Vibration Technical Data Report

October 30, 2019

Prepared for:

Broadway Subway Project
Ministry of Transportation and Infrastructure

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Executive Summary

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (the Project), to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). The scope of the Project includes a 5.7 km tunneled alignment (the Alignment), with six stations, running between the existing VCC-Clark Station and the western terminus at Arbutus Street and Broadway.

In order to support Project planning and procurement, MOTI has undertaken studies to estimate the anticipated ground vibrations during construction and operation at nearby structures close to the Alignment. This Technical Data Report (TDR) presents information including:

- A preliminary estimate of the zone of influence of potential impacts; this is done by comparing estimated vibration levels against typically acceptable levels for buildings and occupants, residents, and special buildings such as those that may contain sensitive medical equipment, and historic buildings along the Alignment. A property survey was not conducted for this report and actual building use and history may differ from that assumed.
- A review of Canadian and international literature on the theory of ground-borne vibrations induced by tunneling and other equipment; measured vibration levels for different types of tunnel boring machines; criteria for assessing vibration levels; and predictive methods.
- An analysis of ground vibration levels for representative mechanized construction equipment operating within the rock type and soil overburden expected for the Project.
- The application of data acquired from the vibration baseline monitoring program (see Appendix A), used for estimating soil and rock attenuation patterns and the sensitivity impacts for ambient background vibrations.
- Geotechnical information including parameters and elevations of soil and rock parameters relative to tunnel, station, and elevated guideway provided in the Golder Geotechnical Characterization Report (2018).

Estimation of ground vibration levels are presented in the form of peak particle velocity (PPV), at distance from the vibration emissions source. PPV is the instantaneous maximum peak vibration (amplitude) of a velocity curve and is commonly evaluated against the frequency of the vibration.

The principal findings arising from the analysis are as follows:

- Baseline monitoring locations represent sensitive receptors at each location. Baseline monitoring values are consistent with an urban environment with roadway traffic, pedestrian foot traffic, rail traffic, construction activities and mechanical equipment within buildings.
- Nine of the 18 baseline vibration monitoring locations are considered highly sensitive locations. These locations experienced baseline vibration levels between 0.071 mm/s to 0.619 mm/s, coinciding with FTA interpretations for sensitive locations with medium to high power optical machines starting to be affected.

- Baseline vibration levels measured across the Project site are often greater than the thresholds for disturbance to building occupants and sensitive equipment/operations. Therefore, construction-induced vibrations would not result in disturbance in many locations where induced vibration is lower than pre-existing baseline vibration levels.
- Most of the tunnel portion of the Alignment will occur in rock, which can attenuate vibration energy less than soil. Sandstone and shale have been identified in preliminary geotechnical studies, as the bedrock types occurring along most of the Alignment. These rock types will attenuate vibration energy more than harder bedrock types, such as granite.
- Soils, including marine fine-grained soils, glacial till, and mixed-face (soil and rock) conditions are anticipated to occur at several locations, including Broadway between Maple Street and Cypress Street, and the western end of the Alignment near Arbutus Street. Vibration from excavation in these areas is anticipated to be greater than locations where excavation is in solid rock.
- Pile driving activities, although not currently anticipated to be required, have potential to generate the greatest ground-borne vibrations compared to other construction methods considered in this report that may be used during underground station excavation. This assumes controlled blasting would not be part of the Project construction methods.
- Project-related vibration may affect buildings, sensitive equipment, residential and commercial properties during construction and operation. The greatest potential for effects are anticipated during station excavations depending on the construction methodology used, among other factors.
- Tunnel excavation and operational vibration may impact human perception and highly sensitive equipment
- Vibration levels generally dissipate (attenuate) within the ground surface and the effects felt by construction or operational vibration is reduced with an increased distance from the vibration source.

Abbreviations

BC	British Columbia
FTA	Federal Transit Administration
LRT	Light Rapid Transit
LFV	Lower Fraser Valley
m	Metres
mm/s	millimetres/second
PPV	Peak Particle Velocity
OMF	Operations and Maintenance Facility
TOR	Terms of Reference
TBM	Tunnel-boring machine
Vrms	Root Mean Square Velocity

1.0 INTRODUCTION

The Ministry of Transportation and Infrastructure (MOTI) is undertaking the development of the Broadway Subway Project (the Project), to meet current and future ridership demands along the Broadway Corridor in Vancouver, British Columbia (BC). The scope of the Project includes a 5.7 km tunnelled alignment, with six stations, running between the existing VCC-Clark Station and a western terminus at Arbutus and Broadway.

This Technical Data Report (TDR) provides information on the vibration analysis undertaken for the Project, including:

- Discussion of potential issues related to Project-induced ground vibration
- Characterization of project-specific vibration baseline monitored data, available codes, standards, and guidelines, as well as literature related to ground vibrations induced during tunneling and station construction and operation.
- Description of the vibration analysis study and the potential for vibration induced by construction and operation activities along the transit corridor by estimating a zone of influence, which is the distance from a vibration source in which vibration effects may be experienced. Ultimately, the Contractor will be responsible for determining the vibration zone of influence based on the Contractor's chosen means and methods.

This study estimates potential vibration levels on specific sensitive receptors within the Review Area and provides general vibration estimates for the entire Alignment. Information will be used to support the assessment of potential effects on the Vibration Review Element as part of the Environmental and Socio-Economic Review being completed for the Project.

The analysis presented in this TDR reflects the reference concept, including the locations of stations and headhouses, available in 2017 when vibration modeling were undertaken.

2.0 REVIEW AREA

2.1 REGIONAL SETTING

The Review Area is within Vancouver, British Columbia (BC), and extends along the Project alignment (the Alignment), from VCC-Clark Station, near Clark Street and Great Northern Way, to the intersection of Arbutus Street and West Broadway Avenue (Figure 1). The Review Area is located within a substantially urbanized part of Vancouver, which includes residential neighborhoods, commercial, institutional, and industrial areas, major roadways, and a rail line.

Figure 1 **Broadway Subway Project Alignment**

2.2 PHYSICAL SETTING

The soil and bedrock underlying the Project Review Area were classified for the purpose of ground vibration using Federal Highway Administration Transit Noise and Vibration Impact Assessment Manual (2006). The ground types found in the Review Area are classified as follows:

- Primarily glacial till, with conglomerate and sub-stratified glacial drift
- Bedrock, including sandstone and mudrocks. Mudrocks contain claystone, mudstone, and siltstone.

Competent bedrock is anticipated to be encountered along the majority of the Alignment.

The distribution of soil types within the Review Area was obtained through the Draft Geotechnical Characterization (April 2018)—Procurement Readiness Stage (Stantec 2018a). This information was used to categorize the different soil and rock types as well as the mixed-face conditions and to assign vibration attenuation parameters.

2.3 VIBRATION-SENSITIVE RECEPTORS

This study analyzes potential vibration effects on specific sensitive receptors within the Review Area and provides general vibration estimates for the Alignment. With regards to potential effects from Project vibration, some specific areas of interest near the Alignment include the residential, institutional, and commercial buildings located near to proposed station construction sites, medical facilities in and around Vancouver General Hospital, and historical buildings located on Broadway.

Eighteen sites considered representative of receptor types along the Alignment were selected for baseline vibration monitoring, in consideration of input from several stakeholder groups(Table 1). Appendix A provides additional information on baseline vibration monitoring and the anticipated zone of influence.

Table 1 Vibration Monitoring Locations

Location ID	Location (Main Intersections)	Setting Description
1B	Foley Street and Finning Way	Open space surrounded by medium density residential, haul truck parking, high density office space and active railway.
3B	Thornton Way and Great Northern Way	Medium density residential area adjacent to a school and mixed office and commercial use.
5A	Cambie Street and West Broadway Avenue	Medium to high density residential area mixed with dense commercial and office space along a major traffic roadway.
5B	Main Street and West Broadway Avenue	High density commercial and office area at a major traffic intersection.
7A	W 10 Avenue and Heather Street	Empty lot surrounded by low to high density office space.
7B	675 W 10 Avenue	Basement of BC Cancer Agency Building
8A	W 11 Avenue between Willow Street and Oak Street	Medium density residential area mixed with high density office buildings. Medical precinct.
8B	W 11 Avenue between Willow Street and Oak Street	Inside MRI Area of Centennial Pavilion
10B	West Broadway Avenue and Oak Street	High density residential mixed with high density commercial and office space along a major traffic roadway.
11A	W 11 Avenue between Heather Street and Oak Street	High density commercial and office space along a major traffic roadway.
14A	West Broadway Avenue and Cypress Street	High density commercial and office space along a major traffic roadway.
15A	West Broadway Avenue and Arbutus Street	Medium density residential mixed with two schools and commercial space.
16A	Oak Street between 10 Avenue and 12 Avenue	Inside basement of Jack Bell Research Centre
16B	Oak Street between 10 Avenue and 12 Avenue	Outside of Jack Bell Research Centre
17	675 West 10th Ave	BC Cancer Research Centre
18	600 West 10th Ave	BC Cancer Agency

Table 1 Vibration Monitoring Locations

Location ID	Location (Main Intersections)	Setting Description
19A	520 East 1st Ave	Emily Carr University of Art and Design theatre and lecture hall
19B	520 East 1st Ave	Emily Carr University of Art and Design motion capture studio

3.0 BACKGROUND

3.1 BASIC PRINCIPLES OF VIBRATION

Construction and operation of the Project will generate vibrations. These vibrations will be transmitted radially through soil and bedrock towards nearby buildings and infrastructure. Vibration is an oscillatory motion described in terms of displacement, velocity, and acceleration. Because the motion is oscillatory, there is no net movement of the ground itself.

Vibration waves propagate through bedrock and soil to the foundations of buildings. The vibration excites the building, propagating from the foundation throughout the remainder of the structure. The extent by which vibration is propagated through the ground depends on the characteristics of the rock and soil. Building vibration will also vary depending on the type of structure and its resonance frequency[1].

Ground-based vibration effects include noticeable movement of building floors, shaking of items on shelves, rattling of windows, disturbance to sensitive equipment such as certain electronics or vibration sensitive equipment that is not adequately dampened, and potentially audible noise. In most cases, construction or operation of a transit project will not cause damage to structures, and the main concern of these projects is annoyance of the building occupants.

Vibrations are most commonly felt when occupants are inactive, or in a horizontal position (e.g., when lying in bed). Generally, as human activity increases, it becomes more difficult to detect oscillatory movements, however the ability to perceive vibration varies by individual.

3.2 SOURCES OF VIBRATION

Sources of vibration included in this analysis are station construction, tunnel boring machine (TBM) tunneling, elevated guideway construction, and train operations.

[1] Resonance Frequency: When a vibrating system or external force acts on another system to oscillate with greater amplitude at specific frequencies.

The greatest sources of vibration from station works are expected to be from station excavation because this will involve breaking apart rock, as well as well as driving or drilling shoring through soil and rock. The construction of the station structure may also cause vibration, but these activities are not expected to produce as much vibration as excavation activities and are therefore not considered further in this report.

Sources of TBM vibration may include vibrations from the trains that are used to haul tunnel segments, personnel, and excavated material between the TBM and the tunnel portal; the erection of tunnel segments; and vibration from the TBM cutter face.

Vibration is also expected from elevated guideway construction. The main source of vibration during elevated guideway construction is expected to come from drilling and excavating of the foundations for the columns supporting the elevated guideway structure. Construction of the elevated guideway structure and columns may also cause vibration, but vibrations associated with these activities are not included in this report as vibration from foundation drilling and excavation is expected to be greater.

Once operational, there is the potential for the trains to cause vibration as they roll along the tracks. This vibration can be transmitted from the tracks, through the tunnel or elevated guideway structure, and into the surrounding ground. Operational vibrations will depend on the final details of the trackwork and track fixation, braking, acceleration, velocity, parameters of train operation as well as the construction of any dampening devices track slabs, curves in the track alignment, and other facilities or structures constructed within the tunnel cross-section.

3.3 PROJECT DESIGN ASSUMPTIONS

The assessment of estimated ground vibration is based on the following assumed design characteristics of the Project:

- Twin bore tunnel design, of approximately 6 km long, with each tunnel having an approximate outside diameter of 5.7 m and a minimum inside diameter of 5.2 m
- Tunnels are oriented side-by side
- Each tunnel would have one level with train cars; trains will travel on rails set approximately 1.2 m above the invert of the tunnel
- Tunnels will be excavated through bedrock and soil, with rock cover and overall overburden depth varying across the Alignment.

3.4 INDICATORS

Table 2 provides a description of the vibration-related measurement units. To evaluate human response and long-term effects on structures, an average of PPVs is determined by estimating the root-mean-square (RMS). RMS velocity (Vrms) measures are positive values representing the average maximum velocities over a specified period. Both PPV and Vrms values are expressed in mm/s.

Table 2: Description of Vibration Terms

Indicator	Unit	Description
Crest Factor		Ratio between PPV and Vrms. Used by the Federal Transit Administration (FTA) as a conversion factor.
Peak particle velocity (PPV)	mm/s	Peak Particle Velocity indicates the maximum speed particles travel resulting from an event's ground vibrations
Root-mean-square (RMS)		The smoothed vibration amplitude using a time-averaged value containing the square root of amplitude of the vibration, typically calculated of a one-second period.
Root Mean Square Velocity (Vrms)	mm/s	The smoothed vibration velocity using a time-averaged value containing the square root of velocity of the signal typically calculated over a one-second period. Generally, only considers the vertical peak particle velocity component because it generally has the greatest amplitude. Typically used to compare human response to vibration.
Zero Crossing Frequency (ZC)	Hz	A method used to calculate vibration by using the time between the largest peak of the waveform to the next largest peak of the waveform over fractions of a second.
Vibration decibels (VdB)	mm/s	Measurement unit of ground-borne noise generated by vibration. Ten times the common logarithm of the ratio of the square of the amplitude of the RMS vibration velocity to the square of the amplitude of the reference RMS vibration velocity.

The frequency is measured as zero crossing (ZC) measured in units of Hertz (Hz). According to the Federal Transit Authority (FTA, 2006), the threshold value of PPV for human perception is 0.018 mm/s. At 0.56 mm/s, individuals typically begin to definitively detect vibration, and at 1.8 mm/s vibratory tolerance is only considered acceptable if experienced infrequently or for short periods of time.

Vibration levels are measured using transducers equipped with three geophones, which measure ground velocity and frequency for each of the transverse, vertical, longitudinal axes. The peak particle velocity (PPV) is the maximum vibration velocity in each measurement interval, measured in units of millimetres per second (mm/s). It is typically used to monitor vibration from blasting vibration as a measure of stress experienced by structures.

Construction equipment vibration references typically provide estimated PPVs for selected pieces of equipment. During construction the equipment used to measure vibration is provided in the unit of measure using PPV. However, thresholds for disturbance to building occupants and interference with equipment are typically provided in terms of V_{rms}. Therefore, a crest factor is used to provide a conversion or ratio between PPV and V_{rms} and is used by the Federal Transit Administration. This report uses a crest factor of 4, based on Federal Transit Administration methodology, to compare estimated PPVs to thresholds in $V_{rms.}$ The following relationship exists for conversion:

$$\mathrm{PPV} = 4 * \mathrm{V_{rms}} \qquad \text{(Equation 1)}$$

Where the crest factor is defined as the ratio of the peak value of a waveform to the V_{rms} (FTA 2006).

3.5 VIBRATION THRESHOLDS

Vibration thresholds used for this study are provided in Table 3. These include thresholds for damage to various building types and sensitive structures, and thresholds for disturbance to different building occupancy types. Thresholds defined in Table 3 are based on guidelines in the U.S. Department of Transportation, Federal Transit Administration (FTA), *Transit Noise and Vibration Impact Assessment* (FTA 2006). Additional descriptions for these damage thresholds can be found in the Caltrans Transportation and Construction Vibration Guidance Manual (2013).

The selected thresholds are considered appropriate for the various building and occupancy types that may be encountered along the Alignment. Thresholds are based upon the sensitivity of structures, equipment located within a building, and building occupation. The lowest thresholds considered in this report are appropriate for a general assessment of sensitive buildings with equipment that is sensitive to vibrations such as hospitals, research centres, and university research operations.

Table 3: Damage and Disturbance Thresholds for Vibration

Threshold	Description	PPV (mm/s)	V_{rms} (mm/s)
Damage to reinforced-concrete streel or timber (no plaster)	Cosmetic or structural damage. Cosmetic damage can be expected at PPVs of 12.7 mm/s with increasing risk of structural damage at higher PPVs.	>12.7	>3.18*
Damage to engineered concrete and masonry (no plaster)	Cosmetic or structural damage. Cosmetic damage can be expected at PPVs of 7.6 mm/s with increasing risk of structural damage at higher PPVs.	>7.6	>1.91*
Damage to non-engineered timber and masonry building	Cosmetic or structural damage. Cosmetic damage can be expected at PPVs of 5.1 mm/s with increasing risk of structural damage at higher PPVs.	>5.1	>1.27*
Damage to buildings extremely susceptible to vibration damage	Cosmetic or structural damage. Cosmetic damage can be expected at PPVs of 3 mm/s with increasing risk of structural damage at higher PPVs.	>3	>0.76*
Disturbance at residences during daytime	This category includes residences that do not have vibration-sensitive equipment, but still have the potential for activity interference	>0.80*	>0.20

Table 3: Damage and Disturbance Thresholds for Vibration

Threshold	Description	PPV (mm/s)	V_{rms} (mm/s)
Disturbance at institutional land uses with primary daytime use	This category includes schools, churches, other institutions, and quiet offices that do not have vibration-sensitive equipment, but still have the potential for activity interference	>0.57*	>0.14
Disturbance at residences and buildings where people normally sleep	This category covers all residential land uses and any buildings where people sleep, such as hotels and hospitals	>0.40*	>0.10
Disturbance at buildings where vibration would interfere with interior operations	Included in this category are sensitive buildings where vibration would interfere with operations within the building, including levels that may be well below those associated with human annoyance. Typical land uses covered by this category are: vibration-sensitive research and manufacturing, hospitals with vibration-sensitive equipment, and university research operations	>0.18*	>0.05
Disturbance at buildings where vibration would interfere with high power microscopes and measuring devices	Included in this category are sensitive buildings with high power optical (1000x) microscopes and 3 microns measuring devices	>0.10*	>0.03

NOTES:
- * Estimated assuming a crest factor of 4
- \- Actual vibration levels to cause disturbance may be higher than the thresholds in this table, as baseline vibration levels are often higher than the disturbance thresholds considered here.

Human perception of vibration is subject to sensitivity of the individual whereas specialized equipment, such as an electron microscope, has a much lower tolerance to vibration. Highly sensitive equipment may also have its own vibration dampening systems, so case-by-case investigation may be important in these cases. The tolerance of structures (e.g., foundations, building elements) to withstand vibration is primarily dependent on design and construction as well as the type of vibration (e.g., transient or continuous).

4.0 EXISTING VIBRATION LEVEL

4.1 SCOPE

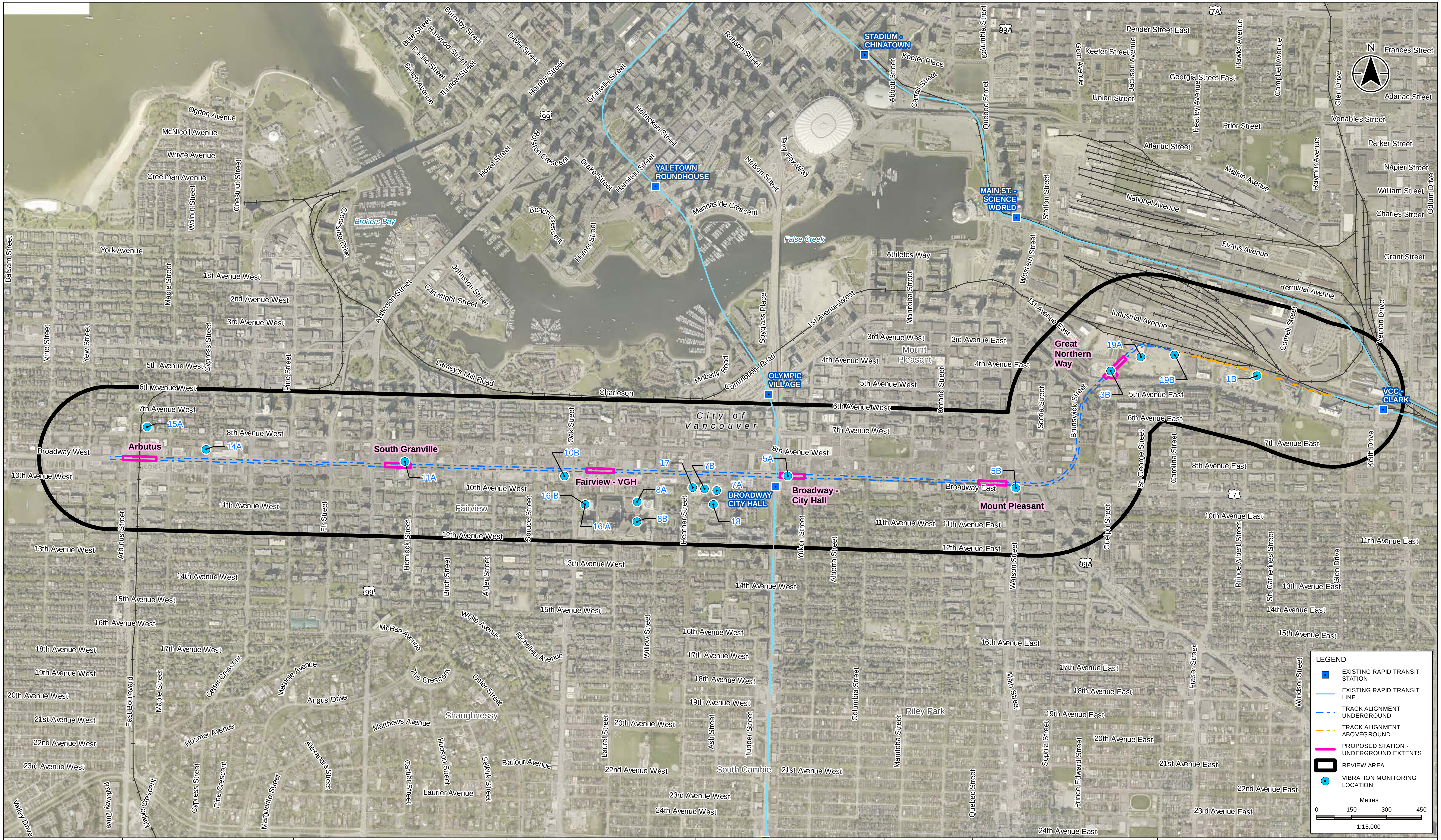
A noise and vibration monitoring program was undertaken in August and September 2017, and March 2018, to characterize existing vibration levels for representative sensitive receptors along the Alignment. The results of this monitoring program represent the existing vibration levels for the Review Area. Additional details of the monitoring program can be found in Appendix A.

4.2 METHODS

The analysis of vibration effects compares vibration levels at receptor locations against established interpretations of effects. It is extremely difficult to differentiate baseline from construction vibrations. Therefore, an understanding of baseline vibration values is important because this informs the selection of appropriate threshold values at receptor locations.

Baseline vibration monitoring was undertaken at 18 key receptor locations along the Alignment. Table 1 lists the vibration monitoring locations and provides a description of the setting observed during each monitoring period. The locations are shown in Figure 2 relative to the Alignment and the six proposed station locations.

Baseline vibration monitoring was completed using an Instantel Blastmate III vibration monitor equipped with Instantel Micromate instrumentation with geophones placed on concrete or asphalt surfaces or placed within shallow excavated subgrade soil. The Blastmate III and Micromate use a standard transducer equipped with three geophones to measure ground vibration for each of the transverse, vertical and, longitudinal axes. The instruments calculate the PPV, ZC Frequency, Peak Acceleration, and Peak Displacement for each of the transverse, vertical, and longitudinal axes.



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DRAWN	MK	18-04-01 DATE
CHECKED	INIT	YY-MM-DD DATE
APPROVAL	INIT	YY-MM-DD DATE

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Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

BASELINE VIBRATION MONITORING LOCATIONS

SCALE	1:15,000	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE	18-04-01			
SHEET NO.			FIGURE 1	A

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4.3 BASELINE VIBRATION VALUES

Table 4 summarizes baseline vibration monitoring results and provides a brief description of the vibration monitoring characteristics at each location. The monitoring results indicate that the vibration environment at monitored locations is typical of a busy urban environment. Baseline vibration data were predominately influenced by road traffic (i.e., passenger vehicles, buses, commercial trucks), localized construction activities (i.e., roadway/service line upgrades and neighboring building construction), and pedestrian traffic. The maximum recorded PPVs for each geophone in the transverse, vertical, and longitudinal axis (0.071 to 0.905 mm/s) at the 18 locations were measured to be typical for occupied residences (PPVs between 0.4 to 0.8 mm/s) as per the FTA (2006) interpretations.

Baseline vibration monitoring included nine sensitive locations near the Alignment: Locations 8A and 8B (Jack Bell Research Centre); 16A and 16B (BC Cancer Agency); 18 (BC Cancer Research);17 and 18; and 19A and 19B (Emily Carr University) near the Alignment. Maximum PPVs recorded at these locations ranged between 0.071 to 0.619 mm/s PPV.

Table 4 Baseline Vibration Monitoring Results

Location ID	Maximum Measured Ground Vibration				Characteristics of Baseline Vibration	Approximate Distance to the Closest Center Line of Alignment (m)
	Peak Particle Velocity (PPV)			Peak Vector Sum (PVS)		
	Transverse (mm/s)	Vertical (mm/s)	Longitudinal (mm/s)	(mm/s)		
1B	0.307	0.631	0.244	0.633	Road traffic, rail traffic, use of haul truck parking lot traffic.	12
3B	0.413	0.413	0.476	0.753	Road traffic, rail traffic, construction activities	3
5A	0.087	0.110	0.071	0.110	Busy road traffic, buses, truck parking nearby.	6
5B	0.441	0.709	0.504	0.780	Busy road traffic, use of public parking lot and pedestrians.	12
7A	0.166	0.166	0.134	0.212	Road traffic.	65
7B	0.087	0.126	0.071	0.129	Road traffic, facility mechanical equipment	60
8A	0.317	0.492	0.619	0.623	Road traffic and pedestrian traffic.	123
8B	0.087	0.110	0.221	0.230	Facility parking lot, facility mechanical equipment within mechanical room.	209
10B	0.111	0.492	0.095	0.493	Busy road traffic, and daytime construction activities.	21
11A	0.159	0.270	0.286	0.297	Busy road traffic, daytime construction activities.	11
14A	0.302	0.619	0.317	0.623	Road traffic, facility mechanical equipment within mechanical room.	41
15A	0.556	0.905	0.286	0.964	Road traffic, some construction activities, school activities, and pedestrians.	131
16A	0.087	0.142	0.071	0.144	Road traffic, electrical equipment within electrical room.	141
16B	0.460	0.317	0.381	0.480	Road traffic and pedestrian traffic.	141
17	0.111	0.190	0.0952	0.197	Pedestrian traffic inside building	56
18	0.0952	0.0952	0.0794	0.112	Pedestrian traffic inside building	126
19A	0.111	0.413	0.0952	0.415	Pedestrian traffic inside building	37
19B	0.111	0.159	0.0952	0.166	Pedestrian traffic inside building	15

5.0 VIBRATION ANALYSIS

An analysis was undertaken to estimate vibration levels for Project construction and operation activities. This section outlines the methodology for estimating vibration levels for various Project activities.

5.1 TUNNEL EXCAVATION VIBRATION ANALYSIS METHOD

Tunnel Boring Machine vibration in rock along the Alignment was estimated based on methodology outlined in "Ground Borne Vibration on the East Side Access Project Manhattan Segment: Issues and Impacts" (Benslimane et al 2005). In that paper, vibration caused by TBMs in rock is estimated as a function of distance from the tunnel face to receptor location. The equation presented below is based on the mean level curve fit to the historical vibration data for three tunnel projects in hard rock which results in the following equation.

$$\mathrm{PPV} = 11.25\ (\mathrm{D})^{-1.4} \qquad \text{(Equation 2)}$$

The formula presents PPV as the peak particle velocity in inches per second and D is the distance in feet from the tunnel face to the site of interest. Although Equation 2 above is based on average vibrations from hard rock TBM tunneling, the equation was assumed to be sufficient for the softer rock expected along the Alignment. Review of other sources (Hiller 2011) also suggests that Equation 2 is an appropriate estimate for vibrations from TBMs mining entirely in soft rock. Vibrations estimated for tunneling in rock are for vibrations propagating from the TBM to the bedrock surface, assuming building foundations are founded on the bedrock surface.

For TBM tunneling in soil, an equation was developed specifically for excavations in soil containing cobbles and boulder used to represent glacial till soil parameters anticipated for the tunnel alignment. Based on a review of case histories where vibrations were measured, analyzed, and published (Hiller 2011), the following equation (equation 3) was developed and is used for this vibration analysis:

$$\mathrm{PPV} = 7.5\ (\mathrm{D})^{-1.3} \qquad \text{(Equation 3)}$$

In some reaches of the tunnel, rock and soil may be excavated simultaneously, which is known as "mixed-face tunneling". For reaches of the tunnel that will be in mixed-face conditions, a conservative approach of applying Equation 2 for rock is used.

For TBM tunneling vibration, the distance provided in equations 2 and 3 are measured from the tunnel face. A plan view contour map is provided in Appendix B. For a given threshold, the distance around the excavated tunnel diameter, over which a given threshold could be exceeded, was projected to the bedrock surface assuming that building foundations (e.g., the closest receptor) are founded on bedrock, as illustrated in Figure 3. Building foundations may, however, be founded above bedrock surface or deeper than the bedrock surface. For the purpose of this analysis the bedrock surface is assumed to be 3.1 m above the crown of the tunnel. Estimated vibration contours from train operations in underground sections are projected radially from the tunnel and were analyzed in the same manner.

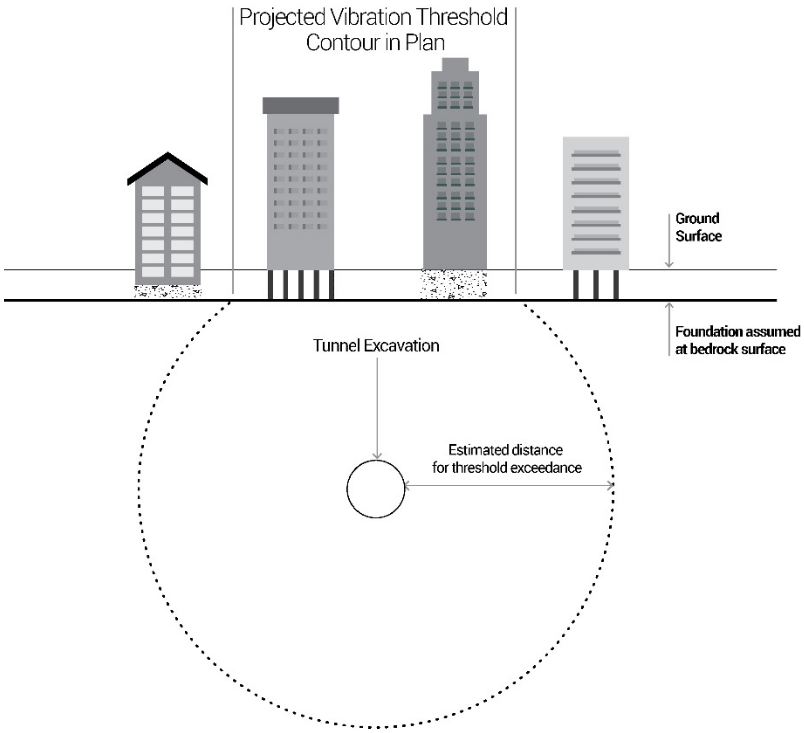

Figure 3 Tunnel Excavation Surface Contour Projection

Table 5 shows the approximate locations along the tunnel alignment where rock, soil or a mixed-face condition is used in the vibration assessment. The bedrock, soil and mixed-face conditions are developed from the Geotechnical Characterization Report (Golder, 2018).

Table 5 Soil and Rock Conditions for Tunnel Alignment

Location	Description	Approximate Length (m)	Equation to estimate PPV
End of tunnel beyond Arbutus Street and West Broadway to West Broadway between Maple Street and Cypress Street.	Mixed Face Tunnel—Primarily Glacial Till, Mudrocks and Sandstone with Conglomerate and sub-stratified Glacial Drift	320	Equation 2
West Broadway between Maple Street and Cypress Street to Burrard Street	Soils—Primarily Glacial Till with sub-stratified Glacial Drift	260	Equation 3
Near West Broadway Burrard Street Intersection	Mixed Face—Glacial till and Sandstone	40	Equation 2
West Broadway Burrard Street to Great Northern Way	Bedrock—Sandstone and Mudrocks (Claystone, Mudstone and Siltstone)	4,020	Equation 2

NOTES:
Actual soil and rock conditions may vary from the Geotechnical Characterization Report.
Geotechnical information provided by Golder Associates in the Draft Geotechnical Characterization Report dated April 20, 2018.
Geotechnical information in this table covers only tunnelled portions of the Alignment.

5.2 Station Excavation and Elevated Guideway Foundation Construction Vibration Analysis Method

The nature and magnitude of vibrations occurring during station excavation and elevated guideway foundation construction will depend on the methods used by contractors. Since the exact construction methodology is not known, several different shoring, foundation and excavation methods were considered to develop conceptual level vibration contours. The equipment considered includes impact pile drivers, sonic pile drivers, caisson drilling, rock hydromills, and hydraulic breakers, but does not represent an exhaustive list of equipment that could be used for construction activities. It should be noted that while most of the equipment listed can apply to either station excavation and elevated guideway foundation construction, use of hydromills are specific to station excavation.

The vibration levels from the various pieces of equipment listed are based on methodology outlined in the Federal Transit Administration (FTA) Noise and Vibration Impact Assessment (2006) and the CalTrans Transportation and Construction Vibration Guidance Manual (September 2013). Equation 4, based on FTA (2006) and CalTrans (2013), was used to estimate vibrations from a PPV at a reference distance of 25 ft.

$$\mathrm{PPV_{equip}} = \mathrm{PPV_{ref}}\ \mathrm{x}\ (25/\mathrm{D})^{\mathrm{n}} \qquad \text{(Equation 4)}$$

where PPV_{ref} is the reference vibration level in inches per second at 25 feet, D is the distance in feet from the equipment to the receiver, and n is a constant based on soil type. PPV_{ref} values for various equipment can be found in FTA (2006) and CalTrans (2013). An "n" value of 1.1 is assumed based on conservative recommendations in the CalTrans (2006), although the n value can range from 1.0 to 1.5 based on soil and rock characteristics.

For station excavation, elevated guideway construction, and train operation on the elevated guideway, the source of vibration was assumed to be at the ground surface with vibrations spreading laterally to the nearest point of a given receptor at the ground surface. Therefore, no additional adjustment was needed to the estimated distances in Equation 4 or to the empirical curves for train operations as shown in FTA (2006) to create threshold contours in plan view.

For the analysis, a rated energy of 36,000 foot-pounds (48.8 kilojoules) is assumed for impact pile drivers and 5,000 foot-pound (6.8 kilojoules) is assumed for hydraulic breakers. Should Project excavation use equipment with different energy ratings than the ones assumed here, then this would change the estimated PPV levels. Vibrations estimated herein are for vibrations propagating from the equipment of interest through the ground surface.

5.3 TRAIN OPERATION VIBRATION ANALYSIS METHOD

Operational vibrations include vibrations due to trains passing through the tunnel while in service. Operational vibrations were estimated using empirical derived curves provided in the FTA (2006). These curves represent upper range vibration levels for in service tracks at representative North American rail-based transit systems. The vibration estimates assume rapid transit or light rail equipment with a speed of 80 kilometres per hour. FTA (2006) provides additional adjustments to estimated vibrations for train speed, vehicle parameters, track conditions, and track treatments that were not included in this analysis, as they are unknown at this time. Adjustments due to attenuation through the foundation and structure of the receiving structure were also not included. Therefore, estimates presented herein are subject to change once further Project refinements become known. Vibrations estimated herein are for vibrations propagating from the track centerline to the assumed bedrock surface, assuming building foundations are founded on the bedrock surface.

6.0 RESULTS

6.1 VIBRATION THRESHOLD CONTOURS

The distances from the vibration source over which a given vibration threshold could be exceeded was estimated using equations 2, 3 and 4 and the empirical curves for vibrations from train operations provided in the FTA (2006) guidelines, based on a variety of assumptions, including ground conditions, structure foundations, and the contractor's means and methods.

Vibration threshold contours, or vibration "zone of influence", are provided in Table 6. These contours represent the horizontal distances from vibration sources to where various vibration threshold levels, identified in Table 3, are estimated to occur. Activities that have higher magnitude vibrations will have wider thresholds than activities with lower magnitude vibrations. For example, pile-driving could affect daytime occupants of buildings up to approximately 165 m from the vibration source, whereas TBM operations in rock may only affect similar receptors located up to approximately 30 m away.

Appendix B through Appendix E provide graphical illustrations of vibration contours, and provide the baseline monitoring locations:

- Appendix B includes selected vibration contours estimated due to TBM construction activities,
- Appendix C displays selected vibration contours estimated due to station excavation and elevated guideway construction using impact pile drivers,
- Appendix D shows selected vibration contours estimated due to station excavation and elevated guideway construction using hydraulic breakers, and
- Appendix E contain selected vibration contours estimated due to train operations

For station construction and elevated guideway construction, only impact pile drivers and hydraulic breakers were included in the report as these provided higher estimated vibrations relative to the other equipment considered in this report. Estimated contour distances for equipment other than impact pile drivers and hydraulic breakers are included in Table 6 for reference. While the report herein provides estimates for the vibration "zone of influence", The boundary for vibration assessment to be used during detailed design is to be determined by the Contractor based on the Contractor's means and methods.

Table 6 Approximate Vibration Threshold Contour Distances

Category	Thresholds (PPV)	Tunnel Construction		Station Excavation and Elevated Guideway Construction					Operations	
		Tunnel Boring Machine (rock)	Tunnel Boring Machine (Soil)	Pile Driver—Impact	Pile Driver—Sonic	Caisson Drilling	Hydromill—Rock	Hydraulic Breaker	Train Above Ground	Train Below Ground
		Distance in Plan from Tunnel Alignment (m)		Distance in Plan from Station Excavation or Elevated Guideway Construction (m)					Distance in Plan from Track Alignment (m)	
Damage to reinforced-concrete, steel, or timber (no plaster)[1]	12.7	N/A	~3.5	~10	~3	~2	~0	~4	N/A	N/A
Damage to engineered concrete and masonry (no plaster)[1]	7.6	~3	~4	~15	~5	~3	~1	~6	N/A	N/A
Damage non-engineered timber and masonry building[1]	5.1	~6	~4.5	~25	~7	~4	~1	~9	N/A	N/A
Damage to buildings extremely susceptible to vibration damage[1]	3	~9	~5	~35	10	~6	~1	~15	N/A	N/A
Disturbance to institutional land uses with primary daytime use[1]	0.57	~30	~10	~165	~50	~30	~6	~65	N/A	10
Disturbance to residences and buildings where people normally sleep[1]	0.4	~35	~15	~225	~70	~40	~8	~90	~3	~20
Disturbance to buildings where vibration would interfere with interior operations[1]	0.18	~65	~25	~465	~140	~80	~20	~190	~15	~40

NOTE:

* N/A—Vibration at that given threshold is not estimated to reach receptors.

[1] Baseline vibration levels are often greater than the disturbance threshold levels considered here. Therefore, disturbance threshold contour distances may be less expansive than shown here.

6.2 ESTIMATED VIBRATION LEVELS AT RECEPTOR LOCATIONS

Table 7 compares baseline vibration levels at receptor locations with estimated levels that would results from various construction and operation activities. Vibration activities associated with construction and operation are determined from the contour maps. For example, if for a particular construction activity, estimated vibration at a monitoring location falls between the threshold contour for “disturbance to institutional land uses with primary daytime use” (PPV of 0.57 mm/s) and “disturbance at residences and buildings where people normally sleep” (PPV of 0.40 mm/s), then the estimated PPV at that location would be 0.40 mm/s < PPV < 0.57 mm/s.

