wyllie, 2018). Using the range of Is_{50} values, Ecora calculated an approximate UCS of 85 MPa.

The PLT results are shown in the attached Figure 3.1.

3.3 Discontinuity Mapping

Ecora carried out field discontinuity mapping of the rock outcrops at the proposed tower locations on June 14, 2023. The principal discontinuity sets identified during our investigation of the tower locations are presented in Table 3-1. Photos of the mapped outcrops are presented as Photos 3 and 4.

Table 3-1 Discontinuity Sets

Discontinuity ID	Type	Dip Angle (°)	Dip Direction (°)	Joint Roughness Coefficient
B	Bedding	31	245	14
J1	Joint	75	172	11
J2	Joint	70	63	11

The stereographic projection indicating the discontinuity orientations are included as Figure 3.2 at the back of the report.

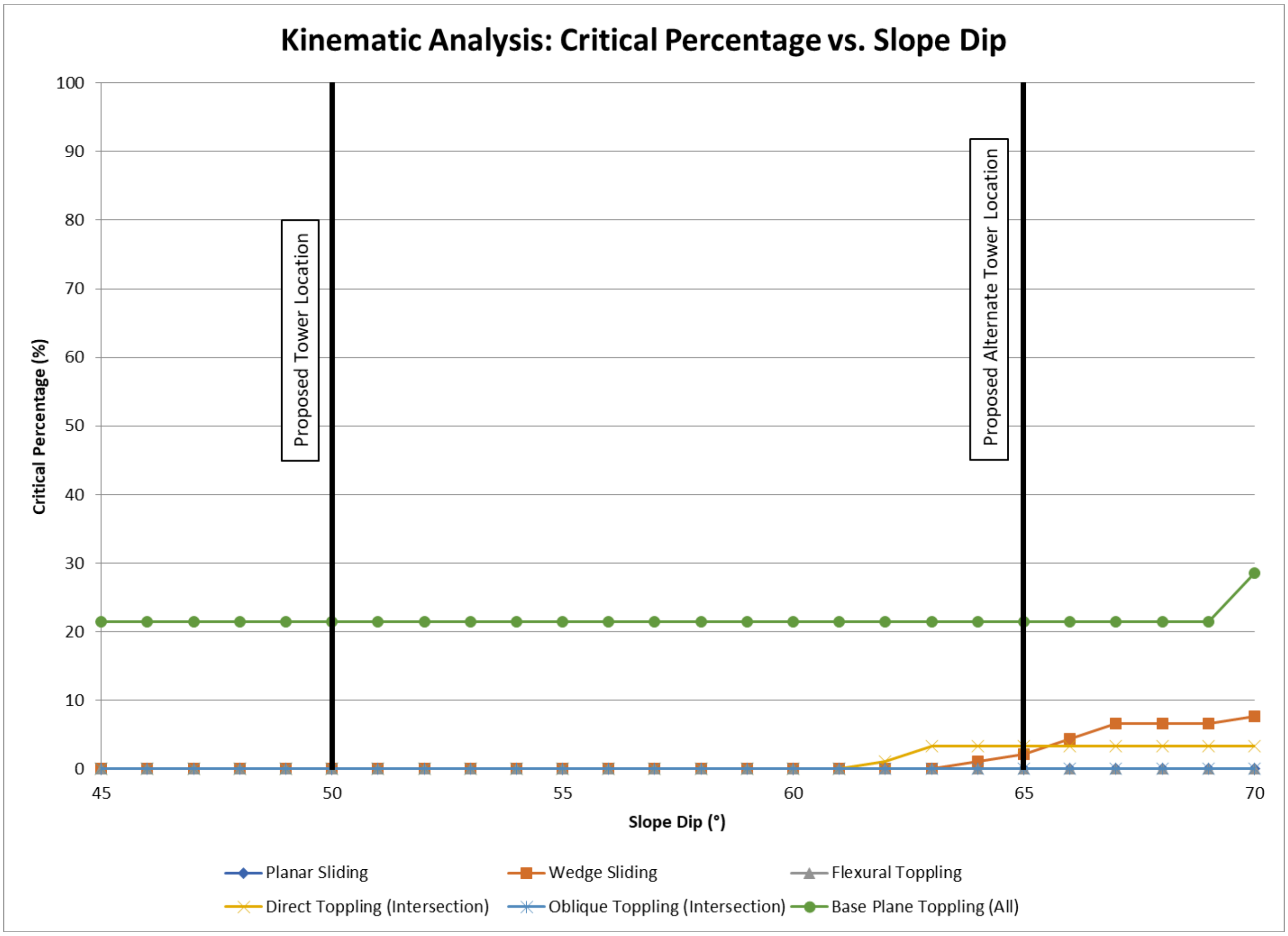
3.4 Geotechnical Structural Analysis

In order to analyse the stability rock slope above the proposed tower locations, a structural assessment has been undertaken using stereographic projection. The stability of the walls is influenced by the orientations of major discontinuities in the rock in relation to the angle of the slope.

The critical percentage of the three major failure modes, namely planar, wedge and toppling, are summarized in Graph 3-1 and the stereographic projections of the failure modes are included as Figure 3.3. The slope of the rock mass immediately above the proposed tower locations are as follows:

- Proposed tower location: 50°

- Proposed alternate tower location: 65°



Graph 3-1 Kinematic Analysis Summary

The analysis indicates that the proposed tower location with a slope of 50° is preferable. At the proposed tower location, the orientations of the discontinuities could result in toppling failure [Base Plane Toppling (All)]. However, the centre of gravity of the potentially unstable rock block must lie outside of its base so toppling can be initiated. This is evaluated with the following equation:

$$\frac{\Delta x}{y} < tan\psi_p$$

where: Δx = block depth

y = block height

ψ_p = plane dipping angle

For this site, the centre of gravity of the rock blocks immediately upslope of the proposed tower location does not fall outside the base of the block and therefore are considered stable.

4. Design of RACS Tower Foundations

4.1 Design Criteria

The Wyssen RACS towers are typically supported by four vertical micro-piles and one inclined shear relief anchor. For the design of the tower foundation elements, the following design references were utilized:

- Canadian Foundation Engineering Manual, 4th Edition
- CSA S6:19, Canadian Highway Bridge Design Code (CHBDC), 2019.
- BC MoTI Volume 1 – Supplement to CHBDC S6:19, 2022.
- BC MoTI Standard Specifications for Highway Construction 2020.
- FHWA-IF-99-015, Ground Anchor and Anchored Systems, Geotechnical Engineering Circular No.4, June 1999.
- PTI DC35.1-14, Recommendations for Pre-stressed Rock and Soil Anchors, 2014.

The tower foundation is designed as a pile cap whereby applied forces are transferred to the underlying strata through the micro-piles and shear relief anchor. Therefore, bearing resistance, overturning, sliding of the base and erosion potential consequences are not considered as would be for shallow foundations, as any contribution arising from direct bearing of the pile cap on the ground shall be neglected.

4.2 Tower Foundation Design Loads

The foundation design loads for RACS tower at Victor Lake as provided by Wyssen are summarized in Table 4-1 below. The tower is supported by four micro-piles and one shear relief anchor.

Table 4-1 Design Loads for Victor Lake RACS Tower

Avalanche Velocity (m/s)	Mast Height (m)	Foundation Design Loads (kN)[1.]	
		Micro-Piles[2.]	Shear Relief Anchor
18	12	146	312

[1.] Factored Loads as provided by Wyssen. [2.] Load is given per pile.

The loads received from Wyssen as provided in Table 4-1 are factored and based on the following:

- Avalanche impact.
- Weight of the tower including deployment box weight.
- Snow creep.
- Wind load.

4.3 RACS Tower Foundation Design

4.3.1 General

The required bond lengths for the micro-piles and shear relief anchor are calculated based on published typical average ultimate bond strengths between rock and grout as found in Table C6.1 from Recommendations for Prestressed Rock and Soil Anchors (Post-Tensioning Institute (PTI) DC35.1-14, 2014) and Foundations on Rock (Wyllie, 1999).

An approximate relationship between the rock-grout bond strength and the UCS of the rock as been developed from the results of load tests in a wide range of rock types and strengths.

The working bond strength is related to the UCS of the rock according to the following:

$$\tau_a \approx \frac{\sigma_{u(r)}}{30}$$ up to a maximum value of 1.4 MPa (Wyllie, 1999)

where: τ_a = working bond strength of the rock-grout interface

$\sigma_{u(r)}$ = uniaxial compressive strength of the rock in the bond zone

Therefore, using a bond strength of 1.4 MPa, the calculated minimum bond length for the threadbar micro-piles and shear relief anchors in competent rock for drill hole diameters of 63.5 mm and 76 mm respectively based on the design loads provided in Table 4-1 is summarized in Table 4-2 below.

Table 4-2 Minimum Bond Length

Avalanche Velocity (m/s)	Mast Height (m)	Minimum Calculated Bond Length (m)	
		Micro-Piles[1]	Shear Relief Anchor[2]
18	12	1.05	1.90

[1.] Micro-pile has a minimum drill hole diameter of 63.5 mm.[2.] Shear Relief Anchor has a minimum drill hole diameter of 76 mm.

The bond lengths were calculated according to the following formula (PTI, 2014):

$$L_b = \frac{P \cdot FS}{\pi \cdot d \cdot \tau_u}$$

where: L_b = bond length

P = design load of anchor

d = diameter of drill hole

τ_u = average ultimate bond strength along interface between grout and ground

FS = factor of safety on average ultimate bond strength

The PTI (2014) Recommendations for Prestressed Rock and Soil Anchors document requires that a minimum bond length of 3.0 m be required for anchors, and therefore the bond length of the shear relief anchor has been increased to 3.0 m.

4.3.2 Services Life Calculations

4.3.2.1 Design Criteria and Material Standards

The design criteria for the tower foundations, is based on a design service life of 75 years. The following material standards apply to the use of steel manufactured products in North America:

- CAN/CSA G164. “Hot Dip Galvanizing of Irregularly Shaped Articles”.
- CAN/CSA G30.18. “Carbon Steel Bars for Concrete Reinforcement”.
- CAN/CSA G40.21. “Structural Quality Steels”.

4.3.2.2 Tower Foundation Minimum Threaded Bar Size

The post threaded bar micro piles and anchors, and all associated components (i.e., bearing plates, nuts, washers) shall be hot dip galvanized as per CAN/CSA G164. Minimum thread bar sizes required for the tower foundations based on the design loads provided in Table 4-1 and zinc coating and sacrificial thickness calculations conducted based on NCHRP Report 675 (2011), as provided in Appendix C, indicate that the selected thread bars meet the 75-year service life requirements. Minimum threadbar sizes for RACS tower foundations are summarized in Table 4-3 below.

Table 4-3 Minimum Threadbar Size

Avalanche Velocity (m/s)	Mast Height (m)	Minimum Calculated Threadbar Diameter (mm)	
		Micro-Piles	Shear Relief Anchor
18	12	32	43

4.3.3 Frost Penetration

Frost susceptibility of earth material refers to the propensity of the ground to grow ice lenses and heave during freeze and thaw cycles and is related to the size distribution of soil particles (CFEM, 2006).

The tower foundations have been designed so that any length of micro-pile or shear relief anchor contributing to supporting the RACS tower is beneath the maximum seasonal frost penetration depth.

Based on a Freezing Index of approximately 347 degree-days below 0°C as calculated from weather station RWS Clanwilliam Station (Station Code: 38124) data between 1999 to 2022, frost depth is estimated utilizing Modified Berggen equation (CFEM 2006). The frost penetration depth is estimated (from normal freezing index) at 1.1 m below ground surface. Therefore, the bonded length of the micro-piles and anchors will start below a depth of 1.1 m.

It is important to note that the construction schedule plays an important role in the short and long-term performance of proposed pavement, foundations, and slabs. Should the construction of any structure be planned to take place over winter, Ecora shall be contacted to review and confirm that the winter-related design concerns (i.e., frost heave of subgrade) are addressed.

4.3.4 RACS Tower Foundation Design Summary

The foundation design summary for RACS tower at Victor Lake is provided in Table 4-4 below.

Table 4-4 RACS Tower Foundation Design Summary

Length (m)	Micro-Piles	Shear Relief Anchor
Minimum Required Bond Length Calculated (m)	1.05	3.0
Frost Penetration (m)	1.1	1.1
Calculated Embedment Length Required (m)	2.55	4.1
Earthing for Lightning Protection (m)	1.45	n/a
Total Recommended Embedment Length (m)	**4.0**	**4.5**

It is assumed that the ground's ability to provide resistance starts only below the depth of frost penetration. Therefore, the *Calculated Embedment Length Required = Frost Penetration + Minimum Calculated Embedment Length Calculated*.

After consultation with Wyssen, it was recommended that the micro-pile lengths be increased to 4.0 m to account for earthing and lightning protection measures.

The design drawings (Issued for Tender) are attached in Appendix A.

5. Construction Considerations

5.1 Accessibility

The site is accessible using a temporary helicopter landing pad located approximately 110 m NE of the proposed rope access point.

5.2 Rock Scaling

Rock scaling may have to be undertaken during construction of the RACS. Rock scaling would create a hazard at the TCH, and temporary rock fall protection work and limited road closures may be required during the execution of the rock scaling works.

Furthermore, temporary rockfall protection measures may be required during construction.

5.3 Tree Felling

In order to ensure effective blast wave propagation, trees in the immediate area of the proposed tower may have to be removed. Tree falling would create a hazard at the TCH limited and road closures may be required during the execution of the tree falling works.

5.4 Quality Control Procedures

The EoR and contractor are responsible for foundation design and construction. Concrete strength, type, rebar spacing, bond length and bar size have been determined by EoR as specified on Drawings (see Appendix A) using standard quality control guidelines. The following aspects in particular must be inspected:

- Micro-pile/anchor location & orientation.
- Micro-pile/anchor hole diameter & length.
- Confirm nominal (design) embedment into competent rock.

- Confirm correct threadbar size, grade & length.
- Check threadbar for loss of galvanization coating.
- Confirm grout preparation is in accordance with specification.
- Cast one set of grout cubes per tower location to verify strength.
- Proof test one shear relief anchor per tower location.
- Confirm correct reinforcing bar size, orientation & spacing for levelling pad.
- Cast one set of concrete cylinders per tower location to verify strength.
- Verification test one sacrificial micro-pile per tower location.
- Confirm exposed threadbar, washer and nut galvanized.

6. Closure

We trust this report meets your requirements. Please contact our office if you have any questions or comments concerning this report.

References

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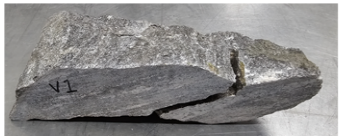
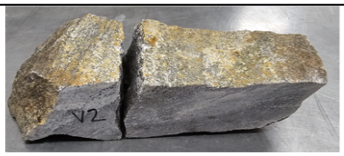
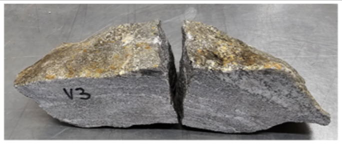
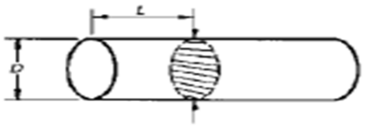
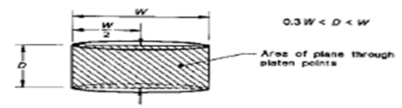
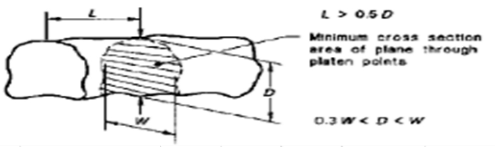
Figures

POINT LOAD STRENGTH INDEX

AS 4133.4.1 - 1994

Client:	BC MoTI	**Project No:**	201740-04	**Date:**	12-Jul-23
Project:	Revelstoke RACS Victor Lake	**Borehole/Test Pit No:**	N/A	**Tested By:**	S. Kraetzer
Location:	Revelstoke, BC	**Borehole/Pit Location:**	N/A	**Checked By:**	D. J. Kruger, MEng

Depth (m)	Sample Number	Rock Description (Including nature and orientation of any defects or planes of weakness)	Moisture Condition	**Dimetral**					**Axial / Irregular Lump**							**Calculated UCS (MPa)**	Photo of Failed Sample
				L (mm)	D (mm)	P (kN)	I_s (MPa)	$I_{s(50)}$ (MPa)	W (mm)	D (mm)	D^2_e (mm^2)	P (kN)	I_s (MPa)	k_{PLT} (mm)	$I_{s(50)}$ (MPa)	**From**	
N/A	V1	Quartzite	Air Dry	-	-	-	-	-	85	60	6494	34.300	5.28	1.24	6.55	79	
N/A	V2	Quartzite	Air Dry	-	-	-	-	-	85	60	6494	35.856	5.52	1.24	6.84	83	
N/A	V3	Quartzite	Air Dry	-	-	-	-	-	70	55	4902	30.704	6.26	7.87	49.31	94	

Shape of Specimen	Cylinder Core		
Direction of Loading	Diametral	Axial	
Required Shape Proportions of Test Specimens			

