SNC·LAVALIN

Sterling Shipyard Remediation and Infill Project

Geotechnical Instrumentation & Monitoring Plan

Prepared for:

Vancouver Fraser Port Authority

July 8, 2021

Revision Index

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1 Introduction

This Geotechnical Instrumentation & Monitoring Plan (GIMP) provides the results of the construction impact analysis (CIAR) and the resulting monitoring requirements for the remediation of the Sterling Shipyard Site (the Project). The report discusses construction impact assessment methodologies, presents the geotechnical Zone of Influence (ZOI) determined as a result of the assessment, and identifies the existing adjacent structures (EAS) within the ZOI that are to be monitored. Installation of instrumentation is required to monitor EAS that are located within the ZOI where in EAS may be impacted as a result of construction activities.

The Vancouver Fraser Port Authority (port authority) is remediating the former Sterling Shipyard site, at 2089 to 2095 Commissioner Street, Vancouver, BC to repurpose for industrial use. The redevelopment of the site will include construction of an embankment, remediation of the intertidal area, and raising the site grading to create additional available land area for use by the port authority and/or for future development.

2 Subsurface Soil and Groundwater Conditions

The subsurface soil conditions and groundwater conditions are described in the geotechnical report prepared for the Sterling Shipyard Remediation (SNC-Lavalin, 2021a). Soil parameters utilized in the assessment of the ZOIs were developed from the information provided in the geotechnical report (SNC-Lavalin, 2021a) and historic sonic drilling logs, CPT, and laboratory testing results at the site (SNC-Lavalin, 2013).

Table 2-1 Soil and Groundwater Conditions and Assumptions

Location	Ground Elevation (masl)	Groundwater Level (masl)	Soil	Layer Thickness (m)	Elastic Modulus (MPa)	Unit Weight (kN/m^3)
Cross-Section C-C	4.50	0	Woodwaste Fill	2.6	15	14
			Sand	2.0	36	18
			Till	15*	80	20
Cross-Section H-H	2.0	0	Woodwaste Fill	2.8	15	14
			Sand	2.3	36	18
			Till	15*	80	20

*Assumed depth for analysis

3 Construction Activities

The conditions and assumptions for which the GIMP has been developed are provided for each of the construction activities listed below. Should the conditions, staging or structures deviate from the assumptions detailed within this report, the GIMP must be updated to remain valid.

1. Sediment remediation and replacement with engineered fill
    - Based on the drawings for the remediation & infill (SNC-Lavalin, 2021b), the analysis assumes the woodwaste fill material is entirely removed to the minimum depth to meet geotechnical requirements and backfilled with a compacted engineered fill.
    - Excavations for sediment remediation is assumed to be facilitated through shored excavations as depicted in the cross-sections for the remediation & infill (SNC-Lavalin, 2021b).
2. Construction of the rockfill berm and revetment
    - The cross-sections used in analysis of the rockfill berm are provided in the drawings for the remediation & infill (SNC-Lavalin, 2021b). The rockfill berm is assumed to be founded on competent till material. The revetment crest is at an elevation of 7.7 masl (Chart Datum), resulting in a varying fill depth of up to approximately 10.5 m, measured from the crest up to the base of the berm near the till interface .
    - The existing soil in front of the proposed berm is assumed to be excavated facilitated by dredging and replaced with fill material.
    - Excavation for the construction of the berm is assumed to be facilitated through sloped excavation, where possible, and the remaining portions, at the property boundaries, by shored excavations to the depth of till.
    - The existing sheetpile and lockblock walls located near the Marco site boundary are assumed to be removed during construction.

4 Construction Impact Assessment

4.1 Assessment of Ground Movements

4.1.1 Ground Movement Due to Stress Relief (Excavation)

Ground movement that may occur as a result of stress relief is best quantified in terms of the lateral displacement and vertical settlement of the adjacent free ground surface following excavation. Evaluation of the ground movements associated with open excavations is highly dependent upon several factors including: soil type, geometry of excavation, groundwater pressure, construction sequencing, construction quality and the overall stiffness of the support system. It is noted that for rectangular excavations, the stiffness of the excavation walls increases approaching and around corners; therefore, reducing the magnitude of ground movements. For instances where a specific building is located with the ZOI of two or more excavations, the anticipated settlements will be superimposed.

