7 Assessment of Potential Effects

7.9 Vibration

7.9.1 Summary

Key highlights of the Vibration Review Element of the Environmental and Socio-economic Review (ESR) for the Surrey Newton-Guildford Light Rail Transit (LRT) (the Project) are as follows:

- Baseline vibration monitoring was undertaken at 12 locations along the Alignment considered to be representative of the local environment. The monitoring results indicate that the vibration environment at monitored locations is typical of an urban residential and commercial land use.
- Construction activities that could result in vibration include site preparation and guideway construction. Vibration modelling was performed to estimate vibrations near construction right-of-way compared with nearby sensitive receptors. Potential effects of these activities were analysed by comparing model results to applicable thresholds established with reference to building industry standards (FTA 2006, Caltrans 2013).
- Operation activities that could result in vibration include train operation. Vibrations from mobile sources (i.e., train movement) along the 10.5 km stretch of the Project right-of-way were estimated at receptors along the Project Alignment. Potential effects of these construction activities are analysed and the results are compared to applicable building industry standards for threshold values (FTA 2006, Caltrans 2013).

7.9.2 Introduction

Construction and operation of the proposed 10.5 km long Surrey Newton-Guildford Light Rail Transit Project (the Project) could result in vibration that could lead to potential damage of buildings or disturbance of people or sensitive equipment along the Project Alignment. Project construction is expected to take approximately three to five years and will include at grade and platform construction activities, with 11 stops proposed along the Project Alignment.

This section reviews the potential of Project-related vibration to cause damage to sensitive receptors, defined as buildings, humans, and equipment that have lower tolerances to vibration than typical structures or receptors. The review of potential Project effects on vibration levels was conducted based on the information requirements identified in the Terms of Reference (TOR) and is summarized in Table 7.9-1. It supports information provided in Section 9.0 Environmental Management Plans.

Table 7.9-1: Potential Effects and Review Indicators for Vibration

Topics Included in Review	Potential Effects	Review Indicators
• Construction vibration • Operational vibration	Change in Vibration Levels	Estimated ground vibration levels at specific receptors during construction and operation phases quantified using the following parameters compared to vibration baseline: • Peak particle velocity (PPV) in mm/s • Root mean square (RMS) velocity in mm/s Estimated vibration levels will be presented in context of potential effects to receptors (e.g., human perception, building damage)

7.9.3 Potential Effects and Selection of Indicators

7.9.3.1 Selection of Review Elements

Vibration was selected as a Review Element because Project construction and operation activities are expected to generate vibrations. These vibrations will be transmitted radially through soil towards nearby buildings and infrastructure such as utilities. Effects of ground-based vibrations may include discernable movement of building floors, shaking items of shelves, rattling of windows, damage to structures, sensitive equipment interference, annoyance to humans, and induced noise. Although induced noise is a potential effect of vibration, noise related effects are addressed separately in the Noise Technical Data Report (Appendix E) and the noise section of the ESR, Section 7.8. Although, construction and operation of a transit project usually does not cause damage to structures or annoyance of the building occupants, Vibration has been included as a Review Element to address public concerns.

This review of potential effects on vibration was conducted based on the information requirements identified in the TOR.

