GEOTECHNICAL REPORT

PROJECT SUNSHINE COAST DFAA SITES – REDROOFFS SITE NEAR SECHELT, BC

BC Ministry of Transportation and Infrastructure
Suite 310 – 1500 Woolridge St.
Coquitlam, BC V3K 0B8

PROJECT NO.: VG07794.600

6 DECEMBER 2022

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1 INTRODUCTION

WSP E&I Canada Limited (WSP), is pleased to provide this geotechnical report to the British Columbia Ministry of Transportation and Infrastructure (MoTI) in support of the Sunshine Coast DFAA Sites – Redrooffs Site Project (the Project), near Sechelt, BC.

The purpose of this geotechnical report is to assist the Project team in advancing culvert replacement design at Kenyon Creek crossing Redrooffs Road east of Cove Beach Road, including adjacent roadway embankment and pavement considerations.

This report is limited to the geotechnical aspects of the Project only and does not include provision of environmental, archaeological, hydrotechnical or other disciplines that may be required for the Project.

2 PROJECT BACKGROUND AND SITE INFORMATION

2.1 PROJECT BACKGROUND

WSP understands that in November 2021 an atmospheric river event occurred that caused flooding Kenyon Creek crossing Redrooffs Road east of Cove Beach Road, near Sechelt, BC. The embankment overlying the culvert was initially replaced by emergency works crews following temporary remediation procedures and included three new small diameter corrugated steel culverts running at a shallow depth under the pavement. MoTI is currently seeking to replace the original culvert (at depth), temporary culverts and embankment with permanent structures that meet current MoTI design standards. The permanent replacement works includes a new realigned culvert structure and new roadway embankment and pavement structure.

Based on our understanding of the permanent culvert replacement 50% Design Drawings, as provided by MoTI dated 21 July 2022 WSP understands that the culvert replacement will comprise:

- Side-by-side concrete box culverts of 2.4 m x 2.4 m and 2.1 m x 2.1 m dimensions.
    - Top of concrete box culvert elevations to match.

The depths of the concrete box culverts have not been provided; however, WSP anticipates that the top elevation of the concrete box culverts will be buried at least 925 to 950 mm below finished roadway surface to allow for the minimum proposed pavement structure.

3 GEOTECHNICAL INVESTIGATION

3.1 DRILLING INVESTIGATION

WSP conducted a geotechnical investigation at the culvert location on 31 May 2022. The investigation comprised one borehole, BH22-01 located west of Kenyon Creek crossing on Redrooffs Road on the existing roadway embankment and drilled to a depth of approximately 8.8 m. The borehole was advanced using air-rotary downhole hammer (ODEX), with standard penetration tests conducted approximately every 1.5 m. The drilling work was conducted using a truck-mounted drill rig owned and operated by VanMars Drilling Ltd. The location of each borehole was measured relative to existing site features and by hand-held GPS typically accurate to within 5 m. Figure 1 attached shows the approximate borehole location.

Prior to the subsurface investigation, WSP prepared a site-specific health and safety plan and a traffic management plan and communicated the details of the plan with our subcontractors. WSP also prepared and submitted an H1080 "Lane Closure Permit" application form that was accepted by MoTI's local area manager for work on roadways. Furthermore, WSP conducted a BC One Call to obtain existing subsurface utility information in the area of the proposed borehole locations and retained GeoScan Subsurface Surveys Inc. to conduct an on-site verification to clear the proposed borehole locations of underground utilities using ground penetrating radar and electromagnetic methods.

All field work was conducted under the supervision of a member of WSP's geotechnical staff who managed the health and safety of the site, directed subcontractors regarding the work, visually observed and recorded the subsurface soil, rock and groundwater conditions within the borehole and obtained representative samples for further classification and laboratory testing. Water samples from the creek were also obtained for further analytical testing. Details of the conditions encountered are provided on the Summary Logs in Appendix A.

Upon completion of drilling the borehole was backfilled with a combination of cuttings and bentonite seal in accordance with the British Columbia Groundwater Protection Regulations. The surface of the borehole was reinstated with asphalt cold patch.

3.2 LABORATORY TESTING

Laboratory testing was conducted on select samples obtained from the drilling investigation for further assessment and classification. Index testing (generally comprising moisture content, sieve analysis and organic content) was conducted by WSP at our Surrey laboratory. Chemical analysis testing of soils (generally comprising pH, chloride, sulphate and resistivity) and creek water (generally comprising pH and sulphate) were conducted by a third-party laboratory, namely CARO Analytical Services Ltd. of Richmond, BC.

Select laboratory testing results are summarized on the Summary Logs in Appendix A and detailed results are provided in Appendix B.

4 SITE CONDITIONS

4.1 SOURCES OF BACKGROUND INFORMATION

The following information was available to WSP for use in this report:

- "Surficial Geology and Sand and Gravel Deposits of Sunshine Coast, Powell River and Campbell River Areas" published by Province of British Columbia, Ministry of Mines and Petroleum Resources, dated 1977.
- "Site Inspection Reports – Redrooffs Road at Kenyon Creek – Culvert Inspections" issued by Urban Systems Ltd., dated 18 January 2022.

4.2 SURFACE CONDITIONS

WSP personnel visited the site on 4 March 2022 to observe the surface conditions.

Redrooffs Road in the area of the Project sites traverses generally east-west. It is constructed on an embankment spanning Kenyon Creek, which flows through the embankment in the culvert (concrete pipe). Redrooffs Road varies in elevation along the east-west profile, gently sloping up towards the west near the vicinity of the culvert. Redrooffs Road is single lane paved road in each direction.

The embankment at the creek location stands at approximately 1 Horizontal to 1 Vertical (1H:1V) with some over-steepened sections on the downstream side. The embankment is approximately 4 m to 5 m above the creek bed. It is understood that the embankment and roadway in the vicinity of the culverts were reconstructed during the initial restoration efforts. The exterior of the embankment slopes comprised of imported material of boulders and cobbles (riprap). Bedrock outcrops were observed within 50 m east along Redrooffs Road in the vicinity of the culvert area and approximately 20 to 30 m upstream of the culvert.

4.3 SUBSURFACE CONDITIONS

Based on the information obtained from the geotechnical investigation, the subsurface conditions from the roadway embankment surface west of Kenyon Creek are described as follows:

Granular Fills: Imported gravelly sand, trace silt to silty, very loose to very dense extending to a depth of approximately 4.6 m. Changes in density throughout the layer are attributed to the variable nature of fills placed during embankment construction/restoration efforts.

Silt: Natural non-plastic to low plasticity silt with organics (wood chunks, rootlets), wet, very loose extending to approximately 5.1 m depth.

Bedrock: Encountered at 5.1 m depth and extended to 8.8 m depth (borehole termination).

Groundwater: Observed at 4.0 m depth based on standing water within the open borehole prior to backfilling. May not represent stabilized groundwater level.

4.3.1 CHEMICAL ANALYSIS OF SOIL AND WATER

Based on laboratory testing of samples obtained from BH22-01 (soil) and the adjacent creek (water) the following results are provided to guide other consultants and/or contractors in the concrete mix design and culvert selection for the headwalls and box culverts. Detailed results are provided in Appendix B.