As described in the geotechnical report (SNC-Lavalin, 2021a) the temporary shoring systems depicted in the remediation & infill drawings (SNC-Lavalin, 2021a) have been included in our analysis. For a shored or supported excavation, the ZOI has been determined based on the empirical methodology published by Peck (1969), resulting in a ZOI varying from 8.0 m to 14.5 m.

4.1.2 Ground Movement Due to Soil Distress (Placement of Fill)

Ground movement that may occur as a result of soil distress is best quantified in terms of the lateral displacement and vertical settlement of the adjacent free ground surface following placement of fill. Evaluation of displacements which may occur as a result of soil distress is dependent on several factors including: soil type, geometry of fill (height, width, and length), anticipated dead load and live load, groundwater conditions, and construction sequencing.

Ground movement due to fill placement for the remediation & infill has been modelled in Settle3 with a varying fill height of up to 10.5 m (Elv 7.7 m Chart Datum) as shown in the remediation & infill cross-sections (SNC-Lavalin, 2021b). The fill height of 10.5 m is measured from the base of the rockfill berm to the crest. The settlement analysis assumes the woodwaste fill material is entirely removed to the minimum depth to meet geotechnical requirements and backfilled with a compacted engineered fill. The ZOI had been determined to where expected settlements exceeds 5 mm. The resulting settlement ZOI was determined to be 5.0 m to 7.5 m from the edge of fill. The maximum settlement is estimated to be 50 mm below the rock berm.

4.1.3 Ground Movement Due to Dewatering

It is anticipated that ground settlement may occur due to the vertical stress change within overburden soils as a result of dewatering activities. Estimation of the settlement associated with lowering the groundwater table is based on one-dimensional effective vertical stress change (Cashman and Preene, 2001). For the purpose of the analysis, horizontal movements due to the effects of groundwater drawdown are expected to be negligible and will not be considered. Son and Cording (2005) specify that settlements of less than 10 mm may be considered to be negligible. Moreover, as the slope of the dewatering curve is gradual, damage to foundations due to differential settlement from dewatering alone is highly unlikely. Due to the aforementioned findings of Son and Cording (2005) as well as the gradual nature of the dewatering curve, the ZOI was determined based on a drawdown induced settlement greater than 10 mm.

Based on the information in the Geotechnical Report (SNC-Lavalin, 2021a), there is expected to be seepage into the subtidal excavation area from all sides. Due to seepage into the excavation, there will be a lowered piezometric level in the areas adjacent to the excavation. At the time of writing, dewatering curves for the site have not been established, so the impact of the lowered piezometric level cannot be assessed. The details about the dewatering and the groundwater management is the responsibility of the construction contractor and will be depends on the duration, time and method of excavation. However, the settlement due to dewatering at EAS shall not exceed 10 mm. As the resulting settlement is predicted to be less than 10 mm, no dewatering ZOI for the excavation is anticipated. Should the conditions, staging or structures deviate from the assumptions detailed within this report, the EOR or its representative needs to be consulted for approval prior to the construction.

4.1.4 Criteria for Potential Damage to Structures

Structural damage typically occurs as a result of differential settlement and distortion across the structure rather than the occurrence of a uniform, total settlement (Cashman, 2001). Therefore, the semi-empirical method proposed by Namazi and Mohamad (2013) has been utilized to determine the potential damage that may occur at each EAS as a result of horizontal strain, angular distortion and relative deflection. As previously stated, the analysis assumes that all EAS are in good condition and free of major structural defects and damage prior to construction. In addition, Son and Cording (2005) specify damage to buildings as negligible for settlements of magnitude less than 10 mm.

The method proposed by Namazi and Mohamad (2013) evaluates the potential risk for EAS to incur damage by considering EAS as a rectangular thick plate as opposed to the traditional deep beam. This critical difference within the method of analysis allows for the behavior of the EAS to be assessed in three-dimensions. The method relies upon horizontal strain, angular distortion and relative deflection; however, twisting or warping and horizontal extension in the out of plane direction is also accounted for. The resultant horizontal strains are summated using superposition to determine the critical tensile strain (εlim) which can then be used to estimate the building damage. Table 4-1 below provides the risk classification system adopted by Namazi and Mohamad (2013), and descriptions of estimated damage categories referenced from Boscardin and Cording (1989).