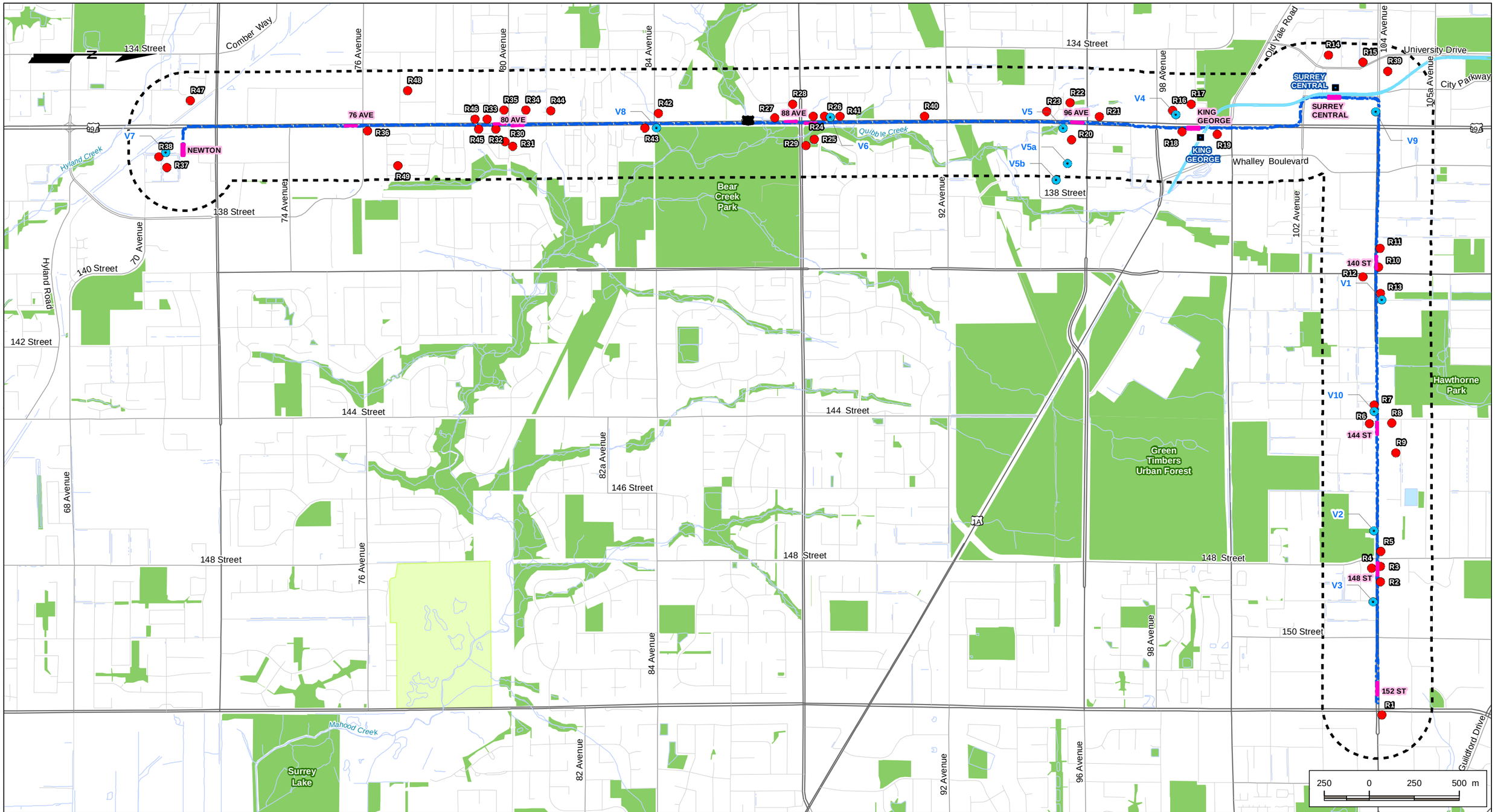
7.9.3.2 Identification of Effects and Indicators

Table 7.9-2 lists the potential Project-related effects on vibration. The table summarizes Project effect mechanisms and indicators used to review the potential effects. Project effect mechanisms define the link between the Review Element and the potential effect and are described in more detail in Section 7.9.7 (Project Interactions). Indicators listed below identify specific parameters used to measure and review potential effects qualitatively or quantitatively.

Table 7.9-2: Potential Effects and Indicators for Vibration

Potential Effects	Project Effects Mechanisms	Indicators	Rationale for Selection of Indicators

Change in vibration levels	Ground-borne vibration during construction and operations (could cause discernible movement of building floors, shaking items of shelves, rattling of windows, and potentially, induced noise).	• Estimated ground vibration levels during construction and operation phases quantified using the following parameters:
		  ◦ Peak particle velocity (PPV) in mm/s
		  ◦ Room mean square (RMS) velocity in mm/s
			• Buildings, sensitive structures and building occupants adjacent to Project Alignment



6	XP-TR-A0-GEN-PLN-PLTF (SXR)	LRT STATIONS (17-09-06)
5	XP-RD-A0-GEN-PLN-104-MSTR (SXR)	104TH AVE ROAD BASE PLAN (17-09-06)
4	C3D-TR-A0-GEN-104-ALG-MSTR (SXR)	KGB ROAD BASE PLAN (17-09-06)
3	XP-RD-A0-GEN-PLN-KGB-MSTR (SXR)	KGB ROAD BASE PLAN (17-09-06)
2	C3D-TR-A0-GEN-KGB-ALG-MSTR (SXR)	KGB TRACK ALIGNMENT (17-09-06)
1	XR-ES-P0-GEN-KGB-ALG-MSTR (SXR)	CITY OF SURREY CADASTRAL
REF.	DRAWING NUMBER	DRAWING TITLE

REFERENCE DRAWINGS

LEGEND:

- EXISTING SKY TRAIN STATION
- EXISTING SKY TRAIN
- LRT TRACK CENTRELINES
- LRT STOP
- WATERCOURSE
- REVIEW AREA
- VIBRATION MONITORING STATION
- NOISE SENSITIVE RECEPTOR

ENGINEER STAMP:

No.	DESCRIPTION	DWN	CHK	APP	YY/MM/DD
P1	FIRST ISSUE	NP	RT	MR	17/11/03

REVISIONS

HATCH steer davies gleave Stantec

CLIENT: TRANSLINK

DESIGNED BY:	RT	17/11/03	ENG. CHECK:	MR	17/11/03
DRAWN BY:	TC	17/11/03	APPROVED BY:	XX	17/11/03

STATUS:

CLIENT REFERENCE DRAWING NO. - FIGURE 7.9-1

SURREY NEWTON-GUILDFORD LINE LRT PROJECT:
BASELINE VIBRATION MONITORING LOCATIONS AND RECEPTOR LOCATIONS

PROJECT/DWG No: 350135-EV-100-A0-VI-0102

REV No: P1

S:\12321\projects\115815008\gis\figures\reports\ers\350135-EV-100-A0-VI_7_9_1_baseline_vibration.mxd Revised: 2018-05-23 By: tcardinal

7.9.3.3 Vibration Standards and Policy Framework

This section summarizes vibration terminology (descriptors) compared to relevant municipal bylaw, provincial policy, and federal guidance. More details on how these documents have been applied are provided in the Vibration Technical Data Report (Appendix F).

