Sterling Shipyard Remediation and Infill Project

90% Geotechnical Report

Prepared for:

Vancouver Fraser Port Authority

October 12, 2021

Revision Index

Revision	Prepared	Reviewed	Date	Remarks
1	IM/MH	MN	2021 02 22	30% Draft
2	IM/MH	MN	2021 03 31	30% Final
3	IM/MH	MN	2021 05 07	60% Draft
5	IM/MH	MN	2021 05 25	60% Final
6	IM/MH	MN	2021-07-23	90% Draft
7	IM/MH	MN	2021-10-12	90% Final

Internal Ref: 677011-0000-4GER-0001 › Final

Signature Page

Prepared By:

Ian Munday, BSc, P.Eng.
Geotechnical Engineer

Geoscience & Materials
Engineering, Design & Project Management

PROFESSIONAL
PROVINCE OF
Dr. S. M. HOSSEYNI
44549
BRITISH COLUMBIA
ENGINEER

SNC-Lavalin Inc.
Permit No. 1002642

2021-10-13

Mehdi Hosseyni, PhD, P.Eng.
Senior Geotechnical Engineer

Geoscience & Materials
Engineering, Design & Project Management

Reviewed By:

Mohsen Nicksiar, PhD, P.Eng.
Geotechnical Operation Manager - Lower Mainland

Geoscience & Materials
Engineering, Design & Project Management

Executive Summary

This report presents the results of a geotechnical drilling program and analyses completed by SNC-Lavalin Inc. (SNC-Lavalin) for a proposed development at the former Sterling Shipyard Site (the "Site") in Vancouver, BC. The investigation was commissioned by the Vancouver Fraser Port Authority (the port authority). The development is expected to consist of remediating the intertidal area, constructing a seawall and raising the site grading to create additional usable land area. As part of the project, available documents from previous investigations completed at the Site were reviewed. Borehole logs and other relevant data were utilized to augment the findings of this field study.

The field investigation involved drilling two boreholes by sonic method in the intertidal area. BH20-01 was drilled to a depth of approximately 7.8 m, while BH20-02 was drilled to a depth of approximately 9.1 m. The encountered subsurface soil conditions consisted of a thin surficial skiff of gravel and cobbles that overlies a low-density woodwaste layer that is unsuitable foundation material. Underlying the woodwaste is a layer of loose uniform fine grained fill sand. More competent native soils underlie the fill materials, with a compact silty sand unit grading into a very dense glacial till, which formed the base of the investigation. These findings were consistent with past investigations carried out at the Site.

The results of the investigation were utilized to choose a viable seawall construction methodology from several options, including a sheet pile wall, combi/secant pile wall, rock-filled berm, and rock berm with interior wall. Due to the presence of the dense glacial till, traditional pile driving, and sheet pile installation methods would be hindered and likely be unfeasible. After consultation with the port authority and SNC-Lavalin teams, it was decided that the seawall would be comprised of a rock-filled berm.

As part of the geotechnical modelling, SNC-Lavalin conducted a slope stability assessment and soil liquefaction with post-liquefaction settlement calculations. Both existing condition and rock berm construction scenarios were considered. The analyses indicate that, without soil densification, a large earthquake would likely induce soil liquefaction in the uniform sand fills, and due to the sloped topography, cause lateral migration (sliding) of up to 300 mm in these fill materials. Post-liquefaction settlement is also predicted to occur, with extents between 15 mm and 80 mm predicted in the modelling. The Site has been designated as Seismic Class "C".

To mitigate the liquefaction and slope stability risks, the proposed berm is recommended to be placed on the dense glacial till, thereby requiring removal (by dredging) of the woodwaste and loose sandy fills from the berm footprint. Behind the berm (landside) only the woodwaste need be removed, though the fill sand would remain (unless removal is recommended for environmental purposes) and be densified. Operations to remove the woodwaste (especially from the intertidal area) should be conducted in staged segments and be monitored by a geotechnical engineer to reduce risk of impacting the adjacent properties. The frequency and the details of geotechnical instrumentation and monitoring plan was provided in a separate cover.

This 90% report has been updated to include details on the development at the Site (including shoring in the intertidal area and compaction methodologies for the fill materials). The recommendations and analysis contained in this report supersede previous versions submitted to the port authority.

Table of Contents

Table of Contents (Cont'd)

In-Text Tables

In-Text Photographs

Appendices

1 Introduction

1.1 General

SNC-Lavalin Inc. (SNC-Lavalin) was commissioned by the Vancouver Fraser Port Authority (the port authority) to complete a geotechnical assessment of the former Sterling Shipyards Site (the "Site") at 2089 to 2095 Commissioner Street, Vancouver. The geotechnical investigation is part of a larger project (in conjunction with SNC-Lavalin environmental and structural design teams) to construct a seawall, remediate the intertidal area, and raise the site grading to create additional available land area for use by the port authority and/or for future development.

The preliminary results of this investigation were utilized to determine the feasibility of several proposed seawall designs and configurations that will maximize the newly developed area and minimize construction time and costs. Seawall options discussed include an anchored sheet-pile wall, full-perimeter combi/secant wall, rock berm, and rock berm with imbedded sheet-pile wall. Much consideration has been given to conduct the work in a manner that is environmentally sound and will reduce impact to Burrard Inlet and adjacent properties, while implementing a stable and functional design. After consideration of the results and consultation between the port authority and SNC-Lavalin teams, it has been decided the seawall will be comprised of a rock-fill berm, with a capped fill area over the available intertidal and foreshore area. The option selection is covered in separate document and will not be elaborated further in this report.

To assist in planning the development, SNC-Lavalin recently completed a geotechnical drilling investigation at low tide in the intertidal area. The newly acquired field data and analysis was combined with the results of multiple investigations carried out at the Site by SNC-Lavalin and others to provide design recommendations on the proposed development and the rock berm, as well as to provide supplemental information for the environmental remediation planning for the Site.

A historical data review using multiple sources was conducted prior to the recent field investigation to better understand the existing geotechnical conditions, to determine drill locations (to fill in data gaps) and better quantify the soil properties. This report summarizes the ground conditions obtained from historical data and presents results from the recent field investigation, which includes a liquefaction analysis, seismic site characterization, slope stability assessment, and provides recommendations for the proposed rock berm design option.

1.2 Project Understanding

It is anticipated that the development will consist of dredging environmentally compromised waste fills and geotechnically problematic (liquefiable) loose fill sands from below the rock berm footprint and intertidal/foreshore areas. The rock berm will be constructed off the existing shoreline (northward into Burrard inlet) and structural fills will be placed to the south of the berm to bring the area up to the approximate elevation of the open property on the western side (Marco Marine Containers). As per the corresponding drawing package, the approximate finished grade of the berm will be in range of EL.+7.7 m CD (Chart Datum); however, the rough finished grade behind the crest of the berm will be EL.+6.0 CD which is approximately the same elevation as the Marco Site.

It is understood that a retaining wall will be constructed to the west end of the berm in the vicinity of the existing outfall structure. It should be noted that design of this retaining wall is beyond the scope of this report.

Additional drilling was performed in the vicinity of the rock berm footprint. The results of that investigation were used to augment the results and analyses found in this report.

2 Historical Data Review

2.1 General

Prior to the site investigation (and during the reporting process), many reports and limited studies from previous investigations at the Site (and surrounding area) were reviewed to better understand site conditions. Most investigations were environmental in nature and focused on the relatively shallow fill soils, with few borings or test pits conducted through to competent native foundation soils. Though collectively, each report has provided some insight or greater understanding into the subsurface conditions and expected challenges faced for the remediation/development stages of the work.

A list of all reports for the former Sterling Shipyard Site can be found in Appendix I. Reports more directly used for comprehensive understanding of the Site (i.e., more exhaustive studies of site history with borehole and test pit logs) are directly referenced in the main body of the report with footnotes. It is noted that some of the documents referenced may have sourced earlier documents that may not have been available in digital form or provided to SNC-Lavalin. Any omissions in this regard are unintentional. The following section briefly summarizes the historical reports and other site information made available to SNC-Lavalin.

2.2 Site Location and Description

The former Sterling Shipyards Site is located at 2089 to 2095 Commissioner St in Vancouver, BC. As currently configured, the Site is bounded to the south by Commissioners St and to the north by the waters of Burrard Inlet. Lafarge-operated concrete facility (Lafarge) is located to the east and the Marco Marine Containers (Marco) yard to the west. A Site Plan that shows the general area and details (with relevant historical borehole and testing locations) can be found in Appendix II.

In contrast to developments to the east and west of the Site, the study area consists of open area that can be divided into three sections: subtidal, intertidal, and foreshore (or “uplands”). All areas have been cleared of structures from past developments, though remnant objects/artifacts (wood and metal debris) and subsurface waste fills from historical operations remain.

The Site slopes gently from the “uplands” or foreshore area down to the shoreline. Due to this shallow slope, the waterline can shift dramatically between low tide and high tide, resulting in a large intertidal area. The foreshore is overgrown with vegetation (bushes, weeds, and small trees), with a large amount of driftwood near the highwater mark. The intertidal area is mostly covered in coarse sand and gravel with cobbles, with large wooden beams (left over from removed pier structures) imbedded in this surficial material. The subsurface soil profile generally follows the surface grading, with the underlying sands and glacial till sloping down towards the inlet.

2.3 Site History

The site history and historical operations have been covered well in several reports, most notably by Hemmera in *“Detailed Site Investigation Sterling Shipyards”* (Hemmera, 2005), which included land title searches, air-photo analysis, and testimonials from site personnel. These reports cover the previous operations and initial environmental studies in greater detail than recounted here. The different stages of operations are briefly recounted here to show how the Site has evolved from pre-development to present day.

Of note, most of the historical reports cover the larger former Sterling Shipyards Site, which once included the eastern portion of the Site now occupied by the Lafarge Plant. Though this study mostly targeted information on the current "open" Site study area, any subsurface information on the adjoining properties was useful for estimating the lateral extent of the fills. The following is a brief description of the operators and their activities at the "larger" Site.

- Excelsior Lumber and Shingle Co. Ltd. operated a shake and shingle mill at the Site from the mid 1920's to the mid 1933's. The Site had two office buildings, with smaller sheds, bins and storage tanks (Hemmera, 2005).
- Sterling Shipyards operated the Site from 1933 to the mid-1980's. The Site included office and storage buildings, a multitude of shops (painting, welding, degreasing, etc.) and other industrial storage bins, machine shop, blacksmith shop, boiler house, paint shops and many other ancillary structures (Hemmera, 2005). Site plans and aerial photographs indicate several boatways, wharfs, and a machine and carpentry shop were in the present-day study area.
- The City of Vancouver used the eastern portion of the greater site (currently occupied by a Lafarge plant) as a public works yard from 1977 to 2002. This area was used for storage of road construction materials, including creosoted timbers, drums of Asphaltic Concrete (AC) compound, and other waste materials.

2.4 Summary of Previous Studies

As noted above, most investigations carried out at the Site were shallow soil or groundwater environmental investigations and provided minimal geotechnical information (beyond logs with descriptions of the encountered shallow soils). As well, many of the boreholes, test pits, and other testing locations were completed on areas currently occupied by the Lafarge plant, and are therefore out of the study area.

Some borehole locations previously completed at the turn of this century were not available in digital form, and when referenced in later reports, did not contain soil logs. The EVS Environmental Consultants (now Golder) report listed the known investigations done (up to that time) in their *"Groundwater Ecological Risk Assessment and Proposed Sediment Investigation Report"* (EVS, 2003), and provided several existing monitoring well logs (though most done in the Lafarge area).

More recent (and readily available) subsurface data was obtained from the 2005 Hemmera investigation, and from the extensive Golder investigation titled *"Supplemental Site Investigation, Former Sterling Shipyards Site"* (Golder, 2006) where 35 test pits and 36 boreholes were conducted over the Sterling/Lafarge area. A technical memorandum entitled "*Additional Investigation of Intertidal Area, Former Sterling Shipyard Site"* (SNC-Lavalin, 2013) was the first to perform cone penetration testing (CPT), with eight total completed (as well as three deeper boreholes by sonic method) primarily in the current study area. For geotechnical investigations, both Golder (2006) and Braun Geotechnical Ltd. (Braun, 2008) completed geotechnical studies, though these both focused on the Lafarge site. For the Marco site, WSP performed a Sonic drilling program (four boreholes), though only the logs were available (WSP, 2019).

Borehole, test pit, and other soil testing data were obtained from the sources listed above. Information from existing logs and CPT data was combined with the data obtained from the November 2020 investigation and used in several analyses found in this report. Further drilling data expected from the upcoming off-shore drilling will be used to augment the existing data in further stages of this study.

3 Geotechnical Field Investigation

3.1 General

A site visit to review drilling logistics was conducted on October 19, 2020. Personnel representing Blue Max Drilling Inc. (Blue Max) and SNC-Lavalin were in attendance to discuss issues pertinent to the geotechnical investigation, including site access (ramp building), vegetation clearing and tree/driftwood log cutting, general drilling requirements, and proposed borehole locations. Photographs were taken to illustrate site conditions for work plan preparation and permitting requirements. The foreshore area (strewn with driftwood requiring removal and/or cutting) is shown in Photograph 3.1.

Photograph 3.1: Driftwood accumulation in the foreshore area.

After the Category A permit was obtained from the port authority and the field investigation was approved, a date of November 16, 2020 was set for the drilling to take advantage of the monthly low tide level. It is noted that night drilling was selected over regular daytime working hours to take advantage of optimal low tides. Blue Max mobilized their drill rig and requisite equipment needed to reach the proposed drill locations. A skid steer was used to create a soil ramp from a Lafarge auxiliary parking area to access the foreshore area. All driftwood that was obstructing rig access to the intertidal area was pushed aside with the skid steer or (if too large) was cut with a chainsaw.

Once tide levels were sufficiently low enough to access on foot, Quadra Utility Locating Ltd. (Quadra) performed a utility sweep of the area with ground penetrating radar and electromagnetic (EM) sensing equipment. Though existing site drawings and data obtained from BC One Call indicated no utility lines were likely present, underground obstructions in the form of metallic objects and other deleterious debris (from previous stages of operations at the Site) were noted in the subsurface layers in past investigations and are to be avoided to prevent equipment damage and drilling delays.

3.2 Borehole Drilling

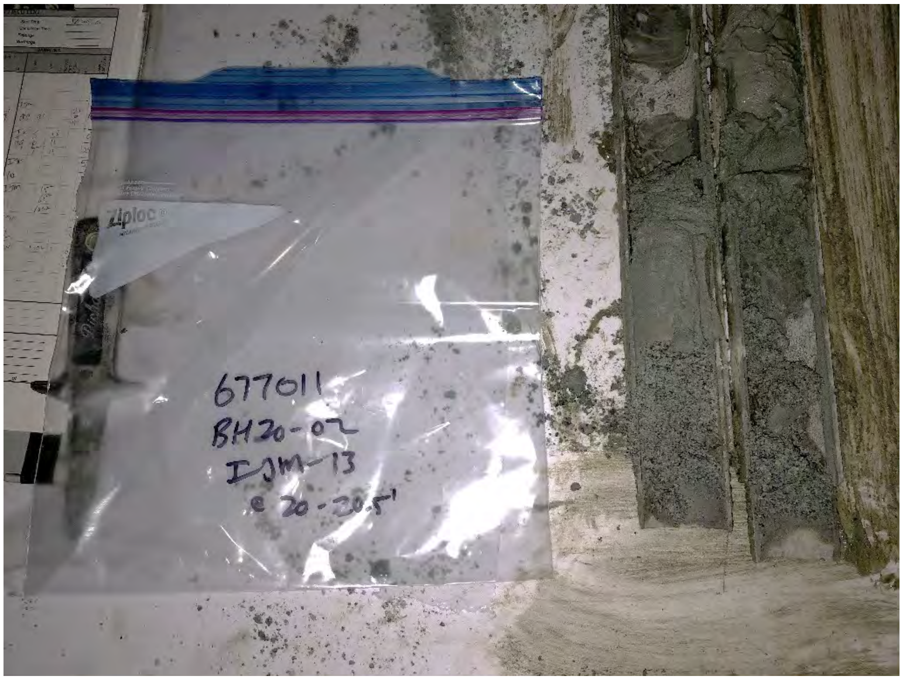
Blue Max completed the drilling of the boreholes utilizing a track-mounted sonic drill rig. Two boreholes were proposed for the field program, with one borehole (BH 20-01) drilled in the central (mid-tide) intertidal area (near the Lafarge property boundary), and one borehole (BH 20-02) at the low tide level to determine subgrade conditions in the area of the seawall. BH20-01 was drilled to a depth of approximately 7.8 m (25.5 ft), while BH20-02 was drilled slightly deeper to approximately 9.1 m (30 ft), where practical refusal was encountered. All drilling was completed in the early morning hours of November 17, 2020. The Blue Max rig used to conduct the drilling is shown in Photograph 3.2.

Photograph 3.2: Blue Max track-mounted sonic drill rig used for borehole drilling.

3.3 Soil Sampling and Standard Penetration Testing

The Blue Max sonic drill rig utilizes a 127 mm diameter solid steel core barrel that allows for near-continuous soil profiles to be recovered during each core run, which can be done in 1.5 m or 3.0 m intervals, depending on sampling needs. Core samples are returned to the surface by extracting the core barrel and extruding the sample (by vibration) into sample bags. Each bag is slit open to inspect soils for logging purposes and for collecting “grab” samples for selected laboratory testing.

Standard Penetration Testing (SPT) was conducted in each borehole. A rig mounted 140 lb hydraulic hammer was used to conduct the SPT. A 51 mm (2 inch) diameter split spoon sampler was advanced approximately 60 cm (24 inches) into the soil (unless sampler refusal is encountered), with the requisite hammer blows recorded to help gauge soil consistency/compactness. A typical split spoon sample can be seen in Photograph 3.3 (with collection bag indicating borehole number and collection depth). SPT results are displayed graphically on the borehole logs in Appendix III.



Photograph 3.3: Typical retrieved split spoon sample.

Both boreholes were partially backfilled with cuttings and hydrated bentonite chips. Only deep glacial till cuttings were used as fill material. All suspected contaminated waste soils were drummed and removed from site. Blue Max then transported the drums to a licenced soil disposal facility.

4 Subsurface Soil Conditions

4.1 General

The soil descriptions discussed herein are based on commonly accepted methods of classification and identification in geotechnical engineering practice and in general accordance with the Unified Soil Classification System (USC). Classification and identification of soils involves judgement and interpretation, and SNC-Lavalin does not guarantee that descriptions are exact, but infers accuracy to the extent that is common in geotechnical engineering practice. The depths of stratigraphic changes are generally approximate and inferred as often there can be a gradual change between soil types. The following presents a brief description of the subsurface conditions encountered at the Site.

Additional descriptions of the conditions encountered in the boreholes during the investigation are summarized on the attached borehole logs in Appendix III. Historical reports and borehole logs from previous investigations have been reviewed for correlation and for augmenting existing cross-sections to illustrate subsurface soil profiles. The updated cross-sections can be found in Appendix IV. Laboratory test results on select soil samples collected during the investigation are summarized in Section 5. Complete laboratory testing results can be found in Appendix V.

4.2 Soil Profile

4.2.1 Surficial Sand and Gravel

A thin gravelly sand with rounded cobbles covers the surface in the intertidal area at the Site, likely a mix of fills and naturally deposited fluvial material. The thickness of this layer varied between approximately 150 mm (BH20-02) and 300 mm (BH20-01), with some historical boreholes having this surficial layer up to approximately 500 mm. Some metallic debris and old timber were noted around the drill areas.

4.2.2 Woodwaste Fill Layer

Common to all investigations done at the Site, is the presence of a “peat-like” black to brown woodwaste layer, comprised of fibrous wood debris mixed with silt/sand. This low-density material is very soft/loose with little to no shear strength and is considered very poor foundation material, with excessive settlement likely should it be loaded by any structure. Waste from all iterations of Site historical use (metal, brick, ceramics, etc.) is commonly found in this layer, as well as black tar-like creosote deposits. Previous investigations have indicated that the woodwaste layer is also an environmental liability and will require full removal as part of any developmental plan. For this investigation, the base of the woodwaste layer was encountered at depths of approximately 2.1 m (BH20-02) and 3.0 m (BH20-01).

4.2.3 Sand Fill

Underlying the woodwaste layer, was a poorly graded silty fine sand, notable for numerous shell fragments. This sand layer was likely formed with dredged sand from the harbour at an early development stage. The sand fill unit is generally loose and non-plastic, with trace silt and gravel. The thickness of this layer varied between 0.3 m (BH20-02) and 1.5 m (BH20-01).