The subsurface soil sample at this location has a pH of 6.95, sulfate ion content of < 0.050 %, a chloride ion content of 0.004 % and a resistivity of 5400 ohm-cm and the creek water sample at this location has a pH of 7.61, a sulfate ion content of 2.3 mg/L, a chloride ion content of 5.05 mg/L, a resistivity of 15800 ohm-cm and a conductivity of 63.9 uS/cm.

5 GEOTECHNICAL DESIGN CONSIDERATIONS

5.1 SEISMIC CONSIDERATIONS

WSP has conducted a site classification assessment following MoTI's Geotechnical Design Criteria (Technical Circular T-04/17) and the National Building Code of Canada (NBCC) 2015 using the subsurface soil conditions and inferred density based on drilling observations. The resultant Site Class has been assessed as:

- Site Class C: Very dense soil and soft rock.
    - It is noted that this Site Class assessment is prepared assuming that the existing embankment will be excavated to allow for construction of the concrete box culvert and as such, controlled backfill with appropriate gradation and density will be utilized within the embankment following MoTI Standard Specifications for culvert bedding, headwall bearing pad and embankment construction.

WSP obtained 2015 National Building Code of Canada (NBCC) seismic hazard values for the Project site from Natural Resources Canada's publicly available seismic hazard calculator. In accordance with MoTI's Supplement to the Canadian Highway Bridge Design Code S6-14 (MoTI Supplement to CHBDC S6-14), embankments for "other" route class are required to maintain stability during and following a 1-in-475 year seismic event.

Based on the seismic hazard values obtained, Table 2 below provides the 5% damped Site Class C values for the site under the design seismic conditions. Detailed seismic hazard values are provided in Appendix C.

Table 1: Site Class C 2015 National Building Code of Canada Seismic Hazard Values

Design Seismic Event	Peak Ground Horizontal Acceleration	Sa (0.2)	Sa (0.5)	Sa (1.0)	Sa (2.0)	Sa (5.0)
1-in-475 year (10% probability of exceedance in 50 years)	0.180 g	0.412 g	0.364 g	0.198 g	0.115 g	0.029 g

Note: Spectral accelerations (SA(T)) indicate the period in which T = seconds.

Based on the soil, groundwater and bedrock conditions anticipated within the upper 30 m depth, WSP assesses the risk of liquefaction for this site to be low under typical drained conditions.

5.2 GEOTECHNICAL PARAMETERS

Based on the subsurface conditions encountered, the geotechnical parameters for the materials to be used in design are provided in Table 1 below. The below parameters assume that any layers containing organics or deleterious material encountered below the embankment will be stripped prior to Type D fill placement.

Table 2: Anticipated Geotechnical Parameters

Layer	Unit Weight (kN/m^3)	Friction Angle (degrees)	Cohesion (kPa)
Local Type D Embankment Fill	19	34	0
Class 50 kg Riprap	24	42	0
Riverbed Deposits	19	33	0

Note: Riverbed Deposits were not encountered within the single borehole conducted through the roadway embankment during the geotechnical investigation; however, parameters and layer thickness are assumed based on on-site observations for the upstream and downstream areas.

5.3 MATERIAL RE-USE

Based on the drilled borehole, the subsurface soil overlying bedrock (and anticipated within excavation depth) comprises generally of mixed sands and gravels with trace silt to silty and a thin (0.5 m thick) silt layer with organics was observed below the imported fills, overlying bedrock.

The subsurface soils are generally considered acceptable for re-use as local Type D embankment fill up to a depth of approximately 4.6 m below ground surface provided that all material containing organics (wood, roots, etc.) and/or deleterious material (garbage, debris, high-fines content soil) are separated out and not utilized in the Type D fills. Below 4.6 m the subsurface soil comprises fine-grained silt with organics and is not considered suitable for re-use as Type D fill. All soils which are saturated, high-fines content, containing organics and/or deleterious material are not acceptable for re-use as Type D fill.

5.4 ROADWAY EMBANKMENTS

Embankments has been preliminarily assessed following MoTI Supplement to CHBDC S6-14 for the following conditions:

- Degree of Understanding: Typical;
- Consequence Factor: Low; and
- Route Category: Other.

Based on the above degree of understanding, consequence factor and route category, the required factor of safety for embankments under static conditions is 1.45 and under seismic conditions is 1.10 (for 1-in-475 year ground motion). In conducting the seismic assessment, WSP utilized a peak ground horizontal acceleration of 0.180 g and horizontal seismic coefficient of 0.090 g (half of the full peak ground horizontal acceleration) to simulate the pseudo-seismic loading.

WSP has conducted a stability analysis using GeoStudio SlopeW 2021.3 for the typical embankment section at Kenyon Creek using the 50% Design Drawings geometry (estimated as 2H:1V embankment slope), our visual

field observations of site geometry and anticipated subsurface conditions/parameters. The typical sections includes excavation and re-instatement of the roadway embankment using local Type D material overlying bedrock. It is critical to the design that the silt layer containing a high percentage of organics that was observed underlying the existing embankment and overlying bedrock be removed and replaced with imported fill.

In conducting the analysis the upstream and downstream stratigraphic conditions, including bedrock profile, were estimated based on our topographic observations on site.

Armoring of the channel base with Class 50 kg Riprap on the upstream and downstream sides is shown on the design drawings; however, armoring of the embankment slopes is not shown. It is understood that riprap armoring of the slope may be implemented during future design phases and as such, unarmored and armored slopes using a nominal 1.0 m thick riprap layer.

The results of the analyses conducted are summarized in Table 3 below and detailed sections are provided in Appendix D.

Table 3: Embankment Stability Assessment Results

Culvert Location	Target Factor of Safety – Static	Design Factor of Safety – Static	Target Factor of Safety – Seismic	Design Factor of Safety – Seismic
Kenyon Creek – no riprap armor	1.45	1.51	1.10	1.23
Kenyon Creek – riprap armored embankment	1.45	1.50	1.10	1.23

Based on the results of the stability analyses, the proposed embankment configuration exceeds the required factors of safety. It is recommended that the embankments be constructed following the configuration outlined prior and be constructed in a manner consistent with the latest iteration of MoTI Standard Specifications (currently v2020), specifically SS201 – Roadway and Drainage Excavation, SS202 – Granular Surfacing, Base and Subbase and SS205 – Riprap.

5.5 LATERAL EARTH PRESSURES

Lateral earth pressures for buried structures have been calculated following Coulomb's (1776) earth pressure theory for cohesionless soils, adjusted for wall friction, non-horizontal backfill and non-vertical soil-wall interface per Mayniel (1908) and Müller-Breslau (1906).

WSP has assumed the following parameters for use in lateral earth pressure coefficient calculations:

- Φ (soil internal friction angle) = 34° (per Section 3.4);
- δ (wall-soil interface friction) = 0.5 * φ = 17° (for soil-concrete interface);
- β (backfill inclination angle) = 0°; and
- θ (camber of structure from horizontal) = 90°.