Table 7 Baseline and Estimated Construction and Operational Vibrations at Baseline Monitoring Sites

Location ID	PPV during Baseline Monitoring Program (mm/s)	Tunnel Construction PPV with TBM (mm/s)	Station Excavation or Elevated Guideway Construction PPV—Impact Pile Drivers (mm/s)	Station Excavation or Elevated Guideway Construction PPV—Hydraulic Breakers (mm/s)	Operation PPV (mm/s)
1B	0.631	PPV < 0.18	7.6 < PPV < 12.7	3 < PPV < 5.1	PPV ~ 0.18
3B	0.476	0.18 < PPV < 0.40	12.7 < PPV	12.7 < PPV	0.57 < PPV < 3
5A	0.11	7.6 < PPV < 12.7	12.7 < PPV	12.7 < PPV	0.57 < PPV < 3
5B	0.709	0.57 < PPV < 3	0.57 < PPV < 3	0.57< PPV <3	0.40 < PPV < 0.57
7A	0.166	PPV < 0.18	0.18 < PPV < 0.40	PPV < 0.18	PPV < 0.18
7B	0.126	PPV < 0.18	0.18 < PPV < 0.40	PPV < 0.18	PPV < 0.18
8A	0.619	PPV < 0.18	0.57< PPV <3	0.18 < PPV < 0.40	PPV < 0.18
8B	0.221	PPV < 0.18	0.18 < PPV < 0.40	PPV < 0.18	PPV < 0.18
10B	0.492	0.57 < PPV < 3	0.57 < PPV < 3	0.18 < PPV < 0.40	0.18 < PPV < 0.40
11A	0.286	0.57 < PPV < 3	12.7 < PPV	5.1 < PPV < 7.6	0.40 < PPV < 0.57
14A	0.619	PPV < 0.18	0.40 < PPV < 0.57	PPV < 0.18	PPV < 0.18
15A	0.905	PPV < 0.18	0.57 < PPV < 3	0.18 < PPV < 0.40	PPV < 0.18
16 A	0.142	PPV < 0.18	0.57 < PPV < 3	0.18 < PPV < 0.40	PPV < 0.18
16 B	0.460	PPV < 0.18	0.57 < PPV < 3	0.18 < PPV < 0.40	PPV < 0.18
17	0.190	0.18 < PPV < 0.40	0.18 < PPV < 0.40	PPV < 0.18	PPV < 0.18
18	0.0952	PPV < 0.18	0.18 < PPV < 0.40	PPV < 0.18	PPV < 0.18
19A	0.413	PPV < 0.18	0.57 < PPV< 3.0	0.57 < PPV< 3.0	0.18 < PPV < 0.40
19B	0.159	PPV < 0.18	5.1 < PPV < 7.6	0.57 < PPV< 3.0	0.18 < PPV < 0.40

6.3 ESTIMATED NUMBER OF BUILDINGS WITHIN VIBRATION THRESHOLDS

Vibration estimates and GIS analysis were used to determine threshold contours along the Alignment, in comparison to the number of buildings potentially affected by vibration. The threshold values reflect FTA guidelines (2006) for general vibration assessments (summarized in Section 3.5). The building count is based on a database provided by the City of Vancouver containing residential, industrial, and commercial zoning types (City of Vancouver 2018).

6.3.1 Project Construction

Table 8 shows the number of buildings that are located within disturbance threshold distances for various construction activities. The analysis indicates that station or guideway construction using impact pile driving, generally has the greatest potential for causing vibration effects on structures, human receptors, or sensitive equipment. The threshold “Disturbance at buildings where buildings would interfere with interior operations/equipment” includes the most buildings, because it is the broadest threshold band (see Table 6). Conversely, the threshold “Damage to reinforced-concrete steel or timber (no plaster)” includes the fewest buildings as it is the narrowest threshold band. The total number of buildings that are contained within a given threshold are shown in Table 8, however, that threshold does not necessarily apply to each building. For example, for “excavation with TBM”, 680 to 690 buildings are contained within the threshold for “disturbance at buildings where vibration would interfere with interior operations/equipment”; however, only a small proportion of the buildings located within this threshold are likely to contain equipment that is sensitive to vibration. Further discussion is provided in Section 7.0.

Table 8 Approximate Number of Buildings within Disturbance Thresholds for Construction Vibration

Threshold		Total Number of Buildings Within or Intersected by Threshold Contour: Excavation with TBM	Station or Guideway construction using Impact Pile Drivers	Station or Guideway Construction using Hydraulic Breakers
Potential Damage to Buildings	Damage to reinforced-concrete steel or timber (no plaster)	0	60 to 70	10 to 20
	Damage to engineered concrete and masonry (no plaster)	5 to 15	80 to 90	25 to 35
	Damage to non-engineered timber and masonry building	30 to 40	85 to 95	50 to 60
	Damage to buildings extremely susceptible to vibration damage	150 to 160	120 to 130	70 to 80
Potential Human Reception and Sensitive Equipment Interference	Disturbance at institutional land uses with primary daytime use	400 to 410	770 to 780	220 to 230
	Disturbance at residences and buildings where people normally sleep	430 to 440	1250 to 1260	305 to 315
	Disturbance at buildings where vibration would interfere with interior operations/equipment	680 to 690	4130 to 4140	945 to 955

NOTES:

Values used to estimate damage, disturbance and interference are approximate. Including a building within a contour interval does not guarantee the vibration will affect the building.

Actual vibration levels to cause disturbance may be higher than the thresholds in this table, as baseline vibration levels are often higher than the disturbance thresholds considered here.

6.3.1.1 TBM Induced Vibrations

The assessment shows TBM-induced estimated vibration is great enough to potentially damage structures (i.e., exceed 3 mm/s). While the majority of buildings within the Review Area are located far enough from the Alignment where the risk of damage from TBM excavation is limited, based on this analysis, up to 150 to 160 buildings could be at risk depending on the building's susceptibility to vibration-related damage. However, it is noted that the threshold contours for damage, as shown in Appendix B, only intersect a small portion of each of these buildings along the Alignment. A survey of buildings potentially at risk is recommended prior to commencement of construction. While potentially damaging vibration levels do not reach beyond the structures immediately adjacent to the Alignment, the vibration levels at buildings further from the Alignment may be great enough to cause disturbance to building occupants (PPV greater than 0.57 mm/s or 0.40 mm/s) and interfere with interior operations, such as use of hospital equipment (PPV of 0.18 mm/s). For estimated distances for damage and disturbance, see Table 6 and Appendix B. The duration of vibrations from TBMs will depend on how quickly the TBM passes a given receptor.

Overall, a total of 680 to 690 buildings are contained within the threshold for disturbance at buildings where vibration would interfere with interior operations/equipment, however it is likely that the majority of these buildings do not house highly sensitive equipment like microscopes or MRI machines. Of the 430 to 440 buildings that are contained within the threshold for "disturbance at buildings and residences where people normally sleep", approximately 420 of the buildings are zoned as commercial or industrial meaning people are not likely to sleep at these building locations. Of the 400 to 410 buildings contained within the threshold for "disturbance at institutional land uses with primary daytime use", approximately 390 are zoned as commercial or industrial.

This analysis does not consider longer-term construction impacts from ground borne vibration associated with supply train movements such as excavated material haulage, precast concrete segment transport to the TBM, roadway-induced vibrations from trucks hauling precast concrete segments to site, or the material haulage away from the site.

6.3.1.2 Station Excavation and Elevated Guideway Construction Vibration

This assessment shows the station excavation and elevated guideway construction may have potential to cause damage and disturbance to buildings or receptors within the Review Areas. Station excavation may have a greater impact to the surroundings than elevated guideway construction, because station excavation limits are closer to commercial and residential developments. Vibrations from station excavation and elevated guideway construction are expected to vary substantially depending on the type of construction method used. Of the equipment considered, impact pile driving would be expected to produce the greatest vibrations while hydromilling would be expected to produce the lowest vibrations.

The assessment shows that station excavation and elevated guideway vibration is great enough to potentially damage structures (i.e., exceed 3 mm/s). Most buildings within the Review Area are located beyond the threshold distance for structural damage such that the risk of damage from station or elevation guideway construction is limited. However, up to 120 to 130 buildings for construction with impact pile drivers or 70 to 80 buildings for construction with hydraulic breakers could be at risk depending on the individual building's susceptibility to vibration-related damage. The threshold contours for damage for hydraulic breakers (Appendix D) only intersect a small portion of each of the buildings along the Alignment.

While potentially damaging vibration levels do not reach far beyond the structures immediately adjacent to the Alignment, the vibration levels at buildings further from the Alignment may be great enough to cause disturbance to building occupants (PPV greater than 0.57 mm/s or 0.40 mm/s) and interfere with interior operations, such as use of hospital equipment (PPV of 0.18 mm/s). For estimated distances for damage and disturbance, see Table 6 and Appendix C and Appendix D. The duration of vibrations from station excavation and elevated guideway construction will depend on how quickly vibration-intensive operations are completed.

Overall, for construction with impact pile drivers, a total of 4,130 to 4,140 buildings are contained within the threshold for “disturbance at buildings where vibration would interfere with interior operations/equipment”. However, it is likely that most of these buildings do not house highly sensitive equipment like microscopes or MRI machines. Of the 1,250 to 1,260 buildings that are contained within the threshold for “disturbance at buildings and residences where people normally sleep”, approximately 820 of the buildings are zoned as commercial or industrial, meaning that people are not likely to sleep at these building locations. Of the 770 to 780 buildings contained within the threshold for “disturbance at institutional land uses with primary daytime use”, 550 are zoned as commercial or industrial use indicating that there may be some temporary disturbance at these locations.

Overall, for construction with hydraulic breakers, a total of 940 to 950 buildings are contained within the threshold for “disturbance at buildings where vibration would interfere with interior operations/equipment”, however it is likely that the majority of these buildings do not house highly sensitive equipment like microscopes or MRI machines. Of the 305 to 315 buildings that are contained within the threshold for “disturbance at buildings and residences where people normally sleep”, approximately 280 of the buildings are zoned as commercial or industrial meaning people are not likely to sleep at these building locations. Of the 220 to 230 buildings contained within the threshold for “disturbance at institutional land uses with primary daytime use”, approximately 210 are zoned as commercial or industrial use indicating that there may be some temporary disturbance at these locations.

6.3.2 Project Operations

Table 9 shows the number of buildings that are located within disturbance threshold distances for operations. Vibrations from the train operations are estimated to be too low to result in building damage, therefore, no buildings are shown as being within the thresholds for building damage. Operation-induced vibration, however, could be a nuisance to residential receptors and/or interfere with the operation of sensitive equipment. As described in Section 6.3.1, the total number of buildings contained within a given threshold are shown, however, that threshold does not necessarily apply to each building.

Table 9 Number of Buildings within Disturbance Thresholds for Operation Vibration

Threshold		Approximate Total Number of Buildings Within or Intersected by Threshold Contour
Potential Damage to Buildings	Damage to reinforced-concrete steel or timber (no plaster)	0
	Damage to engineered concrete and masonry (no plaster)	0
	Damage to non-engineered timber and masonry building	0
	Damage to buildings extremely susceptible to vibration damage	0
Potential Human Reception and Sensitive Equipment Interference	Disturbance at institutional land uses with primary daytime use	220 to 230
	Disturbance at residences and buildings where people normally sleep	240 to 350
	Disturbance at buildings where vibration would interfere with interior operations/equipment	490 to 500

NOTES:
Values used to estimate damage, disturbance and interference are approximate. Including a building within a contour interval does not guarantee the vibration will affect the building.
Actual vibration levels to cause disturbance may be higher than the thresholds in this table, as baseline vibration levels are often higher than the disturbance thresholds considered here.

Overall, a total of 490 to 500 buildings are contained within the threshold for "disturbance at buildings where vibration would interfere with interior operations/equipment", however it is likely that most these buildings do not house highly sensitive equipment, such as microscopes or MRI machines. Of the 340 to 350 buildings that are contained within the threshold for "disturbance at buildings and residences where people normally sleep", approximately 330 of the buildings are zoned as commercial or industrial meaning people are not likely to sleep at these building locations. Of the 220 to 230 buildings contained within the threshold for "disturbance at institutional land uses with primary daytime use", approximately 220 are zoned as commercial or industrial.

6.3.3 Sensitive Receptors

During the baseline monitoring program, several specific locations were identified where vibration related impacts were a concern or where locations were found to be representative of numerous receptors along the Alignment. These locations can be found on the contour maps in Appendix B through Appendix E. While this assessment does not address specific impacts at individual structures in the Project area, results specific to the areas monitored in the baseline monitoring program (Table 7) are discussed below.

6.3.3.1 Buildings where Vibration would Interfere with Interior Operations and Sensitive Equipment

Based on vibration thresholds provided in Table 3, the PPV threshold considered in this study for potential interference with sensitive equipment is 0.18 mm/sec. The baseline study shows that baseline vibrations are greater than the 0.18 mm/sec threshold for sites 8A (W 11 between Willow and Oak Street), 8B (W 11 Ave near Willow Street), 17 (BC Cancer Research Centre), 19A (Emily Carr University of Art and Design theatre and lecture hall) and 16B (Jack Ball Research Centre), indicating that the actual vibration level needed to impact equipment at these locations may be greater than the threshold considered herein and greater than the baseline vibrations recorded. Alternatively, it may be possible at these locations that the structure or equipment itself has dampening features that would reduce any induced vibration. The assessment shows only station excavation with impact pile drivers would produce vibration levels greater than the baselines at either site, while TBM tunneling, station excavation with other methods, and train operations would be less than the baseline vibration levels.

The baseline PPV at locations 7B (BC Cancer Agency Building), 16A (inside basement of Jack Bell Research Centre), 18 (BC Cancer Agency), and 19B (Emily Carr University of Art and Design motion capture studio) is less than the 0.18 mm/sec threshold, therefore the vibration threshold may be applicable. At these locations, station excavation is estimated to result in vibration levels greater than 0.18 mm/s depending on the equipment assumed. At location 19B, train operations may produce vibrations greater than 0.18 mm/s. At these locations, TBM tunneling and station excavation via other methods would result in vibration levels estimated to be less than the 0.18 mm/sec threshold.

6.3.3.2 Residential Structures

The PPV threshold for disturbance to residential structures is 0.40 mm/s (Table 3), which includes disturbance at night. However, other than location 5A (Cambie St and W Broadway Ave), baseline PPVs at residential receptor sites exceed the 0.40 mm/sec threshold. Therefore, other than for location 5A (Cambie St and W Broadway Ave), potential vibration disturbance at residential structures should be compared to baseline levels rather than the 0.40 mm/sec threshold. In consideration of these baseline vibration levels, the assessment shows the following activities may exceed disturbance levels for residential structures at the following locations:

- 1B (Foley St and Finning Ave)—elevated guideway construction with impact pile drivers
- 3B (Thornton Way and Great Northern Way), 5A (Cambie St and W Broadway Ave)—station excavation with impact pile drivers or hydraulic breakers, TBM tunneling, and operations.
- 10B (W Broadway Ave and Oak St)—TBM tunneling and station excavation with pile drivers

6.3.3.3 Commercial Buildings and Office Space

The PPV threshold for disturbance to commercial/office structures is 0.57 mm/sec (Table 3). Baseline PPVs at locations 1B (Foley St and Finning Way), 5B(Main St and W Broadway Ave), 8A (W 11 Ave near Will St), and 15A (W Broadway Ave and Arbutus St) exceed the 0.57 mm/sec threshold and disturbance should be compared against the baselines levels ,while baseline PPVs at 3B (Thornton Way and Great Northern Way), 5A (Cambie St and W Broadway Ave), 7A(W 10 Ave and Heather St), 10B (W Broadway Ave and Oak St), and 11A (W 11 Ave near Heather St) are less than the threshold. Therefore, the assessment shows the following activities may exceed disturbance levels for commercial/office structures at the following locations:

- 1B (Foley St and Finning Way)—elevated guideway construction with impact pile drivers
- 3B (Thornton Way and Great Northern Way), 5A (Cambie St and W Broadway Ave)—station excavation with impact pile drivers or hydraulic breakers, TBM tunneling, and operations.
- 5B (Main St and W Broadway), 11A (W 11 Ave and Heather St)—station excavation with impact pile drivers or hydraulic breakers, TBM tunneling.
- 8A (W 11 Ave near Willow St), 15A (W Broadway Ave near Arbutus)—station excavation with impact pile drivers
- 10B (W Broadway Ave and Oak St)—station excavation with impact pile drivers, TBM tunneling

The preceding discussion assesses threshold values for disturbance to building occupants and operations based on the known baseline vibration levels. It is noted here that structures near locations 1B (Foley St and Finning Way), 3B (Thornton Way and Great Northern Way), 5A (Cambie St and W Broadway Ave), 11A (W 11 Ave near Heather St), and 19B (Emily Carr University of Art and Design motion capture studio) are within the threshold levels for damage to buildings although this would depend on the structure type. It is further noted that station excavation and elevated guideway construction with equipment other than impact pile drivers and hydraulic breakers is not included in the preceding discussion. Other equipment associated with shoring and excavation work was considered in this study and vibration levels were generally less than impact pile drivers or hydraulic breakers.

7.0 SUMMARY AND LIMITATIONS

A vibration assessment was carried out to estimate vibration effects associated with Project construction and operation. As part of this assessment, a field survey was conducted at 18 locations along the Alignment to quantify existing vibration levels. Selected receptors for this assessment include residential areas, educational or medical buildings. These receptors were considered representative of the most affected receptors in the study area. The results from this field survey, together with design information associated with the reference design, were used to estimate Project-related construction and operation vibration.

Baseline vibration data were predominately influenced by road traffic (i.e., passenger vehicles, buses, commercial trucks), localized construction activities (i.e., roadway/service line upgrades and neighboring building construction), and pedestrian traffic. The maximum recorded PPVs at monitoring locations ranged from 0.071 to 0.905 mm/s). This range is typical for occupied residences (PPVs between 0.4 to 0.8 mm/s) as per the FTA (2006) interpretations.

Baseline vibration monitoring included nine sensitive locations near the Alignment: Locations 8A and 8B (Jack Bell Research Centre); 16A and 16B (BC Cancer Agency); 18 (BC Cancer Research);17 and 18; and 19A and 19B (Emily Carr University) near the Alignment. Maximum PPVs recorded at these locations ranged between 0.071 to 0.619 mm/s PPV.

When comparing the baseline conditions to the estimated vibration values, this report finds an average baseline PPV value of approximately 0.5 mm/s for measurements made outdoors which exceeds the threshold for “disturbance at residences and buildings where people normally sleep” and exceeds the threshold for “disturbance at buildings where vibration would interfere with interior operations/equipment”. For vibration to affect existing buildings, the vibration levels would have to exceed pre-existing vibration levels and the applicable threshold. Therefore, many buildings within a given disturbance threshold contour, as shown in Appendices B through E, will not experience vibrations great enough to cause disturbance, as construction-induced vibration may not exceed pre-existing vibration levels.

Vibration effects from Project-related construction activities were estimated at potential receptor locations along the Alignment. Construction-related vibration may cause some disturbance to receptors such as residents sleeping. Damage to certain structures immediately adjacent to the Alignment is possible depending on factors such as the excavation method used and the sensitivity of the building to vibration. Buildings at higher risk of experiencing vibration induced damage would be older buildings located near vibration intensive activities. Newer buildings, or those located further from the Alignment are at less risk.

Meeting the V_{rms} perceptibility criteria of 0.05 mm/s (PPV = 0.18 mm/s) is considered adequate for a general assessment of most medical facilities; however, in some situations, where extremely vibration-sensitive equipment is in use, stricter limits may be required. Construction and operation vibration could affect sensitive receptors located near the Alignment, including facilities within the medical precinct, and Emily Carr University of Art + Design. Baseline vibration studies suggest that existing ground vibration levels in some areas may exceed the threshold values for their intended use (i.e., medical facilities).

Baseline vibration levels measured across the Project site are often greater than the thresholds for disturbance to building occupants and sensitive equipment/operations. Construction-induced vibrations would not result in disturbance in many locations where induced vibration is lower than pre-existing baseline vibration levels.

The assessment shows that vibration levels great enough to reach damaging levels are not reached by vibrations associated with operation of the Project. Vibration levels great enough to interfere with sensitive equipment (PPV of 0.18 mm/s), such as sensitive equipment in hospitals, are not reached except for at structures immediately adjacent to the elevated guideway portion of the Alignment. Operational vibrations may cause disturbance to building occupants close to the Alignment (PPV of 0.40 mm/s and PPC of 0.57 mm/s). The potential for impacts during Project operation depends on the design of the tracks and trains, which are most likely to use the existing Millennium Line train cars and track configuration.

Best management practices, vibration monitoring to limit vibration at these receptors, and other mitigation methods can be employed to limit and, in some cases, eliminate both damage and disturbance from construction vibration. This vibration assessment is based on preliminary Project design information, associated with the reference design, and assumes a conservative construction fleet and operation design parameters to estimate the vibration impact.

7.1 LIMITATIONS

Results and discussion provided in this report are subject to change depending on actual vibrations transmitted to the ground surface based on geological factors, contractor’s means and methods, specific characteristics of buildings along the Alignment, and construction methods. Final design parameters were not fully captured with the simplified empirical equations used in this assessment and the available preliminary design information. These factors have been roughly approximated at this time. While vibration levels and impacts have been estimated, these results should be reassessed as design progresses and more information becomes available and verified during construction (e.g., confirm limits of disturbance within the zone of influence).

The vibration estimates from TBM tunneling and train operation assume that buildings are founded on rock, at an assumed average bedrock depth of 3.1 m above the crown of the tunnel. Structures that are founded on overburden, instead of rock may experience attenuation of vibration levels. Conversely, buildings that are founded deeper than the bedrock surface may experience higher levels of vibration.

Geotechnical conditions may vary relative to what has been assumed for this report, and vibrations would be expected to change accordingly. Vibration levels would also depend on the actual bedrock cover, as an assumed average bedrock cover is used in this study. Actual bedrock cover will vary across the Alignment. Depending on the characteristics of the individual structures along the Alignment, actual vibrations transmitted into structure foundations and up through each floor may be greater or less than the ground vibrations estimated in this report as the structure may dampen vibrations or may experience resonance. Resonance can occur in the event construction or operational induced vibration frequencies are close to the fundamental period of structures which may amplify vibrations.

In consideration of the limitations of this analysis, the threshold contours provided in this report should not be considered definitive predictors of where damage or disturbance may occur. Rather, this information should be used to guide further discussions on monitoring requirements that may be considered during detailed design and construction and potential mitigation methods. In the case of station excavation, the vibration estimates may also be used to limit or modify certain excavation methods that are likely to cause vibration induced damage or disturbance. It is expected that the conclusions of this report will change as the design progresses and more information is gathered on nearby structures and will also depend on the contractors selected equipment and means and methods during construction. Ultimately, the Contractor will be responsible for determining the vibration zone of influence for various receptors based on the contractors means and methods.

Pre-construction monitoring, site specific evaluation, and site inspections will likely be required during construction. Monitoring of sensitive receptors will also likely be required during construction activities or in the areas where vibration levels may exceed allowable limits. Specific monitoring locations would be identified during detailed design and would require review during construction to check measured vibrations against trigger levels on a continuous basis. Additional measures would be incorporated where sensitive structures are identified to be located within the zone of influence.

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APPENDIX A

Broadway Subway Project—Vibration Baseline

Vibration Baseline

October 30, 2019

Prepared for:

Broadway Subway Project
Ministry of Transportation and Infrastructure

Prepared by:

Stantec Consulting Ltd.

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1.0 INTRODUCTION

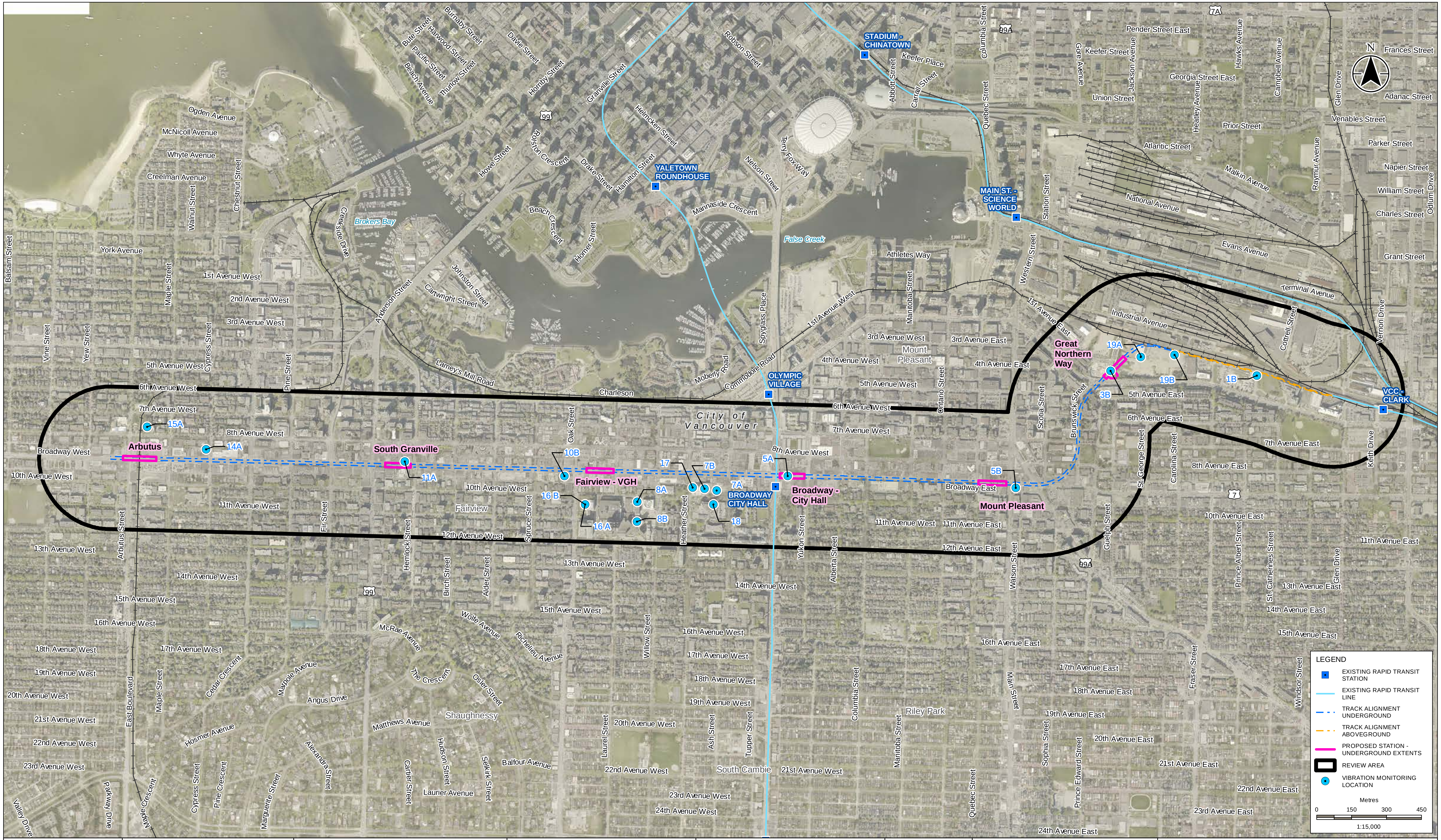
The Broadway Subway Project (the Project) will be constructed beneath West Broadway, with six (6) proposed underground stations located at key intersections (see Figure 1). It is anticipated the tunnel(s) will be constructed using a tunnel boring machine and the station locations will be excavated with typical excavation equipment. As part of the Environmental and Socio-Economic Review (ESR) being undertaken for the Project, vibration from construction and operation of the Project has been identified as a Review Element for further consideration.

The initial component of the evaluation of vibration along the Alignment was the establishment of baseline vibration data. Baseline vibration monitoring was undertaken at 18 receptor locations along the Project Alignment, as shown on Figure 1. Baseline monitoring was conducted over a 24-hour period at 14 receptor locations and over a 48-hour period at four receptor locations, between March and September, 2017.

This report summarizes the baseline vibration monitoring program and the results at the various receptor locations. The report concludes with an explanation of how the data will be used to support the assessment of potential vibration effects of the Project, reported in the ESR Report.

2.0 STUDY AREA

The Project is located in an urban area that includes densely-populated residential neighborhoods, commercial districts, businesses, as well as medical, recreational, and educational facilities. The study area consisted of the key receptor locations shown on Figure 1.



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REFERENCE DRAWING

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BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

BASELINE VIBRATION MONITORING LOCATIONS

SCALE 1:15,000	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
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3.0 METHODS

3.1 BASIC PRINCIPLES OF VIBRATION

Vibration, such as can occur as a result of the construction and operation of infrastructure, is an oscillatory motion described in terms of displacement, velocity and acceleration. Some activities associated with the construction and operation of the Project have the potential to generate ground-based vibration that can be transmitted through soil and bedrock towards adjacent buildings and infrastructure.

The effects of ground-based vibration can include noticeable movement of building floors, shaking of items on shelves, rattling of windows, and potentially audible noise. In most cases, construction and operation of a transit project does not cause damage to structures with the primary effect typically being some disturbance of activities in adjacent developments.

Vibration causing disturbance within adjacent buildings results from vibration that excites the building, propagating from the foundation throughout the remainder of the structure. The degree the vibration is propagated through the ground depends on the characteristics of the rock and soil. Building vibration will also vary depending on the type of structure and its resonance frequency[1]. For the Broadway Subway Project, vibrations within adjacent structures and identified sensitive receptors (i.e., building, humans, or equipment that have lower tolerances to vibration than the typical receptor) are of the greatest interest (see Section 3.5).

Perceptible vibration can also annoy building occupants. Vibrations are most commonly felt when occupants are inactive, or in a horizontal position (e.g., when lying in bed). Generally, as human activity increases, it becomes more difficult to detect oscillatory movements, however the ability to perceive vibration varies by individual.

3.2 INDICATORS

Vibration levels are measured using transducers equipped with three geophones, which measure ground velocity and frequency for each of the transverse, vertical, longitudinal axes. The peak particle velocity (PPV) is the maximum vibration velocity in each cycle, measured in units of millimetres per second (mm/s). It is typically used to monitor vibration from blasting vibration as a measure of stress experienced by structures. The frequency is measured as zero crossing (ZC) measured in units of Hertz (Hz).

Generally, the threshold value of PPV for human perception is 0.018 mm/s. At 0.56 mm/s, individuals begin to definitively detect vibration, and at 1.8 mm/s vibratory tolerance is only considered acceptable if experienced infrequently or for short periods of time.

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[1] Resonance Frequency: When a vibrating system or external force acts on another system to oscillate with greater amplitude at specific frequencies.

To evaluate human response and long-term effects on structures, an average of PPVs is determined by calculating the root-mean-square (RMS). RMS velocity (Vrms) measures are positive values representing the average maximum velocities over a specified period. Both PPV and Vrms values are expressed in mm/s. For a summary of vibration measurements see Table 1.

Table 1 Summary of Vibration Terms

Indicator	Unit	Description
Crest Factor	-	Ratio between PPV and Vrms. Used by the Federal Transit Administration as a conversion factor.
Peak particle velocity (PPV)	mm/s	Peak Particle Velocity indicates the maximum speed particles travel resulting from an event's ground vibrations
Root-mean-square (RMS)		The smoothed vibration amplitude using a time-averaged value containing the square root of amplitude of the signal typically calculated of a one second period.
Root Mean Square Velocity (Vrms)	mm/s	The smoothed vibration velocity using a time-averaged value containing the square root of velocity of the signal typically calculated over a one second period. Generally only considers the vertical components because it generally has the greatest amplitude. Typically used to compare human response to vibration.
Zero Crossing Frequency (ZC)	Hz	A method used to calculate vibration by using the time between the largest peak of the waveform to the next largest peak of the waveform over fractions of a second.
Vibration decibels (VdB)	mm/s	Measurement unit of ground-borne noise generated by vibration. Ten times the common logarithm of the ratio of the square of the amplitude of the RMS vibration velocity to the square of the amplitude of the reference RMS vibration velocity.

3.3 REFERENCE PROTOCOLS AND GUIDELINES

Vibration monitoring was carried out in accordance with the guidance provided in the U.S. Department of Transportation, Federal Transit Administration (FTA), *Transit Noise and Vibration Impact Assessment* (FTA 2006). The FTA guidance provides detailed information on the measurement and impact analysis of noise and vibration generated by transit systems (see Table 2).

The ratio of PPV to Vrms amplitude is defined as the crest factor for the signal. The crest factor is always greater than 1.71, however a crest factor of 8 or more is not unusual for impulsive signals. For ground-borne vibration from trains, the crest factor is usually between 4 and 5 (FTA 2006).

Table 2 Interpretation of Relative Vibration Values

Vrms (mm/s)*	PPV (mm/s)**	Source and Distance of Vibration	Interpretation of Vibration Influence
1.13	4.54	Vibration from heavy construction equipment at 15 m from source	Typical workshop area vibration levels
0.45	1.81	Vibration from commuter rail (upper range) at 15 m	Typical office environment vibration levels
0.25	1.02	Vibration from rapid transit (upper range) at 15 m	Typical occupied residence vibration level, daytime
0.14	0.57	Vibration from commuter rail (typical) at 15 m	Typical occupied residences vibration level, nighttime
0.05	0.18	Vibration from rapid transit (typical) at 15 m	Typical limit of vibration perception Vibration level that may interfere with interior building operations
0.03	0.10	Vibration from typical truck or bus traffic at 15 m	Typical sensitive location vibration level, adequate for high power optical (1000x) microscopes and 3 micron measuring devices
0.01	0.05	Typical Background Vibration at 15 m.	Typical sensitive location vibration level, adequate for 1 micron measuring devices
0.006	0.026	Below Typical Background Vibration Levels.	Typical sensitive location vibration level, most demanding equipment
0.003	0.013	Below Typical Background Vibration Levels.	Typical sensitive location vibration level, extremely sensitive equipment

NOTES:
* values were converted from VdB to mm/s (FTA 2006)
** crest factor of 4 was used for to convert Vrms to PPV (FTA 2006)
Reference
FTA 2006 (Figure 7-3), (Table 8-1) & (Table 8-3)
0.071 to 0.158 mm/s

FTA (2006) provides typical values for vibration frequency. The vibration frequency associated with the operation of subway lines, which is similar to on-grade rail, is classified as low frequency, typical frequency, or high frequency, according to the following sub-surface characteristics:

- Low Frequency: Low frequency vibration characteristics can be assumed for light rail transit systems founded on cohesive sandy soil or whenever a vibration isolation track support system is used.
- Typical Frequency: Unless information is available to indicate otherwise, typical vibration characteristic is the default assumption for light rail transits. This type of frequency should be used in soil that is very stiff with a high clay content.
- High Frequency: High-frequency characteristics should be assumed for light rail transits whenever the transit structure is founded in rock or when there is very stiff clay soil.

3.4 VIBRATION MONITORING EQUIPMENT

Vibration monitoring was conducted at each of the locations identified in Table 3, for 24-hours at 14 of the 18 receptor locations and for 48-hours at four of the receptor locations (during weekdays). The indoor building setup involved sandbagging the transducers to the basement or ground floor slab-on-grades to obtain representative ground vibrations, with the exception of Location 11A where the transducer was placed in soil subgrade within the basement area and sandbagged (see Figure 2c and Figure 2d). Outdoor setup involved placing transducers on an asphalt or concrete surface, or within shallow excavated subgrade soil. The transducers were subsequently sandbagged or covered with soil to obtain representative ground vibrations. Typical vibration monitoring setups are shown in Figure 2.

Baseline vibration monitoring was completed using an Instantel Blastmate III vibration monitor equipped with Instantel Micromate instrumentation. The Blastmate III and Micromate use a standard transducer equipped with three geophones to measure ground vibration for each of the transverse, vertical and, longitudinal axes. The instruments calculate the PPV, ZC Frequency, Peak Acceleration, and Peak Displacement for each of the transverse, vertical, and longitudinal axes.

The Blastmate III and Micromate were set up using the histogram record mode for the long-term recording periods. The histogram mode stores summary event information in intervals rather than in the real time continuous method used in the other record modes. The monitor samples data continuously at the chosen sample rate but only stores the relevant peaks for the interval. The Blastmate III and Micromate were set up to record in 15-second intervals for this project.

Sensor checks of the geophones were completed prior to and after each location recording period. Prior to each monitoring period, a manual sensor check was completed to check the geophones. A sensor check measures the geophones' natural frequency and damping indicated by an Overswing Ratio. The sensor check sends an electric pulse to the geophones and measures the response; in order for monitoring to proceed, the geophones' response must fall within a specified calibration range, otherwise the geophones must be tested or replaced. Blastmate III, and Micromate instrumentation were all laboratory calibrated by Instantel within 12 months of the monitoring program.

a) Transducer sandbagged on basement slab

b) Blastmate III connection to transducer

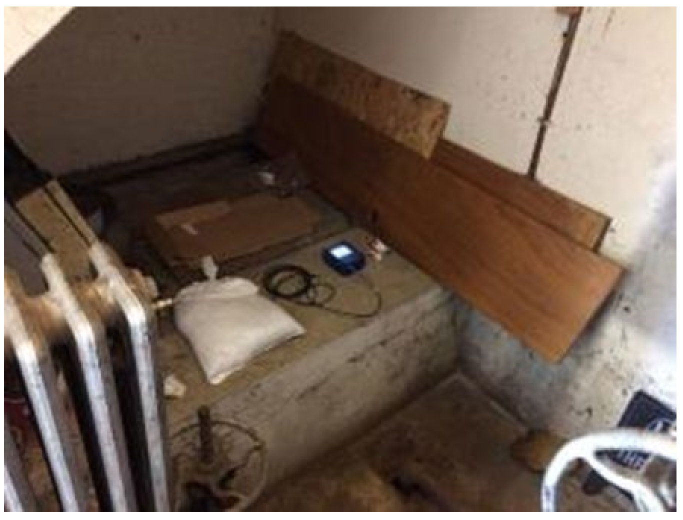
c) Transducer basement setup in soil

d) Blastmate III connection to transducer

e) Transducer vehicle setup on asphalt surface

f) Transducer sandbagged on asphalt

g) Micromate & transducer connection



h) Micromate & Transducer sandbag setup

Figure 2 Typical Vibration Monitoring Equipment Setup

3.5 RECEPTOR LOCATIONS

The baseline vibration field work focused on sensitive receptors identified by Stantec and Project representatives during initial discussions and from a site reconnaissance of the Alignment, prior to implementation of the vibration monitoring program. Sensitive receptors are locations where vibration may affect day to day operations (e.g., residential buildings, educational or medical facilities).

Baseline vibration monitoring was undertaken at 18 key receptor locations along the Alignment. Of the 18 key receptor locations along the Alignment; nine locations are considered as sensitive receptors while seven locations (i.e., locations 7B, 8B, 16A. 17, 18, 19A, 19B; see Figure 1) are considered to be highly sensitive receptors due to the presence of identified sensitive hospital equipment and post-secondary education facilities. Table 3 lists the vibration monitoring locations and provides a description of the setting observed during the monitoring period. The locations are shown in Figure 1 relative to the Alignment and the six proposed station locations.

Table 3 Vibration Monitoring Locations

Location ID	Location (Main Intersections)	Setting Description	Location (UTM)		Monitoring Dates (2017)
			Easting	**Northing**	
1B	Foley Street and Finning Way	Open space surrounded by medium density residential, haul truck parking, high density office space and active railway.	493713	5457151	Sept. 19–21
3B	Thornton Way and Great North Way	Medium density residential area adjacent to a school and mixed office and commercial use.	493085	5457171	Sept. 12–13
5A	Cambie Street and West Broadway Avenue	Medium to high density residential area mixed with dense commercial and office space along a major traffic roadway.	491700	5456720	Sept. 6–7
5B	Main Street and West Broadway Avenue	High density commercial and office area at a major traffic intersection.	492679	5456669	Sept. 13–14
7A	W 10 Avenue and Heather Street	Empty lot surrounded by low to high density office space.	491396	5456658	Sept. 21–22
7B	675 W 10 Avenue	Basement of Cancer Agency Building	491296	5456641	Sept. 21–22
8A	W 11 Avenue between Willow Street and Oak Street	Medium density residential area mixed with high density office buildings.	491055	5456610	Sept. 20–22
8B	W 11 Avenue between Willow Street and Oak Street	Inside MRI Area of Centennial Pavilion	491054	5456524	Sept. 20–21
10B	West Broadway Avenue and Oak Street	High density residential mixed with high density commercial and office space along a major traffic roadway.	490742	5456720	Sept. 6–7
11A	W 11 Avenue between Heather Street and Oak Street	High density commercial and office space along a major traffic roadway.	490058	5456782	Aug. 30–31
14A	West Broadway Avenue and Cypress Street	High density commercial and office space along a major traffic roadway.	489206	5456835	Aug. 31–Sept. 1
15A	West Broadway Avenue and Arbutus Street	Medium density residential mixed with two schools and commercial space.	488953	5456931	Sept. 14–15
16 A	Oak Street between 10 Avenue and 12 Avenue	Inside basement of Jack Bell Research Centre	490832	5456598	Sept. 26–27
16 B	Oak Street between 10 Avenue and 12 Avenue	Outside of Jack Bell Research Centre	490832	5456598	Sept. 26–27
17	675 West 10th Ave	BC Cancer Research Centre	491293	5456671	Mar. 7–8
18	600 W 10th Ave	BC Cancer Agency	491382	5456598	Mar. 7–8
19 A	520 E 1st Ave	Emily Carr University of Art and Design theatre and lecture hall	493215	5457231	Feb. 28–Mar. 2
19 B	520 E 1st Ave	Emily Carr University of Art and Design motion capture studio	493360	5457240	Mar. 2–5

3.6 DATA ANALYSIS

Vibration monitoring data recorded at each of the monitoring locations was downloaded and plotted with the Blastware instrumentation software (See Appendix A). The raw data was analyzed for any events not representative of typical background vibration due to transducer disturbance, such as foot traffic within close proximity to the transducer.

The Blastware software plotted the following vibration data:

- **Peak Particle Velocity (PPV):** Peak Particle Velocity indicates the maximum speed particles travel resulting from an event's ground vibrations. The PPV for each geophone; transverse, vertical, and longitudinal are calculated by the instrumentation.
- **Zero Crossing Frequency (ZC Freq):** The Zero Crossing Frequency calculates the event waveform's frequency at the largest peak. The frequency is determined by calculating the time between the largest peak of the waveform to the next largest peak of the waveform in fractions of a second. The BlastMate III and Micromate measure between zero crossings. The zero crossing implies one cycle of vibration each time the peak is reached. This method is accurate for non-complex ground frequencies which represent a true sine or cosine waveform. For more complex waveforms, such as distortions or vibrations with multiple frequencies, this method for calculating the frequency becomes less accurate compared to techniques like the Fast Fourier Transform method.
- **Date:** The date on which the highest PPV was recorded for each geophone; transverse, vertical, and longitudinal axes.
- **Time:** The time at which the highest PPV was recorded for each geophone; transverse, vertical, and longitudinal axes.
- **Peak Vector Sum (PVS):** Measured magnitudes are tabulated for six different times and represent velocities in each of the three axes; transverse, vertical, and longitudinal. The vector sum represents the resultant particle velocity magnitude and is calculated by squaring and adding the magnitudes and taking the square root. PVS is not used in this assessment, however, has been presented for completeness of data collected by the monitoring equipment.
- **Histogram Plot:** Time versus amplitude plot for each geophone; transverse, vertical, and longitudinal axes

4.0 RESULTS

Baseline vibration monitoring was completed at 18 key receptor locations along the Alignment. Section 4.1 summarizes monitoring results, while Section 4.2 details vibration monitoring characteristics at each receptor location.