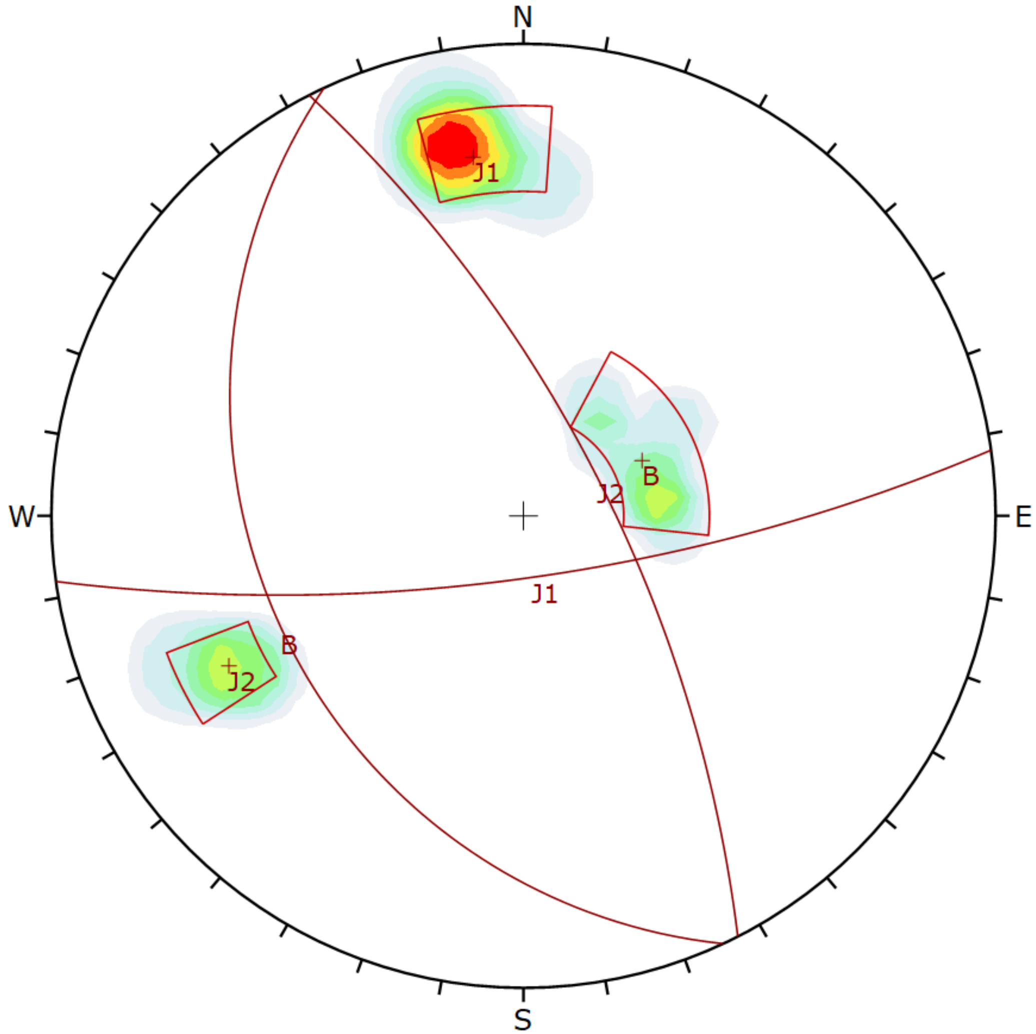
Notes:

Revelstoke RACS Foundation Design Report
Victor Lake (Path No. 14.4)

Point Load Test Results

Project No. 201740-04
Client: BC Ministry of Transportation and Infrastructure
Office: Kelowna
Scale: NTS
Date: JULY 11, 2023
DWN: DJK CHK: MJL Scale: NTS

Figure 3.1



Color	Density Concentrations
	0.00 - 2.70
	2.70 - 5.40
	5.40 - 8.10
	8.10 - 10.80
	10.80 - 13.50
	13.50 - 16.20
	16.20 - 18.90
	18.90 - 21.60
	21.60 - 24.30
	24.30 - 27.00

Contour Data	Pole Vectors
Maximum Density	26.94%
Contour Distribution	Fisher
Counting Circle Size	1.0%

	Color	Dip	Dip Direction	Label
Mean Set Planes				
1m		31	245	B
2m		75	172	J1
3m		70	63	J2

Plot Mode	Pole Vectors
Vector Count	14 (14 Entries)
Hemisphere	Lower
Projection	Equal Angle

Revelstoke RACS Foundation Design Report
Victor Lake (Path No. 14.4)

Stereographic Projection

Project No. 201740-04
Client: BC Ministry of Transportation and Infrastructure
Office: Kelowna
Scale: NTS
Date: JULY 11, 2023
DWN: DJK CHK: MJL

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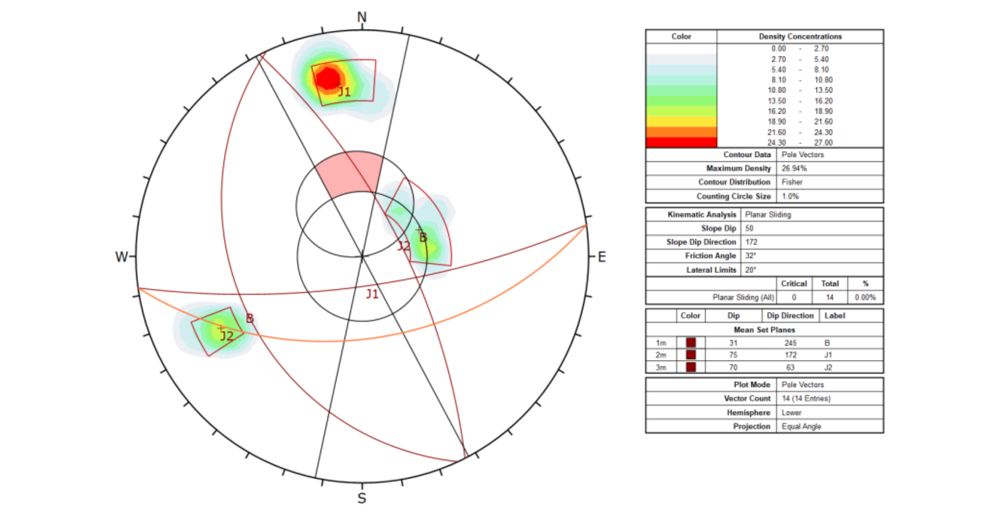
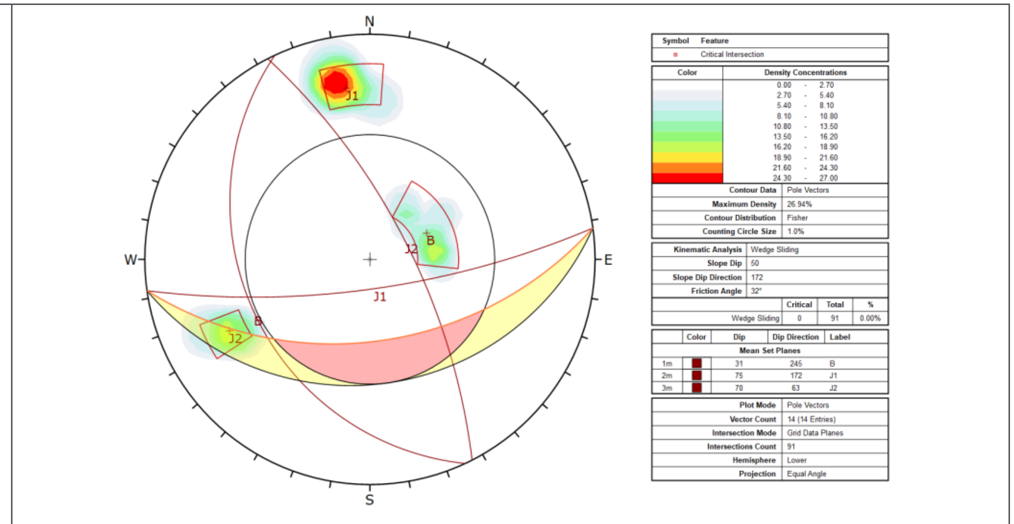
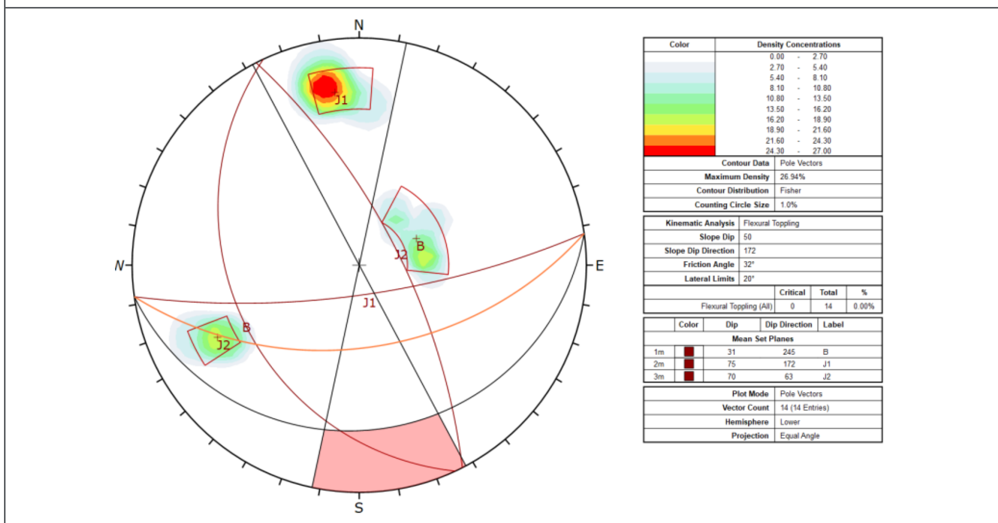
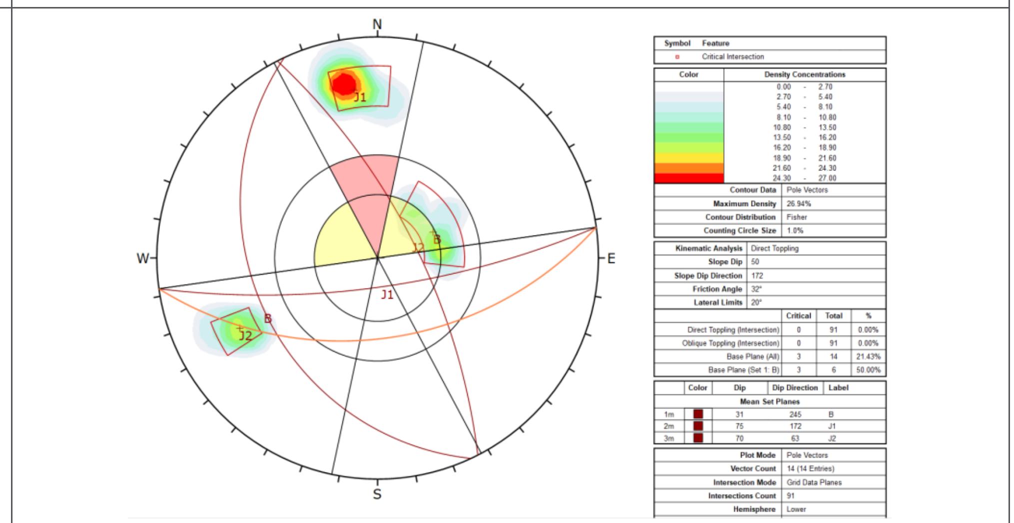
Figure 3.2









Revelstoke RACS Foundation Design Report
Victor Lake (Path No. 14.4)

Kinematic Analysis

Project No. 201740-04
Client: BC Ministry of Transportation and Infrastructure
Office: Kelowna
Scale: NTS
Date: JULY 11, 2023
DWN: DJK CHK: MJL

ecora

Figure 3.3

Photographs

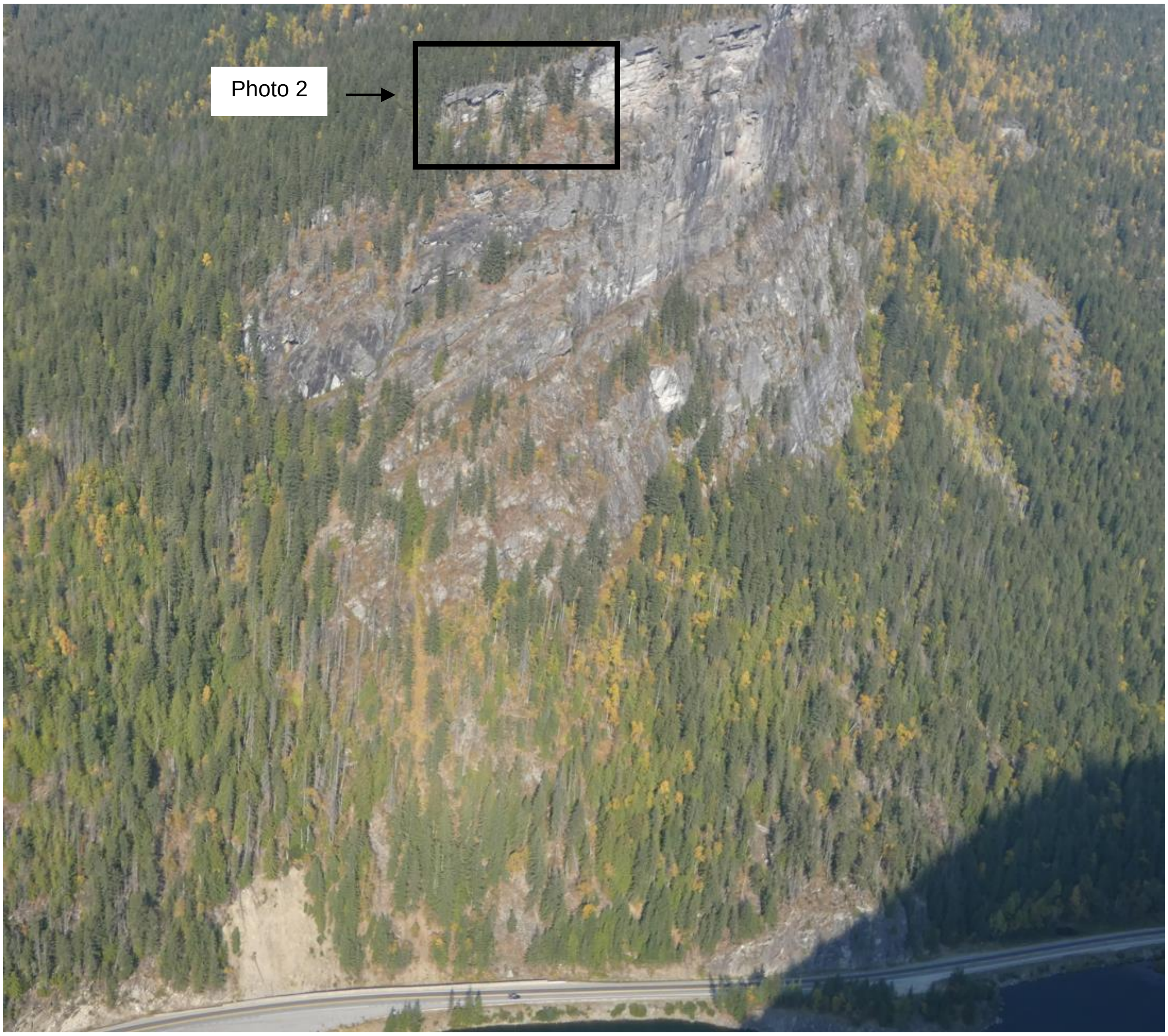


Photo 1 Victor Lake Overview.

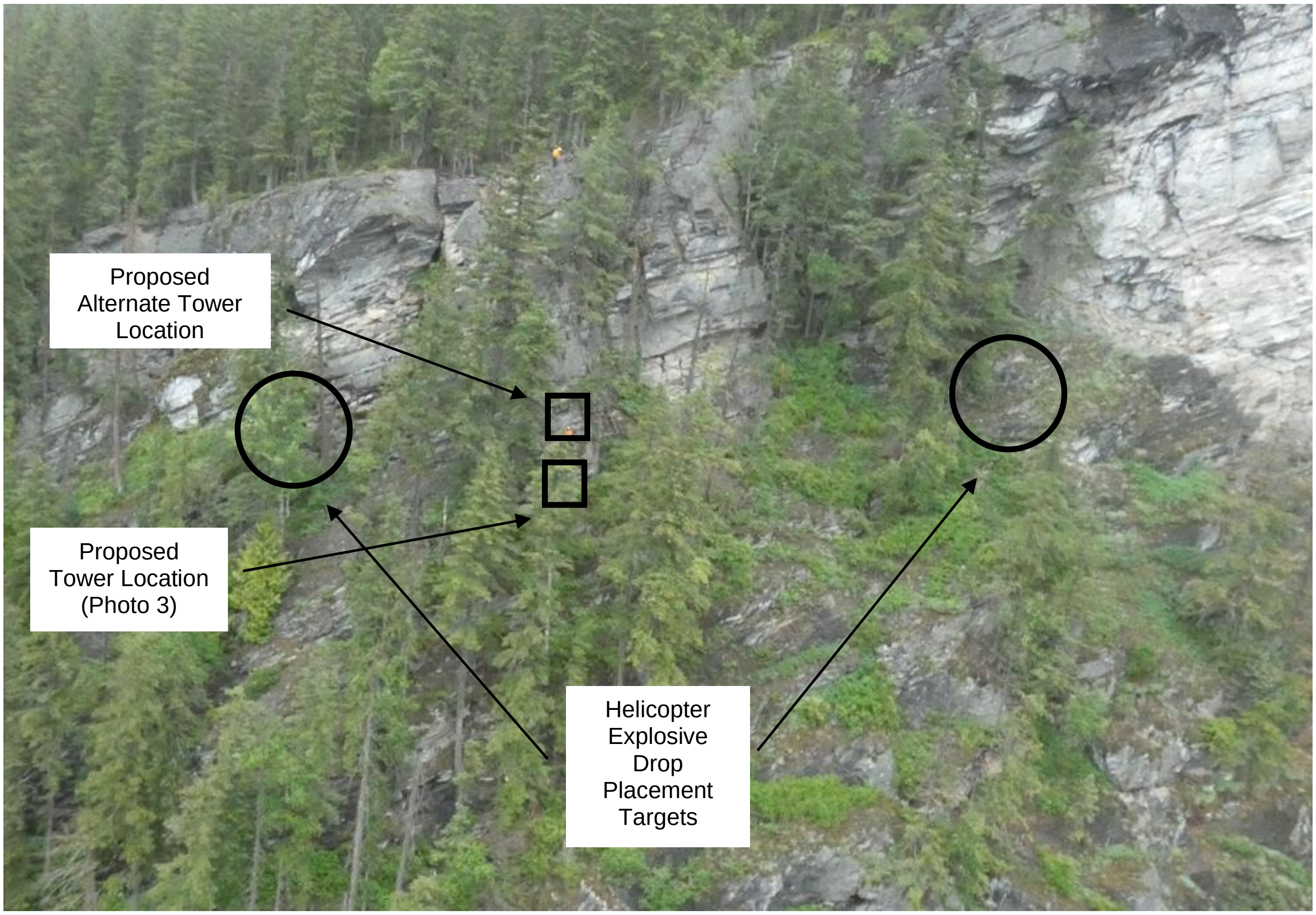


Photo 2 **Proposed Tower Locations and Helicopter Explosive Drop Placement Targets.**