4.2.4 Native Silty Sand

Immediately beneath the Fill is a compact silty sand unit. These soils contain banding and iron staining, indicating the sands are undisturbed, and are therefore readily identifiable from the overlying sandy fill. The native sand is moderately to well graded and had variable amounts of silt and gravel, with rounded cobbles commonly found. This unit is similar in content to the underlying tills, though the soils are compact in contrast to the very dense nature of the till. The native sand was encountered at depths of approximately 2.4 m (BH20-02), though it was not readily identifiable in (BH20-01).

4.2.5 Glacial Till

A very dense glacial till was encountered in both boreholes and formed the base of the investigation. The till matrix was generally well graded, with sub-rounded to sub-angular coarse gravel more frequent with increasing depth. Silt content was variable throughout the unit. Only one sample (IJM-04), which was near the top of the unit, had a higher silt content than sand. The very dense till contact (identified primarily from drill action and sampler refusal) was encountered at depths of approximately 3.0 m (BH20-02) and 4.5 m (BH20-01).

Drilling in this very dense unit was difficult, resulting in slow drill penetration and intense heat generated by the drill bit. SPT penetration was also limited, with split-spoon sampler refusal encountered (with less than 150 mm of penetration) for all tests once completely within the unit, indicating the very high strength and competence of this material. It is noted that the presence of this dense glacial till eliminated the possibility of using conventional sheet-pile installation methods as penetration into this material with vibration or impact hammers is considered unfeasible. Returned cores from the drilling can be seen in Photograph 4.1.

Photograph 4.1: Glacial till core samples.

5 Laboratory Testing Results

Laboratory tests were conducted on select soil samples obtained from the boreholes. No geotechnical testing was performed on the surficial gravels or woodwaste layers, as these soils are considered poor foundation materials and will be removed at early stages in the development. As cohesive soils were not encountered, no Atterberg testing (or index soil characteristic tests) were conducted. Testing was limited to hydrometer analysis for grain size distribution and moisture contents. A summary of the laboratory testing is presented in Table 5.1.

Table 5.1: Laboratory Results Summary

Borehole	Sample ID	Sample Depth		Stratigraphy	Grain Size (%)				Water Content (%)
		(m)	(ft)		Gravel	Sand	Silt	Clay	
BH20-01	IJM-01	2.7	9.0	Woodwaste	-	-	-	-	253.8
BH20-01	IJM-02	3.7	12.0	Silty Sand	5.9	52.4	37.9	3.9	18.2
BH20-01	IJM-03	4.9	16.0	Silty Till	8.9	55.0	32.5	3.6	14.3
BH20-01	IJM-04	5.8	19.0	Sand Till	2.3	35.2	56.2	6.3	16.7
BH20-01	IJM-05	6.1	20.0	Sand Till	-	-	-	-	14.3
BH20-01	IJM-06	7.3	24.0	Sand Till	0.0	57.7	33.0	9.3	12.2
BH20-01	IJM-07	7.6	25.0	Silty Sand	-	-	-	-	12.4
BH20-02	IJM-08	2.7	9.0	Silty Sand	3.5	49.6	39.4	7.6	25.8
BH20-02	IJM-10	4.3	14.0	Sand Till	22.2	47.1	29.2	1.6	15.5
BH20-02	IJM-11	4.6	15.0	Sand Till	25.0	52.7	18.8	3.6	8.8
BH20-02	IJM-12	5.8	19.0	Sand Till	23.0	48.7	23.5	4.9	13.0
BH20-02	IJM-13	6.1	20.0	Sand Till	-	-	-	-	15.8
BH20-02	IJM-14	7.3	24.0	Sand Till	15.5	47.4	27.3	9.8	8.6
BH20-02	IJM-15	7.6	25.0	Sand Till	-	-	-	-	16.2
BH20-02	IJM-16	9.1	30.0	Sand Till	-	-	-	-	10.0

6 Geotechnical Discussion

As described in previous sections, the Site consists of fill materials over native sands and dense glacial tills. Information from existing boreholes and CPT data was combined with the results of this study to perform the following analyses. For discussion purposes, note that elevations provided (EL) use Chart Datum (CD) as opposed to Geodetic Datum (GD), which is based on mean sea levels. Affecting the analysis (especially for soil liquefaction), is the subsurface slope of the denser sand and till layers found at depth, which generally follows the Site gradient seen at surface. The Site slope can be more fully observed when the intertidal area is exposed at low tide. The Site drops from an approximate elevation of +8 m (CD) (high water level) to EL +3 m (CD) (lowest sea level) over an approximate 80 m long section, meaning susceptible soils (when liquefied during seismic shaking) could mobilize downslope (i.e., flow or slide laterally) by force of gravity.

6.1 Seismic Considerations

Based on the available subsurface information, including in-situ and laboratory testing results, the Site is classified as Site Class “C” in accordance with CSA S6-14, NBCC 2015 and BCBC 2018, Table 4.1.8.4.A.

The 5% damped firm ground acceleration response spectrum for the Site was obtained from the interactive website maintained by the Geological Survey of Canada and is summarized in Table 6.1.

Table 6.1: Response Spectrum for 5% Damping at Firm Ground Interpolated for Site Class C

Probability of exceedance in 50 years	2%	40%
Period (S)		
Sa (0.05)	0.429	0.094
Sa (0.1)	0.653	0.144
Sa (0.2)	0.809	0.183
Sa (0.3)	0.81	0.183
Sa (0.5)	0.716	0.151
Sa (1.0)	0.406	0.077
Sa (2.0)	0.247	0.042
Sa (5.0)	0.079	0.009
Sa (10.0)	0.028	0.003
PGA (g)	0.351	0.078

For this project, a performance-based approach was adopted by considering two levels of seismic performance for the seismic design; “Operating Level Event” (OLE) and “Contingency Level Event” (CLE). OLE refers to seismic performance for an earthquake with a 40% probability of exceedance in 50 years (i.e., 1/100 earthquake return period), and CLE refers to seismic performance for an earthquake with 2% probability of exceedance in 50 years (i.e., 1/2,475-year earthquake return period). The performance objective for these two earthquake scenarios are as follows:

- Performance Objective for OLE: minor, easily repairable damage with no interruption to operations; and
- Performance Objective for CLE: repairable damage with some interruption to operations; however, any structure should not collapse after a 2,475-year earthquake event. There may be temporary loss of operations which should be restorable; however, loss of life is to be prevented.

The seismic design was conducted for the above two earthquake-return periods.

6.2 Liquefaction Triggering Event

Data from the CPT conducted by SNC-Lavalin in 2012 was used to obtain the cyclic shear resistance of the soils using the available raw data (digital data) for the eight CPTs (RCPT12-01 to RCPT12-08). Four CPTs were advanced deeper than 5 m and were therefore used for the liquefaction assessment (RCPT12-05 to RCPT12-08). The locations of the CPTs can be found on the Site Plan in Appendix II.

The liquefaction potential of the sandy soils was assessed using the Boulanger & Idriss 2014 CPT-based methodology. The susceptibility of the subsoils to liquefaction at the project site was carried out using the commercially available software CLiq. 3.0, developed by GeoLogismiki and based on the Boulanger & Idriss 2014 method. This procedure compares the Cyclic Resistance Ratio (CRR) with the earthquake induced Cyclic Stress Ratio (CSR) from a specified design earthquake at a given depth. Factor of Safety (FoS) against liquefaction is calculated as the ratio of CRR/CSR. An FoS less than 1.0 represents a high potential for liquefaction.

The deaggregation plot for Vancouver by Halchuk et al. (2007) was used to obtain the earthquake Magnitude for a 2,475-year earthquake, as a seismic hazard assessment and deaggregation was not determined to be necessary. For a liquefaction triggering assessment, a moment magnitude of Mw=8.2 (to consider the subduction hazard) with a PGA= 0.351g for a 2,475-year earthquake return period, and a moment magnitude of Mw=6.72 with a PGA= 0.078g for a 100-year earthquake return period, were considered.

6.3 Post Liquefaction Settlement

Dissipation of the excess pore water pressure develop during shaking and liquefaction would cause ground settlement. Method developed by Zhang et al. (2002) was used to estimate the post liquefaction settlement, assuming no ground densification or other improvements. Post-liquefaction settlement under 2,475-year earthquake events to the end of exploration depth (i.e., depth 6 m), was estimated. Considering the presence of the very dense glacial till layer below the liquefiable layer, no further liquefaction-induced settlement is anticipated below 6 m.

The liquefaction assessment for 100-year and 2,475-year earthquake events indicated the sand layers (between the dense glacial till and woodwaste fill) is susceptible to liquefaction. Results of the assessment indicated that it is unlikely that the soil underlying the Site would liquefy under 100-year earthquake event. However, under 2,475-year earthquake, liquefaction will be expected. Due to the sloped topography of the glacial till beneath the liquefiable sand, flow slide (mobilization) will be likely during/after a 2,475-year earthquake and will generate a substantial lateral movement of the existing sediments. The lateral ground movements (with no densification) would be in the order of 300 mm in 100-year and more than 3 m in 2,475-year earthquake event. The liquefaction assessment details can be found in Appendix VI.

Post-liquefaction settlement under the 100-year and 2,475-year earthquake events to the end of exploration depth, including strain softening settlements from silty soils, is estimated to be in range 15 mm and 80 mm, respectively. It is understood that the existing loose sand layer beneath the wood waste layer will be densified during fill placement. If sand layers are properly densified settlement due to liquefaction as well as lateral ground movement are expected to be very minimal.

6.4 Slope Stability Assessment

Slope stability analyses were conducted under static and seismic loading conditions using soil parameters obtained from the available information and from our field investigation outlined in Section 4. The static slope stability assessment was conducted for the “Lowest Low Tide Level” (LLW) and seismic analyses were completed for the “Mean Water Level” (MWL). The LLW and MWL were considered at EL +0.1 m (CD) and EL +3.1 m (CD), respectively.

Slope stability analyses were completed using the limit equilibrium approach and Morgenstern-Price method included in the commercially available software SLOPE/W, Version 10.2.2 (GeoStudio, 2019). The available borehole logs and CPTs available at the time of this report were used to approximate a typical geological section and groundwater interpretation. The interpreted soil parameters used in the slope stability assessments are presented in Table 6.2.

Table 6.2: Soil Parameters Used in Slope Stability Assessments

Materials	Unit Weight (kN/m^3)	Cohesion (kPa)	Phi (°)	Tau/Sigma Ratio	Minimum Strength (kPa)
Wood waste with some sand	14	0	22	--	--
Sand/silty Sand	18.5	0	30	--	--
TILL-Like	20	0	40	--	--
Engineered Fill*	20	0	36	--	--
Densified Sand/silty Sand*	19.5	0	34	--	--
Liquefied Sand/silty Sand	15	0	--	0.08	10
Rip-Rap*	22	0	40	--	--
Filter Material*	20	0	40	--	--
Hydraulic Fill (Loose Sand)*	18	0	30	--	--
Top soil for planting*	15	0	5	--	--

*assumed values

The seismic (‘pseudo-static’) slope stability assessments were performed for 100-year and 2,475-year earthquake return events. The slope stability was assessed under seismic loading conditions by using a horizontal seismic coefficient (k_h) of 0.5 times the site-adjusted Peak Ground Acceleration (PGA). For cases where the seismic FoS was less than 1.0, the yield acceleration (k_y) was estimated to evaluate the slope displacement. Conventional Newmark-type analyses (e.g., Bray and Travasarou 2007 for slopes and embankments) were used to estimate seismically induced lateral displacement of slopes in non-liquefiable ground conditions. The post-liquefaction stability of the slopes was also analyzed assuming the sand layer behind the rock berm (land side) will not liquefy, assuming it will be compacted during construction (i.e., densified afterward). This layer was modelled as liquefied on the north side (water side) beyond the toe of the berm.

Slope stability analyses were completed for the provided berm geometry. The updated berm geometry indicates that the berm includes a rip-rap layer with minimum thickness of 0.9 m which slopes at 2H:1V (2 Horizontal: 1 Vertical), and a filter layer with minimum thickness of 0.5 m which slopes at 2H:1V. The analyses were completed considering extreme scour conditions at the toe of the berm (north side). Stability of the berm under post-liquefaction ground conditions was completed.

Based on the available information provided by the port authority, it is understood that the proposed development will be used as a container storage yard. Based on this, a maximum surcharge of 18 kPa was assumed, to be placed with a minimum 4-metre set back from the north edge of the berm crest, for the slope stability assessment. However, if the future use of the development indicates that the Site will be under a higher magnitude of live load and traffic load, the geotechnical engineer should be consulted, and the slope stability should be reassessed.

A representative longitudinal cross-section (Section D-D) was analysed for static and seismic condition as discussed above. See Appendix II (Site Plan) for location of Section D-D. However, the analyses were conducted considering final berm elevation (i.e., +7.7m). Results of analyses are presented in Appendix VII. The factor of safeties (FoS) for different loading conditions are provided in Table 6.3.

Table 6.3: Factor of Safety for Slope Stability in Different Loading Conditions

Loading Condition*	Factor of Safety	Minimum Required Factor of Safety
Static	1.6	1.5
Seismic (1:100 years)	1.4	1.2
Seismic (1:2,475 years)	0.9	1.0
Post-Liquefaction	1.0	1.0

For the 2,475-year seismic case, where the FoS was less than 1.0 under 50% PGA event loading, the yield acceleration (k_y) was estimated to evaluate the slope displacement. For such event, seismically induced lateral displacements in non-liquefiable ground conditions were estimated to be in the range of 150 mm to 200 mm. Under this displacement, the berm is anticipated to be repairable after a major earthquake and, hence, it meets the seismic criteria set out for CLE (as mentioned in Section 6.1).

6.5 Temporary Cut Slopes

Earlier in the design phase it was recommended that excavation cut slopes should not be steeper than 5H:1V within the intertidal area on both east and west sides below the high tide level and that slopes above the high tide be no steeper than 3H:1V. These relatively shallow slope recommendations were provided due to the high likelihood of mobilization of the loose fill and woodwaste layers on both the Lafarge and Marco marine sites. An alternative excavation method using temporary shoring on all three sides (east, west and south) was also presented to the port as an alternative approach by SNC-Lavalin via email on April 30, 2021.

In order to maximize the amount of waste material that can be removed, while reducing the impact to the adjacent properties, a temporary shoring system was selected by the port authority (communicated to SNC-Lavalin via email on July 08, 2021) as the preferred option to stabilize the excavation. The shoring system and installation methodology shall be provided by the excavation contractor and follow the criteria presented in Geotechnical Instrumentation and Monitoring Plan (GIMP) report (No. 677011-0000-4GER-0002).

6.6 Seepage Analysis

A set of seepage analyses was completed to provide expected range of seepage rates into the subtidal excavation from the east side (Lafarge site), and the west side (Marco site). It should be noted that the planned rock berm will be constructed without any non/low permeable core to control seepage through of body of the berm. Therefore, it is expected that seawater will freely seep through the rock berm from the subtidal area to reach an equilibrium with the regional groundwater elevation. The following seepage analyses were conducted to estimate a range of seepage rates as discussed above.

- The seepage analyses were completed for two East-West cross-sections; Section G-G and Section I-I, assuming no cut-off wall or seepage barrier to be installed neither on east side nor on west side. See Appendix II (Site Plan) for location of the cross-sections. Available data from deep test holes in the vicinity of each cross-section was used for soil stratigraphy and interpretation of soil parameters. The referenced test holes for each cross-section are as follows:
  - Section G-G: RCPT12-3, BH20-02, RCPT12-4, RCPT12-5, BH06-16, MW04-4; and
  - Section I-I: RCPT12-2, BH06-4, BH06-21, RCPT12-1, BH06-29.

The analyses were conducted based on the following considerations:

- The analyses were done in 2D assuming a section of 1 m thick;
- Discussions on the bottom segment of woodwaste material at the location of the Cross-Section G-G indicate that these materials are not contaminated and could be left in place from an environmental prospective. However, from a geotechnical standpoint, the woodwaste material should be entirely removed, to minimize long-term settlement, and replaced by compacted structural fill material. Therefore, the seepage analyses were completed assuming the entire woodwaste will be removed;
- As the available test holes at location of Section I-I were shallow (i.e., terminated in the wood waste layer), the thickness of wood waste along this section was interpreted from the closest deep test holes;
- Soil stratigraphy within both the Marco and Lafarge sites were extrapolated using available deep test hole data within these sites (reference test hole S18-02);
- Soil hydraulic conductivity (K) for the sand/silty sand layer was provided in the environmental report; however, for the other soil layers, a range of hydraulic conductivity was selected from the literature based on the soil gradation and descriptions; and
- In order to consider the uncertainty in hydraulic conductivity of soil layers, seepage analyses were completed for Lower K value and Upper K value representing anticipated minimum and maximum hydraulic conductivity of a particular soil type. Table 6.4 summarizes soil parameters used for seepage analyses.

Table 6.4: Soil Parameters Used in Seepage Analysis

Materials	Saturated Kx* (m/s)		Ky*/Kx Ratio	Volumetric Water Content
	Lower K Values	Upper K Values		
Compacted Sand and Gravel (Fill)	1e-04	1e-03	1	0.1
Wood waste with some sand	1e-05	1e-03	1	1.4
Sand and Gravel (Engineered Fill)	1e-03	1e-02	1	0.2
Sand/silty Sand	3.7e-06	1.2e-04	1	0.16
Till-Like	1e-08	1e-06	1	0.12
Rip-Rap	0.1	0.1	1	0.05
Lock-Block Wall	1e-04	1e-03	1	0.01
Filter Material	1e-04	1e-03	1	0.1

*Kx and Ky represent hydraulic conductivity in horizontal and vertical direction, respectively.

The following Table 6.5 and Table 6.6 summarize the range of seepage at location of each cross-section:

Table 6.5: Expected Seepage Range at Section G-G

	Water Rate (GPM)/m
East Side	1 to 6
West Side	2 to 11
Bottom	0 to 0.5
Total	3 to 18

Table 6.6: Expected Seepage Range at Section I-I

	Water Rate (GPM)/m
East Side	0.3 to 3
West Side	1.5 to 8
Bottom	0 to 0.5
Total	2 to 12

It should be noted that the seepage rate of water into any excavation is highly dependent on the dimensions of the excavation, method of construction, and materials used for backfilling. The tidal cycle and seasonal variations of groundwater table may also impact the ultimate seepage rate.

6.7 Backfill Material

General structural fill required for both the berm and inland fills should be comprised of 150 mm (6 inch) minus, well graded, free draining (less than 12% passing No. 200 sieve) granular material. Fill gradations are to meet the particle size limits as provided in Table 6.7.

Table 6.7: Accepted Backfill Material Gradation Ranges

150 mm Minus Graded Fill Gradation		
ASTM Sieve	ISO Metric Sieve (mm)	Percent Passing by Weight
6”	150	100
3”	75	80 -100
1.5”	37.5	60 - 100
3/4”	19	35 - 100
3/8”	9.5	25 - 85
#4	4.75	15 - 75
#50	0.297	3 - 30
#200	0.075	0 - 12

Fill materials are to be sampled at the supply location (quarry) and tested by a CCIL-certified laboratory, with results provided to the geotechnical representative prior to site shipment. All loads hauled in are to be inspected by Geotechnical Engineer of Record or its representative to ensure the quality and composition of the backfill materials are consistent with the initial (laboratory tested) materials.

All imported fills are to be free of organics, construction debris, over-sized particles (cobbles/boulders) and/or other deleterious materials and meet environmental standards as determined by the Ministry of Environment & Climate Change Strategy (ENV). Other fill materials (such as rip-rap) are to adhere to the same environmental standards as set forth by ENV for placement of fills in marine environments.

6.8 Backfill Placement and Ground Improvement

Placement of granular fills are typically done in multiple lifts (layers), with a maximum thickness and density specified by the design engineers. QC testing on fill density and moisture content (by nuclear densometer) is conducted on each lift, with compaction equipment (vibratory drum rollers) utilized to densify the material. While this methodology is suitable for most applications (foundations, pavement structures, etc.), the unique challenges posed by the Site in the intertidal portions mean that traditional methodologies as outlined above would result in the fill area being regularly inundated by water, meaning fill activities would be highly dependent on tide levels and would limit the amount of time that fill/compaction work could take place. The daily water ingress would saturate and loosen the compacted granular fills.

