Attachment E
Noise and Vibration Assessment

MEMORANDUM

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Date: February 14, 2019

Subject: EBRC **-** CELR Noise and Vibration Assessment

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1. EXECUTIVE SUMMARY

This technical report documents the findings of potential light rail noise and vibration impacts for the proposed changes to the Eastridge to BART Regional Connector (formerly Capitol Expressway Light Rail) or EBRC-CELR. An assessment has been performed for both the construction and operation of the light rail system and has used assessment criteria established in the Federal Transit Administration's Guidance Manual for *Transit Noise and Vibration Impact Assessment* (2006). The assessment includes all likely sensitive receivers along the corridor. The EBRC-CELR is the last portion of the Capitol Expressway Transit Improvement Project that transforms Capitol Expressway into a multi-modal boulevard offering bus rapid transit, light rail transit and safe connections to the regional transit system. The current assessment provides an update to the 2005 Environmental Impact Report (EIR), 2007 Supplemental EIR (SEIR), 2012 Supplemental Draft Environmental Impact Statement (SDEIS), and the 2014 Subsequent Mitigated Negative Declaration. The basis for the update is a design change in the roadway configuration and aerial guideway near Westboro Drive (973+00), and in the track structure from at-grade ballasted to aerial guideway in the region along Capitol Expressway between Tudor Court (1003+00) and Cunningham Avenue (1050+00). While there are other changes proposed to the project, these changes are not anticipated to affect noise and vibration. This analysis has utilized newly acquired measurements of existing noise performed by ICF, previous measurements that characterize vibration propagation in the project area, and additional data where relevant.

1.1 Summary of Operational Impacts

1.1.1 Operational Noise Impacts

The analysis indicates that for year 2017 the project will result in 78 moderate and 23 severe unmitigated noise impacts and for year 2043 the project will result in 93 moderate and 59 severe unmitigated noise impacts. Table 1 summarizes the predicted light rail operational noise impacts. VTA policy is that for all severe noise impacts, noise mitigation measures will be included in the project if reasonable and feasible. For receivers where a moderate impact is predicted mitigation is not required under CEQA. However, VTA will include open-graded asphalt concrete (OGAC) in the project since VTA will need to repave most of Capitol Expressway at the end of construction. The analysis indicates that for year 2017 the project will result in 45 moderate and 0 severe noise impacts and for year 2043 there are 116 moderate and 0 severe noise impacts after the inclusion of aerial guideway sound walls. With the additional inclusion of OGAC all moderate and severe impacts are eliminated for years 2017 and 2043.

Table 1: Summary of Operational Noise Impacts

Section	Number – Type of Receivers	Existing Noise (Ldn)	Number of Predicted FTA Impacts					
			Unmitigated 2043 (2017)		w/ Aerial Sound Wall 2043 (2017)		w/ Aerial Sound Wall & OGAC 2043 (2017)	
			Mod	Severe	Mod	Severe	Mod	Severe
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 - SFR	70-78	17 (12)	1 (0)	0 (0)	0 (0)	0 (0)	0 (0)
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	72-73	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 - SFR	68-75	38 (5)	3 (0)	28 (3)	0 (0)	0 (0)	0 (0)
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 - SFR	65-67	0 (6)	27 (21)	27 (27)	0 (0)	0 (0)	0 (0)
SB 967+50 to 970+50 S. Capitol Ave.	5 - SFR	67-73	2 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
SB 971+30 to 973+00 S. Capitol Ave.	2 - COM	71-74	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 - SFR	72-75	25 (21)	0 (0)	23 (14)	0 (0)	0 (0)	0 (0)
SB 993+10 to 996+50 Story Rd.	3 - COM	73-74	2 (0)	0 (0)	2 (0)	0 (0)	0 (0)	0 (0)
SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 - SFR	65-73	4 (16)	13 (1)	16 (0)	0 (0)	0 (0)	0 (0)
SB 1009+00 E. Capitol Expy.	1 - COM	74	1 (0)	0 (0)	1 (0)	0 (0)	0 (0)	0 (0)
SB 1012+00 to 1018+00 Foxdale Loop	3 - MFR	69	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 - SFR	65-67	4 (18)	15 (1)	18 (1)	0 (0)	0 (0)	0 (0)
		# Impacts:	**93 (78)**	**59 (23)**	**116 (45)**	**0 (0)**	**0 (0)**	**0 (0)**

SFR: Single-Family Residence, MFR: Multi-Family Residence, COM: Commercial/Office Space. INST: Institutional

1.1.2 Operational Vibration Impacts

The results of this analysis indicate that ground vibration generated on the aerial guideway (direct fixation fasteners) and ballasted track on embankment sections may exceed the FTA detailed vibration analysis nighttime impact criteria at 67 receivers, as shown in Table 2. Nighttime is defined as 10:00 pm to 7:00 am. Potentially, receivers within 100 feet of the aerial guideway may exceed the nighttime criteria. It is noted that beyond approximately 50 feet from aerial guideway supports it is unusual to have vibration levels exceed FTA criteria. Most of these impacts are anticipated to occur between 6:00 am and 7:00 am when VTA would be operating at peak service levels. No daytime vibration impacts are predicted under current train parameters, schedules, headways, and speeds. It is noted that there is no distinction for current year (2017) and future year (2043) vibration predictions, since vibration criteria are not based on cumulative increases in vibration levels as is the case with noise. The analysis indicates that there are 66 vibration impacts after the inclusion of tire derived aggregate (TDA) at the at-grade and embankment sections of the alignment. If a floating slab track (FST) or bridge bearing vibration isolation system is used, all operational vibration impacts could be removed. Since there are only a few examples of FST and bridge bearing isolation systems in operation on an aerial structure, additional analysis of the effectiveness of these measures would be needed to confirm the level of vibration reduction that would be achieved.

Table 2: Summary of Operational Vibration Impacts

Direction/Section	Number – Type of Receivers	Impact Criteria (VdB)[1]	Number of Predicted FTA Impacts	
			Unmitigated	w/ TDA[3]
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 – SFR	72 - 78	10	10
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	78-84[2]	0	0
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 – SFR	72 - 78	4	4
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 – SFR	72 - 78	21	21
SB 967+50 to 970+50 S. Capitol Ave.	5 – SFR	72 - 78	1	0
SB 971+30 to 973+00 S. Capitol Ave.	2 – COM	84[2]	0	0
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 – SFR	72 - 78	2	2
SB 993+10 to 996+50 Story Rd.	3 – COM	84[2]	0	0
SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 – SFR	72 - 78	15	15
SB 1009+00 E. Capitol Expy.	1 – COM	84[2]	0	0
SB 1012+00 to 1018+00 Foxdale Loop	3 – MFR	72 - 78	0	0
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 – SFR	72 - 78	14	14
		# Impacts:	**67**	**66**

[1]FTA nighttime impact criteria of 72 VdB and daytime of 78 VdB.
[2]Impact threshold for offices and non-sensitive areas.
[3]TDA is only at at-grade and embankment sections.

1.2 Summary of Pile Driving Impacts

Pile driving would be conducted to install foundation piles for the aerial guideway. Both noise and vibration produced from the impact pile driving would potentially exceed FTA recommended construction criteria. The number of construction noise and vibration impacts has increased over the 2007 SEIR due to an increase in the number support columns from changing at-grade track to aerial guideway. It is noted that lower impact cast-in-drilled-hole (CIDH) piles will be used as the default installation method from the straddle bent 6-east at 978+00 to the north end of the guideway.

1.2.1 Pile Driving Noise Impacts

Unobstructed homes and businesses (i.e. not shielded by other structures or sound walls) within 300 ft of impact pile driving activity may exceed the FTA construction noise criteria of 80 dBA Leq over an 8-hour workday, as shown in Table 3. The noise impacts would have a duration of eight to fifteen days per receiver. This analysis indicates that 149 receivers in the Project area will exceed the FTA construction noise threshold for an 8-hour day. With the inclusion of an impact cushion the number of construction noise impacts is predicted to be 131, and with the addition of pre-drilling one third of the pile there are 79 predicted noise impacts. After the inclusion of an appropriately designed noise shield around the pile equipment there would be zero predicted noise impacts.

Table 3: Summary of Impact Pile Driving Noise Impacts

Direction/Section	Number – Type of Receivers	FTA Impact Criteria Leq (8-hr) dBA[1]	Number of Predicted FTA Impacts			
			Unmitigated[4]	w/ Impact Cushion[2]	w/ Impact Cushion & Pre-Drill 1/3 of Pile	w/ Impact Cushion & Noise Shield[3]
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 – SFR	80	12	9	9	0
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	80/85	5	3	2	0
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 – SFR	80	41	40	25	0
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 – SFR	80	27	22	9	0
SB 967+50 to 970+50 S. Capitol Ave.	5 – SFR	80	0	0	0	0
SB 971+30 to 973+00 S. Capitol Ave.	2 – COM	85	0	0	0	0
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 – SFR	80	21	21	21	0
SB 993+10 to 996+50	3 – COM	85	3	1	0	0

Story Rd.						
SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 – SFR	80	17	12	2	0
SB 1009+00 E. Capitol Expy.	1 – COM	85	1	1	0	0
SB 1012+00 to 1018+00 Foxdale Loop	3 – MFR	80	3	3	0	0
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 – SFR	80	19	19	11	0
		# Impacts	**149**	**131**	**79**	**0**

[1]Criteria for SFR/MFR is Leq (8-hr) 80 dBA, and for COM it is Leq (8-hr) 85 dBA
[2]Assumes impact cushion provides 5 dBA reduction.
[3]Assumes impact cushion + noise shield provides 15 dBA reduction.
[4]CIDH is the default installation method for piles from 978+00 to the north end of the guideway. The pile in the median of Capital Expressway at straddle bent 6-west is an impact pile.

1.2.2 Pile Driving Vibration Impacts

This analysis has shown that homes within 100 ft of impact pile driving activity may exceed FTA construction vibration criteria, shown in Table 4. There are 64 predicted unmitigated construction vibration impacts, and 0 impacts with the use of non-impact pile driving methods. It is noted that the use of non-impact pile driving methods may not be reasonable and feasible at all locations where minor vibration exceedance are predicted to occur. For the closest receivers the use of drilled piles plus a suitable sound barrier around the work site will eliminate both construction noise and construction vibration impacts.

Table 4: Summary of Impact Pile Driving Vibration Impacts

Direction/Section	Number – Type of Receivers	Annoy. Criteria PPV, (in/s)[1]	FTA Damage Criteria PPV, (in/s)[2]	Number of Predicted FTA Impacts	
				Unmitigated	w/ Non-Impact Piling[3]
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 - SFR	0.03	0.2	9	0
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	0.06	0.5	0	0
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 - SFR	0.03	0.2	5	0
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 - SFR	0.03	0.2	21	0
SB 967+50 to 970+50 S. Capitol Ave.	5 - SFR	0.03	0.2	0	0
SB 971+30 to 973+00 S. Capitol Ave.	2 - COM	0.06	0.5	0	0
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 - SFR	0.03	0.2	0	0
SB 993+10 to 996+50 Story Rd.	3 - COM	0.06	0.5	0	0

SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 - SFR	0.03	0.2	15	0
SB 1009+00 E. Capitol Expy.	1 - COM	0.03	0.5	0	0
SB 1012+00 to 1018+00 Foxdale Loop	3 - MFR	0.03	0.2	0	0
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 - SFR	0.03	0.2	14	0
			# Impacts	**64**	**0**

[1]Annoyance criteria based on an equivalent PPV to RMS value of 78 VdB for SFR/MFR and 84 VdB for COM, assuming a crest factor of 4.
[2]Damage criteria based on FTA Guidance Manual.
[3] CIDH is the default installation method for piles from 978+00 to the north end of the guideway. The pile in the median of Capital Expressway at straddle bent 6-west is an impact pile.

2. INTRODUCTION

This study updates the environmental analysis regarding noise and vibration impacts for the Santa Clara Valley Transportation Authority (VTA) Eastridge to BART Regional Connector (formerly Capitol Expressway Light Rail or CELR) Project (Project). The report has drawn primarily on the noise and vibration study prepared for the Supplemental Environmental Impact Report (SEIR) in 2007 and the Supplemental Draft Environmental Impact Statement (SEIS) in 2012. The purpose of this update is to provide an assessment of two design changes that could potentially affect noise and vibration levels. These design changes consist of a change in the roadway configuration and aerial guideway near Westboro Drive (973+00), and in the track structure from at-grade ballasted to aerial guideway in the region along Capitol Expressway between Tudor Court (1003+00) and Cunningham Avenue (1050+00). The update assesses current year (2017) and future year (2043) impacts due to the planned light rail transit (LRT) system and is performed in accordance to the Federal Transit Administration's (FTA) Guidance Manual for *Transit Noise and Vibration Impact Assessment* (2006)*.

This study addresses the LRT Build alternative. The No-Build alternative has been assessed in the 2012 SDEIS, which includes a bus rapid transit (BRT) system implemented as a separate VTA project. The BRT is currently operational in the Project area along Capitol Expressway.
In this report, the following information is presented:

- Ambient noise survey – updated from the original in 2001, 2006 and 2010
- Noise projections for years 2017 and 2043 (which includes growth in traffic and BRT)
- Vibration projections for the LRT
- Noise and vibration estimates for the construction of the aerial guideway
- Effect of noise and vibration control measures

Figure 1 shows the Project map with major design elements, and Figure 2 shows an aerial overview of the Project along with locations of the current and previous existing noise measurements and locations of the previous vibration propagation measurements.

* *Transit Noise and Vibration Impact Assessment*, Federal Transit Administration Document Number FTA-VA-90-1003-06, May 2006

2.1 Project Noise Concerns

Noise produced from light rail operations includes noise from steel wheels rolling on steel rails (wheel/rail noise) and from propulsion motors, air conditioning and other auxiliary equipment on the vehicles. At the time of this study the maximum operating speed considered for the light rail ranges from 35 to 55 miles per hour (mph). A key assumption in the noise predictions is that the optimal wheel and rail profiles would be maintained through periodic truing of the wheels and rail grinding. The track section in the Project does not include any grade crossings, special trackwork (crossovers, frogs, turnouts), or low radius curves, hence noise concerns from these sources are not anticipated. A traction power substation is planned for the southwest corner of Ocala Avenue, however given the distance from this location to the nearest receiver the substation will not contribute to the Project total noise levels in a meaningful way.

Noise produced during the construction of the aerial structure is a major concern and is included in the analysis. Pile driving in close proximity to a densely populated area has the potential to produce severe, albeit temporary, noise impact to local residents and businesses.

2.2 Project Vibration Concerns

Light rail operations create groundborne vibration that can be intrusive to occupants of buildings close to the tracks. Note that the FTA impact criteria for vibration are based on annoyance, and the predicted levels of light rail vibration at all receivers are well below the thresholds used to protect sensitive and fragile historic structures from damage. The potential for vibration from light rail operations to be annoying to occupants of historic structures is based on the appropriate vibration impact criteria for the current use of the building. A key assumption in the vibration predictions is that the optimal wheel and rail profiles would be maintained through periodic truing of the wheels and rail grinding. There are no anticipated secondary vibration sources such as special trackwork.

Vibration produced during the construction of the aerial structure is a major concern and is included in the analysis. As with noise, pile driving generated vibration in close proximity to a densely populated area has the potential to produce temporary impacts to local residents and businesses.

Figure 1: EBRC – CELR Project Map

Figure 2: EBRC Project Area from STA 965+00 to STA 1003+00. Current and Previous Existing Noise and Vibration Propagation Measurements Indicated

Figure 3: EBRC Project Area from STA 1003+00 to STA 1050+00. Current and Previous Existing Noise and Vibration Propagation Measurements Indicated

3. REGULATORY FRAMEWORK

Noise and vibration impact criteria that apply to this project are described below. As part of the regulatory framework discussion, typical terminology for noise and vibration are used; for more information on the basics of noise and vibration, including definitions of the technical terms used in this report, refer to Appendix A: Noise and Vibration Basics.

3.1 State and Local Noise and Vibration Limits

No state statutes related to noise and vibration apply to the operation of the proposed project and therefore the FTA Noise and Vibration guidelines are used. The FTA guidelines, analysis methods and criteria reflect the best available research on the topic.

Where applicable noise and vibration limits will also follow the City of San José General Plan[*] EC-1.1 to EC-2.4. For construction noise, section EC-1.7 of the General Plan requires construction operations within San José to use best available noise suppression devices and techniques and limit construction hours near residential uses per the City's Municipal Code. The City considers significant construction noise impacts to occur if a project located within 500 feet of residential uses or 200 feet of commercial or office uses would:

- Involve substantial noise generating activities (such as building demolition, grading, excavation, pile driving, use of impact equipment, or building framing) continuing for more than 12 months.

Ordinance Number 26594 of Section 20.100.450 of Chapter 20.100 of Title 20 of the San Jose Municipal Code states that unless otherwise expressly allowed in a Development Permit or other planning approval, no construction activity is permitted within 500 feet of a residential unit before 7:00 AM or after 7:00 PM, Monday through Friday, or at any time on weekends.

In the absence of any explicit local noise and vibration standards for daytime construction activity the FTA Noise and Vibration guidelines are used. Construction noise limits are discussed in Section 7 as part of the construction noise and vibration impact assessment.

The City of San José General Plan defers to FTA guidelines for vibration impact criteria.

3.2 FTA Noise Impact Criteria

The noise impact criteria for use on federally funded transit projects are defined in the FTA Guidance Manual for *Transit Noise and Vibration Impact Assessment* (2006; also referred to as FTA Guidance Manual). The FTA criteria are based on the best available research on community response to noise. This research shows that characterizing the overall noise environment using measures of noise exposure provides the best correlation with human annoyance. Noise exposure characterizes noise levels over a period of time.

FTA noise criteria in terms of the allowable increase in the cumulative noise exposure are shown in Figure 4. The cumulative or total noise is the logarithmic sum of the Existing and Project noise levels. The horizontal axis is the existing noise exposure and the vertical axis is the increase in cumulative noise level due to the transit project. For example, if the Existing noise is 60 dBA then a Project noise level of 58 dBA would cause a moderate impact (total noise of 62 dBA) and Project noise level of 63 dBA would cause a severe impact (total noise of 65 dBA).

[*] http://planning.sanjoseca.gov/planning/gp_update/FinalText/ESJ2040GeneralPlan_12-1-2011.pdf

The FTA noise impact threshold is a sliding scale based on existing noise exposure and land use of sensitive receivers. The measure of noise exposure is Ldn for residential areas (Category 2) and Leq for land uses that do not have nighttime noise sensitivity (Category 1). Since Ldn and Leq are measures of total acoustic energy, any new noise source in a community will cause an increase, even if the new source level is less than the existing level. As the existing level of ambient noise increases, the allowable level of transit noise increases, but the total amount that community noise exposure is allowed to increase is reduced. The land use surrounding the Project area is primarily residential, which falls into FTA Land Use Category 2.

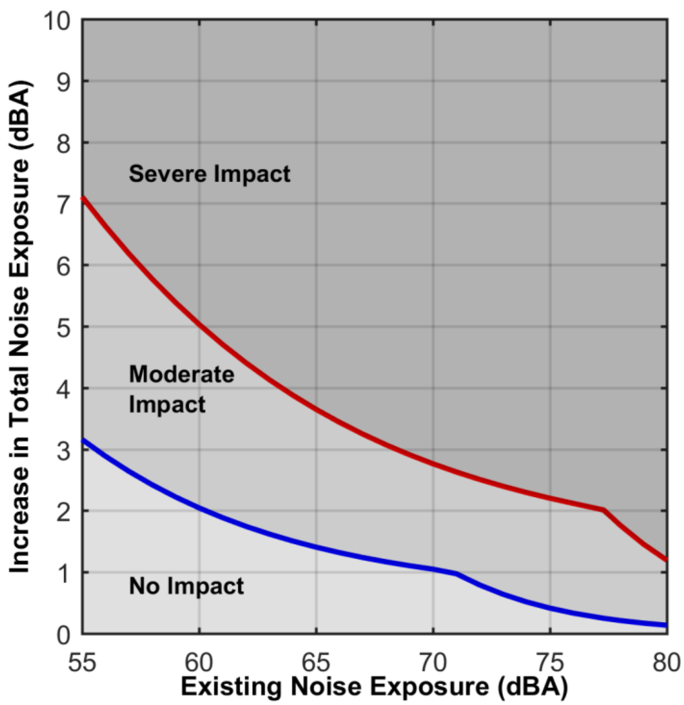

Figure 4: Increase in Cumulative Noise Level Allowed by FTA Criteria for Land Use Categories 1 (Leq) and 2 (Ldn).

3.3 FTA Groundborne Vibration and Groundborne Noise Criteria

The FTA Guidance Manual provides two sets of criteria for groundborne vibration: one based on the overall vibration velocity level for use in General Vibration Impact Assessments, and one based on the maximum vibration level in any 1/3-octave band (the band maximum level) for use with a Detailed Vibration Assessment. A 1/3-octave band is a range of frequencies, and each 1/3-octave band is referred to by the center frequency in that band. Predicting vibration on a 1/3-octave band basis allows vibration mitigation to be designed for the frequency range in which it will be most effective. This study uses the Detailed Vibration Assessment criteria.