Photo 3 **Preferred Tower Location on Rock Ledge.**

Photo 4 **Rock Mass Immediately Upslope of Preferred Tower Location.**

Photo 5 **Victor Lake Helicopter Landing Pad.**

Appendix A

Design Drawings

BRITISH COLUMBIA

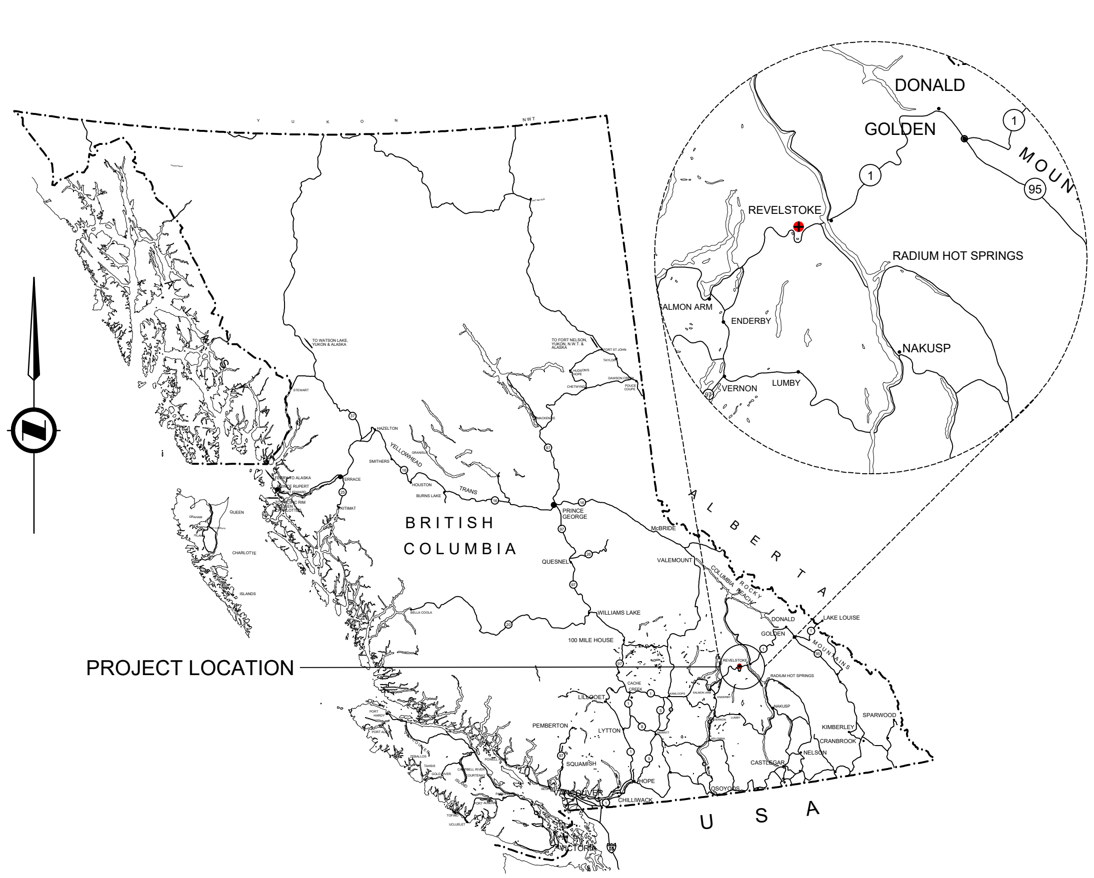
Ministry of Transportation and Infrastructure

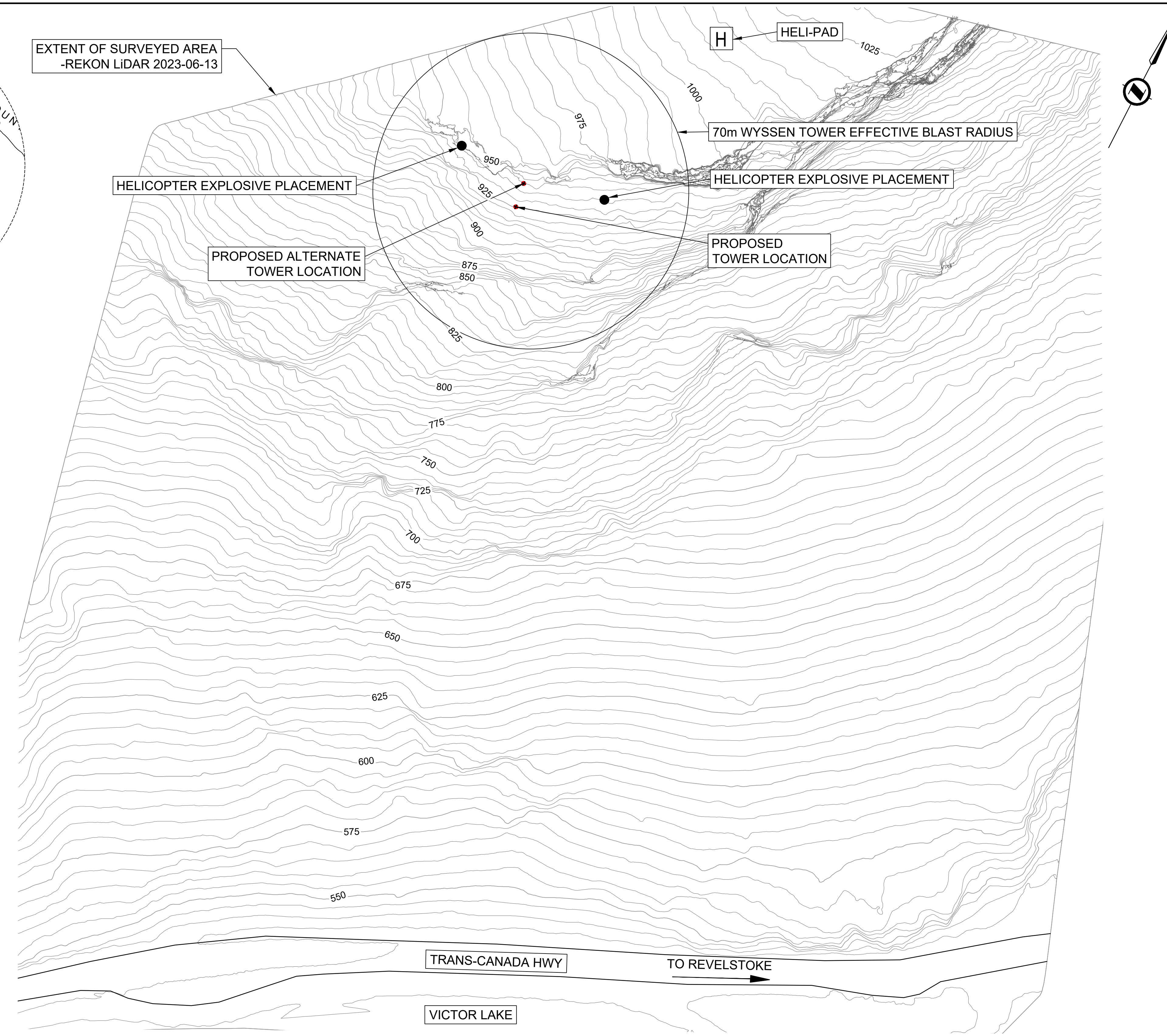
PROJECT No. 26265-0000

REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION

PANTHER (PATH NO. 48) & VICTOR LAKE (PATH NO. 14.4)

AUGUST 4, 2023





KEY PLAN

0 1:1000 50m

DRAWING NO.	DRAWING INDEX DRAWING TITLE
R2-1234-200	LOCATION & KEY PLAN - VICTOR LAKE
R2-1234-201	SITE PLAN - VICTOR LAKE
R2-1234-202	TOWER FOUNDATION DESIGN DETAILS - VICTOR LAKE
R2-1234-203	GEOTECHNICAL CONSTRUCTION NOTES - VICTOR LAKE
R2-1234-204	STRUCTURAL CONSTRUCTION NOTES - VICTOR LAKE

REFER TO TENDER DRAWING PACKAGE APPROVAL FORM

EXECUTIVE REGIONAL DIRECTOR

DATE:

REFER TO TENDER DRAWING PACKAGE APPROVAL FORM

DIRECTOR OF ENGINEERING

DATE:

GENERAL NOTES:

1. Digital base plan provided by REKON SOLUTIONS INC. 5.0 m minor & 25.0 m major LiDAR contour intervals, overall RMSE: 0.026 m.
2. Proposed RACS tower locations by Ecora Engineering & Resource Group Ltd. The locations shown are approximate only and will be field fit and approved by the ministry representative.

Drawing uses UTM Zone11 NAD83 Horizontal Datum, Vertical Datum CGVD28

PROPOSED RACS TOWER LOCATIONS			
PROPOSED TOWER	FOUNDATION LOCATION		ELEVATION
MAIN	401699 E	5646408 N	926 m
ALTERNATE	401698 E	5646419 N	939 m

REV	DATE	REVISIONS	SIGNATURE
0	2023/08/04	ISSUED FOR TENDER	

PROFESSIONAL SEAL

DRAWN BY T.EDMONDS DATE 2023-07-21
DESIGNED BY D. KRUGER & M.ROCHE DATE 2023-07-21
REVIEWED BY M. LAWS DATE 2023-08-04

CAD FILENAME 201740-04
DATE 2023-08-04

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION

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ECORA ENGINEERING & RESOURCE GROUP LTD.
2045 ENTERPRISE WAY, KELOWNA, BC V1Y 9T5
Phone: 250-469-9757 www.ecora.ca

LOCATION & KEY PLAN - VICTOR LAKE

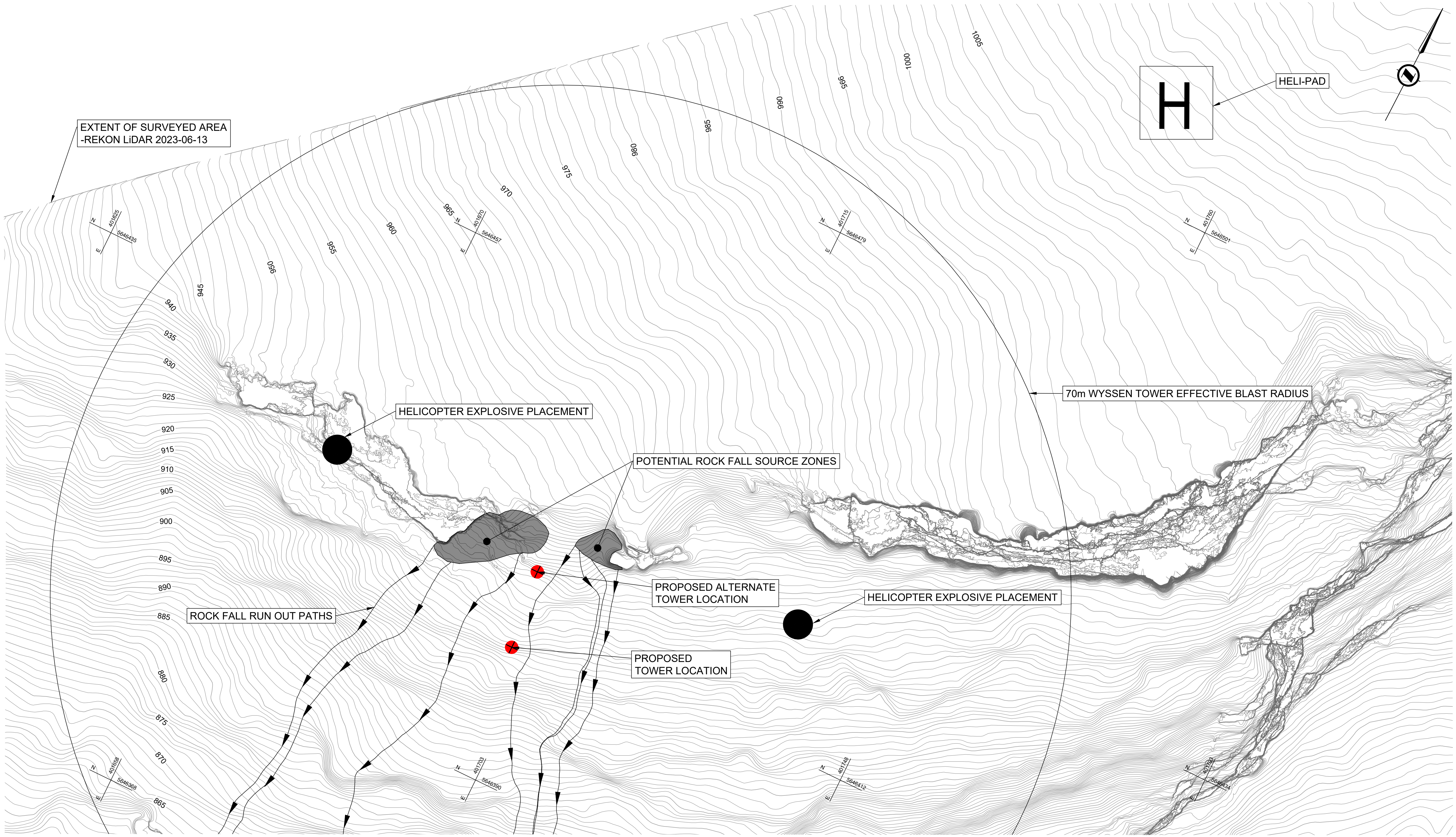
REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION
VICTOR LAKE (PATH NO. 14.4)

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
-	26265-0000	-	R2-1234-200	0

PLOTTED: 2023/08/04 11:55 AM BY: Tomos Edmonds

PLOTTED: 2023/08/04 11:55 AM BY: Tomos Edmonds

Z:\2020\Geotech\201740_bc_moti_as_and_when_geo_transcanada_hwy\04 - Revelstoke RACS\engineering\geotechnical\07_drawings\201740-04 VICTOR LAKE SHEETS - 11X17.dwg 2023/08/04 11:47 AM LAYOUT: 201 USER: tedmonds



PLAN

0 2 1:250 12m

GENERAL NOTES:

1. Digital base plan provided by REKON SOLUTIONS INC. 1.0 m minor & 5.0 m major LiDAR contour intervals, overall RMSE: 0.026 m.
2. Proposed RACS tower locations by Ecora Engineering & Resource Group Ltd. The locations shown are approximate only and will be field fit and approved by the ministry representative.

Drawing uses UTM Zone11 NAD83 Horizontal Datum, Vertical Datum CGVD28

PROPOSED RACS TOWER LOCATIONS			
PROPOSED TOWER	FOUNDATION LOCATION		ELEVATION
MAIN	401699 E	5646408 N	926 m
ALTERNATE	401698 E	5646419 N	939 m

REV	DATE	REVISIONS	SIGNATURE
0	2023/08/04	ISSUED FOR TENDER	

PROFESSIONAL SEAL

DRAWN BY T.EDMONDS DATE 2023-07-21
DESIGNED BY D. KRUGER & M.ROCHE DATE 2023-07-21
REVIEWED BY M. LAWS DATE 2023-08-04

CAD FILENAME 201740-04
DATE 2023-08-04

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION

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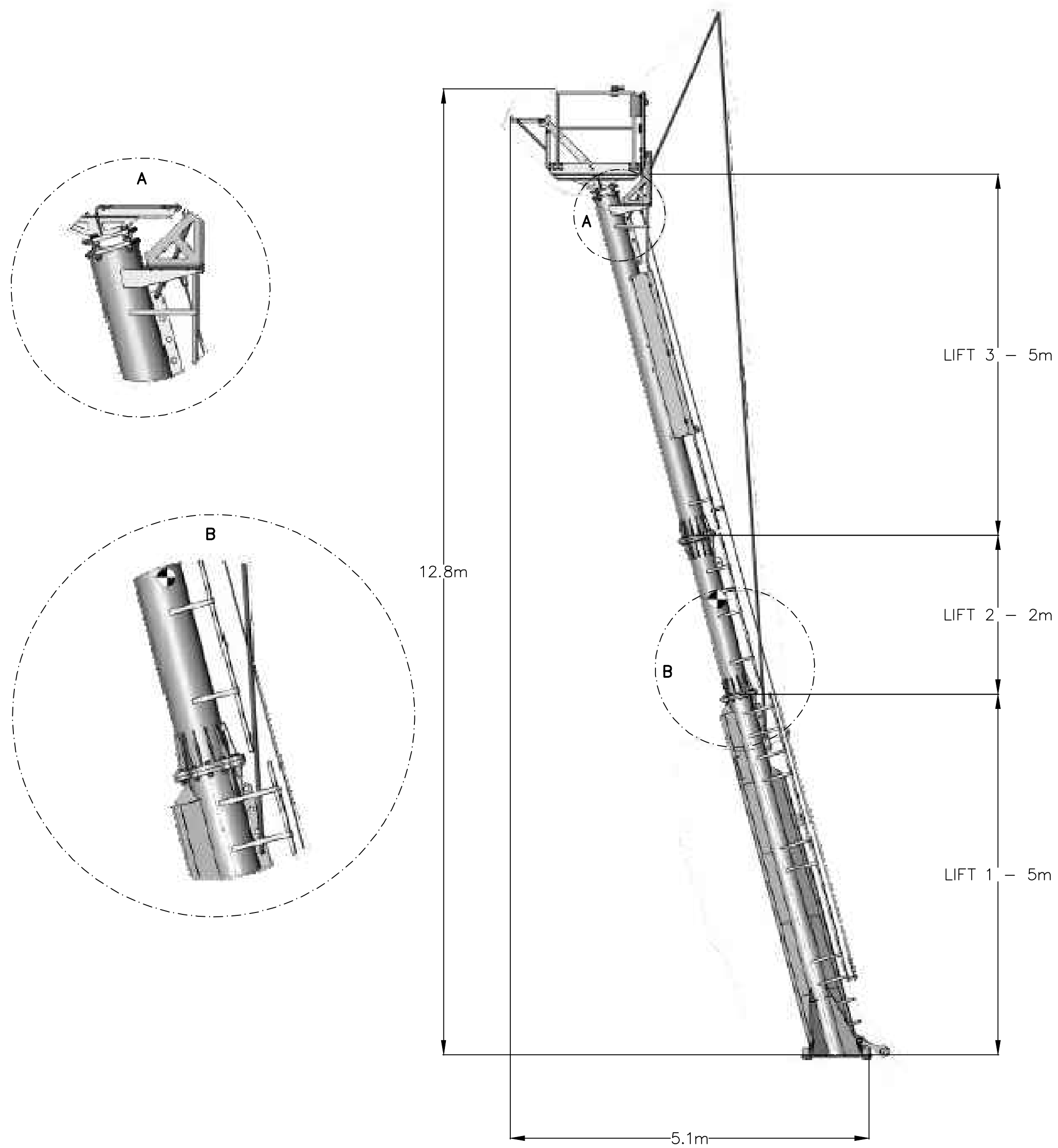
Phone: 250-469-9757 www.ecora.ca