4.1 BASELINE MONITORING RESULTS

Table 4 provides a summary of the baseline vibration monitoring results and provides a brief description of the vibration monitoring characteristics at each location.

Table 4 Baseline Vibration Monitoring Results

Location ID	Monitoring Dates (2017)	Maximum Measured Ground Vibration – Peak Particle Velocity (PPV) Transverse (mm/s)	Maximum Measured Ground Vibration – Peak Particle Velocity (PPV) Vertical (mm/s)	Maximum Measured Ground Vibration – Peak Particle Velocity (PPV) Longitudinal (mm/s)	Maximum Measured Ground Vibration – Peak Vector Sum (PVS) (mm/s)	Zero Crossing (ZC) Frequency Transverse (Hz)	Zero Crossing (ZC) Frequency Vertical (Hz)	Zero Crossing (ZC) Frequency Longitudinal (Hz)	Characteristics of Baseline Vibration	Approximate Distance to the Closest Center Line of the Alignment (m)
1B	Sept. 19–21	0.307	0.631	0.244	0.633	2.0	6.0	3.2	Road traffic, rail traffic, use of haul truck parking lot traffic.	14
3B	Sept. 12–13	0.413	0.413	0.476	0.753	>200	>200	>200	Road traffic, rail traffic, construction activities	3
5A	Sept. 6–7	0.087	0.110	0.071	0.110	N/A	17.1	21	Busy road traffic, buses, truck parking nearby.	2
5B	Sept. 13–14	0.441	0.709	0.504	0.780	31	38	38	Busy road traffic, use of public parking lot and pedestrians.	18
7A	Sept. 21–22	0.166	0.166	0.134	0.212	N/A	<1.0	18.6	Road traffic.	72
7B	Sept. 21–22	0.087	0.126	0.071	0.129	9.2	1.0	26	Road traffic, facility mechanical equipment	59
8A	Sept. 20–22	0.317	0.492	0.619	0.623	54	68	57	Road traffic and pedestrian traffic.	129
8B	Sept. 20–21	0.087	0.110	0.221	0.230	1.4	N/A	171	Facility parking lot, facility mechanical equipment within mechanical room.	215
10B	Sept. 6–7	0.111	0.492	0.095	0.493	49	68	146	Busy road traffic, and daytime construction activities.	27
11A	Aug. 30–31	0.159	0.270	0.286	0.297	20	20	25	Busy road traffic, daytime construction activities.	17
14A	Aug. 31–Sept. 1	0.302	0.619	0.317	0.623	19.7	20	16.0	Road traffic, facility mechanical equipment within mechanical room.	47
15A	Sept. 14–15	0.556	0.905	0.286	0.964	68	37	>200	Road traffic, some construction activities, school activities, and pedestrians.	137
16A	Sept. 26–27	0.087	0.142	0.071	0.144	49	1.2	93	Road traffic, electrical equipment within electrical room.	147
16B	Sept. 26–27	0.460	0.317	0.381	0.480	93	93	93	Road traffic and pedestrian traffic.	147
17	Mar. 7–8	0.111	0.190	0.0952	0.197	7.3	7.6	7.9	Pedestrian traffic inside building	62
18	Mar. 7–8	0.0952	0.0952	0.0794	0.112	7.3	7.6	7.9	Pedestrian traffic inside building	182
19A	Feb. 28–Mar. 2	0.111	0.413	0.0952	0.415	7.3	7.6	7.9	Pedestrian traffic inside building	25
19B	Mar. 2–5	0.111	0.159	0.0952	0.166	7.2	7.5	7.8	Pedestrian traffic inside building	17

4.2 SITE SPECIFIC OBSERVATIONS

4.2.1 Monitoring Location 1B

Monitoring equipment at location 1B was set up in a car along Foley Street, on the east side of the road near Great Northern Way. The location is adjacent to a recreational park to the east, truck parking area to the west, rail tracks/yard to the north, with Great Northern Way and medium density housing to the south. Monitoring was conducted for approximately 48 hours.

Vibration from rail activities (i.e., locomotive and rail car movements) in the adjacent rail yard and active train tracks was intermittent during daytime and nighttime hours. Other sources of vibration included trucking activities (mostly truck tractors and trailers) at the truck parking area to the west of the monitoring location as well as general road traffic along Foley Street and Great Northern Way.

4.2.2 Monitoring Location 3B

Monitoring equipment at location 3B was set up in a car parked on Thornton Street across the street from the building at 417 Great Northern Way. To the west of Thornton Street are medium density residences, to the east is a recreational park and the new Emily Carr University of Art and Design complex, and to the north are rail tracks/rail yard. Monitoring was conducted for approximately 24 hours.

Road and rail traffic vibration dominated the vibration environment at this location. In addition, the recreational park was under intermittent construction during the monitoring period (i.e., construction equipment, water pump). Extraneous sources of construction vibration (e.g., water pump, concrete grinding) were identified.

4.2.3 Monitoring Location 5A

Monitoring equipment at location 5A was set up in a building at 456 West Broadway near the Cambie Street intersection. The area is predominantly commercial, and includes the Cambie SkyTrain and bus stop located adjacent to the monitoring location. Monitoring was conducted for approximately 24 hours.

The vibration environment at 5A was dominated by road traffic along West Broadway Avenue (i.e., vehicles, buses, and trucks), as well as pedestrian activities along the main sidewalk.

4.2.4 Monitoring Location 5B

Monitoring equipment at location 5B was set up in a car in a public parking lot on the northwest corner of the West Broadway Avenue and Main Street intersection. This is a very busy major traffic intersection, surrounded by high density commercial businesses. Monitoring was conducted for approximately 24 hours.

The vibration environment at 5B was dominated by road traffic through the West Broadway Avenue and the Main Street intersection (i.e., vehicles, buses, and trucks), intermittent road construction activities, as well as building construction adjacent to the parking lot, public parking use, and pedestrian activities.

4.2.5 Monitoring Location 7A

Monitoring equipment at location 7A was set up in an empty lot next to the British Columbia Cancer Agency building located at 675 West 10th Ave. in Vancouver, BC, between West 10 Avenue and the alley south of West Broadway Avenue. This location is surrounded by low to high rise office buildings and is not directly adjacent to West Broadway Avenue. Monitoring was conducted for approximately 24 hours.

The vibration environment at 7A was dominated by light road traffic along adjacent roads.

4.2.6 Monitoring Location 7B

Monitoring equipment at location 7B was set up in the basement of the British Columbia Cancer Agency building located at 675 West 10 Avenue in Vancouver, BC. This location is surrounded by low to high rise office buildings and is not directly adjacent to West Broadway Avenue. Monitoring was conducted for approximately 24 hours.

The vibration environment at 7B was dominated by light road traffic outside the building and indoor mechanical equipment.

4.2.7 Monitoring Location 8A

Monitoring equipment at location 8A was set up outside of a multi-story building at 828 West 10 Avenue, near the Vancouver General Hospital. The transducer was placed in a shallow soil excavation at ground floor elevation. The location is surrounded by medium density residential and high rise office buildings, and is not directly adjacent West Broadway Avenue. Monitoring was conducted for approximately 48 hours.

The vibration environment at 8A was dominated by road traffic along adjacent roads and pedestrian activities along adjacent sidewalk. Additionally, some road construction activities were identified during the monitoring period.

4.2.8 Monitoring Location 8B

Monitoring equipment at location 8B was set up on the ground floor slab-on-grade of the mechanical room within the vicinity of the MRI area in the Centennial Building, in the Vancouver General Hospital property, at 899 West 12th Avenue. The location is surrounded by low and high rise office and hospital buildings, and is not directly adjacent West Broadway Avenue. Monitoring was conducted for approximately 24 hours.

The vibration environment at 8B was dominated by the facility parking lot activities, and the mechanical equipment in the vicinity of the monitor.

4.2.9 Monitoring Location 10B

Monitoring equipment at location 10B was set up on the ground floor slab-on-grade in a one-story commercial building at 1004 West Broadway Avenue near the intersection with Oak Street. The area is predominantly high-density residential and high-density commercial. Monitoring was conducted for approximately 24 hours.

The vibration environment at 10B was dominated by busy road traffic along West Broadway Avenue (i.e., vehicles, buses, and trucks), and pedestrian activities along the main sidewalk. Additionally, there was ongoing construction at the southeast corner of the intersection of Oak Street and West Broadway Avenue.

4.2.10 Monitoring Location 11A

Monitoring equipment at location 11A was set up in the basement of a one-story building at 1421 West Broadway Avenue. The location is surrounded by high density commercial and office space along a major traffic roadway. Monitoring was conducted for approximately 24 hours.

The vibration environment at 11A was dominated by road traffic along adjacent roads. Some road construction activities were identified during the monitoring period.

4.2.11 Monitoring Location 14A

Monitoring equipment at location 14A was set up in the basement of a two-story building at 1909 West Broadway Avenue and Cypress Street. The location is surrounded by high density commercial and office space along a major traffic roadway. Monitoring was conducted for approximately 24 hours.

The vibration environment at 14A was dominated by road traffic along adjacent roads. Other sources of vibration include mechanical equipment that would sporadically operate during the daytime and nighttime hours and is included in the overall baseline characterization.

4.2.12 Monitoring Location 15A

Monitoring equipment at location 15A was set up in a car at 2096 West 8th near Arbutus Street. The location is surrounded by medium density residential buildings, and near two schools and commercial spaces. Monitoring was conducted for approximately 24 hours.

The vibration environment was dominated by road traffic along surrounding roads, pedestrian and nearby school activities. There was also intermittent construction during the monitoring period.

4.2.13 Monitoring Location 16A

Monitoring equipment at location 16A was set up in the basement of the Jack Bell Research Centre building at 2660 Oak Street between 10 Avenue and 12 Avenue. This location is surrounded by low to high rise office buildings and is not directly adjacent to West Broadway Avenue. Monitoring was conducted for approximately 24 hours.

The vibration environment at 16A was dominated by light road traffic outside the building and indoor mechanical equipment within the electrical service room.

4.2.14 Monitoring Location 16B

Monitoring equipment at location 16B was set up outside in the southwest corner of the Jack Bell Research Centre building at 2660 Oak Street between 10 Avenue and 12 Avenue. The transducer was placed in a shallow soil excavation at basement floor elevation. This location is surrounded by low to high rise office buildings and is not directly adjacent to West Broadway Avenue. Monitoring was conducted for approximately 24 hours.

The vibration environment at 16B was dominated by road traffic along adjacent roads and pedestrian activities.

4.2.15 Monitoring Location 17

Monitoring equipment at location 17 was set up on the basement floor of the cancer research building at 675 West 10th Avenue. The location was within a storage room in the northwest corner of the building. Monitoring was conducted for approximately 24 hours.

The vibration environment at 17 was of typical day to day activities, which consists primarily of foot traffic.

4.2.16 Monitoring Location 18

Monitoring equipment at location 18 was set up on the basement floor of the cancer agency building at 600 West 10th Avenue. The location was underneath the emergency exit staircase at the northeast corner of the building. Monitoring was conducted for approximately 24 hours.

The vibration environment at 18 was of typical day to day activities, which consists primarily of foot traffic.

4.2.17 Monitoring Location 19 A

Monitoring equipment at location 19A was set up on the ground floor of the university building at 520 East 1st Avenue. The location was within a lecture hall in the northwest corner of the building, and underneath the staircase at the north end of the hall. Monitoring was conducted for approximately 44 hours.

The vibration environment at 19A was of typical day to day activities, which consists primarily of foot traffic.

4.2.18 Monitoring Location 19 B

Monitoring equipment at location 19B was set up on the ground floor of the university building at 520 East 1st Avenue. The location was within the motion capture studio at the northeast corner of the building, and set up in the northeast corner of the studio. Monitoring was conducted for approximately 72 hours.

The vibration environment at 19B was the typical day to day activities, which consists primarily of foot traffic.

5.0 DISCUSSION

The baseline vibration monitoring along the proposed Alignment has provided information on the levels of ambient vibration at the monitoring locations. The monitoring locations were selected to be representative of locations where construction and/or operational vibration may affect the residential, commercial or institutional properties adjacent to the Alignment.

The maximum recorded PPVs for each geophone; transverse, vertical, and longitudinal at the 18 receptor locations over the duration of monitoring were measured to be typical for occupied residences (between 0.4 to 0.8 mm/s) as per the FTA (2006) interpretations. Baseline vibration data recorded were predominately influenced by road traffic (i.e., passenger vehicles, buses, commercial trucks), localized construction activities (i.e. roadway/service line upgrades and neighboring building construction), and pedestrian traffic.

Included in the 18 receptor locations for baseline vibration monitoring were seven highly sensitive locations within the Vancouver General Hospital, BC Cancer Research Centre, BC Cancer Agency, and the Emily Carr facilities located near the Alignment, which included:

- **Location 7B:** Inside basement of Cancer Agency Building
- **Location 8B:** Inside MRI area of Centennial Building
- **Location 16A:** Inside basement of Jack Bell Research Centre
- **Location 17:** Inside basement of the Cancer Research building
- **Location 18**: Inside basement of Cancer Agency building
- **Location 19A**: on the ground floor of the Emily Carr theatre / lecture hall
- **Location 19B**: on the ground floor of the Emily Carr motion capture studio

Maximum PPVs recorded at these three sensitive receptor locations ranged between 0.071 to 0.415 mm/s which coincide with FTA interpretations for sensitive locations, the typical limit of perception and acceptable for medium to high power optical microscopes. The vibration was assumed to be predominately influenced by road traffic, pedestrian traffic and mechanical/electrical room equipment.

Vibrations frequencies are typically classified into two categories: transient and continuous. Transient vibrations are temporary and typically of short duration. In the context of Project construction, most vibration-causing activities will be transient in nature, such as impact pile drivers or jack hammers and pavement breakers, or near the station site during construction. Continuous vibrations can result from vibratory pile drivers, traffic from a nearby highway or static vibratory compaction equipment during construction. These vibrations are generally longer in duration and produce higher vibration frequency over short lengths of time.

The baseline vibration data collected will be used in conjunction with vibration information for typical construction and operational vibration sources to generate predications of the vibrations that may be anticipated at these receptor locations. This information will be documented in the Vibration Technical Data Report prepared in support of the ESR.

6.0 REFERENCES

Instantel Blastware III Operator Manual – 5.2 Theory of Operation. 5.5 Data Analysis Techniques.

U.S. Department of Transportation Federal Transit Administration (FTA). 2006. *Transit Noise and Vibration Impact Assessment*, FTA-VA-90-1003-06.

APPENDIX A

Blastware Data

Instantel

Event Report

Histogram Start Time	10:52:41 September 19, 2017
Histogram Finish Time	11:18:12 September 20, 2017
Number of Intervals	5862.08 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Bryce Boldt/Bryce.MMB

Serial Number	UM11141 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11141_20170919105241.IDFH
Scaled Distance	N/A

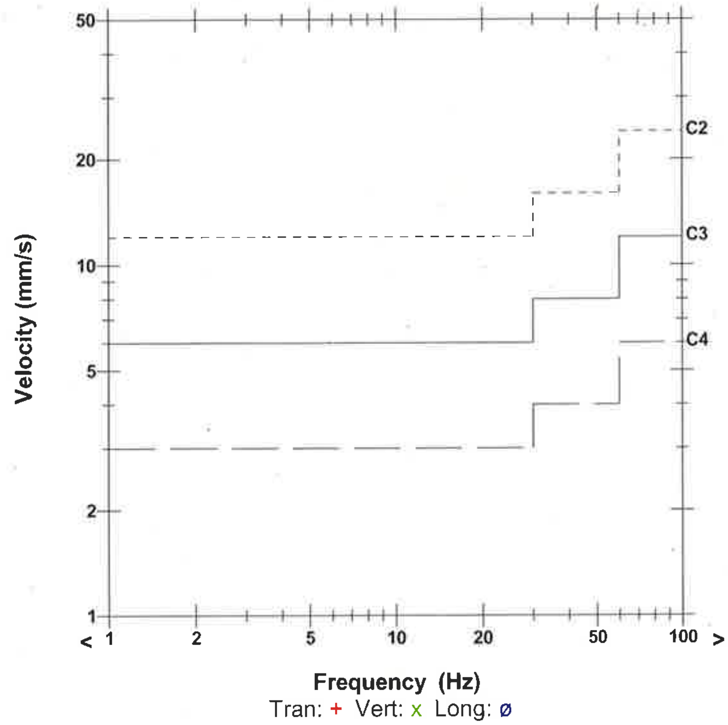
Notes

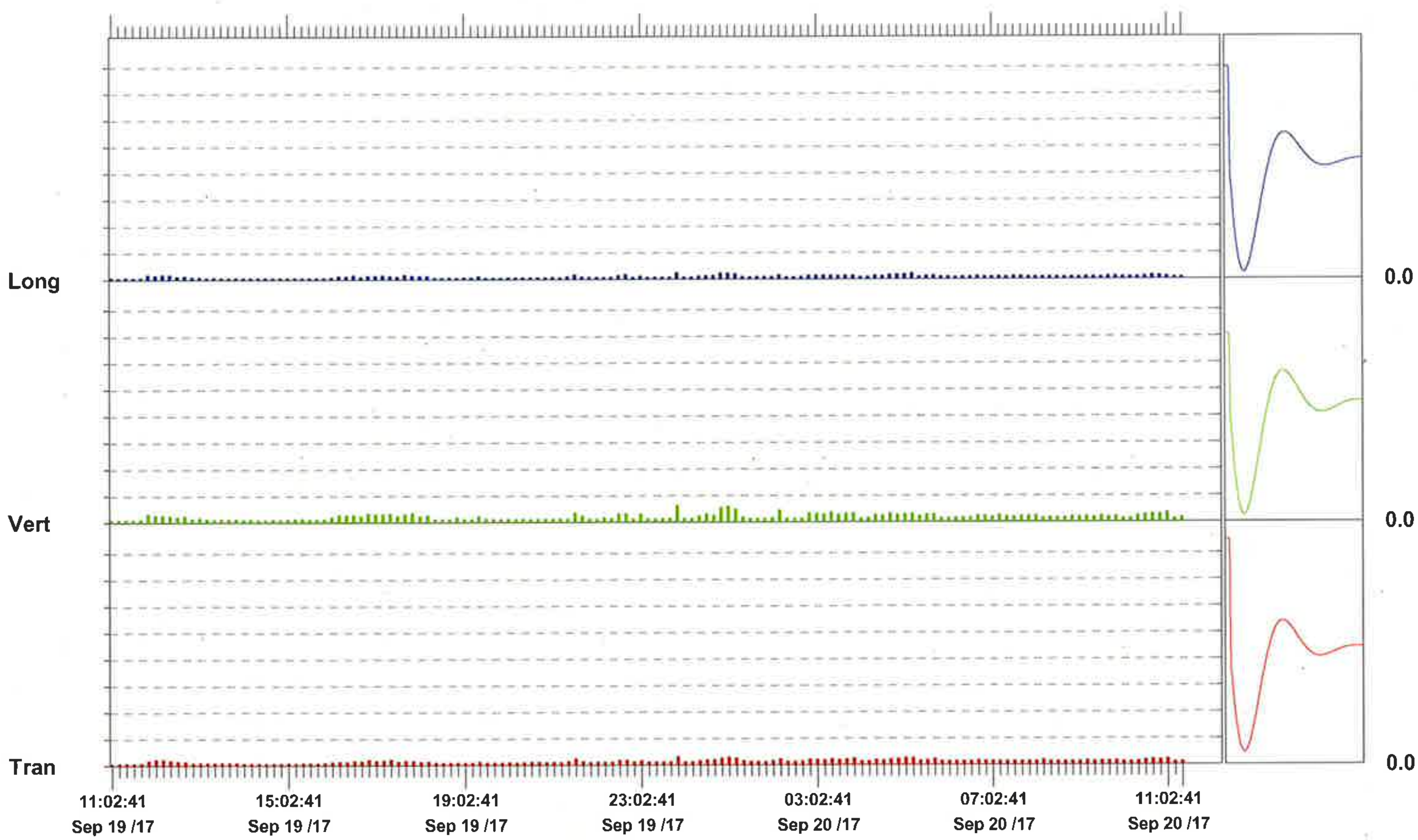
Location:	1B_Great Northern Way & Foley Street
Client:	Translink _ MLBE
User Name:	Stante Consulting Ltd.
General:	Geophone sandbagged on grass curb 1 ft d

	Tran	Vert	Long	
PPV	0.307	0.631	0.244	mm/s
ZC Freq	2.0	6.0	3.2	Hz
Date	Sep 19 /17	Sep 19 /17	Sep 19 /17	
Time	23:45:26	23:46:11	23:45:11	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.7	7.3	Hz
Overswing Ratio	3.7	3.2	3.7	

Peak Vector Sum 0.633 mm/s on September 19, 2017 at 23:46:11

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Sensor Check

Printed: November 6, 2017 (V 10.74)

Instantel

Event Report

Histogram Start Time	11:51:01 September 20, 2017
Histogram Finish Time	12:53:57 September 21, 2017
Number of Intervals	6011.73 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Bryce Boldt/Bryce.MMB

Serial Number	UM11141 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11141_20170920115101.IDFH
Scaled Distance	N/A

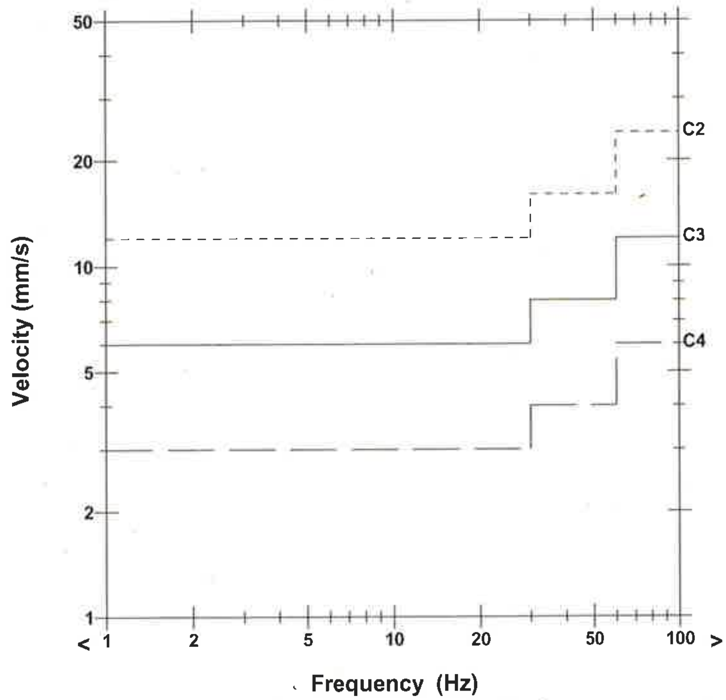
Notes

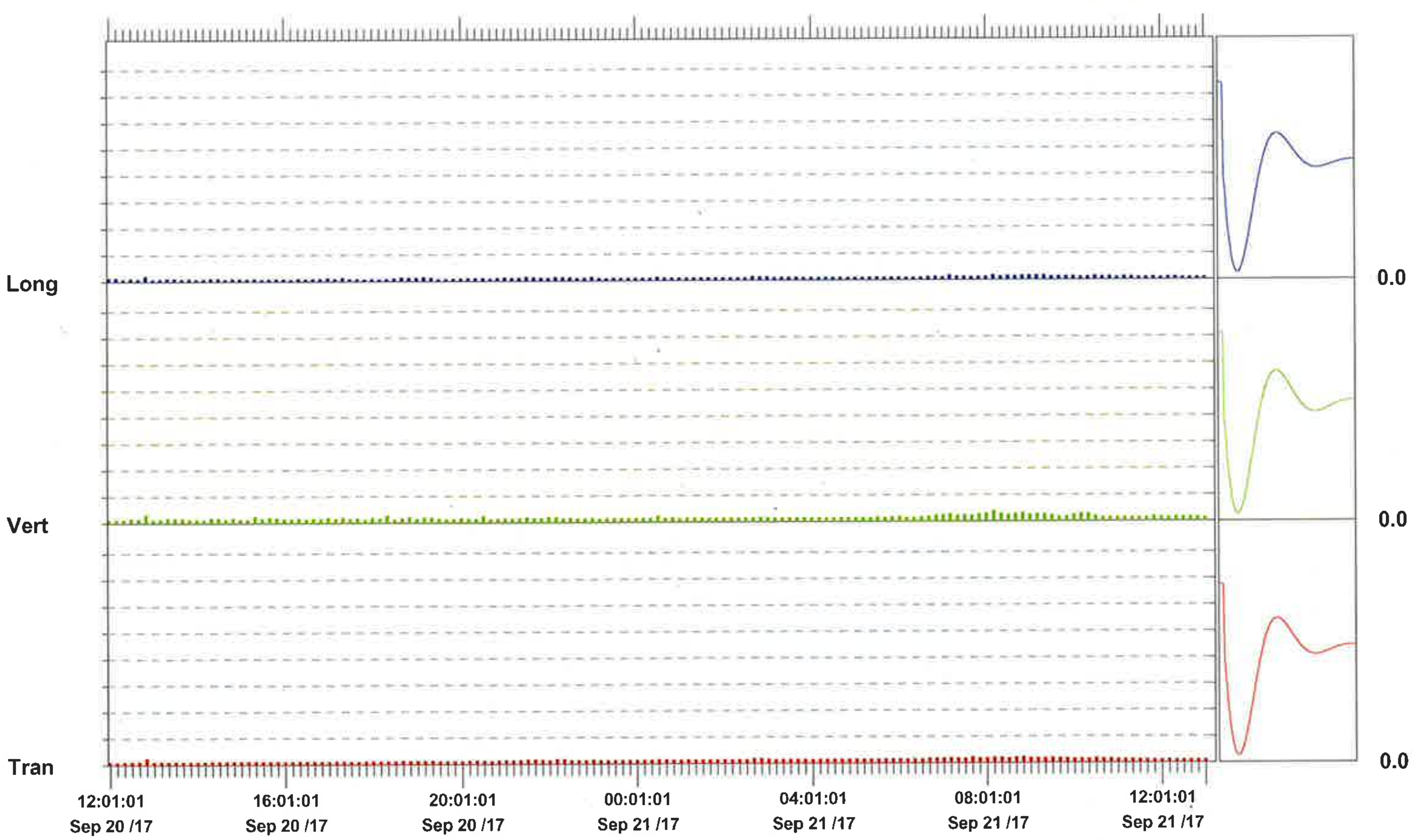
Location:	1B_Great Northern Way & Foley Street
Client:	Translink _ MLBE
User Name:	Stante Consulting Ltd.
General:	Geophone sandbagged on grass curb 1 ft d

	Tran	Vert	Long	
PPV	0.221	0.378	0.189	mm/s
ZC Freq	45	16.5	60	Hz
Date	Sep 20 /17	Sep 21 /17	Sep 20 /17	
Time	12:43:46	08:05:01	12:47:01	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.8	3.2	3.6	

Peak Vector Sum 0.408 mm/s on September 21, 2017 at 08:05:01

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Sensor Check

Event Report

Histogram Start Time	13:47:49 September 12, 2017
Histogram Finish Time	23:59:28 September 12, 2017
Number of Intervals	2446.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.1 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H2BV.NP0
Scaled Distance	99.6 (31.5 m, 0.1 kg)

Notes

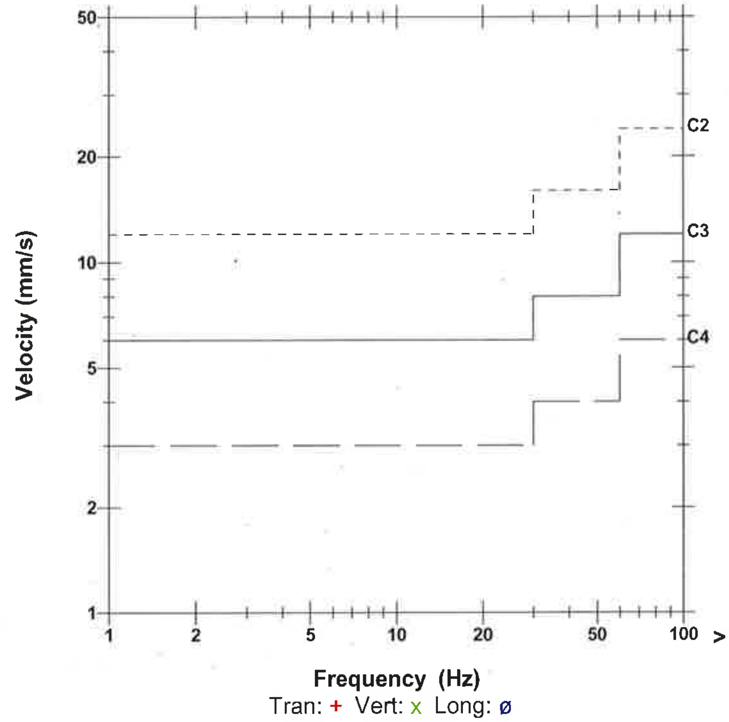
location:Site 3b	Thornton and Great Northern Way
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	and sandbag on asphalt pavement next to

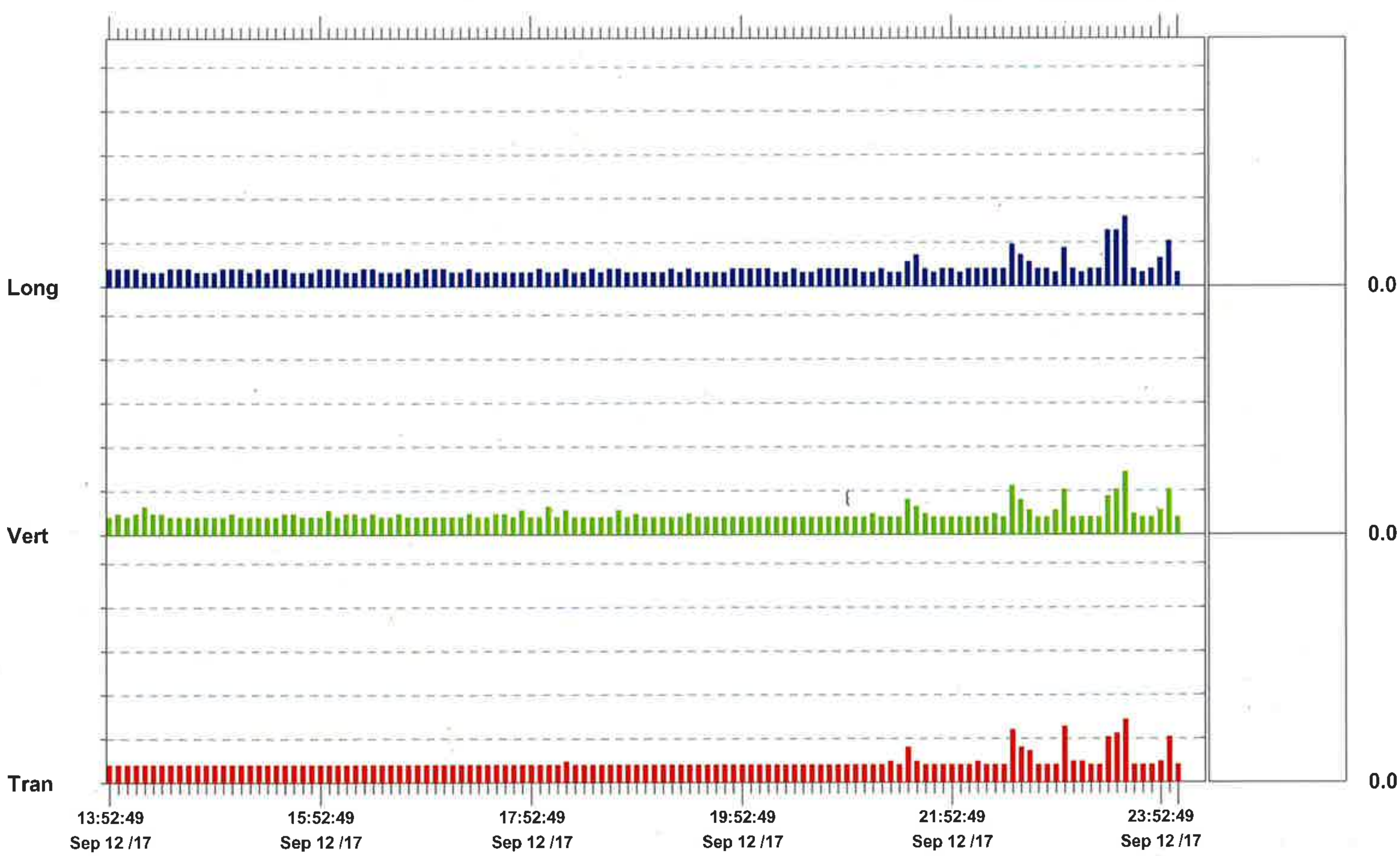
extended notes

curb along Thornton St underneath City vehicle

	Tran	Vert	Long	
PPV	0.286	0.286	0.317	mm/s
ZC Freq	>200	>200	>200	Hz
Date	Sep 12 /17	Sep 12 /17	Sep 12 /17	
Time	23:28:49	23:28:49	23:28:49	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.514 mm/s on September 12, 2017 at 23:28:49





Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Printed: November 6, 2017 (V 10.74)

Instantel

Event Report

Histogram Start Time	23:59:38 September 12, 2017
Histogram Finish Time	13:55:26 September 13, 2017
Number of Intervals	3343.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.0 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H2CN.ZE0
Scaled Distance	99.6 (31.5 m, 0.1 kg)

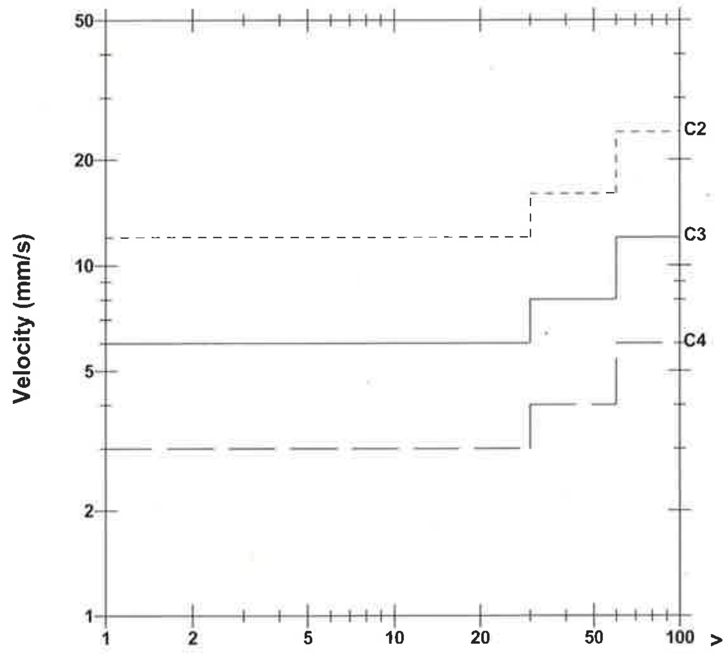
Notes
location:Site 3b Thornton and Great Northern Way
Client:Translink MLBE
User Name:Bryce Boldt
General:Geophone and sandbag on asphalt pavement next to

extended notes
curb along Thornton St underneath City vehicle

	Tran	Vert	Long	
PPV	0.413	0.413	0.476	mm/s
ZC Freq	>200	>200	>200	Hz
Date	Sep 13 /17	Sep 13 /17	Sep 13 /17	
Time	01:39:23	00:18:38	01:41:53	
Sensor Check	Passed	Passed	Passed	
Frequency	7.2	7.5	7.6	Hz
Overswing Ratio	3.7	3.7	3.5	

Peak Vector Sum 0.753 mm/s on September 13, 2017 at 01:41:53

Swiss Piling Standard SN 640 312a



Tran: + Vert: x Long: ø

Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Event Report

Histogram Start Time	13:52:32 September 6, 2017
Histogram Finish Time	13:25:36 September 7, 2017
Number of Intervals	5652.25 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Bryce Boldt/Bryce.MMB

Serial Number	UM11141 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11141_20170906135232.IDFH
Scaled Distance	N/A

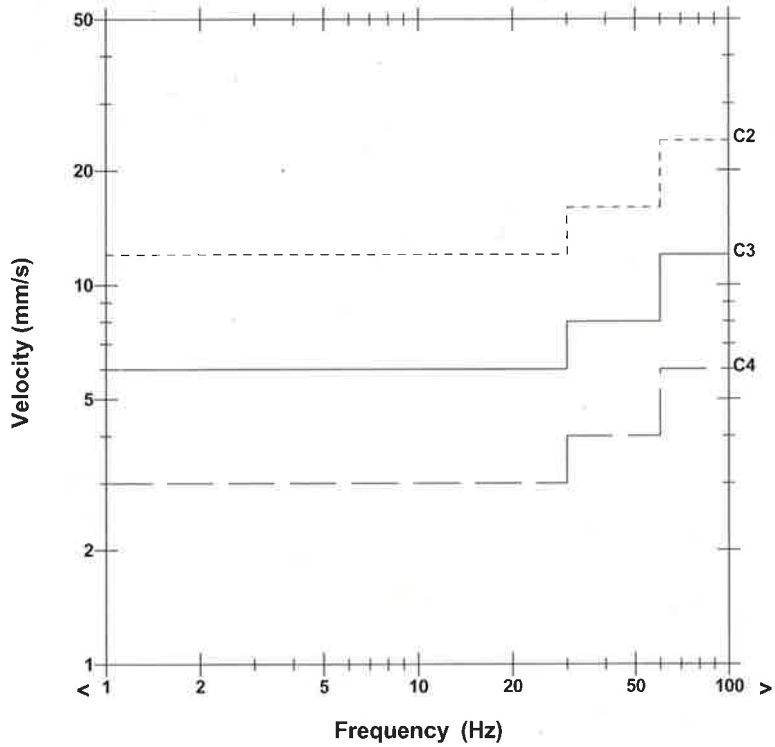
Notes

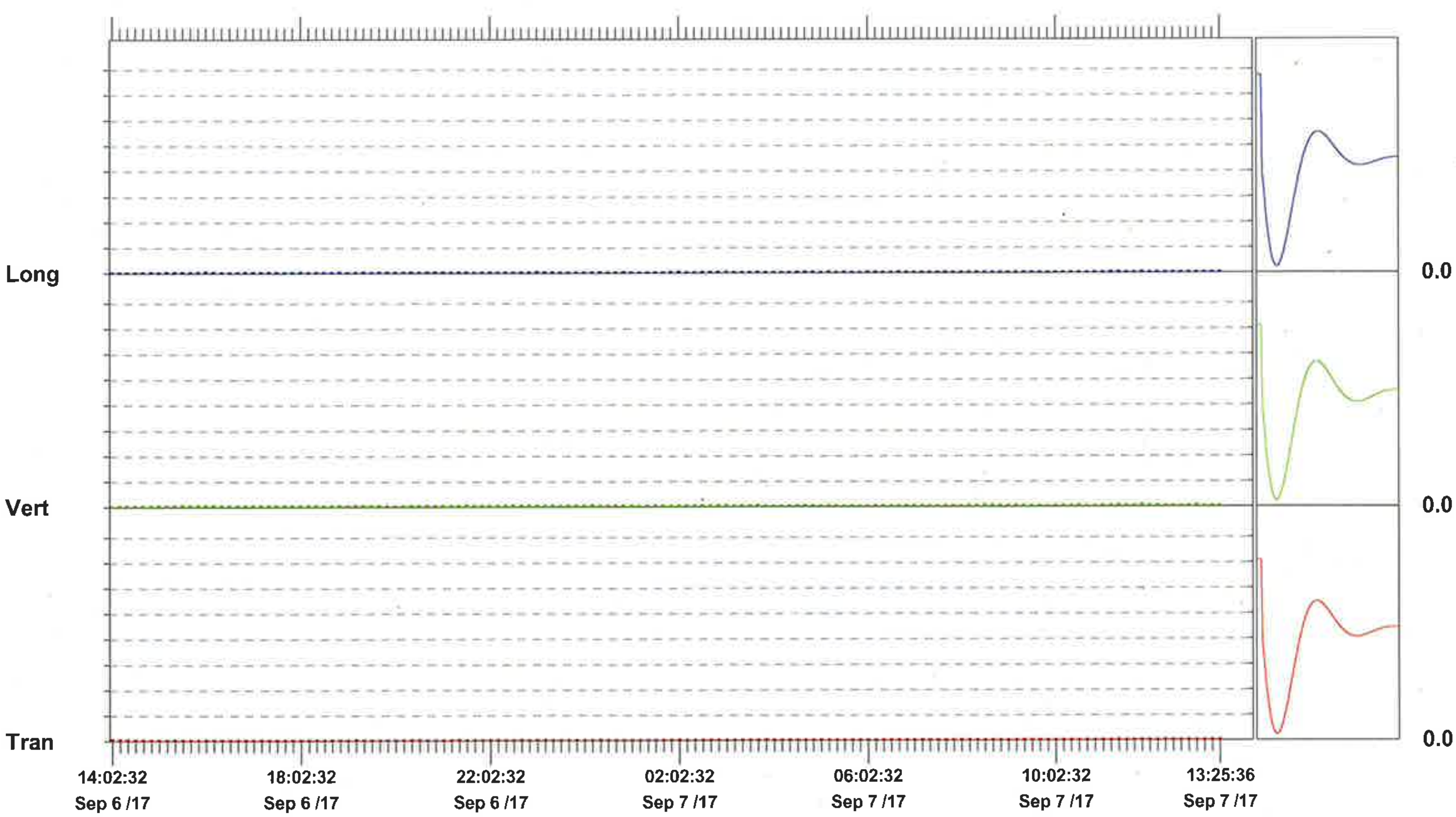
Location:	Site 5A_456 W. Broadway, Vanc @ Cambie
Client:	Translink _ MLBE
User Name:	Stante Consulting Ltd.
General:	Geophone sanbagged on concrete grade bea