Vibration levels generated by rail transit systems do not occur at levels that would approach damage criteria for modern structures. The FTA vibration criteria for train operations are solely for assessing human annoyance to vibration and not for assessing the potential for cosmetic or structural damage to structures and buildings. The FTA criterion curve for residences limits any 1/3-octave level between 8 Hz and 80 Hz to a maximum of 72 VdB nighttime and 78 VdB for daytime. Daytime hours are 7 AM to 10

PM, and nighttime hours are 10 PM to 7 AM (FTA). These detailed analysis criteria curves are shown in Figure 5 with a brief description of each of the curve shown in Table 5. Vibration that exceeds the detailed analysis criteria would be considered a significant impact.

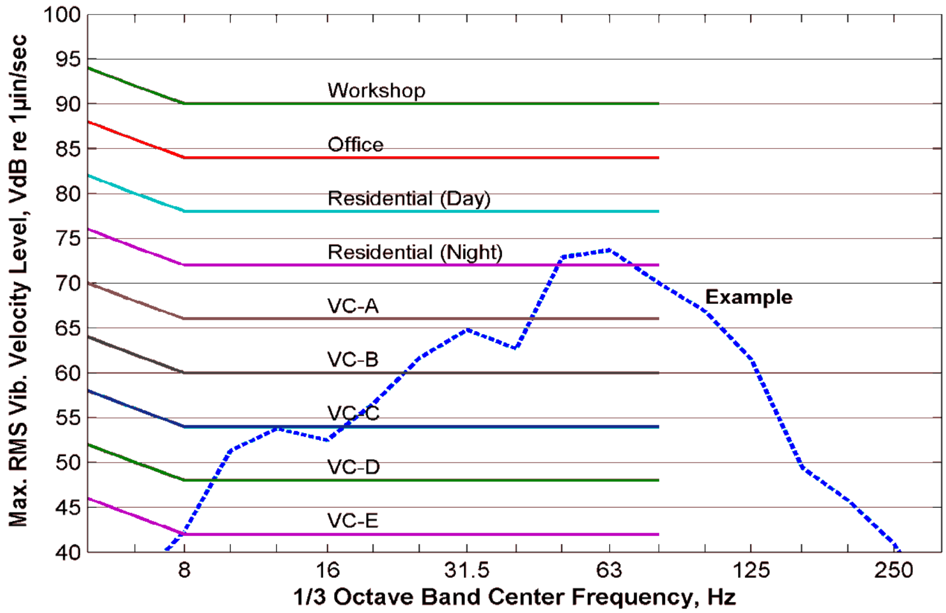

Figure 5: FTA Detailed Vibration Analysis Criteria

Table 5: Interpretation of Vibration Criteria for Detailed Analysis

Criterion Curve	Max Lv[a] (VdB)	Description of Uses
Workshop	90	Distinctly feelable vibration. Appropriate to workshops and non-sensitive areas.
Office	84	Feelable vibration. Appropriate to offices and non-sensitive areas.
Residential Day	78	Barely feelable vibration. Adequate for computer equipment and low-power optical microscopes (up to 20X).
Residential Night, Operating Rooms	72	Vibration not feelable, but groundborne noise may be audible inside quiet rooms. Suitable for medium-power optical microscopes (100X) and other equipment of low sensitivity.
VC-A	66	Adequate for medium- to high-power optical microscopes (400X), microbalances, optical balances and similar specialized equipment.
VC-B	60	Adequate for high-power optical microscopes (1000X), inspection and lithography equipment to 3-micron line widths.
VC-C	54	Appropriate for most lithography and inspection equipment to 1-micron detail size.
VC-D	48	Suitable in most instances for the most demanding equipment, including electron microscopes operating to the limits of their capability.

Criterion Curve	Max Lv[a] (VdB)	Description of Uses
VC-E	42	The most demanding criterion for extremely vibration-sensitive equipment.

Source: Federal Transit Administration (2006), Table 8-3
[a] Maximum allowed vibration velocity in any 1/3 octave band over the range of 8 to 80 Hz.

Groundborne noise is generated from the radiation of structures due to the propagation of groundborne vibration from the source to the structure. When audible groundborne noise occurs, it sounds like a low-frequency rumble.

The FTA Guidance Manual also presents criteria for assessing groundborne noise impact for sensitive land use categories. When railroad tracks are above ground, the groundborne noise is often masked by the airborne noise radiated from the wheels and rails. In those cases, it is not necessary to assess impacts from groundborne noise and the current analysis does not do so. Additionally, groundborne noise primarily occurs above 50 Hz, due to both inefficiencies of structural radiation of sound and the human auditory response below this frequency.

3.4 Construction Noise and Vibration Criteria

3.4.1 Construction Noise

The use of heavy equipment during project construction has the potential to result in substantial, yet temporary, increases in local noise levels along the corridor. Noise from pile driving is expected to be of primary concern due to the use of piles for supporting the aerial guideway. The FTA Guidance Manual recommends using local construction noise limits, if possible. For the City of San Jose, the General Plan and Municipal Code are interpreted as having no specific noise limits that apply. As a result, the construction noise for this project should be examined in terms of the FTA guidance (shown in Table 6) for evaluating the potential community response to construction noise. The guidelines are based on an average Leq over a typical 8-hour workday. The FTA recommended limit of 80 dBA for the daytime Leq has been used in this assessment as the threshold for impact for residential areas.

Construction noise levels depend on the number of pieces and type of equipment, their general condition, the amount of time each piece operates per day, the presence or lack of noise-attenuating features such as walls and berms and the location of the construction activities relative to the sensitive receivers. The majority of these variables are left to the discretion of the construction contractor selected by VTA as the project approaches the construction phase. However, estimates of pile driving noise exposure levels are estimated based on reasonable assumptions of the hours of operation.

Table 6: FTA Construction Noise Guidelines

Land Use	Noise Limit, 8-hour Leq (dBA)	
	Daytime	Nighttime
Residential	80	70
Commercial	85	85
Industrial	90	90

3.4.2 Construction Vibration

The primary concern regarding construction vibration is potential damage to structures. The thresholds for potential damage are much higher than the thresholds for evaluating potential annoyance used to assess impact from operational vibration. The FTA Guidance Manual recommended limits for construction vibration for the various building categories are shown in Table 7. It is important to note that the vibration limits in Table 7 are the levels at which there is a risk for damage for each building category, not the level at which damage would occur. These limits should be viewed as criteria that should be used during the impact assessment phase to identify potential problem locations.

Table 7: FTA Construction Vibration Damage Risk Criteria

Building Category	Peak Particle Velocity (inches/second)
Reinforced-concrete, steel or timber (no plaster)	0.5
Engineered concrete and masonry (no plaster)	0.3
Nonengineered timber and masonry buildings	0.2
Buildings extremely susceptible to vibration damage	0.12

4. EXISTING NOISE

The existing noise environment is dominated by traffic on Capitol Expressway. Capitol Expressway is an 8-lane facility with 6 mixed flow lanes and 2 carpool lanes. Light rail would operate primarily in the median of Capitol Expressway and would involve the removal of the 2 carpool lanes to minimize right-of-way acquisition except between Capitol Avenue and Story Road where VTA is proposing to maintain eight lanes.

Due to the amount of time that has elapsed since the previous existing noise survey (2001, 2006, 2010), the ambient noise environment within the Project area was measured in December 2017[*], with previous and current noise measurement locations shown in Figure 2. As shown, the previous and current locations differed due to access and logistical constraints. To accurately compare previous and current noise measurements and to estimate the noise at each sensitive receiver due to traffic noise along Capitol Expressway, a Federal Highway Administration (FHWA) Traffic Noise Model (TNM)[†] was developed. The TNM model was calibrated with the 2017 noise measurements and 2017 traffic count data[‡] for the Project area south of Story Road, and with 2010 noise measurements[§] and 2009 traffic count data[**] for the Project area north of Story Road. The TNM model accounts for traffic flow, effect of pavements, existing sound barriers and attenuation over/through rows of buildings. Table 8 shows a comparison between the previous and current existing noise exposure levels. The raw measured noise levels and photos of measurement locations are presented in Appendix B.

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[*] December 2017 noise survey conducted by ICF

[†] Menge, C.W., et al., *FHWA Traffic Noise Model, Version 1.0*, U.S. DOT, Report FHWA-PD-96-010, 1998, v2.5 ,2004.

[‡] October 2017 traffic count conducted by Kittelson & Associates.

[§] July 2010, Captiol Expressway Light Rail Project, Noise and Vibration Study for the SEIS. Wilson, Ihrig & Associates.

[**] September 2012, Capitol Expressway Light Rail Project, Transportation Study for the SEIS. AECOM

Table 8: Comparison of Previous and Current Existing Noise Exposure Levels

Label	Location	Land Use	Previous (2010) Ldn	Current (2017) Ldn[1]
N-1	4268 Bambi Ln.	Cat 2	72	73.8
N-2	1276 Capitol Court	Cat 2	73	74.1
N-3	2540 Greenstone Circle	Cat 2	67	67.4
N-4	2015 Supreme Drive	Cat 2	65	66.3

[1] Adjusted to 2010 measurement locations using FHWA TNM model

5. OPERATIONAL NOISE ASSESSMENT AND CONTROL

5.1 Prediction Methodology

The light rail noise prediction model follows the noise impact assessment methodology for detailed noise predictions presented in the FTA Guidance Manual and incorporates assumptions on operating conditions specific to the project, including speeds, vehicle type and train headways.

For well-maintained light rail systems, the wheel-rail noise dominates above 20 mph and the noise from propulsion motors, air conditioning and other auxiliary equipment on the vehicles dominate below 20 mph. The noise predictions for this analysis are based on the reference sound equivalent level SEL_{ref} as a building block for determining the total project noise level. The SEL_{ref} is used to determine the equivalent noise Leq for operational conditions, and the hourly Leq are used to determine the Ldn. The model equations are:

$$\mathrm{Leq(hr)} = \mathrm{SEL_{ref}} + 10\ \mathrm{Log(N)} + 20\ \mathrm{Log}\left(\frac{\mathrm{S}}{50}\right) + 10\ \mathrm{Log(V)} - 10\ \mathrm{Log}\left(\frac{\mathrm{D}}{50}\right) - 35.56$$

$\mathrm{SEL_{ref}}$	Reference SEL at 50 mph and 50 ft for one car
N	Number of cars per train
S	Train speed in mph
D	Distance from source to receiver

For slab track on aerial structure FTA recommends an additional +4 dB to the Leq(hr). The Ldn is then calculated as:

$$\mathrm{Ldn} = 10\ \mathrm{Log}(15 * 10^{\frac{\mathrm{Leq(Day)}}{10}} + 9 * 10^{\frac{\mathrm{Leq(Night)}+10}{10}}) - 13.8$$

Operational parameters for the trains are as follows:

Train Speed	55 mph (35 mph on embankment section near South Capitol Avenue)
Headways	30 minutes (4:30 AM to 6:00 AM), 2-car
	7.5 minutes (6:00 AM to 9:00 AM), peak AM, 3-car
	7.5 minutes (9:00 AM to 3:30 PM), 2-car
	7.5 minutes (3:30 PM to 7:30 PM), peak PM, 3-car

15 minutes (7:30 PM to 11:30 PM), 2-car

30 minutes (11:30 to 1:30 AM), 1-car

This analysis indicates that for current year (2017) there are 78 moderate and 23 severe unmitigated noise impacts. For future year (2043) conditions there are 96 moderate and 59 severe unmitigated noise impacts. Table 9 summarizes the predicted operational total project noise and number of impacts for future year 2043.

5.2 Road Traffic Noise

Road traffic noise due to the Project is estimated similar to the method used for the existing road traffic noise described previously using TNM. Project related changes to the Capitol Expressway road configuration include four lanes of traffic north of Story Road and three lanes of traffic south of Story Road. Noise levels are estimated for current year 2017 and future year 2043. The growth trends for traffic volume along Capitol Expressway were estimated by the VTA Travel Demand Model using traffic counts by Kittelson & Associates in 2017, which predicted traffic volume out to year 2043 under Project Build and No-Build scenarios. Noise from traffic is directly proportional to traffic volume, assuming all other factors remain the same, a doubling of traffic volume increases the noise exposure by 3 dB.

The increase in traffic noise has the effect of substantially increasing the number of noise impacts for future year (2043) conditions over the current year (2017) conditions. The estimated operational LRT noise is combined with the estimated noise increase from road traffic, under the Project Build alternative, to predict the total current and future noise exposure levels, as shown in Table 9.

The location of receivers where future year (2043) operational noise impacts are predicted are as follows:

- Twenty properties located east and west of the alignment, between Wilbur Avenue and Mervyns Way will experience one severe and twenty-two moderate noise impacts.
- Twenty-five properties located west of the alignment between Excalibur Drive and Story Road will experience moderate noise impacts.
- Two commercial properties located west of the alignment near the intersection of Story Road and Capitol Expressway will experience moderate noise impacts.
- Forty-one properties located east of the alignment between Story Road and Ocala Avenue will experience thirty-eight moderate and three severe noise impacts.
- Seventeen properties located west of the alignment between Story Road and Foxdale Loop will experience four moderate and thirteen severe noise impacts.
- One commercial property located west of the alignment near the intersection of Foxdale Loop and Capitol Expressway will experience a moderate noise impact.
- Twenty-seven properties located east of the alignment between Ocala Avenue and Cunningham Avenue will experience severe noise impacts.
- Nineteen properties located west of the alignment between Foxdale Drive and Ocala Avenue will experience four moderate and fifteen severe noise impacts.

5.3 Noise Control Measures

Aerial Guideway Sound Wall: With the incorporation of a 3 ft aerial guideway sound wall there are 45 moderate and 0 severe impacts for year 2017.

With the aerial guideway sound walls there are 116 moderate and 0 severe impacts for year 2043. Future noise levels are dominated by the growth in traffic noise on Capitol Expressway and not by light rail operations.

Wayside Sound Walls: Only about half of all residences in the Project area are behind an existing approximately 8 ft high wayside sound wall, which has been included in the preceding analysis. Typical sound walls provide about 5 dB or more of noise reduction, depending on source-receiver geometry. The construction of sound walls where they do not currently exist would likely remove all the predicted moderate impacts for future year 2043, at those locations. For the remaining receivers, adding an additional height of 3 ft to existing barriers would reduce the noise levels at those receivers by about 1.5 dB, further reducing the number of impacts for future year 2043. It is recommended that a more detailed analysis of the effect of increasing the height of existing sound walls should be conducted if this measure is to be considered.

Home Insulation: Replace or improve sound insulation materials on nearby homes. U.S. Department of Housing and Urban Development (HUD) acceptability threshold for residential interior noise is 45 Ldn dBA. This method would not improve noise levels at outdoor spaces of the homes.

Quiet Pavement: Recent studies by Caltrans indicate that Open Graded Asphalt Concrete (OGAC) produces noticeably less vehicle noise than other pavement types (i.e., concrete and conventional asphalt). Research data collected to date indicates that OGAC results in a 4- to 6-dBA reduction in traffic noise levels in the 750 Hz to 4 KHz frequency range*. The Caltrans study indicates that the OGAC that they tested on I-80 reduces overall noise levels by approximately 3 dBA compared to normal pavements. Assuming a conservative 2 dB reduction, OGAC removes all the predicted moderate impacts that remain after the incorporation of the aerial sound wall. Table 9 includes the effect of OGAC. There are no impacts left after the effects of the aerial guideway sound wall and OGAC are included.

Table 9: Summary of Predicted Total Noise, Year 2043

Station Number	Receiver Address	Rec Type	Horz. Dist. to Near Track (ft)	Existing Noise (Ldn)	Unmitigated Total Noise, (Ldn)	FTA Allowable Increase		FTA Impact Before Noise Control?		FTA Impact After Noise Control?[1]	
						Mod	Severe	Mod	Severe	Mod	Severe
NB 964+50	2705 Wilbur Ave	SFR	69	71.1	71.8	1.0	2.6	--	--	--	--
NB 966+00	2706 Wilbur Ave	SFR	97	71.4	72.3	1.0	2.6	--	--	--	--
NB 967+00	420 Capitol Ave	SFR	80	70.1	71.2	1.0	2.8	Y	--	--	--
NB 967+50	440 Capitol Ave	SFR	81	70.0	71.1	1.1	2.9	--	--	--	--
NB 968+10	460 Capitol Ave	SFR	80	70.1	71.2	1.0	2.8	Y	--	--	--
NB 968+80	480 Capitol Ave	SFR	77	70.3	71.5	1.0	2.8	Y	--	--	--
NB 969+50	13511 Westboro Dr	SFR	65	71.8	72.8	1.0	2.6	Y	--	--	--
NB 970+90	13510 Westboro Dr	SFR	63	72.8	73.6	0.8	2.5	Y	--	--	--
NB 971+70	500 Capitol Ave	SFR	76	71.9	72.7	1.0	2.6	--	--	--	--
NB 972+20	520 Capitol Ave	SFR	79	71.9	73.1	1.0	2.6	Y	--	--	--
NB 973+00	540 Capitol Ave	SFR	77	72.4	73.7	0.8	2.5	Y	--	--	--
NB 973+50	560 Capitol Ave	SFR	79	72.6	73.9	0.8	2.5	Y	--	--	--
NB 974+10	13501 Highwood Dr	SFR	61	72.7	74.2	0.8	2.5	Y	--	--	--
NB 975+80	13500 Highwood Dr	SFR	62	70.8	72.8	1.0	2.8	Y	--	--	--

* Caltrans, 1-80 Davis OGAC *Pavement Noise Study*, 2001.

Station Number	Receiver Address	Rec Type	Horz. Dist. to Near Track (ft)	Existing Noise (Ldn)	Unmitigated Total Noise, (Ldn)	FTA Allowable Increase		FTA Impact Before Noise Control?		FTA Impact After Noise Control?[1]	
						Mod	Severe	Mod	Severe	Mod	Severe
NB 976+50	620 S Capitol Ave	SFR	68	68.6	71.2	1.2	3.1	Y	--	--	--
NB 977+20	640 S Capitol Ave	SFR	63	68.4	71.2	1.2	3.1	Y	--	--	--
NB 977+70	660 S Capitol Ave	SFR	48	68.0	71.4	1.2	3.2	--	Y	--	--
NB 978+50	10301 Dover Way	SFR	131	63.9	67.5	1.6	4.1	Y	--	--	--
NB 979+10	10291 Dover Way	SFR	141	64.4	67.6	1.5	3.9	Y	--	--	--
NB 979+70	10281 Dover Way	SFR	124	65.0	68.2	1.5	3.9	Y	--	--	--
NB 980+50	10271 Dover Way	SFR	107	65.7	68.8	1.4	3.6	Y	--	--	--
NB 981+20	10261 Dover Way	SFR	112	65.7	68.7	1.4	3.6	Y	--	--	--
NB 986+70	888 S Capitol Ave	COM	131	75.1	75.6	1.2	4.9	--	--	--	--
NB 988+30	920 S Capitol Ave	CH	132	75.3	75.6	1.2	4.9	--	--	--	--
NB 990+50	990 S Capitol Ave	CH	126	75.5	75.8	1.2	4.9	--	--	--	--
NB 992+80	2701 Story Rd	COM	137	74.9	75.3	1.5	5.1	--	--	--	--
NB 995+50	2710 Story Rd	COM	118	75.4	75.6	1.2	4.9	--	--	--	--
NB 998+50	2710 Kollmar Dr	MFR	103	74.4	75.6	0.5	2.3	Y	--	--	--
NB 999+90	2709 Sussex Dr	SFR	117	73.4	74.7	0.6	2.4	Y	--	--	--
NB 1001+60	1210 Capitol Ave	SFR	117	73.5	74.8	0.6	2.4	Y	--	--	--
NB 1002+40	1222 Capitol Ave	SFR	116	73.5	74.8	0.6	2.4	Y	--	--	--
NB 1003+90	1244 Tudor Ct	SFR	118	73.6	74.8	0.6	2.4	Y	--	--	--
NB 1004+90	1260 Capitol Ct	SFR	117	73.6	74.8	0.6	2.4	Y	--	--	--
NB 1006+20	1276 Capitol Ct	SFR	118	73.6	74.8	0.6	2.4	Y	--	--	--
NB 1007+10	2703 Murtha Dr	SFR	117	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1008+80	2704 Murtha Dr	SFR	118	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1009+80	1336 Capitol Ave	SFR	117	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1011+10	2706 Bristol Dr	SFR	117	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1012+10	2707 Dublin Dr	SFR	117	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1013+60	2704 Dublin Dr	SFR	118	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1014+50	1440 Capitol Ave	SFR	119	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1016+00	1460 Capitol Ave	SFR	118	73.2	74.4	0.6	2.4	Y	--	--	--
NB 1017+00	1492 Capitol Ave	SFR	120	73.2	74.4	0.6	2.4	Y	--	--	--
NB 1018+30	1512 Capitol Ave	SFR	127	73.2	74.4	0.6	2.4	Y	--	--	--
NB 1019+40	2705 Capitol Ave	SFR	123	73.2	74.4	0.6	2.4	Y	--	--	--
NB 1021+00	2704 Capitol Ave	SFR	119	73.7	74.8	0.6	2.4	Y	--	--	--
NB 1021+60	1564/1566 Capitol Ave	SFR	146	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1022+30	1572 Capitol Ave	SFR	142	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1022+90	1576/1578 Capitol Ave	SFR	146	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1023+50	1584 Capitol Ave	SFR	141	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1024+10	1588/1590 Capitol Ave	SFR	148	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1024+70	1596 Capitol Ave	SFR	140	72.3	73.4	0.8	2.5	Y	--	--	--
NB 1026+00	1606/1608 Capitol Ave	SFR	143	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1026+60	1614 Capitol Ave	SFR	136	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1027+20	1618/1620 Capitol Ave	SFR	141	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1027+90	1624/1626 Capitol Ave	SFR	137	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1028+50	1632 Capitol Ave	SFR	139	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1029+00	1636/1638 Capitol Ave	SFR	134	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1029+60	1654 Capitol Ave	SFR	133	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1030+10	1660 Capitol Ave	SFR	133	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1030+70	1666 Capitol Ave	SFR	133	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1031+30	1672 Capitol Ave	SFR	133	72.3	73.5	0.8	2.5	Y	--	--	--
NB 1031+90	1678 Capitol Ave	SFR	133	72.2	73.4	0.8	2.5	Y	--	--	--
NB 1032+50	1684 Capitol Ave	SFR	135	72.0	73.2	1.0	2.6	Y	--	--	--
NB 1034+00	1701 Capitol Ave	SFR	68	72.0	74.2	1.0	2.6	Y	--	--	--
NB 1034+80	1923 Evermont Ct	SFR	80	69.2	72.1	1.1	2.9	--	Y	--	--
NB 1035+20	1917 Evermont Ct	SFR	82	68.7	71.8	1.2	3.1	--	Y	--	--
NB 1035+90	1911 Evermont Ct	SFR	102	67.6	70.9	1.2	3.2	--	Y	--	--
NB 1037+60	1756 Home Gate Dr	SFR	88	66.7	70.8	1.3	3.4	--	Y	--	--