7.9.3.4 Vibration Terminology

Vibration is an oscillatory motion described in terms of displacement, velocity and acceleration. Vibration waves propagate through bedrock and soil to foundations of buildings and then throughout the remainder of the structure. The extent by which vibration is propagated through the ground depends on the characteristics of the soil. Building vibration will also vary depending on the type of structure and its resonance frequency and other factors. Resonance frequency occurs 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 peak particle velocity (PPV) is determined by estimating the root-mean-square (RMS). RMS velocity (V_{rms}) measures are positive values representing the average maximum velocities over a specified period. Both PPV and V_{rms} values are expressed in millimetres per second (mm/s).

Vibration levels are generally measured in the field of heavy construction projects using transducers equipped with three geophones, which measure ground velocity and frequency for each of the transverse, vertical, longitudinal axes. The PPV is the maximum vibration velocity in each measurement interval, measured in units of mm/s. The frequency is measured as zero crossing (ZC), measured in units of Hertz (Hz). According to the United States Federal Transit Administration (FTA, 2006), the threshold value of PPV for human perception is 0.018 mm/s. At 0.56 mm/s, most individuals typically begin to perceive vibration, and at 1.8 mm/s, vibratory tolerance is only considered acceptable if experienced infrequently or for short periods of time.

A description of vibration terms is provided in Table 7.9-3.

Table 7.9-3: Description of Vibration Terms

Indicator	Unit	Description
Peak particle velocity (PPV)	mm/s	PPV indicates the maximum magnitude speed particles travel resulting from an event's ground vibrations
Root Mean Square Velocity (Vrms)	mm/s	This measure is typically used to compare human response to vibration. Vrms is 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 PPV component because it typically has the greatest amplitude.

7.9.3.5 Regulatory and Policy Setting

There are no municipal or provincial codes for vibration that apply to this Project. As published codes and guidance for vibration levels in Canada are limited, the review has taken into consideration the most applicable examples. Current industry standards for buildings and perceived effects on people relevant to the Project are based on guidance from the documents published within the United States:

- Transit Noise and Vibration Impact Assessment (FTA 2006)
- Transportation and Construction Vibration Guidance Manual (Caltrans 2013)

Vibration thresholds adopted for this review are the PPV and Vrms thresholds for a range of damage categories to sensitive structures and building occupancy types assumed to be located along the Project Alignment (Table 7.9-4). For construction equipment, estimated PPVs are provided for selected pieces of equipment. Thresholds for disturbance to building occupants and interference with equipment are typically provided in terms of V_{rms}. A crest factor of 4 (the ratio of the peak value of a waveform to the V_{rms}) is used to compare estimated PPVs to thresholds in V_{rms} (FTA 2006) using the formula:

$$\mathrm{PPV} = 4 * \mathrm{V_{rms}}$$

Table 7.9-4: Damage and Disturbance Thresholds for Vibration

Threshold		Description	PPV (mm/s)	V_{rms} (mm/s)
Potential Damage to Buildings	Damage to reinforced-concrete steel 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*
Potential Human Reception and Sensitive Equipment Interference	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 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/equipment	This category covers facilities where vibration would interfere with building operations, such as vibration-sensitive research and manufacturing, and hospitals with vibration-sensitive equipment. Levels may be well below those associated with human annoyance.	>0.18*	>0.05

NOTES:

* Value estimated using a crest factor of 4 (FTA, 2006)

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.

Vibration estimates were undertaken to evaluate the distance from specific Project activities within which vibration effects may occur. This distance, defined as the vibration threshold contour, identifies where certain vibration thresholds may be exceeded. Details on how the regulatory and policy documents are applied are provided in the Vibration Technical Data Report (Appendix F).

7.9.4 Spatial Boundaries

The proposed Project Alignment will be constructed and operated in Surrey along King George Boulevard (Blvd) and 104 Avenue (see Figure 7.9-1). The Review Area is within 300 m on each side of the Project Alignment centerline and considered the maximum typical extent of the vibration limits where construction induced vibration would extend laterally from the Alignment. The Review Area fully encompasses the planned construction activities along the Alignment and extends beyond the area where potential vibrations related to the project could be detected. Within this area, 12 monitoring locations were identified that are representative of locations where construction and/or operational vibration may affect the public and businesses adjacent to the Alignment. Ten locations were along the Project Alignment and two were located within Surrey Memorial Hospital.

7.9.5 Influence of Engagement on the Review Process

7.9.5.1 Public Engagement

Vibration interests and issues identified by the public during the ESR Process are listed in Table 5-13 as stated in the Public and Stakeholder Engagement and Information Distribution Section 5.

Key issues identified and response to comments obtained during public engagement are presented in Table 7.9-5.