	Tran	Vert	Long	
PPV	0.087	0.110	0.071	mm/s
ZC Freq	N/A	17.1	21	Hz
Date	Sep 6 /17	Sep 7 /17	Sep 6 /17	
Time	13:54:17	11:47:02	15:53:32	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.7	7.3	Hz
Overswing Ratio	3.7	3.1	3.6	

Peak Vector Sum 0.110 mm/s on September 7, 2017 at 11:47:02
N/A: Not Applicable

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div Sensor Check

Printed: November 6, 2017 (V 10.74)

Instantel

Event Report

Histogram Start Time	15:03:24 September 13, 2017
Histogram Finish Time	15:03:12 September 14, 2017
Number of Intervals	5759.15 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Bryce Boldt/Bryce.MMB

Serial Number	UM11141 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11141_20170913150324.IDFH
Scaled Distance	N/A

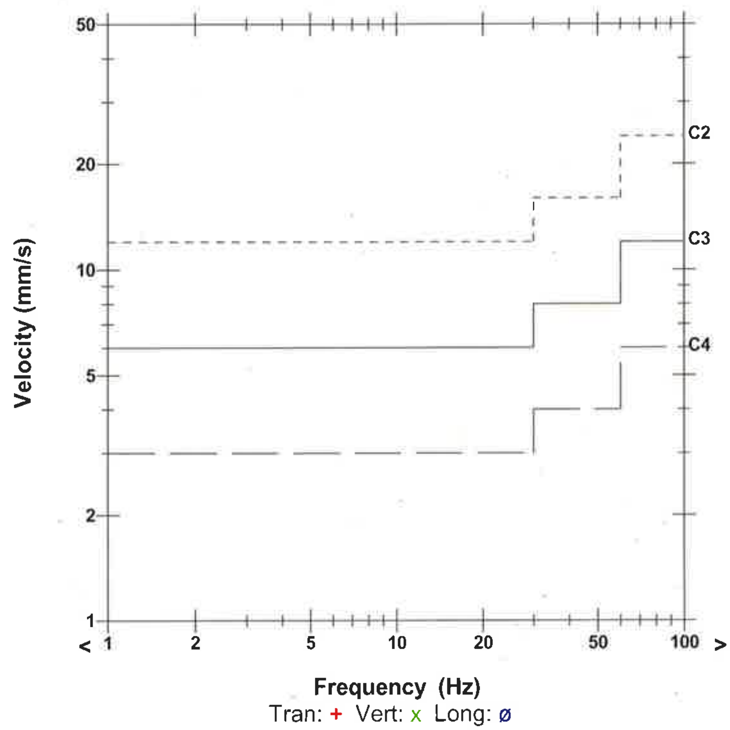
Notes

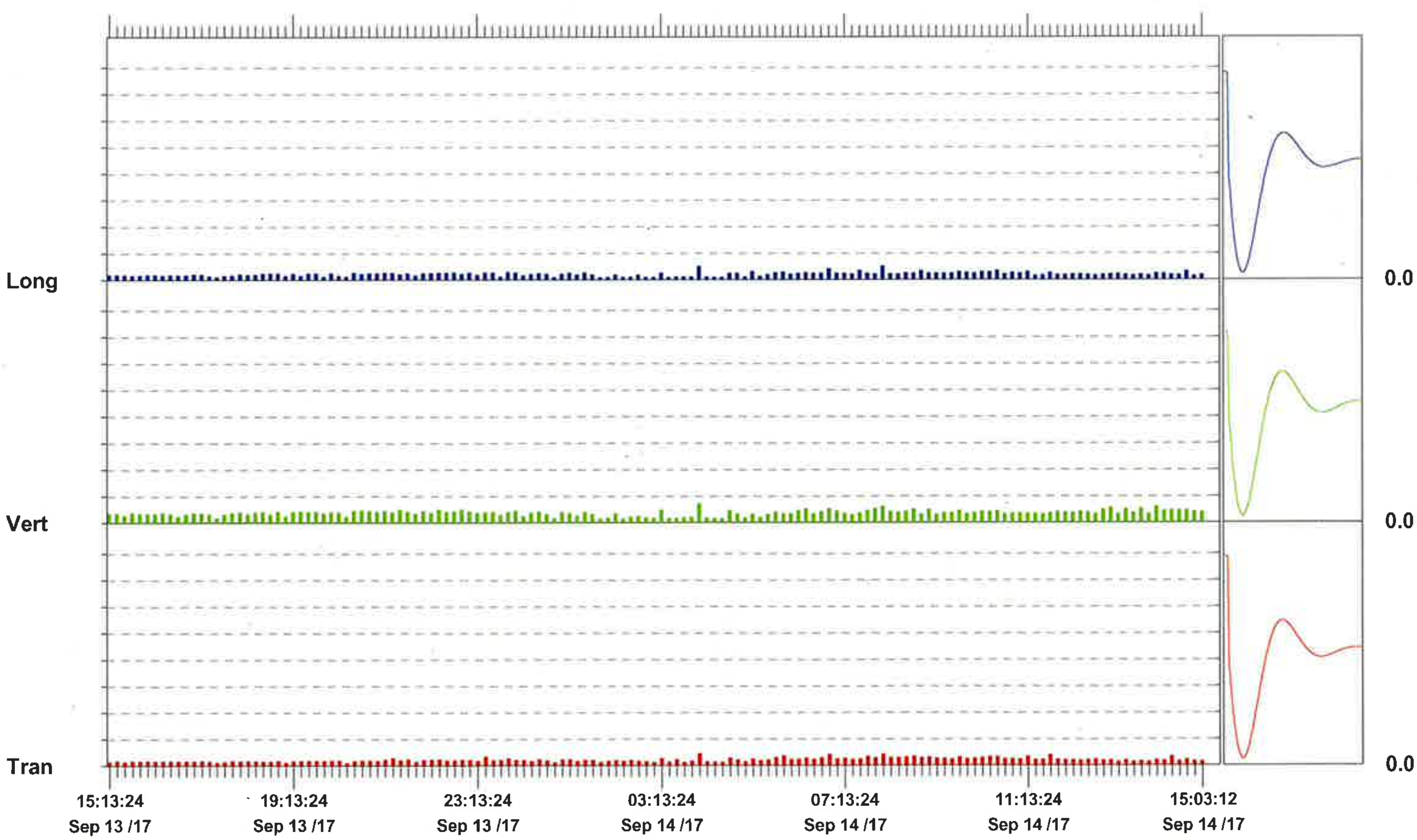
Location:	Site 5B_Main Street & West Broadway
Client:	Translink_MLBE
User Name:	Stantec Consulting Ltd.
General:	Geophone sandbagged on asphalt

	Tran	Vert	Long	
PPV	0.441	0.709	0.504	mm/s
ZC Freq	31	38	38	Hz
Date	Sep 14 /17	Sep 14 /17	Sep 14 /17	
Time	04:02:09	04:02:09	04:02:09	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.7	7.3	Hz
Overswing Ratio	3.8	3.1	3.6	

Peak Vector Sum 0.780 mm/s on September 14, 2017 at 04:02:09

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Sensor Check

Printed: November 6, 2017 (V 10.74)

Instantel

Event Report

Histogram Start Time	13:53:35 September 21, 2017
Histogram Finish Time	13:48:22 September 22, 2017
Number of Intervals	5739.13 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Bryce Boldt/Bryce.MMB

Serial Number	UM11141 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11141_20170921135335.IDFH
Scaled Distance	N/A

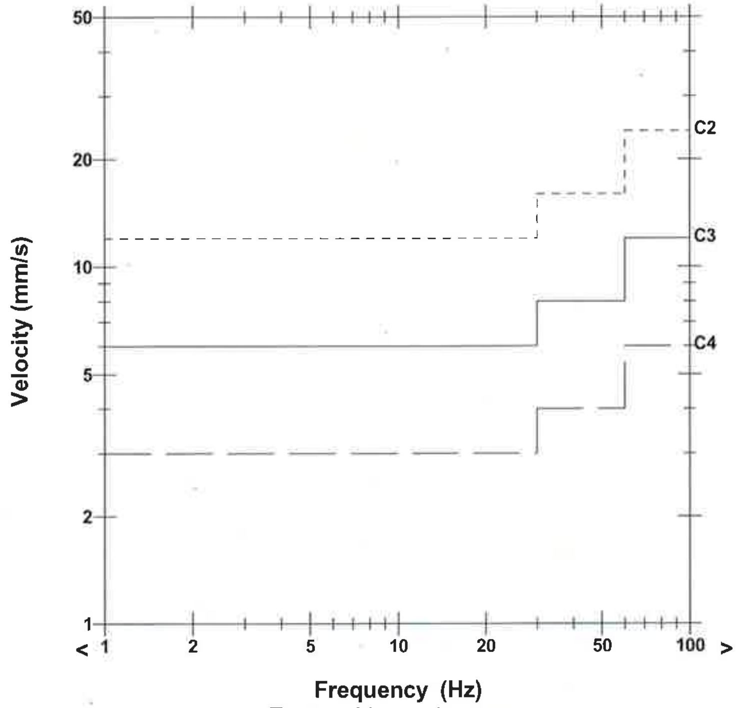
Notes

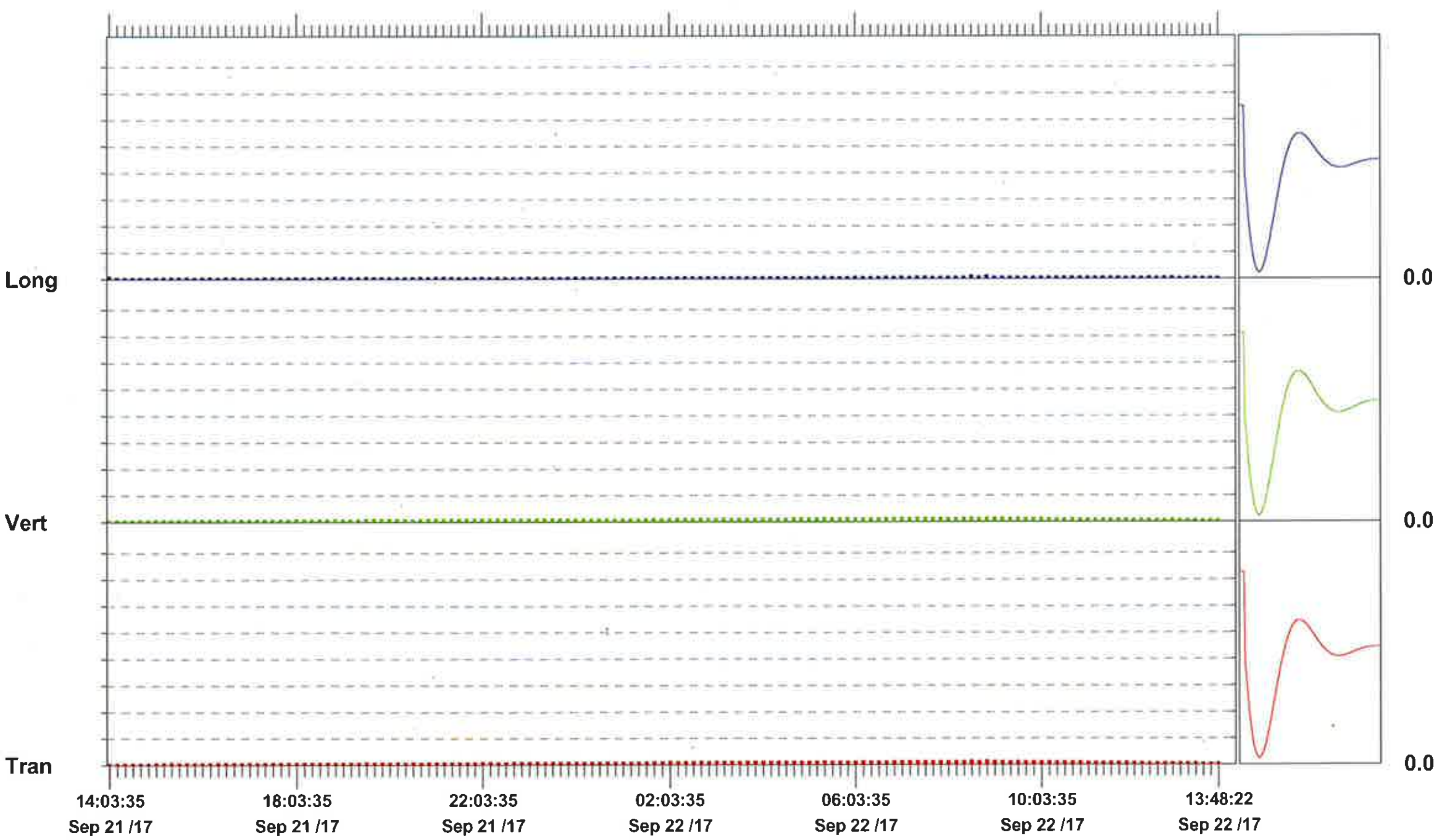
Location:	Site 7a - 10th & Heather, vacant lot Sou
Client:	Translink _ MLBE
User Name:	Stante Consulting Ltd.
General:	Geophone sandbagged on gravel in lot

	Tran	Vert	Long	
PPV	0.166	0.166	0.134	mm/s
ZC Freq	N/A	<1.0	18.6	Hz
Date	Sep 22 /17	Sep 22 /17	Sep 22 /17	
Time	08:50:05	08:28:20	08:50:05	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.7	7.3	Hz
Overswing Ratio	3.8	3.1	3.7	

Peak Vector Sum 0.212 mm/s on September 22, 2017 at 08:50:05
N/A: Not Applicable

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div Sensor Check

Instantel — Event Report

Histogram Start Time	14:58:29 September 21, 2017
Histogram Finish Time	14:25:46 September 22, 2017
Number of Intervals	5629.14 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Operator/Bryce.MMB

Serial Number	UM11142 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11142_20170921145829.IDFH

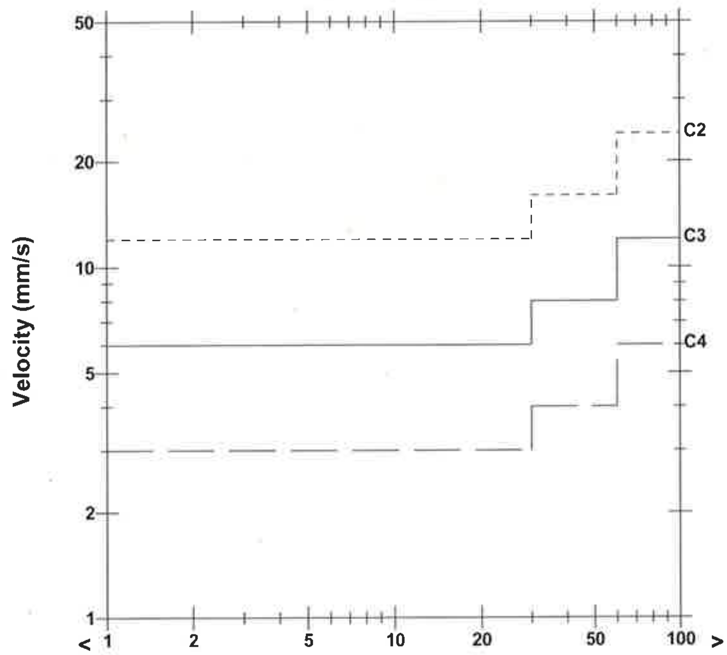
Notes

Location:	Site 7B_Cancer Agency Basement
Client:	Translink-MLBE
User Name:	Stantec Consulting Ltd.
General:	Geophonr sandbagged on concrete slab

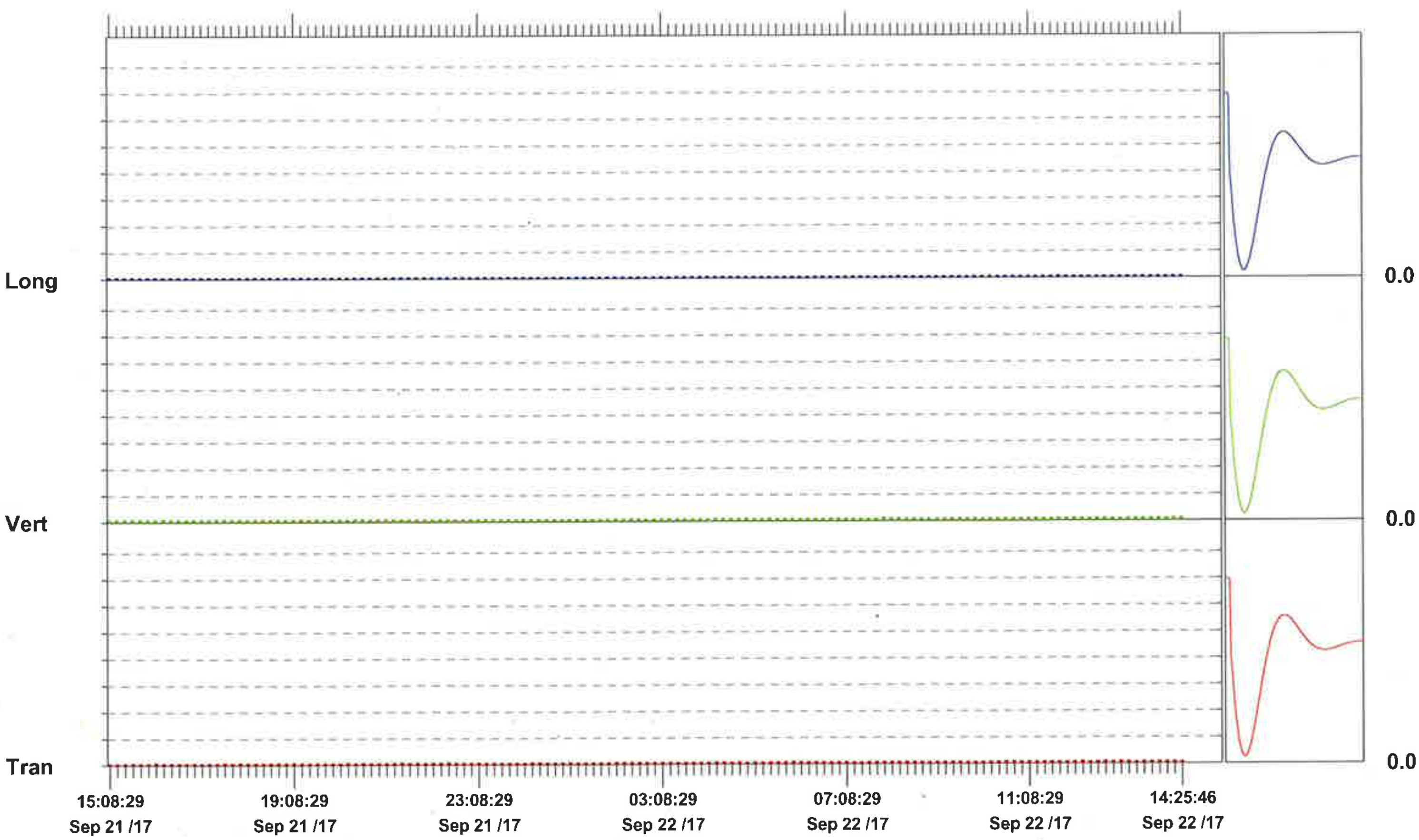
	Tran	Vert	Long	
PPV	0.087	0.126	0.071	mm/s
ZC Freq	9.2	<1.0	26	Hz
Date	Sep 21 /17	Sep 22 /17	Sep 22 /17	
Time	16:05:59	07:49:44	08:13:59	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.5	7.3	Hz
Overswing Ratio	3.5	3.3	3.8	

Peak Vector Sum 0.129 mm/s on September 22, 2017 at 07:49:44

Swiss Piling Standard SN 640 312a



Frequency (Hz)
Tran: + Vert: x Long: ø



Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Sensor Check

Event Report

Instantel

Histogram Start Time	23:59:38 September 20, 2017
Histogram Finish Time	23:59:28 September 21, 2017
Number of Intervals	5759.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.8 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H2RH.BE0
Scaled Distance	22.1 (7.0 m, 0.1 kg)

Notes

location:Site 8a	VGH Research Pavillion
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	burried in landscape area NE corner Bldg

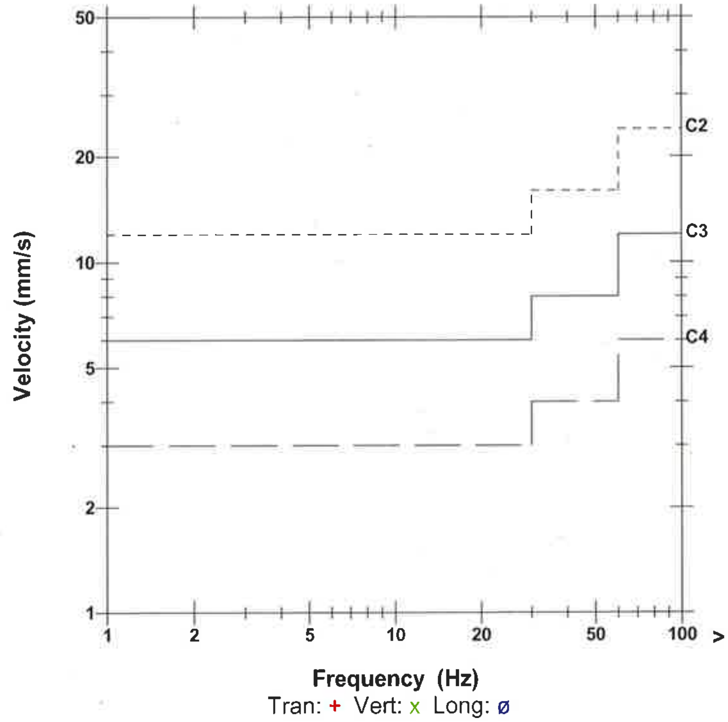
extended notes

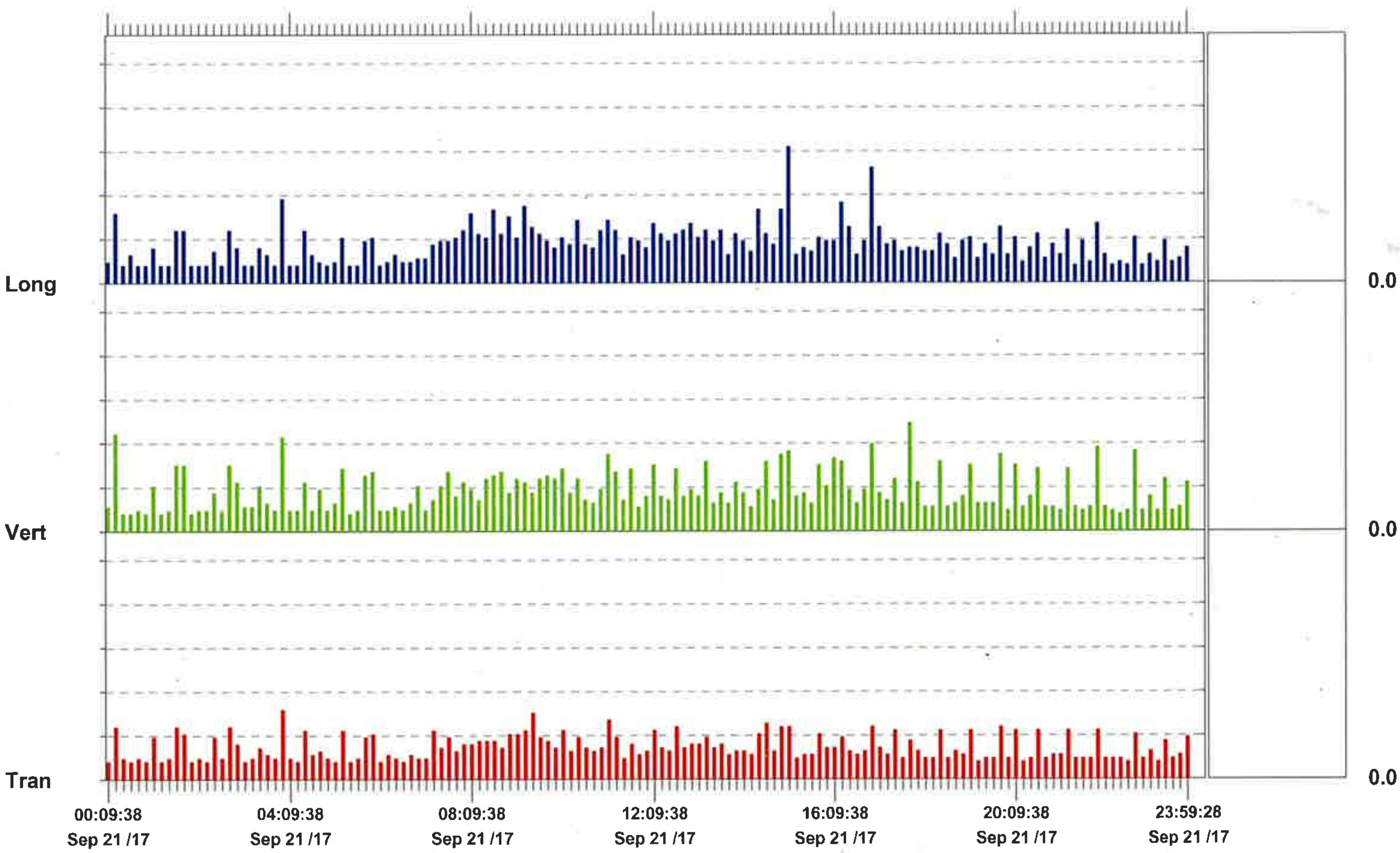
along 10th St. - 828 West 10th

	Tran	Vert	Long	
PPV	0.317	0.492	0.619	mm/s
ZC Freq	54	68	57	Hz
Date	Sep 21 /17	Sep 21 /17	Sep 21 /17	
Time	03:56:08	17:45:08	15:01:38	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.623 mm/s on September 21, 2017 at 15:01:38

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Instantel

Event Report

Histogram Start Time	13:42:39 September 20, 2017
Histogram Finish Time	14:20:55 September 21, 2017
Number of Intervals	5913.05 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Operator/Bryce.MMB

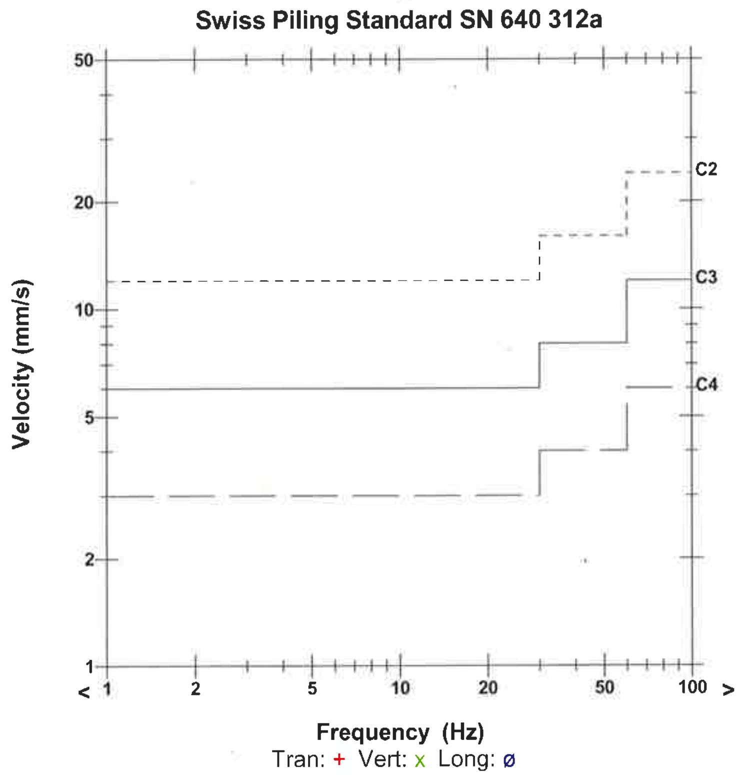
Serial Number	UM11142 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11142_20170920134239.IDFH

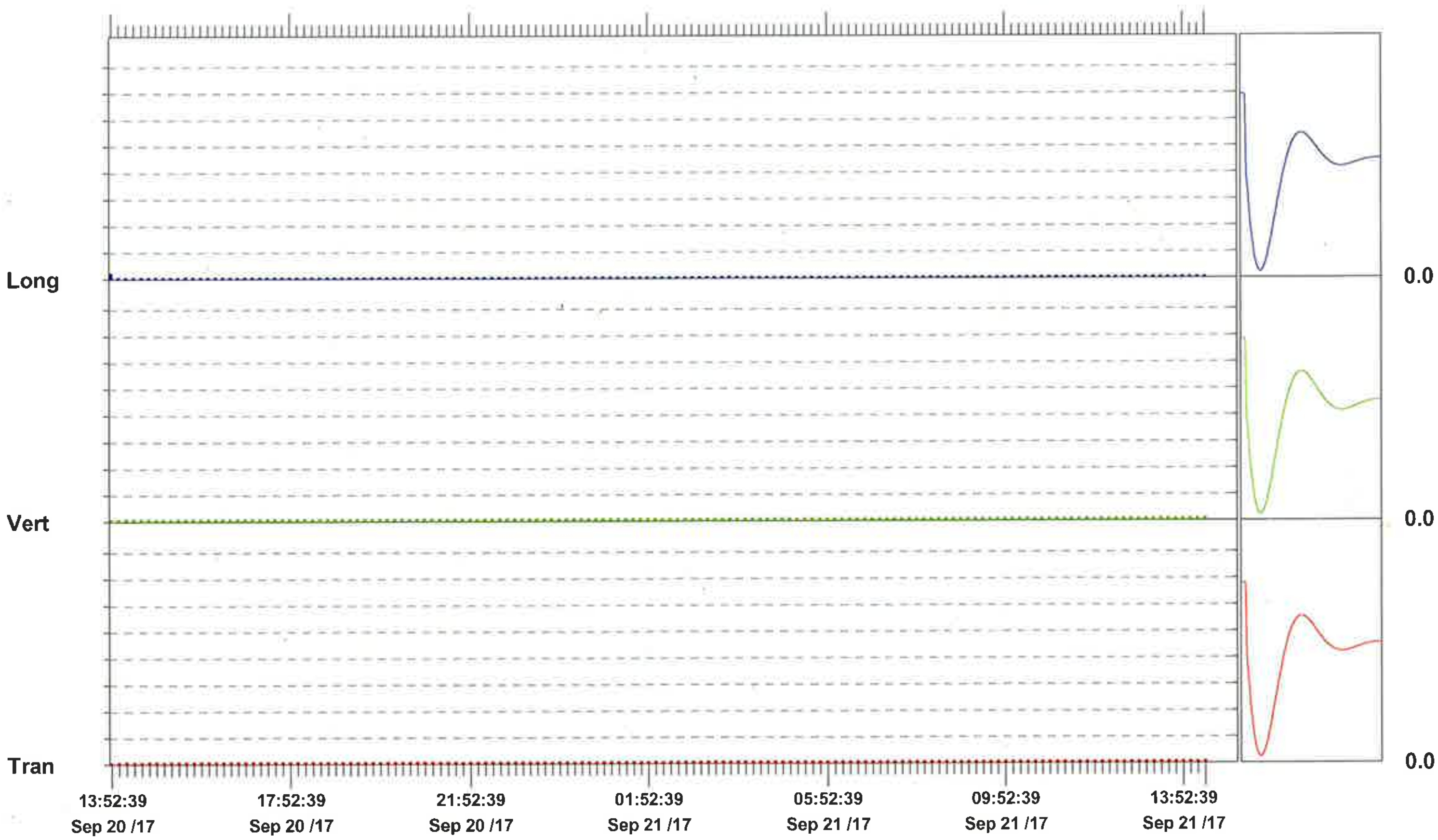
Notes

Location:	Site_8B 998b VGH Blakmore Pavillon Mech Room G319
Client:	Translink-MLBE
User Name:	Stantec Consulting Ltd.
General:	Geophonr sandbagged on concrete slab

	Tran	Vert	Long	
PPV	0.087	0.110	0.221	mm/s
ZC Freq	1.4	N/A	171	Hz
Date	Sep 20 /17	Sep 20 /17	Sep 20 /17	
Time	15:46:24	16:00:24	13:43:54	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.5	7.3	Hz
Overswing Ratio	3.5	3.3	3.8	

Peak Vector Sum 0.230 mm/s on September 20, 2017 at 13:43:54
N/A: Not Applicable





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Event Report

Histogram Start Time	11:45:54 September 6, 2017
Histogram Finish Time	23:59:28 September 6, 2017
Number of Intervals	2934.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.3 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H20M.0I0
Scaled Distance	14.2 (4.5 m, 0.1 kg)

Notes

location:Site 10b	1004 W. Broadway
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	sandbag on tile fround floor slabongrade

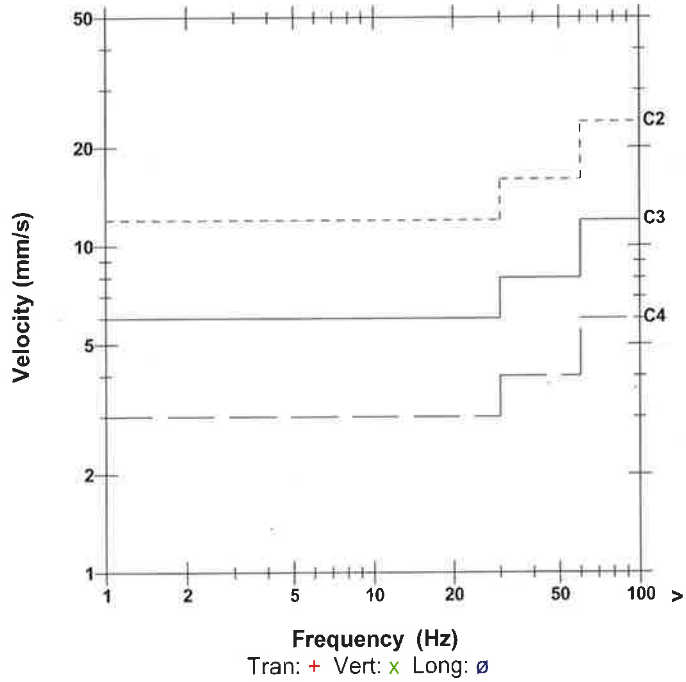
Extended Notes Setup

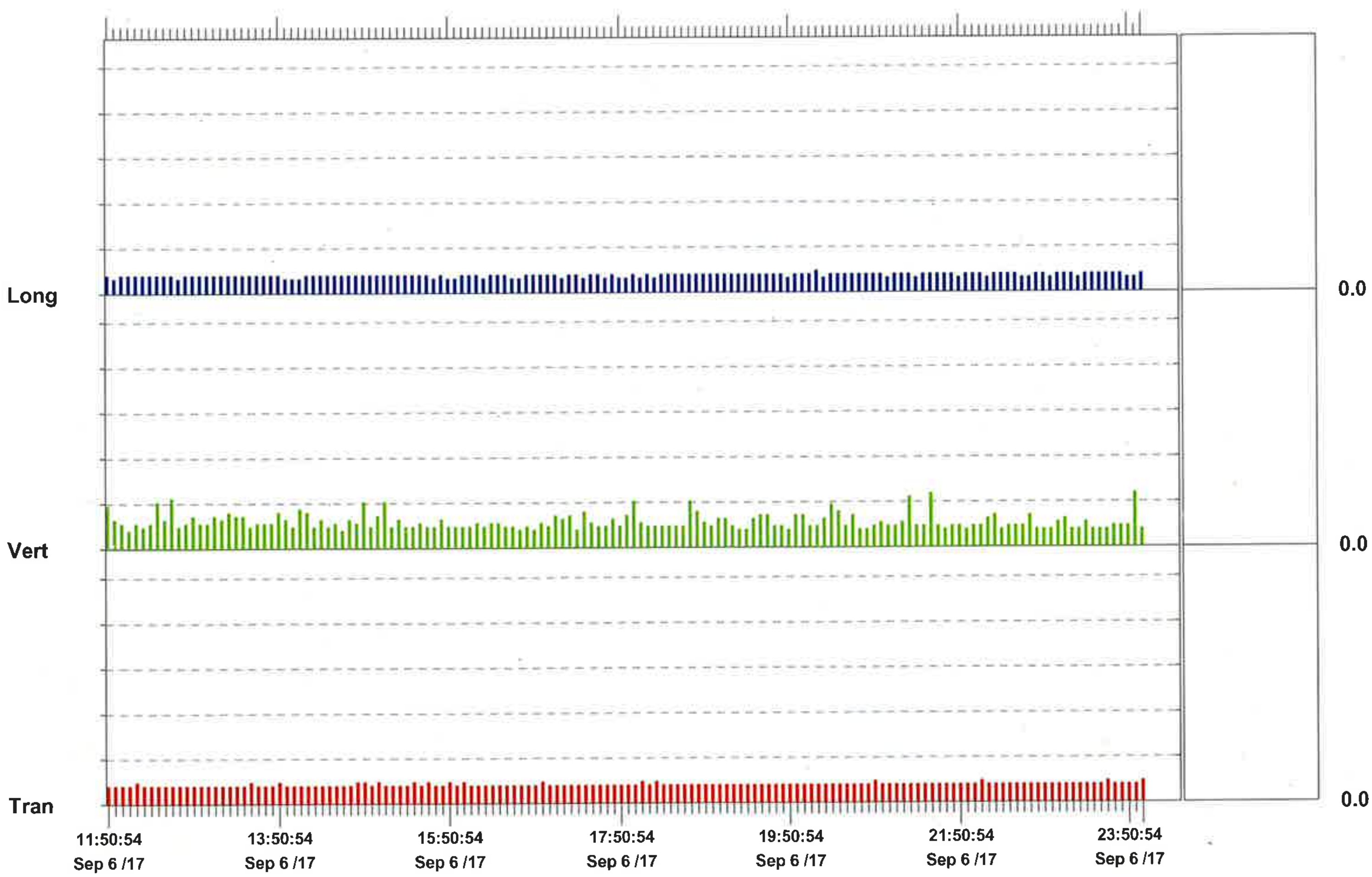
in ~~South~~ end of building old server roomalong Broadway St. no basement in bldg. NORTH

	Tran	Vert	Long	
PPV	0.095	0.238	0.095	mm/s
ZC Freq	47	79	51	Hz
Date	Sep 6 /17	Sep 6 /17	Sep 6 /17	
Time	12:10:24	21:30:39	20:09:54	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.247 mm/s on September 6, 2017 at 21:30:39

Swiss Piling Standard SN 640 312a





Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Instantel Event Report

Histogram Start Time	23:59:38 September 6, 2017
Histogram Finish Time	12:06:34 September 7, 2017
Number of Intervals	2907.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.2 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H21J.ZE0
Scaled Distance	14.2 (4.5 m, 0.1 kg)

Notes

location:Site 10b	1004 W. Broadway
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	sandbag on tile fround floor slabongrade