Station Number	Receiver Address	Rec Type	Horz. Dist. to Near Track (ft)	Existing Noise (Ldn)	Unmitigated Total Noise, (Ldn)	FTA Allowable Increase		FTA Impact Before Noise Control?		FTA Impact After Noise Control?[1]	
						Mod	Severe	Mod	Severe	Mod	Severe
NB 1038+00	1758 Home Gate Dr	SFR	82	66.7	70.8	1.3	3.4	--	Y	--	--
NB 1038+30	1760 Home Gate Dr	SFR	83	66.6	70.7	1.3	3.4	--	Y	--	--
NB 1038+60	1762 Home Gate Dr	SFR	108	66.2	70.0	1.3	3.4	--	Y	--	--
NB 1038+90	1764 Home Gate Dr	SFR	96	66.6	70.5	1.3	3.4	--	Y	--	--
NB 1039+20	1766 Home Gate Dr	SFR	82	66.2	70.5	1.3	3.4	--	Y	--	--
NB 1039+50	1768 Home Gate Dr	SFR	99	66.4	70.3	1.3	3.4	--	Y	--	--
NB 1039+80	1770 Home Gate Dr	SFR	95	66.4	70.3	1.3	3.4	--	Y	--	--
NB 1040+10	1772 Home Gate Dr	SFR	93	66.5	70.4	1.3	3.4	--	Y	--	--
NB 1040+50	1774 Home Gate Dr	SFR	83	66.7	70.6	1.3	3.4	--	Y	--	--
NB 1040+90	1776 Home Gate Dr	SFR	82	66.4	70.4	1.3	3.4	--	Y	--	--
NB 1041+20	1778 Home Gate Dr	SFR	74	66.4	70.5	1.3	3.4	--	Y	--	--
NB 1041+50	1780 Home Gate Dr	SFR	98	66.4	70.2	1.3	3.4	--	Y	--	--
NB 1041+80	1782 Home Gate Dr	SFR	93	66.4	70.2	1.3	3.4	--	Y	--	--
NB 1042+10	1784 Home Gate Dr	SFR	88	66.4	70.3	1.3	3.4	--	Y	--	--
NB 1042+50	1786 Home Gate Dr	SFR	97	66.2	70.1	1.3	3.4	--	Y	--	--
NB 1042+90	1788 Home Gate Dr	SFR	95	66.3	70.2	1.3	3.4	--	Y	--	--
NB 1043+20	1790 Home Gate Dr	SFR	90	66.4	70.3	1.3	3.4	--	Y	--	--
NB 1044+10	1995 Supreme Dr	SFR	97	66.2	70.1	1.3	3.4	--	Y	--	--
NB 1045+10	2001 Supreme Dr	SFR	82	66.1	70.2	1.3	3.4	--	Y	--	--
NB 1046+00	2009 Supreme Dr	SFR	112	65.1	69.1	1.4	3.6	--	Y	--	--
NB 1046+70	2015 Supreme Dr	SFR	119	65.0	69.0	1.5	3.9	--	Y	--	--
NB 1047+20	2021 Supreme Dr	SFR	108	65.8	69.7	1.4	3.6	--	Y	--	--
NB 1047+80	2027 Supreme Dr	SFR	103	65.9	69.8	1.4	3.6	--	Y	--	--
NB 1048+50	2033 Supreme Dr	SFR	115	65.5	69.5	1.4	3.6	--	Y	--	--
NB 1049+00	2039 Supreme Dr	SFR	101	65.7	69.8	1.4	3.6	--	Y	--	--
NB 1049+50	2045 Supreme Dr	SFR	111	65.0	69.6	1.5	3.9	--	Y	--	--
SB 967+50	441 Capitol Ave	SFR	48	73.3	74.3	0.6	2.4	Y	--	--	--
SB 967+50	2685 Lombard Ave	SFR	105	67.5	68.4	1.2	3.2	--	--	--	--
SB 968+90	2686 Lombard Ave	SFR	64	71.0	72.0	1.0	2.8	Y	--	--	--
SB 969+80	353 Capitol Ave	SFR	75	71.4	72.3	1.0	2.6	--	--	--	--
SB 970+50	455 Capitol Ave	SFR	76	71.8	72.7	1.0	2.6	--	--	--	--
SB 971+30	459 S Capitol Ave	COM	65	73.7	74.6	1.8	5.2	--	--	--	--
SB 973+00	461 S Capitol Ave	COM	73	76.4	77.2	1.0	4.8	--	--	--	--
SB 978+00	674 Excalibur Drive	SFR	193	74.6	75.5	0.5	2.3	Y	--	--	--
SB 979+50	692 Excalibur Drive	SFR	196	73.5	74.4	0.6	2.4	Y	--	--	--
SB 979+00	710 Excalibur Drive	SFR	200	72.6	73.6	0.8	2.5	Y	--	--	--
SB 979+50	728 Excalibur Drive	SFR	200	71.9	73.1	1.0	2.6	Y	--	--	--
SB 979+80	731 S Capitol Ave	SFR	113	74.6	76.1	0.5	2.3	Y	--	--	--
SB 980+50	747 S Capitol Ave	SFR	120	74.0	75.7	0.6	2.4	Y	--	--	--
SB 981+10	763 S Capitol Ave	SFR	121	73.7	75.5	0.6	2.4	Y	--	--	--
SB 983+00	2693 Bambi Ln	SFR	115	74.1	76.3	0.5	2.3	Y	--	--	--
SB 984+40	807 Capitol Ave	SFR	135	73.1	75.1	0.6	2.4	Y	--	--	--
SB 985+10	821 Capitol Ave	SFR	134	73.2	75.2	0.6	2.4	Y	--	--	--
SB 985+60	835 Capitol Ave	SFR	136	73.2	75.2	0.6	2.4	Y	--	--	--
SB 986+10	849 Capitol Ave	SFR	138	73.3	75.3	0.6	2.4	Y	--	--	--
SB 986+50	863 Capitol Ave	SFR	139	73.3	75.2	0.6	2.4	Y	--	--	--
SB 987+10	877 Capitol Ave	SFR	137	73.5	75.4	0.6	2.4	Y	--	--	--
SB 987+50	891 Capitol Ave	SFR	136	73.7	75.6	0.6	2.4	Y	--	--	--
SB 988+10	905 Capitol Ave	SFR	133	74.0	75.8	0.6	2.4	Y	--	--	--
SB 988+60	921 Capitol Ave	SFR	135	74.2	75.9	0.5	2.3	Y	--	--	--
SB 989+10	937 Capitol Ave	SFR	129	74.4	76.0	0.5	2.3	Y	--	--	--
SB 989+50	953 Capitol Ave	SFR	129	74.4	75.9	0.5	2.3	Y	--	--	--
SB 990+00	969 Capitol Ave	SFR	121	74.5	75.9	0.5	2.3	Y	--	--	--
SB 990+60	985 Capitol Ave	SFR	119	74.6	76.0	0.5	2.3	Y	--	--	--

Station Number	Receiver Address	Rec Type	Horz. Dist. to Near Track (ft)	Existing Noise (Ldn)	Unmitigated Total Noise, (Ldn)	FTA Allowable Increase		FTA Impact Before Noise Control?		FTA Impact After Noise Control?[1]	
						Mod	Severe	Mod	Severe	Mod	Severe
SB 991+00	1001 Capitol Ave	SFR	114	74.6	76.0	0.5	2.3	Y	--	--	--
SB 991+60	1017 Capitol Ave	SFR	111	74.8	76.2	0.5	2.3	Y	--	--	--
SB 992+20	1033 Capitol Ave	SFR	107	74.9	76.3	0.5	2.3	Y	--	--	--
SB 992+70	1049 Capitol Ave	SFR	105	75.2	76.5	0.4	2.2	Y	--	--	--
SB 993+10	1091 Capitol Ave	COM	93	75.8	77.3	1.2	4.9	Y	--	--	--
SB 994+00	2695 Story Rd	COM	90	76.2	77.7	1.0	4.8	Y	--	--	--
SB 996+50	2690 Story Rd	COM	102	76.2	76.9	1.0	4.8	--	--	--	--
SB 998+80	2598 Brenford Dr	SFR	156	65.0	67.8	1.5	3.9	Y	--	--	--
SB 999+30	2594 Brenford Dr	SFR	92	65.8	69.5	1.4	3.6	--	Y	--	--
SB 1000+00	2590 Brenford Dr	SFR	89	65.8	69.6	1.4	3.6	--	Y	--	--
SB 1000+50	2586 Brenford Dr	SFR	95	65.9	69.5	1.4	3.6	--	Y	--	--
SB 1001+00	2582 Brenford Dr	SFR	81	65.8	69.7	1.4	3.6	--	Y	--	--
SB 1001+60	2578 Brenford Dr	SFR	79	65.6	69.7	1.4	3.6	--	Y	--	--
SB 1002+10	2574 Brenford Dr	SFR	79	65.8	69.9	1.4	3.6	--	Y	--	--
SB 1002+80	2570 Brenford Dr	SFR	82	65.7	69.7	1.4	3.6	--	Y	--	--
SB 1003+20	2568 Brenford Dr	SFR	72	65.3	69.7	1.4	3.6	--	Y	--	--
SB 1003+80	2564 Brenford Dr	SFR	81	65.9	69.8	1.4	3.6	--	Y	--	--
SB 1004+40	2560 Brenford Dr	SFR	93	66.2	69.8	1.3	3.4	--	Y	--	--
SB 1005+00	2556 Brenford Dr	SFR	95	66.1	69.7	1.3	3.4	--	Y	--	--
SB 1005+40	2552 Brenford Dr	SFR	83	65.9	69.8	1.4	3.6	--	Y	--	--
SB 1006+00	2548 Brenford Dr	SFR	82	66.3	70.0	1.3	3.4	--	Y	--	--
SB 1006+60	2544 Brenford Dr	SFR	73	66.8	70.0	1.3	3.4	Y	--	--	--
SB 1007+10	2540 Brenford Dr	SFR	81	68.7	71.6	1.2	3.1	Y	--	--	--
SB 1007+20	2536 Brenford Dr	SFR	122	67.2	70.0	1.2	3.2	Y	--	--	--
SB 1009+00	3501 E Capitol Expy	COM	78	74.2	76.2	1.5	5.1	Y	--	--	--
SB 1012+00	Foxdale Village Foxdale Loop	MFR	125	69.1	71.6	1.1	2.9	--	--	--	--
SB 1014+50	Foxdale Village Foxdale Loop	MFR	124	69.0	71.4	1.2	3.1	--	--	--	--
SB 1018+00	Foxdale Village Foxdale Loop	MFR	125	69.5	71.8	1.1	2.9	--	--	--	--
SB 1021+00	2529 Greenstone Ct	SFR	140	64.7	67.7	1.5	3.9	Y	--	--	--
SB 1021+40	2535 Greenstone Ct	SFR	98	66.1	69.6	1.3	3.4	--	Y	--	--
SB 1022+00	2540 Greenstone Ct	SFR	79	67.3	70.7	1.2	3.2	--	Y	--	--
SB 1022+70	2534 Greenstone Ct	SFR	109	65.8	69.2	1.4	3.6	Y	--	--	--
SB 1024+10	2537 Whitestone Ct	SFR	88	66.1	69.8	1.3	3.4	--	Y	--	--
SB 1024+90	2538 Whitestone Ct	SFR	86	66.3	70.0	1.3	3.4	--	Y	--	--
SB 1025+50	2530 Whitestone Ct	SFR	100	66.1	69.6	1.3	3.4	--	Y	--	--
SB 1026+90	2533 Bluestone Ct	SFR	87	66.2	69.9	1.3	3.4	--	Y	--	--
SB 1027+40	2532 Bluestone Ct	SFR	80	66.0	70.0	1.4	3.6	--	Y	--	--
SB 1027+80	2526 Bluestone Ct	SFR	112	65.7	69.0	1.4	3.6	Y	--	--	--
SB 1029+30	2517 Brownstone Ct	SFR	89	66.4	70.0	1.3	3.4	--	Y	--	--
SB 1030+00	2518 Brownstone Ct	SFR	72	65.6	70.0	1.4	3.6	--	Y	--	--
SB 1030+50	2510 Brownstone Ct	SFR	118	65.5	68.9	1.4	3.6	Y	--	--	--
SB 1032+00	1646 Pinkstone Ct	SFR	94	66.5	69.9	1.3	3.4	--	Y	--	--
SB 1032+70	1652 Pinkstone Ct	SFR	88	66.6	70.1	1.3	3.4	--	Y	--	--
SB 1033+10	1658 Pinkstone Ct	SFR	94	66.4	69.9	1.3	3.4	--	Y	--	--
SB 1034+60	1682 Silverstone Pl	SFR	98	66.4	69.8	1.3	3.4	--	Y	--	--
SB 1035+30	1690 Silverstone Pl	SFR	82	66.4	70.2	1.3	3.4	--	Y	--	--
SB 1035+80	1698 Silverstone Pl	SFR	129	65.2	69.2	1.4	3.6	--	Y	--	--
							# Impacts	**93**	**59**	**0**	**0**

[1]Noise control measures include both aerial guideway sound wall and open graded asphalt concrete layer on Capitol Expressway
SFR: Single-Family Residence, MFR: Multi-Family Residence, COM: Commercial/Office Space, CH : Church

6. OPERATIONAL VIBRATION ASSESSMENT AND CONTROL

6.1 Prediction Methodology

The relation below was used to estimate the vibration levels L_V at interior building spaces.

$$L_V = FDL + LSR + C_{Build} + SF$$

L_V	Predicted, interior vibration level, dB re 1 micro-inch/sec
FDL	Force Density Level, dB re 1 lb/ft$^{1/2}$
LSR	Line Source Response, dB re 1 (micro-inch/sec)/(lb/ft$^{1/2}$)
C_{Build}	Building adjustment factor due to soil-foundation coupling, transmission loss through the building and floor amplification, dB.
SF	Safety factor to account for uncertainties in the predictions, dB

LSR: The line source response is a measure of how efficient vibrational energy propagates through the ground. A large LSR signifies efficient (low attenuation) propagation. The LSR is measured by imparting a calibrated and known force into the ground and collecting the resulting vibration at several distances, typically perpendicular to the rail alignment. These point data are then integrated to account for the extended length of a train. The current analysis uses the averaged LSR from the 2007 SEIR as shown in Appendix C.

FDL: The force density level is a measure of the forces imparted to the ground from a specific track and vehicle type. It is obtained through a measure of the LSR, as described above, and the train vibration as it passes by. The FDL is largely independent of the local geologic conditions.

The FDL used in the 2007 SEIR was based on a measured FDL for a VTA ballasted track running Kinkisharyo vehicles at various speeds and is shown in Figure 7. In that 2007 report, the aerial structure was accounted for by an adjustment based on vibration measurements taken along the VTA Capitol Corridor (see Appendix F of the 2007 SEIR).

There is no clear guidance provided in the FTA Guidance manual or other sources on appropriate approaches for using the FDL/LSR method to predict groundborne vibration generated by train operations on aerial structures. It is clear that the vibration can only reach the ground by propagating through the columns, which means that the vibration source at the ground level is essentially a series of point vibration sources; one point at each column.

A common approach used to estimate vibration from operations on aerial structures is to make a prediction using the procedures for at-grade track and then to add an adjustment factor, as was done in the 2007 SEIR. The adjustment factor suggested by the FTA Guidance Manual is a frequency independent reduction of -10 dB. This makes intuitive sense in that the vibration from an aerial structure must travel through the aerial structure before reaching the ground. Also, measurements that have been performed of vibration adjacent to aerial structures tends to support this -10 dB adjustment. The aerial structure adjustment from the 2007 SEIR is considerably larger than -10 dB for frequencies above 40 Hz, as seen in Figure 8.

In 2013 ATS Consulting and Wilson Ihrig & Associates conducted aerial structure FDL measurements on Sound Transit's Central Link in Seattle that also run Kinkisharyo light rail vehicles. Line source response tests were conducted by impacting in between the tracks upon the aerial guideway and collecting vibration response on the ground at several distances. The LSR combined with the vehicle passby vibration produces the aerial structure FDL. Figure 6 shows the impact location along the guideway and an image from below where the vibration response was collected.

Based on these on-the-structure measurements and additional at-grade LSR measurements an aerial structure adjustment was established and is shown in Figure 8. This adjustment in conjunction with the 2007 SEIR measured ballasted track FDL is used in the current analysis for the aerial structure FDL, as shown in Figure 9 along with the directly measured Sound Transit aerial FDL and an average of all three FDLs.

Except at the very low frequencies these results generally validate the suggested adjustment of −10 dB provided in the FTA Guidance Manual. It is expected that the adjustment is dependent on the design of the aerial structure, particularly the design of the foundation. The foundation for the Seattle test section consisted of 9.8 to 10 ft diameter columns that are approximately 100 ft deep and penetrate into the bedrock. For aerial structures with a similar design the average difference curve shown in Figure 8 should be an appropriate adjustment.

Figure 6: Direct FDL Measurements on Aerial Guideway at Sound Transit, Kinkisharyo LRV

$\boldsymbol{C_{Build}}$**:** The propagation of vibration from the soil into the building foundation and through the building structure is complex and dependent on the specific design and construction of the building. The FTA guidance manual provides some generic adjustments to account for building response and floor resonance. Building adjustment factors include coupling loss as the vibration travels from the soil into the building foundation, transmission loss as the vibration travels though the building, and possible floor amplification (usually away from structural walls).

For lightweight wood-frame structures, the FTA Guidance Manual suggests +6 dB for floor amplification and –2 dB per floor for floor-to-floor attenuation up to five floors above grade, as well as a –5 dB adjustment for coupling loss. Combining the adjustment factors for a wood-frame structure such as a residence, there is −5 dB for the coupling loss, +6 dB for floor amplification and an additional −2 dB for each floor above the grade level. This leads to a net adjustment of between –1 to +1 dB for the vibration inside a typical residence. Therefore, no adjustment is applied to account for coupling loss and floor amplification in the prediction model for small one or two-story residences. For large masonry buildings, the FTA Guidance Manual suggests a –10 dB adjustment for coupling loss. This adjustment has been used at multifamily residences and large office buildings.

SF**:** A safety factor of +3 dB is also added to each one-third octave band. The purpose of the safety factor is to account for measurement uncertainties and other error sources in the predictions. This is a conservative approach, ensuring that in most cases the predicted levels are higher than what would occur during regular operations.