Based on the above assumptions the active static lateral earth pressure coefficient K_a = 0.26 and the passive static lateral earth pressure coefficient K_p = 3.24. The horizontal components of the earth pressure may then be calculated using the lateral earth pressure coefficients per the equations below, where z is the depth of burial in consideration and γ is the unit weight of the backfill (19 kN/m^3 per Section 3.4).

$$\sigma_a = K_a \gamma z cos\beta \text{ (active)}$$

and

$$\sigma_p = K_p \gamma z cos\beta \text{ (passive)}$$

Under seismic conditions, the dynamic lateral earth pressures may be calculated using the above formulae and Kae and Kpe in lieu of Ka and Kp, respectively. Following the above assumptions, peak ground horizontal acceleration defined in Section 4.1 and following Mononobe-Okabe's (1929) dynamic earth pressure theory, the active dynamic lateral earth pressure coefficient Kae = 0.32 and the passive dynamic lateral earth pressure coefficient Kpe = 2.97.

5.6 CONCRETE HEADWALLS

Based on the 50% Design Drawings, WSP estimates the concrete headwall at Kenyon Creek will be at least 4.5 m wide (2.1 m and 2.4 m side-by-side box culverts with one headwall). For calculation purposes, WSP assumed that the concrete headwall will have a minimum length of 5.0 m (culvert width plus 0.25 m on either side) – estimated from the 50% Design Drawing section details.

Based on the results of the geotechnical investigation and 50% Design Drawings, it is anticipated that the concrete headwall will be founded on bedrock. Bedrock subgrade is considered competent for bearing subgrade assuming it is suitably prepared (stripped of organics, undisturbed, unsaturated, levelled, etc.) in accordance with the Standard Specifications. Deeper stripping may be required should organics or deleterious material (saturated, high-fines, debris or other) be encountered at this depth.

Concrete headwalls should not be founded on the silt layer observed at depth overlying bedrock at this site as the silt layer is not anticipated to provide the necessary bearing support.

For levelling purposes, the rock surface may be cleaned, a mud slab placed to level and the headwall may be cast directly over the mud slab.

5.7 PAVEMENT STRUCTURE

WSP has assessed the pavement structure requirements following MoTI Technical Circular T-01/15 *"Pavement Structure Design Guidelines"*. Traffic data was not available for Redrooffs Road at the time of preparing this report however, due to the assumed low volume traffic on Redrooffs Road, limited/infrequent use by heavy commercial vehicles and the roadway not leading to a subdivision, WSP recommends that the pavement design follow Type C typical pavement structure as outlined below.

Pavement Structure (from surface):

- 50 – 75 mm Asphalt
- 225 mm thickness of 25 mm Crushed Base Course (CBC); and
- 150 mm thickness of Select Granular Subbase (SGSB); and
- 500 mm thickness of Type D or SGSB.

Near-surface concrete box culverts underlying pavement structure tend to exacerbate transverse cracking of the surface course. This is due to the immediate transition between low stiffness subgrade and high stiffness concrete within the embankment, in which the soil immediately adjacent to the box culvert compresses under load and the concrete box culvert does not compress, resulting in a differential ground movement that propagates to surface. To mitigate this issue and for longevity of the pavement surface, it is recommended that an additional minimum thickness of 500 mm local Type D or SGSB fill be placed below the minimum 150 mm thick SGSB layer which will allow the pavement surface to compress or “flex” in better uniformity when traversing the concrete box culvert. Additional thickness of Type D or SGSB material below the SGSB will assist in improving the long-term performance and should be included where possible based on geometric constraints.

6 CLOSURE

This report is subject to the attached limitations.

Recommendations and assessments presented herein are preliminary in nature and based on limited subsurface information. The recommendations and assessments presented in this report should not be used for design.

This report has been prepared for the exclusive use of BC Ministry of Transportation and Infrastructure, for the specific application described herein. Any use which a third party makes of this report, or any reliance on or decisions made based on it, are the responsibility of such third parties. WSP E&I Canada Limited accepts no responsibility for damages suffered by any third party as a result of decisions made or actions based on this report.

"Effective September 21, 2022, Wood Environment & Infrastructure Solutions Canada Limited is now operating as WSP E&I Canada Limited. No other aspects of our legal entity, contractual terms or capabilities have changed in relation to this report submission."

Yours sincerely,

WSP E&I Canada Limited

Prepared by:

James Brunswick, P.Eng.

Senior Geotechnical Engineer

Reviewed by:

John Laxdal, P.Eng.

Principal Geotechnical Engineer

Figure 1

Legend

As-Drilled Borehole Location (WSP, 2022)

Note:
1. Image provided by Bing Maps Aerial - © 2022 Microsoft Corporation © 2022 Maxar ©CNES (2022) Distribution Airbus DS.

wsp

CLIENT: BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

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DWN BY:	BB
CHK'D BY:	JB
DATUM:	NAD 83
PROJECTION:	UTM Zone 10
SCALE:	1:2 500

TITLE: SITE PLAN

PROJECT: SUNSHINE COAST DFAA SITES
REDROOFFS ROAD SITE

DATE:	DECEMBER 2022
PROJECT NO.:	VG07794.600
REV. NO.:	0

FIGURE 1

This drawing was originally produced in colour.

Appendix A

Summary Logs

SUMMARY LOG

Ministry of Transportation and Infrastructure — British Columbia

Drill Hole #: BH22-01

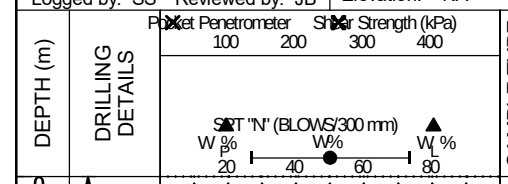
Project: **Sunshine Coast DFAA Sites**
Location: Sechelt, BC

Prepared by: VG07794.600
Wood E&IS Canada Limited

Logged by: SS Reviewed by: JB

Datum: UTM NAD83 Alignment: NA
Northing/Easting: 5481201 , 438039 Station/Offset: NA
Elevation: NA *Coordinates taken with GPS*

Date(s) Drilled: 5/31/2022
Company: VanMars Drilling Ltd.
Driller: NA
Drill Make/Model: Fraste ML
Drilling Method: ODEX Air-Rotary



DEPTH (m)	DRILLING DETAILS	SAMPLE TYPE	SAMPLE NO	RECOVERY (%)	SOIL SYMBOL	SOIL DESCRIPTION	CLASSIFICATION	COMMENTS TESTING Drillers Estimate {G % S % F %}	DEPTH (m)
0						0.0m gravelly SILTY SAND to gravelly SAND trace silt, fine to coarse sand, fine to coarse, sub-angular gravel, grey-brown, dry to moist, very loose to very dense. [FILL]			0
1			G1					**Sieve** (Sa#G1) G:25% S:59% F:16% Note: Sample G1 may have higher fines content due to ODEX drilling methodology.	1
2			SPT 1	9		…at 2.1 m, seepage observed in open hole, soil becomes wet.	SM1		2
3			SPT 2	7				Note: at 3.0 m, SPT sampler sank over 0.3 m after the final hammer blow	3
4	ODEX Air 4.0m							Note: Water level at 4.0 m depth within open borehole following drilling completion.	4
5			SPT3	11		4.6m SILT, non-plastic to low plasticity, with organics (wood chunks, rootlets), brown, wet, very loose. 5.1m	ML	**Organic Content** (Sa#SPT3) 25.9%	5
6			G2			**BEDROCK** … below 5.1 m, slower drilling, small fractured angular rock chips and fine particles in ODEX cuttings, light grey	BR		6
7			SPT4	0					7
8									8
9						8.8m **End of borehole at 8.8 m.**			9
10									

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

Final Depth of Hole: 8.8 m
Depth to Top of Rock: 5.1 m

MOTI-SOIL-REV3 MOTI_REDROOFFS (PHASE 600).GPJ MOTI_DATATEMPLATE_REV3.GDT 12/7/22

Appendix B

Laboratory Test Results

Wood Environment & Infrastructure Solutions
#110 - 18568 - 96th Avenue
Surrey, British Columbia
Canada, V4N 3P9

wood.