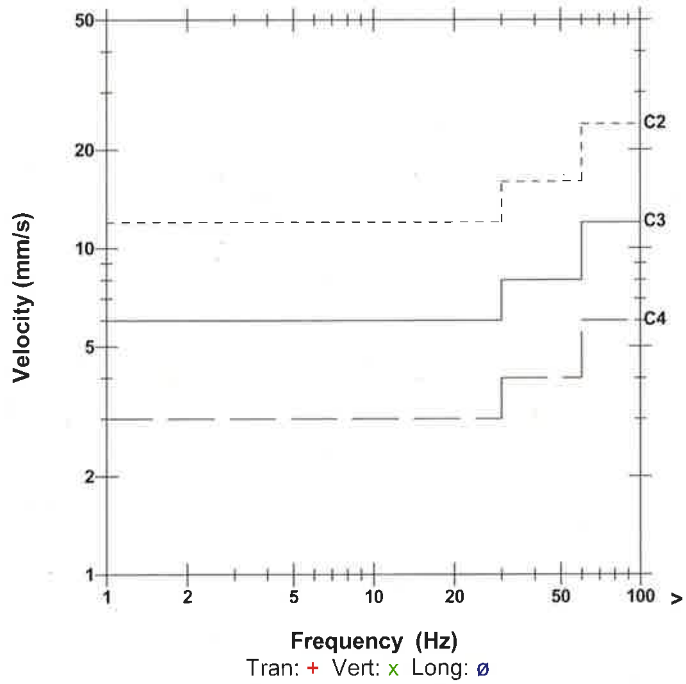
Extended Notes Setup

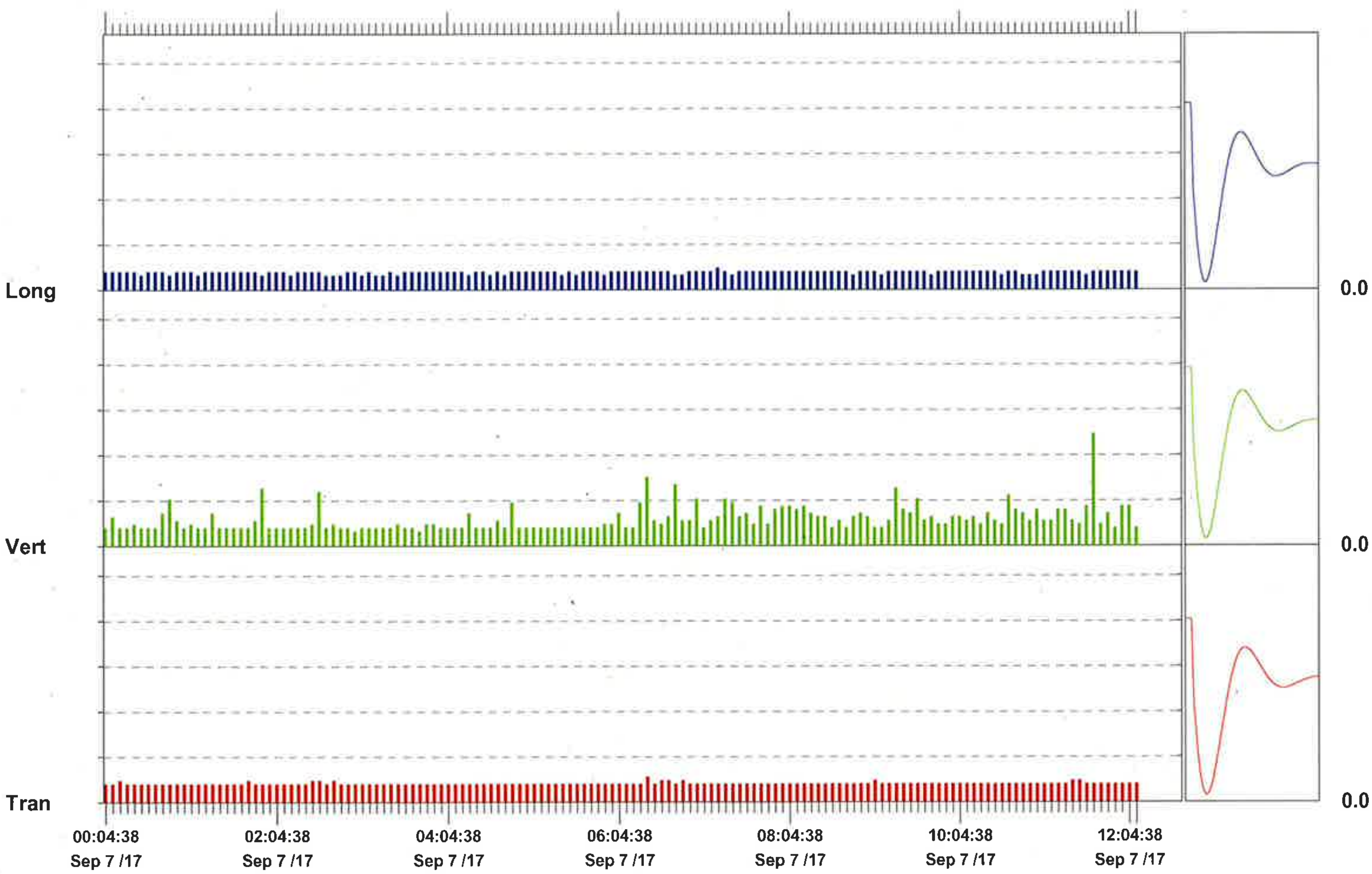
in ~~South~~ end of building old server roomalong Broadway St. no basement in bldg. NoRTH

	Tran	Vert	Long	
PPV	0.111	0.492	0.095	mm/s
ZC Freq	49	68	146	Hz
Date	Sep 7 /17	Sep 7 /17	Sep 7 /17	
Time	06:24:23	11:35:53	07:10:38	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.8	Hz
Overswing Ratio	3.7	3.7	3.4	

Peak Vector Sum 0.493 mm/s on September 7, 2017 at 11:35:53

Swiss Piling Standard SN 640 312a





Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Instantel Event Report

Histogram Start Time	10:27:24 August 30, 2017
Histogram Finish Time	23:59:28 August 30, 2017
Number of Intervals	3248.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.1 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H1NJ.PO0
Scaled Distance	17.4 (5.5 m, 0.1 kg)

Notes

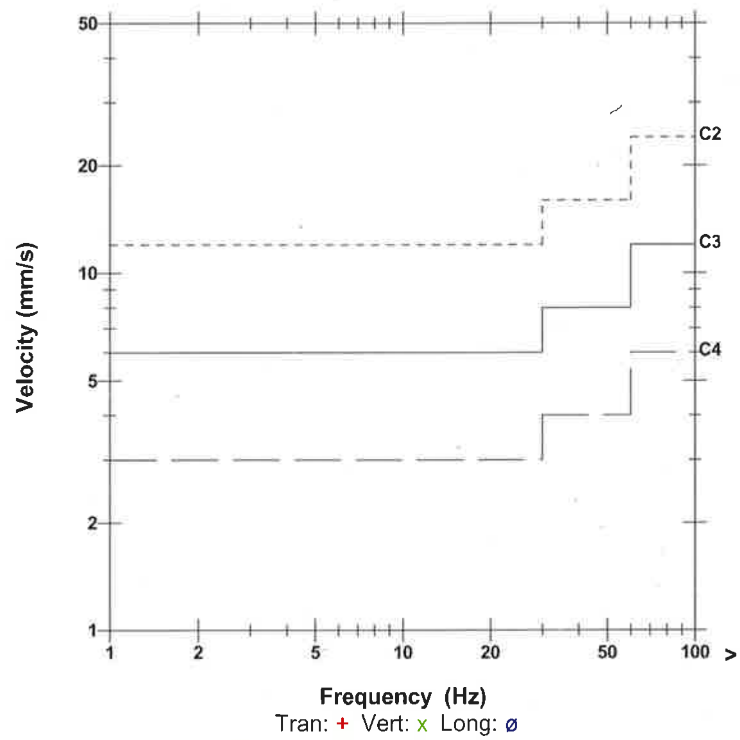
location:	Site 11A_1421 West Broadway & Hemlock
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	sandbagged on soil below basement slab

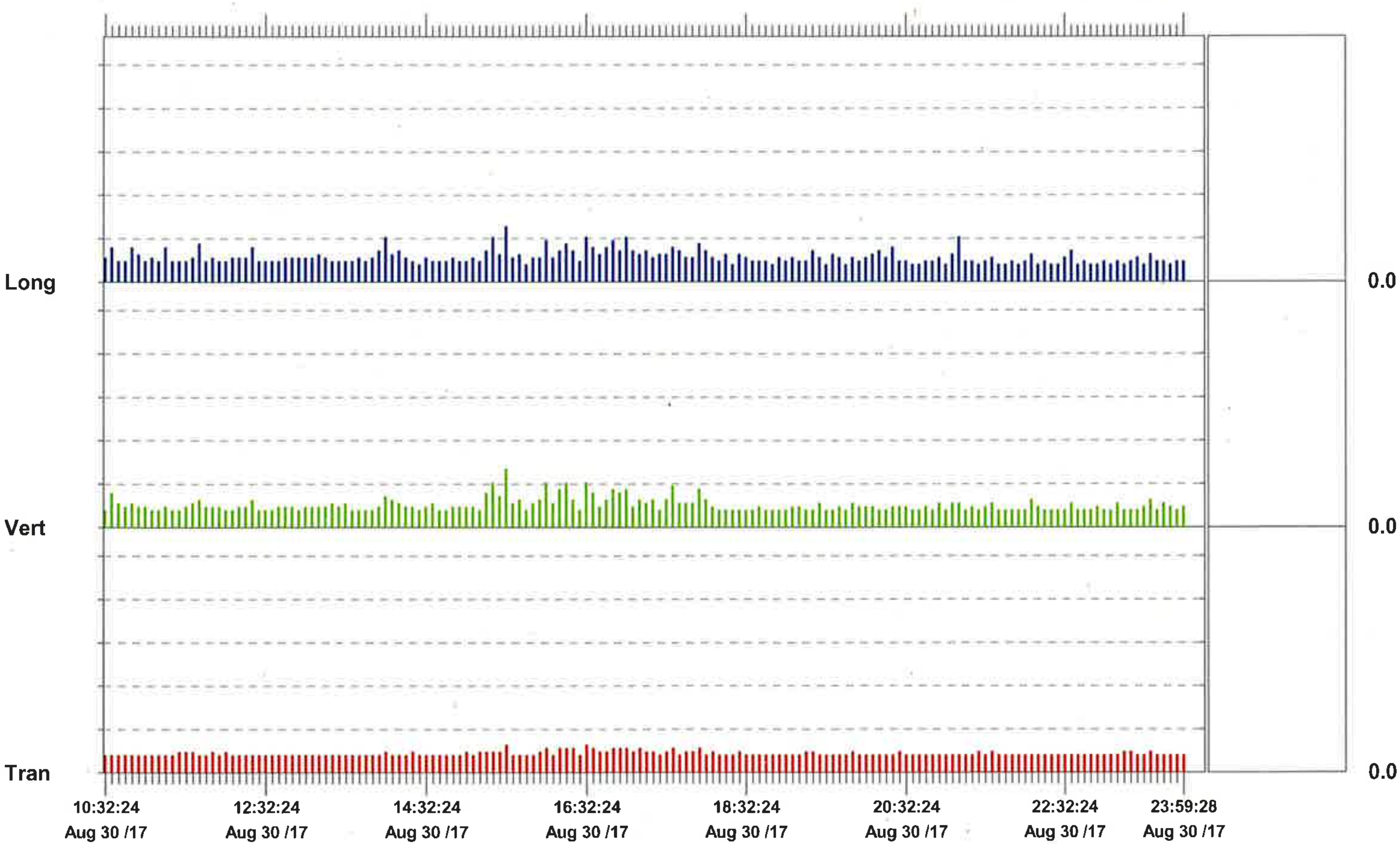
Extended Notes Setup
in North end of building

	Tran	Vert	Long	
PPV	0.127	0.270	0.254	mm/s
ZC Freq	25	20	21	Hz
Date	Aug 30 /17	Aug 30 /17	Aug 30 /17	
Time	15:28:54	15:28:54	15:28:54	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.287 mm/s on August 30, 2017 at 15:28:54

Swiss Piling Standard SN 640 312a





Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Instantel

Event Report

Histogram Start Time	23:59:38 August 30, 2017
Histogram Finish Time	13:12:50 August 31, 2017
Number of Intervals	3172.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.1 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H1OL.BE0
Scaled Distance	17.4 (5.5 m, 0.1 kg)

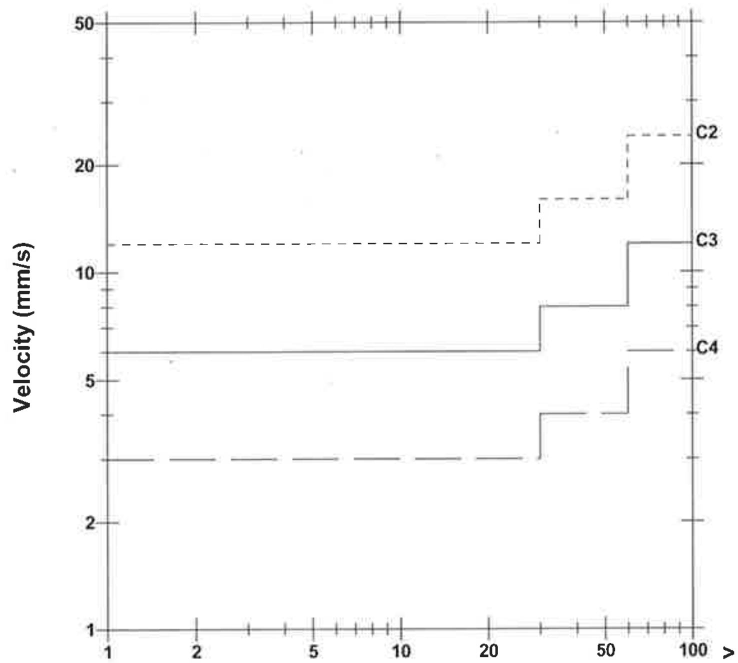
Notes
location:1421 West Broadway & Hemlock
Client:Translink MLBE
User Name:Bryce Boldt
General:Geophone sandbagged on soil below basement slab

Extended Notes Setup
in North end of building

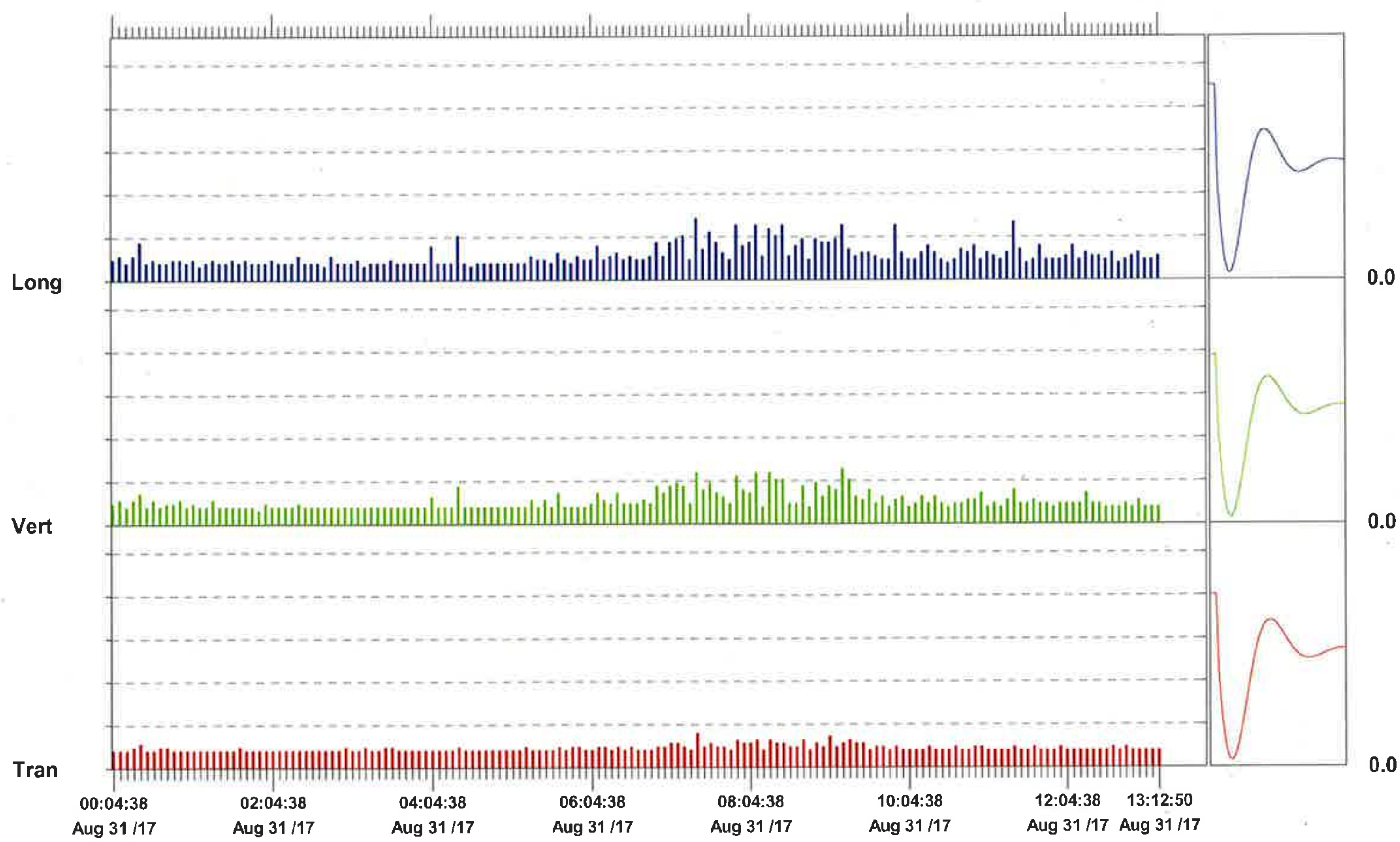
	Tran	Vert	Long	
PPV	0.159	0.254	0.286	mm/s
ZC Freq	20	19.0	25	Hz
Date	Aug 31 /17	Aug 31 /17	Aug 31 /17	
Time	07:23:23	09:13:08	07:21:53	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	8.1	Hz
Overswing Ratio	3.6	3.7	3.3	

Peak Vector Sum 0.297 mm/s on August 31, 2017 at 07:21:53

Swiss Piling Standard SN 640 312a



Frequency (Hz)
Tran: + Vert: x Long: ø



Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Instantel

Event Report

Histogram Start Time	15:51:34 August 31, 2017
Histogram Finish Time	23:59:28 August 31, 2017
Number of Intervals	1951.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.0 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H1PT.DY0
Scaled Distance	20.6 (6.5 m, 0.1 kg)

Notes

location:Site 14A	1909 W. Broadway
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	sandbagged on concrete basement slab

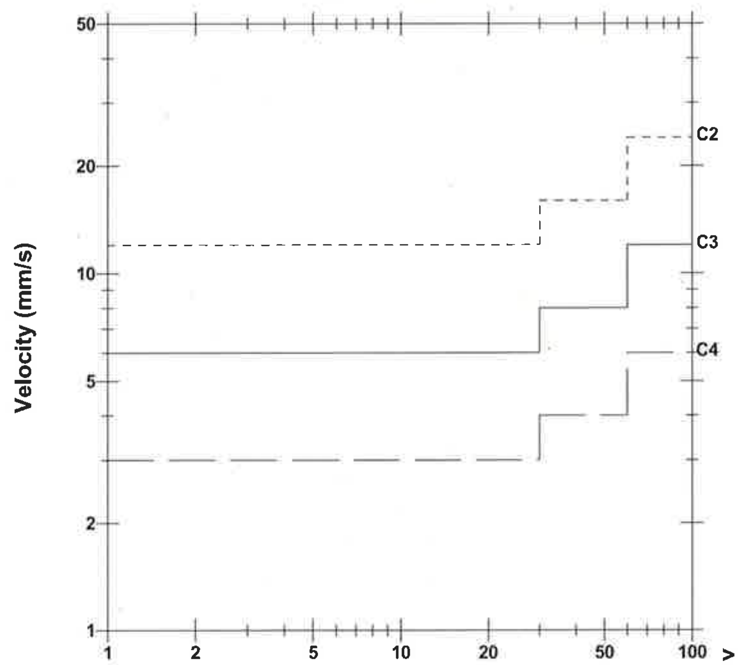
Extended Notes Setup

in NW corner of building mech. room in underground parkade

	Tran	Vert	Long	
PPV	0.238	0.619	0.270	mm/s
ZC Freq	31	20	15.5	Hz
Date	Aug 31 /17	Aug 31 /17	Aug 31 /17	
Time	16:08:34	16:14:04	21:05:04	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

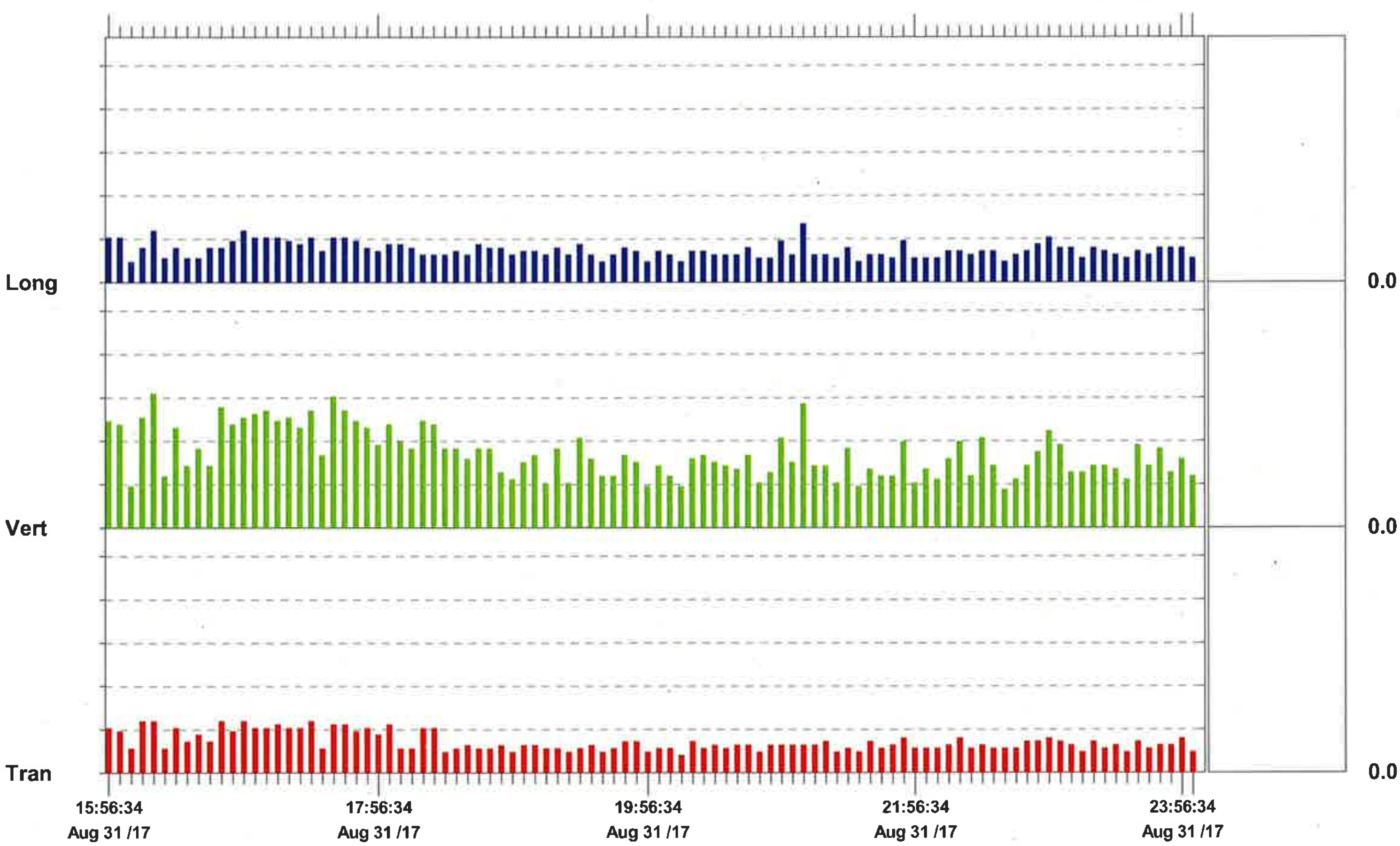
Peak Vector Sum 0.623 mm/s on August 31, 2017 at 16:14:04

Swiss Piling Standard SN 640 312a



Frequency (Hz)

Tran: + Vert: x Long: ø



Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Event Report

Histogram Start Time	23:59:38 August 31, 2017
Histogram Finish Time	14:54:37 September 1, 2017
Number of Intervals	3579.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	5.9 Volts (Battery Low)
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H1QF.ZE0
Scaled Distance	20.6 (6.5 m, 0.1 kg)

Notes

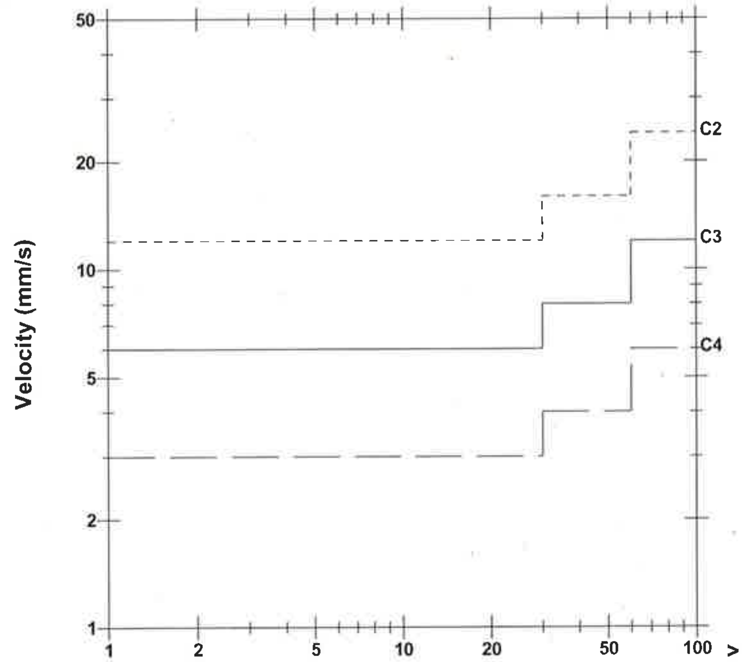
location:Site 14A	1909 W. Broadway
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	sandbagged on concrete basement slab

Extended Notes Setup
in NW corner of building mech. room in underground parkade

	Tran	Vert	Long	
PPV	0.302	0.587	0.317	mm/s
ZC Freq	19.7	15.3	16.0	Hz
Date	Sep 1 /17	Sep 1 /17	Sep 1 /17	
Time	08:00:08	06:11:23	08:00:08	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.8	Hz
Overswing Ratio	3.7	3.6	3.4	

Peak Vector Sum 0.588 mm/s on September 1, 2017 at 08:00:08

Swiss Piling Standard SN 640 312a



Frequency (Hz)
Tran: + Vert: x Long: ø

Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Event Report

Instantel

Histogram Start Time	16:05:54 September 14, 2017
Histogram Finish Time	23:59:28 September 14, 2017
Number of Intervals	1894.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.3 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H2FR.DU0
Scaled Distance	120.2 (38.0 m, 0.1 kg)

Notes

location:Site 15a arbutus christmas tree lot by arbutus
Client:Translink MLBE
User Name:Bryce Boldt
General:Geophone and sandbag on fill dug 1 ft down

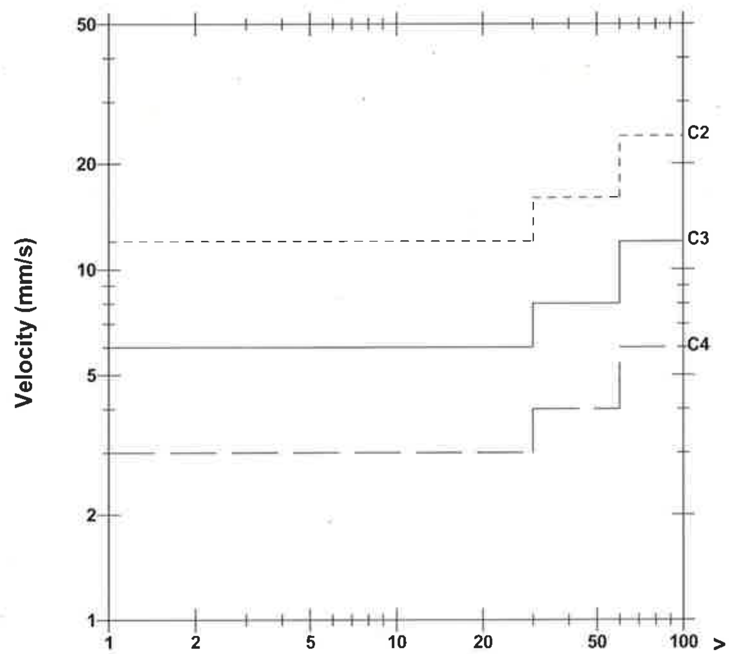
extended notes

in front of vehicle

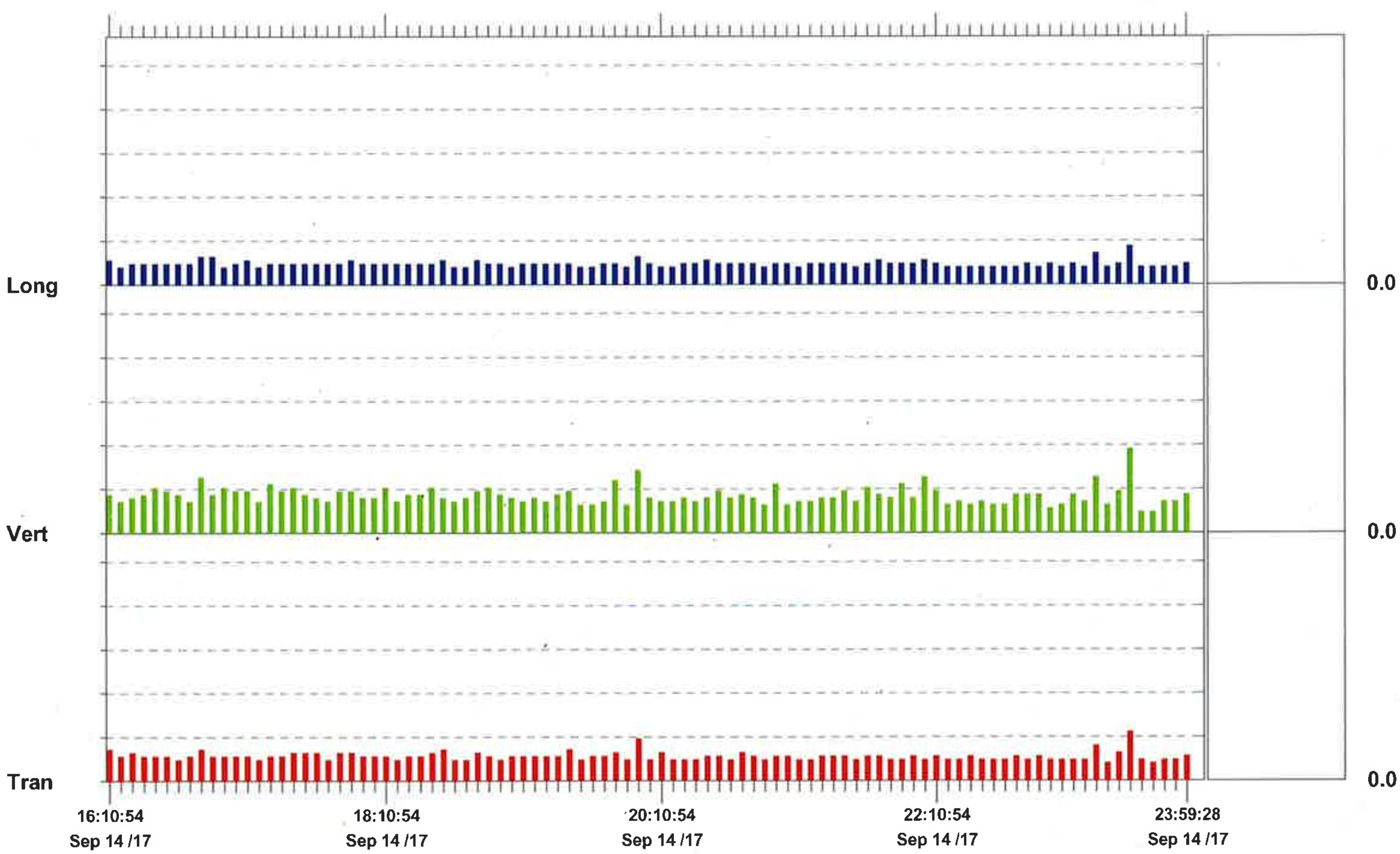
	Tran	Vert	Long	
PPV	0.222	0.381	0.175	mm/s
ZC Freq	14.6	14.8	19.7	Hz
Date	Sep 14 /17	Sep 14 /17	Sep 14 /17	
Time	23:34:24	23:34:24	23:34:24	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.387 mm/s on September 14, 2017 at 23:34:24

Swiss Piling Standard SN 640 312a



Frequency (Hz)
Tran: + Vert: x Long: ø



Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Event Report

Histogram Start Time	23:59:38 September 14, 2017
Histogram Finish Time	16:26:05 September 15, 2017
Number of Intervals	3945.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.2 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H2GD.BE0
Scaled Distance	120.2 (38.0 m, 0.1 kg)

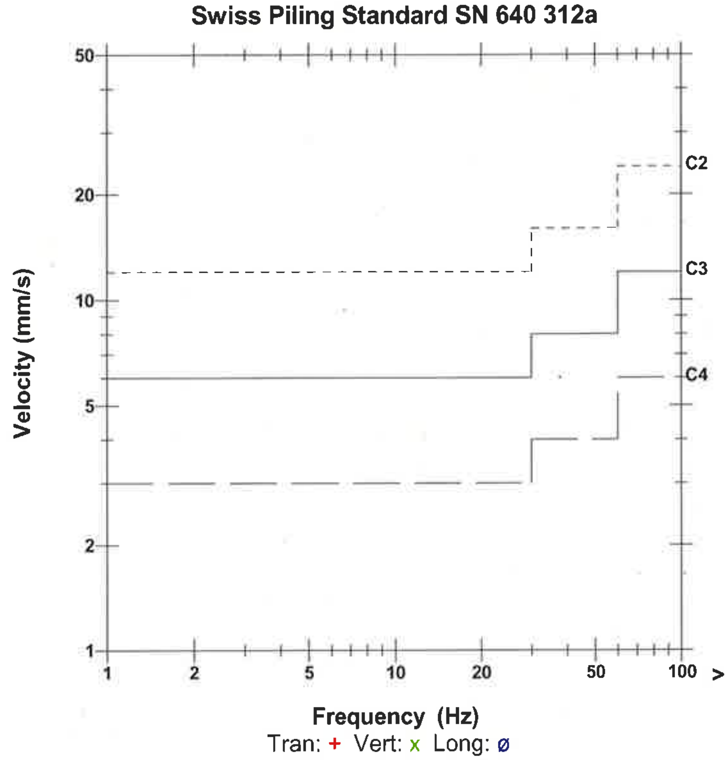
Notes

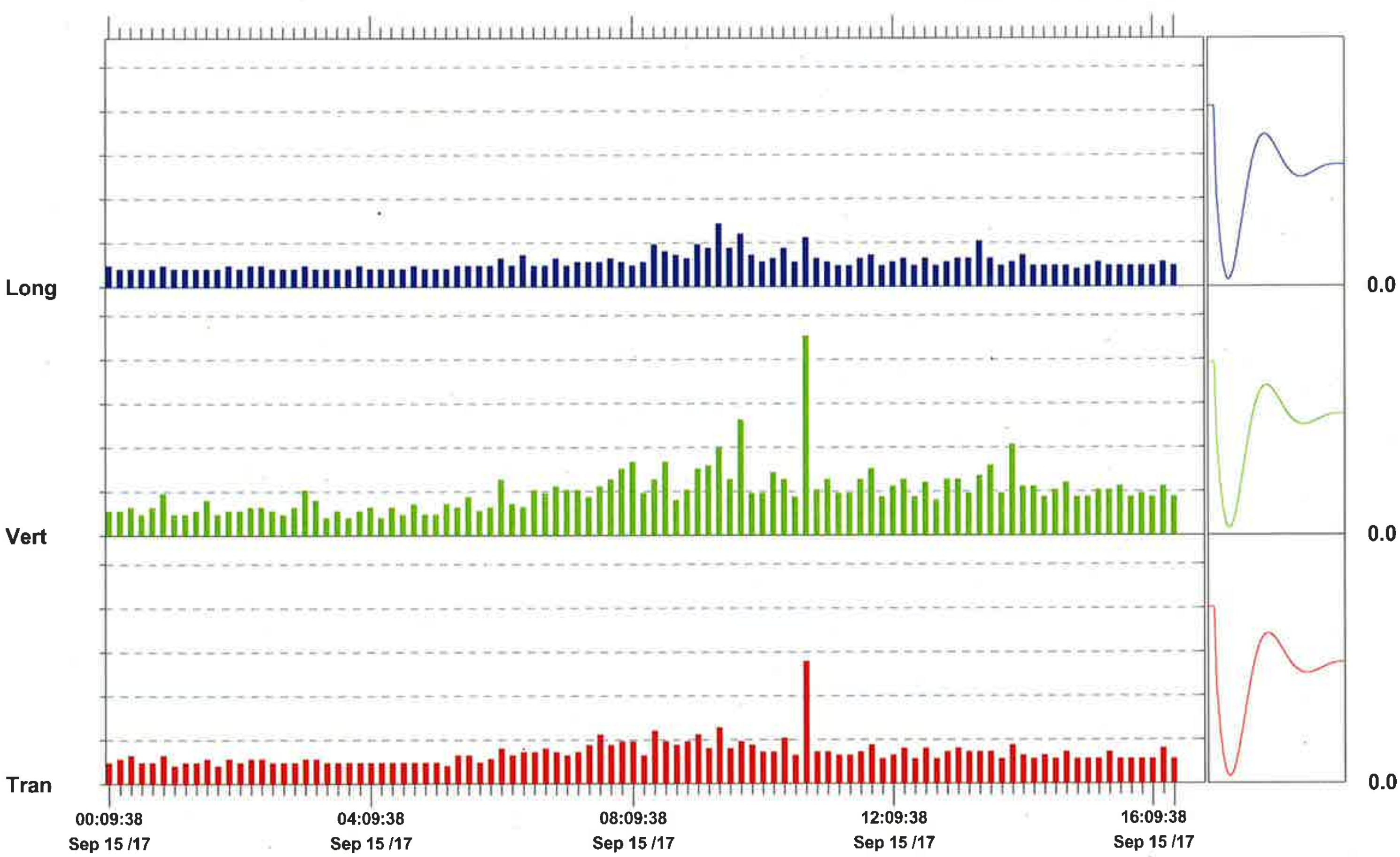
location:Site 15a	arbutus christmas tree lot by arbutus
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	and sandbag on fill dug 1 ft down

extended notes
in front of vehicle

	Tran	Vert	Long	
PPV	0.556	0.905	0.286	mm/s
ZC Freq	68	37	>200	Hz
Date	Sep 15 /17	Sep 15 /17	Sep 15 /17	
Time	10:41:38	10:41:38	09:23:23	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.8	Hz
Overswing Ratio	3.6	3.7	3.4	

Peak Vector Sum 0.964 mm/s on September 15, 2017 at 10:41:38





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Printed: November 6, 2017 (V 10.74)

Event Report

Histogram Start Time	13:53:58 September 26, 2017
Histogram Finish Time	14:23:21 September 27, 2017
Number of Intervals	5877.53 at 15 seconds
Range	Geo:254.0 mm/s
Sample Rate	2048sps
Job Number:	4099
Operator/Setup:	Operator/Bryce.MMB

Serial Number	UM11142 V 10-84 Micromate DIN
Battery Level	3.8 Volts
Unit Calibration	December 19, 2016 by Instantel
File Name	UM11142_20170926135358.IDFH

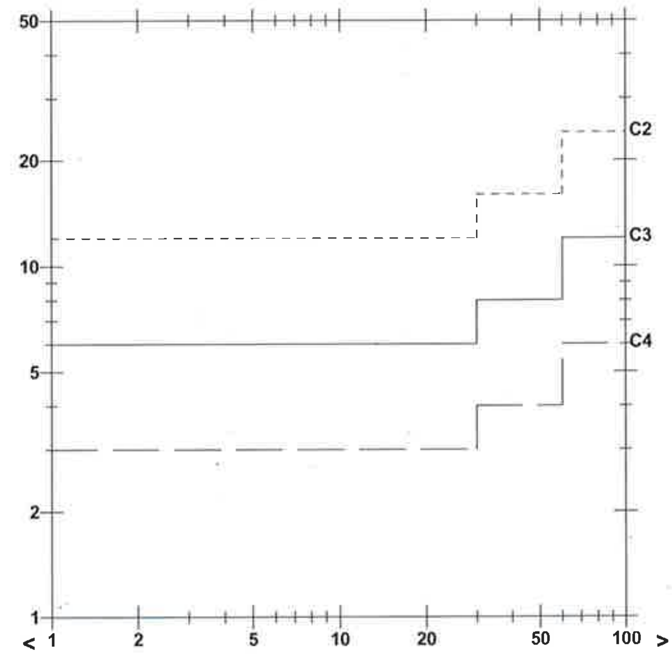
Notes

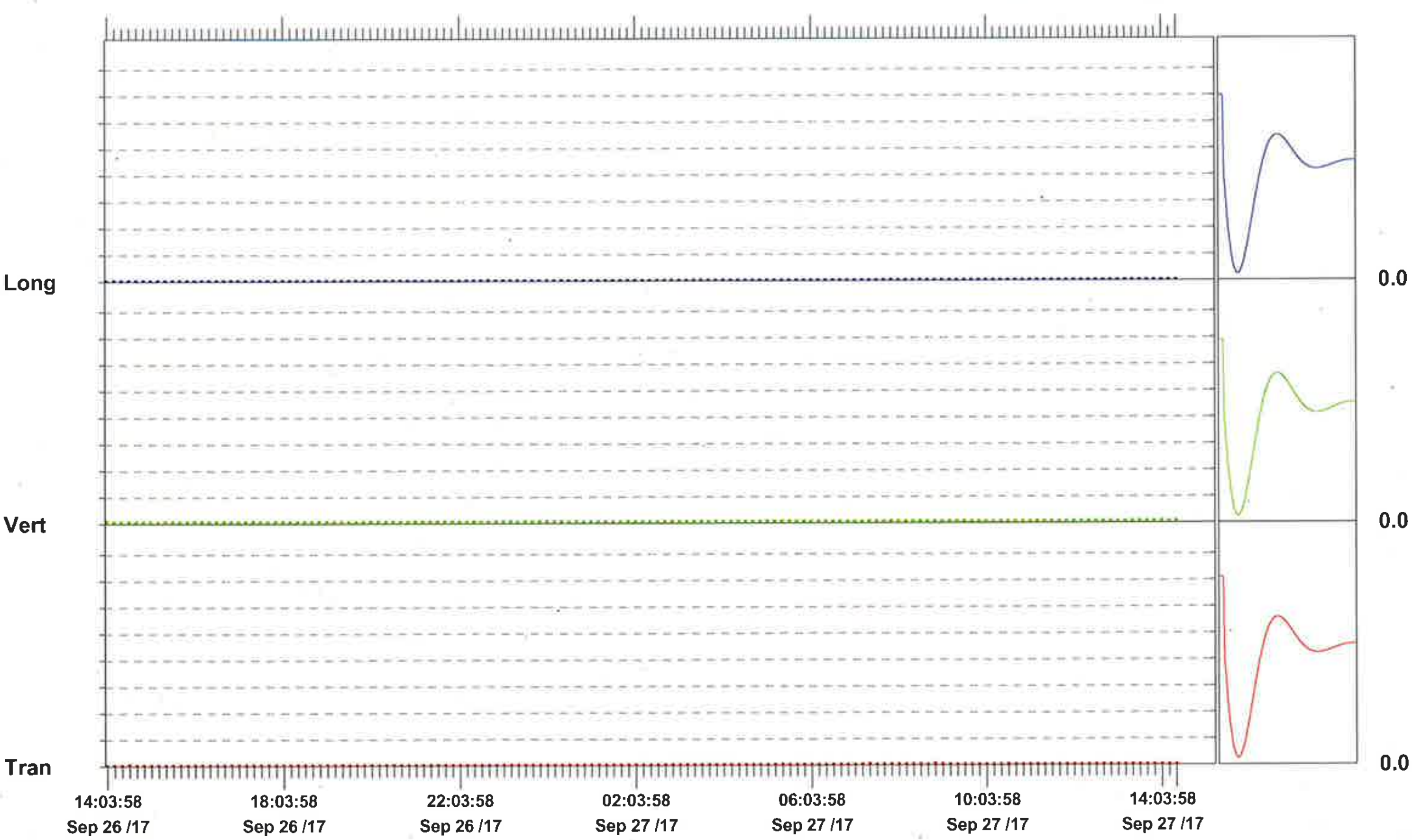
Location: Site 16A - Animal Research [inside]
Client: Translink-MLBE
User Name: Stantec Consulting Ltd.
General: Geophonr sandbag on basement conc. slab