Table 7.9-5: Summary of Key Vibration Issues Identified during Public Engagement

Topic	Area of Interest	Influence on the Review
Project Scope	Does the project consider mitigation measures from noise and vibration during construction and operation?	The Environmental and Socio-economic Review provides potential mitigation measures for Project construction and operation related to vibration.
Project Scope	Will mitigations measures be offered to condos/residents located next to LRT line?	The Environmental and Socio-economic Review will identify potential mitigation measures for all structures, including residences during construction and operation of the LRT related to vibration.
Project Scope	Will seismic studies along track areas be performed to prevent ground settling and sinkholes?	Geotechnical investigations have been undertaken for the Project. However, these are outside of the scope of the vibration review because seismic parameters are not considered to have the same effects as construction induced vibrations due to the different characteristics of the ground motion.
Project Scope	Is the reason we are looking at LRT vs. SkyTrain because there is a benefit of one over the other in the amount of noise and vibration?	The review considers potential vibration effects of the proposed LRT technology only.
Project Scope	These kinds of assessments often assume that the 'receptors' sensitive to noise and vibration are humans, and humans only. Noise and vibration may affect wildlife. Has this report addressed the vibration effects on wildlife?	The Vibration Review Element, outlined in Section 7.8 (Noise) and Section 7.9 (Vibration) of the TOR, focuses on potential effects to human receptors. We acknowledge that noise and vibration may also affect wildlife. Potential effects on wildlife, addressed in the Vegetation and Wildlife Resources Review Element, will consider indirect effects from sensory disturbance as part of the change in habitat.

7.9.5.2 First Nation Engagement

Based on feedback from First Nations groups on the draft TOR, the review of Air Quality and GHG as a Review Element, helped to refine the scope of review, and identified additional discussion topics for inclusion in the review scope.

7.9.6 Baseline Conditions

This section summarizes the baseline conditions used in this review and the methods used to establish baseline conditions. A description of existing vibration conditions allows a characterization of the interaction between the Project and the vibration environment, and places Project effects into context with vibration conditions in the region.

7.9.6.1 Methods

The Project is in an urban area that includes densely-populated residential neighborhoods, commercial districts, business, medical facilities, and recreational and educational facilities. Baseline vibration monitoring was undertaken at 12 locations along the Alignment considered to be representative of locations where construction and/or operational vibration may affect the public and businesses adjacent to the Alignment. The baseline study considers both typical structures such as residences and offices and sensitive structures such as Surrey Memorial Hospital. Monitoring locations are shown in Figure 7.9-1.

Vibration monitoring was conducted for 24 hours on a weekday at each location. Instantel Blastmate III and Micromate transducer instrumentation with a triaxial geophone was used to determine PPV for the transverse, vertical, and longitudinal axes. Data from all three axes were collected at each location. Additional technical details (e.g., locations descriptions, equipment, analysis and key findings) specific to this program are provided in the Vibration TDR (Appendix F).

7.9.6.2 Baseline Conditions

The 12 monitored locations had vibration levels typical of a busy urban environment. The maximum recorded PPV for each geophone in the transverse, vertical, and longitudinal axis at the 12 locations ranged from 0.071 to 0.378 mm/s, as shown in Table 7.9-6. Baseline vibrations of up to 4.745 mm/s recorded at location V3 are attributed to the equipment being bumped and are not considered representative of ambient vibrations. Baseline vibration data were predominantly 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 PPV measurement of 0.536 mm/s is well below the threshold for damage to buildings extremely susceptible to vibration damage (3 mm/s PPV) and is in the range of thresholds for potential human reception and sensitive equipment interference (0.18 to 0.57 PPV) listed in Table 7.9-4.

Table 7.9-6: Summary of Baseline Vibration Monitoring Results

Location ID	Location (Main Intersections)	Setting Description	Distance to Track Centreline	Maximum Measured Ground Vibration (PPV, mm/s)		
			Metres	Transverse	Vertical	Longitudinal
V1	140B St and 104 Avenue	Urban residential neighbourhood (detached homes) adjacent to a major traffic roadway (104 Ave)	31	0.189	0.229	0.118
V2	104 Avenue between 146 Street and 148 Street	Urban setting adjacent to the RCMP detachment, Real Canadian Superstore, and recreational park spaces along a major traffic roadway (104 Ave.)	17	0.260	0.197	0.213
V3[a]	149 St and 104 Avenue	Mixed medium to high rise residential, commercial, and office space setting along a major traffic roadway (104 Ave.)	20	4.745	2.680	1.450
V4	98a Avenue and King George Blvd.	Mixed high rise residential and commercial space along a major traffic roadway (King George Blvd.)	72	0.150	0.229	0.095
V5	King George Blvd. and 94a Ave	Large parking lot in a busy commercial and hospital area along a major traffic roadway (King George Blvd.)	33	0.363	0.536	0.229
V5a	King George Blvd. and 94a Avenue	Large parking lot in a busy commercial and hospital area along a major traffic roadway (King George Blvd.)	227	0.071	0.158	0.087
V5b	King George Blvd. and 94a Avenue	Large parking lot in a busy commercial and hospital area along a major traffic roadway (King George Blvd.)	320	0.095	0.095	0.111
V6	88a Avenue and King George Blvd.	Urban residential neighbourhood (detached homes) adjacent to a major traffic roadway (King George Blvd.)	24	0.284	0.378	0.197
V7	136b St and 71 Avenue	Open space near recreational community centre and low-rise commercial/office developments	93	0.378	0.268	0.260
V8	84 Avenue and King George Blvd.	Busy major traffic intersection (King George Blvd. and 84 Ave.) adjacent to low-rise commercial developments, skate park, automated carwash, and Bear Creek Park	24	0.300	0.441	0.252
V9	104 Avenue and King George Blvd.	Large parking lot in a busy commercial area adjacent to this major traffic intersection (104 Ave. and King George Blvd.)	15	0.197	0.717	0.236
V10	104 Avenue and 144 St	Low rise commercial developments to this major traffic intersection (104 Ave. and 144 St.).	14	0.276	0.205	0.213