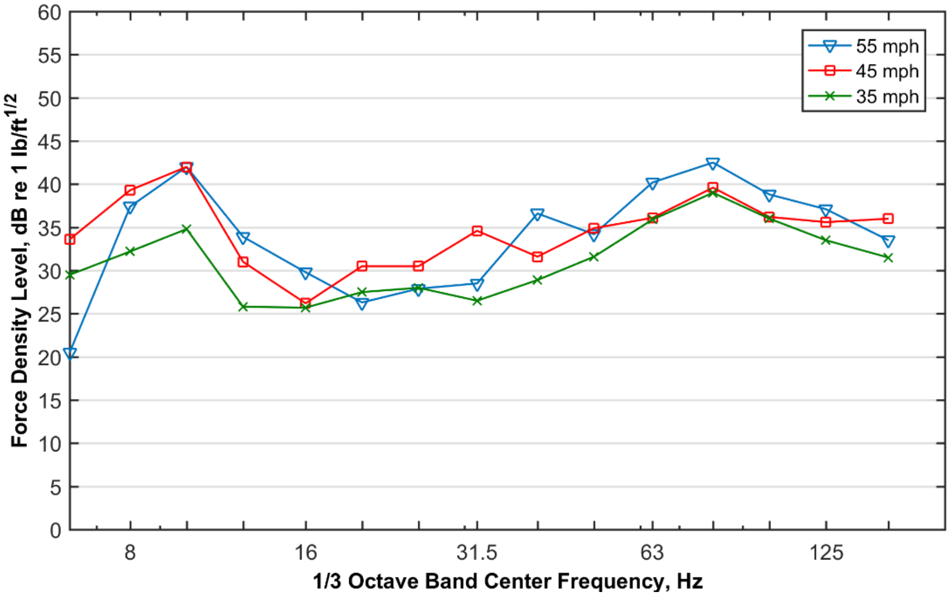

Figure 7: Ballasted Track FDL: VTA Kinkisharyo (SEIR 2007)

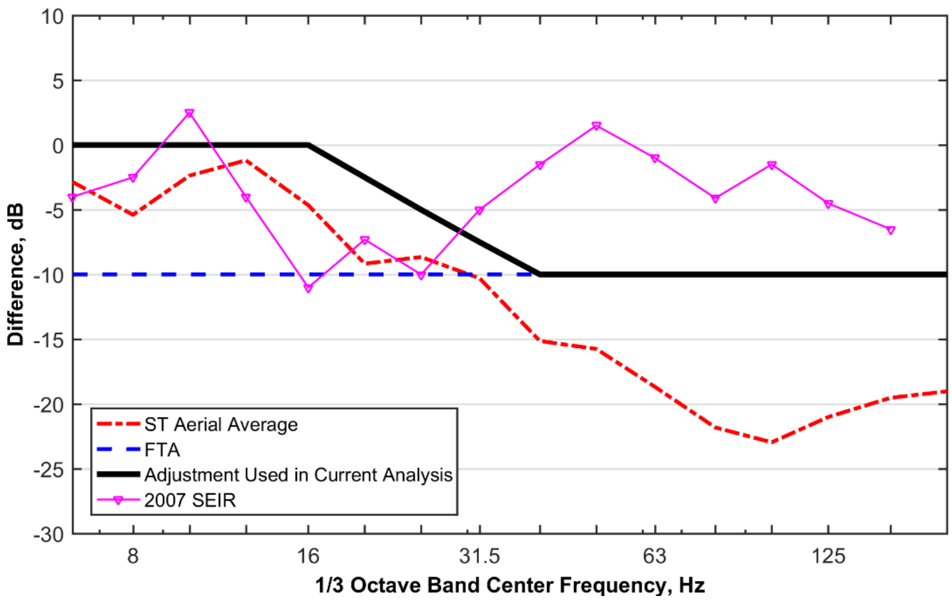

Figure 8: Ballasted Track to Aerial Structure Adjustment Factor

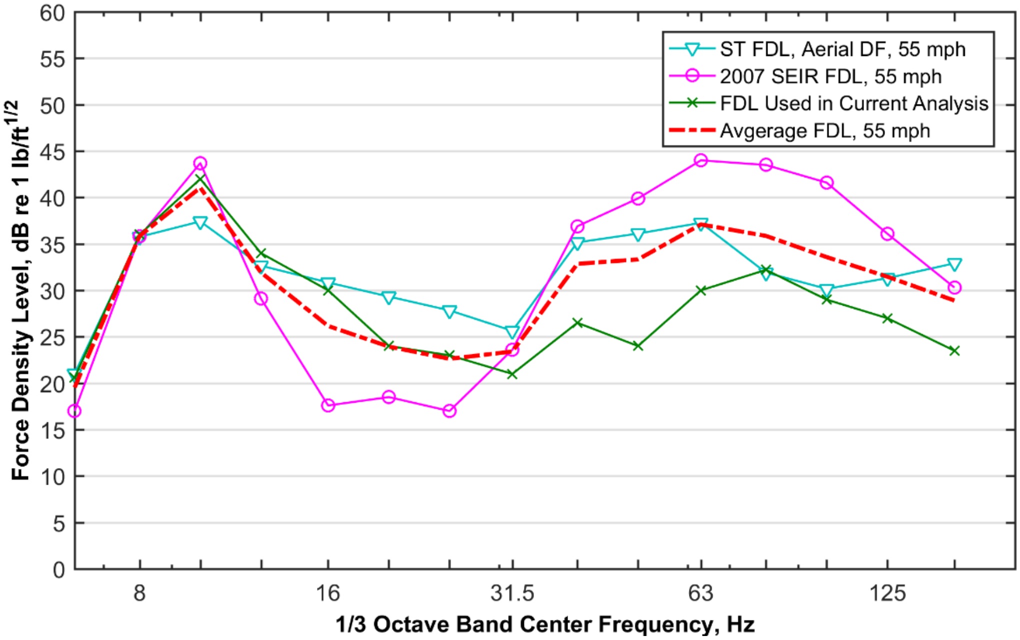

Figure 9: Aerial Structure FDL

Table 10 summarizes the estimated vibration levels at each receiver within the project area that are likely to be impacted. The vibration levels are shown assuming a 3-car train and evaluated against the FTA nighttime and daytime criteria*. Nighttime hours are the most restrictive since peak hour operations would typically start at 6 AM. This analysis indicates that many first-row homes, or homes generally within 100 ft of the closest column, may exceed the FTA detailed nighttime vibration criteria of 72 VdB. It is noted that beyond approximately 50 feet from aerial guideway it is unusual to have vibration levels that exceed FTA criteria. There are 67 nighttime unmitigated impacts predicted. No daytime exceedances are expected. With the inclusion of TDA at the at-grade and embankment sections there are 66 nighttime impacts predicted.

The location of receivers where operational vibration impacts are predicted are as follows:

- Eleven properties located east and west of the alignment between Wilbur Avenue and Mervyns Way will experience operational vibration impacts. One home is within 33 feet of the closest support column.
- Two properties located west of the alignment on Capitol Expressway near Story Road will experience operational vibration impacts.
- Fifteen properties located west of the alignment along Brenford Drive will experience operational vibration impacts.
- Fourteen properties located west of the alignment between Foxdale Drive and Ocala Avenue will experience operational vibration impacts.

* Daytime hours are 7 AM to 10 PM, and nighttime hours are 10 PM to 7 AM (FTA).

- Four properties located east of the alignment between S. Capitol Avenue and Ocala Avenue will experience operational vibration impacts.
- Twenty-one properties located east of the alignment between Ocala Avenue and Cunningham Avenue will experience operational vibration impacts.

Homes that are in the vicinity of NB 977+70 have the highest predicted vibration levels, up to 77 VdB at 660 S. Capitol Avenue. This is due to the proximity of the support columns to the homes, especially those columns supporting the outrigger bent at 978+00.

Figure 10 shows the detailed frequency vibration spectrum for receiver NB 1034+00, which is about 70 ft from an aerial column.

For one home near the transition embankment at SB 968+90, the predicted level is 72 VdB at a frequency of 25 Hz, reaching the nighttime criteria. The vibration for the embankment section was obtained using the measured at-grade to embankment adjustment used in the 2007 SEIR. This adjustment indicated an amplification effect of the embankment in the 20 Hz to 31.5 Hz region.

It is noted that for all receivers indicating exceedances, except for SB 968+90, there is a 10 Hz component of the vibration that is contributing to the nighttime exceedance.

Table 10: Summary of Predicted Operational Vibration Levels: 3-Car Train

Station Number	Receiver Address	Rec. Type	Distance Near Track (ft)	Speed (mph)	Track Type	FTA Detailed Criteria (VdB)	Unmitigated Project Vib., (VdB)	FTA Impact Before Vib. Control?	FTAImpact After Vib. Control?[1]
NB 964+50	2705 Wilbur Ave	SFR	69	35	at	78/72	67	--	--
NB 966+00	2706 Wilbur Ave	SFR	97	35	at	78/72	67	--	--
NB 967+00	420 Capitol Ave	SFR	80	35	at	78/72	66	--	--
NB 967+50	440 Capitol Ave	SFR	81	35	at	78/72	66	--	--
NB 968+10	460 Capitol Ave	SFR	80	35	emb	78/72	69	--	--
NB 968+80	480 Capitol Ave	SFR	77	35	emb	78/72	70	--	--
NB 969+50	13511 Westboro Dr	SFR	63	35	emb	78/72	71	--	--
NB 970+90	13510 Westboro Dr	SFR	63	35	emb	78/72	71	--	--
NB 971+70	500 Capitol Ave	SFR	76	35	emb	78/72	70	--	--
NB 972+20	520 Capitol Ave	SFR	81	55	ag	78/72	73	Y	Y
NB 973+00	540 Capitol Ave	SFR	79	55	ag	78/72	73	Y	Y
NB 973+50	560 Capitol Ave	SFR	81	55	ag	78/72	73	Y	Y
NB 974+10	13501 Highwood Dr	SFR	63	55	ag	78/72	75	Y	Y
NB 975+80	13500 Highwood Dr	SFR	64	55	ag	78/72	75	Y	Y
NB 976+50	620 S Capitol Ave	SFR	72	55	ag	78/72	74	Y	Y
NB 977+20	640 S Capitol Ave	SFR	65	55	ag	78/72	74	Y	Y
NB 977+70	660 S Capitol Ave	SFR	33	55	ag	78/72	77	Y	Y
NB 978+50	10301 Dover Way	SFR	95	55	ag	78/72	72	Y	Y
NB 979+10	10291 Dover Way	SFR	113	55	ag	78/72	71	--	--
NB 979+70	10281 Dover Way	SFR	126	55	ag	78/72	71	--	--
NB 980+50	10271 Dover Way	SFR	109	55	ag	78/72	72	Y	Y
NB 981+20	10261 Dover Way	SFR	114	55	ag	78/72	71	--	--
NB 986+70	888 S Capitol Ave	COM	133	55	ag	84	71	--	--
NB 988+30	920 S Capitol Ave	CH	134	55	ag	84	70	--	--
NB 990+50	990 S Capitol Ave	CH	128	55	ag	84	71	--	--
NB 992+80	2701 Story Rd	COM	139	55	ag	84	70	--	--
NB 995+50	2710 Story Rd	COM	120	55	ag	84	71	--	--
NB 998+50	2710 Kollmar Dr	MFR	105	55	ag	78/72	67	--	--
NB 999+90	2709 Sussex Dr	SFR	119	55	ag	78/72	71	--	--
NB 1001+60	1210 Capitol Ave	SFR	119	55	ag	78/72	71	--	--
NB 1002+40	1222 Capitol Ave	SFR	118	55	ag	78/72	71	--	--
NB 1003+90	1244 Tudor Ct	SFR	120	55	ag	78/72	71	--	--
NB 1004+90	1260 Capitol Ct	SFR	119	55	ag	78/72	71	--	--
NB 1006+20	1276 Capitol Ct	SFR	120	55	ag	78/72	71	--	--
NB 1007+10	2703 Murtha Dr	SFR	119	55	ag	78/72	71	--	--
NB 1008+80	2704 Murtha Dr	SFR	120	55	ag	78/72	71	--	--
NB 1009+80	1336 Capitol Ave	SFR	119	55	ag	78/72	71	--	--
NB 1011+10	2706 Bristol Dr	SFR	119	55	ag	78/72	71	--	--
NB 1012+10	2707 Dublin Dr	SFR	119	55	ag	78/72	71	--	--
NB 1013+60	2704 Dublin Dr	SFR	120	55	ag	78/72	71	--	--
NB 1014+50	1440 Capitol Ave	SFR	121	55	ag	78/72	71	--	--
NB 1016+00	1460 Capitol Ave	SFR	120	55	ag	78/72	71	--	--
NB 1017+00	1492 Capitol Ave	SFR	122	55	ag	78/72	71	--	--
NB 1018+30	1512 Capitol Ave	SFR	129	55	ag	78/72	71	--	--
NB 1019+40	2705 Capitol Ave	SFR	125	55	ag	78/72	71	--	--
NB 1021+00	2704 Capitol Ave	SFR	121	55	ag	78/72	71	--	--
NB 1021+60	1564/1566 Capitol Ave	SFR	148	55	ag	78/72	70	--	--
NB 1022+30	1572 Capitol Ave	SFR	144	55	ag	78/72	70	--	--
NB 1022+90	1576/1578 Capitol Ave	SFR	148	55	ag	78/72	70	--	--
NB 1023+50	1584 Capitol Ave	SFR	143	55	ag	78/72	70	--	--
NB 1024+10	1588/1590 Capitol Ave	SFR	150	55	ag	78/72	70	--	--
NB 1024+70	1596 Capitol Ave	SFR	142	55	ag	78/72	70	--	--
NB 1026+00	1606/1608 Capitol Ave	SFR	145	55	ag	78/72	70	--	--

Station Number	Receiver Address	Rec. Type	Distance Near Track (ft)	Speed (mph)	Track Type	FTA Detailed Criteria (VdB)	Unmitigated Project Vib., (VdB)	FTA Impact Before Vib. Control?	FTAImpact After Vib. Control?[1]
NB 1026+60	1614 Capitol Ave	SFR	138	55	ag	78/72	70	--	--
NB 1027+20	1618/1620 Capitol Ave	SFR	143	55	ag	78/72	70	--	--
NB 1027+90	1624/1626 Capitol Ave	SFR	139	55	ag	78/72	70	--	--
NB 1028+50	1632 Capitol Ave	SFR	141	55	ag	78/72	70	--	--
NB 1029+00	1636/1638 Capitol Ave	SFR	136	55	ag	78/72	70	--	--
NB 1029+60	1654 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
NB 1030+10	1660 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
NB 1030+70	1666 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
NB 1031+30	1672 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
NB 1031+90	1678 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
NB 1032+50	1684 Capitol Ave	SFR	137	55	ag	78/72	70	--	--
NB 1034+00	1701 Capitol Ave	SFR	70	55	ag	78/72	74	Y	Y
NB 1034+80	1923 Evermont Ct	SFR	82	55	ag	78/72	73	Y	Y
NB 1035+20	1917 Evermont Ct	SFR	84	55	ag	78/72	73	Y	Y
NB 1035+90	1911 Evermont Ct	SFR	104	55	ag	78/72	72	Y	Y
NB 1037+60	1756 Home Gate Dr	SFR	90	55	ag	78/72	73	Y	Y
NB 1038+00	1758 Home Gate Dr	SFR	84	55	ag	78/72	73	Y	Y
NB 1038+30	1760 Home Gate Dr	SFR	85	55	ag	78/72	73	Y	Y
NB 1038+60	1762 Home Gate Dr	SFR	110	55	ag	78/72	71	--	--
NB 1038+90	1764 Home Gate Dr	SFR	98	55	ag	78/72	72	Y	Y
NB 1039+20	1766 Home Gate Dr	SFR	84	55	ag	78/72	73	Y	Y
NB 1039+50	1768 Home Gate Dr	SFR	101	55	ag	78/72	72	Y	Y
NB 1039+80	1770 Home Gate Dr	SFR	97	55	ag	78/72	72	Y	Y
NB 1040+10	1772 Home Gate Dr	SFR	95	55	ag	78/72	72	Y	Y
NB 1040+50	1774 Home Gate Dr	SFR	85	55	ag	78/72	73	Y	Y
NB 1040+90	1776 Home Gate Dr	SFR	84	55	ag	78/72	73	Y	Y
NB 1041+20	1778 Home Gate Dr	SFR	76	55	ag	78/72	74	Y	Y
NB 1041+50	1780 Home Gate Dr	SFR	100	55	ag	78/72	72	Y	Y
NB 1041+80	1782 Home Gate Dr	SFR	95	55	ag	78/72	72	Y	Y
NB 1042+10	1784 Home Gate Dr	SFR	90	55	ag	78/72	73	Y	Y
NB 1042+50	1786 Home Gate Dr	SFR	99	55	ag	78/72	72	Y	Y
NB 1042+90	1788 Home Gate Dr	SFR	97	55	ag	78/72	72	Y	Y
NB 1043+20	1790 Home Gate Dr	SFR	92	55	ag	78/72	73	Y	Y
NB 1044+10	1995 Supreme Dr	SFR	99	55	ag	78/72	72	Y	Y
NB 1045+10	2001 Supreme Dr	SFR	84	55	ag	78/72	73	Y	Y
NB 1046+00	2009 Supreme Dr	SFR	114	55	ag	78/72	71	--	--
NB 1046+70	2015 Supreme Dr	SFR	121	55	ag	78/72	71	--	--
NB 1047+20	2021 Supreme Dr	SFR	110	55	ag	78/72	71	--	--
NB 1047+80	2027 Supreme Dr	SFR	105	55	ag	78/72	72	Y	Y
NB 1048+50	2033 Supreme Dr	SFR	117	55	ag	78/72	71	--	--
NB 1049+00	2039 Supreme Dr	SFR	103	55	ag	78/72	72	Y	Y
NB 1049+50	2045 Supreme Dr	SFR	113	55	ag	78/72	71	--	--
SB 967+50	441 Capitol Ave	SFR	48	35	at	78/72	68	--	--
SB 967+50	2685 Lombard Ave	SFR	105	35	at	78/72	64	--	--
SB 968+90	2686 Lombard Ave	SFR	64	35	emb	78/72	72	Y	--
SB 969+80	353 S Capitol Ave	SFR	75	35	emb	78/72	71	--	--
SB 970+50	455 S Capitol Ave	SFR	76	35	emb	78/72	70	--	--
SB 971+30	459 S Capitol Ave	COM	65	35	emb	84	72	--	--
SB 973+00	461 S Capitol Ave	COM	73	55	ag	84	73	--	--
SB 978+00	674 Excalibur Drive	SFR	193	55	ag	78/72	69	--	--
SB 979+50	692 Excalibur Drive	SFR	196	55	ag	78/72	69	--	--
SB 979+00	710 Excalibur Drive	SFR	200	55	ag	78/72	69	--	--
SB 979+50	728 Excalibur Drive	SFR	200	55	ag	78/72	68	--	--

Station Number	Receiver Address	Rec. Type	Distance Near Track (ft)	Speed (mph)	Track Type	FTA Detailed Criteria (VdB)	Unmitigated Project Vib., (VdB)	FTA Impact Before Vib. Control?	FTAImpact After Vib. Control?[1]
SB 979+80	731 S Capitol Ave	SFR	113	55	ag	78/72	71	--	--
SB 980+50	747 S Capitol Ave	SFR	120	55	ag	78/72	71	--	--
SB 981+10	763 S Capitol Ave	SFR	121	55	ag	78/72	71	--	--
SB 983+00	2693 Bambi Ln	SFR	115	55	ag	78/72	71	--	--
SB 984+40	807 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
SB 985+10	821 Capitol Ave	SFR	134	55	ag	78/72	70	--	--
SB 985+60	835 Capitol Ave	SFR	136	55	ag	78/72	70	--	--
SB 986+10	849 Capitol Ave	SFR	138	55	ag	78/72	70	--	--
SB 986+50	863 Capitol Ave	SFR	139	55	ag	78/72	70	--	--
SB 987+10	877 Capitol Ave	SFR	137	55	ag	78/72	70	--	--
SB 987+50	891 Capitol Ave	SFR	136	55	ag	78/72	70	--	--
SB 988+10	905 Capitol Ave	SFR	133	55	ag	78/72	70	--	--
SB 988+60	921 Capitol Ave	SFR	135	55	ag	78/72	70	--	--
SB 989+10	937 Capitol Ave	SFR	129	55	ag	78/72	71	--	--
SB 989+50	953 Capitol Ave	SFR	129	55	ag	78/72	71	--	--
SB 990+00	969 Capitol Ave	SFR	121	55	ag	78/72	71	--	--
SB 990+60	985 Capitol Ave	SFR	119	55	ag	78/72	71	--	--
SB 991+00	1001 Capitol Ave	SFR	114	55	ag	78/72	71	--	--
SB 991+60	1017 Capitol Ave	SFR	111	55	ag	78/72	71	--	--
SB 992+20	1033 Capitol Ave	SFR	107	55	ag	78/72	72	Y	Y
SB 992+70	1049 Capitol Ave	SFR	105	55	ag	78/72	72	Y	Y
SB 993+10	1091 Capitol Ave	COM	93	55	ag	84	72	--	--
SB 994+00	2695 Story Rd	COM	90	55	ag	84	73	--	--
SB 996+50	2690 Story Rd	COM	102	55	ag	84	72	--	--
SB 998+80	2598 Brenford Dr	SFR	156	55	ag	78/72	69	--	--
SB 999+30	2594 Brenford Dr	SFR	92	55	ag	78/72	73	Y	Y
SB 1000+00	2590 Brenford Dr	SFR	89	55	ag	78/72	73	Y	Y
SB 1000+50	2586 Brenford Dr	SFR	95	55	ag	78/72	72	Y	Y
SB 1001+00	2582 Brenford Dr	SFR	81	55	ag	78/72	73	Y	Y
SB 1001+60	2578 Brenford Dr	SFR	79	55	ag	78/72	73	Y	Y
SB 1002+10	2574 Brenford Dr	SFR	79	55	ag	78/72	73	Y	Y
SB 1002+80	2570 Brenford Dr	SFR	82	55	ag	78/72	73	Y	Y
SB 1003+20	2568 Brenford Dr	SFR	72	55	ag	78/72	74	Y	Y
SB 1003+80	2564 Brenford Dr	SFR	81	55	ag	78/72	73	Y	Y
SB 1004+40	2560 Brenford Dr	SFR	93	55	ag	78/72	72	Y	Y
SB 1005+00	2556 Brenford Dr	SFR	95	55	ag	78/72	72	Y	Y
SB 1005+40	2552 Brenford Dr	SFR	83	55	ag	78/72	73	Y	Y
SB 1006+00	2548 Brenford Dr	SFR	82	55	ag	78/72	73	Y	Y
SB 1006+60	2544 Brenford Dr	SFR	73	55	ag	78/72	74	Y	Y
SB 1007+10	2540 Brenford Dr	SFR	81	55	ag	78/72	73	Y	Y
SB 1007+20	2536 Brenford Dr	SFR	122	55	ag	78/72	71	--	--
SB 1009+00	3501 E Capitol Expy	COM	78	55	ag	84	68	--	--
SB 1012+00	Foxdale Village Foxdale Loop	MFR	125	55	ag	78/72	66	--	--
SB 1014+50	Foxdale Village Foxdale Loop	MFR	124	55	ag	78/72	66	--	--
SB 1018+00	Foxdale Village Foxdale Loop	MFR	125	55	ag	78/72	66	--	--
SB 1021+00	2529 Greenstone Ct	SFR	140	55	ag	78/72	70	--	--
SB 1021+40	2535 Greenstone Ct	SFR	98	55	ag	78/72	72	Y	Y
SB 1022+00	2540 Greenstone Ct	SFR	79	55	ag	78/72	73	Y	Y
SB 1022+70	2534 Greenstone Ct	SFR	109	55	ag	78/72	71	--	--
SB 1024+10	2537 Whitestone Ct	SFR	88	55	ag	78/72	73	Y	Y
SB 1024+90	2538 Whitestone Ct	SFR	86	55	ag	78/72	73	Y	Y
SB 1025+50	2530 Whitestone Ct	SFR	100	55	ag	78/72	72	Y	Y