	Tran	Vert	Long	
PPV	0.087	0.142	0.071	mm/s
ZC Freq	49	1.2	93	Hz
Date	Sep 27 /17	Sep 26 /17	Sep 26 /17	
Time	08:46:58	13:54:28	14:09:58	
Sensor Check	Passed	Passed	Passed	
Frequency	7.5	7.5	7.3	Hz
Overswing Ratio	3.4	3.3	3.7	

Peak Vector Sum 0.144 mm/s on September 26, 2017 at 13:54:28

Swiss Piling Standard SN 640 312a





Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 1.000 mm/s/div

Sensor Check

Event Report

Histogram Start Time	14:16:43 September 26, 2017
Histogram Finish Time	23:59:28 September 26, 2017
Number of Intervals	2331.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.1 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H31U.BV0

Notes

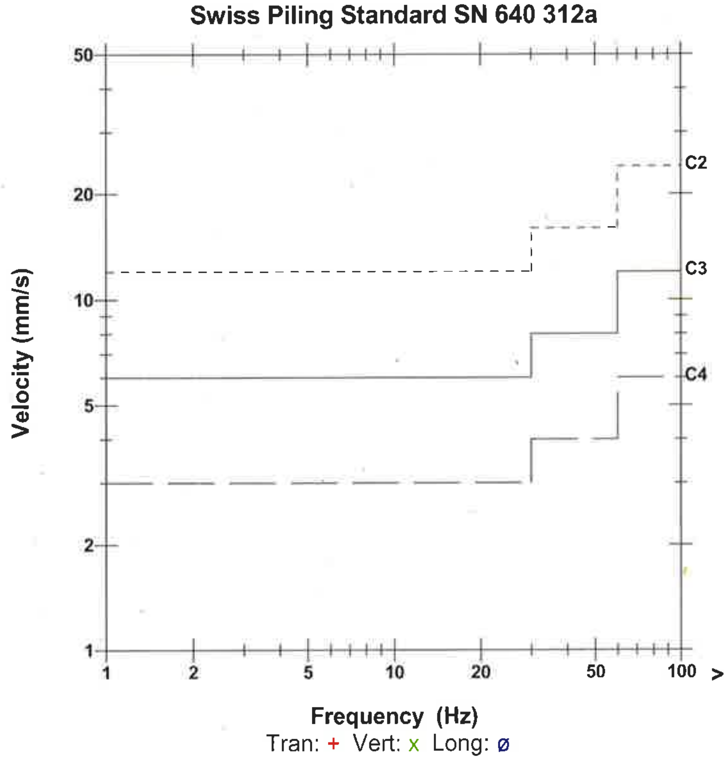
location:Site 16b	VGH Animal Research outside in AC cage
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	burried in landscape area NW corner Bldg

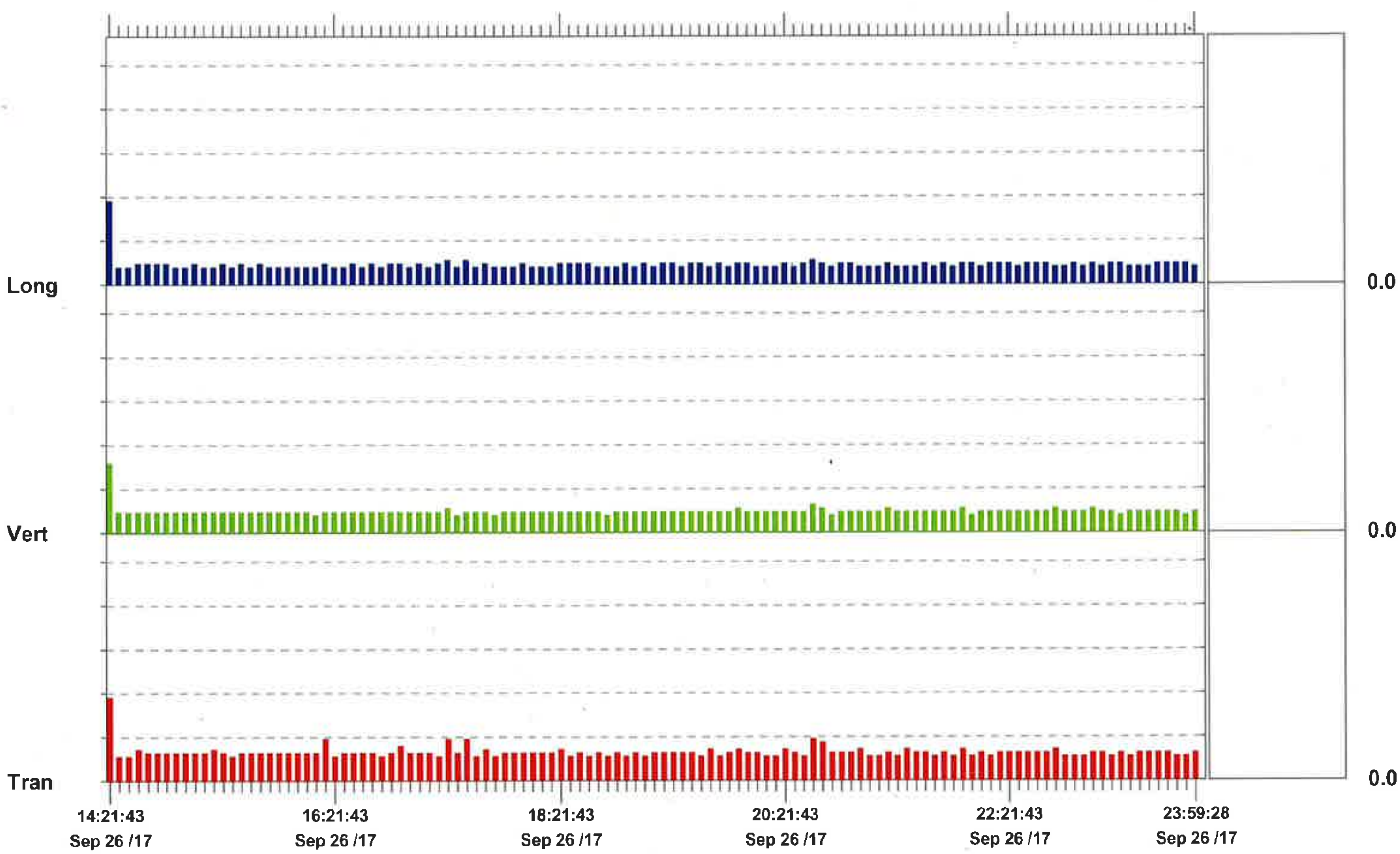
extended notes

lawn outside cage along Oak Street

	Tran	Vert	Long	
PPV	0.381	0.317	0.381	mm/s
ZC Freq	102	93	93	Hz
Date	Sep 26 /17	Sep 26 /17	Sep 26 /17	
Time	14:21:28	14:21:43	14:18:43	
Sensor Check	Disabled	Disabled	Disabled	
Frequency	***	***	***	Hz
Overswing Ratio	***	***	***	

Peak Vector Sum 0.436 mm/s on September 26, 2017 at 14:21:28





Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Printed: November 6, 2017 (V 10.74)

Event Report

Histogram Start Time	23:59:38 September 26, 2017
Histogram Finish Time	14:11:17 September 27, 2017
Number of Intervals	3406.00 at 15 seconds
Range	Geo:31.75 mm/s
Sample Rate	2048sps
Job Number:	4099

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.1 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696H32L.BE0

Notes

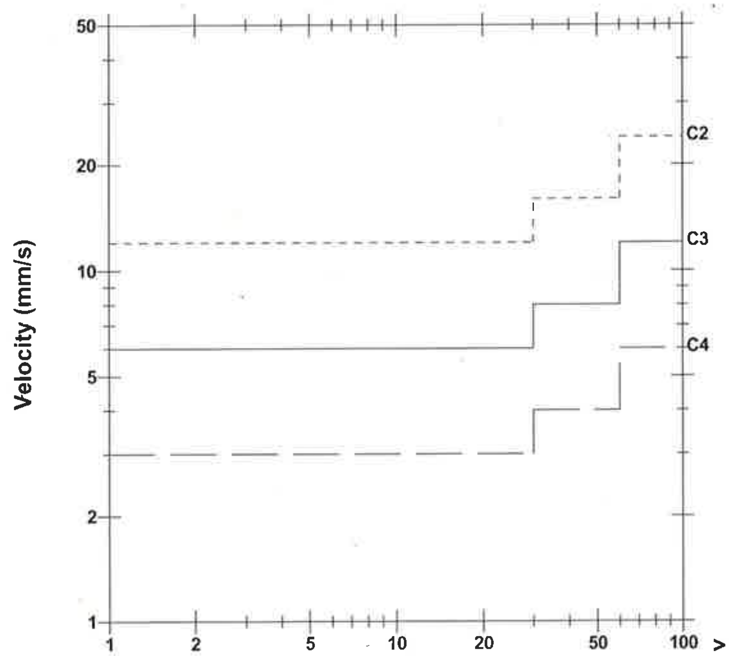
location:Site 16b	VGH Animal Research outside in AC cage
Client:Translink	MLBE
User Name:Bryce	Boldt
General:Geophone	burried in landscape area NW corner Bldg

extended notes
lawn outside cage along Oak Street

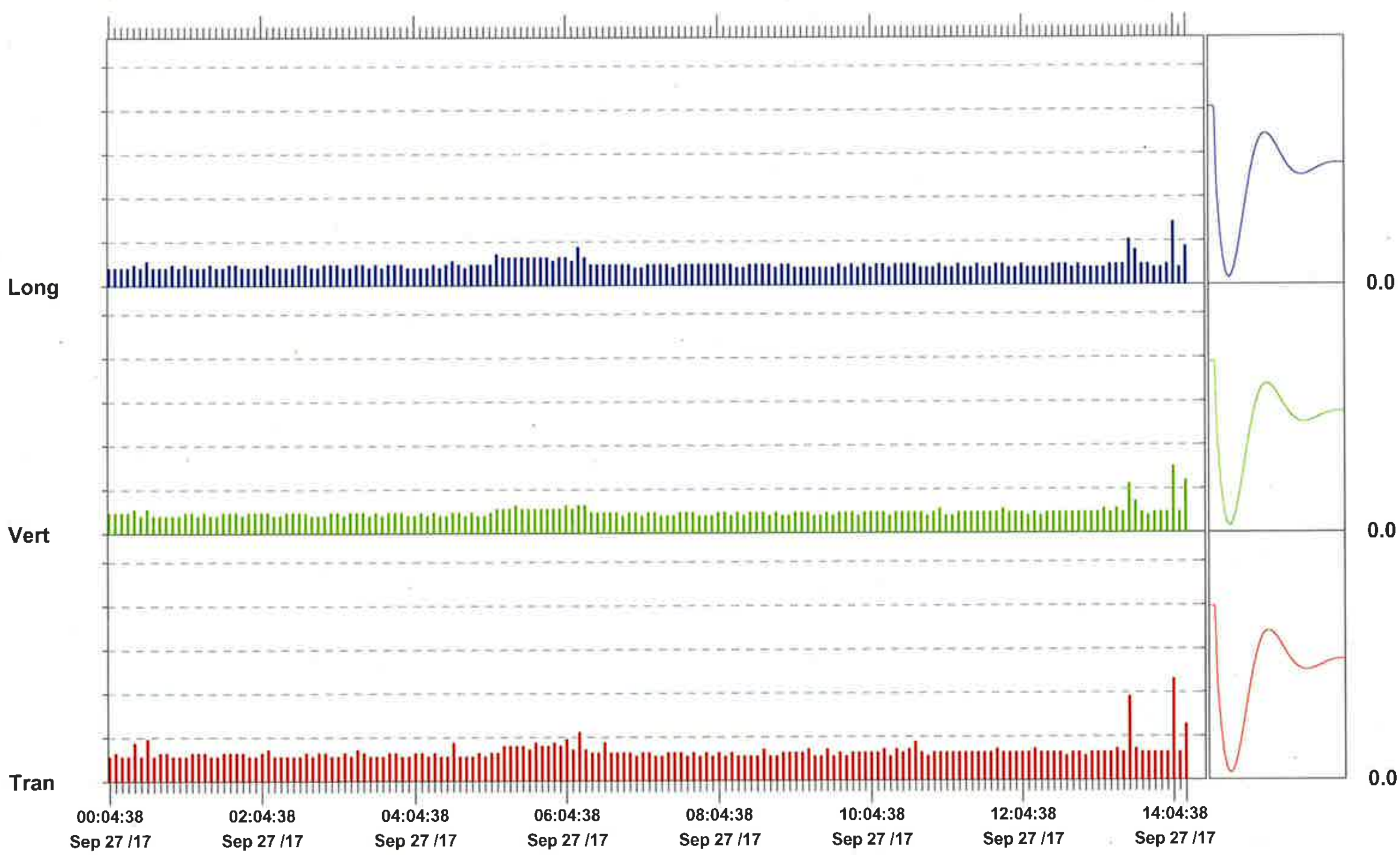
	Tran	Vert	Long	
PPV	0.460	0.302	0.286	mm/s
ZC Freq	93	93	79	Hz
Date	Sep 27 /17	Sep 27 /17	Sep 27 /17	
Time	14:01:08	14:01:08	14:01:08	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.8	Hz
Overswing Ratio	3.7	3.7	3.5	

Peak Vector Sum 0.480 mm/s on September 27, 2017 at 14:01:08

Swiss Piling Standard SN 640 312a



Frequency (Hz)
Tran: + Vert: x Long: ø



Time Scale: 5 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div

Sensor Check

Event Report

Histogram Start Time	10:24:47 March 6, 2018
Histogram Finish Time	10:34:49 March 7, 2018
Number of Intervals	5800.00 at 15 seconds
Range	Geo:31.7 mm/s
Sample Rate	2048sps
Job Number:	1582

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.2 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696HBBO.XB0

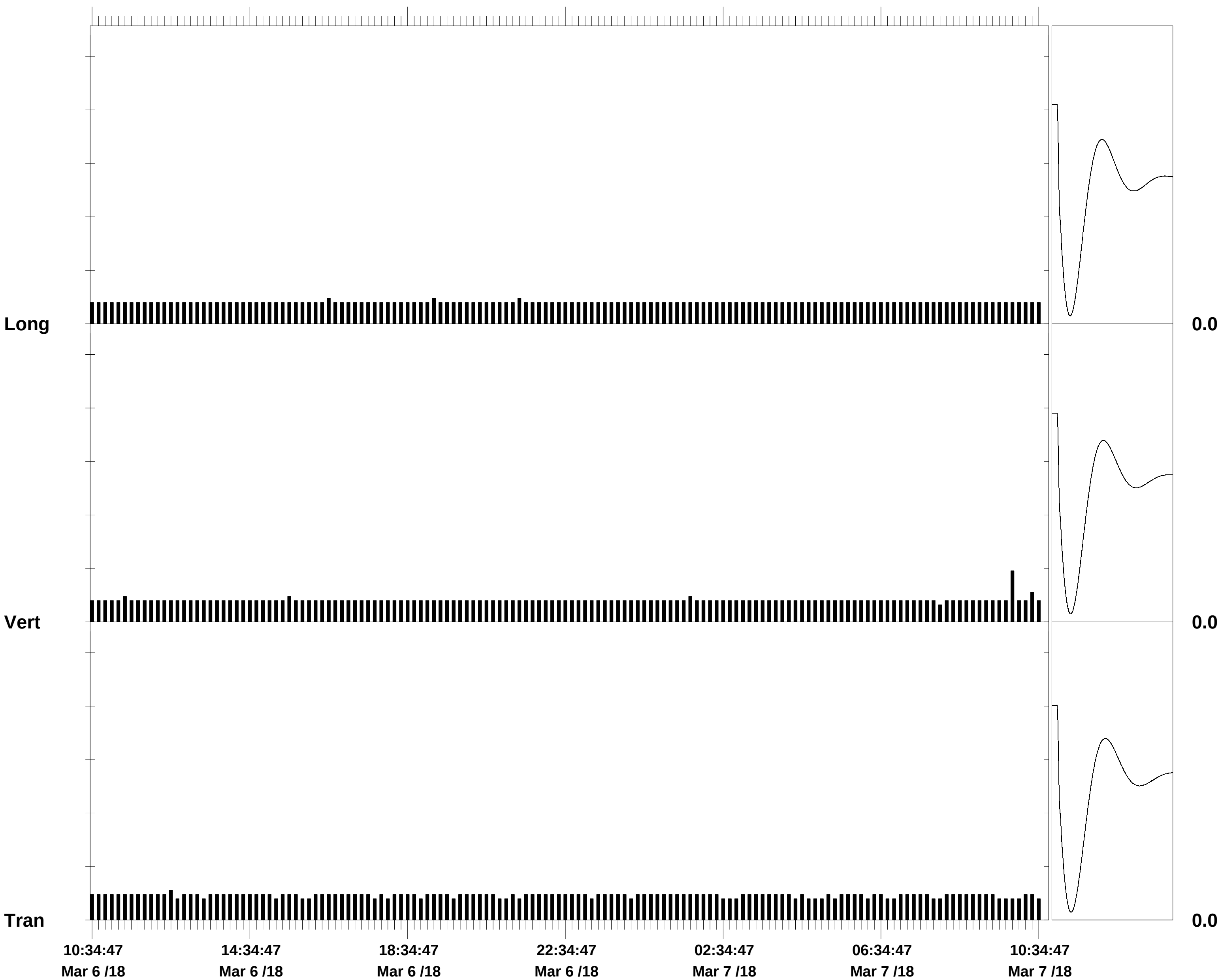
Notes

Location:NW basement VGH
Client:Translink
user Name:Kelvin
General:NW corner

extended notes

	Tran	Vert	Long	
PPV	0.111	0.190	0.0952	mm/s
ZC Freq	38	73	79	Hz
Date	Mar 6 /18	Mar 7 /18	Mar 6 /18	
Time	12:29:02	09:54:17	16:27:32	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.9	Hz
Overswing Ratio	3.7	3.7	3.4	

Peak Vector Sum 0.197 mm/s on March 7, 2018 at 09:54:17



Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Instantel

Event Report

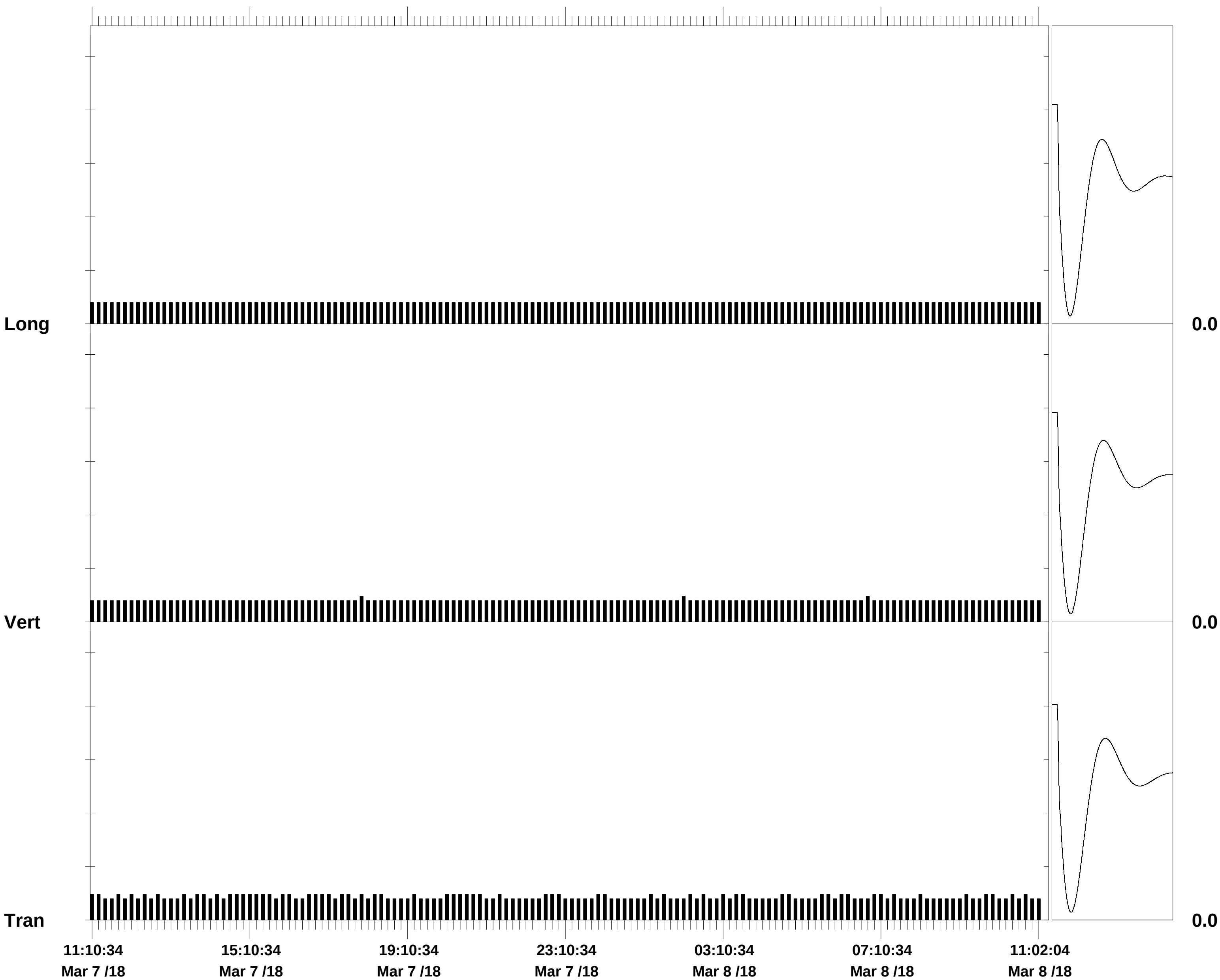
Histogram Start Time 11:00:34 March 7, 2018
Histogram Finish Time 11:02:04 March 8, 2018
Number of Intervals 5765.00 at 15 seconds
Range Geo:31.7 mm/s
Sample Rate 2048sps
Job Number: 1582
Notes
Location:BCCancer Van VGH
Client:Translink
user Name:Kelvin
General:Under stairs

Serial Number BA20696 V 10.72-8.17 BlastMate III
Battery Level 6.0 Volts
Unit Calibration January 20, 2017 by Instantel
File Name V696HBDL.8Y0

extended notes

	Tran	Vert	Long	
PPV	0.0952	0.0952	0.0794	mm/s
ZC Freq	47	128	68	Hz
Date	Mar 7 /18	Mar 7 /18	Mar 7 /18	
Time	11:00:49	17:59:49	11:01:04	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.9	Hz
Overswing Ratio	3.7	3.7	3.4	

Peak Vector Sum 0.112 mm/s on March 7, 2018 at 11:52:49



Time Scale: 10 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Event Report

Histogram Start Time	11:53:49 February 28, 2018
Histogram Finish Time	07:35:32 March 2, 2018
Number of Intervals	10486.00 at 15 seconds
Range	Geo:31.7 mm/s
Sample Rate	2048sps
Job Number:	1582

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	5.9 Volts (Battery Low)
Unit Calibration	January 20, 2017 by Instantel
File Name	V696HB0P.1P0

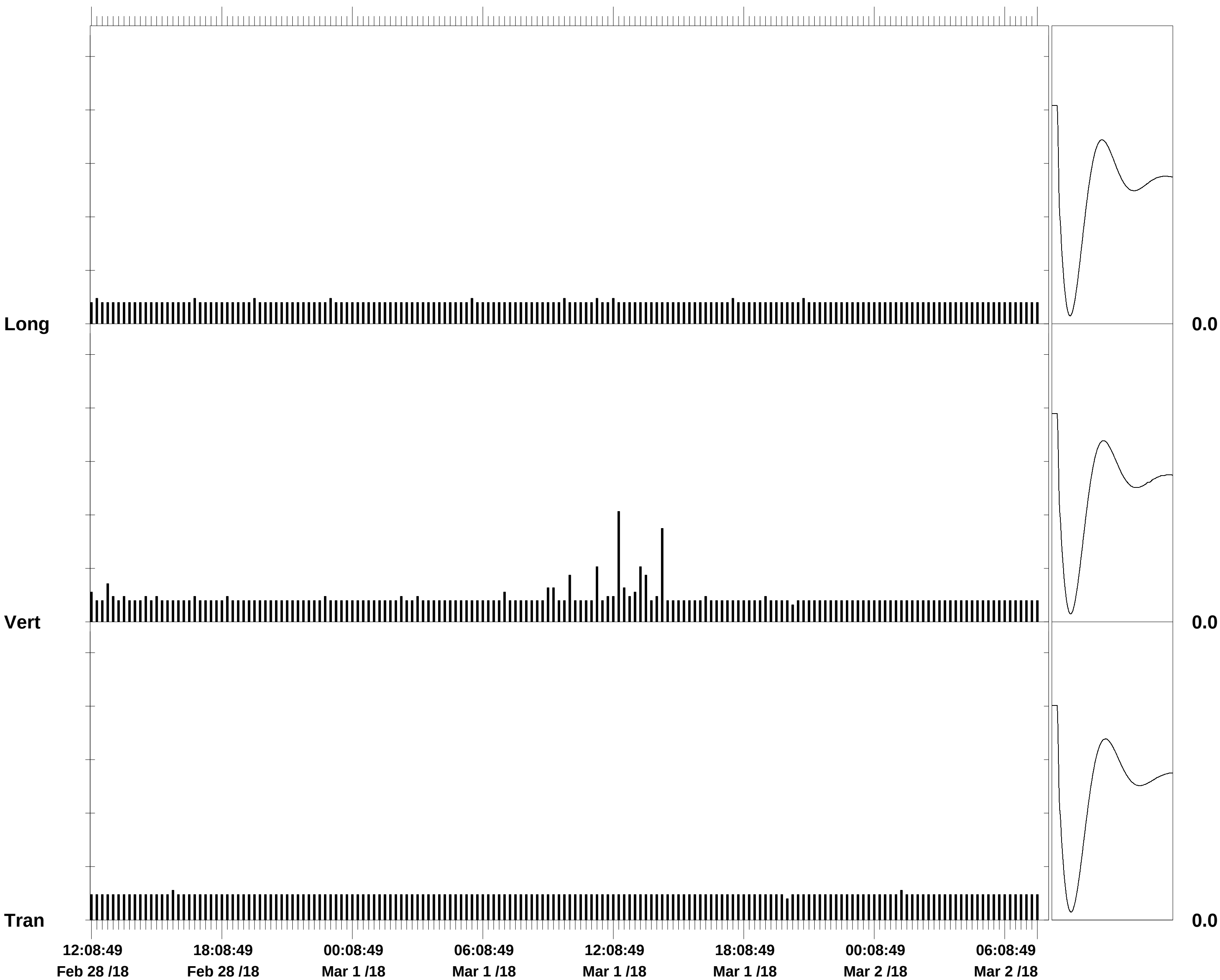
Notes

Location:Theatre ECUAD
Client:Translink
user Name:Kelvin
General:Geophone geophone by student seating area entr

extended notes

	Tran	Vert	Long	
PPV	0.111	0.413	0.0952	mm/s
ZC Freq	8.6	85	24	Hz
Date	Feb 28 /18	Mar 1 /18	Feb 28 /18	
Time	15:48:49	12:21:34	12:15:19	
Sensor Check	Passed	Passed	Passed	
Frequency	7.3	7.6	7.9	Hz
Overswing Ratio	3.7	3.7	3.5	

Peak Vector Sum 0.415 mm/s on March 1, 2018 at 12:21:34



Time Scale: 15 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

Instantel

Event Report

Histogram Start Time	07:43:30 March 2, 2018
Histogram Finish Time	07:42:44 March 5, 2018
Number of Intervals	17276.00 at 15 seconds
Range	Geo:31.7 mm/s
Sample Rate	2048sps
Job Number:	1582

Serial Number	BA20696 V 10.72-8.17 BlastMate III
Battery Level	6.8 Volts
Unit Calibration	January 20, 2017 by Instantel
File Name	V696HB42.SI0

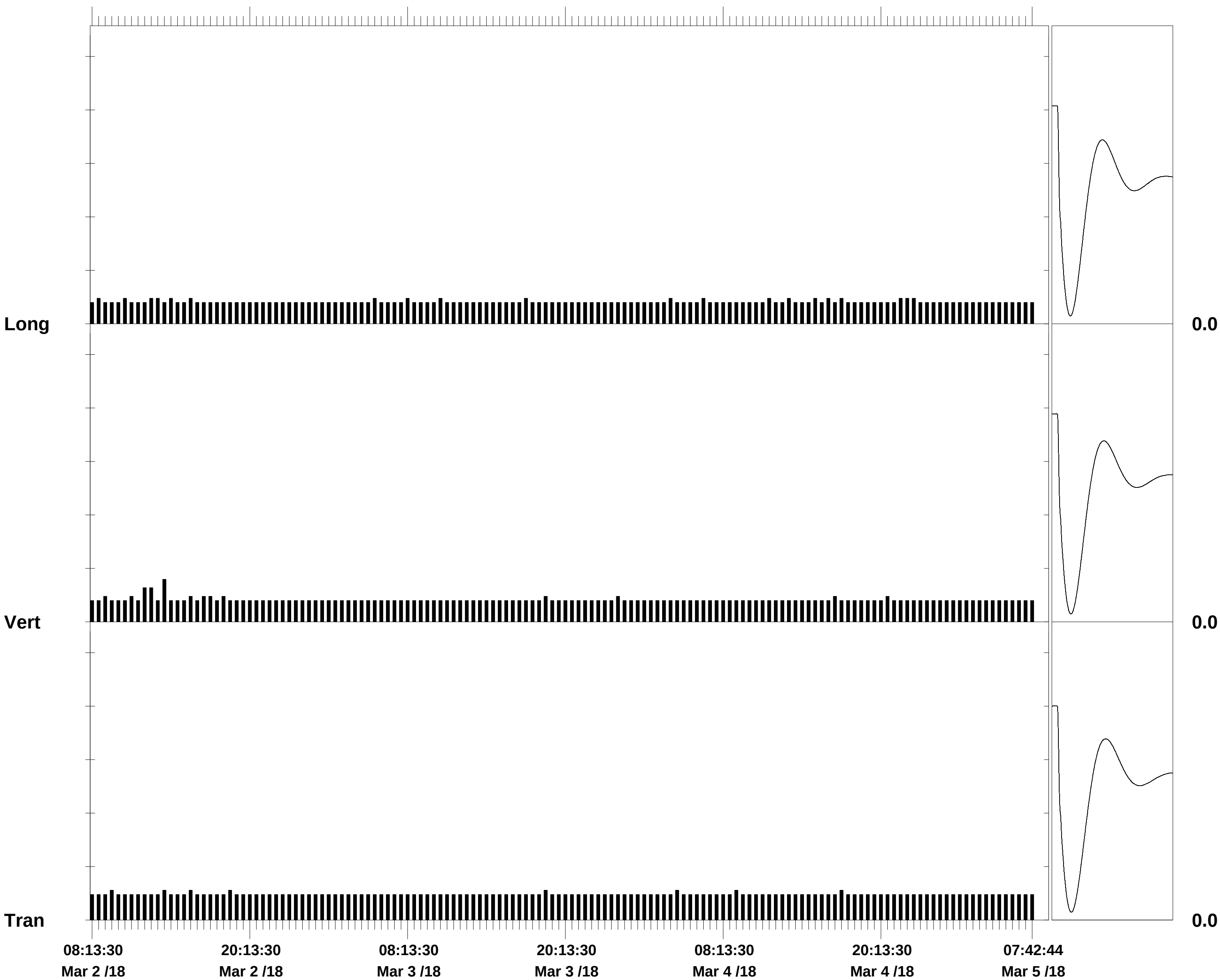
Notes

Location:motion room ECUAD
Client:Translink
user Name:Kelvin
General:NE corner geophone next to storage

extended notes

	Tran	Vert	Long	
PPV	0.111	0.159	0.0952	mm/s
ZC Freq	64	9.8	30	Hz
Date	Mar 2 /18	Mar 2 /18	Mar 2 /18	
Time	09:27:30	13:34:45	08:32:30	
Sensor Check	Passed	Passed	Passed	
Frequency	7.2	7.5	7.8	Hz
Overswing Ratio	3.7	3.7	3.4	

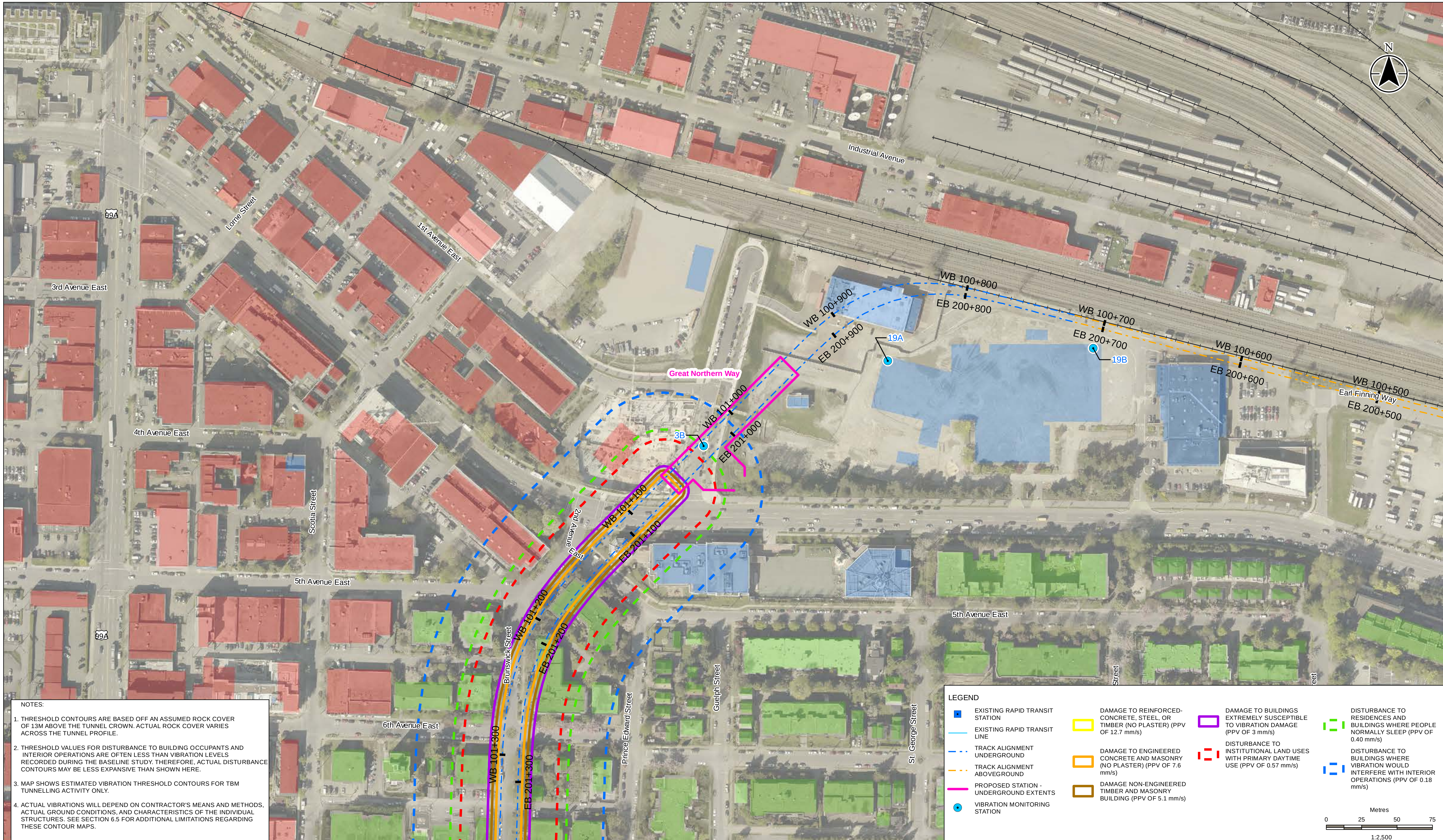
Peak Vector Sum 0.166 mm/s on March 2, 2018 at 13:34:45



Time Scale: 30 minutes /div **Amplitude Scale:** Geo: 0.200 mm/s/div Sensor Check

APPENDIX B

Vibration Threshold Contours for Tunnel Construction



NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR TBM TUNNELLING ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION
Great Northern Way Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX B.1 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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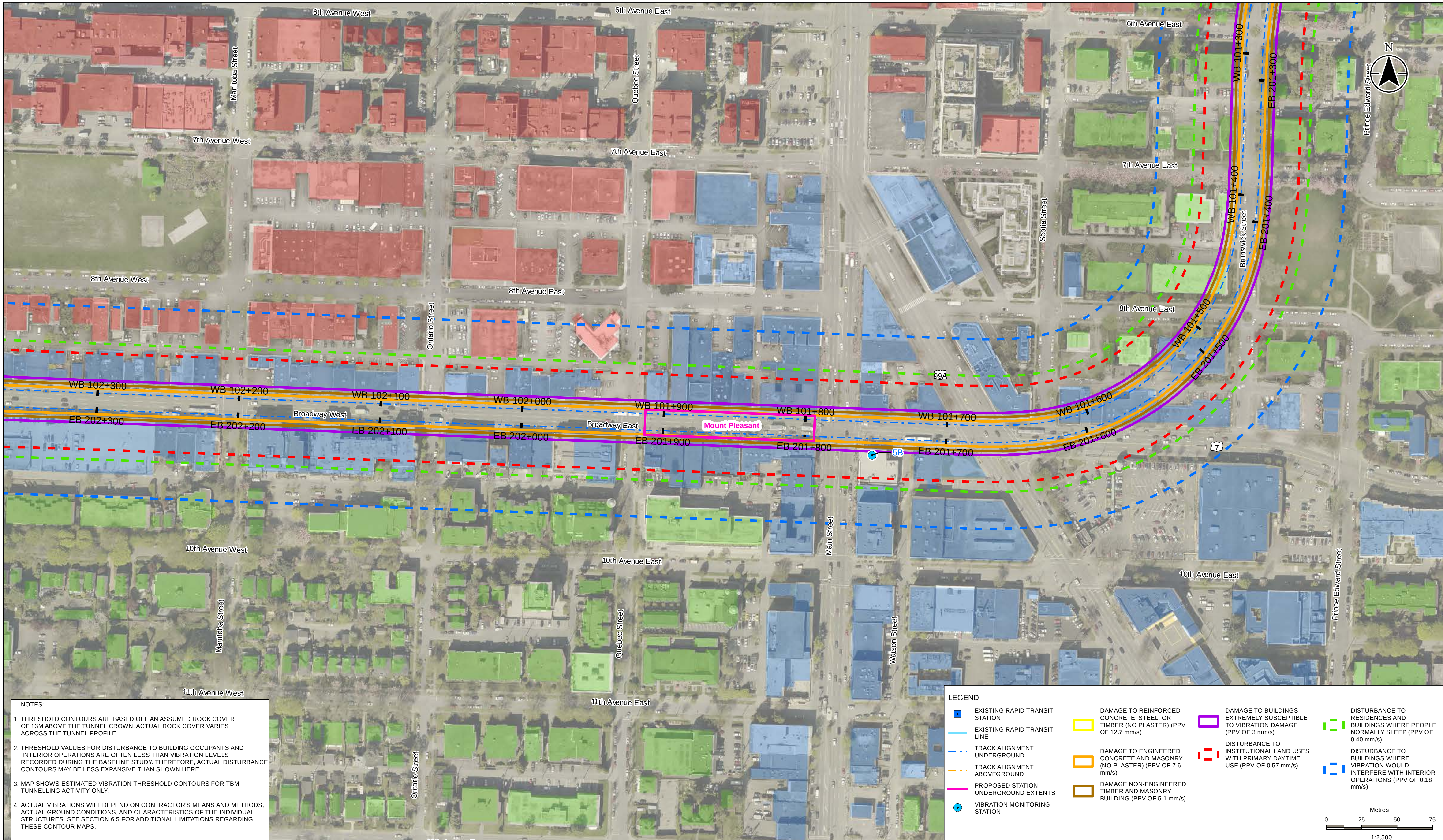