SITE PLAN - VICTOR LAKE

REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION
VICTOR LAKE (PATH NO. 14.4)

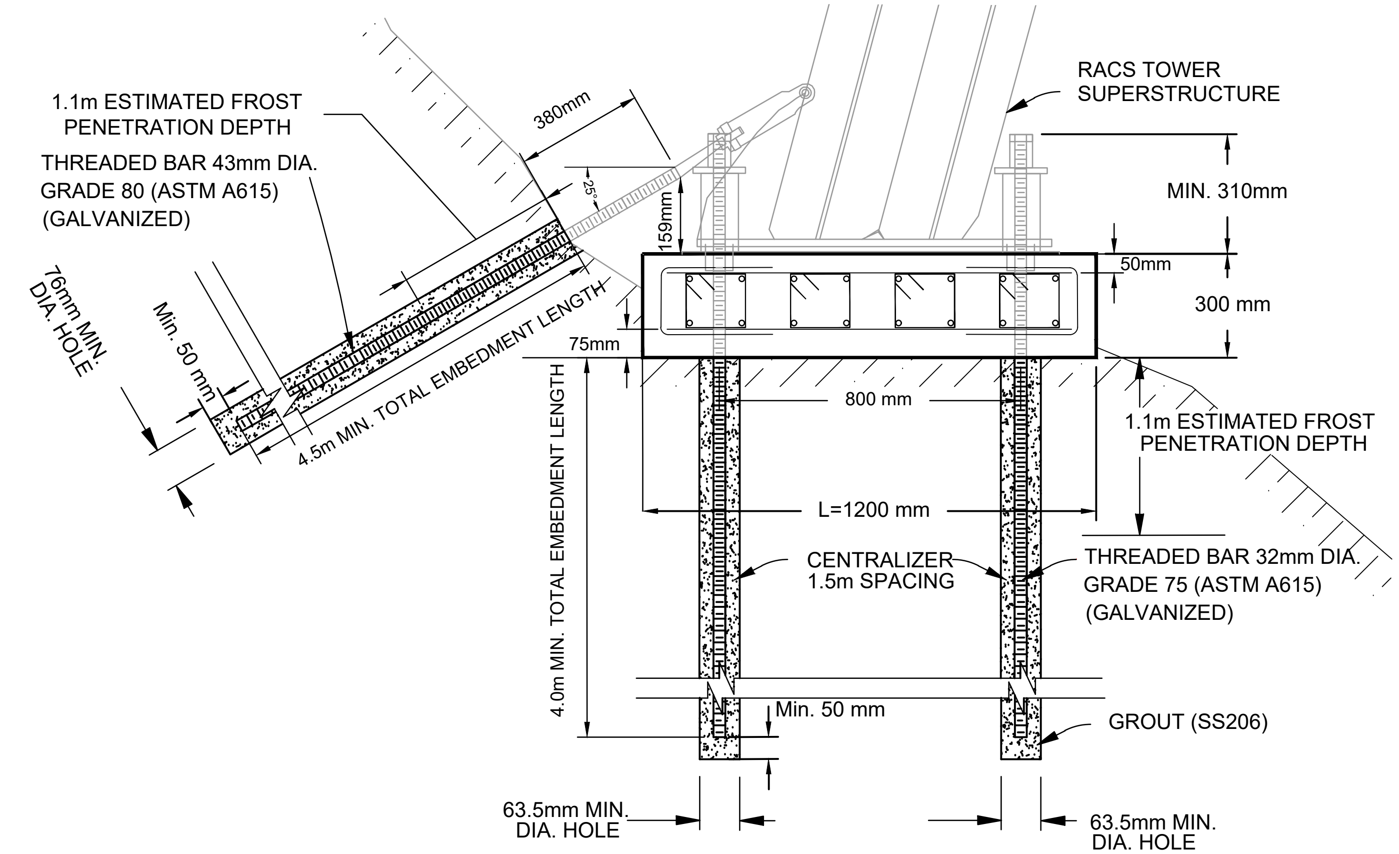
FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
-	26265-0000	-	R2-1234-201	0

PLOTTED: 2023/08/04 11:56 AM BY: Tomos Edmonds



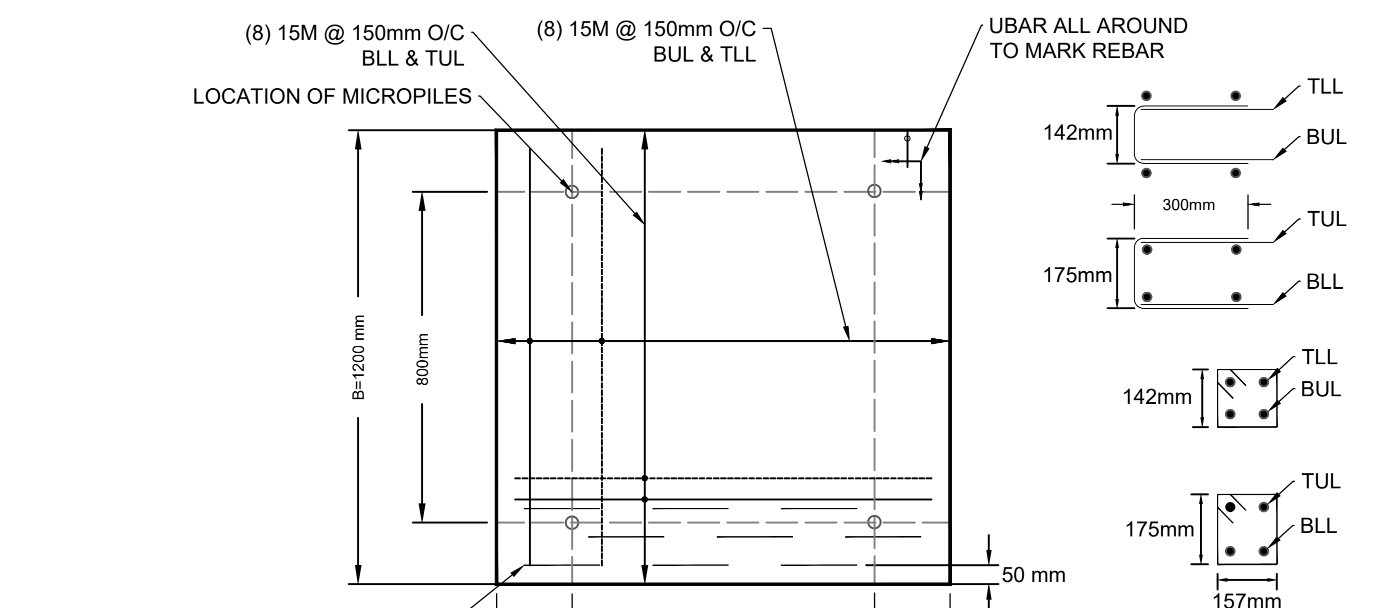
AVALANCHE TOWER (12m HIGH) SIDE VIEW

SCALE 0 0.5 1:50 2.5m



TOWER FOUNDATION MICROPILE/SHEAR RELIEF ANCHOR DETAILS

SCALE 0 0.1 1:10 0.5m



APPLY WHERE REQUIRED PER PLAN. STEEL REBAR FABRICATOR TO CONFIRM EXACT QUANTITIES AND SIZES.

TOWER FOUNDATION DETAIL (FOR ROCK)

SCALE 0 0.1 1:10 0.5m

THE CONTRACTOR SHALL BE RESPONSIBLE FOR THE CONSTRUCTION SEQUENCE OF TOWER ERECTION AND INSTALLATION AS PER MANUFACTURERS SPECIFICATIONS. ALL TEMPORARY WORKS REQUIRED FOR TOWER ERECTION SHALL BE SIGNED AND SEALED BY AN ENGINEER LICENSED TO PRACTICE IN BRITISH COLUMBIA AND EXPERIENCED WITH DESIGN OF TEMPORARY WORKS SIMILAR TO TEMPORARY WORKS REQUIRED FOR THIS PROJECT.

REV	DATE	REVISIONS	SIGNATURE
0	2023/08/04	ISSUED FOR TENDER	

PROFESSIONAL SEAL

DRAWN BY T.EDMONDS DATE 2023-08-02
DESIGNED BY D. KRUGER & M.ROCHE DATE 2023-07-21
REVIEWED BY M. LAWS DATE 2023-08-04
CAD FILENAME 201740-04
DATE 2023-08-04

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION

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TOWER FOUNDATION DESIGN DETAILS - VICTOR LAKE

REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION
VICTOR LAKE (PATH NO. 14.4)

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
-	26265-0000		R2-1234-202	0

1. GENERAL

1.1. The scope of work is outlined by these general notes as defined below for the Revelstoke Remote Avalanche Control System (RACS) - Victor Lake (path no.14.4) Tower Foundation

1.2. All materials, workmanship and construction shall be in accordance with the drawings and the project specifications.

1.3. The Contractor is responsible for field locating all utilities and temporary rockfall protection.

2. MICRO-PILES AND SHEAR RELIEF ANCHORS

2.1. Tower foundation micro-piles and shear relief anchors shall consist of 32 mm and 43 mm Double Corrosion Protection (DCP) threaded bars. The threaded bars shall be Steel Hot Rolled Grade 517 MPa (Fy) and 552 MPa (Fy) respectively meeting ASTM A615/A615M.

2.2. Steel materials shall be hot-dip galvanized conforming to ASTM A123. All grout and steel materials shall be products of established manufacturers regularly engaged in the manufacture of rock anchor and micro-pile materials for at least five years.

2.3. Threaded bars shall be new, straight, undamaged continuous without splices or welds. Cut-thread reinforcing bars not permitted. The threaded bars should not be subjected to the heat of torch or welding. Field cutting should be done with an abrasive wheel or band saw.

2.4. All micro-piles and shear relief anchors shall be carefully handled and shall be stored on supports to keep the steel from contact with the ground. Damage to the shear relief anchors or micro-piles as a result of overstressing, abrasion, cuts, nicks, welds and weld splatter shall be cause of rejection by the ministries representative. Shear relief anchors and micro-piles shall be protected from and sufficiently free of dire, rust, and other deleterious substances prior to installation. Heavy corrosion or pitting of shear relief anchors shall be cause for rejection by the ministries representative. Cut-thread reinforcing bars are not permitted.

2.5. Shear relief anchor and micro-pile lengths shall be installed according to plans, as detailed.

2.6. Shear relief anchor and micro-pile drill hole diameters for the tower foundation shall be minimum of 76 mm and 63.5 mm respectively.

2.7. All nuts and couplers for Tower Foundation shall be manufactured by the manufacturer and be sized for a galvanized bar. Spherical nut or hex nut with steel beveled plate washers may be used to provide the correct angle.

2.8. All shear relief anchors and micro-piles must be installed with the PVC centralizers spaced no more than 1.5 m O.C. beginning no more than 1.0 m from the bottom of the shear relief anchor or micro-pile. Centralizers shall be scheduled 40 PVC and 10 mm smaller in outside diameter than the borehole diameter to allow free grout flow.

3. MICRO-PILES AND SHEAR RELIEF ANCHOR GROUT

3.1. The Contractor shall complete all micro-pile and shear relief anchor grout work in accordance with MoTI SS 206.11 and 206.31 unless otherwise modified by this clause.

3.2. Grout cubes shall be collected and tested for compressive strength, in accordance with CSA A23.2-1B. Three cubes shall be tested at 3 (minimum 3 days & 20 MPa), 7 (minimum 30 MPa), and 28 (minimum 40 MPa) days. One set of nine cubes shall be collected for each of the grout batches mixed for the anchor installation.

4. MICRO-PILES AND SHEAR RELIEF ANCHOR INSTALLATION

4.1. Micro-pile and shear relief anchor holes shall be installed without loss of ground, which may require casing in soils. Holes shall not be drilled with bentonite or water. As soon as the hole drilling is complete, clean Micro-pile and shear relief anchors with centralizers shall be placed in the hole, subsequently the hole shall be tremie grouted.

4.2. Acceptable Tolerances are as follows:

4.2.1. Micro-pile and shear relief anchor position: Contractor shall use template to ensure proper shear relief anchor and micro-pile positioning with +/- 3mm horizontally.

4.2.2. Micro-pile and shear relief anchor Length: No less than specified length.

4.2.3. Micro-pile and shear relief anchor Inclination: +/- 2 degrees.

5. TOWER FOUNDATION DESIGN CONSIDERATIONS:

5.1. Excavate rock to provide a level base.

5.2. For pile caps thicker than 750 mm constructed of 15M rebar, a third 'mat' of rebar is required.

5.3. The additional 'mat' of rebar shall be placed within the cage near the center OR in the case of a rock 'step' additional stirrups are to be provided to encase the additional 'mat' of rebar.

5.4. Should the leveling pad rock subgrade cross fall or step, the bottom mat is to 'loosely' follow the profile of the rock. There shall be no more than 200 mm from bottom of cage to surface of rock through difficult sections, and as close to 75 mm cover as possible through smoother sections.

5.5. An additional mat of rebar can be provided with stirrups or 'U' bars with laps as specified (600 mm for 15M)

LOAD SUMMARY		
STRUCTURE	FOUNDATION TYPE	DESIGN LOAD * (kN)
VICTOR LAKE SITE	VERTICAL MICROPILE	146
	SHEAR RELIEF ANCHOR	312

* The Design Loads are factored

Ultimate Bond Strength (BS) = 279.3 kN/m for 63.5 mm hole diameter (in rock).
334.3 kN/m for 76 mm hole diameter (in rock).

6. MICRO-PILES AND SHEAR RELIEF ANCHOR TESTING

The grout mixture used for the micro-pile and shear relief anchor tests need to have cured at least 72 hours or attained at least their specified 3-day compressive strength at the time of testing.

6.1. VERIFICATION TESTS:

6.1.1. A sacrificial verification test micro-pile shall be installed and tested at a location specified by the engineer.

6.1.2. Verification tests shall be performed according to the verification test load schedule below:

LOAD	HOLD TIME (MINUTES)
AL	1
0.13 VTL	10 - RECORDED AT 1,2,4,5 AND 10
0.25 VTL	10 - RECORDED AT 1,2,4,5 AND 10
0.38 VTL	10 - RECORDED AT 1,2,4,5 AND 10
0.50 VTL	10 - RECORDED AT 1,2,4,5 AND 10
0.63 VTL	10 - RECORDED AT 1,2,4,5 AND 10
0.75 VTL (CREEP TEST)	60 - RECORDED AT 1,2,4,5,6,10,20,30,50,60
0.88 VTL	10
1.00 VTL	10
AL	1

Verification Test Load (VTL) = Test Bond Length (TBL) x Bond Strength (BS)
Unbonded length = 2.0 m & Bonded Length = 1.0 m

a. AL = alignment load (less than or equal to 0.025 VTL).

b. Soil movement must be measured after each load increment has been achieved and at each time step.

c. Permanent micro-pile movement must be recorded.

6.2. VERIFICATION TEST ACCEPTANCE CRITERIA

6.2.1. A verification test micro-pile shall be considered acceptable when all of the following criteria are met:

a. Total creep movement is less than 2 mm between the 6- and 60-minute readings and the creep rate is linear or decreasing through the creep test load hold period.

b. The total movement (δVTL) measured at 1.00 VTL exceeds 80 percent of the theoretical elastic elongation of the unbonded length of the test micro-pile.

c. Pullout does not occur before VTL. Pullout failure is defined as the inability to further increase the test load while there is continued pullout movement of the test micro-pile.

6.3. PROOF TESTS

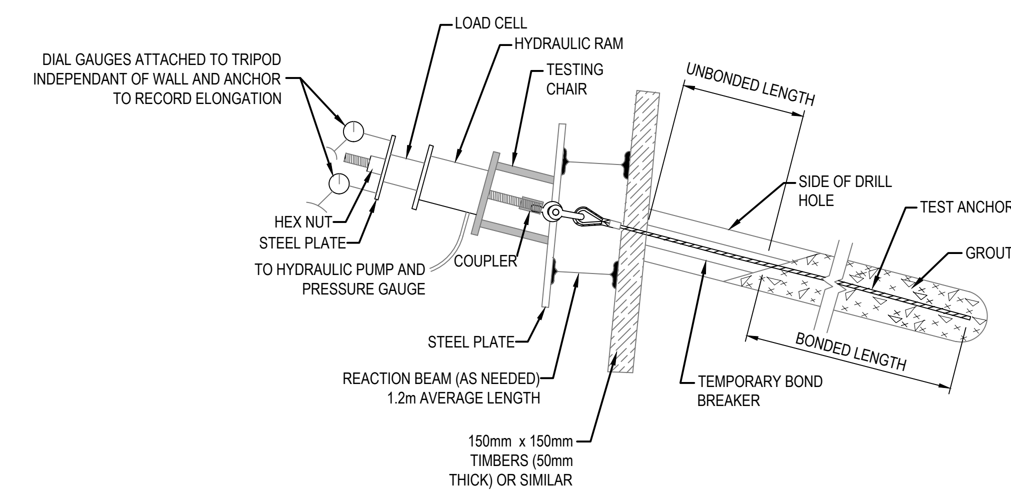
6.3.1. A shear relief anchor proof test shall be undertaken at a location specified by the engineer.

6.3.2. Proof tests shall be performed according to the test load schedule below:

LOAD	HOLD TIME (MINUTES)
AL (0.05 DL MAXIMUM)	UNTIL STABLE
0.25 DL*	UNTIL STABLE
0.50 DL	UNTIL STABLE
0.75 DL	UNTIL STABLE
1.00 DL	UNTIL STABLE
1.25 DL	UNTIL STABLE
1.33 DL CREEP TEST	10**

* Design Load (DL) = Test Bond Length (TBL) x Bond Strength (BS)

** Creep Test, if the anchor moves more than 1mm during the 10-minute hold, maintain load for an additional 50 minutes.
Proof test shear relief anchor shall be fully grouted.