To accelerate the schedule and reduce damage from the tidal action on compacted fills, a mass fill and large-scale vibro-compaction operation will be implemented at the Site. All granular fills behind the berm will be placed in a loose state, with no limits on lift thicknesses and/or extent. This mass filling of the area can be done much more quickly and with less risk than traditional methods. Once filled, ground improvement techniques (vibro-compaction) will be utilized to compact the fills in-situ.

The ground improvement should be planned such that the fill and native materials down to the glacial till level have densified enough to minimize the risk of static and post-liquefaction deformation. This means the fill and native material should achieve a relative density equivalent to the corrected normalized Standard Penetration Resistance ($N1_{60}$) of 25. After the compaction work has been completed, the ground improvement contractor will need to verify that the entire volume of densified soils has been compacted to achieve the criteria mentioned above. As traditional methods to test soil density (by use of a nuclear densometer) cannot be used, a compaction verification plan throughout the entire depth and lateral extent shall be provided to SNC-Lavalin for approval prior to field mobilization.

7 Recommendation

Based on the above preliminary analyses of the existing ground conditions (as the Site is currently configured), potential settlements, soil liquefaction with resulting lateral (flow) sliding, and slope instability should be mitigated for the proposed rock berm.

It is understood that the woodwaste layer will be removed from the entire site for both environmental and structural purposes. The woodwaste material is susceptible to excessive settlement of up to 600 mm under surcharge. The extent of this woodwaste removal to facilitate site remediation has been reviewed. It is recommended that the entire woodwaste layer within the development footprint to be removed to eliminated long-term total and differential settlement. It should be noted, if for any reason the woodwaste cannot be removed entirely settlement is anticipated. Extend of the woodwaste removal, from a geotechnical prospective, is shown on different cross-sections in Appendix IV.

The liquefaction assessment of the proposed rock berm was conducted to evaluate liquefaction and lateral slide potential. For this berm option, it was assumed that up to 6 m of engineered fill will be placed on the existing loose sand layer inland from the berm (after removal of the woodwaste).

Results of the assessment indicate that it is unlikely that the soil underlying the Site will liquefy under 100-year earthquake event. However, the results showed that layers of soil from the original ground surface to the end of exploration (about 6 m depth) are susceptible to liquefaction under 2,475-year earthquake events. Details of liquefaction assessments for the both earthquake-return-periods are presented in Appendix VI.

In order to mitigate the liquefaction and slope instability risks, the following is required for the design and construction of the rock berm and engineered fill:

› The proposed berm should be founded on the dense glacial layer. The existing woodwaste and loose sand layers are to be removed from the footprint of the proposed berm and replaced with engineered granular fill and densified. It is expected that unlink the Marco site, the engineered fill on the Site will not experience significant long-term settlement;

› The existing woodwaste behind the berm (i.e., land side) should be removed and replaced with engineered granular fill. The loose sand layer beneath the woodwaste layer can remain in place (unless is required to be removed from environmental prospective). However, this material should be densified to mitigate the potential liquefaction;

› The north-facing berm slope is not be steeper than 2H:1V (2 Horizontal: 1 Vertical) with a filter layer slopes at 2H:1V;

› The berm should be protected by a minimum 0.9 m thick layer of rip-rap, and a filter layer with minimum thickness of 0.5 m;

› Woodwaste and sand layers immediately past the downstream toe of the berm (north of the berm footprint) should be removed (as much as reasonably practical) to ease construction and dredging activities. The excavated fills are to be replaced by sand (assumed hydraulic fill placement-loose sand);

› The temporary excavation cut slopes are to be shored as noted in above Section 6.5. Full-time geotechnical monitoring is recommended during this critical stage;

- The existing loose sand/sandy layer within the footprint of the development should be densified (to the top elevation of glacial till) to eliminate the potential of liquefaction. The ground-improvement contractor shall consider the depth and extent of the ground improvement to fully cover the existing loose sand. As well, the contractor shall provide a confirmatory testing methodology to verify if the fill and loose sand layer has been suitably densified after the infilling of the intertidal area; and
- The proposed retaining wall to west of the berm should be founded on till layer with minimum 2 m set back from foundation of the existing outfall structure.

8 Conclusion

The analyses provided in this report were completed based on the available information and our understanding of the proposed rock berm option. Based on the above analyses, the existing ground condition is susceptible to large long-term settlement, liquefaction and flow slide, and slope instability during major seismic events. These geotechnical issues can be mitigated by the removal of the low-density woodwaste layer and loose sands from below the proposed berm footprint. Inland, the woodwaste will also be removed, but loose sands (that are not environmentally impacted) can remain in placed and is suitably improved (i.e., densified). The aforementioned geotechnical issues should be considered and mitigated for the proposed design option.

9 References

Canadian Standards Association (CSA), 2019. CSA S6:19 Canadian Highway Bridge Design Code.

British Columbia Building Code (BCBC), 2018. Seismic Hazard Calculation.

Boulanger and Idriss, 2014, R.W. Boulanger, I.M. Idriss, CPT and SPT based liquefaction triggering procedures, Report No. UCD/CGM-14/01, Center for Geotechnical Modeling, Department of Civil and Environmental Engineering, University of California, Davis, USA (2014).

Braun Geotechnical Ltd. (Braun), 2008. Preliminary Geotechnical Report, Lafarge Batch Plant Project, 2095 Commissioner Street, Vancouver, BC.

EVS Environmental Consultants (now Golder), 2003. Groundwater Ecological Risk Assessment with Proposed Sediment investigation Strategy. Former Sterling Shipyards Site, Vancouver, BC.

Golder Associates (Golder) 2006. 10. Preliminary Geotechnical Investigation, Potential Shoreline Expansion, Sterling Shipyards, 2089 Commissioner Street, Vancouver, BC.

Halchuk, S., Adams, J. and Anglin, F. (2007). Revised Deaggregation of Seismic Hazard for Selected Canadian Cities, Proceedings, Ninth Canadian Conference on Earthquake Engineering, 25-29 June 2007, Ottawa, Canada, Paper 1188, 13p.

Hemmera, 2005. Detailed Site Investigation Sterling Shipyards 2089 Commissioner Street, Vancouver, BC.

SNC-Lavalin Inc, 2013. Additional Investigation of Intertidal Area, Former Sterling Shipyard Site, Vancouver, BC. Technical Memorandum.

WSP Global Inc. (WSP), 2019. Site Plan and Sonic Borehole Logs for Marco Marine Containers yard, Vancouver, BC.

Zhang, G., Robertson, P.K., and Brachman, R.W.I (2002). "Estimating Liquefaction-induced ground settlements from CPT for level ground." Canadian Geotechnical Journal, 39(5), 1168-1180.

Morgenstern, N.R., and Price, V.E., 1965. The Analysis of the Stability of General Slip Surfaces. Geotechnique, Vol. 15, pp. 79-93.

Bray, J.D. and Travasarou, T. (2007) "Simplified Procedure for Estimating Earthquake-Induced Deviatoric Slope Displacements," J. of Geotech. & Geoenv. Engrg., ASCE, Vol. 133(4), 381-392.

American Association of State Highway and Transportation Officials (AASHTO), Standard Specifications for Highways and Bridges, 2019.

Appendix I

List of Sterling Shipyard Reports

List of Sterling Shipyard Reports

1) *Phase I ESA*, Golder Associates Ltd., dated 1992, prepared for the City of Vancouver
2) *Environmental Audit of Portions of Stewart Street and the Property at the Foot of Cambridge Street*, prepared by Envirochem Special Projects, dated 1992, prepared for VPA
3) *Report of Findings - Soil, Sediment and Groundwater Investigation, Sterling Shipyard Site, 2089 Commissioner Street, Vancouver, B.C.*, dated May 1997, prepared by Keystone Environmental
4) *Phase II Environmental Site Assessment, Sterling Shipyards, Vancouver, BC*, report dated July 1999, prepared by Hemmera Resource Consultants Ltd.
5) *Baseline Summary Report, Proposed Vancouver Harbor Ready Mix Concrete Plant, V, BC* dated June 2001, prepared by Hemmera Envirochem Inc. for Lafarge Canada Inc.
6) *Delineation Investigation, Sterling Shipyards, Commissioner Street, Vancouver, BC,* dated February 2003, prepared for Hemmera Envirochem Inc. for VPA
7) *Intertidal Habitat Survey, Proposed Vancouver Lafarge Vancouver Harbour Batch Plant,* July 2001, prepared by Aqualibrium Environmental Consulting Inc.
8) *Groundwater Ecological Risk Assessment and Proposed Sediment Investigation Strategy, Former Sterling Shipyard Site, Vancouver, BC*, dated December 2003, prepared by EVS Environment Consultants for VPA
9) *Detailed Site Investigation Sterling Shipyards 2089 Commissioner Street, Vancouver, BC*, dated November 2005, prepared by Hemmera Envirochem Inc.
10) *Preliminary Geotechnical Investigation, Potential Shoreline Expansion, Sterling Shipyards, 2089 Commissioner Street, Vancouver, BC,* dated July 31, 2006, prepared by Golder Associates
11) *Supplemental Site Investigation, Former Sterling Shipyards Site, Vancouver Port Authority*, dated December 5, 2006, prepared by Golder Associates
12) *Subtidal Sediment Quality Investigation, Former Sterling Shipyard, Vancouver, BC*, dated January 14, 2006, prepared by Golder Associates
13) *Preliminary Geotechnical Report, Lafarge Batch Plant Project, 2095 Commissioner Street, Vancouver, BC.* dated September 30, 2008, prepared by Braun Geotechnical Ltd.
14) *Supplementary Detailed Site Investigation, Risk Assessment and Remedial Plan, Former Sterling Shipyards Site, Vancouver Fraser Port Authority,* dated Sept 2009, prepared by Golder Associates
15) *Confirmation of Uplands Remediation (Phase 1) - Former Sterling Shipyards, Vancouver, BC*, dated September 16, 2009, prepared by Golder Associates
16) *Work Plan and Cost Estimate for Remedial Plan Development, Former Sterling Shipyards Site, Vancouver, BC*, dated May 28, 2012, prepared by SNC-Lavalin
17) *Project Update on Intertidal Area Investigation, Former Sterling Shipyard Site, Vancouver, BC* memorandum dated November 13, 2012, prepared by SNC-Lavalin

18) *Additional Investigation of Intertidal Area, Former Sterling Shipyard Site, Vancouver BC* Technical Memorandum, dated May 23, 2013, prepared by SNC-Lavalin

19) *Re: Biophysical Survey of the Former Sterling Shipyard Site, Vancouver, BC*, dated June 13, 2013, prepared by Balanced Environmental

20) *Additional Upland Soil Vapour and Groundwater Sampling Results, Former Sterling Shipyard Site, Vancouver, BC,* Technical Memorandum, dated August 15, 2013, prepared by SNC-Lavalin

21) *Groundwater Model of the Sterling Shipyard Site in Vancouver, British Columbia* dated May 16, 2013, prepared by DHI Environment

22) *Updated Groundwater Model of the Sterling Shipyard Site in Vancouver, British Columbia,* dated December 5, 2013, prepared by DHI Environment

23) *Technical Review of Ecological Risk Assessment Work for (former) Sterling Shipyards* Draft dated August 6, 2013, prepared by Azimuth Consulting Group Partnership

24) *Human Health Risk Assessment Update, Former Sterling Shipyard Site, Vancouver, BC* Technical Memorandum, dated June 5, 2014, prepared by SNC-Lavalin

25) *Fish and Fish Habitat Assessment for Sterling Shipyard Intertidal Reclamation,* Draft Report, dated June 18, 2014, prepared by SNC-Lavalin

26) *Conceptual Intertidal Habitat Offset Plans for Remediation of the Former Sterling Shipyard Site*, Draft Report, dated July 25, 2014, prepared by SNC-Lavalin

27) *Preliminary Geotechnical Review and Recommendations,* dated November 28, 2014, prepared by SNC-Lavalin

28) *Sterling Shipyard Remedial Planning – Summary,* Technical Memorandum, dated July 6, 2015, prepared by SNC-Lavalin

29) *Order of Magnitude Costs for Construction Options - Former Sterling Shipyards, Vancouver, BC,* dated December 21, 2015, prepared by SNC-Lavalin

30) *Results of Groundwater and Intertidal Seepage Water Sampling Event, Former Sterling Shipyard, 2089 Commissioner Street, Vancouver, BC*, dated February 21, 2019, prepared by SNC-Lavalin

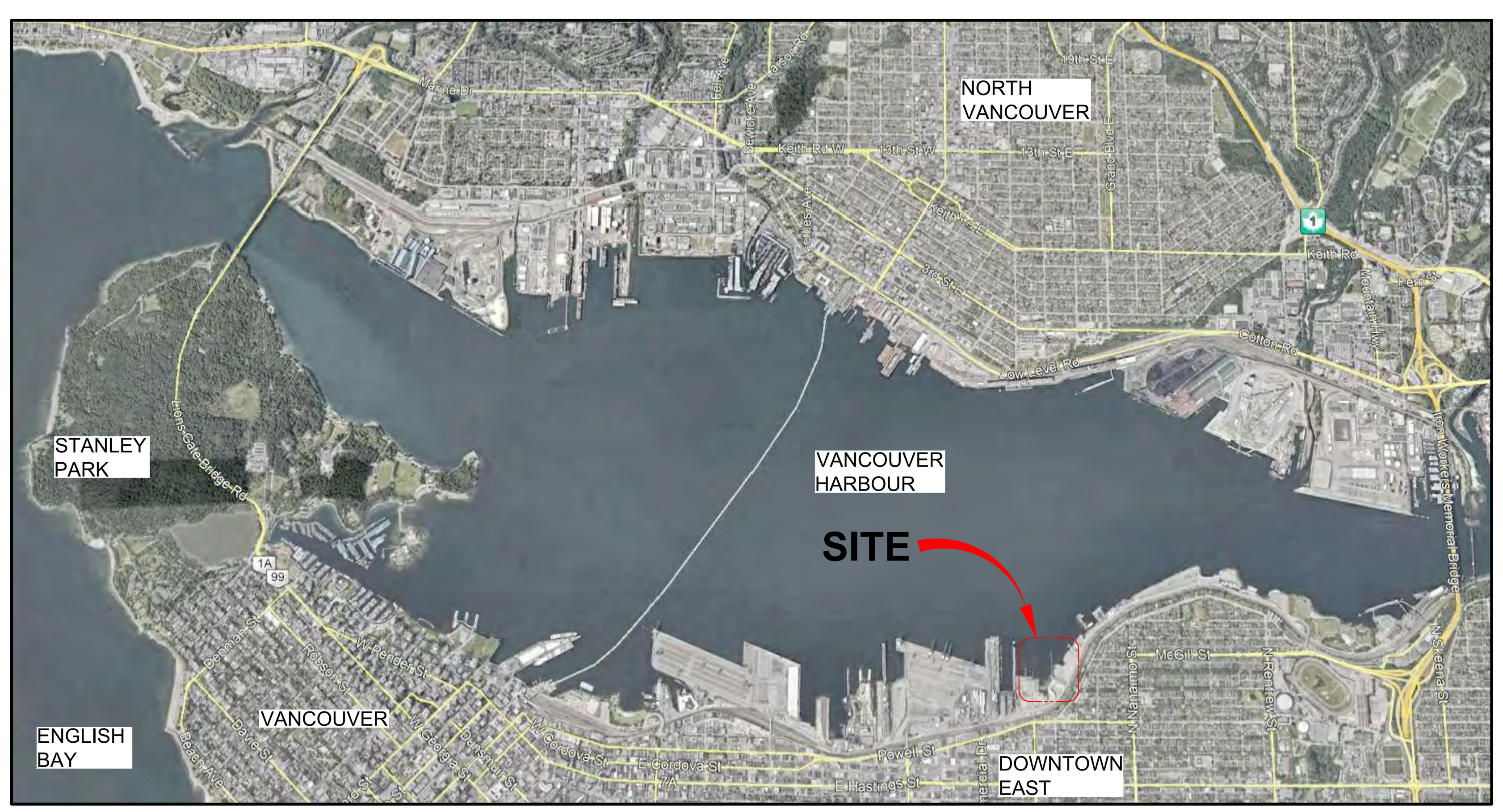
31) *Remedial Options Evaluation, Former Sterling Shipyard,* dated March 12, 2019, prepared by SNC-Lavalin

Appendix II

Site Plan

PORT of vancouver | Vancouver Fraser Port Authority

STERLING SHIPYARD REMEDIATION & INFILL



SITE LOCATION
NTS

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

Ref. No.	REFERENCE

SNC·LAVALIN
677011

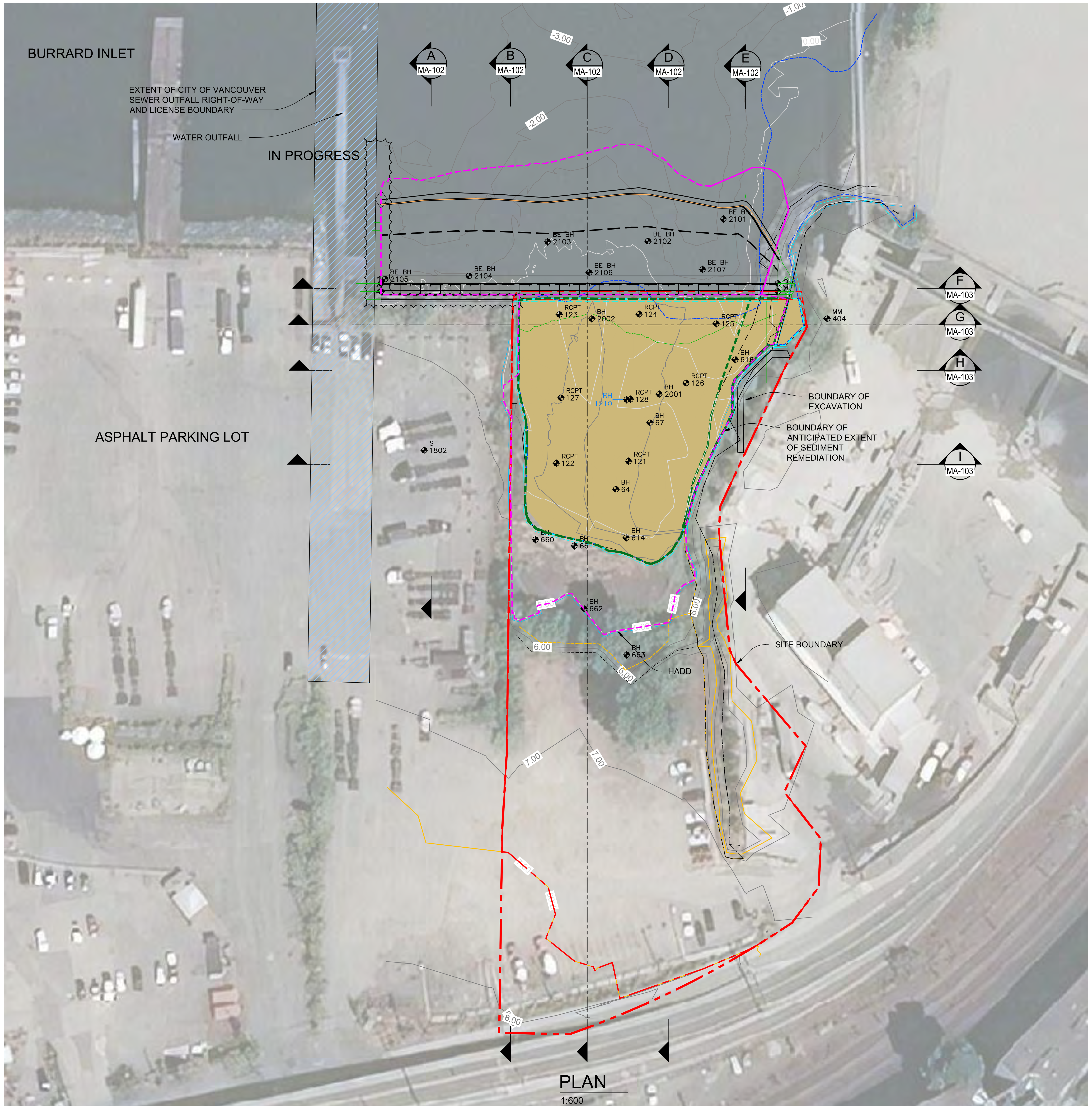
No.	Date	REVISION	Dr'n	Ch'd
PB	21/03/19	ISSUED FOR 30% REVIEW		
PA	21/03/03	30% ISSUED FOR COST ESTIMATE	-	-

PORT of vancouver
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	-
DRAWN BY	J. GENG
APPROVED	-
DATE	2021-MAR-01
SCALE	AS SHOWN
VFPA SITE	VAN 070

STERLING SHIPYARD REMEDIATON & INFILL
COVER SHEET
DRAWING LIST AND SITE LOCATION

SIZE	DWG.	SHEET	REV.
D	20-191-GA-000	1 of X	PB



PLAN
1:600

LEGEND:

- DREDGING AREA
- BERM
- EXCAVATION AREA
- SITE BOUNDARY
- LOT BOUNDARY
- FENCE
- CONTAMINATION AREA
- INTERTIDAL AREA
- PROPOSED EXCAVATION LIMITS
- HADD
- BOREHOLE
- MONITORING WELL
- TEST PIT LOCATION (BY OTHERS)

NOTES:

1. FOR GENERAL NOTES, SEE DWG 20-191-GA-001.

   ELEVATIONS ARE IN METRES, TO CHART DATUM CITY OF VANCOUVER MONUMENT V-2901 LOCATED AT THE INTERSECTION OF VICTORIA DRIVE AND COMMISSIONER STREET.
   ELEVATION = +8.316m (CHART DATUM),
   +5.271m (GEODETIC DATUM).