NOTE:
[a] Readings at location V3 are not representative of ambient vibration levels and are attributed to the monitoring equipment being bumped.

Site-specific details are presented in the Vibration TDR (Appendix F).

7.9.7 Project Interactions

Project components and physical activities that may interact with the Vibration Review Element through the identified potential effects are described in Table 7.9-7. Potential interactions are indicated by check marks and are discussed in detail below in the context of effects mechanisms, standard and Project specific mitigation, and residual effects. Justification for non-interactions are provided after the table and not reviewed further.

Table 7.9-7: Potential Project Interactions and Effects on Vibration

Project Activities and Physical Works	Potential Effects Change in vibration levels
Construction	
Property acquisition	-
Site preparation (e.g., clearing, grading, and set up of temporary facilities), and utility relocation	✓
Roadworks; construction of transitway/guideway, system structures (e.g., substations, power and communication lines), exchanges and stops, excavations, and operations and maintenance building	✓
Vehicle traffic (e.g., road use and construction traffic)	✓
Management and disposal of waste and excavated materials	-
Commissioning and start-up	✓
Operation	
Train operation, including wayside and power	✓
Train or track maintenance, administration, transit police	-
Traffic function (i.e., change in roadways and intersection functions)	✓
NOTES: ✓ Potential interactions that may cause an effect. - Not applicable. Activity does not generate vibrations	

7.9.7.1 Construction

Construction activities that could interact with the Vibration Review Element are surface construction and subsurface construction. These types of activities, and their effects, are similar to those used for road construction. Some activities associated with Project construction will result in vibration but are considered negligible in the context of existing surroundings and proposed mitigation measures and are consequently not quantified in this review. These include:

- Site preparation
- Shoring construction with hydraulic shoring for peat excavation
- Vehicle traffic
- Construction traffic for transporting equipment and materials
- Commissioning and start up

Construction activities that will not interact with the Vibration Review Element is property acquisition, and waste management and disposal. Waste management and disposal of waste and excavated materials is assumed to occur outside of the 300m Review Area for the project, and therefore would not change vibration levels within the Review Area. Truck traffic for removing waste for the project, however, is included in the construction traffic category discussed above.

7.9.7.2 Operation

The operation activity that could interact with the Vibration Review Element is train operation. Train and track maintenance activities associated with Project operation will result in vibration but are considered negligible and are not quantified in this review. Traffic function can result in a change in vibration, as increased use of the light rail may decrease vehicle traffic and vibration associated with vehicle traffic. Conversely, street widening to accommodate the new light rail would move vehicle traffic closer to structures and may increase vibration. However, changes in vibration due to traffic function are not quantified in this review. Operation activities that will not interact with the Vibration Review Element are station operation, administration and transit police, and are not considered further.

7.9.8 Mitigation Measures

Recommended Mitigation measures to avoid or limit effects from Project-related vibrations are summarized in Table 7.9-8. Mitigation measures will be included in the Noise and Vibration Management Plan and implemented during Project construction and operation.

Recommended measures suggested below are based on typical best practices for construction and operation in Metro Vancouver/BC and the Construction Contractor and Operator will be responsible for meeting performance objectives as appropriate to their means and methods