TEST APPARATUS SET-UP FOR VERIFICATION & PROOF TESTING

REV	DATE	REVISIONS	SIGNATURE
0	2023/08/04	ISSUED FOR TENDER	

PROFESSIONAL SEAL

DRAWN BY T.EDMONDS DATE 2023-08-02
DESIGNED BY D. KRUGER & M.ROCHE DATE 2023-07-21
REVIEWED BY M. LAWS DATE 2023-08-04

CAD FILENAME 201740-04
DATE 2023-08-04

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION

WYSSEN switzerland
avalanche control

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ECORA ENGINEERING & RESOURCE GROUP LTD.
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GEOTECHNICAL CONSTRUCTION NOTES - VICTOR LAKE

REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION
VICTOR LAKE (PATH NO. 14.4)

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
-	26265-0000		R2-1234-203	0

PLOTTED: 2023/08/04 11:56 AM BY: Tomos Edmonds

1. GENERAL NOTES

1.1. Pile cap has been designed in accordance with MoTI Standard Specification 2020.

1.2. Contractors, suppliers, subtrades, etc. are to ensure that they are working on current drawings and should verify that they are in possession of the latest issue. Disregard obsolete drawings. Do not build from drawings unless they indicate "issued for construction".

1.3. Specified loads (not factored):

Importance category = Low.

Dead Load of tower = 1.980 kg (LS6-5 Wyssen Avalanche Control Tower).

Refer to Geotechnical Design Report dated 2023-07-21 (Ecora file no. 201740-04) for climatic and seismic information.

1.4. Foundations have been designed with a maximum ULS bearing stress calculated at 820 kPa (17,000psf), for given factored design loads. All site preparation and bearing capacity to be reviewed by a registered geotechnical engineer prior to forming foundation. Pile cap to be placed on well compacted base free of organics.

1.5. All products specified on drawings to be installed in accordance with the manufacturer's written instructions.

1.7. Do not scale drawings.

1.8. The contractor is responsible for all temporary bracing and shoring required for construction loading and stability until the project is completed.

1.9. The contractor is responsible for ensuring that all roof rainwater and foundation drains are discharged in accordance with local authority having jurisdiction.

1.10. All mechanical, electrical, plumbing, ventilation and draining design shall be performed by others if required by the local authority.

1.11. All construction to be in accordance with MoTI Standard Specifications SS 145. All changes shall be forwarded to Ecora prior to proceeding with construction.

1.12. The contractor shall check and verify all dimensions, elevations and conditions prior to starting construction. The engineer shall be notified immediately of any discrepancies or inconsistency between structural drawings and architectural drawings. Any discrepancies not reported become the responsibility of the contractor.

1.13. If site conditions differ from those anticipated or as shown on the drawings (building, building components, property lines, soil conditions etc.), the contractor shall immediately notify the engineer for corrective or remedial work. Failure to notify engineer will make the contractor responsible for all conditions and costs associated.

1.14. The contractor is responsible for all costs associated with the correction of deficiencies as directed by the engineer.

1.15. Contractor must ensure that construction loads imposed on the structure do not exceed the specified loads noted above.

1.16. Contractor to ensure that concrete is ground smooth and tower is plumb prior to tightening of shear relief anchors to structure. Contractor to request leveling grout specification if required and tolerances as per manufacturers guidelines.

1.17. The contractor shall be responsible for the construction sequence of tower erection and installation as per manufacturers specifications. All temporary works required for tower erection shall be signed and sealed by an engineer licensed to practice in British Columbia and experienced with design of temporary works similar to temporary works required for this project.

2. CONCRETE NOTES

The concrete plant, equipment, and materials shall comply with the requirements of SS 211.

2.1. CONCRETE

2.1.1. All cold weather concreting shall be in accordance with MoTI Standard Specifications SS 211.19.

CONCRETE MIX DESIGN REQUIREMENTS

CONCRETE TYPE	PILE CAP
CSA EXPOSURE CLASS	F-1
MIN 28 DAY COMPRESSIVE STRENGTH, MPa	32
MIX W/CM RATIO	0.50
MAX AGGREGATE SIZE, mm	19
CEMENT TYPE	GU
AIR CONTENT, %	5-8%
CURING	TYPE 1

2.1.2. Provide 3/4" (19mm) chamfer on all exposed corners and edges.

2.1.3. Mixing and placing of concrete shall be in accordance with MoTI Standard Specifications SS 211.

2.1.4. Support concrete adequately until it has reached sufficient strength to carry the imposed loads.

2.1.5. Embedded materials shall be free from grease, scale, and other coatings.

2.1.6. Refer to architectural, mechanical and/or electrical drawings (as applicable) for holes, nailers, inserts, etc. that are required to be cast into the concrete.

2.1.7. Cement shall meet the requirements of CSA A3000 and be type 10 (normal) unless otherwise shown in drawings.

2.1.8. Fine and coarse aggregate grading shall be in accordance with CSA-A23.1/A23.2 for normal weight concrete.

2.1.9. Water shall comply with CSA-A23.1, CLAUSE 4.2.2.

2.2. REINFORCEMENT

2.2.1. Minimum splice length unless notes otherwise.

BAR Size: 10M 15M 20M 25M
Lap (mm): 660 965 1320 2032
Lap welded wire fabric 203mm.

2.2.2. Unless otherwise notes, provide clear concrete cover to rebar as follows:

A. Surfaces poured against ground 75mm.
B. Formed surfaces exposed to ground or weather 50mm.

2.2.3. Embedded materials shall be free from grease, scale, and other coatings.

2.2.4 Bars for reinforcing shall be deformed bars complying with CSA-G30.18, and shall be grade 400W unless noted otherwise on the drawings.

2.2.5 Welded steel fabric shall comply with ASTM A1064.

2.2.6 The wire for tying reinforcement shall be minimum 1.6mm diameter (16GA), black annealed wire.

2.3. INSPECTION AND TESTING

2.3.1. During construction, an independent testing agent certified in accordance with CSA A283 shall be engaged to sample, prepare and test concrete materials in accordance with CSA-A23.1/A23.2.

2.3.2. All concrete test results shall be forwarded to the ministry representative within 24 hours of the test.

2.3.3. Transmit delivery slips shall be prepared in accordance with clause 5.2.4.5.1 of CSA-A23.1, and shall be correlated to the placement of each casting. A copy of delivery slips shall be forwarded to the ministry representative within 24 hours of delivery of concrete.

REV	DATE	REVISIONS	SIGNATURE
0	2023/08/04	ISSUED FOR TENDER	

PROFESSIONAL SEAL

DRAWN BY T.EDMONDS DATE 2023-08-02
DESIGNED BY D. KRUGER & M.ROCHE DATE 2023-07-21
REVIEWED BY M. LAWS DATE 2023-08-04

CAD FILENAME 201740-04
DATE 2023-08-04

BRITISH COLUMBIA
MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE
SOUTHERN INTERIOR REGION

wyssen switzerland avalanche control

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STRUCTURAL CONSTRUCTION NOTES - VICTOR LAKE

REMOTE AVALANCHE CONTROL SYSTEMS INSTALLATION
VICTOR LAKE (PATH NO. 14.4)

FILE NUMBER	PROJECT NUMBER	REG	DRAWING NUMBER	REV
-	26265-0000		R2-1234-204	0

Z:\2020\Geotech\201740_bc_moti_as_and_when_geo_transcanada_hwy\04 - Revelstoke RACS\engineering\geotechnical\07_drawings\201740-04 VICTOR LAKE SHEETS - 11X17.dwg 2023/08/04 11:47 AM LAYOUT: 204 USER: tedmonds

Appendix B

Victor Lake Desktop Report

Revelstoke Remote Avalanche Control System (RACS) Desktop Assessment Victor Lake (Path No. 14.4)

Presented To:

Ministry of Transportation and Infrastructure

Dated:	February 2023
Ecora File No.:	201740-04
MoTI Project No.:	26062

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Presented To:

BC Ministry of Transportation and Infrastructure
Southern Interior Region
447 Columbia Street
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Version Control and Revision History

Version	Date	Prepared By	Reviewed By	Notes/Revisions
0	2023-02-17	DT/NM-H/DJK	MJL	ISSUED FOR USE

Limitations of Report

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Appendix A

Acronyms and Abbreviations

AEP	Annual Exceedance Probability
AGS	Australian Geomechanics Society
ARD	Acid Rock Drainage
ASCE	American Society of Civil Engineers
BC	(Province of) British Columbia
BCBC	British Columbia Building Code (2018)
BC AGRI	British Columbia Ministry of Agriculture
BC MoE	British Columbia Ministry of Environment
BC MoTI	British Columbia Ministry of Transportation and Infrastructure
BC SIFT	British Columbia Soil Finder Information Tool
CFEM	Canadian Foundation Engineering Manual
CHBDC	Canadian Highway Bridge Design Code (2016)
CPR	Canadian Pacific Railway
DEM	Digital Elevation Model
EGBC	Engineers and Geoscientists British Columbia
FoS	Factor of Safety
GIC	Geographic Information Centre
GSC	Geologic Survey of Canada
G.I.T	Geoscientist in Training (registered with EGBC)
LiDAR	Light Detection and Ranging
LKI	Landmark Kilometer Inventory
m asl	meter(s) above sea level
MCRR	Maintenance Contractor Rockfall Reports
ML	Metal Leachate
NBCC	National Building Code of Canada (2020)
NRCan	Natural Resources Canada
P.Eng.	Professional Engineer (registered with EGBC)
P.Geo.	Professional Geoscientist (registered with EGBC)
PGA	Peak Ground Acceleration
PLT	Point Load Test
PTI	Post-Tensioning Institute
RACS	Remote Avalanche Control System
RISC	Resource Inventory Standards Committee
Sa(T)	Spectral Acceleration
SSHC	Standard Specifications for Highways
TCH 1	Trans-Canada Highway 1
UBC	University of British Columbia
UCS	Uniaxial Compressive Strength

1. Introduction

1.1 General

Ecora Engineering & Resource Group Ltd. (Ecora) has been retained by the British Columbia Ministry of Transportation and Infrastructure (BC MoTI) to provide geotechnical engineering services for three proposed Remote Avalanche Control System (RACS) sites to be situated along the Trans-Canada Highway (TCH) near Revelstoke, BC. The project may also include the construction of a RACS Support Building (avalanche materials storage structure) that is expected to go into Jumping Creek Pit.

The three Priority Paths are Panther, Silver Creek (approximately 46 km and 30 km, respectively, east of Revelstoke), and Victor Lake (approximately 15.5 km west of Revelstoke). Typically, the RACS towers are eight to ten metres high and are inclined to overhang an avalanche initiation zone. The system allows the BC MoTI to undertake avalanche control during all weather conditions, at any time, thereby reducing the risk of uncontrolled avalanches impacting highway traffic and allows the BC MoTI to better manages its assets.

This desktop geotechnical assessment focuses on the Victor Lake Priority Path (Path Number 14.4) and is intended to provide high level geohazard and geotechnical engineering inputs to assist with the design of the RACS. It is understood that the project objective it to install the proposed RACS towers at the Victor Late site in the fall of 2023.

This work was approved by Heidi Evensen, (P.Eng.) Geotechnical Engineer with MoTI. Work will be carried out in accordance with applicable BC MoTI Standards and Technical Circulars, the *Professional Governance Act* (2021), and relevant Professional Practice Guidelines, as published by Engineers and Geoscientists British Columbia (EGBC).

1.2 Scope of Work

The geotechnical scope of work for this project was outlined in Ecora's *Geotechnical Work Plan: TransCanada Highway (HWY 1) – RACS-TCH Revelstoke East and West* (2023), and included a phased approach; however, this report pertains to Phase 1, Task 3, as outlined below:

- Phase 1:
  - Task 1: Project Planning, Coordination, and Project Management.
  - Task 2: Background Review and Site Reconnaissance with a stand-alone Site Reconnaissance Report.
  - Task 3: Desktop Review Reports for each Priority Path (Panther, Silver Creek, and Victor Lake).

1.3 Site Description

The TCH is a major transcontinental west-east highway that traverses the breadth of Canada between the Pacific and Atlantic Oceans. With in within British Columbia (BC) it traverses through a number of mountain passes, which are subject to seasonal avalanches. The Victor Lake Priority Path is located just outside the eastern boundary of Victor Lake Provincial Park, BC.

The Victor Lake Priority Path is located on a southeast facing slope in the Selkirk Mountain range and lies at a starting elevation of approximately 1,060 m above sea level (m asl) down to 535 m asl (TCH elevation). Victor Lake lies immediately downslope (south) of the project site, below the TCH, and drains to the southwest via Victor Creek into the Eagle River.

The site is characterized by steep rock faces with little to no overburden materials observed. Scattered trees are located in areas with nominal soil cover. Large rock outcropping is prevalent at the site, and the rock mass appears to consist of horizontally layered widely spaced beds and is anticipated to be of medium to high strength. From the site reconnaissance, the rock mass can be described to consist of two main joint sets which are wide to very widely spaced that intersect to create tabular blocks, and the joint persistence seem to vary from medium to very high. The rock mass does not appear to be highly weathered, and it is anticipated that the failure mechanism of the rock mass is structurally controlled.

A flat area behind the crest of the bedrock face, above the snow avalanche start zone, has been identified as a potential area for construction of the foundation.

A Digital Elevation Model (DEM) has been produced from LiDAR data using GEM4D software of the Victor Lake Priority Path. The DEM has been constructed from high-resolution LiDAR data received from the BC MoTI which was supplemented by publicly available information (Terrain Resource Information Management, GeoBC). Unfortunately, the high-resolution LiDAR data did not cover the full extent of the project area; therefore, lower resolution data was used to supplement the evaluation of the proposed RACS location.

The DEM has been used to evaluate the steepness of terrain, and the proposed RACS locations are indicated in Figure 1-1.

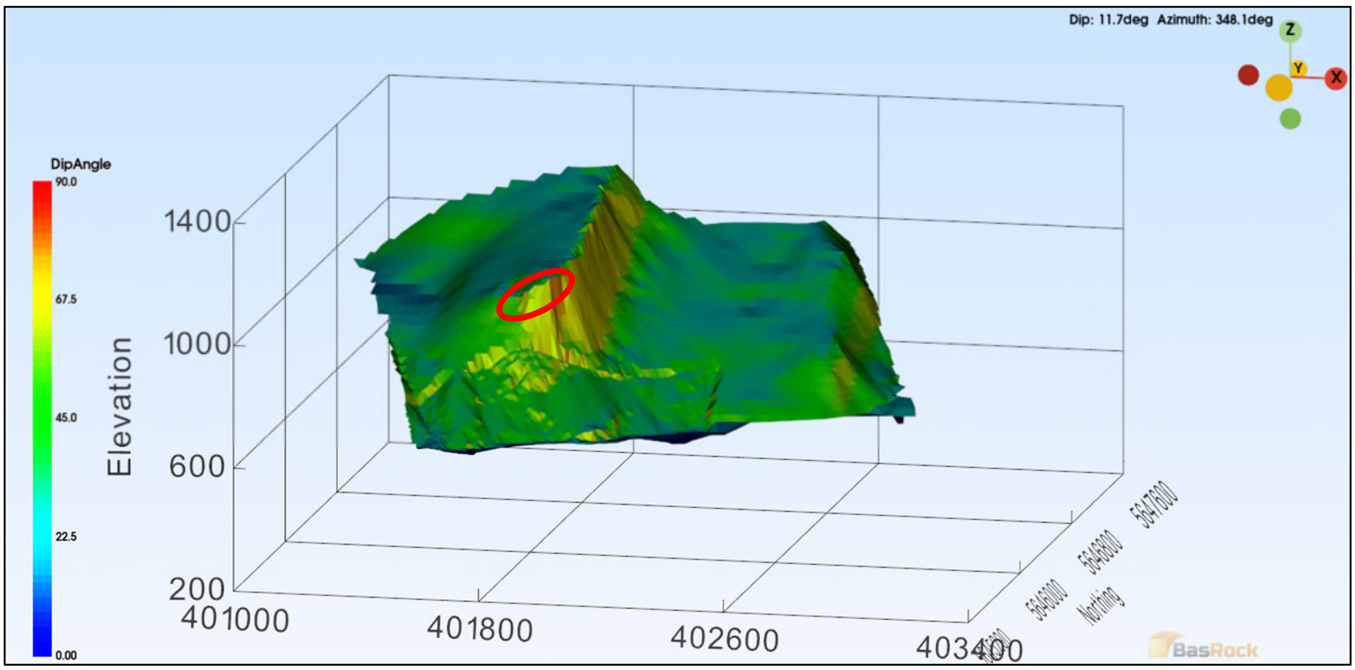

Figure 1-1 DEM constructed from higher and lower resolution LiDAR.

It can be seen from Figure 1-1 that the slope of the terrain around the proposed RACS location varies from approximately 45° to in excess of 67.5° and that rope access and fall arrest equipment will have to be used during investigation and construction of the RACS. Ecora has inferred bedrock at locations with slopes greater than 60° (Hungr, 2014).

2. Background Review

2.1 Sources of Information

Ecora reviewed the following relevant background information related to the project.

- *Revelstoke Remote Avalanche Control Systems (RACS), Site Reconnaissance Report* (Ecora, 2023).
- BC MoTI Columbia Program Snow Avalanche Atlas (BC MoTI, 2015).
- BC MoTI Road Weather Stations (RWS) data.
- The University of British Columbia (UBC) Geographic Information Centre (GIC) – historic aerial photographs.
- Readily available published sources of geologic data.
- iMapBC Water Well database.
- The National Resources Canada (NRCan) seismic hazard information.
- Point cloud information, contour maps and orthophotos) for received from MoTI.
- MC MoTI Maintenance Contractor Rock Fall Reports (MCRR)records for the Victor Lake area.

2.2 BC MoTI Snow Avalanche Atlas

The BC MoTI Columbia Program Snow Avalanche Atlas (BC MoTI, 2015) provides a high-level overview of the Victor Lake Priority Path site (attached in Appendix A).The report describes Victor Lake Path #14.4 as starting within the steep rock cliffs, and tracking downslope via breaks in vegetation, generally where gullies exist. The majority of avalanches impacting the TCH follow the dominant gully on the west side of Path 14.4.