2. CHART DATUM = CVD28GVRD GEODETIC DATUM + 3.045m

IN PROGRESS

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

0 1:600 30000

Ref. No.	REFERENCE

SNC·LAVALIN
677011

No.	Date	REVISION	Dr'n	Ch'd
PB	21/03/19	ISSUED FOR 30% REVIEW		
PA	21/03/03	30% ISSUED FOR COST ESTIMATE	-	-

PORT of vancouver
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	-
DRAWN BY	J. GENG
APPROVED	-
DATE	2021-FEB-26
SCALE	AS SHOWN
VFPA SITE	VAN 070

STERLING SHIPYARD REMEDIATON & INFILL
GENERAL ARRANGEMENT

SIZE	DWG.	SHEET	REV.
D	20-191-MA-101	1 of X	PB

TITLE BLOCK: DL-TB.dwg

DATE: 2021/05/07 - 9:01am
PATH: Q:\677011 Sterling Shipyard R&R\40_Execution\45_GIS_Dwgs\MA-Marine\C3D\processing info for engineers\3D model Berm -Mehdi.dwg

Appendix III

Borehole Logs

RECORD OF BOREHOLE No. BH20-01 Co-Ord. N 5459374 E 495317

Project Number:	677011	Drilling Location:	BH20-01	Logged by:	IM
Client:	Vancouver Fraser Port Authority	Drilling Method:	125 mm Sonic	Compiled by:	JE
Project Name:	Sterling Shipyards	Drilling Machine:	Track Mounted Drill	Reviewed by:	IM
Location:	Vancouver, B.C.	Date Started:	Nov 16, 2020 Date Completed: Nov 16, 2020	Revision No.:	0

LITHOLOGY PROFILE | SOIL SAMPLING | FIELD TESTING | LAB TESTING

Field Testing: Penetration Testing — ○ SPT ● DCPT; Su △ Intact; Vane* ◇ Intact ◆ Remould; scale 0 50 100 150 200

Lab Testing: ★ Rinse pH Values 2 4 6 8 10 12; △ Soil Vapour Reading parts per million (ppm) 100 200 300 400; ▲ Lower Explosive Limit (LEL); ✱ Passing 75 um (%); ○ Moisture Content (%); Atterberg Limits W_P — W_L; 20 40 60 80

Local Ground Surface Elevation:

Depth (m)	Description	Sample Type	Sample Number	Recovery (%)	SPT 'N' Value	Moisture Content (%)	Comments
0	COBBLE and GRAVEL, coarse, some sand, rounded, wet, seabed.						
0.3	WOOD WASTE, fibrous, some sand, brown, wet, FILL, poor sample recovery.	GS	IJM 01			18	Poor recovery in SPT at this depth.
3.0	SAND, silty, trace gravel, trace clay, fine grained, poorly graded, grey, oxidized, loose, wet, sea shell fragments.	GS	IJM 02			14	G: 6% S: 52% Sl: 38% CL: 4%
4.5	SAND, silty, trace gravel, trace clay, grey with orange staining, oxidized, very stiff, low plasticity, moist, iron staining, TILL.	GS	IJM 03			17	G: 9% S: 55% Sl: 33% CL: 3%
5.4	SILT with SAND, trace rounded gravel, some rounded cobbles, trace clay, grey, hard, non plastic, moist, trace iron staining, TILL.	GS	IJM 04			17	G: 2% S: 35% Sl: 56% CL: 6%
6.0	SAND, silty, trace fine to coarse gravel, trace to some clay, grey to dark brown colour bands, very hard, non-plastic, moist, some lenses of silt, TILL.	SS	IJM 05	22000	REF	14	SPT refusal. 75 blowcounts in 4".
		GS	IJM 06			12	G: 0% S: 58% Sl: 33% CL: 9%
		SS	IJM 07	14000	REF	12	
7.8	EOH at ~ 7.8 m. Split spoon sampler refusal at this depth.						SPT refusal. 100 blowcounts in 5".

SNC·LAVALIN

Borehole details as presented, do not constitute a thorough understanding of all potential conditions present and requires interpretative assistance from a qualified Geotechnical Engineer. Also, borehole information should be read in conjunction with the geotechnical report for which it was commisioned and the accompanying'Notes to Record of Boreholes'.

Scale: 1 : 47

RECORD OF BOREHOLE No. BH20-02 Co-Ord. N 5459393 E 495300

Project Number:	677011	Drilling Location:	BH20-02	Logged by:	IM
Client:	Vancouver Fraser Port Authority	Drilling Method:	125 mm Sonic	Compiled by:	JE
Project Name:	Sterling Shipyards	Drilling Machine:	Track Mounted Drill	Reviewed by:	IM
Location:	Vancouver, B.C.	Date Started:	Nov 16, 2020 Date Completed: Nov 16, 2020	Revision No.:	0

LITHOLOGY PROFILE | SOIL SAMPLING | FIELD TESTING | LAB TESTING

Field testing: Penetration Testing: ○ SPT ● DCPT; Su △ Intact; Vane* ◇ Intact ◆ Remould; scale 0 50 100 150 200

Lab testing: ★ Rinse pH Values 2 4 6 8 10 12; △ Soil Vapour Reading parts per million (ppm) 100 200 300 400; ▲ Lower Explosive Limit (LEL); ✱ Passing 75 um (%); ○ Moisture Content (%); Atterberg Limits W_P — W_L 20 40 60 80

Local Ground Surface Elevation:

Depth (m)	Description	Sample Type	Sample Number	Recovery (%)	SPT 'N' Value	Field Testing	Lab Testing	Comments
0.1	COBBLE with GRAVEL, coarse, some sand, rounded, wet, seabed.							
2.1	WOOD WASTE, sandy, silty, brown to black, some garbage, FILL.							
2.4	SAND, silty, trace gravel, trace clay, fine grained, poorly graded, grey, oxidized, loose to compact, non plastic, wet to moist, sea shell fragments.							
3.0	SAND and SILT, trace to some clay, trace rounded gravel, grey, oxidized, compact, low plasticity, moist. At ~ 2.7 m, becoming till like.	GS	IJM 08				○ 26	G: 4% S: 50% SI: 39% CL: 8%
4.5	SAND, silty, gravelly, some cobbles, trace clay, grey, compact to dense, no to low plasticity, moist, TILL.	SS	IJM 09	0	26	○		
		GS	IJM 10				○ 16	G: 22% S: 47% SI: 29% CL: 2%
	SAND, gravelly, some silt, trace clay, grey, oxidized, very dense, moist to dry, TILL.	SS	IJM 11	28000	REF		○ 9	SPT refusal. 100 blowcounts in 10". G: 25% S: 53% SI: 19% CL: 4%
		GS	IJM 12				○ 13	G: 23% S: 49% SI: 23% CL: 5%
		SS	IJM 13	28000	REF		○ 16	SPT refusal. 100 blowcounts in 5".

SNC·LAVALIN

Borehole details as presented, do not constitute a thorough understanding of all potential conditions present and requires interpretative assistance from a qualified Geotechnical Engineer. Also, borehole information should be read in conjunction with the geotechnical report for which it was commisioned and the accompanying'Notes to Record of Boreholes'.

Scale: 1 : 32

Continued on Next Page

RECORD OF BOREHOLE No. BH20-02 Co-Ord. N 5459393 E 495300

Project Number: 677011 Drilling Location: BH20-02 Logged by: IM

Lithology Plot	DESCRIPTION	Sample Type	Sample Number	Recovery (%)	SPT 'N' Value	DEPTH (m)	ELEVATION (m)	FIELD TESTING	LAB TESTING (Moisture Content %)	INSTRUMENTATION INSTALLATION	COMMENTS
	SAND, gravelly, some silt, trace clay, grey, oxidized, very dense, moist to dry, TILL.										
	SAND, silty, some fine to coarse gravel, trace to some clay, grey, very dense, non plastic, dry to moist, TILL. (6.9)					7					
		GS	IJM 14						9		G: 16% S: 47% SI: 27% CL: 10%
		SS	IJM 15	28000	REF				16		SPT refusal. 100 blowcount in 5".
		GS	IJM 16						10		
						8					
						9					
	EOH at ~ 9.1 m. (9.1)										

Legend — Field Testing: Penetration Testing: ○ SPT ● DCPT; Su △ Intact; Vane* ◇ Intact ◆ Remould; scale 0 50 100 150 200.
Lab Testing: ★ Rinse pH Values 2 4 6 8 10 12; △ Soil Vapour Reading parts per million (ppm) 100 200 300 400; ▲ Lower Explosive Limit (LEL); ✱ Passing 75 um (%); ○ Moisture Content (%); Atterberg Limits W_P ■—● W_L; 20 40 60 80.

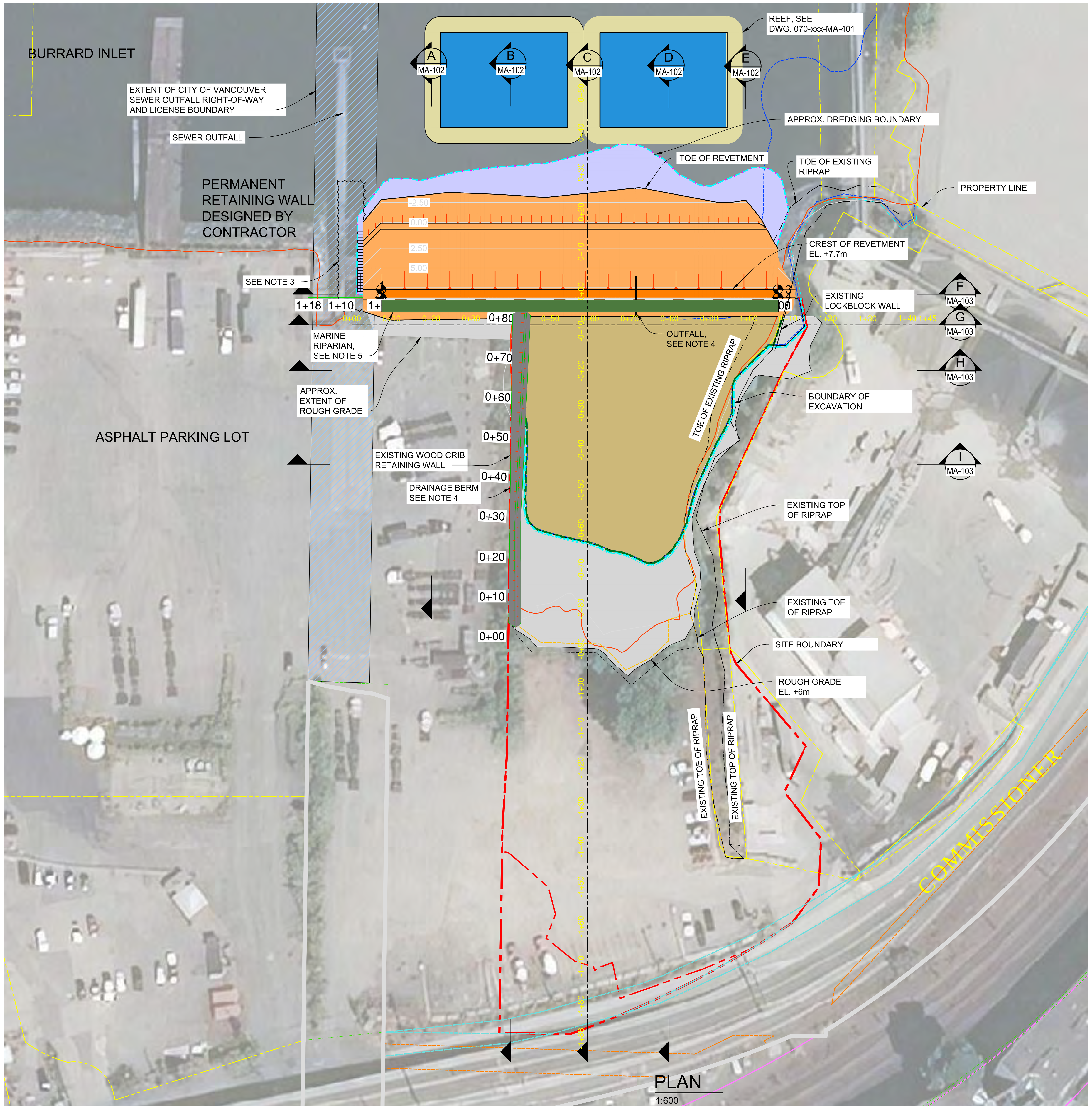
Borehole details as presented, do not constitute a thorough understanding of all potential conditions present and requires interpretative assistance from a qualified Geotechnical Engineer. Also, borehole information should be read in conjunction with the geotechnical report for which it was commisioned and the accompanying'Notes to Record of Boreholes'.

SNC·LAVALIN

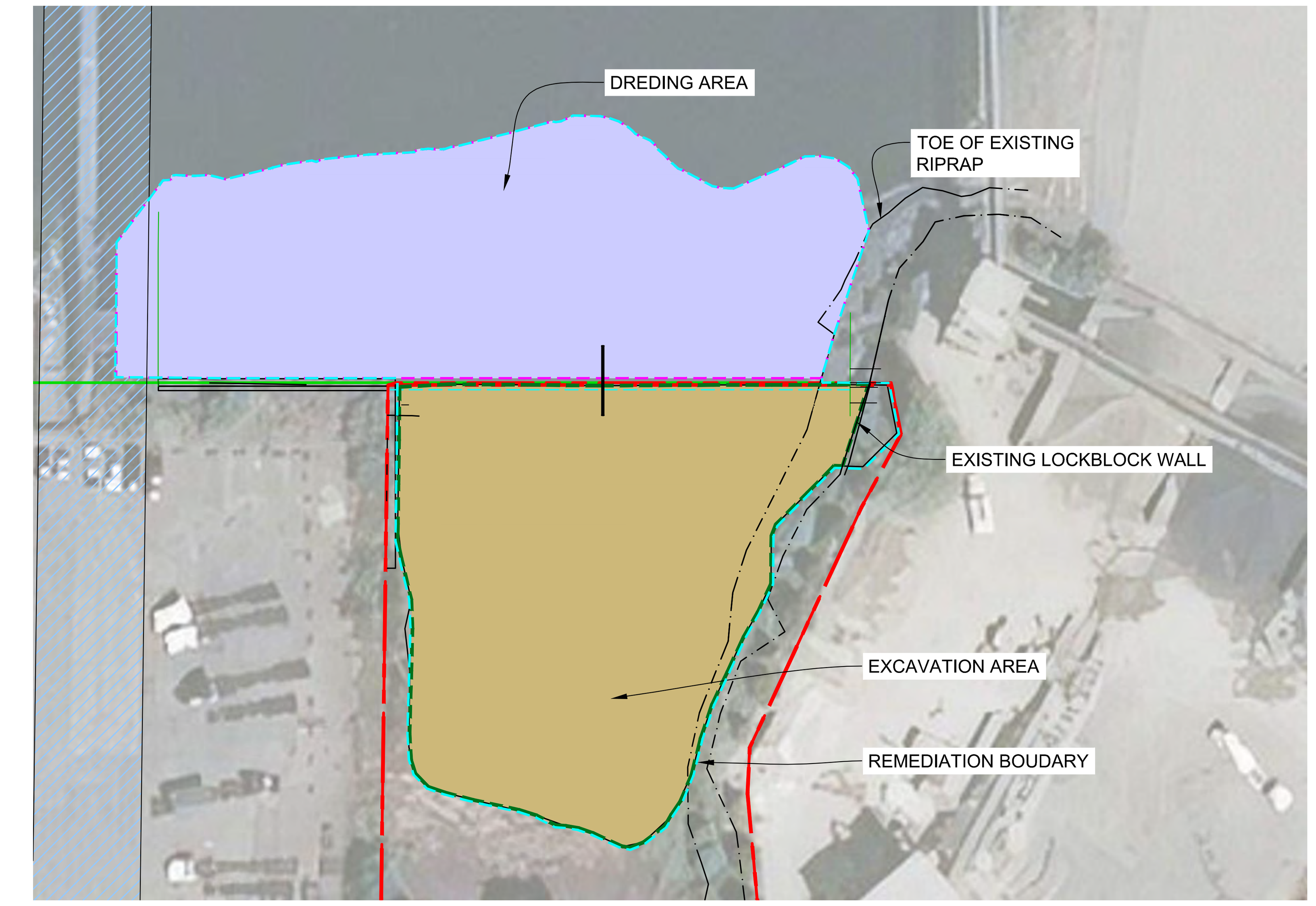
Scale: 1 : 32

Appendix IV

Cross-Sections



PLAN
1:600



PLAN - REMEDIATION EXTENT
1:1000

LEGEND:

- DREDGING AREA
- REEF & EDGE
- REVETMENT
- MARINE RIPARIAN
- EXCAVATION AREA
- +6.0m ROUGH GRADE AREA
- SITE BOUNDARY
- LOT BOUNDARY
- FENCE
- BOUNDARY OF ANTICIPATED EXTENT OF SEDIMENT REMEDIATION
- INTERTIDAL AREA
- PROPOSED EXCAVATION LIMITS

NOTES:

1. FOR GENERAL NOTES, SEE DWG 070-010-GA-001. ELEVATIONS ARE IN METRES, TO CHART DATUM CITY OF VANCOUVER MONUMENT V-2901 LOCATED AT THE INTERSECTION OF VICTORIA DRIVE AND COMMISSIONER STREET.
   ELEVATION = +8.316m (CHART DATUM), +5.271m (GEODETIC DATUM).
2. CHART DATUM = CVD28GVRD GEODETIC DATUM + 3.045m.
3. BATHYMETRY AND SURVEY IN THIS AREA OF THE RIGHT OF WAY IS NOT CONFIRMED AND PRESUMED TO BE SIMILAR TO ADJACENT AREA TO EAST WHICH WAS CONFIRMED BY 2021 FIELD SURVEY. CONTRACTOR TO FIELD CONFIRM BATHYMETRY AND PROVIDE 2 WEEKS IN ADVANCE OF PROCEEDING WITH WORK TO ALLOW ENGINEER TO CONFIRM DESIGN DIMENSIONS.
4. DRAINAGE SYSTEM REFER TO DWG. 070-010-MA-301.
5. HABITAT COMPENSATION REFER TO DWG. 070-010-MA-401.