Table 7.9-8: Recommended Mitigation Measures for Vibration

Review Element	No.	Objective	Proposed Mitigation	Project Phase	Environmental Management Plan
Vibration	7.9-1	• Limit Project-related vibration to meet applicable thresholds • Limit vibration effects on nearby receptors	Develop and implement a Noise and Vibration Management Plan that outlines measures, monitoring protocol, notification procedures, and other information necessary to manage vibration levels	Construction Operation	Noise and Vibration Management Plan
	7.9-2	• Limit Project-related vibration to meet applicable thresholds • Limit vibration effects on nearby receptors	Limit construction activities identified as sources of vibration (e.g., roller compaction) to daytime hours to the extent feasible.	Construction	Noise and Vibration Management Plan
	7.9-3	• Limit Project-related vibration to meet applicable thresholds • Limit vibration effects on nearby receptors	As part of the Noise and Vibration Management Plan, describe the protocol for: • Tracking and documenting public complaints and addressing them in a timely manner and promptly communicating this information to the Owner, • Conducting pre- and post-construction surveys of structures along the Alignment to baseline any damage before construction begins and check intermittently and at construction completion for any new signs of damage.	Construction Operation	Noise and Vibration Management Plan
	7.9-4	• Limit Project-related vibration to meet applicable thresholds • Limit vibration effects on nearby receptors	Require a vibration monitoring specification in the contract and requirements for instrumentation.	Construction	Noise and Vibration Management Plan
	7.9-5	• Document any damage to structures along Alignment to verify if damage may be Project related or pre-dates Project • Limit vibration effects on nearby receptors	Conduct pre- and post-construction surveys of structures along the Alignment to baseline any damage before construction begins and check intermittently and at construction completion for any new signs of damage after construction is completed.	Construction	Noise and Vibration Management Plan
	7.9-6	• Limit Project-related vibration to meet applicable thresholds • Limit vibration effects on nearby receptors	Trackwork design should incorporate options that reduce vibrations. Examples of vibration dampening-features include: use of double-tie design, double-ended pocket tracks or crossovers, floating slabs, ballast mats, resilience fasteners, and regular maintenance and condition assessments. Actual features to be included would be addressed during detailed design.	Operation	Noise and Vibration Management Plan

7.9.9 Discussion of Review Results

Project activities during construction and operation will create vibrations. This section compares Project-related vibration levels to baseline vibration levels. Equations and assumptions used to estimate the Project-related change in vibration are provided in the Vibration TDR (Appendix F). Vibration levels were estimated for the 12 monitoring locations used to reflect baseline conditions (Table 7.9-9) and presented as values within contour intervals. The calculations consider soil types underlying the Project review area, for their ability to transmit vibration. Soil types include weak or soft soils (including peat and muck), competent soils, and hard, densely compacted soils, classified according to Caltrans (2013) using soils data from Project source information.

Project-induced vibration is unlikely to affect buildings, sensitive equipment, and building occupants where the estimated levels exceed the existing baseline conditions but are equal to or less than the vibration thresholds. Where the estimated levels exceed the vibration thresholds and existing baseline conditions, mitigation measures will be used to manage vibration effects on buildings, equipment and people to below the thresholds described in Table 7.9-4.

Actual vibration levels during construction and operation will depend on a number of factors, including site-specific soil conditions, contractors means and methods, building structure and foundation types, and detailed design parameters.

7.9.9.1 Construction

To consider potential effects of Project construction on existing surroundings, vibration estimates were used to quantify vibrations generated from track and stop construction. It was assumed construction activities will rely on a fleet of equipment used in similar projects, including vibratory rollers, hoe rams (breaker), loaded trucks, and bulldozers. Vibration levels (PPV_{equip}) associated with these types of equipment, derived from Caltrans (2013), were used in the calculations. Of these, vibratory rollers are expected to create the greatest vibration. Vibratory rollers will be used intermittently to compact aggregate or asphalt, and the transient vibration may cause temporary effects due to vibration on structures located relatively close to the Alignment in the localized area.

GIS analysis was undertaken to identify the number of buildings that occur within vibration threshold contours, as defined in Table 7.9-4, with results summarized in Table 7.9-9. The threshold “Disturbance at buildings where vibration would interfere with interior operations/equipment” includes the most buildings (1,449) because it is the broadest threshold band; including buildings located up to 85 to 165 m of the construction area. However, few of these buildings are likely to include vibration-sensitive equipment sensitive. At Surrey Memorial Hospital (considered the most sensitive structure because it contains potentially sensitive medical equipment), construction induced vibrations are not expected to exceed ambient vibration levels or create vibration levels great enough to interfere with sensitive equipment. However, this location should be monitored closely during construction and consideration should be given for mitigation measures at this location if necessary.

Most buildings are located more than 13 m from construction activity and thus unlikely to be at risk of construction-induced vibration damage. Of the 22 structures located within 13 m of the construction, most would be potentially at risk to construction induced vibration damage only if

they were extremely susceptible to such damage (Table 7.9-9). There are six buildings located closer to the Alignment that could be susceptible to construction induced vibration damage due to their closer proximity to construction activities. Pre- and post-construction surveys of buildings located near the Alignment is recommended to baseline any damage before construction begins and check intermittently and at construction completion for any new signs of damage. Additional mitigation levels at these locations may be necessary.

Occupants of buildings within 48 to 80 m of the construction activities may be disturbed by vibration from vibratory rollers, depending on building type and occupancy. Of the 618 buildings within the "disturbance to residences and buildings where people normally sleep" threshold, 232 are zoned as residential buildings, with the balance being commercial, industrial, or institutional buildings. Vibration related sleep disturbance to occupants within residential buildings would be limited by avoiding night-time construction.

Table 7.9-9: Damage and Disturbance Thresholds for Construction Vibration

Threshold		Total Number of Buildings Within Threshold Contour
Potential Damage to Buildings	Damage to reinforced-concrete steel or timber (no plaster)	3
	Damage to engineered concrete and masonry (no plaster)	4
	Damage to non-engineered timber and masonry building	6
	Damage to buildings extremely susceptible to vibration damage	22
Potential Human Reception and Sensitive Equipment Interference	Disturbance at institutional land uses with primary daytime use	436
	Disturbance at residences and buildings where people normally sleep	618
	Disturbance at buildings where vibration would interfere with interior operations/equipment	1,449

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.