MOISTURE CONTENT REPORT

Client: MOTI

Project Number: VG07794.600
Date: 6/20/2022

Project: MOTI SCR AAW - Sunshine Coast DFAA Sites
Lab no: L6787 - 2

Date Sampled : 5/31/2022
Sampled by: Soheil Sayedinazad

Date Tested : 6/13/2022
Tested by: Wenjing Ke

Hole #	Grab Sample	Depth (m)	Mass of Water (g)	Mass Dry Sample (g)	Moisture Content (%)	Remarks
BH22-01	SPT1	1.5	2.7	115.8	2.3%	Low Sample Recovery
BH22-01	SPT3	4.6	26.0	46.7	55.7%	Low Sample Recovery
BH22-01	G2	5.2	18.2	288.1	6.3%	

Comments:

Reported by: Wenjing Ke

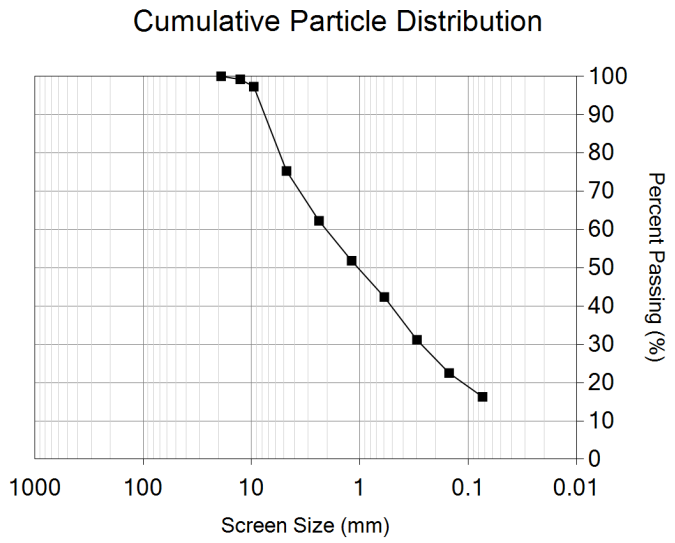
Reviewed by: [signature]
Scott Forsyth

Sieve Analysis

Report Date: June 21, 2022

Client		Project	
Name:	BC Ministry Of Transportation and Infrastructure	**Name:**	(VG07794) South Coast As and When
Address:	310 - 1500 Woolridge Street Coquitlam, BC V3K 0B8	**Address:**	1500 Woolridge St, Coquitlam, BC
Attention:	Salem Bahamdun	**Phase:**	.600 **Task:**
PO Number:		**Manager:**	Eric Mohlmann
Sample Date:	6/1/2022 by Soheil Sayedinazad	**Lab/Ref. #:**	BH22-01, G1
Source:	BH22-01 G1 3'-4'		

Type of Specification: No project specification was provided.



Sieve Analysis: (ASTM C117-17/C136-19)

200 Wash Procedure: A

Sieve Size	Passing	Specification Min	Specification Max
19.0mm	100%		
12.5mm	99%		
9.5mm	97%		
4.75mm	75%		
2.36mm	62%		
1.18mm	52%		
600µm	42%		
300µm	31%		
150µm	22%		
75µm	16%		

Moisture Content (%): 9.9% **(ASTM D2216-19)**

Particle Size (bold indicates value was interpolated)							
Over 3" / 76mm	Gravel		Sand			Fines	
	Coarse	Fine	Coarse	Medium	Fine	Silt	Clay
0.0%	0.0%	25.0%	**16.0%**	**23.0%**	**20.0%**	16.0%	

Remarks:

Distribution: Surrey, Wood

Reviewed By: Scott Forsyth, P.Eng.

Reporting of these test results constitutes a testing service only. Engineering evaluation of the test results is provided only on written request.

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Canada, V4N 3P9

wood.

Organic Content Report
ASTM D 2974

Project No:	VG07794.600	**Project:**	MoTI SCR AAW - Sunshine Coast DFAA Sites
Client:	MoTI	**Report Date:**	6/15/2022
Date Sampled:	5/31/2022	**Source:**	Redrooffs
Tested by:	Wenjing Ke	**Date Tested:**	6/14/2022

Test Hole	**BH22-01**	-
Sample I.D	SPT3	**-**
Depth (m)	4.6	-
% Moisture Content	55.7	-
% Ash Content	74.1	-
% Organic Matter	25.9	-

Comments:
- Organic content tests were conducted in accordance with ASTM D 2974, Test Method A.
- Oven temperature for moisture content was 110 °C and for organic matter was 440 °C.
- Ash Content is the percentage by dry weight of materials remaining after an oven dry organic soil or peat is burned by a prescribed method.

Reported by: Wenjing Ke

Reviewed by: S Forsyth
Scott Forsyth

CERTIFICATE OF ANALYSIS

REPORTED TO	Wood Plc. (Vancouver) 400-111 Dunsmuir Street Vancouver, BC V6B 5W3		
ATTENTION	James Brunswick	**WORK ORDER**	22F1777
PO NUMBER	VE249979	**RECEIVED / TEMP**	2022-06-10 11:00 / 19.5°C
PROJECT	VG07794.600	**REPORTED**	2022-06-21 14:55
PROJECT INFO	Redrooffs	**COC NUMBER**	No #

Introduction:

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

Big Picture Sidekicks

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

We've Got Chemistry

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

Ahead of the Curve

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

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

Authorized By:

Team CARO
Client Service Representative

TEST RESULTS

REPORTED TO	Wood Plc. (Vancouver)	**WORK ORDER**	22F1777
PROJECT	VG07794.600	**REPORTED**	2022-06-21 14:55

Analyte	Result	RL	Units	Analyzed	Qualifier
BH22-01 Redrooffs (22F1777-01) | Matrix: Soil | Sampled: 2022-05-31					
General Parameters					
pH (1:1 H2O Solution)	**6.95**	0.10	pH units	2022-06-15	
Sulfate, Water-Soluble	< 0.050	0.050	%	2022-06-15	
Chloride, Water-Soluble	**0.004**	0.002	%	2022-06-17	
Resistivity	**5400**	100	ohm-cm	2022-06-20	
BH22-01 Reddrooffs (22F1777-02) | Matrix: Water | Sampled: 2022-05-31					
Anions					
Chloride	**5.05**	0.10	mg/L	2022-06-15	
Sulfate	**2.3**	1.0	mg/L	2022-06-15	
General Parameters					
Conductivity (EC)	**63.9**	2.0	µS/cm	2022-06-18	
pH	**7.61**	0.10	pH units	2022-06-18	HT2
Resistivity	**15800**	10	ohm-cm	2022-06-21	

Sample Qualifiers:

HT2 The 15 minute recommended holding time (from sampling to analysis) has been exceeded - field analysis is recommended.