Table 4-1 Classification of damage based on critical strain and approximated crack width.

Estimated Damage Category[1]	Estimated Damage Category[2]	Approximate Crack Width (mm)[3]	ε_{lim} (%)[4]
Negligible	Hairline cracks of less than about 0.1 mm are classified as negligible.	< 0.1	0 – 0.05
Very Slight	Fine cracks that can be easily be treated during normal decoration. Perhaps isolated slight fracture in building. Cracks in external brickwork visible on close inspection.	< 1	0.05 – 0.075
Slight	Cracks easily filled. Redecoration probably required. Several slight fractures showing inside of building. Cracks are visible externally and some repointing may be required externally to ensure weather tightness. Doors and windows may become sticky.	1 - 5	0.075 – 0.167
Moderate to Severe	The cracks require some opening up and can be patched by a mason. Recurrent cracks can be masked by suitable linings. Repointing of external brickwork and possibly a small amount of brickwork to be replaced. Doors and windows sticking. Service pipes may fracture. Weather tightness often impaired.	5 – 15 Or a number of cracks > 3	0.167 – 0.333
	Extensive repair work involving breaking out and replacing sections of walls, especially over doors and windows. Windows and door frames distorted, floor sloping noticeably. Walls leaning or bulging noticeably, some loss of bearing in beams. Service pipes disrupted.	15 – 25, but also depends on number of cracks	
Severe to Very Severe	This requires a major repair job involving partial or complete rebuilding. Beams lose bearing; walls lean badly and require shoring. Windows broken with distortion. Danger of instability.	> 25	> 0.333

Notes:

1. Estimated Category of Damage initially determined by Burland et al., (1977); later modified by Son and Cording (2005).
2. In assessing the degree of damage, account must be taken of the location of the damage in the building or structures.
3. Crack width is only one aspect of damage and should not be used on its own as a direct measurement of damage.
4. Limiting strain as determined by Namazi and Mohamad (2013).

4.1.5 Assumptions and Limitations

Assumptions and limitations of the analysis methods are listed below:

1. The EAS are in good condition and free of major structural defects and damages prior to the construction;
2. Buildings are founded at-grade, and on spread footings;
3. The analysis is based on the information available at the time of writing. Geological formations are heterogeneous and actual site conditions may be significantly different; and,
4. The CIAR is contingent on the validity of the assumptions and conditions outlined within Section 4. Should the design or conditions on-site deviate from those assumed, or construction methodologies change, the CIA must be updated.

4.2 CIAR Results

The ZOI and EAS identified as a result of the assessment are shown on the site plan in Appendix A. A summary of the ZOI is provided in Table 4-2. The EAS identified within the ZOI for each construction activity are also provided in Table 4-2.

Table 4-2 Summary of Ground Movement ZOI.

Construction Activity	Ground Movement ZOI (m)	EAS in Service
Fill Placement	5.0 – 7.5 m (from the edge of placed material)	Existing Sheetpile wall (to be removed) Existing Timber wall (to be removed) East Lockblock wall
Sloped/Shored Excavations	0 m – 14.5 m (from the edge of excavation)	Existing Sheetpile wall (to be removed) Existing Timber wall (to be removed) East Lockblock wall Lafarge Conveyor Building

Proper clearance of the work area is required prior to the start of construction. **Should additional EAS be found or conditions change, the CIAR must be reassessed to remain valid.**

The settlement ZOI due to fill placement has been determined to be 5.0 m to 7.5 m from the edge of fill, as modeled in Rocscience Settle3. The excavation ZOI has been determined to be 0 to 14.5 m from the edge of the excavation. The 14.5 m excavation ZOI results from the shored excavations at the property boundaries. The impact to the existing sheetpile and timber walls near the Marco property boundary has not been considered, as the EAS are to be removed during construction.