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR TBM TUNNELLING ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION
Mount Pleasant Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX B.2		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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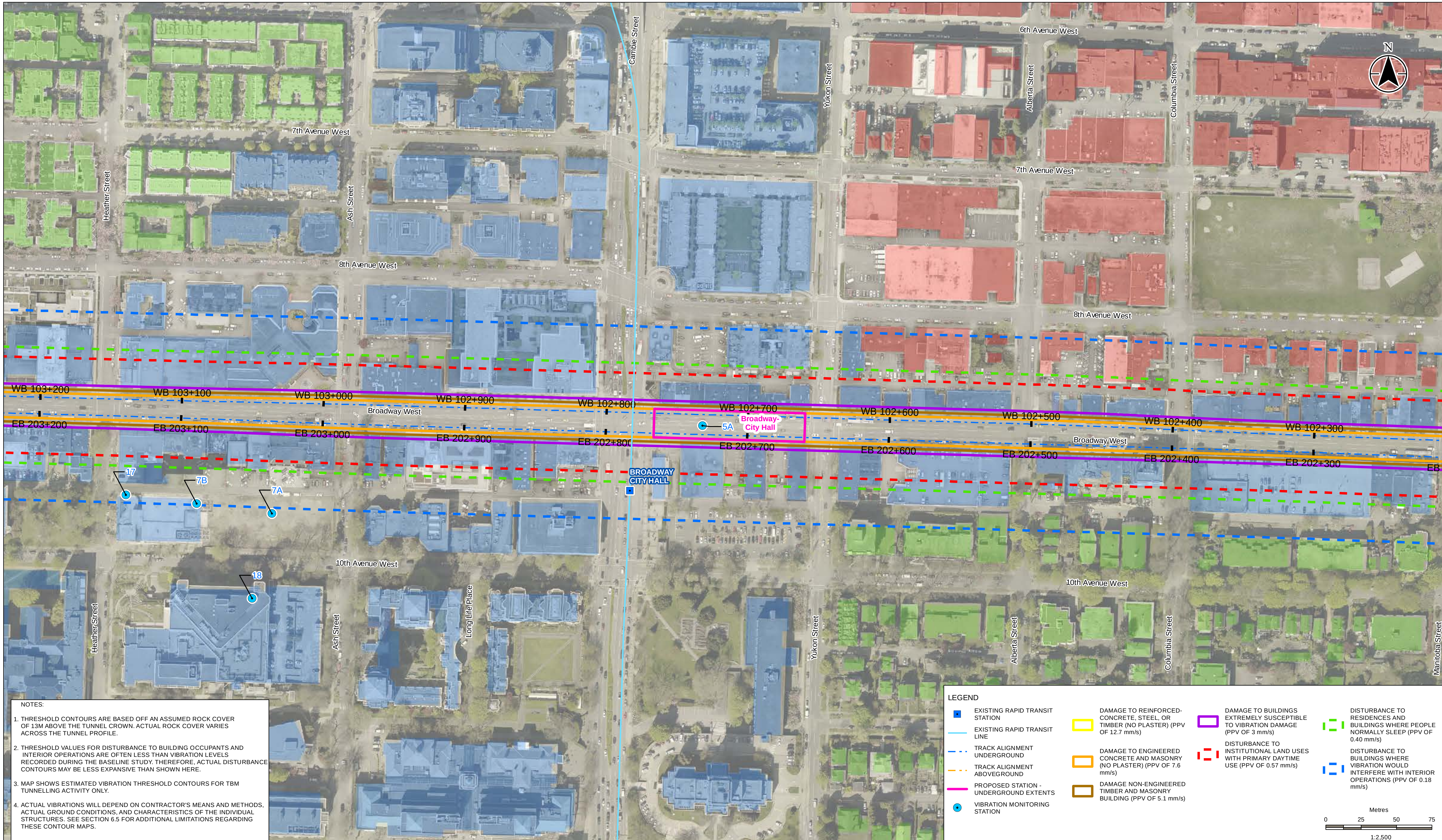

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
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3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR TBM TUNNELLING ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION
Broadway-City Hall Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX B.3		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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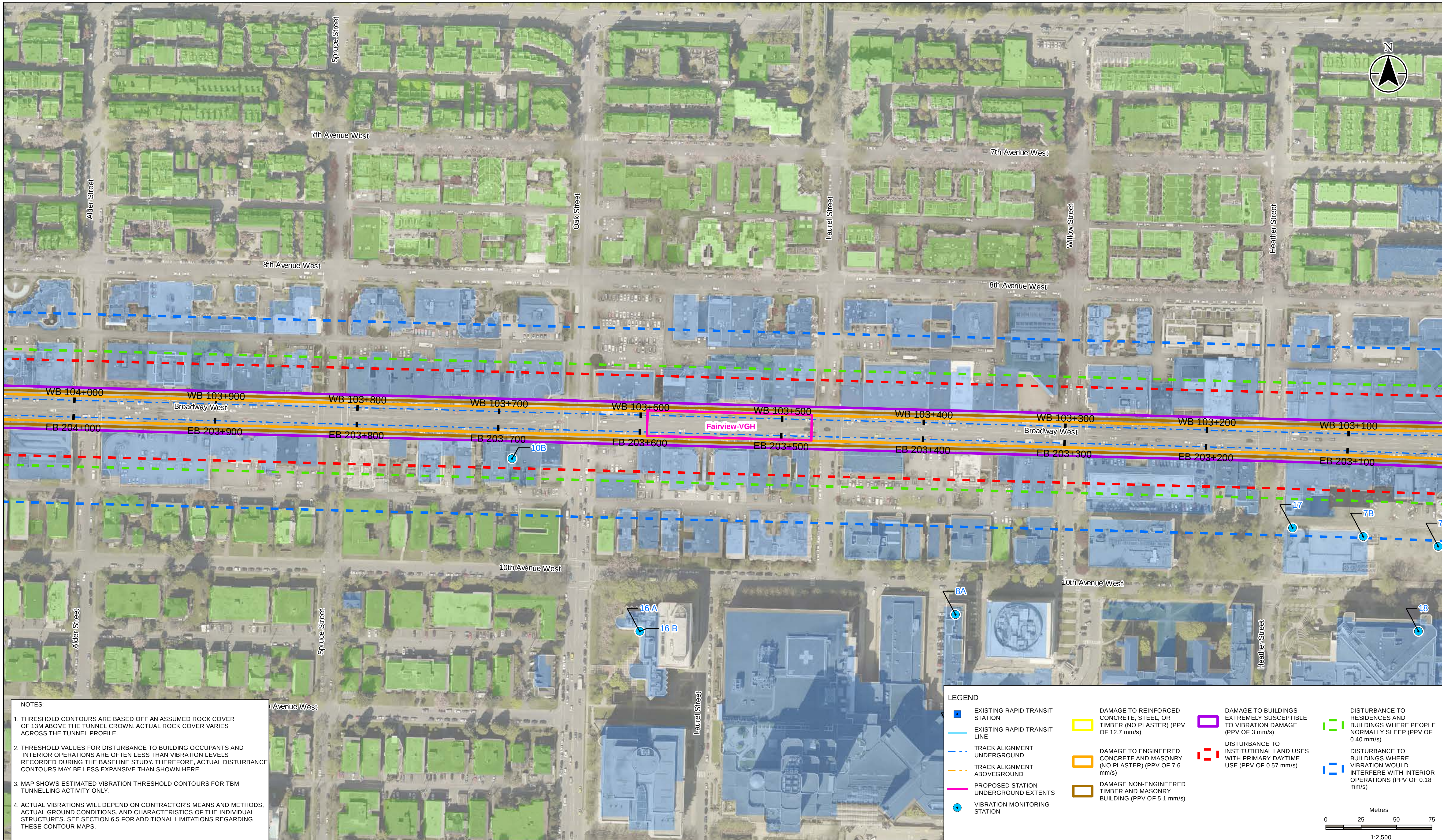

NOTES:

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3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR TBM TUNNELLING ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
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- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

DESIGNED	JP	18-02-16 DATE
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CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION
Fairview-VGH Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX B.4		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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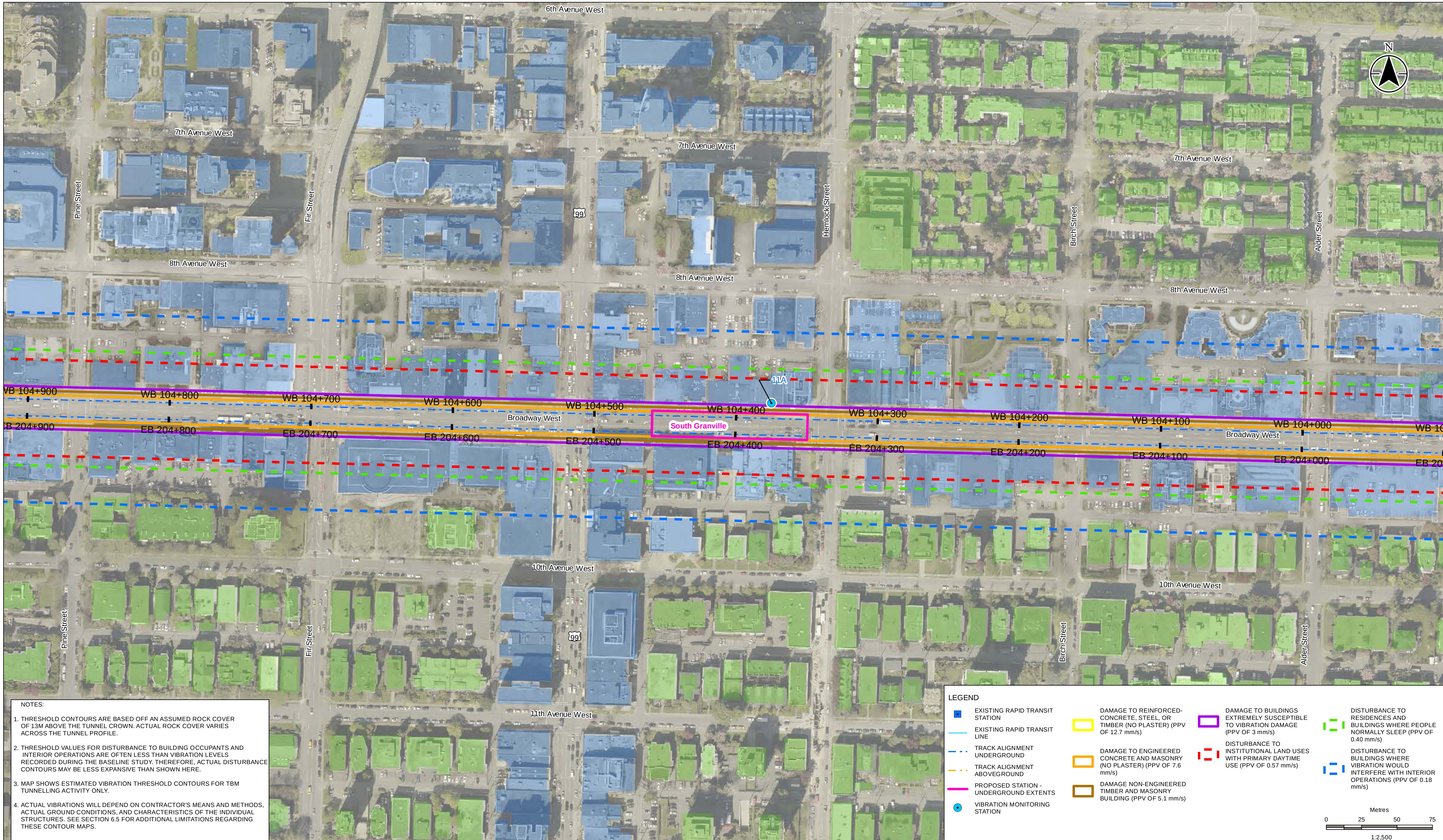

NOTES:

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3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR TBM TUNNELLING ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
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- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

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DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
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APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

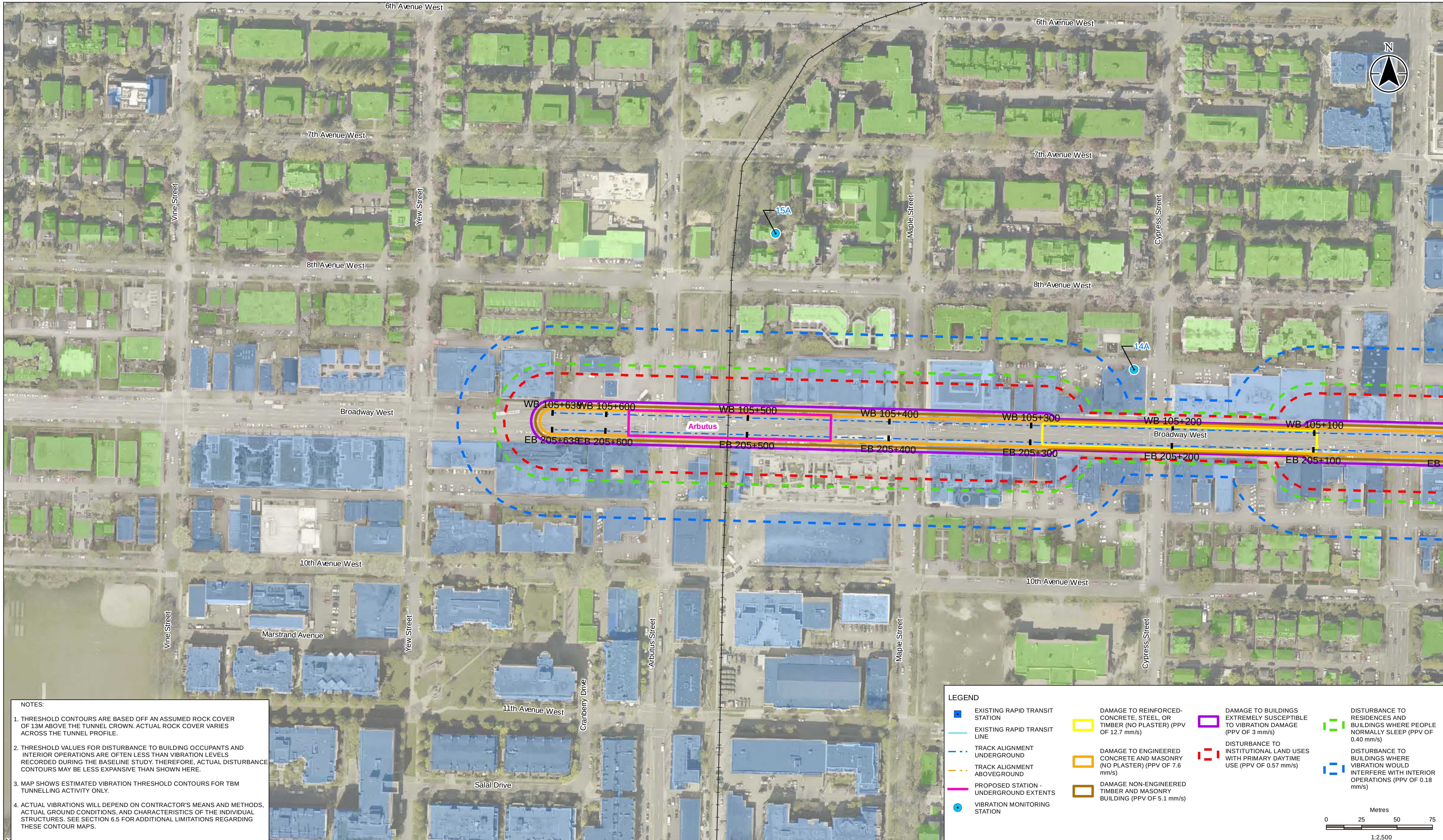
PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION
South Granville Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX B.5		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



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LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
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- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
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- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75

1:2,500

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR TUNNEL CONSTRUCTION

Arbutus Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX B.6		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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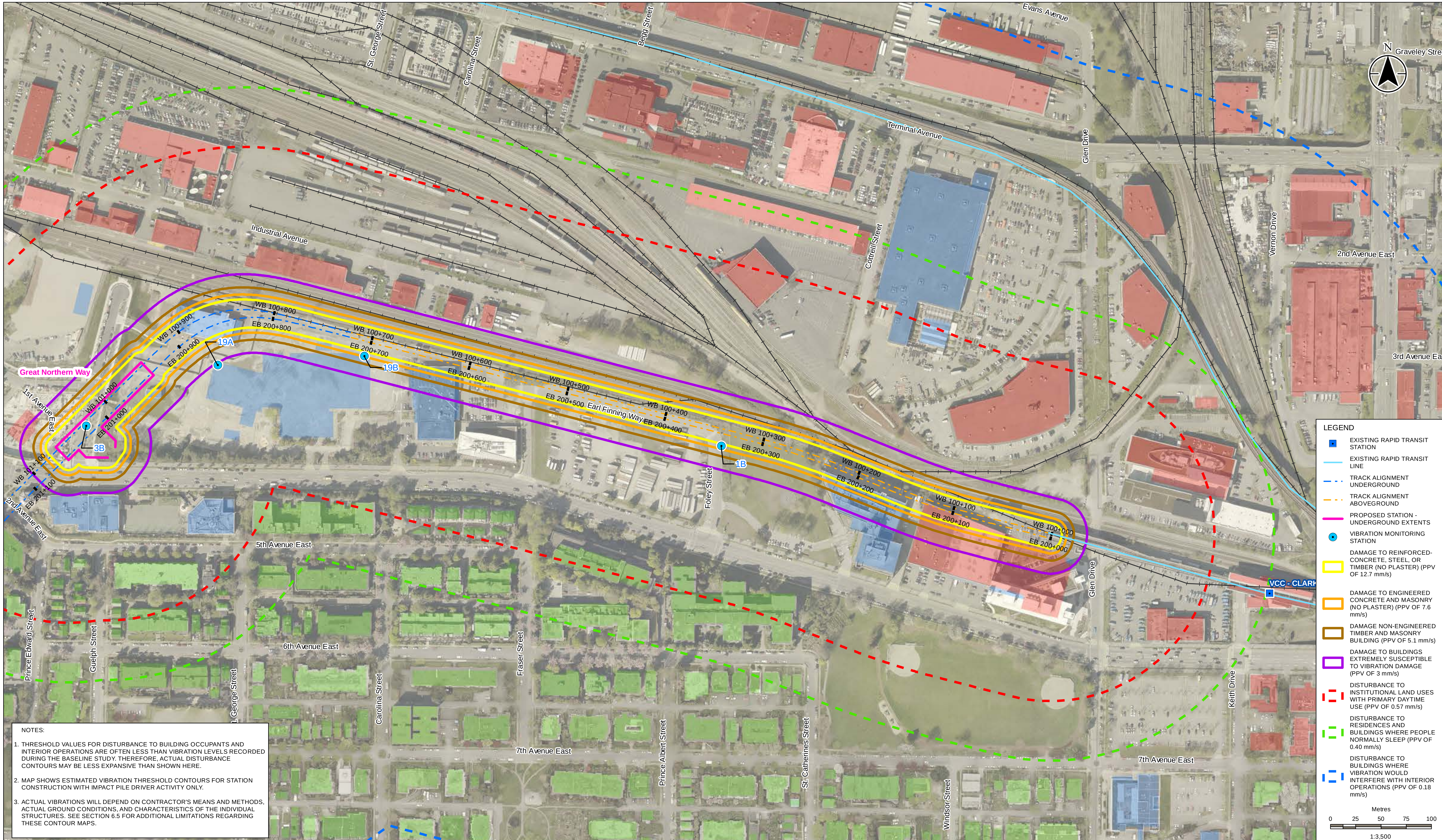
APPENDIX C

Vibration Threshold Contours during Station Excavation and Elevated Guideway Construction with Impact Pile Drivers



LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
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- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75 100

1:3,500

NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING CATEGORY
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

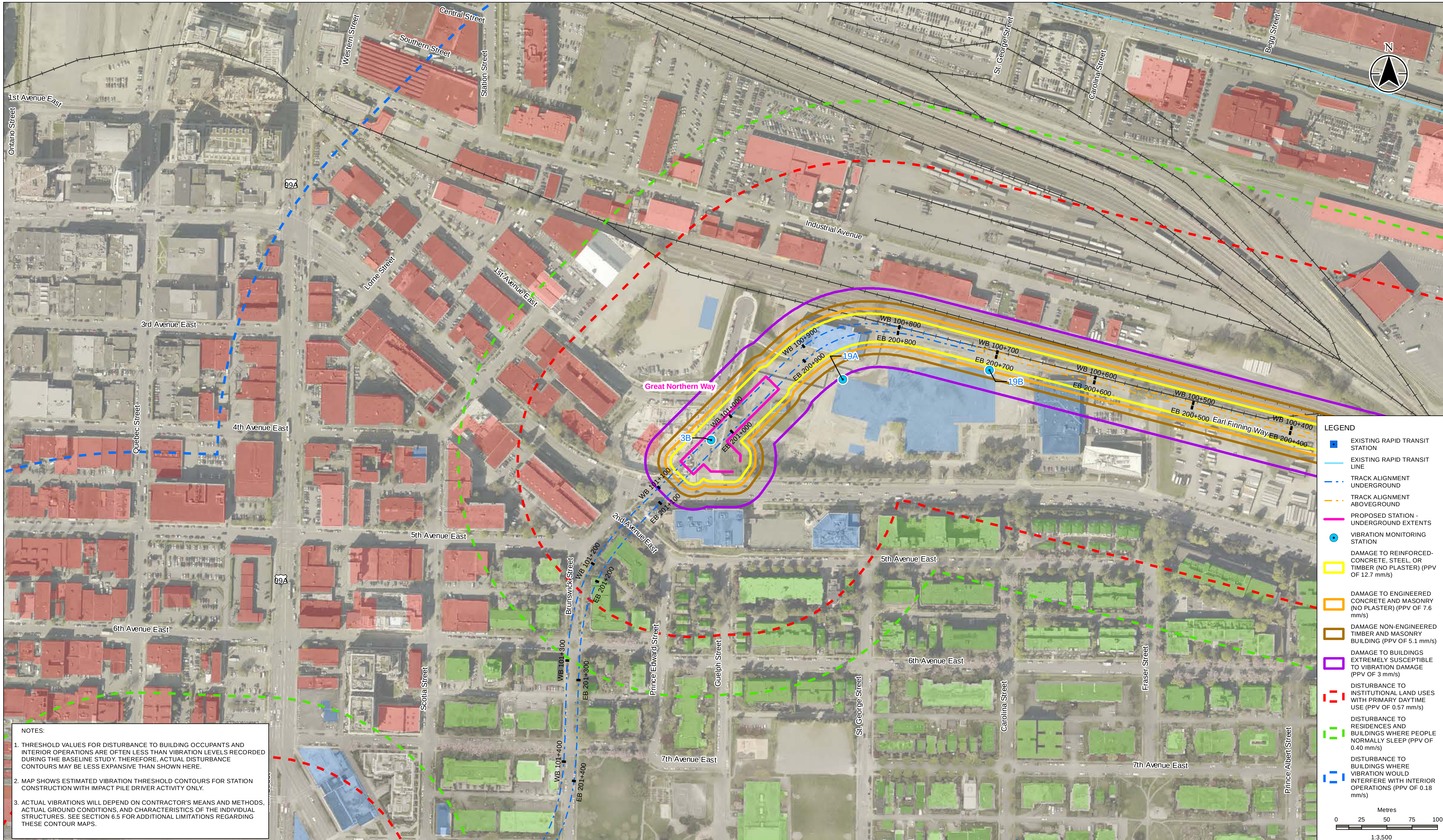
PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR ELEVATED GUIDEWAY CONSTRUCTION WITH IMPACT PILE DRIVERS

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX C.1 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



NOTES:

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
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RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

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ZONING
COMMERCIAL
INDUSTRIAL
RESIDENTIAL

PROFESSIONAL SEAL

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS
Great Northern Way Station

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX C.2 A

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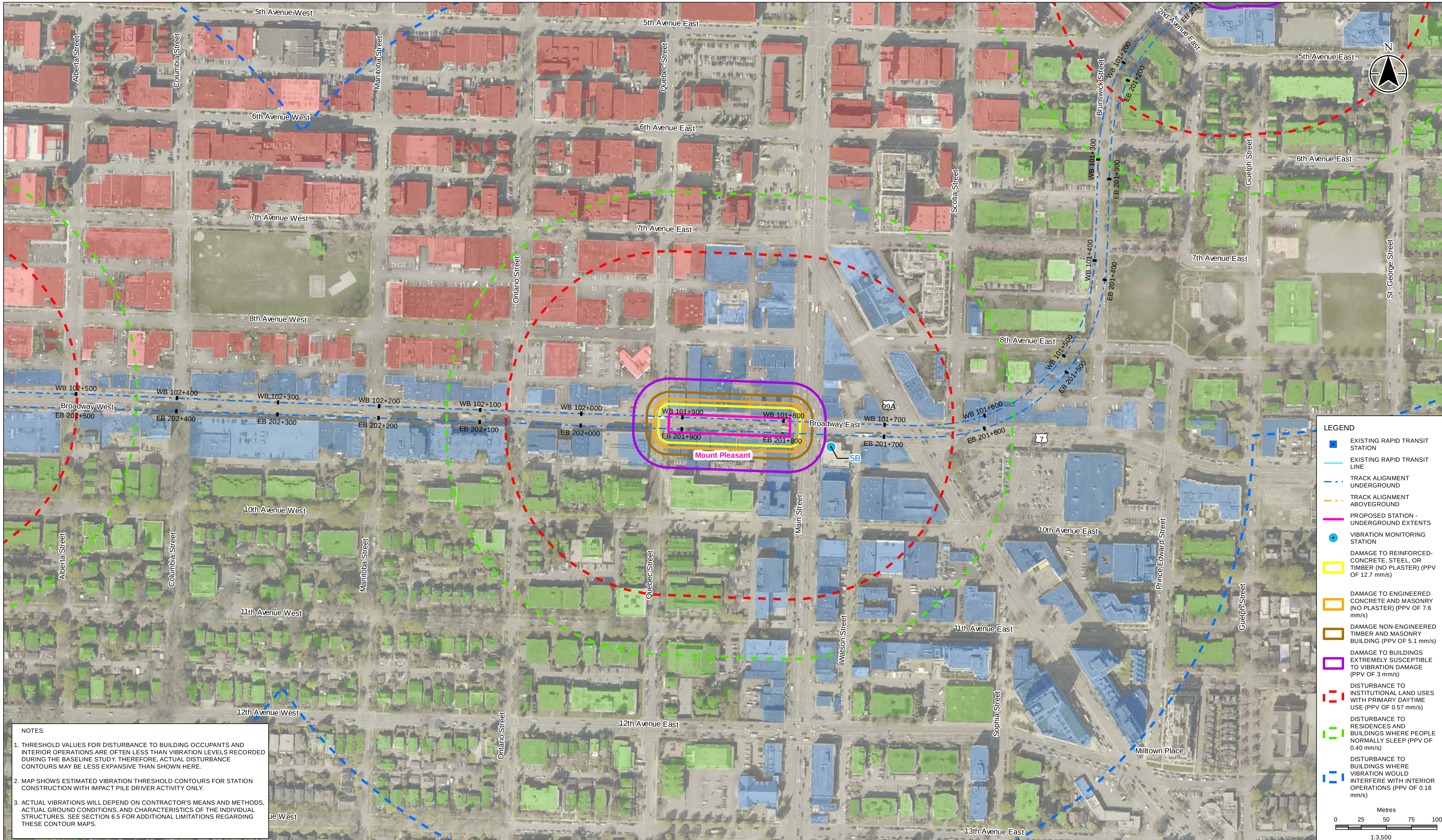

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- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
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Metres
0 25 50 75 100
1:3,500

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16 DATE
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BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS

Mount Pleasant Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX C.3	A

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NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS
Broadway-City Hall Station

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX C.4 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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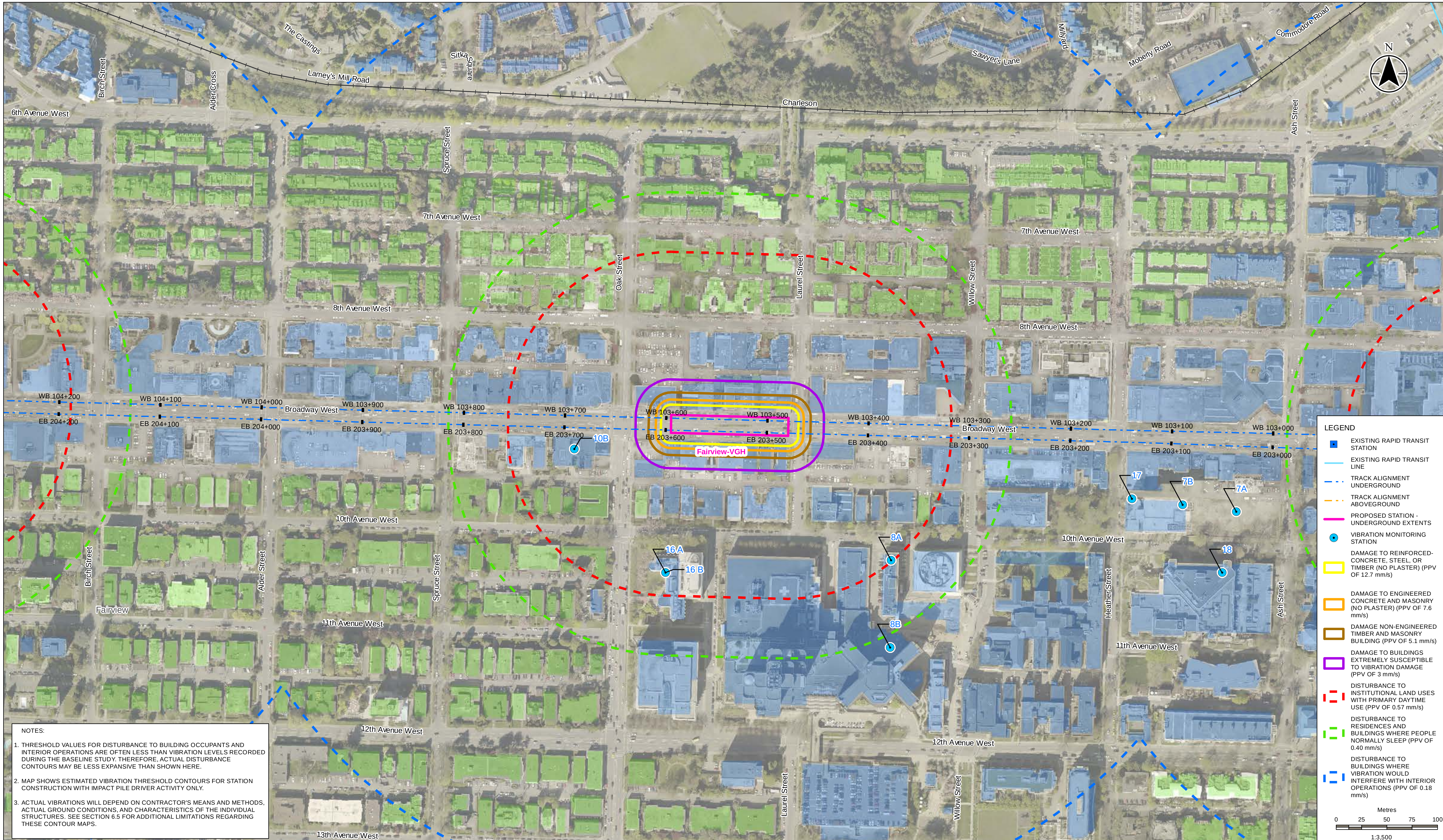

NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

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DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

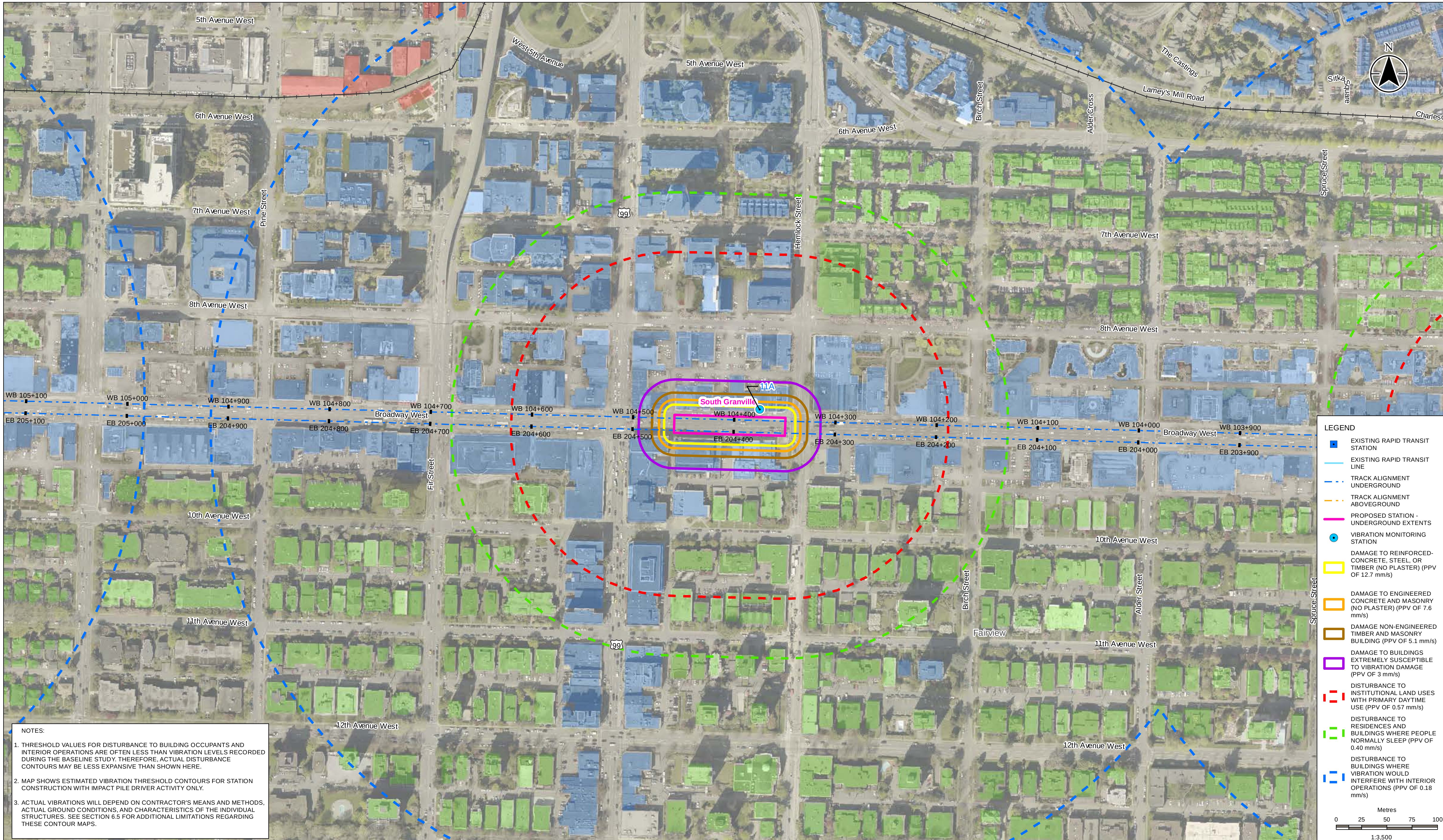
PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS
Fairview-VGH Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX C.5	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



NOTES:

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3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75 100

1:3,500

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS

South Granville Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX C.6	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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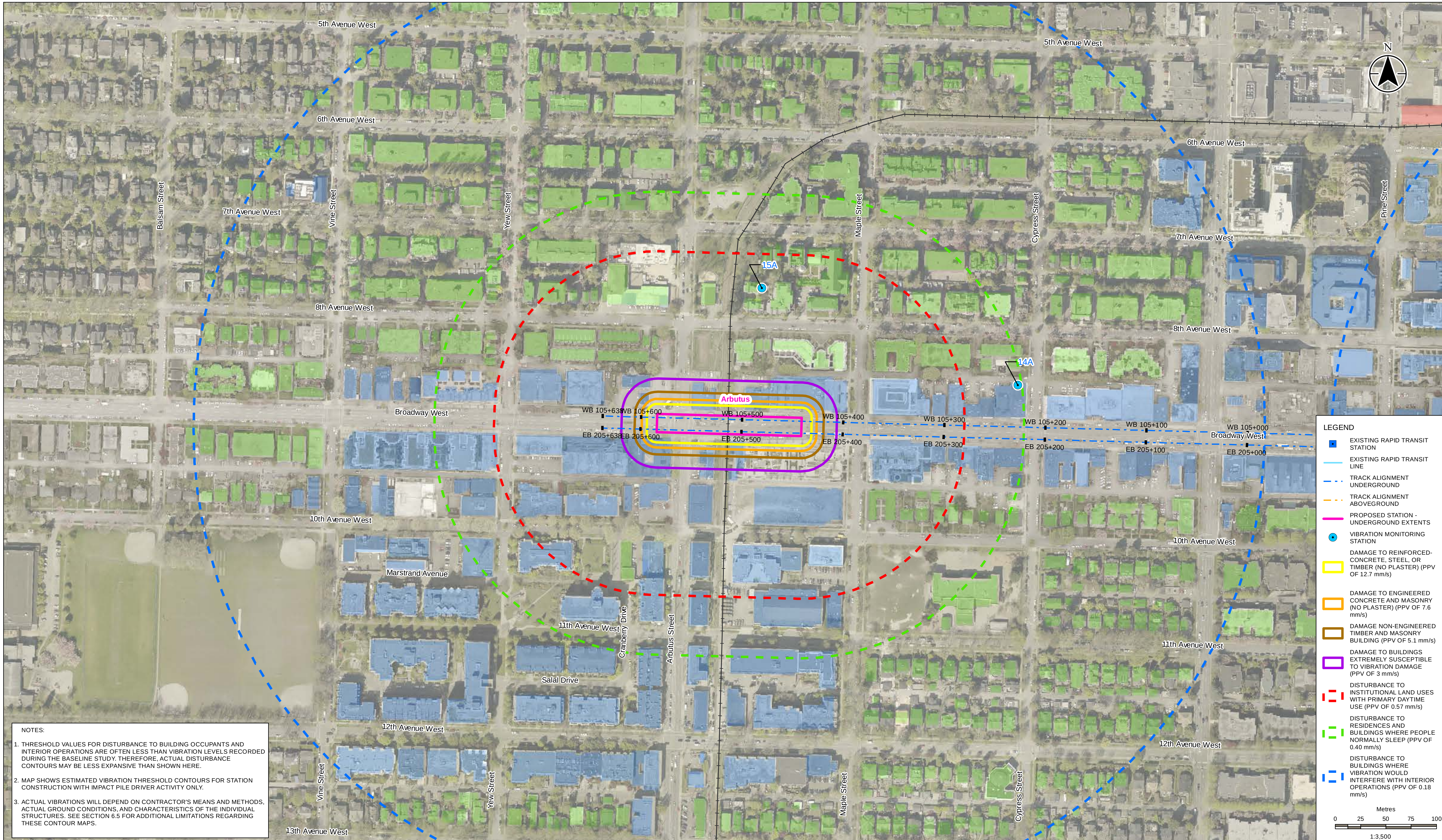

NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
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3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH IMPACT PILE DRIVERS

Arbutus Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX C.7	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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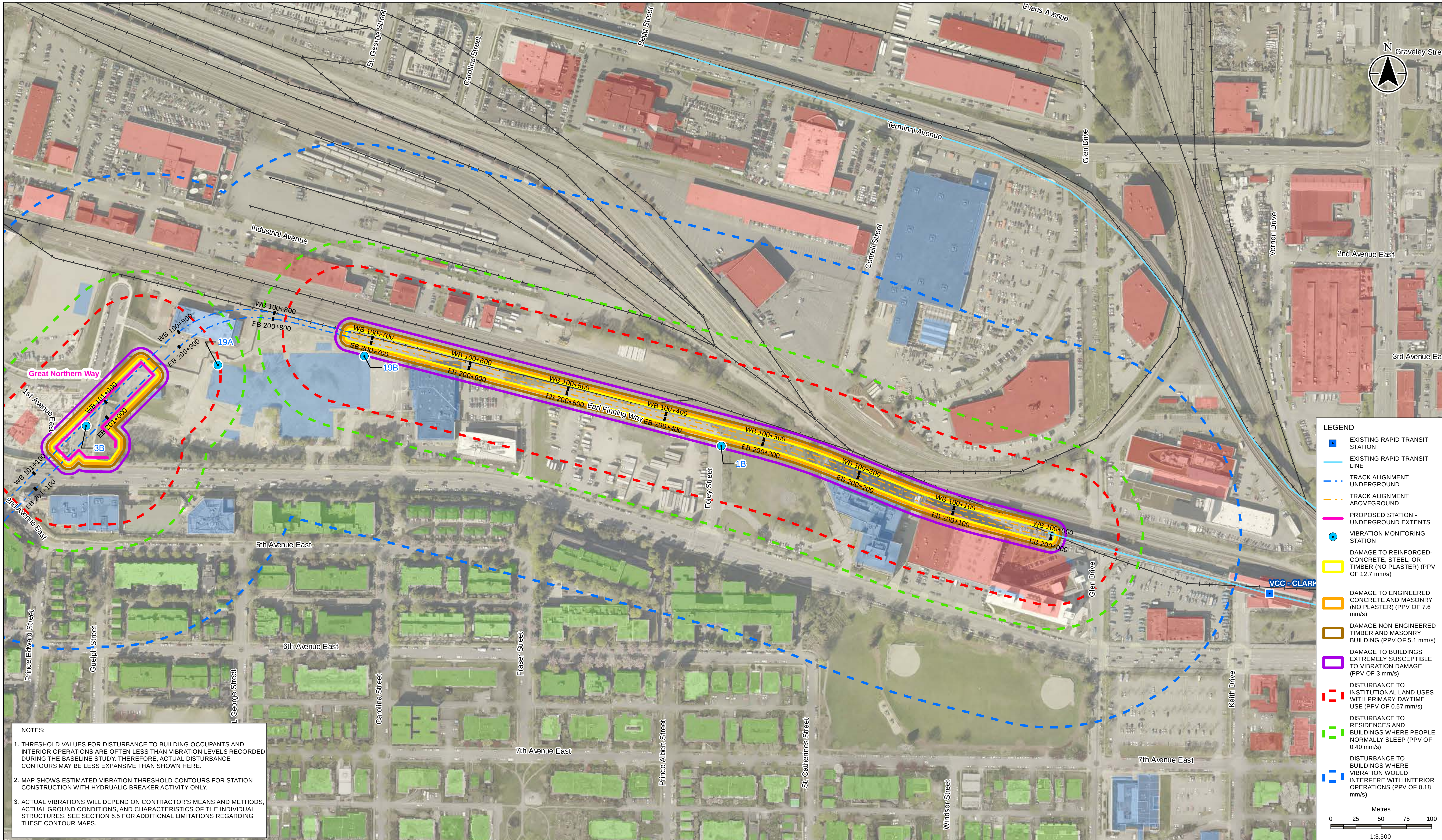
APPENDIX D