Station Number	Receiver Address	Rec. Type	Distance Near Track (ft)	Speed (mph)	Track Type	FTA Detailed Criteria (VdB)	Unmitigated Project Vib., (VdB)	FTA Impact Before Vib. Control?	FTAImpact After Vib. Control?[1]
SB 1026+90	2533 Bluestone Ct	SFR	87	55	ag	78/72	73	Y	Y
SB 1027+40	2532 Bluestone Ct	SFR	80	55	ag	78/72	73	Y	Y
SB 1027+80	2526 Bluestone Ct	SFR	112	55	ag	78/72	71	--	--
SB 1029+30	2517 Brownstone Ct	SFR	89	55	ag	78/72	73	Y	Y
SB 1030+00	2518 Brownstone Ct	SFR	72	55	ag	78/72	74	Y	Y
SB 1030+50	2510 Brownstone Ct	SFR	118	55	ag	78/72	71	--	--
SB 1032+00	1646 Pinkstone Ct	SFR	94	55	ag	78/72	72	Y	Y
SB 1032+70	1652 Pinkstone Ct	SFR	88	55	ag	78/72	73	Y	Y
SB 1033+10	1658 Pinkstone Ct	SFR	94	55	ag	78/72	72	Y	Y
SB 1034+60	1682 Silverstone Pl	SFR	98	55	ag	78/72	72	Y	Y
SB 1035+30	1690 Silverstone Pl	SFR	82	55	ag	78/72	73	Y	Y
SB 1035+80	1698 Silverstone Pl	SFR	129	55	ag	78/72	71	--	--
							# Impacts	67	66

at: At-grade, emb: Embankment, ag: Aerial guideway

[1]Vibration control is TDA only. If bridge bearings or floating slab track is used all operational vibration impacts could be removed.

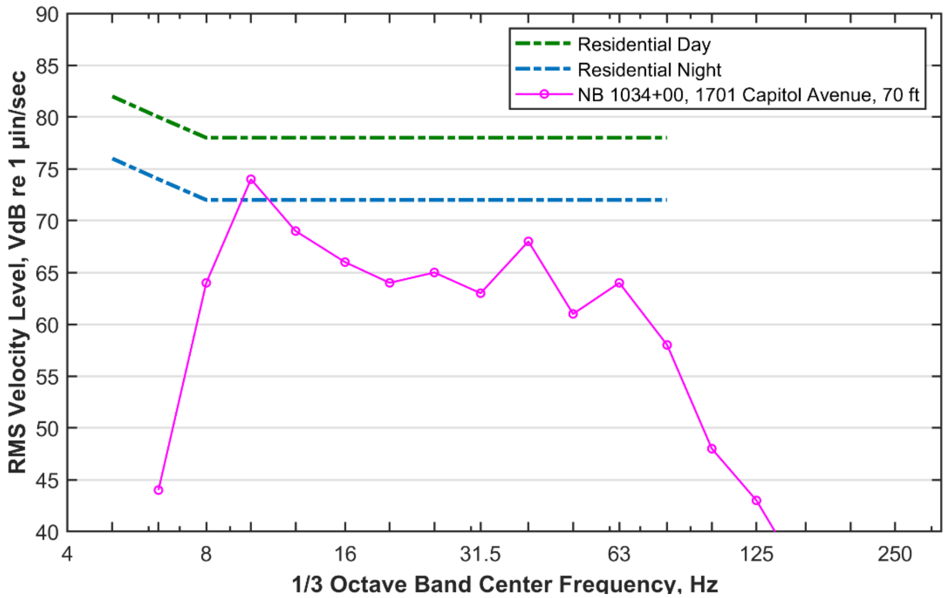

Figure 10: Estimated Vibration Spectrum for Receiver NB 1034+00, 70 ft.

6.2 Potential Vibration Control Measures

Vibration isolation systems provide no reduction at or below the system's resonant frequency, they tend to amplify vibration at frequencies near the resonant frequency and they isolate vibration at frequencies one or two 1/3-octaves above the resonance frequency. Since any isolation system may both amplify and attenuate vibration at different frequencies, the spectrum of vibration that is being mitigated must be considered when choosing an appropriate isolation system. This analysis has indicated that the 10 Hz 1/3-octave band is the frequency range in which the vibration is estimated to exceed the FTA detailed vibration criteria at most receivers. 10 Hz is considered low frequency. This feature around 10 Hz may be due to the LRV primary suspension, which typically has a resonant mode in the 8 to 12 Hz range. It is not conclusively known if this is currently the case and positively identifying the primary suspension resonance in FDL data can be ambiguous. However, an examination of the FDL data from the 2007 SEIR (both ballasted and aerial track), and the 2013 Sound Transit FDL data (both aerial and at-grade DF track) all showed a similar trend of elevated FDL levels between 35 mph and 55 mph at 10 Hz, thus supporting the notion that the effect is vehicle based. The other contributing factor are the LSRs, which have high levels at low frequencies. The combination of these two is giving rise to high operational vibration levels at unusually large distances from the track.

It is noted that the predictions made in this analysis are conservative and as such are designed to be higher than those seen in measurements under normal operating conditions. For the operational vibration predictions this conservatism arises from the use of the building adjustment factors, the safety factor and the empirically established aerial structure adjustment factor, particularly below 40 Hz (see Figure 8). This should be kept in mind when selecting mitigation measures, as many of the predicted operational vibration impacts are at or just above the impact criteria.

Mitigation is recommended to reduce the vibration impacts to the homes in vicinity of NB 977+70, where the support bents are within 33 feet of one home (660 S. Capitol Avenue). Reducing the operational speed to 35 mph in this section would also remove the nighttime impacts. Relocating the supports further from the homes would decrease the vibration exceedances though it would not remove them unless the distances are approximately 100 feet.

Potential operational vibration mitigation measures are summarized below.

Tire Derived Aggregate: Tire derived aggregate (TDA) is a resilient underlayment for ballasted track and has vibration mitigating properties potentially above 16 Hz. Use of TDA would likely remove any exceedances in the 20 Hz to 31.5 Hz range for the homes near the embankment.

Resilient Fasteners: Highly compliant rail fasteners, such as the in-shear Cologne Egg, are an effective solution for controlling groundborne vibration and groundborne noise. However, resilient fasteners mitigation properties are poor below about 31.5 Hz and may even cause vibration amplification at lower frequencies. Given that most vibration impacts are occurring in the 10 Hz band, resilient fasteners are not a recommended solution.

Floating Slab Track: Floating slab tracks (FST) are effective for reducing low frequency vibration. They have been used on many transit systems throughout North America and abroad, though not commonly on aerial structures. Floating slab isolation systems tend to scale up in size and cost as the targeted frequency spectrum for mitigation decreases. To effectively control vibration at 10 Hz, a floating slab with a target resonance frequency of 5 to 6 Hz would be required. However, we are aware of only a single FST on aerial guideway in operation. The system is in Hong Kong and we have not seen reports of its in-service performance. Therefore, this mitigation measure is still theoretical and would need to be analyzed further to assess its effectiveness.

Isolation Bearings: Low frequency vibration isolation can also be accomplished between the aerial structure and the support bent by the use of either tuned steel coils or rubber bridge bearings that are installed on top of the columns. Resilient bridge bearings are designed and function like the springs or rubber pads that support floating slab track. However, in an elevated structure application, the springs have to support much greater structural loads, which complicate the design. As in the case with floating slab track on aerial guideway, there are only a few of these systems in operation. Such a system (www.gerbusa.com) has been installed at Miami Central Station, on the All Aboard Florida-Brightline network. This system is just recently completed and is currently undergoing in-service testing.

It is noted that the use of either FST or isolation bearings for the aerial guideway vibration mitigation are complicated solutions requiring extensive additional analysis and design from a structural and vibrational perspective.

Operational Measures: Generally, reducing train speed typically results in lower groundborne vibration levels. However, this effect is not always apparent when the changes in speed are small, for example less than 10 mph, and the effect may have a complex frequency dependency. The 2007 SEIR FDL, Figure 7, generally shows a reduction in input forces with decreasing speed. However, it is noted that at 10 Hz there is no difference between trains moving 55 mph and those at 45 mph. A substantial decrease at 10 Hz is seen when the train speed is reduced to 35 mph, thus demonstrating the complicated and non-intuitive nature in which the train speed and track dynamics are related. Running the train at 35 mph would eliminate all 10 Hz exceedances.

Reducing the number of cars could also potentially reduce the vibration levels depending on the local soil conditions and distance from the column to the receiver. Close to the column the difference would be diminishingly small, therefore the effect of train length varies depending on site specific conditions. The current analysis assumes a 3-car consist. A vibration adjustment based on a spreadsheet model was determined for the difference between a 3-car and 2-car consist and is shown in Figure 11. The horizontal axis is the distance from the tracks and the vertical axis is the expected increase in vibration levels for a 3-car train compared to a 2-car train. The different lines on the plot represent different soil propagation characteristics. For example, the blue line represents soil where vibration travels very efficiently, and the pink line represents soil where vibration does not travel very efficiently.

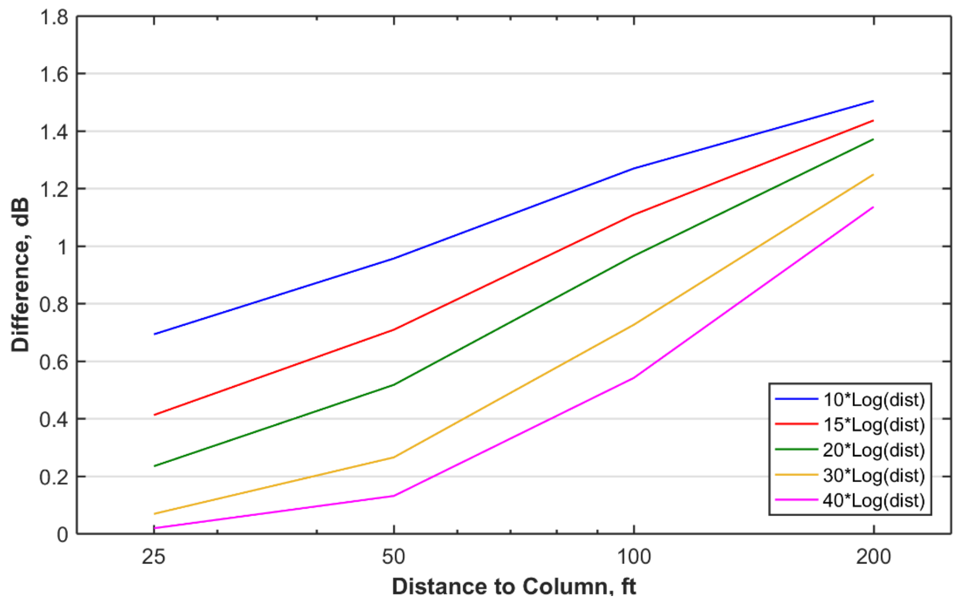

Figure 11: Expected Vibration Difference for a 3-Car Train Compared to a 2-Car Train

7. PILE DRIVING NOISE AND VIBRATION

The aerial guideway in the Project area will be supported by approximately 76 columns spaced 130 to 150 ft apart and positioned along the center of Capitol Expressway, however only about 60 columns are relevant to noise and vibration concerns due to their proximity to sensitive receivers. Previous geotechnical information has indicated that the subsurface conditions in the Project area are composed of fairly homogenous soil with firm to stiff clay, and it is anticipated that a traditional percussive or impact hammer will be employed to drive the foundation piles at each column location to support a cast-in-place pilecap.

Based on the 2008 design, the precast concrete piles are 18 in square and will be up to 72 ft long. There are on average 30 piles per column location. Each pile may require up to 60 minutes of hammering to drive to depth. Assuming six hours of continuous driving there may only be 6 piles driven per day for a total duration of approximately four to five days of driving per column location. Given that there are about 60 column sites and with two construction crews working simultaneously, there would be approximately 120 to 150 days of piling activity in the Project area.

Noise and vibration measurements concerning pile driving should be conducted in a test phase that will be useful to confirm actual levels based on the contractor's equipment, means and methods. Maximum and equivalent noise levels should be collected to test any noise control measures. Vibration monitoring should measure the vibration velocity as a function of pile depth and at several distances from the pile.

Because soil conditions may vary within the project site, vibration monitoring should be performed at most column locations. Pending the outcome of noise and vibration levels from test piles, it will be determined how many columns must separate simultaneous work crews.

7.1 Pile Driving Noise

For impact driven piles the primary noise source is generated by the contact between the hammer and the pile. As opposed to metal piles, concrete piles have less noise generated along the length of the exposed pile when struck (i.e. less ringing). Research has shown that impact piles can achieve unmitigated noise levels up to 101 dBA at 50 ft from the source, while noise levels up to 96 dBA at 50 ft can be generated from vibratory driven piles[*].

Though no standardized criteria have been developed for assessing construction noise impacts, FTA detailed assessment guidelines recommend daytime limits of 80 Leq (8-hour) dBA for residential land use and 85 Leq (8-hour) dBA for commercial land use. Additionally, a maximum noise level of 90 Leq (1-hour) dBA is recommended for residential land use and 100 Leq (1-hour) dBA for commercial land use. Pile driving will only occur during daytime hours. As the total duration of impacting time decreases in a work day, a higher noise level threshold is allowed to comply with FTA criteria, as shown in Table 11.

Table 11: Noise Level Adjustment for Daily Piling Driving to Comply with FTA Criteria

Hours (in 8-hour day) of Construction Activity	Allowed 1-Hour Leq (dBA) for Pile Driving	Allowable Increase, dB
1	89	9
2	86	6
3	84	4
4	83	3
5	82	2
6	81	1
7	81	1
8	80	0

The projected noise levels for pile driving activities were modeled using CadnaA version 4.0, a three-dimensional graphics-oriented noise modeling program that uses the International Standards Organization (ISO) 9613.2, a general purpose standard for outdoor noise propagation. CadnaA incorporates the following elements:

- The noise generated by the equipment at a reference distance.
- A propagation model that calculates how the noise level varies with distance.
- A prediction model that sums the noise of each source at sensitive locations.
- The effects of ground cover, topography, elevation of construction equipment and/or receivers, and shielding of building structures.

Pile driving noise predictions are summarized in Table 12, assuming 6 hours of pile driving each day. A detailed list of construction noise levels for each receiver is given in Table 14. The modeled noise exposure indicates that unshielded receivers within 300 ft of pile driving locations may exceed a Leq (8-

[*] U.S. Environmental Protection Agency, *Noise from Construction Equipment and Operations, Building Equipment and Home Appliances*. NTID300.1, December 31, 1971.

hour) of 80 dBA and receivers within 110 ft may exceed 90 dBA. The analysis indicates that most first row homes will potentially exceed the 80 dBA threshold. The noise model reflects the location of columns as given in the most recent general arrangement drawings obtained from VTA.

The location of receivers where pile driving noise impacts are predicted are as follows:

- Twelve residential properties located east of the alignment between Wilbur Avenue and Mervyns Way will experience construction noise impacts. One home is within 25 feet of the closest pile.
- Five institutional/commercial properties located east of the alignment between Mervyns Way and Story Road will experience construction noise impacts.
- Forty-one residential properties located east of the alignment between Story Road and Ocala Avenue will experience construction noise impacts.
- Twenty-seven residential properties located east of the alignment between Ocala Avenue and Cunningham Avenue will experience construction noise impacts.
- Twenty-one residential properties located west of the alignment between Excalibur Drive and Story Road will experience construction noise impacts.
- Three commercial properties located west of the alignment near the intersection of Capitol Expressway and Story Road will experience construction noise impacts.
- Seventeen residential properties located west of the alignment between Story Road and Foxdale Loop will experience construction noise impacts.
- One commercial property located west of the alignment near the intersection of Capitol Expressway and Foxdale Loop will experience a construction noise impact.
- Three residential properties located west of the alignment between along Foxdale Loop will experience construction noise impacts.
- Nineteen residential properties located west of the alignment between Foxdale Drive and Ocala Avenue will experience construction noise impacts.

Table 12: Predicted Impact Pile Driving Noise

Direction/Section	Number – Type of Receivers	FTA Impact Criteria Leq (8-hr) dBA[1]	Unmitigated Noise Level Leq (8-hr) dBA[2]		Number of Predicted FTA Impacts[5]			
			Nearest Pile	Next-Nearest Pile	Unmitigated[6]	w/ Impact Cushion[3]	w/ Impact Cushion & Pre-Drill 1/3 of Pile	w/ Impact Cushion & Noise Shield[4]
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 - SFR	80	61 - 88	60 - 88	12	9	9	0
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	80/85	86 - 87	83 - 86	5	3	2	0
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 - SFR	80	83 - 90	80 - 88	41	40	25	0
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 - SFR	80	84 - 89	79 - 86	27	22	9	0
SB 967+50 to 970+50 S. Capitol Ave.	5 - SFR	80	60 - 73	57 - 70	0	0	0	0
SB 971+30 to 973+00 S. Capitol Ave.	2 - COM	85	80 - 83	74 - 80	0	0	0	0
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 - SFR	80	78 - 89	76 - 87	21	21	21	0
SB 993+10 to 996+50 Story Rd.	3 - COM	85	88 - 90	85 - 87	3	1	0	0
SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 - SFR	80	83 - 88	80 - 86	17	12	2	0
SB 1009+00 E. Capitol Expy.	1 - COM	85	91	87	1	1	0	0
SB 1012+00 to 1018+00 Foxdale Loop	3 - MFR	80	85 – 86	83 - 85	3	3	0	0
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 - SFR	80	85 - 89	81 - 85	19	19	11	0
				# Impacts	**149**	**131**	**79**	**0**

[1]Criteria for SFR/MFR/INST is Leq (8-hr) 80 dBA, and for COM it is Leq (8-hr) 85 dBA
[2]Noise levels assume the height of the impact is 30 ft. Existing wayside sound walls provide an increasing level of reduction to noise levels as the height of the impact location is reduced to ground height.
[3]Assumes impact cushion provides 5 dBA reduction.
[4]Assumes impact cushion + noise shield provides 15 dBA reduction, does not include pre-drilling.
[5]Number of impacts due to noise generated from nearest pile.

[6]CIDH is the default installation method for piles from 978+00 to the north end of the guideway. The pile in the median of Capital Expressway at straddle bent 6-west is an impact pile.

7.2 Pile Driving Vibration

The primary concern regarding construction vibration relates to risk of damage. Vibration is generally assessed in terms of peak particle velocity (PPV) for risk of building damage. PPV is the appropriate metric for evaluating the potential of building damage and is often used when monitoring blasting and construction vibration because it relates to the stresses that are experienced by the buildings. This is in contrast to rail transit operational vibration that is expressed as RMS vibration levels, which has been shown to be a metric more correlated to human annoyance.

Research has indicated that the upper threshold for maximum particle velocity for impact piling is about 1.52 in/s at 25 ft from the source, while vibration levels of 0.73 in/s at 25 ft are an upper limit for vibratory driven piles[*]. Conservative estimates for impact piling vibration levels are calculated by distance adjusting the upper threshold particle velocity value of 1.52 in/s at 25 ft. Human perceptibility of vibration is strongly dependent on the total exposure time of the vibration disturbance. For example, a steady state vibration of 0.05 in/s may be strongly perceptible, whereas a short transient vibration of 0.05 in/s is barely perceptible[†]. Table 13 summarizes the expected vibration amplitudes from impact pile driving and indicates that receivers within 100 ft of piling activity are likely to exceed FTA damage criteria. Results assume that the closest column is directly in front of each receiver and the next closest column is 130 ft further down the centerline of the alignment. Although the expected vibration due to piling would fluctuate as the pile toe depth increases, the values in Table 13 are a conservative estimate that do not account for the increased depth of the pile toe. A detailed list of construction vibration levels for each receiver is given in Table 14.