Table 2.1 Columbia Program Path #14.4 Overview

<table>
<tr><th colspan="6">Victor Lake Terrain Characteristics Path Number: 14.4</th></tr>
<tr><td colspan="6">Terrain Characteristics:</td></tr>
<tr><td colspan="3">Vertical Fall: 670m</td><td colspan="3">Starting Zone: 1220m asl - 915 m asl</td></tr>
<tr><td colspan="3">Aspect: Southeast</td><td colspan="3">Runout Zone: 570m asl - 550 m asl</td></tr>
<tr><td colspan="6">Slope:</td></tr>
<tr><td colspan="2">Starting Zone: 41°</td><td colspan="2">Track: 40°</td><td colspan="2">Runout Zone: 0°</td></tr>
<tr><td colspan="6">Slope Hazards:</td></tr>
<tr><td colspan="3">Type: Avalanche, Rockfall</td><td colspan="3">Event Frequency: 4 per year (3-month return period)</td></tr>
<tr><td colspan="6">Infrastructure in Path:</td></tr>
<tr><td colspan="3">Road Width: 7 m</td><td colspan="3">Road Length: ~750m</td></tr>
<tr><td colspan="6">Slope Hazard Infrastructure Installed:</td></tr>
<tr><td colspan="3">Structure Type: Lock-block Wall</td><td colspan="3">Location: West side of runout path</td></tr>
<tr><td colspan="3">Install Date: 2002</td><td colspan="3">Maintenance: Ongoing – Debris Cleanout</td></tr>
</table>

2.3 Climate

The BC MoTI weather station RWS Clanwilliam Station (Station Code: 38124) is located approximately 1.5 km east of the Victor Lake Priority Path site, at an elevation of approximately 550 m asl, and provides historical weather records relevant to the site between December 6, 1999 and October 17, 2022. Data was collected twice per day at 06:00 hours and 18:00 hours; however, only between the months of October to April, annually.

The RWS Clanwilliam weather station data indicates that the average daily maximum temperature generally remains below freezing (<0°C) between December through to February. Average monthly new snow accumulation peaks in December (1.61 m), while the average total snowpack peaks in February (1.19 m). Table 2.2 provides a summary of the average minimum and maximum temperatures, average monthly sum of new snow, and average total snowpack for the months of October through to April, recorded at the RWS Clanwilliam station between 1999 and 2022.

Table 2.2 Historical Weather Data Summary Clanwilliam Station #38124 (1999-2022)

Month	Average **Maximum Temperature (°C)**	Average **Minimum Temperature (°C)**	**Average** Monthly **Sum of New Snow (m)**	Average Total **Snowpack (m)**
October	7.4	4.1	0.07	0.01
November	1.8	-0.3	0.79	0.12
December	-1.8	-3.9	1.61	0.55
January	-1.8	-4.1	1.52	0.98
February	-0.9	-4.3	1.03	1.19
March	2.6	-1.3	0.55	1.18
April	7.0	1.2	0.13	0.72

2.4 Historical Aerial Photographs Review

Available historic aerial photography obtained from the Geographic Information Centre (GIC) at the University of British Columbia (UBC) for the area between 1945 and 2008 was reviewed to assist with identifying large scale geomorphological features that would be difficult to identify in the field. Identification of features is limited to the resolution and the elevation at which the aerial photography was taken. Table 2.3 summarizes the aerial photographs (year, scale, type) used.

Table 2.3 Summary of Aerial Photographs Reviewed

Year	Aerial Photo No.	Scale	Type
1945	A9423: 4-7; 74-75; 78-79	Not available	Black and White
1951	BC1392:61-63; 69-73	Not available	Black and White
1961	BC4002: 155-156 BC4003: 39-40; 156-160	1:15,840	Black and White
1970	BC7265: 128-130; 159-161; 228-233; 254-258 BC7266: 6-8	1:16,000	Black and White
1975	BC7776: 162-163; 217-220; 221-224	Not available	Black and White
1984	BC84077: 59-62; 72-74; 129-133	1:20,000	Black and White
1991	BCB91133: 158-160 BCB91148: 218-222	1:15,000	Black and White

Year	Aerial Photo No.	Scale	Type
	BCB91150: 11-15 BCB91151: 10-14		
1996	BCB96042: 33-35; 40-44; 118-121; 122-123	1:15,000	Black and White
2001	BCC01025: 92-93 BCC01026: 171-173; 229-232	1:30,000	Colour
2007	BCC07006: 118-121; 128-132; 179-181; 214-216	1:20,000	Colour

Review of the aerial photographs noted the following (see Figure 3.1):

- By 1945, the Canadian Pacific Railway (CPR) line had been established, and a paved, single lane roadway had been constructed along the existing the TCH alignment. North of the Victor Lake Priority Path site, historic records (iMapBC) indicate a wildfire occurred in 1931, impacting approximately 14.85 km^2 (1485.2 ha), upslope of the TCH between elevations of 560 m to 980 m asl. The impacts were observed in the 1945 aerial photos, which showed sparse vegetation cover.

  The project area is bedrock controlled with evidence of several historic rockslides/landslides upslope and to the east (indicated as $\frac{Cw-Am}{Rs}$ and $\frac{Cv}{Rs}$ in Figure 3.1) of the bedrock outcrop (indicated as $Rs - Rf$) of where the proposed RACS are to be located. The slope east-adjacent to- and below the bedrock outcrop at the proposed RACS was observed to have active slope raveling and/or seasonal avalanches. A large historic rockslide/landslide path was observed on the lower slope, below the bedrock outcrop at the proposed RACS site (at approximately 720 m asl) which extended down to the TCH. Another historic lower slope rockslide/landslide was observed to the west of the RACS site bedrock outcrop, from approximately 800 m asl extending down to the TCH.

  Victor Creek lies to the east of the proposed RACS location, draining south towards Victor Lake, and was observed to have been infilled with debris from rockslides/landslides upslope along the creek. The right side of the creek (looking upstream) was observed to have avalanche track-like features, initiating from the crest of the bedrock outcrop, traversing the slope westwards down to the creek (indicated as $\frac{Cx}{Rs}$ in Figure 3.1).

- By 1961, work to realign and widen the TCH had commenced. The vegetation was observed to have significantly recovered, with moderate density coverage across the impacted area.

  It should be noted that the flight line for this time period did not cover a portion of the area to be assessed.

- By 1970, construction to realign and widen the TCH had been completed, which included a rest stop along the eastbound lane, downslope of the proposed RACS bedrock outcrop, and apparent grading of the slope along the highway. The vegetation was observed to have continued to recover, with dense coverage across the impacted area.

  A 'fresh' rockslide/landslide was observed to the west of the bedrock outcrop of the proposed RACS location, in an area previously identified as having historic landslides (with in the area mapped as $\frac{Cx}{Rs}$). Active raveling and/or avalanche tracks continue to be apparent (indicated as $\frac{Cv}{Rs}$ in Figure 3.1).

Historic Google Earth™ images were used to supplement the aerial photography of the project site between 2001 and 2020. It is noted that there is only partial coverage for the available years across the project site, and the resolution is very coarse in some areas. The following additional observations were made:

- By 2001, above Clanwilliam Lake (east of Victor Lake) a large rockslide/landslide, approximately 900 m long was observed, initiating at approximately 1180 m asl, and impacting the CPR tracks below.

- By 2011, the project area appears relatively unchanged. except for minor vegetation regrowth and active raveling paths from the crest of the bedrock outcrop.

2.5 Geology

MapPlace2 (beta) (Cui et al., 2017) indicates the underlying geology at the Victor Lake Priority Path lies at the interface of "calcsilicate gneiss, amphibolite, carbonite, marble" of the Monashee Complex, and is of Proterozoic to Lower Paleozoic age; and "paragneiss metamorphic" rocks of Paleoproterozoic age. A band of "quartzite, quartz arenite sedimentary rock" of the Monashee Complex lies between the two predominant bedrock types.

The Geologic Survey of Canada (GSC) 1:50,000 scale map "*Geology, Revelstoke, British Columbia*" (Thompson, 2004) indicates the site is predominantly underlain by biotite-quartz-feldspar paragneiss characterized by lenses and boudins of garnetiferous amphibolite; extensive lenticular masses of pegmatite". A chevron fold-like layer is shown to comprise "quartzite; sillimanite garnet biotite schist; biotite quartz feldspar paragneiss" of the Monashee Complex, with the apex of the fold pointing to the west. The band of quartzite, quartz arenite sedimentary rock was observed above the project site and appears to be confined by two faults trending northwest / southeast, approximately 1.4 km apart (see Figure 3.1).

The BC Soil Information Finder Tool (BC SIFT), developed by the BC Ministry of Agriculture (BC AGRI) and the BC Ministry of Environment (BC MoE), indicates the surficial soils, at the project site above approximately 580 m asl, are predominantly colluvial deposits overlying undifferentiated bedrock (indicated by polygon codes with Surficial Material beginning with $\frac{C}{R}$). The colluvial deposits are described as "massively to moderately-well stratified, non-sorted to poorly sorted sediments with any range of particle sizes from clay to boulders that have reached their present position only by direct, gravity-induced movement. Processes include slow displacements such as creep and solifluction and rapid movements such as earth flows". The colluvial soils are considered well drained, whereby "Water is removed from the soil readily but not rapidly…" The surficial soils below 580 m asl are described by the BC SIFT as fluvial deposits "…generally consist of gravel and sand with a minor fraction of silt and rarely of clay. The gravels are typically rounded and contain interstitial sand". The fluvial deposits are also described as well drained.

A normal fault (Victor Lake Fault) trending northwest / southeast lies to the west of the Victor Lake Priority Path, immediately west of Victor Lake, and coincides with the alignments of Victor Creek flowing down the south facing slope and Eagle River flowing down the north facing slope. Approximately 750 m east of Victor Lake lies another northwest / southeast trending fault.

2.6 Water Well Database

Reference to the Provincial Well Database, iMapBC, indicates that there is no water well records within close proximity to the project site, or at a comparable elevation.

The nearest water way is Victor Lake, approximately 40 m vertical distance downslope of the TCH.

2.7 Seismicity

The *Bridge Standards and Procedures Manual, Supplement to CHBDC S6-19* (MoTI, 2022) stipulates that structures shall be designed for no-collapse under multiple earthquake design levels (475, 975, and 2,475), with peak ground acceleration (PGA) values as determined by the GSC and reported in the National Building Code of Canada (NBCC, 2020).

The GSC has developed a probabilistic (6^{th} Generation) seismic hazard model (Kolaj et al., 2020) that forms the basis of the seismic design provisions of the 2020 National Building Code of Canada (NBCC, 2020), British Columbia Building Code (BCBC, 2018), and Canadian Highway Bridge Design Code (CHBDC; CSA, 2019).

Peak Ground Accelerations (PGA) and Spectral Accelerations (Sa(T)) for a reference “Site Class C” (very dense soil and soft rock) can be obtained from the Earthquakes Canada website for various return periods, with the reference values for the proposed RACS at the Victor Lake Priority Path is summarized in Table 2.4 below.

Table 2.4 “Site Class C” Design PGA and Sa(T) for the RACS at the Victor Lake Priority Path

Annual Exceedance Probability (AEP)	PGA (g)	Sa(0.2) (g)	Sa(0.5) (g)	Sa(1.0) (g)	Sa(2.0) (g)
1/475	0.0285	0.0644	0.0546	0.0353	0.0219
1/975	0.0454	0.104	0.0814	0.0521	0.0339
1/2,475	0.079	0.184	0.132	0.0813	0.0557

2.8 Maintenance Contractor Rock Fall Records

The BC MoTI provided Maintenance Contractor Rockfall Report (MCRR) records for the Victor Lake area at LKI km 55.89 to km 56.18 (RFI LM km 2.90 to km 3.19), between 1994 and 2018. The MCRR reports indicate that 44 events have occurred and reached the highway, which is an approximate average of two events per year, as detailed in Table 2.5.

Table 2.5 Estimated Volume of Rock Fall Events, based on the BC MoTI MCRR near Victor Lake Priority Path

Estimated Volume (m^3)[1]	Number of Events	Cumulative %
< 0.03	15	34
0.03 - 0.1	9	55
0.1 – 0.3	6	68
0.3 – 0.5	2	73
0.5 – 1.0	5	84
1.0 – 5.0	1	86
> 5.0	6	100

The MCRR reports indicate that March has the highest incidence of rock fall events along the TCH in the vicinity of Victor Lake with approximately thirteen reported incidents. June recorded twelve incidents, the second highest occurrence.

Based on historical weather data for Revelstoke BC (Environment Canada, 2023), freeze thaw conditions (when the temperature fluctuates below and above 0°C) occurs frequently during the months of March and April. These weather conditions could contribute to ice jacking and higher pore water pressures in the rock mass, leading to increased frequency in rock fall events (Wyllie, 2015 after Peckover, 1975).

3. Overview-Level Terrain Classification

Ecora has developed an overview-level terrain classification map (see Figure 3.1) based on historical aerial photography, LiDAR data, and additional publicly available information reviewed. The terrain classification was undertaken in accordance with the BC Terrain Classification System (Howes & Kenk, 1997), and following the BC Province methods for terrain mapping (RISC, 1996). These methods represent current standards of practice for terrain mapping in BC and provide a consistent standardized approach.

Interpretation of the terrain indicates the project area is bedrock controlled and predominantly underlain by a colluvial veneer. At the foot of the slope, along the TCH, the terrain is comprised of alluvial deposits.

Table 3.1 Terrain Classification for Victor Lake Priority Pass

Material Type	Map Symbol	Interpretation	Description
Alluvial Sediments	F^A	Active fluvial deposits.	Materials transported by water, typically comprised of rounded gravel, sand, and/or silt.
	$F^A f$	Alluvial fan deposits.	
Colluvial Sediments	C	Undifferentiated colluvial deposits.	Represents historic and/or active erosion and deposition of unconsolidated and unsorted sand, gravel, cobbles, and boulders through the process of mass movement.
	$\frac{C}{F}$	Undifferentiated colluvial deposits overlying fluvial deposits.	
	$\frac{Cv}{Rs}$	Veneer of colluvial deposits overlying moderately steep to steeply sloping bedrock.	
	$\frac{Cx}{Rs}$	Thin veneer of colluvial deposits overlying moderately steep to steeply sloping bedrock.	
	$\frac{Cw}{Rs}$	Mantle of colluvial deposits overlying steep to steeply sloping bedrock.	
	$\frac{Cw-Am}{Rs}$	Mantle of colluvial deposits overlying steep to steeply sloping bedrock with evidence of minor active snow avalanche tracks.	
	$\frac{Cw-Ao}{Rs}$	Mantle of colluvial deposits overlying steep to steeply sloping bedrock with evidence old snow avalanche tracks.	
Bedrock	$Rs-Rf$	Moderately steep to steeply sloping bedrock with periodic rapid surficial rock fall by falling, bouncing, and/or rolling.	Exposed bedrock comprising moderately steep to steep slopes (27° to >35°).

4. Summary of Anticipated Site Conditions

4.1 Overview

Based on Ecora's understanding of the project, the background review of available information, and the site reconnaissance we found the following:

- The geology of the project area is underlain by Paleoproterozoic metamorphic rock, and Monashee Complex metamorphic rock. A band of sedimentary Monashee Complex rock lies between the two metamorphic types.
- The site is confined by two northwest-southeast trending faults, one of which corresponds to Victor Creek.
- iMapBC shows a wildfire that had impacted the project area in 1931.
- Historic aerial photographs show the project area has been subject to a number of historic rockslides/landslides to the east of the bedrock outcrop the RACS are proposed at, and down the backslope, leading to Victor Creek.
- The aerial photographs also show the project area is subject to active raveling and avalanche activity. At the crest of the proposed RACS location, active rock fall was observed in the aerial photos.
- Based on the site reconnaissance, the proposed location of the RACS may be subject to rock fall. Rock fall events are expected to be ongoing from the bedrock outcrop source zone, as observed by two main linear rock fall paths extending downslope to the TCH.

- The topography and disturbance pattern indicates avalanche events in this area. The source zone of both patterns of snow avalanches is believed to be the open area below the bedrock outcrop indicated as $\frac{Cv}{Rs}$ in Figure 3.1. Areas with laterally wide disturbance lobe shapes along the tree line and a closed forest canopy downslope potentially indicate attenuation of laterally wide sheet avalanches at the tree line. The gully shaped disturbance paths extending downslope from the disturbance lobes lacking a funnel shape slope profile into the source zone indicate narrow events avalanche events may occur but do not channelize all of the snow in the source zone.

4.2 Anticipated Geohazards at RACS location

Landslides are classified in general by two distinct aspects, the material type, and the movement type. The material type includes rock, soil, and snow; with soil being further separated into earth for composition of sand and fine material, and debris for mainly coarse soil. The movement type can be described as fall, topple, slide, spread, or flow.

The following preliminary geohazards have been identified at the proposed RACS location:

- Debris and Snow Avalanche
  - Avalanches are described as a type of flow movement associated with abrupt and extremely rapid travel speeds. Debris avalanches are "*large, extremely rapid, often open-slope flows formed when an unstable slope collapses and the resulting fragmented debris is rapidly transported away from the slope*" (Highland & Bobrowsky, 2008). Snow avalanches often result from the detachment of a snow layer within the snowpack on an exposed slope.
  - Potential for occurrence in $\frac{Cw}{Rs}, \frac{Cx}{Rs}, \frac{Cv}{Rs}, \frac{Cw-Am}{Rs}$ and $\frac{Cw-Ao}{Rs}$ in Figure 3.1
- Rock Fall
  - Rock falls are described as "*abrupt, downward movements of rock or earth, or both, that detach from steep slopes or cliffs. The falling material usually strikes the lower slope at angles less than the angle of fall, causing bouncing. The falling mass may break on impact, may begin rolling on steeper slopes, and may continue until the terrain flattens*" (Highland & Bobrowsky, 2008).
  - Potential for occurrence primarily in slope below $Rs - Rf$ in Figure 3.1
- Shallow Debris Slide and Rock Slide
  - Landslides are described as "*downslope movement of soil, rock and organic materials under the effects of gravity*" (Highland & Bobrowsky, 2008). Shallow slides are often associated with movement along a shallow interface, often a soil veneer on bedrock.
  - Potential for occurrence in $\frac{Cw}{Rs}, \frac{Cx}{Rs}, \frac{Cv}{Rs}, \frac{Cw-Am}{Rs}$ and $\frac{Cw-Ao}{Rs}$ in Figure 3.1

5. Preliminary Geotechnical Design Considerations

5.1 Proposed RACS Target Locations

The proposed RACS explosive target locations have been identified as indicated in Figure 5-1, as received from the BC MoTI on January 27th, 2022, based on the primary helicopter explosive placements currently used to reduce snow avalanche hazard.