Lockblock Wall

The lockblock wall of the east side of the site is estimated to undergo 9 mm of settlement at the front-edge of the wall, and approximately 6 mm at the back-edge due to fill placement. The resulting tilt on the lockblock wall is 1/500, assuming a 1.5 m base length. Based on the minimal resulting settlement and tilt, the lockblock wall is anticipated to have negligible damage due to fill placement. During the excavation that temporary shoring is used in the vicinity of the lockblock wall, as currently depicted in the remediation &

infill drawings (SNC-Lavalin, 2021b), 59 mm and 45 mm of deformation is anticipated at the front-edge and back-edge of the wall, respectively, due to shored excavation. The resulting critical strain is 0.972%, resulting in severe to very severe damage. For construction, it is the responsibility of the construction contractor to design the shoring system such that the maximum total settlements are limited to 10 mm. .

Lafarge Conveyor Building

The Lafarge Conveyor Building located to the east of the proposed rockfill berm is within the 14.5 m excavation ZOI. The building is located approximately 13.5 m from the proposed shored excavation. Based on the empirical correlation by Peck (1969) the resulting settlement at the closest point of the building to the excavation is less than 10 mm, immediately resulting in negligible damage as predicted by Son & Cording (2005). The analysis conservatively assumes the building is founded at-grade on spread footings.

5 Geotechnical Instrumentation and Monitoring

5.1 Design of Monitoring Plan

5.1.1 Introduction

The proposed excavations and fill placements may result in ground movements. Ground movements may potentially cause damage to structures/utilities located within the ZOI.

The instrumentation and monitoring plan has been developed based on the following three key principles:

1. Geotechnical instruments must be specified to monitor the magnitude and distribution of ground movements in the areas surrounding the operations, to measure ground movements near existing structures;
2. Structural monitoring points must be installed to verify vertical and horizontal displacements of structures (e.g., buildings, bridges, railroad tracks, etc.) in areas where anticipated ground movements may potentially cause damage to the structure; and,
3. Utility monitoring points must be used to observe vertical and horizontal displacements of utilities that are to be supported in-place during construction.

5.1.2 EAS Identified

Instruments shall be installed to monitor the potential impact to EAS within the ZOI. The ZOI was determined as an output of the CIAR. All EAS identified within the ZOI must be monitored during construction. The EAS to be monitored include:

1. Lockblock wall along the eastern property line;
2. Lafarge conveyor building located east of the proposed rockfill berm; and,
3. Sewer Outfall.

The sewer outfall does not fall within the settlement ZOI's established in Section 4.2, however due to the proximity and significance of the structure, it should still be monitored for vibrations during construction. Consultation with key stakeholders is required prior to finalizing the monitoring plan. Stakeholders should confirm the monitoring frequency, alert levels, and mitigation methods used are acceptable.

Lockblock Wall

The required monitoring points for the lockblock wall are depicted in Appendix I. The lockblock wall is anticipated to undergo negligible damage due to settlement from fill placement. However, during the excavation and the installation of temporary shoring in close proximity to the lockblock wall is likely to induce moderate to severe amounts of settlement, depending on the stiffness of the shoring system. As a result, it is anticipated for the lockblock wall to exceed the review and alert level settlement thresholds provided in Section 5.2, unless mitigation strategies are put in-place prior to construction.

Lafarge Conveyor Building

The Lafarge conveyor building is expected to have negligible damage as the predicted settlements due to excavation are less than 10 mm. The required monitoring points for the Lafarge Conveyor Building are depicted in Appendix I.

5.1.3 Instrumentation Details

The type of instrumentation used to monitor EAS is at the discretion of the Contractor, but subject to the approval of the Geotechnical Engineer of Record (EOR). Recommended details for each type of instrument is provided in the following section.

All monitoring equipment shall be selected such that the ranges of pressures and temperatures that they may be subject to are within the manufacturers prescribed limits.

Installation of the instruments shall be in accordance to the Environmental Management Plan for the project and all applicable regulatory requirements.

Building Monitoring Points / Utility Target Points

Building Monitoring Points (BMPs) or Utility Target Points (UTPs) are distinctive target points installed on structures to be monitored by topographic survey instruments. Target points specified in this section are monitored using permanent non-moving survey benchmarks.

BMPs/ UTPs are survey targets securely affixed to the structure. Survey stickers, masonry nails, or equivalent means may also be considered, including the possibility of using an existing feature on the structure that may serve the required purpose. Target points must be resilient and durable, such that they are functional throughout the entire monitoring period. In the event that a target point must be replaced due to weather, attachment failure, or human (public) action, it must be replaced (including baseline readings) immediately upon detection and prior to the next scheduled reading. An example target point is shown in Figure 5-1.