The location of receivers where pile driving vibration impacts are predicted are as follows:

- One property located east of the alignment between Wilbur Avenue and Mervyns Way will experience construction vibration impacts. One home is within 25 feet of the closest pile.
- Five properties located east of the alignment between Story Road and Ocala Avenue will experience construction vibration impacts.
- Twenty-one properties located east of the alignment between Ocala Avenue and Cunningham Avenue will experience construction vibration impacts.
- Fifteen properties located west of the alignment between Story Road and Foxdale Loop will experience construction vibration impacts.
- Fourteen properties located west of alignment between Foxdale Drive and Ocala Avenue will experience construction vibration impacts.

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[*] D.J. Martin, *Ground Vibrations from Impact Pile Driving during Road Construction*, Supplementary Report 544, United Kingdom Department of the Environment, Department of Transport, Transport and Road Research Laboratory, 1980

[†] Wiss, J.F. (1967). *Damage Effects of Pile Driving Vibration*. Highway Research Board Record no. 155

Table 13: Predicted Impact Pile Driving Vibration

Direction/Section	Number – Type of Receivers	Annoy. Criteria PPV, (in/s)[1]	FTA Damage Criteria PPV, (in/s)[2]	Unmitigated Vibration Level PPV, (in/s)	Number of Predicted FTA Impacts	
				Nearest Pile	Unmitigated	CIDH Piles[3]
NB 964+50 to 981+20 Wilbur Ave. to Mervyns Way	22 - SFR	0.03	0.2	<0.01 – 0.22	1	0
NB 986+70 to 995+50 Mervyns Way to Story Rd.	5 – INST/COM	0.06	0.5	0.13 - 0.16	0	0
NB 998+50 to 1035+90 Story Rd. to Ocala Ave.	41 - SFR	0.03	0.2	0.11 – 0.39	5	0
NB 1037+60 to 1049+50 Ocala Ave. to Cunningham Ave.	27 - SFR	0.03	0.2	0.10 – 0.32	21	0
SB 967+50 to 970+50 S. Capitol Ave.	5 - SFR	0.03	0.2	<0.01	0	0
SB 971+30 to 973+00 S. Capitol Ave.	2 - COM	0.06	0.5	<0.03	0	0
SB 978+00 to 992+70 Excalibur Dr. to Story Rd.	25 - SFR	0.03	0.2	0.08 – 0.19	0	0
SB 993+10 to 996+50 Story Rd.	3 - COM	0.06	0.5	0.20 – 0.25	0	0
SB 998+80 to 1007+20 Story Rd. to Foxdale Loop	17 - SFR	0.03	0.2	0.10 – 0.35	15	0
SB 1009+00 E. Capitol Expy.	1 - COM	0.03	0.5	0.31	0	0
SB 1012+00 to 1018+00 Foxdale Loop	3 - MFR	0.03	0.2	0.15	0	0
SB 1021+00 to 1035+80 Foxdale Dr. to Ocala Ave.	19 - SFR	0.03	0.2	0.12 – 0.35	14	0
				# Impacts	**56**	**0**

[1]Annoyance criteria based on an equivalent PPV to RMS value of 78 VdB for SFR/MFR and 84 VdB for COM, assuming a crest factor of 4.
[2]Damage criteria based on FTA Guidance Manual. These criteria are only to identify hot spots and are not to indicate thresholds where actual residential building damage may occur. Several studies in the U.S. and abroad have shown that particle velocities in excess of 4.0 in/s are required to cause plaster cracks in dwellings. With appropriate conservatism, studies have agreed that vibration levels of 2.0 in/s are safe with regard to plaster cracks in residential structures. See Wiss, J.F. (1967).
[3] Cast in drilled hole piles (CIDH). CIDH is the default installation method for piles from 978+00 to the north end of the guideway. The pile in the median of Capital Expressway at straddle bent 6-west is an impact pile.

7.3 Piling Driving Noise Control Measures

At a rate of four to five days per column site, the noise from impact pile driving would potentially exceed the FTA impact criteria for a minimum of four days at most receptors. Results indicate that FTA criteria may be exceeded due to pile driving at distances of three columns, resulting in potentially twelve to fifteen days of exceedances for each receiver. To reduce the level of noise such that only nearest column locations produce an exceedance (four to five days of exceedance per receiver) it is sufficient to implement a noise control measure that provides at least 5 dB of reduction.

Impact Cushion: Up to 5 dB of noise reduction may be obtained by the use of a suitable pile cap cushion. Figure 12 shows the use of both a wood block and burlap bags as noise mitigating cushions. The crew initially uses only burlap bags that reduce noise but provides high energy transfer. The crew adds in the wood block when driving becomes more difficult.

Pre-Drilling: Pre-drilling piles will reduce the total duration of impact time. If one third (one half) of the pile is pre-drilled this will reduce the total impact time from 6 hours per day to 4 (3) hours per day, which decreases the total noise in the 8-hour work day by 2 (3) dB. Further discussion on non-impact piling methods is given below in the section on construction vibration control measures.

Noise Shield: A noise reduction of 5 to 10 dB may require the use of a noise shield for the impact pile driver and/or reducing the total daily time spent pile driving, as shown in Table 11. A noise shield can reduce noise levels by a minimum of 5 dB if properly constructed and installed, see Figure 13. The following noise shield properties are recommended:

- Use a frame to secure the acoustic blankets or paneling
- Have a minimum height of 20 ft to cover the bottom half of the hammer and the top 10 ft of the pile or to the ground.
- Use a solid material with a minimum surface density of 3 lb/ft^2 or mass-loaded acoustic blankets with at least STC 25.
- The shield should surround the pile and hammer by at least 75 % (can be open toward the crane operator). Ideally, the hammer and pile will be completely surrounded.
- Position the crane such that the opening of the shield does not face any sensitive receivers.
- Overlap or seal any gaps in the shield.

Contractor Controls: It is recommended that the contractor incorporate into their means and methods of construction specification the following:

- Comply with construction noise criteria indicated in Section 3.4
- Comply with construction vibration criteria indicated in Section 3.4.
- Use electrically-powered equipment to the extent practical.
- Temporary noise barriers and sound-control curtains should be erected where project activity is unavoidably close to noise-sensitive receivers.
- Designated haul routes would be used based on the least overall noise impact route, with heavily-loaded trucks away from residential streets, if possible. Identification of haul routes would consider streets with the fewest noise sensitive receivers if no alternatives are available.
- Earth-moving equipment, fixed noise-generating equipment, stockpiles, staging areas, and other noise-producing operations would be located as far as practicable from noise-sensitive receivers.
- Use of horns, whistles, alarms, and bells would be limited.
- Perform an initial piling noise and vibration survey to determine baseline levels. Perform noise and vibration monitoring throughout the progression of piling activities in the Project area.
- Conduct a detailed pre-construction crack survey at homes where FTA impacts are predicted.

Table 14: Individual Construction Noise and Vibration Predictions

Station Number	Receiver Address	Rec. Type	Unmitigated Noise Level Leq (8-hr) dBA		Unmitigated Vibration Level PPV, (in/s)	Unmitigated FTA Exceedance?	
			Nearest Pile	Next Nearest Pile	Nearest Pile	Noise	Vib.
NB 964+50	2705 Wilbur Ave	SFR	61	60	0.00	--	--
NB 966+00	2706 Wilbur Ave	SFR	63	62	0.00	--	--
NB 967+00	420 Capitol Ave	SFR	64	63	0.00	--	--
NB 967+50	440 Capitol Ave	SFR	65	64	0.00	--	--
NB 968+10	460 Capitol Ave	SFR	66	65	0.00	--	--
NB 968+80	480 Capitol Ave	SFR	68	66	0.00	--	--
NB 969+50	13511 Westboro Dr	SFR	70	67	0.00	--	--
NB 970+90	13510 Westboro Dr	SFR	76	72	0.01	--	--
NB 971+70	500 Capitol Ave	SFR	80	75	0.01	Y	--
NB 972+20	520 Capitol Ave	SFR	82	78	0.02	Y	--
NB 973+00	540 Capitol Ave	SFR	82	79	0.02	Y	--
NB 973+50	560 Capitol Ave	SFR	82	79	0.02	Y	--
NB 974+10	13501 Highwood Dr	SFR	85	78	0.03	Y	--
NB 975+80	13500 Highwood Dr	SFR	86	78	0.03	Y	--
NB 976+50	620 S Capitol Ave Bent 6E[1]	SFR	83	82	0.02	Y	--
NB 976+50	620 S Capitol Ave Bent 6W[2]	SFR	82	78	0.02	Y	--
NB 977+20	640 S Capitol Ave Bent 6E[1]	SFR	84	84	0.02	Y	--
NB 977+20	640 S Capitol Ave Bent 6W[2]	SFR	84	79	0.02	Y	--
NB 977+70	660 S Capitol Ave Bent 6E[1]	SFR	87	88	0.09	Y	--
NB 977+70	660 S Capitol Ave Bent 6W[2]	SFR	88	78	0.22	Y	Y
NB 978+50	10301 Dover Way Bent 6E[1]	SFR	75	79	0.01	--	--
NB 978+50	10301 Dover Way Bent 6W[2]	SFR	79	79	0.10	--	--
NB 979+10	10291 Dover Way	SFR	80	78	0.18	Y	--
NB 979+70	10281 Dover Way	SFR	80	79	0.15	Y	--
NB 980+50	10271 Dover Way	SFR	79	78	0.19	--	--
NB 981+20	10261 Dover Way	SFR	82	82	0.17	Y	--
NB 986+70	888 S Capitol Ave	COM	87	86	0.14	Y	--
NB 988+30	920 S Capitol Ave	CH	87	84	0.13	Y	--
NB 990+50	990 S Capitol Ave	CH	86	86	0.14	Y	--
NB 992+80	2701 Story Rd	COM	87	84	0.13	Y	--
NB 995+50	2710 Story Rd	COM	87	83	0.16	Y	--
NB 998+50	2710 Kollmar Dr	MFR	90	85	0.20	Y	Y
NB 999+90	2709 Sussex Dr	SFR	88	83	0.16	Y	--
NB 1001+60	1210 Capitol Ave	SFR	88	87	0.16	Y	--
NB 1002+40	1222 Capitol Ave	SFR	89	86	0.16	Y	--
NB 1003+90	1244 Tudor Ct	SFR	88	88	0.16	Y	--
NB 1004+90	1260 Capitol Ct	SFR	89	86	0.16	Y	--
NB 1006+20	1276 Capitol Ct	SFR	89	87	0.16	Y	--
NB 1007+10	2703 Murtha Dr	SFR	89	85	0.16	Y	--
NB 1008+80	2704 Murtha Dr	SFR	88	87	0.16	Y	--
NB 1009+80	1336 Capitol Ave	SFR	89	86	0.16	Y	--
NB 1011+10	2706 Bristol Dr	SFR	88	87	0.16	Y	--
NB 1012+10	2707 Dublin Dr	SFR	88	87	0.16	Y	--
NB 1013+60	2704 Dublin Dr	SFR	88	87	0.16	Y	--
NB 1014+50	1440 Capitol Ave	SFR	88	87	0.16	Y	--
NB 1016+00	1460 Capitol Ave	SFR	88	86	0.16	Y	--
NB 1017+00	1492 Capitol Ave	SFR	87	86	0.16	Y	--
NB 1018+30	1512 Capitol Ave	SFR	88	85	0.14	Y	--

Station Number	Receiver Address	Rec. Type	Unmitigated Noise Level Leq (8-hr) dBA		Unmitigated Vibration Level PPV, (in/s)	Unmitigated FTA Exceedance?	
			Nearest Pile	Next Nearest Pile	Nearest Pile	Noise	Vib.
NB 1019+40	2705 Capitol Ave	SFR	88	85	0.15	Y	--
NB 1021+00	2704 Capitol Ave	SFR	88	85	0.16	Y	--
NB 1021+60	1564/1566 Capitol Ave	SFR	88	84	0.11	Y	--
NB 1022+30	1572 Capitol Ave	SFR	86	85	0.12	Y	--
NB 1022+90	1576/1578 Capitol Ave	SFR	86	84	0.11	Y	--
NB 1023+50	1584 Capitol Ave	SFR	86	85	0.12	Y	--
NB 1024+10	1588/1590 Capitol Ave	SFR	86	85	0.11	Y	--
NB 1024+70	1596 Capitol Ave	SFR	86	84	0.12	Y	--
NB 1026+00	1606/1608 Capitol Ave	SFR	86	85	0.12	Y	--
NB 1026+60	1614 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1027+20	1618/1620 Capitol Ave	SFR	87	84	0.12	Y	--
NB 1027+90	1624/1626 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1028+50	1632 Capitol Ave	SFR	87	84	0.12	Y	--
NB 1029+00	1636/1638 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1029+60	1654 Capitol Ave	SFR	86	84	0.13	Y	--
NB 1030+10	1660 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1030+70	1666 Capitol Ave	SFR	87	84	0.13	Y	--
NB 1031+30	1672 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1031+90	1678 Capitol Ave	SFR	86	85	0.13	Y	--
NB 1032+50	1684 Capitol Ave	SFR	87	83	0.13	Y	--
NB 1034+00	1701 Capitol Ave	SFR	89	86	0.39	Y	Y
NB 1034+80	1923 Evermont Ct	SFR	85	84	0.30	Y	Y
NB 1035+20	1917 Evermont Ct	SFR	85	80	0.29	Y	Y
NB 1035+90	1911 Evermont Ct	SFR	83	83	0.20	Y	Y
NB 1037+60	1756 Home Gate Dr	SFR	86	84	0.26	Y	Y
NB 1038+00	1758 Home Gate Dr	SFR	87	80	0.29	Y	Y
NB 1038+30	1760 Home Gate Dr	SFR	86	81	0.28	Y	Y
NB 1038+60	1762 Home Gate Dr	SFR	84	82	0.18	Y	--
NB 1038+90	1764 Home Gate Dr	SFR	86	84	0.22	Y	Y
NB 1039+20	1766 Home Gate Dr	SFR	87	83	0.29	Y	Y
NB 1039+50	1768 Home Gate Dr	SFR	84	79	0.21	Y	Y
NB 1039+80	1770 Home Gate Dr	SFR	86	82	0.23	Y	Y
NB 1040+10	1772 Home Gate Dr	SFR	85	84	0.23	Y	Y
NB 1040+50	1774 Home Gate Dr	SFR	86	83	0.28	Y	Y
NB 1040+90	1776 Home Gate Dr	SFR	84	80	0.29	Y	Y
NB 1041+20	1778 Home Gate Dr	SFR	84	81	0.34	Y	Y
NB 1041+50	1780 Home Gate Dr	SFR	86	85	0.22	Y	Y
NB 1041+80	1782 Home Gate Dr	SFR	86	81	0.23	Y	Y
NB 1042+10	1784 Home Gate Dr	SFR	86	81	0.26	Y	Y
NB 1042+50	1786 Home Gate Dr	SFR	84	81	0.22	Y	Y
NB 1042+90	1788 Home Gate Dr	SFR	86	84	0.23	Y	Y
NB 1043+20	1790 Home Gate Dr	SFR	86	81	0.25	Y	Y
NB 1044+10	1995 Supreme Dr	SFR	86	81	0.22	Y	Y
NB 1045+10	2001 Supreme Dr	SFR	88	84	0.29	Y	Y
NB 1046+00	2009 Supreme Dr	SFR	85	82	0.17	Y	--
NB 1046+70	2015 Supreme Dr	SFR	87	86	0.16	Y	--
NB 1047+20	2021 Supreme Dr	SFR	87	85	0.18	Y	--
NB 1047+80	2027 Supreme Dr	SFR	88	86	0.20	Y	Y
NB 1048+50	2033 Supreme Dr	SFR	87	82	0.17	Y	--
NB 1049+00	2039 Supreme Dr	SFR	88	83	0.20	Y	Y
NB 1049+50	2045 Supreme Dr	SFR	87	86	0.18	Y	--
SB 967+50	441 Capitol Ave	SFR	65	64	0.00	--	--
SB 967+50	2685 Lombard Ave	SFR	60	57	0.00	--	--

Station Number	Receiver Address	Rec. Type	Unmitigated Noise Level Leq (8-hr) dBA		Unmitigated Vibration Level PPV, (in/s)	Unmitigated FTA Exceedance?	
			Nearest Pile	Next Nearest Pile	Nearest Pile	Noise	Vib.
SB 968+90	2686 Lombard Ave	SFR	69	66	0.00	--	--
SB 969+80	353 S Capitol Ave	SFR	71	68	0.00	--	--
SB 970+50	455 S Capitol Ave	SFR	73	70	0.00	--	--
SB 971+30	459 S Capitol Ave	COM	80	74	0.01	--	--
SB 973+00	461 S Capitol Ave	COM	83	80	0.02	--	--
SB 978+00	674 Excalibur Drive	SFR	78	77	0.08	--	--
SB 979+50	692 Excalibur Drive	SFR	79	76	0.09	--	--
SB 979+00	710 Excalibur Drive	SFR	79	77	0.08	--	--
SB 979+50	728 Excalibur Drive	SFR	78	77	0.08	--	--
SB 979+80	731 S Capitol Ave	SFR	89	87	0.17	Y	--
SB 980+50	747 S Capitol Ave	SFR	88	87	0.16	Y	--
SB 981+10	763 S Capitol Ave	SFR	87	87	0.15	Y	--
SB 983+00	2693 Bambi Ln	SFR	89	85	0.17	Y	--
SB 984+40	807 Capitol Ave	SFR	87	86	0.13	Y	--
SB 985+10	821 Capitol Ave	SFR	88	86	0.13	Y	
SB 985+60	835 Capitol Ave	SFR	87	86	0.13	Y	--
SB 986+10	849 Capitol Ave	SFR	87	86	0.13	Y	--
SB 986+50	863 Capitol Ave	SFR	87	84	0.12	Y	--
SB 987+10	877 Capitol Ave	SFR	87	86	0.13	Y	--
SB 987+50	891 Capitol Ave	SFR	87	84	0.13	Y	--
SB 988+10	905 Capitol Ave	SFR	87	86	0.13	Y	--
SB 988+60	921 Capitol Ave	SFR	87	86	0.13	Y	--
SB 989+10	937 Capitol Ave	SFR	87	85	0.14	Y	--
SB 989+50	953 Capitol Ave	SFR	87	86	0.14	Y	--
SB 990+00	969 Capitol Ave	SFR	88	85	0.15	Y	
SB 990+60	985 Capitol Ave	SFR	87	87	0.16	Y	--
SB 991+00	1001 Capitol Ave	SFR	89	85	0.17	Y	--
SB 991+60	1017 Capitol Ave	SFR	88	86	0.18	Y	--
SB 992+20	1033 Capitol Ave	SFR	88	87	0.19	Y	--
SB 992+70	1049 Capitol Ave	SFR	89	85	0.19	Y	--
SB 993+10	1091 Capitol Ave	COM	89	86	0.23	Y	--
SB 994+00	2695 Story Rd	COM	90	85	0.25	Y	--
SB 996+50	2690 Story Rd	COM	88	87	0.20	Y	--
SB 998+80	2598 Brenford Dr	SFR	85	82	0.10	Y	--
SB 999+30	2594 Brenford Dr	SFR	85	80	0.24	Y	Y
SB 1000+00	2590 Brenford Dr	SFR	84	82	0.25	Y	Y
SB 1000+50	2586 Brenford Dr	SFR	86	82	0.23	Y	Y
SB 1001+00	2582 Brenford Dr	SFR	83	82	0.29	Y	Y
SB 1001+60	2578 Brenford Dr	SFR	85	84	0.30	Y	Y
SB 1002+10	2574 Brenford Dr	SFR	84	82	0.30	Y	Y
SB 1002+80	2570 Brenford Dr	SFR	85	81	0.29	Y	Y
SB 1003+20	2568 Brenford Dr	SFR	83	82	0.35	Y	Y
SB 1003+80	2564 Brenford Dr	SFR	85	81	0.29	Y	Y
SB 1004+40	2560 Brenford Dr	SFR	87	86	0.23	Y	Y
SB 1005+00	2556 Brenford Dr	SFR	88	85	0.23	Y	Y
SB 1005+40	2552 Brenford Dr	SFR	86	82	0.28	Y	Y
SB 1006+00	2548 Brenford Dr	SFR	85	82	0.29	Y	Y
SB 1006+60	2544 Brenford Dr	SFR	85	82	0.35	Y	Y
SB 1007+10	2540 Brenford Dr	SFR	84	82	0.29	Y	Y
SB 1007+20	2536 Brenford Dr	SFR	86	83	0.15	Y	--
SB 1009+00	3501 E Capitol Expy	COM	91	87	0.31	Y	--
SB 1012+00	Foxdale Village Foxdale Loop	MFR	85	85	0.15	Y	--