The information obtained in this analysis will be used to refine the mitigation measures and to limit the potential for vibration levels to exceed thresholds for disturbance of people and sensitive equipment, with a process to be described in more detail in the Noise and Vibration Management Plan. Notification of nearby building occupants about expected noise and vibration and about duration of construction activities will help manage community expectations, as will a process for addressing complaints (see Table 7.9-8). No additional mitigation measures are indicated for sensitive equipment operation at Surrey Memorial Hospital, given the low vibration levels estimated for this location. Limiting construction activities to the hours defined in the City of Surrey Noise Bylaw will limit or eliminate disturbance of people during sleeping hours at night.

Overall, construction induced vibrations are expected to exceed baseline vibration levels along the Alignment in localized areas. The analysis was conservative, assuming use of equipment that causes the highest vibration levels (vibratory rollers), which will not be used in all areas or used continuously. Hence, for many locations along the Alignment, and at many times, vibration levels will be lower than estimated in this analysis. It is assumed that disturbance of building occupants

and interference with sensitive equipment will be greatest in the active construction area and that vibration will decrease to baseline levels with distance from the active construction. Also, construction will progress along the 10.5 km long Project Alignment according to the construction schedule, limiting the duration over which a specific area will be affected.

Table 7.9-10: Baseline and Estimated Construction and Operational Vibrations at Baseline Monitoring Sites

Location ID	Location	PPV during Baseline Study (mm/sec)	Baseline Conditions	Contour Interval PPV (mm/s) - Stop and Track Construction - Vibratory Rollers	Contour Interval PPV (mm/s) – Train Operation
V1	140b St and 104 Ave	0.229	Residential	0.57 < PPV < 3	PPV < 0.18
V2	104 Avenue between 146 St and 148 St	0.260	Commercial	0.57 < PPV < 3	0.18 < PPV < 0.40
V3	149 St and 104 Ave	4.745*	Residential / Commercial	0.57 < PPV < 3	0.18 < PPV < 0.40
V4	98a Avenue and King George Blvd.	0.150	Residential / Commercial	0.40 < PPV < 0.57	PPV < 0.18
V5	King George Blvd. and 94a Ave	0.363	Medical	0.57 < PPV < 3	PPV < 0.18
V5a	King George Blvd. and 94a Avenue	0.071	Medical	PPV < 0.18	PPV < 0.18
V5b	King George Blvd. and 94a Avenue	0.095	Medical	PPV < 0.18	PPV < 0.18
V6	88a Avenue and King George Blvd.	0.284	Residential	0.57 < PPV < 3	0.18 < PPV < 0.40
V7	136b St and 71 Ave	0.378	Residential / Commercial	0.18 < PPV < 0.40	PPV < 0.18
V8	84 Avenue and King George Blvd.	0.300	Residential / Commercial	0.57 < PPV < 3	0.18 < PPV < 0.40
V9	104 Avenue and City Parkway	0.197	Commercial	0.57 < PPV < 3	0.18 < PPV < 0.40
V10	104 Avenue and 144 St	0.276	Commercial	0.57 < PPV < 3	0.18 < PPV < 0.40

NOTE:
* Baseline Vibration readings at location V3 are not representative of ambient vibration levels and are attributed to the monitoring equipment being bumped.

7.9.9.2 Operation

Vibration estimates were used to determine vibration threshold contours from train operation along the extent of Project Alignment relative to existing structures and buildings, including sensitive structures and buildings. The upper range of vibration levels associated with light rail operation reported in FTA (2006) were used to estimate vibration effects during operation. Vibrations were adjusted for speed from the reference speed of 80 km/h to 60 km/h, assuming a maximum train speed of 50 km/h across the entire Alignment.

Vibration levels were estimated for the 12 monitoring locations used to reflect baseline conditions (Table 7.9-10), and presented as values within contour intervals, as described in the Vibration TDR (Appendix F). Train operation at these locations was estimated to result in PPV values of less than 0.18 mm/s (the threshold for disturbance at buildings where vibration would interfere with interior operations/equipment) or less than 0.40 mm/s (the threshold for disturbance at residences where people normally sleep). The thresholds are described in Table 7.9-4. At some locations along the Alignment, vibration caused by train operation may temporarily exceed baseline levels but would not exceed thresholds for damage or disturbance. The estimated values were well below thresholds for damage to buildings (PPV of >3 to >12.7, depending on building type). Four locations are identified (V6, V8, V9 and V10) may temporally feel the operational vibration, which may exceed the baseline value measured. Transient vibration may be felt when the light-rail train passes, however the transient vibration will be within the same vibration range of the baseline values (PPV between 0.18 to 0.40). The vibration will not cause damage to buildings or structures but can cause effects to sensitive receptors. Operational effects to the Surrey Memorial Hospital (baseline monitoring locations V5, V5a, V5b) and sensitive equipment located within are not likely to occur due to estimated PPV levels at these locations below 0.18 mm/s.