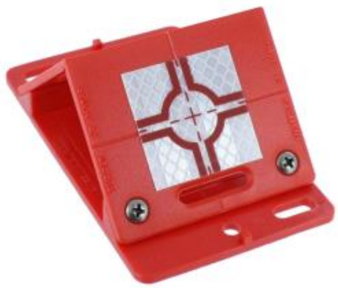

Figure 5-1 - Typical BMP/UTP.

5.2 Monitoring Requirements

5.2.1 Stop Work Criteria

Two action levels are assigned to each group of instruments based upon the allowable movements. The allowable limits shall be dependent upon the structure or utility to be monitored:

1. **Review Level**: If this level is reached, construction activities may continue, and the data shall be assessed by the Geotechnical EOR (or their designate). Additional monitoring may be required as determined by the Geotechnical EOR. Review levels are subject to stakeholder approvals.
2. **Alert Level**: If this threshold is reached, all construction activities must be suspended immediately in the affected area with the exception of those actions necessary to avoid exceeding the Alert Level or to make the work and affected properties safe. The monitoring data shall be reviewed and approved by the Geotechnical EOR prior to re-initiating construction activities. Any mitigation methods must be approved by the Geotechnical EOR prior to the resumption of work. Alert levels are subject to stakeholder approvals.

The Review and Alert Levels are set low, this is to allow the Geotechnical EOR to perform an analysis to give an activity specific response, before the threshold limits can cause notable damage to EAS. If movement is deemed to exceed tolerable levels, inspection by qualified personnel shall be completed prior to resuming construction.

5.2.2 Vibration

Vibration shall be monitored during construction activities. The vibration limits summarized in Table 5-1 modified from USBM (1989) outline the maximum peak particle velocities that are acceptable to structures and pipelines. Note that these guidelines were devised for blasting operations, but they are still applicable for preventing damage to EAS by limiting induced vibration. The closest EAS to the source of vibration should be monitored preferentially and the data from that monitoring can be extrapolated to determine the impact on further EAS.

Table 5-1 Limiting peak particle velocity values for structures and pipelines (USBM)

Element	Frequency (Hz)	PPV (mm/s)
Structures and Pipelines	≤ 40	20
	>40	50

The vibration monitoring will allow an actual recording of the vibration at the EAS locations and thus an appropriate reassessment can occur. It is recommended that vibration should be monitored at EAS. If any vibration at the EAS reaches 75% of the limiting value (i.e. 15 mm/s for structures at a frequency ≤ 40Hz) an alarm should be initiated, and the construction procedures should be reassessed. If the monitoring at the EAS is not possible, monitoring should be done within 7.5 m from the source.

It is assumed that excavation activities produce vibration frequencies of less than 40 Hz. For vibro-compaction activities, the research by Hamidi et al. (2011), shows that the vibration frequency for the studied vibro-compaction equipment measured up to 53 Hz and the PPV varies based on the power of the vibro-compaction equipment. Given the plots from Hamidi et al. (2011), 120 kW vibro-compaction equipment results in a PPV of 20 mm/s at approximately 7.5 m from the source of vibration. The magnitude and frequency of the vibro-compaction equipment used shall be measured prior to compacting within 10 m of any EAS. Once the magnitude and frequency of the vibrations produced by the vibro-compaction equipment is known, the limit of approach to the EAS may be relaxed by the Geotechnical EOR.

Vibration shall be measured on the rigid elements of foundations, structures, pipes, equipment or in the immediate vicinity of these elements, in three orthogonal axes (transverse, longitudinal, vertical). For linear structures such as walls and pipes, the vibration must be measured at the point closest to the work and the measuring point must be moved to follow the progress of the work. The measuring equipment must be autonomous, thus being able to operate continuously with or without operator supervision.

5.2.3 Monitoring Frequency and Thresholds

Monitoring frequency and thresholds for each instrument type can be found in Table 5-2 below.