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

0 1:600 30000

No.	Date	Revision	Dr'n	Ch'd
PD	21/09/21	ISSUED FOR 90% REVIEW		
PC	21/05/07	ISSUED FOR 60% REVIEW		
PB	21/03/19	ISSUED FOR 30% REVIEW		
PA	21/03/03	30% ISSUED FOR COST ESTIMATE	-	-

Ref. No. | REFERENCE

SNC·LAVALIN
677011

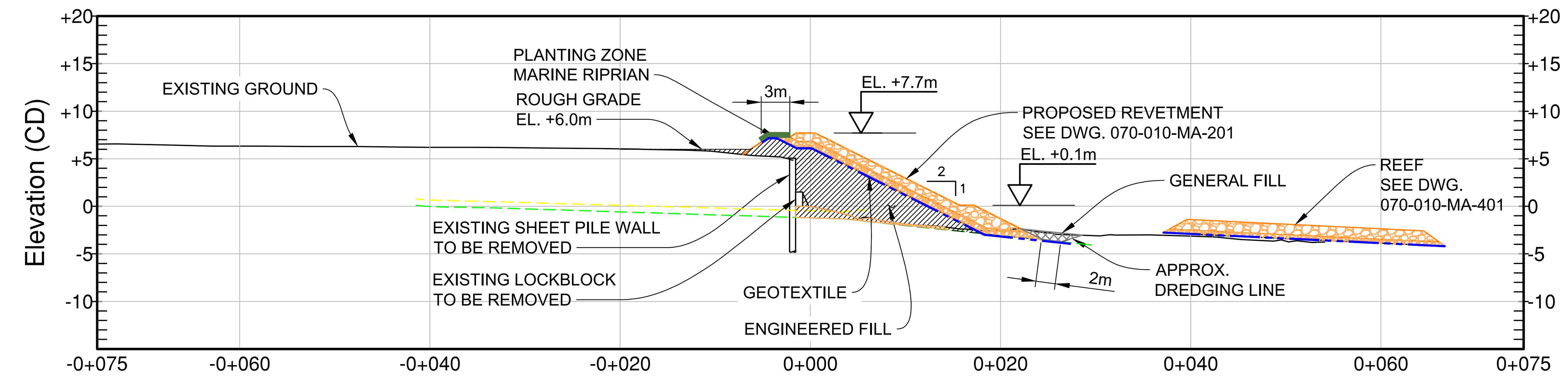
PORT of vancouver
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	-
DRAWN BY	J. GENG
APPROVED	-
DATE	2021-FEB-26
SCALE	AS SHOWN
VFPA SITE	VAN 070

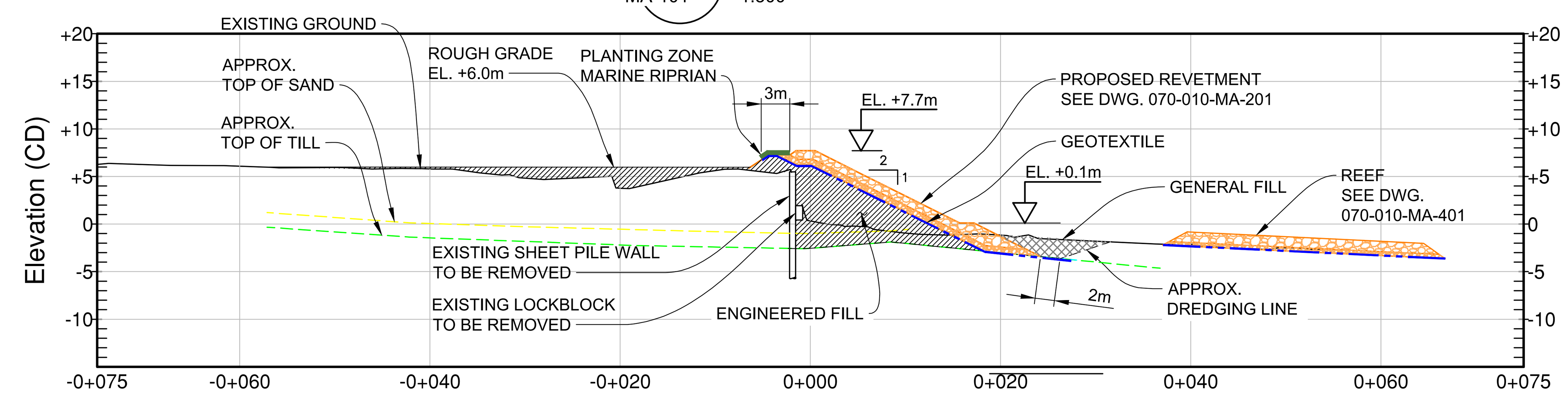
STERLING SHIPYARD REMEDIATON & INFILL
GENERAL ARRANGEMENT

SIZE D | DWG. 070-010-MA-101 | SHEET 1 of X | REV. PD

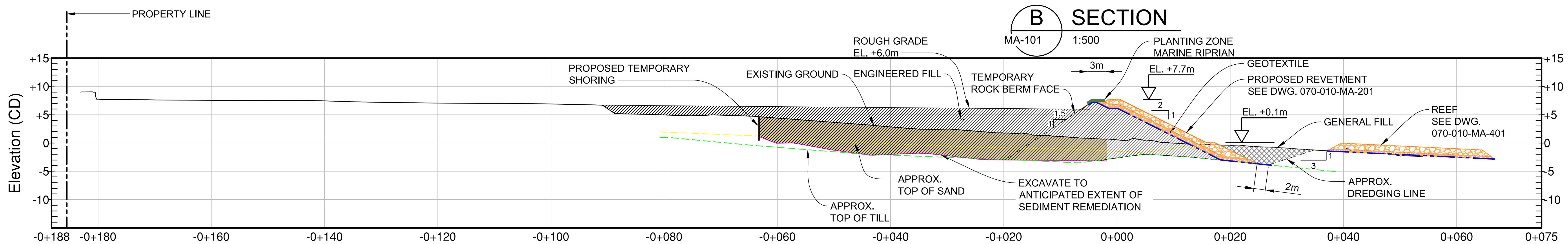
DATE: 2021/09/21 - 12:27pm
PATH: Q:\677011 Sterling Shipyard R&R\40_Execution\45_GIS_Dwgs\MA-Marine\070-010-MA-101-102-103-201.dwg
TITLE BLOCK: DL-TB.dwg



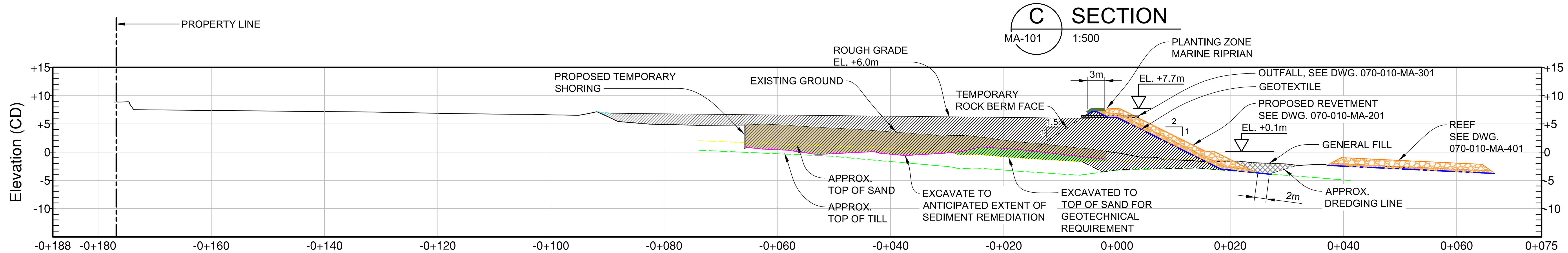
A SECTION
MA-101 1:500



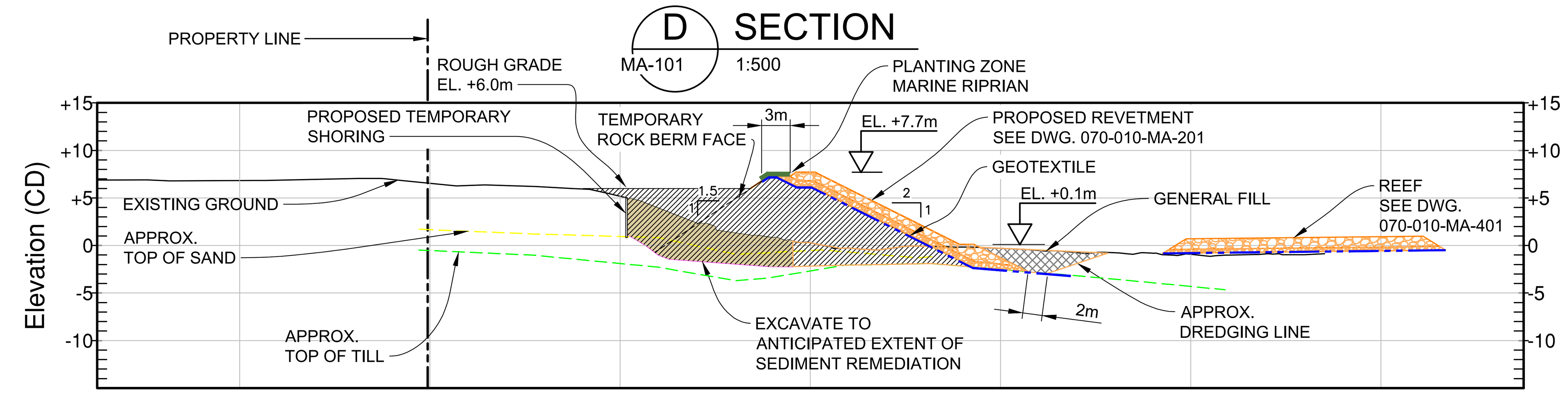
B SECTION
MA-101 1:500



C SECTION
MA-101 1:500



D SECTION
MA-101 1:500



E SECTION
MA-101 1:500

NOTES:

1. FOR GENERAL NOTES, SEE DWG 070-010-GA-001.

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

0 1:500 25000

Ref. No.	REFERENCE

SNC·LAVALIN

No.	Date	REVISION	Dr'n	Ch'd
PD	21/09/21	ISSUED FOR 90% REVIEW		
PC	21/05/07	ISSUED FOR 60% REVIEW		
PB	21/03/19	ISSUED FOR 30% REVIEW		
PA	21/03/03	30% ISSUED FOR COST ESTIMATE		

PORT of vancouver

VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

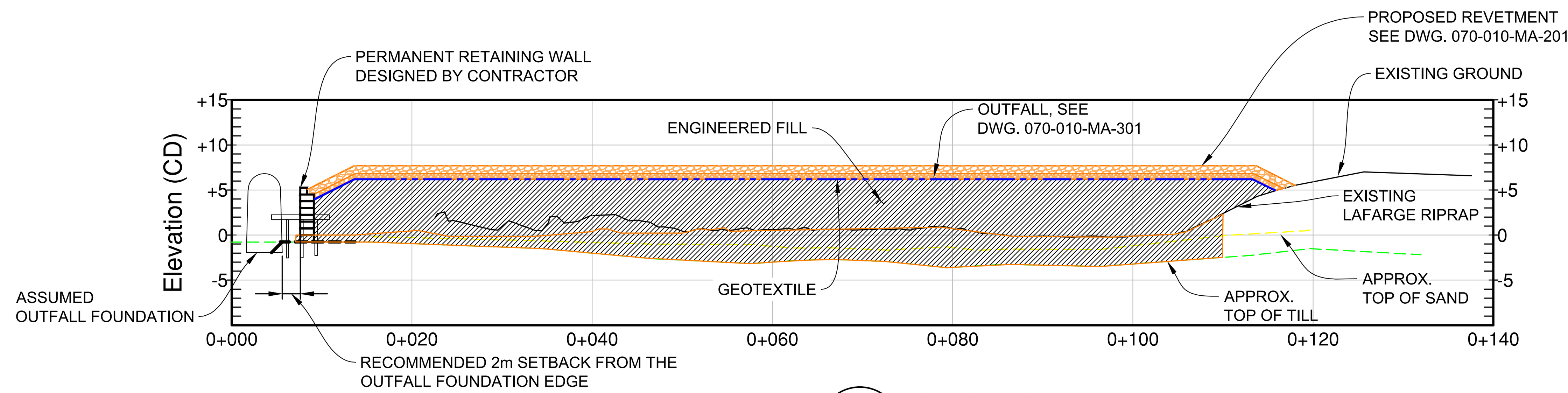
DESIGN BY	-
DRAWN BY	J. GENG
APPROVED	-
DATE	2021-MAR-01
SCALE	AS SHOWN
VFPA SITE	VAN 070

STERLING SHIPYARD REMEDIATON & INFILL
SECTIONS

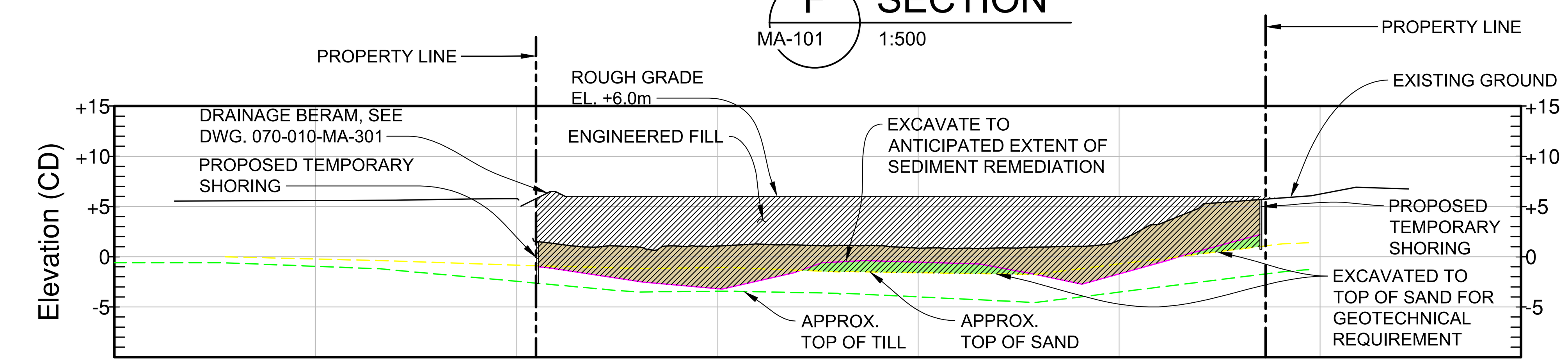
SIZE	DWG.	SHEET	REV.
D	070-010-MA-102	1 of X	PD

DATE: 2021/09/21 - 12:27pm
PATH: Q:\677011 Sterling Shipyard R&R\40_Execution\45_GIS_Dwgs\MA-Marine\070-010-MA-101-102-103-201.dwg

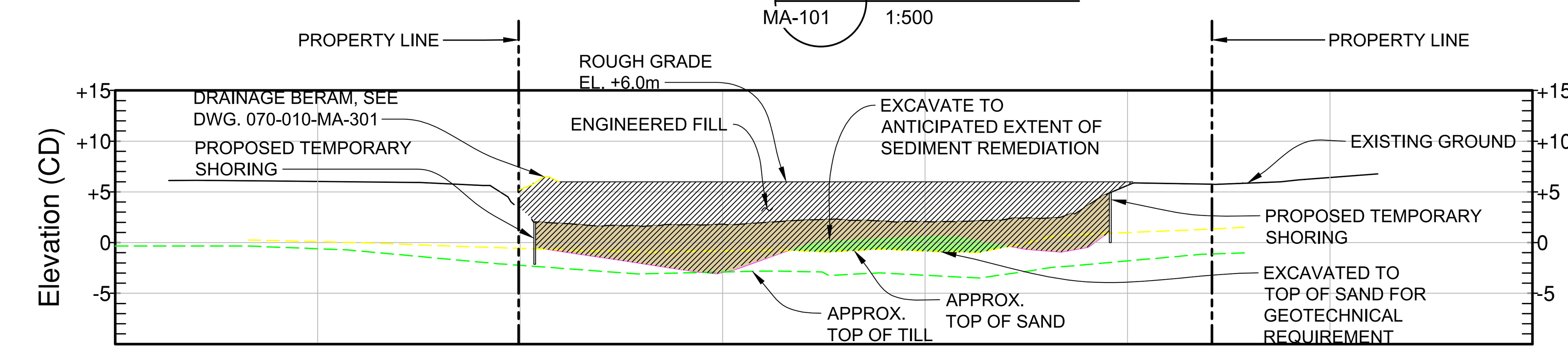
TITLE BLOCK: DL-TB.dwg



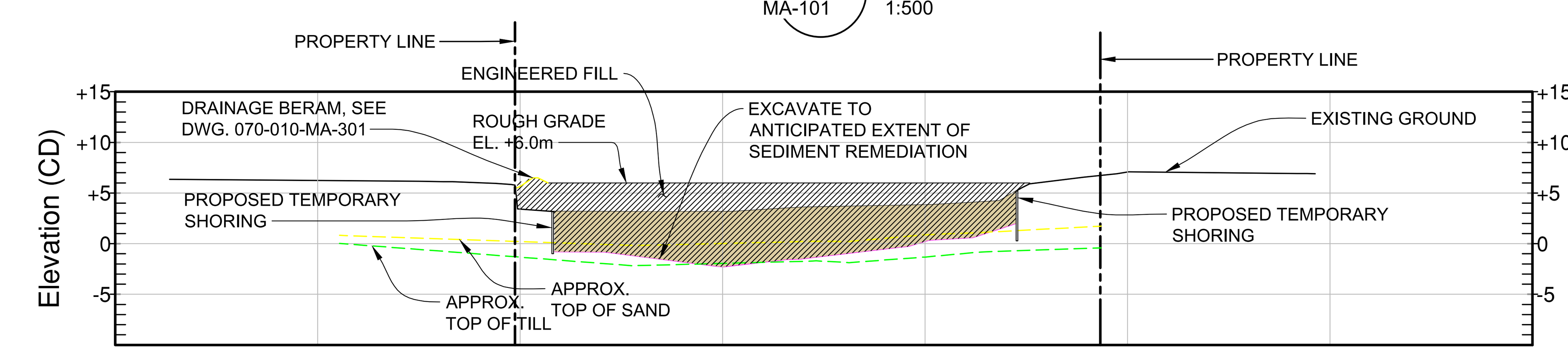
F SECTION
MA-101 1:500



G SECTION
MA-101 1:500



H SECTION
MA-101 1:500



I SECTION
MA-101 1:500

NOTES:

1. FOR GENERAL NOTES, SEE DWG 070-010-GA-001.

PRELIMINARY
DO NOT USE FOR CONSTRUCTION

0 1:500 25000

TITLE BLOCK: DL-TB.dwg

DATE: 2021/09/21 - 12:34pm
PATH: Q:\677011 Sterling Shipyard R&R\40_Execution\45_GIS_Dwgs\MA-Marine\070-010-MA-101-102-103-201.dwg

Ref. No.	REFERENCE

SNC·LAVALIN

No.	Date	REVISION	Dr'n	Ch'd
PD	21/09/21	ISSUED FOR 90% REVIEW		
PC	21/05/07	ISSUED FOR 60% REVIEW		
PB	21/03/19	ISSUED FOR 30% REVIEW		
PA	21/03/03	30% ISSUED FOR COST ESTIMATE		

PORT of vancouver

VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	-
DRAWN BY	J. GENG
APPROVED	-
DATE	2021-MAR-03
SCALE	AS SHOWN
VFPA SITE	VAN 070

STERLING SHIPYARD REMEDIATON & INFILL
SECTIONS

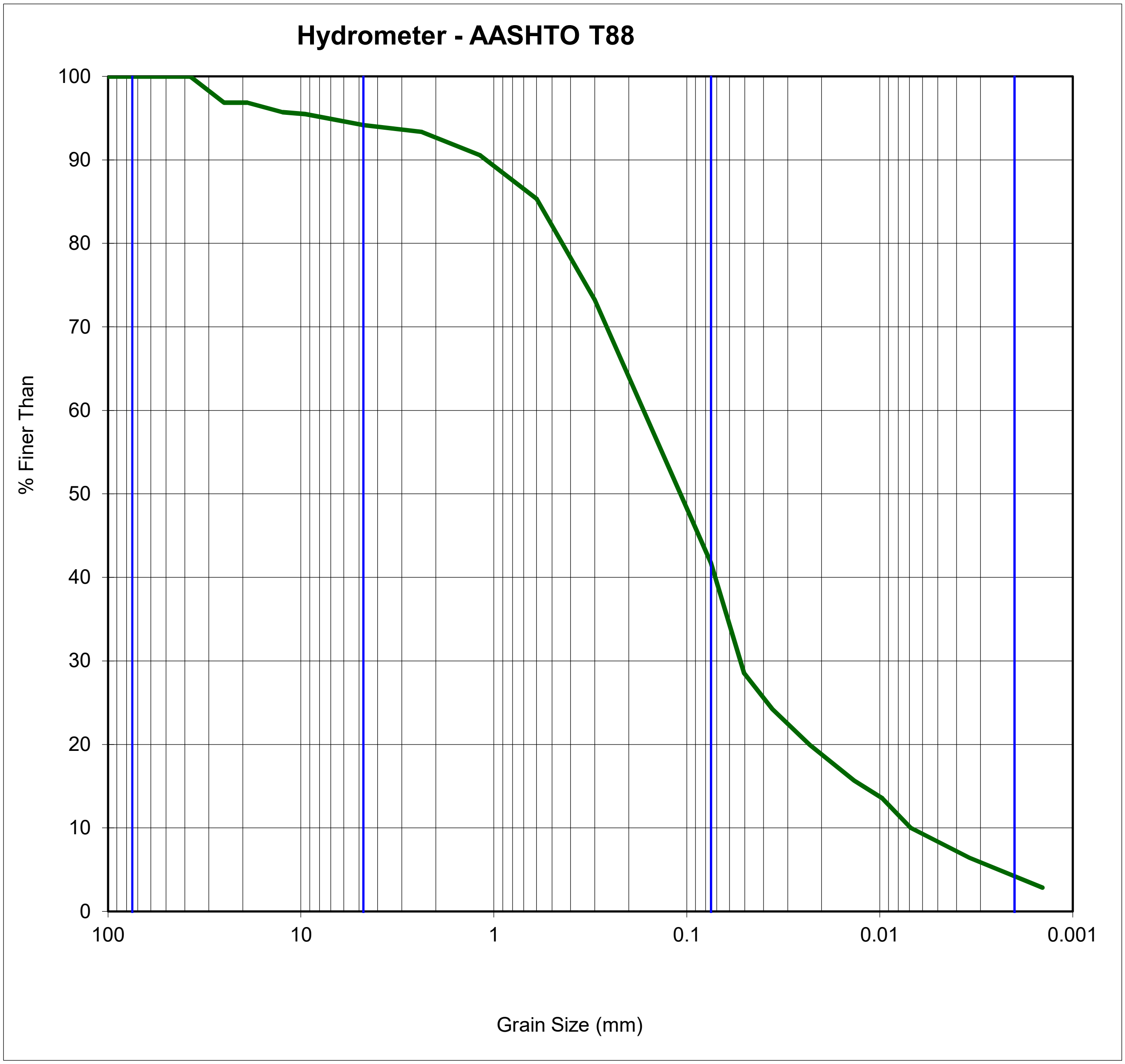
SIZE	DWG.	SHEET	REV.
D	070-010-MA-103	1 of X	PD