Train operations could result in temporary interference with sensitive equipment located within 27 m of the track. GIS analysis shows that there are 229 buildings located wholly or partially within 27 m of the track (Table 7.9-11); however, it is anticipated that the majority of these buildings do not house any vibration-sensitive equipment. The Surrey Memorial Hospital is set back at least 80 m from the track, and operation-induced vibrations are not expected to exceed ambient vibration levels or to be great enough to interfere with sensitive equipment. The Royal Canadian Mounted Police station, located at 10395 148 St is located within 27 m of the track, but no vibration sensitive equipment has been identified at this location.

Operational vibration levels are estimated to be too low to potentially result in any building damage. Occupants of 13 buildings that are wholly or partially located within 11 m of the track, may feel operation induced vibration (Table 7.9-11). However, of these 13 buildings, only three are zoned as residential. Recommended mitigation measures include procedures for tracking and responding to vibration-related enquiries by residents and other receptors.

Table 7.9-11: Damage and Disturbance Thresholds for Operational Vibration

Threshold		Total Number of Buildings Within Threshold Contour
Potential Human Reception and Sensitive Equipment Interference	Disturbance at institutional land uses with primary daytime use	4
	Disturbance at residences and buildings where people normally sleep	13
	Disturbance at buildings where vibration would interfere with interior operations/equipment	229

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.

In summary, vibration associated with train operation is low and is unlikely to damage buildings or to disturb most building occupants, although estimated levels will be higher than baseline conditions at some locations. The disturbance will occur for the short period during which a train passes a location and will occur regularly according to the train schedule. Short-term vibration effects may be experienced, which will not likely cause damage, and the effects can be reversed. Based on the estimated levels of vibration during operation, with the application of mitigation measures incorporated into the design and operation of the LRT system (see Mitigation Measure 7.9-6), adverse effects requiring additional mitigation are unlikely to be required.

7.9.10 Conclusion

Construction and operation induced vibrations may exceed baseline vibration levels along the Project Alignment in some locations, as construction proceeds along the Alignment. At the most sensitive location studied, Surrey Memorial Hospital, estimated vibrations from construction and operation are not expected to exceed baseline vibration levels or to produce vibration levels great enough to interfere with sensitive equipment. Actual vibrations during construction and operation will depend on a number of factors including local ground conditions, Construction Contractor means and methods, building structure and foundation types, detailed design parameters, and proximity to the Project Alignment.

During project construction it is anticipated that vibration effects will be similar to those experienced during major road construction. Vibration levels will be greatest in areas closest to active construction and decrease with distance from construction.

Vibration levels are estimated to be below thresholds for most buildings within the Review Area. Most buildings within the Review Area are located more than 13 m from construction activity and thus not likely to experience damage related to construction induced vibration. It is recommended that buildings potentially susceptible to vibration damage (i.e., located within 13 m of construction activity) be monitored for vibration effects during construction. Occupants of buildings within 48 to 80 m of the construction activities may be disturbed by vibration from vibratory rollers, depending on building type and occupancy. Buildings within these distances will be identified and evaluated in more detail closer to the time of construction as part of the Noise and Vibration Management Plan. As well, the concerns of residents located near the Alignment

should be addressed through public communications processes as part of the construction environmental management plan.

During operation, LRT-induced vibration levels are estimated to be below thresholds for disturbance, with the following potential exceptions:

1. There are 13 buildings located within 11 m of the track, which is within the threshold of disturbance for the category “residences and buildings where people normally sleep.” Of these 13 buildings, 4 are identified as residential buildings. .

There are 229 buildings within 27 m of the track, which is within the threshold of disturbance for category “buildings where vibration would interfere with interior operations/equipment”. At this time, there are no buildings identified within 27m of the track where vibration could interfere with interior operations and/or sensitive equipment. The Royal Canadian Mounted Police Station, located at 10395 148 St is within 27m of the track. However, no sensitive equipment has been identified at this location. Surrey Memorial Hospital was identified as a building potentially housing sensitive equipment, however, at its closest, the hospital is roughly 80 m from the projected location of the track indicating that interference is unlikely.

Where exceedances of vibration thresholds are estimated, vibration-limiting mitigation measures can be applied to lower these levels and to limit the likelihood of annoyance and complaints made by vibration-sensitive receptors.

7.9.11 References

California Department of Transportation (Caltrans). Transportation and Construction Vibration Guidance Manual, CT-HWANP-RT-13-069.25.3. September 2013. Available at: http://www.dot.ca.gov/hq/env/noise/pub/TCVGM_Sep13_FINAL.pdf

Federal Transit Administration (FTA). Transit and Noise Vibration Impact Assessment, FTA-VA-90-1003-06. May 2006. Available at: https://www.transit.dot.gov/regulations-and-guidance/environmental-programs/noise-and-vibration

Stantec Consulting Ltd (Stantec) Appendix E. Noise Technical Data Report. March 2018

Stantec Consulting Ltd (Stantec) Appendix F. Vibration Technical Data Report. March 2018