Station Number	Receiver Address	Rec. Type	Unmitigated Noise Level Leq (8-hr) dBA		Unmitigated Vibration Level PPV, (in/s)	Unmitigated FTA Exceedance?	
			Nearest Pile	Next Nearest Pile	Nearest Pile	Noise	Vib.
SB 1014+50	Foxdale Village Foxdale Loop	MFR	85	84	0.15	Y	--
SB 1018+00	Foxdale Village Foxdale Loop	MFR	86	83	0.15	Y	--
SB 1021+00	2529 Greenstone Ct	SFR	85	81	0.12	Y	--
SB 1021+40	2535 Greenstone Ct	SFR	88	82	0.22	Y	Y
SB 1022+00	2540 Greenstone Ct	SFR	86	83	0.30	Y	Y
SB 1022+70	2534 Greenstone Ct	SFR	87	84	0.18	Y	--
SB 1024+10	2537 Whitestone Ct	SFR	87	81	0.26	Y	Y
SB 1024+90	2538 Whitestone Ct	SFR	86	81	0.27	Y	Y
SB 1025+50	2530 Whitestone Ct	SFR	87	84	0.21	Y	Y
SB 1026+90	2533 Bluestone Ct	SFR	87	83	0.26	Y	Y
SB 1027+40	2532 Bluestone Ct	SFR	86	81	0.30	Y	Y
SB 1027+80	2526 Bluestone Ct	SFR	87	85	0.17	Y	--
SB 1029+30	2517 Brownstone Ct	SFR	89	85	0.25	Y	Y
SB 1030+00	2518 Brownstone Ct	SFR	86	85	0.35	Y	Y
SB 1030+50	2510 Brownstone Ct	SFR	87	85	0.16	Y	--
SB 1032+00	1646 Pinkstone Ct	SFR	89	84	0.23	Y	Y
SB 1032+70	1652 Pinkstone Ct	SFR	85	81	0.26	Y	Y
SB 1033+10	1658 Pinkstone Ct	SFR	88	83	0.23	Y	Y
SB 1034+60	1682 Silverstone Pl	SFR	89	83	0.22	Y	Y
SB 1035+30	1690 Silverstone Pl	SFR	85	84	0.29	Y	Y
SB 1035+80	1698 Silverstone Pl	SFR	86	83	0.14	Y	--
					# Impacts	**149**	**56**

[1]Predictions due to straddle bent 6-east, which will be installed using CIDH
[2]Predictions due to straddle bent 6-west, which will be installed using impacted piles

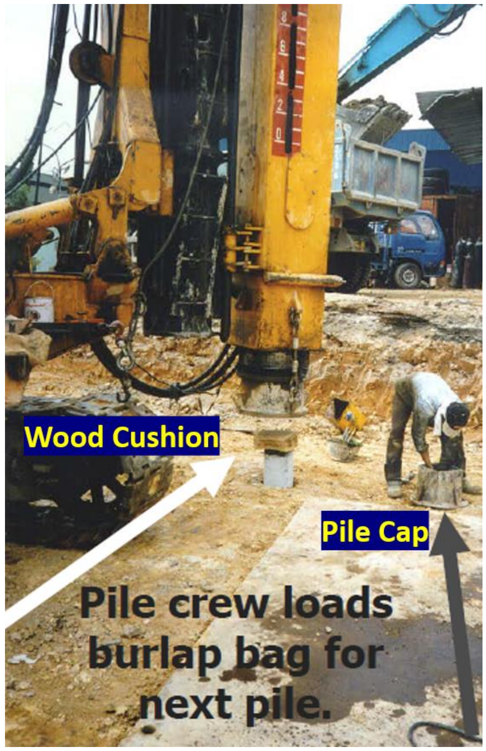

Figure 12: Using Wood and Burlap Bags as a Pile Cushion on Concrete Piles, Singapore.

Figure 13: Impact Pile Noise Shrouds. Image on the left shows an effective enclosure. Image on the right shows a marginally effective barrier.

7.4 Piling Driving Vibration Control Measures

As previously stated, homes within 100 ft of piling activities are likely to exceed FTA damage criteria and a crack survey should be conducted on these homes, pending the outcome of on-site vibration monitoring of test piles.

Hammer Energy: A straightforward way to reduce PPV is to lower the hammer energy since there is a direct relationship between hammer energy and the resultant ground vibration. Ground PPV generally follows a square root relationship with hammer energy (i.e. $\text{PPV} \sim \sqrt{\text{Hammer Energy}}$)*. The degree of hammer energy reduction must be balanced against the likelihood/severity of expected exceedances, increase in total driving time and ability to drive to required friction tolerances.

Reducing hammer energy can be accomplished by pre-drilling the pile. The larger the hole the less hammer energy required to drive the pile into the ground, with the PPV scaling approximately as $\sqrt{1 - \frac{\text{hole size}}{\text{pile size}}}$. It is also noted that only receivers closest to the vibration source (i.e. the pile driver) benefit meaningfully from pre-drilling due to larger *relative* changes in the source-to-receiver distance as the pile deepens.

It is recommended that if pre-drilling is considered a test be conducted to determine the surface vibration levels generated under several pre-drill depths. This may be accomplished with the actual equipment intended for the work, albeit the test would need to be conducted at smaller input energies or at a location distant to sensitive receivers. An alternative would be a drill rig used in standard borehole testing (e.g. cone penetration test) for geologic surveys, with the impacts from a borehole rig having substantially lower energies than for impact pile driving. Impact forces can be measured in the borehole test and may be scaled and related to the energies of the actual impact pile driver, if they can be estimated.

Bored Piles: Where FTA damage criteria is estimated to be exceeded, the use of bored piling methods can reduce vibration levels as compared to impact methods. This method is different than pre-drilling an impact pile.

Receivers near NB 977+70 are in close proximity to the straddle bent that will span Capitol Expressway. At this location construction noise levels from traditional impact pile driving may reach 97 dBA and construction vibration levels may reach 1.52 in/s PPV. However, drilled pile installation methods will be used at this location and for all piles from the straddle bent 6-east at 978+00 to the north end of the guideway.

Noise emission levels from bored pilling methods are approximately 10 to 15 dB lower and PPV levels may be greater than 15 times lower than those due to traditional impact piling. Bored piling methods include auger displacement, cast-in drilled-hole (CIDH) and continuous flight auger (CFA) piling. The use of these methods will eliminate the vibration impacts at all receivers. These methods will also substantially reduce the noise impacts and in most cases these impacts will also be eliminated. At the closest receivers (those within 75 feet of equipment) a sound wall of reasonable height (at minimum breaking line of sight between major noise source and receiver) will be effective in reducing the noise levels to below impact criteria. This is due to the piling equipment such as diesel engines, concrete pumps and the auger all of which have lower source levels and are considerably closer to the ground than impact piling noise sources.

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* D.M. Hiller and G.I. Crabb, "Groundborne Vibration Caused by Mechanised Construction Works," Transport Research Laboratory Report No. 429 (2000)

WIB: Wave impedance barriers (WIB) have shown to provide some measure of vibration reduction, however performance degrades as the distance between the sensitive receiver and the WIB increases. A WIB is either a massive block placed on top of the ground (to impede surface waves) or an embedded barrier of high impedance contrast to the surrounding soil that acts similar to a sound wall (to impede both surface and body waves). A WIB placed directly on top of the ground would not provide control to an ever-deepening pile. Designing a suitable WIB as a temporary control measure would likely be an infeasible option given the cost and questionable performance such a measure is likely to have.

7.5 Community Outreach

Education of the affected community should involve communication of the following basic facts either during individual or community meetings. Such meetings are obviously more effective if they are held prior to the start of piling activities.

1. Cracks are caused by a variety of construction defects.
2. Homes contain numerous cracks (of which the owner is unaware) that increase in number and size each year without construction vibration. Vibration that is perceived to be detrimental to a homeowner’s property can cause them to inspect their home more carefully causing them to find cracks they believe are new, yet pre-date the construction activities.
3. These cracks are predominately cosmetic and are not structurally harmful.
4. Slamming doors and passing traffic may vibrate homes more than do pile driving.
5. Human beings are far more sensitive to noise and vibration than are structures.

This information is most easily transmitted through well publicized community meeting and should be followed by several residential crack surveys. Homes that are estimated to exceed the FTA construction vibration criteria of 0.2 in/s should have a before and after crack inspection survey conducted by a qualified technician.

7.6 Additional Nighttime Construction

In addition to the daytime pile driving activities there may be construction work necessary during nighttime and early morning hours in order to minimize traffic disruption along Capitol Expressway. This work may consist of the following activities,

- Partial or complete closures of the major intersections along Capitol Expressway for the erection of falsework, pre-fabricated steel spans and other major lift work.
- Roadway striping, testing of equipment and trenching for underground utilities.

Equipment used for these activities may include: cranes, concrete trucks, concrete pumps, concrete saws, pavement grinders, backhoes, flatbed trucks, pick-up trucks, trenchers, compressors and pneumatic tools. These activities would be considered as a significant impact to local residences based on the City of San José Municipal Code as discussed in Section 3.1, and would require a Development Permit from the City of San José for work occurring before 7:00 AM or after 7:00 PM, Monday through Friday, or at any time on weekends. The FTA construction noise limit for nighttime work is 70 Leq (8-hr), dBA.

7.6.1 Nighttime Construction Noise

Noise levels generated by the nighttime work were estimated using CadnaA as before, yet in this case only the expected distance to the FTA criteria is estimated, not the levels at each individual receivers as in the pile driving noise predictions. This is because the specific means and methods for construction of these activities is not fully known. To perform the estimation a representative set of equipment was chosen, with general usage factors (percent time equipment is operating at full power) obtained from the Federal Highway Administration's (FHWA) Roadway Construction Noise Model (RCNM) User Guide. Issues such as back-up alarms and slamming of tailgates is not accounted for in the noise model.

Figure 14 shows the estimated 70 Leq (8-hr), dBA criteria contour for both unmitigated and mitigated cases. All receivers within the contour would signify a noise exceedance. The mitigation is in the form of a 10-foot high temporary movable sound wall that encloses the work area. The results in Figure 14 also assume all the noise generating equipment is near the ground (no higher than 6-feet off the ground) and as such the 10-foot temporary sound wall is effective at reducing the noise to below threshold levels at most receivers. With no temporary sound wall almost all first-row receivers would exceed that criteria, as the unmitigated contour extends out to approximately 250 feet, unobstructed. With a 10-foot temporary sound wall the criteria contours extends out to approximately 100 feet, potentially impacting about half of the receivers. However, many of the receivers within 100 feet of the alignment have an existing 8-foot sound wall. For receivers protected by this existing sound wall as well as the use of the 10-foot temporary construction noise wall, levels will be below the nighttime criteria level. One area of concern are receivers between Westboro Road and Capitol Expressway (NB 970+90 to NB 977+70) where homes may be between 40 feet and 70 feet from construction work sites. These close receiver can be protected by increasing the temporary construction noise wall height from 10 feet to 14 feet.

Some of the work may take place off the ground, though typically much of this work will not generate significantly high noise levels. The location of the dominate noise source for much of the equipment for the elevated work usually is nearer the ground (generators, compressors, diesel engines etc.) and therefore protected by noise walls.

A survey by state DOTs found that the primary causes of nighttime construction noise issues were related to back-up alarms (41%), slamming tailgates (27%), hoe rams (24%), milling/grinding (16%), earthmoving equipment (14%) and crushers (6%).

In addition to the contractor controls specified in Section 7.3 the following are recommended to reduce and control the noise levels for nighttime work:

- To the extent possible use modern equipment, which has better engine insulation and mufflers.
- Only operate equipment at power levels needed for the work and avoid unnecessary idling of construction equipment near residences.
- Use noise walls that at minimum break line of site between noise sources and receivers. Ensure all gaps in noise walls are completely sealed.
- If available use broadband, low-noise or automatic "smart" back-up alarms. Smart alarms can continuously adjust to 5 dB above ambient (https://brigade-electronics.com/). The use of spotters may be permissible in lieu of back-up alarms.
- Use dump trucks lined with a sound deadening material.
- Hire or retain the services of an acoustical engineering to be responsible for preparing and overseeing the implementation of a noise control and monitoring plan.
- Conduct periodic measurements in accordance with an approved noise monitoring plan specifying monitoring locations, equipment, procedures, and schedule of measurements and reporting methods to be used.

Since it is not anticipated that heavy machinery will be used within 25 feet of any receiver for the nighttime work, groundborne vibrations will not exceed FTA construction vibration criteria.

Figure 14: FTA Nighttime Construction Noise Criteria Contours for Unmitigated and Mitigated (10-foot Noise Wall) Cases.

8. CONCLUSIONS

A noise and vibration assessment has been conducted to update the 2007 Supplemental EIR and the 2012 Supplemental Draft EIS for the Capitol Expressway Light Rail Project. The assessment has analyzed the possibility for noise and vibration impacts due to the light rail operations and due to the impact pile driving required for the construction of the aerial guideway.

The analysis has indicated that unmitigated noise for year 2043 (2017) light rail operations would cause 93 (78) moderate and 59 (23) severe FTA impacts. With an aerial guideway sound wall and an OGAC layer on Capitol Expressway as noise control measures, all 2017 and 2043 noise impacts are removed. All year 2043 impacts are due the expected increase in road traffic noise along Capitol Expressway.

The analysis has indicated that vibration from light rail operations would exceed FTA detailed vibration criteria for nighttime at 67 residential receivers in the project area, with nighttime hours being 10 PM to 7 AM. It is noted that the peak nighttime hour of 6 AM to 7 AM is of particular concern since the train headways are at their shortest duration and the trains consist of three cars. As previously discussed, vibration predictions are made on the assumption of a 3-car consist and reduced vibration levels are possible for those nighttime hours running 2- and 1-car consist.

Vibrations levels in the 10 Hz 1/3-octave band have been identified as the primary offending frequency causing the exceedances, with exceedance occurring in the 20 Hz to 31.5 Hz range for one receiver near the ballasted transition embankment. The use of tire derived aggregate as an embankment underlayment removes the 20 Hz to 31.5 Hz impact. The use of a floating slab track or bridge bearing design to isolate the trackbed could remove all vibration impacts. However, the use of either floating slab track or isolation bearings for the aerial guideway vibration mitigation would require extensive additional analysis as there are only a few of these systems in operation without substantial reporting of in-service performance available, as described in Section 6.2.

It is recommended that supplemental LSR and FDL measurements be conducted to confirm local propagation characteristics and assess the influence of low frequency traffic vibrations occurring in the 10 Hz region. If nighttime vibration impacts still remain, it is recommended that trains run at a reduced speed. Trains running at 35 mph would remove all vibration impacts.

Pile driving would generate substantial noise and vibration levels. The noise would potentially impact unobstructed homes within 300 ft of the pile driving activity for piles driven 6 hours out of an 8-hour work day. Vibration would impact residences within 100 ft of the pile driving activity. Noise and vibration control measures include scheduling and coordination with the public, pre-construction crack surveys and vibration monitoring is recommended for buildings close to pile driving activity, as discussed above. Impact cushions and noise shields should be considered as well as reducing impact hammer energies by pre-drilling piles or using bored method for the piles at the closest receivers.

Additional construction work may occur at night. The use of a suitable movable noise wall as well as existing sound walls will protect most receivers from criteria exceeding noise levels. Close receivers in the vicinity of NB 970+90 to NB 977+70 may need a higher noise wall or supplemental enclosures of specific high noise generating tasks/equipment. Vibration due to these activities will not exceed criteria.

APPENDIX A: NOISE AND VIBRATION BASICS

A.1 Noise Fundamentals

Sound is mechanical energy transmitted by pressure waves in a compressible medium such as air. Typically, noise is defined as unwanted or excessive sound. Sound can vary in intensity by over one million times within the range of human hearing. Therefore, a logarithmic scale, known as the decibel scale (dB), is used to quantify sound intensity and compress the scale to a more convenient range. In addition, human response to sound is better correlated to decibels than to linear measures of sound intensity.

Sound is characterized by both its amplitude and frequency (or pitch). The human ear does not hear all frequencies equally. In particular, the ear deemphasizes low and very high frequencies. The A-weighted decibel scale (dBA) better approximates the sensitivity of human hearing. On this scale, the human range of hearing extends from approximately 3 dBA to around 140 dBA. As a point of reference, Figure A-1 includes examples of A-weighted sound levels from common indoor and outdoor sounds.

Using the decibel scale, sound levels from two or more sources cannot be directly added together to determine the overall sound level. Rather, the combination of two sounds at the same level yields an increase of 3 dB. The smallest recognizable change in sound level is approximately 1 dB. A 3 dB increase in the A-weighted sound level is considered generally perceptible, whereas a 5 dB increase is readily perceptible. A 10 dB increase is judged by most people as an approximate doubling of the perceived loudness.

The two primary factors that reduce levels of environmental sounds are (1) increasing the distance between the sound source and the receiver and (2) having intervening obstacles such as walls, buildings or terrain features that block the direct path between the sound source and the receiver. Factors that act to make environmental sounds louder include moving the sound source closer to the receiver, sound enhancements caused by reflections and focusing caused by various meteorological conditions.

Following are brief definitions of the measures of environmental noise used in this report:

Maximum Sound Level (Lmax): Lmax is the maximum sound level that occurs during an event such as a train passing. For this analysis, Lmax is defined as the maximum sound level using the slow setting on a standard sound level meter.

Equivalent Sound Level (Leq): Environment sound fluctuates constantly. The equivalent sound level (Leq) is the most common means of characterizing community noise. Leq represents a constant sound that, over a specified period, has the same sound energy as the time-varying sound. Leq is used by FTA and FRA to evaluate noise impacts at institutional land uses, such as schools, churches and libraries, from proposed transit projects.

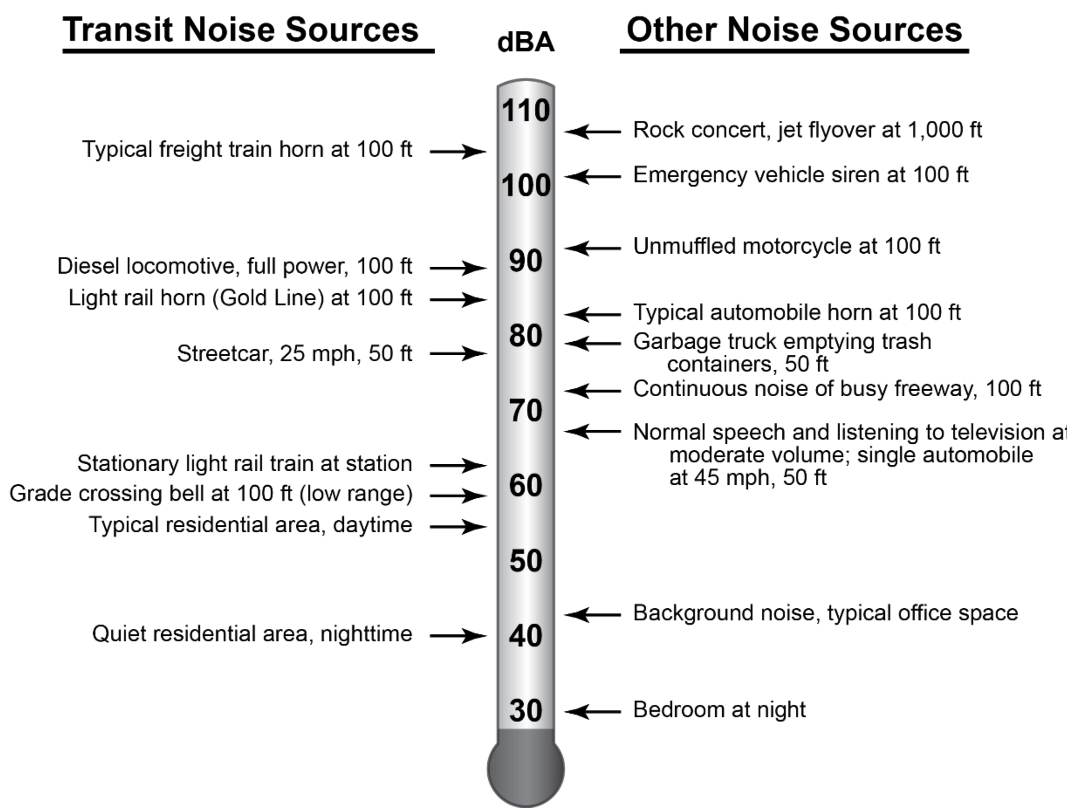
Day-Night Sound Level (Ldn): Ldn is a 24-hour Leq with an adjustment to reflect the greater sensitivity of most people to nighttime noise. The adjustment is a 10 dB penalty for all sound that occurs between the hours of 10 p.m. to 7 a.m. The effect of the penalty is that, when calculating Ldn, any event that occurs during the nighttime is equivalent to ten occurrences of the same event during the daytime. Ldn is the most common measure of total community noise over a 24-hour period and is used by FTA to evaluate residential noise impacts from proposed transit projects.

Lxx: This is the percentage of time a sound level is exceeded during the measurement period. For example, the L99 is the sound level exceeded 99 percent of the measurement period. For a 1-hour period, L99 is the sound level exceeded for all except 36 seconds of the hour. L1 represents typical maximum sound levels, L33 is approximately equal to Leq when free-flowing traffic is the dominant noise source, L50 is the median sound level and L99 is close to the minimum sound level.

Sound Exposure Level (SEL): SEL is a measure of the acoustic energy of an event such as a train passing. In essence, the acoustic energy of the event is compressed into a 1-second period. SEL increases as the sound level of the event increases and as the duration of the event increases. It is often used as an intermediate value in calculating overall metrics such as Leq and Ldn.