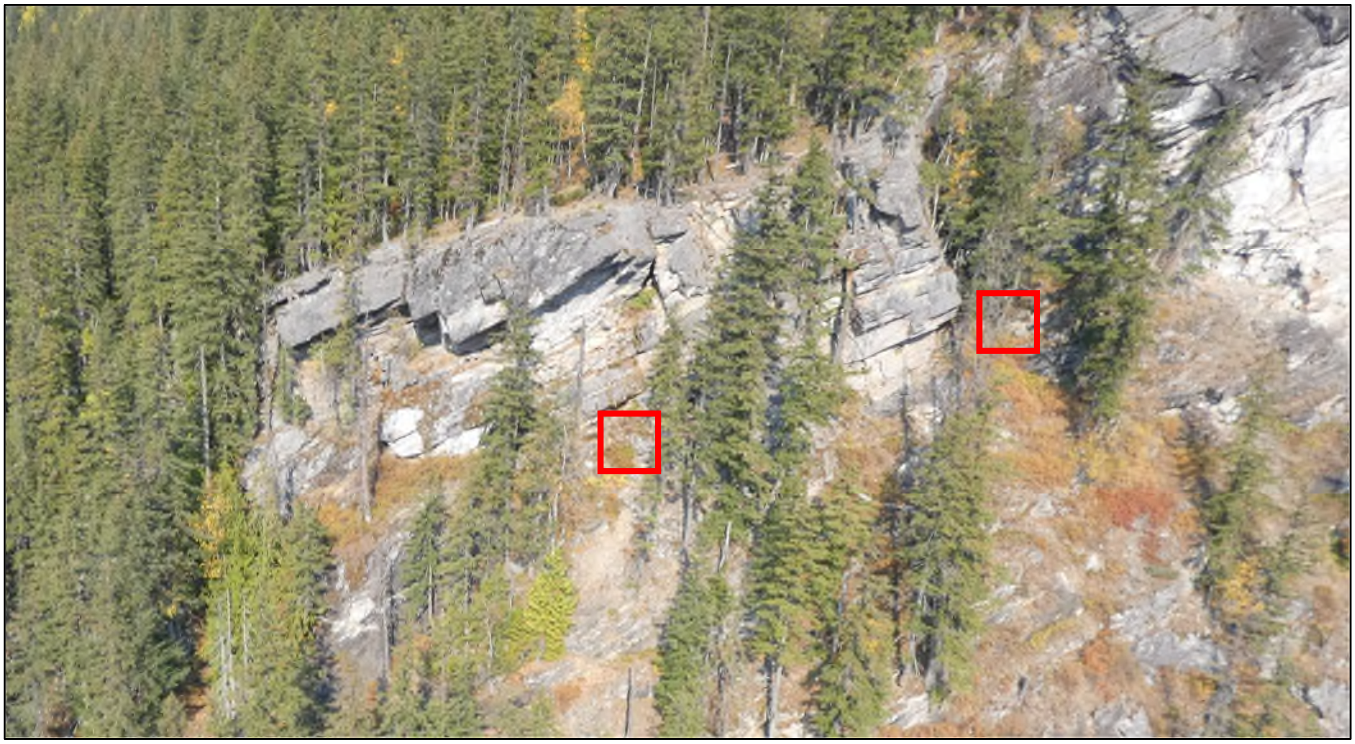

Figure 5-1 Proposed RACS explosive locations.

It is desirable that the final tower locations be selected to avoid geohazards completely. Avoidance of geohazards is generally preferable, as opposed to the use mitigation or stabilisation measures that would require additional workings or periodic maintenance above the TCH.

5.2 RACS Type

Ecora understands that there are four types of RACS being used in BC:

1) The North American Avalanche Guard System.
2) Gazex Avalanche Exploders.
3) Wyssen Avalanche Towers.
4) O'Bellx.

Ecora understands that currently, the BC MoTI is considering the use of the Wyssen Avalanche Towers RACS for the Victor Lake Priority Path.

The Wyssen RACS towers are typically eight to ten metres tall and are inclined so the deployment box overhangs an avalanche initiation zone. The deployment box holds up to twenty-four explosive charges, which can be individually detonated by dropping a retaining line at a pre-set height above the snow cover to trigger the avalanches.

5.3 Anticipated Ground Conditions

A helicopter site reconnaissance was carried out prior to snowfall on October 17th, 2022, and the results of the reconnaissance was issued in a report by Ecora (2023). The following additional information is provided:

- A thin veneer of colluvium overlying bedrock is anticipated immediately downslope of the steep rock faces.
- Sparse vegetation coverage, predominantly mature conifers, and sparse shrubs along the gently sloping horizontal discontinuities.
- The potential modes of failure include rock fall.

6. Geotechnical Recommendations for Detailed Design

As it is proposed to install the RACS towers at the Victor Late site in the fall of 2023 the project schedule will not accommodate the undertaking of an intrusive geotechnical site investigations in advance of detailed design. The geotechnical design of the proposed towers will be based on past experience from previous RACS tower sites in the TCH corridor and the desktop study. Assumptions used in the geotechnical design will be verified by a detailed site reconnaissance of each individual RACS tower location in early summer and verification testing of foundations during construction.

6.1 Proposed Geotechnical Analysis

After the tower locations have been selected, it is proposed that numerical analyses be undertaken to confirm the suitability of the proposed locations, as follows:

- Rock Fall Run Out Assessment
  - It is proposed that the use of spatial analyst tools to determine the expected rock fall trajectories (flow direction) at the tower catchment area.
- Micro-pile and inclined shear relief anchor design:
  - The determination of types, embedment length and number of piles/anchors required.
- Kinematic Stability Analysis
  - The analysis will identify potential failure modes based on the orientation and intersection of rock mass discontinuities.
- Global Stability Analysis
  - Limit state equilibrium stability analyses will be carried out to evaluate the long-term global stability of the slope at and above each of the tower locations under static and pseudo-static conditions and the determination of Factor of Safety (FOS).

A schedule for delivery and timelines is discussed in Section 8 of the report.

6.2 Anticipated Foundation Design

6.2.1 General

It is anticipated that structural support to the tower is to be provided by vertical micro-piles and inclined shear relief anchors. It is proposed that following design references be used in the design:

- CSA S6:19, Canadian Highway Bridge Design Code (CHBDC), 2019.
- BC MoTI Volume 1 – Supplement to CHBDC S6:19, 2022.

- BC MoTI Standard Specifications for Highway Construction 2020.
- FHWA-IF-99-015, Ground Anchor and Anchored Systems, Geotechnical Engineering Circular No.4, June 1999.
- PTI DC35.1-14, Recommendations for Pre-stressed Rock and Soil Anchors, 2014.

Figure 6-1 is provided below as an indication of anticipated foundation design for the RACS.

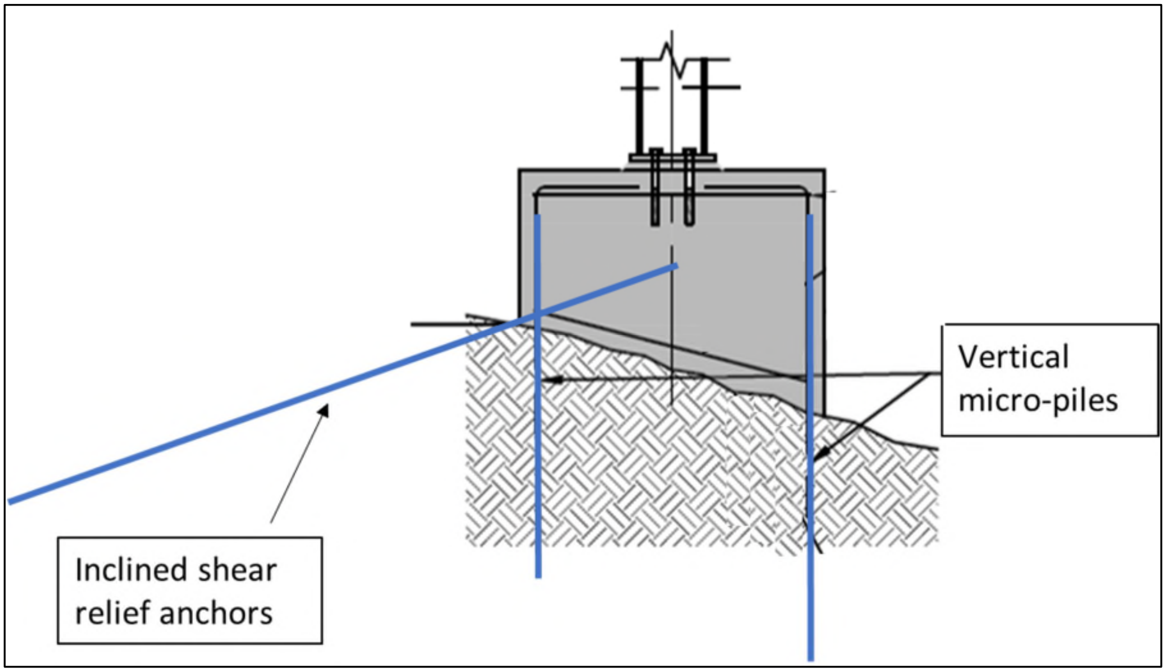

Figure 6-1 Anticipated foundation design.

The required bond lengths for the micro-piles and shear relief anchors will be calculated based on published typical average ultimate bond strengths between rock and grout as found in Table C6.1 from *Recommendations for Prestressed Rock and Soil Anchors* (Post-Tensioning Institute (PTI) DC35.1-14, 2014).

Based on Ecora's past experience for RACS tower structures (i.e., at 3-Valley Gap), in similar ground conditions, micro-piles and shear relief anchors are designed to resist factored design loads of up to 250 and 420 kN respectively. It is anticipated that the following foundation requirements would likely be required for the Victor Lake RACS towers as summarized in Table 6.1.

Table 6.1 Anticipated Foundation Specifications

Method	Threaded Bar Diameter (mm)	Drill Hole Diameter (mm)	Steel Grade (MPa)	Minimum Required Bond Length (m)	Comments
Micro-piles	32	63.5	517	4.0	Hot dip galvanized
Shear Relief Anchors	43	76	517	5.0	Hot dip galvanized

6.3 Proposed Detailed Site Reconnaissance

It is proposed that a detailed geotechnical reconnaissance be carried out of all proposed RACS tower sites to verify all assumptions utilized in site selection and detailed design of the foundations which could consist of the following:

- Rock fall hazard inspection:
  - Identification and evaluation of rock fall hazard zones that could affect the tower locations.
- Detailed structural and geological field mapping:
  - The mapping of rock outcrops to provide suitable inputs into kinematic stability analysis and foundation design. This would include an estimation of the maximum resistance of the rock mass to shearing (Barton-Bandis) based on the geometric properties of mapped discontinues and rock type. The geological field mapping will also identify rock fall sources zones, talus slopes and run-out zones to delineate areas of rock fall hazard and to provide suitable inputs into rock fall analysis utilized in the rock fall assessment.
- Estimation of Uniaxial Compressive Strength (UCS) or intact rock:
  - In situ field strength will be estimated using a Schmidt Rebound Hammer. Select samples could also be collected for laboratory testing using a Point Load Test (PLT) apparatus.

6.3.1 Chemical Degradation of Reinforced Concrete

Chemical degradation of reinforced concrete testing should be carried out on samples collected from the site, where required. The type of chemical degradation that occur in concrete is associated primarily with chemical changes occurring within the hydrated cement matrix, of which sulphate attack is commonly the most widespread threat to concrete durability. Concrete durability can also be affected by the introduction of chloride salts either as contaminants within the concrete during manufacture or during its subsequent exposure to a chloride-laden environment, for example where it comes into contact de-icing salt.

Due to the compressed project schedule that may not permit soil testing and the relatively small volume of concrete utilized in the RACS foundation construction, the foundation design could conservatively assume the use of C-1 concrete exposure class.

6.3.2 Frost Penetration

Frost susceptibility of soils refers to the propensity of the soil to grow ice lenses and heave during freeze and thaw cycles and is related to the size distribution of soil particles (CFEM, 2006).

Foundations shall be designed so that any length of micro-pile or shear relief anchor contributing to supporting the RACS tower is beneath the maximum seasonal frost penetration depth.

It is important to note that the construction schedule plays an important role in the short- and long-term performance of foundations. Should construction be carried out over winter, a Qualified Professional Engineer shall conduct a review to confirm any winter-related design concerns (i.e., frost heave out of the subgrade) are addressed.

7. Preliminary Construction Considerations

7.1 Accessibility

Based on the site reconnaissance, no existing areas near the proposed RACS locations for a helicopter to safety land. It would be recommended that a qualified tree falling team be inserted ahead of time to create a suitable temporary helicopter pad. An area may be identified by the helicopter pilot where they may be able to toe-in or hover exit.

Furthermore, preliminary areas identified for access by helicopter with hover exit has been identified northwest in a boulder field approximately 350 m away from the proposed RACS location.

7.2 Rock Scaling

Rock scaling may have to be undertaken during construction of the RACS. The details of any scaling required are to be verified during the geotechnical investigation.

Rock scaling at the proposed RACS location would create a hazard at the TCH and temporary rock fall protection work, and limited road closures may be required during the execution of the rock scaling works.

7.3 Potential RACS Tower Locations

Photos 1 to 3 (see attached) are provided as additional information. Photo 2 illustrates potential RACS tower locations, where preferred areas have been identified according to generalized ease of construction and geohazard considerations:

- Green = Easy accessibility, minimal surface bed preparation, competent rock mass (founding medium), uncomplicated construction with minimal geohazard exposure.
- Yellow = Easy accessibility, minimal surface bed preparation, less competent rock mass that may require stabilization or scaling, uncomplicated construction with minimal geohazard exposure.
- Red = Difficult accessibility, minimal surface bed preparation, less competent rock mass that may require significant stabilization or scaling, complicated sloped construction with geohazard exposure.

These areas and comments provided should be considered preliminary and are dependent on-site conditions and are subject to change. The larger area considered is dictated by the target locations and discussed in Section 5.1.

8. Schedule for Delivery

Ecora understands that an aggressive timeline is required for the overall project delivery and that BC MoTI aims to construct the tower during the 2023 construction season when the ground is snow free. To achieve this, Ecora proposes that complete the majority of the detailed design prior to conducting the detailed site reconnaissance, with the results from the reconnaissance used to finalize the design.

For the Victor Lake Priority Path, the following is envisaged:

1. Preliminary detail design, March to May 2023
2. Detailed Site Reconnaissance, June 2023
3. Tendering, July 2023
4. Construction, September to October 2023

Based on Ecora's experience from other similar RACS projects, the construction for tower foundations (including the installation of micro-piles and shear relief anchors), and curing of the pile cap concrete (until tower erection can occur) typically takes 14 days.

9. Closure

We trust this report meets your requirements. Please contact our office if you have any questions or comments concerning this report.

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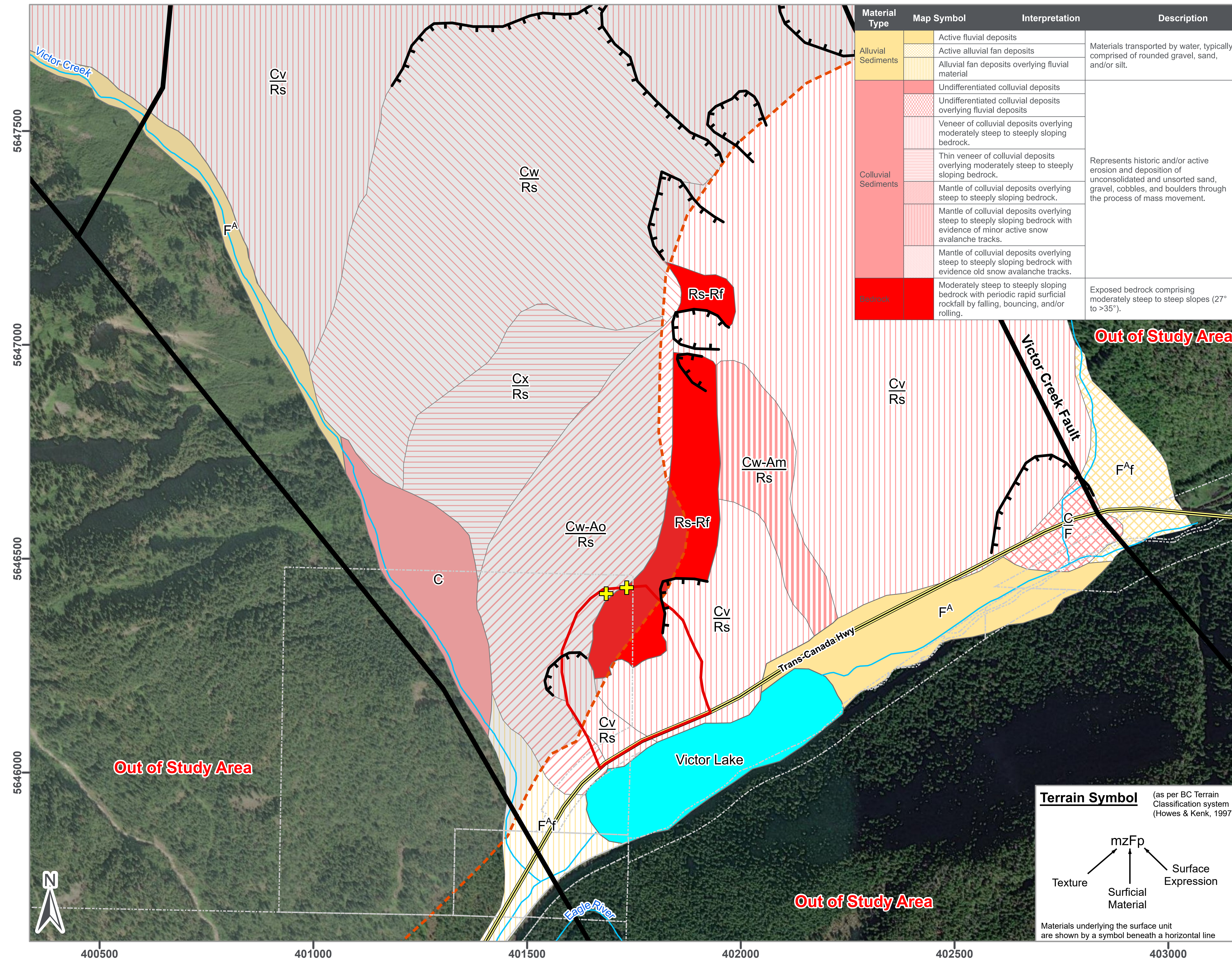
Figures

PRELIMINARY TERRAIN MAP - VICTOR LAKE

ecora

GEOTECHNICAL ASSESSMENT
VICTOR LAKE RACS TOWER
SITE LOCATION
REVELSTOKE, BC



Material Type	Map Symbol	Interpretation	Description
Alluvial Sediments		Active fluvial deposits	Materials transported by water, typically comprised of rounded gravel, sand, and/or silt.
		Active alluvial fan deposits	
		Alluvial fan deposits overlying fluvial material	
Colluvial Sediments		Undifferentiated colluvial deposits	Represents historic and/or active erosion and deposition of unconsolidated and unsorted sand, gravel, cobbles, and boulders through the process of mass movement.
		Undifferentiated colluvial deposits overlying fluvial deposits	
		Veneer of colluvial deposits overlying moderately steep to steeply sloping bedrock.	
		Thin veneer of colluvial deposits overlying moderately steep to steeply sloping bedrock.	
		Mantle of colluvial deposits overlying steep to steeply sloping bedrock.	
		Mantle of colluvial deposits overlying steep to steeply sloping bedrock with evidence of minor active snow avalanche tracks.	
		Mantle of colluvial deposits overlying steep to steeply sloping bedrock with evidence old snow avalanche tracks.	
Bedrock		Moderately steep to steeply sloping bedrock with periodic rapid surficial rockfall by falling, bouncing, and/or rolling.	Exposed bedrock comprising moderately steep to steep slopes (27° to >35°).