Table 5-2 Monitoring Frequency and Thresholds

Instrumentation	Threshold	Monitoring Frequency
Building Monitoring Point (BMP)	Vertical Displacement: Review - 5 mm Alert - 10 mm	During construction: -Daily when construction activities within 30 m of instrument.
Vibration Monitoring Point (VMP)	Vertical Displacement: Review - 10 mm/s (for ≤ 40Hz) Alert - 15 mm/s (for ≤ 40Hz)	During construction: -Continuous real-time monitoring

5.2.4 Instrumentation Quantities

Appendix I shows instrumentation installation locations based on available data and assumptions. The location and number of monitoring points is subject to change with additional information or field conditions. Consultation with each EAS owner is required prior to finalizing the monitoring plan. Changes to the monitoring plan may occur based upon consultation with the EAS owner.

Table 5-3 Instrumentation Quantities

Instrumentation	Quantity of Instruments	Schedule for Installation	Schedule for Removal
Building Monitoring Point (BMP)	5	Installed at a minimum 48 hours prior to start of construction. Baseline readings to be completed before start of construction	Instruments can be removed at a minimum of 48 hours after the completion of construction within the ZOI The Geotechnical EOR or their designate may review the monitoring data and provide an alternate schedule for removal.
Vibration Monitoring Point (VMP)	2	Installed at a minimum 48 hours prior to start of construction. Baseline readings to be completed before start of construction	Instruments can be removed at a minimum of 48 hours after the completion of construction within the ZOI The Geotechnical EOR or their designate may review the monitoring data and provide an alternate schedule for removal.

6 Closure

This document was prepared with information and documents available and assumptions made based on that information. Any deviation from the conditions identified in the Level 1 CIAR or GIMP may result in the modification of the instrumentation type, number of instruments, and/ or the frequency of readings.

If deemed necessary, the CIAR & GIMP can be reassessed and further developed to match the expected site conditions as the Contractor's means and methods are better understood. Detailed analysis of the temporary support system and a detailed vibration assessment can be provided as the plans are developed, if deemed necessary. Additional plans for instrumentation recommendations, survey requirements, monitoring reporting requirements, and decommissioning can also be provided.

The Level 1 CIAR analysis is a method of screening to predict potential settlement and associated damage to buildings. The analysis is cost and time efficient as it employs empirical and semi-empirical methods to predict settlement as well as the resulting damage to buildings. A Level 2 CIAR analysis utilizes finite element software, such as PLAXIS, which is capable of modelling complex soil interactions. The Level 2 CIAR analysis requires more time, resources, and information to conduct, but is able to predict settlement much more accurately and precisely than the empirical methods utilized by the Level 1 CIAR in this report.

Due to limitations of the analysis methods used in the Level 1 CIAR assessment, EAS of concern should be further reviewed through a Level 2 CIAR assessment before an accurate assessment of damage can be made. The identified EAS should be monitored during construction.