APPENDIX 1: SUPPORTING INFORMATION

REPORTED TO	Wood Plc. (Vancouver)	**WORK ORDER**	22F1777
PROJECT	VG07794.600	**REPORTED**	2022-06-21 14:55

Analysis Description	Method Ref.	Technique	Accredited	Location
Anions in Water	SM 4110 B (2017)	Ion Chromatography	✓	Kelowna
Chloride, Water Soluble in Soil	ASTM C1218-17	Hot Water Extraction / Hot Water Extraction		Richmond
Conductivity in Water	SM 2510 B (2017)	Conductivity Meter	✓	Kelowna
pH in Soil	AASHTO T289-91	1:1 Soil/Water Slurry / 1:1 Soil to Water Extraction, pH Meter		Richmond
pH in Water	SM 4500-H+ B (2017)	Electrometry	✓	Kelowna
Resistivity in Soil	AASHTO T288-91	Resistivity Meter		Sublet
Resistivity in Water	SM 2510 B (2017)	Conductivity Meter		Kelowna
Sulfate, Water-Soluble in Soil	CSA A23.2-3B / CSA A23.2-2B	Extraction (HCl) / Gravimetry (Barium Sulfate Precipitation)		Richmond

Glossary of Terms:

RL	Reporting Limit (default)
%	Percent
<	Less than the specified Reporting Limit (RL) - the actual RL may be higher than the default RL due to various factors
mg/L	Milligrams per litre
ohm-cm	Ohms-centimetre
pH units	pH < 7 = acidic, ph > 7 = basic
µS/cm	Microsiemens per centimetre
AASHTO	American Association of State Highway and Transportation Officials, Methods of Sampling and Testing
ASTM	ASTM International Test Methods
CSA	Canadian Standards Association Chemical Test Methods
SM	Standard Methods for the Examination of Water and Wastewater, American Public Health Association

General Comments:

The results in this report apply to the samples analyzed in accordance with the Chain of Custody document. This analytical report must be reproduced in its entirety. CARO is not responsible for any loss or damage resulting directly or indirectly from error or omission in the conduct of testing. Liability is limited to the cost of analysis. Samples will be disposed of 30 days after the test report has been issued or once samples expire, whichever comes first. Longer hold is possible if agreed to in writing.

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

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

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Wood Plc. (Vancouver)	**WORK ORDER**	22F1777
PROJECT	VG07794.600	**REPORTED**	2022-06-21 14:55

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

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

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

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
Anions, Batch B2F1783										
Blank (B2F1783-BLK1)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	< 0.10	0.10	mg/L							
Sulfate	< 1.0	1.0	mg/L							
Blank (B2F1783-BLK2)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	< 0.10	0.10	mg/L							
Sulfate	< 1.0	1.0	mg/L							
Blank (B2F1783-BLK3)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	< 0.10	0.10	mg/L							
Sulfate	< 1.0	1.0	mg/L							
LCS (B2F1783-BS1)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	16.1	0.10	mg/L	16.0		100	90-110			
Sulfate	15.9	1.0	mg/L	16.0		100	90-110			
LCS (B2F1783-BS2)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	16.0	0.10	mg/L	16.0		100	90-110			
Sulfate	15.9	1.0	mg/L	16.0		99	90-110			
LCS (B2F1783-BS3)				Prepared: 2022-06-15, Analyzed: 2022-06-15						
Chloride	16.0	0.10	mg/L	16.0		100	90-110			
Sulfate	15.8	1.0	mg/L	16.0		99	90-110			
General Parameters, Batch B2F1024										
Blank (B2F1024-BLK1)				Prepared: 2022-06-14, Analyzed: 2022-06-14						
Sulfate, Water-Soluble	< 0.050	0.050	%							
General Parameters, Batch B2F1882										
Blank (B2F1882-BLK1)				Prepared: 2022-06-15, Analyzed: 2022-06-17						
Chloride, Water-Soluble	< 0.002	0.002	%							
General Parameters, Batch B2F1933										

APPENDIX 2: QUALITY CONTROL RESULTS

REPORTED TO	Wood Plc. (Vancouver)	**WORK ORDER**	22F1777
PROJECT	VG07794.600	**REPORTED**	2022-06-21 14:55

Analyte	Result	RL	Units	Spike Level	Source Result	% REC	REC Limit	% RPD	RPD Limit	Qualifier
General Parameters, Batch B2F1933, Continued										
Duplicate (B2F1933-DUP1)	**Source: 22F1777-01**			Prepared: 2022-06-15, Analyzed: 2022-06-15						
pH (1:1 H2O Solution)	6.92	0.10	pH units		6.95			< 1	20	
General Parameters, Batch B2F2356										
Reference (B2F2356-SRM1)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
pH	7.01	0.10	pH units	7.01		100	98-102			
Reference (B2F2356-SRM2)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
pH	7.00	0.10	pH units	7.01		100	98-102			
General Parameters, Batch B2F2387										
Blank (B2F2387-BLK1)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	< 2.0	2.0	µS/cm							
Blank (B2F2387-BLK2)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	< 2.0	2.0	µS/cm							
Blank (B2F2387-BLK3)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	< 2.0	2.0	µS/cm							
LCS (B2F2387-BS4)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	1350	2.0	µS/cm	1410		96	95-105			
LCS (B2F2387-BS5)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	1370	2.0	µS/cm	1410		97	95-105			
LCS (B2F2387-BS6)				Prepared: 2022-06-18, Analyzed: 2022-06-18						
Conductivity (EC)	1380	2.0	µS/cm	1410		98	95-105			

Appendix C

2015 National Building Code of Canada Seismic Hazard Calculation

2015 National Building Code Seismic Hazard Calculation

INFORMATION: Eastern Canada English (613) 995-5548 français (613) 995-0600 Facsimile (613) 992-8836
Western Canada English (250) 363-6500 Facsimile (250) 363-6565

Site: 49.480N 123.856W **User File Reference:** Kenyon Creek at Redrooffs Road 2022-06-23 01:24 UT

Requested by: Wood Environment & Infrastructure Solutions

Probability of exceedance per annum	0.000404	0.001	0.0021	0.01
Probability of exceedance in 50 years	2 %	5 %	10 %	40 %
Sa (0.05)	0.433	0.299	0.213	0.090
Sa (0.1)	0.660	0.458	0.328	0.139
Sa (0.2)	0.818	0.573	0.412	0.174
Sa (0.3)	0.829	0.584	0.419	0.174
Sa (0.5)	0.743	0.515	0.364	0.144
Sa (1.0)	0.435	0.292	0.198	0.074
Sa (2.0)	0.267	0.174	0.115	0.040
Sa (5.0)	0.087	0.051	0.029	0.009
Sa (10.0)	0.031	0.018	0.010	0.004
PGA (g)	0.358	0.252	0.180	0.075
PGV (m/s)	0.554	0.372	0.253	0.090