Appendix V

Laboratory Testing Results

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM02**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-01**	Sample Depth (m)	**3.66**			Natural Moisture	**18.2%**
Project No.	**677011**					Tech.	**MK/DY**



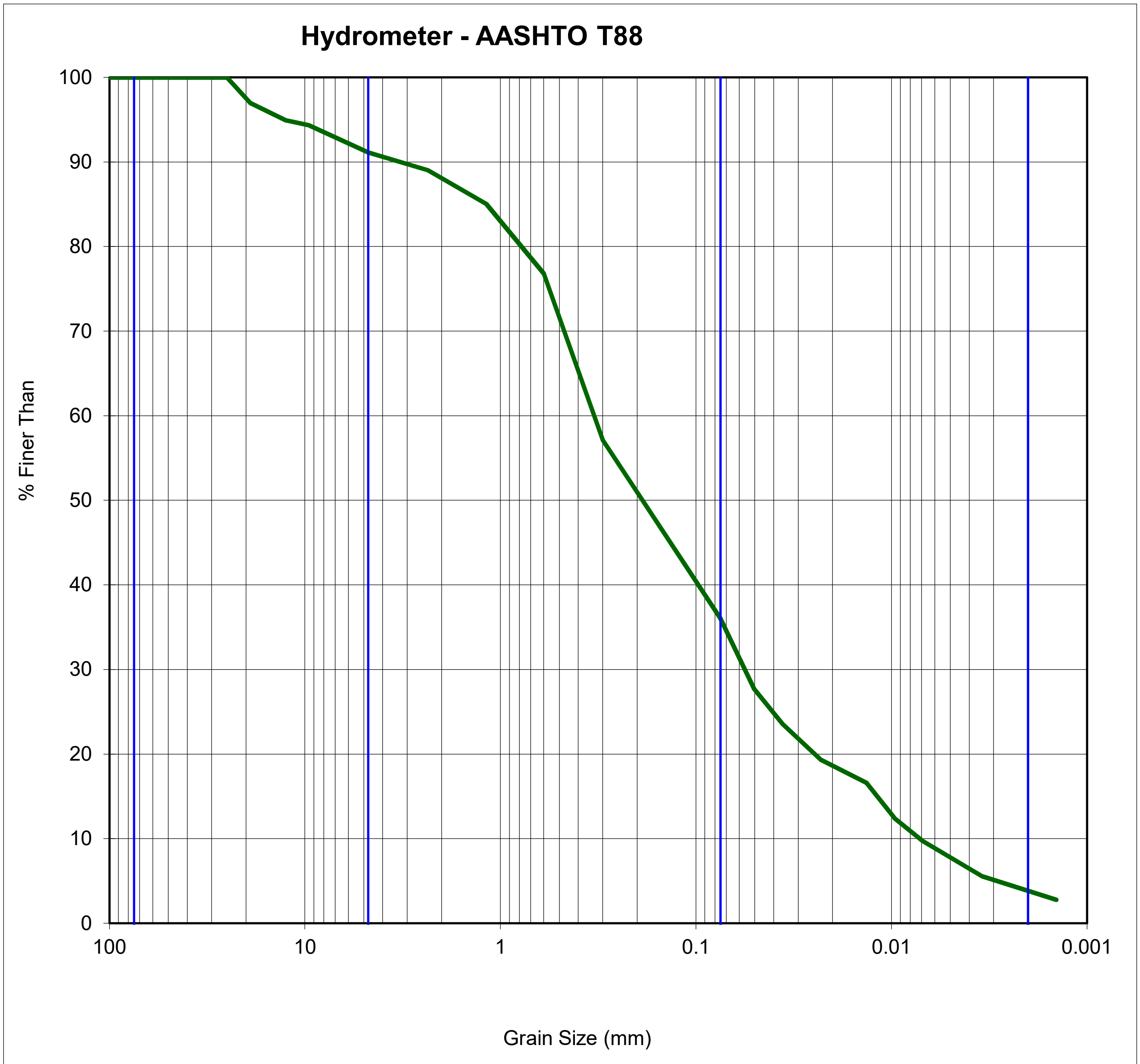
Gravel = **5.9%** Sand = **52.4%** Silt = **37.9%** Clay = **3.9%**

Hydrometer Classification: **Sand and silt, trace gravel, trace clay.**

SNC•LAVALIN	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-01**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM02**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM03**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-01**	Sample Depth (m)	**4.88**			Natural Moisture	**14.3%**
Project No.	**677011**					Tech.	**MK/DY**



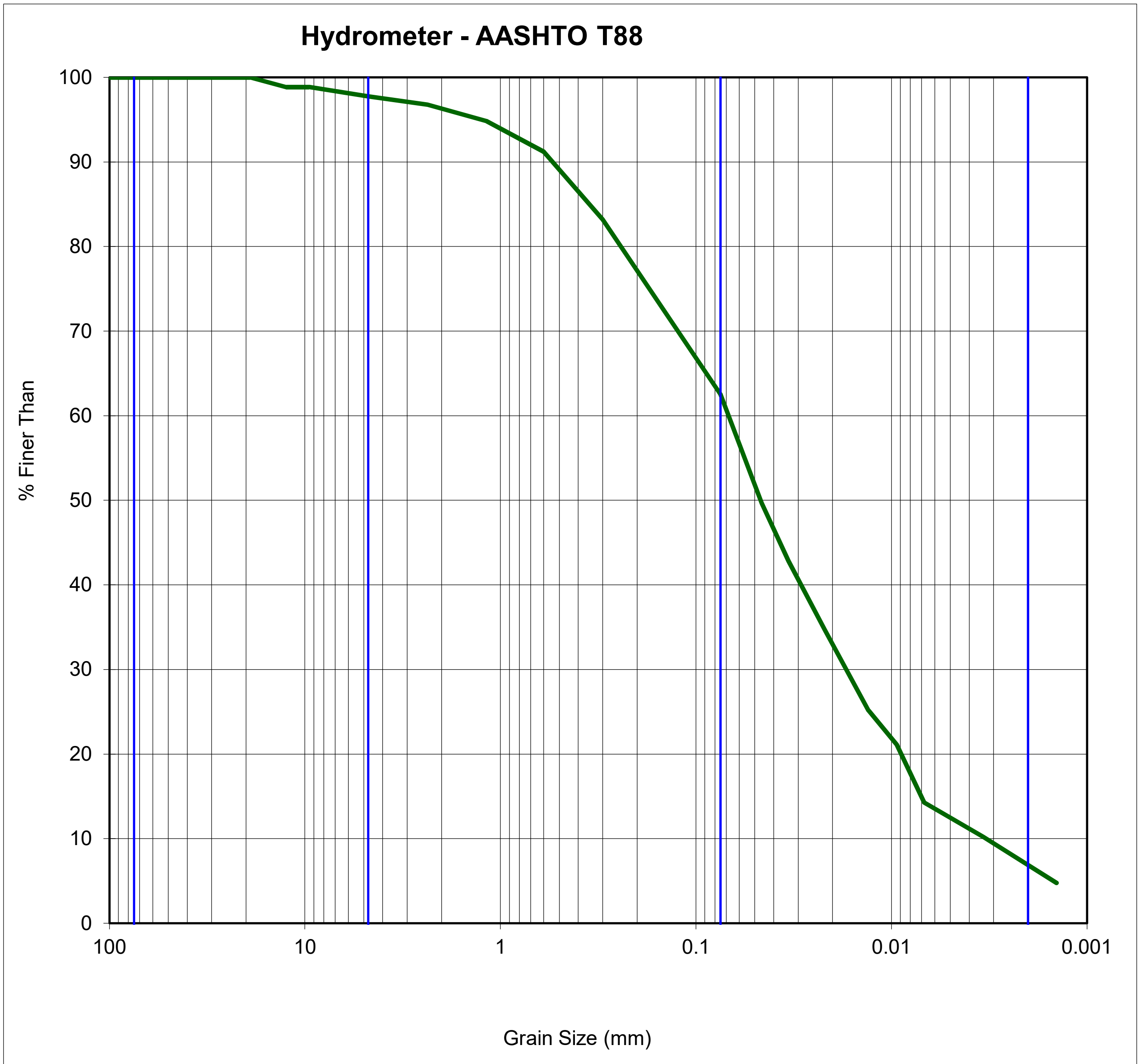
Gravel = **8.9%** Sand = **55.0%** Silt = **32.5%** Clay = **3.6%**

Hydrometer Classification: **Sand, silty, trace gravel, trace clay.**

Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-01**
Location	**Vancouver, British Columbia**	Sample No.	**IJM03**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM04**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-01**	Sample Depth (m)	**5.79**			Natural Moisture	**16.7%**
Project No.	**677011**					Tech.	**MK/DY**



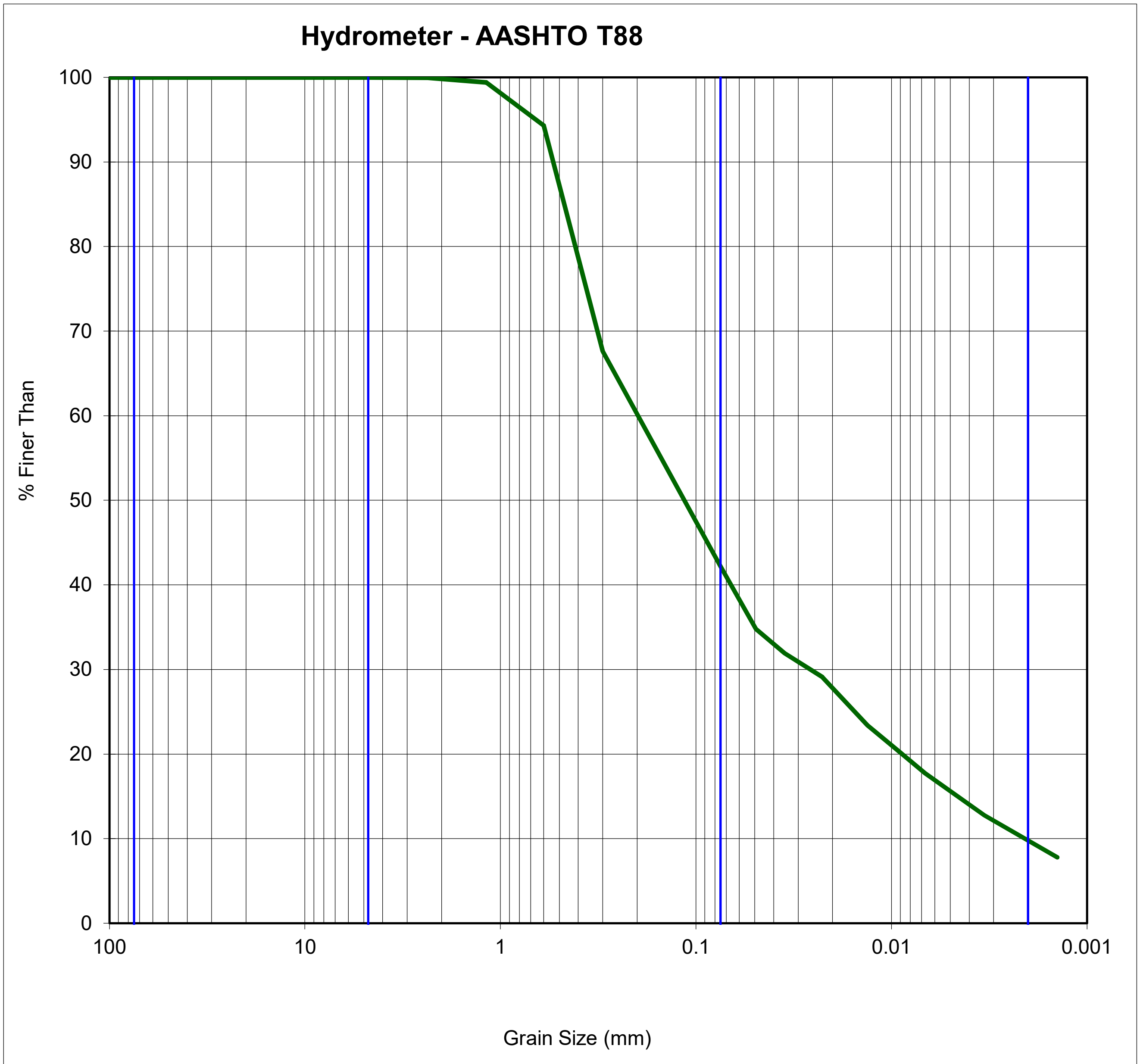
Gravel = **2.3%** Sand = **35.2%** Silt = **56.2%** Clay = **6.3%**

Hydrometer Classification: **Silt and sand, trace clay, trace gravel.**

SNC•LAVALIN	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-01**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM04**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM06**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-01**	Sample Depth (m)	**7.32**			Natural Moisture	**12.2%**
Project No.	**677011**					Tech.	**MK/DY**



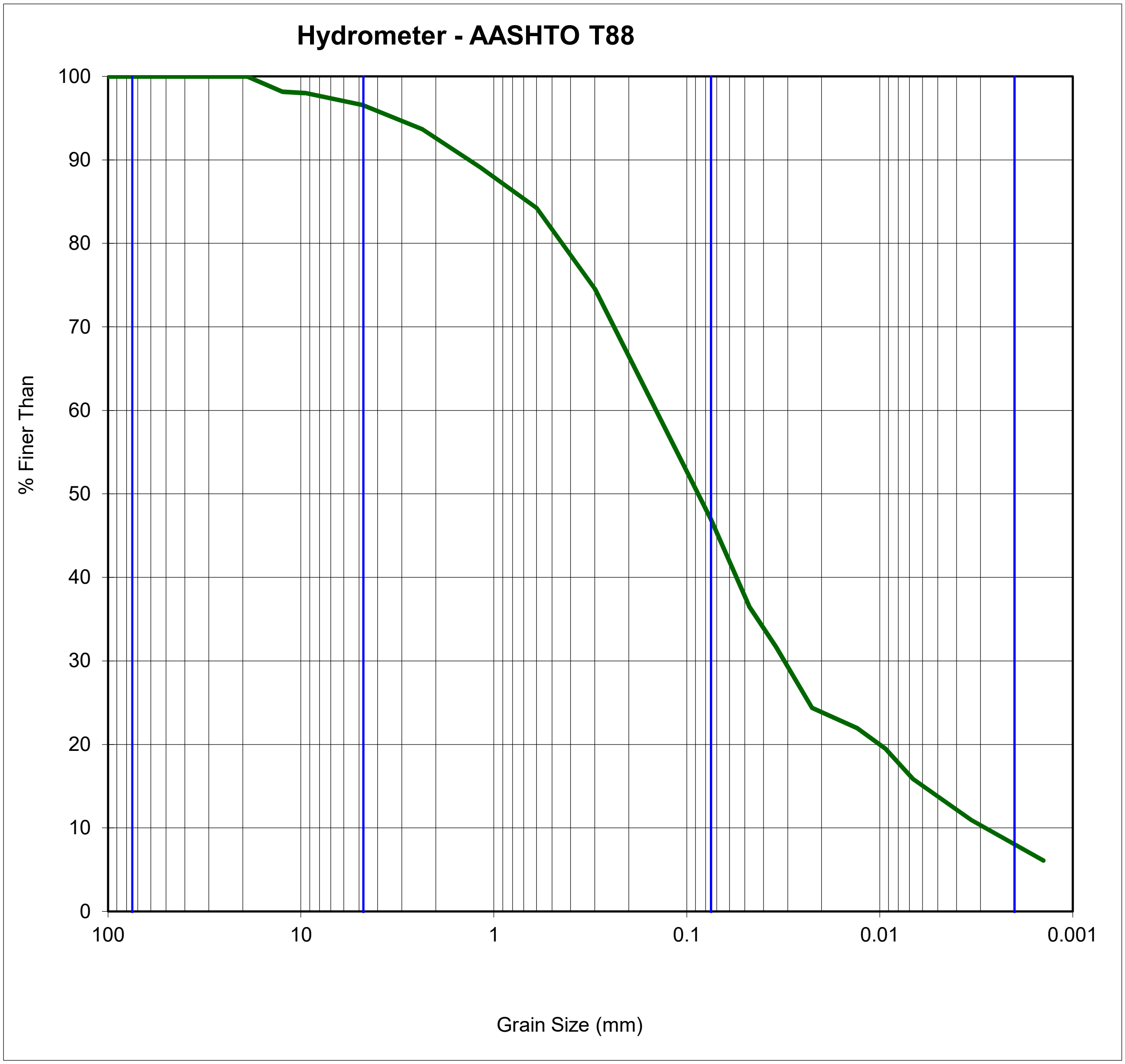
Gravel = **0.0%** Sand = **57.7%** Silt = **33.0%** Clay = **9.3%**

Hydrometer Classification: **Sand, silty, trace clay.**

SNC•LAVALIN	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-01**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM06**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM08**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-02**	Sample Depth (m)	**2.74**			Natural Moisture	**25.8%**
Project No.	**677011**					Tech.	**MK/DY**