Sound Transmission Class (STC): STC ratings are used to compare the sound insulating effectiveness of different types of noise barriers, including windows, walls, etc. Although the amount of attenuation varies with frequency, the STC rating provides a rough estimate of the transmission loss from a particular window or wall.

FIGURE A-15: SOUND LEVELS FROM COMMON SOURCES



A.2 Vibration Fundamentals

One potential impact to buildings is vibration that is transmitted from the tracks through the ground to the adjacent buildings. This is referred to as groundborne vibration. When evaluating human response, groundborne vibration is expressed in terms of decibels using the root mean square (RMS) vibration velocity. RMS is defined as the average of the squared amplitude of the vibration signal. To avoid confusion with sound decibels, the abbreviation VdB is used for vibration decibels. All vibration decibels in this report use a decibel reference of 1 micro-inch/second (μin/sec).[*]

The potential adverse impacts of rail transit groundborne vibration are as follows:

Perceptible Building Vibration: The vibration of the floor or other building surfaces that the occupants feel. Experience shows that the threshold of human perception is around 65 VdB and that vibration that exceeds 75 to 80 VdB is perceived as intrusive and annoying to occupants.

Rattle: The building vibration can cause rattling of items on shelves and hangings on walls, and various rattle and buzzing noises from windows and doors.

Reradiated Noise: The vibration of room surfaces radiates sound waves that are audible to humans (groundborne noise). Groundborne noise sounds like a low-frequency rumble. Usually, for a surface rail system the groundborne noise is masked by the normal airborne noise radiated from the transit vehicle and the rails.

Damage to Building Structures: Although it is conceivable that vibration from a light rail system can damage fragile buildings, the vibration from rail transit systems is one to two orders of magnitude below the most restrictive thresholds for preventing building damage. Hence the vibration impact criteria focus on human annoyance, which occurs at much lower amplitudes than does building damage.

Vibration is an oscillatory motion that is described in terms of the displacement, velocity or acceleration of the motion. The response of humans to vibration is very complex. However, the general consensus is that for the vibration frequencies generated by rail trains, human response is best approximated by the vibration velocity level. Therefore, this study uses vibration velocity to describe light rail-generated vibration levels.

Figure A-15 shows typical vibration levels from rail and non-rail sources as well as the human and structure response to such levels.

Although there is relatively little research into human and building response to groundborne vibration, there is substantial experience with vibration from rail systems. In general, the collective experience indicates that:

It is rare that groundborne vibration from rail systems results in building damage (even minor cosmetic damage). Therefore, the primary consideration is whether or not the vibration is intrusive to building occupants or interferes with interior activities or machinery.

The threshold for human perception is approximately 65 VdB. Vibration levels in the range of 70 to 75 VdB often are noticeable but acceptable. Beyond 80 VdB, vibration levels are often considered unacceptable.

For human annoyance, there is a relationship between the number of daily events and the degree of annoyance caused by groundborne vibration. The FTA Guidance Manual includes an 8 VdB higher

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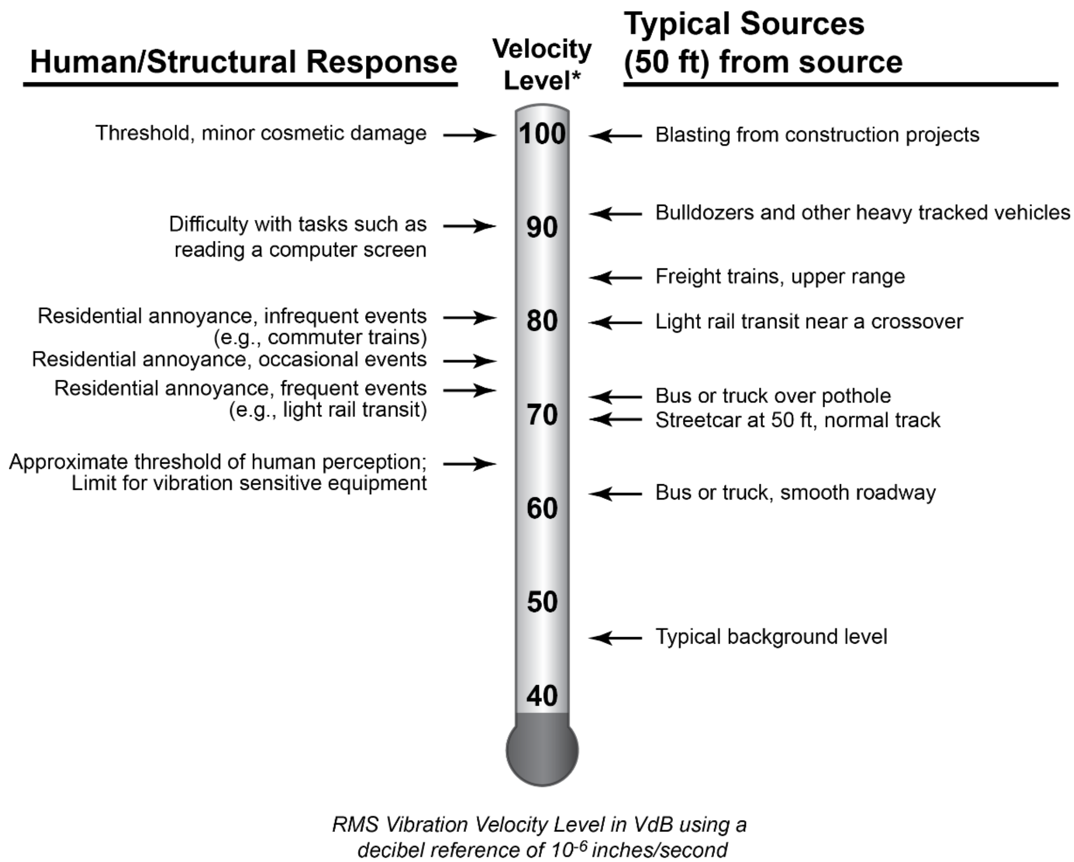
[*] One μin/sec = 10^{-6} in/sec

impact threshold if there are fewer than 30 events per day and a 3 VdB higher threshold if there are fewer than 70 events per day.

FIGURE A-16: VIBRATION LEVELS FROM COMMON SOURCES



Often it is necessary to determine the contribution at different frequencies when evaluating vibration or noise signals. The 1/3-octave band spectrum is the most common procedure used to evaluate frequency components of acoustic and vibration signals. The term *octave* is borrowed from music, where it refers to a span of eight notes. The ratio of the highest frequency to the lowest frequency in an octave is 2:1. For a 1/3-octave band spectrum, each octave is divided into three bands, where the ratio of the lowest frequency to the highest frequency in each 1/3-octave band is $2^{1/3}$:1 (1.26:1). An octave consists of three 1/3 octaves.

The 1/3-octave band spectrum of a signal is obtained by passing the signal through a bank of filters. Each filter excludes all components except those that are between the upper and lower range of one 1/3-octave band.

APPENDIX B: MEASURED NOISE LEVELS

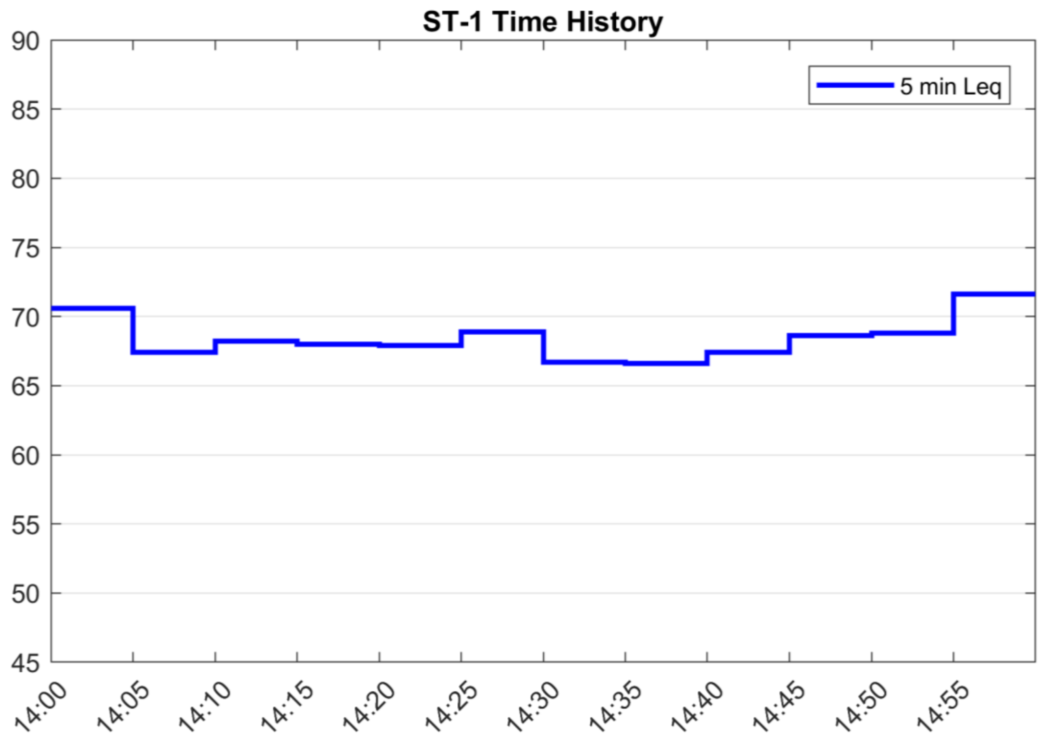
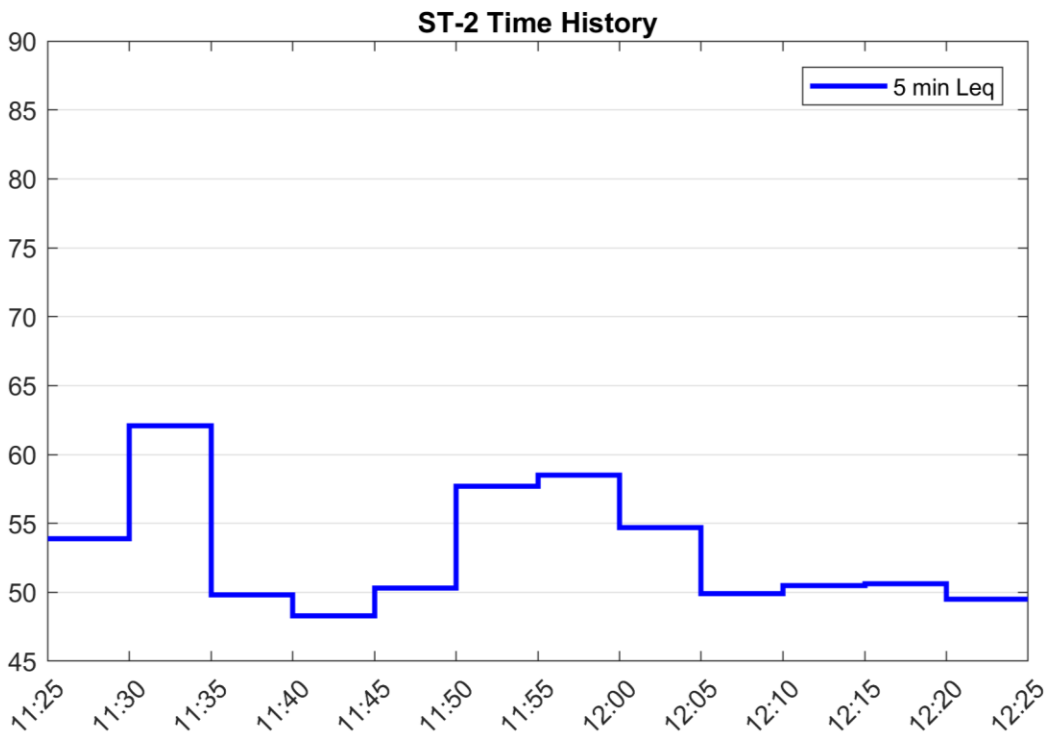


Figure B-17: ST-1, 1624 S. Capitol Avenue



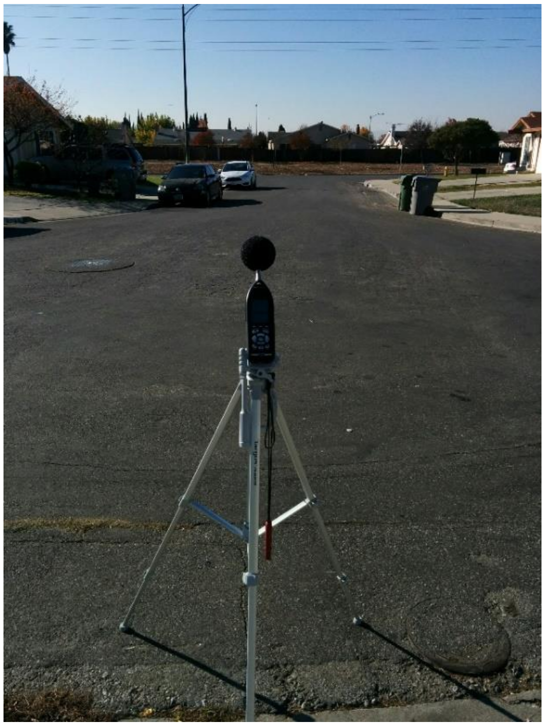


Figure B-18: ST-2, 2517 Brownstone Place

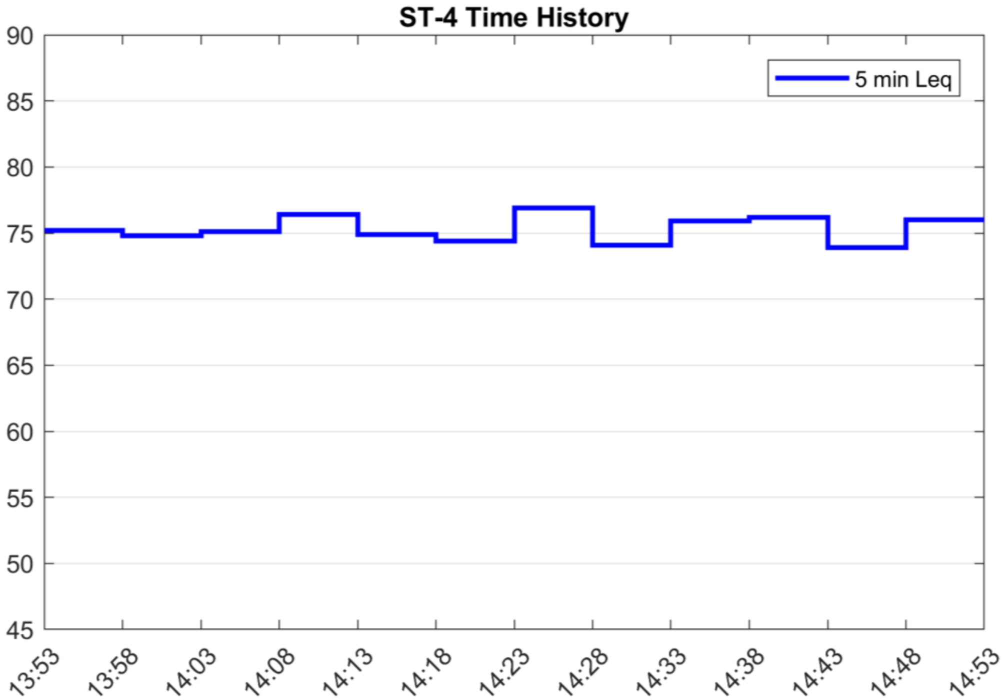


Figure B-19: ST-4, Capitol Expressway, behind 2001 Supreme Drive

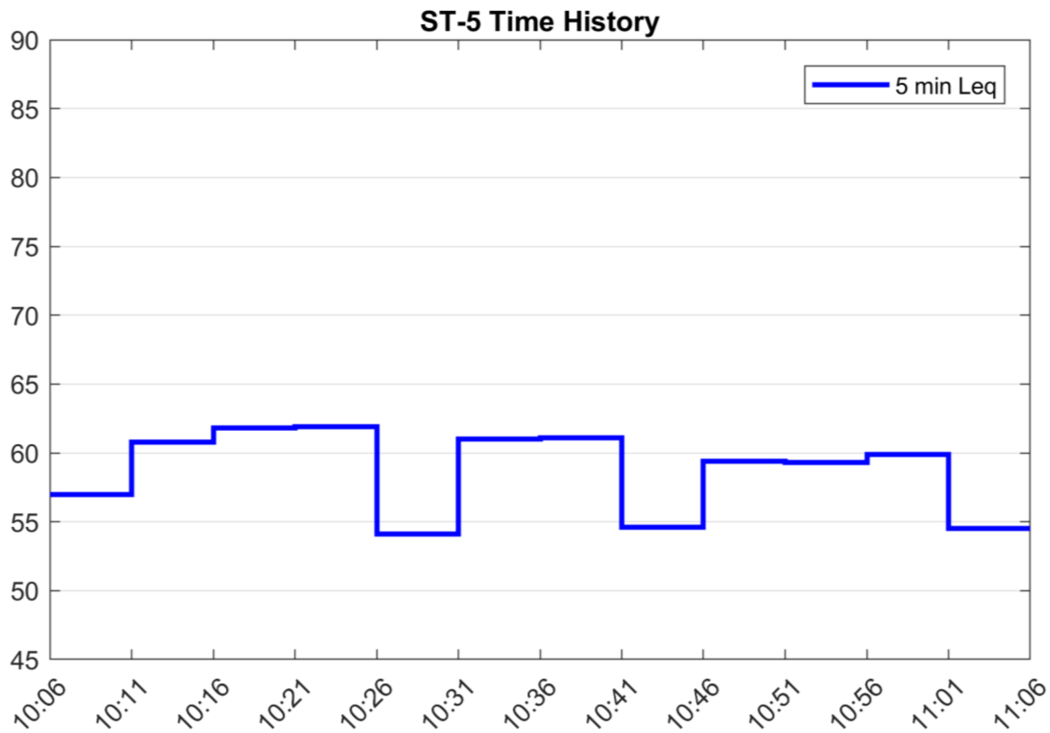


Figure B-20: ST-5, 1698 Silverstone Place

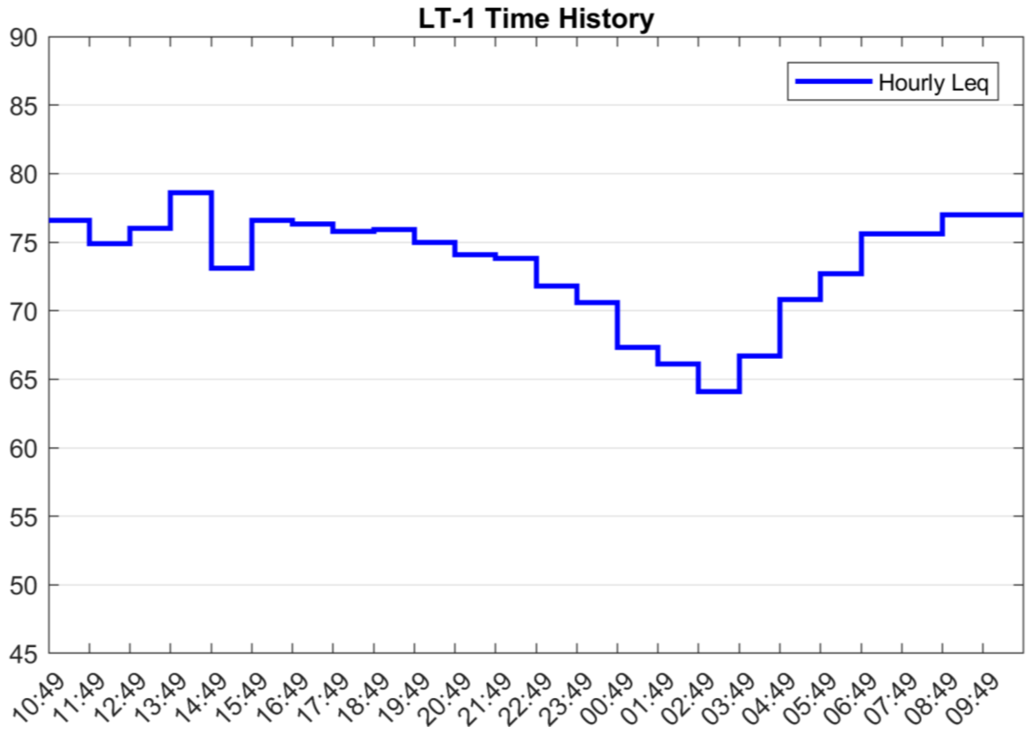


Figure B-21: LT-1, Corner of Foxdale Drive and Capitol Expressway

APPENDIX C: LINE SOURCE RESPONSE COEFFICIENTS

Table 15: Average LSR Used in Current Analysis

Frequency	A	B	C
6.3	25.8	7.8	-5.7
8	41.3	-5.7	-1.6
10	36.5	3.5	-4.1
12.5	18.9	27.3	-11.1
16	12.3	39.4	-15.2
20	6.9	48.4	-18.2
25	-0.5	59.3	-22.0
31.5	4.7	56.7	-22.8
40	39.4	18.7	-13.4
50	-0.7	59.0	-24.6
63	-11.0	80.4	-34.2
80	83.6	-24.8	-7.4
100	115.9	-73.3	7.4
125	114.0	-75.0	8.1
160	105.4	-83.1	13.5
$LSR = A + B*Log(d) + C*(Log(d))^2$,d = distance in feet			