Notes: Spectral (Sa(T), where T is the period in seconds) and peak ground acceleration (PGA) values are given in units of g (9.81 m/s^2). Peak ground velocity is given in m/s. Values are for "firm ground" (NBCC2015 Site Class C, average shear wave velocity 450 m/s). NBCC2015 and CSAS6-14 values are highlighted in yellow. Three additional periods are provided - their use is discussed in the NBCC2015 Commentary. Only 2 significant figures are to be used. **These values have been interpolated from a 10-km-spaced grid of points. Depending on the gradient of the nearby points, values at this location calculated directly from the hazard program may vary. More than 95 percent of interpolated values are within 2 percent of the directly calculated values.**

References

National Building Code of Canada 2015 NRCC no. 56190; Appendix C: Table C-3, Seismic Design Data for Selected Locations in Canada

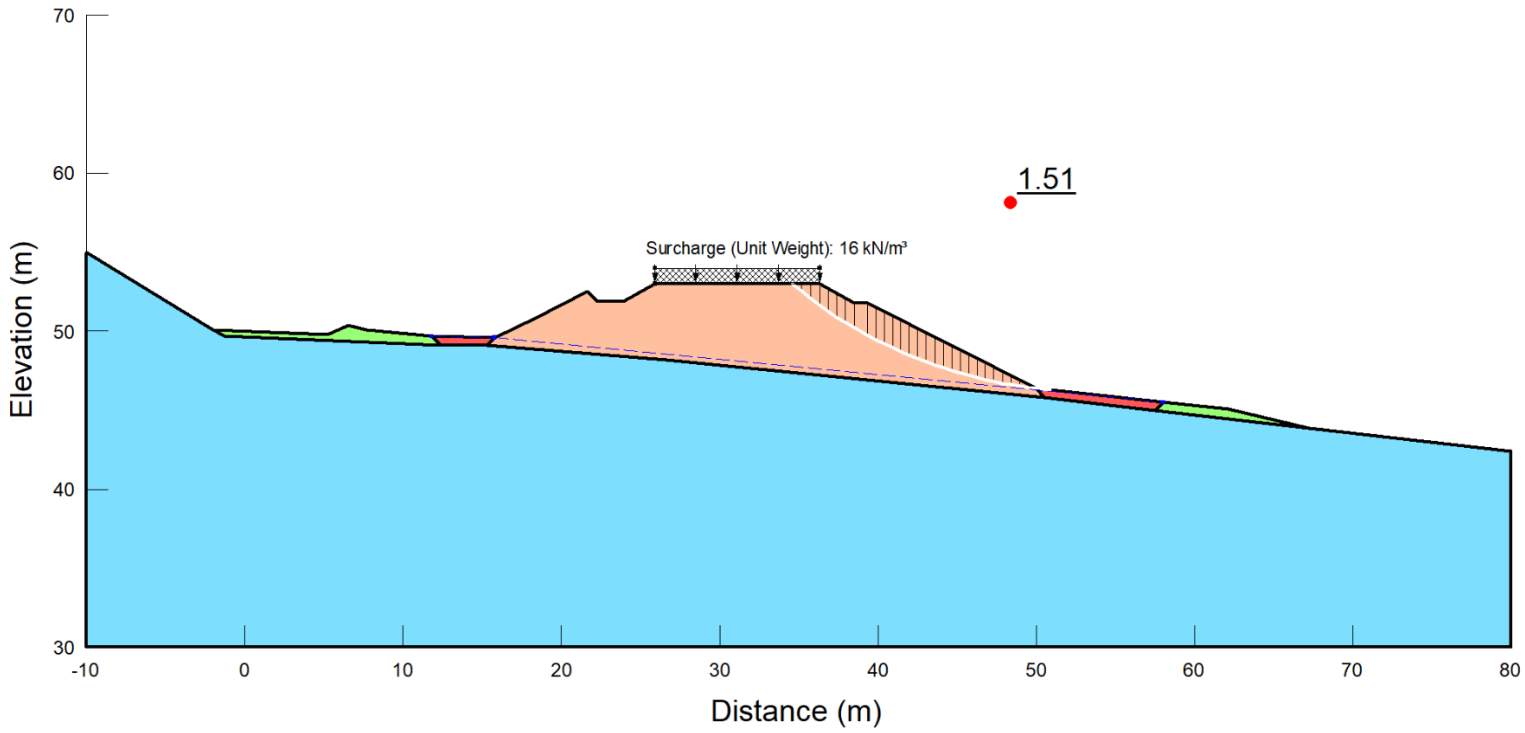
Structural Commentaries (User's Guide - NBC 2015: Part 4 of Division B)
Commentary J: Design for Seismic Effects

Geological Survey of Canada Open File 7893 Fifth Generation Seismic Hazard Model for Canada: Grid values of mean hazard to be used with the 2015 National Building Code of Canada

See the websites www.EarthquakesCanada.ca and www.nationalcodes.ca for more information

Appendix D

Slope Stability Sections



Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
	Bedrock		
	Class 50kg Riprap	24	42
	Local Type D Embankment Fill	19	34
	Riverbed Deposits	19	33

CLIENT
BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

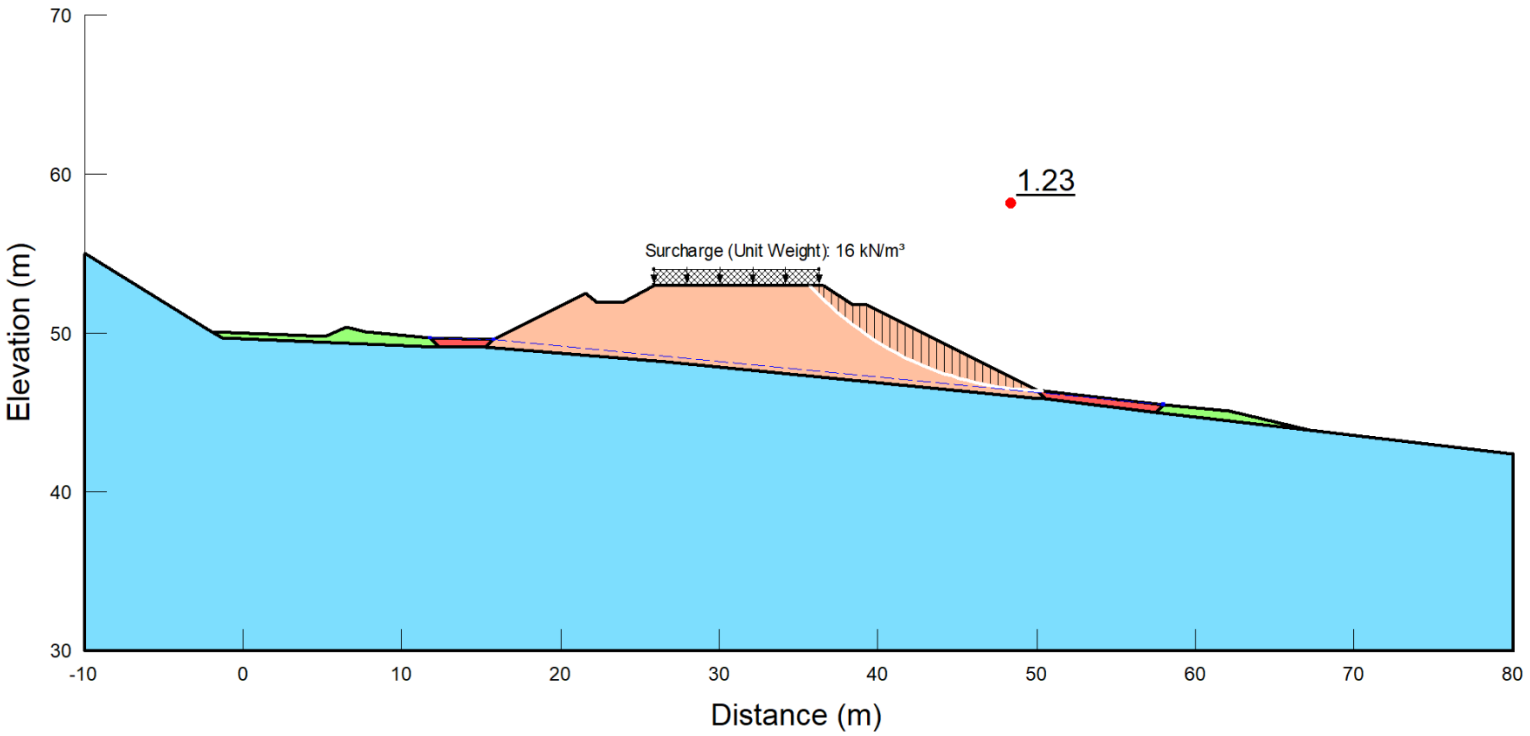
PROJECT
SUNSHINE COAST DFAA SITES – REDROOFFS ROAD