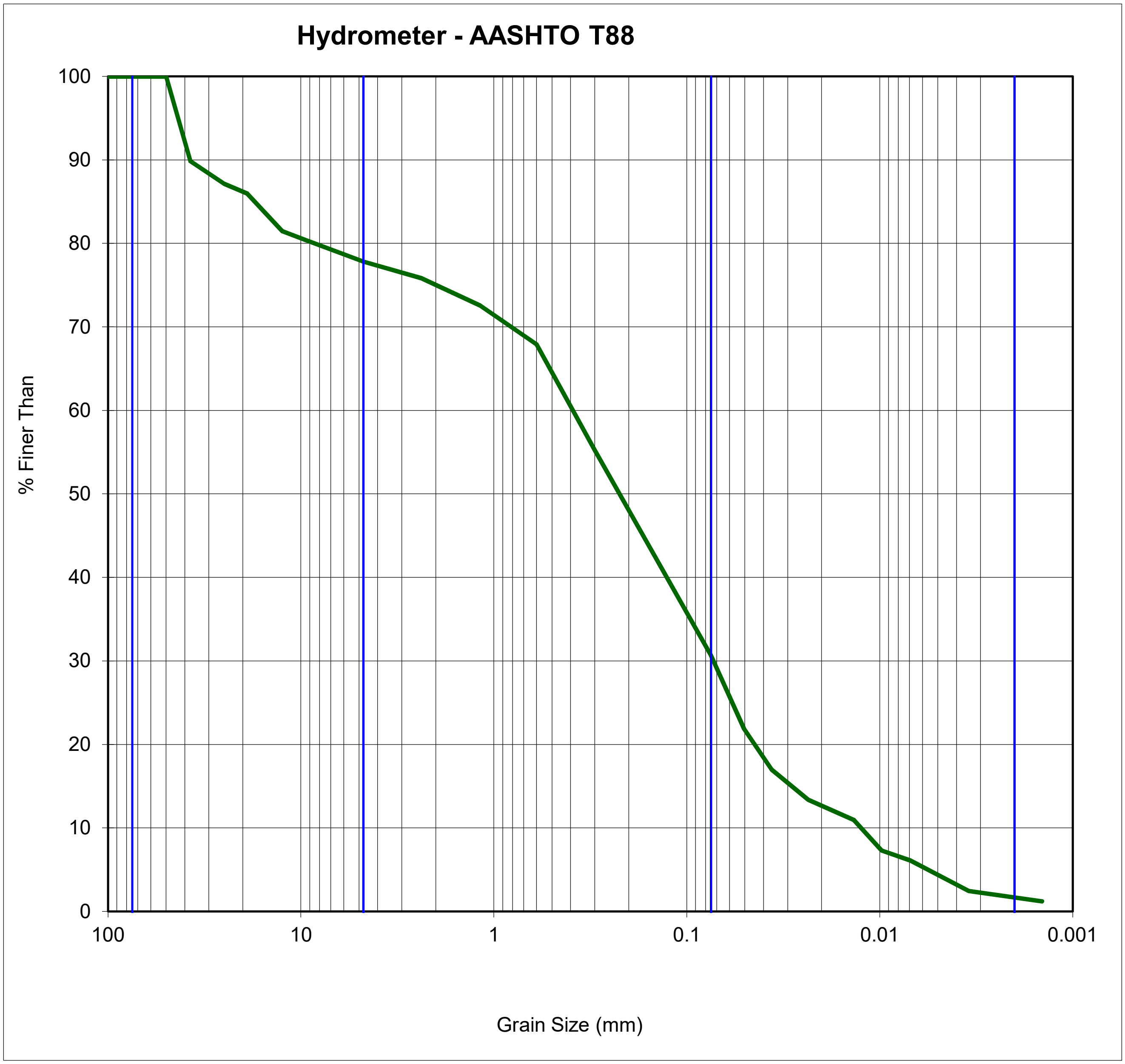
Gravel = **3.5%** Sand = **49.6%** Silt = **39.4%** Clay = **7.6%**

Hydrometer Classification: **Sand and silt, trace clay, trace gravel.**

SNC•LAVALIN	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-02**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM08**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM10**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-02**	Sample Depth (m)	**4.27**			Natural Moisture	**15.5%**
Project No.	**677011**					Tech.	**MK/DY**



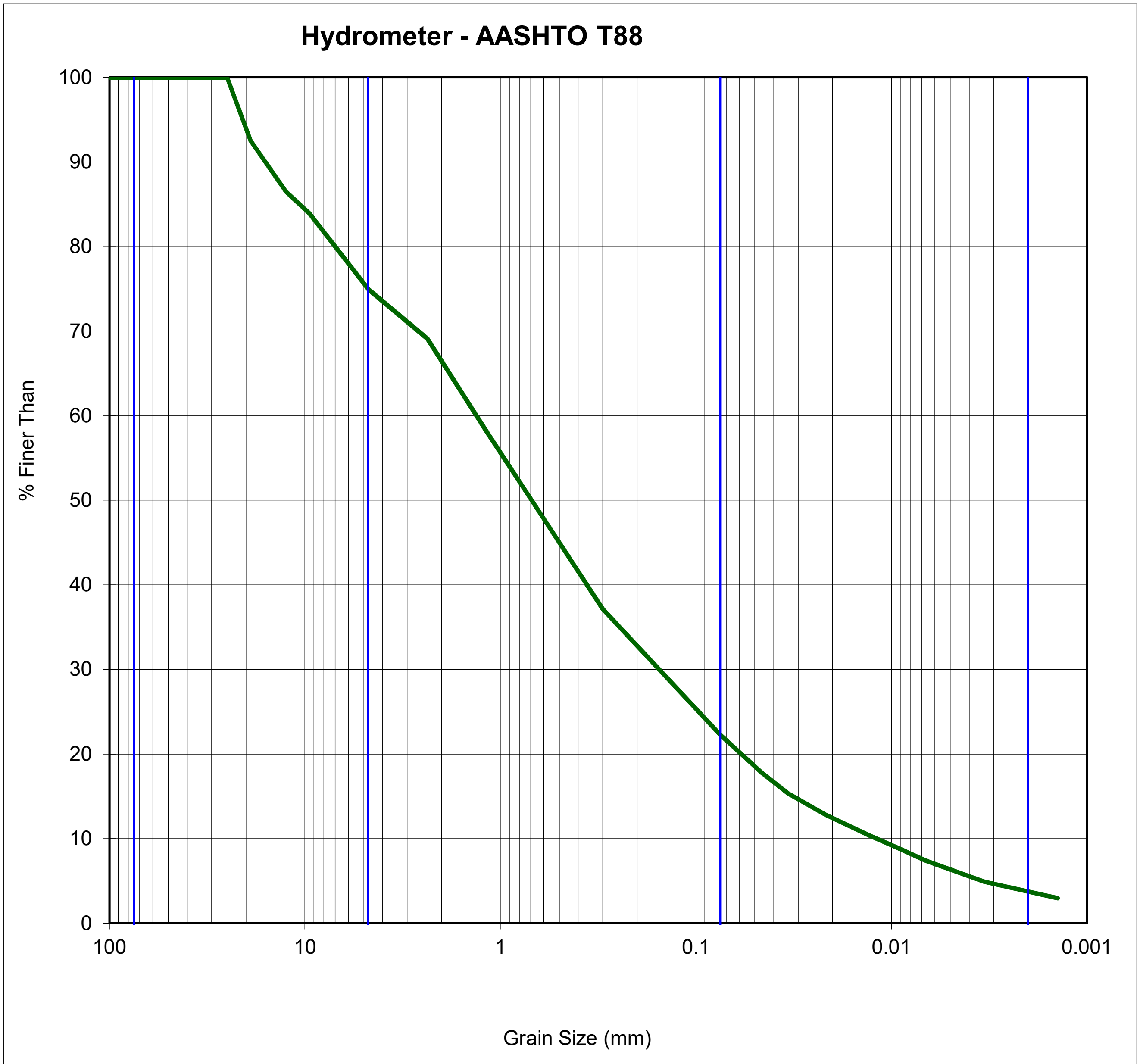
Gravel = **22.2%** Sand = **47.1%** Silt = **29.2%** Clay = **1.6%**

Hydrometer Classification: **Sand, silty, gravelly, trace clay.**

SNC•LAVALIN	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-02**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM10**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM11**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-02**	Sample Depth (m)	**4.57**			Natural Moisture	**8.8%**
Project No.	**677011**					Tech.	**MK/DY**



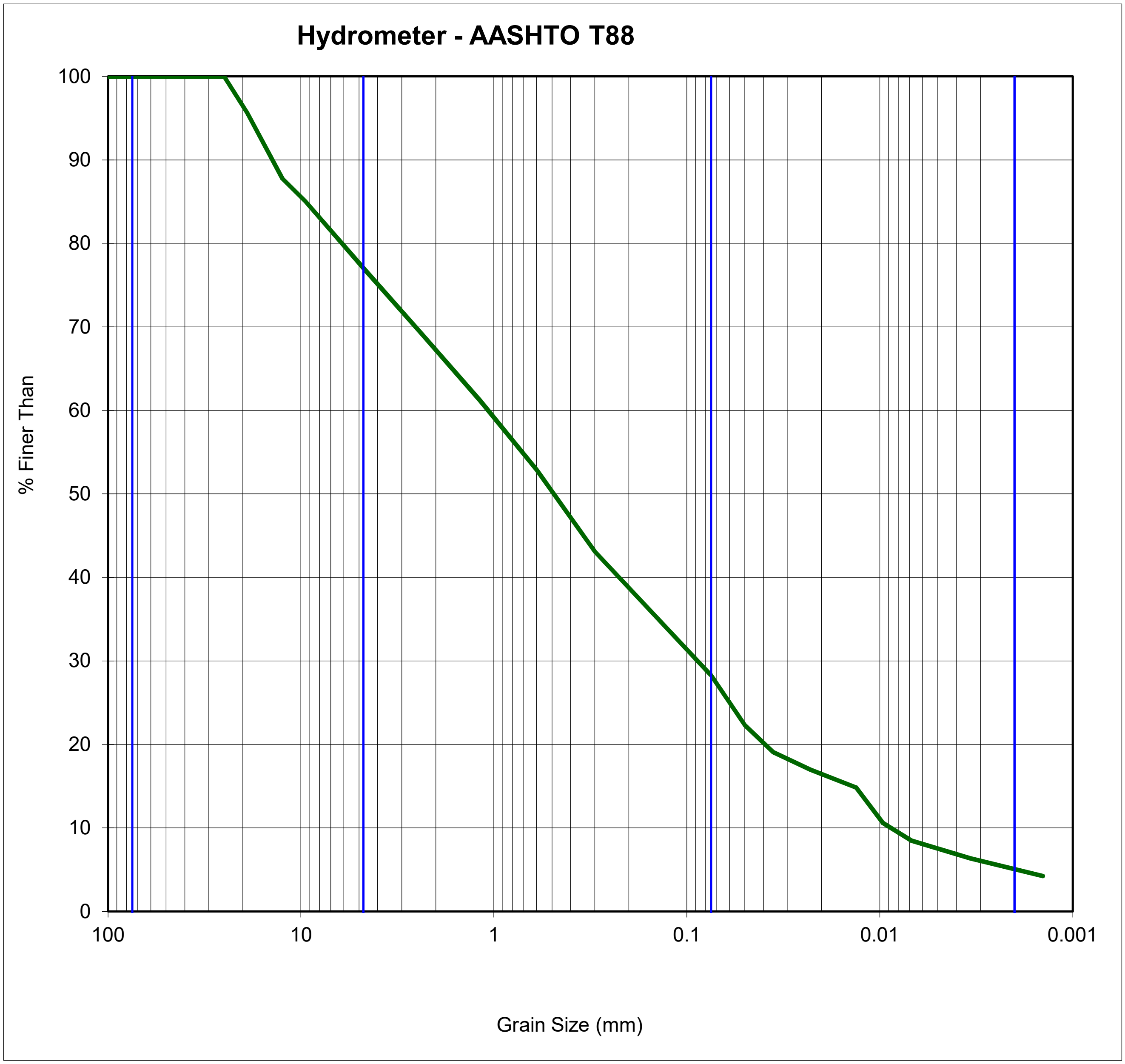
Gravel = **25.0%** Sand = **52.7%** Silt = **18.8%** Clay = **3.6%**

Hydrometer Classification: **Sand, gravelly, some silt, trace clay.**

SNC·LAVALIN				
	Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
	Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-02**
	Location	**Vancouver, British Columbia**	Sample No.	**IJM11**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM12**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-02**	Sample Depth (m)	**5.79**			Natural Moisture	**13.0%**
Project No.	**677011**					Tech.	**MK/DY**



Gravel = **23.0%** Sand = **48.7%** Silt = **23.5%** Clay = **4.9%**

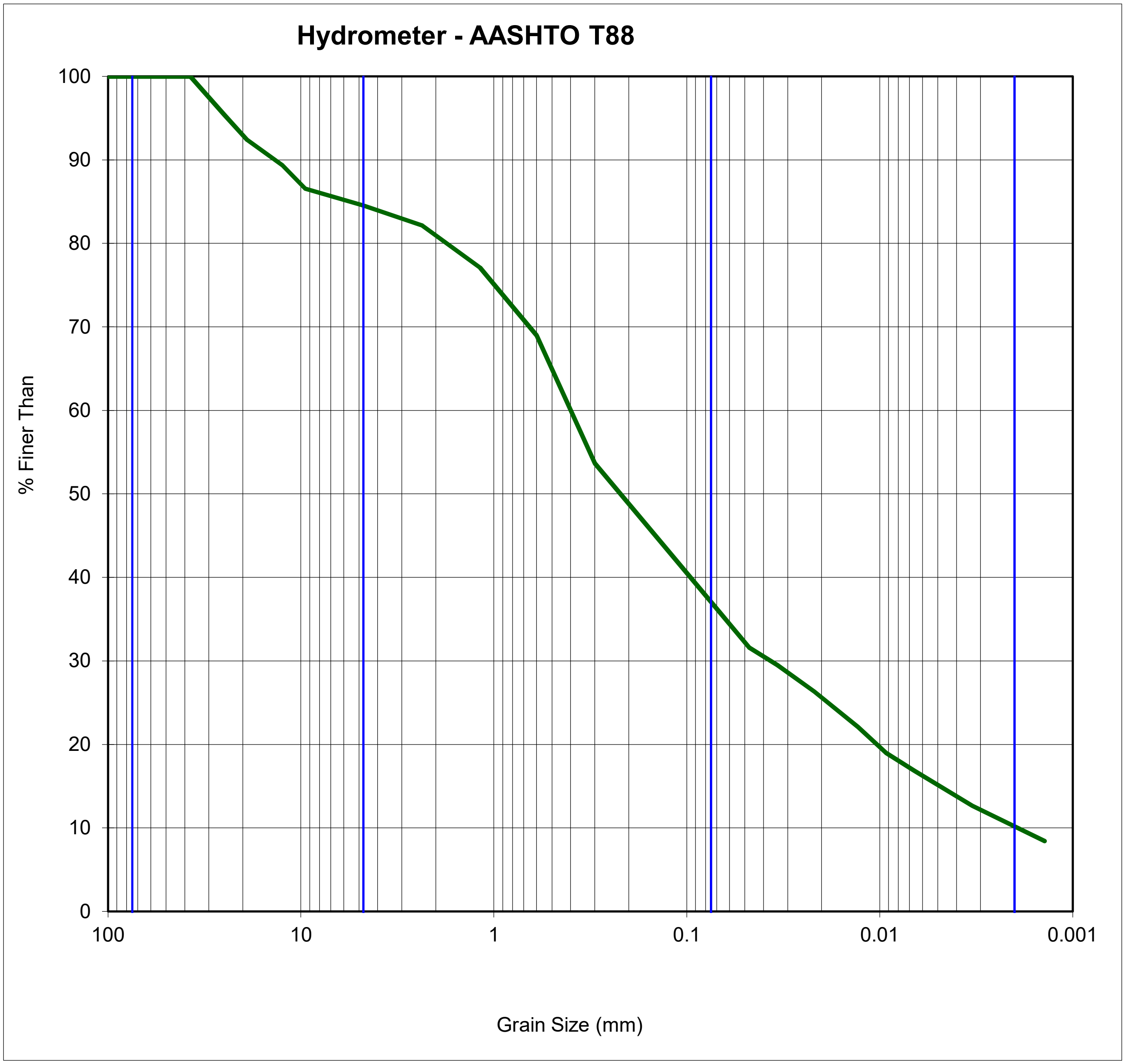
Hydrometer Classification: **Sand, silty, gravelly, trace clay.**

SNC•LAVALIN

Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-02**
Location	**Vancouver, British Columbia**	Sample No.	**IJM12**

PARTICLE SIZE ANALYSIS - HYDROMETER

Sample No.	**IJM14**	Date Sampled	**16-Nov-20**	By	**IM**	of	**SNC-Lavalin Inc.**
Borehole No.	**BH20-02**	Sample Depth (m)	**7.32**			Natural Moisture	**8.6%**
Project No.	**677011**					Tech.	**MK/DY**



Gravel = **15.5%** Sand = **47.4%** Silt = **27.3%** Clay = **9.8%**

Hydrometer Classification: **Sand, silty, some gravel, trace clay.**

Client	**Vancouver Fraser Port Authority**	Date	**3-Dec-20**
Project	**Sterling Shipyards R&R**	Borehole No.	**BH20-02**
Location	**Vancouver, British Columbia**	Sample No.	**IJM14**

MOISTURE CONTENT

Sample No.	BH20-01	IJM01	IJM02	IJM03	IJM04	IJM05	IJM06	IJM07	
Depth (ft)		9	12	16	19	20	24	25	
Depth (m)		2.74	3.66	4.88	5.79	6.10	7.32	7.62	
Wt Tare (g)		1.41	1.51	1.54	0.76	0.69	0.77	1.36	
Wt Wet+Tare (g)		24.83	44.24	54.46	42.21	25.78	32.98	45.17	
Wt Dry+Tare (g)		8.03	37.66	47.82	36.28	22.65	29.49	40.33	
Wt Water (g)		16.8	6.58	6.64	5.93	3.13	3.49	4.84	
Wt Dry Soil (g)		6.62	36.15	46.28	35.52	21.96	28.72	38.97	
Moisture Content (%)		**253.8**	**18.2**	**14.3**	**16.7**	**14.3**	**12.2**	**12.4**	

Sample No.	BH20-02	IJM08	IJM10	IJM11	IJM12	IJM13	IJM14	IJM15	IJM16
Depth (ft)		9	14	15	19	20	24	25	29
Depth (m)		2.74	4.27	4.57	5.79	6.10	7.32	7.62	8.84
Wt Tare (g)		0.84	1.49	1.43	1.42	1.42	1.43	1.42	1.43
Wt Wet+Tare (g)		38.04	59.67	27.77	42.26	41.22	33.07	36.28	39.49
Wt Dry+Tare (g)		30.4	51.86	25.63	37.55	35.8	30.57	31.43	36.03
Wt Water (g)		7.64	7.81	2.14	4.71	5.42	2.5	4.85	3.46
Wt Dry Soil (g)		29.56	50.37	24.2	36.13	34.38	29.14	30.01	34.6
Moisture Content (%)		**25.8**	**15.5**	**8.8**	**13.0**	**15.8**	**8.6**	**16.2**	**10.0**

Sample No.									
Depth (ft)									
Depth (m)									
Wt Tare (g)									
Wt Wet+Tare (g)									
Wt Dry+Tare (g)									
Wt Water (g)									
Wt Dry Soil (g)									
Moisture Content (%)									

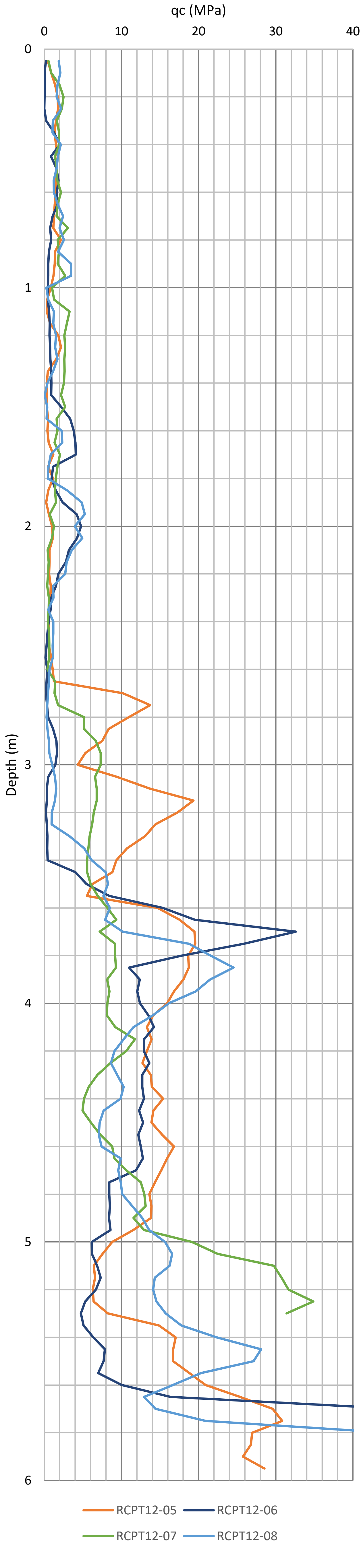
Sample No.									
Depth (ft)									
Depth (m)									
Wt Tare (g)									
Wt Wet+Tare (g)									
Wt Dry+Tare (g)									
Wt Water (g)									
Wt Dry Soil (g)									
Moisture Content (%)									