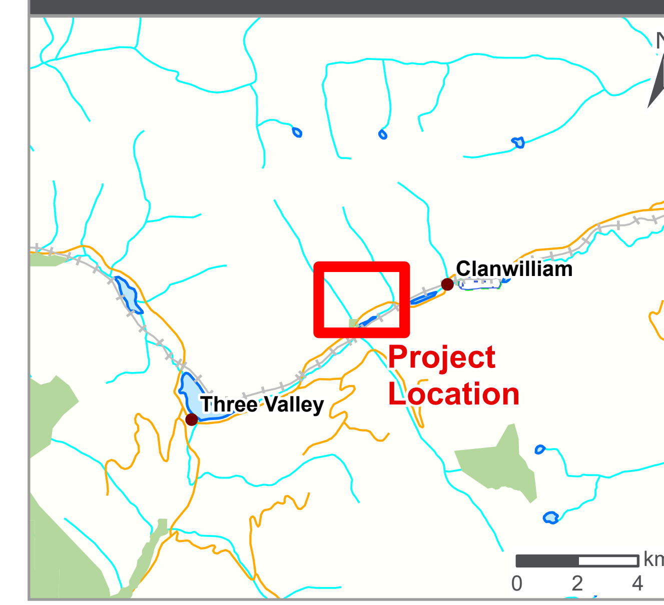
Legend

- Proposed RACS Locations
- Fresh Water Atlas Streams
- Highways
- Digital Atlas Roads
- Fault Lines
- Escarpment
- Proposed Avalanche Target Paths
- Historical Fire Extent (1931)
- PMBC Legal Parcels

References

Aerial Imagery: *Province of British Columbia, 2007*
LiDAR: *MoTI, 05/2021*
Historical Fire Extent: *iMapBC*
Contours: *TRIM*

LOCATION MAP



1:9,000

0 100 200 300 400 500 Meters

Project No.: 201740-04
Date: 2023/02/16
Client: Ministry of Transportation and Infrastructure
Drawn: SC Check: DK
NAD 1983 UTM Zone 11N

Figure 3.1

Photographs

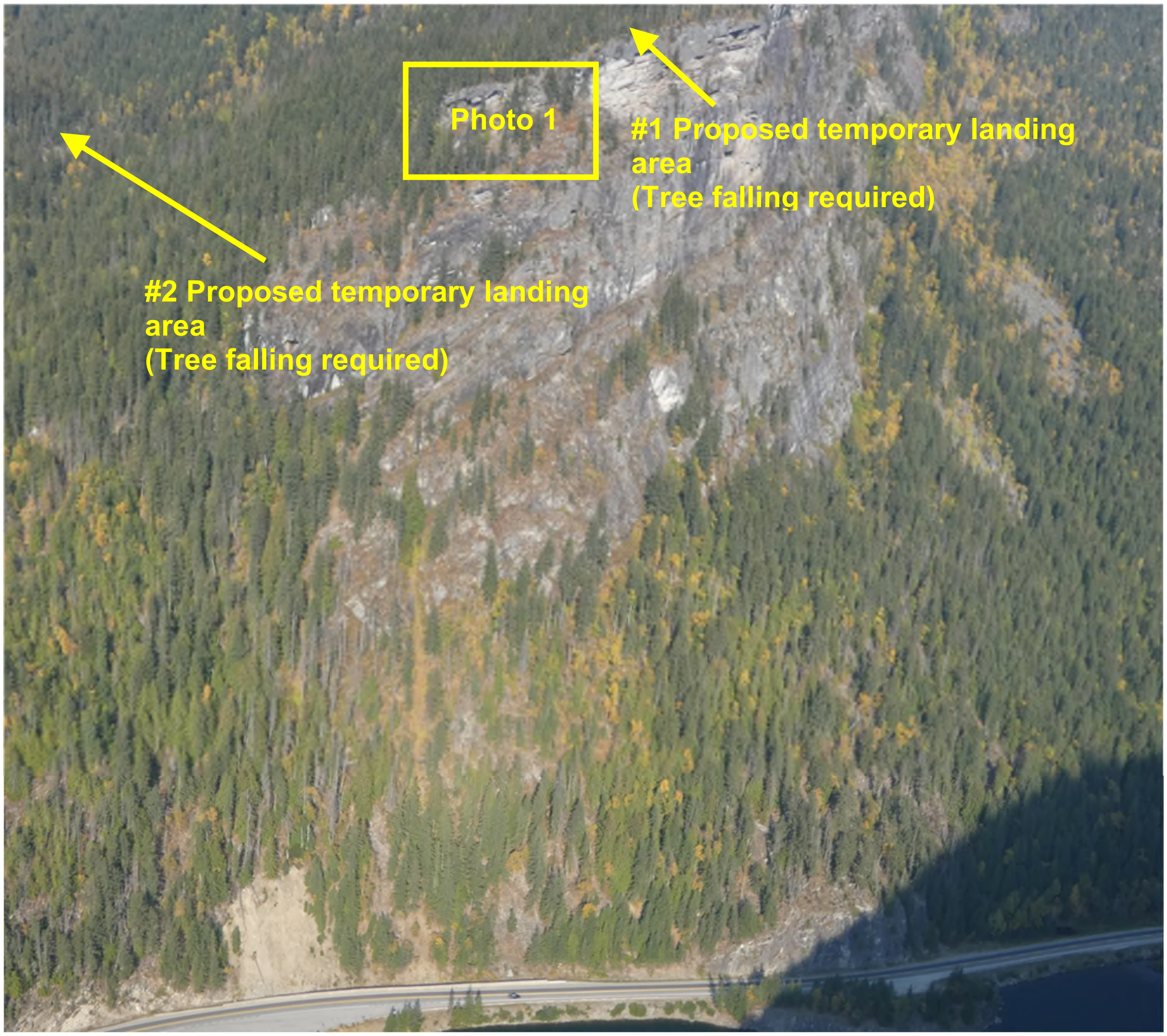


Photo 1 **Victor Lake overview**

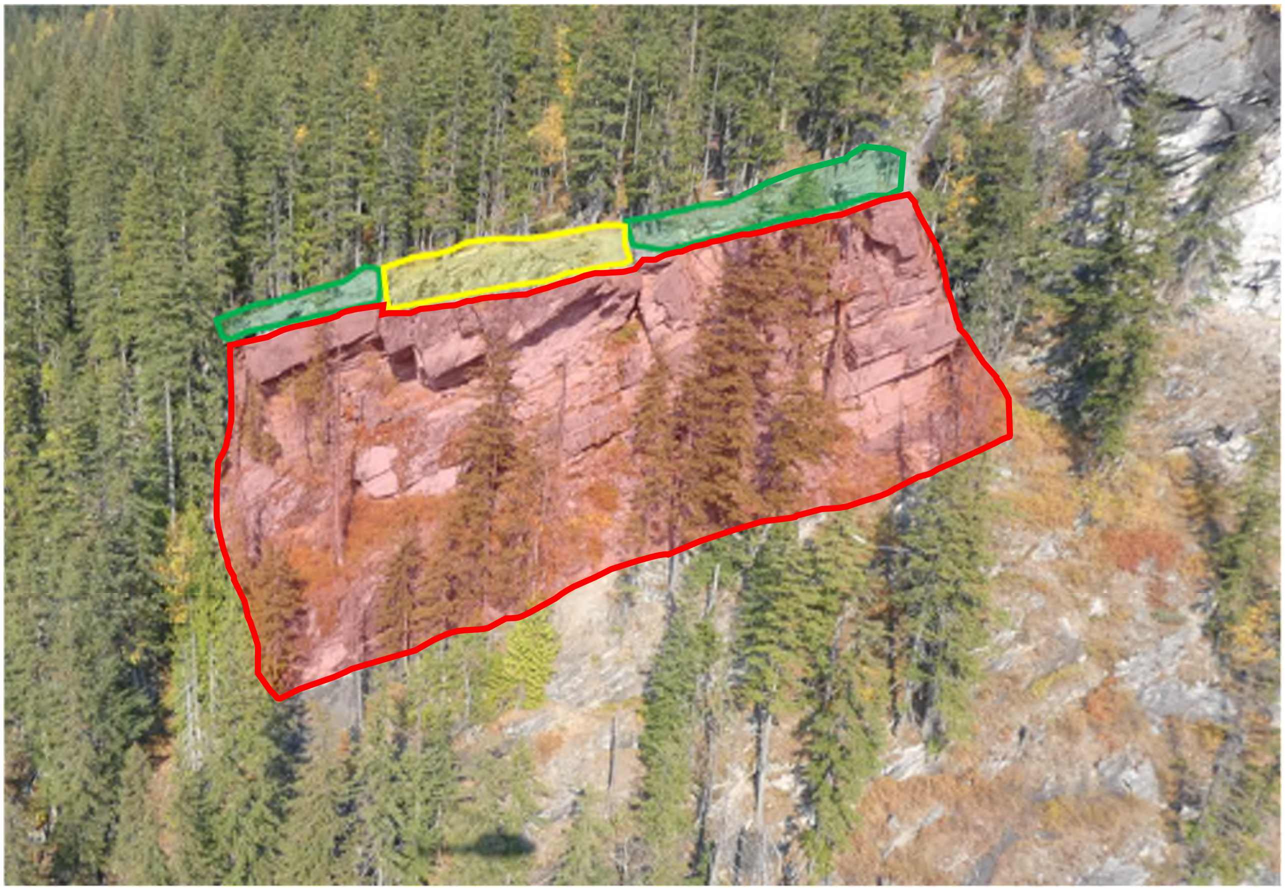


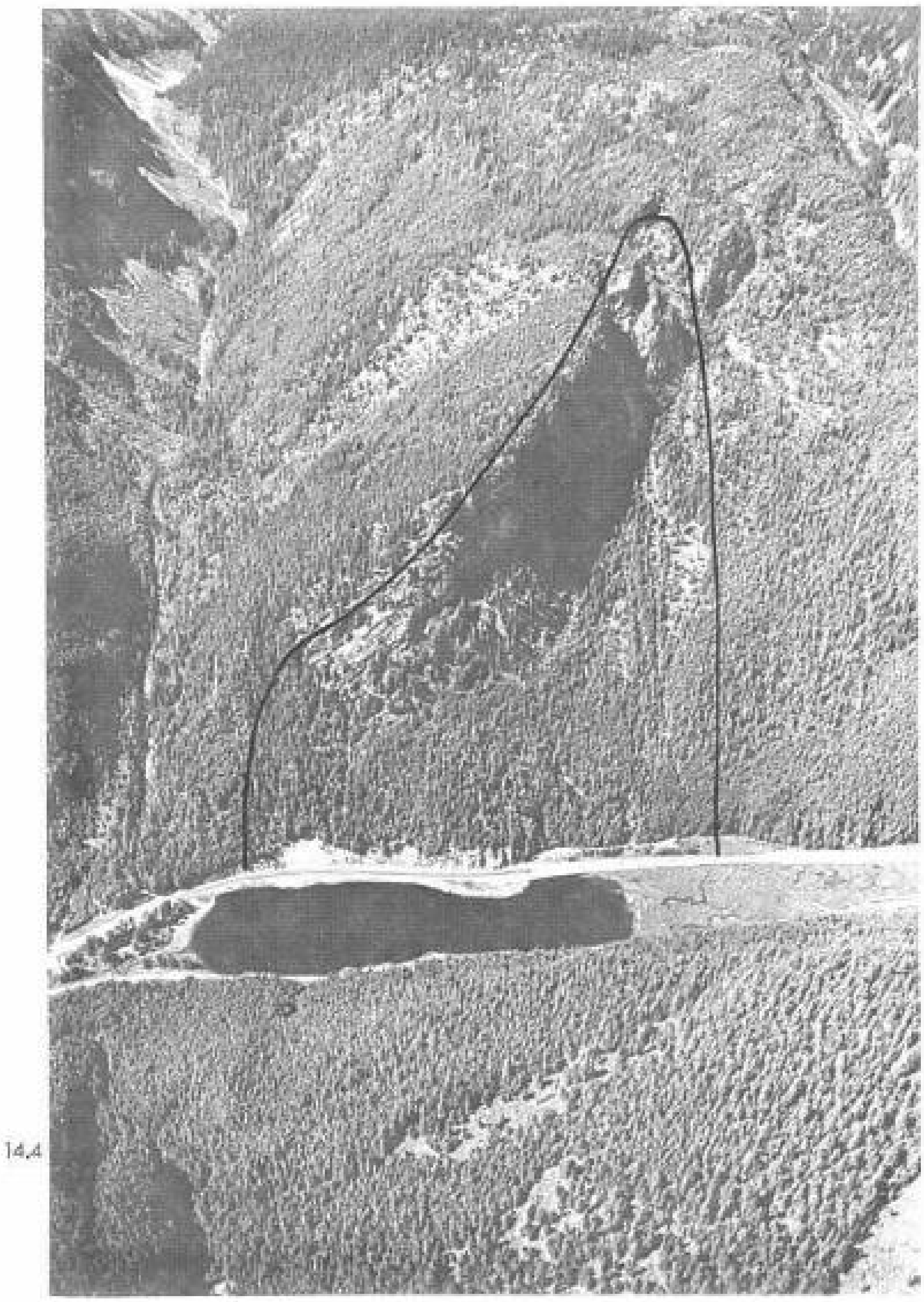
Photo 2 **Victor Lake preliminary preferred areas**

Photo 3 Victor Lake boulder field for helicopter hover exit

Appendix A

BC MoTI Columbias Program Snow Avalanche Atlas – Victor Lake (pg. 82-83)

VICTOR LAKE



Path #   14.4   [BULK UPLOAD]

VICTOR LAKE PATH SUMMARY

Path Name: VICTOR LAKE **Path Number:** 14.4

Active Path: Yes **Potential Path:** No

Location:

At Victor Lake.

TERRAIN CHARACTERISTICS

Vertical Fall:	670 m	**Slope Length to Road:**	
Starting Zone Area:		**Site Angle to Road:**	
Runout Area:		**Aspect:**	South East
Road Width:	7 m	**Length of Highway Affected:**	m

ELEVATIONS

Starting Zone: 1220 — 915 m **Runout Zone:** 570 — 550 m

INCLINES

Starting Zone: 41 ° **Track:** 40 ° **Runout Zone:** 0 °

GENERAL DESCRIPTIONS

Starting Zone:

Consists of steep rock cliffs covered with sparse vegetation. The elevation of the starting zone decreases from east to west.

Track:

An steep slope covered with coniferous and deciduous vegetation. Most avalanches run in narrow channels through the vegetation but they can flow down anywhere on the slope.
The majority of avalanches, that affect the highway, run down the predominant gully located in the centre of the slope with the southern aspect on the western side of the avalanche area. This gully is positioned directly below the western end of the major bench, which slopes east to west, located in this area.

Runout Zone:

Begins at the highway, crosses it, and extends to Victor Lake.

Technician Description of Path Characteristics

Length of highway affected is approximately 750m. Sluffing and avalanches are each estimated to affect the highway an average of four times per year.
Rock falls are also a hazard at this site.
A Lockblock wall was constructed on the west side of the runout of this path in the 2002 summer season to contain reockfall. This wall was left in place during the 2004-05 winter season and contains the majority of avalanches as long as the snow deposits are cleaned out from behind the wall as required.

Appendix C

Tower Foundation Calculations

PROJECT NAME	Victor Lake RACS Detail Design
PROJECT NO	201740
DATE	28-Jun-23

Bond Capacity	1.40	MPa	(Based on PTI DC35.14, Table C6.1 and Foundations on Rock, Wyllie 1999))
Bond Safety Factor	2		(Based on PTI DC35.14 and Foundations on Rock, Wyllie 1999)
Min. Desired Design Life	75	years	
Anchor Bar Resistance Factor	0.6		(Based on FHWA, June 1999, Table 9)
Frost depth	1.1	MPa	

Desciption	**Avalanche Velocity (m/s)**	**Forces on Foundation Anchors**		**Borehole Diameter**		**Estimated Load Transfer**		**Minimum Required Anchor Bond Length (In Rock Largely Free of Fissures)**		**Min. Required Anchor Diameter/Type to Achieve 75-Year Design Life Grade 75 (ASTM A615)**	
		Horizontal (kN)	**Vertical (kN)**	**Horizontal (mm)**	**Vertical (mm)**	**Horizontal (kN/m)**	**Vertical (kN/m)**	**Horizontal (m)**	**Vertical (m)**	**Horizontal (Bar Size)**	**Vertical (Bar Size)**
Factored load	18	312	146	76	63.5	334	279	**1.87**	**1.05**	43	32

	Grade 75						**Grade 80**
Bar designation	**#6**	**#7**	**#8**	**#9**	**#10**	**#11**	**#14**
Starting diameter (mm)	**19**	**22**	**25**	**29**	**32**	**36**	**43**
Initial minimum yield stress (Mpa)	517	517	517	517	517	517	552
Nominal cross sectional area (mm2)	284	387	510	645	819	1006	1452
Initial minimum yield load (kN)	147	200	264	334	424	520	801
Service life (years)	75	75	75	75	75	75	75
Loss of steel (mm)	2.53	2.53	2.53	2.53	2.53	2.53	2.53
Loss of steel both sides (mm)	5.06	5.06	5.06	5.11	5.06	5.06	5.06
End diameter (mm)	13.94	16.94	19.94	23.89	26.94	30.94	37.94
End area (mm2)	153	225	312	448	570	752	1131
Reduced tensile yield capacity (kN)	79	117	161	232	295	389	624
Factored resistance 0.6 (kN)	47	70	97	139	177	233	374

Notes

1. Based on NCHRP (2011), Loss of steel in 75 years:

$$X\ (mm) = 80 \times t_f^{0.8}$$

2. DYWIDAG threadbar properties

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