CONSULTANT
wsp

YYYY-MM-DD	2022-12-01
PREPARED	J.BRUNSWICK
DESIGN	J.BRUNSWICK
REVIEW	J.LAXDAL
APPROVED	J.LAXDAL

TITLE
CRITICAL SLOPE STABILITY MODEL
KENYON CREEK – STATIC CONDITIONS

PROJECT No.	Phase	Rev	FIGURE
VG07794	600	0	D1



Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
	Bedrock		
	Class 50kg Riprap	24	42
	Local Type D Embankment Fill	19	34
	Riverbed Deposits	19	33

CLIENT
BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

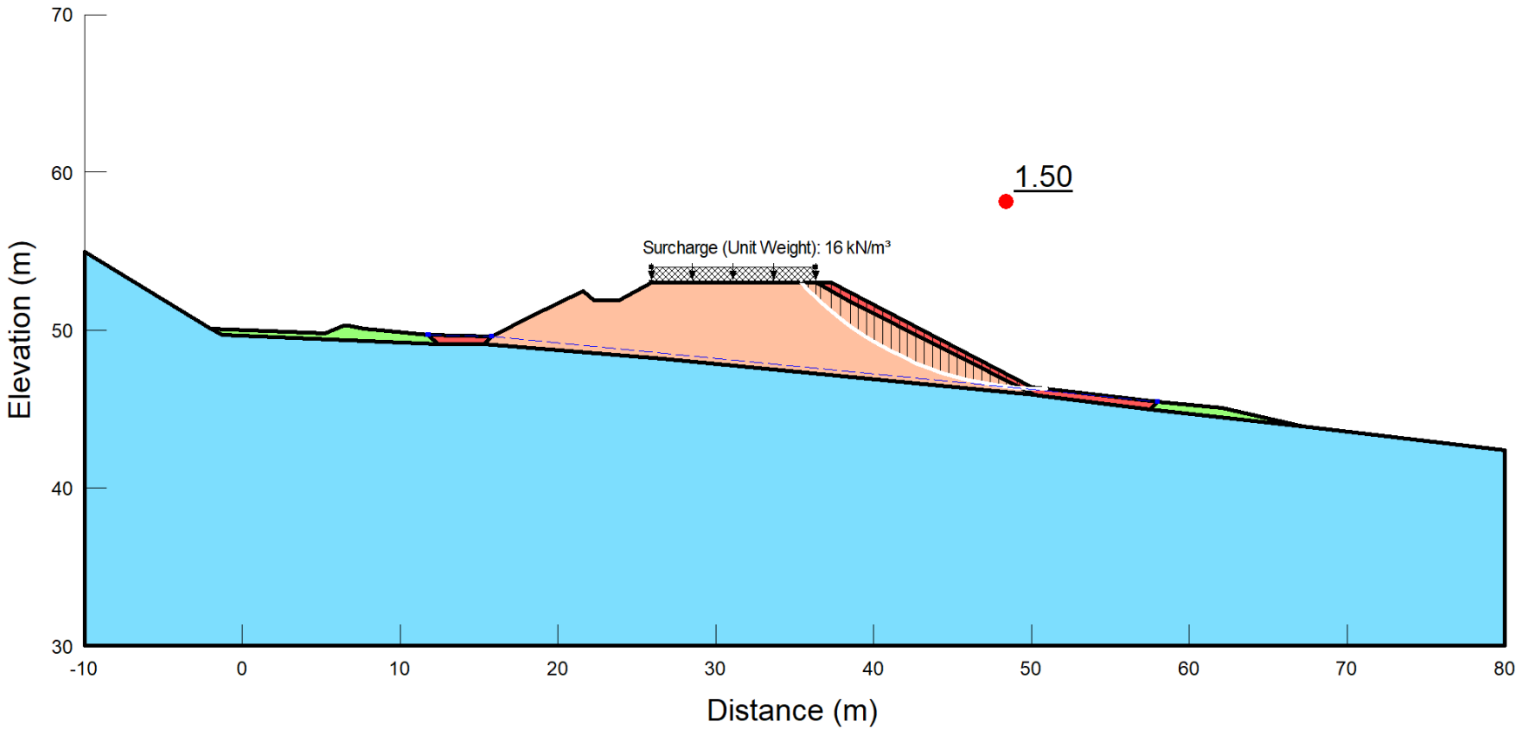
PROJECT
SUNSHINE COAST DFAA SITES – REDROOFFS ROAD

CONSULTANT
wsp

YYYY-MM-DD	2022-12-01
PREPARED	J.BRUNSWICK
DESIGN	J.BRUNSWICK
REVIEW	J.LAXDAL
APPROVED	J.LAXDAL

TITLE
CRITICAL SLOPE STABILITY MODEL
KENYON CREEK – SEISMIC CONDITIONS

PROJECT No.	Phase	Rev	FIGURE
VG07794	600	0	D2



Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
	Bedrock		
	Class 50kg Riprap	24	42
	Local Type D Embankment Fill	19	34
	Riverbed Deposits	19	33