7 References

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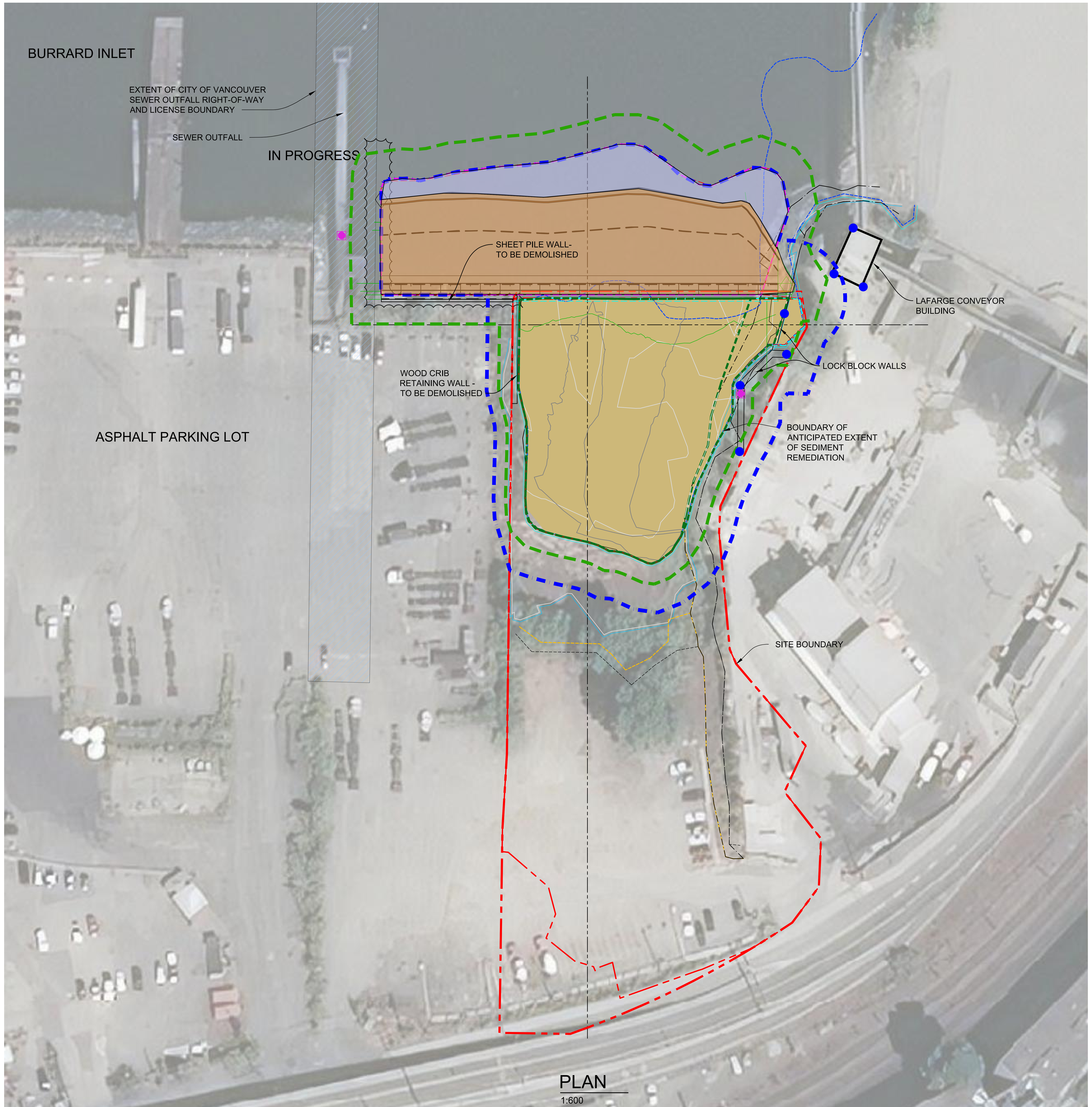
Appendix I

Site Plan and Instrumentation



LEGEND:

DREDGING AREA
BERM
EXCAVATION AREA
SITE BOUNDARY
LOT BOUNDARY
FENCE
CONTAMINATION AREA
INTERTIDAL AREA
PROPOSED EXCAVATION LIMITS
ZONE OF INFLUENCE (ZOI) - FILL PLACEMENT
ZONE OF INFLUENCE (ZOI) - EXCAVATION
BUILDING MONITORING POINT (BMP)
VIBRATING MONITORING POINT (VMP)

TYPE	QUANTITY	MONITORING FREQUENCY
BMP	7	DURING CONSTRUCTION: - DAILY WHEN CONSTRUCTION ACTIVITIES WITHIN 30 METRES OF INSTRUMENT
VMP	2	DURING CONSTRUCTION: - REAL TIME MONITORING

NOTES:

1. 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

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DATE: 2021/06/28 - 2:48pm
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Ref. No.	REFERENCE

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No.	Date	REVISION	Dr'n	Ch'd
PB	2021-JUN-24	ISSUED FOR REVIEW	PB	DS
PA	2021-JUN-01	ISSUED FOR REVIEW	PB	DS

PORT of vancouver
VANCOUVER FRASER PORT AUTHORITY
ENGINEERING DEPARTMENT

DESIGN BY	D. SAYESE
DRAWN BY	P. BIRNIE
APPROVED	-
DATE	2021-JUN-24
SCALE	1:600
VFPA SITE	VAN 070

STERLING SHIPYARD REMEDIATON & INFILL
GIMP & CIAR SITE PLAN

SIZE	DWG.	SHEET	REV.
D	20-191-GT-FIGURE 1	1 of 1	PA

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