Vibration Threshold Contours during Station Excavation and Elevated Guideway Construction with Hydraulic Breakers



NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING CATEGORY
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

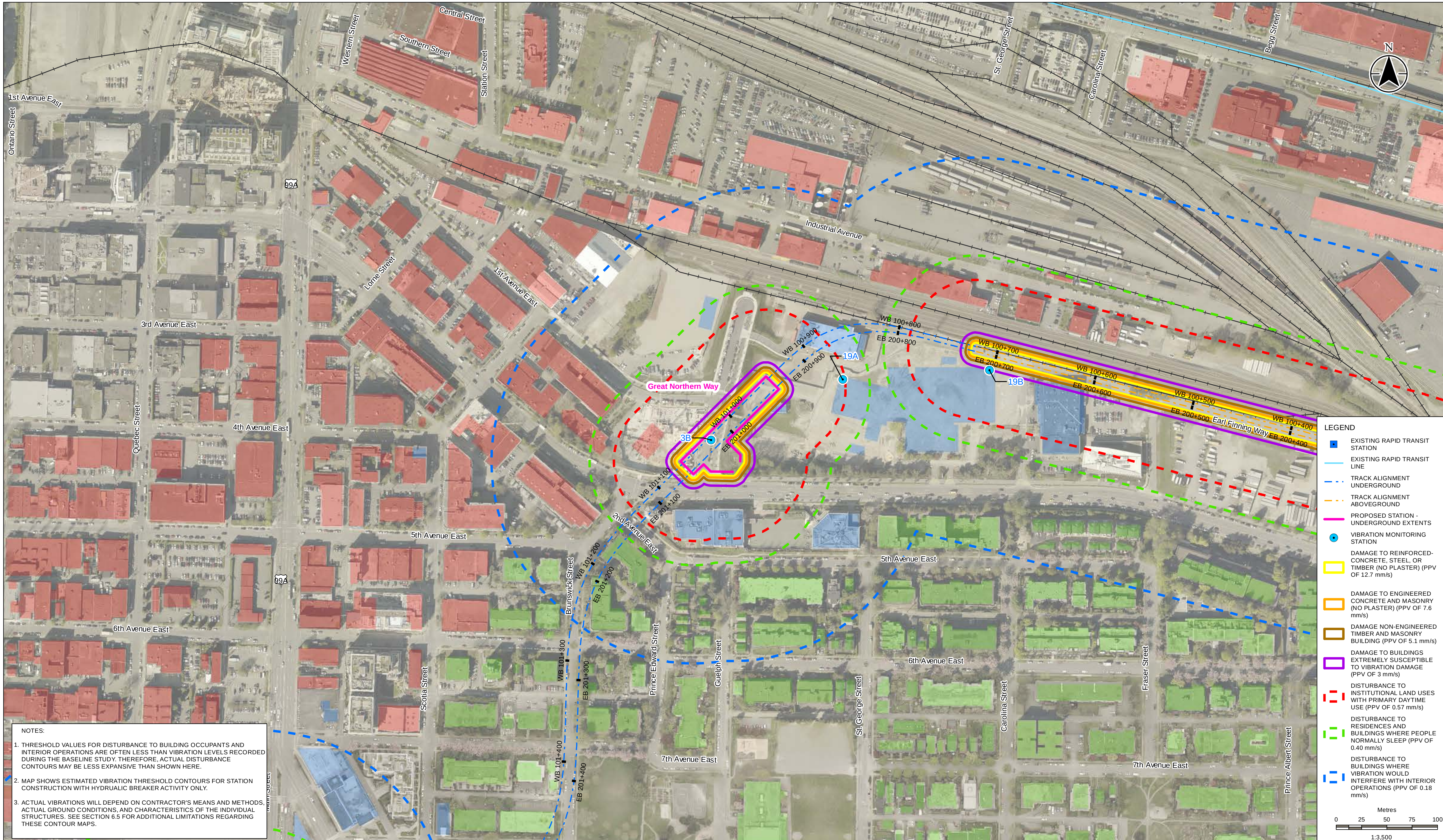
Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR ELEVATED GUIDEWAY CONSTRUCTION WITH HYDRAULIC BREAKERS

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX D.1
A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



NOTES:

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3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

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DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

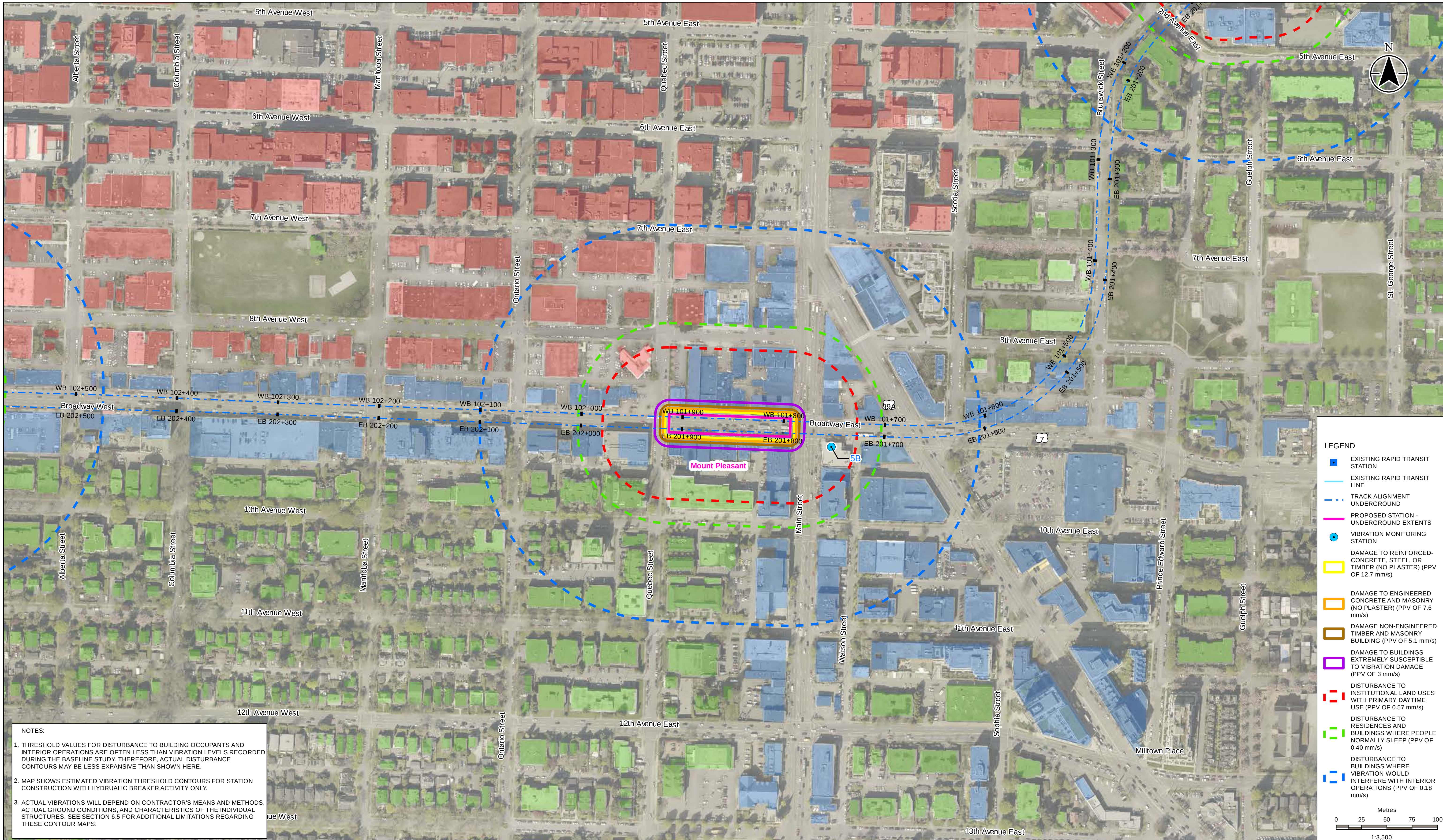
BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS

Great Northern Way Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX D.2	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



NOTES:

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LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
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- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS
Mount Pleasant Station

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX D.3 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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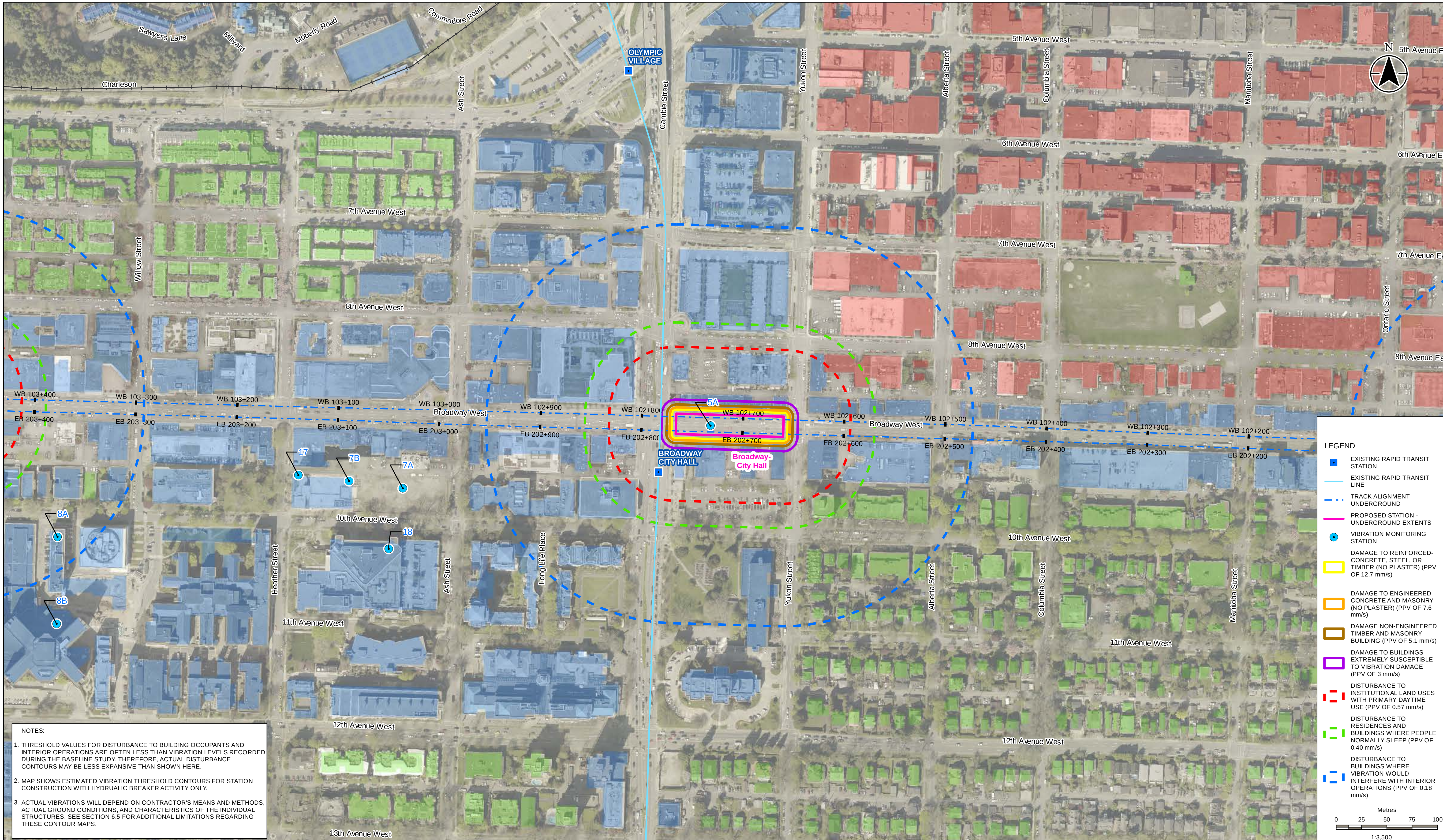

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Metres
0 25 50 75 100
1:3,500

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS
Broadway-City Hall Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX D.4		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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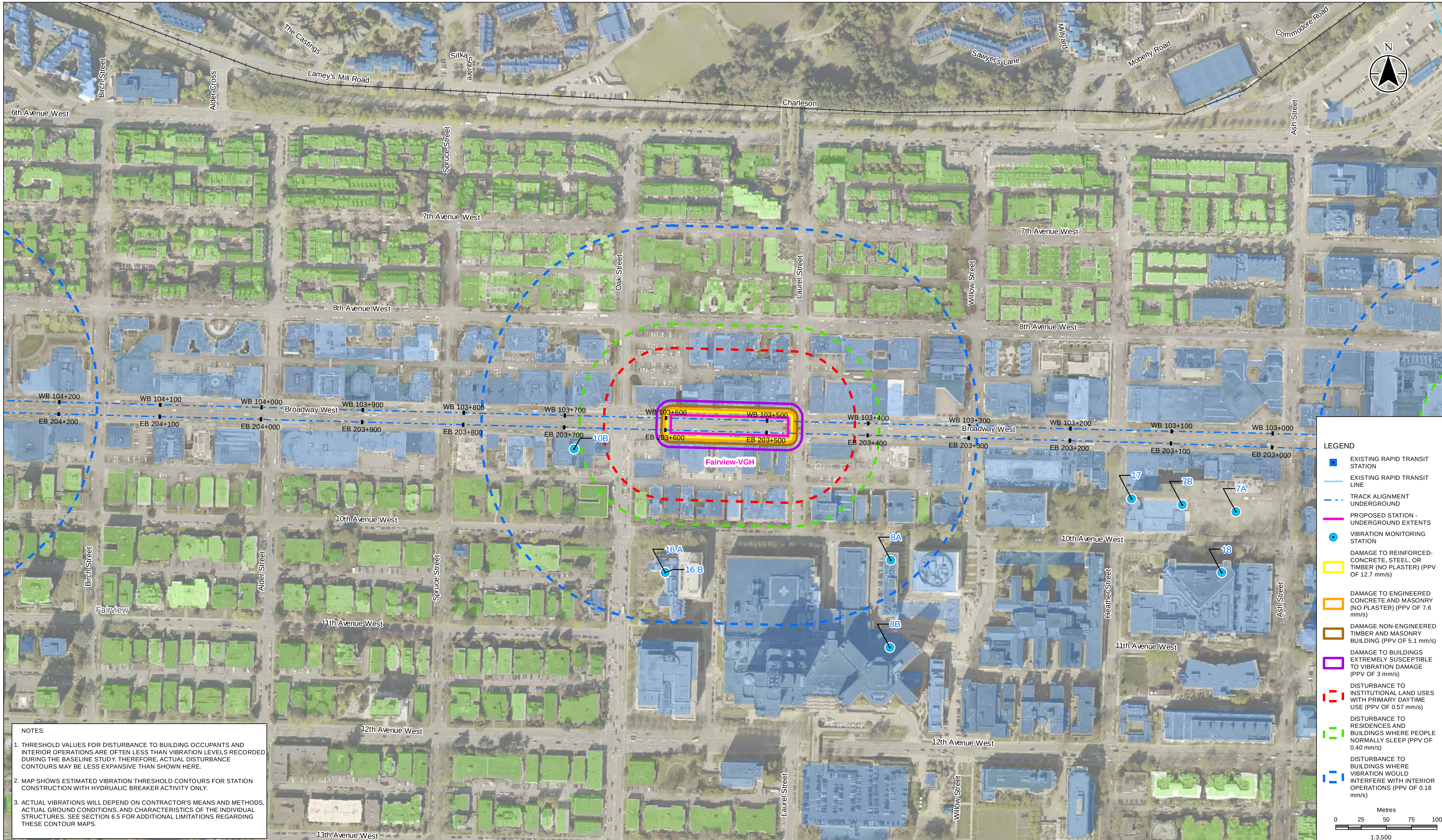

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LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75 100
1:3,500

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

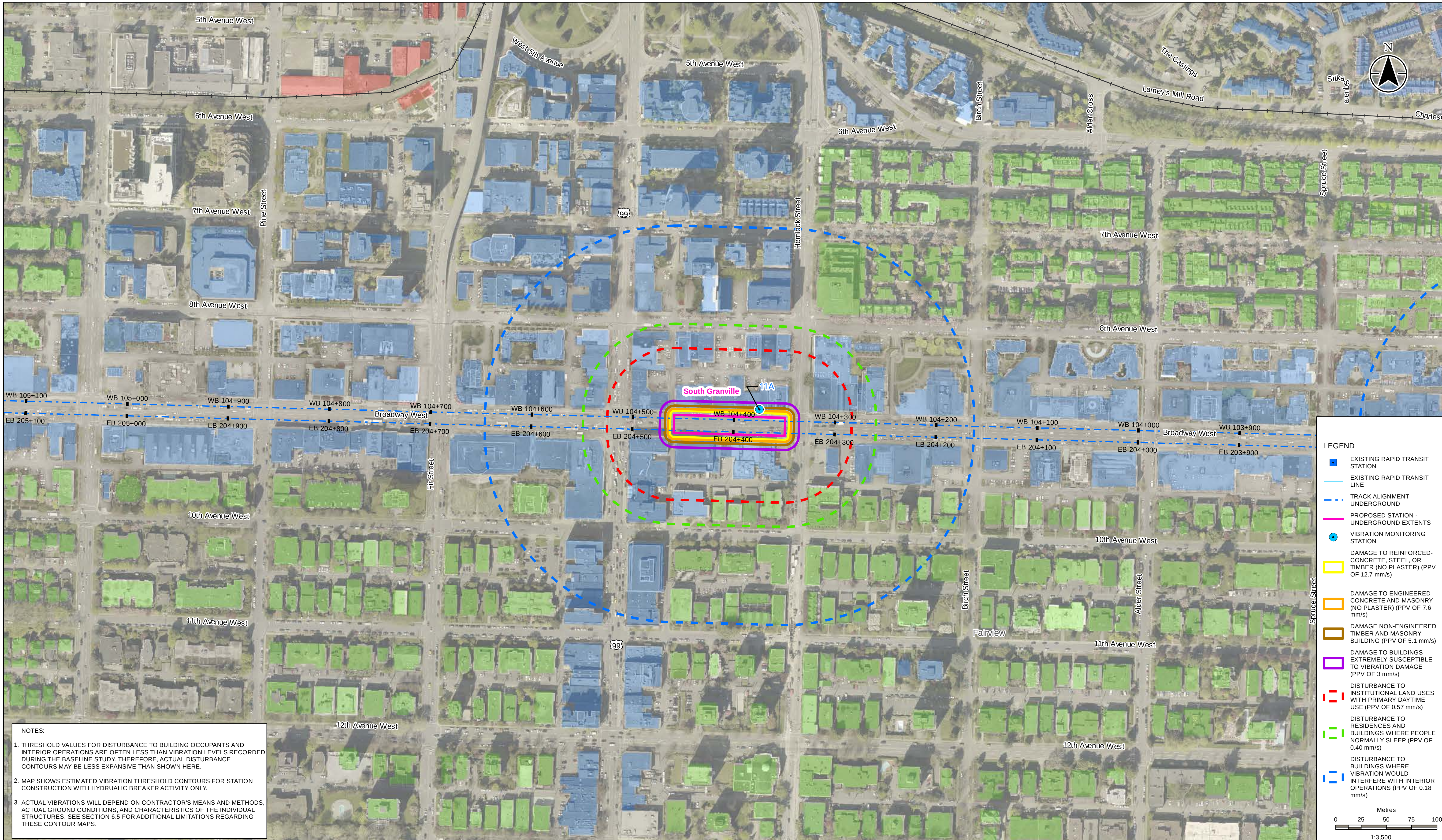
Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS
Fairview-VGH Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.		APPENDIX D.5	A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

S:\12232\projects\115814099\gis\figures\reports\technical_data_report_final\vibration\appendix_d\EN-V-000 - app_d_2-d_7_hydraulic_breakers_station.mxd Revised: 2020-01-22 By: tcardinal



NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75 100

1:3,500

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

PROFESSIONAL SEAL

BROADWAY SUBWAY PROJECT

Stantec

BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS

South Granville Station

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX D.6 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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NOTES:

1. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
2. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRUALIC BREAKER ACTIVITY ONLY.
3. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DAMAGE TO REINFORCED-CONCRETE, STEEL, OR TIMBER (NO PLASTER) (PPV OF 12.7 mm/s)
- DAMAGE TO ENGINEERED CONCRETE AND MASONRY (NO PLASTER) (PPV OF 7.6 mm/s)
- DAMAGE NON-ENGINEERED TIMBER AND MASONRY BUILDING (PPV OF 5.1 mm/s)
- DAMAGE TO BUILDINGS EXTREMELY SUSCEPTIBLE TO VIBRATION DAMAGE (PPV OF 3 mm/s)
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE (PPV OF 0.57 mm/s)
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75 100

1:3,500

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

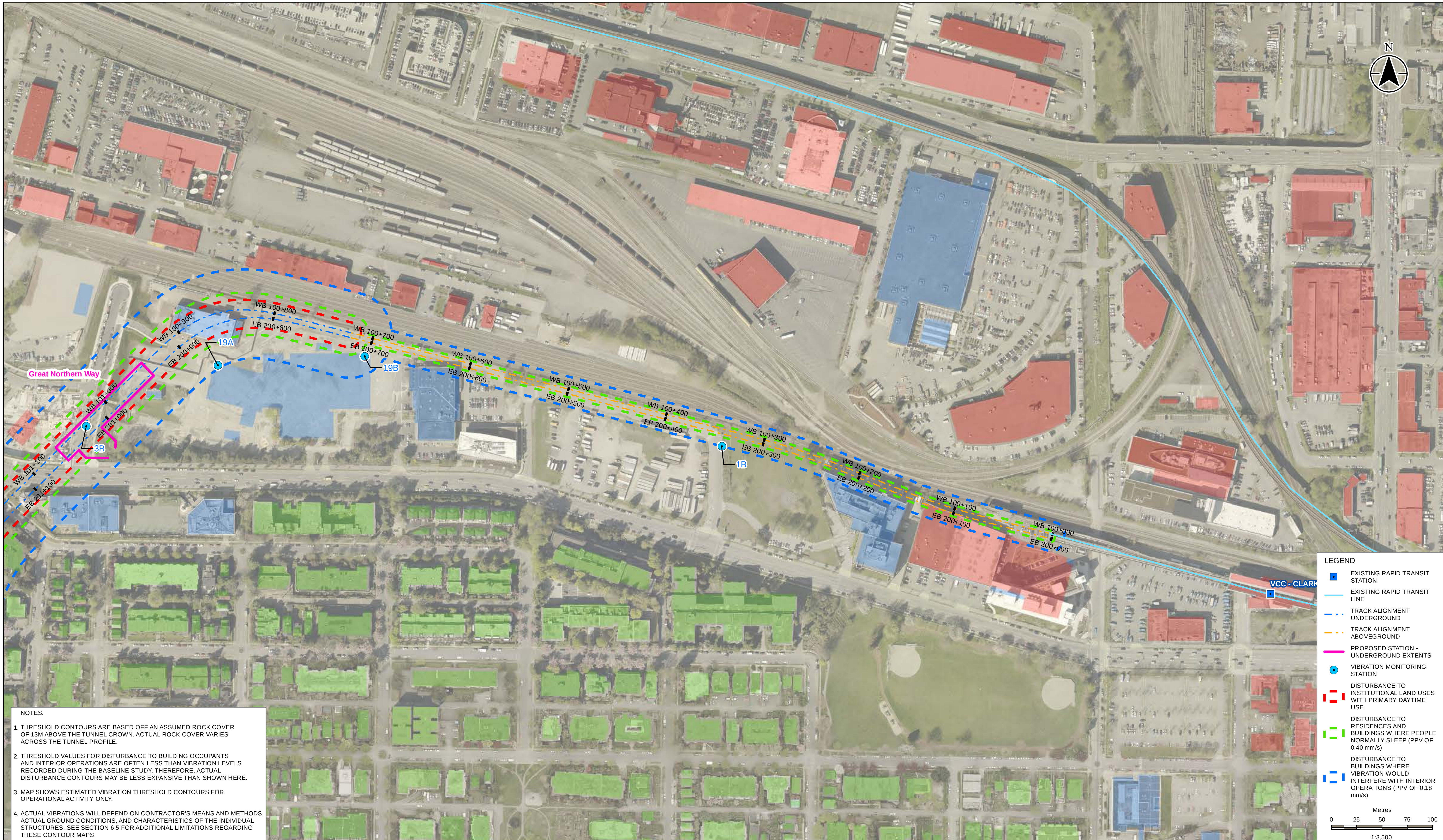
BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS FOR STATION CONSTRUCTION WITH HYDRAULIC BREAKERS
Arbutus Station

SCALE 1:3,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX D.7		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

APPENDIX E

Vibration Threshold Contours during Operation



NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75 100

1:3,500

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING CATEGORY

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

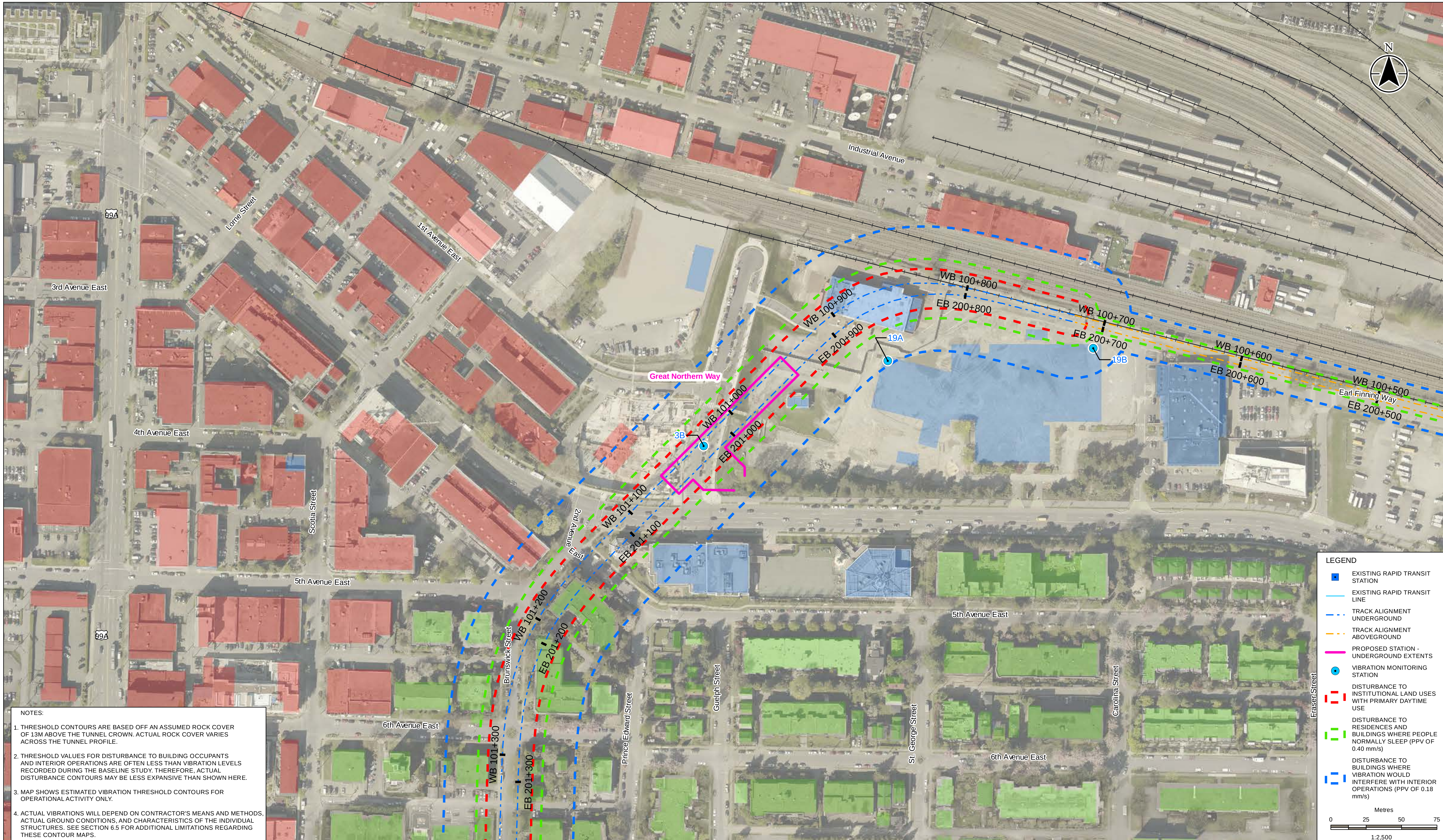
BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS DURING OPERATION FOR ELEVATED GUIDEWAY

SCALE 1:3,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.1
A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

\\CA0183-PBAGF01\workgroup\1232\projects\115814099\gis\figures\reports\technical_data_report_final\vibration\appendix_e1\EN-VI-000 - app_e_1_operation_elevated_guideway.mxd Revised: 2020-01-20 By: tcardinal



NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75

1:2,500

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS DURING OPERATION
Great Northern Way Station

SCALE 1:2,500	CONTRACT NO.	SUB CONSULTANT PROJECT NO.	115814099
DATE 18-02-16			
SHEET NO.	APPENDIX E.2		A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS DURING OPERATION
Mount Pleasant Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.3 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

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DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS DURING OPERATION
Broadway-City Hall Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.4
A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres

0 25 50 75

1:2,500

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DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING

- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

PROFESSIONAL SEAL

Stantec

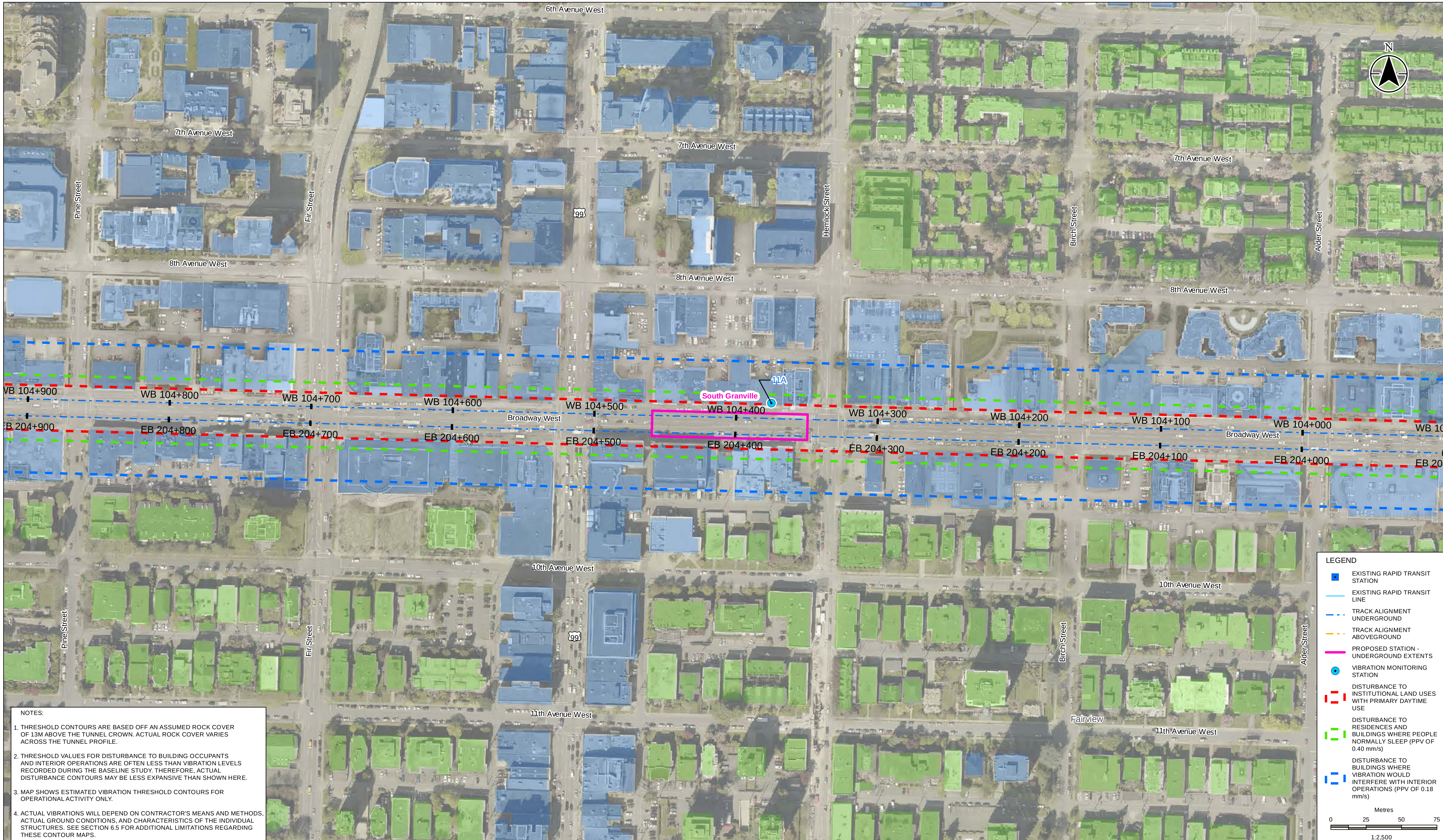
BROADWAY SUBWAY PROJECT

VIBRATION THRESHOLD CONTOURS DURING OPERATION

Fairview-VGH Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.5 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO



NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
3. MAP SHOWS ESTIMATED VIBRATION THRESHOLD CONTOURS FOR OPERATIONAL ACTIVITY ONLY.
4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

LEGEND

- EXISTING RAPID TRANSIT STATION
- EXISTING RAPID TRANSIT LINE
- TRACK ALIGNMENT UNDERGROUND
- TRACK ALIGNMENT ABOVEGROUND
- PROPOSED STATION - UNDERGROUND EXTENTS
- VIBRATION MONITORING STATION
- DISTURBANCE TO INSTITUTIONAL LAND USES WITH PRIMARY DAYTIME USE
- DISTURBANCE TO RESIDENCES AND BUILDINGS WHERE PEOPLE NORMALLY SLEEP (PPV OF 0.40 mm/s)
- DISTURBANCE TO BUILDINGS WHERE VIBRATION WOULD INTERFERE WITH INTERIOR OPERATIONS (PPV OF 0.18 mm/s)

Metres
0 25 50 75
1:2,500

ZONING
- COMMERCIAL
- INDUSTRIAL
- RESIDENTIAL

DESIGNED	JP	18-02-16	DATE
DRAWN	NP	18-02-16	DATE
CHECKED	NG	18-02-16	DATE
APPROVAL	INIT	YY-MM-DD	DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS DURING OPERATION
South Granville Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.6 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

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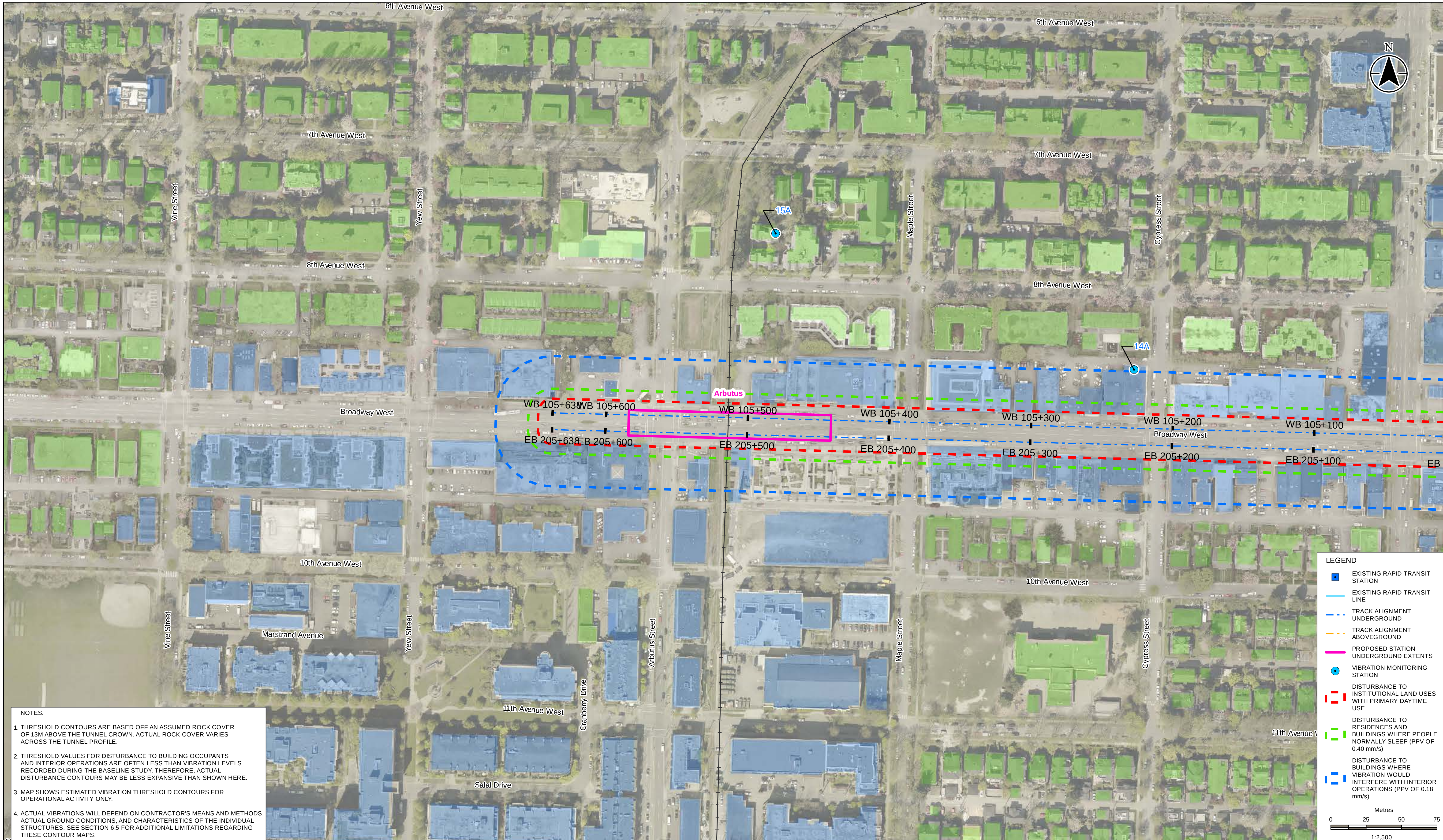

NOTES:

1. THRESHOLD CONTOURS ARE BASED OFF AN ASSUMED ROCK COVER OF 13M ABOVE THE TUNNEL CROWN. ACTUAL ROCK COVER VARIES ACROSS THE TUNNEL PROFILE.
2. THRESHOLD VALUES FOR DISTURBANCE TO BUILDING OCCUPANTS AND INTERIOR OPERATIONS ARE OFTEN LESS THAN VIBRATION LEVELS RECORDED DURING THE BASELINE STUDY. THEREFORE, ACTUAL DISTURBANCE CONTOURS MAY BE LESS EXPANSIVE THAN SHOWN HERE.
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4. ACTUAL VIBRATIONS WILL DEPEND ON CONTRACTOR'S MEANS AND METHODS, ACTUAL GROUND CONDITIONS, AND CHARACTERISTICS OF THE INDIVIDUAL STRUCTURES. SEE SECTION 6.5 FOR ADDITIONAL LIMITATIONS REGARDING THESE CONTOUR MAPS.

DESIGNED	JP	18-02-16 DATE
DRAWN	NP	18-02-16 DATE
CHECKED	NG	18-02-16 DATE
APPROVAL	INIT	YY-MM-DD DATE

RAV-SNC-DSIZE-SHEET.dwg
Rev. PC 558.8mm x 836.6mm METRIC

REFERENCE DRAWING

DWG No.	DESCRIPTION

REVISIONS

DATE	BY	DESCRIPTION	REV

BROADWAY SUBWAY PROJECT

ZONING
COMMERCIAL
INDUSTRIAL
RESIDENTIAL

PROFESSIONAL SEAL

Stantec

BROADWAY SUBWAY PROJECT
VIBRATION THRESHOLD CONTOURS DURING OPERATION
Arbutus Station

SCALE 1:2,500
DATE 18-02-16
CONTRACT NO.
SUB CONSULTANT PROJECT NO. 115814099
SHEET NO. APPENDIX E.7 A

SUPERCEDED PRINTS OF THIS NUMBER WITH LETTERS PREVIOUS TO

S:\1232\projects\115814099\gis\figures\reports\technical_data_report_final\vibration\appendix_e\EN-VI-000 - app_e_2-e_7_operation.mxd Revised: 2020-01-22 By: tcardinal