CLIENT
BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

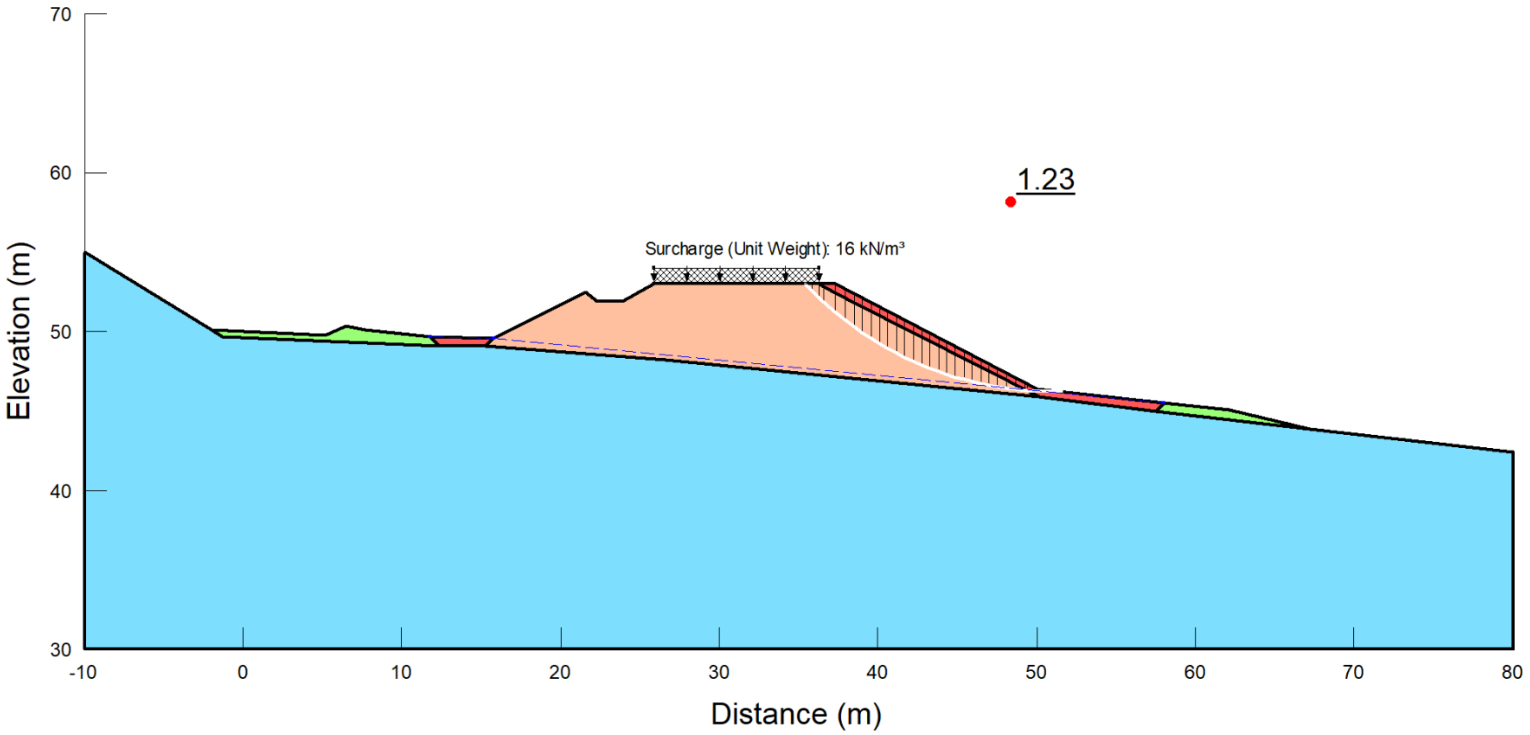
PROJECT
SUNSHINE COAST DFAA SITES – REDROOFFS ROAD

CONSULTANT
wsp

YYYY-MM-DD	2022-12-01
PREPARED	J.BRUNSWICK
DESIGN	J.BRUNSWICK
REVIEW	J.LAXDAL
APPROVED	J.LAXDAL

TITLE
CRITICAL SLOPE STABILITY MODEL
KENYON CREEK – STATIC CONDITIONS
RIPRAP ARMORED SLOPE

PROJECT No.	Phase	Rev	FIGURE
VG07794	600	0	D3



Color	Name	Unit Weight (kN/m³)	Effective Friction Angle (°)
	Bedrock		
	Class 50kg Riprap	24	42
	Local Type D Embankment Fill	19	34
	Riverbed Deposits	19	33

CLIENT
BC MINISTRY OF TRANSPORTATION AND INFRASTRUCTURE

PROJECT
SUNSHINE COAST DFAA SITES – REDROOFFS ROAD

CONSULTANT
wsp

YYYY-MM-DD	2022-12-01
PREPARED	J.BRUNSWICK
DESIGN	J.BRUNSWICK
REVIEW	J.LAXDAL
APPROVED	J.LAXDAL

TITLE
CRITICAL SLOPE STABILITY MODEL
KENYON CREEK – SEISMIC CONDITIONS
RIPRAP ARMORED SLOPE

PROJECT No.	Phase	Rev	FIGURE
VG07794	600	0	D4

Appendix E

Limitations

Limitations

1. The work performed in the preparation of this report and the conclusions presented are subject to the following:

   a. The Standard Terms and Conditions which form a part of our Professional Services Contract;

   b. The Scope of Services;

   c. Time and Budgetary limitations as described in our Contract; and

   d. The Limitations stated herein.

2. No other warranties or representations, either expressed or implied, are made as to the professional services provided under the terms of our Contract, or the conclusions presented.

3. The conclusions presented in this report were based, in part, on visual observations of the Site and attendant structures. Our conclusions cannot and are not extended to include those portions of the Site or structures, which are not reasonably available, in WSP's opinion, for direct observation.

4. The environmental conditions at the Site were assessed, within the limitations set out above, having due regard for applicable environmental regulations as of the date of the inspection. A review of compliance by past owners or occupants of the Site with any applicable local, provincial or federal bylaws, orders-in-council, legislative enactments and regulations was not performed.

5. The Site history research included obtaining information from third parties and employees or agents of the owner. No attempt has been made to verify the accuracy of any information provided, unless specifically noted in our report.

6. Where testing was performed, it was carried out in accordance with the terms of our contract providing for testing. Other substances, or different quantities of substances testing for, may be present on-site and may be revealed by different or other testing not provided for in our contract.

7. Because of the limitations referred to above, different environmental conditions from those stated in our report may exist. Should such different conditions be encountered, WSP must be notified in order that it may determine if modifications to the conclusions in the report are necessary.

8. The utilization of WSP's services during the implementation of any remedial measures will allow WSP to observe compliance with the conclusions and recommendations contained in the report. WSP's involvement will also allow for changes to be made as necessary to suit field conditions as they are encountered.

9. This report is for the sole use of the party to whom it is addressed unless expressly stated otherwise in the report or contract. Any use which any third party makes of the report, in whole or the part, or any reliance thereon or decisions made based on any information or conclusions in the report is the sole responsibility of such third party. WSP accepts no responsibility whatsoever for damages or loss of any nature or kind suffered by any such third party as a result of actions taken or not taken or decisions made in reliance on the report or anything set out therein.

10. This report is not to be given over to any third party for any purpose whatsoever without the written permission of WSP.

11. Provided that the report is still reliable, and less than 12 months old, WSP will issue a third-party reliance letter to parties that the client identifies in writing, upon payment of the then current fee for

such letters. All third parties relying on WSP's report, by such reliance agree to be bound by our proposal and WSP's standard reliance letter. WSP's standard reliance letter indicates that in no event shall WSP be liable for any damages, howsoever arising, relating to third-party reliance on WSP's report. No reliance by any party is permitted without such agreement.