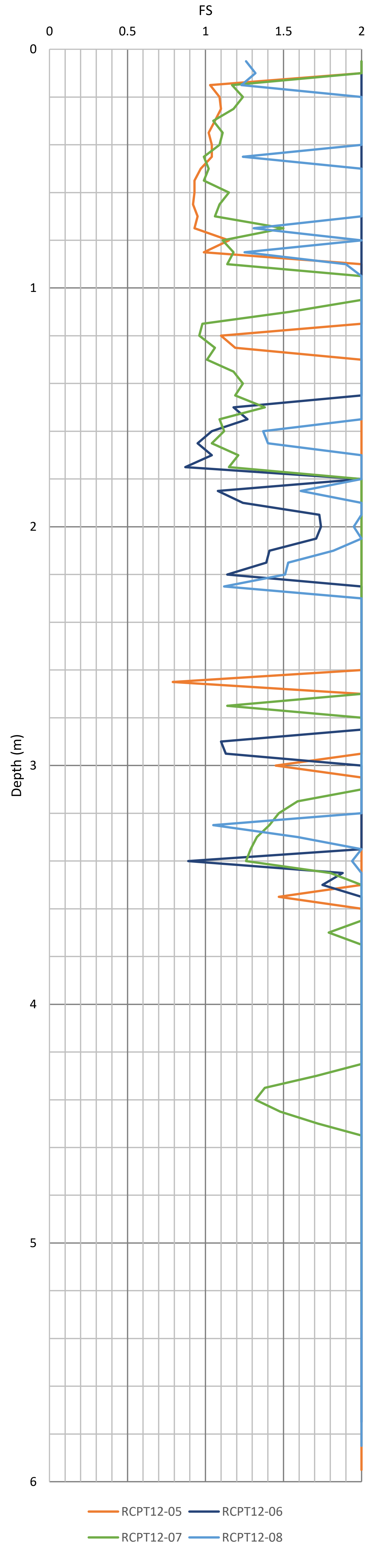
SNC•LAVALIN

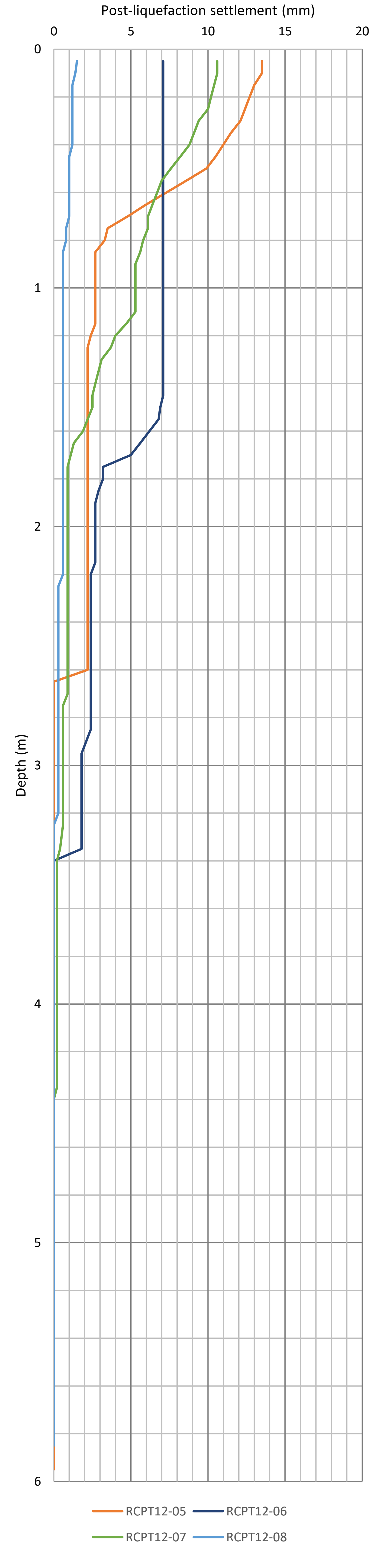
CLIENT:	**Vancouver Fraser Port Authority**	DATE:	**1-Dec-20**
PROJECT:	**Sterling Shipyards R&R**	FILE No.:	**677011**
LOCATION:	**Vancouver, British Columbia**	TECH:	**MK/DY**

Appendix VI

Soil Liquefaction Assessment



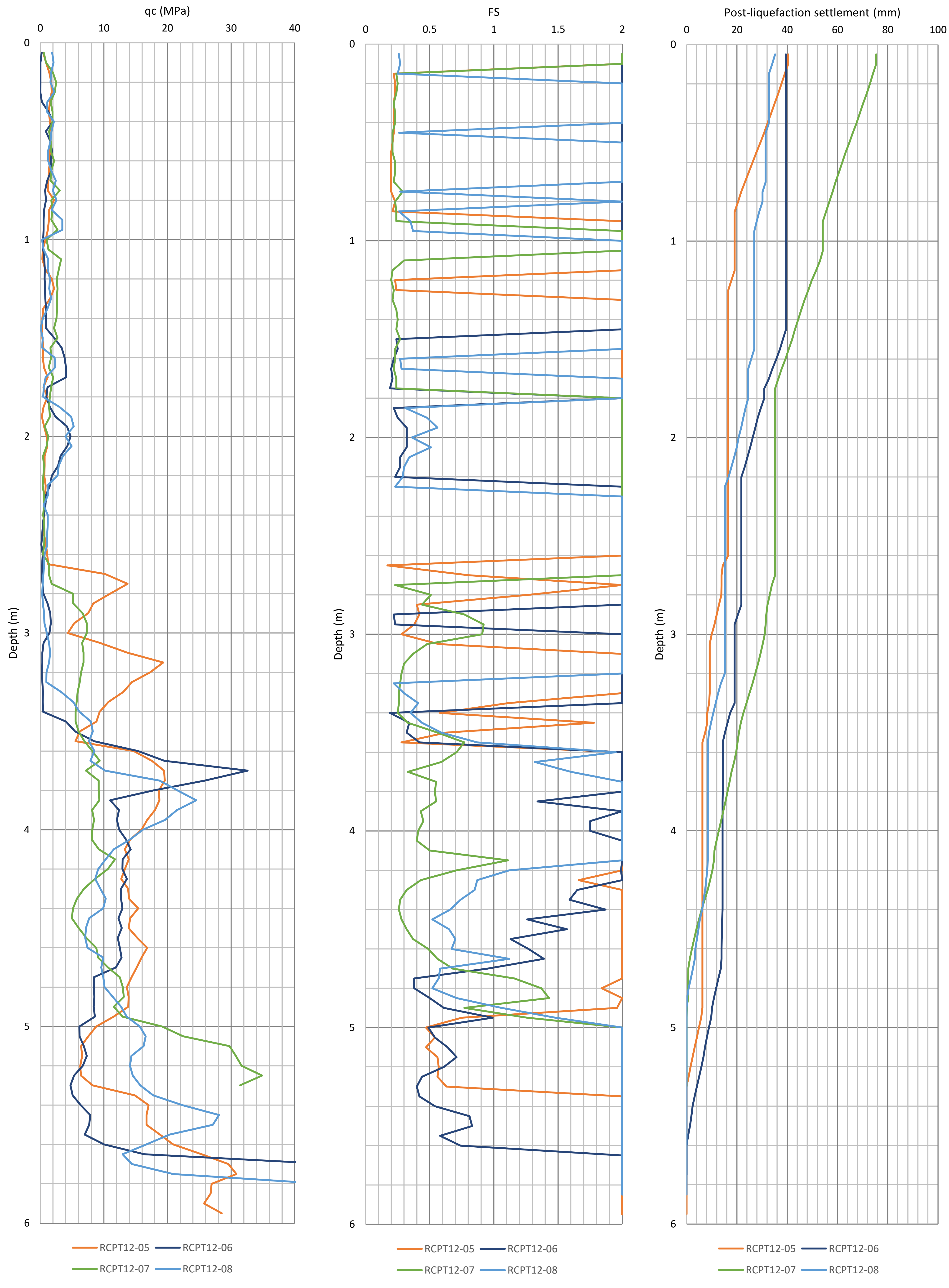




SNC·LAVALIN

CLIENT: VFPA				TITLE: Liquefaction Assessment for Selected CPT/SCPTs - 100 EQ	
PROJECT: Sterling Shipyard					
PROJECT NO. 677011	DFTR.	DSGN. MH	CHK. MN	DATE: 2021-02-17	FIGURE:

\\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\42_Eng\Seismic\Liquefaction\[Liq. Summary 100 EQ Updated 2021-02-17.xlsx]



SNC·LAVALIN	CLIENT: VFPA				TITLE: Liquefaction Assessment for Selected CPT/SCPTs - 2475 EQ
	PROJECT Sterling Shipyard				
	PROJECT NO. 677011	DFTR.	DSGN. MH	CHK. MN	DATE: 2021-02-17	FIGURE:

\\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\42_Eng\Seismic\Liquefaction\[Liq. Summary 2475 EQ Updated 2021-02-17.xlsx]

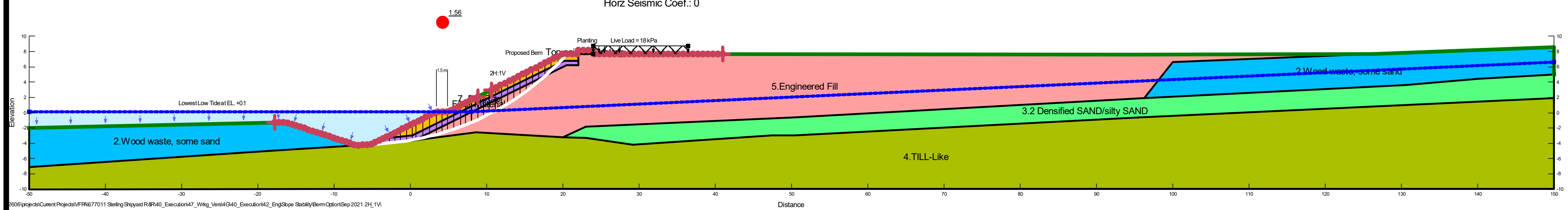
Appendix VII

Slope Stability Assessment

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	2.Wood waste, some sand	Mohr-Coulomb	14	0	22	0	1
	3.2 Densified SAND/silty SAND	Mohr-Coulomb	19.5	0	34	0	1
	4.TILL-Like	Mohr-Coulomb	20	0	40	0	1
	5.Engineered Fill	Mohr-Coulomb	20	0	36	0	1
	7. Rip-Rap	Mohr-Coulomb	22	0	40	0	1
	Filter Material	Mohr-Coulomb	20	0	40	0	1
	Top soil for planting	Mohr-Coulomb	15	0	5	0	1

Horz Seismic Coef.: 0

PGA (2475-y)=0.351g
PGA (9475-y)=0.247g
PGA (475-y)=0.178g
PGA (100-y)=0.078g



Method: Morgenstern-Price

SNC·LAVALIN

CLIENT: VFPA

PROJECT: Sterling Shipyard

PROJECT NO.: 677011

TITLE: Section B-B (Longitudinal) Static Proposed Berm

ANLYS: MH

CHK: MN

FIGURE:

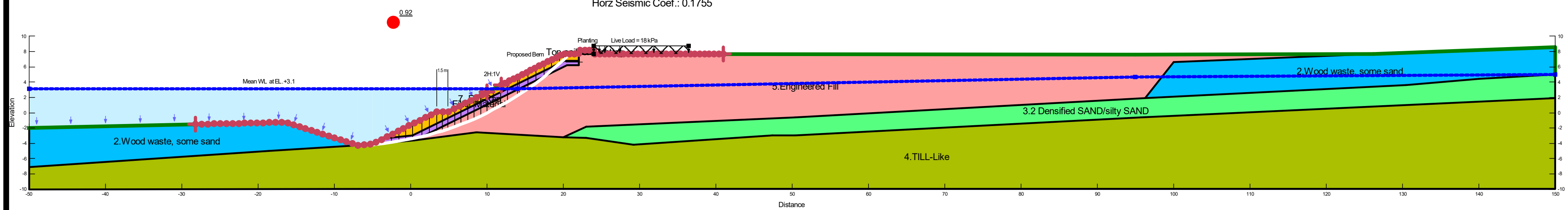
DATE: Date: 2021-09-14

Directory: \\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\47_Wrkg_Vers\4G\40_Execution\42_Eng\Slope Stability\Berm Option\Sep 2021 2H_1V\

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	2.Wood waste, some sand	Mohr-Coulomb	14	0	22	0	1
	3.2 Densified SAND/silty SAND	Mohr-Coulomb	19.5	0	34	0	1
	4.TILL-Like	Mohr-Coulomb	20	0	40	0	1
	5.Engineered Fill	Mohr-Coulomb	20	0	36	0	1
	7. Rip-Rap	Mohr-Coulomb	22	0	40	0	1
	Filter Material	Mohr-Coulomb	20	0	40	0	1
	Top soil for planting	Mohr-Coulomb	15	0	5	0	1

Horz Seismic Coef.: 0.1755

PGA (2475-y)=0.351g
PGA (9475-y)=0.247g
PGA (475-y)=0.178g
PGA (100-y)=0.078g



Method: Morgenstern-Price

SNC·LAVALIN

CLIENT: VFPA

PROJECT: Sterling Shipyard

PROJECT NO.: 677011

TITLE: Section B-B (Longitudinal)
Seismic Proposed Berm: 2475-y EQ

ANLYS: MH

CHK: MN

FIGURE:

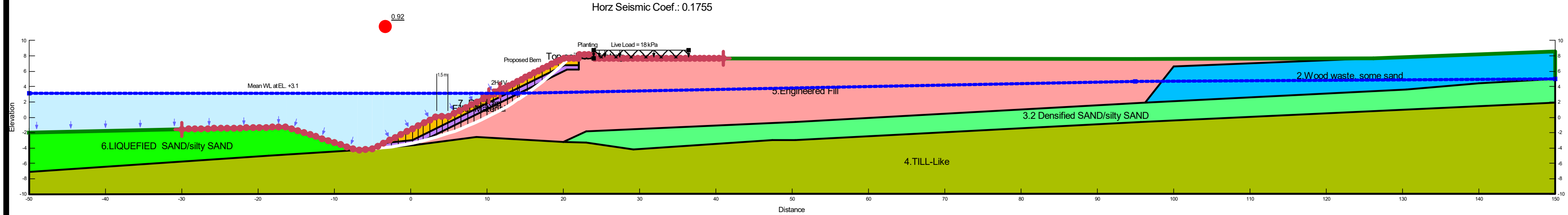
DATE: Date: 2021-09-14

Directory: \\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\47_Wrkg_Vers\4G\40_Execution\42_Eng\Slope Stability\Berm Option\Sep 2021 2H_1V\

Color	Name	Model	Unit Weight (kN/m³)	Minimum Strength (kPa)	Tau/Sigma Ratio	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	2.Wood waste, some sand	Mohr-Coulomb	14			0	22	0	1
	3.2 Densified SAND/silty SAND	Mohr-Coulomb	19.5			0	34	0	1
	4.TILL-Like	Mohr-Coulomb	20			0	40	0	1
	5.Engineered Fill	Mohr-Coulomb	20			0	36	0	1
	6.LIQUEFIED SAND/silty SAND	SHANSEP	15	10	0.08				1
	7. Rip-Rap	Mohr-Coulomb	22			0	40	0	1
	Filter Material	Mohr-Coulomb	20			0	40	0	1
	Top soil for planting	Mohr-Coulomb	15			0	5	0	1

PGA (2475-y)=0.351g
PGA (9475-y)=0.247g
PGA (475-y)=0.178g
PGA (100-y)=0.078g

Horz Seismic Coef.: 0.1755



Method: Morgenstern-Price

CLIENT: VFPA

PROJECT: Sterling Shipyard

PROJECT NO.: 677011

TITLE: Section B-B (Longitudinal)
Seismic Proposed Berm: Post-Liquefaction

ANLYS: MH

FIGURE:

CHK: MN

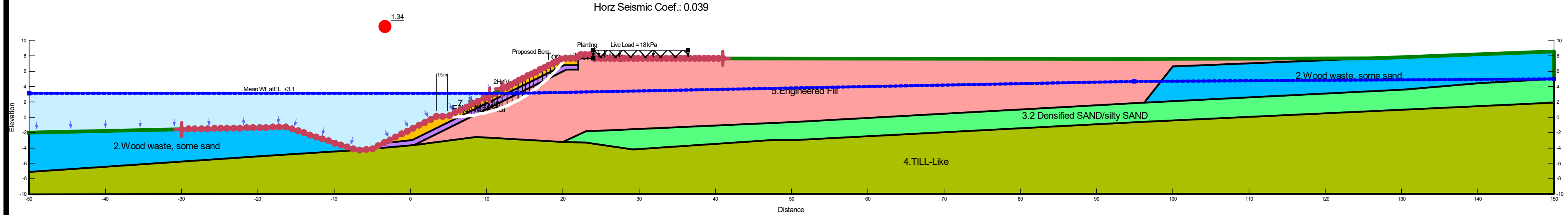
DATE: Date: 2021-09-14

Directory: \\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\47_Wrkg_Vers\4G\40_Execution\42_Eng\Slope Stability\Berm Option\Sep 2021 2H_1V\

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	2.Wood waste, some sand	Mohr-Coulomb	14	0	22	0	1
	3.2 Densified SAND/silty SAND	Mohr-Coulomb	19.5	0	34	0	1
	4.TILL-Like	Mohr-Coulomb	20	0	40	0	1
	5.Engineered Fill	Mohr-Coulomb	20	0	36	0	1
	7. Rip-Rap	Mohr-Coulomb	22	0	40	0	1
	Filter Material	Mohr-Coulomb	20	0	40	0	1
	Top soil for planting	Mohr-Coulomb	15	0	5	0	1

Horz Seismic Coef.: 0.039

PGA (2475-y)=0.351g
PGA (9475-y)=0.247g
PGA (475-y)=0.178g
PGA (100-y)=0.078g



Method: Morgenstern-Price

SNC·LAVALIN

CLIENT: VFPA

PROJECT: Sterling Shipyard

PROJECT NO.: 677011

TITLE: Section B-B (Longitudinal)
Seismic Proposed Berm: 100-y EQ

ANLYS: MH

CHK: MN

FIGURE:

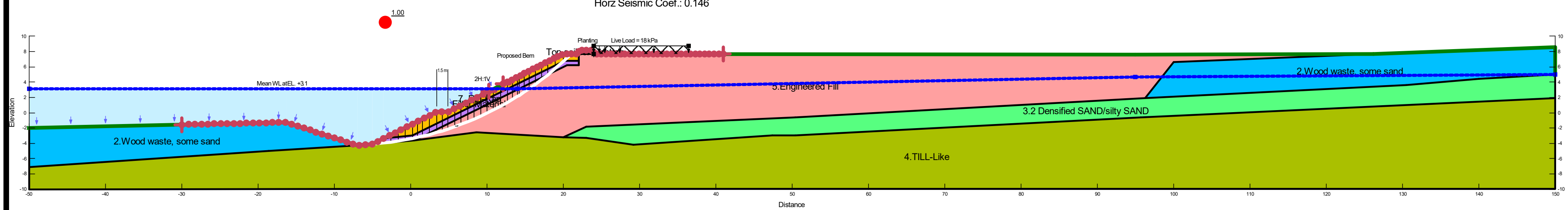
DATE: Date: 2021-09-14

Directory: \\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\47_Wrkg_Vers\4G\40_Execution\42_Eng\Slope Stability\Berm Option\Sep 2021 2H_1V\

Color	Name	Model	Unit Weight (kN/m³)	Cohesion' (kPa)	Phi' (°)	Phi-B (°)	Piezometric Line
	2.Wood waste, some sand	Mohr-Coulomb	14	0	22	0	1
	3.2 Densified SAND/silty SAND	Mohr-Coulomb	19.5	0	34	0	1
	4.TILL-Like	Mohr-Coulomb	20	0	40	0	1
	5.Engineered Fill	Mohr-Coulomb	20	0	36	0	1
	7. Rip-Rap	Mohr-Coulomb	22	0	40	0	1
	Filter Material	Mohr-Coulomb	20	0	40	0	1
	Top soil for planting	Mohr-Coulomb	15	0	5	0	1

PGA (2475-y)=0.351g
PGA (9475-y)=0.247g
PGA (475-y)=0.178g
PGA (100-y)=0.078g

Horz Seismic Coef.: 0.146



Method: Morgenstern-Price

SNC·LAVALIN	CLIENT: VFPA	TITLE: Section B-B (Longitudinal) Seismic Proposed Berm: Yield Acceleration
	PROJECT: Sterling Shipyard	ANLYS: MH / FIGURE:
	PROJECT NO.: 677011	CHK: MN / DATE: Date: 2021-09-14

Directory: \\Sli2606\projects\Current Projects\VFPA\677011 Sterling Shipyard R&R\40_Execution\47_Wrkg_Vers\4G\40_Execution\42_Eng\Slope Stability\Berm Option\Sep 2021 2H_1V\

SNC-Lavalin Inc.
Suite 1300 - 3777 Kingsway Avenue
Burnaby, British Columbia, Canada V5H 3Z7
604.515.5151 604.515.5150
www.snclavalin.com